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Archaeobotanical Investigations at Khok Phanom Di, Central Thailand

by
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This work is a thesis submitted for the Degree of Doctor of Philosophy at the Australian National University

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This research has been conducted as part of a large multi-disciplinary project, but the archaeobotanical investigations are entirely my own work. Except where otherwise stated in the acknowledgements or in the text, this thesis is based entirely upon my own fieldwork and research.

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ABSTRACT

This thesis concerns the role of plants in the lives, and especially the diet, of the prehistoric potting community at Khok Phanom Di, a large mound situated on the Bang Pakong floodplain at the head of the Gulf of Thailand. The site lies on the southeastern seaboard, currently more than 20 km from the coast, but was occupied between 2000-1500 BC, on a higher shoreline. Excavations during 1985 involved extensive and systematic flotation to extract charred plant remains from a 500 year stratigraphy, almost 7 m deep. Charcoal, seeds and the remains of rice have been examined, together with remarkably well preserved coprolites, mineralised wood, and fibres, possibly the remains of burial shrouds. There were also impressions of leaves and stems for which identification has not been attempted. The archaeobotanical materials from the site contribute to environmental reconstruction and an understanding of the use of plant resources by this mangrove-based community.

This archaeobotanical study stands in isolation in mainland Southeast Asia in its scope and methodology. Reference collections have been established and ethnobotanical surveys undertaken in the mangroves and adjacent lowlands of southeastern Thailand. Special emphasis was given to the taphonomy of rice. An ethnographic model of rice processing is explored. Comparisons between methods of post-harvest processing of rice and those for wheats and barley, show that rice waste products are less likely to be exposed to fire during processing, which helps to explain why rice is less well represented in the charred archaeobotanical record.

Diagnostic criteria for distinguishing between the remains of wild and domesticated rice using SEM studies of lemma and palea features have been investigated. Reniform abscission scars and the absence awns in some of the archaeological husks suggest that the Khok Phanom Di people had access to domesticated rice supplies. Shell harvesting knives and stone hoes confirm that the community was involved in some form of cultivation, probably in ephemeral, freshwater swamps inland.

This research has extended beyond the analysis of the plant remains to a broader view of the plant communities (mangrove, saltflats and freshwater swamps) within access of the site. Ethnographic, ethnobotanical and ecological observations are used are used to examine these habitats in terms of possible resource use, and thus to the broad subsistence base beyond the carbohydrate staple.
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1.1 Background to the research problem, hypothesis formulation and research strategies

This thesis deals with the recovery, identification and interpretation of plant remains from an excavation of a large habitation mound on the deltaic-estuarine floodplain at the head of the Gulf of Thailand referred to as the Central Plain. It takes as its focus the problem of reconstructing prehistoric human-plant relationships and interactions at the site. The area under consideration comprises the mangrove swamps and adjacent plains around the estuary of the ancestral Bang Pakong river and the time is the second millennium BC, to use the Christian calendar which is standard in discussions of the region (cf. Bellwood 1985:ix; Higham 1989:xv-xvi). The site is Khok Phanom Di, lying in the lower Bang Pakong Valley between the provincial towns of Chachoengsao and Phanat Nikhom, in the residential district (tambon) Tha Kham, in Chonburi Province (changwat). It lies a little more than 70 km to the southeast of Bangkok and about 22 km from the coast, located about 8 km east-south-east of the southern bank of the Bang Pakong River, at 13°36'E, 101°08'N (Figure 2.1). The site is a circular mound of around 5 ha, with its highest point 12 m above the rice paddies, which are in turn 3 m above sea level.

The mound was first recognised as a human prehistoric rather than a natural feature during the mid 1970's, when a road was cut through to the summit and to the monastery being built there. Initial investigation of the deposits involved a stratigraphic interpretation of exposed sections along the roadcutting, followed by two excavations. These produced samples of mangrove/mudflat molluscs Anadara nodifera, Geloina ceylonica and Cerithidea obtusa, many fishbones and claws 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).
Five factors pointed to the possibility of 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.

Firstly, 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 380-390 cm 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 Damrongkiart Noksakul provided dates of 6410 ± 400 bp (=uncalibrated) and 6800 ± 420 bp (see Table 2.2) 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 at the site, attracted the interest of Charles Higham of the Department of Anthropology, University of Otago (Dunedin, New Zealand), who inferred that the earliest occupation at Khok Phanom Di was in the fifth millennium BC, with the considerable depth of cultural deposits, up to 12 m in some parts of the mound, suggesting a long sequence of prehistoric occupation (Higham 1984:100).

Thus, the initial chronological framework was taken to indicate that the occupation at Khok Phanom Di might overlap with the earliest domesticated rice from China. At that point the evidence for this was from Hemudu and Luo-jia-jiao (both in Zhejiang Province on the lower Yangtze valley) in the fourth to fifth millennium BC (You 1976; Team of Luo-jia-jiao Site 1981, cited by Chang 1989:411). Yet the Chinese evidence, from the Yangtze valley sites could not be said to reflect incipient agriculture because these are established agricultural communities. This critical process remained enigmatic in the Southeast Asian archaeological record.

Secondly, Khok Phanom Di's past ecological situation, with possible access to ephemeral freshwater swamps behind chenier ridges, contributed to Higham's hypothesis that the site might yield not only the remains of domesticated rice but also evidence for the elusive transition from the use of gathered wild grasses to
cultivated varieties (cf. Higham 1990:11). The trigger to new resource exploitation strategies was hypothesised as being environmental instability brought about by fluctuating land-sea relations. Coastal resources including stands of wild rice were thought to have been removed from the site catchment, and rice gradually brought into cultivation in order to maintain supply. This is in line with Burkill's (1952) suggestion that the initial isolation of wild plants from their cultivated relatives took place as humans moved food plants out of their natural habitats into new environments.

In 1985 Higham set out to examine his hypothesis by marshalling evidence from a number of different directions, from palynological and sedimentological studies of cores taken around the site to a major excavation at the centre of the mound, where emphasis was given to the comprehensive recovery of botanical remains. 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 occupation there (Yen 1982:52). In the case of Khok Phanom Di, I was asked to take charge of the archaeobotanical investigations.

In addition to expectations of finding evidence relating to prehistoric economies and environments, 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 organics 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 (A. Clarke and I. Glover pers. comms.; Welch and McNeill 1988-89:107, 109). I was involved in the excavation and coring programme at the site during the first six and a half of the seven-month field-season (January through July) and took responsibility for flotation of soil samples as well as the recording and curation of additional plant macroremains: leaf impressions, occasional nuts and large seeds, mineralised wood and fibres. Processing the flotation samples was straightforward and the field techniques employed are described in chapter 3.
At the outset, as has been indicated, 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 in the region. Nowhere, however, was there undisputed and published archaeological evidence of rice remains spanning the foraging to farming transition at a single location, such as has been established 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, although even there 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 might be preserved for rice at Khok Phanom Di. The lithic assemblage encountered during Higham’s 1985 excavation pointed to participation in a widespread trade network (cf. Pisinupong 1988; Higham 1991) and the absence of metal finds, whether from trade or local manufacture, was taken to support the initial view of an early occupation.

Some time after the excavation, however, as the radiocarbon chronology began to emerge (see Table 2.1), the dating of the initial occupation was revised upward, first and tentatively to 4000 BC (Higham et al. 1987:154) on the basis of dates from the central phase of the site by the DSIR (Department of Scientific and Industrial Research) laboratory in New Zealand. This was again revised to 2000 BC, once the stratigraphically lower samples had been processed at the Australian National University (Maloney et al. 1989:364). 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 coastal Khok Phanom Di, and especially those of rice, were eventually examined in 1989-90 more in terms of assemblage diversity than of temporal change. New experimental and simulation data (Hillman and Davies 1990a, 1990b) radically abbreviating the period over which phenotypic change may be induced in cereals by reaping and reseeding,
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.

1.2 Southeast Asia and the origins of tropical agriculture

Mainland Southeast Asia has long been seen as the home of a broad range of cultivated food plants (de Candolle 1884; Haudricourt and Hédin 1943; Pelzer 1948; Vavilov 1950; Sauer 1952; Barrau 1970; Li 1970). Besides rice (Oryza sativa)*, these include tubers like taro (Colocasia esculenta) and the other aroids Alocasia macrorrhiza 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 contributing carbohydrates, for example from breadfruit (Artocarpus altilis), fruits from Citrus sinensis and C. aurantium among others, and protein- and fat-rich nuts such as Indian almond (Terminalia catappa) and candlenut (Aleurites moluccana) (Harris 1984:30).

The agricultural antecedents in Southeast Asia have attracted the attention of a number 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 Southeast Asia, 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 setting, although theirs was a marine-estuarine orientation rather than a riverine one. 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

* Authorities to Latin names are those in the Flora of Java except where otherwise stated.
archaeobotany in the region, linked with improved methods for identifying tuberous remains (cf. Hather in press) is, however, improving prospects now. Sauer's unsubstantiated but influential theory, based on strong diffusionist concepts, was formulated at a time when archaeological evidence for mainland Southeast Asia was very scarce. Mangelsdorf (1954:90), in a review *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 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 today in mainland Southeast 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 regarding agricultural origins, they may nevertheless contribute to the debate about the processes of rice domestication.

1.3 Conceptual approaches to the domestication of rice

The history of archaeobotanical research in Southeast 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 succinctly summarised by Hutterer (1983:177) who explains 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 in the plant
were brought about by the unconsciously selective agronomic practices of the
cultivators. The issue of incipient rice domestication has a long history in Southeast
Asian archaeology, 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 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
African rices will not concern us further. 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:161) which in turn derived from the perennial O. rufipogon Griff. (Whyte 1972,
1974; Harlan et al. 1973:317; Shastri and Sharma 1974; Chang 1976a:427,428 Fig.1,
1976b:143; Second 1985:29), or directly from the perennial O. perennis Moench.
without an intermediate annual stage (Morishima et al. 1963; Chandraratna 1964:3-
4; Sampath 1964; Oka 1975:21-25, 1988; Morishima et al. 1963). A third proposed
progenitor for the cultivar is an intermediate perennial-annual type of rice,
considered to have given risen 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 the morphological criteria used for identification
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 Southeast Asia, *japonica* (or *sinica*) at higher altitudes in southern China (Oka 1974, 1975; Oka and Morishima 1982), and *javanica* in tropical island Southeast Asia (Chang 1976a:432, 1976b:145), although the timing and location of these changes remain to be resolved. Second (1982:28, 1985:28) argues on the basis of electrophoretic data for two independent domestications of rice in Asia, creating *O. sativa* var. *indica* and *O. sativa* var. *japonica*, again in monsoonal Southeast Asia and southern China respectively.

Introgressive hybridisation between the two wild and the cultivated rices has produced weedy or spontaneous intergrades adapted to disturbed environments and found growing in or alongside rice fields. In many ways 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). In Harlan and de Wet's (1971:511, 513) terms 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. 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 distinguish between the perennial and annual forms of wild rice, in a conceptual sense.
FIGURE 1.1
SCHEMATIC REPRESENTATION OF THREE HYPOTHETICAL PHYLOGENETIC PATHWAYS FOR THE ASIAN RICES

Time (t) is indicated along the horizontal axis, with the point of domestication marked as D. (Adapted from Second 1985:28)

1. Adapted from Chang (1976a). The current distribution of wild rices was the result of the fragmentation of Gondwanaland. Two parallel evolutionary series took place in Asia and Africa, from the perennial form through the annual to the cultivar. The adventitious forms were produced by introgression between the various types.

Gondwanaland
ancestor

\[ \text{O. rufipogon} \rightarrow \text{O. nivara} \rightarrow \text{O. sativa} \]

\[ \text{wild} \rightarrow \text{annual} \rightarrow \text{cultivar} \]

\[ \text{O. sativa f. spontanea} \]

weedy race

D

2. Adapted from Oka (1974), Morishima et al. (1963) and Oka and Morishima (1982). *O. sativa* was domesticated independently in different places and at different times. The differentiation into two types principally resulted from disruptive selection by people.

\[ \text{O. rufipogon} \rightarrow \text{O. sativa} \]

\[ \text{wild perennial} \rightarrow \text{annual cultivar} \]

\[ \text{O. sativa} \]

\[ \text{tropical race} \]

\[ \text{type indica} \]

\[ \text{type japonica} \]

\[ \text{type javanica} \]

D

3. Adapted from Second (1985). Three primary domestications. The differentiation of cultivated rice resulted in part from the geographic differentiation of the ancient wild annual or intermediate ancestor. Not only were there introgressions between wild and cultivated types but also independently between the cultivars domesticated separately, which was the basis for the diversity among cultivated varieties and certain adventitious forms.

\[ \text{common ancestor} \]

\[ \text{O. rufipogon in China} \]

\[ \text{O. rufipogon in Southeast Asia} \]

\[ \text{O. rufipogon in South Asia} \]

\[ \text{wild perennial} \]

\[ \text{wild annual} \]

\[ \text{indica subsp.} \]

\[ \text{japonica subsp.} \]

\[ \text{O. sativa annual cultivar} \]

D

\[ \text{t} \]
Domestication in cereals almost never produces a new species in biological terms (cf. Harlan and de Wet 1971:511; Harlan et al. 1973:311; de Wet 1981:177), 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", while 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 hybridisation. Given the difficulty, widely acknowledged by taxonomists, in separating between these taxa even in perfect herbarium specimens, it is perhaps 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.

1.4 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 in open parts of inundated tropical forest, whereas their annual relatives are adapted to temporarily flooded areas, in shallow ponds and along 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 1974:141; Chang 1976b:145; Harlan 1977:371). This represents a shift in opinion from the idea that dry-rice shifting cultivation in the uplands preceded swamp paddy (cf. Whyte 1972:142; An 1989:645), an argument based on the distribution of the "simplest" agricultural techniques, with the practice among the hill tribe communities throughout Southeast Asia. However, the semi-aquatic nature 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 1989:412). Wetland cultivation would fit more closely 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 (15,000 to 10,000 years ago) (Whyte 1972:142, 1985:261). The
region of incipient rice domestication and agricultural origins has been demarcated
variously as China (de Candolle 1884), India (Vavilov 1926, 1950; Ramiah and
Ghose 1951), mainland Southeast 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:433 Figure 2) and recently, on linguistic grounds, central and
southeastern China and adjacent areas of Southeast Asia (Bellwood 1990:24). The
most widely respected and quoted view is that of T.-T. Chang (1976a), whose
analysis was founded on the contemporary biogeography of the relatives of wild rice,
though these may well have been different in the past due to variable climatic
conditions in the early Holocene, and the fact that wild rices are known to follow
their cultivated relatives into new areas. The putative range for early rice
domestication is thus diffuse and imprecisely defined. It also diverges from the
archaeological data, in that the earliest archaeological specimens of cultivated rice
have been found in China and in western India in the Belan valley at Koldiwa,
although the dating of these remains to the fifth millennium BC is inconsistent with
the chronology for nearby Mahagara (Sharma et al. 1980:198-200; Chakrabarti

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 remains wanting in Southeast 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", without reference to faunal or floral evidence (Higham 1989:44-45). The archaeobotanical research undertaken at Khok Phanom Di was designed to provide a more rigorous approach to the subject.

1.5 Archaeobotanical research in mainland Southeast Asia

The search for early rice cultivation has been the major motivation for archaeobotanical research in Southeast Asia. The second main stimulus for archaeobotanical reports, if not for systematic research, has been the identification of occasional, individual and conspicuous remains from archaeological sites, such as the wooden coffins from Ongbah Cave (Sørenson 1988:28) and the historic-period shipwrecks from the Gulf of Thailand, which have provided waterlogged wooden artefacts including planks, pegs, bamboo and rattan walling, as well as the boats themselves (Howitz 1977:22).

Archaeobotany in Thailand has been strongly integrated with ethnobotanical research, in part because of the later inception of prehistoric archaeology there, at a time when such themes were being explored worldwide, but also because, in regions such as this where little success had been achieved in the recovery of plant remains, what archaeobotanical evidence there was was better understood in the light of ethnobotanical models of plant exploitation. The plant remains might offer only shadowy 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 by White at Ban Chiang (1982a, 1982b, 1984, 1989), whose method was complementary to Yen's assemblage-focused research, in that she concentrated on an in-depth study of a single community and its plant resources, in order to address questions which are not readily answered by the archaeobotanical record alone.
In like fashion, archaeobotanical analyses of material from Hoabinhian sites in the Ban Kao district of west-central Thailand (Pookajorn 1984:53; Na Songkla 1984, cited by Pookajorn 1987:77; Pyramarn 1989) were integrated with the study of contemporary plant use, especially medicinal applications, by the Mlabri, a forager group living in the northwest 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 included evidence for stimulants, medicinal, poisonous and adhesive plants, as well as nuts and tree fruits (Gorman 1969; Yen 1977).

There was, nevertheless, a tendency to use the evidence of rice from archaeological sites for tracing the phylogenetic and biogeographical evolution of the cultigen (e.g. Chang 1976a:430-1) rather than to consider the place of these plants 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). Higham's initial approach to the retrieval of plant remains at Khok Phanom Di followed in this traditional path, but the archaeobotanical data to have 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.
1.6 Aims and organisation of the thesis

The focus of this thesis is on the site, since the archaeobotanical work described, pioneering in the region for its attempt at completeness of recovery and detail of attention, was pursued side by side with other specialist enterprises aimed at exploring the entire information potential of the excavated data. One major concern was to investigate, as fully as possible, the prehistoric environmental setting of the site. Work on this thesis began with the intention, through the most meticulous examination of the plant remains recovered, of contributing to both the environmental reconstruction offered by parallel palynological, sedimentological, geomorphological and microfaunal investigations, and the economic base of Khok Phanom Di society. This was strengthened by the short time span of occupation, which, as we have seen, rendered inappropriate some of the aims with which the project had originally started. In respect of the site economy, the objective was to look specifically at the plant versus animal contribution, the terrestrial as opposed to the aquatic inputs and especially the relative contributions of domestic and wild plants to the diet. Environmental and economic aspects were to be integrated throughout the occupation sequence as the plant remains were derived from the local vegetation but filtered by human selection and other taphonomic factors, and in circumstances of environmental change.

The overall aims were limited by two circumstances. One was the nature of the archaeobotanical materials recovered. The second was the fact that complementary investigations were going on at the same time, but in another country, so that only provisional results were available during progress with the plant remains and interpretations inevitably changed during the course of the research.

The thesis first discusses the archaeology of Khok Phanom Di and its past and present surroundings in chapter 2, through an outline of the results of archaeological and palynological research at the site, together with broader aspects of the region’s Holocene history. The cultural and temporal sequence against which the botanical data will be examined are set out, along with a tentative correlation between the cultural and palynological data.
The following chapter (3) describes 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 emphasised, so that underlying assumptions are made explicit and the results may be assessed in terms of the contributing techniques.

The main classes of plant remains from the site are discussed at length in each of the succeeding four chapters (4-7) with the applicability of the archaeobotanical method to a number of research questions demonstrated in each material-related chapter. Chapter 4 deals with the charcoals and woods as a basis for reconstructing the arboreal vegetation around the site and exploring the evolution of its environment in the context of changing land-sea relations. Chapter 5 examines the seed remains extracted from the flotation samples, and the contribution they make to the interpretation of the vegetation in the site's environment. Chapter 6 then moves on to a consideration of food plants, with a dual focus, substantively on the many rice remains from the excavation and methodologically with a critical exploration of identification criteria for fragmentary *Oryza* husks. 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 7 through observations of agricultural practice from lowland Thai farming communities. These lay the foundation of an ethnographic model for the interpretation of rice remains from archaeological sites. The processing sequence for rice is compared with post-harvest technologies for wheat and barley and suggestions made to account for the poorer preservation of rice in the archaeological record.

Finally, a synthesis of the archaeobotanical results is presented in chapter 8 together with discussions on the resource potential of the habitats indicated by the plant remains, and some taphonomic consideration of the plant component to the tropical coastal diet.
Chapter Two

KHOK PHANOM DI,
THE PREHISTORIC SITE AND ITS ENVIRONMENTAL SETTING

2.1 INTRODUCTION TO KHOK PHANOM DI

Until about 10,000 years ago sea level was 40-60 m below present as water was immobilised in high-altitude and high-latitude icesheets (Chappell and Thom 1977:281). The subsequent post-glacial eustatic rise in sea level had profound implications for the Southeast Asian region as vast, low-lying areas of the Pleistocene landmass (Sundaland) were submerged, causing human populations to move inland with the ever-receding strandline. The coastal position of Hoabhinian sites like Gua Kepah and Bukit Chuping in present-day peninsular Malaysia, located on steep shores or in areas without a broad shelf, changed little relative to the rising post-Pleistocene sea (Gorman 1971:308), while the economy of long-occupied inland sites like Lang Rongrien on the western side of the Thai peninsula intermittently incorporated marine products in their resource base as sea level fluctuated bringing coastal habitats in and out of the site's catchment (Anderson 1990:4). Elsewhere though, on gently shelving shores such as those around the Gulf of Thailand and along the northeast coast of Sumatra (Tweedie 1953), localities occupied during this period have been lost to archaeology by burial under deep deposits of marine clay.

In Central Thailand, which is the common designation for the lowlands at the head of the Gulf, some evidence occasionally comes to light when deep fishponds or canals are dug through the marine clay down to previous landsurfaces, while the numerous offshore islands along the southeastern seaboard, such as Ko Si Chang, Ko Chang, Ko Samet and Ko Kut, extensions of the north-south ridges crossing the southern plain (Donner 1982:325) and the interior plains, could offer a window on the cultural landscape of more than 4000 years ago which is when it is thought that the sea reached its highest level in the area (Geyh et al. 1979; Tija 1980; Tija et al. 1977, 1983). The only known sites remaining from these earlier millennia are upland
rockshelters (Higham 1989:31) like Sai Yok (van Heekeren and Knuth 1967) and a
group of caves in the Ban Kao area, Khao Thalu, Ment, Heap and Petch Kuha Caves
(Pookajorn 1984, 1990), together with the Bang and Lue sites (Sørenson 1967),
briefly and intermittently occupied by bands of hunters, while the earliest complete
evidence of coastal occupation, and for settled communities, is from those groups
which came to occupy shorelines above those of today, after 4000 years ago. This
was the period after the transgression, when sea levels stabilised, albeit temporarily,
at a position 2-3 m higher than today. The coastline fluctuated, then receded to its
present location. Dunn (1971) has argued that the coastal adaptation undoubtedly
well developed among the Pleistocene and early Holocene occupants of the extensive
mangroves and lowland swamps is expressed in the sites along the raised shorelines
of Southeast Asia.

A number of coastal settlements relating to this higher sea level was identified in
1984 during an intensive field survey in the lower Bang Pakong valley, encompassing
part of the delta and adjacent alluvial foothills (Bannanurag 1989:4; Higham 1990:1-2).
Pre-eminent among them is the mound called Khok Phanom Di.

As indicated in the previous chapter, Khok Phanom Di has been the focus of a
number of archaeological investigations since Suchitta's (1980, 1984)
ethnoarchaeological research there in 1978 and his detailed interpretation of the
exposed sections along a roadcutting. Excavations by Noksakul (of Chachoengsao
Teacher Training College) in 1979 and by Pisnupong in 1982 (Pisnupong 1984), on
behalf of the Royal Thai Fine Arts Department, Bangkok (SPAFA 1987b:28), laid the
basis for the ambitious excavation of 1985. This on-going multi-disciplinary project,
of which this study is part, was undertaken by the Fine Arts Department in
conjunction with the Anthropology Department of Otago University, Dunedin, New
Zealand, and directed by Rachanie Bannanurag and Charles Higham. The
palynological analyses associated with the project have been carried out at Queen's
University, Belfast, by Bernard Maloney and Judith Brown.

As the contour map of the site illustrates, the mound of Khok Phanom Di is
depressed in the centre with a slightly elevated rim around its margin (Figure 2.2).
FIGURE 2.1
GENERAL MAP OF SOUTHEAST ASIA INDICATING PREHISTORIC SITES MENTIONED IN THE TEXT

Stippled area is land over 182 m

Adapted from a base map prepared in the Department of Anthropology, University of Otago
Noksakul excavated a 5 x 3 m area, revealing 12 inhumation burials set in a complex stratigraphy 8.8 m deep, while Pisnupong's investigation, closer to the centre of the mound, was somewhat larger, 7 x 3 m, and revealed a further 13 graves in a shallower stratigraphy (Bannanurag 1989:12-13; Higham 1990:1). Their findings indicated at the base of the sequence an abundance of molluscs collected from a mangrove coast, declining in numbers through time, which confirmed Suchitta's (1980, 1984) hypothesis that the site had a previous marine orientation. The excavations also provided a range of cultural materials, including a few small polished stone tools, large quantities of ceramic sherds, clay anvils and burnishing stones, indicative of pottery production, and clay net sinkers, bone fish hooks and harpoons, supplying additional evidence of a fishing economy. Shell beads and bracelets and part of a stone bangle were also found, singly or in association with the burials.

2.1.1 The 1985 excavation at Khok Phanom Di

The combined evidence from the 1978, '79 and '82 investigations, together with the outstandingly large size of the mound, indicated that the site warranted a much larger excavation. This took place during the first seven months of 1985.

A 10 m by 10 m square, sides aligned to the cardinal points, was sub-divided into four quadrants (A-D). Two quadrants were actively excavated at a time, while the other two were planned or had features removed. The excavators encountered a complex stratigraphic sequence 6.8 m deep, including graves, pits, postholes, midden, ash spreads and hearths. Eleven major layers were recognised. Each layer was removed in arbitrary 10 cm spits. The surface of each spit was cleaned in order to identify changes in the matrix indicating the edge of a feature, after which the feature in question was treated as a separate entity by excavation and recording (Bannanurag 1989:14; Higham 1990:15). Most of the stratigraphic references in this thesis are to layers and spits, abbreviated, so that, for example, layer 5 spit 4 is given as 5:4 and layer 10:25 means spit 25 in layer 10. The stratigraphy is described in detail in Higham and Bannanurag (1990a:19-21, 31-48), but an example of the
FIGURE 2.2
KHOK PHANOM DI MOUND SHOWING THE LOCATION
OF EXCAVATIONS AND POLLEN CORES

Adapted from Maloney et al. (1989:364)
intricacy of lensing and intercutting features is illustrated here in the profile of the southern section (Figure 2.3).

The area investigated in 1985 was first briefly used for habitation and for firing pottery, then for several centuries as a cemetery and in its final years as a ceramic workshop, where vessels were prepared using a paddle and anvil technique before being taken to the edge of the mound for firing. The site stratigraphy has been subdivided for analytic purposes into three phases (Higham et al. 1987:149). Zone A is the bottom 3 m of deposits, comprising layers 10 (26 spits) and 11 (two spits), while Zone B refers to the next 2.8 m of stratigraphy, incorporating layers 4-9, that is, from 4.16 m to 1.10 m below datum. The top 110 cm comprise Zone C.

The site chronology has been established through 18 conventional radiocarbon dates on well-provenanced charcoal samples from layers 6-11 of the deposit (Higham and Bannanurag 1990a:19), while the associated pollen cores have nine AMS dates (Maloney and McAlister 1990:376) (Table 2.1).

The Zone A deposits were laid down from around 2000 BC. The stratigraphically lowest radiocarbon date, taken from a hearth in 11:2, is 3560 ± 80 bp (=uncalibrated) (ANU-5493) (2130-1700 BC), though a second sample from 20 cm higher up the profile, in 10:25, is about 200 years older, 3720 ± 100 bp (ANU-5490, 2450-1905 BC). Within this zone were 104 inhumation burials, the earliest six arranged in a dispersed manner and devoid of grave goods, the later 98, with heads pointing to the rising sun, and separated by spaces of several metres (Figure 2.4). Deposits 40 cm deep intervened between the early dispersed burials and the later regularly arranged ones. The remainder of the Zone A deposits comprised habitation debris, complicated small lenses, overwash deposits, charcoal spreads, ash lenses and shell middens. Intercutting and disturbance by pits and postholes were greater during this phase than in any other part of the stratigraphy.

Between Zones A and B a major stratigraphic break was observed, where burials were absent (Higham and Bannanurag 1990a:37). Zone B was then dominated in the northeast quadrant (C) by a raised rectangular platform (Figure 2.4) with 43 successive floors of smooth plaster, interpreted as a mortuary structure. Burials
FIGURE 2.3
THE SOUTH SECTION AT KHOK PHANOM DI

Source: Higham and Bannanurag (1990a:52)
continued elsewhere in a nucleated distribution, with a total of 51 graves being excavated in the zone. The general character of the deposits was more homogeneous, the matrix sandier and the intercutting of pits, postholes and other features less pronounced than in Zone A. The precise dating of this phase is difficult and exemplifies the problem of overlapping dates throughout the sequence at the site. The lowest sample from Zone B, taken from a hearth in 9:7 (NZ-7063, 4410 ± 300 bp, 3685-2275 BC), is evidently too old for the general sequence (Higham and Bannanurag 1990a:19), while the date from charcoal under lens 9 in 9:6 (NZ-7060, 3680 ± 90 bp, 2390-1780 BC) is around 500 years older than that from 10:6 (ANU-5484, 3280 ± 140 bp, 1925-1225 BC). The date of the upper boundary of Zone B remains unknown due to a lack of dateable material; the radiocarbon sample with the stratigraphically highest position, was from 6:6, at 3310 ± 128 bp (ANU-5482, 1930-1310 BC).

Due to a lack of well-provenanced charcoal in layers 1-5, it has not proved possible to date Zone C which occupies the upper metre or so of deposit, but this is considered to have been of short duration, probably no more than a century, between 1500 and 1400 BC (Higham and Bannanurag 1990a:19) and to have postdated the local fall in sea level. This final phase was a dark humic deposit, devoid of burials, the greater part of the material culture being ceramics and the raw materials and tools for their construction. Specifically, the assemblage comprised stone bangles and polished axes, together with large quantities of broken potsherds, clay cylinders, piles of clay and implements for pottery manufacture: anvils and burnishing pebbles.
FIGURE 2.4
THE DISTRIBUTION OF FEATURES IDENTIFIED IN LAYER 6.4, INCLUDING THE RAISED PLATFORM

Abbreviations: *: depth at this point below datum, Q: quadrant, F: feature, L: layer, SB: shell disc/bangle. The number after the shell bangle is its catalogue number.

Source: Higham and Bannanurag (1990a:104)
2.1.2 The mortuary evidence

Khok Phanom Di is outstanding in the Southeast Asian archaeological record in the large number and excellent preservation of human burials excavated at the site. A total of 153 inhumation burials was found, with the earliest grave cut at 6.51 m below datum and the latest at 1.20 m. A detailed analysis of the temporal and spatial distributions of the Khok Phanom Di burials has been presented as Bannanurag's (1989) doctoral thesis and in Higham and Bannanurag (1990a:19-363).

Individual mortuary practice followed complex ritual. The body was clothed and often adorned with strings of shell beads, shell and stone bangles and anklets. It was perhaps wrapped in a winding cloth (see chapter 5 on putative tapa) and dusted with red ochre before being placed in an extended position, on the back, in a shallow grave. The graves were almost always set out with the head pointing to the rising sun. The remains of wooden biers were found and are discussed further in chapter 4. Some of the women and children were accompanied by the raw material (piles of processed clay) and the tools (clay anvils and burnishing stones) for pottery-making, while the men were buried with carved turtle carapace breast-plates. Many people were buried with exquisite complete ceramic vessels, while infants were often buried inside a large pot. Lines of postholes, sometimes with shell midden banking up against the walls, are taken to signify fences around burial clusters or even structures covering them in (Higham and Bannanurag 1990a:35).

The seven meters of deposit removed during the 1985 excavation are accounted for by only 500 years or so of occupation, the rapid rate of deposition being brought about largely by the discard of massive quantities of shell and other food remains. This means that we have a situation where burials are preserved in a well-differentiated vertical sequence, with horizontal clustering observed to persist through time. The mortuary sequence provided evidence for burials interred as family groups over as many as 20 generations. From her study of a number of genetically controlled markers, revealed as skeletal abnormalities, Choosiri (1988) has demonstrated that individuals were buried in horizontal and vertical clusters with others with similar attributes. In addition to these features of the cranial and limb bones were indications of ritual removal of teeth strongly distinctive of specific
burial clusters. These lines of evidence have led to the conclusion that the people of Khok Phanom Di interred their dead in family-based lineages, with successive generations being superimposed above one another.

Evidence from the spatial arrangement of the burials and the increasingly inequitable distribution of wealth in the form of grave-goods suggests the development of social ranking during the occupation of the site, notably within Zone B. The fact that the mortuary wealth displayed by certain women was followed during successive generations in the same family by less elaborate burials has been interpreted as status gained through personal skills in pottery making, rather than through inheritance. This, it has been argued, was the basis of a matrilineally oriented society (Bannanurag 1989:372; Higham and Bannanurag 1990b; Higham 1991). The increasing population density associated with the sedentary nature of the occupation and the community's position at a strategic trading node, together with the emergent social hierarchy, have led Higham (1989:82) to propose the concept of the domestication of society rather than of biological resources at Khok Phanom Di.
Table 2.1 Radiocarbon dates from Khok Phanom Di and associated pollen cores. All are based on a 5570 year half-life. They are calibrated according to Pearson and Stuiver (1986) and expressed at the 95% confidence interval except where indicated. Dates earlier than 2500 BC are corrected using Klein et al. (1982).

<table>
<thead>
<tr>
<th>Context</th>
<th>Source</th>
<th>Lab. No.</th>
<th>Radiocarbon yrs ±</th>
<th>yrs BC/AD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KPD 1985 EXCAVATION SAMPLES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layer 6:6</td>
<td>charcoal</td>
<td>ANU-5482</td>
<td>3310 ± 128</td>
<td>1930-1310 BC</td>
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<tr>
<td>Layer 8:2</td>
<td>lens 4 ash lens</td>
<td>NZ-7020</td>
<td>1910 ± 235</td>
<td>590 BC-665 AD (92%)</td>
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<tr>
<td>Layer 8:2</td>
<td>lens 4 ash lens</td>
<td>ANU-5483</td>
<td>3430 ± 80</td>
<td>1930-1525 BC</td>
</tr>
<tr>
<td>Layer 8:3</td>
<td>lens 6 ash charcoal</td>
<td>NZ-7021</td>
<td>3780 ± 120</td>
<td>2565-1895 BC</td>
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<tr>
<td>Layer 8:7</td>
<td>lens 10 charcoal</td>
<td>NZ-6973</td>
<td>3280 ± 140</td>
<td>1925-1225 BC</td>
</tr>
<tr>
<td>Layer 9:1</td>
<td>white ash lens</td>
<td>NZ-7033</td>
<td>3290 ± 110</td>
<td>1812-1310 BC (94%)</td>
</tr>
<tr>
<td>Layer 9:6</td>
<td>charcoal under lens 9</td>
<td>NZ-7060</td>
<td>3680 ± 90</td>
<td>2390-1780 BC</td>
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<tr>
<td>Layer 9:7</td>
<td>hearth</td>
<td>NZ-7063</td>
<td>4410 ± 300</td>
<td>3685-2275 BC</td>
</tr>
<tr>
<td>Layer 10:6</td>
<td>lens 3 hearth</td>
<td>ANU-5484</td>
<td>3280 ± 140</td>
<td>1925-1225 BC</td>
</tr>
<tr>
<td>Layer 10:13</td>
<td>lens 10 charcoal lens</td>
<td>ANU-5485</td>
<td>3410 ± 110</td>
<td>1975-1545 BC</td>
</tr>
<tr>
<td>Layer 10:15</td>
<td>lens 11 ash lens</td>
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<td>3610 ± 90</td>
<td>2270-1740 BC</td>
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<tr>
<td>Layer 10:19</td>
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<td>ANU-5492</td>
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<td>charcoal</td>
<td>ANU-5490</td>
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<tr>
<td>Layer 11:2</td>
<td>hearth 1</td>
<td>ANU-5493</td>
<td>3560 ± 80</td>
<td>2130-1700 BC</td>
</tr>
</tbody>
</table>

| **POLLEN CORE SAMPLES** | | | | |
| KL2 | 0.87-0.91 m | OxA-1354 | 3360 ± 120 | 1955-1410 BC |
| KL2 | 1.46-1.50 m | OxA-1355 | 560 ± 150 | 1125-1665 AD |
| KL2 | 2.25-2.29 m | OxA-1356 | 5560 ± 160 | 4770-4040 BC |
| KL2 | 3.50-3.54 m | OxA-1357 | 6060 ± 200 | 5370-4515 BC |
| KL2 | 4.82-4.86 m | OxA-1358 | 6280 ± 130 | 5475-4940 BC |
| KL2 | 4.91-4.95 m | OxA-1359 | 6400 ± 300 | 5870-4685 BC |
| BMR2 | 0.88-0.92 m | OxA-1449 | 3960 ± 100 | 2770-2145 BC (88%) |
| BMR2 | 3.96-4.00 m | OxA-1360 | 6560 ± 100 | 5635-5310 BC (94%) |
| BMR2 | 6.60-6.64 m | OxA-1361 | 6610 ± 140 | 5735-5240 BC |

Sources: Higham and Bannanurag (1990a:23)
Maloney and McAlister (1990:376)
Table 2.2 Radiocarbon dates from the 1979 excavation at Khok Phanom Di.

<table>
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<th>Source</th>
<th>Layer</th>
<th>Depth below datum</th>
<th>Date (uncalibrated 5730 half life)</th>
</tr>
</thead>
<tbody>
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<td>Skeleton 2</td>
<td>layer 6</td>
<td>230-240 cm</td>
<td>2100 ± 290 bp</td>
</tr>
<tr>
<td>Skeleton 5</td>
<td>layer 6</td>
<td>230-240 cm</td>
<td>2120 ± 320 bp</td>
</tr>
<tr>
<td>Skeleton 7</td>
<td>layer 6</td>
<td>320-330 cm</td>
<td>2540 ± 320 bp</td>
</tr>
<tr>
<td>Skeleton 8</td>
<td>layer 6</td>
<td>320-330 cm</td>
<td>2020 ± 320 bp</td>
</tr>
<tr>
<td>Skeleton 6</td>
<td>layer 7</td>
<td>350-370 cm</td>
<td>5640 ± 400 bp</td>
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<tr>
<td>Skeleton 9</td>
<td>layer 7</td>
<td>420-450 cm</td>
<td>6470 ± 370 bp</td>
</tr>
<tr>
<td>Skeleton 10</td>
<td>layer 7</td>
<td>430-450 cm</td>
<td>6410 ± 400 bp</td>
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<tr>
<td>Charcoal</td>
<td>layer 8</td>
<td>580-600 cm</td>
<td>6060 ± 400 bp</td>
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<tr>
<td>Skeleton 11</td>
<td>layer 8</td>
<td>670-700 cm</td>
<td>6800 ± 420 bp</td>
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<tr>
<td>Shell</td>
<td>layer 8</td>
<td>670-700 cm</td>
<td>4900 ± 350 bp</td>
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<tr>
<td>Shell</td>
<td>layer 10</td>
<td>780-800 cm</td>
<td>4520 ± 310 bp</td>
</tr>
</tbody>
</table>

Source: Bannanurag (1989:19)
2.1.3 A review of the faunal remains

The faunal assemblages from Khok Phanom Di have been examined by Grant and Higham, dealing with the terrestrial large mammalian remains, and West the bird bones and other microfauna, most of which were rats, while Mason has identified the molluscs and Kijngam the fishbones. The summary presented here is drawn from their accounts (in press). Their results give information about surrounding habitats as well as the subsistence choices and hunting, trapping, fishing and gathering techniques by the occupants of the site. The faunal spectrum is almost exclusively of wild animals. None of the mammalian remains are considered to come from domestic animals (Higham and Maloney 1989:657; Grant and Higham in press), but the occurrence of jungle fowl outside its usual dry interior distribution has been taken as possible indication of bird domestication (West in press:188).

Throughout Zones A and B the majority of the faunal remains were aquatic: fish, turtle, squid, crustacea and shellfish, mainly from mangrove and mudflat habitats, with a small minority probably derived from sandy areas. Mammalian bones and antler from a limited range of taxa and few individuals constitute a small but consistent proportion of the faunal remains in Zones A and B. These are of small and medium-sized deer, macaques and wild pigs. The macaques are possibly Macaca fascicularis, the crab-eating macaque, while the deer, Cervus eldi and C. schomburgki, could have browsed through freshwater swamp forest, which the pollen evidence suggests as occurring in the vicinity of the site. Zone C witnessed a major change in the faunal assemblage, with the marine taxa almost disappearing from the spectrum and a great increase in the quantity and variety of mammalian remains, including swamp-woodland animals like pig (Sus scrofa), monkey (Macaca sp. and Presbytis sp.), Schomburgk’s, Eld’s and pig deer (Cervus schomburgki, C. eldi and Axis porcinus) and the wild water buffalo (Bubalis bubalis). These changing proportions in the faunal assemblage are compatible with the establishment of herbaceous swamps within the site catchment during the final century of occupation.
2.2 THE SITE'S CURRENT SETTING ON THE BANGKOK PLAIN

All the faunal evidence from the site indicates its initially marine-estuarine orientation, with a situation on the coast during a stillstand in sea-level fluctuations and later abandonment after sea-level fell away. The timing of occupation and the activities undertaken there are closely related to the site's relationship with the coast, so geological, geomorphic and eustatic factors are important as background to human occupation of the area. This section of the thesis will outline the site's contemporary situation before moving on to a summary of the Holocene history of the area. The vegetation will be introduced here, but greater detail, based on botanical surveys carried out as part of this research, will figure in later chapters.

2.2.1 Geology, Topography and Soils

The area under consideration is the eastern flank of the Chao Phraya delta, at the head of the Gulf of Thailand, where the lowlying swampy coastal region is juxtaposed against alluvial foothills. Khok Phanom Di is situated in the lowlying, lower reaches of the Bang Pakong Valley, the most easterly of the four main rivers flowing into the upper Gulf. The confluence of the Nakorn Nayok and Prachinburi Rivers about 25 km north of Chachoengsao creates the wide, meandering river known as the Bang Pakong in its coastal stretch. The gradient of this river system is so slight that tidal influence penetrates as far as 80 km upstream. Groundwater throughout the coastal plains is saline.

The extensive catchment, which covers 19,252 km² (Donner 1982:327), is bounded to the north by the Samkamphaeng Range and to the south by rolling lowlands which barely exceed 100 m a.s.l. (Donner 1982:320). The valley stretches east from the coast, providing easy access to Tonle Sap and associated river systems, as well as to the Mun Valley further north. The Samkhamphaeng mountains to the north belong to the Korat Group, comprising pre-Triassic porphyry at the western end and sandstones, conglomerates, siltstones and shales in the centre and at higher altitudes in the east, together with micaceous shales along the southern flanks (Donner 1982:321). The parts of the region which concern us here, however, are the Quaternary and Recent sediments.
The lower Bang Pakong Valley is a southeastward extension of the Bangkok Plain, an extensive deltaic region, with flat terrain and minimal microrelief of only around 2 m amplitude and lying 2-3 m above sea level. The area comprises extensive greenish marine clays with yellowish weathering mottles (Takaya 1972) underlying dark grey brackish clays, both deposited during times of higher sea level, when the coastline was 20 - 100 km inland and 2 - 3 m higher than today (Thiramongkol 1984). These interdigitate with coarser fluvial materials deposited by the major rivers, the Chao Phraya and the Bang Pakong. The brackish clays have been used to delimit the distribution of the former mangrove and Nypa swamps fringing the coast during the +2.5 m stillstand, thereby marking the higher shoreline (van der Kevie 1971). Khok Phanom Di lies on the marine clays, just landward of the junction between them and brackish water deposits which reflects the mound's prehistoric coastal location.

In physiographic terms, the lower Central Plain, Takaya's (1971) delta flat, has low elevation, lying 2-3 m above sea level, with virtually no relief. It is bordered along the margins by alluvial fans, and terraces at slightly higher elevations. The soils around Khok Phanom Di are silty clays, derived from the marine and brackish-water clays laid down after the marine transgression, while a broad band of acid sulphate soils coincides with the marine deposits around the landward margins of the delta (van Breemen 1976:161). These cover 36% of the Bangkok Plain according to Attanandana and Vacharotayan (1986:154-5) causing acidity problems when drained for cultivation.

2.2.2 Climate

The region under study, indeed most of mainland Southeast Asia, falls within the tropical savanna as defined by Kyuma (1978:164) and the humid savanna regime according to Harris (1980:4), with 2.5 to 5 arid months per annum. Temperatures in this part of Thailand are high throughout the year, with greater day/night contrasts than between seasons (Table 2.3). The dominant climatic pattern derives from the seasonal distribution of rainfall, concentrated in the southwest monsoon, from May/June to October/November (Table 2.4). The mean annual precipitation for the
area around Khok Phanom Di is between 1300 and 1400 mm. Precipitation in the region is greatest along the coast, with total rainfall decreasing in an easterly direction up the Bang Pakong Valley due to the rainshadow effect of the Samkhamhaeng Range (Donner 1982:333). Annual rainfall at Chachoengsao is 1,372 mm, with more than 70% of the precipitation falling during the southwest monsoon from June to October, September being the wettest month (269.3 mm). The hot dry season is intermittently punctuated by convection showers in April and the monsoon proper begins in May or June, so that the beginning of the rainy season is less well marked than its end. The rest of the year is dry, as the shift in the winds brings dry air from continental Asia down to the head of the Gulf.

Temperature records from the closest meteorological stations to the site are available for inland Prachinburi and coastal Chonburi. Maritime areas usually experience a narrower annual temperature range than the interior, where seasonality is more pronounced, although the difference is not great in the data below, perhaps because Chonburi town is a few kilometres from the coast, and an urban area which has been totally deforested and where the weather pattern is strongly influenced by air currents over the landmass. Taking the rainfall and temperature data together, then, the local climate at Khok Phanom Di is dominated by three seasons, the hot and wet months of June to October, a cool dry period from November to January and a hot dry spell between February and May. Maximum temperatures hover around 35°C in the hottest months and temperatures can fall to as low as 12°C at night in December.

The seasonal climate, in combination with the low, flat topography, brings great change to the landscape as heavy rainfall coincides with large volumes of water flowing through the catchment during the monsoon. Together these cause flooding in the downstream portion of the catchment and transform the delta into a wide expanse of water during the wet season, though it reverts to a waterless desert later in the year. This annual flooding regime creates Takaya's (1971:388) "amphibious terrain", with a number of implications for the human occupation of the region which will be discussed further in chapter 8.
Table 2.3  *Mean temperatures in the Khok Phanom Di region*

<table>
<thead>
<tr>
<th>Station</th>
<th>Years</th>
<th>Mean Maximum</th>
<th>Annual Mean</th>
<th>Mean Minimum</th>
<th>Difference (Max./Min.)</th>
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<tbody>
<tr>
<td>Prachinburi</td>
<td>1952-70</td>
<td>33.0</td>
<td>28.0</td>
<td>23.0</td>
<td>10.0</td>
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<tr>
<td>Chonburi</td>
<td>1945-70</td>
<td>32.0</td>
<td>27.8</td>
<td>23.6</td>
<td>8.4</td>
</tr>
</tbody>
</table>

(source: Donner 1982:336)

Table 2.4  *Monthly and annual norms of rainfall in the Khok Phanom Di region (mm; averages of 30 years)*

<table>
<thead>
<tr>
<th>Station</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>Ann. Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chachoengsao</td>
<td>10</td>
<td>17</td>
<td>45</td>
<td>80</td>
<td>148</td>
<td>137</td>
<td>207</td>
<td>180</td>
<td>280</td>
<td>177</td>
<td>86</td>
<td>7</td>
</tr>
<tr>
<td>Chonburi</td>
<td>11</td>
<td>21</td>
<td>44</td>
<td>78</td>
<td>153</td>
<td>133</td>
<td>185</td>
<td>152</td>
<td>293</td>
<td>29</td>
<td>56</td>
<td>2</td>
</tr>
</tbody>
</table>

(source: Donner 1982:336)
2.2.3 Present day land-use

The term "savanna" has greater applicability to the climate of the lower Bang Pakong Valley than it does to the vegetation. Its biogeographical sense has been lost due to last century's agricultural expansion throughout the coastal lowlands, and the land around Khok Phanom Di is now completely under rice cultivation. Agriculture in the area is essential sedentary and market-oriented. Very few smallholders can be said to operate purely for subsistence. Traditional aspects of rice cultivation in the area, especially relating to harvesting and the subsequent processing of the crop, are discussed in greater detail in chapter 7.

There is a broad degree of correspondence between landform, soil type and land use. Around Khok Phanom Di a single rice crop is planted in June and harvested in December or January. Later in the year a dry season crop of melons or beans, for example, is grown on some of the dry paddies. Closer to the Bang Pakong, in the area around and particularly to the north of Chachoengsao, where the land is wetter, two crops per year are harvested (Lokaphadhan 1976). The dominant land use throughout the region is rice cultivation, although there are pockets of coconut plantations in brackish enclaves near the Bang Pakong estuary and occasional mango orchards in drier areas, while gardens are cultivated around individual households. These home-gardens provide a selection of fruit and spice trees and vegetables for domestic use.
2.3 THE EVOLVING ENVIRONMENTAL SITUATION

2.3.1 Holocene sea level change in the Gulf of Thailand

The Holocene sea level curve for the Gulf of Thailand has been reconstructed through the mapping of Quaternary and Holocene deposits (e.g. Takaya 1972; Dheeradilok and Kaewyana 1984) and the geomorphological investigation of the Bangkok Plain (e.g. Thiramongkol 1984), supported by palynological and palaeontological studies (e.g Hastings and Pramojanee 1983; Somboon 1988).

Radiocarbon dates on peat, wood and sub-fossil shell from the clays suggest that the last marine transgression across the plain began about 8000 years ago (Somboon 1988:206), which broadly concurs with a $8400 \pm 1300$ bp date for the same event at Chantaburi on the southeast coast (Hastings and Pramojanee 1983). At the height of the Holocene transgression between 5000 and 6000 years ago, the rising shoreline penetrated as far north as Ayutthaya, now more than 90 km inland, at +4 m altitude (Geyh et al. 1979; Nutalaya and Rau 1981; Dheeradilok 1987:153). Subsequent oscillations of the marine regression brought the sea level to +2.5 m at about 2000 BC. The position of this higher shoreline has been mapped using the current topography and the extent of the brackish deposits, although these are not always congruent along the eastern margins of the lower Central Plain due to tectonic displacement of the young sediments (Thiramongkol 1987).

A more detailed analysis is available for peninsular Malaysia, where the post-Pleistocene transgression has been reconstructed on the basis of more than 40 radiocarbon ages along raised shorelines (Tija et al. 1977). Here too the evidence indicates a period of raised sea level between 5000 and 3500 years ago. A broadly similar set of stratigraphic and palynological results from the north Australian coast, demonstrate a transgression leading to a major mangrove phase from 6500 to 7000 years ago, followed after a thousand year stillstand by sedge and grass plains in wet areas and hypersaline plains in drier regions. These sequences have been interpreted in terms of relative sea level change brought about by "sedimentation, after the sea level stabilized, progressively eliminating intertidal environments, effectively choking out most of the mangrove swamp by $\sim 5500$ yr BP" (Woodroffe et al. 1985a:712; developed further in Woodroffe et al. 1985b and c). This picture offers an
alternative perspective on the ecological transformation witnessed during the mid-Holocene in the Gulf of Thailand and the eustatic explanation offered for it. The immediate issue here, though, is that of the biogeographical consequences of sea level change, as translated into resource availability and above all, in terms of the human response, rather than the precise mechanisms and underlying reasons for the changes themselves.

2.3.2 Pollen analyses close to Khok Phanom Di

The pollen and stratigraphic investigations undertaken as part of the Khok Phanom Di project set out to reconstruct a three-dimensional picture of the vegetation around the site. Fifteen cores were taken, many in close proximity to the site (Figure 2.3) and others up to 7 km away at Bang Ban Hak, towards the Bang Pakong river. Six of the cores were eventually analysed, together with the stratigraphic record from a monolith extracted from a fishpond close to the mound which was dug in early 1985 (Maloney in press:37). The cores have been dated by accelerator mass spectrometry (AMS) (Table 2.1) and cross correlated by bands with high particulate charcoal frequencies. The upper metre of core deposits is tentatively thought to correlate with the human occupation which gave rise to the site excavated, but further indications of human activity are seen lower in the sequence. The results are published by Maloney (1986, 1987, 1988, in press; Maloney and Brown 1990; Maloney and McAlister 1990; Maloney et al. 1989), but a short summary will be presented here.

In brief, the pollen record in the lower parts of the cores was dominated by mangrove taxa *Rhizophora* and *Bruguiera/Ceriops* for most of their length, with Gramineae generally at low levels but becoming dominant in the upper metre of deposit. The grass taxa include *Eragrostis, Paspalum* and possibly *Coix*. This picture is consistent with the incursion of mangrove forest into the area at the time of the mid-Holocene transgression. Two burning episodes represented by rises in charcoal particle levels in core KL2 suggest possible human activity in the area at 4755-5800 BC and 4555-5300 BC, but as they do not coincide with a rise in grass pollen, the burning may have been due to natural causes or hunting burn-offs (Higham and Maloney 1989:661). These early indications of burning, however, are absent from
core BMR2, only 4 m away. Increasing grass pollen frequencies in both KL2 and BMR2 coincided with another rise in charcoal particles around 6000 years ago (3960-4710 BC). Thus, it is suspected that rice was growing and being used in the area by the end of the 5th millennium BC (around 4300 BC) but that the habitation sites associated with this early phase of activity were buried by marine clays (Maloney et al. 1989).

The upper parts of the cores are seen as providing strong evidence for human impact on the vegetation, through rising microfossil charcoal concentrations, indicating forest disturbance within the catchment, the increase of pollen types like Scirpus comp., which may have been growing as a weed in rice paddies, and grass pollens with diameters in the range of those of modern cultivated rice from Sumatra (Maloney et al. 1989). The pollen analyses also suggest that the prehistoric mound was intertidal from c. 6000-4300 BC and that during Zones A and B Khok Phanom Di was probably an island, in the inter-tidal zone, surrounded by very shallow water and exposed mudflats as the tide fell (Maloney in press).

The pollen spectra offer very little evidence for climate change (Maloney in press:78), although it is considered that "[t]he minor rise in sea-level probably did bring relatively short-lived moister conditions near the coast .." (Maloney 1987:158). The absence of climatic indicators in the pollen record is perhaps not surprising given the altitude and latitude of the area. There is as yet little palynological evidence for the Holocene vegetation of Thailand. Maloney's work as part of this project has made a major contribution to our understanding of the coastal plant communities, but in mangrove forests most of the pollen deposition is from a relatively restricted catchment compared with other depositional settings and other pollen taxa, so for a historical perspective on the regional vegetation, including inland forest, it would be necessary to look to an inland lake or bog (Maloney 1985:541), similar to that described for Tasek Bera (Morley 1981) and Lower Perak (Hillen 1983/4) in West Malaysia.
FIGURE 2.5
POLLEN DIAGRAMS FROM CORES KL 2 AND BMR 2,
SHOWING SELECTED TAXA ONLY

KL 2

1955 - 1410 BC
1125 - 1665 AD
3805 - 4040 BC
5370 - 4515 BC
5415 - 4940 BC
5870 - 4685 BC

Depth: meters

Source: Maloney et al. (1989:366-7)

BMR 2

2370 - 2146 BC
5635 - 5310 BC
5735 - 5240 BC

Depth: meters

Source: Maloney et al. (1989:366-7)
### Table 2.5 List of recorded tree and shrub species in the mangrove formations in Thailand

Source: Thawatchai Santisuk (1983)

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

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Vernacular Name</th>
<th>Family</th>
<th>Habit</th>
<th>C &amp; SE</th>
<th>E</th>
<th>W</th>
</tr>
</thead>
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<td>ngueak plaamo</td>
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<td>S</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>A. ilicifolius*</td>
<td>ee kreng</td>
<td>Acanthaceae</td>
<td>S</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
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<td>Pteridaceae</td>
<td>S</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>A. speciosum**</td>
<td>prong nuu</td>
<td>Pteridaceae</td>
<td>S</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
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<td>lep mue naang</td>
<td>Plumbaginaceae</td>
<td>S</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
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<td>Aegiceras carinatum*</td>
<td>to sai</td>
<td>Sapindaceae</td>
<td>S</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<td>+</td>
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<td>+</td>
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<td>chik suan</td>
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<td>T</td>
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<td>+</td>
<td>+</td>
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<td>+</td>
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<td>Apocynaceae</td>
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<td>+</td>
<td>+</td>
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<td>+</td>
<td>+</td>
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<td>Sam ma nga</td>
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<td>-</td>
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<td>S</td>
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### Scientific Name

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<td>T</td>
<td>+ + +</td>
</tr>
<tr>
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<td>khluu</td>
<td>Myrsinaceae</td>
<td>T</td>
<td>+ + +</td>
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<tr>
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<td>chaa lueat</td>
<td>Myrsinaceae</td>
<td>ST</td>
<td>- - +</td>
</tr>
<tr>
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<td>phrung nok</td>
<td>Myrsinaceae</td>
<td>ST/T</td>
<td>+ + +</td>
</tr>
<tr>
<td>R. umbellulata**</td>
<td>kongkaang bailek</td>
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<td>T</td>
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</tr>
<tr>
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<td>Euphorbiaceae</td>
<td>ST/T</td>
<td>+ + +</td>
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<tr>
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<td>Goodeniaceae</td>
<td>S</td>
<td>+ + +</td>
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<tr>
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<td>nam taeng</td>
<td>Flacourtiaceae</td>
<td>ST</td>
<td>- + +</td>
</tr>
<tr>
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<td>Rubiaceae</td>
<td>ST</td>
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<tr>
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<td>chee ngam</td>
<td>Rubiaceae</td>
<td>ST</td>
<td>+ + +</td>
</tr>
<tr>
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<td>paat</td>
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<td>T</td>
<td>+ + +</td>
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<td>T</td>
<td>+ + +</td>
</tr>
<tr>
<td>S. caseolaris*</td>
<td>lam phaen hin</td>
<td>Sonneratiaceae</td>
<td>T</td>
<td>+ + +</td>
</tr>
<tr>
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<td>Sonneratiaceae</td>
<td>T</td>
<td>- + +</td>
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<td></td>
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<td>T</td>
<td>+ + +</td>
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<tr>
<td>Sueada maritima*</td>
<td>cha khräm</td>
<td>Chenopodiaceae</td>
<td>US</td>
<td>+ + +</td>
</tr>
<tr>
<td>Thespesia populnea**</td>
<td>phi thale</td>
<td>Malvaceae</td>
<td>T</td>
<td>+ + +</td>
</tr>
<tr>
<td>Xylocarpus gangeticus**</td>
<td>ta bun</td>
<td>Meliaceae</td>
<td>T</td>
<td>+ - +</td>
</tr>
<tr>
<td>X. granatum*</td>
<td>ta buun khao</td>
<td>Meliaceae</td>
<td>T</td>
<td>+ + +</td>
</tr>
<tr>
<td>X. moluccensis*</td>
<td>ta buun dam</td>
<td>Meliaceae</td>
<td>T</td>
<td>+ + +</td>
</tr>
</tbody>
</table>

* Trees and shrubs absolutely bound to salt or brackish water (true mangrove species)

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

Additional mangrove plants of Thailand, as listed by Aksornkoae and Panichsuko (n.d.), Sangdee (1985:45), Aksornkoae et al. (1984) and Chapman (1988:54-5) are:

- Atalantia monophylla
- Caesalpinia cristoides
- Calliandra floribunda
- Combretum lelecomathum
- Cordia cochinichinensis
- Erythrina rhomboidea
- Grisebachia balanophora
- Terminalia sertocarpa
- Oncosperma filamentosum
- Caesalpinia digyna
- Litosansbes biflora
- Cassytha filiforma
- Kamphaeng chetchan
- Rang kasaa
- Santalaceae
- Rutaceae
- Leguminosae
- Combretaceae
- Erythraeaceae
- Tiliaceae
- Verbenaceae
- Meliaceae
- Leguminosae
- Rubiaceae
- Santalaceae
The main biota of concern here is the mangrove forest, which has a relatively narrow taxonomic range, listed in Table 2.5.

Information about the natural vegetation of the Khok Phanom Di area before its nineteenth century alteration is offered both by palaeoenvironmental reconstruction based on pollen counts and by historical records of the recent past. The environment of the lower Bang Pakong river has been transformed from one of wide herbaceous swamplands to a productive agricultural landscape in less than a century. Reports of nineteenth century travellers about the eastern coast of the Gulf of Thailand tell of a thin strip of mangrove forest, barely inhabited apart from a few fishing villages and charcoal burners, with uninhabited backswamps and managed salt flats behind (Warington Smyth 1898:56; Pallegoix 1854:68-69; Takaya 1987:179-181). Prior to the extensive canal-building and rapid colonisation of the 1880s and '90s, the coastal lowlands east of Bangkok were vast unoccupied grasslands and sedgelands renowned for their dangerous herds of wild elephants and endemic fevers (Johnston 1976b:28,40). Writing about the Khlo'ng Samron in 1807, Sunth'n Phu states that shortly after entering the canal "the landscape soon became an open savanna dominated by wild grasses, the horizon formed by jungle" (Terwiel 1989:153).

Palynological and historical sources contribute to the long-term vegetation history of the lowlands, but they bracket the prehistoric period of concern here. We thus have to turn to the macrobotanical data, and phytoliths from excavations at the site (Maloney 1986; Maloney and Rovner in press) for environmental information exactly contemporary with the 2000-1500 BC occupation.

Plate 1

Khok Phanom Di mound, the circular, darkly vegetated area in the centre of the photograph, set among paddy fields seen from the air.
3.1 ON-SITE METHODS. THE RECOVERY OF PLANT MACROFOSSILS

An integral part of the excavation was the retrieval of plant remains. These may be 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 soil from the site was sieved. In the event, flotation provided less research material than anticipated, but it did produce a great number of charred seeds which have contributed to our understanding of the herbaceous vegetation growing around the site (see chapter 5), as well as a diverse range of micromolluscs which are proving equally useful for paleaeoenvironmental reconstruction (G. Mason pers. comm.). 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. The low numbers and poor preservation of plant remains are partly attributed to the open, exposed nature of the site, where charred plant remains would be disturbed and broken down by heavy tropical rainfall and perhaps monsoonal flooding. Additional possible reasons, especially with regard to cultivated plants, will be discussed later in the light of traditional food processing practices for Southeast Asia.
3.1.1 Flotation

Reasons for flotation

Before the development of flotation techniques, the archaeobotanical record was typically confined to waterlogged sites where macroscopic plant remains and other organics were often remarkably well preserved, and in occasional instances of dessication in dry sites, but more often to plant impressions in pottery, mudbrick and daub or chance finds of large quantities of charred grain, usually from bulk storage contexts. This was true of areas such as the Near East until the 1960s, Northern Europe until the 1970s and is still largely the case in South and Southeast Asia today. 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 1979:10; Liu 1985; Zhao and Wu 1986-7); sites where there have been discoveries of small quantities of visible rice preserved through proximity to metal, such as Ban Don Tha Phet (Thailand) where spikelets were associated with a bronze bowl (Glover 1990:178) and Hallur (India) where rice was found encrusted around iron arrow points (Vishnu-Mittre 1971:125-132, cited by Kumar 1988:78); or areas where 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 1968:128; Vishnu-Mittre 1969:230), 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 remains and provided evidence for the history of the rice agriculture.

The various parts of the rice plant respond to burning in different ways, so that some parts 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, greatly outnumbering other plant parts in Vishnu-Mittre's (1974:16-17)
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 1979:22). In such cases, the silica skeletons may be examined for macroscopic features or by 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, northwestern India (Vishnu-Mittre 1969:229-30), at Non Nok Tha in northeastern Thailand (Vishnu-Mittre and Gudzer 1983:86) and at K'en-ting in Taiwan (Li 1982:241). 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 even 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 1968:225), 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 the region, 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 Tha Phet (I. Glover and A. Clarke pers. comm.), at Ban Chiang (White 1982c:17), Phimai (Welch and McNeill 1988-89:107, 109) and at Lang Rongrien (Anderson 1990:8). Prior to these efforts, soil samples were often sieved. Charred rice caryopses were found in the course of dry screening sediments at Ban Na Di (Higham and Kijngam 1984:353; Chang and Loresto 1984) and fine screening for plant remains was carried out at Spirit Cave (Higham 1989:49).

The Khok Phanom Di excavations were the first time that large-scale processing of soil samples by flotation was undertaken in Southeast Asia and this is the reason why full details of field sampling and flot processing are presented here. We set out to process all types of archaeological contexts, not just potentially productive storage areas or hearths, and hoped to find plant remains with wide species diversity. Soil samples were processed through a flotation tank. This works on the principal 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
bias and suited to analysis where the aim is to reconstruct aspects of past environments and the economic use of plants.

**Flotation technique**

The flotation system used at Khok Phanom Di (Figure 3.1) was a mechanical one, based on French's (1971) Ankara flotation system, as modified by Hillman (pers. comm.). This design has been widely used, adapted and tried under many different field conditions (Diamant 1979; Limp 1974; Williams 1973, 1976). It uses a continuous water flow 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 artifacts, 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 also 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. While chemically aided flotation is an efficient means of recovering plant remains, chemicals were not used at Khok Phanom Di due to their cost, given the large quantities of soil we wanted to process.

In brief, the Khok Phanom Di 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 which fitted inside the tank at a level beneath the spillway and rested on metal cross-struts, and a stack of geological sieves positioned so that the water flowing out of the main tank via the weir passed through them. The smallest mesh was 0.25 mm.
FIGURE 3.1
THE FLOTATION TANK USED
IN THE 1985 EXCAVATION AT
KHOK PHANOM DI

Field collections 47
Flotation is a labour-intensive operation and we had three people working on the task. It is also a repetitive job, liable to errors, so flotation crews were changed daily, with most people involved in flotation having one day a week with the flot tank. The importance of standardised procedures in order to achieve consistent results was emphasised to these workers, and this was helped by the continuous supervision of one person (myself). Cleanliness in all stages of the flotation procedure was emphasised, in order to minimise contamination from modern plants and cross contamination between samples. Between each sample all flotation equipment was scrupulously washed, scrubbed and checked for damage.

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 on labelled sheets of newspaper on specially constructed tables. These had mesh tops, which speeded up drying by allowing air
to reach the damp samples from below as well as from above. Once dry, the samples were sorted by naked eye, with small bones and shells being removed. This fraction was also checked for visible, non-buoyant plant remains, but these consisted 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 the flot sample. 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. When necessary, because the sieves were needed for wet work, the flot was gently removed from the sieve onto a weighted-down, labelled piece of newspaper. To avoid excessively rapid drying of wet flot, which can cause damage to the plant remains, flot samples were dried inside a building. Once dry, the materials were placed in plastic or glass vials and placed 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, much as was done in the innovatory work at Feddersen Wierde (Körber-Grohne 1967, 1981) and many subsequently excavated sites. In the event, this turned out to be over-ambitious. At the beginning, flot samples were taken from normal 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 site and the speed of excavation, it was obviously not possible to float all material. It was decided to sample each 10 cm spit from each of the four quadrants. Thus, sampling for flotation became a routine aspect of excavation. Composite or "pinch" sampling was used (Pearsall 1989:96), whereby 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.

At the outset it was decided that wherever possible, a standard volume of soil should be processed from each context and initially this was set at ten buckets (100 litres). This is a notably larger amount than the sample size of one or two litres often chosen by palaeoethnobotanists (e.g. Bohrer and Adams 1977:13; Ford 1979:302), but as the density and quality of plant remains from lowland sites in Thailand was not known in advance, it was considered prudent to oversample at the outset until the density of plant macrofossils 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, it was decided that the volume of soil for each sample should be reduced from ten to five buckets, in order to maintain the number of samples processed.

Records
Data concerning the sampling of archaeological contexts were kept by Pirapon Pisnupong of the Fine Arts Department, who maintained all the site logs. Each context sampled for flotation was allocated a unique flotation number which was used as a shorthand means of identifying samples at all stages of the flotation and laboratory sorting procedures. 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 litres), for example from small pits, the type of feature and number of buckets were noted.
The products of flotation
The light flot included comminuted charcoal fragments, finely fibrous roots, disaggregated soil particles, microgastropods, small bones, occasional coral fragments and occasional charred seeds.

3.1.2 In situ 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 it introduces a number of biases to the data. The recovery tends to be poor, spatially uneven, unreliable for areas which are excavated quickly and depends on the interest and skills of the excavators (Pearsall 1989:16). Nevertheless, at Khok Phanom Di in situ collection provided us with classes of material which was 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. We would break open soil blocks along their natural lines of cleavage and find patches of such organic remains preserved on the surface. These were bagged as found and retained for analysis. These were the same types of rice remains as were later detected in the flot, once the samples were sorted in the laboratory, as impressions in and husk fragments adhering to soil particles.

The second class of material to be collected in situ was charcoal and again this was found to be more effective than flotation. Lumps of charcoal were commonly seen in layers 4-11. Priority use for this was as samples for radiocarbon analysis (Bannanurag 1989:17), but once the densest areas of charcoal had been removed for dating, 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 pieces fragmented during transit to Canberra. Because each had been packaged individually, it was necessary to identify only one fragment from each piece of foil and this speeded up the identification stage of the work considerably.
Occasionally there were rare finds of large seeds, white fibres in burials (to be described in chapter 5), slipped ceramics with rice husks (chapter 6) and pieces of mineralised wood *in situ* in postholes (chapter 4). These were also plotted, recorded, bagged and retained for identification.

3.1.3 Archaeobotanical remains retrieved by screening

Bulk sieving of all the soil removed during excavation at Khok Phanom Di, except that which was floated, was carried out using a 5 mm mesh to recover faunal and artifactual materials, but occasionally items such as coprolites were also 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 6.

3.2 LABORATORY METHODS

3.2.1 Sorting flot

Flot produced by floating soil samples is a concentration of plant remains from excavated soil, but also includes other buoyant items such as fine twigs and rootlets. It was decided *not* to refloat the material in the laboratory, which is sometimes done to reduce excess quantities of silt and other contaminants which would slow down sorting. This was because the repeated wetting and drying of botanical remains have been shown to damage archaeological seeds and charcoal (Jarman *et al.* 1972:45) and a cursory inspection of the flot showed that these charred materials 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. Sorting flot was carried out by myself, with the help of six short-term laboratory assistants.

**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
was to sort samples covering the entire length of the stratigraphic sequence, so materials from a total of 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.

For each flot sample a Flotation Data Record Sheet was completed using a documentation system broadly along the lines of that devised for Salmon Ruin, New Mexico (Bohrer and Adams 1977:185) (Figure 3.2). The total volume of the flot was measured and the sample then split into three subsamples using 1.0, 0.5 and 0.25 mm sieves. Sorting flot from a single size class is generally recognised 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 1977:40). Each fraction was examined in turn, with useful materials being placed in separate vials or gelatine capsules according to size and type. The two larger fractions were sorted in their entirety, but sorting of the finest fraction was limited to a point where 200 "seeds" had been extracted. The proportions of the sorted and unsorted parts of this third fraction were noted on the Flot Data Record Sheet. When identification of seeds was begun, it was discovered that many of them were not plant remains after all, rendering this part of the sampling inaccurate. As there were very few genuine seeds in the 0.25 mm fraction sorted, it is considered that the loss of additional seeds in the unsorted portion was small.

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. A range of tools, from fine flexible tweezers to dental probes and fine paintbrushes, was employed, and glass petri dishes were used in preference to plastic ones, in order to reduce electrostatic problems. Each class of material was then bagged, labelled with its provenance and
boxed according to seed type. The faunal remains were sent to Dunedin for identification, while the seeds and other plant macroremains from the flot were retained for identification in Canberra. These identifications are taken up in chapter 5.

All records from the archaeological samples and the reference collection were entered on a computer database using PC FILE:dB. This allowed 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.

3.2.2 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 summarised before focusing on those characters which have potential for application to archaeological plant remains. This work was carried out at the Department of Prehistory (Research School of Pacific 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.
**FIGURE 3.2**

**FLOTATION DATA RECORD SHEET**

KHOK PHANOM DI, THAILAND, 1985

Flotation Sample No: 312

<table>
<thead>
<tr>
<th>Flotation Data Record</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROVENIENCE:</strong> Layer 8 / Quadrant A / Spur 7 / Feature lens 12</td>
</tr>
<tr>
<td><strong>DATE sorting completed:</strong> 8.6.88</td>
</tr>
<tr>
<td><strong>TIME TO SORT:</strong> 2 hours 30 minutes</td>
</tr>
<tr>
<td><strong>TOTAL TIME TO SORT:</strong> 10 hours</td>
</tr>
<tr>
<td><strong>TOTAL VOLUME OF SOIL BEFORE FLOATING:</strong> 10 buckets</td>
</tr>
<tr>
<td><strong>FLOTATION DATA</strong></td>
</tr>
<tr>
<td><strong>PARTICLE SIZE VOLUMES</strong></td>
</tr>
<tr>
<td>76 ml = particle size #1 (1mm +)</td>
</tr>
<tr>
<td>23 ml = particle size #2 (.5 - 1mm)</td>
</tr>
<tr>
<td>14 ml = particle size #3 (.25 - .5mm)</td>
</tr>
<tr>
<td><strong>AMOUNT EXAMINED</strong></td>
</tr>
<tr>
<td>56 ml = #1</td>
</tr>
<tr>
<td>23 ml = #2</td>
</tr>
<tr>
<td>14 ml = #3</td>
</tr>
<tr>
<td><strong>PRESENCE / ABSENCE CATEGORIES</strong></td>
</tr>
<tr>
<td><strong>Location in screen size</strong> (circle screen size)</td>
</tr>
<tr>
<td>Charred seeds</td>
</tr>
<tr>
<td>Mineralised seeds</td>
</tr>
<tr>
<td>Husk fragments</td>
</tr>
<tr>
<td>Wood charcoal</td>
</tr>
<tr>
<td>Bones</td>
</tr>
<tr>
<td>Shell</td>
</tr>
<tr>
<td>Coral</td>
</tr>
<tr>
<td>Other <em>insect faeces</em></td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>CHARRED SEEDS (circle seed types)</td>
</tr>
<tr>
<td>&quot;</td>
</tr>
<tr>
<td>&quot;</td>
</tr>
</tbody>
</table>
3.3 CREATING A REFERENCE COLLECTION

Identifying archaeobotanical material proceeds by making comparisons between the morphology of unknown archaeological specimens and their modern securely identified counterparts. It is useful to have the voucher specimens in the same form (eg. charred) as the archaeological materials, so modern specimens of wood and seeds collected for reference purposes were later charred. One set of herbarium specimens was kept in the laboratory and duplicate sets deposited with the Royal Forest Department and at the Botany Department of Chulalongkorn University, both in Bangkok. A further set of specimens will be lodged at the Australian National Herbarium at a later date. A set of charcoal reference material was left with the Archaeology Division of the Fine Arts Department in Bangkok and a second set are held at the Department of Prehistory, in the Research School of Pacific 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 (December 1986 to July 1987) dedicated to collecting botanical specimens and gathering ethnobotanical and ecological data. The work was carried out with the invaluable help of Anat Bamrungwongse, then an affiliate of the Fine Arts Department.

During this fieldwork frequent reference was made to Watson (1928), Merrill (1946), Santisuk (1983) and Chayamarit (1984) as guides to taxa existing in modern-day Southeast Asian mangal. Since then, the very useful, small book on Thai mangroves by Aksornkoae and Panichsuko (n.d.) has been published. As it is well illustrated with colour plates of each plant this would be useful for preliminary identifications. During the field-survey we used the 1:250,000 (1965) and 1:50,000 (1982) Thai Military Survey maps for the areas visited, as well as air photographs of the Khok Phanom Di area and the Welu estuary supplied by the Thai Military Survey Department (2023BE).

Plant specimens were collected using standard plant presses and straps, with newspaper and cardboard spacers to speed up drying, along the line of procedures set out by the USDA (1971). Where possible, four complete flowering or fruiting
specimens were collected, and where a particular plant part was likely to be of specific archaeobotanical use, such as the fruit, wood or seeds, additional quantities were collected. Notes on the location of collection, the vernacular name of the plant and the topography, aspect, soil and associated vegetation of the area were made. 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. We also enquired about uses of the plant known to local informants as well as on seasonality of plant resources, their distribution and associated taxa. Each collection was given a unique serial number and the notes were kept in duplicate field notebooks. Specimens were pressed in the field, at the time of collection, which was preferable to pressing wilted material after a day of collecting. The presses were dried, often on the roof, exposed to strong sunlight, however, 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 of the initial identifications, to genus level, were done by myself, 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 Corner (1952), Smitinand (1980), Boonkerd et al. (1982) and the Flora of Java (Backer and Bakhuysen van der Brink 1963). Further identifications were made by Kuhn Chamlong Phengklai, and occasionally Professor Tem Smitinand, at the Royal Thai Forest Department's herbarium, and by Acharn Kosum Pyramarn, Acharn Bussaban Na Songkhla and Acharn Obchan Thaithong of the Botany Department, Chulalongkorn University. 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 not known to me at the time of fieldwork, Lear and Turner (1977)

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 principle aim was to characterise 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, housegardens 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. 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.

Field collections of plant specimens were influenced by the biogeography of the plant
communities of interest, by a concern for collecting information on economic plants
and especially those gathered for food and thirdly the need to collect traditional
landraces of rice cultivars and to document agrarian practices for raising and
harvesting rice. Each of these aspects will be examined in turn.
3.3.1 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 1971; Suchitta 1980, 1984; Pisnupong 1984), together with the then incomplete palynological and phytolith data, as present in the region of prehistoric Khok Phanom Di (Higham et al. 1987; Maloney pers. comm.; cf. Maloney 1986). Though the most important palynological studies were still underway, they 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 1987:14). Interpretation of the pollen evidence at that stage was equivocal as to whether the mangrove were replaced by brackish or freshwater forest with Carallia sp. (Maloney 1986:7; Maloney and Brown 1990:80). Subsequently the pollen analyses have been extended, refined and revised 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 4 and 5 respectively (cf. Maloney 1988, in press; Maloney and Brown 1990; Maloney and McAlister 1990; Maloney et al. 1989).

Plant collections were made throughout a wide geographic area and encompassed a number of targeted examples of vegetation types on the deltaic lowlands and along the eastern seaboard of Thailand, from changwat Chonburi down the coastline to changwat Chantaburi and the Maenam Welu estuary (Figure 3.3). The goal was to collect herbarium specimens representing the dominant plants in a number of distinct plant 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, it was necessary to spread the plant collections 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).

From a base at the village of Saam Khaa (tambon Nong Bua, amphoe Ban Pho, changwat Chachoengsao) only 6 km to the northwest 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 (khlongs) 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, Nypa-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 Nypa (chaak) and its associates Acanthus ilicifolius (naam plaa mor), Thespesia populnea and Pandanus odoratissimus, within which the climbing palm Caryota mitis (tau rang) and the stinging climbers Columella trifolia and Mucuna gigantea (mamui) were growing. In the damp areas in the orchards just behind the band of Nypa were the herbs Coccinea grandis (phak tamlung), Corchorus capsularis (bor), Vernonia sp. and Wedelia sp. and in standing water Cyperus sp. (kok liam). 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 in order to allow industrial development and the establishment of shrimp farms and salt pans. We therefore moved progressively down the southeastern seaboard, examining areas which might still have mature stands of mangrove. Extensive and well-developed mangrove
FIGURE 3.3
LOCALITIES FOR PLANT COLLECTION AND ETHNOBOTANICAL FIELDWORK

- Ban Nong Pru
- Phanat Nikhom
- Nong Jap Tao

GULF OF THAILAND

- CHANTABURI
- CHONBURI
- RAYONG
- Sattahip
- Ko Yo
- Ko Samae San
- Samet Nang Khun
- Laem Sing
- Ban Chai Thep

Mangrove

0 25 km
forests exist on the Thai peninsula, especially along its western coast, and these areas would in some respects have been preferable locations for this aspect of the fieldwork, but the southeastern seaboard was logistically more convenient.

In February 1986, we moved base to join the Underwater Archaeology team at Nong Jap Tao (amphoe Ban Amphoe, changwat 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, while behind the dunes were the herbs *Micromelum* cf. *minutum* and *Triumfetta grandiflora* and the scrubby xerophytes *Kalanchoe pinnata*, *Connarus* cf. *paniculatus* and the introduced *Opuntia* sp., in addition to the evergreen *Casuarina, Calophyllum inophyllum* and *Terminalia catappa*, all typical of the Southeast Asian strand flora (Foxworthy 1927:133,180). 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 seen here are fruit trees like *Avrroha 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 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 \textit{Derris trifoliata} and \textit{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 Maenam Welu estuary, seaward of \textit{amphoe} Khlung. This lies between 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, less accessible reaches, less impacted plant communities were found.

On subsequent more extended visits 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: \textit{Avicennia alba}, \textit{A. officinalis}, \textit{Bruguiera} sp., \textit{Ceriops tagal}, \textit{Excoecaria agallocha}, \textit{Ficus microcarpa}, \textit{Intsia bijuga}, \textit{Lumnitzera} spp., \textit{Melaleuca leucadendra}, \textit{Rhizophora apiculata}, \textit{R. mucronata}, \textit{Scyphiphora hydrophyllacea}, \textit{Sonneratia ovata} and \textit{Xylocarpus moluccensis}. In the drier, cleared and disturbed areas, the fern \textit{Acrostichum aureum} was prominent in monospecific stands. An understorey is poorly developed in mangroves (Christensen 1983), but it proved possible to collect the climbers \textit{Flagellaria indica}, \textit{Sarcolobus globosus}, the low shrub \textit{Clerodendrum inerme}, the woody herb \textit{Acanthus} sp., \textit{Pluchea indica}, \textit{Wedelia biflora} and various sedges and grasses including \textit{Coix lachryma-jobi} from backswamp areas. In the swampy area just behind the mangrove belt were sedge and grass communities dominated by \textit{Eleocharis} (\textit{phong kratium}) and \textit{Scirpus} sp. (\textit{khok samrian}), sometimes with the exotic \textit{Zizania latifolia} (\textit{nomai naam}).

Situated at the ecotone between \textit{Nypa} 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 resources. Here we collected samples of the following wild but edible plants: \textit{Dioscorea hispida}, \textit{Lasia spinosa}, \textit{Amorphophallus} sp., \textit{Typhonium trilobatum}, \textit{Diplazium esculentum}, \textit{Melientha suavis} and \textit{Tacca leontopetaloides}. 
Finally, the monsoon months of June and July 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 to mature trees other than house gardens, which are much smaller in area and usually comprise small fruit trees. Most of the trees on the mound are self-propagated but many are tended and protected by monks of the temple on the summit, or members of the village community, and a few have 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 and from certain trees which grow on the mound and are rare within many kilometres radius. The mound is also well known for supplying good bamboo, which grows, especially along the western flank, in abundance. 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* (*maay paay tong*) and *Thyrostachys* cf. *siamensis* (*maay paay ruak*).

Trees on the summit at Khok Phanom Di which were collected as herbarium and wood specimens include *Adenanthera pavonina* (*makhlam ton*), *Aegle marmelos* (*matum*), *Acacia rugata* (*som poi*), *Albizia lebbeck* (*thon*), *Anona reticulata* (*noi nong*), *Azadirachta indica* var. *siamensis* (*sadao*), *Bridelia* sp. (*kaangplaa*), *Capparis microcantha* (*ching chi*), *Cassia siamea* (*khiilek*), *Crataeva religiosa* (*kum*), *Delonix regia* (*haan nok yung farang*), *Dimocarpus longan* (*lamyay*), *Diospyros montana* (*taan saan*), *Flacourtia indica* (*tha kop*), *Hylocarpus calvipetalus* (*krachao*), *Leucaena leucocephala* (*kratin*), *Millingtonia hortensis* (*ton bip*), *Pithecellobium dulce* (*makhaam theet*), *Randia* sp. (*naam khat khaaaw*), *Samanea saman* (*jamjuli*), *Sindora siamensis* (*maka*), *Sterculia foetida* (*samrong*), *Tamarindus indica* (*ma khaam*), *Tectona grandis* (*maay sak*), *Zolleringeria* sp. (*khii non*) and, around the pond on the southeastern flank of the mound, *Anacardium occidentale* (*mamuang hima paan*).
Amongst the tall trees and undergrowth are climbers Abrus precatorius (ma khlaam daeng), Azima sarmentosa (naam phung do), Caryota urens (tao raang), Cissus hastata (som sandaan), Tiliacora triandra (tee yaa naang) and the wild yam Dioscorea cf. bulbifera (mun kraboon), with understorey plants Lepisanthes fruticosa (chumariang), Cassia tora (chum heet thay), Zingiber sp. (king haeng), Z. casumanar (plaay) Z. cf. zerumbet (krateu), Curcuma sp. (kamin ooy) and C. domestica (kamin chan). In the more open areas are the herbs Abutilon indicum (fan sii), Amaranthus gracilis (phak hom), Asparagus racemosus (sam sip), Boerhavia diffusa (pak khom hin), Boesenbergia pandurata (krachay), Cleome viscosa (sak sian pii), Cynodon dactylon (yaa phraek), Melochia corchorifolia (seng lek), Ocimum gratissimum (yiraa), Ricinus communis (la'hung), Sida acuta (yung kwaat), Synedrella nodiflora (tam yee dua mia) and Stachytarpheta indica (sii baat). All of these were collected.

In addition to the meditation centre at Khok Phanom Di are seven houses where the occupants have planted in their gardens the fruit trees Annona reticulata (noinong), Carica papaya (malakor), Cynometra cauliflora (nang-ai), Durio zibethinus (thurian), Eugenia jambos (chompuu), Flacourtia sp. (ta khop paà), Garcinia dulcis (ma’phut), Lansium domesticum (langsaat), Mangifera indica (ma’muang), Phyllanthus acidus (mayom), Psidium guajava (farang) and Sandoricum koetjape (krathorn).

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.
3.3.2. Plants of traditional economic value

The second criterion for collection was plants with economic value, for fuelwood, fibre, construction and medicine, although the study had a definite bias 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. While hunting and gathering are today economically insignificant for most people living at Khok Phanom Di, 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.

It was not possible to make comprehensive collections of cultivated plants sold in the markets, but 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* (*het tab tau*), the shoots of ferns such as *Ceratopteris thalictroides* (*phak khaakhiat*), *Pteridium aquilinum* (*phak kud*) and *Diplazium esculentum* (*phak kuud kaao*), and the young leaves and flowers of shrubs and herbs, including the legumes *Acacia rugata* (*som pai*), *Caesalpinia mimosoides* (*chalueat*), *Cassia siamea* (*khi lek*) and *Leucaena leucocephala* (*krathin thai*), together with *Litsea umbellata* (Lauraceae), *Momordia subangulata* (*phak mae*) (Cucurbitaceae) and *Spondias pinnata* (*ma kok*) (Anacardiaceae). Some of the most common freshwater plants for sale were *Ipomoea aquatica* (*phak bung*), *Nelumbo nucifera* (*bua*) and *Neptunia oleracea* (*phak krachet*), while some of the edible flowers gathered for home use and for sale in the market were from the trees *Caesalpinia mimosoides* (*chalueat*), *Sesbania grandiflora* (*sano kin dok*), the climber *Antigonon leptopus* (*phuang chompu*) and the banana flower *Musa* sp. (*kluai*). 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*. 
3.3.3. **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 northeast of Phanat Nikhom. The results are considered in detail in chapter 7. 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 out-moded 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 4, the seed remains and the few miscellaneous botanical finds (white fibres from graves, leaf impressions and nuts) are described in chapter 5, then a detailed consideration of the remains of rice is presented in chapter 6.
Chapter Four

THE CHARRED AND MINERALISED WOOD REMAINS

4.1 CHARRED WOOD

Among the plant macroremains from Khok Phanom Di was abundant wood charcoal, the examination of which had two main aims: (i) to estimate the relative density of charcoals through the profile, and (ii) 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 tree species brought onto the site, and by inference, the nature of the site's 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. 1986:21; Bird 1986:72), industrial activity (but not metal-working, as the excavations provided no evidence for this, nor even the import of metal goods from elsewhere) and even some rituals carried out when burying the dead (see White 1986:161-164 and 1988:64-66 for Southeast Asian ethnographic references to charcoal use in death rituals).

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 and so on, where offcuts and broken or discarded objects may 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 Southeast Asian uses recorded for mangrove and mangrove-associate woods are compiled in Appendix 3 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 1989:292-3), with the latter interpretation being favoured (Higham and Bannanurag 1990b:38). Meehan (1982:97) describes Anadara granosa, the most common type of mollusc found at Khok Phanom Di, being cooked directly in hot ashes by members of the Anbarra community in Arnhem Land, northern Australia.

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 where 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 1987:169,174). 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 northeastern Thailand, as reported by Bayard (1977b:241) and White (1982c:30). The preferred fuels for present-day potters working with this technique tend to be dried grasses, especially rice straw or husks (Solheim 1964:160, 1967:83; Bayard 1977a, 1977b:241; McGovern et al. 1985:104,111; White 1982c:30, 1988:64), in combination with palm leaves (Arafín 1990), bark or dried manure (Lefferts 1988:124) or split bamboo (Bayard 1977b:241; Longacre et al. 1991:11), all chosen for producing instantaneous high heat (Rye 1981:98,104). 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 1987:174).

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 site 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 1973:66, 1979:153). However, if the building was well ventilated, as Southeast 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.

Clearly recognisable hearths at the site were largely confined to layers 10-8 (Higham and Bannanurag 1990a:33-39) and were less common than the widespread charcoal spreads which were sampled for charcoal identification. As White (1988:63) points out from her interviews and observations of village life in northeast 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 being intermittently dropped to the ground below. Here they might be dispersed across a wide area by natural and human agency.

In modern-day Thai villages, cooking food is undoubtedly the most common fire-generating activity and, in the absence of compelling evidence to the contrary, 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 later in the charcoal analysis.

4.1.1 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 the environmental interpretation of a site as well as for generating 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; 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 (1985:333) studies of modern pollen traps in northern Queensland have demonstrated that certain mangrove pollen types, namely Bruguiera/Ceriops and Avicennia, tend to be so deposited. Their presence in the fossil record may therefore indicate that the site was probably very close to the trees in question, within the landward mangrove zone. Secondly, Maloney's coring programme emphasised drilling 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 1990:376) (Table 2.3). The charcoal data continue, albeit weakly, through to Zone C, thereby extending the vegetation record into the uppermost 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 hydologically rather than climatically controlled at low latitudes (Blasco 1984:33).

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 (cf. Shay and Shay 1978:55; van Zeist et al. 1984:221), together with choices in firewood gathering and fuel resource management (Johannessen and Hastorf 1990; Miller 1985; Pearsall 1983; Smart and Hoffman 1988). 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 of the archaeobotanical record is profoundly difficult and both are relevant in the interpretation of the Khok Phanom Di charcoal identifications. 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.
4.2 MINERALISED WOODS

A few samples of mineralised timber, whose original purpose may be specified unequivocally, were also recovered. The remains of wooden linings, coffins, biers or even pillows (cf. Radcliffe-Brown on Andaman mortuary practices, 1932:112) from two Zone A graves are described from beneath the skeletons in burials 100 and 107 (Bannanurag 1989:51,55,77,80; Higham and Bannanurag 1990a:156,200). A third sample was found with burial 43 in Zone B (Higham, personal communication, August 1991). In six rare instances mineralised stumps or slivers of wood were discovered in situ within postholes and been examined as part of this study:

- 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 mineralised 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 mineralised 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 mineralised surfaces, while SEM revealed that much of
the anatomy had been obscured by crystallisation. The fact that the wood may have
become rotten and degraded during partial waterlogging in situ may also have
reduced the recognisable anatomical characters (W.E. Boyd pers. comm.).

Splinters or thin plates of the mineralised wood from each sample were immersed in
distilled water and cleaned in an ultrasonic bath before being slowly air-dried and
mounted on Cambridge-type (circular, aluminium) SEM stubs using nail polish.
SEM demonstrated that 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 mineralised infill of the vessels was
recognisable in an undifferentiated groundmass, while in another specimen the
surface gave the overall impression of being a radial longitudinal section. Although
it was possible to confirm these are petrified woods, diagnostic features are not
adequately preserved to allow identification (Plates 4.1).

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
burial 107. Slivers of mineralised wood were found 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 1989:77). 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, wrapped in tapa (barkcloth, the identification of which will be mentioned in
section 5.4.1) and accompanied by a burnishing stone, the jaw of a sambar deer and a
macaque femur (Bannanurag 1989:77-78). The only way 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 mineralised 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 1982:75; Ilic 1987:44)(Plate 4.1). This was, then, not a Rhizophoraceae-type wood, but one of the mangrove associates, most probably Xylocarpus.

4.3 METHODS OF CHARCOAL ANALYSIS

4.3.1 Quantifying the charcoal assemblage
The meaningful quantification of charcoal and fossil wood assemblages has long been overlooked, but is now receiving more attention as an issue in the archaeobotanical literature (Miller 1985:4; Boyd 1988a:316, 1988b:616), 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 1971:37; Johannessen and Hastorf 1990:81), weights (e.g. Spratling 1979:146) and even volumetric measurements (e.g. van Zeist and Heeres 1973:37; van Zeist et al. 1984:214) have superceded the simple listing of taxa found at a site (e.g. Chowdury and Ghosh 1954-5:120; Hyde 1932:340; Mabey and Hyde 1940:152; Salisbury and Jane 1940:310). 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 1985:4). 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 this site could not be predicted from accounts of mangrove charcoal identifications in the archaeobotanical literature, so both weight and fragment count 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, but is less appropriate 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 overemphasised 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.

4.3.2 Sample collection and selection

Charcoal was available for analysis from the entire depth of the site and had been collected from all four quadrants of the excavation. However, since (i) the primary aim was to examine temporal changes in the charred wood assemblage and (ii) there were time constraints limiting the amount of material 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 multi-floored, raised clay platform, interpreted as a mortuary structure, was found (Higham et al. 1987:152; Higham and Bannanurag 1990a:20), which 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 southwestern area, Quadrant A, was selected for analysis.
4.3.3 Sampling the charcoal assemblage

The basic on-site sampling of charcoal has been outlined in a preceding section (3.1.2). 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 which arrived in the laboratories at A.N.U. 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 (i) retained for radiocarbon dating and (ii) some was included in the soil processed by flotation, while (iii) 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 charcoal ignored or accidentally overlooked in excavation and this type of sampling error is particularly hard to quantify. While the policy may have been to collect all charcoal, the practice seems to have been less than complete. The fact that only 30 fragments of charcoal were retained for identification from layer 11:2 in Quadrant A, and that all of these were large, would seem to be indicative of both selection in favour of large fragments and incomplete retrieval (as noted by Pals and Voorrips 1979).

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 and destroyed, although records were kept of the total sample weights and have been made available for inclusion here (C.F.W. Higham pers. comm.). 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 4.5 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 localised concentrations.
As mentioned in the previous section, a sample of soil from each excavated spit was used for flotation, 100 litres for layers 1-9:3 and 50 litres for layers 9:4 to the bottom of the cultural deposit at 11:2. The charcoal included in these provenanced samples was recovered either for weighing, counting or identification for reasons set out later. In principle, it should be possible to estimate the weight of charcoal in these samples, because they constituted a known proportion (100 or 50 litres) of spits of known volume (5 m² x 0.1 m). In practice this is not so, because clearly defined features of or 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.

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 the samples 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; the volume of the spits from which the analysed charcoal samples were recovered was not constant.

It would have been possible to reduce the problems caused by varying spit volumes by calculating the volumes of features and lenses from the plans and profiles. This complex operation was not undertaken because the most heavily disrupted spits had the highest charcoal concentrations, suggesting that there would have been no great effect on the final interpretation. It seems, then, that the volume of charcoals held at ANU will provide some general indication of the amount of charcoal through the soil profile.

Parenthetically, another way of addressing the issue of charcoal density would have been to make an assessment of the amount of charcoal in a measured volume of soil using the flot samples and to extrapolate from there, but there were technical problems preventing this. Wetting and drying the charcoals proved to be destructive. Many of the large charcoal fragments disintegrated on contact with water. Such degradation of charred macrofossils by immersion in water is widely
reported (e.g. Bohrer 1970:421; Ford 1979:302; Streuver 1968:357). This results from
the impact of the charcoal with the water, together with the force required to lift the
charred remains from the matrix, and internal stresses induced by wetting and
drying (Brady 1989:210). Moreover, the recovery of charcoal in the flot was
incomplete since some charcoals were not buoyant, so were not extracted as part of
the light fraction. To improve recovery, it might theoretically have been possible to
refloat the flotation residue at the site, using chemicals to raise the specific gravity of
the water. This would have removed any charred material which had sunk during
flotation (Bodner and Rowlett 1980; Streuver 1968:355-357). Although in a much
comminuted form, the combined flot and residue charcoals could have been
weighed, providing evidence of the ratio between charcoal and soil volume. In the
event, this was not feasible because of a lack of resources: chemicals, staff and time.

4.3.4 Identifying charred woods
A total of 775 charcoal fragments were identified from 22 of the 61 Quadrant A
charcoal samples. Where possible, a standardised number of 50 fragments per
sample was 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 20 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 reliably 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 be
overlooked or underestimated. It became apparent when breaking fragments for identification that members of the Rhizophoraceae-type tended to fracture more easily than the others. There was a tendency for them 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, with the preferential choice of large fragments for identification has detrimentally skewed the data is explored further below (see section 4.3.10.c).

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 20 fragments are given as acceptable elsewhere (Johannessen and Hastorf 1990:79; Miller 1985:3; Smart and Hoffman 1988:181) but, as pointed out by Smart and Hoffman (1988:184), optimal sample size should ideally increase with floristic complexity. 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 4.2. This ranged from only 12% of a very large sample in layer 10:3 lens 2 to 100% for a number of small samples from the upper part of the site.

4.3.5 Preparation of reference material
As outlined previously, voucher specimens of both twig and mature timber were taken from trees and shrubs growing in the mangroves, backswamp, sandy coastal and other lowland areas of southeastern Thailand. Additional plant parts, such as Bruguiera hypocotyls (embryonic roots), which ethnographic evidence suggests may have been brought into a settlement or camp as food (see Chapter 8), 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 southeastern 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 evidence now suggests. Freshwater lowland forest is restricted to low-altitude depressions in peninsular Thailand (Smitinand and Pheng Khla 1973:108) and would be the destination for future fieldwork to augment the reference collections. Occasional relict mangrove associates grow alongside canals and roads as shadetrees in changwat Chonburi, their growth permitted by the saltwater wedge which may extend many kilometres inland (Whitten et al. 1987:101). Specimens of their leaves, fruits and timber were added to the reference collection whenever feasible.

4.3.6 Preparation and examination of archaeological specimens

The weights of individual charcoal fragments were recorded and each fragment was placed in a numbered glass vial. The grain of each piece was identified under low power stereo-microscope 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 Blutak. This mounting medium was strong enough to hold the charcoal in place under the microscope, but also permitted 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 all examined. Specimens were viewed using an epi-illuminating petrographic microscope (Olympus BH2) at magnifications of x100-x1,000. The lowest
magnification was most 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 later examined using SEM so that a photographic record of each category could be kept and supplementary diagnostic features noted. SEM provides good depth of field, which is critical for photography of materials with an uneven surface, such as charred wood. 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. 1974:470). This is particularly true for charred archaeological plant remains, containing impurities which charge under the electron beam (J. Hather, pers. comm.).

With careful fracturing it was possible to expose the structural details of all three planes in a single fragment. The use of an adjustable stage then allowed the specimen stubs to be tilted and rotated to view all orientations. The 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 1988:190). 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 crystallised within fissures and/or cell lumina.
4.3.7 Identification criteria

The recognition of diagnostic characters in wood is relatively simple using the illustrations and photographs in general anatomical texts (Barefoot and Hankins 1982; Butterfield and Meylan 1980; Ilic 1987; Metcalfe and Chalk 1983; Wilson and White 1986). These were compared with published descriptions of Southeast Asian and Pacific woods (Coode 1969; Foxworthy 1909; Gamble 1902 [1972]; Janssonius 1952; 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 Mukherjee (1969), Panshin (1932), Patanaprasith (1966) Rao et al. (1989) and van Vliet (1976). These were all consulted, in conjunction with the 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 observed and considered to be most informative were: vessel perforation plate types (scalariform or simple) and the number of bars in the case of the 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 1985:255). An exception, however, is the genus *Avicennia*, where the transverse view is indeed helpful (Ilic 1987:158). This wood has "concentric, branching bands of interxylary phloëm" (Panshin 1932:199) 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 phloem. In general, the tangential and radial longitudinal sections expose more informative characters, including the type, width and distribution of rays, plus intervessel pitting and type of perforation plates.
Mangrove is a distinctive and relatively species-poor habitat compared with adjacent lowland regions (Banijbatana 1957:23). The identification of woods from this zone should be more straightforward than for other tropical forests, though it is undoubtedly rather more complex than when working with, for example, the limited temperate European or semi-arid West Asia floras (Smart and Hoffman 1988:180). 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 quantitative features are often employed and their validity is limited when examining tiny fragments. Pyrolysis does not preclude wood identification, but it does tend to distort and eliminate certain features, making charcoal identification rather more challenging than for that of non-charred timber (McGinnes et al. 1971; Rossen and Olson 1985). An example of a conventional identification criterion not reliably recognised in charred specimens of a mangrove timber is the presence of lysigenous break-down areas in the rays of *Aegiceras corniculatum* (Ilic 1987:104). 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 to be used with charcoal rather than fresh timber.

The particular problems of identifying charred archaeological wood have been addressed in certain temperate regions (eg. Minnis 1987; Prior 1983, 1988; Rossen and Olson 1985; Schweingrüber 1976), but although these accounts provide methodological insights applicable to Thai material, none directly addresses Southeast Asian taxa. A summary of the characters found useful for identifying common burnt mangrove timbers has been compiled after consulting the literature and checking the features against modern, identified, charred woods (Table 4.1). I am not aware of any other 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 1988:2), at Shark Bay, Western Australia (Bowdler 1990) and various middens excavated in the Andaman
Islands (Cooper 1985:34), the Niger Delta of West Africa (Nzewunwa 1980), and in northeastern Venezuela (Sanoja 1989:528).

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 intervacular pits running the entire length of the vessels. These are seen most clearly in tangential longitudinal section. Ilic (1987:30) defines perforation plates as "the collective end wall where two vessels abutt [sic] to form the vessel. They have multiple elongated and parallel perforations separated by portions of cell wall known as bars."

Scalariform intervessel pitting, on the other hand, comprises "[t]angentially elongated bordered pits which stretch across the width of a vessel and occur regularly one above each other creating a ladder like appearance". Both features were clearly visible in both the reference material and the archaeological specimens.

As with pollen (Maloney 1988:289), separation of charcoals in the Rhizophoraceae can be difficult at the generic level. Within the Rhizophoraceae sub-division of the family, mangrove genera are partially distinguished from one another by the numbers of bars in their scalariform perforation plates, but the range of bars per perforation plate overlaps between genera (van Vliet 1976:63) (Table 4.1). It is thus 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 the 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 may be seen.
Van Vliet (1976:57) has pointed to two potential diagnostic features for Ceriops: the shape of the vessel-ray pitting, which is "vertically unilaterally compound ... with ± oval ray pit[s]" (also illustrated by Illic 1987:127), and the fact that this genus is the only one lacking septate fibres. These two features were not reliably observed in the experimentally charred woods, as adjoining cell walls sometimes appeared to fuse, obscuring the presence of septa and the form of vessel-ray pits. Such characters are thus not reliable 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. Plate 4.2 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. In these cases the intervessel pitting is of the alternate bordered variety. Determination can be taken further by examining the width and form of the rays in longitudinal sections. The details of these are summarised in tabular form (Table 4.1). Archaeological specimens have been classified according to this provisional key and seven different types are described in Appendix 1, but as published descriptions and reference materials are lacking for many of the possible contributing taxa, the charcoal would only tentatively be identified to genus in the most favourable of 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 Aksornkoe and Panichsuko (n.d.) (Table 2.5). 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 with alternate pits have been assembled in a single category for the purposes of analysis.

This class of timbers with alternate bordered pits is not exclusive to mangrove and associated habitats. Trees with this character undoubtedly 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 evidence for hunting far afield (West in press:188), 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 specialised purposes, and are unlikely to be represented in bulk amongst the charcoal. When discussing the manufacture of fish traps with people living in the mangrove area close to Khlung, near Chantaburi, we were told that special vines (tawan khieow and tau mongkut) were brought from the upland forest as this produced stronger twine for tying traps. This is an example of a highly specialised 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. J. Hather has examined these Indeterminate specimens and ruled out the possibility that they may be parenchyma from tubers, offering a second opinion that they were indeed distorted or degraded wood. Many examples may have been rotten prior to burning, while others may be from roots, bark, twigs, juvenile wood, compression or tension woods. Identification of root wood, for example, is problematic, though not impossible with the aid of authenticated specimens (Cutler 1976; Cutler *et al.* 1987). The presence of rootwood 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. Furthermore, other woody plant parts, such as the spike pneumatophores of *Sonneratia*, have specific traditional uses for making fishing floats and corks (Burkill 1966:2089; Chapman 1976:379) and could therefore be present in the charcoal record, but 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.
Table 4.1 Notes towards a key to the identification of common charred archaeological woods from mangroves and mangrove associates in Thailand, using microscopic criteria (based on data from Coode 1969, Panshin 1932, Patanaprasith 1966 and van Vliet 1976)

WOOD WITH SCALARIFORM PERFORATION PLATES

<table>
<thead>
<tr>
<th>Ray width</th>
<th>Intervessel pitting</th>
<th>Ray type</th>
<th>Genus</th>
<th>Key characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>multiseriate</td>
<td>scalariform</td>
<td>heterogeneous</td>
<td><em>Rhizophora</em></td>
<td>scalariform perforation plates, 5-11 bars; septate fibres present</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Bruguiera</em></td>
<td>scalariform perforation plates, 6-11 bars; septate fibres present</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Ceriops</em></td>
<td>scalariform perforation plates, 5-8 bars; no septate fibres</td>
</tr>
</tbody>
</table>

WOOD WITH SIMPLE PERFORATION PLATES

<table>
<thead>
<tr>
<th>Ray width</th>
<th>Intervessel pitting</th>
<th>Ray type</th>
<th>Genus</th>
<th>Key characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>uniserate uniquely</td>
<td>alternate, bordered</td>
<td>homogeneous</td>
<td><em>Lumnitzera</em></td>
<td>radial files of vessels in groups of 2-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Allophyllus</em>*</td>
<td>rays homo/heterogeneous</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Excoecaria</em></td>
<td>rays short (&lt;10 cells tall)</td>
</tr>
<tr>
<td>predominantly uniserate</td>
<td>alternate bordered</td>
<td>homogeneous</td>
<td><em>Dolichandrone</em>*</td>
<td>some perforation plates reticulate; ray-vessel pits in 3-4 horiz. rows septate fibres</td>
</tr>
<tr>
<td>(plus some biseriate)</td>
<td></td>
<td></td>
<td><em>Amoora</em>*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Sonneratia</em></td>
<td>25% perforations scalariform or reticulate, parenchyma lacking, fibres septate, vestured pits</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Scyphiphora</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Cerbera</em>*</td>
<td>rays 12+ cells tall, 4-8 rows of pits in vessel-ray walls</td>
</tr>
<tr>
<td>Ray width</td>
<td>Intervessel pitting</td>
<td>Ray type</td>
<td>Genus</td>
<td>Key characteristics</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------------</td>
<td>-------------</td>
<td>-------------</td>
<td>---------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Predominantly</td>
<td>alternate,</td>
<td>homogeneous</td>
<td>Intsia**</td>
<td>aliform parenchyma</td>
</tr>
<tr>
<td>biseriate</td>
<td>bordered</td>
<td>heterogeneous</td>
<td>Amoora**</td>
<td>septate fibres</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Avicennia*</td>
<td>concentric branching bands of interxylary phloem. rays uni-, bi and triseriate, but sometimes up to 6 cells wide</td>
</tr>
<tr>
<td>Predominantly</td>
<td>alternate,</td>
<td>homogeneous</td>
<td>Aegiceras*</td>
<td>fibres and vessels storied, ray-vessel pits in 4-5 horizontal rows/cell</td>
</tr>
<tr>
<td>biseriate (with 3-4 s.)</td>
<td>bordered</td>
<td>heterogeneous II</td>
<td>Xylocarpus* /**</td>
<td>rays mostly 2-3 seriate rays, but some uniseriate. rays storied</td>
</tr>
<tr>
<td>Predominantly</td>
<td>alternate,</td>
<td>heterogeneous II</td>
<td>Hibiscus**</td>
<td>occasional 4-seriate rays; large tails to rays</td>
</tr>
<tr>
<td>triseriate</td>
<td>bordered</td>
<td></td>
<td>Barringtonia**</td>
<td>tri- and biseriate rays; rays 50+ cells high</td>
</tr>
<tr>
<td>Multiseriate</td>
<td>alternate,</td>
<td>homogeneous</td>
<td>Heritiera*/**</td>
<td>rays rarely heterogeneous, mostly 3-4 seriate, plus many uniseriate rays</td>
</tr>
<tr>
<td>(4-10 seriate)</td>
<td>bordered</td>
<td>(or hetero III according to Boonyarith)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Brownlowia**</td>
<td>rays storied</td>
</tr>
<tr>
<td></td>
<td></td>
<td>heterogeneous II</td>
<td>Thespesia**</td>
<td>rays 2-4 cells wide (mostly 3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clerodendron**</td>
<td>??scalariform perforation plates??</td>
</tr>
</tbody>
</table>

* Trees and shrubs absolutely bound to salt or brackish water (true mangrove species)
** Trees and shrubs belonging to the littoral vegetations and/or inland vegetation which regularly make their appearance in the back-mangroves (mangrove associates) (Santisuk 1983)
4.3.8 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 would have allowed identification with greater taxonomic precision, since additional diagnostic features would have been 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. Even though preparing specimens 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.

4.3.9 Intensity of occupation

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

(a) 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 1983:129). Each charcoal sample from Quadrant A was weighed (Table 4.5; Figure
FIGURE 4.1
TOTAL WEIGHTS OF CHARCOAL SAMPLES
FROM SPITS AND LENSES IN QUADRANT A

CHARCOALS 93

TOTAL WEIGHT OF SAMPLE (grammes)

* Charcoal used for radiocarbon dating
** < 4 grammes of charcoal
4.1) in order to provide a general indication of the density of charcoal within the matrix, subject to the provisos mentioned earlier in 4.3.3. Various taphonomic factors which may affect these data and their subsequent interpretation are outlined below.

**b) 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 would have larger fragments than redeposited charcoal spreads. Similarly, sediments deposited and sealed quickly would 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 alternate for fragment size, with the justification for this demonstrated by the high correlation between proportions of the assemblage calculated either by %weight or %numbers and the sample splitting exercise reported in 4.3.10 (b) 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 22 samples where identifications were made, together with 16 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
FIGURE 4.2
MEAN WEIGHTS AND RANGES FOR
38 CHARCOALS SAMPLES FROM QUADRANT A

MEAN WEIGHT (grammes) and RANGE FOR SAMPLE
the data differed from a normal distribution, minimum and maximum values for each sample are given rather than the standard distribution (Table 4.6, Figure 4.2). The relationship between mean fragment weight and depth below datum is illustrated in Figure 4.2. Once identifications had been made, it was also possible to take differential fragmentation between taxa into consideration (Figure 4.4).

4.3.10 Further discussions on methodology and quantification

(a) Differences in charcoal density 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. 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 60-70 lbs/cu.ft. (Morton 1965:115). At the other end of the spectrum are the woods of *Excoecaria agallocha* (*taatum thale*) and *Melaleuca leucadendra* (*samet*), which are so light that they are used as fishing floats (Blasco 1975:162; Burkill 1966:1455). Mangrove woods have been classified in terms of specific gravity as follows (adapted from Walsh 1977:350 who uses the data of Cox 1911 and Becking et al. 1922):

<table>
<thead>
<tr>
<th>Specific gravity</th>
<th>Taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.90</td>
<td><em>Rhizophora</em> spp., <em>Bruguiera</em> spp., <em>Ceriops</em> spp., <em>Heritiera littoralis</em>, <em>Cynometra ramiflora</em></td>
</tr>
<tr>
<td>0.75-0.90</td>
<td><em>Lumnitzeria</em> spp., <em>Sonneratia alba</em></td>
</tr>
<tr>
<td>0.60-0.75</td>
<td><em>Xylocarpus</em> spp., <em>Aegiceras corniculatum</em></td>
</tr>
<tr>
<td>0.45-0.60</td>
<td><em>Dolichandrone longissima</em></td>
</tr>
<tr>
<td>0.30-0.45</td>
<td><em>Avicennia</em> spp., <em>Sonneratia acida</em>, <em>Excoecaria agallocha</em>, <em>Cerbera manghas</em></td>
</tr>
</tbody>
</table>

It is not known, though, 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. While the relatively dense Rhizophoraceae-types are abundant, it is unknown whether any of the woods from the light end of the spectrum are present in the charcoal assemblage.

(b) Exploring the relationship between charcoal weight and fragment size

A large charcoal sample from layer 10 (10:23) was split by being passed through a stack of sieves with mesh of 6, 4 and 2 mm. Thirty fragments were taken from each of the sub-samples, then individually weighed. The aim was to provide an indication of the relationship between fragment size and fragment weight, which was to be used as a quantitative measure. This would permit the data to be compared with other analyses where charcoal occurrences have been reported in terms of fragments falling into particular size categories. In order to establish the weight threshold between the three different size fractions, the smallest fragments retained by the 6 mm sieve were selected, together with the largest fragments in the 2 mm fraction (Table 4.7, Figure 4.3). The results from this test showed that fragments of charcoal in the 6 mm category tended to weigh at least 0.9 g, while those in the 2 mm fraction tended 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.

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

Manual collection of charcoal samples during excavation is thought to favour larger fragments, thereby overrepresenting taxa with relatively robust structure or the least tendency to shrink in charring (Pals and Voorrips 1979:228), so that in our attempts to retrieve and curate charcoal fragments large enough for identification it could be said that we had inadvertently biased our samples at the outset. As mentioned above, a policy of extracting and examining only 50 large pieces of charcoal from each sample was adopted in order to gain a standardised sub-sample from the sometimes very large amounts of charcoal available for investigation. Standardised counts are commonly applied for analysing archaeobotanical assemblages, though
FIGURE 4.3
COMPARING CHARCOAL IDENTIFICATIONS BETWEEN THREE SIZE FRACTIONS

Rhizophoraceae

Non-Rhizophoraceae
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 4.8 and graphed in Figure 4.4 so that comparisons can be made between and within contexts. Standard deviations were also calculated but were found to be inappropriate for these data as the distributions differed from normal. The distributions of charcoal weights around the mean were skewed by the presence of a small number of exceptionally large pieces in most samples. The bars extending from the mean points in Figures 4.2 and 4.4 indicate the minimum and maximum values for each sample and illustrate the extent of 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 concentrated 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, the combined sampling and preservation bias is therefore towards detecting any change in assemblage composition and not to be regarded as a fundamental problem.

A further point arising from Table 4.8 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 1988:178), but was not a problem here.
FIGURE 4.4
COMPARING THE MEAN WEIGHT OF FRAGMENT FOR THE THREE CHARCOAL TYPES IN EACH SAMPLE

RHIZOPHORACEAE-TYPE

NON-RHIZOPHORACEAE

INDETERMINATE

Symbols indicate the mean and bars indicate the range of the data
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 randomly 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 4.9. 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.

4.4 THE RESULTS

<table>
<thead>
<tr>
<th>Context</th>
<th>Rhizophoraceae-type</th>
<th>Non-Rhizophoraceae</th>
<th>Indeterminate</th>
<th>Total</th>
<th>% examined</th>
</tr>
</thead>
<tbody>
<tr>
<td>3:1</td>
<td>-</td>
<td>1.06 14</td>
<td>0.15 3</td>
<td>1.21 17</td>
<td>100</td>
</tr>
<tr>
<td>3:2</td>
<td>0.91 3</td>
<td>1.3 14</td>
<td>-</td>
<td>2.21 17</td>
<td>89</td>
</tr>
<tr>
<td>3:4</td>
<td>-</td>
<td>0.32 4</td>
<td>-</td>
<td>0.32 4</td>
<td>100</td>
</tr>
<tr>
<td>5:2</td>
<td>0.08 2</td>
<td>1.27 9</td>
<td>0.05 3</td>
<td>1.46 14</td>
<td>98</td>
</tr>
<tr>
<td>5:4</td>
<td>0.11 2</td>
<td>-</td>
<td>0.20 7</td>
<td>0.38 9</td>
<td>100</td>
</tr>
<tr>
<td>5:5</td>
<td>0.08 2</td>
<td>0.2 4</td>
<td>0.06 2</td>
<td>0.35 8</td>
<td>100</td>
</tr>
<tr>
<td>6:1</td>
<td>-</td>
<td>0.08 3</td>
<td>0.05 4</td>
<td>0.13 7</td>
<td>100</td>
</tr>
<tr>
<td>6:2</td>
<td>1.55 20</td>
<td>1.57 23</td>
<td>1.04 7</td>
<td>4.16 50</td>
<td>100</td>
</tr>
<tr>
<td>7:1</td>
<td>0.2 4</td>
<td>0.05 4</td>
<td>0.45 2</td>
<td>0.7 10</td>
<td>100</td>
</tr>
<tr>
<td>8:1</td>
<td>0.98 24</td>
<td>-</td>
<td>0.02 1</td>
<td>1.02 25</td>
<td>17</td>
</tr>
<tr>
<td>8:2</td>
<td>1.71 29</td>
<td>0.05 1</td>
<td>-</td>
<td>1.76 30</td>
<td>32</td>
</tr>
<tr>
<td>8:3</td>
<td>2.17 37</td>
<td>0.35 11</td>
<td>0.07 2</td>
<td>2.59 50</td>
<td>36</td>
</tr>
<tr>
<td>9:1</td>
<td>6.43 39</td>
<td>1.54 6</td>
<td>0.85 5</td>
<td>10.82 50</td>
<td>34</td>
</tr>
<tr>
<td>9:6 lens 9</td>
<td>2.52 30</td>
<td>3.3 16</td>
<td>0.43 4</td>
<td>6.25 50</td>
<td>100</td>
</tr>
<tr>
<td>10:3 lens 2</td>
<td>34.56 50</td>
<td>-</td>
<td>0.43 4</td>
<td>34.56 50</td>
<td>12</td>
</tr>
<tr>
<td>10:7</td>
<td>16.88 49</td>
<td>0.19 1</td>
<td>-</td>
<td>17.07 50</td>
<td>33</td>
</tr>
<tr>
<td>10:11</td>
<td>12.7 44</td>
<td>1.25 4</td>
<td>0.44 2</td>
<td>14.39 50</td>
<td>59</td>
</tr>
<tr>
<td>10:16</td>
<td>18.99 46</td>
<td>1.42 4</td>
<td>-</td>
<td>20.41 50</td>
<td>41</td>
</tr>
<tr>
<td>10:20</td>
<td>16.38 47</td>
<td>0.91 1</td>
<td>0.72 2</td>
<td>18.01 50</td>
<td>75</td>
</tr>
<tr>
<td>10:23</td>
<td>11.32 38</td>
<td>4.91 12</td>
<td>-</td>
<td>16.23 50</td>
<td>32</td>
</tr>
<tr>
<td>10:26</td>
<td>38.22 50</td>
<td>-</td>
<td>-</td>
<td>38.22 50</td>
<td>86</td>
</tr>
<tr>
<td>11:1</td>
<td>10.48 48</td>
<td>0.81 1</td>
<td>0.44 1</td>
<td>11.73 50</td>
<td>62</td>
</tr>
<tr>
<td>11:2</td>
<td>5.15 30</td>
<td>-</td>
<td>-</td>
<td>5.15 30</td>
<td>100</td>
</tr>
</tbody>
</table>
Data on the taxonomic composition of charcoal samples are presented in the following table (4.3), in terms of proportions, 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 by Y. Pittelkow, summarised in later discussions. Standardised figures in the form of percentage frequencies will be 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 like this where sample size varies.

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 (1985:5). 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. Charcoal samples would preferably be split into different size categories, with 2 mm as the minimum mesh, and a standard number of fragments selected randomly from each of these.

Another and perhaps more justifiable means of summarising the data is simply to use presence analysis or ubiquity. In this approach, the presence of a category or taxon is expressed as a percentage of the total number of samples analysed (Table 4.4). For example, Rhizophoraceae charcoals were identified from one third of the Zone C samples, 92% 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, even though the uppermost phase is less well represented in this respect. Interpretations drawn from Table 4.4 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 4.3 Relative frequencies for the three charcoal categories, percentages by weight (bold) and by fragment count

<table>
<thead>
<tr>
<th>Context</th>
<th>Rhizophoraceae-type</th>
<th>Non-Rhizophoraceae</th>
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Table 4.4 Presence analysis of charcoal types in samples: comparisons between zones

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<tbody>
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<td>Zone C</td>
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<td>33%</td>
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<tr>
<td>Zone B</td>
<td>92%</td>
<td>75%</td>
<td>83%</td>
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<tr>
<td>Zone A</td>
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<td>75%</td>
<td>33%</td>
</tr>
<tr>
<td>Context</td>
<td>Total Weight of Charcoal Sample (g)</td>
<td>Context</td>
<td>Total Weight of Charcoal Sample (g)</td>
</tr>
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<td>-----------------------------------</td>
<td>---------</td>
<td>-----------------------------------</td>
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<tr>
<td>2:1</td>
<td>27.27</td>
<td>9:2 lens 4</td>
<td>11.04</td>
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<td>2:2</td>
<td>1.99</td>
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<td>18.59</td>
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<td>2.47</td>
<td>9:6 lens 9</td>
<td>6.25</td>
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<tr>
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<td>0.04</td>
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<td>41.57</td>
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<td>-</td>
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<td>-</td>
<td>10:4</td>
<td>35.25</td>
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<td>0.08</td>
<td>10:5</td>
<td>24.97</td>
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<tr>
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<td>-</td>
<td>10:6</td>
<td>47.27</td>
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<tr>
<td>5:3</td>
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<td>10:10</td>
<td>76.38</td>
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<td>0.43</td>
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<td>30.62</td>
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<td>-</td>
<td>10:16</td>
<td>50.19</td>
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<td>176.72</td>
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<td>54.32</td>
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<td>0.14</td>
<td>10:19</td>
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<td>-</td>
<td>10:20</td>
<td>24.07</td>
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<td>10:21</td>
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<td>19.72</td>
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<td>5.31</td>
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<td>44.33</td>
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<td>6.37</td>
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<td>18.81</td>
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<td>9:1</td>
<td>25.82</td>
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<td>5.16</td>
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* charcoal sample used for radiocarbon dating
- no charcoal sample
### Table 4.6  Mean weight of charcoal fragments (in grammes) for each of 38 charcoal samples from Quadrant A

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<tr>
<th>Context</th>
<th>Mean fragment weight</th>
<th>Range</th>
<th>No. of fragments weighed</th>
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</tr>
<tr>
<td>3:2</td>
<td>0.13</td>
<td>0.01 - 0.89</td>
<td>17</td>
</tr>
<tr>
<td>3:4</td>
<td>0.08</td>
<td>0.01 - 0.26</td>
<td>4</td>
</tr>
<tr>
<td>5:2</td>
<td>0.04</td>
<td>0.01 - 0.07</td>
<td>2</td>
</tr>
<tr>
<td>5:4</td>
<td>0.106</td>
<td>0.01 - 0.70</td>
<td>14</td>
</tr>
<tr>
<td>5:5</td>
<td>0.042</td>
<td>0.01 - 0.17</td>
<td>9</td>
</tr>
<tr>
<td>6 lense 1</td>
<td>0.044</td>
<td>0.02 - 0.06</td>
<td>8</td>
</tr>
<tr>
<td>6:2</td>
<td>0.013</td>
<td>0.01 - 0.02</td>
<td>7</td>
</tr>
<tr>
<td>7:1</td>
<td>0.083</td>
<td>0.02 - 0.59</td>
<td>50</td>
</tr>
<tr>
<td>7:5</td>
<td>0.07</td>
<td>0.01 - 0.44</td>
<td>10</td>
</tr>
<tr>
<td>8:1</td>
<td>0.041</td>
<td>0.01 - 0.26</td>
<td>25</td>
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<tr>
<td>8:2</td>
<td>0.059</td>
<td>0.01 - 0.26</td>
<td>30</td>
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<tr>
<td>8:3</td>
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<td>0.01 - 0.35</td>
<td>50</td>
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<tr>
<td>9:1</td>
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<td>0.05 - 0.96</td>
<td>50</td>
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<tr>
<td>9:4</td>
<td>0.165</td>
<td>0.03 - 0.67</td>
<td>50</td>
</tr>
<tr>
<td>9:6 lense 9</td>
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<td>0.01 - 1.83</td>
<td>50</td>
</tr>
<tr>
<td>9:7</td>
<td>0.303</td>
<td>0.07 - 2.88</td>
<td>50</td>
</tr>
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<td>50</td>
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<td>0.02 - 0.41</td>
<td>50</td>
</tr>
<tr>
<td>10:3 lense 2</td>
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<td>0.20 - 3.26</td>
<td>50</td>
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<tr>
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<td>0.11 - 0.88</td>
<td>50</td>
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<tr>
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<td>0.341</td>
<td>0.06 - 1.27</td>
<td>50</td>
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<td>10:10</td>
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<td>50</td>
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<td>50</td>
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<td>0.11 - 3.04</td>
<td>50</td>
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<td>0.08 - 1.40</td>
<td>50</td>
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<td>50</td>
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<tr>
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<td>0.03 - 0.93</td>
<td>50</td>
</tr>
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<td>0.325</td>
<td>0.09 - 1.47</td>
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<td>0.02 - 1.71</td>
<td>50</td>
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<td>0.764</td>
<td>0.04 - 7.00</td>
<td>50</td>
</tr>
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<td>0.235</td>
<td>0.03 - 0.89</td>
<td>50</td>
</tr>
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<td>11:2</td>
<td>0.172</td>
<td>0.01 - 0.76</td>
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</table>
### Table 4.7 Comparing the mean fragment weights in three different size fractions

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<th>Size fraction</th>
<th>Mean weight (grammes)</th>
<th>Std dev.</th>
<th>Range</th>
</tr>
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<tbody>
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<td>6 mm</td>
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<td>0.033</td>
<td>0.5 - 0.34</td>
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<tr>
<td>4 mm</td>
<td>0.039</td>
<td>0.024</td>
<td>0.1 - 0.11</td>
</tr>
<tr>
<td>2 mm</td>
<td>0.015</td>
<td>0.007</td>
<td>&lt;0.01 - 0.4</td>
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### Table 4.8 Comparisons between the mean fragment weight (and the range of the data) for the three main categories of charcoal within each context

<table>
<thead>
<tr>
<th>Context</th>
<th>Rhizophoraceae -type</th>
<th>Non-Rhizophoraceae</th>
<th>Indeterminate</th>
</tr>
</thead>
<tbody>
<tr>
<td>3:1</td>
<td>-</td>
<td>0.076 (.01-.21)</td>
<td>0.05 (.01-.12)</td>
</tr>
<tr>
<td>3:2</td>
<td>0.303 (.03-.69)</td>
<td>0.093 (.01-.89)</td>
<td>-</td>
</tr>
<tr>
<td>3:4</td>
<td>-</td>
<td>0.08 (.01-.26)</td>
<td>-</td>
</tr>
<tr>
<td>5:2</td>
<td>0.04 (.01-.07)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5:4</td>
<td>0.07 (.01-.13)</td>
<td>0.141 (.02-.70)</td>
<td>0.027 (.03-.04)</td>
</tr>
<tr>
<td>5:5</td>
<td>0.09 (.01-.17)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6 lens 1</td>
<td>0.045 (.04-.05)</td>
<td>0.05 (.04-.06)</td>
<td>0.03 (.02-.04)</td>
</tr>
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<td>0.013 (.01-.02)</td>
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<td>7:1</td>
<td>0.078 (.03-.19)</td>
<td>0.068 (.02-.22)</td>
<td>0.149 (.03-.59)</td>
</tr>
<tr>
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<td>0.013 (.01-.02)</td>
<td>0.225 (.01-.44)</td>
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<td>0.041 (.01-.26)</td>
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<td>0.04</td>
</tr>
<tr>
<td>8:2</td>
<td>0.059 (.01-.26)</td>
<td>0.05</td>
<td>-</td>
</tr>
<tr>
<td>8:3</td>
<td>0.059 (.01-.35)</td>
<td>0.032 (.01-.09)</td>
<td>0.03 (.07-.04)</td>
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<td>9:1</td>
<td>0.165 (.05-.96)</td>
<td>0.257 (.08-.64)</td>
<td>0.17 (.05-.44)</td>
</tr>
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<td>0.084 (.01-.31)</td>
<td>0.206 (.01-.183)</td>
<td>0.108 (.03-.26)</td>
</tr>
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<td>10:3 lens 2</td>
<td>0.691 (.20-.326)</td>
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<td>-</td>
</tr>
<tr>
<td>10:7</td>
<td>0.344 (.06-1.27)</td>
<td>0.19</td>
<td>-</td>
</tr>
<tr>
<td>10:11</td>
<td>0.289 (.06-.133)</td>
<td>0.312 (.15-.46)</td>
<td>0.22 (.17-.27)</td>
</tr>
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<td>10:16</td>
<td>0.413 (.07-1.48)</td>
<td>0.355 (.17-.59)</td>
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<tr>
<td>10:20</td>
<td>0.349 (.08-1.40)</td>
<td>0.91</td>
<td>0.36 (.25-.47)</td>
</tr>
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<td>0.298 (.09-1.26)</td>
<td>0.409 (.12-1.47)</td>
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</tr>
<tr>
<td>10:26</td>
<td>0.764 (.04-7.00)</td>
<td>-</td>
<td>-</td>
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<td>11:1</td>
<td>0.218 (.03-.89)</td>
<td>0.81</td>
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<tr>
<td>11:2</td>
<td>0.172 (.01-.76)</td>
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Table 4.9 Comparing charcoal identifications between three different size fractions

<table>
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<tr>
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<th>Non-Rhizophoraceae</th>
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<td>Count</td>
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</tr>
<tr>
<td>4 mm</td>
<td>0.43</td>
</tr>
<tr>
<td>2 mm</td>
<td>0.19</td>
</tr>
</tbody>
</table>

4.5 DISCUSSION

4.5.1 Local vegetation reflected in the charcoal assemblage

One of the primary aims of the charcoal analysis was to contribute to reconstruction of past vegetation around the site, by reference to modern phyto-ecological models. The data will be interpreted here in terms of the local arboreal flora. Additional comments on their implications for resource availability will be reserved until chapter 8.

The interpretation of charcoal types from an archaeological assemblage in terms of the plant communities around a site is complex, given the variety of factors influencing wood selection, combustion and fragmentation patterns mentioned above. 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 minimise the distance they haul fuelwood. Thus, in areas where there is no shortage of wood, fuels are 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 soil profile
and the fires which generated them were probably of similar nature, a temporal pattern in charcoal sample composition can be discerned.

4.5.2 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 Southeast Asia (Brown 1958; Chapman 1976, 1988; Watson 1928; 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 exhibit well-marked zonation of habitats with bands of plant communities running parallel to the coastline and 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) recognised 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 (Carter 1988:348).

The zonation of undisturbed mangal communities in Thailand is schematically summarised in Figure 4.5. 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 (samae dam), A. alba (samae khao), Sonneratia alba (paat) and S. caseolaris (lamphu) (Santisuk 1983:65; Miyawaki, Fujiwara et al. 1985:14; Miyawaki, Okuda et al. 1985:10). Behind this community may lie a belt of Bruguiera cylindrica (thua kao). Along the shores of
FIGURE 4.5
THE DISTRIBUTION OF FLORAL ASSOCIATIONS WITHIN THE MANGROVES

(Source: Miyawaki, Fujiwara et al. 1985:18)

Lumnitzeretum littoreae

Phoenico - Excoecarietum

Acrosticho - Xylocarpetum moluccensis

Rhizophoro apiculatae
Bruguieretum gymnorrhizae

Ceriopo-Xylocarpetum granati subass. of B. gymnorrhiza

Rhizophoretum mucronatae

Ceriopo-Xylocarpetum granati typical subass.

Sonneration albae
Avicenietum albae

Sonneratietum caseolaris

Sonneratietum ovatae

inl nd

Phoenico - Excoecarietum

extensive

inl nd

seaward

water's edge

thallassina

mounds

limited

lower

stream

upper
estuaries *Rhizophora* (*kong kang*) tends to grow in pure stands, with *R. mucronata* (*kong kang baiyai*) growing in the muddier, wetter, shoreward positions and the smaller *R. apiculata* (*kong kang bailek*) on slightly drier ground. Aksornkoae (1976:35) 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* (*chaak*), but this is more usually confined to the banks of smaller fresher streams running through the mangrove as well as 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 1976:35). The plants here require slightly fresher water and comprise members of the Rhizophoraceae, primarily *Bruguiera gymnorrhiza*, *B. sexangula* (*prasak dok khao*), *B. cylindrica* and *Ceriops tagal* (*prong daeng*), as well as individual *Rhizophora apiculata*, *Xylocarpus obovatus* (= *granatum*) (*ta buun kao*) and *X. moluccensis* (*ta bun dam*) (Meliaceae). Associated taxa are *Heritiera littoralis* (*ngonkai thale*), plus two members of the Malvaceae, *Thespesia populnea* (*pho thale*) and *Hibiscus tiliaceus* (*po thale*). Moving landward, *Lumnitzera* spp. (*faat daeng*, *faat khao*), *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 1976:34; Miyawaki, Fujiwara et al. 1985:16). After felling the fern *Acrostichum aureum* is a swift coloniser in open areas, often associated with *Xylocarpus moluccensis* (Miyawaki, Fujiwara et al. 1985:16).

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* (*samet*) with *Cassytha filiformis* (*rang nokkasa*), and on drier ground *Intsia bijuga* (*lumpho thale*), the climber *Flagellaria indica* (*waay ling*), *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* and *Scyphiphora hydrophyllacea* or (b) *Pandanus* sp., *Hibiscus tiliaceus*, *Ardisia littoralis* and *Cerbera manghas* (Miyawaki, Fujiwara *et al.* 1985:16-17).

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, while 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, growing as they do, in sandy littoral areas along the coast and on the islands around Sattahip, as well as in the drier parts of the mangrove backswamp (Santisuk 1983:82,84; van Steenis and Veldkamp 1987:424). *Avicennia* is another example of an adaptable genus, tolerant of a range of salinities. The three species of *Avicennia* occupy different niches, ranging from water's edge to dryland, but as the charcoal cannot be identified below the generic level, *Avicennia* is a poor ecological indicator (MacNae 1968:131 and Chai 1975, cited by Maloney in press:25,28).

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 expected 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 illifolius* and *A. ebracteatus*, with the climbers *Derris trifoliata* and *Finlaysonia maritima*, while in the littoral zone *Rhizophora* and *Bruguiera* are replaced by *Nypa*, *Ceriops* or *Avicennia* (Sukardjo and Akhmad 1982:118; Miyawaki, Fujiwara *et al.* 1985:20; Singh *et al.* 1986:170). 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 low-lying *Clerodendrum inerme* and the shrub *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 tilaceus*, replaces *Lumnitzera* and *Excoecaria*. Eventually, with repeated logging, all that remains is bare mud, devoid of vegetation (Miyawaki, Fujiwara *et al.* 1985:20-1).

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. Indeed the pollen evidence suggests just this for the prehistoric surrounds of Khok Phanom Di during its earliest occupation, as the sediments from cores JB 2 and BMR 2, just 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 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 burial 107 (see 4.2) 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.

### 4.5.3 Firewood use by modern mangrove dwellers

Southeast 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 1955:7). It is the woods of the Rhizophoraceae, *Rhizophora* and *Ceriops* in particular, which are sought
for conversion into charcoal, and these 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 fuelwoods 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, with the heartwood and proproots having higher calorific values than the bark (Rollet 1975b:299; Aksornkoae 1982:27). They may even be set alight when still green (Cobban 1968:15; Rollet 1975b:299). Another good charcoal producer is *Cerbera manghas* (Burkill 1966:520), while poorer alternatives include *Pemphis acidula*, *Heritiera littoralis* and *Xylocarpus* spp., according to Percival and Womersley (1975:28) 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 cut for commercial charcoal production though, where careful removal of the bark prior to felling reduces the danger from the irritant sap (Burkill 1966:1106). In the Philippines (Rollet 1975a:225) and Malaysia (Burkill 1966:275) 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. 1990:23). By contrast, in tropical northern Australia, it is the wood of *Rhizophora mucronata* which is selected for smoking bêches de mer (Rollet 1975a:225). While the wood from Rhizophoraceae trees is prized as a major fuel, the bark of *Melaleuca leucadendra* is regarded as good tinder. Bundles of *samet* 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 minimise 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.

4.5.4 Discussing charcoal assemblage composition

At the base of the cultural deposits at Khok Phanom Di were dense deposits of charcoal within layer 11. 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 1990:78). 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 covered 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. Rather, the trees at the site prior to human occupation were more likely to be 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 northwest of the mound (Maloney in press:62). As already mentioned, 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 during the 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 in close proximity to the site. It has been suggested that the latest, but undated core, JB 2, also coincides with the occupation of the archaeological site (Maloney in press:78) (although his grounds are not explicit), and
FIGURE 4.6
PERCENTAGE FREQUENCY OF CHARCOAL TYPES, BY WEIGHT

- Rhizophoraceae-type
- Non-Rhizophoraceae
- Indeterminate
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 estuary 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. 1987:149-50) and "fine loess derived from mud-flats" (Maloney 1988:28), implying that the area occupied was not beyond the reach of storm surges and barnacle-encrusted potsherds from the lowest levels add supporting evidence to this view (Higham et al. 1987:175), but recently presented ostracod and foraminifera data conversely suggest that the site was never inundated (McKenzie in press:130). The issue currently remains unresolved, but on-going sedimentological analyses may clarify the matter. The charcoal data do not support the early idea that the cultural deposits were laid down on a spit or barrier beside a lagoon (Higham et al. 1987:156), because such a geomorphological feature is unlikely to have been covered with mature trees. Equally, the charcoal evidence does not support an alternative hypothesis that the founding population of Khok Phanom Di settled a chenier ridge (Maloney and Brown 1990:77; Maloney in press:6), 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 moving into mangroves (Bird 1986:72) and are similarly favoured for settlement in the Malay Peninsular (Allen 1988/89:167). 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 1987:309; Short 1989:348). Ecological reports for Thailand are silent on present-day chenier ridge flora, but in northern Australia this stands out from the adjacent mudflat and mangrove floras and includes *Celtis paniculata*, *Trema aspera*,...
Manilka kauki, Minusops eleni and Cochlospermum gillivraei, Osbornia sp. and Ipomoea pes-caprae (MacNae 1968:100; Grindrod 1985:327). 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 Southeast Asian coasts, are vegetated by stands of Casuarina equisetifolia (MacNae 1968:79). If the occupants of Khok Phanom Di were indeed colonising a chenier ridge with a distinct flora, this has not shown up in the charcoal record. The high proportion of Rhizophoraceae-type charcoals are more compatible with an estuarine bank or coastal location and this fits well with the recent results of sedimentological analysis. These suggest that the natural substrate underlying the cultural stratigraphy was a river floodbank deposit (Lee Aitken’s data, C.F.W. Higham pers. comm., August 1991).

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% at the top of layer 8 to less than 10% of the assemblage in layer 5 (Figure 4.6). 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 upwards, there is a continuing decline in Rhizophoraceae, associated with the concomitant rise in the proportion of Non-Rhizophoraceae charcoals, alongside an increase in Indeterminates. 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 recognisable even in poor specimens.

The changing ration of Rhizophoraceae-type to Non-Rhizophoraceae type charcoals in relation to depth has been modelled statistically (using GLIM version 3.77), with the boundary between a hypothetical mangrove-dominated zone located at different depths. The modelling confirms the view tha the A,B,C zonation which had originally been derived on sedimentological and artefactual grounds was 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 (Y. Pittelkow pers. comm.).

There was no evidence for burnt bamboo among the charcoal samples from Khok Phanom Di. Where the charred remains of bamboos with diameters up to 14 cm were found at Spirit Cave these were interpreted as having been used as cooking vessels (Gorman 1971:312). 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 grown in the vicinity during the latest phase of occupation.

4.5.5 Discussing charcoal density
If we now examine the charcoal density data, it is apparent that 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, post-dating 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 boundary 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. 1987:152-3). Bannanurag (1989:15) emphasises 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-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 significantly greater than elsewhere, suggesting that the variation in sample size has not seriously affected these general inferences.

The charcoal density and fragmentation data (Tables 4.5 and 6, and Figures 4.1 and 2) 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 (Figures 4.1 and 4.6). The Zone A samples derive from charcoal spreads associated with complex ash lenses (Bannanurag 1989:14). 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 characterises 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. 1987:154). Layers 1-6, which make up Zone C and the top of Zone B, contained virtually no charcoal at all, so there are no radiocarbon dates for the upper contexts (Bannanurag 1989:17) 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 topmost 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 more likely indicates a remarkable 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. Recently emerging ceramic evidence points to radical differences between the pottery traditions of layers 11 and 10, which have come to be interpreted as separate unconnected occupations at the site (B. Vincent's data, C.F.W.Higham pers. comm., September 1991). 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.

4.5.6 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 1989:18), notably after the decline in charcoal abundance and after the A/B zone boundary. The zonation of the site into three major periods on cultural/artefactual grounds does not appear to be an appropriate framework for summarising the charcoal data, when these are interpreted in environmental terms. 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 preponderance of Non-
Rhizophoraceae woods a reflection of 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 are sufficient to indicate these are repetitive and well integrated into local tradition across a wide geographical area (see Appendix 3). One could also hypothesise 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* spp., 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 of 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 a change in activity at the site could therefore explain the paucity of charcoal in the upper part of the stratigraphy.

4.5.7 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 vegetation reconstruction of the Khok Phanom Di environment. 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 in press:124) and the ostracods and forams (McKenzie in press:132), all of which provide reliable baseline data for environmental reconstruction as their remains have been deposited by natural rather than cultural means. Together they indicate that the archaeological site was situated close to an estuary forested with mangroves, with a marshy hinterland of brackish and freshwater swamps. With falling sea levels the local hydrology became more brackish and prograding alluvial deposits allowed fresher water taxa to colonise the area through time, so that the mangrove shore receded to the south, to be replaced by brackish marshland habitats. The presence of freshwater ostracods 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 in press:128, 130).

Even greater precision regarding the evolving environmental situation is found with the molluscan data as the taxonomic diversity is high (up to 43 species 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 in press:296-8). Moreover, these remains are from the archaeological contexts rather than the associated sediment cores so meet fewer correlation problems. From this it is concluded (Mason in press:298) that "the earliest inhabitants of Khok Phanom Di settled on a slightly elevated river levee close to an open coast bearing patches of clean, sandy and coraline 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 in press) contribute to our knowledge of the environment and diet at Khok Phanom Di during the major occupation phases. The mammalian and avian faunal 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. 1987:151), with a marked increase in abundance and diversity of mammals in the uppermost phase (Grant and Higham in press:173). The Zone C remains of woodland and grassland species include pig (Sus scrofa), macaque (Macaca sp.) and the swamp cervids, Eld's deer (Cervus eldi) and Schomburgk's deer (C. schomburgki) plus forest-dwelling sambar (C. unicolor) (Grant and Higham in press:140-2). Environmental indicators restricted to this period are the bones and teeth of tiger (Pantheris tigris), porcupine (Hysterix brachyura/hodgsoni), crow (Corvus sp.) and the dusky broadbill (Corydon sumatranus) (West in press:184-6), all typically 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 1987:161), 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 data 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 (1987:153,155) suggests that the stands of Combretum quadrangulare (sakae) commonly seen across the young delta areas today and the rarer but previously more extensive Melaleuca leucadendra (samet), could be survivors from former swamp forest. Other possible components are Mitragyna javanica var. microphylla (kratham nam), currently growing in the swammier areas of the old delta (Murata and Matsumoto 1974:290). 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 in press:104).

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 1985:346; Clark and Guppy 1988:681). 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 1983/4:55). The former conclusion seems more plausible here and is allied with the possible lateral movement of the river (the ancestral Bang Pakong) away from the site when a meander was cut and the river relocated its course (Mason in press:298).

Plate 4.1

Mineralised Woods

Plate 4.1.1 Mineralised wood from layer 10:2, Quadrant D, feature 12. Transverse section. Radial files of 2-3 vessels. Rays 2-3 cells wide. Scale = 200 microns

Plate 4.1.2 Mineralised wood from layer 10:15, Quadrant A, feature 10. Radial longitudinal section. Scale = 1 mm

Plate 4.1.3 Mineralised wood from burial 107. Transverse section. Scale = 200 microns

Plate 4.1.4 Mineralised wood from burial 107. Tangential longitudinal section. Rays bi- and tri-seriate. Scale = 200 microns

Plate 4.1.5 Mineralised wood from burial 107. Radial longitudinal section. Scale = 200 microns

Plate 4.1.6 Mineralised wood from burial 107. Alternate bordered intervacular pitting. Scale = 200 microns
Plate 4.2

Rhizophoraceae-type Charcoals

Archaeological Specimens

Plate 4.2.1 Rhizophoraceae-type charcoal from layer 10:26. Transverse section. Scale = 200 microns

Plate 4.2.2 Rhizophoraceae-type charcoal from layer 10:26. Tangential longitudinal section illustrating broken scalariform perforation plates. Scale = 100 microns

Plate 4.2.3 Rhizophoraceae-type charcoal. Radial longitudinal section illustrating scalariform intervessel pitting. Specimen from layer 10:26. Scale = 50 microns

Modern Reference Specimens

Plate 4.2.4 Modern charred Ceriops tagal (an example of Rhizophoraceae-type) wood in transverse section. Scale = 200 microns

Plate 4.2.5 Modern charred Ceriops tagal wood in tangential longitudinal section. Illustrating scalariform intervessel pitting and a fragmented scalariform perforation plate. Scale = 50 microns

Plate 4.2.6 Modern charred Bruguiera sp. hypocotyl in longitudinal section. Scale = 50 microns
5.1 METHODS OF SEED IDENTIFICATION

This section is primarily concerned with the description and identification of charred seed remains from Khok Phanom Di in order to evaluate plant use at the site including possible food remains and even weed seeds contaminating rice, as well as to provide an indication of habitats which may have surrounded the prehistoric settlement. Conclusions from the seed remains complement those from the charcoal record by providing information on the herbaceous as distinct from the arboreal taxa. The seed evidence is important here as other lines of evidence summarised in chapters 2 and 4, particularly the pollen, phytolith and molluscan data, all indicate the presence of herbaceous swamp in the vicinity of the site, especially in the later phases of the occupation.

The term "seed" is applied here in its broad, conventional, rather than its strictly botanical usage, to apply to disseminules/fruiting bodies of all kinds, including caryopses (of Gramineae) and achenes or nuts (of Cyperaceae), and parts of those fruits. Charred seeds were found throughout the archaeological contexts at the site, although their concentration varied from one horizon to another. Non-charred seeds were few in number, assumed to be modern contaminants and have not been included, although one type which was not carbonised but equally does not look modern has been described with the archaeological material. In the case of midden sites with alkaline water percolating through the sediments, the potential arises for seeds to be preserved by mineralisation, but no obviously mineralised seeds were segregated in the flot. The seed concentrations were low in comparison with some other archaeological sites (e.g. Crawford 1983) and quantitative aspects of the data will be discussed at greater length later in the chapter.
The source of the data is the 46 samples of flot from contexts in Quadrant A, as described in 3.3.1. More than fifty types of "seeds" were provisionally classified according to their gross morphology, as seen using low power binocular microscopy at magnifications of x20 to x64. Early optimism about good preservation of charred seeds at the site had been based on a swift microscopic perusal of a few flot samples during the excavations in 1985, but had to be revised after closer inspection in the laboratory at ANU. As description and measurements were made and higher power microscopy was used, it became clear that the most abundant groups could be eliminated as they were actually insect faecal pellets rather than seeds (R. McInnis and J. Luly pers. comm.). Other groups could be amalgamated because the first classifications had separated different parts of the same seed into different categories. Once whole specimens had been examined and dissected and the range of variation within one type observed, it was possible to simplify the classification scheme and move towards identifying the seeds.

The majority of seeds and seed fragments were from the Cyperaceae (sedges) and Gramineae (grasses), but few could be securely identified to the generic level. They have been tabulated together (Tables 5.28 and 5.29), along with notes, measurements, photographs of each type and comparisons with the reference seeds considered in moving toward each identification. 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 are given in Appendix 2. These unknown seeds found at very low frequencies are not considered further.

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 Southeast Asian seeds, and Tadulingam and Venkatanarayana (1985) for southern India. These were supplemented by general seed identification manuals for other regions (eg. Winton and Winton 1932; Martin and Barkley 1961; Musil 1963; Berggren 1969, 1981; Montgomery 1977) and the family-level descriptions given by Gunn (1972:94-136), along with discussions of seed morphology and taxonomy for

Conventional keys for identifying seeds often rely on features such as colour and enclosing structures which are not usually preserved in the archaeological record, especially in charred material. More appropriate is the use of interactive computer databases of taxonomic information which can be sorted on a range of features from fruit alone (eg. see Watson and Dallwitz 1988 and Bruhl 1990). The application of keys narrows the range of possible determinations for archaeological seeds, and preliminary identifications may be verified or the identity narrowed further by comparing the unknown material with fully identified reference material. The collections used in this case were primarily the herbarium specimens collected during fieldwork in 1986-7 and seed accessions at the National Weed Science Research Institute, Bangkhen, Bangkok, supplemented by fruits on the herbarium sheets at three Canberra institutions: the Australian National Herbarium, the Gauba Herbarium (School of Life Sciences, Faculty of Science, the Australian National University), together with weed seeds at the Commonwealth Scientific and Industrial Research Organisation (CSIRO: Department of Plant Introductions). This extended the source of reference materials from Southeast 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 1976:483). The fact that some of the reference material had an Australian source may have been a minor limiting factor.

A further factor taken into consideration was the present-day distributions of native plant taxa. The identity of the unknown archaeological specimens could be narrowed by concentrating on genera currently found in lowland Central Thailand and by eliminating exotic taxa. Highest priority was given in the first instance to herbaceous taxa associated with mangrove backswamps and freshwater wetlands, since these communities had been indicated by pollen analysis and other data as existing around the site during its prehistoric occupation. While climatic change is not thought to be have been responsible for significant shifts in vegetation zones in
mainland Southeast Asia in the last 4,000 years, anthropogenic factors have had major effects on both distributions and components of plant associations, especially in the intensively farmed lowland areas under consideration here. The range of possible taxa was therefore extended to plants recorded throughout lowland Thailand.

Identification of Thai plants, even complete herbarium specimens, is not always straightforward since the flora is not yet fully documented. The *Flora of Thailand* (Smitinand and Larsen 1970-84) is being published in instalments, as each family is addressed, and other publications relating specifically to Thailand 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 Southeast Asia provided additional information relevant to Thailand. The *Flora Malesiana* (van Steenis 1950-in progress), *Flora of the Malay Peninsula* (Ridley 1922-25), *Flore du Cambodge, du Laos et du Viêtnam* (Aubréville and Tardieu-Blot 1960-in progress) and *Malayan Wild Flowers* (Henderson 1954) were particularly useful. Smitinand's *Thai Plant Names (Botanical Names - Vernacular Names)* (1980) provides a list of most taxa in the country and was a guide, although it is not comprehensive in all instances.

Dimensions and proportions of seeds can contribute to identification and, where possible, measurements were taken from both the archaeological specimens and a range of closely related taxa, both in fresh and charred form. In the first instance, a number of samples of seeds was measured using the micrometer in the eyepiece of a binocular microscope and subsequently repeated using scanning electron microscopy. The correspondence between the two data sets was high, so the remaining measurements were routinely made using the low power light microscope. Metric data (in mm) were recorded in a standardised way, following guidelines recommended by Helbaek (1970:191):

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

\[ B = \text{breadth, width; in cereal grains maximum dimension between the flanks; in discoid seeds (e.g. lentil) the greatest diameter.} \]
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 of measurements are presented only where it is possible that the archaeological seeds may have derived from a single population, that is, for seeds from a single archaeological context, and not where they originated from a range of contexts within the site.

Modern reference material was charred, whenever reference materials had been collected and where herbarium specimens had an excess of seeds, in a form as close as possible to the archaeological specimen. For example, where an archaeological seed was found naked, its putative extant 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 (Abdel-Magid 1989:76; Helbaek 1970; Smith and Jones 1990; D.G. Wilson 1984), moisture (Stewart and Robertson 1971) and the morphology and chemistry of the seed (Wasylikowa 1986:576). 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, then wrapped in aluminium foil and 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 of these charred specimens were then dissected to investigate the condition and shape of the cotyledons. The effect of charring temperature on seed morphology was difficult to judge in this instance as it was not possible to use electron spin resonance (Hillman et al. 1983, 1985) to investigate their thermal histories and determine the temperature of charring. These could then have guided experimental charring conditions. Nevertheless, the shape of some of the surviving archaeological seeds was closer to modern fresh specimens than those which were experimentally
charred, so perhaps a lower temperature for a longer period or different oxidising conditions would have provided better reference material.

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 presence/absence and type of reticulation potentially provide clues to a precise identification but preferentially require the high resolution and magnification provided by SEM. In this case, SEM complemented conventional light microscopy in the investigation of potential diagnostic features for identification of unknown archaeobotanical material. Although there is already a significant corpus of information on testa topography (see Brisson and Peterson 1976 for a broad survey and numerous examples), many of the features conventionally recorded are modified by charring, so it is valuable for archaeobotanical purposes to examine additional charred reference material. Extensive use of SEM allowed very fine surface detail on the testa of both archaeological specimens and modern reference material to be observed and recorded photographically.

Clean dry mature seeds were mounted on circular SEM specimen holders using nail polish. Sometimes a small amount of additional conductive colloidal silver or carbon was applied to the undersurfaces to prevent charging. Specimens were coated with 250Å of gold using a Dynavac 12/14 C evaporative coater and examined using a Cambridge Stereoscan 360 Scanning Electron Microscope with the accelerating voltage set at 15 kV. Photographs were taken using Ilford FP4 or Kodak PXP film. Gross morphology was photographed at x40 - 100 and seed surface topography was viewed at magnifications up to x3,000. The extent to which testa topography was documented was controlled largely by the quality of preservation in the archaeological specimens.
5.2 RESULTS

In this section descriptions and photographs of each class of material are presented along with data on preservation and distortion. The identifiable seeds are listed first, followed by one unknown type. As with many archaeobotanical assemblages, there are some seeds which remain "indeterminate" or "unknown" after searching through the reference material to hand. These may be anonymous because of a lack of appropriate comparative collections or because their poor preservation means they are atypical. Basic descriptions of unidentified specimens are listed in Appendix 2.

Diagnostic criteria as well as reasons for eliminating similar and/or closely related taxa are discussed, as advocated by Wasylikowa (1986:576), so that identifications presented here may be assessed by others. This is followed by a summary of occurrences and a consideration of alternative methods of quantifying seed data. Finally there is discussion of the habitats represented in 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 1977:2-7; Berggren 1981). Assessments of preservation were made according to the following schema set out by Hubbard and al Azm (1990:104).

Standardised codes on preservation and distortion

Preservation
1  Perfect
2  Epidermis virtually intact; rhachillae etc. observable
3  Epidermis incomplete; rhachillae, hairs etc. occasionally preserved
4  Fragments of epidermis remaining; other features virtually unobservable
5  Identifiable by gross morphology only
6  "Clinkered"

Distortion
1  No noticeable distortion
2  Slight puffing of seeds noticeable
3  Clearly distorted
4  Gross distortion
5  Seeds fused together in a solid lump; facetted when free
6  Carbonized tarry material exuded from distal end of caryopses
7  Sides of the seed longitudinally wrinkled, partially collapsed and concave
8  Sprouting; as (7) but with the radical greatly elongated.
The level of confidence of each identification follows the terminology of Crawford (1983:29), which is in principle similar to the five-point scheme used by Yen (Bodner 1986:304). The level of confidence is qualified by the terms "questionable", "possible" and "probable", where "questionable" is the least certain. A seed is only named to species where the genus is monospecific in the region. Seeds descriptions follow below, with Monocotyledons before Dicotyledons. Within these the commonest families are treated first and in each family the most secure identifications take precedence.

**MONOCOTYLEDONS**

**CYPERACEAE**

(a) *Fimbristilis*-type (possibly *F. dichotoma*) (Plate 5.1.1)

A single broadly ovoid seed, biconvex, cross section very broadly ovate. Prominently reticulate over the entire surface, with longitudinal striae slightly more conspicuous than the transverse ridges.

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>layer 8:7 lens 12</td>
<td>1.15</td>
<td>0.85</td>
<td>0.60</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

This seed is very probably a member of the genus *Fimbristilis*. It resembles the example of *Fimbristilis* sp. illustrated by Noda *et al.* (1986:42) and conforms with the generic description supplied by Haines and Lye (1983:77). The species of *Fimbristilis* listed by Smitinand (1980:155) are:

- *F. acuminata* Vahl
- *F. aestivalis* Vahl
- *F. dichotoma* Vahl
- *F. dipsacea* Clarke
- *F. eragrostis* Hance
- *F. fusca* Benth.
- *F. globulosa* Kunth
- *F. hookeriana* Boeck.
- *F. juniflorus* Kunth
- *F. miliacea* Vahl
- *F. monostachyos* Hassk.
- *F. pauciflora* R. Br.
- *F. quinquangularis* Kunth
- *F. rigidula* Nees
- *F. savannicola* Kern
- *F. smitinandii* T. Koyama
- *F. thomsonii* Boeck.
- *F. tristachya* R. Br.
Additional taxa are recorded by Kern (1955, 1962a, 1962b, 1965, 1967a, 1967b, 1967c) and Harada et al. (1987:2). The variation in surface topography and gross morphology between species in this genus would allow identification to proceed to a higher level, given a well-preserved archaeological specimen, but this was not possible in this instance because of 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*, while the remaining species are described in Ridley (1925). *F. acuminata, F. globulosa* and *F. pauciflora* can be eliminated on the grounds of gross morphology as they are trigonous (Sastroutomo n.d.; Henderson 1954:261). The following are also inappropriate because of their surface patterning: *F. acuminata* has "five transverse ridges" (Ridley 1925:153) (observed in material at the Australian National Herbarium); *F. fusca* is "obscurely warty"; and *F. globulosa* is "very finely warty" (Henderson 1954:263). Of the two species of *Fimbrystilis* in the collection at the National Weed Science Research Institute, Bangkok, *F. miliacea* is too small to be the archaeological *Fimbrystilis* seed and has a surface morphology very different from that of the archaeological specimen, while *F. dichotoma* is near the appropriate size and has 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).

<table>
<thead>
<tr>
<th></th>
<th>Before charring</th>
<th>After charring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length</td>
<td>Width</td>
</tr>
<tr>
<td>Mean</td>
<td>1.31</td>
<td>0.84</td>
</tr>
<tr>
<td>Std dev.</td>
<td>0.072</td>
<td>0.053</td>
</tr>
</tbody>
</table>
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 uncharred seeds and more pronounced in the charred specimens. The *Fimbristylis* seed could be the species *dichotoma*, but this remains only as a possibility as the full range of taxa in this genus were not compared with the archaeological specimen.

*(b) Eleocharis-type* (Plate 5.1.2)

A total of 57 seeds ranging in shape from broadly elliptic to ovate in outline and with a biconvex, very broadly ovate to depressedly ovate cross section. Longitudinal section obovate. The margin is keeled and the style-base swollen. The remains of perianth segments (hypogynous bristles) occasionally preserved, but the barbs are absent or damaged. It is impossible to state the length of the bristles or the direction in which the barbs originally pointed, on account of imperfect preservation. Testa surface shows finely reticulate transverse cell patterning, especially beneath the perianth bristles, around the margins and near the base and apex. Internal surface of testa is finely striate transversely. Some specimens have split open along marginal cracks to reveal charred cotyledons. The endosperm is firm and the embryo at the acuminate apex appears to be more fragile than the cotyledon. Cross section of cotyledon very broadly to depressedly ovate. The flatter side of the cotyledon is sometimes slightly concave.

Perianth bristles are restricted to the tribes of Rhyncosporeae and Scirpeae (Haines and Lye 1983:19) and suggest the genera *Rhyncospora*, *Schoenoplectus* (=*Scirpus*) and *Eleocharis*. All of these are reported in the pollen samples taken adjacent to the site (Maloney in press:42). However, the distinctive swollen style-base is only found in *Eleocharis* and *Rhyncospora* (Martin and Barkley 1961:136). The members of these taxa reported for Thailand are *E. spiralis* (Noda *et al.* 1985:36) and, according to Smitinand (1980:136,289):
E. acutangula Schult.  
E. dulcis Trin.  
E. fistulosa Schult.  
E. geniculata Roem. and Schult.  
E. ochrostachys Steud.  
E. tuberosa Schult.

R. corymbosa Britt.  
R. rubra Makino  
R. wallichii Kunth (= R. rubra Makino)

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 as members of this genus were not available as reference material.

Table 5.3 Dimensions in mm of Eleocharis-type seeds

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:1</td>
<td>1.10</td>
<td>0.80</td>
<td>0.55</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
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<td>0.65</td>
<td>0.45</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>8:5</td>
<td>1.40</td>
<td>1.00</td>
<td>0.65</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
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<td>0.90</td>
<td>0.60</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
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<td>1.10</td>
<td>0.70</td>
<td>0.50</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
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<td>0.95</td>
<td>0.75</td>
<td>0.50</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>8:12 lens 12</td>
<td>0.95</td>
<td>0.70</td>
<td>0.35</td>
<td>2</td>
<td>1</td>
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<tr>
<td>9:1</td>
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<td>0.50</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
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<td>0.80</td>
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<td>3</td>
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<td>10:15</td>
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<tr>
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</tr>
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<td>0.50</td>
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<td>0.50</td>
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<td>1</td>
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<tr>
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<td>0.70</td>
<td>0.50</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:21</td>
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<td>0.70</td>
<td>0.50</td>
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<td>1</td>
</tr>
<tr>
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<td>0.85</td>
<td>0.55</td>
<td>0.45</td>
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### Table 5.4 Dimensions in mm of Eleocharis-type cotyledons

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<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
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<td>0.60</td>
<td>0.40</td>
<td>2</td>
<td>1</td>
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<td>0.35</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>5:5</td>
<td>0.60</td>
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<td>1</td>
</tr>
<tr>
<td>6:7</td>
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<td>1</td>
</tr>
<tr>
<td>6:7</td>
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</tr>
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<td>0.30</td>
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</tr>
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</tr>
<tr>
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<td>0.35</td>
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<td>1</td>
</tr>
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<td>0.60</td>
<td>0.40</td>
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</tr>
<tr>
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<td>0.75</td>
<td>0.55</td>
<td>0.40</td>
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</tr>
<tr>
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<td>0.35</td>
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</tr>
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<td>0.40</td>
<td>2</td>
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</tr>
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</tr>
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<td>0.60</td>
<td>0.40</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
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<td>2</td>
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</tr>
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<td>0.70</td>
<td>0.40</td>
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<td>1</td>
</tr>
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<td>0.75</td>
<td>0.50</td>
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</tr>
</tbody>
</table>

### Table 5.5 Mean dimensions for ten seeds of Eleocharis spiralis and E. dulcis before and after 30 minutes of charring at 250°C. (Seeds from the National Weed Science Research Institute, Bangkok)

<table>
<thead>
<tr>
<th></th>
<th>Before charring</th>
<th>After charring</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length</td>
<td>Width</td>
<td>Thickness</td>
<td>Length</td>
</tr>
<tr>
<td><strong>Eleocharis spiralis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.39</td>
<td>1.00</td>
<td>0.67</td>
<td>1.31</td>
</tr>
<tr>
<td>Std dev.</td>
<td>0.110</td>
<td>0.082</td>
<td>0.067</td>
<td>0.117</td>
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<tr>
<td><strong>Eleocharis dulcis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.48</td>
<td>1.04</td>
<td>0.74</td>
<td>1.45</td>
</tr>
<tr>
<td>Std dev.</td>
<td>0.079</td>
<td>0.061</td>
<td>0.047</td>
<td>0.112</td>
</tr>
</tbody>
</table>
(c) *Schoenoplectus*-type (=*Scirpus*-type) (Plate 5.1.5)

A total of 27 achenes of this type come from samples spanning almost the entire depth of the site. Achenes broadly obovate in longitudinal section, tapering to an acuminate stylebase; cross section transversely elliptic. Surface slightly striated parallel to long axis, with cell pattern most distinct at apices. Some specimens had broken along fractured margins, releasing cotyledons. Whole specimens were dissected to examine the internal structure of cotyledons and embryo and some specimens were found simply in the form of cotyledons, without their testa. The cotyledons generally have an elliptic cross section, with one side more plano-convex than the other. Distal area (embryo?) often broken or missing. Transverse striations across cotyledon.

The archaeological specimens were initially thought to compare superficially with published illustrations of *Polygonum* spp. (Martin 1954) and resemble the Type B knotweed seeds illustrated and described by Crawford (1983:37,40) as *Polygonum*, although the Thai archaeological specimens are somewhat smaller than the Japanese examples. Individual species in *Polygonum* were eventually eliminated on size and morphological grounds and attention turned to the family Cyperaceae. According to Martin, *Polygonum* seeds may be mistaken for *Rumex* or members of the Cyperaceae, but distinguishing characters include features of internal anatomy, for example the position of the embryo and the fact that achenes of the Cyperaceae are noted for "finely striate markings on their inner surface" (Martin 1954:514). These markings were observed on the inner face of the walls of the archaeological seeds, indicating that they belong in the 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 1970:417). While the archaeological seeds closely conform to descriptions of these genera, and a tentative nomination of *Schoenoplectus* was confirmed by Bruhrl's automated database, it has been impossible to match exactly the archaeological specimens with any of the herb-
Table 5.6 *Dimensions in mm for whole Schoenoplectus-type achenes*

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:1</td>
<td>1.40</td>
<td>1.00</td>
<td>0.70</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6:1</td>
<td>0.75</td>
<td>0.95</td>
<td>0.45</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>8.7 lens 12</td>
<td>1.20</td>
<td>broken</td>
<td>broken</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:7</td>
<td>1.10</td>
<td>0.90</td>
<td>0.40</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>10:17</td>
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<td>0.65</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10:18</td>
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<td>1.25</td>
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<td>2</td>
</tr>
<tr>
<td>10:19</td>
<td>1.20</td>
<td>1.00</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10:19</td>
<td>1.40</td>
<td>1.20</td>
<td>0.65</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10:19</td>
<td>1.50</td>
<td>1.25</td>
<td>0.55</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10:19</td>
<td>1.40</td>
<td>1.30</td>
<td>0.65</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>0.60</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>1.20</td>
<td>0.50</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:19</td>
<td>1.60</td>
<td>1.15</td>
<td>0.55</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10:19</td>
<td>1.20</td>
<td>1.00</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10:19</td>
<td>1.25</td>
<td>1.05</td>
<td>0.55</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10:19</td>
<td>1.60</td>
<td>1.15</td>
<td>0.50</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:19</td>
<td>1.40</td>
<td>1.00</td>
<td>0.50</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
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<td>1.10</td>
<td>0.65</td>
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<td>1</td>
</tr>
<tr>
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<td>0.45</td>
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<td>1</td>
</tr>
<tr>
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<td>1.10</td>
<td>0.55</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>11:1</td>
<td>1.40</td>
<td>1.10</td>
<td>0.60</td>
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Table 5.7 *Dimensions in mm for Schoenoplectus-type cotyledons*

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
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<tbody>
<tr>
<td>6:1</td>
<td>0.70</td>
<td>0.95</td>
<td>0.40</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>0.45</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>7:7</td>
<td>0.75</td>
<td>0.80</td>
<td>0.35</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8:5</td>
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<td>0.95</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8:7 lens 12</td>
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<td>0.90</td>
<td>0.35</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8:7 lens 12</td>
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<td>1</td>
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<td>10:16</td>
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<td>0.85</td>
<td>0.40</td>
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<td>1</td>
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<tr>
<td>10:19</td>
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<td>0.30</td>
<td>1</td>
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<tr>
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<td>0.90</td>
<td>0.45</td>
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<tr>
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<td>0.80</td>
<td>0.45</td>
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<td>1</td>
</tr>
<tr>
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<td>0.90</td>
<td>0.85</td>
<td>0.30</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Seeds

arium collections for these genera. Members of these taxa listed by Smitinand (1980:300-301, 68-69) are:

- *S. articulatus* L.
- *S. erectus* Poir.
- = *S. juncoides* Roxb.
- *S. grossus* L.f.
- *S. grossus* var. *kysoor* Clarke
- *S. mucronatus* L.

C. *baccans* Nees.
C. *cruciata* Vahl
C. *cryptostachys* Brogn.
C. *indica* Linn.
C. *stramentita* Boot. & Boeck.
C. *thailandica* T. Koyama
C. *tricephala* Boeck.

*S. articulatus*, *S. grossus* and *S. juncoides* are illustrated by Noda *et al.* (1985:38, 1986:45-47). None of these resemble the unknown archaeological material because they 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 such topography was not observed in the archaeological specimens. *S. juncoides*, on the other hand, is biconvex, which is a point of similarity. Although Henderson (1954:255) describes *S. mucronatus* as trigonal, other accounts point to intraspecific phenotypic diversity. For instance, it is stated that the nuts may be "strongly dorsiventrally compressed, planoconvex, or trigonous but the dorsal angle indistinct, broadly obovate, shortly apiculate, scarcely rugulose to smooth, .... 1\(\frac{1}{4}\) - 2\(\frac{1}{4}\) by 1\(\frac{1}{2}\) - 1\(\frac{3}{4}\) mm" (Kern 1974:512). It is quite possible that the archaeological material lies within this broad range variability, but is closer to part of the spectrum which is not represented in the reference material.

Fresh specimens of *Schoenoplectus mucronatus* from the Australian National Herbarium were charred and the data comparing sizes of achenes before and after charring are presented in Table 5.8. These seeds are much larger than the archaeological specimens, but their proportions are similar. The L/W 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.
Table 5.8 Dimensions in mm for ten Schoenopectus mucronatus (= Scirpus mucronatus) seeds charred for 30 minutes at 250°C. (Seeds from the Australian National Herbarium, sheet Paijmans 2067)

<table>
<thead>
<tr>
<th></th>
<th>Before charring</th>
<th>After charring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length  Width  Thickness</td>
<td>Length  Width  Thickness</td>
</tr>
<tr>
<td>Mean</td>
<td>1.94  1.55  0.83</td>
<td>1.96  1.51  0.88</td>
</tr>
<tr>
<td>Std dev.</td>
<td>0.094 0.160 0.103</td>
<td>0.050 0.148 0.101</td>
</tr>
</tbody>
</table>

(d) cf. Cyperaceae cotyledons (type A) (Plate 5.1.7)

This is the second most frequent "seed" in the analysis, totalling 387 items. Subcircular "seed" (or more probably a cotyledon because the specimens appear to be incomplete, with a few having a fragment of testa attached) with sub-rectangular cross section. Small circular scar (diameter approximately 1mm) on proximal end and large elliptical scar for distal end (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, 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.

The identification of archaeological seeds which have lost their seed coats is highly problematic (Pearsall 1989:145), as the comparative internal anatomy of seeds has not been well documented (Martin 1946:513, who provides the seminal study). Even where the "fruit contents" have been found in archaeological 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 1982:217). Nevertheless, in this case a clue to possible identity was provided by other whole charred achenes which were dissected (or fell apart) to release their cotyledons. Some variation in the L:W:T ratios amongst the cotyledons was noted, and there remains the possibility 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 cotyledons (type B). Dimensions for the two types are set out in Table 5.14.
Table 5.9  Dimensions in mm for cf. Cyperaceae cotyledons (type A) from layer 8:1

<table>
<thead>
<tr>
<th>Seed No.</th>
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<th>Thickness</th>
<th>W/T</th>
<th>L/W</th>
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<td>1.40</td>
<td>1.00</td>
</tr>
<tr>
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<td>0.50</td>
<td>0.40</td>
<td>1.25</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
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<td>0.60</td>
<td>0.35</td>
<td>1.71</td>
<td>0.92</td>
</tr>
<tr>
<td>4</td>
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<td>0.50</td>
<td>1.20</td>
<td>1.08</td>
</tr>
<tr>
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<td>0.55</td>
<td>0.50</td>
<td>0.35</td>
<td>1.43</td>
<td>1.10</td>
</tr>
<tr>
<td>6</td>
<td>0.55</td>
<td>0.65</td>
<td>0.40</td>
<td>1.63</td>
<td>0.85</td>
</tr>
<tr>
<td>7</td>
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<td>0.35</td>
<td>1.71</td>
<td>0.92</td>
</tr>
<tr>
<td>8</td>
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<td>0.50</td>
<td>0.45</td>
<td>1.11</td>
<td>1.30</td>
</tr>
<tr>
<td>9</td>
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<td>0.65</td>
<td>0.40</td>
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</tr>
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</tr>
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<td>0.71</td>
</tr>
<tr>
<td>13</td>
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<tr>
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</tr>
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</table>

Mean: 0.57  0.57  0.40  1.46  1.01
Std dev.: 0.075  0.071  0.063  0.223  0.13

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

Producing reference material for comparison with these charred cotyledons 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 exact 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 cotyledons. The experimentally charred seeds were more fragile and fused than the archaeological specimens, suggesting that the conditions which led to preservation involved perhaps lower temperatures and longer exposure than the experimental situation.
Table 5.10  Dimensions in mm for cf. Cyperaceae cotyledons (type A) from layer 8:5

<table>
<thead>
<tr>
<th>Seed No.</th>
<th>Length</th>
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<th>Thickness</th>
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<th>L/W</th>
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<td>1.40</td>
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<td>1.44</td>
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<td>0.55</td>
<td>0.50</td>
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<td>0.40</td>
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<td>1.50</td>
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Preservation for all specimens = 1. Distortion for all specimens = 1.
Table 5.11  Dimensions in mm for cf. Cyperaceae cotyledons (type A) from layer 8:7 lens 12

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<th>Thickness</th>
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<td>0.60</td>
<td>0.40</td>
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<td>1.40</td>
<td>0.71</td>
</tr>
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<td>0.40</td>
<td>1.50</td>
<td>0.83</td>
</tr>
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<td>0.60</td>
<td>0.35</td>
<td>1.71</td>
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</tr>
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<td>1.44</td>
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</tr>
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<td>0.40</td>
<td>1.50</td>
<td>0.92</td>
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<td>0.70</td>
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<td>1.56</td>
<td>0.86</td>
</tr>
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<td>1.75</td>
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Mean  0.60  0.66  0.42  1.60  0.91
Std dev.  0.067  0.054  0.043  0.195  0.108

Preservation for all specimens = 1. Distortion for all specimens = 1.
Table 5.12  Dimensions in mm for cf. Cyperaceae cotyledons (type A) from layer 9:3 lens 6

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<tr>
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<tr>
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Preservation for all specimens = 1. Distortion for all specimens = 1.

(e) cf. Cyperaceae cotyledons (type B) (Plate 5.1.8)

Broadly ovate cotyledons with acuminate apex. Cross section depressed ovate. These cotyledons have a small circular scar on the base similar to the *Eleocharis*-type achenes and cf. Cyperaceae cotyledons (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 cf. Cyperaceae cotyledons (type A).

In order to compare the two varieties of probably Cyperaceae cotyledons, measurements were taken of the type B cotyledons from the base (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 form. These "length" measurements are incorporated in the L/W ratio of Table 5.14. 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 seed. However, the resemblances are probably enough to say that they are from members of the Cyperaceae.
Table 5.13  *Dimensions in mm for cf. Cyperaceae cotyledons (type B) from 8:7 lens 12*

<table>
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<th>Width</th>
<th>Thickness</th>
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<th>L2/W</th>
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<td>0.40</td>
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<tr>
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<td>0.60</td>
<td>0.45</td>
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<tr>
<td>3</td>
<td>0.70</td>
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<td>0.60</td>
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<td>0.55</td>
<td>0.40</td>
<td>1.38</td>
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</tr>
</tbody>
</table>

Mean  
\[
\begin{array}{ccccc}
\text{Length 1} & 0.81 & 0.59 & 0.64 & 0.46 & 1.39 & 0.79 \\
\text{Mean W/T} & 0.096 & 0.054 & 0.063 & 0.043 & 0.148 & 0.344 \\
\end{array}
\]

* A measurement could not be taken due to damage or because the demarcation between embryo and cotyledons was not clear.

Length 1 refers to the full dimension from the apex to the base of the cotyledon. Length 2 refers to the distance between the base (proximal end, with small circular scar) and the change in texture between the embryo and cotyledon, where a fracture might possibly occur to produce a Type A "seed". This is the figure used in comparisons between the two types in Table 5.14.

Table 5.14  *Summary of metric data for selected samples of cf. Cyperaceae cotyledons, type A and B*

<table>
<thead>
<tr>
<th>Seed type</th>
<th>Context</th>
<th>Mean W/T</th>
<th>Mean L/W</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td></td>
<td>8:5</td>
<td>1.58</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>8:7 lens 12</td>
<td>1.60</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>8:1</td>
<td>1.46</td>
<td>1.01</td>
</tr>
<tr>
<td>Type B</td>
<td>8:7 lens 12</td>
<td>1.39</td>
<td>0.79</td>
</tr>
</tbody>
</table>
GRAMINEAE

(a) Gramineae, type A, cf. Paniceae (Plate 5.2.1)
Naked caryopses - lemmas and paleas absent, embryos also missing; distinctly elliptic in longitudinal section, with a hilum on the ventral surface, extending along two-thirds of the grain’s length. Each grain is widest around the midpoint of the length and thickest towards the distal end. Distal end usually rounded and sometimes more or less pointed. The proximal end is split by the hilum on the ventral surface. Dorsal surface is flat or concave, sometimes with a slight groove running parallel to the margin. One specimen has a small, protruding, oval "pad" 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. Cross section: flat or slightly concave dorsal surface, ventral surface markedly convex. For dimensions see Table 5.15.

The relatively large size of the embryo in proportion to the seed indicates a Panicoid grass (Kozlowski 1972:131). 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 1946:542; Martin and Barkley 1961:134) and also that of Echinochloa spp. and Setaria spp. depicted by Hubbard (1975-85). In fresh material Panicoid caryopses are typically tightly enclosed by lemmas and paleas in contrast to the 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.

The caryopses in question bear a strong morphological resemblance to the photographs of seeds identified as Echinochloa-type (barnyard grass) by Crawford (1983:31-34) but are significantly smaller than the Japanese specimens.
<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Hilum length</th>
<th>Hilum width</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:1</td>
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<td>missing</td>
<td>missing</td>
<td>0.50</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2:1</td>
<td>1.10</td>
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<td>0.50</td>
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<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2:1</td>
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<td>0.50</td>
<td>0.80</td>
<td>0.45</td>
<td>2</td>
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</tr>
<tr>
<td>2:1</td>
<td>0.90</td>
<td>0.70</td>
<td>0.50</td>
<td>0.60</td>
<td>0.40</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2:1</td>
<td>0.80</td>
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<td>0.30</td>
<td>0.30</td>
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<td>3</td>
<td>1</td>
</tr>
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<td>0.25</td>
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</tr>
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<td>1</td>
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<tr>
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<td>0.30</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:9</td>
<td>1.05</td>
<td>0.80</td>
<td>0.55</td>
<td>0.75</td>
<td>0.40</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:9</td>
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<td>0.70</td>
<td>0.50</td>
<td>0.40</td>
<td>0.30</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>10:9</td>
<td>0.95*</td>
<td>0.90</td>
<td>0.50*</td>
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<td>0.40</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
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<td>0.60</td>
<td>Hilum missing</td>
<td>Hilum missing</td>
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<td>1</td>
</tr>
<tr>
<td>10:13</td>
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<td>0.50</td>
<td>0.60</td>
<td>0.30</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:17</td>
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<td>0.45</td>
<td>0.55</td>
<td>0.25</td>
<td>3</td>
<td>1</td>
</tr>
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<td>0.95</td>
<td>0.55</td>
<td>0.50</td>
<td>0.20</td>
<td>3</td>
<td>1</td>
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<td>0.75</td>
<td>0.50</td>
<td>Hilum missing</td>
<td>Hilum missing</td>
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<td>0.50</td>
<td>Hilum missing</td>
<td>Hilum missing</td>
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<td>1</td>
</tr>
<tr>
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<td>1.00</td>
<td>0.60</td>
<td>0.80</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
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<tr>
<td>10:17</td>
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<td>1.00</td>
<td>0.50</td>
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<td>0.55</td>
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<td>1</td>
</tr>
<tr>
<td>10:21</td>
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<td>2</td>
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<td>0.90</td>
<td>0.40</td>
<td>4</td>
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<td>10:21</td>
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<td>0.50</td>
<td>0.65</td>
<td>0.50</td>
<td>3</td>
<td>2</td>
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<td>0.55</td>
<td>0.65</td>
<td>0.50</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

* measurement incomplete because specimen is broken or abraded.
### Table 5.16 Dimensions in mm and descriptions for various indeterminate Gramineae caryopses

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Hilum length</th>
<th>Hilum width</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
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<td>2:3</td>
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<td>0.25</td>
<td>0.30</td>
<td>0.20</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Elliptic caryopsis with very broadly ovate cross section. Dorsal end rounded and proximal end less so. Well-defined and shallow hilum 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 hilum 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 hilum. Surface topography not preserved.

| 10:15   | 0.75   | 0.50  | 0.45      | 0.30         | 0.20        | 3            | 2          |


| 10:15   | 0.75   | 0.45  | 0.25      | 0.30         | 0.20        | 3            | 2          |

Description as above.
<table>
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<tr>
<th>Context</th>
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<th>Hilum length</th>
<th>Hilum width</th>
<th>Preservation</th>
<th>Distortion</th>
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<td>0.85</td>
<td>0.45</td>
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<td>1</td>
</tr>
</tbody>
</table>

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 hilum on ventral surface.

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Hilum length</th>
<th>Hilum width</th>
<th>Preservation</th>
<th>Distortion</th>
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<td>1.00</td>
<td>0.35</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Broadly elliptic caryopsis, widest at midpoint to length; cross section transversely elliptic. Well-defined hilum 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.

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Hilum length</th>
<th>Hilum width</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:2</td>
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<td>1.0</td>
<td>0.75</td>
<td>missing</td>
<td>missing</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Broadly elliptic caryopsis. Proximal end blunt; distal end rounded. Ventral surface largely abraded, hilum not visible. Dorsal surface flat to concave.
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 1990:77), but none of these is comparable to the charred caryopses. The level of identification therefore remains at the tribe Paniceae.

(b) *Indeterminate Gramineae* (Plate 5.2.2)
This class includes all the remaining 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 5.16.

**DICOTYLEDONS**

(a) *Chenopodiaceae: Suaeda maritima* Dum. (Plate 5.2.3)
This is the most abundant seed type found at the site, with large numbers in two samples from layer 10 accounting for the bulk. These are horizontal, ovoid seeds with a slight notch between the tip of the radicle and the cotyledons. Radicle tip projects from seed. Margin rounded; cross section lenticular; sides biconvex. Slight furrows running parallel to margin along radicle. A few specimens have a distinctly mottled surface. SEM studies of the surface suggest that the mottling is perhaps more an artefact of charring than due to cell patterning.

These seeds were usually hollow and about ten percent had 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 1986:578).

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 (1963:63-64) as occurring in Thailand. The only taxon in this family to be found in mangrove swamps or adjacent areas is
Seeds 151

*Suaeda maritima*, a small herbaceous plant which grows on open saline plains near the coast (Larsen 1963:64), but *Chenopodium* should not be eliminated on biogeographical grounds alone. While *Chenopodium* spp. are neither listed in Smitinand’s dictionary (1980) nor IRRI’s summary of weeds of rice in Thailand (Moody 1989:331), *C. ficifolium* Smith ssp. *blomianum* (Aellen) Aellen is mentioned as a ruderal in north and northeast Thailand (Harada et al. 1987:71) and *C. album* is reported as having a "cosmopolitan" distribution through the country (Larsen 1963:63). The *Flora of Thailand* does not yet cover these taxa, but the following are known to grow today in adjacent parts of mainland Southeast Asia: *C. botrys*, *C. ambrosioides*, *C. hybridum*, *C. polyspermum*, *C. filicifolium* and *C. acuminatum* subsp. *virgatum* (Larsen 1989:92), although *C. ambrosioides* is an introduction from tropical America (P. Wilson 1984:147). The archaeological specimens under discussion were compared with each of the taxa above, 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 5.18, combined with 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 in a flat spiral and in *Chenopodium* it is ringshaped (Berggren 1981:33) (illustrated by Martin 1946:563). It was impossible to use this criterion to verify the identification of the archaeological specimens from this site because most were hollow. The internal surfaces of some broken testa were examined using SEM to see whether the impression of the cotyledons and embryo could be seen, but none was visible.
Table 5.17  Dimensions in mm for Suaeda maritima seeds from layer 10:19, a subsample of 20 seeds from a total of 268

<table>
<thead>
<tr>
<th>Seed No.</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.95</td>
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<td>1</td>
</tr>
<tr>
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<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0.90</td>
<td>0.80</td>
<td>0.50</td>
<td>1</td>
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</tr>
<tr>
<td>4</td>
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</tr>
<tr>
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</tr>
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</tr>
<tr>
<td>8</td>
<td>1.00</td>
<td>0.90</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
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<td>0.75</td>
<td>0.50</td>
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<td>1</td>
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<td>0.90</td>
<td>0.60</td>
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<td>0.50</td>
<td>1</td>
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<td>1</td>
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<td>0.75</td>
<td>0.55</td>
<td>1</td>
<td>1</td>
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<td>0.75</td>
<td>0.50</td>
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<tr>
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<td>0.95</td>
<td>0.75</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
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<td>0.45</td>
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<td>17</td>
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<td>0.50</td>
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<td>18</td>
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<td>0.85</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>1.05</td>
<td>0.90</td>
<td>0.55</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>1.05</td>
<td>0.95</td>
<td>0.55</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Mean        | 0.99   | 0.84  | 0.521     |
Std dev.    | 0.085  | 0.086 | 0.033     |

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 protuberance in the incurvation between the radicle tip and the median part of the fruit" is diagnostic for this genus (van Zeist and Heeres 1982:214). The lenticular cross section also fitted *Suaeda* better 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* (Berggren 1981:173, Montgomery 1977:71; van Zeist and Bakker-Heeres 1984:180, 1985:253) and examples from the reference collections from Thailand, the testa surfaces differed. The testa of modern charred and uncharred examples of *Suaeda maritima* seeds has a rectangular patterning, not observed in the archaeological material. The latter has grooves and ridges, especially around the
Table 5.18 Dimensions in mm of Suaeda maritima and Chenopodium spp. seeds

<table>
<thead>
<tr>
<th>Type</th>
<th>Length</th>
<th>Width</th>
<th>L/W</th>
<th>Thickness</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPD S. maritima</td>
<td>0.99</td>
<td>0.84</td>
<td>1.18</td>
<td>0.52</td>
<td>Khok Phanom Di excavations</td>
</tr>
<tr>
<td>S. maritima</td>
<td>1.18</td>
<td>0.98</td>
<td>1.20</td>
<td>0.62</td>
<td>Thai fieldwork collection</td>
</tr>
<tr>
<td>S. maritima *</td>
<td>1.07</td>
<td>0.88</td>
<td>1.22</td>
<td>0.51</td>
<td>Thai fieldwork collection</td>
</tr>
<tr>
<td>S. maritima</td>
<td>1.2-1.7</td>
<td>1.4-2.0</td>
<td>1.22</td>
<td>0.7-0.9</td>
<td>Berggren (1981:46)</td>
</tr>
<tr>
<td>S. maritima</td>
<td>1.1-1.2</td>
<td>1.1-1.4</td>
<td>1.22</td>
<td>0.6-0.7</td>
<td>Berggren (1981:46)</td>
</tr>
<tr>
<td>S. maritima</td>
<td>1.60</td>
<td>1.80</td>
<td>0.89</td>
<td>0.90</td>
<td>Montgomery (1977:71)</td>
</tr>
<tr>
<td>S. maritima</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
<td>Martin and Barkley (1961:152)</td>
</tr>
<tr>
<td>Chenopodium album</td>
<td>1.45</td>
<td>1.36</td>
<td>1.07</td>
<td>0.70</td>
<td>Australian National Herbarium, sheet Albrech 520</td>
</tr>
<tr>
<td>C. album *</td>
<td>1.32</td>
<td>1.24</td>
<td>1.06</td>
<td>0.84</td>
<td>Australian National Herbarium, sheet Albrech 520</td>
</tr>
<tr>
<td>C. album</td>
<td>1.1-1.6</td>
<td>1.24</td>
<td>1.06</td>
<td>0.6-0.8</td>
<td>Berggren (1981:46)</td>
</tr>
<tr>
<td>C. album</td>
<td>1.20</td>
<td>1.00</td>
<td>1.20</td>
<td>0.50</td>
<td>Montgomery (1977:69)</td>
</tr>
<tr>
<td>C. album</td>
<td>0.8-1.4</td>
<td>1.00</td>
<td>1.20</td>
<td></td>
<td>Engstrand &amp; Gustafsson (1974:20)</td>
</tr>
<tr>
<td>C. ambrosioides</td>
<td>0.74</td>
<td>0.67</td>
<td>1.10</td>
<td>0.45</td>
<td>Australian National Herbarium, sheet Pullen 3642</td>
</tr>
<tr>
<td>C. ambrosioides *</td>
<td>0.69</td>
<td>0.61</td>
<td>1.13</td>
<td>0.59</td>
<td>Australian National Herbarium, sheet Pullen 3642</td>
</tr>
<tr>
<td>C. ficifolium</td>
<td>0.8-1.2</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
<td>Australian National Herbarium, sheet Pullen 3642</td>
</tr>
<tr>
<td>C. ficifolium *</td>
<td>1.03</td>
<td>0.98</td>
<td>1.05</td>
<td>0.53</td>
<td>Australian National Herbarium, sheet Blom.C.sn.Canb.123089</td>
</tr>
<tr>
<td>C. polyspernum</td>
<td>1.01</td>
<td>0.96</td>
<td>1.05</td>
<td>0.54</td>
<td>Australian National Herbarium, sheet Blom.C.sn.Canb.123089</td>
</tr>
<tr>
<td>C. polyspernum *</td>
<td>0.96</td>
<td>0.91</td>
<td>1.05</td>
<td>0.64</td>
<td>Australian National Herbarium, sheet Leenhouts 2856</td>
</tr>
<tr>
<td>C. botryodes</td>
<td>0.6-1.0</td>
<td>1.00</td>
<td></td>
<td>0.3-0.4</td>
<td>Berggren (1981:46)</td>
</tr>
<tr>
<td>C. botrys</td>
<td>0.70</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
<td>Montgomery (1977:69)</td>
</tr>
</tbody>
</table>

* 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.
margin of the radicle. The differences may be due to the high degree of polymorphism in this taxon (Backer 1954:106) or to charring conditions, but insufficient reference material from a wide number of locations was available to investigate these possibilities. Certain atypical seeds did have a mottled appearance, due to surface cracking, which was typically hexagonal and compatible with formation by shrinkage on cooling and splitting along the cell walls of the testa.

This group of seeds is thought to be from *Suaeda maritima* Dum. (*chak khraam*), 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 1963:64).

(b) Amaranthaceae: *Amaranthus* sp. (Plate 5.2.5)
Circular/lenticular seeds with distinct narrow marginal rim. Notched margin. Testa black and shiny. Many of this group are hollow, squashed, split or distorted in other ways.

The narrow rim distinguishes this group from members of *Chenopodium* which have a rounded margin (Martin and Barkley 1961:153).

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 low 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.
Table 5.19  Dimensions in mm for Amaranthus sp. seeds

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:1</td>
<td>0.95</td>
<td>0.85</td>
<td>*</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2:1</td>
<td>0.85</td>
<td>0.80</td>
<td>*</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2:1</td>
<td>0.80</td>
<td>0.75</td>
<td>0.50</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2:1</td>
<td>0.75</td>
<td>0.75</td>
<td>0.55</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2:1</td>
<td>0.70</td>
<td>0.70</td>
<td>0.45</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2:3</td>
<td>0.70</td>
<td>0.60</td>
<td>*</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2:3</td>
<td>0.75</td>
<td>0.70</td>
<td>*</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2:3</td>
<td>0.90</td>
<td>0.80</td>
<td>*</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3:1</td>
<td>0.90</td>
<td>0.80</td>
<td>*</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3:1</td>
<td>0.90</td>
<td>*</td>
<td>*</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>4:1</td>
<td>1.00</td>
<td>0.95</td>
<td>0.65</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4:1</td>
<td>0.95</td>
<td>0.95</td>
<td>0.75</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4:1</td>
<td>0.90</td>
<td>0.85</td>
<td>0.60</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4:1</td>
<td>1.05</td>
<td>*</td>
<td>*</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4:1</td>
<td>0.75</td>
<td>0.75</td>
<td>*</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4:1</td>
<td>1.00</td>
<td>0.95</td>
<td>0.60</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5:1</td>
<td>1.25</td>
<td>*</td>
<td>0.50</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>6:1</td>
<td>0.80</td>
<td>0.75</td>
<td>*</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>6:1</td>
<td>1.00</td>
<td>0.90</td>
<td>0.70</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>6:1</td>
<td>1.00</td>
<td>0.95</td>
<td>0.50</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>8:3</td>
<td>0.90</td>
<td>0.75</td>
<td>0.40</td>
<td>1</td>
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</tr>
<tr>
<td>8:5</td>
<td>0.75</td>
<td>0.75</td>
<td>0.35</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>8:5</td>
<td>0.90</td>
<td>0.90</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8:5</td>
<td>0.90</td>
<td>0.90</td>
<td>0.55</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9:3</td>
<td>0.90</td>
<td>0.80</td>
<td>0.60</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9:3</td>
<td>0.95</td>
<td>0.95</td>
<td>0.60</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>10:9</td>
<td>0.85</td>
<td>0.80</td>
<td>0.55</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:9</td>
<td>0.70</td>
<td>0.70</td>
<td>0.20</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:19</td>
<td>0.80</td>
<td>0.75</td>
<td>0.50</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>10:20</td>
<td>1.05</td>
<td>1.20</td>
<td>0.75</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>11:1</td>
<td>1.00</td>
<td>1.00</td>
<td>0.75</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Mean 0.94 0.88 0.57 * measurement not taken
Std dev. 0.13 0.14 0.13 due to excess distortion

Table 5.20  Dimensions for groups of ten seeds of Amaranthus spinosus and A. viridis before and after charring for 30 minutes at 250°C. (Specimens from National Weed Science Research Institute, Bangkhen, Bangkok)

<table>
<thead>
<tr>
<th>Before charring</th>
<th>After charring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Width</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
</tr>
<tr>
<td>A.spinosis</td>
<td>Mean 0.83</td>
</tr>
<tr>
<td>Std dev. 0.049</td>
<td>0.064</td>
</tr>
<tr>
<td>A.viridis</td>
<td>Mean 1.03</td>
</tr>
<tr>
<td>Std dev. 0.063</td>
<td>0.072</td>
</tr>
</tbody>
</table>
(c) Amaranthaceae: *Amaranthus*-type

Flat discoid seeds with lenticular cross section, slightly grooved, but having a rounded margin and a small notch on the margin. Radicle is not pronounced. All specimens hollow, some cracked and missing a large portion of the testa. Apparently not charred, but not looking modern either (they are possibly degraded modern contaminants, possibly mineralised archaeological specimens). Black outer coat has rubbed away to reveal cream/white/grey, possibly mineralised surface. Testa topography around the margins, fading into the central area of the seed, has rectangular grooves and 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 share a similarly rounded form. The cross sections differ in that this type does not have the markedly compressed rim typical of the genus *Amaranthus*. In lateral view their rounded profile is closer in shape 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 reliable identification for this seed type, which has tentatively been ascribed to *Amaranthus*-type.

**Table 5.21** Dimensions in mm of *Amaranthus*-type seeds from layer 10:20

<table>
<thead>
<tr>
<th>Seed No.</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.75</td>
<td>0.75</td>
<td>0.55</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.80</td>
<td>0.70</td>
<td>0.50</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>0.70</td>
<td>0.40</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0.70</td>
<td>0.65</td>
<td>0.40</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>0.75</td>
<td>0.70</td>
<td>0.45</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>0.70</td>
<td>0.65</td>
<td>0.45</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0.75</td>
<td>0.75</td>
<td>0.50</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0.80</td>
<td>0.75</td>
<td>0.50</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>0.75</td>
<td>0.80</td>
<td>0.50</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Mean 0.75 0.72 0.47
Std dev. 0.035 0.05 0.051
(d) Portulacaceae: *Portulaca cf. oleracea* (Plate 5.2.7)

Seeds compressed, obovate in outline, faces convex. Elliptic in cross section. Entire surface covered with short rounded warty papillae in lines parallel to the margin. Papillae on margin slightly smaller than those on the sides. Surface partly obscured by soil adhering between tubercules.

**Table 5.22** Dimensions in mm for *Portulaca cf. oleracea* seeds

<table>
<thead>
<tr>
<th>Context</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Thickness (mm)</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:1</td>
<td>0.70</td>
<td>0.60</td>
<td>0.30</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2:1</td>
<td>0.70</td>
<td>0.60</td>
<td>0.25</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2:3</td>
<td>0.60</td>
<td>0.45</td>
<td>0.15</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2:3</td>
<td>0.60</td>
<td>0.50</td>
<td>0.15</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>5:1</td>
<td>0.90</td>
<td>0.80</td>
<td>0.30</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

These seeds are charred and hollow. They are a good match for modern specimens of *Portulaca oleracea* 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 1977:169; Noda et al. 1985:61; Noda et al. 1986:101). 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 1976:126-133).

**Table 5.23** Dimensions for ten *Portulaca oleracea* seeds charred for 30 minutes at 250°C. (Seeds from the National Weed Science Research Institute, Bangkhen, Bangkok)

<table>
<thead>
<tr>
<th></th>
<th>Before charring</th>
<th>After charring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length</td>
<td>Width</td>
</tr>
<tr>
<td>Mean</td>
<td>0.59</td>
<td>0.56</td>
</tr>
<tr>
<td>Std dev.</td>
<td>0.097</td>
<td>0.080</td>
</tr>
</tbody>
</table>
(e) Aizoaceae: *Trianthema (=Sesuvium) portulacastrum* L.  (Plate 5.3.1)

Two shell-shaped seeds, with marked ridges running perpendicular to the margin, tapering from a thick cross section to a narrow one close to the radicle. Hollow and probably missing the area near the radicle.

The reniform shape, dimensions and, most notably, the ridged margin of these subfossil 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, as well as to descriptions and illustrations of seeds from the same taxon in the *Flora of Australia* (c. 1.5 - 2 mm wide) (Prescott and Venning 1984:55,60). This prehistoric seed type does not have the "round reticulum" noted by Noda *et al.*(1985:65) but is similar in shape to their published photograph.

<table>
<thead>
<tr>
<th>Table 5.24 Dimensions in mm for <em>Trianthema portulacastrum</em> seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context</td>
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<tr>
<td>10:8</td>
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<tr>
<td>10:18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5.25 Dimensions in mm for ten <em>Trianthema portulacastrum</em> seeds, before and after charring for 30 minutes at 250°C. (Seeds from the Australian National Herbarium, sheet Kenneally 9393)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed No.</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Before charring</td>
</tr>
<tr>
<td>Mean Length</td>
</tr>
<tr>
<td>Std dev. Width</td>
</tr>
<tr>
<td>Thickness</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Width</td>
</tr>
<tr>
<td>Thickness</td>
</tr>
</tbody>
</table>

*Trianthema portulacastrum* L. (*phak khom hin* or *phak bia hin*) is a procumbent, rather succulent herb, having thick fleshy linear leaves with reddish stems, which is common in the saline soils around the Gulf of Thailand today, especially along riversides (Larsen 1963:63). 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 1983:2; Prescott and Venning 1984:60).
INDETERMINATE SEEDS

(a) Unknown: Type 1 (Plates 5.3.3 and 5.3.4)
Asymmetrical, "pear-shaped" seeds, with pointed, slightly curved beak, approximately 0.3 mm long, at the distal end. A slight ridge runs the length of each seed along the margins. Cross section transversely broadly elliptic at the proximal end, becoming flatter (transversely elliptic) towards the distal end. Longitudinal section ovate. Proximal end has circular scar. All specimens are split along one margin and the seeds have flared open, which means that none of the width measurements is a true representation of the full breadth of the seed. The split reveals the cotyledons 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 not the cotyledon surfaces show any distinctive features of possible diagnostic value. Where this type of cotyledon occurred without a testa covering them, they were in a particularly poor condition. Preservation of the cotyledons was generally 5 or 6 on the Hubbard and al Azm scale (1990:104), but they did not appear to be significantly distorted.

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
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<td>1.10</td>
<td>0.90</td>
<td>2</td>
<td>1</td>
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<tr>
<td>10:25</td>
<td>1.00</td>
<td>0.80</td>
<td>0.60</td>
<td>2</td>
<td>2</td>
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<td>10:25</td>
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<td>1.05</td>
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<tr>
<td>10:25</td>
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<td>0.60</td>
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</tr>
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<td>10:25</td>
<td>1.15</td>
<td>0.80</td>
<td>0.60</td>
<td>2</td>
<td>1</td>
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<td>0.60</td>
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<td>0.65</td>
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<tr>
<td>10:25</td>
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<tr>
<td>10:25</td>
<td>1.70</td>
<td>0.90</td>
<td>0.90</td>
<td>2</td>
<td>1</td>
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<tr>
<td>10:25</td>
<td>1.50</td>
<td>1.10</td>
<td>0.90</td>
<td>2</td>
<td>1</td>
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</table>

These seeds are "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 along with seeds like Suaeda maritima suggests that they could be the fruiting bodies of another saline mudflat plant.
(b) Other indeterminate seeds
The remaining categories are indeterminate dicotyledonous seeds. They are only represented by a small number, sometimes only one seed in a class. Brief descriptions are presented as Appendix 2.

5.3 DISCUSSION AND INTERPRETATION
Charred seeds found in an archaeological matrix may be derived from cultural and noncultural sources and be biased by numerous factors: seed production rates (known to vary widely between taxa and between seasons), differing preservation conditions (notably charring regimes), a broad range of site-formation processes, as well as sampling and flotation procedures. While ethnobotanical and ecological models may help to tease out certain biases in the archaeobotanical record, it is difficult to control for all these extrinsic sources of patterning.

One of the potential problems in a palaeoethnobotanical analysis is sample contamination, from redeposition of disturbed older material, intrusion of younger material from further up the profile (by slipping down cracks, insect or burrowing action) or poor sampling and flotation procedures. 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 in Zone A at Khok Phanom Di, that the seed assemblages have been evened out by post-depositional factors. It was possible, due to time constraints, to examine the extent of this smoothing/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 1986:581), 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 (1977:226) and Minnis (1981:147), the uncharred seeds found in the flot were treated as if they were modern contaminants and excluded from the analyses on this basis,
for example, six non-charred seeds of *Acalypha indica*, 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 part of the modern seed rain at the site during excavation and flotation.

### 5.3.1 Seed frequencies

Interpretations based on raw frequencies of seeds in a sample are known to overlook complexities inherent in the data (Popper 1988:60) and counts are usually, at the very least, standardised for the volume of soil processed. In this analysis, the amount of soil sampled for flotation had, for pragmatic reasons, to vary at different stages during the excavation, but sample volumes were recorded (see section 3.1.1) and have been used to provide an indication of the total number of seeds recovered per 10 litres of earth from each context (Table 5.27, Figure 5.1), as well as to standardise the seed identification frequencies (see Table 5.29).

Seed concentrations at Khok Phanom Di range from 0.2 to 65 seeds per 10 litres of soil, with most contexts yielding less than one item. These figures are similar to other sites in tropical regions (cf. Miksicek 1987:215; Allen [1988]:366), although there are no directly comparable data from Southeast Asia. The notion of sample splitting in order to minimise 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 litres of soil were processed by flotation, the numbers of archaeological seeds were still smaller than would constitute a statistically valid sample according to Hansen (1980:10) or van der Veen and Fieller (1982).

A macrofossil concentration diagram for the numbers of seeds from samples of equivalent size is presented alongside the total weights for charcoal samples (from Table 4.5) as Figure 5.1. This shows 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
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 for other organics to be preserved by charring is higher than in charcoal-free deposits (Miller 1988:75).

Seed frequencies varied 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 4, but that does not account for the anomalously 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 1947:295,300; Ungar 1974:261, 1982:143) have led to its prominence in the seed bank. Its presence at much lower levels in other samples suggests 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, at the site or being used by the community. The documented uses of this plant are few (see Appendix 3), as 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 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 seen at Khok Phanom Di are consistent with Dennell's (1976:235) model of deposition by plants without economic use. 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 will be indicative of the *local* character of the vegetation.
**Table 5.27** Density of seeds in the cultural matrix

<table>
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<tr>
<th>Context</th>
<th>Total number of seeds in sample</th>
<th>Buckets of soil floated</th>
<th>Seeds per 10 litres of soil</th>
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<tr>
<td>2:1</td>
<td>24</td>
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<td>2:3</td>
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<td>4.2</td>
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</table>
FIGURE 5.1
COMPARING CHARRED SEED AND CHARCOAL DENSITY THROUGH THE STRATIGRAPHIC PROFILE

SEEDS/LITRE SOIL
TOTAL WEIGHT OF CHARCOAL SAMPLE (g)
Table 5.29 Frequency of seed types, weighted for the volume of soil processed in each context

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- **Fimbristylis** sp. (Cyperaceae)
- **Elocharis**-type (Cyperaceae)
- cf. **Schoenoplectus**-type (Cyp.)
- cf. Cyperaceae Cotyledons (A)
- cf. Cyperaceae Cotyledons (B)
- Combined Cyperaceae
- cf. Paniceae (Gramineae)
- Indeterminate Gramineae
- **Suaeda maritima** Dum.
- **Trianthema portulacastrum** L.
- **Portulaca** cf. aeracea
- **Amaranthus** sp.
- cf. **Amaranthus** sp.
- Unknown, Type 1
- All Indeterminates

---

Table 5.29 Presence of seed types at Knock Phnum Di.
5.3.2 Assessing the seed remains: qualitative and quantitative results

Standardised frequencies are presented in Table 5.28, along with presence/absence data in Table 5.29, and together they form the baseline for interpretation of the charred seed assemblages. While absolute counts are considered to be too strongly affected by taphonomy and are notorious for introducing a spurious sense of accuracy to the data, 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 1988:61). 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 indices 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 would be inappropriate for analysing these assemblages as the samples do not meet the prerequisites of good preservation and high seed frequency (Popper 1988:66). Furthermore, there is inadequate information on seed productivity for the taxa examined here.

### Table 5.30 Ubiquity indices for seed classes found in entire charred seed assemblage at Khok Phanom Di and the three major stratigraphic divisions (% of contexts in which the seed type occurs)

<table>
<thead>
<tr>
<th>Seed Type</th>
<th>Zones A</th>
<th>Zones B</th>
<th>Zones C</th>
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<tbody>
<tr>
<td>Mutelyric-type</td>
<td>2</td>
<td>5</td>
<td>-</td>
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<tr>
<td>Elephant-type</td>
<td>32</td>
<td>36</td>
<td>-</td>
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<tr>
<td>Schoenoplectus-type</td>
<td>41</td>
<td>41</td>
<td>-</td>
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<tr>
<td>cf. Cyperaceae cotyledons, type A</td>
<td>72</td>
<td>81</td>
<td>33</td>
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<tr>
<td>cf. Cyperaceae cotyledons, type B</td>
<td>9</td>
<td>40</td>
<td>-</td>
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<tr>
<td>Combined Cyperaceae</td>
<td>91</td>
<td>90</td>
<td>33</td>
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<tr>
<td>Gramineae-type A (cf.Paniceae)</td>
<td>27</td>
<td>10</td>
<td>66</td>
</tr>
<tr>
<td>Indeterminate Gramineae</td>
<td>23</td>
<td>5</td>
<td>33</td>
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<tr>
<td>Suaeda maritima Dum.</td>
<td>68</td>
<td>40</td>
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<tr>
<td>Trianthema portulacastrum L.</td>
<td>9</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Portulaca cf. oleracea</td>
<td>5</td>
<td>5</td>
<td>66</td>
</tr>
<tr>
<td>Amaranthus sp.</td>
<td>14</td>
<td>33</td>
<td>100</td>
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<tr>
<td>cf. Amaranthus-type</td>
<td>5</td>
<td>-</td>
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<tr>
<td>Unknown, Type 1</td>
<td>14</td>
<td>-</td>
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<tr>
<td>Combined Indeterminate</td>
<td>77</td>
<td>90</td>
<td>100</td>
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5.3.3 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. 1973:287-8) and many palynologists prefer to group Chenopodiaceae and Amarathaceae 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 1989:62), 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, identifications of pollen grains have been taken to a more refined level than with the seeds. This is due to the careful taxonomic work on Cyperaceae pollen by Maloney, who has managed to take the determinations further than usual during his investigations at Khok Phanom Di, and to the generally 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 separated: *Carex* comp., *Cyperus* comp., *Eleocharis, Fimbristylis* comp., *Scirpus* comp., *Rhynchospora* sim., plus a further group of undifferentiated Cyperaceae (Maloney in press:42). 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. The majority of the Cyperaceae-type remains are found as incomplete specimens where the cotyledons have been stripped of their diagnostic outer testa. These have been identified through comparison with the contents of whole but broken examples of *Eleocharis*-type and *Schoenoplectus*-type specimens and their identifications are regarded as questionable.

Analyses of 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. 1973:288; Somboon 1990:90). 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.
5.3.4 Habitats indicated by the identified seeds

Mangrove forest is dominated by arboreal plants, with very little shrubby undergrowth and virtually no herb layer within the forest. The taxa which might have contributed to seeds found at Khok Phanom Di are restricted to secondary communities or disturbed, degraded mangrove areas, to herbaceous swamps, and to the saltflats at the inner 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 but adjacent herbaceous communities close to the mound: flat, open, saline plains behind the mangrove, and brackish to freshwater swamps. 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 1974:280). Thus the presence of seeds from a group of plants with similar ecological requirements not only indicates particular floral communities but, by association, provides evidence for landforms and hydrology too.

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 those of *Trianthema portulacastrum* (= *Sesuvium portulacastrum*) were produced by members of saltmarsh communities. These plants grow today on the open, hypersaline plains in the upper inter-tidal zone, landward of the mangrove and on the beach ridges interdigitating with mudflats around the Gulf of Thailand (Figure 5.2). Both halophytes, these taxa are limited to saline conditions and will not grow in non-saline soil (Chapman 1947:295), so are effective indicators for palaeoenvironmental reconstruction. At the landward fringe to mangrove, *T. portulacastrum* may be found as an understorey beneath *Avicennia marina* in open parkland (MacNae 1968:99,102), but *Suaeda maritima* is not shade-tolerant (Chapman 1947), so is more likely to be found on 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 1987:155).
FIGURE 5.2
THE VEGETATION ZONES IN THE CHAO PHRAYA DELTA

Redrawn from Takaya (1987:154)
Floristically sparse and with patchy plant cover, the saltflat flora tends to be restricted to salt-tolerant members of the Aizoaceae, Chenopodiaceae and Poaceae (Hutchings and Saenger 1987:152). In the Thai situation, 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 1962:145,164,190; MacNae 1968:119; Lazarides 1980:169,132).

These areas, then, are relatively bare fringes at the highwater-mark, intermittently inundated by extreme tides, lying behind 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 1968:80; Grindrod 1985:327).

As soil salinity declines inland with slightly higher altitudes, 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 contemporary herbaceous flora includes *Wedelia biflora* and *Pluchea indica* (Compositae), *Symostemon bacciformis* (Euphorbiaceae), *Amaranthus* spp. (Amaranthaceae), with some *Indigofera hirsuta* (Leguminosae) and the grasses *Aeluropus lagopoides*, *Spinifex littoreus* and *Zoysia matrella* (Bor 1962:153; Lazarides 1980:196; McMakin 1988). One of the sedges with a Thai distribution and a wide distribution through mangroves, backswamps and less saline soils is *Bulbostylis barbata* (Henderson 1954:265; Caratini et al. 1973:284; Smitinand 1980:56).

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 brought higher up the soil profile by increased evaporation during the dry season.

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 1980:127-8). Some annuals have specific physiological requirements or tolerances. For example, in the area of annual herbs to the east of the Chao Phraya, the sedge *Scleria poaformis* (ton pru) marks the zone of acid sulphate soils (Takaya 1987:155), 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 1974:289).

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 1982:10). The present distribution of *Scirpus grossus*, in particular, coincides with permanently swampy conditions. These sedges are often accompanied by *Eleocharis* spp. and occasionally *Melaleuca leucadendra*. This tree marks freshwater swamplands and is known to have been more extensive in the recent past (Takaya 1987:151,155). Other hydrophytic perennials in this permanently flooded area are *Monochoria, Aneilema, Typha, Juncus, Scirpus, Cyperus, Cladium, Scleria, Fimbristylis, Hydrocera, Aeschynomene, Sesbania, Anmannia, Rotala, Gratiola, Lindernia* and *Torenia* (Murata and Matsumoto 1974:289). The effects of seasonal flooding are weak in this area as the soil is permanently wet.

The remaining identified seed types in the Khok Phanom Di flot samples are *Amaranthus* sp. and *Portulaca* cf. *oleracea*, which are both widespread in places disturbed by human activity. These and other weedy annuals may have been growing within the settlement or quickly colonised parts of the site during times of temporary abandonment.
5.3.5 Plants as resources

Some of the taxa in the archaeological assemblage grow in the vicinity of the site today as arable weeds. For example, *Fimbristylis* sp. has a wide tolerance of flooding, being found in deepwater- as well as shallow-flooded rice (Moody 1989:35-37,336), but 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 1985:327; van Steenis and Veldkamp 1987:428).

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 indicators of 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. Although rice husks were found in abundance in the prehistoric deposits at Khok Phanom Di, this important economic plant is, however, not recorded amongst the charred plant remains found during the 1985 excavation. 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 a bias in recovery techniques. The remains of rice are described in chapter 6 and possible taphonomic reasons for the lack of charred rice remains in the archaeological record at Khok Phanom Di are explored at length in chapter 7.

Furthermore, there are no charred macroscopic remains capable of supporting the supposition of Maloney and Brown (1990:77) 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 are within the size range of cultivated millets like *Echinochloa crus-galli* (cf. Crawford 1983:31,33).

While no cultivars were found, and none of the seeds that were recovered are considered likely to be food debris, it is conceivable that some may represent gathered wild plants where other parts, 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 diet (Bye 1981). For example,
Suaeda maritima leaves are reported as being eaten as a vegetable in Indonesia and India (Burkill 1966:2146; Backer 1954:106; Singh and Arora 1978:38). Parallel uses are cited for Portulaca oleracea (Geesink 1975:270, 1976:129), while the leaves and sometimes the stems of several species of Amaranthus are also rainy season foods throughout the lowlands of South and Southeast Asia (Smitinand and Scheible 1966:207; Lugod and de Padua 1979: 13; Westphal and Jansen 1989:34; Jacquat and Bertossa 1990:59). Amaranthus leaves are reputed to be good sources of iron (Singh and Arora 1978:16,87) and protein (National Academy of Sciences 1975:15) and their derivatives also have a variety of medical applications (Burkill 1966:126; Dastur 1985:18). It is the youngest, non-lignified leaves and stem tips which may be eaten, raw or lightly steamed. In Thailand, where they are much relished, they are often accompanied by the spicy sauce naam prik. Uncultivated edible greens are still widely traded in Thai markets and gathered for home-consumption, but despite their culinary popularity, their use would probably have low archaeological visibility. There do not appear to be any non-food/medicinal uses for these herbs.

Returning to the Cyperaceae achenes, these too are possible by-products of foodplants, though here, it is the corm, of Eleocharis and Cyperus for example, which are eaten raw, boiled or after being roasted on hot coals (Smitinand and Scheible 1966:212; Phengkhrai and Khamsai 1985:131; Russell-Smith 1985:252; Jacquat and Bertossa 1990:120; Smith 1991:19-20).

The evidence for plant use is tenuous. The presence of plants which may in some instances provide food is no proof that they were used in that way at Khok Phanom Di. However, their existence at the site sets up hypotheses which may be tested by cross comparison with other data, such as the analysis of coprolites or chemical composition of bones.
5.3.6 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, has already been demonstrated by the charcoal and other lines of evidence. The halophytic taxa are more prominent, by frequency as well as ubiquity, during Zone A, although the seeds of *Suaeda maritima* do 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, 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 and the resource potential of such areas will be explored in the final chapter.

5.4 MISCELLANEOUS BOTANICAL FINDS FROM THE 1985 EXCAVATION

5.4.1 "Tapa": white fibres found in graves
White fibres found in close association with the skeletons in a number of graves at Khok Phanom Di are considered by the directors 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:146, 155, 157, 173, 188, 196, 200-4, 215, 231, 251, 255, 272, 274, 284, 310, 313, 344). A further indication that the bodies were bound in perishable materials prior to interment is that the bones of the upper arms were sometimes (e.g. burial 129, Higham and Bannanurag 1990a:187) found unnaturally close to the upper torso. 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 1990:2). The fibres sometimes ran over the ceramic gravegoods, such as in burial 130, suggesting that the body and its accompaniments were bound together.
before being placed in the grave (Higham and Bannanurag 1990a:188). Remnants of similar material were also found attached to one of the human skeletons (burial 11) from the 1979 excavation, but no such evidence was recorded during the 1982 investigations (Bannanurag 1989:20, 23, 25).

**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., with especially fine and pliable products being 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* spp. and *Rhizophora mangle*, the roots of *Curcuma viridiflora*, the seeds of *Aleurites moluccana* and the fruit of *Piper* (Bell 1988:42, 72; Kooijman 1988:15-9; Aragon 1990:37,40). 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 mangrove associates *Hibiscus tiliaceus* and *Thespesia populnea* (Hotta 1962:72, Kooijman 1972:Table A). 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, though their remains have not been positively identified at the generic level in either the charcoal or pollen assemblages (see chapter 4; Maloney in press:110).

*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 Southeast Asia to the Pacific islands in the 2nd millennium B.C. (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 1979:368) 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 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 in press). 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 1988:12). The gloss and striations on the archaeological tools were definitely not similar to those created by experimental cutting of *tapa* and as they closely matched 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 thought to be no investigations of this to date (B. Fankhauser pers. comm.).

The presence of stone bark beaters in a number of Southeast 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 2,000 B.C. contexts at Huaca Prieta in north coastal Peru (Bell 1988:74), presumably preserved through dessication. Stone beaters with grooved surfaces, thought to be implements for *tapa* manufacture, date to the 3rd millennium B.C. in
Taiwan (Chang 1970:63 citing Chang 1954a, 1977:85), the 2nd millennium B.C. in the
Philippines (Tolstoy 1963) and the same timeframe in peninsular Malaysia
(Sieveking 1956; Dunn 1971:327), where recent finds at Jendaram Hilir (Leong
1990:72) 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 in Appendix 3, a number of plants
from the mangrove and associated plant communities are used for fabric or cord
production, but *Hibiscus tiliaceus* is said to be the prime source of bast fibres in the
region, being exploited wherever it grows, including the coastal regions of Thailand
(Burkill 1966:119; Phengklai and Khamsai 1985:113). 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 1913:138). It is said that steeping improves the
quality of the end-product, which is more often cordage than fabric, and commonly
put to use in fishing lines, nets and traps. Other members of the coastal flora with
fibre-making uses are *Dolichandrone spathacea*, *Ficus* spp., the seagrass *Enhalus
acoroides* (Burkill 1966:863, 937, 1018) and species of the climber *Derris* (Foxworthy
1922:182). Records of barkcloth production in mainland Southeast Asia include brief
references to the use of *tapa* for clothing by highland agricultural people in central
Vietnam (Colani 1936:239) and the use of barkcloth by the indigenous groups of
peninsular Malaysia, the Sakai, Semang and the Jakun. The trees they all exploit are
the wild breadfruit, *Artocarpus* sp., *Antiaris toxicaria* and various *Ficus* species. In
peninsular Malaysia the bark is made supple by minimum preparation, either by
being pounded between stones or 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 leached to remove toxins by
immersion in running water for as long as a month, prior to being beaten. There are
even instances among the Semang people of Kedah, where unbeaten strips of leached and dried bark are worn as loincloths (Skeat and Blagden 1906:vol 1, 380-2).

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 Phengkhrai and Khamsai (1985:108-115), 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, 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 given as they include taxa like *Artocarpus* sp. which has been identified in the Khok Phanom Di pollen record (Maloney in press:69,101). 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 they formed part of a locally produced commodity, they would have come from one of the mangrove 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.
Examining 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 1986:8, 1988:287; Maloney and Brown 1990:78; Maloney and Rovner in press:124).

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.... [T]he form and condition of this material is such that we are unable to match it positively with any ... reference material." (T. Lawrence pers. comm., December 1985). 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 by Maloney 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 others from Fiji and Tikopia considered most probably to have been made from *Broussonetia* sp. (D. Roe pers. comm.) (Plates 5.3.7 and 5.3.8). 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. Firstly, the material from burials 125, 151 and 136 and from 10:7 feature 29 all comprised numerous, long, fine fibres of even diameter (Plate 5.3.5). 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 (Plate 5.3). 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 (Plate 5.3.6). 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 Kuhn Tiraporn of the Fine Arts Department in Bangkok has subsequently identified as asbestos fibres, on morphological grounds and the fact that they did not burn. 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 and to have access to a more extensive reference collection including plant products in the ethnobotanical data reviewed above. Strictly speaking, the identification of fabrics and bast fibres should be straightforward using polarised light (Körber-Grohne 1991a:18, 1991b:94), 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.
Plate 5.1

Archaeological Seeds and Examples from the Reference Collection

Plate 5.1.1  *Fimbristylis*-type achene from 8:7 lens 12.  
Scale = 500 microns

Plate 5.1.2  Modern charred achene of *Fimbristylis dichotoma*.  
Scale = 500 microns

Plate 5.1.3  *Eleocharis*-type testa from context 8:5.  Scale = 100 microns

Plate 5.1.4  Modern charred achene of *Eleocharis dulcis*.  
Scale = 100 microns

Plate 5.1.5  *Schoenoplectus*-type achene from 10:19.  
Scale = 500 microns

Plate 5.1.6  Modern charred achene of *Schoenoplectus mucronatus*.  
Scale = 100 microns

Plate 5.1.7  cf. *Cyperaceae* cotyledon, type A, from 8:7 lens 12.  
Scale = 100 microns

Plate 5.1.8  cf. *Cyperaceae* cotyledon, type B, from 8:7 lens 12.  
Scale = 100 microns
Plate 5.2

Plate 5.2.1  An example of the Indeterminate Gramineae caryopses, type A (cf. Paniceae), from layer 2:1. Scale = 500 microns

Plate 5.2.2  An example of the Indeterminate Gramineae caryopses, from layer 2:3. Scale = 200 microns

Plate 5.2.3  Suaeda maritima seed from layer 10:19. Scale = 500 microns

Plate 5.2.4  A modern charred Suaeda maritima seed. Scale = 500 microns

Plate 5.2.5  An Amaranthus sp. seed from layer 10:19. Scale = 500 microns

Plate 5.2.6  A modern example of a charred Amaranthus viridis seed. Scale = 500 microns

Plate 5.2.7  One of the Portulaca cf. oleracea seeds from layer 2:1. Scale = 100 microns

Plate 5.2.8  A modern charred Portulaca oleracea seed. Scale = 200 microns
Plate 5.3

Plate 5.3.1  An example of one of the *Trianthema portulacastrum* seeds from layer 10:18. Scale = 500 microns

Plate 5.3.2  A modern *Trianthema portulacastrum* seed. Scale = 500 microns

Plate 5.3.3  One of the Unknown, Type 1 seeds from 10:25. Scale = 500 microns

Plate 5.3.4  The same Unknown, Type 1 seed in lateral view. Scale = 500 microns

Plate 5.3.5  Unidentified white fibres from burial 136. Scale = 100 microns

Plate 5.3.6  Unidentified white fibres from layer 10:15 feature 23. Scale = 100 microns

Plate 5.3.7  An example of the fibres comprising Fijian *tapa*, which is probably made from *Broussonetia* sp. bark. Scale = 200 microns

Plate 5.3.8  More fibres in Fijian *tapa*. Scale = 100 microns
Plate 5.4

Miscellaneous Macroscopic Plant Remains

Plate 5.4.1  A single large seed, possibly the remains of the wild mangosteen, *Sandoricum indicum* (*krathon*). From 10:2 feature 27. Scale = 1 cm

Plate 5.4.2  The impression of a large nut, from 10:2. Quadrant C. Scale = 1 cm

Plate 5.4.3  Impressions of possible rice straw in soil from 10:18, Quadrant C. Scale = 1 cm

Plate 5.4.4  The impressions of leaves preserved in soil from 9:3, Quadrant A. The specimen on the left is the impression and that on the right is the cast of the leaf. Scale = 1 cm
Chapter Six

THE RICE REMAINS

As indicated earlier in the thesis, one of the main aims of the 1985 excavation at Khok Phanom Di was the extraction and investigation of the remains of rice. The primary research problem to be addressed was whether, as Higham (1984) originally hypothesised, the prehistoric occupants of the site took to cultivating rice when the land-sea relations changed and they found themselves progressively more isolated from their established swampland food resources, which may have included wild rice. This chapter will first describe the remains of rice found at the site in terms of their retrieval, preservation, occurrence and abundance through the stratigraphic profile. It then goes on to outline the various ways in which it may be possible to distinguish between the remains of domesticated and wild rices in the archaeological record and apply some of the techniques to the macroremains in question here. The following chapter will examine one possible interpretive framework for cereal remains, namely the use of ethnographic models of harvesting and crop processing procedures, both in general and with reference to the materials from Khok Phanom Di.

6.1 RICE REMAINS FOUND AT KHOK PHANOM DI

The remains of rice found during the 1985 excavation at Khok Phanom Di largely comprise fragments of husk, preserved in the soil, in pottery and within coprolites and other gut/faecal deposits. Usually the most useful and best preserved macroscopic plant remains found on dry open archaeological sites are those preserved by charring, but these were not found during the 1985 excavation. Although a small cache of charred caryopses or spikelets are known to have been recovered by Damrongkiart Noksakul during earlier investigations at the site (C.F.W. Higham pers. comm., 1985) (3 grains were found with skeleton 3, according to Bannanurag 1989:21), descriptions have not been published and the plant remains
themselves were not available for examination as part of this study. The lack of this particular class of plant remains was surprising, given that elsewhere experience has shown that "[i]t is a rare habitation site that fails to yield charred remains of food plants once one of the systems of flotation recovery is applied" (Hillman 1981:123). The absence of charred remains of rice will be discussed further in a subsequent section on the taphonomy of rice through crop processing operations.

As explained in chapter three, concerted efforts were made to recover plant remains via systematic flotation of sediment, but this was, in the event, less successful than the manual retrieval of husks during excavation. Parallel classes of material were collected then through flotation and in soil samples with the latter providing fewer but better preserved examples.

While the flot samples indicated the presence of rice remains throughout virtually the entire stratigraphy, soil samples for rice were only 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.10 cm\(^3\) to 15 x 20 x 10 cm. 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. Concurrent research is being undertaken on a soil monolith which was removed at the end of excavation and taken to the Otago University Anthropology Department for sedimentological analysis. This may confirm the deposition of rice husks throughout the profile and provide additional evidence on the density of these remains.

We turn now to the pottery with rice husk inclusions, of which there were two kinds: inclusions as temper in the slip of one category of pottery and in the fabric of another, with a few examples exhibiting both. Unfortunately it is not possible to be certain of the full range of contexts for this class of material. As regards the slipped sherds, rice inclusions were first noticed after four months of excavation. Subsequently, the ceramics were washed less vigorously and the slipped sherds put aside so that their organic inclusions could be examined. The material available for analysis was from 47 contexts, from layers 8 to 10, but other examples of this kind
are known to have occurred in layers 7 and above, because examples were found later amongst the discarded sherds on the spoil heap.

As regards the rice-tempered sherds, requirements of the ceramic analysis were somewhat in conflict with those of archaeobotany. In the face of the huge amounts of sherdage recovered by the excavation, there was on-site categorisation of sherds by fabric, finish and type, with the retention of all rims and informative boydsherds, and a sample of uninformative ones for more detailed consideration in New Zealand. Two classes of this sherdage proved to be rice-tempered: locally-made pottery in the uppermost strata at the site (Vincent 1987:173), corresponding to Higham's Zone C and Vincent's Period 4 when the excavation area is interpreted as a potting workshop, now more removed from the coast (Higham et al. 1987:151); and "exotic" pottery in the lower two zones.

1. Unfortunately, the opportunity was lost to collect a sample of typologically uninformative sherds from Zone C not included in the collections to be sent to New Zealand and instead discarded on the spoil heap. This was because the presence of rice-tempering was not appreciated at this stage. As a result my sample from the three layers of zone C is restricted to nine sherds from layer 3 sent from New Zealand. The fact the sherds provided were rimsherds is unfortunate as, according to Yen's (1982:55) comparisons of the density of organic inclusions in different parts of the pot, this is the area with least temper. Bodysherds may well have provided a larger number of chaff fragments.

Locally-made rice-tempered pottery is confined to the uppermost strata at Khok Phanom Di (Vincent 1987:173). Nine rimsherds of local ware from layer 2:3 were broken up to extract their rice temper. These sherds contributed well-preserved material, and from them more than 180 small fragments of rice husk were examined and photographed using SEM.

2. As regards the exotic ware, only a single sherd per context could be spared for archaeobotanical analysis from the ceramic collections under examination in New Zealand, and these often measured less than 1 cm². The representativeness of these
data is then, highly dubious. The sherds came from: layers 5:1, 6:4, 6:7, 7:1, 7:7, 8:2, 8:5, 9:6, 10:4, 10:8 and 10:26.

Vincent (1989:1) stresses that "exotic wares suggestive of rice agriculture were present from the outset", but it has been impossible, given the material available, to examine the variability of rice from imported and local wares. Of course, there is a temporal difference too. In this respect, consideration of temporal differences in rice types is also limited by the small number of husks extracted from the slip.

A single very thick sherd of heavily rice-tempered pottery from layer 10:17, fortunately sent from Thailand with the slipped sherds and provided an opportunity to examine a larger number of organic temper fragments from this early period than from the small exotic sherds provided by Vincent. The portion of this sherd, sent to Dunedin for identification, was unfortunately too small for thin sectioning, so a full petrographic analysis could not be undertaken. Nevertheless, the very fact that it contained rice husk at a phase when the local wares were not rice-tempered suggests that it was exotic (Vincent pers. comm., January 1991). The richness of this single rice-tempered specimen indicates the value of this source of rice remains and is a reminder of what has been lost to the analysis because of the circumstances described above.

Each class of material will now be described in terms of its state of preservation and its potential contribution to the analysis. The classes are listed 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 lemmas and paleas, preserved with a high degree of detail. The occurrence of each type is summarised in Table 6.1. The flot samples were all from Quadrant A, while the soil blocks and the ceramic materials were from all three quadrants.
Table 6.1  Summary table of the occurrence of rice husk remains at Khok Phanom Di

<table>
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<th>Soil</th>
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<th>Coprolite</th>
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<tr>
<td>10</td>
<td>F</td>
<td>S</td>
<td>GOOD</td>
<td>MEDIUM</td>
<td>GOOD</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td>S</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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 preservation

In addition to these fragments from spikelets, there were a few instances where monocotyledon leaves and/or stems were found adhering to bedding planes within the soil samples. The possibility that this represents rice straw could be confirmed by means of phytolith analysis (which has regrettably been beyond the scope of this thesis) and, if confirmed, could be an important indicator of both the harvesting method employed and would even provide evidence supporting the notion that Khok Phanom Di was a rice producer site (see the section on crop processing below).

6.1.1 Rice remains from the soil matrix

The remains of rice are found in the soil throughout the stratigraphic sequence at Khok Phanom Di, apart from layer 1. This is evidenced by indications of husk in flot samples from Quadrant A spanning layers 2:1 to 11 and from the husks themselves, 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. While the material was very poorly preserved, the impressions were similar to, but considerably more degraded than, those in pottery and the condition of husk fragments was uniformly poor. Most of the specimens in both classes 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. These husks were not charred and were not discrete items. Sometimes, where the surface layer had been removed, the inner cell structure was exposed (Plate 6.1.2). Occasionally, where small pieces of husk occurred in the flot samples, as in flot sample 112, from layer 6:1, the surface was obscured and although tubercules were visible, their morphology was not clear (Plate 6.1.1). The overall poor preservation of rice remains recovered by flotation is probably because the specimens had been immersed in water, causing some of the silica skeletons to separate from the soil matrix and the siliceous husk fragments to break apart, as well as disaggregating soil particles which had, in situ, been part of an impression.

The chequerboard arrangement of tubercules on these husk epidermal fragments and impressions, as well as the occasional broken trichome found embedded within the impression, suggest that the remains are most likely to belong to the genus *Oryza*, but if not found in combination with the other classes of material, little more could be said about them. These specimens in the flot were neither complete enough 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 6.2, Plates 6.1.1-3).

<table>
<thead>
<tr>
<th>Context</th>
<th>Condition and type of rice remains</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:1</td>
<td>poorly preserved husk fragments</td>
</tr>
<tr>
<td>9:1</td>
<td>poorly preserved husk fragments, some showing sub-surface anatomy</td>
</tr>
<tr>
<td>10:5</td>
<td>poorly preserved husk fragments, tubercules and a single trichome visible</td>
</tr>
<tr>
<td>10:21</td>
<td>poor impressions, some husk fragments showing sub-surface anatomy</td>
</tr>
<tr>
<td>10:22</td>
<td>husk fragments, with tubercules obscured by soil accretions</td>
</tr>
<tr>
<td>10:23</td>
<td>impressions and husk fragments showing sub-surface anatomy</td>
</tr>
<tr>
<td>10:25</td>
<td>poorly preserved husk fragments, some with sub-surface features visible</td>
</tr>
<tr>
<td>10:26</td>
<td>poorly preserved impressions</td>
</tr>
<tr>
<td>11:1</td>
<td>poorly preserved impressions</td>
</tr>
<tr>
<td>11:2</td>
<td>poorly preserved impressions, some fragmentary husks with sub-surface features visible</td>
</tr>
</tbody>
</table>
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 has been difficult to confirm this by looking at fine anatomical details using SEM, since the blocks of soil were not sufficiently coherent to resist being placed under vacuum without first being stabilised by chemical impregnation, which was not attempted.

Silica skeletons of rice husks preserved in this way were very fragile indeed. Separating them from the soil using fine paintbrushes, scalpels and dental probes led more often than not to their immediate disintegration. This class of remains is, however, important, because it provided 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 1974:13; Yen 1977:584) and are discussed below. In the case of the Khok Phanom Di material, though, it was rare to find specimens where both the length and width were found intact (Plate 6.1.4). 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 1987:530). The threshold level of alkalinity beyond which point phytoliths are lost in solution is pH 9.0 (Rovner 1983:235). Soil pH values for the matrix at Khok Phanom Di are not known, but are thought to be in the range of pH 7.0 - 9.0, given the excellent preservation of mollusc remains (G. Mason pers. comm.), although this is higher than from other middens, for example the extreme value of pH >7.0 within a shell-filled feature at a Japanese site (Koike 1979:72).

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, according to Rovner (1987), may predispose silica-accumulating plants to selection as crops. One remarkable feature
of *Oryza* is that it accumulates silica in abundance - more than other cereals (Yoshida *et al.* 1962b:40; Brandenburg *et al.* 1985:1511). 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; Kaufman *et al.* 1985; Dayanandan *et al.* 1983; Takeoka *et al.* 1983), 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:20, 1962b:40; Juliano 1985). The high mineral content, up to 20% of dry matter, with 99% of this being silica (Thomas and Jones 1970:276), prevents rice straw, ploughed into the soil by farmers, from rotting away for many years (Jones 1975). This may account for the preservation of rice remains, and spikelets in particular, in the soil at Khok Phanom Di. The high proportion of silicon 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 by Robinson and Straker (1991), but the example they cite for rice mentions siliceous remains from the Megalithic site at Keppa, S. India, which, like those from Khok Phanom Di, were not actually burnt but nevertheless preserved in the soil (M. Kajale pers. comm., cited by Robinson and Straker 1991:9).

### 6.1.2 Rice remains from the pottery

**(a) Slip.** Complete or near-complete husks or, more commonly, impressions of rice husk were also observed in a layer of fired clay on the external surfaces of certain potsherds. This will be referred to here as a slip, even though it was thicker and more substantial than a normal slip and had organic inclusions. 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 so that clay and spikelet fragments accidentally adhered to the underside of the vessel. This second
explanation might account for the absence of slipped rimsherds in the ceramic assemblages at Otago.

The thick external slip was sometimes as hard as the ceramic matrix, suggesting that there had been 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 (R. Fordham-Edwards pers. comm., 1990). The combination of a high-fired internal surface and a rough, low-fired external one could possibly have been used in pots for cooling liquids through evaporation.

A quantitative assessment of the abundance of these slipped sherds could not be made, not only because of the lack of material from the upper part of the site, but also because of damage during washing, particularly when the slip was of the low-fired and friable type. Within each context there was a range of preservation conditions. Colours of the slip ranged from pale buff, through pale yellow to reddish orange. While plant remains were clearly visible both as husk fragments and their impressions in all of these materials, it was the darker clays which 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 prised apart using a scalpel or dental tools, while in the softer sherds, organic inclusions were exposed by flaking or gently brushing away the slip. 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, but occasionally there were lemma or palea tips (notably without awns) and, very rarely, what appeared to be part of a hollow rachilla. Occasionally the distal portion of a lemma or palea was recovered. The significance of the lack of awns will be addressed later.

The husk fragments, especially when examined under SEM, were more informative than the impressions from the slip, which proved difficult to analyse due to the poor resolution of anatomical details in the coarse sandy matrix. Most skeletons were
resolution of anatomical details in the coarse sandy matrix. Most skeletons were extremely delicate and many disintegrated during extraction, but SEM examination of the survivors revealed that the cellular structure and topography of the silica-rich husks were clearly preserved (Plate 6.1.6). Fine details such as microhairs were visible between the rows of tubercules, while macrohairs or trichomes were often observed intact.

In the case of husks from both the soil and the slipped 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 6.3 and 6.4 respectively. Numbers of observations per context were very small and there were few spikelets where both length and width dimensions were available, so length/width ratios could be calculated in only a few cases. Some 15% of the slipped sherds examined had spikelet remains or impressions where either a complete length or width dimension was measurable, but fewer than 5% of the husks were intact (Plate 6.1.5). Impressions were very dense in the slip, but the fragmentary preservation made identification of the rice inclusions far from straightforward.

(b) 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 1981:34) and in rice-growing areas the material chosen for temper is often broken rice husks.

Vishnu-Mittre (1969:230) tried thin-sectioning potsherds to examine rice husk inclusions but found this technique to be unsatisfactory due to the fragility of the plant remains, so this was not attempted here. Rather, fired husks were observed on the broken surfaces of the sherds or fell out of the matrix when the pottery was broken open. It was found that these separate fragments were more amenable to SEM examination than those which remained attached to the pottery. Mounting the individual husk fragments for SEM examination provided better results than the
technique of mounting small sherds, as Yen had done for the Ban Chiang ceramics (Yen 1982:55). Pieces of pottery with husk fragments attached 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 slip provided superior SEM images (Plate 6.1.7).

An early attempt to screen sherds for organic inclusions by xeroradiography was found 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. There were no impressions on the sherd surfaces as is reported for Ban Chiang pottery (Yen 1982:55). 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 that from the slip, but there was greater variation in samples from pottery, in terms of quality of preservation and fragment size, than was the case with the slip. This probably reflects 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

It is unclear how the Khok Phanom Di husk-tempered pottery compares with equivalent wares from other Thai sites. At Nong Nok Tha, where the pottery classification system was based on temper 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:75). 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, in addition, 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:21; McGovern 1989:74). 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 1986:100; McGovern 1989:75). 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 will be discussed in the following chapter, as they 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.

6.1.5 Rice remains in coprolites

Finally, rice was also found at Khok Phanom Di in coprolites, which seem to be of two kinds: fossilised ?dog faeces, where husks were present as poorly preserved impressions in a hard, mineralised matrix, and a second type, represented by a single coprolite found in burial 67, consisting of, amongst other things, discrete husks. Thirdly there was an instance of food remains found in the lower abdominal area of burial 56. This was dominated by fine fish bones but small rice husk fragments were also found (Higham et al. 1987:176; Higham and Bannanurag 1990a:305).
Rice remains

(a) Dog faeces. Mineralised coprolites were 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 were usually sub-cylindrical, with a relatively smooth outer surface, a length up to 60 mm and diameter up to 20 mm. Such dimensions are much smaller than the typical human coprolite and are more compatible with a canine source (A. Jones pers.comm.). The colour of the outer surfaces was usually obscured by soil, but the inner fractured surfaces were pale yellow to cream (7.5 YR 7/4 (pink) to 10YR 7/4 (very pale brown)). 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.

A tiny fragment of coprolite, together with a piece of chalk for comparative purposes, were dropped into dilute hydrochloric acid. As the coprolite fragment effervesced less than the chalk, the indication is that the mineralised faeces are partially composed of calcium carbonate. This chemical reaction and the creamy-yellow colour of the matrix leads one to suggest that the coprolites are largely calcium phosphate, with a lesser amount of calcium carbonate. The high phosphate content is considered to be related to the considerable amount of bone within the faeces, while the carbonate may well have derived by leaching of shell remains deposited at higher stratigraphic levels in the site.

Non-destructive X-radiography was applied to four specimens 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 fossilised faeces. Poor resolution in the photographic images was partly due to the thickness of these objects. 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 4:4 feature 2, weighing 12.4 g, was immersed in 30% alcohol and cleaned using ultrasound for 60 minutes. The specimen was then fractured with a scalpel and 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% 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 (Hillman, pers. comm.).

Four further specimens from layer 4 were manually fractured and fragments mounted on aluminium stubs for SEM viewing. The typical fracture pattern was different from that for pottery, which tended to break along the line of weakness formed by husk. In the mineralised coprolites, cleavage was through rather than along the husk fragments, which reduced the number of rice husks to be examined in terms of surface topography (Plate 6.2.2).

(b) The coprolite from burial 67. This unique find has provided, in some respects, the best preserved botanical specimens from the site. They supply data on the gross morphology of spikelets (Plate 6.3.3) 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 in press:202). 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 (Bannanurag 1989:197). This included a few comminuted husk fragments amongst hundreds of small fish bones.

The origin of this coprolite has been questionable as it has been uncertain whether it originated from a human, a dog, or even a pig (Maloney and Brown 1990:78). While few canid remains were found in the excavation (Higham *et al.* 1987:176; Higham and Maloney 1989:655, Figure 42.5; Grant and Higham in press:139), it was initially surmised that it is more likely that dogs rather than humans would have consumed rice husk, which is not only barbed and 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 fossilised faeces (Cummings 1989; cf. Netolitzky 1911, 1912; Wood Jones 1910, all cited by Cummings 1989:27). Ninety percent of Nubian human coprolites included large numbers of tiny lemma and palea fragments from sorghum and wheat (up to even 99% of the total volume of individual coprolites) (Cummings 1989:85-86,94) 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. This shows that humans may well consume comminuted chaff, although those of rice would be more silicified and barbed than those of wheat and barley. New evidence in the form of a tentative identification of a parasite egg in this coprolite as *Fasciolopsis buski*, a "common parasite of man and pigs" (Morseth in press:242), argues more strongly for a human origin. The possibility remains, of course, that this coprolite represents both canine and human food, since a dog may have consumed some human faeces.

6.2 DISTINGUISHING BETWEEN THE ARCHAEOLOGICAL REMAINS OF WILD AND DOMESTICATED RICES

This section discusses methodologies for distinguishing between wild and domestic rices, using micromorphological criteria which have been developed from modern material and can be applied to archaeological specimens. One of the major research areas frequently addressed by archaeologists working in Southeast 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 in mind 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:200; 1990b:72), who doubt the archaeological visibility of what could potentially have been a quick transition, in the order of only 20-30 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 a mere 500-600 year period 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.

6.2.1 Terminology for describing rice anatomy (Plates 6.4.1-4 and Figure 5.1)
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, the palea and the flower which develops into the caryopsis (the "grain" or "seed", but morphologically a fruit) (Chang and Bardenas 1965:7). 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. 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 1964:316) (Plate 6.4.4).

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 (Katayama 1969; Chang and Bardenas 1965:14; Clifford and Watson 1977:26) or a glume, as in much of the archaeobotanical literature (e.g. Glover 1979; Yen 1982), should rather be called termed a lemma (Santos 1933; Clifford and Watson 1977:26; Vaughan 1989:4; Weatherwax 1929). 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 1934:40-41). It is thicker in the central area and thinner towards its base and apex. These thicker parts are stronger, a
FIGURE 6.1
PARTS OF A RICE SPIKELET

Source: Chang and Bardenas (1965:10)
reason for their greater representation in the archaeological record. Both 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 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 surfaces, has stomata (Maeda 1972:466). In addition to these two fertile bracts, there are also two small vestigial glumes or sterile lemmas at the base of the spikelet, which will be described at greater length in section 6.2.4.iii.

6.2.2 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 of the economically important plant parts, and by the loss of protection from predators (eg. loss of spines or toxicity). Concomitant physiological changes affect "rate and uniformity of seed germination, reaction to day length and length of life cycle" (Pickersgill and Heiser 1976:55) and are less likely to be detectable in the archaeological record (though see work of Butler 1988, 1989, 1991 for 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 bards 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:161, summarising the work of many crop geneticists). In wheats, the wild-types 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 1980:214).

6.2.3 General features distinguishing wild and domesticated rices

The analysis of intrageneric variation in *Oryza* (eg. Morishima and Oka 1960) has conventionally used life-forms and macroscopic anatomical characters for species separation (Table 6.3). These aspects of the plant have little direct value to the archaeobotanist, since they emphasize vegetative plant parts like leaves (Metcalfe 1960:xxxix) which are not commonly found in the archaeological record.

Distinctions between wild and domesticated plants are also often made in terms of *population* characteristics, such as wild plants having a high rate of seed shedding, small grain weight and small spikelet numbers per panicle (Oka and Morishima 1971:357), or the cultivars exhibiting synchronous maturity (Second and Ghesquiere 1985). Such characters are not easily assessed for archaeobotanical material.
**Table 6.3** Key to differentiation of wild rice species *Oryza rufipogon and O. nivara from cultivated O. sativa*

<table>
<thead>
<tr>
<th>Character</th>
<th><em>O. rufipogon</em></th>
<th><em>O. nivara</em></th>
<th><em>O. sativa</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Branching</td>
<td>Extravaginal</td>
<td>Intravaginal</td>
<td>Erect</td>
</tr>
<tr>
<td>Growth habit</td>
<td>Decumbent</td>
<td>Semidecumbent</td>
<td>Erect</td>
</tr>
<tr>
<td>Spikelet shape</td>
<td>Slender</td>
<td>Bold</td>
<td>Variable</td>
</tr>
<tr>
<td>Apiculus</td>
<td>Blood red</td>
<td>Purple or green</td>
<td>Green</td>
</tr>
<tr>
<td>Pericarp</td>
<td>Red or purplish</td>
<td>Reddish-dirty white</td>
<td>Variable</td>
</tr>
<tr>
<td>Anther length</td>
<td>Long</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Awn</td>
<td>Slender/flexuous and frequently reddish</td>
<td>Stout, long and frequently reddish</td>
<td>Slender/awnless to awned</td>
</tr>
<tr>
<td>Life-span</td>
<td>Perennial</td>
<td>Annual</td>
<td>Annual</td>
</tr>
<tr>
<td>Habitat</td>
<td>Stagnant and seasonal swamps</td>
<td>Drainage ditches and shallow ponds</td>
<td>Domesticated culture</td>
</tr>
<tr>
<td>Grain shattering</td>
<td>Readily before fully ripe</td>
<td>Before fully ripe</td>
<td>Variable but less shattering than wild</td>
</tr>
<tr>
<td>Grain dormancy</td>
<td>High</td>
<td>High</td>
<td>Variable</td>
</tr>
</tbody>
</table>

(source: Wirjaharja et al. 1983:321)

### 6.2.4 Archaeologically applicable criteria for distinguishing between wild and domesticated rices

Conventional criteria for distinguishing wild from domestic rices exist (Table 6.3; Duistermaat 1987), 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 grains. The taxonomic resolution to which specimens in each of these classes of material may confidently be ascribed varies and a brief summary of each is provided in the following discussion.
Microscopic remains

i) 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, dispute on the possibility of separating fossil pollen of *O. sativa* from that of its wild relatives, even using SEM or phase-contrast microscopy (Maloney 1990:139). 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 Southeast Asian grasses, size alone cannot be relied upon for identifying rice pollen (Maloney, in press:2). Nevertheless, Maloney points to a similarity in size between the Gramineae pollen from the cores taken around Khok Phanom Di and those from present-day cultivars from Sumatra, together with identifications of herbaceous plants which may be ruderals, and uses these as circumstantial evidence for rice cultivation in the area of the site (Higham and Maloney 1989:661; Maloney in press:77). 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 within *Oryza*, but this criterion remains to be evaluated using SEM before applications to routine light microscopy can be developed (Maloney 1990:146).

ii) 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 distinction between species is more problematic. 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 given highest priority. 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, in both Japan and the United States, on the identification of rice
phytoliths both in terms of their separation from other members of the Gramineae and the wild/domestic dichotomy (Pearsall 1990:71).

iii) Starch Grains. As with phytoliths, the common starches can readily be identified microscopically at a generic level (Schoch and Maywald 1967:638), 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 1969:48,74-77). The starch grains of *Oryza* are compound, 2-10 microns in diameter (Fahn 1974:22; Jackson and Snowdon 1990:226), and united in aggregates similar to oats (Juliano and Aldama 1934:55), but prospects for pursuing finer identifications of starch grains preserved within archaeological ceramics are slim.

iv) Chemical properties. Recently, chemical research has set out to fingerprint 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 1988:168; Hill and Evans 1989:421, 1990), and the encouraging results from the Southwest 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
The inability of microscopic plant remains like pollen and phytoliths to distinguish unambiguously between wild and domestic plants using current techniques means that attention turns to macroscopic materials in order to track the process of past plant domestications. 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 informative parts of the rice plant are rarely found, while the 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.

i) 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 summarised by their length/width ratio, has been used to indicate the degree to which their stock has undergone domestication (Vishnumittre 1972), but this is brought into question in the discussion below. The grain surfaces of freshly dehusked caryopses have also been examined by Savithri (1976:50), 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 for separating wild from cultivated rice than the number of longitudinal ridges and furrows along the grain. 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. This line of research would seem to be worth more attention, as analysis of the transverse cells of caryopses of modern wild, domesticated and weedy wheats and ryes has shown cellular differences along the domestication gradient (Körber-Grohne and Piening 1980; Körber-Grohne 1981:202; Colledge 1988).

ii) Husk. This is the plant part most commonly represented in the archaeobotanical assemblage at Khok Phanom Di and possible diagnostic characters will be discussed at length. The first three features described below arise from the fact that while wild plants are well adapted for seed dispersal, domesticates have been selected to retain their grains for human use and are dependent on humans for reproduction. Thus, domesticates can be recognised by the lack of some seed-dispersing characters, such as natural seed shedding, and the reduction of others, like the backwards-facing barbs on the sterile lemmas, as well as the absence of self-implantation features like awns. Other features described below have less weight because they are derivative and not direct indicators of the plant's mode of reproduction and hence its degree of domestication. These secondary characters, such as grain size and husk topography,
would be less responsive to changes in human use of the plant and their status would not be indicative of the earliest phases of domestication. They are nonetheless useful in the absence of rachilla fragments with abscission scars and the distal portions of lemmas and paleas.

**i. Presence or absence of awns on the fertile lemma**

One character which could potentially be used for distinguishing between wild and domesticated rices is the presence or absence of awns. An awn is a single, long, straight, tapering, bristle-like projection from the apical end of the spikelet, as we have seen above (Figure 6.1). 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 1968:7). Round in cross-section and with a thick-walled epidermis, awns have a heavy siliceous cuticle with numerous small trichomes on the surface. Awns mostly seem to be associated with seed dispersal or implantation into the soil. The presence of awns is fairly constant within most species of *Oryza* (Sano and Morishima 1982:520), but in cultivars very many variations are noted, ranging from complete absence to awns up to 6 cm in length (Hoagland and Paul 1978:619; Duistermaat 1987:162). Thus, while the presence of an awn does not necessarily mean that the spikelet came from a wild plant, its absence could only imply that the spikelet was from a domesticate. Although, as suggested by Vishnu-Mittre (1974:12), rice remains rarely include awns, they are not entirely unknown in the archaeological record (e.g. at Hastinapura, Chowdhury and Ghosh 1954-5:123 and at Homudu, Second 1985:140).

Some of the husk 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 (Plates 6.2.5-7).

**ii. Shedding habit**

One of the primary differences between wild grasses and their domestic counterparts is that wild plants are well adapted for reproduction and disseminating seed, whereas domesticates rely on human intervention. In wild rices, reproduction
may be by vegetative means, as in the case of 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 (Oka and Morishima 1967:254). By contrast, harvesting with a sickle, followed by reseeding (Harlan *et al.* 1973:314), preferably in a new plot (Hillman and Davies 1990b:58), unconsciously selects for plants with a non-shedding habit (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 varieties (Harlan *et al.* 1973:314-5), and in rice, *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 through a change in the abscission scar and this is a feature sometimes, albeit rarely, detected in archaeobotanical remains. This line of enquiry has been profitably followed in the study of progenitors of barleys and wheats in the Middle East (Hillman and Davies 1990a; Kislev 1989).

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.* 1961:330; Oka and Morishima 1971:358; Oka 1974:484). Grain shedding (or lack of it) is, therefore, a potentially sensitive indicator 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 "one or a few major genes [and] relatively simple patterns of inheritance" (Pickersgill and Heiser 1976:56). 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 1980:216), while according to others, more than two genes are involved (Chang 1964, cited by Harlan *et al.* 1973:315). 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 that the establishment of non-shattering traits is genetically straightforward. In the wild type, shattering is partially dominant (Sethi 1933, cited by Richharia and Misro 1962:22) or simply dominant (Jones 1933, cited by Richharia and Misro 1962:22) over non-shattering types.

**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 thinner-walled cells within the abscission zone (Takeuchi 1922, cited by Hu et al. 1964:175). This occurs at "the junction of the lower sterile lemma and the facet (rudimentary glumes) [at the apex of the pedicel]. The base of the lower sterile lemma as it disarticulates from the pedicel is horizontal or oblique in appearance" (Chang and Bardenas 1965:10-11). In longitudinal section, the abscission layer comprises one or two layers of thin-walled parenchymatous cells (Jin 1986:457), 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 *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. 1979:79).

Zee and colleagues conclude from their comparative studies of pedicel histology 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 variously linked to the thickness of sclerenchyma between the abscission layer and the central vascular bundle (Inouye et al. 1985:82), the abscission layer and the development of cracks in it (Hu et al. 1964:176) and the number of cells in and the length of the abscission layer (Zee et al. 1979:5), as well as the development of lignified cells in the supporting zone of the pedicel (Srinivas et al. 1979:81). Seed shedding is not, however, completely confined to wild-type rices (Sharma and Shastry 1965b:165; Yamasaki 1928). Both 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 1936:241; Srinivas et al. 1978). This is evidenced by up to 30% loss of crops due to grain shedding (Bhalerao 1930; Ramiah and Rao 1936). Indeed, there is a wide spectrum in ease of detachment (Jin and Inouye 1982; Takenouchi 1924; Yamasaki 1928) under both genetic and environmental control (Srinivas et al. 1979), 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. The environmental conditions include insolation, temperature and humidity during ripening (various authors cited by Inouye et al. 1985:81). The process of selection for non-shedding types which presumably occurred with the earliest harvests continues today. It is noted that native varieties grown in Japan until the 1920's, which were threshed by beating against a wooden frame, had a lesser tensile strength than the improved japonicas of today (Jin and Inouye 1981), while non-shedding is still a character bred into the improved strains of "miracle rice".

There are also differences in grain shedding amongst the subspecies. Generally, indicas are known to have higher shedding rates than japonicas. This has been demonstrated by Jin and Inouye (1985:378), who examined Indonesian cultivars comprising 58 bulu rices (similar to indica) and 54 tjereh (similar to japonica) and found an abscission layer in all but three varieties. The shedding habit in the bulu rices was attributed not so much to the presence of an abscission layer, as to the cracking of that layer.
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 both wild and certain cultivated cereals and, presumably, various grades in between. These could be regarded as cultivated but not fully domesticated crops (Hillman and Davies 1990a:158). 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 might be seen in the archaeological record through a gradual change in ratios between predominantly wild and predominantly mutant, non-shedding plants. For many generations, the two types would co-exist in the population and intermediate forms might also occur.

Abscission scars
When the spikelet falls away from the pedicel, an abscission scar is left on the rachilla which can indicate whether the spikelet was threshed or detached naturally. This feature does not appear to have been reported widely in the literature on rice anatomy. 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. All published illustrations of abscission zones in rice known to me are in longitudinal view and, while useful in providing a histological perspective on the development of the abscission zone, they do not show the aspect which would most readily be 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 study (1981), so have been investigated here and are described below (6.3.2.i) for both modern and archaeological specimens.

**iii. Hairiness of the sterile lemmas**
A pair of sterile lemmas are the "two flowerless bracts at the base of the spikelet" (Chang and Bardenas 1965:15). These are triangular to linear-lanceolate and slightly
Rice remains 211

concave, with hairs along their margins, keel and at the apex (Juliano and Aldama 1934:40), which 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 1965:184) and within the cultivars the range extends from extreme glabrousness in javanicas to extreme pubscence in japonicas, with indicas intermediate (Gopalakrishnan and Shastry 1965:179). 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 retaining their rachilla lacked sterile lemmas due to mechanical breakage (or chemical deterioration through digestion), although a couple of the more complete specimens did show the feature. Preservation was inadequate, however, to see the degree of pubescence there.

iv. 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 (cf. Hopf 1978; van Zeist and Heeres 1973; van Zeist and Bakker-Heeres 1982; Amblard and Pernes 1989:123) and stems from the fact that in many cereals domestication is accompanied by selection for larger grain size (Harlan et al. 1973:318). The use of this character the examination of a large range of specimens, since the size of grains varies between spikelets on the same plant, between plants in a single population and between populations of a given taxon.

Size and shape are generally recognised to be derivative features and not symptomatic of a particular stage of domestication (Kislev 1989:147). These characters are themselves problematic means of describing and categorising archaeological plant remains because there may have been post-depositional distortion in the form of shrinkage with charring or desiccation, or even swelling if the grains were waterlogged. For this reason it is more reliable to calculate ratios
which summarise shape rather than to use absolute measurements. The effect on rice of charring under various temperature regimes has been explored by Garton (1979).

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 (1972:20), who pointed to the tendency of modern wild grains to be slender in comparison with domestic caryopses. Using modern reference indices (Table 6.4), 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 his modern reference material are very general initial guidelines, pointing to gross morphological differences between grains from wild and domestic plants, but as no indication of standard deviation or the range of values for each sample is provided, it is difficult to assess the degree to which the populations from which the samples were taken overlap. The reliability of this criterion for separating wild from domestic grains has been brought into question by Savithri (1976:49) (Table 6.4), substantiated by Sharma (1983:38) 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, human selection has been mostly in the direction of an increase in grain size, but also for certain small varieties, such as *khao met lek*, one of the reference collections studied below. Thus, although the charred caryopses found by Chester Gorman from the 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 northwest Thailand, without taking into consideration the shrinkage effects of charring (Yen 1982:54).
Table 6.4 Length/(breadth x thickness) ratios for wild and cultivated rice grains

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<td>(n=100)</td>
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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 characterising 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 given in the course of taxonomic and agronomic papers, but 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 disparate sources to establish whether the length/width ratio of a spikelet can be used as 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 1965:607-618; Hamada 1965:544-583; Morishima et al. 1984:52,73-75). Equivalent data are available for wild *O. perennis* from the west coast of Sri Lanka (Sakai et al. 1961c:63) and from India (Sharma and Shastry 1965a), while both wild and cultivated rices from Thailand have been included in studies by Akihama and Watabe (1970:342-3) and Morishima et al. (1961:330). These data are combined in Figures 6.2 - 6.4 and Tables 6.9 - 6.10 and indicate considerable inter- and intra-specific variability, as well as significant overlap between the distributions of the two types, which makes the length/width criterion less than satisfactory for making the
distinction between wild and cultivated rices in either modern or archaeological specimens.

Table 6.5  Mean length/width ratios for spikelets from 1573 populations of Southeast Asian cultivated rice, *Oryza sativa*

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TOTAL 335 112 1126 1573
FIGURE 6.2
MEAN LENGTH/WIDTH RATIOS FOR SPIKELETS FROM 150 POPULATIONS OF CULTIVATED AND WILD THAI RICE
Source: Morishima et al. (1961: 330)

FIGURE 6.3
MEAN LENGTH/WIDTH RATIOS FOR SPIKELETS FROM 1573 POPULATIONS OF CULTIVATED RICE

FIGURE 6.4
MEAN LENGTH/WIDTH RATIOS FOR SPIKELETS FROM 65 POPULATIONS OF WILD RICE
Sources: Akhama and Watabe (1970: 342-3)
Sakai et al. (1961c: 63)
Sharma and Shastry (1965a: 248)
Table 6.6 *Mean length/width ratios for spikelets of wild rice*

<table>
<thead>
<tr>
<th>Taxon/Type</th>
<th>Colln. No.</th>
<th>L/W Ratio</th>
<th>Taxon/Type</th>
<th>Colln. No.</th>
<th>L/W Ratio</th>
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<td>3.22</td>
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<td>3.22</td>
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<tr>
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<td>30</td>
<td>3.27</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sakai <em>et al.</em> (1961c:63)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O. perennis</td>
<td></td>
<td></td>
<td>Ky</td>
<td>3.25</td>
<td></td>
</tr>
<tr>
<td>(50 seeds measured in each</td>
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<td></td>
<td>Nt</td>
<td>2.80</td>
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</tr>
<tr>
<td>case except Th-(2) where</td>
<td></td>
<td></td>
<td>Th-(1)</td>
<td>2.51</td>
<td></td>
</tr>
<tr>
<td>27 were measured)</td>
<td></td>
<td></td>
<td>Th-(2)</td>
<td>3.30</td>
<td></td>
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<td>Md</td>
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Table 6.6 (continued)

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<tr>
<th>Taxon/Type</th>
<th>Collection Number</th>
<th>L/W Ratio</th>
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<tbody>
<tr>
<td><strong>Sharma and Shastry (1965a:248)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Balunga:</em> 'B' type; procumbent perennial plants, swamp habitat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nowgong</td>
<td>SC 159</td>
<td>4.00</td>
</tr>
<tr>
<td>Burdwan</td>
<td>SC 170</td>
<td>3.54</td>
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<td>Cuttack</td>
<td>SC 120</td>
<td>3.75</td>
</tr>
<tr>
<td>Raipur</td>
<td>SC 155</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Balunga-like: 'B(S)' type; similar to 'B' type, except decumbent, swamp habitat</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manipur</td>
<td></td>
<td>2.33</td>
</tr>
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<tr>
<td>Cuttack</td>
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<tr>
<td></td>
<td></td>
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<tr>
<td><em>Nivara:</em> 'N' type; semi-erect or erect, annual plants, found in seasonal ditches</td>
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<td></td>
</tr>
<tr>
<td>Kanpur</td>
<td>SC 81G</td>
<td>2.53</td>
</tr>
<tr>
<td>Dangs</td>
<td>SC 377</td>
<td>2.33</td>
</tr>
<tr>
<td>Bilaspur (M.P.)</td>
<td>SC 85E</td>
<td>2.67</td>
</tr>
<tr>
<td>W. Godavari</td>
<td>SC 31</td>
<td>2.83</td>
</tr>
<tr>
<td>Darwin</td>
<td>SC 57</td>
<td>3.15</td>
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<td></td>
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<tr>
<td><em>Nivara-like: 'N(S)' type; similar to 'N' type, but erect rather than semi-erect, found in seasonal ditches</em></td>
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<td></td>
</tr>
<tr>
<td>Dangs</td>
<td>SC 75</td>
<td>2.33</td>
</tr>
<tr>
<td>Bilaspur (M.P.)</td>
<td>SC 85F</td>
<td>2.68</td>
</tr>
<tr>
<td>Koraput</td>
<td>SC 41</td>
<td>2.67</td>
</tr>
<tr>
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<td></td>
<td></td>
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<tr>
<td><em>Sativa-like: 'S(B)' type; &quot;field spontaneas&quot;; similar to sativa type, but shattering, with awns and black husks; resembling balunga-type; found in cultivated fields</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sibsagar</td>
<td>SC 30</td>
<td>2.67</td>
</tr>
<tr>
<td>Cuttack</td>
<td>SC 19</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sativa-like: 'S(N)' types; &quot;field spontaneas&quot;; similar to sativa type, but shattering, and with awns and black husks; resembling nivara-type; found in cultivated fields</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aligarh</td>
<td>SC 79C</td>
<td>3.00</td>
</tr>
<tr>
<td>Gaya</td>
<td>SC 63</td>
<td>3.00</td>
</tr>
<tr>
<td>Raigarh</td>
<td>SC 83E</td>
<td>3.00</td>
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The discriminating power of length/width ratios for whole spikelets is no stronger, then, than for charred grains. While it is important to include basic dimensions as part of the description of an archaeobotanical assemblage, the indices based on them cannot be used as a definitive means of determining the taxonomic status of the parent plant. Nevertheless, these criteria have been rather uncritically 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).
v. Surface morphology of lemmas and paleas

Rice husks were recovered from the deposits at Khok Phanom Di, some with surface anatomical features clearly retained, particularly those preserved in faecal material and as temper in pottery and in slip. The great majority of these husks were fragmented, probably having been broken down by threshing and milling in the course of preparing grain for consumption (see Chapter 7). 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 1980:220). The potential application of this approach to the archaeobotany of rice has long been recognised by Indian scientists like Chowdhury and Gosh (1954-55:124) and Buth and Saraswat (1972), although their results have not been published.

Comparative SEM studies examining fine structural differences in the morphological characteristics of the inflorescence bracts have usually dealt with widely separated taxa and very few studies have focused on variation within a single species or comparisons between cultivars and their wild relatives (Hoagland and Paul 1978:619). 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 collected as part of this research. The ways in which these features have previously been applied at various taxonomic levels will be outlined, before turning to the possibility of using lemma and palea topography for distinguishing between wild and domesticated 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 inter-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 as previously identified by Sarma (1972), on the basis of epidermal characteristics, the type of stomata and silica bodies, together with the shape of the hairbases (Vishnu-Mittre and Savithri 1973:125). It is noted that the epidermis in the cuticle of extant wheat and barley are [sic] made up of sinuous cell walls with the sinuosities narrow or round and swollen filling three-fourth [sic] of the lumina of the cells in barley, but moderately wavy cell walls are seen in wheat. In rice on the other hand, the epidermal cell walls are thrown up into long, acute, pointed and straight projections spread out in the entire space of the lumina of the cells and dovetailing with the projections of the opposite cell wall. (Vishnu-Mittre and Savithri 1973:125)

Sharma (1983:26) has 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 between the four sections of *Oryza* (Kihara and Katayama 1960, 1962; Sharma and Shastry 1965c:178; Katayama 1969).

Distinguishing between wild and cultivated rices through lemma and palea topography

**General description.** The surface topography of *Oryza* spp. lemmas and paleas has has been described by Katayama (1969), in general terms for *Oryza sativa* by Zee (1981:50) and with great attention to anatomical and histological detail by Juliano and Aldama (1934:40-46). Published illustrations by 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. The abaxial (outer) surfaces of the lemma and
palea are similar in topography, covered with numerous, closely-spaced tubercules (papillae) projecting from the surface. Some authors refer to a double apex to the tubercules in wild rices (Katayama 1969:92), but these are features of cultivated varieties too (Maeda 1972:471). 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. Tubercule diameters range from 50 to 150 microns. Silica is deposited throughout the cell walls of the rice husk but is mainly localised in the inner and outer epidermal cells, especially in the papillae (Santos 1933:482; Yoshida et al. 1962b:40, 1962c:5; Soni and Wynn Parry 1973:115; Kaufman et al. 1981:440; Balasta et al. 1989:2360). 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 (Katayama 1969:92). The margins of these anastamosing 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 Oryza.

In the longitudinal depressions between the tubercules are two kinds of distally pointing hair: thick-walled unicellular macrohairs or trichomes, sometimes referred to as prickle-hairs (Metcalfe 1960; Terrell and Wergin 1981:700; Terrell et al. 1983:425), together with smaller, more fragile two-celled microhairs (Zee 1981:40). Microhairs have been found on the husks from ceramic temper at Khok Phanom Di, but their value for diagnostic purposes is limited by the fact that the distal cells are easily distorted or destroyed. These smaller hairs could be well preserved in fresh comparative material by critical point drying, but even if taxonomically valid differences were observed, these could probably not be used for characterising the archaeological material due to inconsistent preservation.

The trichomes, by contrast, are 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 and the middle nerve or keel and
at the tip of the lemma (the apiculus). They are more common in the wild rices *O. rufipogon* and *O. nivara* (Sharma and Shastry 1965b:159,163) and conspecific weedy red rice (Hoagland and Paul 1978:621) 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 crop plant 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). Savithri (1976:92, text figs. 28-30), after careful dissection of *Oryza sativa, O. perennis* and *O. rufipogon* spikelets, illustrates the inter-specific differences between hair bases, particularly the size of the lumen, which she considers a taxonomically useful feature.

**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). The results of these last two studies are unpublished theses which were not available to me until late in this research (December 1990), by which time the analysis of the Khok Phanom Di rice remains was almost complete.

These workers had access to 20 accessions of wild *Oryza* spp. (many beyond the range of the putative ancestors of domestic rice) and 14 varieties of cultivars from
the herbarium of the Royal Botanic Gardens, Kew. Savithri (1976:53) has measured the number of tubercules in one cm² of a x20 photomicrograph of the central part of the spikelet, which is equivalent to an area of 0.5 mm² on the specimen. One of her main conclusions is that the density of tubercules is diagnostic at the species level, although this is not self-evident in her data (Table 6.7). Moreover, the density of tubercules varies between different areas of the spikelet (see Figures 6.7) and accurately using the density index to categorise husk used as temper in pottery 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 compiled from Savithri's thesis (Table 6.7) repeats the now familiar wide intraspecific variation and overlap between the cultivars and their wild relatives.

Table 6.7 Density of tubercules in a range of reference specimens of wild and cultivated rices

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Number of granules [tubercules] per 0.5 mm² of the central lemma [photographed at x20]</th>
</tr>
</thead>
<tbody>
<tr>
<td>O. nivara</td>
<td>42</td>
</tr>
<tr>
<td>O. rufipogon</td>
<td>42</td>
</tr>
<tr>
<td>O. sativa var. sativa</td>
<td>42</td>
</tr>
<tr>
<td>O. sativa var. mutica</td>
<td>56</td>
</tr>
<tr>
<td>O. sativa (medium-sized variety from Roxburgh)</td>
<td>72</td>
</tr>
<tr>
<td>O. sativa (large-sized variety from Roxburgh)</td>
<td>42</td>
</tr>
<tr>
<td>O. sativa subsp. brevis</td>
<td>72-81</td>
</tr>
<tr>
<td>O. sativa L.</td>
<td>49-56</td>
</tr>
<tr>
<td>O. sativa (from Philippines)</td>
<td>81</td>
</tr>
<tr>
<td>O. sativa (from Siam mountains)</td>
<td>81</td>
</tr>
<tr>
<td>O. sativa var. spontanea</td>
<td>49</td>
</tr>
<tr>
<td>O. sativa (from Afghanistan)</td>
<td>56</td>
</tr>
<tr>
<td>O. sativa (medium-sized variety from Sri Lanka)</td>
<td>42</td>
</tr>
<tr>
<td>O. sativa (large-sized variety from Sri Lanka)</td>
<td>56-63</td>
</tr>
<tr>
<td>O. sativa var. sativa (from Kashmir)</td>
<td>56</td>
</tr>
<tr>
<td>O. sativa var. sativa forma mutica</td>
<td>48</td>
</tr>
<tr>
<td>O. sativa var. sativa (from Jalpaiguri)</td>
<td>36</td>
</tr>
<tr>
<td>O. sativa (medium-sized variety from Roxburgh)</td>
<td>56-64</td>
</tr>
</tbody>
</table>

(Source: Savithri 1976:63-67)

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 easily accessible to workers outside India. Savithri (1976:63-65), 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 close to one another and well raised from the general surface. A squarrish [sic] dark area seen between every four granules. Number of granules in one sq. cm 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 [trichomes] which are neither completely cubical nor completely rectangular. Slits dark in straight lines between them. Number of granules in one sq. cm 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 squarrish [sic] dark area. Dark slits mostly invisible or absent. These characters shared by several cultivated varieties of *O. sativa* with minor differences between them.

Sharma (1983:52-53), who, working several years later, was able to take advantage of technical advances and new equipment, the scanning electron microscope together with the SUMP (Suzuki Universal Microprinting) method, 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 squarrish [sic] 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 case where the four granules meet. More spacing between the granules (SEM), a squarrish or circular dark area, each with 2 smooth horn-like structures.
The other major contribution to this issue has been the analysis of Yen (1982) on the Ban Chiang pottery with rice-husk inclusions. Working with the advice of IRRI geneticist Dr T.-T. Chang (Table 6.8), and after further metric studies of cell patterns and tubercule arrangement in 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 *O. sativa*, with a range extending beyond the minimum and maximum readings for husk cells from the cultivar.

**Table 6.8 Cell shape characters of Oryza husks**

<table>
<thead>
<tr>
<th>Species</th>
<th>Cell Shape</th>
<th>Trichomes- Papillae</th>
<th>Cell Wall Thickenings</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>O. perennis</em></td>
<td>square, rectangular</td>
<td>present</td>
<td>double wall, serrated</td>
</tr>
<tr>
<td><em>O. spontanea</em></td>
<td>square with raised cells (gives a small roundish appearance)</td>
<td>few</td>
<td>thick, cells walls not distinct</td>
</tr>
<tr>
<td><em>O. rufipogon</em></td>
<td>square</td>
<td>few</td>
<td>thick wall, distinct (gives a roundish appearance to cells)</td>
</tr>
<tr>
<td><em>O. sativa (indica)</em></td>
<td>big squares</td>
<td>none</td>
<td>double wall</td>
</tr>
<tr>
<td><em>O. sativa (japonica)</em></td>
<td>small squares</td>
<td>none</td>
<td>thick double wall</td>
</tr>
</tbody>
</table>

(Source: T.-T. Chang, pers. comm. in Yen 1982:56)

Some of the criteria originally passed on from Chang to Yen are now questioned, since it was suggested that *O. sativa* husks would have no trichomes. As Yen points out (1982:61) and has been confirmed in 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 the presence or absence or the density of trichomes is not a reliable diagnostic character. Furthermore, while trichome morphology may, for some taxonomic groups, have systematic importance (Carlquist 1961:32), 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 identical to the Banyan Valley rice spikelets in lacking awns (Yen 1977:586), 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 (Chang, pers. comm. quoted in Yen 1977:588).

6.3 ASSESSING THE COMPARATIVE RICE COLLECTIONS AND THE ARCHAEOLOGICAL MATERIAL

With all 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 southeastern Thailand, as well as 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.

6.3.1 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 southeastern seaboard of Thailand today. The loss of natural habitats for wild rices has been due to accelerated urbanisation 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.* 1961:327). 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 1965:174), thus making them...
less than ideal candidates 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 (Anderson and Stebbins, cited by Morishima and Oka 1960:164) in the c.4000 years since the archaeological rices were alive, so that their modern counterparts may be somewhat different from the cultivars of past times. Thus, our modern voucher specimens are unlikely to be exact analogues to the plants growing in the prehistoric situation.

Wild rices in Thailand today
Perennial wild rice species (O. officinalis, O. perennis, O. obtusifolia and O. rufipogon), as well as the annual O. nivara and O. sativa f. spontanea, grow in Thailand today, with the last being the most common species, especially as it is found as a weed of rice paddies (Tateoka 1964; Vongsaroj n.d.). O. 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 1962:151; Akihama and Watabe 1970:339), while O. punctata (Lazarides 1980:184) and O. latifolia (yaa lamaan) (Smitinand 1980:246) are additional members of the genus recorded for Thailand. Not all these are putative ancestors of cultivated rice, so SEM analysis was restricted to O. rufipogon, O. nivara and O. sativa.

6.3.2 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 Å of 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 (commonly referred to as the husk or the hull), the rachilla and the abscission scar. Naked caryopses were not studied, since they are not represented in the collection of archaeobotanical specimens from the site.
Gold-coated specimens were used for acquiring secondary electron images, while 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* were observed and photographed, in addition to silicon X-ray maps of husks, but the minor differences between them were inadequate for differentiating between taxa, while the uneven surface topography in such specimens confused the back-scattered 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.

1. **The application of abscission characteristics to archaeological specimens**

The archaeobotanical assemblage from Khok Phanom Di produced some remarkably well-preserved husk fragments in the coprolite found in burial 67. These included not only fragments of lemmas and paleas, but also rachillas showing their abscission scars. Rachis fragments and pedicels were absent from the Khok Phanom Di 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 materials were 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 rachillas complete with abscission scars have sometimes been noted, for example, the plant remains from Atranjikhera (Chowdhury et al. 1977:19) 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.

Modern reference material of abscission scars
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. All specimens were coated with 250Å of gold and observed using a Cambridge S360 Stereoscan scanning electron microscope operating 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. This is in line with the procedure specified by Stemler and Falk (1981:193). Occasionally, where a spikelet had slipped slightly, presenting an oblique view of the abscission area, the stub was tilted in order to have a direct view of the scar. Photographs were taken at magnifications of x200 and measurements were made of the maximum width and length of the scar, as illustrated in Table 6.9 and Figure 6.5. Length was measured parallel to the long axis of the spikelet and width measurements were perpendicular to that.

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 rices (Plate 6.3.1) were found to have a circular scar remaining after seed detachment, similar to the case in oats (Yeung et al. 1987:391). The scar margins were smooth and well defined, with the vascular bundle clearly visible as a circular pit at the centre of the scar. The wild-type scars were shallower than the domestic ones (also noted by Chalam 1942:340 and Srinivas et al. 1979:81), while the
parenchymatous tissue, which had sheared naturally at abscission, had thin-walled parenchymatous cells. Domesticates typically had a reniform scar (Plate 6.3.2), deeper and more ragged than the wild-types, while in the central area the vascular bundle was often irregularly broken, sometimes leaving an upstanding stump of tissue and at others a sub-circular hole.

<table>
<thead>
<tr>
<th>Table 6.9</th>
<th>Length and width dimensions for abscission scars in modern wild and cultivated rices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxon (Accession No.)</td>
<td>Mean length (microns)</td>
</tr>
<tr>
<td></td>
<td>(standard deviation)</td>
</tr>
<tr>
<td><strong>O. rufipogon</strong> (41)</td>
<td>349.1 (23.1)</td>
</tr>
<tr>
<td><strong>O. rufipogon</strong> (132)</td>
<td>333.4 (36.1)</td>
</tr>
<tr>
<td><strong>O. rufipogon</strong> (142)</td>
<td>338.1 (28.7)</td>
</tr>
<tr>
<td><strong>O. rufipogon</strong> (143)</td>
<td>345.7 (23.1)</td>
</tr>
<tr>
<td><strong>O. rufipogon</strong> (602)</td>
<td>311.0 (50.6)</td>
</tr>
<tr>
<td><strong>O. nivara</strong> (603)</td>
<td>358.8 (24.5)</td>
</tr>
<tr>
<td><strong>O. sativa</strong> (220)</td>
<td>343.7 (25.8)</td>
</tr>
<tr>
<td><strong>O. sativa</strong> (222)</td>
<td>339.8 (33.1)</td>
</tr>
<tr>
<td><strong>O. sativa</strong> (224)</td>
<td>347.1 (23.9)</td>
</tr>
<tr>
<td><strong>O. sativa</strong> (258)</td>
<td>350.4 (27.4)</td>
</tr>
<tr>
<td><strong>O. sativa</strong> (262)</td>
<td>336.8 (31.8)</td>
</tr>
</tbody>
</table>
The rice remains from burial 67: abscission scars

The coprolite found in burial 67 was disaggregated by Charles Higham in the laboratories of the Department of Anthropology at the University of Otago in New Zealand. Specimens of what were considered to be rice husks were sent to me in small gelatine capsules. On receipt, these husks were soaked in alcohol for five minutes and 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 not greatly distorted. All parts of the spikelet (except awns) were represented in the collection (Table 6.10). Every item was damaged in some way and the fractures were not always clean.

<table>
<thead>
<tr>
<th>Plant part</th>
<th>Number of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete spikelet</td>
<td>1</td>
</tr>
<tr>
<td>Rachilla</td>
<td>13</td>
</tr>
<tr>
<td>Rachilla with lemma</td>
<td>5</td>
</tr>
<tr>
<td>Rachilla with palea</td>
<td>8</td>
</tr>
<tr>
<td>Distal end of lemma or palea</td>
<td>22</td>
</tr>
<tr>
<td>Palea fragment</td>
<td>37</td>
</tr>
<tr>
<td>Lemma/palea fragment</td>
<td>109</td>
</tr>
</tbody>
</table>

There were 27 items showing abscission scars. Some of these were just 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 scanning electron microscope 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 much 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 material remained adhering to them and this sometimes obscured the abscission zone. The
area of this zone was also pitted and "weathered", where the external layer of epidermal cells had been partially removed (Plate 6.3). 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, the length and width dimensions of the scar were measured (Table 6.11). These data have been superimposed on Figure 6.5, 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 the 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.

<table>
<thead>
<tr>
<th>Specimen (stub/specimen no.)</th>
<th>Length (microns)</th>
<th>Width (microns)</th>
<th>L/W ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7/1</td>
<td>285</td>
<td>330</td>
<td>0.86</td>
</tr>
<tr>
<td>T7/2</td>
<td>270</td>
<td>obscured</td>
<td>-</td>
</tr>
<tr>
<td>T7/4</td>
<td>317</td>
<td>422</td>
<td>0.75</td>
</tr>
<tr>
<td>T7/5</td>
<td>288</td>
<td>335</td>
<td>0.86</td>
</tr>
<tr>
<td>T7/6</td>
<td>272</td>
<td>295</td>
<td>0.92</td>
</tr>
<tr>
<td>T7/8</td>
<td>350</td>
<td>360</td>
<td>0.97</td>
</tr>
<tr>
<td>T7/9</td>
<td>275</td>
<td>314</td>
<td>0.88</td>
</tr>
</tbody>
</table>
FIGURE 6.5
FREQUENCY DISTRIBUTION OF LENGTH/WIDTH RATIOS FOR ABSCISSION SCARS IN WILD AND DOMESTICATED RICES

KPD specimens from coprolite in burial 67

- O. RUFIPOGON
- O. NIVARA
- O. SATIVA
ii Length and width measurements of spikelets

As mentioned earlier, length and width measurements were taken from spikelet impressions and husks found in soil samples and ceramic slip (Tables 6.12 and 6.13). Only a handful of specimens were well preserved with both dimensions intact, so the number of length/width ratios calculated 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 vouchedered 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 a continuous gradient from short and broad to long and narrow. If one examines solely the length/width distributions from Morishima et al. (1961:330) (Figure 6.2), where all the samples were from Thailand, then some of the Khok Phanom Di specimens fall into the cultivar side of the distribution and others into the overlap between wild and domestic types. The greater regional perspective provided by other data summarised in Figures 6.3 and 6.4 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 slip is unknown. Less than 2% 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 1983:96).
Table 6.12 Measurements of length and width of spikelets from soil samples

<table>
<thead>
<tr>
<th>Context</th>
<th>Length (mm)</th>
<th>Complete?</th>
<th>Width (mm)</th>
<th>Complete?</th>
<th>Length/width ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/A/7</td>
<td>-</td>
<td>-</td>
<td>2.40</td>
<td>Y</td>
<td>-</td>
</tr>
<tr>
<td>10/C/8</td>
<td>8.0</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/C/14</td>
<td>6.0</td>
<td>N</td>
<td>2.5</td>
<td>Y</td>
<td>2.60</td>
</tr>
<tr>
<td>10/D/16</td>
<td>6.0</td>
<td>N</td>
<td>2.6</td>
<td>Y</td>
<td>-</td>
</tr>
<tr>
<td>10/D/16</td>
<td>-</td>
<td>-</td>
<td>2.2</td>
<td>N</td>
<td>-</td>
</tr>
<tr>
<td>10/A/16</td>
<td>8.0</td>
<td>Y</td>
<td>3.5</td>
<td>N</td>
<td>-</td>
</tr>
<tr>
<td>10/A/16</td>
<td>8.0</td>
<td>Y</td>
<td>2.5</td>
<td>Y</td>
<td>3.12</td>
</tr>
<tr>
<td>10/D/19</td>
<td>8.0</td>
<td>Y</td>
<td>2.8</td>
<td>Y</td>
<td>2.68</td>
</tr>
<tr>
<td>10/D/19</td>
<td>8.0</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/C/19</td>
<td>-</td>
<td>-</td>
<td>2.6</td>
<td>Y</td>
<td>-</td>
</tr>
<tr>
<td>10/B/19</td>
<td>8.0</td>
<td>Y</td>
<td>3.0</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td>10/B/19</td>
<td>8.0</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/B/19</td>
<td>8.0</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/B/19</td>
<td>8.0</td>
<td>Y</td>
<td>2.4</td>
<td>N</td>
<td>-</td>
</tr>
<tr>
<td>10/B/19</td>
<td>6.0</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/D/20</td>
<td>8.0</td>
<td>Y</td>
<td>2.0</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td>10/C/20</td>
<td>8.0</td>
<td>Y</td>
<td>3.0</td>
<td>Y</td>
<td>2.67</td>
</tr>
<tr>
<td>10/C/21</td>
<td>8.0</td>
<td>Y</td>
<td>2.5</td>
<td>Y</td>
<td>3.00</td>
</tr>
<tr>
<td>10/A/22</td>
<td>8.0</td>
<td>Y</td>
<td>2.8</td>
<td>?</td>
<td>-</td>
</tr>
</tbody>
</table>

Y = complete dimension  N = incomplete dimension  ? = possibly incomplete dimension
Table 6.13 Measurements of length and width of spikelets from slip

<table>
<thead>
<tr>
<th>Context</th>
<th>Length (mm)</th>
<th>Complete?</th>
<th>Width (mm)</th>
<th>Complete?</th>
<th>Length/width ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/C/6</td>
<td>6.0</td>
<td>Y</td>
<td>2.5</td>
<td>Y</td>
<td>2.40</td>
</tr>
<tr>
<td>9/C/6</td>
<td>6.5</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9/C/6</td>
<td>5.0</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9/C/6</td>
<td>5.5</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9/C/7</td>
<td>7.0</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/C/1</td>
<td>6.5</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/D/1</td>
<td>5.0</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/D/1</td>
<td>5.0</td>
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</tr>
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<td>Y</td>
<td>1.8</td>
<td>N</td>
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<td>Y</td>
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<td>Y</td>
<td>-</td>
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<tr>
<td>10/C/5</td>
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<td>Y</td>
<td>-</td>
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<td>-</td>
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<tr>
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<td>1.8</td>
<td>Y</td>
<td>3.33</td>
</tr>
<tr>
<td>10/D/6</td>
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<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>1.5</td>
<td>Y</td>
<td>3.33</td>
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<tr>
<td>10/D/7</td>
<td>-</td>
<td>-</td>
<td>2.5</td>
<td>Y</td>
<td>-</td>
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<tr>
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<td>1.5</td>
<td>Y</td>
<td>3.67</td>
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<tr>
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<td>3.20</td>
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<td>-</td>
<td>2.5</td>
<td>Y</td>
<td>-</td>
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<tr>
<td>10/B/17</td>
<td>6.8</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/B/17</td>
<td>-</td>
<td>-</td>
<td>2.5</td>
<td>Y</td>
<td>-</td>
</tr>
</tbody>
</table>
Measurements of cell size were taken for archaeological specimens along the lines of Yen (1982:60), so that the Khok Phanom Di material could be compared with the rice remains from Ban Chiang, as well as Yen's characterisation 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 taken at x200, using the Jandel Sigma Scan (version 3.1) image analysis program. A minimum of thirty cells was measured per 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, 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 it was decided to take the measurements from these wherever possible, even though they included fewer cells per image. The measurements were taken from the midpoint of one depression between two adjacent tubercules to the next depression, parallel to the long axis of the spikelet. This corresponded to the cell dimension rather than that for 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, while at other times these appeared to be more closely spaced. The spacing of tubercules did not bear a close relationship to the taxonomic groups.

As it was not clear from Yen's text how his "cell length/index" had been calculated, cell size measurements from the Khok Phanom Di material were converted to a mean cell width per husk fragment (Table 6.16, Figure 6.8). In the data presented here, the mean cell widths span the range from 57 to 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 to be correct for the current work. This inconsistency would not affect the validity of Yen's original conclusions, but it has made it difficult to integrate the new results with his 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 6.14, Figure 6.6) and (b) between cells in the central lemma area of several spikelets within each type (Table 6.15, Figure 6.7).

The graphs in Figure 6.6 indicate the variation in width of cells 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 middle region of the lemma and at its proximal end, declining in size towards the distal end. Rather than all rows tapering towards the narrow ends of the spikelet, some rows 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 this criterion for making archaeobotanical identifications, as the original position of an archaeological husk fragment is usually difficult to discern.
FIGURE 6.6
COMPARISONS BETWEEN MEAN CELL WIDTHS
FOR SEVEN AREAS ACROSS A SINGLE SPIKELET

Bars indicate the standard deviation from the mean
Table 6.14  Comparisons between seven different areas of cells across four individual spikelets

<table>
<thead>
<tr>
<th>Taxon / Part of the spikelet</th>
<th>Mean cell width (microns) (n=70)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oryza rufipogon (R4/1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal end of lemma</td>
<td>57</td>
<td>10</td>
</tr>
<tr>
<td>Lemma</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>Mid lemma</td>
<td>80</td>
<td>16</td>
</tr>
<tr>
<td>Mid palea</td>
<td>70</td>
<td>13</td>
</tr>
<tr>
<td>Mid lemma</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>Lemma</td>
<td>73</td>
<td>17</td>
</tr>
<tr>
<td>Proximal end of lemma</td>
<td>97</td>
<td>22</td>
</tr>
<tr>
<td>Oryza nivara (R2/1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal end of palea</td>
<td>67</td>
<td>14</td>
</tr>
<tr>
<td>Palea</td>
<td>71</td>
<td>14</td>
</tr>
<tr>
<td>Distal end of lemma</td>
<td>70</td>
<td>18</td>
</tr>
<tr>
<td>Lemma</td>
<td>85</td>
<td>16</td>
</tr>
<tr>
<td>Mid lemma</td>
<td>82</td>
<td>16</td>
</tr>
<tr>
<td>Lemma</td>
<td>82</td>
<td>14</td>
</tr>
<tr>
<td>Proximal end of lemma</td>
<td>85</td>
<td>16</td>
</tr>
<tr>
<td>Oryza sativa (khao haa loi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal end of lemma</td>
<td>72</td>
<td>15</td>
</tr>
<tr>
<td>Lemma</td>
<td>82</td>
<td>15</td>
</tr>
<tr>
<td>Palea</td>
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<td>18</td>
</tr>
<tr>
<td>Mid palea</td>
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<td>19</td>
</tr>
<tr>
<td>Mid lemma</td>
<td>80</td>
<td>16</td>
</tr>
<tr>
<td>Palea</td>
<td>85</td>
<td>13</td>
</tr>
<tr>
<td>Proximal end of lemma</td>
<td>84</td>
<td>17</td>
</tr>
<tr>
<td>Oryza sativa (khao luang patiew)</td>
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<td></td>
</tr>
<tr>
<td>Distal end of lemma</td>
<td>79</td>
<td>16</td>
</tr>
<tr>
<td>Lemma</td>
<td>87</td>
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<td>12</td>
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<tr>
<td>Proximal end of lemma</td>
<td>93</td>
<td>14</td>
</tr>
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</table>
FIGURE 6.7
COMPARING MEAN CELL WIDTHS
(a) BETWEEN SPIKELETS WITHIN A POPULATION, AND
(b) BETWEEN WILD AND DOMESTICATED RICES

Bars indicate the standard deviation from the mean
Rice remains

Table 6.15  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

<table>
<thead>
<tr>
<th>Oryza rufipogon</th>
<th>Oryza nivara</th>
<th>(i)</th>
<th>Oryza sativa</th>
<th>(ii)</th>
<th>(iii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>86 (16)</td>
<td>83 (15)</td>
<td>75 (17)</td>
<td>76 (14)</td>
<td>58 (15)</td>
<td></td>
</tr>
<tr>
<td>81 (16)</td>
<td>71 (12)</td>
<td>81 (19)</td>
<td>86 (19)</td>
<td>69 (20)</td>
<td></td>
</tr>
<tr>
<td>85 (16)</td>
<td>82 (14)</td>
<td>82 (17)</td>
<td>86 (17)</td>
<td>60 (12)</td>
<td></td>
</tr>
<tr>
<td>79 (17)</td>
<td>82 (18)</td>
<td>79 (18)</td>
<td>71 (15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>81 (13)</td>
<td>80 (16)</td>
<td>78 (19)</td>
<td>63 (13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>88 (17)</td>
<td></td>
<td></td>
<td>56 (10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>78 (13)</td>
<td></td>
<td></td>
<td>70 (11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>78 (19)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Three traditional cultivars: (i) *khao haa loi* (ii) *khao luang patiew* (iii) *khao met lek*

Turning now, to data comparing a number of spikelets from a single population (Table 6.15; Figure 6.8), 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 is comparable to that within a single spikelet. The specimens of the perennial wild *O*. *rufipogon* stand out, however, as having a greater range of variation within an individual spikelet than within the sample of eight spikelets when only the central part of the spikelet was measured. Taking all this into account then, it seems that these data both confirm and augment Yen's (1982:59) general results. The wide range of variation between different areas of a spikelet, between different spikelets from a single population and between the three taxonomic groups means that this criterion cannot be relied upon for discriminating between archaeological husk fragments from wild and cultivated rices.

The data on cell widths taken from rice husk fragments from eighteen contexts at Khok Phanom Di are presented as Figure 6.8. This shows that the husks used as ceramic temper from the early phase do not differ significantly from those in the later phases, in terms of cell size. In the two instances where husks were extracted from both sherds and slip from a single context (10:17 and 10:3), those from the slip had consistently smaller cells than specimens from the body of the sherd. It might be suggested that this is the reverse of the differential effects of heat, although the results go against intuition as husks from temper, presumably exposed to higher
FIGURE 6.8
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>30).

Bars indicate the standard deviation from the mean.
firing temperatures had smaller cell sizes than those from the slip. Alternatively, the difference could add weight to the argument that the rice in the slip was of a second type, applied after the pot was fashioned and initially fired.

iv Cell shape and arrangement
The chequerboard pattern of tubercules on the husks of *Oryza* spikelets makes the remains of rice and its wild relatives clearly distinctive from other plant debris in the Asian archaeological record. To use that patterning for making identifications at the specific level is less reliable, however, on general taxonomic principles as well as close inspection of modern reference material undertaken for this study. Savithri (1976:69) and Sharma (1983:52), whose characterisations of husk morphology have been quoted earlier, claim 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 variety level (Savithri 1976:69-73; Sharma 1983:74-81), though they acknowledge the significant variability within taxa and the smallness of the samples they have analysed, both highly important points.

With verbal descriptions, even accompanied by photomicrographs or illustrations, it is often difficult to convey accurately one's personal and impressionistic view about a surface texture. Both photographs and descriptions are perceived subjectively and are open to reinterpretation. Savithri's and Sharma's identifications may have relied heavily upon personal familiarity with the material, as Chang's evidently rests on his personal expertise, but they have not reported their diagnostic criteria in useable terms. Replicating the results of these Indian 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 which are being described.
There is a strong need, then, for a more objective approach, with formal standardised descriptions and the explicit definition of diagnostic criteria, if we are to adopt tubercule arrangement as an aid to archaeobotanical identification. One potentially profitable direction for future research would be the development and application of automated image processing, particularly texture analysis, which could classify the complex surface textures of lemmas and paleas, matching those of archaeological remains with patterns from authenicated specimens of modern rice.

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 (P. Sobey pers. comm., 1990). These could be applied to digitised 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 acknowledged in the field of palynology, where research into novel techniques for automated pollen grain identification, based on exine texture and features, is well underway (Langford 1988, cited by Flenley 1989; Langford et al. 1986; Witte 1988). In archaeobotany, computer-assisted image analysis has been used in the categorisation 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
Rice remains

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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 degree of regularity to the texture has been indicated, in rather a simplified way, by the standard deviations for the mean cell widths in Table 6.16, with the greatest standard deviations corresponding with the least regular patterns. In the modern specimens, *O. rufipogon* had a greater range in cell size across the spikelet than its cultivated relatives, 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 remarkable feature of the rice husk remains from Khok Phanom Di which was not observed in the modern voucher specimens was split and twisted trichomes (Plates 6.6.6-8). These were divided into two strands at approximately the midpoint and were often twisted in their central portion. They 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 typology of Theobald *et al.* (1979:45) (albeit for dicotyledons) although it appears to be an elaboration of their "simple (unbranched), long, thin" class without surface patterning.
Conclusions

The general themes pervading this assessment of the various diagnostic characters for identifying archaeological rice 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 plant 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 Southeast Asia under current excavation methods. The need has been highlighted, and is worth reiterating, for standardised means of assessing and comparing the regularity of husk topography. Computerised texture analysis offers potential here, but is technically complex and would demand mathematical competence. 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 may be recovered. These have been the most informative examples of rice remains within the Khok Phanom Di assemblages, 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 greater resemblance to those of the modern cultivars than the 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. The implications of this for the occupants of the site will be explored in chapter 8.
Plate 6.1

Archaeological Rice Remains from Flot, Soil, Slip and Temper

Plate 6.1.1 A fragment of rice husk from the flot from layer 6:1. Tubercules can be seen although their morphology and arrangement are obscured. Scale = 200 microns

Plate 6.1.2 The remains of degraded rice husk with the surface stripped away, from the flot sample of layer 10:25. Scale = 200 microns

Plate 6.1.3 Rice husk preserved among the flot from layer 11:2. A husk fragment adheres to a soil particle. Scale = 200 microns

Plate 6.1.4 The remains of an entire spikelet preserved within the soil. Scale = 2 mm

Plate 6.1.5 The impression of a whole spikelet found in slip. Scale = 1 mm

Plate 6.1.6 Rice husk from slip on pottery from layer 10:6, typical of the preservation of husk from ceramics. Scale = 200 microns

Plate 6.1.7 Husk as temper in pottery from layer 2:3. Scale = 200 microns

Plate 6.1.8 A fragment of 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
Plate 6.2

Archaeological Rice Remains

Plate 6.2.1  Rice remains from flot. Scale = 200 microns

Plate 6.2.2  The impression of a rice husk with a ?dog coprolite from layer 4. Scale = 200 microns

Plate 6.2.3  The burial 67 coprolite provided some unusually large fragments of husk indicating gross morphology which could not be seen in specimens from the ceramics. Scale = 1.0 mm

Plate 6.2.4  A closer view of the same material from the burial 67 coprolite. Scale = 200 microns

Plate 6.2.5  The rounded distal end of a lemma from the coprolite found in burial 67. Scale = 200 microns

Plate 6.2.6  Another example of the rounded distal end of a lemma or palea from the coprolite found in burial 67. Scale = 200 microns

Plate 6.2.7  A distal end of a lemma or palea from the slip on pottery from layer 10:7. Scale = 100 microns

Plate 6.2.8  The distal end of a modern spikelet of *Oryza sativa*. Scale = 1 mm
Plate 6.3

Abscission Scars in Modern and Archaeological Rice Specimens

Plate 6.3.1  The circular, smooth abscission scar on a spikelet of modern wild *Oryza rufipogon*. Scale = 200 microns

Plate 6.3.2  The reniform, rough abscission scar on a spikelet of modern cultivar *Oryza sativa*. Scale = 200 microns

Plate 6.3.3  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

Plate 6.3.4  The proximal portion of a spikelet from the burial 67 coprolite illustrating the position of the abscission scar. Scale = 500 microns

Plate 6.3.5  Another example of an abscission scar from a spikelet preserved as part of the burial 67 coprolite. Part of the scar is obscured but the general morphology is closer to reniform than to circular. Scale = 200 microns

Plate 6.3.6  The sole specimens of a rachilla (with poorly preserved abscission scar) found as temper in pottery. Scale = 500 microns
Plate 6.4

General Features of the Spikelet

Plate 6.4.1  An *Oryza sativa* spikelet attached to the pedicel (P) indicating the rudimentary glumes (RG) at the distal end of the pedicel. Scale = 2.00 mm

Plate 6.4.2  The distal part of a spikelet of *O. rufipogon* indicating the denser growth of trichomes around the base of the awn. Scale = 500 microns

Plate 6.4.3  A single large trichome and smaller microhairs between the rows of tubercules. Scale = 100 microns

Plate 6.4.4  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

Anatomical Details of *Oryza rufipogon*

Plate 6.4.5  An entire spikelet of the wild *Oryza rufipogon*. Scale = 2.00 mm

Plate 6.4.6  Central lemma surface. Scale = 2.00 mm (left) and 500 microns (right)

Plate 6.4.7  Lemma surface with distally pointing tubercules. Scale = 200 microns

Plate 6.4.8  Detailed view of lemma surface with pointed tubercules and microhairs between the rows. Scale = 100 microns
Plate 6.5

Anatomical Details of Modern *O. nivara*

Plate 6.5.1  A spikelet of the wild annual rice *O. nivara*. Scale = 2.00 mm

Plate 6.5.2  Details of tubercule arrangement in the central area of the lemma. Scale = 2.00 microns (left) and 500 microns (right)

Plate 6.5.3  Rectangular shaped tubercules in the central part of the husk. Scale = 200 microns

Plate 6.5.4  Scale = 200 microns

Modern *O. sativa* specimens

Plate 6.5.5  A spikelet of the traditional Thai cultivar *khao luang patiew*. Scale = 2.00 mm

Plate 6.5.6  Scale = 2.00 mm (left) and 500 microns (right)

Plate 6.5.7  Central area of the lemma. Scale = 200 microns

Plate 6.5.8  Siliceous granules visible along the flanks of the tubercules of this example of the traditional Thai cultivar *khao haa loi*. Scale = 100 microns
### Plate 6.6

**More Archaeological Rice Specimens**

| Plate 6.6.1 | Smoothly rounded tubercules. Specimen from the coprolite found in burial 67. Scale = 200 microns |
| Plate 6.6.2 | Widely spaced tubercules in husk from temper from ceramics in layer 5:1. Scale = 200 microns |
| Plate 6.6.3 | The siliceous tip to a tubercule from the husk found in slip from 10:7. Scale = 100 microns (left) and 25 microns (right) |
| Plate 6.6.4 | Rectangular or laterally elongate tubercules in the husk in slip from 10:7. Scale = 200 microns |
| Plate 6.6.5 | Numerous enlarged trichome bases, with the trichomes broken away, at the distal end of a lemma or palea. The specimen was one of those preserved in the burial 67 coprolite. Scale = 500 microns |
| Plate 6.6.6 | Husk found as temper in ceramics from layer 2:3. Split trichomes. Scale = 200 microns |
| Plate 6.6.7 | A closer view of the previous specimen showing an example of a split and twisted trichome. Scale = 100 microns |
| Plate 6.6.8 | Twisted and split trichome attached to a husk found in slip in layer 9:5. Scale = 100 microns. The length of the trichome is 300 microns |
Chapter Seven

DEVELOPING ETHNOGRAPHIC MODELS FOR INTERPRETING RICE REMAINS FROM AGRARIAN SITES

7.1 INTRODUCTION

Models of post-harvest processing have been developed for a range of crops such as glume wheats in Turkey (Hillman 1973, 1981), free-threshing wheats and pulses in Turkey (Hillman 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, cited by Hastorf 1988:128). These involve the detailed study of present-day pre-mechanised 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 1984:19-38) 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 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 the archaeobotanist interested in rice have yet to be carried out in the same detail as for crops traditional in the Middle East and the Mediterranean, but the investigations described here make an initial contribution.

7.2 DEVELOPING A MODEL FOR PREDICTING WHERE AND HOW SPECIFIC PARTS OF THE RICE PLANT MIGHT APPEAR IN THE ARCHAEOLOGICAL RECORD

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, 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.

7.2.1 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 are useful in developing 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 1984:64). The methods employed for gathering wild rice in the ethnographic present point to possible incipient domestication processes, but none of these strategies for plant exploitation necessarily represent the exact applications by prehistoric populations.

Seed collection from wild rices has been done until present times in some areas in India (Oka and Morishima 1971:363), West Africa (Oka and Chang, 1964, cited by Oka and Morishima 1971:363; Morishima 1984:20), and South America (le Cointe, 1947:52, cited by Oka and Morishima, 1971:361). There is little written about the way in which gathering communities process their harvest of wild rice, with most writers focusing on the harvest rather than post-harvest practices and patterns of refuse
disposal. These are said to range from beating the spikelets of long-stemmed floating rice into boats (Coyaud 1950:11; Delvert 1961:323), 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 1984:20). 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 (Isaacs 1987:115; Cribb and Cribb 1974:101-2). 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 1958:484). An additional phase of grinding the grain into flour was practiced by the Anbarra Gidjingali people in this region (Fujiwara et al. 1985:155). 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 1989:128). It is difficult to predict precisely the kinds of waste which would be generated by 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.

7.2.2 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 southeast Asia often appear as secondary products rather than as prime grain. The abundance of by-products (charred husks, stem fragments, culm nodes and so on) 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 cultivated types. The focus is shifted, 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 mechanised 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 1978:246). 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.

i) The crop is harvested from the field.

ii) It is threshed and winnowed, to separate the spikelets from the stems.

iii) Whole spikelets are stored.

iv) Immediately prior to cooking and consumption, the spikelets are milled, dehusked and winnowed again, to separate the prime grain from the waste fractions.

v) 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 in the archaeobotanical record. In a self-sufficient community, evidence for all stages of the process may be seen in the archaeological record, but in a consumer community,
where the grain supply has been traded in from elsewhere, presumably as whole spikelets, there would only be indications of the stages (iii) to (v). Such a distinction is critical at a coastal site like Khok Phanom Di, where the question is whether the rice was cultivated and processed locally or produced elsewhere and brought in as a trade commodity.

7.2.3 Harvest and 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 Figure 3.2) 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. 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. Terms for the major stages in the sequence, the most important tools and the (by-)products are given in both English and central Thai. 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 of Southeast Asia, anthropologists and geographers who have documented agricultural practice and the recollections of elderly Thaws and their descendants. All these sources will contribute to a taphonomic model of agrarian practices which may be of some application to the interpretation of plant macrofossil assemblages from archaeological sites in Asia.

It is commonly stated that 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 were a watershed (Fukui 1978:246), with the expansion of more intensive techniques such as irrigation, drainage and fertiliser 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 these more productive strains in the Chachoengsao area (Fukui 1978:259-60). 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 round 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 there is a range of methods employed for harvest and post-harvest technology. The smaller farmers without access to mechanised technology and HYVS continue 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, extending from December into most of January throughout the central lowlands. The higher areas with better drainage are the first to be harvested, as are the early season rices (khao bao). Late season types (khao nak) 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 types.

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 for this season, 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 mechanised 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 are dwindling in numbers in the villages of the southeast today (Tsuijii 1978:394), while foot-treading by people continues in a minority of communities in the northeast of the country. The sequence of harvest and post-harvest techniques described here emphasises the most traditional methods of crop husbandry used in the area. Some of the tools employed are illustrated in Figure 8.1.

1. Laying the rice (naab khao). Ten days prior to cutting, a person (usually a man) moves through the paddy field, carrying a long bamboo 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 1961:355).

2. Preparing the threshing floor. The threshing floor (laan nouat khao) is a wide flat area, around 15 m in diameter, in the farm compound and immediately next to the house. It has become overgrown over 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 (kieow khao). 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
FIGURE 7.1
TRADITIONAL IMPLEMENTS FOR HARVEST AND POSTHARVEST PROCESSING OF RICE

(source: Rajadhon 1961:379-80)

19. harrow
20. khan of the harrow
21. harrow teeth
22. iron rake, Chinese style
23. iron shovel
24. wooden shovel, old style
25. spade
26. hoe
27. sickle
28. chick-head shovel
29. li'am, a kind of big curved knife with long or short handle
30. bamboo pole for carrying rice seedlings over the shoulder

SMALLER FARM IMPLEMENTS
31. straw hook, made of bamboo, used in threshing and picking out straw
32. threshing "chopsticks" of hardwood and bamboo for holding rice sheaves and beating them
33. shovel with groove, made of lightweight hardwood, for tossing rice
34. mats for shaking out rice dust, woven entirely of bamboo including the border
35. board for pushing rice, of the kind having ropes which they vie in pulling ceremonially
36. thadthaa
37. kachee or sād for measuring rice, woven
38. kābung or lāung sād
39. lever pestle, for pounding
40. lever-pestle mortar of wood, buried in the ground
41. tail of the lever
42. pestle for pounding
43. pestle for sōom
44. hand mortar, of wood
45. big hammer-shaped pestle, for hand mortar
46. pestle for hand mortar
47. rice mill, woven
48. winnowing basket woven of bamboo bark with wooden cross-piece, for winnowing rice

THRESHING, POUNDING, MILLING, WINNOWING, AND MEASURING IMPLEMENTS
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. 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. As with the Kantu' of 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).

The 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 1961:356), or ties made using long straws twisted and tied into a rough cord (khaned). These and other ancillary operations tend to be carried out by 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 fields for a couple of days before being moved to the threshing ground. This allows some of the moisture in the grains to evaporate before threshing. The moisture content of rice at harvest is around 20% and the preferable level at threshing is 13-14% (Krishnashreni 1981).

Nowadays, the harvested rice may be moved to the home compound for threshing, for security reasons, but in the past more of this work was carried out in the fields to minimise grain losses during transport and handling (Chung and Lee 1978:3; Kaga n.d.:40). Such losses must have been more apparent to people in the past, tending 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. Here 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 losses by shattering.

In the past it was common to burn the stubble to fertilise the fields, as Koenig (1894:162) describes during his visit to Thailand in 1779, but now the straw is often cut to feed the livestock during the wet season. A less important use of straw is as a fuel, especially in the braziers lit to keep the harvesters warm at night. Straw is treated as a useful commodity and may be cut by the workers in a second bout of reaping as part payment for their labour (Sharp et al. 1953:135).

4. **Gleaning** (*kep khao tok*). 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.

4. **Laying out the sheaves to be threshed.** Threshing is carried out with the blessing of the Rice Goddess, Mē Phosop, who is worshipped with ceremonial food and other offerings. This, and the Making Merit 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.

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.

5. **Threshing** (*nouat khao*). The main objective in threshing is to separate the spikelets from the straw and to produce grain for storage. This separation was done
in the past 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" in the past. 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 1964:144). This is 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-handed, 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 (kho chaay), while the kenoon (finer straw fragments, leaves, many panicle branches and unthreshed spikelets) are removed with a coarse rake and brushes. Those rice spikelets, which had fallen through to the bottom layer of the straw pile, are scraped together with a bar-bladed scraper (thadtha) (Figure 7.1, item 36) and stray spikelets brushed to the centre of the threshing floor, scooped into large storage baskets (krabung) and put to one side until the threshing operation is completely over.

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 drop during transport to the threshing floor due to excessive shattering. 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 extreme 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 held tightly in a two-handed grip,
raised above the head and slammed down on the edge of a large wooden threshing
tub. The shock of the straw hitting the tub caused the spikelets to drop off. Bamboo
mats screening three sides of the tub prevented the rice from spilling and scattering.
Similar threshing techniques seen in the northeast of 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). Such methods are also
used in parts of Cambodia, where it has been calculated that one person can produce
150-200 kg of rice per day, compared with a pair of buffaloes trampling out 300-
500 kg (Tichit 1981:106).

6. Primary winnowing (fad khao). 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, then 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 grains and other heavy fragments like culm nodes fall
at the feet of the winnowers, while the lighter fragments including dust 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 spikelets and
dense nodes as well as on the fraction which has settled a little downwind. This
latter consists largely of empty spikelets with straw fragments, but also contains
small grains which are separated by being skilfully shaken backwards and forwards
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. All the rice is swept up into a single pile on the
threshing floor, measured in a standard-sized basket and bagged into hessian or jute
sacks for transport to the storehouse.

7. Drying. Often the moisture content of the paddy needs to be further reduced
before it is put into storage. This will prevent 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 over the grain. At night it is raked together and the pile protected from dew and rain with mats. An additional factor, as Dove (1985:285) points out, is that dry grain is lighter, so requires less labour when being shifted 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.

8. **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 (yung khao) 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 1-8, 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, all subsequent work being carried 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:248) and today the vast majority of the farmers in the southeastern lowlands sell their harvest to the mills, as well as sending the rice for domestic consumption to be milled mechanically, paying for the service with a proportion of their crop. A few farmers 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 Prū, not on the intensively farmed coastal lowlands but in a marginal dryland area on one of the alluvial terraces 7 km northeast 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.

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

9. Milling: separating grains from husk (sii khao). A small mill (mo khao) 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, 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).

Similar equipment was noted as the most popular means of milling rice in lowland
Burma during the early years of this century (Anon. 1913:454). The operation of
such a machine was 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.

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 (*kloong*) 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*). Both techniques were observed in use by members of a single household at Ban Nong Prü.

10. **Secondary winnowing.** The milled rice mixture is extracted and winnowed in a large flat circular basket (*kradong*) 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 is grains and husks of 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, 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 used as kindling and fuel for domestic fires or for smouldering fires beneath the house, to ward away mosquitoes (Tichit 1981:116).

Samples were taken of the *klæb* before and after being burnt in a kitchen fire. The degree of combustion varied through the burnt sample, where 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.

The *klæb* 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 in this instance, it would most probably be the 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 *khrok* for (a second round of) pounding.

11. **Pounding** (*tam khao*). At this point the grain mixture is largely comprised of polished grain, mostly whole but some broken, with about 5% of the sample covered with bran. There are also some whole filled spikelets which were not split open by the milling or initial pounding, along with broken husks. This combination is pounded to remove the bran and polish the grain by means of a heavy long-handled mallet (*saak ta lampuk*) in a large wooden mortar (*krok*) made from tough dipterocarp timber (*yang*). If stage 9 of the process was carried out by manual pounding, the mixture may be transferred to a second, smaller mortar (*saak muu*) for this second round of pounding, where it may be worked on 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.

12. **Coarse sieving** (*lon khao*). The grain is still contaminated with small pieces of straw and some long husk fragments, so it is sieved through a basket (*ta klaeng*) with 2 mm mesh. This divides the rice into a coarse fraction retained in the sieve (c.90% of the total) and finer-grade material which passes through (see stage 15 below for further treatment of this material). The coarse fraction held in the sieve comprises grain (polished rice), husks and straw fragments larger than the grain.

14. **Repeated winnowing.** The coarse fraction is then separated further by being slowly poured (*loi khao*) from a basket onto a round flat woven tray. 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 plus a few large fragments of husk) is deftly shaken back and forwards in the tray to further separate items of similar density and the chaff discarded.
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*). The clean rice (*khao saan*), some of which is broken, is washed to remove dust, then cooked, most 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 dogs.

16. **Fine sieving.** The fine fraction from stage 14 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 (*khao saan*) as human food, but normally it is 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 included in Figures 7.2 and 7.3.

7.2.4 **Traditional agricultural practice in lowland Thailand**

One problem with documenting the most basic traditional *lowland* rice-production technology is that the southeast and the central plains of Thailand are the very areas where the greatest changes have taken place, especially in the lowlying irrigated lands where two crops per year can be sown. Within Thailand, and throughout mainland Southeast 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 initially during the late fifteenth- to early sixteenth-centuries (Hubbard 1977:17-19) preceding the more concerted efforts of reclamation in the late-nineteenth century (Johnston (1976b:41; Hanks 1972:78). 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 Prawetburiram 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 nypa palms and salt flats, followed further from the coast by coconut and areca groves, citrus orchards and finally rice paddies (Koenig 1894a; Warington Smyth 1898:56). Koenig was a Danish botanist who, in 1779, documented numerous plant collections during his journey up the Chao Phraya to Bangkok and then along the southeastern seaboard to Chantaburi (Koenig 1894a:125-182). His descriptions of the mangrove and swamp flora and the villages of the estuary and along the coast offer a picture of stilted houses, 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 1972:78), as well as in 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 1974:25). In general, though, we have little information about the cropping systems other than their existence. According to Takaya (1980:633), prior to the Bowring Treaty (1855) there were probably three groups of people living in the Chao Phraya and Bang Pakong deltas: firstly, the sedentary rice growers located along the major watercourses, practising broadcast agriculture; secondly "shifting rice growers who planted along the coast" using transplanting techniques, who were "mainly engaged in fishing and wood cutting"; and thirdly, the people of Bangkok and adjoining towns. Johnston (1976a:199) surmises that shifting cultivation was probably not widely practiced in the historic period, although we may note that Hanks (1972:78), 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 "colonised" 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 Southeast Asia, it was estimated that only in the Outer Islands of Indonesia were there shifting cultivators on level lowlands (Pelzer 1948:17).

Present-day shifting swampland rice agriculture in Sarawak (Padoch 1982), Kalimantan (Dove 1985; Watson 1985, 1987) and peninsular Malaysia (Lambert 1985) offers the closest ecological analogue 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.

7.2.5 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 southeastern 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-harvesting techniques 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 in the course of their journeys 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 southeast Asia (e.g Hanks 1972; Kaufman 1960). Together, these sources indicate the range of techniques applied to a single problem, the harvesting and preparation of a staple grain crop, 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 are ones which 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 than at lower altitudes, because of the abbreviated 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 northeast to an almost
straight one in the north (Kanokpongchai 1985). The method of reaping is broadly similar though, with a number of panicles being cut by each cutting motion.

An alternative to the sickle is the rice knife (kær'), an implement comprising a small flat horizontal blade, made of iron, tin, copper or even the sharpened edge of a sardine can (Dove 1985:270), set in a vertical handle of bamboo, bone or metal (Miles 1979:226). 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 Fischer (1938), Colani (1936:216-7) and Miles (1979:226), along with Indonesian examples (Fischer-Utrecht 1937:plates II-IV; 1939:148-9), which even include implements made from shell (Fischer-Utrecht 1937:86; 1939:148). 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 (T. Higham 1988).

The finger knife is currently used throughout island Southeast 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 northeastwards into China. In peninsular Thailand, the current border between the two technological provinces lies just south of the Isthmus of Kra (Boeles 1966:49). The hill tribes of mainland Southeast Asia also use the finger knife for harvesting (Barney 1970:166), though not the northern Thai (Kingshill 1960:43; Judd 1964:50; 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 1987:240). 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 1985:274). This ability to cut individual panicles may have originally
stemmed 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 this is too short to be tied as sheaves, so 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 rices. Rice cut by finger-knife may sometimes be stored on the panicle, without being threshed first (Ja'far 1897:303; Jenks 1905; Conklin 1980; Bodner 1986:157; Prill-Brett 1986:66), 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 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, used as the main harvesting technique by the Lamet swidden cultivators of northern Laos (Burling 1963:41; Izikowitz 1979:253) and for overripe fragile panicles as an adjunct to finger knives by the Kantu' of Kalimantan (Dove 1985:272). This a rare form of "gathering" actually selects for the shattering type of rice, but within a cultivated situation.

**Threshing.** The current methods of threshing rice in southeast 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 (1907:207) 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 1988:372). Alternative methods for threshing are as follows:

i) Flailing the crop to dislodge the spikelets, using sticks, bamboo, coconut leaves (Kaga n.d.:41) (Indonesia) or a hinged wooden device (Philippines) (Saunders et al. 1980:34).
ii) Stamping or treading the panicles barefoot or rubbing the rice between the feet is widespread throughout both island and mainland Southeast Asia and has been documented in parts of northern Thailand (Judd 1964:53) and in Malaysia (Gianno 1990:36), as well as in Assam (Barney 1970:126) and amongst the Lamet of northern Laos (Izikowitz 1979:253). Working on a woven pandanus mat, the treaders grip a horizontal bamboo and work the rice between their feet to release the spikelets. Sherman and Sherman (1990:128-9) 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 any remaining grains free. 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 which has fallen between the slats, while the pedicels and straw remain above (Copeland 1924, cited by Grist 1975; Dove 1985:283-4). This technique can thresh rice twice as fast as the simpler foot-threshing method (Watson 1987:254). 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.:42, citing Rice Post Harvest Technology 1976). The rate of production has been calculated as 100 kg/hr (Tichit 1981:106) or 300 kg/6hr day (Watson 1987:254).

iii. Stripping, by pulling the straw or panicle through a comb (Japan) or a V cut in a piece of wood (Philippines) (Saunders et al. 1980:34). Stripping is used, and the comb is thought to have been invented, in Japan (Grist 1975:165).

Winnowing. The natural wind may be augmented by hand-wafted bamboo mats or, nowadays, a mechanical wind-generator. In Burma, bamboo platforms are sometimes constructed in the threshing area and baskets of threshed paddy passed up to a man 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 (1987:257) 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 are varied in construction and scale, ranging from individual baskets or bins to capacious buildings (see Clément 1985 for extensive descriptions). Baskets are regarded by the farmers to be best, because they provide good aeration, as well as being cheap and durable, but wood or bark generally offer better rat protection. The woven mud-plastered baskets may be placed high on a raised platform and protected by a roof of leaves (Young 1907:208). Additional measures may be taken to protect the crop from insect and pest infestation during storage. These may include the placement with the grain of particular plants or plant extracts, such as the wood of *Azadirachta indica* (*sadao india*), oils or minerals (Golob and Webley 1980:3).

De Young (1966:90-1) 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, to 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 very 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 grain.

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 1983:196), tree leaves and rice straw (Gillogly 1988:153), although the high silica content of straw limits its palatability and digestibility (van Soest and Jones 1968; Rovner 1987:108-9). A prominent feature of lowland farmyards is a tall pole around which a straw stack is built, but alternative means of storing the feed is in a covered enclosure, or even in the branches of a tree (Niezen 1986:50, cited by Gillogly 1988). Additional uses for the straw are as a fuel for firing pottery, for kindling and for making minor products like straw rope, paper, woven shoes and medicines (Elvin 1982:18).

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

**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 and is of two kinds, a pair of horizontal grindstones described earlier or a pestle and mortar, which may be a levered or a manual device.

A foot-powered mortar and pestle is still in use in the uplands of Thailand today through Burma (Anon. 1913:454) and eastern India (Raychaudhuri 1961:32). 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.

Foot-powered mortars in dry upland areas have a water-powered equivalent in other places, for example amongst the Man of Vietnam (Dement'eva-Leskinen 1969:6). Burling (1963:303) attributes the replacement of the simple mortar and pestle by foot-operated rice pounders 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.

Simpler wooden pestles with hand-held poles, fundamentally similar to the technique described for Ban Nong Prū in the research area, have been described amongst the Mnong Gar or Phi Bree and the Brou, upland swiddeners respectively in Vietnam (Condominas 1957:28) and Cambodia (Matras-Troubetzkoy 1978:112-7). This is the simplest milling technique in operation in southeast 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, in press:478). 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. The results indicate that the breakage patterns found in prehistoric spikelets from Banyan Valley in northwestern Thailand are better replicated by stone pounding implements used with a rocking motion than
1. HARVESTING using sickles

- straw + panicles (spikelets + panicle branches)
- straw remains in field as stubble

2. SUN-DRYING of sheaves in the field (to improve threshing)

- whole spikelets drop

3. THRESHING to separate spikelets from pedicels (by trampling, beating or flailing)

4. RAKING

- free spikelets
- panicle branches (free and attached to spikelets)
- short straw fragments

5. PRIMARY WINNOWING (one or two rounds)

- spikelets (filled and unfilled)
- spikelets with pedicels attached
- broken straw
- heavy culm nodes

- light chaff, khao lieb
- (whole unfilled spikelets)
- broken straw
- panicle branches

6. SUN-DRYING light grains unfilled spikelets + panicle branches

6. BULK GRAIN STORAGE for up to 10 years

- MILLING FOR DOMESTIC CONSUMPTION
  (see Figure 7.3)

- INFESTED GRAIN BURNT

Components are listed in declining order of abundance. These examples were non-awned varieties.
FIGURE 7.3
SCHEMATIC DIAGRAM OF THE TRADITIONAL MILLING AND POUNDING OF RICE, THE COMPOSITION OF PRIME PRODUCTS AND BY-PRODUCTS, PLUS THEIR USES

9. MILLING *sii khao* to dehusk hulled grain
(using rotary mill, foot-operated rice pounder
or pestle and mortar)
grain + whole lemmas and paleas + husk fragments + small stem fragments

10. SECONDARY WINNOWING *fad khao*
using flat winnowing tray *kradong*
to separate light spikelets and broken chaff by wind

broken grains
*khoi khrung met*
dense grain *khaok nak*
caff *klaeb*: whole split husks
+k dense large pieces of chaff
+ whole, partially-split spikelets
  + some with spikelet bases attached
  + unfilled spikelets + stem

STORED FOR
DUCK AND
CHICKEN FEED

11. POUNDING *tam khao* using small mortar
to remove bran and polish grains

12. COARSE SIEVING *lon khao* using 2 mm sieve

Retained in sieve
Falls through sieve

13. WINNOWING *loi khao* mixture is poured from
a basket to a flat winnowing tray on the ground

14. HAND PICKING

15. FINE SIEVING

16. COOKING
AND CONSUMPTION
the pestle-and-mortar or mill used by subsistence farmers living in the area today (Yen 1977:589).

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 transformed and incorporated into durable materials which may be 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, feed chickens (Gillogly 1988:191,195). These uses are not likely 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 the materials, favouring preservation. Husks have been used to power industrial-scale rice mills since the early years of this century (Graham 1904:155; Johnston 1976a:248), but also have a long tradition of use as kindling and for firing pottery. 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 way 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.
7.3 APPLYING THE MODEL OF CROP-PROCESSING TO ARCHAEOLOGICAL RICE REMAINS

The crop products and by-products have been described here in terms of their progressive breakdown, 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 the kinds of plant parts which might be discarded and appear in the archaeologica[el record at a producing site (Figure 7.2) compared with a consumer site (Figure 7.3), where rice is brought in as spikelets and milled close to consumption. Distinguishing between the two could be in terms of 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) 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 and the coprolite samples) along with monocotyledon stems (most probably rice) preserved within the soil and rarely as temper in potsherds. The occurrence of these stem fragments, if confirmed as rice by phytolith analysis (regrettably beyond the scope of this thesis), 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 would extend to charring experiments and the examination of assemblages of archaeological specimens to assess which
plant parts are those most likely to survive. 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 characterise them, and to classify archaeological material.

7.4 ADDITIONAL CONSIDERATIONS FROM 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*, *T. sphaerococcum*, bread wheat (*T. aestivum*) or barley (*Hordeum vulgare*), ryes (*Secale cereale*) and oats (*Avena sativa*), where "the grains fall free when the ears are threshed" (Hillman 1985:4). 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:125-6), whereas the rice is put directly into storage at this point. A main difference, archaeobotanically, is that processing of wheats and barley has broken the ear and stem down into many more discrete parts.

There are, however, two 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 storage is as grain (Hillman 1986b:130). 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.
7.4.1 Crop contamination by weed seeds

European archaeobotanists have emphasised the potential of weed seeds for characterising, and statistically differentiating between, the various crop-processing by-products and have shown that the composition of archaeological assemblages of charred seeds provide information for elucidating past agrarian practice (Jones 1984a, 1987; Englemark 1989). The utility of this approach to rice, and especially to the pond-field agriculture of Southeast 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 1982:427), 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 (1982:57) for samples from an upland harvest. The absence of weed seeds is probably due to a combination of ecological and cultural factors. Floristic diversity in weeds of rice is related to a combination of physical and agronomic factors, namely the landform and the soil moisture regime, along 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-mechanised, 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 1978:247). 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. They include:
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. This means that upland and deepwater rices tend to suffer more from weed competition than swamp or irrigated crops. 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', which 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. 1983:205). 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 1985:225).

Agronomic practices most likely to affect the degree of weed infestation are the method of planting, with transplanted rices having fewer weeds than transplanted ones where the young seedlings have a competitive advantage over their competitors. The reaping method may also play a role in the cleanliness of the rice

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**Weeds of rainfed rice**
- Chara zeylanica
- Cyperus difformis
- C. pulcherrimus
- Echinochloa crus-galli
- Fimbrystilis littoralis
- Leptochloa chinensis
- Ludwigia hyssopifolia
- Marsilea minuta
- Mimulus orbicularis
- Monochoria vaginalis
- Scirpus juncioides
- Sphenocloa zelanica
- Utricularia aurora

**Weeds of deepwater rice**
- Pentapetes phoenicia
- Aeschynomene indica
- Alternathera philoxeroides
- Cyanothis axilaris
- Ipomoea aquatica
- Melolochia concatenata
- Commelina diffusa
- Echinocloa colona
- Panicum cambogiense
- Leptochloa chinensis
- Echinochloa crus-galli
- Paspalum scrobiculatum
- Ischaemum barbatum
- Cyperus pulcherrimus
- Fimbrystilis littoralis
- Cyperus rotundus

**Weeds of upland rice**
- Dactylolcenis aegyptium
- Digitaria addecens
- Eleusine indica
- Eragrostis tenella
- Panicum repens
- Cynodon dactylon
- Chloris barbata
- Brachiaria repens
- Ageratum conysoide
- Amaranthus viridis
- Commelina benghalensis
- Euphorbia hirta
- Gomphrene celiodes
- Heliotropium indicum
- Mollugo pentaphylla
- Phyllanthus nirurai
- Cyperus rotundus

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

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

7.4.2 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 Southeast Asian food plants such as Job's Tears (Coix lachryma-jobi) are, however, roasted as part of their preparation (Bodner 1986:209), providing more chances for cooking accidents. Thus, Coix would theoretically be more likely to occur in charred archaeobotanical record than rice.

What heat rice does require during processing is 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 required, such as in the mountains of Vietnam where 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 this 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, thus opening up the possibility of charring accidents and hence increasing archaeological visibility, is the preparation of *khao mao* (*mpin* in Kalimantan, Dove 1985:269; *emping* in Malaysia, Kato 1988:124). 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*; *khao nieow*) are roasted in the husk. This was seen at Samet Ngaam, near Chantaburi (see Figure 3.2), 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 Southeast Asia, but restricted to specialised 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 last year's stored grain is almost depleted. It is also appropriate as a festive dish, for celebrating the harvest season. The sequence of operations in preparing *khao mao* is as follows (see also Figure 7.4):

i) **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.

ii) **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% of these still attached to broken pedicels and panicle branches. Breaks in the panicle were typically at the secondary branch.
iii) Winnowing (loi khao). 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% of the sample taken was of spikelets attached to their pedicels and panicle branches.

iv) Second winnowing. The main product was retained and treated further by being 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.

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

vi) 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.

vii) 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% of the sample comprised paired lemmas and paleas.

viii) Secondary pounding. The prime product was returned to the mortar for further pounding, which removed the bran from the outer surface of the grains and squashed the polished caryopses. Subsequent winnowing for the 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.
ix) **Hand sorting.** The prime grain was finally sorted through 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% 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 greater chances for cooking accidents than the conventional sun-dried techniques do, and food prepared in this way would have a greater chance of being accidentally charred and thereby being preserved for incorporation in the archaeological record. However, most of the rice remains from Khok Phanom Di were preserved as temper in pottery and the processing of crop waste for this purpose would warrant further exploration, in order to better understand the taphonomic processes affecting rice remains.
FIGURE 7.4
SCHEMATIC DIAGRAM OF THE PREPARATION OF KHAO MAO

i. REAPING at mid-stem
   panicles with c.25 cm stem attached

ii. THRESHING by trampling in a sack
to separate spikelets from panicles
   stems + leaves, some with unfilled spikelets attached

iii. PRIMARY WINNOWING loi khao

filled spikelets
   unfilled spikelets + small light filled spikelets
   + some spikelets with pedicels and panicle branches attached

iv. SECOND WINNOWING by shaking on a winnowing tray
   small light whole husks
   + panicle branches with pedicels
   + straw and leaf fragments

v. PARCHING using a small brazier
   parched whole spikelets

vi. POUNDING using a wooden pestle, mortar and paddle
to break open parched spikelets and release grain

vii. THIRD WINNOWING

   clean grain
   whole split husks + straw and leaf fragments
   + finer broken husk fragments
   + broken and a few complete grains

viii. MORE POUNDING to polish and squash the grain

ix. FOURTH WINNOWING

   flattened toasted prime grain
   fine fragments of broken husk
   + bran + a few grains

x. HAND CLEANING to remove remaining husk fragments

   flattened toasted prime grain
   very few small husk fragments
Plate 7.1

Plate 7.1.1 Rice sheaves are carried from the field to the farm for threshing.

Plate 7.1.2 The sheaves are laid out in a circle ready for threshing.

Plate 7.1.3 Rice sheaves are threshed by tractor.
Plate 7.2

Plate 7.2.1  After threshing the straw is raked away from the loose spikelets and retained for animal feed.

Plate 7.2.2  Rice sheaves being threshed by hand.
Rice spikelets being pounded by pestle and mortar to release the grain from the husks.

Winnowing the husks away in the wind, to leave the prime grain in the basket on the ground.
Plate 7.4

Plate 7.4.1  The mixture of spikelets, broken straw and splintered husk in the mortar.
Plate 7.4.2  Cleaning the grain to remove husk fragments.
Plate 7.4.3  Further cleaning of the grain to remove the finest husk fragments.
Plate 7.5

Plate 7.5.1 A rotary rice mill of the kind described by Halliday (1917), as quoted on page 261.

Plate 7.5.2 Anat Bamrungwongse sketches the interior of the rotary mill.
Chapter Eight

INTERPRETATIONS AND CONCLUSIONS:
FURTHER THOUGHTS ON KHOK PHANOM DI SUBSISTENCE

The purpose of this final chapter is two-fold, primarily to summarise and integrate the archaeobotanical evidence for ecology and subsistence presented in previous chapters, but also to question the archaeologically invisible role of plant foods in the prehistoric tropical diet. We shall return to the problems set out in the introductory remarks, those of the evolving 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 of the major habitats indicated by the plant macroremains will be explored briefly, as these provide clues to plant use beyond the important role of a dietary staple.

8.1. Methodological issues arising from the archaeobotanical work at Khok Phanom Di

The research reported here is part of an ambitious, long-term survey and excavation program in the lower Bang Pakong Valley, with special emphasis on the site of Khok Phanom Di. Numerous specialists have been involved, with the palynology undertaken in Northern Ireland and the post-excavation analysis carried out by Thai and New Zealand archaeologists in Dunedin, New Zealand. This multi-disciplinary approach is the only practical and effective way of tackling such a large and challenging site in a comprehensive manner within a reasonable timeframe. Nevertheless, a few logistical difficulties arose from being part of a geographically disparate team. Working in Australia, in distant association with others in the United Kingdom, Thailand and New Zealand has impinged somewhat on sharing ideas and research materials. The archaeobotany has been investigated in comparative isolation from the core research group, with limited access to their interim results and without informal discussions. There were also difficulties
gaining access to materials under analysis overseas, due to conflicting research strategies, priorities and schedules. For instance, certain charcoal samples despatched for radiocarbon dating were unavailable for identification, and more importantly, work on the ceramics in Dunedin precluded their archaeobotanical assessment in Canberra. Both the total number of rice specimens per excavation context and the number of contexts represented were restricted because the material culture was accorded higher priority. As the investigation of biological populations is ideally based on numerous observations, the small sample numbers have limited the scope of the archaeobotanical analysis and interpretation. The new understanding arising from this research, that the remains of rice are most predictably preserved as ceramic temper, offers a pointer to organising future collaboration, wherever questions of subsistence and crop history are central to an archaeological project. Any further work would benefit from extending access to research materials to a wider range of specialists, including an archaeobotanist.

One final problem in identifying the archaeobotanical remains from Khok Phanom Di has been the limited comparative materials. This is only to be expected for an initial foray into the palaeoethnobotany of the region, where plant communities are highly diverse, documentation of the modern flora is incomplete and the reference collection reflects only a small proportion of that total biological diversity. Voucher specimens were assembled in Thailand but the archaeological identifications made in Australia. Return trips were not feasible when the need for additional comparative material arose, so access to Australian herbaria with Southeast Asian accessions was essential for many identifications. The foundations of a reference collection from lowland taxa have now been established, and this will be augmented over time.

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 is to demonstrate that useful plant remains can be recovered from such sites by conventional means. The utility of analysing botanical remains from Southeast Asian archaeological sites is increasingly recognised, 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 changwat Chiang Mai failed to find charcoal or seeds despite considerable effort (Santoni et al 1990:42), while the alkalinity of midden layers was thought to have destroyed plant material at the historic period sites of Non Ban Kham and Ban Tamyae, near Phimai on the Khorat plateau (Welch and McNeill 1988-89:107, 109). The recovery of charred remains at Khok Phanom Di did not entirely meet our optimistic expectations 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 mineralisation of organics, like the remnants of wooden coffins or biers at Khok Phanom Di. As this is one of the few archaeological sites in mainland Southeast 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 these 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 mineralised specimens was not predicted. There were coprolites, leaf impressions, rare large seeds and splinters of wood from burial contexts. Conversely, other classes of preservation were less common than anticipated. Carbonised rice was absent, but charred seeds from wild plants were successfully retrieved by flotation. Their frequencies (.03-6.5 seeds per litre of soil) were comparable to, and sometimes greater than, those for other lowland tropical sites (.11-.94 seeds per litre) (Miksicek 1987:215).

Standard identification methods were generally applied to the wood and seeds, but 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 7 help explain why the lemma and palea 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, within populations and even within individual spikelets makes these measures difficult to quantify, apply and communicate. Minute husk fragments therefore offer less reliable features for distinguishing between wild and domesticated types than do abscission scars or the presence/absence of awns. As these 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.

8.2 Ecological interpretation from the archaeobotanical assemblages

From an interpretive 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 alongside the ancestral Bang Pakong estuary, within 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 in press:112), while 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 site contained good quantities of charcoal from stratified deposits, with abundant material for dating and identification providing a chronological framework and information on vegetation and its resource use. 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 (confirming pollen evidence from cores JB 2 and BMR 2), 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 in press; Maloney *et al.* 1989:369) and although the charcoal data cannot adjudicate on this, the general picture is confirmed.

Ash and charcoal spreads were common features of the Zone A deposits and have been interpreted as the debris from cooking shellfish for mortuary feasting at the time of a burial (Bannanurag 1989:292-3; Higham and Bannanurag 1990b:38). Charcoal density decreased while fragmentation increased after layer 9, post-dated by changes in sample composition around the layer 7/8 interface. 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 into layer 8 where the most reasonable of the three dates is from 8:2, at 3430 ± 80 bp (1930-1525 BC, ANU-5483). At this point mangrove-dominated samples were followed by others largely comprising Non-Rhizophoraceae woods. If the possibility of new charcoal-generating activities influencing charcoal assemblage composition, are set aside, the combined aspects of charcoal deposition suggest a major change in local vegetation cover. The favoured reconstruction is for declining fuelwood supply, perhaps due to a shift from a timber-rich to a timber-poor setting, from forest to open plain. Thus, the charcoals are interpreted as reflecting the continued but rationed use of fuels from an area with declining woody resources and fewer highly prized timbers, like mangrove wood. Charcoal representation in the archaeological deposits is filtered by a number of human decisions based on how people perceive resources and respond to changes in resource availability. This means that a radical change in timber supply could be overcome by new behaviours, collecting firewood further afield or switching to a
second-rate but logistically more convenient wood. For additional information on the nature and the timing of the environmental change naturally deposited indicators, especially mobile fauna occupying precise ecological niches are more sensitive.

The interpretations from the charcoal data, are entirely consistent with the results for independent lines of analysis. The molluscan data also point to a remarkable change in the local environment, from layer 7 and the upper part of 8, as seen in the diminishing mangal taxa, with the sudden intrusion of pulmonate landsnails into the previously marine-estuarine molluscan assemblage (Higham et al. in press:10; Mason in press). Freshwater habitats became more prominent as estuarine and even riverine environmental signals faded. The same situation is seen in the fish bones and crab remains identified by Kijngam (in press), with the gradual decrease in marine fish like *Plotosus canius* and a simultaneous increase in freshwater *Clarius* sp. (Higham et al. in press:15), as well as greater exploitation of terrestrial resources like deer from layer 8 and wild waterbuffalo from layer 6 (Grant and Higham in press).

The seeds and charcoal offer complementary information on local ecology, especially here 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 number of sources of biological data including plant remains. The molluscs are particularly 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 cannot be differentiated by plant remains, but the presence of *Trianthema portulacastrum* and *Suaeda maritima* seeds at the site indicate a further habitat with the site catchment not recognised by faunal or pollen analyses. This is the barren, dry, open, saline or hypersaline plain commonly found 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 levels 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, expanding in Zone B and falling off dramatically in Zone C (Higham *et al.* in press:9). 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 preceding deposits. They nevertheless include the remains of *Amaranthus* and *Portulaca oleracea*. Both are small herbs which often colonise 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, ostracods and foraminifera.

As indicated by the charcoals evidence and further emphasised by the seeds, phasing the site in terms of material culture (Zones A,B and C, according to Higham *et al.* 1987) or 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 environments 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. Mason (in press) has postulated that the site's surroundings changed because the river shifted its course laterally, possibly in response to a major flood. An alternative explanation could be that the mangrove migrated downstream as the river prograded, or the vegetation change was prompted by a marine regression affecting the entire Gulf of Thailand.
A combination of the three is possible, but would be difficult to dissociate from the bioarchaeological data. Distinguishing 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 together 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 by other specialists in the team.

Ecological reconstruction on the basis of micro-molluscs, ostracods and foraminifera certainly 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 in addition to 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.

8.3 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 in press:60). 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 5. Both types of
data are, however, limited in their ability to unequivocally identify agriculture, as the range of paddy field weeds overlaps closely with the natural herbaceous flora of swamplands. All the data point to the existence of ephemeral ponds and 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 practiced 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 1990:142-3; Maloney in press:61). Thirdly, high levels of microfossil charcoal coincide with markedly increased Gramineae pollen. The stratigraphic core KL 2 provides evidence of burning vegetation in the catchment 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. 1989:366-7). Though each of these three aspects is circumstantial, they are taken as strong evidence for burning stands of vegetation and expanding the range of freshwater swamp within which rice was thought to be cultivated, more than 2000 years before archaeological evidence of occupation at the mound (Maloney in press:79; Maloney et al. 1989:368-9). Research was redirected to the excavated remains of rice for definitive evidence on domestication and cultivation (Higham et al. 1987:175; Maloney et al. 1989:368).

From the excavation, further supporting evidence was found in the artefacts thought to be associated with rice exploitation (Maloney et al. 1989:365). These include polished stone axes and leucogranite hoes (Pisnupong 1988, in press:482) possibly used for clearing plots and breaking ground, together with shell knives for reaping grasses (Higham 1988). Today in Thailand most other tools for post-harvest rice processing are made of wood or bamboo, so are less likely to be visible in the archaeological record than stone 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 investigated 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 and in ceramic slip, and as 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 domesticated crop. Nothing conclusively suggested 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 foodstuff, rice and its byproducts are put to numerous additional uses, as detailed in chapter 7. 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 1987:172-3). 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 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 unsolved: 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 mangrove villagers do today (Aksornkoae et al. 1984:40; Mathur 1986:144). We know that Khok Phanom Di was a highly specialised 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 1987); good quality lithics for axes and adzes, and the sandstone grinders for sharpening them came from even further
afield (Pisupong 1988); while exotic ceramic artefacts were brought from widely separated sources (Vincent 1987:175). In return the Khok Phanom Di people probably supplied pottery and shell jewellery fashioned from trochus, tridachna and cowrie. Additional possibilities for export are salt, plant resins, dyes and even preserved/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 1976:15) 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 delta (Takaya and Thiramongkol 1982:10) and brackish tidal land is used for forestry, shrimp breeding, salt evaporation and also has been ridged for coconut groves. 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. Widespread rice production in the area was not started until the mid-nineteenth century when major drainage and canal-building initiatives were underway (Johnson 1976a and b).

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 like slaked lime (Fukui and Takahashi 1969:970; Watson 1975:41; van Breemen 1976:1, 150-1; Hattori and Kyuma 1978:201) although soils developed under Avicennia are said to be more productive than 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 4mmho/cm (Barnes 1990:5) 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 1979:82). Rice
yields under acid-sulphate soil conditions are 500 - 700 kg/ha (Sin 1990:61), only about a third of the average productivity of inland freshwater paddies (1.8 tonnes/ha) (Fukui and Takahashi 1969:962).

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 1987:177), 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. 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 1991:566). Novel varieties of salt-resistant rice for planting in saline soils were not produced in southeastern China until early in the "late traditional" period (1350 AD - 1900 AD) (Rawski 1972:42; Elvin 1975:92, 1982:19). 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).

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. 1985:237), and a similar situation might possibly have developed in the Bang Pakong lowlands. The tidal range is significantly less in the Gulf of Thailand than in Australia, though, and this is an important influence on the geomorphology of fluvial systems near their estuary so the situations are not directly analogous (G. Brierly pers. comm.). The geomorphology of the lower Bangkok Plain is less well documented but, as van Breemen (1976:6) points out, 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.

We cannot suppose that the coastal hinterland was particularly suited to rice cultivation, without natural levée formation, for which we have no evidence, or the coordination of a labour force to dig drainage ditches and build dams. Infrastructural improvements like land levelling and bund digging are usually associated with centrally-organised societies. Burial rites indicate that Khok Phanom Di was a hierarchical community, but status was apparently based on personal craft skills rather than central or hereditary authority. Despite all these problems with establishing rice agriculture next 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 400 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 1988:31) providing further confirmation that the Khok Phanom Di people were involved in harvesting their own cereals. These shell reaping knives mean that 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 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 communications 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 essentially extensive, with minimal attempts at land levelling, soil preparation or water control (Padoch 1988:24). 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 and 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 swamp (Dove 1985:189). 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 just the situations where early experimentation with rice harvesting probably took place.
8.4 Issues of incipient domestication

Returning to Higham's (1984:100) initial rice domestication hypothesis 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 (1977:371) on the likelihood of the deltas of Southeast 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 1977:371). 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. Higham's 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, he considered, stands of wild rice. 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 rice were found in some form in all levels of the site, both before and after the major change from a marine-estuarine position to a more inland one, and they showed neither an increase in abundance nor a marked change in morphology through the sequence. Although the general concept of environmental trigger postulated as prompting cultivation therefore seems inappropriate. Indeed, with the shift from mangrove to inland conditions, access to freshwater wetlands with rice would probably have improved.
The rice remains from the 1985 excavation 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 ~500 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 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 and slip. Comparisons of plant anatomy from a series of large samples through the site were therefore not possible.

The cultivation of wet rice in the low-lying hinterland behind the coast of the Gulf of Thailand adds additional weight to previous rice finds in the piedmont of northeastern 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 to extend rice into more marginal habitats arose.

The dating for rice cultivation in Southeast Asia remains sketchy, with the Non Nok Tha chronology still uncertain (Reed 1977:912-916) and the secondary evidence from Spirit Cave inadequate. Here the putative rice-cutting knives at about 6000 BC could equally have been used for reaping wild grasses. Recent results from excavations at Pentoushan (on the middle Yangtze in Hunan Province) have pushed back the Chinese dates for early riziculture to 5500-7000 BC (Yan 1991) as yet unparalleled in neighbouring Southeast Asia. The plant remains from Khok Phanom Di, dated at 2000 BC are not remarkably early but the adjunct pollen evidence, albeit circumstantial, suggest the possibility of rice cultivation by people living on the Bang Pakong lowlands around 4300 bc, some 500 years earlier than the dates for rice in the basal deposits at Ban Chiang (White 1986:194).

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 entire 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 affirms the storage of grain at the site which would have provided food at least into the dry season if not year-round.

The Khok Phanom Di excavations may not push back the chronology of rice cultivation in Southeast Asia, but they offer well-dated and documented remains of rice with clear signs of domestication which will contribute to an expanding database and our increasing understanding of changing subsistence strategies in Southeast Asia. Unfortunately the plant remains examined here cannot contribute to the debate over whether tuber crops 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.

### 8.5 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 more likely. The mineralised coprolites proved intractable to analysis, 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 identification is uncertain due to lack of comparative material. 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.
Khok Phanom Di’s current delta flat environment barely resemble those of the coastal/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 data 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 evidence for five major plant communities, but quantitative assessments of their extent and proximity to the site are impossible 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 saltflats 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:104), *Catenella nipae*, gathered from mangroves for sale in Burmese markets (Post 1939, cited by Chapman 1980:88; Rollet 1975a:208), as well as *Caulerpa racemosa* and *Gracilaria crassa* from the coast around Phuket in southern Thailand (Chapman 1980:88; Jacquat and Bertossa 1990:26-27). Although seaweed seems an unlikely botanical find on an archaeological site, charred remains have been found in Scotland, at Dunadd in Argyll (Milles 1985:3) 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 1966:939), but the mangrove forest warrants greater attention as this appears to have surrounded the site during the first half of its occupation. 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 (see Appendix 3 for details). They 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 1979:138), 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, rather than the plant life offered there. The reasons for this are complex. Low floristic diversity and the absence of a specialised understorey, in conjunction with high levels of toxins in many plants mean that mangrove forest offers only limited plant foods compared with a wide range of edible animals.

To outline the 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. The fruits of Avicennia, Intsia retusa and Sonneratia are 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 Appendix 3). 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 (Rollet 1975:205). In the mangal, the only plant product used 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 was a sweetmeat or supplementary food, in widespread mangrove-based communities, from the Andaman Islands (Burkill 1966:1935), through mainland Southeast Asia (Burkill 1966; Phengklai 1985:205) and northern Australia (Specht 1958:495; Harris 1977:432,
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1979:94), across the Pacific (Barrau 1959:162; Rollet 1975a:205; David 1985:52) to Fiji (Seeman 1918:65-73). 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 1977:432). In Torres Strait and Cape York Peninsular of northern Australia, the mangrove "fruits" were the carbohydrate staple during the wet season when otherwise mobile groups were semi-sedentary (Harris 1979:94). In the Welu estuary of southeastern Thailand, *Bruguiera* hypocotyls were available and used at all times of the year, if only as an occasional dessert. As a result of their abundance and good nutritional value they are a potential major carbohydrate source. A starch-rich food like mangrove shoots, yam tubers 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 (Plate 4.2.6) 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 recently been reported from a cave with archaeological deposits, Nara Inlet 1 in central Queensland, where preservation was by dessication (Barker 1991:103). The food debris was not accompanied by artefacts such as worked shell or stone grinders (Barker pers. comm., December 1991) to provide an indication of associated technology. There are mid-nineteenth century accounts of processing from the Torres Strait Islands and Cape York Peninsular, that after baking the mangrove "fruits" in ashes or an earth oven, their contents were scraped out with a shell (Moore 1978:38) but similar tools are not reported from coastal archaeological sites, to my knowledge. 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 should be detected archaeobotanically through charred plant remains.

Traditional Thai diet incorporates many young succulent leaves from trees, wild herbs and aquatic plants, as mentioned in chapter 3 (cf. Phengklai and Khamsai 1985:141-148). In 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*. Young leaves are also eaten raw or cooked from the following trees and shrubs: *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* (see Appendix 3 for details). 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 relatively alkalinity (pH 5-6.7) enables them to digest tannin-rich leaves and mangrove bark (Whitten *et al.* 1987:136) 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 through all phases of the site (Grant and Higham in press:155). The prehistoric human population therefore tapped into the mangrove food web at a higher trophic level than in adjacent habitats where a wider range of edible plants were 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, wet rice paddies, continue to supply Thai villagers with many wild vegetable products. Some of the most conspicuous aquatics in Thai markets, used mainly for their leaves and stems, are: *Blyxa* spp. (*santawaa bai khao* and *santawaa khon kai*), *Centella asiatica* (*bua bok*), *Ipomoea aquatica* (*phak bung*), *Limnocharis flava* (*bon cheen*), *Neptunia oleracea* (*phak krachet*), *Nymphaea nucifera* (*bua*) and *N. nouchali* (*bua khaap*) and *Spilanthes paniculata* (*ram*).
In assessing the possible range of starch-rich plant foods from wetlands, an example is provided by plant use pattern in swamplands in northern Australia. In lowland Thailand paddy fields have been almost completely replaced the natural swamps and rice has long been the staple food, whereas in northern Australia unaltered freshwater swamps still exist and are regularly exploited. Some contemporary patterns of wild plant exploitation by Aborigines in monsoonal Australia may therefore shed light on incipient use and even domestication of allied taxa in Southeast Asia. Here, the ethnobotany of foraging communities in similar wetland ecosystems has been carefully and extensively documented through historical records and specifically ethnographic/ethnobotanical research (cf. Specht 1958; Golson 1971; Harris 1977; Meehan 1977, 1982, 1988, 1991; Jones 1980; Russell-Smith 1985; Waddy 1986; Jones and Meehan 1989; Smith 1991). Parallels in plant use between Southeast Asian and Australian Aboriginal peoples, 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).

Without going into great detail, freshwater swamp resources include edible water lilies, *Nelumbo nucifera* (*bua*), taro *Colocasia* spp. (*pueak*) (Petterson 1977:72) and wild rice *Oryza rufipogon* (*yaa lamaan, khao nok*). They also support sedges like *Cyperus esculentus* (*haeo thai*) and water chestnut *Eleocharis dulcis* (*haeo song krathiam*), often growing in monospecific stands. Their roasted corms are eaten (Singh and Arora 1978:7; Meehan 1982:148; Phengklai and Khamsai 1985:131) throughout the dry season. By the end of that season they are very sweet but difficult to dig from the dry swamp-bed (Meehan 1982:33, 1988:6; Waddy 1986:148; Jones and Meehan 1989:124). 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 consumed raw or boiled.

The remains of Cyperaceae achenes were prominent and persistent in the Khok Phanom Di seed assemblage, but their dietary significance is difficult to assess. Sedges, for example *Scirpus grossus*, are a common source of raw materials for
making mats and baskets (Ridley 1891:12) 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 plants. 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 summarise, we see that the mangroves are not abundant in food plants, nor are the saline saltflats immediately inland. High species diversity among aquatic animal resources contrasts with the low diversity of terrestrial foods in the immediately accessible mangrove and its 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 in the freshwater swamps further afield. The resource-rich wetlands offer a range of starchy corms, leafy green vegetables and fruits, as well as rice, apparently the nutritional mainstay 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, and to the seasonal availability of resources. 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 1988:16). 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 away from Khok Phanom Di, 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 foods daily in the vicinity, and established temporary camps beside freshwater swamps when food were seasonally available there. Year-round occupation of the site has been concluded on the grounds of the repeated superimposition of graves, the volume of intervening occupation buildup and architectural features suggestive of houses (Higham and Maloney 1989:661-2). This sedentism is thought to have been facilitated by the ample estuarine resources, particularly molluscs and fish (cf. Yesner 1989:730), but the input of domestic rice surely helped underpin the stability too. Bellwood (1990:21) 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 "characterise themselves as sedentary saltwater people who live chiefly on fish and shellfish" (Meehan 1991:202) 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 degree of movement across the landscape. Despite a recent graphic, hypothetical reconstruction of the site and its surroundings, based largely on molluscan data (Mason in press:297; Higham et al. in press:10), 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.

8.6 Other lines of evidence for diet at Khok Phanom Di
The diet for Khok Phanom Di residents was evidently more than adequate. Faunal remains found during the excavations attest to the use of fish from the sea, the estuary and the river, as well as shellfish and crabs mainly from estuarine mudflats. From the skeletal remains we learn of their robust bone structure and the early onset
of menses in women, construed as indicating a well-balanced diet (C.F.W. Higham pers. comm.). They also indicate a genetic anaemia and the prevalence of malaria, together considered responsible for the high infant and childhood morbidity and mortality, especially in Zone A (Tayles in prep.; Higham in press:14-15).

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 1989:89). 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 is indicated by unopened Anadara shells in the midden deposits (Suchitta 1984:8; Higham and Bannanurag 1990a:34).

Anadromous fish, like Lates calcarifer, provided a seasonally abundant, predictable and easily harvested food supply and shellfish could have been a reliable, year-round staple resource (Yesner 1980:729), at least during estuarine phase of occupation (Zone A and early Zone B, i.e. layers 11-8/7). The general trend in the dental data is for an abrasive diet from shellfish and dried fish consumption, giving way to softer, more cariogenic foods after the river shifted its course impeding access to estuarine resources (Tayles in prep.; Higham et al. in press:13). As seen in chapter 6, 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 juncture, 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. Skeletal features and evidence of demographic structure from the burials indicate that the general health of the population improved after the layer 8 environmental change. This is attributed not to dietary change, but rather to declining exposure to mosquitoes, the vector for malaria (Tayles in prep; Higham et al. in press:15).
The archaeological visibility of the plant and animal components of the diet are disproportionate to their nutritional contribution to the diet and the human effort expended in their procurement. 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 1980:733; Erlandson 1988; Noli and Avery 1988). The limitations of a protein-rich and carbohydrate-poor diet have been touched on earlier. A balanced diet, preventing "protein poisoning", limits the protein intake and incorporates carbohydrate- and fat-rich foods, many of which are plants, especially grains and tubers. Supplying bulk carbohydrates, vitamins and minerals, these and other plant resources complement the protein component of a coastal diet. In the savanna tropics of northern Australia, an estimated 50% of the total calorific intake for the Anbarra people of Arnhem Land was from plant foods (cf. Meehan 1979:182, 1982:151, Meehan and Jones 1986; Jones and Meehan 1989:126). These assessments further emphasise the importance of plant foods among coastal communities, and at Khok Phanom Di the plant macroremains show that this role was at least partially fulfilled by rice.

8.7 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, fishhooks and netweights, but much of the allied extractive equipment was probably made from plants and has been not preserved archaeologically. Lines and nets, floats and harpoon shafts are all fashioned from plant products. Indeed, strong, durable fibres from plants like *Hibiscus tiliaceus* (Burkill 1966:1163), are major assets enabling or limiting the exploitation of anadromous or deep sea fish (Sallis 1989). Sather (1985:173) describes the Bajau Laut (sea nomads) of southeastern 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 levels of tannin which make 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 (cf. Chapman 1976 for a long list of historic records). Poisons from plants like Aegiceras, Barringtonia asiatica, Cerbera manghas, Derris sp., Diospyros and Excoecaria agallocha are to stupify fish.

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 fuelwood is finally used to cook the catch, perhaps flavoured with aromatic leaves 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 Appendix 3.

Possible links between early fishing technology and the cultivation of plants useful for fibre manufacture, have been raised by Sauer (1969:23-24), 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 (1970:496). The antiquity of fibre plant cultivation or the use of fish poisons in Southeast Asia are yet to be demonstrated archaeologically. Well preserved specimens 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.

8.8 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 constraints to population density in these areas is the lack of fresh, potable drinking water (Kundstadter 1986:1). "Freshwater stress" in Chappell and Thom's (1977) terms, 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 (Takaya 1978:187-8; Kundstadter 1986:1). Khok Phanom Di's initial location on an estuarine bank fits well with the modern settlement distribution and that described for prehistoric landscapes (eg. Cooper 1985:30 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, when freshwater habitats ceased to contribute to the molluscan assemblage at the site. The abandonment of the mound 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 and tanks during the wet season for use during the dry. This is practiced at Khok Phanom Di, where well-water cannot be used 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 supplied. This is stored in large water pots inside or under the house. Water is rationed, and recycled whenever possible. In certain mangrove villages such as those in the Thai peninsular studied by Sangdee (1986:48) fresh water is carried precariously by boat from an island with freshwater wells. Additional possible
water sources, for people with access to marine resources, are fish and coconuts (Engelhardt 1989:138) both of which were used by the sea gypsies, or Bajau Laut, who live on boats at sea for extended periods, and have little access to fresh 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. Sangdee (1986:47) points to fungal infections associated with poor hygiene. 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 1863:309) but the skeletal analyses mentioned earlier indicate that the Khok Phanom Di population suffered significantly from malaria carried by mosquitoes.

After the water shortage, a second striking limitation to life in the mangroves is mobility. 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 stilts 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 1986:59; C. Sather pers. comm., August 1990). This simple but highly appropriate means of transport allows access to distant shellfish beds. Resting one knee on the sledge, and using the other to propel the board across the mud, distant shell beds can be reached.

Moving around on foot in the seaward side of mangal areas can be even more difficult, if not impossible. One reason for this is that the substrate underfoot is usually mud, sometimes very soft, another is that the long, aerial roots of *Rhizophora* are hazardous, slippery and difficult to clamber over or around. Small boat 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 constraints 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 for more than 20 generations and over ~500 years. The broad resource diversity, with rice and fish as dietary staples, allowed a more or less sedentary 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, probably 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 and stratigraphic data. The charcoals, seeds, rice and other plant remains described in this thesis have provided a sound basis for interpreting the vegetational history of the area. Moreover, with additional ethnobotanical understanding of coastal and freshwater swamp ecology, they have pointed to the critical importance of terrestrial resources, above all domestic rice, in an archaeological record dominated by aquatic remains.
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UNKNOWN CHARCOAL TYPES:
Non-Rhizophoraceae type

Amongst the Non-Rhizophoraceae charcoals, seven individual types were recognised 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.

Plate I.1

Type i: *cf. Lumnitzera* sp. Plates I.1.1-3
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. This type resembles reference material of *Lumnitzera* sp.

Plate I.1.1 Transverse section. Scale = 200 microns
Plate I.1.2 Tangential longitudinal section. Scale = 200 microns
Plate I.1.3 Radial longitudinal section. Scale = 200 microns

Type ii: Plates I.1.4-6
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. In this respect it resembles the wood of *Ficus benghalensis* but the reference material for this taxon has longer biseriate sections to its rays.

Plate I.1.4 Transverse section. Scale = 100 microns
Plate I.1.5 Tangential longitudinal section. Scale = 100 microns
Plate I.1.6 Radial longitudinal section. Scale = 100 microns
Type iii: Plates I.2.1-3
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.

Plate I.2.1 Transverse section. Scale = 200 microns
Plate I.2.2 Tangential longitudinal section. Scale = 200 microns
Plate I.2.3 Radial longitudinal section. Scale = 200 microns

Type iv: Plates I.2.4-6
Occurrence: 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 two to five 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.

Plate I.2.4 Transverse section. Scale = 100 microns
Plate I.2.5 Tangential longitudinal section. Scale = 100 microns
Plate I.2.6 Radial longitudinal section. Scale = 100 microns
Type v: Plates I.3.1-3
The Type 5 fragment illustrated is taken from 9:1, but this variety was also found in other Zone A samples eg. 10:16. 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.

Plate I.3.1 Transverse section. Scale = 200 microns
Plate I.3.2 Tangential longitudinal section. Scale = 200 microns
Plate I.3.3 Radial longitudinal section. Scale = 200 microns

Type vi: Plate I.3.4
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 6 is diffuse porous with sparse solitary pores. Its rays are heterogeneous, 8-10 cells tall and dominantly biseriate, with a few uniseriates and triseriates. In each case the tail cell to the ray is large and wide.

Plate I.3.4 Tangential longitudinal section. Scale = 200 microns

Type vii: Plates I.3.5-6
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.

Plate I.3.5 Transverse section. Scale = 100 microns
Plate I.3.6 Tangential longitudinal section. Scale = 100 microns
Appendix Two

UNIDENTIFIED SEED TYPES

Type i. Two tranversely broadly elliptic seeds from 10:20. Preservation poor: approximately 20% of the margin has broken away. Cross section transversely narrowly elliptic. Rounded margin. Dimensions: 0.75 x 0.90 x 0.50 mm 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 and the seed has a hollow (possibly damage rather than a structural feature) on one end. Dimensions: 0.65 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 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 flot sample from 2:3. This is morphologically similar to but larger than the seeds of Typha angustifolia, which also differs from this archaeological 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 cotyledon with mottled surface, possibly a distorted or fragmented example of a cf. Cyperaceae cotyledon. Occurrence: 10:20. Dimensions: 0.95 x 0.90 x 0.30 mm.
Type viii. Two circular seeds, one more globular than the other, having a rough surface. Dimensions: 0.55 x 0.55 x 0.40 mm (from 10:5) and 0.55 x 0.55 x 0.55 mm (from 10:18).

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.

Table II.1 Dimensions for unidentified type xi seeds

<table>
<thead>
<tr>
<th>Context</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
<th>Preservation</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:2</td>
<td>0.60</td>
<td>0.45</td>
<td>0.45</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>9:6</td>
<td>0.60</td>
<td>0.50</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9:6</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9:6</td>
<td>0.60</td>
<td>0.50</td>
<td>0.50</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>9:6</td>
<td>0.55</td>
<td>0.50</td>
<td>0.50</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

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 in 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. Condition: poorly preserved.
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 Caryophyllaceae, but neither *Agrostemma githago*, which is too large at 3 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.
This appendix 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 Southeast Asian, Pacific and Australian sources. Many plant uses are similar over a wide geographical area. The broad geographical scope is in part a reflection of the relatively limited ethnobotanical literature regarding mainland Southeast 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 Southeast Asia where grain crops have become dominant, but occupied a more minor part in a more diverse subsistence round in former times.

Some of the more detailed ethnobotanical accounts come from mangrove areas furthest from Thailand, the Andaman Islands, from northern Australia and parts of the Pacific, but for areas of mainland Southeast Asia there is sometimes information on long-established but outmoded wild plant use 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, are 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 these were used in small quantities, are probably undetectable in the archaeological record by current analytical techniques, and very numerous, they are excluded from the appendix.
The principal difficulty in using this database for archaeobotanical purposes is that the sources are insufficiently detailed to provide guidance on how a useful parts of a plant are prepared and consumed, as food for example, and to indicate therefore, the degree and manner of its 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. These kinds of information are 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 here cannot remedy that, but aims to provide a starting point for examining the wide variety of reasons for plant use in a mangrove-based community.

Note: Where a plant has food uses these are given as a second entry in the table

<table>
<thead>
<tr>
<th>TAXON</th>
<th>USE</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acrostichum aureum</em></td>
<td>Dried fronds are used for roof thatching. Burns rapidly with little ash (Annam).</td>
<td>Burkill (1966:41)</td>
</tr>
<tr>
<td><em>Acrostichum aureum</em></td>
<td>Fiddleheads &amp; young leaves are edible.</td>
<td>FAO (1985:36)</td>
</tr>
<tr>
<td></td>
<td>The young red leaf-tips are eaten (Thailand).</td>
<td>Dy Phon (1982:158)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Burkill (1966:41)</td>
</tr>
<tr>
<td><em>Aegialites</em> sp.</td>
<td>The wood produces a little tannin.</td>
<td>Burkill (1966:54)</td>
</tr>
<tr>
<td></td>
<td>Salt is extracted from burnt wood.</td>
<td>Chapman (1976:379)</td>
</tr>
<tr>
<td><em>Aegialites rotundifolia</em></td>
<td>Honey from this tree is highly valued, &amp; collected at end of the dry season (Andamans).</td>
<td>Blasco (1975:161)</td>
</tr>
<tr>
<td><em>Aegiceras</em> sp.</td>
<td>Firewood, but inferior to other mangroves. Bark is a fish poison. Seeds contain saponin. Used for charcoal production, especially when firewoods are in short supply (Indonesia).</td>
<td>Burkill (1966:54-5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FAO (1985:36)</td>
</tr>
<tr>
<td><em>Aegiceras</em> sp.</td>
<td>Leaves formerly eaten, raw or cooked (Moluccas).</td>
<td>Burkill (1966:54-5)</td>
</tr>
<tr>
<td><strong>Sp.</strong></td>
<td><strong>Description</strong></td>
<td><strong>References</strong></td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td><em>Amoora cucullata</em></td>
<td>Wood used for posts &amp; firewood. Some tannin in the trunk bark.</td>
<td>Burkill (1966:139)</td>
</tr>
<tr>
<td><em>Ardisia littoralis</em></td>
<td>The young shoots are eaten.</td>
<td>Burkill (1966:221)</td>
</tr>
<tr>
<td><em>A. marina</em></td>
<td>The fruits are eaten. The young leaves are used as a vegetable. Leaves used to flavour mussel meat when this is cooked in an earth oven (Groote Eylandt, N. Australia).</td>
<td>Lear &amp; Turner (1977) FAO (1985:36) Levitt (1981:84)</td>
</tr>
</tbody>
</table>
Fruits not eaten on Groote Eylandt but consumed on Roper River (on the mainland) & by the Borroloola people of Arnhem Land. Fruits are soaked in water for 3 nights first, then either wrapped in bark & baked or baked in an earth oven.

The fruits were once roasted on hot ashed but this was clearly only when other foods were in short supply.

**A. nitida**

- Sweetmeats made from propagules.
- Sweet-smelling honey is produced from the flowers of this tree.

**A. officinalis**

- Seeds & seedlings edible, & good honey from this tree. Salt is extracted from the wood ash.
- "Vegetables"
- The flowers are sometimes chewed (India).

**Barringtonia asiatica**

- Pulped seeds & bark (containing saponins) are thrown into rivers for fish poison.

**B. racemosa**

- Fruits used to poison wild pigs (Philippines).
- Seeds yield an oil which should be good for illumination.

**Barringtonia asiatica**

- Cooked pods eaten in Indo-China, though cooking must be long enough to remove the poisonous saponin.

**B. edulis**

- The seeds are edible.

**B. racemosa**

- Young leaves eaten raw.
- The Sakai pound the fruits, which are washed with water; the starch is allowed to settle, then made into cakes.

**Bruguiera spp.**

- An adhesive is made from the bark.
- This is a very hard wood, used for the interior ribs in boats.
- The wood is used in temporary construction as well as for firewood & charcoal.

**B. conjugata**

- The tannin is good for preserving fishing-nets. Malays sometimes use the wood for piling, house-posts & rafters.
- Good for charcoal production.
- Bark used as a dye (black, orange-reds, brown & violet).
<table>
<thead>
<tr>
<th>Species</th>
<th>Description</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>B. cylindrica</em></td>
<td>Fishermen say that the wood has a peculiar odour which frightens away fish; many do not like to use it for making fish-traps (peninsular Malaysia).</td>
<td>Burkill (1966:378)</td>
</tr>
<tr>
<td><em>B. parviflora</em></td>
<td>Inferior firewood, but this is its primary use. Wood also used for making fish-traps &amp; fishing stakes, though some fishermen complain about the smell from the wood frightening the fish.</td>
<td>Burkill (1966:378) Specht (1958:495) Bird (1986:73)</td>
</tr>
<tr>
<td><em>B. rheedii</em></td>
<td>Wood hard &amp; durable. Aerial roots used for making bows (Fiji)</td>
<td>Seeman (191865-73, [1974:92)</td>
</tr>
<tr>
<td><em>B. conjugata</em></td>
<td>&quot;Fruits&quot; sometimes used as an astringent in betel-quid. Fruits also eaten, but not when anything better is available. In Annam, fruit given two boilings. Leaves served raw as a flavouring. The bark is sometimes used to flavour a preparation of raw fish, but eating much is dangerous (Indonesia).</td>
<td>Burkill (1966:377) citing Rumphius</td>
</tr>
<tr>
<td><em>B. cylindrica</em></td>
<td>Young radicles are occasionally eaten after being boiled or preserved.</td>
<td>Burkill (1966:378)</td>
</tr>
<tr>
<td><em>B. eriopetala</em></td>
<td>Radicle peeled, sliced, soaked in water for several days, then steamed, boiled or eaten with coconut cream (Papua New Guinea, Solomons, New Caledonia &amp; other places throughout the Pacific).</td>
<td>Barrau (1959:162)</td>
</tr>
<tr>
<td>Species</td>
<td>Description</td>
<td>Source</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>B. gymnorrhiza</td>
<td>The radicles are eaten as &quot;famine&quot; food in Queensland. and used for food in Cape York. Radicles used as a staple food in Torres Strait Islands &amp; southern coastal Papua New Guinea. Radicles used as vegetables (Indonesia). The fruit is chewed as a betel substitute.</td>
<td>Hale &amp; Tindale (1933:115) Flecker et al. (1948:12) Golson (1971:203) citing Roth (1901) Harris (1977:432, 1979:94) FAO (1985:36)</td>
</tr>
<tr>
<td>B. parviflora</td>
<td>The fruits are eaten. Malays sometimes use the germinating embryo as a vegetable.</td>
<td>Specht (1958:495) Burkill (1966:379)</td>
</tr>
<tr>
<td>B. reedii</td>
<td>Fiji: &quot;fruits&quot; made into &quot;bread&quot; in times of scarcity &amp; radicles &quot;of the other mangroves also eaten, but at best it must be but poor food&quot; Hypocotyls consumed in Cape York (N. Australia)</td>
<td>Seeman (1918:65-73) [1974:92] Golson (1971:203) citing Roth (1901)</td>
</tr>
<tr>
<td>B. rumphii</td>
<td>The leaves are eaten in New Caledonia.</td>
<td>Rollet (1975a:205)</td>
</tr>
<tr>
<td>B. sexangula</td>
<td>Fruits sometimes used as a masticatory. In Sulawesi the embryo is cooked, soaked all night &amp; then eaten. Condiments are made from the bark.</td>
<td>Burkill (1966:379)</td>
</tr>
<tr>
<td>Camptostemon spp.</td>
<td>This soft, light wood is used for making floats for harpoons (N. Australia)</td>
<td>Bird (1986:73)</td>
</tr>
<tr>
<td>Carallia brachiata</td>
<td>&quot;The fruit, which ripens towards the end of the dry season, is edible.&quot; The ripe fruits are eaten raw. Small black berry, ripens in December. An unimportant source of food because berries are rather small. These reddish fruits have &quot;scanty edible pulp&quot;.</td>
<td>Specht (1958:495) Levitt (1981:119,133) Singh &amp; Arora (1978:53)</td>
</tr>
<tr>
<td>Ceratopteris thalictroides</td>
<td>The young fronds of this aquatic fern are blanched and eaten with a spicy sauce (Thailand).</td>
<td>Jacquat &amp; Bertossa (1990:17)</td>
</tr>
<tr>
<td>Cerbera manghas</td>
<td>Wood gives a fine charcoal. Seeds contain oil: they are sun-dried &amp;</td>
<td>Burkill (1966:520-1)</td>
</tr>
</tbody>
</table>
pressed to remove oil. This is used for illumination, but the smoke is intolerable & the oil dangerous because of the poisons removed from the seeds at the same time. Seeds used in Philippines for stupifying fish in small streams.

The wood was used in eighteenth century Thailand for making gunpowder.

<table>
<thead>
<tr>
<th><strong>Ceriops tagal</strong></th>
<th>Bent branches used as knees for boats &amp; trunks for house-building; this is the most durable of mangrove woods. Very high fuel-value. Excellent for tanning. Malas use bark for toughening fishing lines. The bark is used for dye (black, purple, brown &amp; yellowish-red). This is said to make the best tannin; used for colouring clothes in coastal Kampuchea. Wood used for temporary construction, firewood &amp; charcoal. This bark yields the best tannin.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>Ceriops decandra</strong></th>
<th>Honey.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C. tagal</strong></td>
<td>The Andamanese sometimes eat the fruit. The hypocotyls are eaten in Cape York (N. Australia). Tea substitutes.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Cordia cochinchinensis</strong></th>
<th>The sap around the seeds can be used for glue (Thailand).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aksornkoae &amp; Panichsuko (n.d.:101)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Cycas rumphii</strong></th>
<th>Large seeds poisonous fresh but processed flour is eaten (pounded, soaked in repeatedly changed water). May be dried for later use. Very young, uncurled leaves eaten as a vegetable by peninsular Malays. Sago may be made from the trunk. Starch obtained from the trunk &amp; young leaves are eaten as a potherb (peninsular Malaysia). Seeds poison if eaten raw but can be eaten cooked (Thailand).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant/Species</td>
<td>Description/Uses</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><em>Derris</em> sp.</td>
<td>Fish poison made from the roots &amp; a similar preparation as an abortifacient.</td>
</tr>
<tr>
<td><em>Diospyros</em> sp.</td>
<td>Some species have poisonous properties. Used for stupifying fish; dyes made from immature fruits.</td>
</tr>
<tr>
<td><em>Dolichandrone spathacea</em></td>
<td>Wood is light, so Javanese fishermen use this for floats for nets. A blackish fibre is made from the bark.</td>
</tr>
<tr>
<td><em>Enhalus acoroides</em></td>
<td>This sublittoral seagrass leaves behind a durable fibre once it has become rotten and this is used for making fishing nets (peninsular Malaysia).</td>
</tr>
<tr>
<td><em>Enhalus acoroides</em></td>
<td>This sublittoral seagrass has edible fruits, which can be eaten raw but are better cooked (Malay Peninsula).</td>
</tr>
<tr>
<td><em>Excoecaria agallocha</em></td>
<td>The sap from the wood is renowned for its irritant effect on skin &amp; for blinding, if it splashes in the eye. Careful removal of the bark before cutting the tree can prevent this though &amp; the wood can then used for firewood or charcoal. The latex is used as a fish poison or dart poison (India &amp; Indonesia). Timber for firewood, boxes &amp; matchwood (Indonesia).</td>
</tr>
<tr>
<td><em>Excoecaria agallocha</em></td>
<td>Condiments are made from the bark. Honey.</td>
</tr>
<tr>
<td><em>Flagellaria indica</em></td>
<td>Stems used for basketwork (peninsular Malaysia). The split stems are used for binding roofing panels made from <em>Nypa</em> leaves (Thailand). The stems are split into four, softened by soaking in water &amp; used to sew bark bowls, to join the halves of the dress-barks worn by the women &amp; woven into bracelets. Thicker stems (about 1.5 cm diameter) are split &amp; softened in the same way &amp; used to sew the ends of bark canoes (Groote Eyland, N. Australia).</td>
</tr>
<tr>
<td><em>Flagellaria indica</em></td>
<td>The stem &amp; fruit are eaten by the Shompen of Great Nicobar Island.</td>
</tr>
<tr>
<td>Plant Name</td>
<td>Description</td>
</tr>
<tr>
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</tr>
<tr>
<td><em>Ficus spp.</em></td>
<td>Bark is very fibrous &amp; made into rough twine. Some species used formerly for making clothing (eg. among Pangan of Malaysia.)</td>
</tr>
<tr>
<td><em>F. microcarpa</em></td>
<td>Fibres from the bark were used to make fishing nets and cordage.</td>
</tr>
<tr>
<td><em>Glochidion littorale</em></td>
<td>Too little wood in stem for timber.</td>
</tr>
<tr>
<td><em>Guettarda speciosa</em></td>
<td>&quot;The large leaves are ideal to use as plates or to wrap around dampers before baking them in hot sand. The wood may be used as a fire-making tool&quot; (N. Australia).</td>
</tr>
<tr>
<td><em>Heritiera littoralis</em></td>
<td>A tough &amp; durable timber. Twigs are used for toothbrushes.</td>
</tr>
<tr>
<td></td>
<td>The timber is recommended for boat-building.</td>
</tr>
<tr>
<td></td>
<td>Teredo-resistant woods used for piling (Philippines).</td>
</tr>
<tr>
<td></td>
<td>Corner posts for houses (Philippines).</td>
</tr>
<tr>
<td><em>Heritiera littoralis</em></td>
<td>Seeds eaten with fish when seeds of <em>Parinarium glaberrimum</em>, which are preferred, cannot be obtained.</td>
</tr>
<tr>
<td></td>
<td>Seeds are eaten with fish (Papua New Guinea).</td>
</tr>
<tr>
<td><em>Hibiscus tiliaceus</em></td>
<td>One of the most important fibre-making plants in Malaysia. Used for cordage &amp; for caulking boats and making nets, fishing lines &amp; coarse bags. A light timber; sometimes used for floats. Resistant to moisture; supports for houses.</td>
</tr>
<tr>
<td></td>
<td>N. Australia: wood used for spearthrowers &amp; sometimes for the shafts of fish spears &amp; other spears requiring light shafts. Flat sticks used as splints for broken fingers &amp; strips of inner bark to bind the splints for broken bones in place. Firesticks were made from the wood.</td>
</tr>
<tr>
<td></td>
<td>The inner bark used to make rope.</td>
</tr>
<tr>
<td></td>
<td>Very rarely, in some parts of Malaysia, youngest leaves may be eaten as an addition to human food.</td>
</tr>
<tr>
<td></td>
<td>The inner bark may be eaten</td>
</tr>
<tr>
<td>Species</td>
<td>Details</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Intsia spp.</strong></td>
<td>The bark produces a durable yellow-brown dye used for colouring mats &amp; fabric.</td>
</tr>
<tr>
<td></td>
<td>This is a good timber for boat keels &amp; frames.</td>
</tr>
<tr>
<td><strong>Intsia retusa</strong></td>
<td>The fruits are poisonous but when heated, shelled &amp; soaked in water for 3-4 days, they serve as famine food in E. Malaysia.</td>
</tr>
<tr>
<td><strong>Lumnitzera coccinea</strong></td>
<td>Timber hard &amp; durable; used as firewood.</td>
</tr>
<tr>
<td><strong>L. racemosa</strong></td>
<td>Timber less useful than <em>L. coccinea</em>. Bark can be used for tanning. Firewood: &quot;lights quickly but burns slowly, keeping alight all day, &amp; generates much heat. The flames are difficult to douse, so this wood is valued for fires in very wet weather such as during cyclones. Wood sometimes used for making firesticks. A good source of nectar for wild bees. Wood used for fighting spears&quot; (Groote Eyland, N. Australia).</td>
</tr>
<tr>
<td><strong>Lumnitzera racemosa</strong></td>
<td>The leaves are eaten as a vegetable in Melanesia &amp; other Pacific islands.</td>
</tr>
<tr>
<td><strong>L. coccinea</strong></td>
<td>The leaves are eaten in India.</td>
</tr>
<tr>
<td><strong>Lygodium spp.</strong></td>
<td>A climbing fern which is used in basketry (Thailand).</td>
</tr>
<tr>
<td><strong>Lygodium sp.</strong></td>
<td>The young leaves are boiled/steamed and eaten (Thailand).</td>
</tr>
<tr>
<td><strong>Melaleuca leucadendra</strong></td>
<td>Timber durable in contact with sea water, so useful for posts, piles &amp; ship-building. It burns well. Bark seals the seam in boats &amp; with dammar is made into torches.</td>
</tr>
</tbody>
</table>
The wood is also used as floats for fishing nets.

Cajeput oil is made from the leaves. Foxworthy (1922:172)

Teredo-resistant woods for piling (Malay Peninsula). Foxworthy (1909:418)

Used for boat hulls (Maluku). "The bark swells when moistened by seawater so used as caulking."

Groote Eylanders use the bark to make waterproof shelters. Thinner pieces of bark used to wrap items to be carried. Ellen (1988:580,581)

<table>
<thead>
<tr>
<th>Melaleuca leucadendra</th>
<th>Young leaves are consumed cooked (everyday food - not famine food) (Cambodia). Dy Phon (1982:162)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nypa fruticans</td>
<td>Thatching material for roofs of houses or boats (Sea-gypsies). Baskets, bags, mats etc.</td>
</tr>
<tr>
<td></td>
<td>Leaves used as wrappers for dammar torches.</td>
</tr>
<tr>
<td></td>
<td>Young leaves for cigarette papers.</td>
</tr>
<tr>
<td></td>
<td>Leaf stalks burned as fuel.</td>
</tr>
<tr>
<td></td>
<td>Arrows made from petioles (Mentawi Islands).</td>
</tr>
<tr>
<td></td>
<td>Sap from inflorescence made into sugar, vinegar &amp; alcohol (toddy).</td>
</tr>
<tr>
<td></td>
<td>Submerged leaves are used as a fish lure.</td>
</tr>
<tr>
<td></td>
<td>The leaves are converted into brooms, palm-leaf raincoats and matting. The leaves are made</td>
</tr>
<tr>
<td></td>
<td>into panels of roofing and the petioles as rafters to support them (Indonesia &amp; widely in</td>
</tr>
<tr>
<td></td>
<td>Thailand too).</td>
</tr>
<tr>
<td></td>
<td>Salt is sometimes extracted from the ashes of the roots.</td>
</tr>
</tbody>
</table>

| Nypa fruticans        | Young inner part boiled with syrup made from the fruit. Sap used for sugar, alcohol & vinegar. | Phengklai (1985:206)                |
|                       | Young seeds are edible, as is the bud of the stem.                                              | FAO (1985:37) & Burkill (1966:1586) see Davis (1988) for details and further references |
|                       | The "albumen" of the young fruit is eaten.                                                      | Koenig (1894a)                                                                 |
|                       | The burnt leaves yield salt.                                                                  | Foxworthy (1922:159)                                                             |
| Oncosperma tigillaria | Wood is very hard & durable with great elasticity. Used in deeply planted fishing stakes.     | Burkill (1966:1608)                                                              |
|                       |                                                                                               | Foxworthy (1922:160)                                                            |
Spines studding the stem are used as blowpipe darts & as the head of javelins when spearing fish. Sheaths of flowers commonly serve as buckets & as containers for boiling water. Baskets are made from the leaves (Annam).

Poles used as piles to support riverside housing (peninsular Malaysia, Indonesia).

**Oncosperma tigillaria**

The flower is added to rice & the fleshy fruit & terminal buds are used as vegetables & in salads.

Cambodia: everyday not famine food

The "cabbage" is excellent.

Flowers used for flavouring rice.

Small, flat, pulpy fruits made into a preserve or chewed as a betel-substitute.

**Pandanus odoratissimus**

Leaves cooked with rice to impart the smell of new rice.

**Peltophorum pterocarpum**

Timber good for boat-building.

Bark used for a yellow-brown dye (Java).

Cattle will eat the leaves.

**Pemphis acidula**

Wood is very hard, used for anchors, treenails, pestles, etc. & for fuel.

"The branches were used to make digging-sticks (namanjirrija). Branches us to 3 cm in diameter were cut, the bark was peeled off & one end, usually the thinner end, was sharpened. The finished product was a slender, straight, pointed stick about 1 m long, sometimes shorter. Digging-sticks were used to loosen the earth when digging for yams & other root vegetables. The loosened earth was then scraped out with the hands. Digging-sticks were sometimes used for spearing mud crabs."

also described by Specht (1958:495)

**Pemphis acidula**

Its acid leaves may be eaten raw.

**Phoenix paludosa**

Young inner parts of upper stem boiled/steamed & eaten as a vegetable or in soup.

The terminal shoots or the "cabbage" are eaten as everyday rather than famine food.

"The pith is edible & the Siamese are said to eat its fruit in curries."

Chan (1986:50)

FAO (1985:37)

Chapman (1976:379)

Dy Phon (1982:160)

Foxworthy (1922:160)

Burkill (1966:1608.)

Lugod & Padua (1979:62)

Burkill (1966:1716)

Burkill (1966:1716)

Levitt (1981:98)

Burkill (1966:1743)

Phengklai (1985:206)

Dy Phon (1982:160)
The fruits (called sea dates) are edible (India).

<table>
<thead>
<tr>
<th>Species</th>
<th>Uses</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pluchea indica</em></td>
<td>&quot;légume des dieux&quot; The young shoots are everyday food - not famine food (Cambodia).</td>
<td>Dy Phon (1982:160)</td>
</tr>
<tr>
<td></td>
<td>Leaves are eaten as flavourings (Thailand &amp; Java).</td>
<td>Burkill (1966:804)</td>
</tr>
<tr>
<td><em>Premna integrifolia</em></td>
<td>Leaves sometimes cooked with fish of an objectionable flavour to mask the taste.</td>
<td>Burkill (1966:1838)</td>
</tr>
<tr>
<td></td>
<td>W. Indian fishermen have always rubbed their fishing lines with the cut end of, or pulled them through a groove in a hypocotyl &amp; soaked their nets in the red liquid from boiled hypocotyls. Sap applied as a red hair dye by the women of Fiji. The sap is also mixed with sap from <em>Hibiscus moschatus</em> &amp; used by potters as an external application to pottery immediately after firing. The aerial roots are elastic &amp; used for making bows.</td>
<td>Morton (1965:115) citing various other authors Seeman (1918:65-73) [1974:91]</td>
</tr>
</tbody>
</table>
| *R. mangle*              | The water in which red mangrove fruits are steeped & allowed to ferment is a popular beverage in Brazil & Venezuela. W. Indies & Mexico: starchy interior of fruit & hypocotyl eaten in times of famine. | Morton (1965:118) Morton (1965:117)
<table>
<thead>
<tr>
<th>Species</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>R. mucronata</td>
<td>&quot;Fruits&quot; sometimes eaten in the Andaman Islands, where the outside is scraped off before they are eaten. Boiling with wood ashes is said to make the preparation less unpalatable.</td>
<td>Burkill (1966:1935) &amp; citing Man (1885:127) citing Brown (1922:447)</td>
</tr>
<tr>
<td>Sarcolobus globosus</td>
<td>The seeds of this climber are very poisonous, but their mesocarp may be eaten once it has been cooked (Thailand).</td>
<td>Chewalit Niyomdham (pers. comm.)</td>
</tr>
<tr>
<td>Sapium indicum</td>
<td>The chief use is as a dye (yellow-green &amp; black). The pounded fruits are thrown into the water to kill fish.</td>
<td>Burkill (1966:1995)</td>
</tr>
<tr>
<td>Sapium indicum</td>
<td>Seeds can be eaten when quite ripe, but care should be taken to put nothing more than the seed into the mouth, as the latex in the fruit-wall is caustic.</td>
<td>Burkill (1966:1996)</td>
</tr>
<tr>
<td>Scaevola taccada</td>
<td>The leaves are eaten (India).</td>
<td>Singh &amp; Arora (1978:37)</td>
</tr>
<tr>
<td>Sonneratia spp.</td>
<td>Pneumatophores converted to corks by shaping them &amp; boiling them in water (Borneo, Ceylon, Thailand). Also used as floats. Wood has high ash content. High calorific value but inferior to &quot;true mangrove&quot;.</td>
<td>Burkill (1966:2089)</td>
</tr>
<tr>
<td></td>
<td>Branches used in making fishtraps &amp; as firewood.</td>
<td>Vu Van Cuong (1965:201)</td>
</tr>
<tr>
<td></td>
<td>Teredo-resistant woods for piling (Philippines). Roots have a fine structure, so are used for corking &amp; as floats for fishing nets.</td>
<td>Foxworthy (1909:418)</td>
</tr>
<tr>
<td></td>
<td>&quot;Sea-water resistant, does not split or burst.&quot;</td>
<td>Ellen (1985:581)</td>
</tr>
</tbody>
</table>
Ideal rib & knee timber."

<table>
<thead>
<tr>
<th>Species</th>
<th>Description</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S. alba</strong></td>
<td>Timber used as firewood but not chosen when other types are available. Some tannin in the bark.</td>
<td>Burkill (1966:2088)</td>
</tr>
<tr>
<td></td>
<td>Pneumatophores as fishing floats. Wood used as tinder during the conversion of <em>Rhizophora</em> to charcoal &amp; for making boxes.</td>
<td>Chapman (1976:379); Vu Van Cuong (1965:199)</td>
</tr>
<tr>
<td></td>
<td>Leaves for cattle food (Indonesia).</td>
<td>FAO (1985:37)</td>
</tr>
<tr>
<td><strong>S. caseolaris</strong></td>
<td>Leaves for goat fodder.</td>
<td>FAO (1985:37)</td>
</tr>
<tr>
<td><strong>S. griffithii</strong></td>
<td>Wood resistant to teredo attack. Large posts used for supporting quays, but iron spikes, nails &amp; bolts are soon rusted by the wood's high salt content.</td>
<td>Burkill (1966:2090); MacNae (1968:234)</td>
</tr>
<tr>
<td><strong>Sonneratia</strong> spp.</td>
<td>P.N.G.: the fruits are edible. The fruits were gathered for food in eighteenth century Thailand. These fruits are also attractive to monkeys.</td>
<td>Percival &amp; Womersley (1975:29); Koenig (1894a:127)</td>
</tr>
<tr>
<td><strong>S. acida</strong></td>
<td>Fruit slightly acid; used for food &amp; making vinegar.</td>
<td>Brown (1958:43)</td>
</tr>
<tr>
<td><strong>S. alba</strong></td>
<td>Fruit eaten when quite ripe (Malaysia &amp; Java) &amp; as a flavouring for fish (Maluku). The leaves may be eaten raw or cooked.</td>
<td>Burkill (1966:2088); citing Ridley (1902)</td>
</tr>
<tr>
<td><strong>S. caseolaris</strong></td>
<td>The fruit are edible (Indonesia). &quot;The fruits are acidic.&quot; The young fruit are sour &amp; used for flavouring chutnies &amp; curries. Ripe fruits have cheese-like taste &amp; are eaten raw or cooked.</td>
<td>FAO (1985:37); Singh &amp; Arora (1978:72); Burkill (1966:2089)</td>
</tr>
<tr>
<td></td>
<td>Cooked leaves are eaten, sometimes in a &quot;potage aux poissons&quot; (Vietnam, Cambodia &amp; Laos).</td>
<td>Vu Van Cuong (1965:210)</td>
</tr>
<tr>
<td><strong>S. griffithii</strong></td>
<td>The fruits are very acid. Sometimes used for making vinegar.</td>
<td>Burkill (1966:2090); citing Foxworthy (1922:213)</td>
</tr>
<tr>
<td><strong>S. ovata</strong></td>
<td>Fruits eaten as a raw vegetable (Thailand). The fruit are edible (Indonesia).</td>
<td>Phengklai (1985:206); FAO (1985:37)</td>
</tr>
<tr>
<td>---------------------</td>
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<td>--------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Fleshy leaves eaten as a vegetable (India).</td>
<td>Singh &amp; Arora (1978:38)</td>
</tr>
<tr>
<td><strong>Thespesia populnea</strong></td>
<td>Fibrous bark used for caulking boats &amp; making cordage. Also made into fishing lines.</td>
<td>Burkhill (1966:2192) Crevost &amp; Lemarie (1919:684)</td>
</tr>
<tr>
<td></td>
<td>Tannin in the bark &amp; wood. Timber is hard &amp; almost indestructible underwater. The wood is better than <em>Hibiscus tiliaceus</em> but fibre inferior (peninsular Malaysia).</td>
<td>Foxworthy (1922:198)</td>
</tr>
<tr>
<td></td>
<td>Wood renowned for being almost indestructable underwater (Fiji).</td>
<td>Seeman (1918:65-73) [1974:19]</td>
</tr>
<tr>
<td></td>
<td>Wood used to make spear shafts for spears requiring light shafts, such as those used for fishing, but as this is heavier than <em>Hibiscus tiliaceus</em>, used only when well dried. It was too heavy for use with stone-headed spears. Leaves sometimes used as plates for cooked fish (Groote Eyland, N. Australia).</td>
<td>Levitt (1981:100)</td>
</tr>
<tr>
<td><strong>Thespesia populnea</strong></td>
<td>The leaves are eaten by the Shompen of the Great Nicobar Islands.</td>
<td>Rao (1984:89)</td>
</tr>
<tr>
<td><strong>Trianthema portulacastrum</strong> (=<em>Sesuvium portulacastrum</em>)</td>
<td>The green leaves of this herb are eaten (India).</td>
<td>Das (1960) Christensen (1983:8)</td>
</tr>
<tr>
<td><strong>Tupistra grandisis</strong></td>
<td>An edible succulent herb.</td>
<td>Phengkhai (1985:206-7)</td>
</tr>
<tr>
<td></td>
<td>Teredo-resistant woods for piling (Philippines).</td>
<td>Foxworthy (1909:418)</td>
</tr>
<tr>
<td><strong>X. moluccensis</strong></td>
<td>High calorific value. Bark is used for tanning &amp; for toughening fishing nets (Java). The bark produces dyes of umber colour &amp; is included in poisons (Maluku). Highly valued timber for furniture making. Oil from seed used as an illuminant &amp; as hair oil (peninsular Malaysia).</td>
<td>FAO (1985:37) Foxworthy (1922:171) Chapman (1976:379)</td>
</tr>
</tbody>
</table>