

A comprehensive archaeological map of the world's largest preindustrial settlement complex at Angkor, Cambodia

Damian Evans^{*†}, Christophe Pottier[‡], Roland Fletcher[§], Scott Hensley[¶], Ian Tapley^{||}, Anthony Milne^{**}, and Michael Barbetti^{††}

^{*}Archaeological Computing Laboratory and [§]Department of Archaeology, University of Sydney, Sydney NSW 2006, Australia; [‡]École Française d'Extrême-Orient, Siem Reap, Cambodia; [¶]National Aeronautics and Space Administration Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109; ^{||}Horizon Geoscience Consulting, Perth WA 6020, Australia; ^{**}School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney NSW 2052, Australia; and ^{††}School of Physical Sciences, University of Queensland, Brisbane QLD 4072, Australia

Edited by Michael D. Coe, Yale University, New Haven, CT, and approved June 29, 2007 (received for review March 17, 2007)

The great medieval settlement of Angkor in Cambodia [9th–16th centuries Common Era (CE)] has for many years been understood as a “hydraulic city,” an urban complex defined, sustained, and ultimately overwhelmed by a complex water management network. Since the 1980s that view has been disputed, but the debate has remained unresolved because of insufficient data on the landscape beyond the great temples: the broader context of the monumental remains was only partially understood and had not been adequately mapped. Since the 1990s, French, Australian, and Cambodian teams have sought to address this empirical deficit through archaeological mapping projects by using traditional methods such as ground survey in conjunction with advanced radar remote-sensing applications in partnership with the National Aeronautics and Space Administration (NASA)/Jet Propulsion Laboratory (JPL). Here we present a major outcome of that research: a comprehensive archaeological map of greater Angkor, covering nearly 3,000 km², prepared by the Greater Angkor Project (GAP). The map reveals a vast, low-density settlement landscape integrated by an elaborate water management network covering >1,000 km², the most extensive urban complex of the preindustrial world. It is now clear that anthropogenic changes to the landscape were both extensive and substantial enough to have created grave challenges to the long-term viability of the settlement.

archaeology | geographic information systems | remote sensing | Southeast Asia | urbanism

The first century of scholarship on Angkor, in Cambodia, was dominated by the need to conserve and restore the monuments, to locate Khmer civilization within broader cultural history, and to establish a basic chronological framework for Angkor and its Southeast Asian empire [9th–16th centuries Common Era (CE)]. In the early 1950s, Bernard-Philippe Groslier of the École Française d'Extrême-Orient (EFEO) became the first scholar to pay serious attention to the traces of a hydraulic network that had been partially mapped in the first half of the 20th century. Groslier surmised that it was both built and used for irrigation, specifically, to ameliorate variations in agricultural output caused by an unpredictable annual monsoon and to support a huge population of greater than a million people (1) in a constellation of suburbs. He also argued that the extent and breakdown of the network was implicated in the demise of Angkor (1, 2).

As one of the very few scholars in the 20th century with both an awareness of and an interest in the settlement pattern surrounding the monuments, Groslier also understood that a comprehensive and integrated program of archaeological research, including ground survey, remote sensing, and archaeological mapping, was needed to broaden the perspective beyond the great monuments and to provide a firm basis for assessing his theory (1–5). Importantly, he commissioned topographic maps of Angkor at 1:10,000

scale (5) that provided a much-needed foundation for archaeological mapping.

However, the burden of the *conservation d'Angkor* in the 1960s and the dire circumstances of Cambodia from the 1970s to the early 1990s made it impossible to fully realize his agenda: his archaeological mapping never went beyond the preliminary and raw topographic base maps, which remained unpublished until 1993 (6). Additionally, these maps were never completed for the area north of Angkor Thom, thus reinforcing a longstanding focus on the central and southern areas at the expense of the northern region. As a result, Groslier continued to use simple schematic maps to develop his theory (1) and Angkor remained, until the early 1990s and still to some extent even today, only partially understood as a settlement, as an inhabited space in which much of the economic, residential, agricultural, and probably even ritual activity took place beyond the walled enclosures and great stone temples of central Angkor.

Since the early 1990s, successive cartographic projects have sought to address this empirical deficit by producing detailed archaeological maps of the Angkor region. These maps include the main temples but also detail the residential areas, fields, and infrastructure that stretched far beyond the massive sandstone constructions (7–10). In the 1990s, the temple-centric focus of Angkorian studies was, for the first time, comprehensively challenged by the development of a new map of the central and southern areas of Angkor by Christophe Pottier of the EFEO (9, 10). His work originally grew out of the need to map and document the landscape of Angkor for the purposes of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage nomination and site management. Noticing the puzzling dichotomy between the clusters of monuments on the earlier maps and the hundreds of newly identified local temples dispersed across the landscape, Pottier then developed the mapping on a more precise scale by collating existing maps and documentation, analyzing aerial photographs and undertaking systematic field surveys. His final map, completed in 1999 (10), thus documented a built landscape of occupation mounds, local temples, and household ponds interspersed among the great monuments and the hydraulic works associated with them (Fig. 1).

Author contributions: D.E., C.P., R.F., and M.B. designed research; D.E., C.P., S.H., I.T., and A.M. performed research; D.E., C.P., R.F., S.H., I.T., and A.M. analyzed data; and D.E. and R.F. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Abbreviation: CE, Common Era.

[†]To whom correspondence should be addressed at: Archaeological Computing Laboratory, Madsen Building F09, University of Sydney, NSW 2006, Australia. E-mail evans@acl.arts.usyd.edu.au.

© 2007 by The National Academy of Sciences of the USA



Fig. 1. Oblique aerial views of remnant Angkorian urban features. (Upper Left) Occupation mounds and ponds. (Upper Right) Canals and embankments. (Lower Left) Multifunction roadway/canals. (Lower Right) Classic “village temple” configuration.

Pottier also showed decisively that the great reservoirs, or *barays*, had inlets and outlets and were connected to a network of channels and embankments, contrary to the assertions of critics of Groslier’s hydraulic thesis from the 1980s onwards (11–14). Moreover, the longstanding assumption (2, 11) that the extensive agricultural field systems visible on the surface today might date from Angkorian times was supported by his new map, which displayed the integral connection between the local temples and their agricultural space (15). Various other elements of the classical Angkorian landscape, in particular, the small ponds described in an account of Angkor in the 13th century (16), have also persisted on the surface, were clearly identifiable from the air and have often been renovated and reused by the contemporary Khmer population. Archaeological evidence of Angkorian occupation (in particular, brick and ceramic debris) was consistently found at the sites that had been identified from the air and was documented and collected wherever appropriate (10). Field verification continues across the greater Angkor region in a process that has consistently matched aerial observations with surface evidence. Recent excavations at the Siem Reap airport (17) and elsewhere have provided further stratigraphic evidence of continuity between subtle topographic features visible on the surface today and the urban landscape of medieval Angkor.

Pottier’s new study used the maps commissioned by Groslier as a cartographic base (because they were the only available ones at that time), and began the process of creating a comprehensive archaeological map of Angkor by recording several thousand of these features and part of agricultural field system within an area of $\approx 1,000$ km². The coverage of that survey was limited to the southern and central parts of Angkor by the available cartographic base and by the persistent security risks in Siem Reap Province until 1998. However, it was clear from remote sensing that the contiguous settlement space of Angkor extended well beyond what had been mapped; further survey was therefore required.

Since the completion of Pottier’s initial mapping in 1999, the Greater Angkor Project (GAP), an international research program (Australian, Cambodian, and French) focusing on the spatial structure, the water management network, and the reasons for the

decline of Angkor, has continued to extend the spatial coverage of detailed archaeological mapping by using a diverse range of data sources, field techniques, and, notably, airborne imaging radar (AIRSAR) data acquired for GAP in 2000 by National Aeronautics and Space Administration (NASA)/Jet Propulsion Laboratory (JPL).

Mapping

One of the first tasks was the digitization of Pottier’s 1999 hand-drawn map and the conversion of its data into a geographic information system. Subsequent mapping work has concentrated on the use of airborne radar imaging (AIRSAR/TOPSAR) for archaeological survey, in particular using data acquired over Angkor in September 2000 by NASA/JPL on behalf of GAP (18), expanding on previous radar data acquisitions in 1994 on behalf of the World Monuments Fund (SIR-C/X-SAR) and in 1996 on behalf of Elizabeth Moore of the University of London, London, U.K. (AIRSAR). The first stage of GAP’s analysis, begun in 2001 and completed in 2002, was undertaken with a view to very quickly producing a “broad-brush” picture of the settlement pattern to the north of Pottier’s study area. The specific aims were to gain an understanding of the interaction of microwave sensors with the archaeological landscape, to develop and refine methods of systematically applying imaging radar to an archaeological investigation, and to assess the feasibility and likely outcome of a more detailed survey incorporating heterogeneous data sources.

The AIRSAR instrument is an active sensor with the ability to penetrate clouds. On its 2000 deployment over Angkor, multiple channels of data (C band at 3 cm, L band at 25 cm, and P band at 64 cm, with polarisation measured at transmit and receive) were acquired over $\approx 8,000$ km² through 98% cloud cover. The ability of the AIRSAR instrument to produce high-quality, high-resolution data sets describing surface roughness and electrical properties is well documented [Jet Propulsion Laboratory (2006) *AIRSAR Airborne Synthetic Aperture Radar Documentation*. Available at <http://airsar.jpl.nasa.gov/documents/index.html>] and does not warrant detailed treatment here. It is, however, worth noting that the ability of the instrument to distinguish very subtle differences in surface vegetation and surface moisture was of particular use in uncovering the archaeological landscape at Angkor. The distinctive spatial patterning of features manifests itself primarily in slight variations in topographic relief, which in turn produces variations in the species of surface vegetation and soil humidity. These strongly influence the amplitude or “brightness” of the radar signal returned to the sensor.

A very important example of this phenomenon is the local temple, which usually consists of a ≈ 20 -m square central mound of ≈ 0.5 m to 2 m in height, surrounded by a shallow moat of less than ≈ 1 m in depth and usually traversed by an earthen causeway on its eastern side, lending the moat-and-mound complex a distinctive spatial structure. This complex in turn typically has a small rectangular reservoir immediately to the east, whose orientation is generally east-to-west and whose ratio of length to width is $\approx 2:1$. Some of the local temples have architectural remains such as bricks scattered on the surface and are well known as temple sites, whereas many others have been completely subsumed by modern residential or agricultural developments and are essentially undetectable on the ground. Most of these temples, however, can be detected in the radar imagery. For example, in many cases the slightly lower elevations of the rice fields in the former moat and reservoir and the slightly higher elevations of the fields built on top of the remnant mound and reservoir banks result in different stages of rice maturity and in differential levels of soil moisture content, which strongly affect the returned radar signal. Moreover, the bunds of the rice fields act as very bright corner reflectors to the radar signal. The fact that remnant moats and reservoirs are usually subdivided into these fields serves to delineate the typical spatial configuration of a temple site very clearly within the radar imagery. For the same

reasons, the identification and mapping of Angkorian field systems, linear features such as roads and canals, and the ponds that surround the local temples can be performed very quickly and effectively using these data (19).

From 2000 to 2002, some 1,500 km² of the landscape beyond Pottier's 1999 map were studied from the AIRSAR images (7), with all features documented and mapped within a geographic information system environment. The results of this initial survey were extremely promising. A highly complex linear network to the north of Angkor was revealed, adding great detail to the area described by Groslier, as well as significant residential and agricultural development throughout a large part of the study area. The GAP excavations have indicated a degree of human occupation along some of the embankments and channels of the network (8), connecting the infrastructure to the residential pattern of Angkor. The mapping also showed that Angkor had a complex, tripartite, water management network for systematically stabilizing, storing, and dispersing water.

The preliminary archaeological map of the Angkor area resulting from the AIRSAR study has, until now, represented the most complete picture of the settlement. Importantly, although the map and any conclusions drawn from it were highly provisional, it became increasingly clear from this work that the site represented possibly the largest complex of low-density urban development in the preindustrial world.

Ultimately, however, the ability of this map to provide a final, decisive picture of the settlement landscape of Angkor was limited by the horizontal spatial resolution of the radar data. At 5 m it did not allow the consistent recognition of occupation mounds and made the identification of local temples and small ponds problematic. Also, the methodology was dedicated as much toward assessing the radar's capabilities as it was toward the particular historical problem of urban development at Angkor.

The next stage of mapping, from 2003 to 2007, was designed to move the cartographic project toward a definitive conclusion. A notable change from previous surveys of Angkor was the specification of a nonarbitrary survey boundary. In light of the GAP focus on the extent of human manipulation of water resources, it was decided to use the watershed catchment boundaries of Angkor's rivers^{††} to define a study area. The study area covers 2,848 km², divided into 1-km grid squares. Each was analyzed individually in detail, with consideration given to all of the available evidence, including the diverse site inventories, every archaeological map produced over the last century, topographic data sets, and remotely sensed data from a range of sources, including Landsat, ASTER, SPOT, AIRSAR, Ikonos, Quickbird, and conventional aerial photography, in particular the 1:25,000-scale Finnmap 1992 coverage already used by Pottier (10).

The understanding of radar's interaction with the archaeological landscape developed in the previous study was brought to bear heavily on this work, which was considerably enhanced by the delivery in 2003 by NASA/JPL of a digital elevation model derived from the September 2000 AIRSAR deployment. This TOPSAR data set specifies a height value for every 5 m² of the landscape with submeter accuracy and allows for extremely precise analyses of the subtle topographic variations that characterize remnant Angkorian features.

In contrast to the radar-derived preliminary archaeological map of 2002, the 2007 map is conservative in the features mapped and displayed. A feature had to be visible in at least two different data sources or to be verified from ground level or low-altitude aerial-survey to satisfy the criteria for inclusion. It is anticipated, therefore, that a number of features will be added to the map as verification

continues, just as some features will inevitably prove to be post-Angkorian and will need to be removed. This process continues even for Pottier's map, which has been well verified and covers areas that have been intensively studied for over a century. It is extremely unlikely, however, that the addition or subtraction of a relatively small number of minor features will qualitatively alter the current representation of settlement space and the overall layout of the water management network. In this sense the map presented here can be considered definitive.

Results

The final phase of the mapping work, completed in 2007 and presented here (Fig. 2), reveals Angkor as an extensive settlement landscape inextricably linked to the water resources that it increasingly exploited over the first half of its existence. It was not simply a succession of spatially distinct ceremonial centers or a carefully planned sacred space but, as Coe suggested in 1957 (20), a low-density urban complex like the Classic Maya cities of the Yucatan peninsula such as Tikal (21). As with modern low-density cities and the Classic Maya cities, Angkor was a cumulative settlement palimpsest, with an organic and polynuclear form arising from social and environmental processes operating over more than half a millennium.

Angkor is visibly an infrastructural network, along which people also lived, imposed on the regional pattern of the residential landscape north of the Tonle Sap. The large-scale infrastructure gave coherence to the scatter of traditional residential units and "created" Greater Angkor as a corporate entity. The key question is the extent of the low-density urban complex. The critical point is that the smaller component of the settlement pattern (the local temples, the occupation mounds, the ponds, and the durable and highly structured web of agricultural space that binds them) occurs with remarkable consistency within ≈ 15 – 25 km of the current high-water mark of the lake. Furthermore, an analysis of the Landsat data shows that this form of small-scale, low-density occupation continues essentially uninterrupted far beyond the north-western and south-eastern boundaries of the study area, and there is evidence of contiguous, even lower-density occupation across a large swathe of the Cambodian landscape (see Fig. 3). Although there are areas of somewhat more concentrated occupation, there is, at this stage, no particular spatial or temporal pattern that lends itself to a convenient boundary definition.

For the time being, perhaps the most satisfactory solution to the question of Angkor's extent is therefore to take the infrastructural network as an indicator of cohesion in relation to the major monuments in the central 200–400 km². The sheer scale of the network and its capacity to impact profoundly, regularly, and immediately on large areas of the inhabited landscape integrated an extended area into a single operational system within a circuit of great monuments and hilltop shrines located ≈ 20 – 25 km out from the center. Within this area of $\approx 1,000$ – $1,200$ km², the northeast quadrant near Banteay Srei is largely empty of visible occupation features. The "boundary" of the urban complex of Angkor, as it can be loosely defined from the infrastructural network, encloses ≈ 900 – $1,000$ km² compared with the ≈ 100 – 150 km² of Tikal (21), the next largest preindustrial low-density city for which we have an overall survey. Mirador, a Pre-Classic Maya urban complex, and Calakmul, a Classic site near Tikal, may be more extensive, but as yet we do not have comprehensive overall surveys for these sites; it is nonetheless clear that no site in the Maya world approaches Angkor in terms of extent (M. Coe, personal communication).

Notably, amongst a variety of significant outcomes, the mapping has resulted in the identification of two massive earthen structures, whose precise function remains unclear, east of the East Baray and to the southwest of Phnom Dei 1 (Figs. 4 and 5). Eventually, several thousand individual features (mostly ponds) were mapped as part of this process. A large number of these features do not appear in previous maps or within existing site inventories, including, for

^{††}Kummu, M., 5th World Archaeological Congress, June 21–26, 2003, Washington, DC, available at http://users.tkk.fi/~mkummu/publications/kummu_WAC_Washington_DC_2003.pdf.

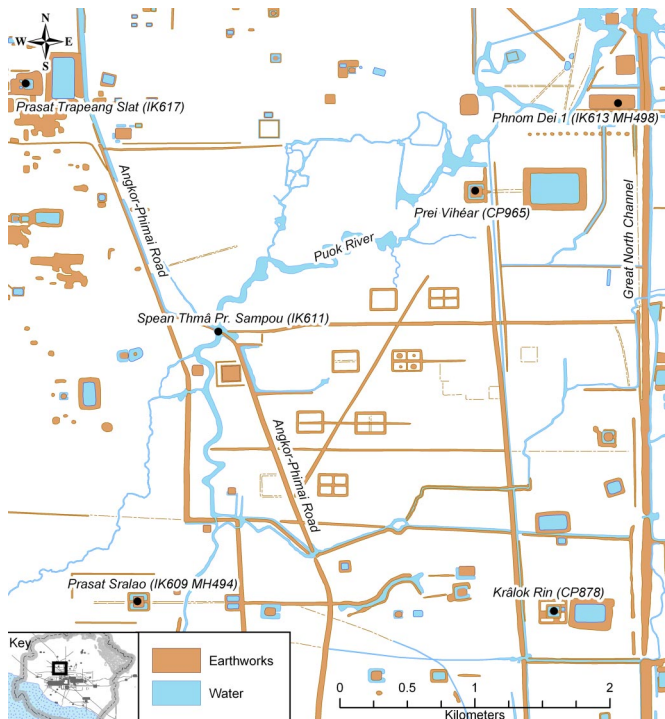


Fig. 4. An arrangement of eight grid-like enclosures between the Angkor-Phimai Road and Prei Vihear/Phnom Dei. Note that the road partially obliterates one of the enclosures, indicating that the structure is older than the (circa 11th- to 12th-century) road. Note the large Angkorian embankments running south from the Puok River toward the northeast corner of the West Baray, the size and great complexity of the infrastructure in the area, and also the numerous breaches of dykes and embankments by later watercourses.

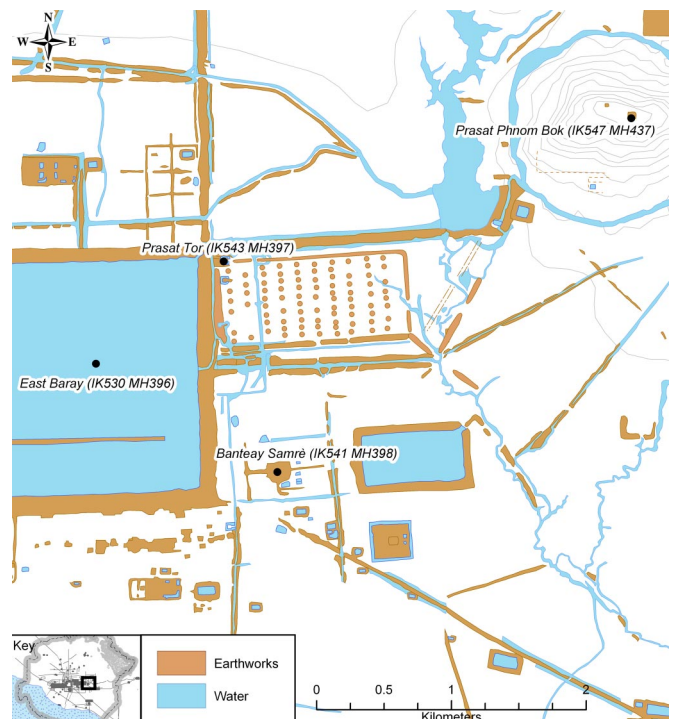


Fig. 5. An enclosed grid of mounds to the east of the East Baray. Note that it is isoclinal with Banteay Samre and with the eastward extension of the northern wall of the baray, rather than with the baray or its outlet. Note also the extremely complex water management system in the area, including a northeast corner entry to the baray and the Krol Romeas distribution outlet from the center of the east bank of the East Baray into the Roluos River system.

Khlor hills to the north. The new maps show that landscape modification at Angkor was both extensive and substantial enough to have produced a number of very serious ecological problems, including deforestation, overpopulation, topsoil degradation, and erosion. Whatever the functions of the infrastructural network, the impact of extensive clearance for rice fields, the economic and demographic consequences of constant modifications to the landscape, and unpredictable events such as flooding or warfare would potentially have been extremely serious for such an elaborate and interlinked system. The Siem Reap river is now incised 5–8 m into the Angkorian floodplain, and a major canal in the south of Angkor that postdates the 14th century CE is entirely filled with cross-bedded sands, indicating rapid movement of large quantities of sediment-laden water (8). There is also evidence, particularly in the newly mapped northern region, of ad hoc adaptations, breaches, modifications, and failures within this system, suggesting that it became increasingly complex and unmanageable over several centuries of development (Figs. 4 and 5). Current work by the GAP, including annual seasons of coring and excavations, is focused on dating those events.

Discussion

From a theoretical point of view, the key issue with the current map is the common problem of chronological resolution within an extraordinarily large collection of temporally undiagnostic surface data (22). Although it is unrealistic to expect archaeologists to be able to excavate a substantial proportion of the newly mapped sites in the near future, efforts to attach temporal attributes (derived from inscriptions, artifacts, architectural analyses, absolute dating methods, and so on) to critically important features within the map data are ongoing as part of the GAP. From this research, the spatial and temporal development of urban form at Angkor will be

amenable to modeling with a much greater degree of precision. Early settlement may have been along the lakefront and perennial water sources as Groslier suggested (1), a theory that has also been supported by recent excavations (23, 24). For the time being, the new mapping is consistent with Pottier’s (10) observation, based on his 1999 map of the south, that there appears to have been a gradual increase in occupation across all of the areas that were eventually inhabited over the course of about a millennium. This gradual process appears to have been punctuated by occasional, localized rapid development, for example in the Roluos area in the 8th and 9th centuries CE. However, this observation is based largely on the development of the major temple sites, and it remains to be demonstrated that the phenomenon is an accurate reflection of the nature of smaller-scale residential development. Ceramics found throughout Angkor are also consistent with Groslier’s (1) assumption that, at its peak in the 11th to 13th centuries CE, the entire settlement space as mapped was largely inhabited. At this stage, the only compelling evidence of the decline of an entire area during the Angkor era comes from the Roluos region, in particular the Bakong temple, where palynological studies (25) and archaeological excavations (23, 24) suggest a marked decrease in both agriculture and occupation in the late 9th and early 10th centuries. The Bakong moat fell into disrepair at around the same time. However, the spatial extent of abandonment beyond the temple, which saw very substantial redevelopment in the 12th century (26), cannot be precisely determined from the pollen data at this stage (D. Penny, personal communication).

Angkor meets the material requirements of Groslier’s proposed “hydraulic city” in that it possessed an immense, integrated, and highly complex system of water catchment, storage, and redistribution. The fact that the hydraulic city concept has previously been associated with the outmoded ideas of Wittfogel (27) is, as Pottier (15) points out, insufficient grounds for abandoning the entire

concept and its various implications, especially in light of evidence emerging from recent archaeological research. Although ground-based archaeological investigations at Angkor are nowhere near as advanced as at comparable sites in Mesoamerica, for example, surface surveys (10) and excavations (8, 17, 23, 24) have consistently demonstrated that the features identified through remote sensing are of Angkorian origin and have the potential to provide crucial data about the rise and fall of urbanism in this area and the role of water management systems in that process.

Around the ponds and the local temples and on the occupation mounds it is now possible to see the fabric of residential life stretching around and far beyond the infrastructural network. The areal extent of the urban complex remains to be clarified by detailed analysis of its network connectivity. What is critical is that the present study has affirmed Groslier's essential propositions about the structure of Angkor and now directs attention to his overall hypothesis that the collapse of Angkor was due to overexploitation of the landscape (1). The discussion of the implications must therefore be broadened well beyond the prevalent debate about whether or not the network was used to irrigate rice. As Groslier himself pointed out (1), this aspect of the hydraulic city was just one among many, even if it was the one that he elaborated on the most and that he clearly believed to be the most important.

Although it is important to recognize that certain elements of Angkor (for example, the temple of Angkor Wat) were never entirely abandoned, it is nonetheless very clear from the new maps that the settlement declined dramatically from a level of high complexity in the mid-second millennium AD, and that this constitutes a "collapse" by any standard definition (28–30). By pursuing both the ideas and the methods proposed by Groslier combined with innovative techniques, such as airborne radar, the GAP will continue to investigate the degree to which the water management network and the environmental effects of the urban expansion of Angkor were implicated in that decline.

The size and settlement pattern of Greater Angkor have substantial implications for its management as a cultural resource. The

well preserved remains of the urban complex extend far beyond the designated World Heritage zone that surrounds the central temples, highlighting the need to reappraise, in due course, how this remarkable heritage site is to be managed.

The outcomes presented here are also of considerable relevance for understanding the nature of urban settlements in Southeast Asia (31) and the analysis of past landscapes in the same region (32) and in particular for research on other temple complexes of the 1st millennium CE in the tropical world. Many of these, like Angkor and the Maya temples, may also lie at the center of previously undetected low-density urban settlements that are often obscured by vegetation or modern settlements. The key sites to be examined in South and Southeast Asia include Pagan in Myanmar, Anuradhapura and Pollonuruwa in Sri Lanka, Borobudur and Prambanan in Indonesia, Sukhothai in Thailand, Sambor Prei Kuk and Koh Ker in Cambodia, and My Son in Vietnam. Although there may prove to be no substantial occupation around the monuments at these sites, further analysis is critical, because similar discoveries in these locations would transform our understanding of their social, cultural, and environmental contexts in much the same way as has happened for the Maya settlements and now for Angkor. This, in turn, will provide a foundation for comparative studies of the great cities that emerged and then collapsed in fragile tropical ecosystems, an important and topical field of research that has received minimal attention thus far.

We thank Dan Penny, Terry Lustig, Andrew Black, and Michael Coe for their comments on drafts of this paper; Bruce Chapman of the Jet Propulsion Laboratory for his work on processing the radar data; and Donald Cooney, Eddie Smith, Alexandra Rosen, and the crew of the Angkor Ultralight Survey Group for their support of this project. Funding was principally from the Australian Research Council but also from the Mekong River Commission, the University of Sydney, l'École Française d'Extrême-Orient, the Authority for the Protection and Management of Angkor and the Region of Siem Reap, the Carlyle Greenwell Bequest (D.E.), and the Iain A. Cameron Memorial Travel Grant Fund (D.E.).

- Groslier B-P (1979) *Bull Éc Fr Extrême-Orient* 66:161–202.
- Groslier B-P (1958) *Angkor et le Cambodge au XVIe Siècle d'Après les Sources Portugaises et Espagnoles* (Press Univ France, Paris).
- Groslier B-P (1956) *Sciences et Voyages* 125:24–28.
- Groslier B-P (1970) *Indochina* (Barrie & Jenkins, London).
- Groslier B-P (1962) *Programme de Recherches Urgentes à Angkor* (École Française d'Extrême-Orient, Siem Reap, Cambodia).
- Pottier C, Dumarçay J (1993) *Documents Topographiques de la Conservation des Monuments d'Angkor* (École Française d'Extrême-Orient, Paris).
- Evans DH (2002) BA Honors thesis (University of Sydney, Sydney).
- Fletcher RJ, Barbetti M, Evans D, Than H, Sokrithy I, Chan K, Penny D, Pottier C, Somaneath T (2003) *Udaya* 4:107–121.
- Pottier C (1994) in *Southeast Asian Archaeology 1994: Proceedings of the 5th International Conference of the European Association of Southeast Asian Archaeologists, Paris 24th–28th October 1994*, ed Manguin P-Y (Centre for Southeast Asian Studies, Hull, UK), pp 179–194.
- Pottier C (1999) PhD thesis (Université Paris III, Sorbonne Nouvelle, Paris).
- Van Liere WJ (1980) *World Archaeol* 11:265–280.
- Acker R (1998) *South East Asia Res* 6:5–47.
- Higham C (2001) *The Civilisation of Angkor* (Weidenfeld & Nicolson, London).
- Pottier C (2001) *Aséanie* 8:167–176.
- Pottier C (2000) *J Sophia Asian Stud* 18:1–21.
- Chou Ta-Kuan (1993) *The Customs of Cambodia*. (The Siam Society, Bangkok, Thailand).
- Baty P (2005) *Extension de l'Aéroport de Siem Reap 2004: Rapport de Fouille Archéologique* (Authority for the Protection and Management of Angkor and the Region of Siem Reap–Institut National de Recherches Archéologiques Préventives, Siem Reap, Cambodia).
- Fletcher RJ, Evans DH, Tapley IJ, Milne AK (2004) *Bull Indo-Pacific Prehistory Assoc* 24:133–138.
- Fletcher RJ, Evans DH, Tapley IJ (2002) in *Proceedings of the 2002 AIRSAR Earth Science and Application Workshop, NASA/JPL* (National Aeronautics and Space Administration, Pasadena, CA). Available at <http://airsar.jpl.nasa.gov/documents/workshop2002/papers/P1.pdf>.
- Coe M (1957) *Am Antiquity* 22:409–410.
- Puleston DE (1983) *The Settlement Survey of Tikal* (The University Museum, University of Pennsylvania, Philadelphia).
- Ashmore W (1981) in *Lowland Maya Settlement Patterns*, ed Ashmore W (Univ New Mexico Press, Albuquerque), pp 37–69.
- Pottier C, Bolle A, Chhem RK, Demeter F, Gabillault C, Guerin A, Than H, Chan K, Latinis K, Boer-Mah T, et al. (2004) *Mission Archéologique Franco-Khmère sur l'Aménagement du Territoire Angkorien (MAFKATA): Rapport Préliminaire sur la Campagne de Fouilles 2004* (Authority for the Protection and Management of Angkor and the Region of Siem Reap–Ministère des Affaires Étrangères (France)–l'École Française d'Extrême-Orient, Siem Reap, Cambodia).
- Pottier C, Bolle A, Llopis E, Soutif D, Tan C, Chevance JB, Vireak K, Socheat S, Sang S, Demeter F et al (2005) *Mission Archéologique Franco-Khmère sur l'Aménagement du Territoire Angkorien (MAFKATA): Rapport préliminaire sur la campagne de fouilles 2005* (Authority for the Protection and Management of Angkor and the Region of Siem Reap–Ministère des Affaires Étrangères (France)–l'École Française d'Extrême-Orient, Siem Reap, Cambodia).
- Penny D, Pottier C, Fletcher RJ, Barbetti M, Fink D, Hua Q (2006) *Antiquity* 80:599–614.
- Boisselier J (1952) *Bull Éc Fr Extrême-Orient* 46:187–238.
- Wittfogel KA (1957) *Oriental Despotism: A Comparative Study of Total Power* (Yale Univ Press, New Haven, CT).
- Diamond JM (2005) *Collapse: How Societies Choose to Fail or Succeed* (Penguin, New York).
- Tainter JA (1988) *The Collapse of Complex Societies* (Cambridge Univ. Press, Cambridge, UK).
- Yoffee N (1988) in *The Collapse of Ancient States and Civilizations*, eds Yoffee N, Cowgill GL (University of Arizona Press, Tucson), pp 1–19.
- Miksic JN (2000) *World Archaeol* 32:106–120.
- Stark M (2006) *Annu Rev Anthropol* 35:407–432.