WORLD MONUMENTS FUND

WORKSHOP ON RADAR IMAGING AND CULTURAL RESOURCE MANAGEMENT AT THE ANGKOR ECO-SITE

and

SYMPOSIUM ON NEW TECHNOLOGIES AND GLOBAL CULTURAL RESOURCE MANAGEMENT

Report of the Second Scientific Roundtable
University of Florida, Gainesville

April 15-19, 1996

WORLD MONUMENTS FUND ▪ UNIVERSITY OF FLORIDA ▪ ROYAL ANGKOR FOUNDATION
▪ *New York* ▪ *May 1997*

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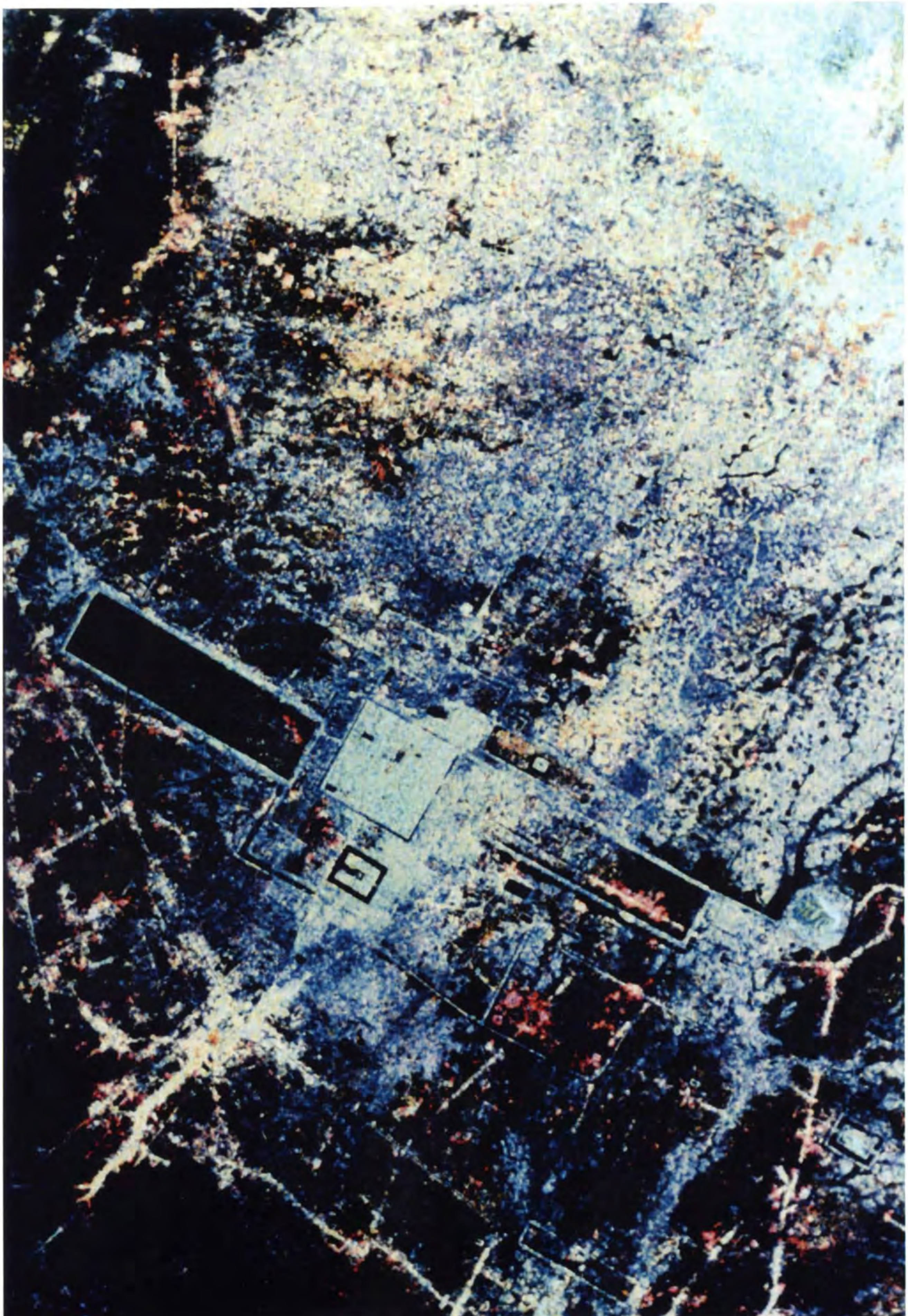
COVER PHOTOGRAPH: Using Dr. Tony Freeman's three component scattering model, conference participants study SIR-C/X-SAR L-band radar image of Central Angkor.

FRONTISPIECE: SIR-C/X-SAR radar image of the Angkor Eco-Site taken by the space shuttle *Endeavour* on September 30, 1994; the colors shown represent the following radar channels: red, the L-band; green , the L-band; and blue, the C-band.



The Second Scientific Roundtable convened thanks to the generous support of numerous benefactors and institutions who have understood the potential that remote sensing offers to the field of cultural resource management and the particular beneficial application of space-borne radar imagery at the Historic City of Angkor in Cambodia.

A grant from the Exploration and New Technologies Program of the J.M. Kaplan Fund in New York made possible the roundtable, with additional funding from the Samuel H. Kress Foundation in New York. The World Monuments Fund (WMF) in New York and the University of Florida in Gainesville provided significant supplemental support.

The Second Scientific Roundtable was honored by the attendance and participation of Cambodia's Minister of State for Culture and Fine Arts, H.E. Vann Molyvann. He has played a crucial role in the conservation of Angkor, notably through his leadership of APSARA, the government body in charge of the Historic City. His presence at the roundtable signified the Royal Cambodian Government's confidence in WMF's work at Angkor. The conference organizers were very pleased to welcome one of the Cambodian government's key advisors, anthropologist Dr. Ang Choulean.

WMF extends its gratitude to the University of Florida for hosting the roundtable. Special thanks go to University of Florida President John Lombardi, to Dean Wayne Drummond of the College of Architecture, and to Professor and Chair of the Department of Landscape Architecture, R. Terry Schnadelbach. Thanks to their staffs and students for granting access to facilities, including a roundtable "headquarters" in the GeoPlan Center, and for providing administrative support. The conference organizers and participants appreciated their warm hospitality.

The support and technical expertise of the Jet Propulsion Laboratory (JPL) in Pasadena, California, that manages the Sir-C project for the National Aeronautics and Space Administration (NASA) as part of the Mission to Planet Earth program, was critical to roundtable's success. Since the First Scientific Roundtable at Princeton University, JPL's radar imagery experts—Dr. Diane Evans, Dr. Tony Freeman, and Ms. Ellen O'Leary—have provided ongoing assistance in the interpretation of radar data and have promoted cultural resource applications at JPL and the National Aeronautics and Space Administration (NASA). The conference organizers also wish to thank Ms. Mary Hardin, JPL's Public Information Representative for Mission to Planet Earth, who has done a tremendous job in continually promoting the dissemination of our accomplishments to the public.

Our gratitude is extended to Hungarian Ambassador to Vietnam, Cambodia, and Laos, H. E. János Jelen, whose Royal Angkor Foundation (RAF) has developed an extensive Geographical Information System (GIS) of data on the Angkor Eco-Site.

The roundtable was organized and managed by the World Monuments Fund's Vice President for Programs, John H. Stubbs, and Program Administrator, Felicia Mayro, with generous assistance from the University of Florida's Department of Continuing Education and College of Architecture. This report was written by Keith Eirinberg, rapporteur and participant, and prepared in-house at WMF by the staff: Rebecca Anderson, director of publications; Jon Calame, projects coordinator; Felicia Mayro; Katherine Rodway, new media coordinator; and Julie Sumsion, freelancer.

Finally, thanks to all the experts who participated. Their presentations took the roundtable participants to sites as varied as Cambodia, the Crimea, Borneo, and Chaco Canyon in the United States. This resulted in the identification of common interests and goals in the application of remote sensing to global cultural resource management. The success of this Second Scientific Roundtable reflects their strong commitment to the use of state-of-the-art technologies in the preservation of cultural heritage.

Site Map of Angkor

ROUNDTABLE BACKGROUND

THE FIRST SCIENTIFIC ROUNDTABLE

The Jet Propulsion Laboratory directed the space shuttle *Endeavour* during its September-October 1994 mission to collect images of specific sites (cultural, natural, mixed, and archaeological) in swaths that included the historical site of Angkor in Cambodia using the SIR-C/X-SAR Earth Imaging Radar system. *Endeavour* collected these images as a first step in what proved to be a new way to assist in the documentation, analysis, monitoring, and management, of the Historic City of Angkor.

World Monuments Fund and the Royal Angkor Foundation jointly organized the First Scientific Roundtable at Princeton University in February 1995. The roundtable aimed to assemble a research team, assess the radar data collected, establish criteria for analyzing the data, and determine directions for research.

THE INTERIM PERIOD

French, Japanese, Hungarian, Thai, and British specialists at Angkor have in particular shown special interest in the use of this new technology with which it is now possible to see aspects of Angkor's history that have never been seen before. R. Terry Schnadelbach, Dr. Elizabeth Moore, and H. E. János Jelen have been in close touch with NASA's Jet Propulsion Laboratory in Pasadena, creating more direct communications between their institutions.

In May 1995, John Stubbs and H. E. János Jelen presented the report of the First Scientific Roundtable, *Radar-Imaging Survey of the Angkor Eco-Site* (WMF and Royal Angkor Foundation, 1995) to the International Coordinating Committee for the Conservation of Angkor (ICC). Ambassador Jelen presented the radar data on CD-ROM to H. E. Vann Molyvann, Cambodia's Minister of State for Culture and the Fine Arts.

Although to date the introduction of this technology has probably raised more questions than it has solved, the perception of Angkor as a vast ecosystem has advanced greatly in only fourteen months. There is now a greater body of data describing changes at the site over its chronology, the structure of Angkor's vast hydrological system, and what preceded the remains that exist today.

The scopic views afforded by radar imaging hastened to unify and to some degree harmonize the various research efforts at Angkor. In addition, since 1994, many institutional relationships, important intergovernmental relationships, and personal collaborations have developed. The Second Scientific Roundtable, "New Technologies and Global Cultural Resource Management," was held at the University of Florida, Gainesville, April 15-19, 1996. It comprised a three-day "Workshop on Radar Imaging and Cultural Resource Management at the Angkor Eco-Site" followed, on day four, by a two-day "Symposium on New Technologies and Global Cultural Resource Management." The international workshop and symposium brought together archaeologists, ecologists, architects, historians, and scientists who are working to apply remote sensing tools at global cultural heritage sites.

OBJECTIVES FOR THE SECOND SCIENTIFIC ROUNDTABLE

There was wide support for an international meeting that would address how these new technologies—radar imaging and other remote sensing applications—could significantly augment global cultural resource management. WMF proposed the organization and management of a follow-up meeting to discuss and synthesize information generated in the previous fourteen months, and to maintain momentum. The second roundtable offered an opportunity to move forward from the initial phase of space-borne radar imaging research towards applications and methodologies.

The Workshop was designed to tie ideas generated by analysis of radar imaging data and similar technological advances to the specific site and to be able to use these new techniques to study the past, present, and future of the Historic City of Angkor.

The Symposium offered the unique opportunity to study how radar imaging could complement other remote sensing applications at cultural heritage sites around the world.

THE WORKSHOP

OVERVIEW

The Workshop dealt specifically with space-borne radar imaging as a potential framework for all available remote sensing, land survey, and other relevant scientific data gathered at the Eco-Site of Angkor in Cambodia. The Workshop aimed to synthesize the various discoveries and advancements made since the First Scientific Roundtable, "Radar Imaging Survey of the Angkor Eco-Site," held at Princeton University in February 1995.

In addition, the Workshop further interpreted the SIR-C/X-SAR radar data of Angkor taken by the space shuttle *Endeavour* during its September-October 1994 mission. In doing so, three main topics were addressed: data management; prehistoric, historic, and archaeological discoveries; and ecological finds. The GeoPlan Center in the College of Architecture, equipped with computer work stations and software programs needed to conduct radar data analysis, served as the headquarters for the Workshop.

DATA MANAGEMENT

The Royal Angkor Foundation has thus far combined radar band data on Angkor with SPOT (Satellite for Terrestrial Observation) and ERS (European Remote Sensing) satellite imagery and aerial photography to achieve ninety-three different views of the Angkor area within its Geographical Information System (GIS). The RAF has added cartographic and topographical information to these layers along with newly amassed data from the 1992-93 UNESCO Zoning and Environmental Management Plan (ZEMP) for Angkor. The future RAF database will take information to new spheres, to platform independence where the data-base will be usable in any GIS system, including, but not limited to, ARC/INFO and INDRISI.

PREHISTORICAL, HISTORICAL, AND ARCHAEOLOGICAL DISCOVERIES

Over the last year, Dr. Elizabeth Moore, Department Head for Art and Archaeology of Southeast Asia at the School of Oriental and African Studies, University of London, studied three sites included in the Angkor radar data: Puok, central Angkor, and the ancient capital of Hariharalaya. She described her purpose as two-fold: "to characterize the scattering mechanisms as calculated for SIR-C data for known forms within these areas and eventually use the results to classify unknown areas, and to understand the use of the terrain and local hydrology in the transition from the prehistoric era to the era of historic settlement and water management."

In these three cases, Dr. Moore identified and studied four site "types": dikes, proto-mounds and mounds, temples, and water (e.g. barays, tanks, inundated zones). The use of radar imagery enabled Dr. Moore to study these ancient settlements and features that were not apparent from aerial photography or satellite remote sensing. Many could not be explored on land due to the threat posed by land mines. Thanks to some recent data processed by JPL, Dr. Moore hopes to compare settlements in northeast Thailand with those around Angkor.

ECOLOGICAL

Professor R. Terry Schnadelbach of the Department of Landscape Architecture, University of Florida, has studied the radar imagery of Angkor and discovered new features in the ecology of the site, which will help scholars understand the hydrology of the Angkor area and the Khmer civilization's management of water. These findings include 1) the presence of a large alluvial fan stretching out below the Kulen Hills, northeast of Angkor, 2) unique patterns of possible sinkholes within the fan, where pockets of water caused the land to collapse, and 3) springs cropping up along the way as water travels through internal aquifers to the Tonle Sap. Professor Schnadelbach has compared data from soil borings with the radar data and has postulated that Angkor was built upon the site of an ancient beach, where sand deposits lay near the surface. He suggests that sedimentation did not form the elevated area of Angkor's Western Baray. He believes radar data, SPOT satellite imagery, and topographic information show that the walls of the baray were possibly constructed to retain something besides water within the reservoir's boundaries. The elevated areas within may have served as an animal pen.

FUTURE APPLICATIONS

Radar imaging of the Tonle Sap has great potential use for the country's future. At a time when a plan for damming the lake's tributaries is being considered, the radar may offer a new and improved understanding of the life-cycle of this unusual body of water. The radar data may help Cambodia in its proposal to inscribe the Tonle Sap as a bio-reserve on the World Heritage List maintained by UNESCO.

In December 1996, NASA/JPL flew its airborne radar system known as AIRSAR/TOPSAR on missions in Southeast Asia, including an overflight of Angkor. Situated aboard a DC-8 jet, this system was able to collect data using a combination of polarizations and radar frequencies and it was able to generate topographic height data. This mission made use of radar's P-band, which penetrated the tree canopy and gathered data not obtained by the L-, C-, and X-bands used on the space shuttle mission. TOPSAR data would enable the construction of a computer-generated three-dimensional topographic map of the Angkor area.

THE SYMPOSIUM

OVERVIEW

The Symposium examined the use of radar imaging and other forms of remote sensing technology in worldwide cultural resource management. The common theme was the application of remote sensing to current archaeological work and cultural heritage sites. Participants were able to compare methodologies and learn about the development and use of new technologies. The benefits and drawbacks of remote sensing systems were examined: the limits of their technology, their effectiveness in different terrain, and their place within the priorities of site management. Symposium participants confronted the challenge of finding new ways to manage and disseminate the huge wealth of remote sensing data, especially by space-borne radar imaging.

The Symposium presentations offered a range of experiences and perspectives on remote sensing as a scientific tool.

- Project co-chair H. E. János Jelen discussed the challenges inherent in managing and disseminating the enormous amount of data emanating from remote sensing, especially radar imaging.
- Dr. Diane Evans of the Jet Propulsion Laboratory described the capabilities of space-borne radar imaging in different terrain and for archaeological and ecological purposes.
- Dr. Moore, Professor Schnadelbach, and Professor Claude Jacques of the Sorbonne related the latest developments in the use of radar imaging at Angkor and described their experiences using this technology in a tropical ecosystem.
- Dr. Farouk El-Baz of Boston University spoke about how radar imaging in desert regions has altered views on the evolution of the Egyptian desert and revealed new possible sites of ancient human habitation.

- Alexis Thomas of the University of Florida discussed how remote sensing data of a mountainous site, Kinabalu Park in Borneo, has been of limited assistance for the GIS he is building.
- Dr. James Wiseman of Boston University described the "Nikopolis Project" in northwestern Greece, where remote sensing by satellite has been used from the outset of the project.
- Dr. Joseph Carter and Dr. Jon Morter of the University of Texas spoke about the use of aerial remote sensing in the search for ancient land boundaries at Metaponto in southern Italy and Chersonesos in Crimea.
- Dr. Margaret McLean and Dominic Powlesland of The Getty Conservation Institute discussed the limitations of remote sensing, where a site manager must first determine its cost and effectiveness in managing the cultural heritage site. Their examination of these factors was discussed in the context of their field work at Chaco Canyon National Historical Park in New Mexico.
- Dr. Douglas Comer of the U.S. National Park Service explained the relative simplicity and cost-effectiveness of low altitude aerial remote sensing.
- Dr. John Alexander of the University of Florida described his ideas for technological breakthroughs, including the incorporation of satellite navigation equipment in cameras and laptop computers to assist researchers in the field.

CONCLUSIONS

The Symposium participants found radar data crucial for developing site context, monitoring, and management. Radar imaging's advantages include the use of radar interferometry for three-dimensional topographical mapping; its combination with other data types to provide a more comprehensive analysis of cultural heritage sites; its use in analyzing environmental change and projecting hazardous conditions; its assistance in developing ecological controls of human sites; and its use in determining archaeological features such as rivers, roads, and settlements. Ground penetration achieved by radar imaging can be used to study sites threatened by geological hazards such as volcanoes, earthquakes, and floods. However, there are limitations to what information radar data can supply. For example, it is not useful in interpreting large-scale regions.

At the conclusion of the week, three main areas of agreement emerged: radar imaging should be augmented by other remote sensing methods; remote sensing is best undertaken in particular seasons; and flexible and platform-independent software is needed to maximize applicability and results. Multidisciplinary teams are the most effective in analyzing data.

The participants encouraged the use of remote sensing data to assist the monitoring of sites and that the information gained through its use be shared with cultural resource managers. The opportunity exists at present to use available data to discourage projects that would have a negative impact on cultural resources, especially World Heritage sites and biodiversity reserves.

The participants agreed that future priorities should include the collection of additional data, the sharing of information on the use of remote sensing for cultural resource management, and widening the network of its users. While radar imaging and state-of-the-art technology will not solve all problems, both are valuable enhancements to understanding past civilizations and present environments.

THE WORKSHOP

THE PROCESS

The Workshop of the Second Scientific Roundtable centered around interaction between the archaeologists, ecologists, architects, and historians who study Angkor, and the scientists who help interpret the SIR-C/X-SAR radar data taken of the site by the space shuttle *Endeavour*.

The Workshop brought together Angkor researchers who have worked with the *Endeavour* radar data over the last year. Dr. Elizabeth Moore has worked with JPL in interpreting the data for prehistoric sites at Angkor. Professor Terry Schnadelbach has used the radar data to interpret the ecology of the historic site. Ambassador János Jelen and Robert Kuszinger have organized and introduced the radar data into the RAF geographic information system. John Stubbs has studied the radar data for new clues to the history and function of the Preah Khan temple complex and its adjacent areas.

Angkor researchers consulted technical specialists. Alexis Thomas of the University of Florida worked alongside the researchers in analyzing radar data on the GeoPlan Center's computers. JPL's Dr. Tony Freeman and Ellen O'Leary provided expert advice on analysis of the radar data. Robert Kuszinger demonstrated the sophistication and value of the RAF's GIS of Angkor.

WORKING SESSIONS

Distinguished Cambodian guests, H.E. Vann Molyvann and Dr. Ang Choulean, participated with JPL scientists and computer experts in "real-time" analysis of radar data pertaining to their country's most treasured cultural site. They were equally interested in determining what the radar images could say about Cambodia's great lake, the Tonle Sap.

Dr. Tony Freeman conducted an in-depth presentation on the SIR-C/X-SAR mission and radar imaging. His analysis centered on the physics of radar imaging. Later in the Workshop, Dr. Freeman discussed the benefits of AIRSAR/TOPSAR radar imaging at Angkor.

Robert Kuszinger presented a history of the digitization of Angkor remote sensing and ground-truthing data. His detailed history of the Royal Angkor Foundation's GIS led to a larger discussion of the need for innovation in data management.

RESULTS

The Workshop concluded with presentations on the topics of new realizations and theories about Angkor, based on interpretation of radar data.

GIS AND DATA MANAGEMENT

A geographical information system facilitates the layering of different data related to a specific area. To this end, the Royal Angkor Foundation has thus far combined radar band data on Angkor with SPOT and ERS satellite imagery and aerial photography to achieve ninety-three different views of the Angkor area. The RAF has added cartographic and topographical information to these layers along with newly acquired data from the 1992-93 UNESCO Zoning and Environmental Management Plan for Angkor. RAF's GIS was a key resource in the workshop.

The future RAF database will take information to new levels, to platform independence to enable the data-base to be used in any GIS system, including, but not limited to, ARC/INFO and INDRISI. The database will accommodate additional data sources and more integration when needed. System mobility will be one of its key attributes. It will facilitate multiple users and a shared data environment. This GIS-based data system will be both hardware- and software-flexible and include modular subsystems.

"The radar image reveals unique patterns of possible sinkholes within the fan, where pockets of water caused the land to collapse."

PREHISTORY, HISTORY, AND ARCHAEOLOGY

Over the last year, Dr. Elizabeth Moore chose three areas from the Angkor radar data for intensive study: Puok, central Angkor, and the ancient capital of Hariharalaya. According to Dr. Moore the purpose of the study was : "to characterize the scattering mechanisms as calculated for SIR-C data for known forms within these areas and eventually use the results to classify unknown areas, and to understand the use of the terrain and local hydrology in the transition from the prehistoric era to the era of historic settlement and water management."

In these three locations, Dr. Moore focused on four site "types": dikes, proto-mounds and mounds, temples, and water (e.g. barays, tanks, inundated zones). Two of these historic sites are found in central Angkor. One site, Hariharalaya, is in the Roluos area southeast of Angkor. The third is to the west along the north-south ancient river bed of the Puok. She also discovered ancient river beds immediately north of Lolei temple, a ninth century A.D. structure. Radar imagery enabled Dr. Moore to detect distinctive features of each site that had not been revealed by aerial photography and SPOT satellite imagery. Many sites could not be explored by ground because of land mines. Recent data processed by JPL may allow Dr. Moore to compare northeast Thailand settlements with those near Angkor.

In both the workshop and symposium, historian and epigrapher Professor Claude Jacques, Director of Studies at l'Ecole Pratique des Hautes Etudes, Paris, discussed his use of SPOT satellite images in his work at Angkor. At the GeoPlan Center's work stations, Dr. Jacques was able to compare these satellite images with the composite radar images of the site.

R. Terry Schnadelbach, Chair and Professor of Landscape Architecture at the Department of Landscape Architecture, University of Florida, has studied the radar imagery of Angkor over the past year to try to understand why the Khmers established Angkor at its particular location and how they modified the land area to build a better civilization. Professor Schnadelbach has discovered new features in the ecology of the site which will help scholars understand both the hydrology of the Angkor area and Khmer water management.

Professor Schnadelbach has found in the radar data the presence of a large alluvial fan that stretches out below the Kulen hills located northeast of Angkor. The data shows very clearly how earth and stream deposits fan out and move toward the Tonle Sap. The alluvial fan traverses Angkor, going directly through the Western Baray. The radar image reveals unique patterns of possible sinkholes within the fan, where pockets of water caused the land to collapse. The radar also indicates the occurrence of springs along the way as the water travels through internal aquifers to the Tonle Sap. Understanding this system, the Khmers adopted their water system accordingly, diverting the streams and taking advantage of the numerous springs.

Radar data has led Professor Schnadelbach to theorize why Angkor was built at its particular site. He has compared data from soil borings conducted by Japan's Sophia University with the radar data and has postulated that Angkor was built upon the site of ancient sand deposits that lay near the surface of this high terrace area. The builders of Angkor probably liked this area of higher ground because the subsurface sand contributed to the area's distinct vegetation.

Analysis of radar data on plant life has convinced Professor Schnadelbach that Angkor's builders maintained an existing tree cover. He suggested that they probably desired an arboreal canopy for shade in the tropical climate. Thus, the "city forest" vegetation now seen in Angkor Thom is not merely the result of an untamed jungle closing in on a neglected ruin. Professor Schnadelbach views Angkor as distinct from ancient cities in the West, where large areas of vegetation were generally cleared before urban construction was started.

Professor Schnadelbach theorizes that sedimentation did not form the elevated area of Angkor's Western Baray. He takes exception to current belief, and maintains that the radar data, layered with SPOT satellite imagery and topographic information, indicates that the walls of the baray were possibly constructed to keep something besides water within the reservoir's boundaries. He speculates that the elevated area at the east end of the baray served as an animal pen to contain water buffalo or elephants.

RADAR AS A RESEARCH TOOL

The use of radar as a research tool is new to archaeology and cultural resource management, and the Angkor researchers spent the last year learning about its application. Dr. Elizabeth Moore visited the Jet Propulsion Laboratory to work with Dr. Tony Freeman, Group Supervisor, Data Utilization and Outreach Group, in interpreting the radar data (see Dr. Freeman's paper, "What is Imaging Radar?" Appendix A). Dr. Freeman taught Dr. Moore how to use a scattering model containing red, green, and blue channels that reveal different features of the terrain. This model aided Dr. Moore in studying prehistoric sites. Dr. Moore also found that the digitalization of the radar data allowed her to quantify the changes in land mass or foliage that she had already perceived visually.

In the last year, Professor Schnadelbach was able to study radar images of the Tonle Sap taken by the space shuttle in both the rainy and dry seasons, providing him with an invaluable contrast that aided his understanding the workings of the great freshwater lake.

RADAR AND THE TONLE SAP

While radar has indicated new avenues of research into Cambodia's past, the radar imaging of the Tonle Sap holds great potential for the country's future. At a time when a plan for damming the lake's tributaries is being considered, the radar may offer a new and improved understanding of the life cycle of this unusual body of water. Using the radar data, Professor

Schnadelbach discovered new features in the lake's tributaries near Angkor, indicating the historic roots of the Tonle Sap river. The radar also revealed nutrient-rich areas of the great lake.

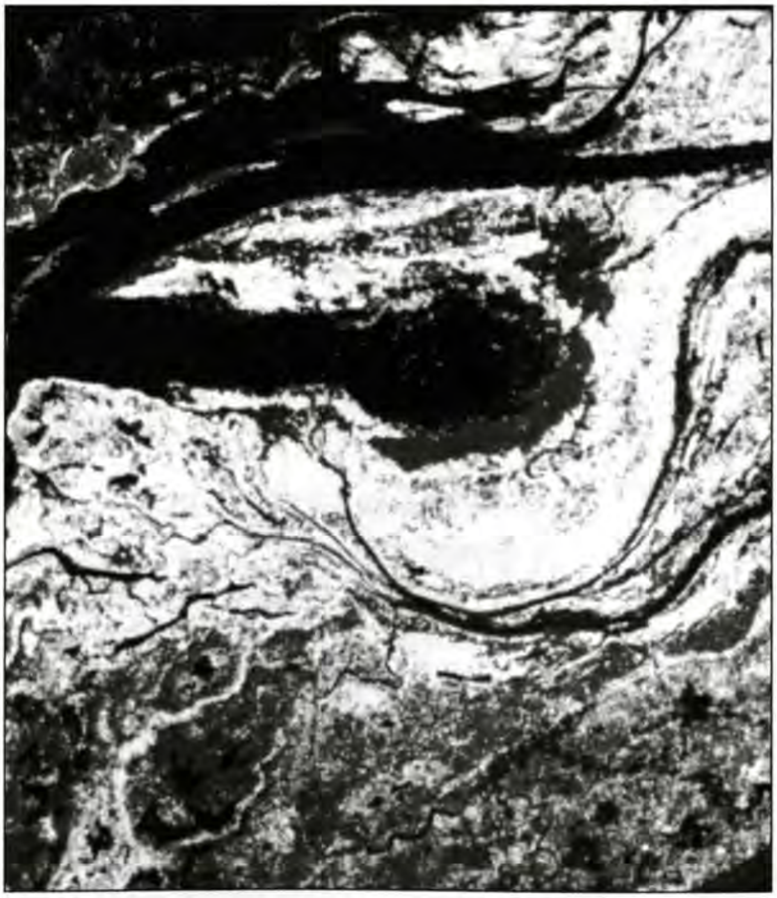
"The Tonle Sap is the heart of Cambodia and it is essential that this heart is living," said Minister of State for Culture and Fine Arts H. E. Vann Molyvann in viewing the radar imagery of the lake. The radar data may help Cambodia in its nomination of the Tonle Sap for inclusion as a bio-reserve on the World Heritage List maintained by UNESCO.

AIRSAR/TOPSAR AT ANGKOR

In December 1996, NASA/JPL flew its airborne radar system known as AIRSAR/TOPSAR on missions in Southeast Asia. The overflight of Angkor was carried out to augment the data collected from *Endeavour*. Situated aboard a DC-8 jet, this system collected data using a combination of polarizations and radar frequencies and of generated topographic height data .

This type of mission made use of radar's P-band, which penetrated the tree canopy and gathered data not obtained by the L-, C-, and X-bands used on the space shuttle mission. TOPSAR data enables the construction of a computer-generated three-dimensional topographic map of the Angkor area. This type of data organization may allow researchers to pinpoint sites for further study and research subjects more effectively.

TO RIGHT: **Man-made canal and basin at entrance to the Tonle Sap.**



THE SYMPOSIUM

PRESENTATIONS

Introduction

The Symposium on new technologies and global cultural resource management brought together top archaeologists, ecologists, architects, and historians to explore the use of remote sensing—including radar imaging—at global cultural heritage sites. Through case study presentations, the participants compared methodologies and learned about the development and use of new technologies. As a forum for intellectual exchange and debate, the Symposium examined the benefits and limits of remote sensing systems in terms of their technology, effectiveness in different terrain, and place within the priorities of site management. Symposium participants confronted the challenge of finding new ways to manage and disseminate the huge wealth of data produced by remote sensing, especially by space-borne radar imaging.

REMOTE SENSING AND THE INFORMATION AGE

Ambassador János Jelen dealt with two major concerns in working with the results of remote sensing. How does one make sense of the huge accumulation of raw data? How can the data best be organized for interpretation and disseminated to those who have an interest in using it for the study of cultural heritage sites? At a time of rapid technological change, it is daunting to merely keep abreast of new forms of hardware and software, understand their functions, and recognize their potential use. The Information Age, however, presents opportunities as well as challenges, as Ambassador Jelen explained in his presentation.

RADAR IMAGING AND REMOTE SENSING

Dr. Diane Evans participated in the First Scientific Roundtable at Princeton University in February 1995. As SIR-C Project Scientist at the Jet Propulsion Laboratory, Dr. Evans has worked closely with the World Monuments Fund and Royal Angkor Foundation since the launch of the Space Radar Laboratory aboard the STS-68 space shuttle mission on September 30, 1994.

At the Symposium, Dr. Evans explained the Space Radar Laboratory, part of NASA's Mission to Planet Earth, and described the mechanics of radar imaging. In particular, she addressed the uses of radar imaging at archaeological sites and in different terrain, as well as the potential usefulness of radar imaging as an analytic tool.

Because of her familiarity with the physical characteristics of the Angkor site, Dr. Evans explained the possibilities and limitations of radar imaging in that tropical rain forest environment.

RADAR IMAGING AT ANGKOR: LATEST DEVELOPMENTS

The Symposium participants learned of the latest developments in the interpretation of radar imaging of Angkor in presentations by Dr. Elizabeth Moore, Professor R. Terry Schnadelbach,and Professor Claude Jacques. A discussion of the work and findings of Dr. Moore and Professor Schnadelbach can be found in the Workshop section of this report. Professor Claude Jacques, who has studied the history and culture of Angkor for more than thirty years, addressed the Symposium about the importance of remote sensing in learning more about Angkor's history. Professor Jacques has studied images of Angkor from a SPOT remote sensing satellite. The scientific roundtable provided him with the opportunity to discuss his experiences using SPOT and to examine the space-borne radar imaging data of the site. As Professor Jacques noted in his presentation, the radar allowed him to see beyond the layer of vegetation that SPOT images failed to penetrate. Excerpts from Professor Jacques' presentation follow.

RADAR IMAGING IN DIFFERENT TERRAIN

The presentations on Angkor explored the uses and challenges of radar imaging in a tropical ecosystem. Radar is affected by vegetation and soil moisture. Unlike arid climates, where the radar can penetrate very dry sand up to a depth of 2 m (depending on the wavelength), radar cannot see through wet and/or clayey jungle soil. While this may obscure subsurface archaeological features, the radar's sensitivity to moisture has been helpful to archaeologists studying hydrological features and biomass change, which can also provide important clues for archaeological investigation. These are subjects of great importance at Angkor.

Desert

Dr. Farouk El-Baz of Boston University discussed the value of radar imaging in the study of desert regions. A pioneer in the use of radar imaging in archaeology, Dr. El-Baz's fieldwork in Egypt has greatly enhanced the study of the evolution of the Egyptian desert and has led to the discovery of possible sites of ancient human habitation hidden beneath the sands.

Mountain

University of Florida doctoral candidate Alexis Thomas is conducting fieldwork at Mt. Kinabalu in Sabah (Malaysia). Only two clear satellite images are useful for the geographic information system (GIS) he is building for Kinabalu Park. Mr. Thomas depicts the difficulties of conducting global positioning system (GPS) surveys in mountainous areas. Radar imaging, however, may one day provide enhanced GIS maps of the Park that global positioning systems have been unable to capture.

REMOTE SENSING AT CLASSICAL ARCHAEOLOGICAL SITES

Two presentations examined remote sensing at classical archaeological sites in Greece, Italy, and the Ukraine. The "Nikopolis Project" conducted by the Department of Archaeology of Boston University under its chairman, Dr. James Wiseman, has utilized remote sensing from the start to add a layer of "visual" information to the project's geographic information system. In their fieldwork at Metaponto and Chersonesos, Dr. Joseph Carter and Dr. Jon Morter of the University of Texas have made extensive use of aerial photographs to help determine ancient land division. But the limitations of that remote sensing method has led their team to investigate the use of satellite imagery. They plan to determine if multispectral images can be manipulated to help locate division lines. Excerpts from the presentation of Dr. Carter and Dr. Morter follow the presentation of Dr. Wiseman.

LIMITATIONS OF REMOTE SENSING

The presentation of Dr. Margaret McLean and Mr. Dominic Powlesland of The Getty Conservation Institute (GCI) raises key questions about the use of remote sensing at cultural heritage sites. While there are benefits to remote sensing (which were described throughout the Symposium presentations), Dr. McLean and Dr. Powlesland suggested it is important for site managers to initially evaluate whether remote sensing is practical for their site, in terms of cost and usefulness. After exploring the limitations of remote sensing, the presenters described the application of remote sensing in their field work at Chaco Canyon National Historical Park in New Mexico, a World Heritage Site.

REMOTE SENSING AND OTHER NEW TECHNOLOGIES

The Symposium featured presentations on alternative methods of remote sensing and new technologies that will augment ground truthing. Dr. Douglas Comer of the U.S. National Park Service uses very low altitude aerial remote sensing in his fieldwork. This relatively simple and inexpensive system provides low-level aerial photographs. H. E. Vann Molyvann, Cambodian Minister of State for Culture and the Fine Arts, expressed interest in applying low-altitude remote sensing in his country. Following Dr. Comer's presentation, Dr. John Alexander of the University of Florida conducted a workshop. He demonstrated high-tech equipment he invented that places navigation devices in computers and cameras. The breadth and scope of Dr. Alexander's work presents a vision of possible future breakthroughs in technologies used in archeological fieldwork.

CONCLUSION TO PRESENTATIONS

The Symposium presentations revealed common themes. Remote sensing is a valuable tool, especially when used as part of a geographic information system, but the value of remote sensing systems can vary considerably depending resolution appropriateness and on topography. The use of radar imaging, as an application of remote sensing analysis, can overcome some of the difficulties of mapping (i.e., clouds, vegetation cover, darkness) that limit the effectiveness of satellite and aerial imaging, but the study of radar imaging for archaeological purposes is in its infancy and much remains to be learned. It has, however, revealed data thus far unobtainable from other remote sensing sources, which may have a profound effect on our knowledge of cultural heritage sites. Advances in the analysis of this data (i.e. scientific modeling and manipulation of polarizations) and the development of new technologies means that the management and dissemination of the plethora of new data and information is a major concern. Overall, new vistas are opening in the use of remote sensing, including radar imaging, which may lead to new knowledge of the history and function of cultural heritage sites and to better management of them.

SYMPOSIUM PRESENTATION ABSTRACTS

THE CASE FOR GLOBAL MONITORING OF CULTURAL HERITAGE SITES

Presenter: Ambassador János Jelen, Chairman, Royal Angkor Foundation

Let us try to answer the question whether the use of radar imaging at Angkor makes the case for global monitoring of cultural heritage sites. Common to all of the presentations on individual sites is the study of the ancient remains of human activities. Is there any way to bring together all of this knowledge in just three days? Is it possible to heed the diversity of interests in an organized manner that would continuously appeal to audiences of interested individuals? Based on my experience at Angkor, my answer is a very cautious "yes." What makes this possible is a new dimension which may be called "cyberspace" or "virtual reality" or "the tacit dimension of the Nyman galaxy." It is reflected in the over two million people who now use the Internet.

During the time I have been involved with activities at Angkor, a huge amount of information has been collected, but only a very small part has ever been digitized. The Royal Angkor Foundation has amassed hundreds of thousands of photographs, thousands of maps and charts, thousands of drawings, books—in short a tremendous amount of knowledge—all in non-digitized form. In addition, we now have many new satellite photos and gigabytes of radar data. Some are consolidated and available and some are not. As a result, most of the latest information is still spread out without any hope of coming together again, even in the hands of those who would make the best use of it.

After the radar data of Angkor was first provided to us in Hungary, it became clear to us that a completely new approach should be developed, one that I call "managing chaos." We have questioned why relevant information should remain in a non-digitized form and what could or should be done to encourage those who have this information to make it known through the new media.

I would think that this random accessibility of data should be taken as a principle of the future. We should not try to concentrate all of this knowledge into one hand, one institution, or one medium. It should be viewed as a challenge of the new era. All of this data now can be brought together to a certain degree. Somebody should deal with these aspects and try to find new exotic forms of knowledge, then see how that particular area of knowledge might be made available.

When we were working on our Angkor database, we noticed again and again that new types of data provided great challenges for us. For example, microchannel measurements are difficult to put in digitized form. It also is very hard to bring together the radar images. Three-dimensional topographical maps posed new challenges as well. Because of the constant changes in dimensions, adding this information is extremely difficult.

We noticed that the different kinds of media about all of the World Heritage sites might not be available, but a great many of them are accessible for radar and are available on satellite pictures. Some sites have had aerial photographs taken of them. While the World Heritage List to date has 463 sites inscribed, radar images are available for just 128 of these sites.

There are three categories on the World Heritage List: one category for the cultural sites, the second for natural sites, and the third for mixed sites. The mixed sites are the most interesting ones, for our purposes, because they contain data which is very suitable for examination using radar imaging. More research has been done on making data from these sites more readily available. Of sixteen mixed sites, we have radar information on eight. But when you scrutinize them, three sites are especially interesting, even in the early stages of research, because of factors such as moisture content, vegetation content, and geological features.

The processing of radar images of World Heritage Sites is a valuable first step. A diversity of experts should look at these images and meet from time to time, like the community of experts concerned with Angkor. Although difficult to do, all this knowledge should be digitized and made available on a constant and continuous basis. We have found that the present Angkor Eco-Site project is a breakthrough for radar and thus for all World Heritage sites.

OVERVIEW DESCRIPTION OF RADAR IMAGING AND ARCHAEOLOGY

Presenter: Dr. Diane Evans, SIR-C Project Scientist, Jet Propulsion Laboratory

Radar is a particularly unique imaging mode. It has the capability to see through and be unaffected by the earth's atmosphere. This means that we can see through volcanic eruptions or through rain. In Rwanda, we were able to spot habitats of the endangered mountain gorilla despite the heavy cloud cover. Synthetic aperture radar (SAR) provides its own illumination. It can be operated at night and can be optimized to manipulate the look and the viewing geometry for a particular site that we are trying to image.

We are able to measure through radar interferometry, using two radar antennae to get very accurate topographic maps. We are able to go into a monitoring track and map topographic changes on a centimeter scale. We have mostly been using this for tectonic studies, trying to identify areas that are under stress and might be subject to slides, like the Los Angeles Basin. Clearly, this would be of great value to any site which is subsiding or where there is sliding.

With other types of remote sensing (satellite, aerial imagery), you are looking at reflected sunlight. Because radar provides its own illumination, we have complete control over how we want to view the surface and we can optimize the energy geometry to highlight or subdue surface characteristics.

What SIR-C and X-SAR brought to bear is a much more sophisticated approach. Through polarization you can select the orientation of the radar wave as it leaves the radar and then select which orientation of the radar wave that you see after it has bounced off the surface or vegetation. It is a way of optimizing the viewing of a target or site. Radar gives us the ability to measure the differences in soil, the differences in the vegetation canopy, and, by highlighting a double-bounce, to see structures obscured by the vegetation canopy. Using radar imaging, we send out waves of different lengths to penetrate the vegetation canopy or the subsurface; this cannot be matched by other remote sensing systems. In addition to the wavelengths used in the space-borne mission, the AIRSAR airborne radar system uses a P-band that has a longer wavelength of sixty-three cm which can easily penetrate the vegetation canopy and the sand cover.

The SIR-C/X-SAR venture was intended to look at environmental developments, but JPL is realizing how this radar data can be important for cultural resource preservation. Radar imaging can provide numerous benefits to your field. For example, it can discover flooding under the vegetation canopy and monitor vegetation growth. It can reveal how much water is available for agriculture. Its ability to help monitor seismic events can also be important. On another front, JPL is just beginning to study urban expansion and encroachment using this imaging system. Desertification through deforestation is another process monitored by radar that may have an effect on cultural resource management.

Excerpts from "DESCRIPTION OF ANGKOR AND OVERVIEW OF HISTORY: THE IMPORTANCE OF REMOTE SENSING FOR THE KNOWLEDGE OF THE ANGKORIAN CIVILIZATION"

Presenter: Professor Claude Jacques, Director of Studies, École Pratique des Hautes Études, Sorbonne, Paris

Studies on Angkor and Khmer civilization have been underway for more than a century. There now exists extensive data, especially on the temples, which are the most visible part of this civilization. They are also a part of its history, which has been patiently reconstructed, principally from the data found on inscriptions cut on steles and door jambs of sanctuaries. We know the general plan of Angkor. In particular it shows important hydraulic works, which are still a cause of controversy, two quite impressive barays, all the other less extensive barays, and the numerous canals, which were used for supplying water (where it was necessary) and as means of communication. Bernard-Philippe Groslier, after some others (among whom was Victor Goloubew), wrote several papers on the study of hydraulics in Angkor—hydraulics which prove very complex, all the more so since they have evolved over time. These hydraulic works were not only symbolic, but served those inhabitants who built the temples. We are continuously asking ourselves questions about the hydraulic system of Angkor.

Angkor has a great fault. Its temples are beautiful. They have been marveled at so much and have attracted so much attention, that we have more often than not forgotten to pay attention to the men who built them. Therefore, I shall mention these temples only in historical perspective.

It is true that the name of Angkor immediately brings to mind the image of Angkor Wat and of all the temples in the area. It is too often forgotten that the word Angkor simply means "the town." I propose to define Angkor as the area where the different capitals of the Khmer Empire were established between the beginning of the ninth century to the end of the twelfth century. The last capital survived at least two and a half centuries, perhaps longer. It is clear that so far we have not paid sufficient attention to all the capitals (at least seven), to the towns around the temples, to suburbs of these cities, and to the men who lived in these cities.

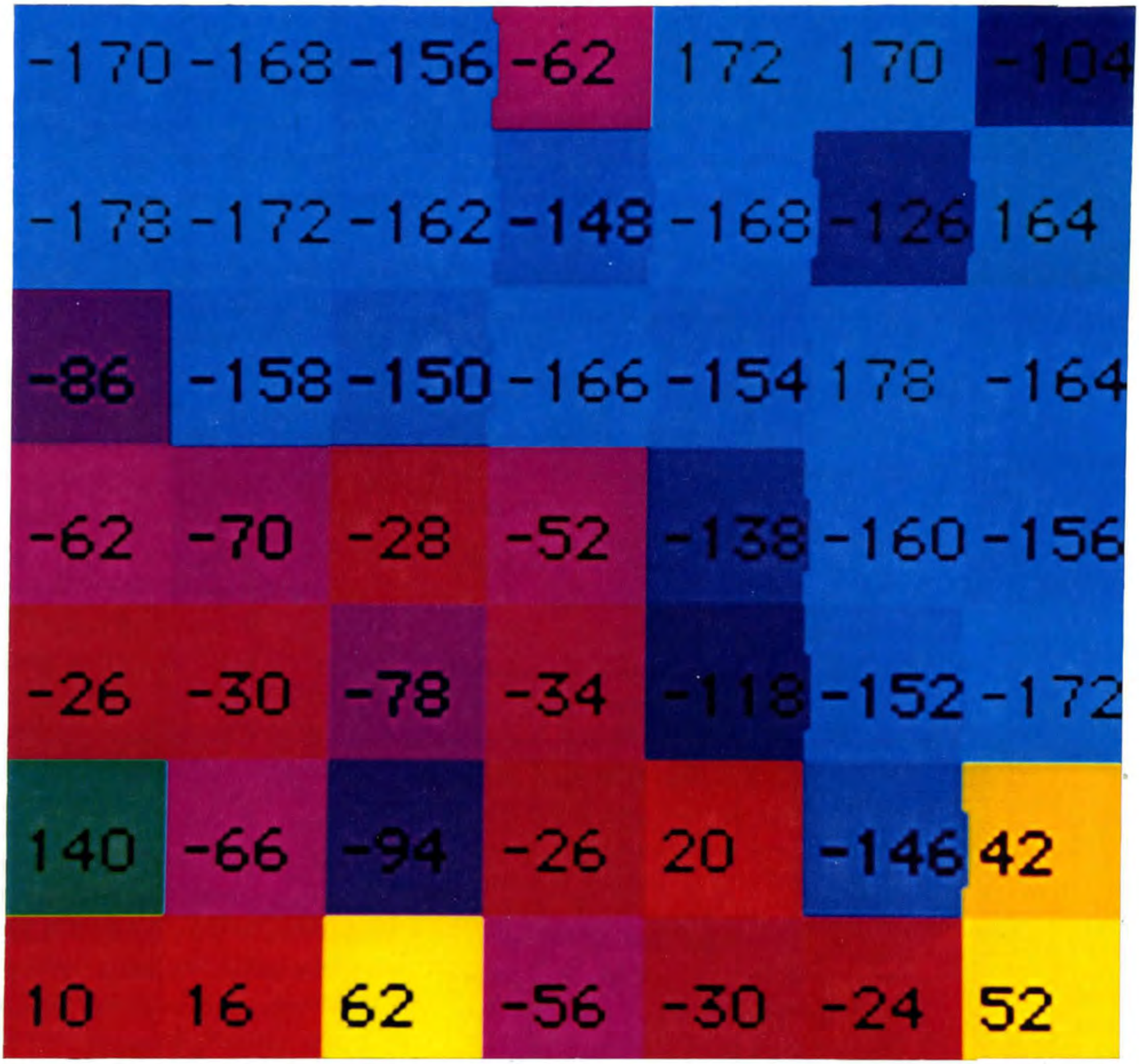
From the remote sensing images, we may find much important data on these cities. A satellite image is probably unable to help us discover new temples, because the scale is inappropriate, but this very scale should be perfect for the study of ancient towns, of their limits, and of the road or aquatic ways uniting these towns with each other. All in all, we may expect from the satellite image important assistance for imagining ancient life in Angkor.

A satellite image presents, aesthetically speaking, the most beautiful plan of Angkor. Its different parts are clearly distinguished: Angkor Thom; Angkor Wat; the Western, Eastern, and Northern Barays; not to mention towns like Preah Khan, Ta Prohm or Bantei Kdei, or even smaller points, such as isolated temples. In the same manner, we see perfectly well a part of the dike which surrounded the first city of Angkor, whose center was the Phnom Bakheng and the state temple which crowns the hill. All of this could certainly be observed on the ancient maps drawn a long time ago, but these maps did not have the required precision. We must admit that the requisite attention has not been brought to this issue, again because of our fascination with the monuments.

Note that Khmer kings have very often used parts of previous works in order to establish their own works. Again, in the case of Jayavarman V's capital, the SPOT image is not very useful, since the vegetation is rather dense. The town could not be square, and the placement of the palace prevents us from trying to find a fifth gate of the town. In fact, this town and its central temple were the least completed of all. Jayavarman V died in or around A.D. 1000, and his successor Jayaviravarman in Angkor was defeated and probably killed by Suryavarman I slightly before 1010. But it is possible that Jayaviravarman built the huge wall between the Eastern Baray around what is now Angkor Thom. This is not seen by SPOT, but can be seen by radar.

After his complete victory, Suryavarman I clearly abandoned this part of Angkor. He made a royal palace which almost could be said to be "fortified," since it was surrounded by a wall and a moat. Inside the vast area delimited by this enclosure, he made the Phimeanakas temple, used probably as a state temple, the smallest of this kind of temples. He probably built the Western Baray, but amazingly enough, no inscription mentions this huge reservoir. There is no problem seeing it through the satellite images, but it would be very interesting to have a clear view of roads under the water. Suryavarman I's son, King Udayadityavarman II, who reigned between 1050 and 1066, probably found the Phimeanakas temple too small for the empire, and instead constructed the much more audacious Baphuon temple. It could be supposed that the limits of this town were at least very close to those of the future Angkor Thom. There again, vegetation makes it impossible to see anything with SPOT.

After this king, and little-known episodes under at least two kings (episodes which ended with the conquest of the Khmer capital by a Cham king in 1177) the great Jayavarman VII gained supreme power. He proved himself to be the most intemperate builder in Khmer history, even though it seems that he could not have built all the temples that are attributed to him. His capital, Angkor Thom, measures three km on one side and is clearly seen on the satellite images. As the last capital, its boundaries, consisting of a large moat and a huge



A detail of the radar image of Angkor's west baray offers a glimpse of how experts interpret this unorthodox data: in this pixel display, colors along a spectrum correspond to varying degrees of reflectiveness of the ground surface when exposed to specific radar wavelengths. Here, red squares indicate a "double-bounce" and the possible presence of impenetrable material above or slightly below the ground surface.

wall, remain intact. The SPOT images, however, generally show little more than the tops of trees, and outside of the royal palace limits and terraces we can hardly see the internal organization of the town. As it was strong, and capable of ensuring protection of its king and inhabitants, it could have lasted up to the end of Angkor as the center of the Khmer empire, but it is quite obvious that it suffered many modifications to its internal planning during the two or three centuries after Jayavarman VII's reign. It would be an error to neglect the thirteenth century and the many, more than sixty, so-called "Buddhist terraces" that were the basis of pagodas after the fourteenth century. It is also clear that the works made for the Baphuon and Bayon temples must have completely obliterated the northern dike of the first Angkor, if it ever was built.

I have explained Angkor through its temples and through the data offered by stone inscriptions. So far, the SPOT images have not been much more useful than a map for the historian, but there are many other things to be discovered. For example, through a special treatment, images may show us streams and canals, old or more recent, modified or filled in. A careful investigation could permit us to outline a relative chronology of these canals or streams. This is especially important at Angkor, where we know that so many modifications have been made to the hydrological system. We can see traces of many more earlier streams, and it should not be difficult now to pinpoint the Siem Reap River before, for example, the ninth century. Generally it is said that only two permanent rivers flowed from the Phnom Kulen. To the north of the Western Baray, we can see several ancient rivers cut by canals. Through the Eastern Baray, we can see traces of another river in an area as distinguished by vegetation patterns. This river probably goes under the northern dike, and can be seen continuing to the south.

RADAR IMAGING OF DESERT REGIONS

Presenter: Dr. Farouk El-Baz, Director, Center for Remote Sensing, Boston University

Why don't geologists understand deserts as well as other land forms? There are three reasons: 1) earth science was developed in Europe, the only continent that does not have any deserts; 2) the vast expanse of most deserts allows one to study only small parts without knowing what is going on regionally; and 3) very few scientists study the desert due to the hardships involved in field work.

In the 1960s, the first photos of earth from space demonstrated how valuable remote sensing could be, especially in the desert. Deserts are generally free from clouds, allowing clear photos to be produced, including remote images of large areas. The lack of vegetation means that an image of the desert is at once a chemical map of the exposed rock, soil, and sand.

Landsat satellite images of the Egyptian Desert reveal several important features. Infrared images will differentiate bodies of water, areas of vegetation, and arid desert because each has different reflective properties. Bodies of water, such as the Red Sea, absorb infrared rays; areas of vegetation, such as the Nile Valley, reflect most infrared light; and the open desert shows varied reflective properties.

Remote sensing from space shows that the dunes of Mauritania originate in Morocco and migrate across the Sahara. Those of the Arabian Desert originate as far north as Jordan and Iraq and end up in the Empty Quarter. The cause is the prevailing wind from the north, which has been going on for over five millennia.

Fifteen years ago, however, the advent of radar imaging allowed one to see the previous topography, the way the desert used to look. This technology provides a whole new view of deserts, allowing one to see how they originate and evolved in space and time. This helped correct a basic misunderstanding of deserts. Until recently, the prevailing view was that the "wind is king" in the desert. The wind is the only agent of erosion, transportation and deposition. Deserts were thought of chiefly as the product of wind when, in fact, nothing could be more wrong.

In Egypt, for example, traditional thought assumed that the sand was a product of wind erosion, which originated in the north. In fact, the source rocks found north of Egypt's sand deposits are made of limestone, while the sand itself consists of quartz. Just south of the sand deposits, all the land is made of sandstone (containing quartz). The source of the sand, therefore, must be in the south, not the north, and it was brought to its current location by water, not wind. Water erosion, transportation, and deposition brought sand to lower topography in the form of depressions where it is found today. Only after the climate had changed and the water had evaporated did the wind re-shape the layers of sand into dunes.

This product of radar imaging has two very significant implications: first, radar can be used to search for remaining water that seeped through the rock as groundwater beneath the desert. Second, the location of water indicates sites of probable human habitation. One can therefore use radar imaging to search for old sites of human habitation.

I am working on a region that is located in the southwestern part of Egypt. The desert there is vast, but entirely flat. Two hills found there are actually islands left over from ancient rivers. With the knowledge that a river used to flow in the area, seventeen wells were drilled in a 200,000 acre area. This action may eventually make the area habitable, as at the Kufra Oasis, in Libya, where groundwater was able to support human habitation for 200 years. These new wells are capable of supporting agriculture. Remote sensing has made it possible to find the locations of ancient rivers and brought the water to the Kufra Oasis area during wetter eras of the past. Radar images of Arabia also allow us to map ancient "delta" features that could only be formed by water action. Remains of human or animal habitation in areas now inhospitable further indicate the presence of water in ancient times in both the deserts of Arabia and the Sahara (c. 5000 years ago).

REMOTE SENSING IN BORNEO

Presenter: Mr. Alexis G. Thomas, Ph.D. candidate, Project Director, GeoPlan Center, and Research Associate, Department of Urban and Regional Planing, University of Florida at Gainesville

My area of focus is Mt. Kinabalu in Sabah, Malaysia. This mountain rises 4101 m above sea level, which is only 50 km away. To date, only two clear satellite images of it exist, due to the mountain's location six degrees above the equator where cloud cover is frequent.

The park in which Mt. Kinabalu is located is 735 sq. km and has significant amounts of primary forest. Above 3,700 m, there is virtually no vegetation save for scattered lichens and other alpine plants. Much of the mountain is granite. The peak was the only part of Southeast Asia that experienced glaciation during the last ice age. The mountain was not climbed until the mid-1850s due to local religious superstition. Outside the granitic upper portion, the lower slopes are still densely forested. The park encompasses six vegetation zones, from tropical to alpine. This range combined with the mountain's equatorial location makes it of extreme interest to botanists. Four thousand species of vascular plant have been categorized on only one-third of the park. Some of the species there that have attracted attention include a variety of rarities such as the pitcher plant, five of whose seven species are found only in the Kinabalu Park.

With Reed Beamon, a doctoral candidate in botany at the University of Florida, I have developed a GIS for the park which includes points, lines and polygon features. Point features include some of the historic plant specimen collection localities based on written descriptions, collection sites recorded with global positioning system (GPS) units, locality, and place names.

From the initial topographical maps, we generated line cover of 500-foot contours. From that, a three-dimensional model was developed to show what features will have to be crossed in getting from point to point.

A vegetation map was prepared by the East-West Foundation in Hawaii that was later converted to a digital map. There are twenty distinct vegetation communities. Some of the marked attributes are elevations, stream markers, names of plants and places, ecological data, and geology. The area has been divided into six altitudinal zones based on vegetation communities. Many areas have yet to be reached for plant collecting.

The granite mountain is still subject to earthquakes and landslides. Soil quality varies. Some areas have little growth, but are nevertheless diverse in species. Three hundred species were found in a four hectare area. The geology of the park often produces such isolated populations. Identifying such "treasure trove" areas for protection is a challenge. By using GPS points to mark an area of interest, other points with similar characteristics can be located. The database can be queried to find 1,000 m^2 "cells" meeting criteria of a given geology, vegetation, altitude, slope, and proximity to water. This is useful for planning expeditions in advance to identify specific areas to visit, or to search separate but similar areas for the same species.

This technique could be extrapolated for use on cultural features. Since cultures often develop within a certain proximity to a water source, or given types of vegetation or resources, the database could be queried for these criteria. There are almost limitless possibilities for use of this technology, that are based on quality of data. These programs are available for PCs and MACs, which allow for ready use in the field or in universities around the world.

I have not yet applied radar imaging to my study of the site. I believe radar imaging has great potential in Kinabalu Park for geologic mapping due to the frequent cloud cover associated with the area, the dense forest canopy, and the loose soil conditions in areas affected by landslides.

REMOTE SENSING AND ARCHAEOLOGY IN NORTHWESTERN GREECE

Presenter: Dr. James Wiseman, Chairman, Department of Archaeology, Boston University

The area I will be discussing is Epirus, where we have been carrying out a large-scale interdisciplinary archaeological survey since 1991. The project is called the "Nikopolis Project, " named after Nikopolis, the city founded by the Roman Emperor Augustus to commemorate his victory over Antony and Cleopatra at the Battle of Actium in 31 B.C.

Nikopolis was a large city from the time of its foundation, because of the forced settlement of neighboring peoples from Acarnania, Aetolia, and Epirus. The city walls extended almost across the entire Nikopolis peninsula, from the Ionian Sea to the Ambracian Gulf. It was the metropolis for the region, and yet has been subject only to small excavations to the present time.

The project is concerned, however, not just with Nikopolis or any single site, but with a large region. We have sampled by archaeological and geologic survey some 1,200 km^2 of southern Epirus. The survey area is bounded by the Louros River valley in the east, the Acheron River in the north, and the Ionian Sea and Ambracian Gulf in the west and south.

Our aim was to try to understand the relationship between the different human groups that had occupied this region and the changing landscape over time. We wanted to see what kind of changes had taken place in the landscape, and the changes in how people exploited that land. One reason for choosing southern Epirus was that the earliest human inhabitants in Greece had been found along the Louros River valley. In the early 1960s, Eric Higgs had discovered evidence of Middle Paleolithic activity. Another important consideration for us is that the entire area is subject to very rapid industrial and residential development, and we wanted to act before more sites are lost.

One of the first things we did was to purchase satellite imagery from the French company SPOT. The reason was to have visual imagery to correlate with cultural information as a layer within a computer-aided geographic information system. It was thus not intended primarily for site detection. We felt it would also be an important aid to the survey in complementing our topographical maps, and would give us immediate information about the present ground cover. During the first season, 1991, our team learned to use the imagery in the field and at the same time gained a close up experience with the terrain. An initial investigation of Kokkinopilos, where Higgs had worked, yielded an Acheulean hand ax, the first Lower Paleolithic artifact found in Greece in secure geological context. The team wondered if satellite imagery might be useful in making similar discoveries, because the eroded Pleistocene red sediments of Kokkinopilos, covered by a sparse vegetation, were very distinctive. Staff members carried out a supervised classification of the satellite imagery, so that other areas in the survey zone with landscape similar to that of Kokkinopilos could be located in the imagery. Teams were sent out to six of the locations indicated by the computer image, and found that five of them were indeed Pleistocene landscapes, and Paleolithic tools were found on the surface of all five; the sixth site had been covered over by new construction since the imagery was recorded in 1988.

Geologists with the team were engaged in investigating landscape changes over time, including the changing shorelines. Geological coring showed that a bay near Nikopolis once extended further inland, and surface survey using computer mapping revealed the main harbor town of Nikopolis around the bay.

Digitization of maps enabled the production of three dimensional maps used to plot both geographic and cultural survey information. Other types of remote sensing were used including ground-penetrating radar, electrical resistivity, and magnetometry wherever there seemed to be the possibility of locating sub-surface features. In one case, the presence of ancient metalworking was determined. Four fortified towns of Greco-Roman times were sampled by survey, and one of those was intensively surveyed by teams picking up all identifiable artifacts.

The area of Nikopolis' aqueduct was surveyed using an electronic transit and the data put into a computer to assist with mapping the water supply. Aerial photography from a tethered blimp was used to document sites in the region. Aerial photos by the Greek Air Force were also useful in the survey, especially in the bay at the mouth of the Acheron river. The surveys, aided by remote sensing, geological coring, and aerial photography, revealed that the bay had extended several kilometers further inland in ancient times.

Excerpts from "HOW THE GREEK COUNTRYSIDE WAS DIVIDED IN SOUTHERN ITALY AND CRIMEA: THE ACHIEVEMENTS AND POTENTIAL OF REMOTE SENSING"

Presenter: Dr. Joseph Carter and Dr. Jon Morter, Department of Classics, University of Texas at Austin, Texas

In 1974, the University of Texas began an interdisciplinary study of the chora (agricultural territory immediately outside the urban center) of Metaponto. The project has evolved from the excavation of several rural sites to include:

(1) a surface survey of a large 42 km^2 representative area of the chora with some 700 sites recorded so far. Most are Greek farmhouses of the period 600–250 B.C.

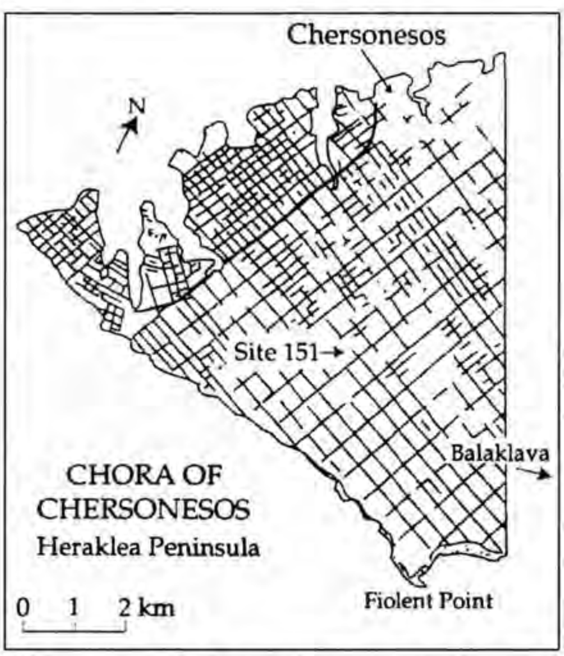
(2) excavation of selected rural sites from among the principal site types; the homestead farms, kilns and rural sanctuaries, and necropoles from the principal periods of settlement that represented an arc of time stretching from Neolithic village to Roman villa rustica of the fourth century A.D.

The emphasis, however, has always been on the period of Greek contact and colonization (see the accompanying figure: the plan of the University of Texas survey in chora of Metaponto with known division lines).

The investigation of systems of ancient land division is one area where real progress has been made in the last four decades, primarily through the application of methods of remote sensing, in the first instance, aerial photographs.

One of the early objections to the interpretation of the Metapontine lines as "division lines" was that the farm sites were not as uniformly placed at the corners or along the boundaries of the plots, as they were in the case of Chersonesos. The location of Metapontine farm sites, as work by a geologist and a geomorphologist has shown, was determined by proximity to the sources of springs, while in the chora of Chersonesos, every farmhouse had a cistern.

By combining the information from the aerial photographs and location of farm sites by period from the survey (and with some assumptions about the basic units involved) it has been possible to create, at least, a hypothetical plan of farms in the chora, which is a first attempt to describe how land was divided and distributed among the colonists. In the first-half of the fifth century B.C., the first period of maximum occupation of the chora, farms ranged from 4.4 to 52.8 hectares with the average at 13.2 hectares. This is half the size of the larger plots in the chora of Chersonesos, in the fourth century B.C., when that territory was divided.

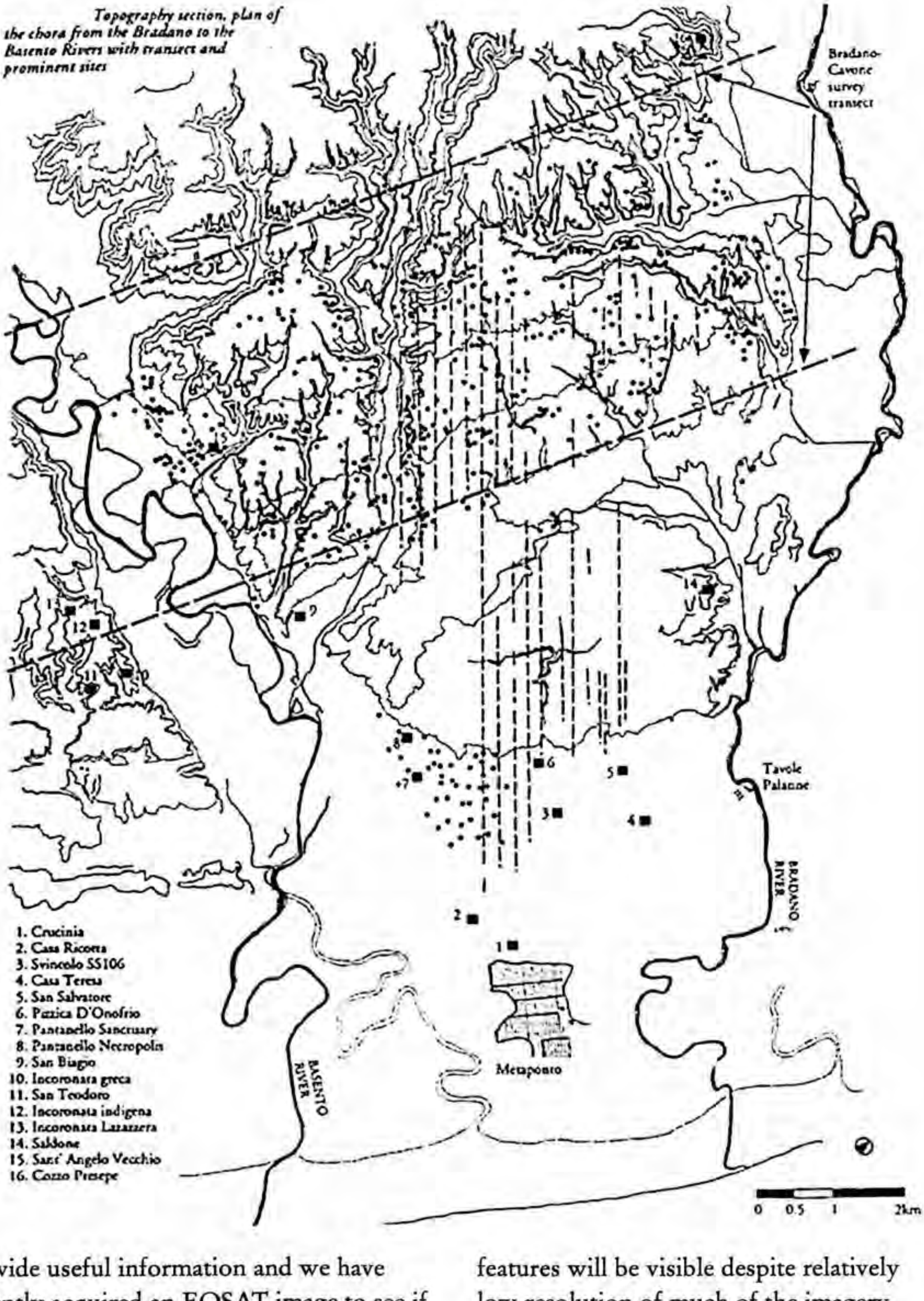


Chora of Chersonesos

The aerial photographs made during the 1940s and '50s are basic to understanding this most important example of Greek land division in the Western Greek colonies, but many problems remain. The lines on the photos define very long strips. So far no transverse line, making a quadrangular unit, has been convincingly identified. There have been subsequent studies of the photographs by specialists such as Max Guy of CNR (Centre Nationale de Researches) in Paris, and those from the University of Aix-en-Provence, to attempt to resolve the problems of the range in the width of strips between the Bradano and Basento Rivers and the existence of a system or systems, with still wider strips (lines 240 m apart) in the southern Metapontine chora between the Basento and Cavone Rivers. The photographs used, however, are always the same ones.

What is needed to advance this study is more factual data about the "lines" themselves. Post-1960 aerial photography has not added significantly to what is known. This is because beginning in the 1960s, a government financed program of agricultural development, including plowing a meter deep or more and the introduction of irrigation, has transformed the Metapontine countryside. In place of wheat fields, which are ideal for archaeological photographs, we now have kiwi fruit and orange plantations in prime areas.

Given these problems, the Texas team is now exploring alternative approaches to remote sensing. Satellite imagery could



Topography section, plan of the chora from the Bradano to the Basento Rivers with transect and prominent sites

Chora of Metaponto

provide useful information and we have recently acquired an EOSAT image to see if the multispectral data available from these images can be manipulated to give a signature (or signatures) for the division lines. We hope that the long linear nature of these features will be visible despite relatively low resolution of much of the imagery.

With the help from Melba Crawford and Amy Neuenschwander of the UT Austin Center for Space Research, a start has been made with the chora of Metaponto. Here we can match the features plotted from aerial photography to the satellite view to guide the search. The initial results are tentative at this stage. We believe we have found a couple of features that might be lines. However, the intense agricultural activity is causing problems.

The research problem, we feel, presents an interesting challenge in the use of this kind of data, but it is clear that in taking up that challenge it will probably be necessary to explore other space based imagery such as the higher resolution of SPOT, and if it is available for our area, the SIR-C imagery.

The ultimate objective is to add both satellite and aerial coverage to a geographic information system database now under construction. This will allow us to combine the archaeological, topographical, and geomorphological data with the imagery. The ground level data that will enable us to go a long way with any results from the satellite views is especially detailed and abundant.

Should the results of the satellite imagery from the chora of Metaponto indicate any trace of lines, we can turn to other colonial chorai in southern Italy where photography did not provide results. A prime candidate would be the chora of Croton. Beginning in 1983, the University of Texas team has carried out surface survey of the area of the chora, comparable in size to that of Metaponto. Chronologically and spatially, the distributions of sites (over 500 have been put on the archaeological maps so far) are closely comparable in size to those at Metaponto. In one area targeted for a major NATO airbase in 1988 (the construction of the base was later canceled), a survey carried out by Cesare D'Annibale in collaboration with the Soprintendenza della Calabria identified a dense area of farmhouses. These finds indicated that the chora was also divided up by a grid pattern. Aerial photographs from the 1950s do not indicate "division" lines-like features, but they were surely there, either as country lanes or perhaps ditches, or simply as unplowed strips. It is to be hoped that they will have left some trace detectable from space.

At this point I return to the starting point, the chora of Chersonesos in Crimea. There was no mention of the use of aerial photography in the Soviet years for a very specific reason. Ancient Chersonesos lies within the city limits of modern Sevastopol, headquarters of the Black Sea fleet and one of the most secret places of the Cold War.

Aerial photographs of the ancient territory do exist—wonderful ones! One series was taken by the Soviet Air Force in the 1960s. No others that we know from any other part of the ancient world reveal with such precision the features of an ancient countryside. We include the well-known examples of Roman centurion presence from northern Italy and North Africa.

The applicability to the problem we have been discussing is obvious. For the same reason of security, accurate contour maps of the area have also been unavailable. The only plan of the chora of Chersonesos that has been published, until now, was the one of 1786.

The archaeologists of the Soviet era were nothing if not resourceful. Working with copies of classified aerial photographs and maps, our colleague Galina Nikolaenko has produced a map of the chora at a scale of 1:5,000 that also includes the results of surface survey and excavation. At last it will be possible to study the best preserved of all Greek countrysides in an accurate and highly detailed reconstruction.

The chora of Chersonesos is unique for the extraordinary degree to which the visible remains of the ancient territory have been preserved, but it is not alone among the colonies of the northern Black Sea coast in having a regularly divided territory. Aerial photograph studies by Alexander Sceglov and his associates of the chorai of Greek centers such as Kerkenitis and Kalos Limen, subcolonies of Chersonesos on the Tarkankout Peninsula of western Crimea, have revealed that much of the coastal area was divided in an analogous way. Thousands of hectares, literally, were under cultivation. Here the conditions of preservation are like those in southern Italy, so there is hope that radar imagery could succeed here, too.

Sceglov's and Nikolaenko's teams have team verified the results of the aerial photographic studies with an extensive program of excavation carried out over thirty years. Only now are the results of this enormous enterprise becoming known in the West. The basic work has been published in Russian, but much remains unpublished and this is the greatest challenge for Ukrainian and Russian archaeologists in the post-Soviet era.

An international collaboration which aims at making this work known to archaeologists and the general public in the West might also sponsor ongoing research. It could apply, for example, satellite based remote sensing to the chora of western Crimea and southern Italy in a comparative study of ancient Greek territories. At last the satellite imagery of classified areas made during the 1960s in the former USSR is being released to the scientific community by U.S. agencies. If they exist for western Crimea they would surely prove useful for this purpose.

For the chora of Chersonesos itself, satellite imagery could hardly improve on the eloquent aerial photographs. It remains, however, to realize a thorough publication of the decades of work in the premier Greek chora.

Unfortunately, now the results of the aerial surveys at Chersonesos are verifiable in only a relatively few areas due to the rapid expansion of the city of Sevastopol in the last thirty years. The proliferation of dachas, as the result of liberalization in the last few years, is proving to be the most immediate threat. Fortunately, one area consisting of six contiguous plots of twenty-six hectares (for a total of 360 acres), and containing three excavated Greek farmhouses and three unexcavated ones, has been set aside as an archaeological park. Our excavation of farm site 151 in the park began in 1994 as a joint project of the Archaeological Museum of Chersonesos and the University of Texas. We and the Ukrainian authorities are delighted that the park in the territory, along with the ancient city and Museum, have been listed by the World Monuments Fund among 100 endangered monuments of world cultural significance requiring immediate assistance.

PROBLEMS AND POTENTIALS IN THE APPLICATION OF REMOTE SENSING IN THE CONTEXT OF WORLD HERITAGE SITES: THE CHACO CANYON EXPERIMENT

Presenters: Dr. Margaret Mac Lean, Director, Documentation Program, Getty Conservation Institute; and Mr. Dominic Powlesland, consultant to the Getty Conservation Institute

The Getty Conservation Institute is one of seven Getty organizations that operate independently. While all are dedicated to some aspect of the arts and humanities, the GCI works to preserve the world's cultural heritage, and undertakes research, fieldwork, and laboratory science to further this end; the GCI also organizes conferences and symposia. The work has focused on museum collections and environments, cultural sites, site management, and enhancing training of professionals.

The interest of the GCI in remote sensing is part of a larger effort to examine and test the tools available to gather and manage information in support of the long-term protection of cultural sites. In recent years, remote sensing has been proposed as having a key role to play in monitoring and management. The GCI project looks at how the technology of remote sensing might be used to monitor change and manage the information efficiently.

There are obvious limits to the uses of these tools. The strengths of remote sensing allow examination of isolated sites that have little local staff or infrastructure; its weaknesses include its inability to monitor from space some of the more damaging threats to a site. For example, one can monitor only at a fairly gross scale, from very high angle viewing platforms. While one can detect changes in use patterns and seasonal vegetation fluctuations, one cannot monitor theft of statuary, illegal excavation, or the structural integrity of exposed architecture. Recognizing the abilities and limitations of remote sensing by crafting appropriate research questions is the only realistic place to start.

Threats to a particular site must be well defined and prioritized before remote sensing can be seen as a significant benefit to monitoring at that place. That is, if the most serious threats to the protection of a place are related to the lack of supervision of visitors, or to the local need for the stones from the site, monitoring by remote sensing will not be of significant value. Second, in most cases, remote sensing even of large scale change must be supported by on-site analysis so that the data generated by the sensing tools can be verified. That is, the nature of the information made available by remote sensing technology is often specific to the thermal cues of the place. So, in order to determine the relationship between the digital information and the actual situation on the ground, some comparison must be done to ensure accurate interpretation of the data.

With these limitations in mind, the project moved into the field to test other ideas and assumptions. Chaco Canyon National Historical Park in New Mexico is a World Heritage Site, and one of the icons of North American archaeology. It was a population center of the Anasazi, a sedentary Native American culture that achieved its height in the tenth and eleventh centuries A.D. It boasts thousands of acres of mesa and ravine landscape and many stone architectural complexes of various sizes, including multi-story complexes such as Pueblo Bonito.

The Park has been investigated extensively, and is somewhat at risk due to its fragile nature and its popularity with visitors.

At Chaco Canyon, the GCI team worked with the Park staff to frame a few critical questions: What are the significant threats to the values of the site? What monitoring techniques are in place presently? Which of the threats that pose a risk to the integrity of the architecture and context might be a candidate for monitoring from high altitude? Can the Park use remotely sensed data in their work without large investments in data gathering, and in hardware and software for its use? Is the staff able to manage the resulting status information effectively for site management and monitoring purposes?

A range of data from sources such as Landsat and multi-spectral imaging have been gathered to study Chaco Canyon. These multiple layers of knowledge include data from sources as diverse as U.S. geographical surveys and color infrared photography. Neither Landsat nor SPOT is particularly helpful for analysis of individual sites; traditional aerial photography is more appropriate for small-scale scenarios. Elements from all these data sets are being built into a model to demonstrate the strengths and weaknesses of the various technologies now available.

Some good results are emerging from the initial stages of this research. A clear understanding of the topography of such a site prone to seasonal flooding is necessary for a management and monitoring plan. By combining a digital model with the satellite imagery, the potential for damaging erosion can be examined. A "risk map" for predicting and tracking both environmental and human threats can be generated. Remote imaging can also be useful in determining how much space beyond a "core area" needs to be incorporated by a government in order to protect a site from outside stresses on the land. These issues are particularly important in the Park, as the environment is fragile.

Many countries with important heritage to protect do not have the financial resources to commission the collection of this expensive data, or the human resources or infrastructure to manage the resulting data. It is not yet feasible for the space agencies to fly over each country and collect data. Therefore, it seems unwise to invest heavily in the new technologies if the results are not usable.

In many cases, site managers may not be aware of the tools they have at their disposal. At the Chaco Canyon Park, staff is using and will continue to use all information available. Useful data sets from currently held sources can be combined to create very effective management tools, such as detailed maps.

There is enormous potential for remote sensing in research and protection, but the managers of sites must examine their needs and resources, and articulate how new information might be used. A cost/benefit analysis would help clarify the issues. If remote sensing data is made available to site managers, or if managers are considering acquiring them, then the results of the GCI research will help them make decisions about what might be most useful for the investment.

VERY LOW ALTITUDE AERIAL REMOTE SENSING FOR ARCHAEOLOGICAL SITES AND FEATURES

Presenter: Dr. Douglas C. Comer, Chief, Applied Archaeology Center, U.S. National Park Service

The U. S. National Park Service is finding low-altitude aerial remote sensing to be a cost-effective means for locating archaeological sites or features, photographing them, and producing useful maps. It is developing the capability to employ and interpret low-altitude aerial remote sensing by using miniature airplanes and helicopters to fly over the sites.

The technology and techniques for this type of remote sensing are relatively simple and inexpensive. The high resolution output of the technology can be used by itself or in conjunction with imagery obtained at higher elevations or by different means. The airplane has a wingspan of 108 inches and the cost of its materials averages around $1,200 with a global positioning system (GPS) receiver adding slightly to the cost. The helicopter is more costly to operate and more difficult to pilot. Software used in the remote sensing can be run on a personal computer and bought off the shelf.

The airplane flies over the target at 12 mph no lower than 100 ft above the ground and no higher than 700 ft. The normal altitude is between 200 and 500 ft.

Low altitude remote sensing is most commonly used where the terrain is flat and the vegetation is sparse. It is often deployed in the western United States.

I have recently used remote sensing in South Pass on the Continental Divide in western Wyoming, at Pueblo Bonito in New Mexico, and in Hawaii. I hope to teach low altitude aerial remote sensing to students in Thailand in 1997.

GLOBAL POSITIONING FOR WORLD HERITAGE SITES

Presenter: Dr. John Alexander, Head of the GeoPlan Center, University of Florida at Gainesville

In working with geographic information systems and remote sensing data, one of the things that became apparent to me about ten years ago was that computers were going to work and be affordable. Software was improving and so collecting data in the field, especially control data, was a very important thing to work on.

Finding your location in fieldwork is essential. I have seen many cases where people come in and show me what they are doing with plant species identification and they really don't have a clue where they are. You drive back in north Florida for a couple of hours around a curvy road and unless you have a good instrument to locate your position, you try to find it on the map and it's pretty hopeless. There are very few features that you can really locate.

The idea that I have been working on is that it would be useful if you could walk in the field with a small computer, look at your map, know your location and take pictures. I have been trying to develop a way to work in the field without actually having to even use paper maps. We see a lot of pieces of that around, but it is very difficult to remember where a slide was taken, or from what position. I've been trying to integrate the different pieces. I convinced the IBM Corporation to help me with this and as a result I have received a series of grants from IBM. Also, Trimble Navigation and several other companies have been very kind in helping me in this research.

The idea centers on a global positioning system. Suddenly, they have become quite small. I have worked closely on a GPS receiver. The original ones of the type I am showing you were built by Trimble Navigation under a subcontract from us as one of our projects. They have a fairly small satellite dish antenna, which is quite smaller than the ones you might normally see en route. You can just carry it around in your hand. The reason for having a cable on it is that if you are in a rather dense area, you might want to put it up on a pole or if you are driving around in a car, you might want to put it on the roof.

This equipment has the ability to give us global position to about 1 m, 1 m absolute accuracy in the x and y, and a couple of meters in the z direction. Not only can you record the location but if you are good you can record location and you can pick up velocity if that is useful in the three dimensions. It seems to me that this technology has enormous application in global positioning.

One spin-off from this is a commercial item. Trimble is selling a product that we developed where you take a little GPS card, put it in a hand-held or laptop computer, and it ties the GPS receiver directly to the device. You can imagine the mouse pointing to your position on the globe rather than having to do it manually. So as you walk, drive, or fly around, anywhere you move, the cursor follows you around on the map.

My "Gator Communicator" invention is a machine with an embedded digital camera, so as you point it, you get an image on the screen. The one I have is very light and has a high resolution, color, LCD display with a touch screen. Eventually, I hope to make the device watertight. You have to have a solar panel to charge it up. I've been working on the problem of showing the direction in which the camera is pointing and have found that a digital camera with a sensor allows you to take a picture with the location indicated. I tested the Gator Communicator by taking some pictures of Hurricane Andrew and we had good map coverage of the hurricane area.

I'll now show you a small digital pocket instrument made by Precision Navigation. It shows the magnetic direction within about one degree. It also has another interesting capability, the pitch and roll. When you take pictures, it's not always easy to hold the camera straight, but you can now use the computer to straighten the image, because it knows the tilt at which the picture was taken and the direction. I have all of those pieces working.

What I want to do is use a two-headed camera, so that rather than having just one lens, I have two lenses to provide a stereoscopic pickup. For example, I can take a picture of the beautiful flower that you saw. By touching different parts of the flower, you can figure out how far the parts of the flower were from you. You also can sketch the flower and produce a dimensional picture. That has great application for environmental work and for work at monuments.

It takes a lot of work to climb monuments. It would be very useful to be able to make a sketch that established the dimensions of the monument and issued a high quality color picture. With numbers you could document the position and with a working GPS system, you could pinpoint the location of different things happening on the ground. You could take the map with you and zoom it on the radar imagery or photo and locate it. There are, however, some tradeoffs. If you bring too much software, you will use a lot of power, but there are hard drives now that are as a big as a gigabyte.

You can't take a desktop computer to the field to walk around and do desktop analysis. Therefore, I'm trying to make a simple data collection system that uses icons. I want to be able to take a picture, get a location, and make sure the picture is correct while we're there. For it to be correct, I want to make sure that it is exposed properly; while recording the direction, the location, and the temperature (which it can do). The whole system is in solid-state memory and is permanently in the computer. I'm trying to make it extremely reliable and am using industrial quality components.

We have been working on an inexpensive hand-held computer using the Apple Newton and adding the other components to it. We have a GPS receiver application just using a little card. But we thought the Newtons are inexpensive, just $700, so in building a prototype we're taking the same ideas and putting them on. For example, one little thing that goes on the back of a Newton is a tiny computer that collects data for you. You interact with it on the Newton and store it on a flash memory card in that computer. I think we'll be able to demonstrate this system within a couple of months. What we're hoping to do is have a little data collector module that allows you to add the components that you want. There are several hardware companies that are interested in helping find a way to manufacture this inexpensively.

Technology is changing rapidly. Color screens once cost $1,100. Since I bought it, this active matrix screen price has been reduced to about $300. It is reasonable to expect that prices will continue to come down. I want my machine to be available in the field for $2,000.

CONCLUSIONS AND RECOMMENDATIONS

RADAR IMAGING AND CULTURAL RESOURCE MANAGEMENT

The unique properties of radar imagery provide new avenues of analysis. For example, the use of radar interferometry for three-dimensional topographical mapping is a major advantage of this type of remote sensing. Radar imaging can be combined with other data types to provide a comprehensive analysis of cultural heritage sites. Radar data can be used to analyze environmental change and project hazardous conditions; it can assist in developing ecological controls of human sites; and it can be used to determine archaeological features such as rivers, roads, and settlements. In addition, the ground penetration achieved by radar imaging is an extremely useful tool for analyzing sites threatened by geological hazards such as volcanoes, earthquakes, and floods. Overall, radar data is crucial for developing site context, monitoring, and management.

"Overall, radar data is crucial for developing site context, monitoring, and management. However, there are limitations to what information radar data can supply...radar imaging should be augmented by other remote sensing methods..."

However, there are limitations to what information radar data can supply. For example, it is not useful for interpreting large scale regions. The participants of the present symposium are aware that radar imaging and state-of-the-art technology will not solve all problems, but both are valuable first steps towards understanding past civilizations and present environments.

In reviewing the information conveyed over the week, three main areas of agreement emerged: radar imaging should be augmented by other remote sensing methods; remote sensing is best utilized if undertaken in different seasons; and flexible and platform independent software is necessary to maximize results. Radar imaging should, where possible, be used in conjunction with other remote sensing methods. The merging of radar images with other satellite data will be highly useful and, in general, information gathered using remote sensing information should be correlated with other types of data and research. In analyzing the data, multidisciplinary teams are the most effective and will draw out more information from the data.

There are definite advantages to comparing remote sensing in different seasons (multiple temporal imaging for seasonal change). The best conditions for radar imaging are believed to be hot arid climates, but the radar images of Angkor show that wet tropical regions provide equally good subjects. Radar sampling shots have proved useful for analysis of the Cambodian lake, Tonle Sap, documenting changing shorelines and shallow water areas. Tree cover, growth rates, and movement patterns (fishing routes) have been revealed. To assist in these studies, Dr. Diane Evans's list of surface changes that can affect radar back scatter should be distributed.

Flexible and platform independent software is needed for data analysis. There is serious promise in multi-platform data consolidation. The symposium was reminded that a GIS is irrelevant if it does not contain accurate data.

REMOTE SENSING AND CULTURAL RESOURCE MANAGEMENT

The participants encouraged the use of remote sensing data to assist the monitoring of sites and the sharing of this information for cultural resource management. It was stated that the technology alone is a means to facilitate cross-cultural collaborations.

The opportunity exists at present to use available data to discourage actions that adversely affect cultural resources. For example, it can be used for the monitoring of tourism development at Angkor, Petra, Chaco Canyon, the Kathmandu Valley, and Luxor. The technology should be applied where the threats are greatest, such as at endangered sites, especially World Heritage sites, and bio-diversity reserves. The Symposium participants agreed to advocate quality in remote sensing services used for cultural resource management purposes.

Above all, data technology must be shared with cultural resource managers at the site on a continuous basis, predominately through training and application. Ground-based pilot projects, such as mapping and documentation, should be taken in conjunction with all remote sensing applications to increase the overall understanding of the site.

To facilitate the use of the data, training and community participation are important. Cultural and archaeological resource managers should be familiarized with remote sensing technology. Education should include case studies that help "disarm" skepticism and resistance to using remote sensing to monitor sites.

ORGANIZING INFORMATION EXCHANGE

The experts discussed various ways to establish centers for sharing information. Data access of World Heritage sites and other sites should be made available on a continuous basis. Suggestions ranged from organizing a home page on the World Wide Web as a base of operation, to establishing a network with others using the radar data or developing a not-for-profit consortium of research institutions focused on heritage preservation and cultural resource management of World Heritage and archaeological sites. This consortium could take the form of an expanded World Heritage Documentation Center. A repository of all related information could also be established. These clearinghouses would be responsive to copyright issues. In preparation for these bodies, organizers must first determine how to fund and sustain these activities.

"Above all, data technology must be shared with cultural resource managers at the site on a continuous basis, predominately through training and application."

Symposium participants were encouraged to document and share their process in working with remote sensing data. They were urged to record and publish their work, and to use mediums such as CD-ROMs to do so.

The first two scientific roundtables organized by the World Monuments Fund were an integral part of the organizational plan. It was proposed that a follow-up workshop be held in Cambodia and that the symposium participants should reconvene the scientific roundtable in one year, perhaps at Boston University.

GOALS AND NEW DIRECTIONS

The Symposium participants agreed to certain measures intended to maintain the momentum in the use of remote sensing for cultural resource management. Various steps were outlined that centered on the collection of additional data, the sharing of all data, and widening the network of its users.

Various proposals for accumulating new data were set forth: 1) inform other commercial satellite companies (including those using radar) of the needs of cultural resource managers and issue an appeal for them to do their testing on cultural heritage sites, thus providing a good way of obtaining free data; 2) develop cooperation between the SPOT, German, Landsat, and Mons satellite programs with the NASA/JPL radar imaging program; and 3) work to secure other relevant remote sensing data, such as Russian and CIA high resolution material.

The sharing of information was a high priority. The relative advantages of the various remote sensing methods should be a significant element of this goal. The property rights of data should be shared with the local users. As discussed above, the organizational and informational networks should be improved.

Different sites were mentioned for special study. A focus on the Tonle Sap was proposed as a case study, as well as studies of Angkor Borei, Phnom Penh, and Kulen in Cambodia. The application of radar in areas overbuilt by subsequent generations, such as Rome and Los Angeles, was cited as another goal.

The importance of the burgeoning relationship with NASA/JPL was stressed. There is a need to encourage NASA and its affiliates to further discuss methods of mutual assistance. JPL, for example, might think of cultural resource management as it plans remote sensing missions; therefore it was recommended that Dr. Diane Evans add "cultural resource" to her "Beyond SIR-C/X-SAR" diagram.

The participants agreed to engage NASA/JPL regarding the space agency's future airborne and space-borne remote sensing missions.

The Symposium participants also expressed an interest in other forms of remote sensing. They agreed to pursue a very low altitude remote sensing mission at Angkor, similar to the one described in the presentation of Dr. Douglas Comer of the U.S. National Park Service.

The participants concluded by agreeing to keep in closer touch in the future. They pledged to continue with the program outlined in the symposium until it firmly takes root.

APPENDICES

The Roundtable Agenda

NEW TECHNOLOGIES AND
GLOBAL CULTURAL RESOURCE MANAGEMENT
Second Scientific Roundtable at
University of Florida, Gainesville

WORKSHOP ON RADAR IMAGING AND CULTURAL RESOURCE MANAGEMENT AT THE ANGKOR ECO-SITE
April 15-17, 1996

WORKSHOP PROGRAM

(Location: Architecture Building)

DAY ONE
Monday
April 15

9:30 AM **Welcome, Introductions, and Orientation**
Co-Chairs for Workshop:
Mr. John H. Stubbs, Vice President, Programs, World Monuments Fund
H. E. János Jelen, Ambassador, Chairman of the Board of Trustees, Royal Angkor Foundation
(Location: Atrium/Outdoor Space of Architecture Building)

10:30 AM **Definition of Tasks and Description of Work Process**
Overview of Radar Imaging Techniques and Technology
Presenters:
Dr. Tony Freeman, Group Supervisor, Data Utilization and Outreach Group, Jet Propulsion Laboratory
Dr. Elizabeth Moore, Head of Department, Department of Archaeology, School of Oriental & African Studies, University of London
Supplementary Remarks:
H. E. János Jelen
Mr. John H. Stubbs
(Location: GeoPlan Center at Architecture Building)

12:15 PM Lunch at Chaucer's Restaurant

2:00 PM **Demonstration of GeoPlan Center**
(Location: GeoPlan Center)

3:00 PM Coffee break
(Location: GeoPlan Center)

3:30 PM **Initial Work Meeting**
Remarks by Group Leaders and Coordination and Assignment of Affinity (Specialty) Groups. Affinity Groups Meet Separately to Define Scopes.
(Location: GeoPlan Center)

7:00 PM Dinner at Restaurant 706

DAY TWO
Tuesday
April 16

9:00 AM	**Brief General Meeting** (Location: Atrium/Outdoor Space)
9:30 AM	**Meeting of Affinity Groups** **Group I: Archaeology & History** *Leader:* Dr. Elizabeth Moore (Location: GeoPlan Center) **Group II: Tools and Methods: GIS and Data Acquisition and Management** *Leaders:* H. E. János Jelen Mr. Robert Kuszinger, Scientist, M.S.C. Fellow of Royal Angkor Foundation, Angkor Geoinformatic Center, Hungary (Location: GeoPlan Center) **Group III: Regional Planning and Cultural Resource Management—Potential Related Technologies for Global Monitoring** *Leader:* R. Terry Schnadelbach, Professor and Chair, Department of Landscape Architecture, University of Florida at Gainesville (Location: Atrium Gallery at Architecture Building)
12:15 PM	Buffet Lunch at Atrium/Outdoor Space
2:00 PM	**Progress Reports by Affinity Groups** (Location: URP Conference Room at Architecture Building)
2:45 PM	Coffee Break (Location: GeoPlan Center)
3:15 PM	**Progress Reports by Affinity Groups** (Location: GeoPlan Center)
4:00 PM	**Options:** 1) Continue Meetings of General Assembly 2) Meet in Affinity Groups

DAY THREE
Wednesday
April 17

9:30 AM	**Continued Work/Supplementation; Synthesis and Drafting of Results** Affinity Groups Meet Separately **Group I: Archaeology and History** (Location: GeoPlan Center) **Group II: Tools and Methods: GIS and Data Acquisition and Management** (Location: GeoPlan Center) **Group III: Regional Planning and Cultural Resource Management—Potential Related Technologies for Global Monitoring** (Location: Atrium Gallery)

12:15 PM Buffet Lunch at Atrium/Outdoor Space

1:30 PM Coffee and Tea
Meet Arriving Respondents
(Location: Atrium/Outdoor Space)

2:00 PM **Presentation of Results and Discussion**
With Participation of Invited Respondents
(Location: Room 213 at Architecture Building)

3:00 PM **Continue Presentation of Results and Discussion**
(Location: GeoPlan Center)

4:30 PM **Conclusion of Workshop**

6:00 PM Informal Gathering of Workshop Participants
and Arriving Symposium Participants for Drinks

7:00 PM Dinner at Hotel Restaurant

SYMPOSIUM ON NEW TECHNOLOGIES AND GLOBAL CULTURAL RESOURCE MANAGEMENT

April 18-19, 1996

SYMPOSIUM PROGRAM

(Location: Center for Performing Arts, Black Box Auditorium)

DAY FOUR
Thursday
April 18

Chair for Morning Sessions: Ms. Bonnie Burnham, President,
World Monuments Fund

Chair for Afternoon Sessions: H. E. János Jelen, Chairman of the Board of Trustees,
Royal Angkor Foundation

9:00 AM **OPENING REMARKS**
Dr. Wayne Drummond, Dean, College of Architecture, University of Florida
Ms. Bonnie Burnham, President, World Monuments Fund

10:30 AM **The Case for Global Monitoring of Cultural Heritage Sites**
Presenter: H. E. János Jelen

Overview Description of Radar Imaging and Archaeology
Presenter: Dr. Diane Evans, SIR-C Project Scientist, Jet Propulsion Laboratory

12:15 PM Lunch

2:00 PM **Session Opened by John Lombardi**
President, University of Florida

Field Projects—Presentation I: Radar Imaging at Angkor—Latest Developments
Presenters:
Professor Claude Jacques, Director of Studies, École Pratique des Hautes Études, Sorbonne, Paris—**Description of Angkor and Overview of Angkor's History**
Dr. Elizabeth Moore—Prehistory and Archaeology at Angkor
Professor R. Terry Schnadelbach—**Ecological Concerns and Land Use Management**

Remarks by **H. E. Vann Molyvann**
Minister of State for Culture and Fine Arts
Royal Cambodian Government

6:00 PM Cocktails at home of Ms. Marcia Raff

DAY FIVE
Friday
April 19

Chair for Day's Sessions: Mr. John H. Stubbs

9:00 AM **Field Projects—Presentation II: Radar Imaging of Desert Regions**
Presenter: Dr. Farouk El-Baz, Director, Center for Remote Sensing, Boston University

Field Projects—Presentation III: Remote Sensing and Archaeology in Northwestern Greece
Presenter: Dr. James Wiseman, Chairman, Department of Archaeology, Boston University

Field Projects—Presentation IV: Problems & Potentials —The Chaco Canyon Experiment: The Application of Remote Sensing in the Context of World Heritage Sites
Presenters: Margaret MacLean, Director, Documentation Program, The Getty Conservation Institute and Mr. Dominic Powlesland, Consultant to the Documentation Program, The Getty Conservation Institute

12:15 PM Lunch

2:00 PM **Short Reports on Ongoing Projects**
(10-15 minutes each)

The Use of Remote Sensing in Comparing Ancient Metapontum in Southern Italy and Ancient Chersonesos in Sevastopal, Ukraine
Presenters: Dr. Joseph Carter and Dr. John Morter, Department of Classics, University of Texas at Austin

Remote Sensing in Borneo
Presenter: Mr. Alexis G. Thomas, Ph.D. candidate, Project Director, GeoPlan Center, and Research Associate, Department of Urban and Regional Planning, University of Florida at Gainesville

DAY FIVE
Friday
April 19

Workshop on Global Positioning for World Heritage Sites
Presenter: Dr. John Alexander, Head of the GeoPlan Center, University of Florida at Gainesville

Very Low Altitude Aerial Remote Sensing for Archaeological Sites and Features
Presenter: Dr. Douglas C. Comer, Chief, Applied Archaeology Center, U.S. National Park Service

3:30 PM **Panel Discussion: Future Directions in Remote Sensing and Cultural Resource Management**
Questions and Answers

5:30 PM Farewell

DAY SIX
Saturday
April 20

Saturday, April 20—Optional Event for principal participants
8:30 AM Departure for Cape Canaveral for special tour

List of Participants

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Supplementary Readings

Carter, Joseph, and Jon Morter. "How the Greek Countryside was Divided in Southern Italy and Crimea: The Achievements and Potential of Remote Sensing." Paper presented at Symposium on New Technologies and Global Cultural Resource Management, April 1996.

Chandler, David L. "Space Dig: Radar Images From Shuttle Unearth Ancient History," *Boston Globe*, April 29, 1996, p. 25:1.

Eirinberg, Keith W. "New Technology Rediscovers Cambodia's History," *Phnom Penh Post*, May 17-30, 1996, p. 17.

Evans, Dr. Diane. *Overview Description of Radar Imaging and Archaeology.* New York: Simon and Schuster, 1995.

Freeman, Tony. "What is Imaging Radar?" Jet Propulsion Laboratory. January 26, 1996. World Wide Web server site at URL: <http://southport.jpl.nasa.gov/>(April 10, 1996).

Jacques, Claude. "Description of Angkor and Overview of History: The Importance of Remote Sensing for the Knowledge of the Angkorian Civilization." Paper presented at Symposium on New Technologies and Global Cultural Resource Management, April 1996.

James, Jamie. "Shuttle Radar Maps Ancient Angkor." *Science Magazine,* vol. 267, no. 5200, February 17, 1995, p. 965.

Jelen, János. "The Case for Global Monitoring of Cultural Heritage Sites." Paper presented at Symposium on New Technologies and Global Cultural Resource Management, April 1996.

NASA. *NASA DC-8 Airborne Laboratory Aircraft Program.* Washington, D.C.: U.S. Government Printing Office, January 1993.

Schnadelbach, R. Terry. "The Ecology of Angkor, Cambodia: The Ancient Capitol, Current Settlements and Future Tourism," *Proceedings of the International Federation of Landscape Architects' World Congress.* Bangkok, 1995.

Stille, Alexander. "Farsighted Tools Bring Ruins Into Focus," *Washington Post*, September 2,1996, sec. A 3:2.

Wilford, John Noble. "Space Radar to Study Khmer Temples at Angkor." *New York Times*, February 7, 1995, sec. C 11:1.

Wiseman, James. "Space Missions and Ground Truth," *Archaeology.* New York: Simon and Schuster, July/August 1996, p. 11-13.

World Monuments Fund and Royal Angkor Foundation. *Radar Imaging Survey of the Angkor Eco-Site.* Report of the First Scientific Roundtable. New York: 1995.