Was Medieval Sawankhalok like Modern Bangkok, Flooded Every Few Years but an Economic Powerhouse Nonetheless?

▲ • ▲ • ▲

PAUL BISHOP, DONALD HEIN, AND DAVID GODLEY

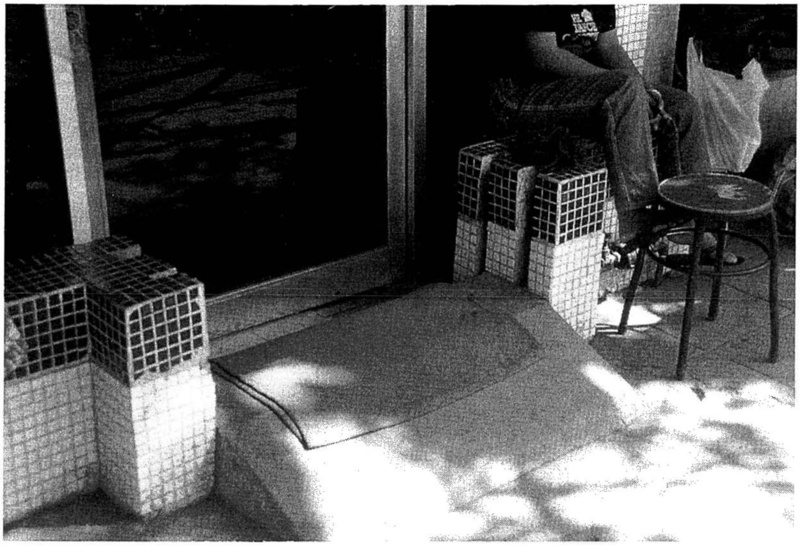
> The shape of . . . the drainage system of each landscape would invite or limit or prohibit human agency when history began. For no matter if human settlers were few and subsisted in relative harmony with the rest of nature, or were many and obliged to harvest extensively, no matter if they were animistic or Judeo-Christian, passive or entrepreneurial, technologically primitive or sophisticated—morphology and climate, and drainage most of all, would direct them.
>
> —Jack Temple Kirby, *Poquosin: A Study of Rural Landscape and Society* (University of North Carolina Press, 1995)

HEAVY MONSOONAL RAIN in Bangkok results in the ponding of water to depths of a meter or more in low-lying parts of the city, threatening commerce and other business activities and inconveniencing daily life in general (Pl. I). This flooding is caused by several interacting factors, including the heavy monsoonal rains themselves, rapid and efficient runoff from a sealed, highly urbanized catchment area, and ground subsidence due to groundwater extraction (Prinya and Rau 1981; ESCAP Secretariat 1988). High-capacity pumps are required to pump the flood waters to the Chao Phraya river, which often involves lifting the water up to the elevated water levels of the Chao Phraya, itself in flood. These problems notwithstanding, however, Bangkok life continues, albeit amid repeated calls for changes to be made and promises that they will be.

The reasons for this persistence of Bangkok in its present location are, of course, complex and multifaceted. The site was originally chosen, in part, for its defensibility, and the annual flooding was a critically important element in this, just as it had been for Ayutthaya (Sumet 1988 : 167). Strategies of attack and defense of Ayutthaya were timed in relation to the arrival of the annual flood (Phra

Paul Bishop is an associate professor in the Department of Geography and Environmental Science at Monash University, in Clayton, Victoria, Australia.
Donald Hein is a master's student in the Department of History, Monash University, Clayton, Victoria, Australia.
David Godley is a master's student in the Department of Geography and Environmental Science, Monash University, Clayton, Victoria, Australia.

Asian Perspectives, Vol. 35, No. 2, © 1996 by University of Hawai'i Press.



Pl. I. A shop doorway in Sukhumvit Road, Bangkok, incorporating a structure for flood protection. A barrier is fitted into the slots to keep flood waters out of the door of the shop.

Praison Salarak 1956), thereby saving the city, at least for a short period. The Bangkok urban center has grown enormously since its original founding, and the associated development of considerable infrastructure means that simple inertia must now be a powerful factor in the city's persistence.

More subtle factors may also be operating to explain the tolerance of Bangkok's regular flooding. Sumet Jumsai, the prominent Thai architect and principal source of the viewpoint that Thais are fundamentally an aquatic society, has suggested (Sumet 1988 : 172):

> Every year, as water takes over the roads and the city is paralysed, children become suddenly full of life and joy. . . . [O]ld folks tend to their amphibious gardens with potted plants raised on wooden planks or *chan-ban* high above the flood level. In the dense traffic of Bangkok, lorry drivers manipulate their "craft" in a carefree manner, trusting that the *mae-yanang* [colored cloth and flowers traditionally attached to the bows of boats] which they attach above their steering wheels will give them safe passage across the timeless waters.

Sumet's interpretation suggests that the tolerance of annual flooding reflects the notion that the Thais constitute an "aquatic" society, with primordial memories of, and affinities for, a water-based lifestyle. Van Beek (1994) would probably characterize this attitude not so much as tolerance but as resignation, but the essential point remains the same.

Even if Thai society is founded on an aquatic character, which explains Bangkok's tolerance of flooding, such an interpretation is patently inadequate to explain the apparent general lack of impact of physical environmental factors in other modern Asian "supercities," as Sumet (1988) calls them. Flash flooding in Singapore, a second Asian supercity of major economic importance and considerable complexity, is inconvenient but does not threaten the city's social or economic fabric. Storms and flooding are handled with increasingly sophisticated engineering solutions, which means that, even though evacuation of people from homes and damage to property still occur from time to time, these responses are much less frequent and of a lower magnitude than they have been in the past (Gupta 1992*a*). Drainage works are now of sufficient capacity and complexity to handle virtually all floods: "Rainwater in Singapore travels almost exclusively on a concrete path to the sea" (Gupta 1992*a*: 317). Moreover, future increases in flooding caused by ongoing urbanization of the island will evidently be efficiently handled by further engineering works so that Singaporeans will not be seriously inconvenienced by flood waters (Gupta 1992*a*, 1992*b*).

A third example of the impacts of extreme physical environmental events on a major Asian urban center is provided by the typhoons and the associated rain and winds that are a feature of the physical environment of Hong Kong, an Asian supercity of probably greater sophistication and complexity than Bangkok. These typhoons are taken very seriously, but their impacts are evidently decreasing with time, as geotechnical advances and increasingly sophisticated transportation, communication, and warning systems enable rapid and efficient responses to typhoon warnings. A recent compilation of the impacts of Hong Kong typhoons since 1937, when more than 11,000 people were killed and 2000 junks destroyed, shows a clear decline in typhoon-related deaths and injuries over the last 60 years (*Hongkong Standard,* 1 September 1995 : 3).

The question therefore arises: what is the impact, if any, of physical environmental factors in the great Asian cities? Our suspicion that the role is minimal prompts the further question: what role did the physical environment play in the development of early urban centers and protocities? Tradition and the famous Inscription #1 tell us, for example, that the glory of thirteenth-century Sukhothai, the capital of the first supposed unified Thai kingdom, was founded on the bounty of the physical environment:

> In the time of Ramkamhaeng this land of Sukhothai is thriving.
> There are fish in the water and rice in the fields. (Chulalongkorn University 1984 : 40)

Despite recent questioning of the conventional attribution of this inscription to the legendary thirteenth-century King Ramkhamhaeng (Chamberlain 1991)—and, indeed, there are uncertainties about many aspects of the traditionally accepted interpretations of Thai history, especially as related to the Sukhothai era (e.g., Vickery 1990; Piriya 1993)—Inscription #1 nonetheless embodies a tradition that Sukhothai and its great ruler were closely tied to, and dependent upon, the physical environment, a point of view not too dissimilar to that presented by Ng (1979).

The more economically "developed" is the society under consideration, however, the less likely is the physical environment to be incorporated as a critical factor in an understanding of the development and life of the city. Rather, economic and sociopolitical arguments evidently carry more weight in considerations of social change and development of an urban center subsequent to its initial founding. This is neatly illustrated in Section II of the proceedings of the Siam Society symposium on Culture and Environment in Thailand (Siam Society 1989). Anderson's (1989: 119) discussion of prehistoric human adaptations in Thailand concludes thus:

> During the Pleistocene, man-habitat relationships changed slowly, influenced primarily by long-term climatic changes in which man himself played little active role. When man began to produce food through agriculture, he became an active agent in his relationship with the environment.... As populations increased and became more settled, man increasingly dominated the relationship, until now it seems as if climate plays a minor role.

Higham's (1989) discussion of the rise and expansion of domestic communities in Southeast Asia has elements of the same viewpoint. Physical environmental conditions were important in the development of early hunter-gatherer societies adjacent to ready food and water supplies and in the emergence and expansion of domestic communities on favorable coastal, marshland, and riverine sites (see Higham 1989: 185, for example). Rice domestication required favorable environmental conditions (see White 1995) and may have allowed the development of larger urban centers (Higham 1989: 234), although Jacobs (1972) would probably disagree with the detail of the latter point. Environmental factors, however, seem less important, and perhaps ultimately almost irrelevant, in Higham's (1989) treatment of the subsequent emergence of chiefdoms and their evolution into the "mandalas." For example, one of the most obvious changes in land use and location of population centers during the emergence of the chiefdoms in northeast Thailand was the move away from topographically lower and better-watered alluvial surfaces to moisture-deficient localities, such as the topographically higher middle and high terraces (Higham 1989; Moore 1986). This move may have been stimulated by a desire to be closer to different environmental requirements that were then emerging (such as metallic ores and the timber of the high terrace and bedrock hills; see Higham 1989) and necessitated, in turn, the development of systems for water harvesting and management, themselves evidence of the move away from village autonomy toward more centralized authority.

In short, many authors, be they concerned with the development of Thai society or of society in general (see the quotation from Kirby at the head of this paper), seem to take the view that the importance of physical environmental factors in social development is inversely related to the degree of political, technological, and economic "development" of the society, an idea apparently confirmed by the persistence of modern Bangkok despite its ongoing flooding problem.

This paper takes up this theme in an examination of the nature and development of the medieval Thai city of Sawankhalok.[1] Particular emphasis is placed on an examination of the interactions between medieval urban development and activity of the Yom River on the banks of which is located the ancient city. The central issue in our discussion is the widespread evidence that the city was constructed on a ground surface about 2 m below the present ground level and has experienced 2 m of sedimentation since it was built (Bishop et al. 1994). We ask whether a city of Sawankhalok's importance could have tolerated the flooding and sedimentation that these deposits suggest when, as is understood, it was one of the most important cities in the Sukhothai kingdom. Our initial treatment of this topic (Bishop et al. 1994) is here extended by a fuller discussion of the development and importance of the city and by examining independent data on the timing of regional flooding. We summarize evidence for the antiquity of occupation of the locality and contrast this with indications of ongoing flooding and sedimentation at the site over many centuries. We argue that this apparent disincentive to occupation of the site was balanced by powerful cosmological and economic forces that encouraged its initial settlement and subsequent development as one of the most important cities of the era. Interestingly, however, the independent data on the timing of flooding suggest that the peak development of the city coincided with a period of lower flood activity and that physical environmental factors may therefore have been important in the development of the city.

OCCUPATION OF THE SITE AND THE EVIDENCE FOR FLOODING

Sawankhalok

The full glory of the Sukhothai kingdom, which is understood to have ruled the northern Central Plain of Thailand between 1220 and 1438, after which it was administered by a governor appointed by the new kingdom of Ayutthaya (Coedes 1966), is traditionally identified with the great King Ramkhamhaeng. This legendary figure is believed to have reigned between 1279 and 1299 (Piriya 1993). Inscription #1 records that Ramkhamhaeng buried relics at Sisatchanalai (i.e., Sawankhalok) and built a *chedi* (religious monument) over them. Sawankhalok is understood to have then operated as a sister city to Sukhothai, the kingdom's central power base 50 km to the south. The accepted history and ages of founding, development, and demise of both cities are currently being reevaluated, along with many elements of the traditional understanding of the Sukhothai era (Chamberlain 1991; Vickery 1990; Piriya 1993). Nonetheless, palynological evidence that is independent of the historical lines of evidence (such as art, architecture and the "historical" chronicles) certainly demonstrates that the Sawankhalok area was significantly depopulated for a period prior to the nineteenth-century influx of the current population (Bishop et al. 1992).

Sawankhalok (the "old city") is located on the banks of the Yom River at the northern edge of the Central Plain of Thailand (Figs. 1 and 2). The Yom is one of the four great rivers that drain northern Thailand and ultimately combines to become the Chao Phraya that flows through Bangkok, 500 km to the south of Sawankhalok (Van Beek 1994). Adjacent to the old city, the Yom cuts through a low bedrock ridge at the Royal Rapids (Kaeng Luang), traces a tight meander loop at the Wat Phra Prang (WPP; the locality at the eastern end of the city), and then resumes its low-sinuosity course to the south (Fig. 1). The course through the bedrock ridge was evidently established about 1700 years ago when the Yom abandoned a more westerly course around the bedrock ridge that it had occupied for much of the Holocene (Bishop and Godley 1994).

The city is surrounded on essentially all sides by hills or water and has a west-east elongation that parallels the local geomorphological configuration (Figs. 1 and 2). It is quite clear that the ground surface at Sawankhalok has experienced aggradation of between 1.5 and 3.5 m (2 m, for ease of description[2]) since the

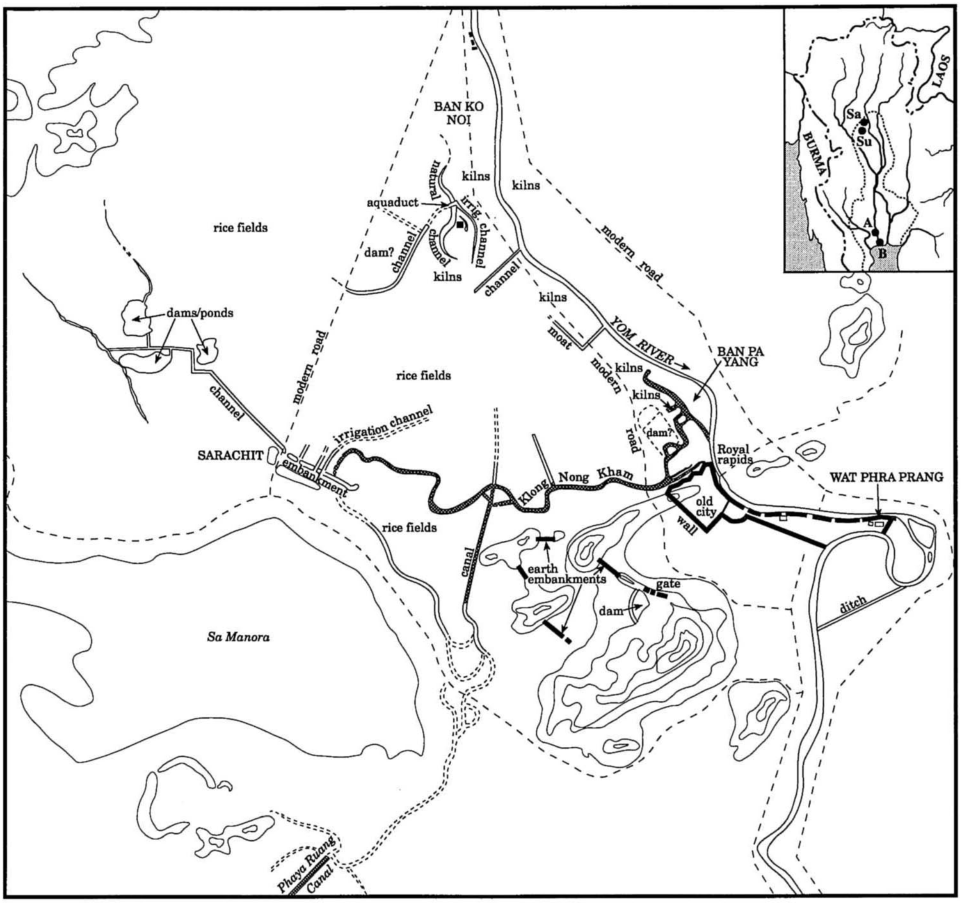


Fig. 1. The regional setting of Sawankhalok, showing various embankments, canals, and other features of the area. The inset shows the location of Sawankhalok (Sa), Sukhothai (Su), Ayutthaya (A), and Bangkok (B) within Thailand and the four great northern rivers (west to east: the Ping, the Wang, the Yom, and the Nan). The dotted line outlines the Central Plain of Thailand.

city monuments were constructed (Pl. II) (Bishop et al. 1994). In short, the old city buildings were built on a ground surface of the order of 2 m lower than present, and the ground surface generally throughout the city has been aggraded by this amount, thinning toward the hills (Fig. 3).

The lower 1 to 1.5 m of this city-wide sedimentation is generally a dark grey brown occupation layer consisting of a chaotic mix of charcoal, stoneware and earthenware shards, and sand and clay; the Thai Department of Fine Arts (DFA) calls this unit the "Sukhothai" unit. Organic staining, indicative of a former soil, is commonly found immediately beneath the upper boundary of this unit, and many former water wells have clearly been dug from this former surface. The laterite "aprons" surrounding these wells lie on the organic-stained upper surface of the Sukhothai unit (Fig. 4), as does a laterite path to one of these wells in the DFA Wat Chao Chan excavation. The upper 0.5 to 1 m of the city-wide sedi-

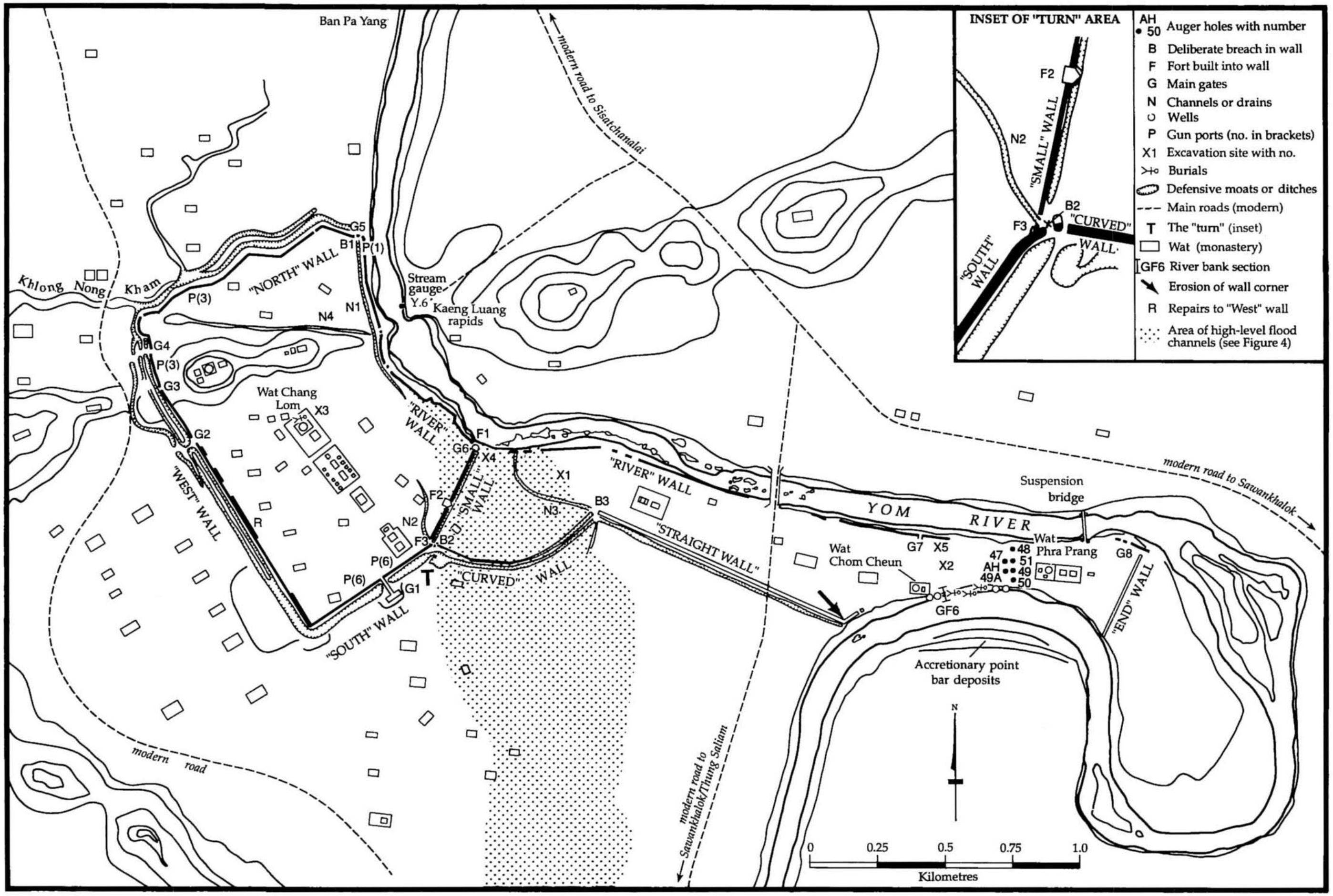


Fig. 2. Map of the old city commonly called Sawankhalok (Chaliang-Sawankhalok in Vickery's [1990] terminology). Numbered gates (G) are: 1. Ramnarong; 2. Saphanchan; 3. Chanasongkram; 4. Tao Mor; 5. and 6. Unnamed; 7. Donlaem. Only wells (circles) in the vicinity of Wat Chom Cheun are shown; there are many laterite-lined and a few brick-lined wells within and outside the walls of the old city. Fig. 5 gives details of the flood channels.

Pl. II. The eastern wall and gate of Wat Mahathat, the main building *(prang)* at Wat Phra Prang, showing flood sedimentation of the wall and gateway. Lunet de Lajonquière (1904:332) was told that in former times fully harnessed elephants (presumably carrying full elephant saddles) could pass easily through this gate. He attributed the burial of the massive walls surrounding Wat Mahathat to settling into the ground as a result of their massive weight, but the ubiquity of this effect throughout the old city means that settling is an inadequate explanation.

mentation consists of clean, sterile clays, loams, and fine sands, in marked contrast to the dark coloration of the underlying Sukhothai unit.

Flooding and associated sedimentation are consistent with the city's riverside location. Water and sediment would have flowed into the city from the Yom and, perhaps more importantly, from a series of sinuous high-level channels that cut across the inside of the meander bend (Fig. 5) (Bishop et al. 1994). Bishop et al.'s (1994) previous interpretation of these traces as high-level flood chutes is confirmed by the characteristically lenticular geometry of the deposits that underlie these channel traces cutting through the city (Fig. 6). The distinct lack of buildings along the traces of the flood chutes through the old city is noteworthy (Fig. 2).

Hydrological analyses of the modern Yom's flows at the Royal Rapids (stream gauge Y.6, Fig. 2) show that the recurrence interval of present bankfull (the flow necessary to flow over the modern bank tops under the present flow regime) is of the order of 10 years, depending on the extreme-event statistical distributions chosen for the flood analyses (Fig. 7). The recurrence interval of overbank flow when the ground surface was 2 m lower is less than 5 years (Fig. 7). Flow would have to have been deeper than simply overtopping the banks at −2 m (in order to carry sediment into the city), but this detail notwithstanding, the hydrological analyses point clearly to the conclusion that present flow and flood regimes in the Yom would have inundated the city quite regularly.

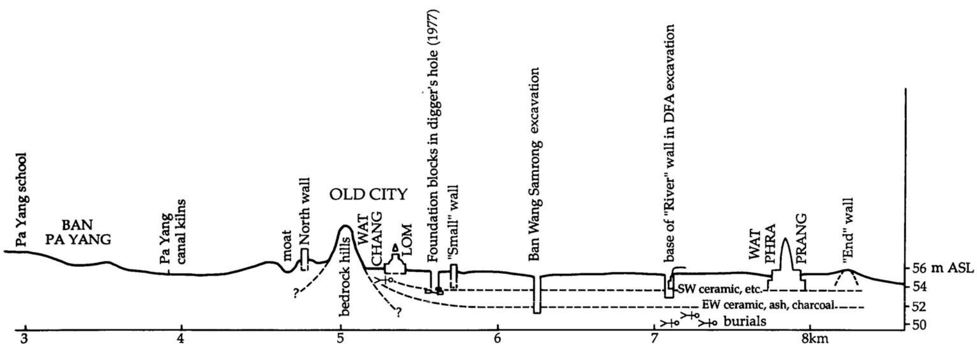


Fig. 3. Portion of a surveyed profile from Ban Ko Noi (0 km; Fig. 1) to Wat Phra Prang, showing subsurface relationships in the area of the old city and WPP and highlighting the deeper and intermediate occupation levels beneath the old city. SW: stoneware; EW: earthenware. (Profile surveyed by Peter Hein.) The older ground surface about 4 m below the present ground level was occupied 1200 years ago (Bishop et al. 1994). The inhumation burials associated with the −4 m level (Hein et al. 1989) mean that the people living at this level could not have been Buddhist.

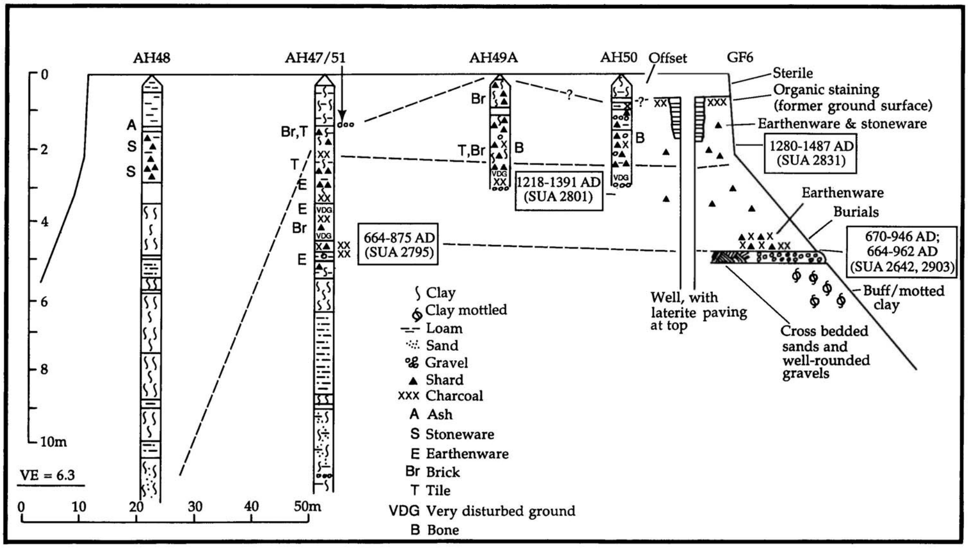


Fig. 4. Cross section of the neck of land at the meander loop at Wat Phra Prang (see Fig. 2 for auger drill hole locations). Full details of the radiocarbon determinations are provided by Bishop et al. (1994).

Earlier Occupation

Earlier human occupation at the site of the old city is represented by inhumation burials found at depths of 5 to 7 m below present ground level at the meander loop (Hein et al. 1988). The people responsible for the burials (which are currently being excavated by the DFA and for which final excavation reports are not yet available) could not have been Buddhist, since Thai Buddhists cremate their dead. Our radiocarbon determinations on charcoal from the ground surface to which the burials are related (at 4 to 5 m below the present ground surface—the

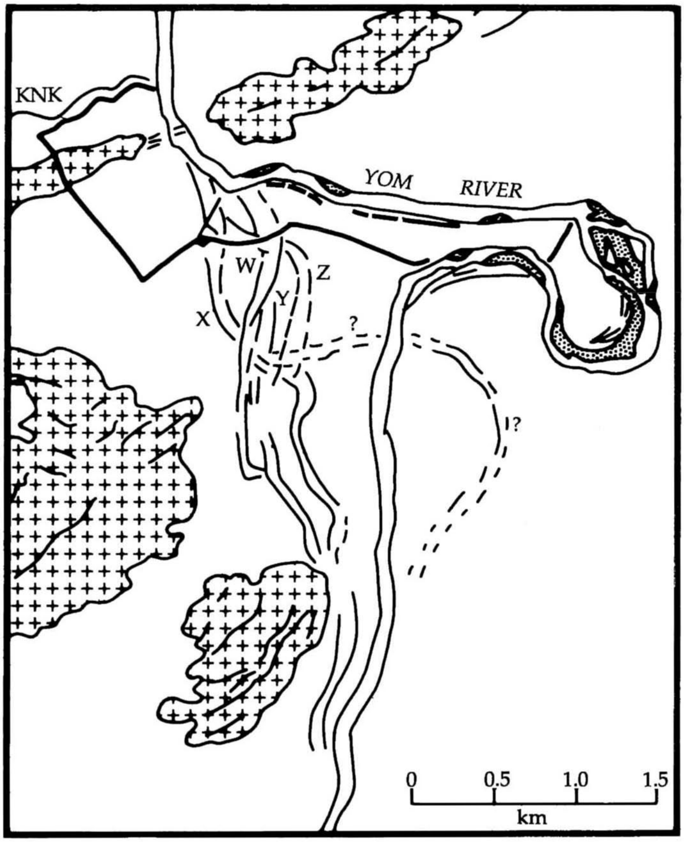


Fig. 5. The Yom River's high-level flood channels, W to Z (youngest to oldest; see Bishop et al. [1994] for more details). The map is based on stereoscopic interpretation of aerial photographs flown 1 January 1954 at an approximate scale of 1 : 45,000.

"−4 m" level) show that people occupied this riverine site in the late seventh to late ninth centuries A.D. (Hein et al. 1988; Bishop et al. 1994).

The ground surface at this time sloped down to the −4 m level at the meander bend from the bedrock hills and laterite beds that are known to underlie the ground closer to the hills. The meander loop site at −4 m therefore gave ready access to the river without the climb down to the water that would have been necessary further west toward the hills, although there is yet insufficient evidence to determine whether people 1200 years ago lived all over the area underlying the future city. The site was therefore probably chosen for its access to water and to the plentiful fishing at the Royal Rapids.

The −4 m level is abruptly succeeded in the river bank stratigraphy and the DFA excavations by about 2 m of clean and generally well-sorted buff to pale yellow fine to medium sand which we interpret as flood deposits predating the founding and occupation of Sawankhalok. We find the abruptness of the early occupants' disappearance significant and suggestive of being related to the onset of flood sedimentation.

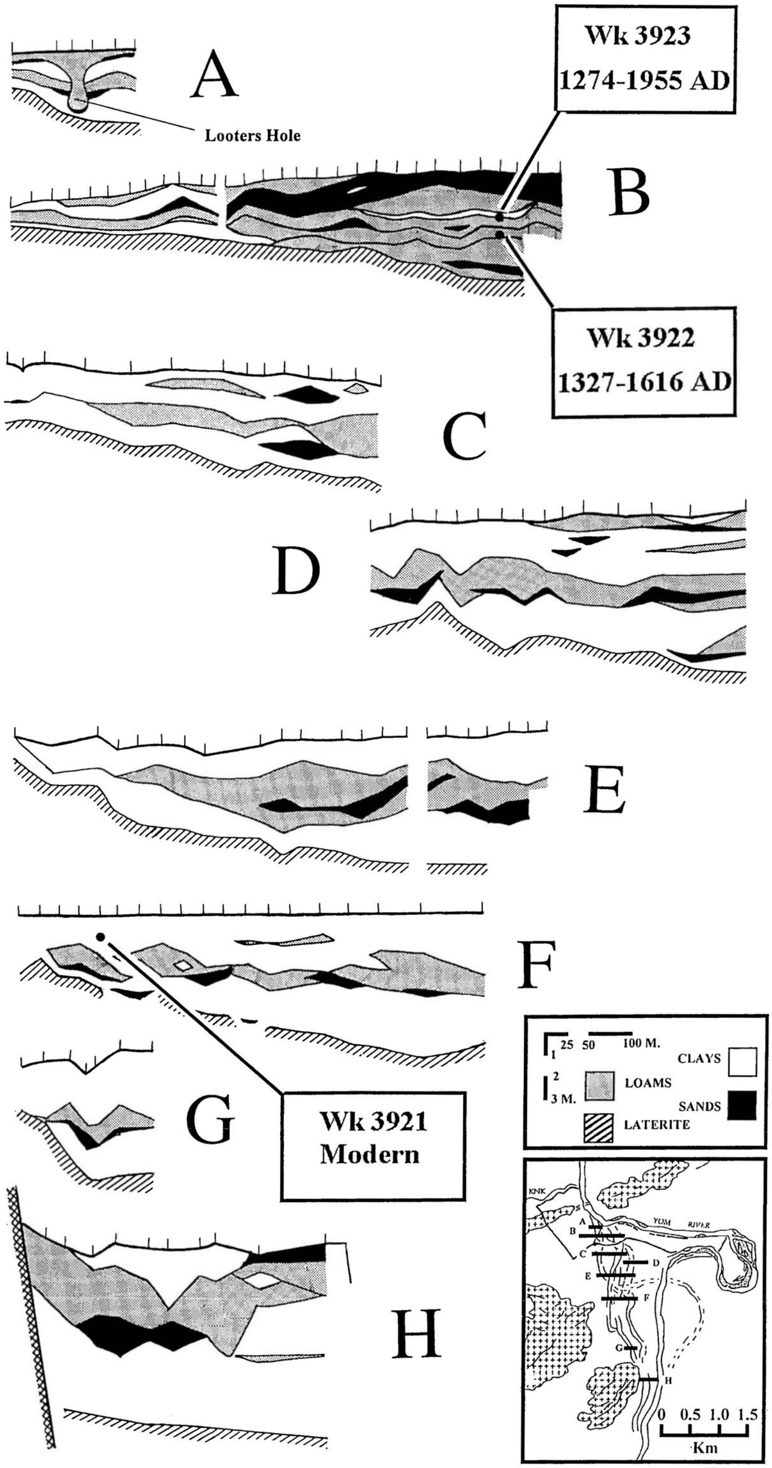


Fig. 6. Stratigraphy of the flood chutes based on augering along the section lines indicated in the insets. The auger hole locations are indicated by the tick marks along the top of each section.

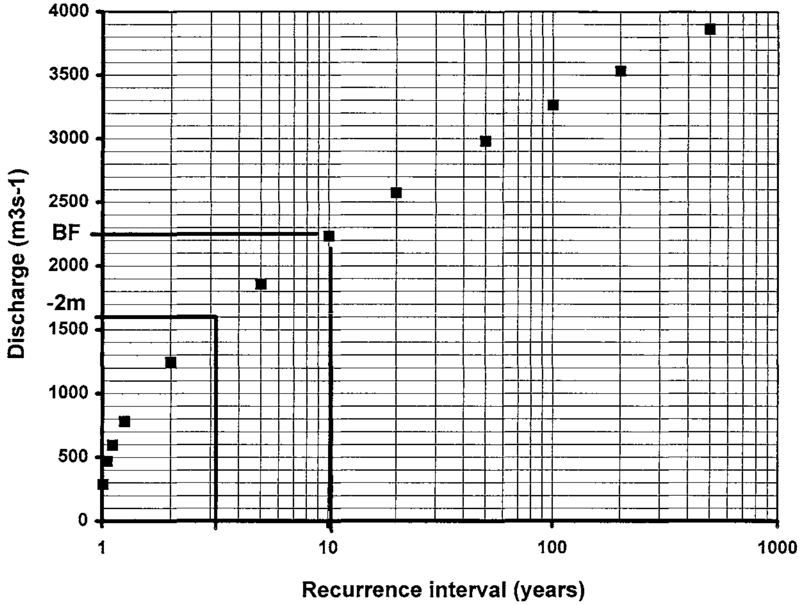


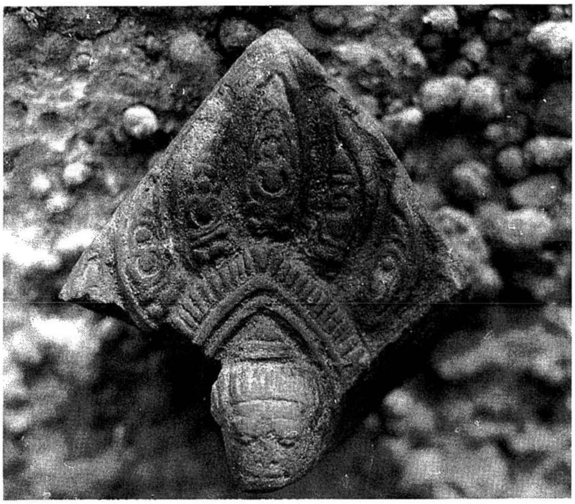
Fig. 7. Flood frequency plot for the Yom at the Kaeng Luang gauging station (gauge Y.6 at the Royal Rapids, Fig. 2). Flow records are collected by the Hydrology Division of the Royal Irrigation Department, Bangkok. The recurrence interval (return period) of floods high enough to overtop the bank and flow into the old city were determined by standard flow frequency analysis of annual floods (annual peak instantaneous discharge) using the AQUAPAK software (Gordon et al. 1991) for the full period of record (1952 to 1989) except 1961 (because the 1961 instantaneous peak discharge is significantly, and inexplicably, inconsistent with other years). These determinations were based on the log-Pearson III distribution, following common practice (Gordon et al. 1991), but the general conclusions drawn from the analysis are not sensitive to the particular distribution chosen, nor to whether annual peak discharges or a full range of channel discharges are used. The statistically determined recurrence interval (about 10 years) may be a little low, given that the highest flood in the 38-year record (8 September 1980) only just reached banktop and apparently did not flow into the city (pers. comm., Royal Irrigation Department officials, Kaeng Luang gauging station, 1993). Nonetheless, this is probably an appropriate water depth (~2 metres) at the time of construction of the city wall when the ground surface was ~2 m lower.

COSMOLOGICAL AND ECONOMIC HINTERLANDS

The key to whether flooding had a major impact on the medieval city lies in the ages of the flooding. Before this issue is examined, we consider the role of economic and Buddhist cosmological factors in determining the location of the city. We wish to highlight the range of nonphysical environmental factors that were apparently important determinants of the city's location in order to provide a foundation for our discussion of the flooding.

The Location of the City and Its Cosmological Hinterland

The initial development of Sukhothai and Sawankhalok was as part of the great Khmer kingdom of the early part of the second millennium (Chandler 1993). Van Liere (1989) and Sumet (1988), among many others, have noted that Sukho-



Pl. III. Khmer votive photographed by one of the authors (DH) after it was recovered by a local from the Yom River in old Sawankhalok.

thai exhibits clear evidence of Khmer hydraulic works; the Khmer-styled buildings, Wat Phra Pai Luang (Sukhothai) and Wat Chao Chan (Sawankhalok), are further evidence of this Khmer presence. Vickery notes that Wat Chao Chan is certainly Khmer (Vickery 1990 : 22, 29), and even if the interpretation of the buildings as Khmer is ultimately challenged (cf. Piriya 1993), the recovery from the Yom River at Sawankhalok of unmistakably Khmer votives is clear evidence of a former Khmer presence (Pl. III).

The reasons people chose to occupy the site at the −2 m level, after the flooding and sedimentation that may have been implicated in the demise of the people who had lived at the −4 m level, were probably partly the same as the reasons for its original occupation, namely, access to water and the opportunities for fishing at the Royal Rapids. This protourban occupation may have been restricted to the meander loop, where are found the ?Khmer Wat Chao Chan and Wat Mahathat, another supposedly early building, at least in its inner core (Gosling 1991; but see Vickery 1990).

The old city may have Khmer roots, but the siting and layout of the city have been clearly influenced by Thai Buddhist cosmology. Wilaiwan (1989 : 237) and Srisakra (1989 : 360) note the importance in the traditional Tai/Thai world view of the natural setting (water and earth) in locating a settlement, and Nid (1989) provides the details of the necessary disposition of various natural elements when locating a Thai city, noting that hills, representing the celestial mountain and Nirvana, should lie to the west of the city, and the land should slope down to the east, toward water. Temples and Buddha images should face east, so that the praying faithful are facing west toward Sukhavadi, the celestial mountain.

These natural elements are appropriately disposed at Sukhothai and Chiang Mai (Nid 1989), and the location of Sawankhalok can be seen to be equally appropriate in these terms (Fig. 1). Sawankhalok is essentially a west-east elongate city extending from the old river channel at the "north" wall (Khlong Nong Kham; Bishop and Godley 1994) to the "end" wall, at the eastern end of WPP in the meander loop (Figs. 1 and 2). The land surface slopes eastward from hills in the west to the waters of the Yom. Remembering that the Sawankhalok buildings were built on the −2 m level, this slope would have been more pronounced at the time the city was founded. The conjunction, therefore, of a west-east reach of the Yom River, and hills to the west sloping down to the river water, must have represented a very strong incentive to Buddhists to continue settlement at the site. Other localities along the Yom, which both upstream and downstream of the old city follows a north-south course, do not exhibit this suitability. Moreover, hills are not found along the river downstream of the old city.

The Economic Hinterland: Ceramic Production

Earthenware pottery is associated with all periods of occupation in the Sawankhalok area. In the eleventh or twelfth century, the crossdraft kiln appeared and stoneware production began (Hein et al. 1986; Barbetti and Hein 1989). The development of stoneware production evidently predated the emergence of Sawankhalok, but this development laid the foundations for what would become one of the city's major economic activities.

Ceramic production was concentrated on both banks of the Yom in the area of the modern village of Ban Ko Noi, about 6 km upstream (north) of the old city and the Royal Rapids (Fig. 1). The early stages of the ceramic industry were probably managed by individual families. The kilns are small, and when no longer tied to a terrace embankment (the tie having been broken by the innovation of the firing pit), they are scattered and orientated at various angles, suggesting that decisions such as location were made on an individual or small-group basis (Hein and Barbetti 1988). The site's early production (the so-called Mon wares) served nearby habitation sites, monasteries, and cremation burials. Finds of such wares are most abundant at Sarachit, about 5 km west of the old city (Fig. 1), where, incidentally, the greatest concentration of water management works are found (see below). Most of the domestic finds at Sarachit are in shallow dammed areas or low ground, suggesting that houses were built on piles in areas that were flooded for at least part of the year. It appears that most production, at least initially, was for local use, but some of the wares are found in neighboring towns and sites up to several hundred kilometers distant, a result of market exchange overland and along the river systems (Shaw 1986).

The location of the kilns upstream of the communications barriers posed by both the Royal Rapids and the laterite outcrops in the bed of the Yom in the old city implies that trade to the south must have been negligible at the time of the foundation of the industry (and, indeed, that the potters did not originate from this direction; their origins seem more likely to have been the west and north). The finding of large quantities of Sawankhalok ceramics in grave sites in the mountains to the west implies that this was one of the main trade directions to Marbatan (Shaw 1986). Srisakra (1986) has argued, in a similar vein, that most of the locations in the northern Central Plain of Thailand (namely, Kampaengphet, Sukhothai, Sawankhalok, and Phitsanulok) exploited the trade routes between the Mekong and the Salween.

The ceramic industry was evidently highly successful and contributed to the growth and prosperity of the community. Kiln design improved to allow the production of better wares in greater quantities (Hein et al. 1986; Hein and Barbetti

1988; Barbetti and Hein 1989). Trade became more important, leading to a greater emphasis on quality glazed wares with well-executed decoration of various kinds. Finally, additional kiln areas were established at the modern village of Ban Pa Yang, on the northern edge of the city (Fig. 1). Trade continued to the west but by the fifteenth century a flourishing export industry had developed to the south through the port of Ayutthaya to insular Southeast Asia and further abroad (including the Middle East) (Barbetti and Hein 1989; Guy 1989; Shaw 1986).

By the fifteenth century in the later phases of production, particularly at Ban Pa Yang, the kilns were ordered into rows and employed a common infrastructure indicative of a central management. The final phase of Pa Yang production involved a complex system of mounds and surrounding canals (Fig. 1; Hein and Barbetti 1988). These canals led to a larger channel that linked in turn to the Phra Ruang Canal and thence to Sukhothai, 50 km to the south (Hein and Barbetti 1988; Godley et al. 1993). Curiously, the obvious suggestion that the Phra Ruang Canal may have been the transport route south for export ceramics, thereby circumventing the barrier to river transportation provided by the Royal Rapids, is not confirmed by evidence of ceramics finds along the canal, as would be expected along a heavily used transport route (Godley et al. 1993). The reasons for this remain to be clarified.

The place of the ceramic industry in the economy of the area has yet to be defined completely. The later, export phases of the industry were probably the main element of trade and therefore one of the prime sources of the city's wealth; this importance continued until the late sixteenth and possibly seventeenth centuries when the industry finally died out. The proximity of the Ban Pa Yang production area to the city, and the centralized management suggested by the organization of Pa Yang and its connection to a complex network of canals and other water management infrastructure, may imply centralized authority based in the nearby city.

The Economic Hinterland: Agriculture

A yearly rainfall of about 1800 mm is required for successful cultivation of rice (Tomosugi 1966). Uttaradit, the nearest rainfall station to Sawankhalok (40 km to the east) has a mean annual rainfall of 1428 mm for the period of modern records (1956 to 1985) (Meteorological Department 1987), meaning that the Sawankhalok area is today marginal for rice production. It would have been the same during medieval times. Water management for irrigation was therefore probably necessary to supplement rainfall for agriculture, particularly if, as we argue below, the rainfall regime when the city was flourishing delivered less rainfall than today.

Evidence of agriculture at Sawankhalok extends north and west from the bedrock hills to the hills further west and the Sa Manora backswamp/lake southwest of the city (Fig. 1). This evidence consists of clear traces on aerial photographs of small rice fields, which can be discerned through the patterns of the modern, larger fields. Bruneau (1973) has dated these to the Sukhothai era; Van Liere (1989) identifies a similar pattern closer to Sukhothai. Catchment dams, artificial lakes, and many channels show sophisticated systems of water harvesting, conservation, and management for irrigation (Fig. 1).

In at least one case, a shallow catchment can be discerned to have fed into a raised channel that leads via an aqueduct (Fig. 1) across low ground and a water course to feed irrigation channels and a Buddhist monastery moat. Within the hills immediately to the southwest of the city, we have identified a 2 m high earthen wall that dams the catchment above (dam in Fig. 1). The precise function and age of this dam are not yet clear, but it is reasonable to suggest that it was yet one more part of a water-management strategy for the city and its hinterland.

The Sawankhalok water-management systems apparently also served an important role for Sukhothai. The Phra Ruang canal system that runs from Sawankhalok to Sukhothai may have served both to supply water to Sukhothai and irrigation systems between the two cities and as a transportation system (Godley et al. 1993). Charnvit (1973) reports that Sukhothai was obliged to import rice from Lopburi in the thirteenth century, which suggests that the TPR canal system could have delivered rice and water south from Sawankhalok as well.

Whatever the precise roles of the various water-management systems at Sawankhalok, it is clear from the city's complexity and the large number of monuments and other buildings in the city and its hinterland that the area supported a considerably larger population than it does today. The city was clearly a major economic center noted for the production of ceramics and perhaps rice. Water harvesting and management were clearly important elements in the functioning of the economy of the city and its hinterland.

THE CITY WALL AND THE AGE OF FLOODING

Having established the importance of the city and its economic context, we now return to a consideration of the timing of flooding and sedimentation of the city. The most informative data on the age(s) of flooding are provided by the city wall, which forms the focus of the following discussion. The discussion uses descriptive names shown in Figure 2 to identify the various sections of the wall.

Characteristics and History of the Wall

The extant city wall, which exhibits a uniformity of design, construction, and materials that demand that the wall be treated as a single feature, encloses a large and irregular area encompassing the higher ground near the rapids and a strip of land several kilometers long extending eastward to the river bend (Figs. 1 and 2). The irregularity of the city outline is not yet well understood, but tradition would have certainly demanded conformity with the Buddhist cosmological criteria noted above and there was probably a desire to include the old and venerable monuments at the meander neck. Contemporary cities, such as Sukhothai and Chiang Mai, were square, and there seems to have been an attempt to create that form in the approximately rectangular (western) part of the city. It is not clear why a curved wall is used to connect the square (western) section to the elongate (eastern) strip; it may be noteworthy, however, that the curved wall occupies the low ground of the flood chute traces.

The wall is constructed of laterite blocks and sits on the −2 m ground surface. Where the wall faces out onto land, it was constructed on an earthen mound, the soil being provided by a ditch (moat) dug on the outer side. Along

TABLE 1. RADIOCARBON DETERMINATIONS REPORTED FOR THE FIRST TIME

SAMPLE POSITION AND MATERIAL[a]	STRATIGRAPHIC POSITION	LAB. NO.	AGE ± ERROR	CALIBRATED AGE A.D.[b]
Pit 1, 90–110 cm Charcoal	Within upper flood deposits	Wk 3921	Modern	1σ: **Younger than 1750** 2σ: **Younger than 1750**
Pit 2, 310–320 cm Charcoal and burnt bone	Base of Sukhothai-era occupation unit	Wk 3922	480 ±60	1σ: 1410–**1436**–1454 2σ: 1327–**1436**–1616
Pit 2, 230 cm Bone	Top of Sukhothai-era occupation unit	Wk 3923	300 ± 100	1σ: 1410–**1641**–1955 2σ: 1274–**1641**–1955

[a]For information on radiocarbon determinations not detailed here, see Bishop et al. (1994). Determinations reported here were by conventional radiocarbon analysis. See Fig. 6 for locations and stratigraphic positions of dated samples.

[b]Calibrated ages were calculated using CALIB 3.0 (Stuiver and Reimer 1993). They are reported at 1σ (68%) and 2σ (95%) confidence limits, with the median calibrated age (the age with the highest probability of being the true age of the sample) in bold. The true age can lie anywhere within the range given, but the probability of this decreases away from the median age. The radiocarbon determinations were made at the Radiocarbon Dating Laboratory at the University of Waikato; this laboratory reports ages less than 200 years as Modern.

the river bank, no mound was needed (the river bank providing the height advantage) and the wall sits directly on the −2 m ground surface (e.g., Fig. 4). The earliest radiocarbon ages for this −2 m surface have been obtained from auger drill holes at WPP and record the onset of intensive occupation between the early thirteenth and fifteenth centuries (Fig. 4; Bishop et al. 1994). A new radiocarbon determination of the base of the Sukhothai era occupation unit has also returned a median calibrated age of mid-fifteenth century (Wk 3922; Table 1; Fig. 6).

The DFA excavation of the river wall (excavation X5, Figs. 2 and 8) shows that this section of the wall was built directly onto flood deposits at about −2 m below present ground level in the fourteenth or early fifteenth century, which is taken to be the age of the start of construction of the whole wall. The reddened (burnt) ground on flood clays in the south face of X5 (Fig. 8) suggests in situ burning immediately prior to the deposition of the flood sands on which the wall sits. This burning is consistent with a substantial fire, which could reasonably be interpreted as the clearing of a previous defensive wooden palisade. The lack of significant statistical difference between the two radiocarbon determinations from beneath the wall and the slightly different stratigraphic positions of the dated samples (Fig. 8) point to rapid deposition of the flood sands.

The west and south walls are the highest and most impressive wall remains, with deep ditches that form moats in the rainy season. At the opposite (eastern) end of the city, the remains of the end wall consist of an earth rampart/embankment closing the city from one bank of the river to the other. No wall remains are extant along the southern side of WPP between the end and straight walls because of river-bank erosion, which continues to the present. The "corner" at the eastern end of the straight wall that can be identified on 1954 aerial photographs (Fig. 2) has been largely lost to this erosion in the last 40 years. Unlike the

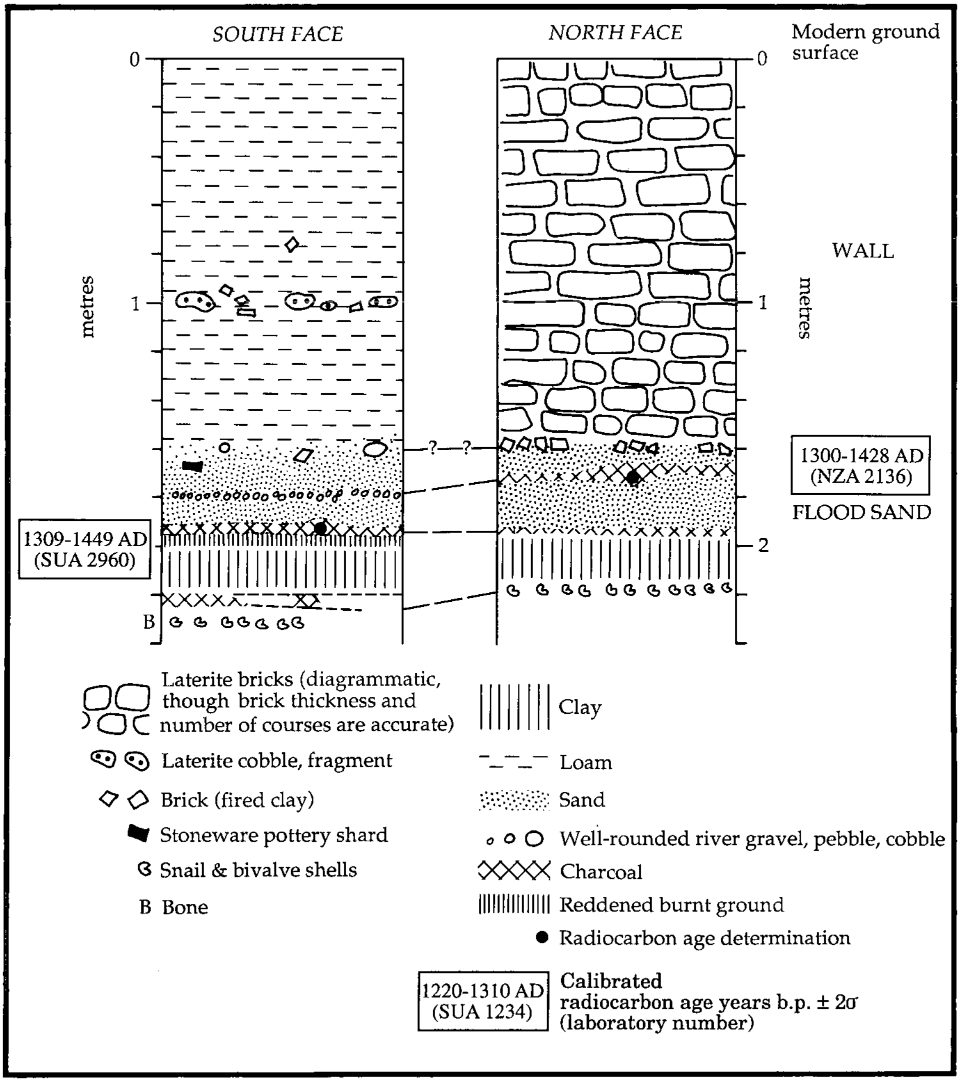


Fig. 8. North and south faces of the DFA excavation X5 of the city wall between the Royal Rapids and WPP (see Fig. 1 for location of X5).

rest of the extant wall, the end and straight walls are now marked only by an earth embankment, with little or none of the overlying laterite wall itself. The Pongsawadan Nua (Northern Chronicles) report that laterite blocks were removed from Sawankhalok to Bangkok in the nineteenth century. The straight and end walls are the closest to the navigable limit of the Yom and were probably the source of these blocks.

The Ramnarong gate in the south wall in the "square" part of the city (G1 in Fig. 2) is clearly the city's main entrance and faces the line of approach from Sukhothai. Sukhothai's wall was relatively modest, and it is very unlikely that Sawankhalok would have been permitted during the Sukhothai era to have had a grand wall and gate that were more impressive and imposing than those of the kingdom's principal city (particularly on Sawankhalok's south wall, facing toward Sukhothai). National power passed to Ayutthaya in the fifteenth century, and by the sixteenth century Sukhothai was in serious decline and unable to enforce its former hegemony. Sawankhalok, on the other hand, continued to prosper, presumably partly as a result of the successful ceramics export industry. The full grandeur of the city wall is probably therefore a relatively late feature dating from the sixteenth century (Gosling 1991 : 111).

Major repairs have replaced substantial parts of the west wall that had collapsed, perhaps following a deepening of the moat and consequent subsidence of the mound (Fig. 2). Other modifications of the north, west, and south walls include breastwork structures interpreted as gunports and therefore dating from the sixteenth century (Fig. 2; Vickery 1990 : 27). Moreover, lead shot found in the area of the Ramnarong gate is thought to be evidence of a major battle in A.D. 1584 in which guns were used (DFA plaque at the Ramnarong gate). In short, the city wall seems to have been functioning at least until the late sixteenth century.

The river wall now has significant sections that are missing or damaged (Fig. 2). Unlike the straight and end walls, however, these sections are some distance above the limit of navigation of the Yom, and the damage to them is quite clearly the result of flooding. Sections of the wall, particularly in the vicinity of the flood chutes (Figs. 2 and 5), have been realigned and roughly repaired using salvaged bricks, architectural blocks, and natural rocks (e.g., sections of the extant river wall at the modern complex of DFA offices and amenities block). We take the roughness and makeshift nature of the repairs to the river wall to be an indication of their having been undertaken after the city had passed the peak of its power.

Flood damage to the river wall is also clear on the right bank of the youngest flood chute W, in the DFA excavation (X4) at Fort (F1) and the modern Donlaem gate (G7) (Figs. 2 and 9). Erosion and collapse of the river wall have been followed by repair and the construction over the river wall of Fort F1 (Fig. 9; Pls. IV*a*, IV*b*, and V). Periods of flood sedimentation are clearly interspersed with these various construction phases: Pls. VI and VII clearly show that flood sedimentation is interbedded between the river wall and the overlying construction of the fort.

Fort F1 is one of three forts associated with the small wall which evidently represents the last phases of the use of the city wall for defense of the city (Fig. 2). It appears that all but the square part of the city, on the slightly higher ground within the bedrock hills, was abandoned during or soon after the erosion of the river wall at Fort F1 and the modern Donlaem gate. The small wall closes the square from the south wall to the river, and three small forts were incorporated to strengthen its defensive value. The abandoned straight and curved walls would have been a ready source of laterite blocks for the small wall and its forts. The final decline of the wall is represented by breaches to drain rainwater from the city (B in Fig. 2); these breaches would certainly have been inappropriate while the wall served a defensive role.

Flooding and the City's Development

The following flood chronology may be deduced from the history of the city and its wall. The city was located in a flood-prone site which had experienced pre-

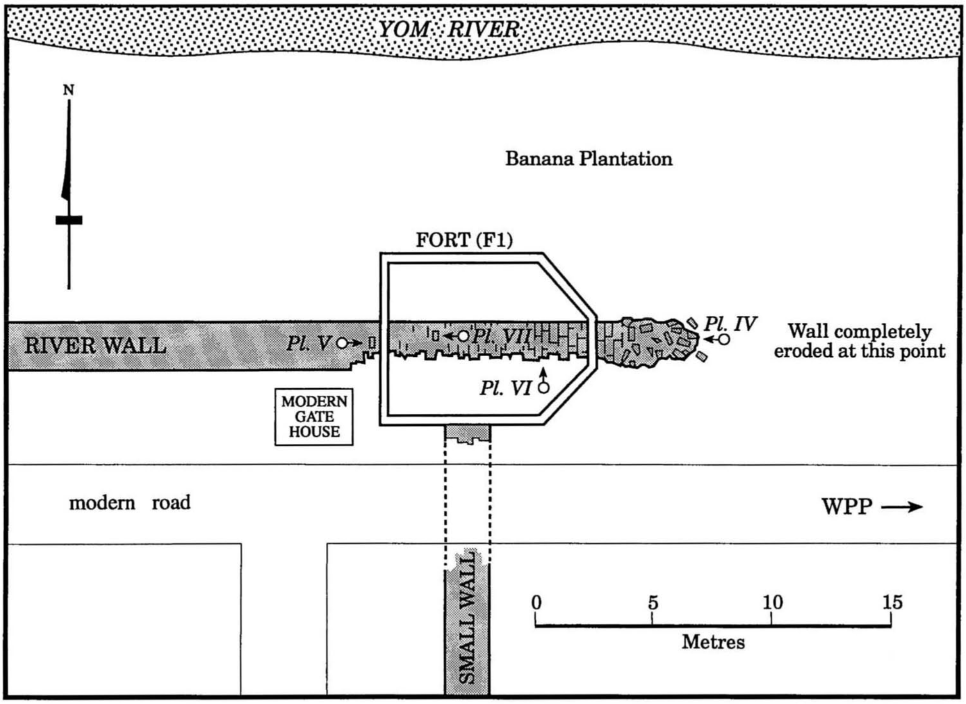


Fig. 9. Map of the modern Donlaem gate area (Fig. 2) showing the relationship between the river wall and the overlying Fort F1 and the spill of bricks at the eroded end of the river wall on the right bank of flood chute W; the directions of view of the photographs in Pl. IV, V, VI, and VII are also given.

vious flooding that could account for the demise of the people who lived on the site at the −4 m level, 600 to 700 years before the earliest occupation of medieval times. The medieval city wall was built directly onto flood deposits sometime in the fourteenth to early fifteenth centuries. The immediate superposition of the wall on flood sediments may mean that the decision to build the wall was taken with the knowledge that the city site was prone to flooding, although it is difficult to imagine that the wall builders would have decided to proceed with the building of the 8 km or so of very substantial construction that the wall represents in the knowledge that the site would be regularly flooded. In any event, the lack of buildings along the trace of the flood chutes and the locations of the evidently earlier buildings at WPP (the lowest parts of the −2 m landscape) and the evidently later buildings on the slightly higher ground closer to the Royal Rapids seem to indicate fairly clearly that the city dwellers learned that the site was flood prone.

Flooding certainly occurred late in the life of the city, resulting in bank erosion and wall collapse on one of the flood chutes at the modern Donlaem gate and damage in general to the river wall. The lateness of this flooding in the city's life is indicated by several lines of evidence. Firstly, the damage and reconstruction of the river wall, especially at the modern Donlaem gate, are associated with the small wall, which itself almost certainly reflects diminished city power and a lack of the workforce necessary to maintain the full city wall. Secondly, the flood sediments exposed in the south face of the X5 excavation (Fig. 8) indicate at least two major floods after wall construction. The thin scatter of bricks and laterite fragments between the two floods is consistent with low population densities. Flooding late in the city's life, at a time of low population densities, is indicated by the various drains and breaches of the wall. These must represent continued occupation and flooding of the city well after it had passed its zenith and the need for a defensive wall.

A new radiocarbon determination at the boundary between the top of the Sukhothai-era occupation unit and overlying flood deposits returned a calibrated median age of mid-seventeenth century (Wk 3923; Table 1; Fig. 6). This radiocarbon age indicates that the final sedimentation that we see today (e.g., the well tops covered by about 0.5 m of flood sedimentation observed in river bank sections at WPP; Fig. 4) postdates the mid-seventeenth century. The lack of occupation remains (sherds and charcoal) in this upper 0.5 m where it has not been dug by modern looters implies final sedimentation when the area had been substantially depopulated. Photographs of the WPP area taken at the turn of the century (Lunet de Lajonquière 1912) and northern Thailand hydrological data from the 1920s onward (Godley, unpublished data from work in progress) both strongly suggest that this sedimentation occurred prior to the turn of the twentieth century. This is consistent with the modern (post 1750) radiocarbon age determination that was obtained from about 1 m depth in the flood sedimentation (Wk 3921; Table 1, Fig. 6). In sum, if the city remained a key organizational and management element of the ceramics industry until its decline in the late sixteenth or seventeenth century, final sedimentation must have occurred between the seventeenth and nineteenth centuries.

Further insight into the flood history of the Sawankhalok area over the last thousand years is provided by long regional meteorological records from China; we turn to these now.

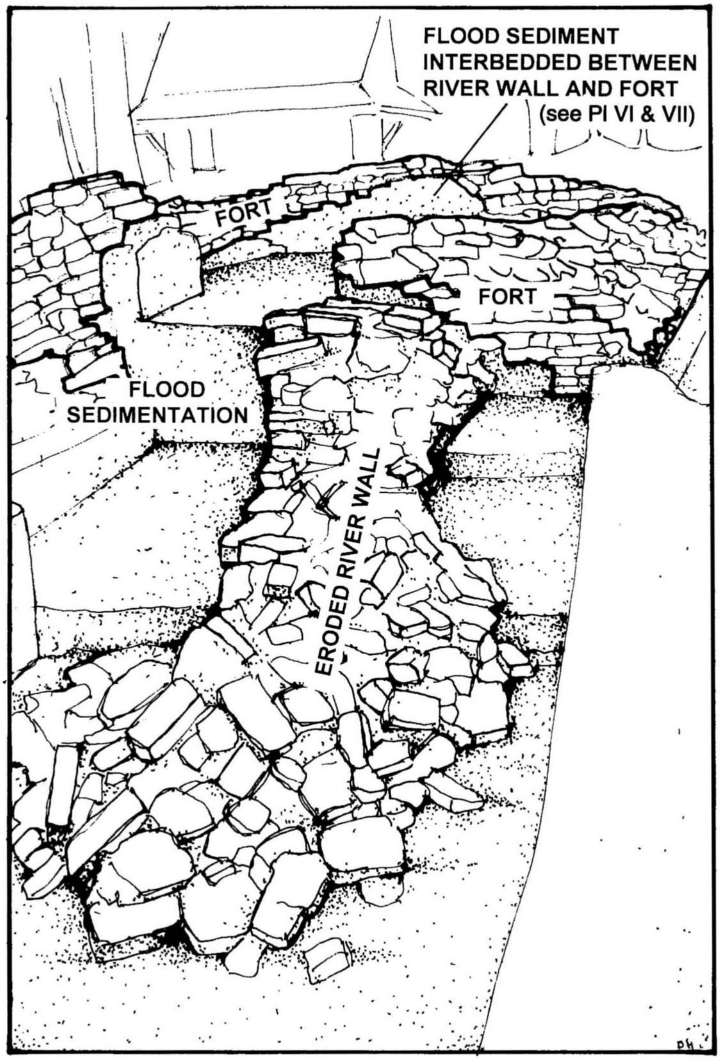
LONG RECORDS OF REGIONAL FLOODS AND DROUGHTS

Regular inundation is an integral part of the economies of Asia, providing the water essential for nonirrigated rice production. Because of this importance, meteorological records have been maintained in parts of Asia for many centuries, and there has been a tremendous growth in the use of these data since the publication of the classic work of Chu Coching (1973) (e.g., Hinsch 1988; Wang and Zhang 1990; Wang et al. 1991; Yan et al. 1992; Pfister et al. 1994). There has been a similar interest in using the some 50,000 extant reports of floods and droughts that are recorded in the official histories, personal diaries, travelogues, and literature of China (Chen et al. 1975; Hu and Lo 1992 ; Luo 1987; Gong and Hameed 1991).

The monsoon exercises a regional control of annual rainfall, and through rainfall, river discharge. Modeling of the summer monsoon shows that in years when the monsoon is strong, it is strong throughout the region and is associated with higher rainfalls and greater river discharges; in years when the monsoon is suppressed, lower regional rainfalls are characteristic (Ju and Slingo 1995; Joseph et al. 1994; Webster and Yang 1992). The wet season of 1995 has provided an

Pl. IV*a*. Photograph of flood damage to the river wall at the modern Donlaem gate, looking toward the right bank of the flood chute W (Figs. 5 and 9). The spill of bricks toward the viewer in the foreground (the "Eroded River Wall") is the spill of bricks down the right bank of the flood chute that resulted from flood erosion of the bank of the flood chute and flood damage to the river wall. Flood sedimentation surrounds the eroded wall, and the Fort (F1) is built over the river wall and post-wall sedimentation. Flood sedimentation between the river wall and the Fort can be seen in the background. (See Pls. VI and VII.) See Pl. IV*b* for explanatory drawing, on facing page.

excellent example of the regionality of the impacts of a strong monsoon: the 1995 wet season has been associated with major to severe flooding in Cambodia, Thailand, Bangladesh, and India, and major storms in Hong Kong, northern Vietnam, southern China, and the Philippines. In short, there tends to be a parallelism

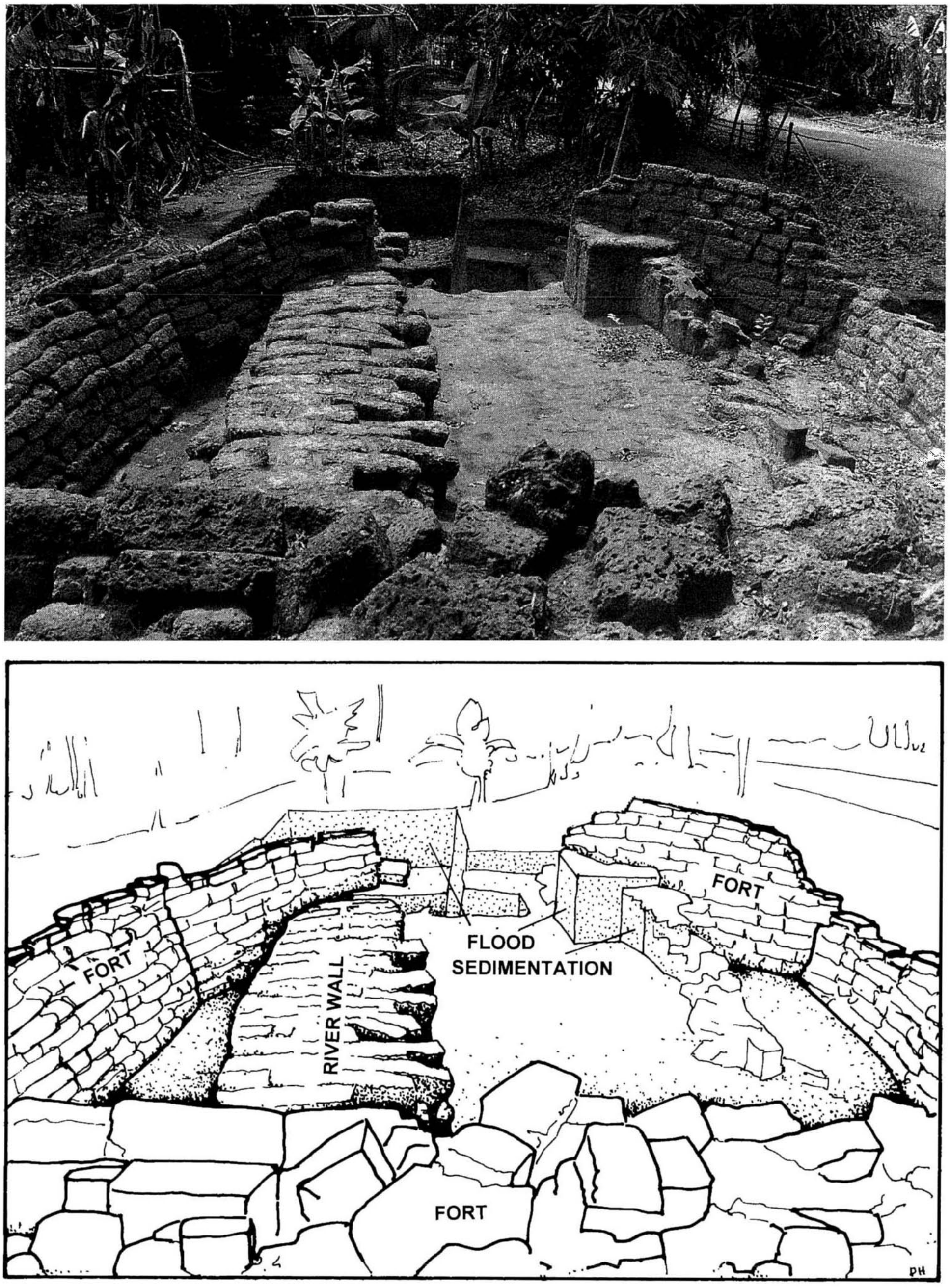


Pl. IV*b*. Explanatory drawing showing features of photograph in Pl. IV*a*, on facing page.

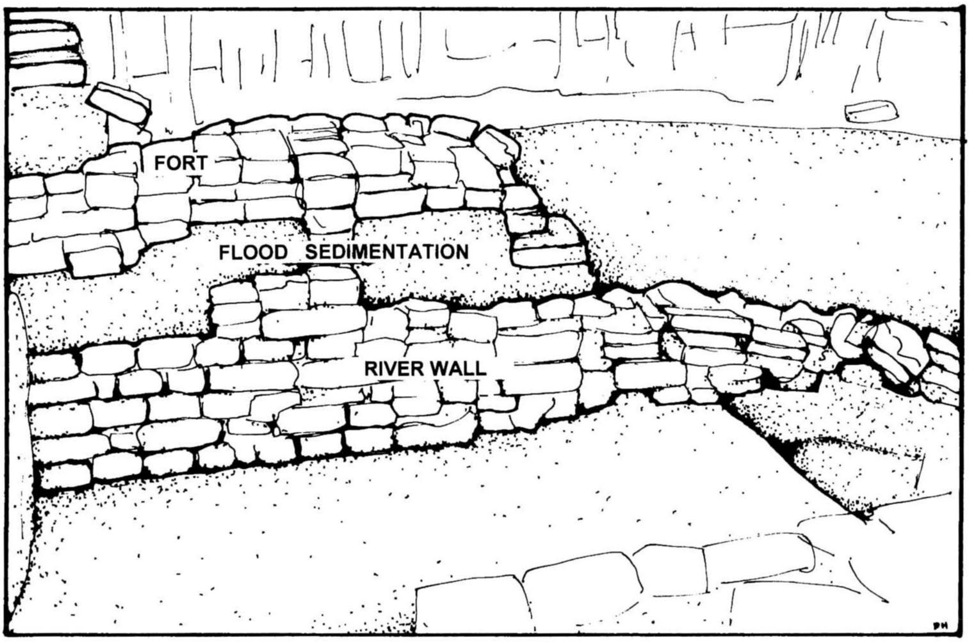
between hydrological records throughout Southeast Asia, and it should, therefore, be possible, at least at a general level, to use other records that reflect regional hydrological conditions as a proxy recording of the conditions of the Yom at the same time. The long hydrological and meteorological records from China cover the period during which Sawankhalok blossomed and waned and are therefore very appropriate for such a comparison.

The Long Records

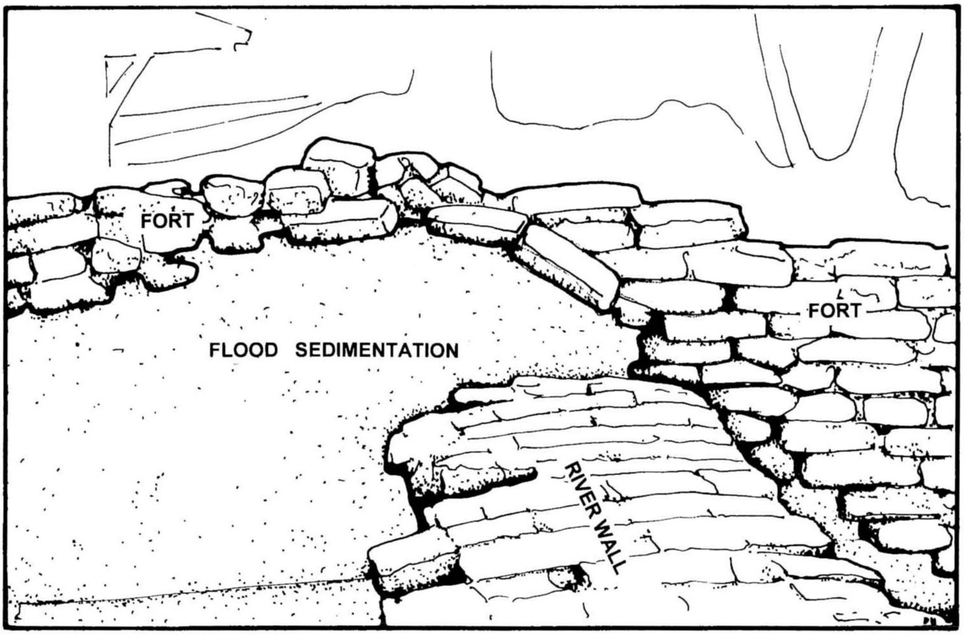
Chinese historical materials provide a wealth of information concerning weather and climate because the Chinese recorded weather patterns as historically impor-



Pl. V. Photograph *(top)* and explanatory drawing *(bottom)* showing that Fort F1 is built over the river wall at the Donlaem gate (see Fig. 9 for location of view). The fort post-dates the river wall, and Pls. IV*a*, IV*b*, VI, and VII show that the wall and the fort are separated by a period of flooding and sedimentation.



Pl. VI. Photograph *(top)* and explanatory drawing *(bottom)* showing flood sedimentation interbedded between the river wall and Fort F1 constructions at the modern Donlaem gate (see Fig. 9 for location of view).



Pl. VII. Photograph *(top)* and explanatory drawing *(bottom)* showing flood sedimentation interbedded between the river wall and Fort F1 constructions at the modern Donlaem gate (see Fig. 9 for location of view).

tant events. This interest related largely to the belief that the emperor was the son of the gods and could only be punished by them (Young 1981). Unusual events such as flood, drought, or famine were seen as punishment or at least a sign of heavenly displeasure and were recorded as a sign of the heavenly mandate of the emperor (Wang 1979). Poetry, diaries of scholars, military reports, records of produce prices, local and state chronicles, and gazettes have all yielded information about historical weather patterns. Zhang (1988) provides a good overview on the assessment of the meteorological content of such sources, especially with respect to bias and errors in the data.

Part of our interest here relates to the fact that the onset of the Indian monsoon and the "Mei-yu" rains in central and southern Yunnan Province are closely correlated (Bao 1987), and much of the moisture that falls as these rains originates in the Bay of Bengal (Chang 1984). This moist air must pass over northern Thailand on its way to China, meaning that hydrological conditions in the middle reaches of the Changjiang and Huaihe (Yangtze and Yellow Rivers) basins should mirror conditions at Sawankhalok. Indeed, our work in progress shows that there are good correlations between the two regions in both extremely wet and extremely dry years (Godley unpublished data). This means, in turn, that the flood chronologies of the Yangtze and Yellow Rivers (Fig. 10) should be good surrogates of the long-term flood history at Sawankhalok.

Long-term records of two winter meteorological phenomena in northern China (dustfall and the occurrence of winter thunder), which are not immediately and obviously related to regional hydrology, also seem to show the trends exhibited by records of flooding in the Yangtze and Yellow Rivers (Fig. 10). Importantly, records of these two phenomena are not subject to the sorts of biases that could be introduced into the flood data by the linking of, say, central government tax relief to reports of the severity of flooding. The levels of the two winter phenomena can be indirectly related, however, to moisture conditions. Winter thunder (Wang 1980) and dustfall (Zhang 1984) are reported to reflect winter temperatures and mean annual temperatures, respectively; high occurrences of both phenomena are associated with cooler conditions. Ju and Slingo (1995) have suggested that a colder than usual winter may, in turn, result in a weaker Asian monsoon in the following summer. A weak Asian monsoon is also known to be associated with a stronger Indian monsoon (Bao 1987), meaning that indicators of a cooler winter in northern China, such as high frequencies of winter thunder or dustfall, may imply a weaker Asian monsoon and hence a correspondingly stronger Indian monsoon. This stronger Indian monsoon results in higher flood frequencies in the Yangtze–Yellow River basins, even though the weaker, coeval Asian monsoon is responsible for general dryness in northern and southern China. Analysis of 500 years of flood/drought distributions produced by the Central Meteorological Office and Meteorological and Scientific Research Institute of China (1981) (see also summary by Zhang 1988) shows that this pattern of higher rainfall in the Yangtze–Yellow River basins accompanied by general dryness in northern and southern China is, in fact, one of three most common rainfall distributions in China.

All four Chinese data sets are consistent with the establishment and development of Sawankhalok during a period of generally decreased flooding in the thirteenth and fourteenth centuries (Fig. 10). Later in the city's life, a return to

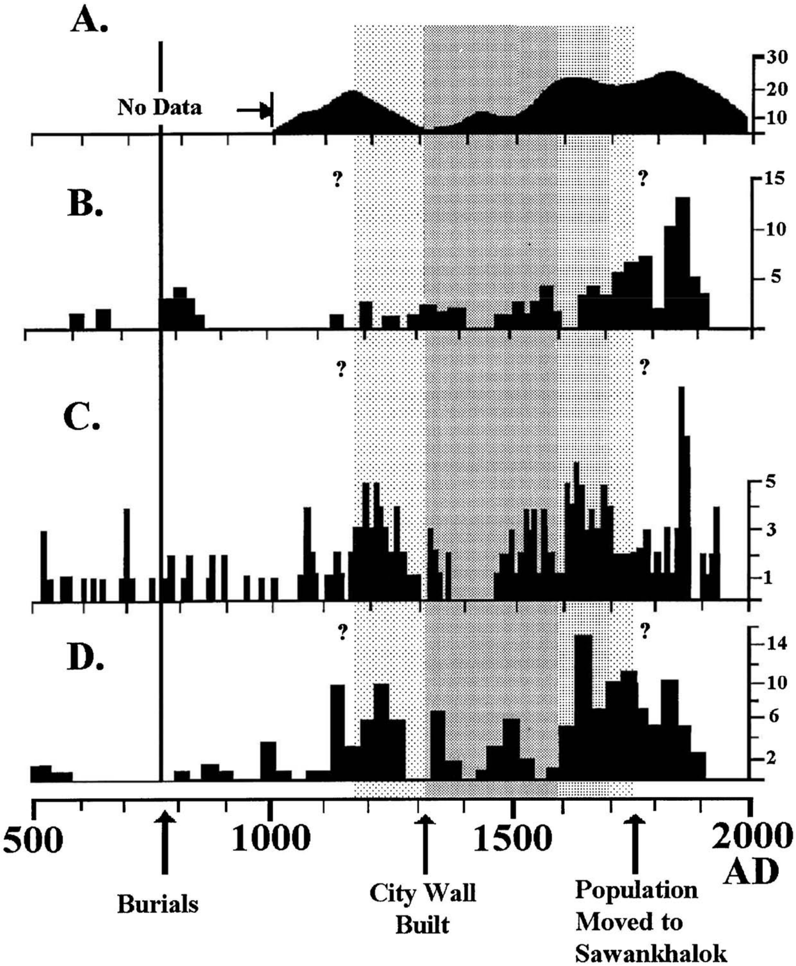


Fig. 10. The four long-term records of Chinese meteorological phenomena. The shading indicates the suggested lifetime of the city. A. Flood reports from the Yangtze River between Gongan and Shashi. B. Floods per century in the middle reaches of the Yellow River. C. Decadal frequency of dustfalls. D. Winter thunderstorms per 30 years.

moister conditions or higher flood frequencies is apparent, as indicated by evidence from the city itself, including the flood damage to the walls late in the city's life and the even later draining of the city by the digging of drains and the breaching of the wall.

DISCUSSION

Wyatt (1989:189) noted in his discussion of historical variations in the culture-environment relationship in Thailand that often "Thai history has been presented dryly in terms of political developments, economic movements through time, and the rise and fall of kings and kingdoms." Of course, it is almost a platitude that the environment must also have a profound impact on human activity, including urban location (Ng 1979). The demises of many of the great civilizations as a result of natural or human-induced environmental changes are sufficient illustration of this point (e.g., Ponting 1991). Indeed, understanding the interactions between people and environment is a venerable tradition, having found expression in some of the great debates in the disciplines of geography, archaeology, and palaeoanthropology, debates such as environmental determinism and the origins of agriculture. Overly simple environmental determinism has rightly been surpassed, despite occasional reappearances, such as in Rapee Sagarik's chapter in the proceedings of the Siam Society symposium on Culture and Environment in Thailand (Rapee 1989). The waning of environmental determinism often seems to mean, however, that the natural environmental dimension is now completely absent from many interpretations of social change and development in post-hunter-and-gatherer society. Indeed, we ourselves have argued in a somewhat similar vein that physical environmental issues, related to river erosion, were irrelevant to the decline of the Sawankhalok ceramics industry (Bishop et al. 1992).

The location of Sawankhalok was, of course, probably chosen initially because of the excellent source of food provided by the Royal Rapids. The propitious mix or conjunction of physical environmental characteristics at the site, including the disposition of the hills with respect to the river, and indeed perhaps the very orientation (west-east) of the river itself was also probably important certainly after Buddhists came to the site. The founding and subsequent development of the city appear also to have depended on the window of opportunity provided by a lower flood frequency. Once there had developed a city of sufficient economic importance (as a result of the flourishing ceramic export trade and, perhaps, irrigated agriculture) and political power (in relation to the demise of Sukhothai), these nonphysical factors (as well as inertia) would have meant that the city continued despite a return to higher levels of flooding and associated damage to the wall, particularly in the vicinity of the flood chutes. Some adaptation to this flooding may be signaled by the general lack of buildings in the area of the flood chutes and the apparent concentration of later buildings on the higher ground toward the hills. Nonetheless, the city appears to have continued to operate in the difficult environment associated with flooding, remembering that the inundation associated with this flooding involved sediment as well as water. This is a key difference between Sawankhalok and Bangkok (to return to our opening theme) and Venice (to take a further example); the latter are regularly flooded, but little sedimentation is associated with this flooding. Sawankhalok was evidently inundated by both water and sediment in the later phases of its life, presumably making it even more difficult to cope with the flooding. Nonetheless, the city persisted, surpassing Sukhothai. It is interesting to consider whether modern Bangkok (or Venice or Singapore or Hong Kong) could continue to function under the dual impacts of inundation by water and sediment.

The great political and economic power that urban centers both possess and represent will clearly tolerate significant negative physical impacts once the urban centers are established. In the case of Sawankhalok, the greatest impacts of flooding in the city appear to have occurred when it was at the center of a thriving ceramics export industry founded in part on a solid agricultural base that exploited complex and extensive water-management systems. This wealth evidently gave the city its overall resilience to flooding and sedimentation.

The transition from hunter-gatherer systems to urban society is rightly taken to signal less reliance on the physical environment, but the case of Sawankhalok shows that the physical environment can exercise significant influence on a city's founding and development in both obvious and less obvious ways. The physical environment at Sawankhalok was very appropriate for an urban location. Indeed, the configuration of the physical environment and the economic resource provided by the river may have been the fundamental reasons for choosing the site. The critical conjunction of hills, slopes, and river can be identified at several northern cities, including Chiang Mai, Sukhothai, Sawankhalok, and even, perhaps, Vickery's (1990) alternative location for Sawankhalok. The defensibility provided by the meander loop would also have been important.

The return to a regime characterized by more frequent or deeper flooding was tolerated while the economic base provided by the ceramic industry and irrigated agriculture continued, but the city ultimately declined, perhaps as the economics of the ceramics industry became more marginal, or power increasingly shifted to the south, or Sawankhalok became more and more vulnerable to invasion. It is tempting to add to these sociopolitical and economic reasons for Sawankhalok's decline and abandonment a final blow delivered by flooding and sedimentation. Regardless of whether or not this final flooding occurred before or after the city was abandoned, the final irony in the history of Sawankhalok is that the city's replacement location, modern Sawankhalok, is regularly inundated by flooding.

ACKNOWLEDGMENTS

The research reported here has been carried out over more than a decade with generous support from the Australian Research Council (grant to Hein and multiple grants to Bishop), The University of Sydney, Monash University, the Department of Fine Arts (Thailand), and the Hydrology Division of the Royal Irrigation Department (Thailand). We thank all these agencies and the National Research Council of Thailand for permissions and support. Thiva Supajanya (Chulalongkorn University, Bangkok) kindly lent us aerial photographs and discussed many aspects of the work presented here. Finally, our willing field assistants, Goh and Duang from Ban Ko Noi, have provided valuable help over many years.

NOTES

1. The site is traditionally and popularly known as Sisatchanalai, a practice we followed in earlier publications (Bishop and Godley 1994; Bishop et al., 1992, 1994; Godley et al., 1993). Vickery (1990) has argued, however, that the cluster of ruins and monuments being considered here represents the remains of the urban center Chaliang-Sawankhalok and that the remains of the city of Sisatchanalai are the deserted habitation areas and ruined temples 20 km to the south, on the Fakradan River. This argument awaits final resolution, but we follow Vickery in our use of "Sawankhalok" for the cluster of ruins enclosed by remnants of a city wall or embankment between the Royal Rapids (Kaeng Luang) and Wat Phra Prang (WPP) (Figs. 1 and 2). We use WPP for the locality enclosed by the meander loop, at the eastern end of the old city. Note that Sawankhalok, Sisatchanalai, and Sukhothai are the names of modern towns near the ancient cities. We use the city names here to refer to the ancient sites.
2. For ease of discussion in this paper, we use the term "−2 m" to designate the ground surface on which the Sukhothai-era buildings were constructed. This surface is not, of course, perfectly pla-

nar and horizontal, and the −2 m designation is simply an easy label. This surface is overlain by the occupation remains that the Thai Department of Fine Arts colloquially refers to as the Sukhothai unit.

REFERENCES

ANDERSON, D. D.
1989 Prehistoric human adaptations to environment in Thailand, in *Culture and Environment in Thailand: A Symposium of the Siam Society*: 101–123. Bangkok: Siam Society.

BAO CHENGLAN
1987 *Synoptic Meteorology in China*. Beijing: China Ocean Press.

BARBETTI, M., AND D. HEIN
1989 Palaeomagnetism and high resolution dating of ceramic kilns in Thailand: A progress report. *World Archaeology* 21 : 51–70.

BISHOP, P., AND D. GODLEY
1994 Holocene palaeochannels at Sisatchanalai, north central Thailand: Ages, significance and palaeoenvironmental indications. *The Holocene* 4 : 32–41.

BISHOP, P., D. HEIN, M. BARBETTI, AND THADA SUTTHINET
1994 Twelve centuries of occupation of a river-bank setting: Old Sisatchanalai, northern Thailand. *Antiquity* 68 : 745–757.

BISHOP, P., D. HEIN, B. MALONEY, AND A. FRIED
1992 River bank erosion and the decline of the Sisatchanalai ceramics industry of north central Thailand. *The Holocene* 2 : 159–163.

BRUNEAU, M.
1973 Dynamique des paysages et organization de l'espace dans la plaine de Sukhothaï (Thaïlande). *L'espace géographique* 3 : 207–223.

CENTRAL METEOROLOGY OFFICE AND METEOROLOGICAL AND SCIENTIFIC RESEARCH INSTITUTE OF CHINA
1981 *500 Years of Wetness/Dryness in China*. Beijing: Map Publishing House (in Chinese).

CHAMBERLAIN, J. R., ED.
1991 *The Ram Khamhaeng Controversy*. Bangkok: The Siam Society.

CHANDLER, D.
1993 *A History of Cambodia,* 2nd ed. Sydney: Allen and Unwin.

CHANG JENHU
1984 The monsoon circulation of Asia, in *Climate and Agricultural Land Use in Monsoon Asia*: 3–34, ed. M. M. Yoshino. Tokyo: University of Tokyo Press.

CHARNVIT KASETSIRI
1973 The Rise of Ayudhya: A History of Siam in the Fourteenth and Fifteenth Centuries, Ph.D. diss. Cornell University, Ithaca, NY.

CHEN JIA QI, YE YONG YI, AND TAN WEI YAN
1975 The important role of historical flood data in estimation of spillway design floods. *Scientia Sinica* 18 : 669–680.

CHU COCHING
1973 A preliminary study on the climatic fluctuations during the last 5,000 years in China. *Scientia Sinica* 16 : 226–256.

CHULALONGKORN UNIVERSITY, ED.
1984 The Inscription of King Ramkamhaeng the Great. Bangkok: Chulalongkorn University.

COEDES, G.
1966 *The Making of South East Asia,* Trans. H. H. Wright. London: Routledge and Kegan Paul.

ESCAP SECRETARIAT
1988 Geological information for planning in Bangkok, in *Geology and Urban Development. Atlas of Urban Geology* vol. 1 : 24–60. Bangkok: United Nations Economic and Social Commission for Asia and the Pacific.

GODLEY, D., P. BISHOP, AND THIVA SUPAJANYA
1993 Recent data on Thanon Phra Ruang: Road or canal? *Journal of the Siam Society* 81:98–109 (issued in 1995).

GONG GAOFA AND S. HAMEED
1991 The variation of moisture conditions in China during the last 2000 years. *International Journal of Climatology* 11:271–283.

GORDON, N. D., T. A. MCMAHON, AND B. L. FINLAYSON
1991 *Stream Hydrology: An Introduction for Ecologists.* Chichester: John Wiley.

GOSLING, B.
1991 *Sukhothai: Its History, Culture, and Art.* Singapore: Oxford University Press.

GUPTA, A.
1992*a* Flood and sediment production in Singapore, in *Physical Adjustments in a Changing Landscape. The Singapore Story*: 301–326, ed. A. Gupta and J. Pitts. Singapore: Singapore University Press.
1992*b* The urban environment of a tropical city: Study of a physical ecosystem, in *Physical Adjustments in a Changing Landscape. The Singapore Story*: 417–423, ed. A. Gupta and J. Pitts. Singapore: Singapore University Press.

GUY, J.
1989 *Ceramic Traditions of South-East Asia.* Singapore: Oxford University Press.

HEIN, D., P. BURNS, AND R. J. RICHARDS
1986 An alternative view of the origins of ceramic production at Sisatchanalai and Sukhothai, Thailand. *SPAFA Digest* 7(1):22–33.

HEIN, D., AND M. BARBETTI
1988 Sisatchanalai and the development of glazed stoneware in Southeast Asia. *Siam Society Newsletter* 4(3):8–18.

HEIN, D., M. BARBETTI, AND P. BISHOP
1988 Inhumation burials found at Sisatchanalai. *Siam Society Newsletter* 4(2):12–15.

HIGHAM, C.F.W.
1989 *The Archaeology of Mainland Southeast Asia.* Cambridge: Cambridge University Press.

HINSCH, B.
1988 Climatic change and history in China. *Journal of Asian History* 22:131–159.

HU MINGXI AND LO CHENGZHENG, EDS.
1992 *Great Historical Floods of China.* Beijing: Science Press (in Chinese).

JACOBS, J.
1972 *The Economy of Cities.* Harmondsworth: Penguin Books.

JOSEPH, P. V., J. K. EISCHEID, AND K. M. WEICKMANN
1994 Interannual variability of the onset of the Indian summer monsoon and its association with atmospheric features, El Nino and sea surface temperature anomalies. *Journal of Climate* 7:81–105.

JU JIANHUA AND J. SLINGO
1995 The Asian summer monsoon and ENS. *Quarterly Journal of the Royal Meteorological Society* 121:1133–1168.

LUNET DE LAJONQUIÈRE, E.
1986 *Le Siam et les Siamois.* Paris. Reprint of 1904 ed. (with introduction). Bangkok: White Orchid Press.
1912 Essai d'inventaire archéologique du Siam. *Bulletin de la Commission Archéologique de l'Indochine* 12:19–181.

LUO CHENG-ZHENG
1987 Investigation and regionalization of historical floods in China. *Journal of Hydrology* 96:41–51.

METEOROLOGICAL DEPARTMENT
1987 Climatological Data of Thailand 30 year period (1956–1985). Bangkok: Ministry of Communications.

MOORE, E.
1986 The moated Mu'ang of the Mun River Basin. Ph.D. diss. University of London.

NG, R.C.Y.
1979 The geographical habitat of historical settlement in mainland South East Asia, in *Early South East Asia*: 262–272, ed. R. B. Smith and W. Watson. New York: Oxford University Press.

NID SHIRANAN
1989 The contemporary Thai city as an environmental adaptation, in *Culture and Environment in Thailand: A Symposium of the Siam Society*: 371–391. Bangkok: Siam Society.

PFISTER, C., YAN ZHONGWEI, AND H. SCHULE
1994 Climatic variations in western Europe and China, AD 1645–1715: A preliminary continental-scale comparison of documentary evidence. *The Holocene* 4 : 206–211.

PHRA PRAISON SALARAK
1956 Our wars with the Burmese, trans. H.R.H. Prince Damrong Rajanubhap. *Journal of the Burmese Research Society* 38 : 121–297.

PIRIYA KRAIRIKSH
1993 A historiography of Sukhothai art: A framework in need of revision. *Journal of the Siam Society* 81(1) : 11–36.

PONTING, C.
1991 *A Green History of the World*. London: Sinclair-Stevenson.

PRINYA NUTALAYA AND J. L. RAU
1981 Bangkok: The sinking metropolis. *Episodes* 4 : 3–8.

RAPEE SAGARIK
1989 The traditional natural environment, cultural surroundings and forces of change in the Thai way of life, in *Culture and Environment in Thailand: A Symposium of the Siam Society*: 1–6. Bangkok: Siam Society.

SHAW, J.
1986 The kilns of Lan Na and the Tak hilltop burial sites. *Siam Society Newsletter* 2(4) : 1–13.

SIAM SOCIETY
1989 *Culture and Environment in Thailand: A Symposium of the Siam Society*. Bangkok: Siam Society.

SRISAKRA VALLIBHOTAMA
1986 Ancient settlements of Sukhothai, in *Papers from a conference on Thai studies in honor of William J Gedney*: 231–238, ed. R. J. Bickner, T. J. Hudak, and Patcharin Peyasantiwong. Ann Arbor: University of Michigan.
1989 Traditional Thai villages and cities: An overview, in *Culture and Environment in Thailand. A Symposium of the Siam Society*: 359–369. Bangkok: Siam Society.

STUIVER, M., AND P. J. REIMER
1993 Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35 : 215–230.

SUMET JUMSAI
1988 *Naga: Cultural Origins in Siam and the West Pacific*. Singapore: Oxford University Press.

TOMOSUGI, T.
1966 Historical development of irrigation in the Chao Phraya Delta, in *Water Resource Utilization in Southeast Asia*: 165–176, ed. Y. Fujioka. Kyoto: Center for South East Asian Studies.

VAN BEEK, S.
1994 *The Chao Phya*. Kuala Lumpur: Oxford University Press.

VAN LIERE, W. J.
1989 Mon-Khmer approaches to the environment, in *Culture and Environment in Thailand: A Symposium of the Siam Society*: 143–159. Bangkok: Siam Society.

VICKERY, M.
1990 The old city of "Chaliang"-"Sri Satchanalai"-"Sawankhalok." *Journal of the Siam Society* 78 : 15–29.

WANG PAO KUAN
1979 Meteorological records from ancient chronicles of China. *Bulletin of the American Meteorological Society* 60 : 313–318.

1980 On the relationship between winter thunder and the climatic change in China in the past 2,200 years. *Climatic Change* 3 : 37–46.

WANG PAO KUAN AND ZHANG DE'ER
1990 Use of historical documents of China to reconstruct past climate. *World Resource Review* 2 : 359–374.

WANG RISHEN, WANG SHAOWU, AND K. FRAEDRICH
1991 An approach to reconstruction of temperature on a seasonal basis using historical documents from China. *International Journal of Climatology* 11 : 381–392.

WEBSTER, P. J., AND S. YANG
1992 Monsoon and ENS; selectively interactive systems. *Quarterly Journal of the Royal Meteorological Society* 118 : 877–926.

WHITE, J. C.
1995 Modeling the development of early rice agriculture: Ethnoecological perspectives from northeast Thailand. *Asian Perspectives* 34 : 37–68.

WILAIWAN KHANITTANAN
1989 The order of the natural world as recorded in Tai languages, in *Culture and Environment in Thailand: A Symposium of the Siam Society*: 233–242. Bangkok: Siam Society.

WYATT, D. K.
1989 Discussion Leader's Comments, in *Culture and Environment in Thailand: A Symposium of the Siam Society*: 187–189. Bangkok: Siam Society.

YAN ZHONGWEI, YE DUZHENG, AND WANG CUN
1992 Climatic jumps in flood/drought historical chronology of Central China. *Climate Dynamics* 6 : 153–160.

YOUNG, S. B.
1981 The concept of Justice in pre-imperial China, in *Moral Behavior in Chinese Society*: 38–72, ed. R. W. Wilson, S. L. Greenblatt, and A. A. Wilson. New York: Praeger.

ZHANG DE'ER
1984 Synoptic-climatic studies of dust fall in China since historic times. *Scientia Sinica B* 27 : 825–836.

ZHANG JIACHENG
1988 *The Reconstruction of Climate in China for Historical Times*. Beijing: Science Press.

ABSTRACT

"Sawankhalok" is the name of the medieval city that was part of the Sukhothai kingdom and was located on the banks of the Yom River about 50 km north of Sukhothai. This city shows evidence of flood sedimentation of up to 2 m since its founding, prompting the question of when the flooding occurred and why the city was founded in an evidently flood-prone site. Several elements of the physical environment, especially the disposition of hills and river, are propitious in terms of Thai cosmology and almost certainly constitute one element in the decision to locate the old city at the site. Flood damage to the walls of the city indicate, however, that the city's founding and early growth probably occurred during a period of lower flooding. This conclusion is consistent with the long Chinese records of regional meteorological phenomena that are related to the strength of the monsoon, one of the key controllers of river flow at the old city. After being founded, the city persisted at this location despite a return to a regime of higher and, possibly, more frequent floods. This persistence was almost certainly related, at least in part, to the economic and political power that resided in the city and was founded on flourishing ceramics and agricultural industries and the decline of Sukhothai itself. The history of old Sawankhalok shows that the physical environment remains an important element in understanding the emergence of protourban sites, despite the lack of attention paid to this currently unfashionable element of urban development. It seems

that the old city would have been hard-pressed to develop had it been subject to inundation and sedimentation by floods. The modern Asian supercities are evidently likewise resilient to the extremes of the physical environment. Inertia is a strong factor in this resilience, but one might suggest that Bangkok would also find it very difficult to cope with regular inundation by flood waters and sediment.
KEYWORDS: geoarchaeology, historical climatology, urbanism, Thailand, Southeast Asian archaeology.