社会開発調査部報告書

No. 14

TOPOGRAPHIC MAPPING FOR ANGKOR ARCHAEOLOGICAL AREA IN SIEM REAP REGION OF THE KINGDOM OF CAMBODIA

FINAL REPORT

(SUMMARY)

JULY 1998

INFRASTRUCTURE DEVELOPMENT INSTITUTE
KOKUSAI KOGYO CO., LTD.

TOPOGRAPHIC MAPPING FOR ANGKOR ARCHAEOLOGICAL AREA IN SIEM REAP REGION OF THE KINGDOM OF CAMBODIA

FINAL REPORT

(SUMMARY)

INFRASTRUCTURE DEVELOPMENT INSTITUTE
KOKUSAI KOGYO CO., LTD.

Preface

In response to a request from the Government of the Kingdom of Cambodia, the Government of Japan decided to conduct the study on the Topographic Mapping for Angkor Archaeological Area in Siem Reap Region of the Kingdom of Cambodia and entrusted the Japan International Cooperation Agency (JICA).

JICA sent a study team four times to Cambodia, headed by Mr. Yoshitake Egawa, from January 1997 to May 1998.

The Team held discussions with the officials concerned of the Government of the Kingdom of Cambodia, and conducted field surveys at the study area. Consequently, the present results were prepared based on these surveys.

I hope that these results will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Kingdom of Cambodia for their close cooperation extended to the team.

July 1998

Kimio Fujita

President

Japan International Cooperation Agency

Letter of Transmittal

Mr. Kimio Fujita
President
Japan International Cooperation Agency

July 1998

Dear Sir,

It is a great honour for me to submit herewith the final report of the Study on the Topographic Mapping for Angkor Archaeological Area in Siem Reap Region of the Kingdom of Cambodia.

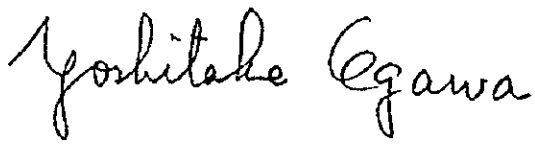
A study team, which consists of Infrastructure Development Institute and Kokusai Kogyo Co., Ltd. headed by myself, conducted field surveys and data analysis based on the terms of references instructed by the Japan International Cooperation Agency (JICA), from January 1997 to July 1998.

The study team held thorough discussions and investigations with officials concerned of the Government of the Kingdom of Cambodia. The results were collected in the final report.

On behalf of the team, I wish to express my heartfelt appreciation to the officials concerned of the Government of the Kingdom of Cambodia for their warm friendship and cooperation extended to us during our stay in Cambodia.

Also, I wish to express my sincere appreciation to JICA, the Ministry of Foreign Affairs, the Ministry of Construction, the Embassy of Japan in Cambodia, Japanese Government Team for Safeguarding Angkor and other concerned government authorities for their valuable advices and cooperation given to us in the course of the site surveys and preparation of the final report.

Yours faithfully,



Yoshitake Egawa
Team Leader
The Topographic Mapping for Angkor Archaeological Area in Siem Reap Region of the Kingdom of Cambodia

TOPOGRAPHIC MAPPING FOR ANGKOR

ARCHAEOLOGICAL AREA

IN

SIEM REAP REGION OF THE KINGDOM OF CAMBODIA

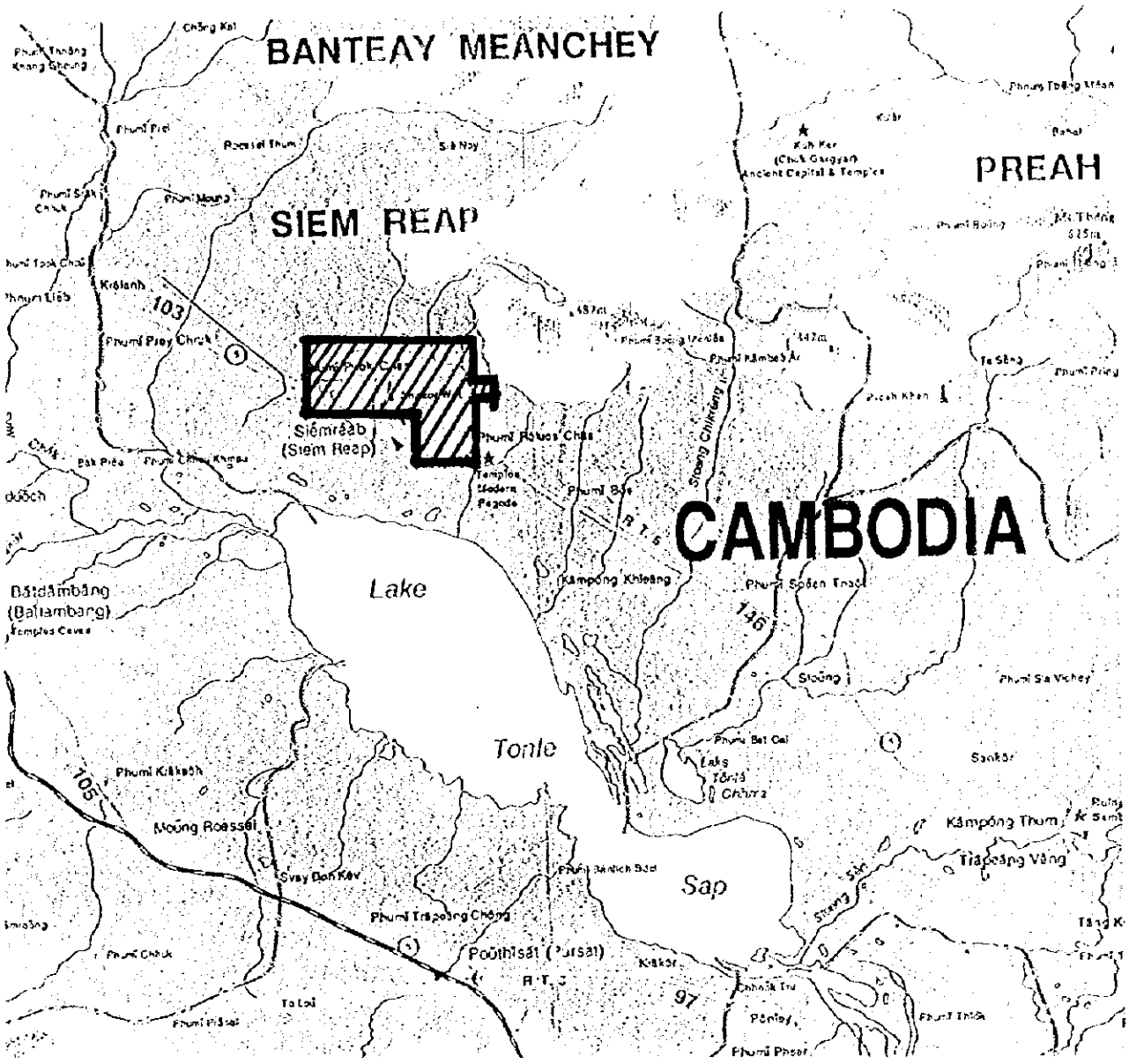
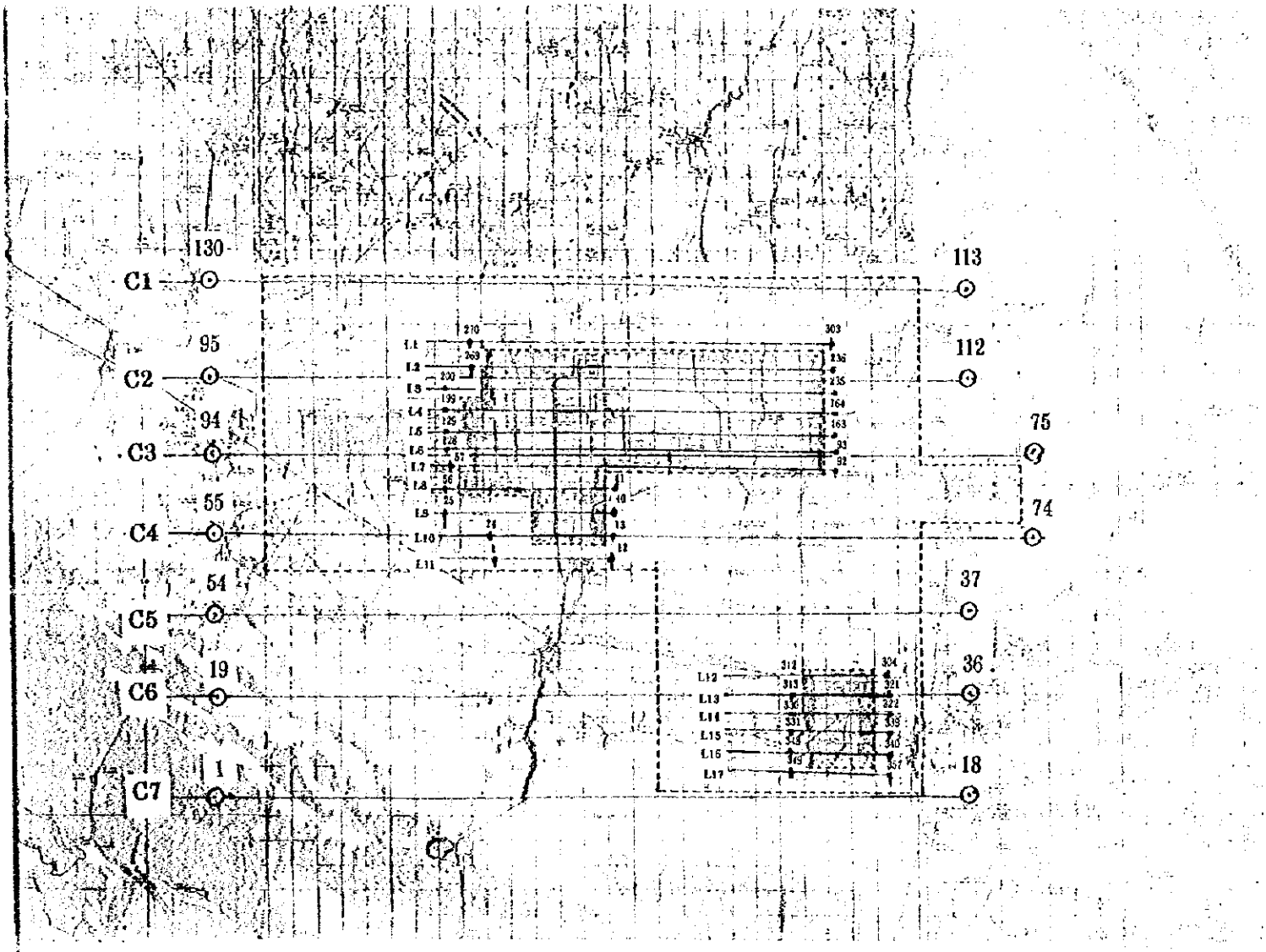


PHOTO INDEX
OF
TOPOGRAPHIC MAPPING
FOR
ANGKOR ARCHAEOLOGICAL AREA
IN
SIEM REAP REGION OF THE KINGDOM
OF
CAMBODIA

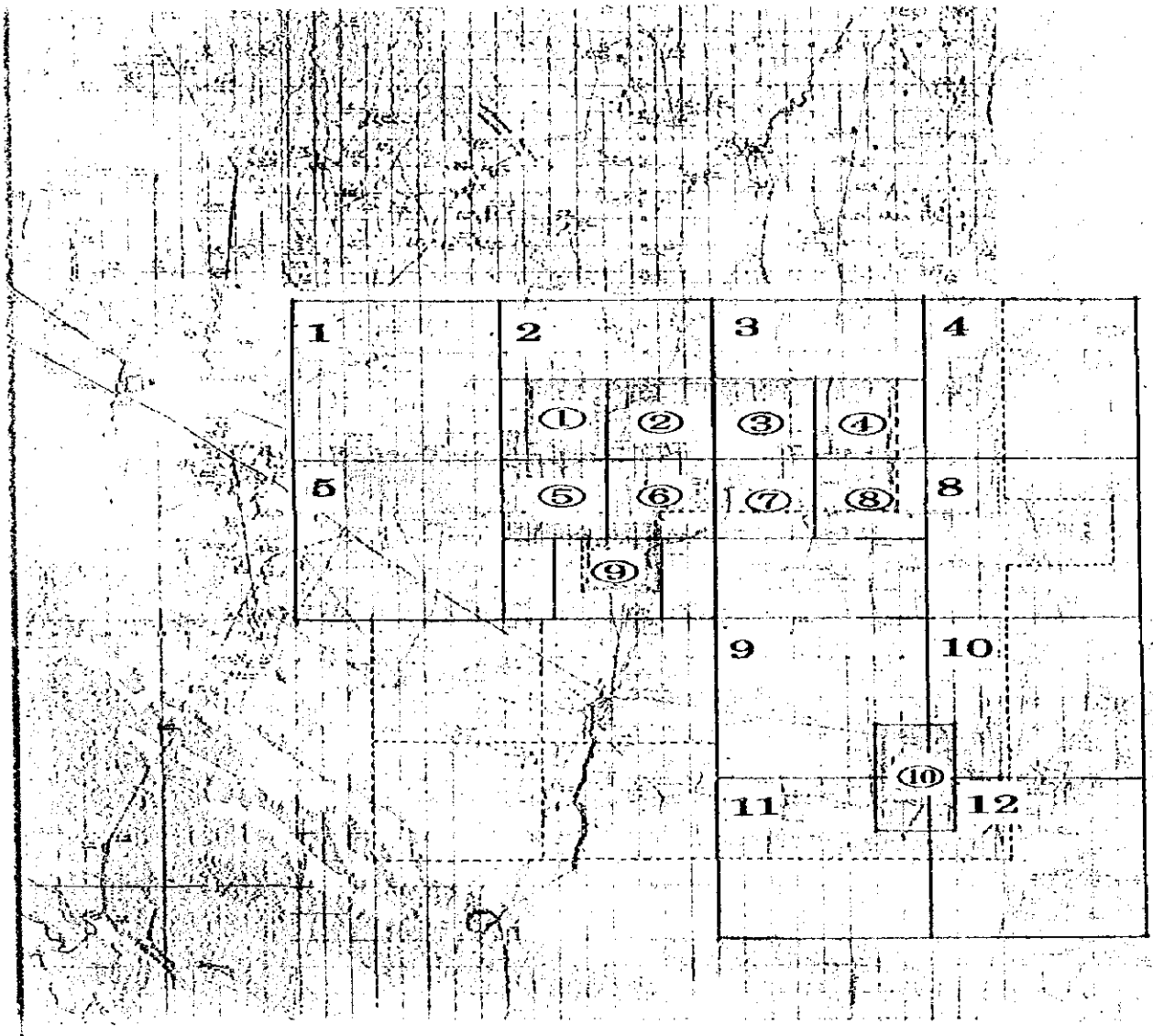
SCALE: 1/250,000



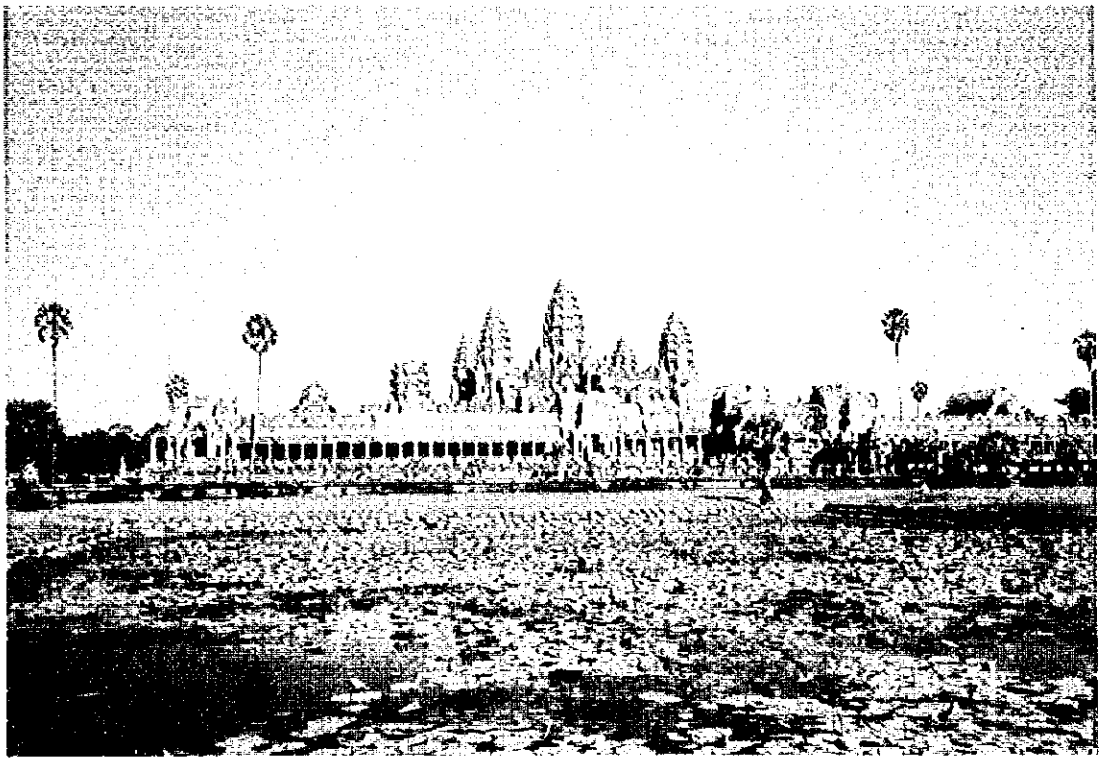
Mapping area	1:10,000 1:5,000	430 km² 100 km²
1:20,000 photo index	7 courses	130 photographs
1:5,000 photo index	17 courses	357 photographs

SHEET INDEX
OF
TOPOGRAPHIC MAPPING
FOR
ANGKOR ARCHAEOLOGICAL AREA
IN
SIEM REAP REGION OF THE KINGDOM
OF
CAMBODIA

SCALE: 1/250,000

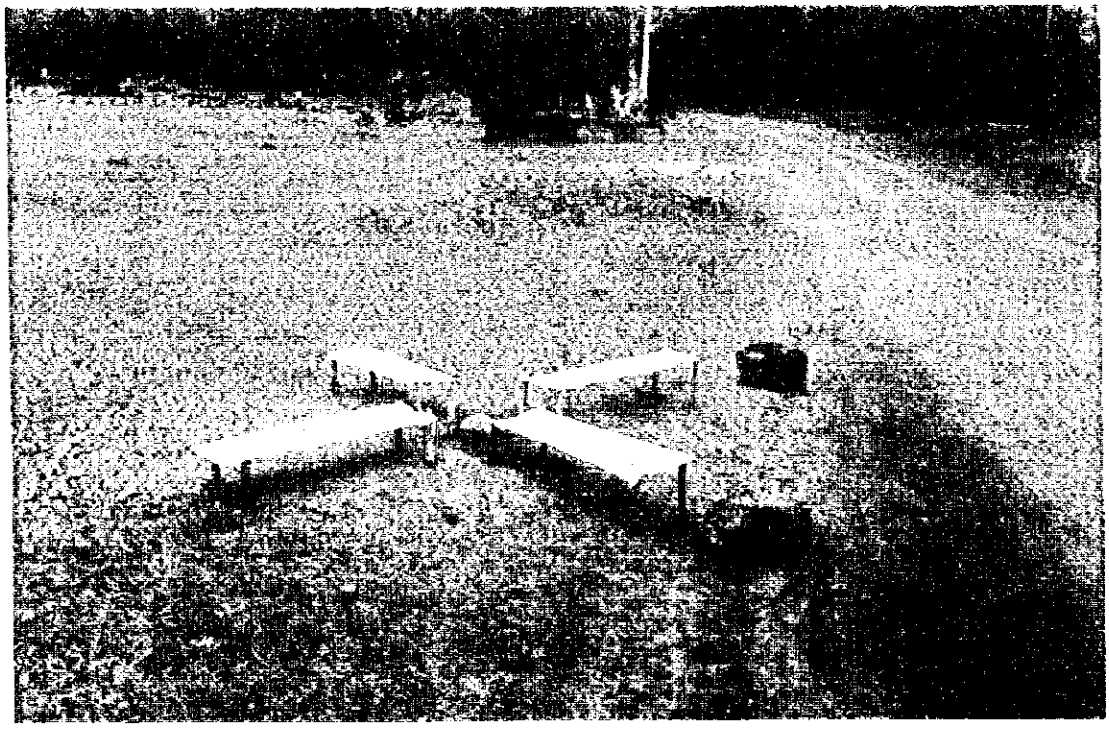


Mapping area	1:10,000 1:5,000	430 km² 100 km²
1:10,000 sheet index		12 sheets
1:5,000 sheet index		10 sheets

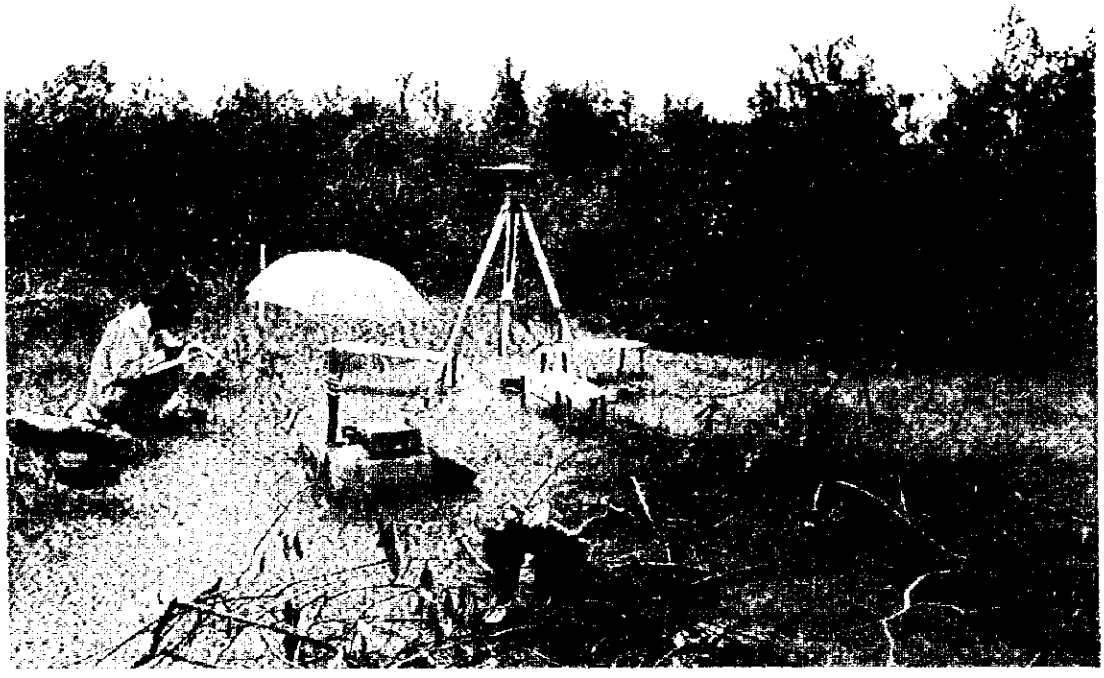


Angkor Wat

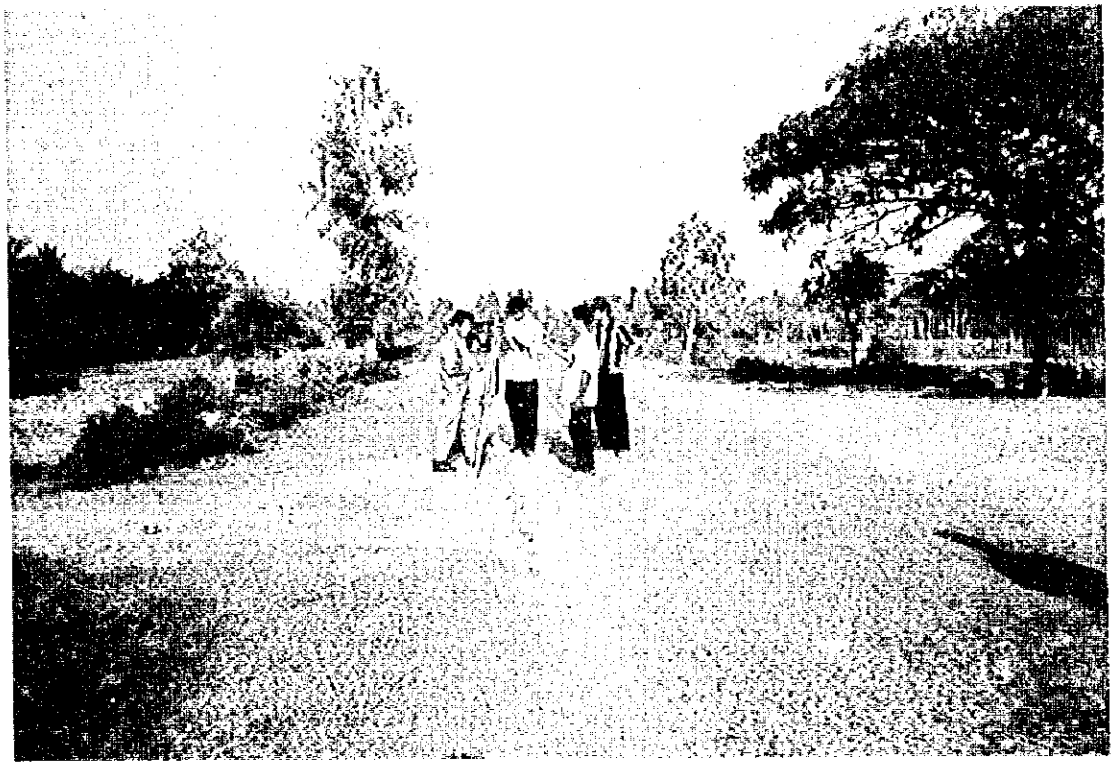
Preparation



Air Photo Signal

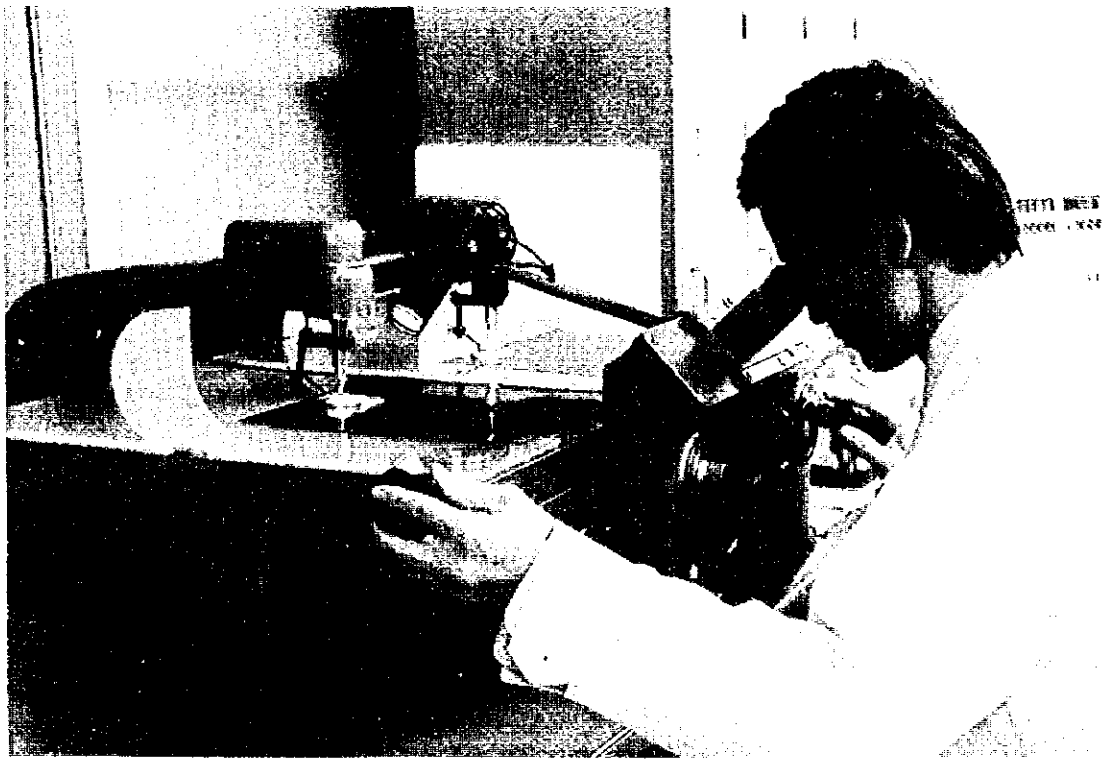


GPS Observation



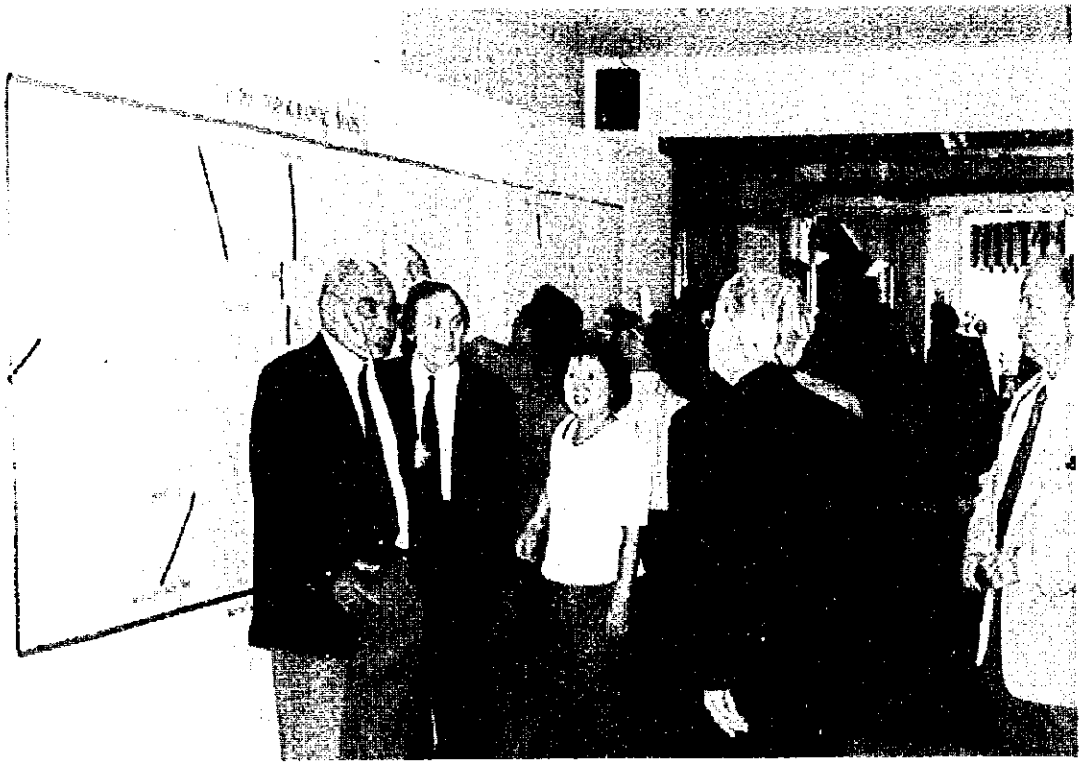
Levelling

Field Completion



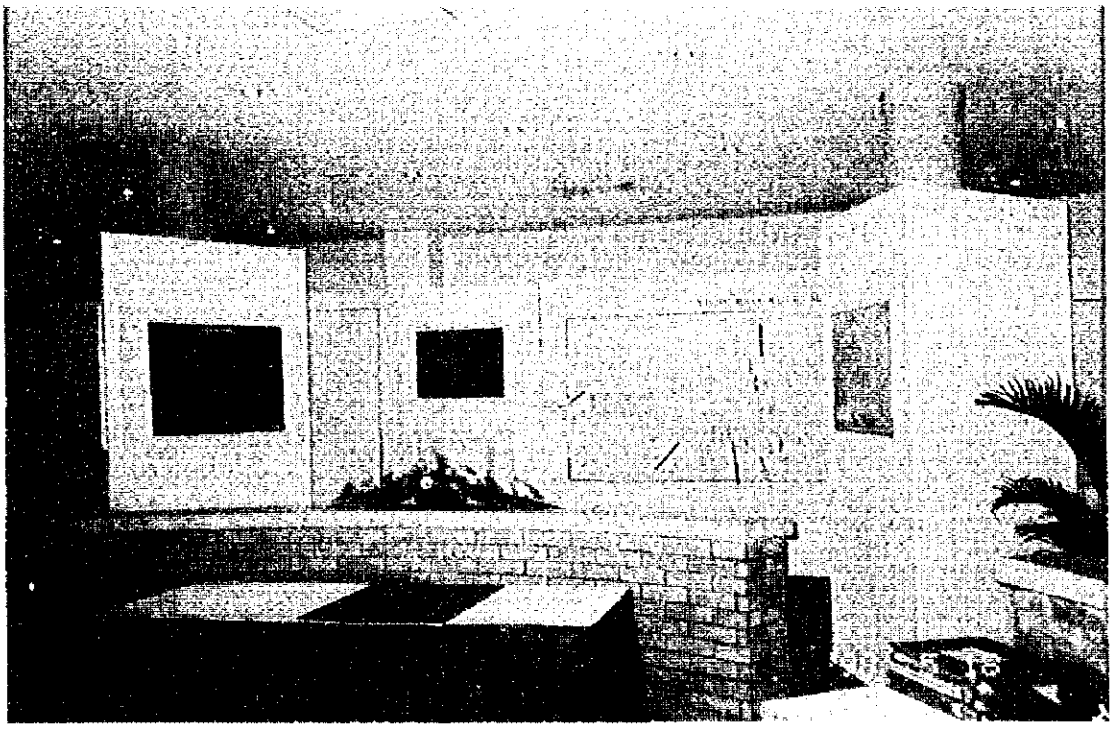
Aerial Triangulation Instrument (PUG- II)

Aerial Triangulation Instrument (STECOMETER)

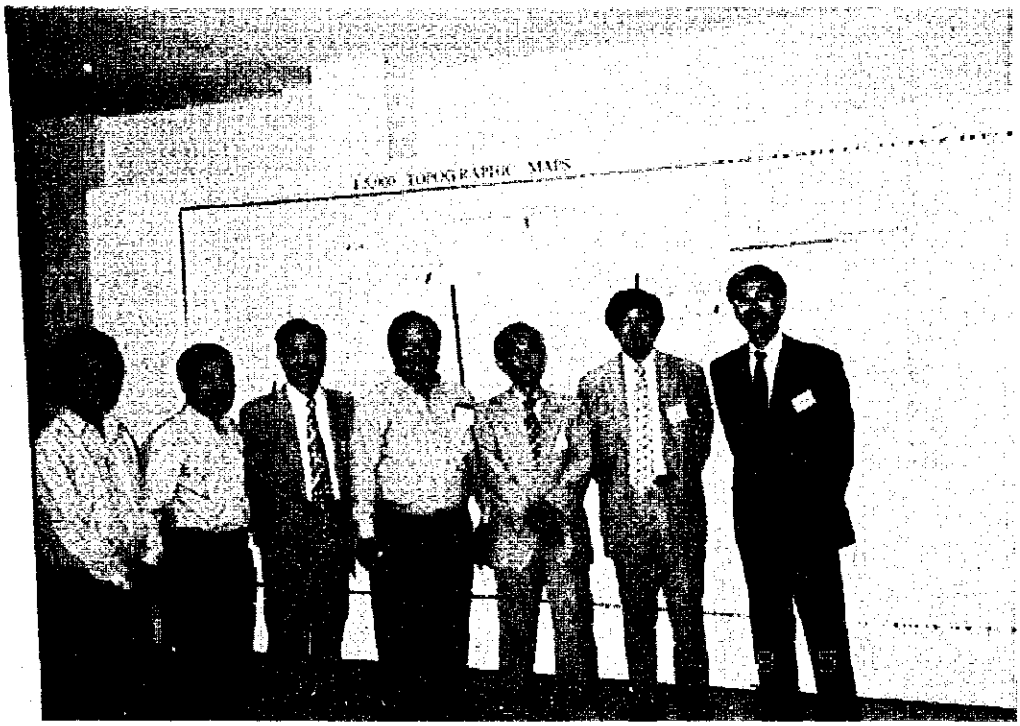


Map Exhibition in Phnom Penh
H.E. Mr. Vann Molyvann (left)

Map Exhibition in Phnom Penh

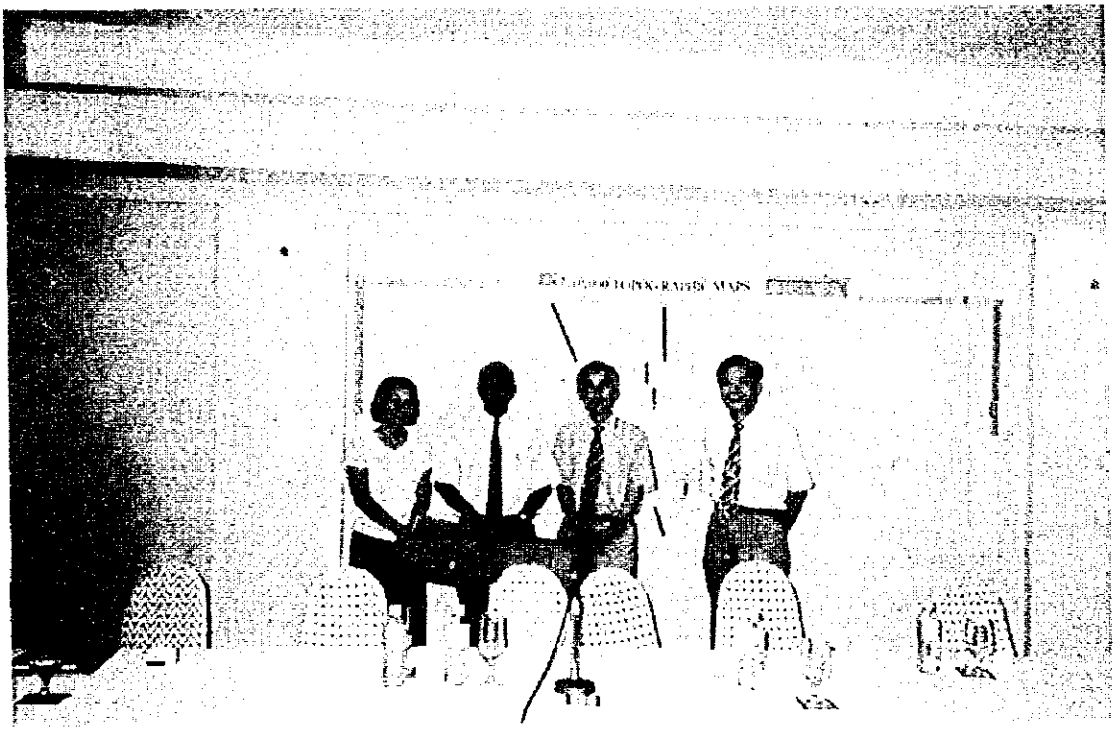


Map Exhibition in Phnom Penh

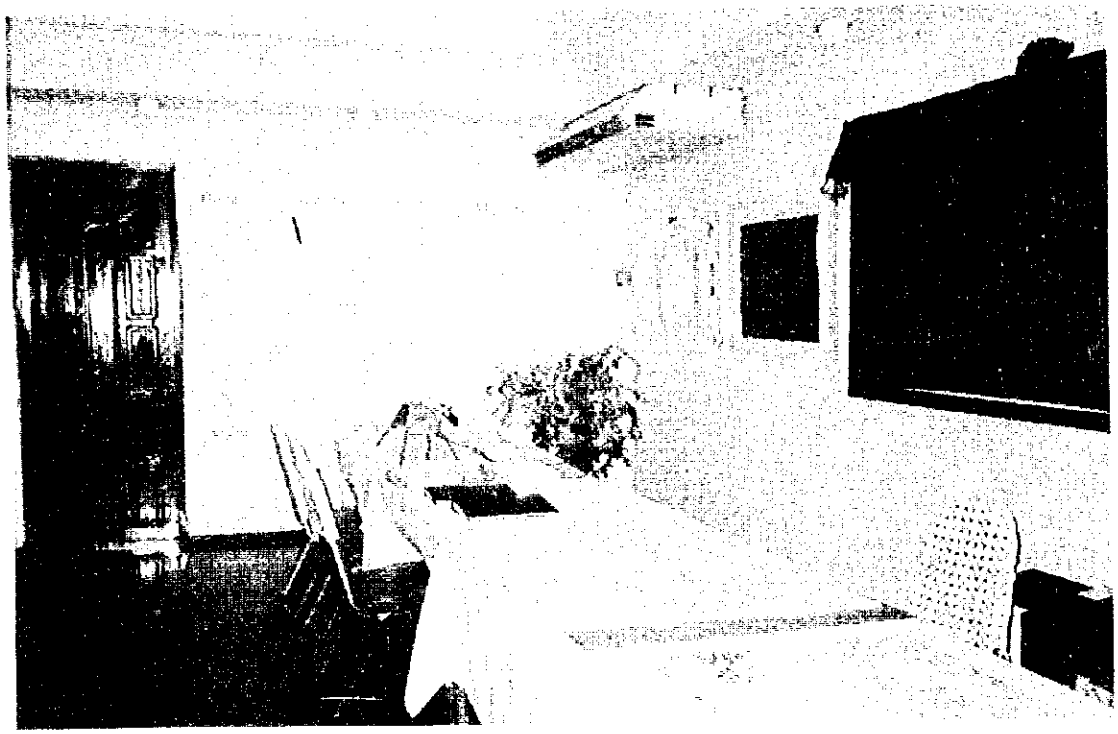


Map Exhibition in Phnom Penh

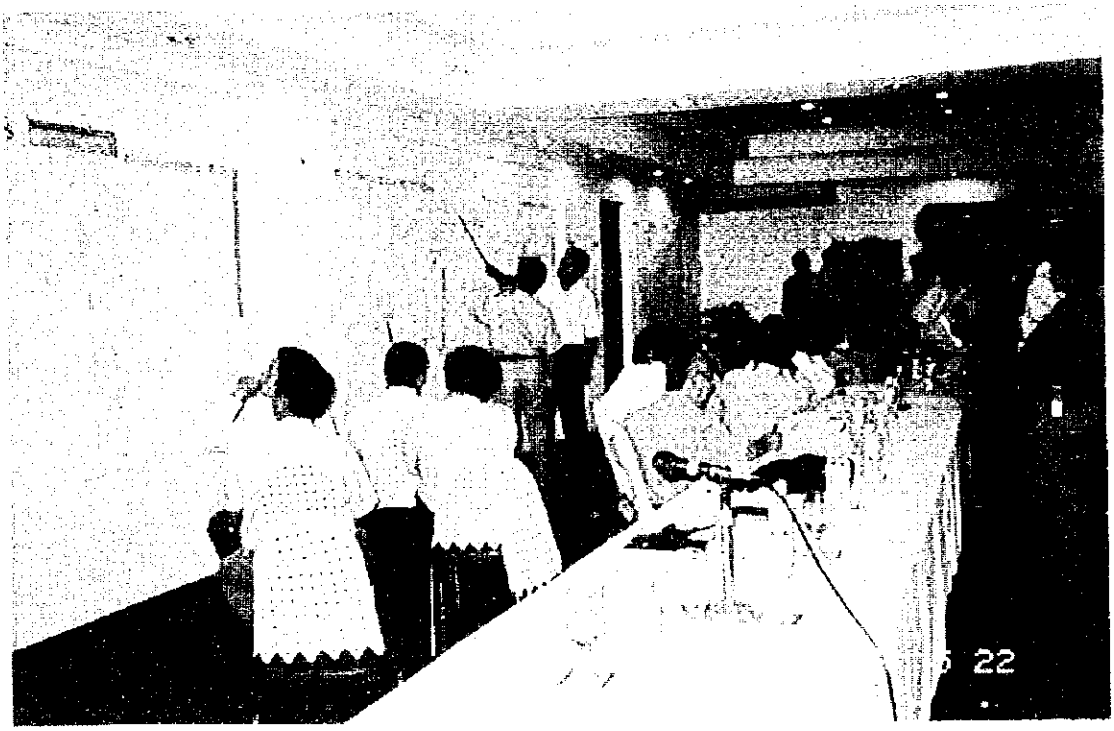
Workshop in Geographic Department



Workshop in Siem Reap



Workshop in Siem Reap



Workshop in Siem Reap

CONTENTS

1. OUTLINE AND OBJECTIVES OF THE PROJECT

This project has been implemented in accordance with the Scope of Work and the Minutes of Meeting agreed upon on 26 September 1996.

The objective of this study was to prepare a number of data (listed hereunder) on the area shown in the attached map covering Angkor Archaeological Area including Angkor Wat and Angkor Thom. This data will contribute to the future formulation of an infrastructure development plan for the surroundings of Angkor, and a plan for the excavation, survey and preservation of Angkor ruins. In addition, another objective of this study was to transfer technology to the counterpart.

Topographic map at a scale of 1:10,000	430 km^2
Topographic map at a scale of 1:5,000	100 km^2
Monochrome aerial photography at a scale of 1:20,000	577 km^2
Colour aerial photography at a scale of 1:5,000	100 km^2

The above maps were adjoined to the 4-sheet 1:10,000-scale topographic map produced by IGN France International in 1994 covering Siem Reap City and its vicinity, in the south-west corner of the study area.

The work items, quantity and schedule are shown in the following table.

Work Items	Quantity	Phase I (1997/1 ~ 3)	Phase II (1997/4 ~ 1998/3)	Phase III (1998/4 ~ 7)
Monumentation	22 points	—		
Air Photo Signals	30 points	—		
Aerial Photography	B&W 7 courses Colour 17 courses	—		
Control Point Survey	GPS 22 points	—		
Leveling	3rd order leveling 178 km	—		
Aerial Triangulation	7 courses 95 models		—	
Photo Classification	430 km^2		—	
Digital Plotting	1:10,000 430 km^2 1:5,000 100 km^2		—	
Digital Compilation	1:10,000 430 km^2 1:5,000 100 km^2		—	
Field Completion	1:10,000 430 km^2 1:5,000 100 km^2		—	
Inspections of results			—	
Workshops				—
Final Report				—

During Phase I of the Study, Japanese experts were dispatched to the Kingdom of Cambodia for the survey work such as aerial photography and control point survey.

During Phase II, aerial triangulation, digital plotting and digital compilation were implemented in Japan, while photo classification and field completion were carried out in the Kingdom of Cambodia.

During Phase III, the final results were delivered to the Kingdom of Cambodia, and various workshops were held to explain these results and show how to use them.

2. METHODS

1) Work in Cambodia

① Monumentation

Permanent monuments were installed at the 22 control points established through GPS.

② Air Photo Signals

Prior to aerial photography, air photo signals were installed at 8 existing points and 22 new points.

Air photo signals were formed using three white pieces of cloth, each measuring 90cm × 30cm.

③ Control Point Survey (GPS Survey)

Twenty two (22) points were established by GPS using as given points GPS control points established by IGN in 1994.

Relative positioning survey, which simultaneously uses four or more satellites, was carried out to conduct one set of observations lasting at least two hours and acquire data at an interval of 30 seconds. Four GPS Trimble 4000SSE were used for the observations.

When the control points and the 1:10,000-scale topographic map of the adjacent area, installed and produced respectively by IGN in 1994 were adjoined with the existing 1:50,000 topographic map, discrepancies of ΔX=350m and

ΔY=400m were observed. Therefore, the grid lines of the existing 1:50,000-scale topographic map were shifted 500m south-easterly to coincide with the grid lines used in this Study.

④ Leveling (Third Order Leveling)

Third order leveling was carried out using as given points some bench marks established by IGN in 1994 along highway 6 and the road to Angkor Wat. Direct leveling covered a total route length of 178 km.

Error limits for leveling were set at $1.5cm\sqrt{S}$ (S in km) for the errors of closure between existing points, and at $1cm\sqrt{S}$ (S in km) for the errors of closure of loops and double running observations. The observations were carried out using four Nikon AE-5 levels.

⑤ Aerial Photography

Aerial photography was carried out by a subcontractor, FINNMAP FM-International Oy, under the supervision of a Japanese expert.

Aircraft used:	Rockwell Turbo Commander 690A
Aerial camera used:	Wild RC-20
Focal length of camera:	153.18 cm
Direction of flight course:	East-West both for 1:20,000 and 1:5,000 scales

⑥ Photo Classification

Photo classification was carried out using enlarged black and white aerial photos (1:20,000) to confirm planimetric features that were unclear in the photos and the names of roads, rivers, schools, etc. for annotation.

⑦ Field Completion

Field completion was carried out using 1:10,000 and 1:5,000-scale sheets to confirm annotation items and planimetric features that were unclear during digital plotting and digital compilation.

2) Work in Japan

① Aerial Triangulation

Aerial triangulation was carried out on 95 models obtained within 7 flight courses, using black and white aerial photos (1:20,000). The analytical method was adopted.

Pricking instrument: WILD PUG-II

Measuring instrument: ZEISS JENA STECOMETER

The bundle block adjustment method was adopted using GPS points for XY coordinates and direct leveling points for elevation.

② Digital Plotting

In accordance with the S/W, the plotting scale was 1:10,000 for 430km² and 1:5,000 for 100km². However, according to the details of the meeting held on 23 February 1998, the mapping (1:5,000) of the Roluos area in the south-east region will be moved 1km to the north to include the Indratataka ruins.

An analytical plotter was used to carry out digital plotting of planimetric features and contour lines. The topographic map was found to be accurate when adjoined with the three adjacent sheets of the 1:10,000 topographic map of the south-west area produced by IGN in 1994.

The plotting density of single points was one point for every 3cm to 4cm square. Intermediate contour lines were set at an interval of 10m for the 1:10,000 map scale and 5m for the 1:5,000 map scale. Supplementary contour lines, especially for areas that are essential for the indication of the ruins, were set at intervals of 2.5m and 1.25m, respectively.

Plotting instrument: ZEISS PLANICOMP P-3

Contour intervals:

1:10,000	Intermediate contour lines	10m
	Half interval contour lines	5m
	Quarter interval contour lines	2.5m
	Supplementary interval contour lines	1.25m
1:5,000	Intermediate contour lines	5m
	Half interval contour lines	2.5m
	Quarter interval contour lines	1.25m

③ Digital Compilation

Digital compilation was carried out using a Microstation in accordance with the specified map symbols. Names of villages, roads, rivers, public facilities, etc. were annotated in English and Khmer. The annotations were sent to the Cambodian counterpart for confirmation, then sent back to Japan to be compiled in the compilor.

3 . Evaluation and Accuracy of the Results

Aerial photography was completed in 3 days, from February 19 to 21, 1998, under providentially clear skies. After the photography work, the aerial films were developed and contact prints were produced. Inspections as to whether overlaps and side laps were within the permissible limits, and whether the aerial photos were fit for use in subsequent operations, were strictly carried out.

The results of these inspections proved highly satisfactory.

During the GPS control point survey using GPS points installed by IGN in 1994 as given points, 22 new points were installed by GPS observations and three-dimensional network adjustment computations. Adjustment computation results showed that standard deviations for the new point No. 21, which had the largest errors, were X=0.012m and Y=0.014m.

Concerning elevation measurements, bench marks installed by IGN along highway No. 6 and the road to Angkor Wat were used as given points, and 22 new GPS points were set by direct leveling. As a result, the errors of closure between existing points were within $1.5\ \sqrt{S}$ cm (S in km).

Digital plotting for 1:5,000 and 1:10,000-scale maps was carried out using 1:20,000-scale aerial photos taken in February 1997. The accuracy set for horizontal and vertical positions was approximately 60cm.

Planimetric features that were unclear on the photos were checked in the field by photo classification, and then again during the field completion in order to secure accuracy.

4. Technology Transfer

Seven counterpart staff members from APSARA and the Geographic Survey Department participated in the work carried out in Cambodia under the guidance of the Japanese Study Team. It was a valuable experience for most counterpart members, who had never participated in such work before. During Phase III of the Study, the following workshops and events were held:

① Workshop in Phnom Penh

A workshop was held at the Geographic Survey Department to promote the efficient use of the results. The cooperation extended by both countries for a combined period of over a year in the course of this study was acknowledged, and a lecture was given on the significance of topographic maps and interpretation examples discussed in Chapter 3 of the Final Report. Also, for two and a half days, lectures and practical exercises were held on how to display and print data contained in the procured CD-ROM, and the way to edit and analyse data using GIS software Arc Info.

② Workshop in Siem Reap

JICA and APSARA jointly held a workshop titled "Importance of Recently Produced Maps of the Angkor Archaeological Ruins". As APSARA in Siem Reap does not have the necessary equipment, the workshop did not cover CD-ROM output or compilation/analysis of data using Arc Info. However, an exhibition similar to the Phnom Penh exhibition mentioned hereunder was held, and map reading examples and the significance of map data were introduced. In addition to all the expected government agencies existing in Siem Reap, representatives of the French Institute for the Far East and aid organisations were also present, and a lively debate on topographic map interpretation ensued. Many participants were impressed with the significance and high quality of the topographic maps produced in this study, and a number of organisations immediately requested copies of the maps from APSARA.

③ Map Exhibition

JICA and APSARA jointly held the "Exhibition of Newly Produced Maps for the Angkor Archaeological Area" for two days in the Hotel Sofitel Cambodiana. The objectives of this exhibition were to announce the completion of the

"Topographic Map for Angkor Archaeological Area" and to promote the use of this map. The venue, dates and time of this exhibition were chosen to coincide with the "Fifth Plenary Session of the International Co-ordinating Committee for the Safeguarding and Development of the Historic Site of Angkor", held by UNESCO, and its preliminary meeting. A total of approximately 100 persons, e.g. government officials such as H.E. Minister Vann Molyvann and various embassy representatives including the Japanese ambassador, participated actively to an enthusiastic Question & Answer session.

④ Others

At the "Fifth Plenary Session of the International Co-ordinating Committee for the Safeguarding and Development of the Historic Site of Angkor" mentioned above, Prof. Yoshiaki Ishizawa, the head of the foreign department of Sophia University and an Angkor specialist, presented his paper entitled "Investigation of the Ruins of the Angkor Region and Regional development--Uses for the New 1:5000 Topographic Map". He confirmed the significance of the information provided by the topographic maps produced in this Study.

5. Final Results

The final results and quantities delivered to APSARA and the Geographic Survey Department are listed hereunder.

1) Results delivered to APSARA

① Black and white contact prints of aerial photos	1 set
② Colour contact prints of aerial photos	1 set
③ Results of control point survey (copy)	1 set
④ Results of aerial triangulation (copy)	1 set
⑤ 1:10,000 and 1:5,000 topographic maps – duplicated draft map	2 sets of each
⑥ 1:10,000 and 1:5,000 topographic maps – blue print	3 sets of each
⑦ 1:10,000 and 1:5,000 topographic maps – digital data on CD-ROM	5 sets of each

2) Results delivered to the Geographic Survey Department

① Black and white positive films of aerial photos	1 set
② Black and white contact prints of aerial photos	1 set
③ Colour contact prints of aerial photos	1 set
④ Results of control point survey (original and copy)	1 set of each
⑤ Results of aerial triangulation (original and copy)	1 set of each
⑥ 1:10,000 and 1:5,000 topographic maps – draft map	1 set of each
⑦ 1:10,000 and 1:5,000 topographic maps – duplicated draft map	2 sets of each
⑧ 1:10,000 and 1:5,000 topographic maps – blue print	3 sets of each
⑨ 1:10,000 and 1:5,000 topographic maps – digital data on CD-ROM	5 sets of each

Negatives of aerial photographs shall be kept by JICA in Tokyo until the Cambodian side prepares equipment and an appropriate storage facility. During this period, the Japanese side shall reproduce paper prints when requested by APSARA or the Geographic Survey Department through the JICA Cambodia Office under the following procedures.

① The user that requests prints of aerial photographs shall submit a copy of the order to either APSARA or the Geographic Survey Department.

② APSARA or the Geographic Survey Department shall convey the order to JICA Cambodian side.

③ All expenses including shipping and transportation shall be borne by the requester and paid to the Infrastructure Development Institute-Japan.

The Cambodian side agreed that JICA can reproduce paper prints for research and internal use from negatives of aerial photographs.

6. INTERPRETATION OF TOPOGRAPHICAL MAPS FOR THE ANGKOR RUINS

1) The significance of topographical maps and aerial photography

Although a large number of scientific surveys have been made in Angkor ruin area, most of them have concentrated on researching inscriptions, carvings, and buildings. Irrigation networks, roads, and other aspects of infrastructure have received secondary treatment. This is partly because there used to be no detailed topographical map covering the entire Angkor area. The rise of the Angkor Empire was supported by well-developed irrigation and road networks. And the decline of the irrigation and road network is agreed by many observers to have led to its fall. If his is so, it should be particularly important today to learn from past experience and lessons, with a view to the immediate issue of rebuilding Cambodia's infrastructure.

The present survey was based on information from above ground, i.e. aerial photography. As a result, we were able to make detailed and precise records of topography that is thought to have unknown archaeological significance.

In this Section, we shall introduce some results of the interpretation.

2) The Fan and the rise of the Angkor Empire

Although the topographical and geological characteristics of the survey area have not been discussed until now, various features are clearly indicative of an alluvial fan of the river Siem Reap.

Fans require unified management of the entire river basin, and soil on which is continually renewed and generally rich, avoiding the leaching characteristic of tropical zones. Consequently, massive accumulations of power tend to occur in fan areas. The fact that the foundations of the Angkor Empire were built on an alluvial fan is extremely provocative.

3) Lost of Baray (reservoir) functions and Riverbed lowering

In the days of the Angkor Empire, the Baray apparently lost its functions and the reason why is told to be sedimentation. But these precise maps show rather than the bed of the all Barays, being lower than the surrounding area. Thanks to the newly produced maps, ancient riverbed which shows the proper nature of

Angkor Era is discovered. About 2 kilometres downstream from the point where the south-flowing river Siem Reap arrives at the East is the best example. The depth of the valley in this vicinity is about 9 metres. But the site of the original artificial channel still remains as it was, terraced with a height differential of only about 3 metres compared to the Fan surface.

At a point 700 metres east of the Victory Gate at Angkor Thom, the remains of the Spean Thma bridge can be seen. At this point the ancient riverbed is preserved as a terraced riverbank. This shows the riverbed lowering is 4-5m.

The area along the Ou Phaat River includes extensive arable land from its upstream areas, is not so badly eroded as the Siem Reap River. The difference between the Siem Reap is the criss-crossed by numerous crude embankments of up to 2 metres in height (functioning as canal walls) rather than systematic and massive irrigation facilities.

4) The cause of riverbed lowering

The Siem Reap Fan has an extremely small inclination of about 1:1,000. Consequently, when riverbed lowering occurs, it has a significant impact on irrigation systems; for example, it may make it impossible to draw water. It is certain that the bed was higher at the height of the Angkor Empire. But whether the lowering of the riverbed and the decline of the Angkor Empire from the 13th century onwards are temporally related is an important question.

The lowering of the riverbed may have been caused by (1) reduced water levels in Lake Tonle Sap, (2) changes in the amount of rainfall, (3) changes in flow volume due to changes in the catchment area, and (4) short cuts in the flow course.

If we assume (1), reduced water levels in Lake Tonle Sap, to be the cause, a similar lowering of riverbeds would be seen in all the rivers, or to the same extent in downstream areas as upstream (or more so) for any one river. But this is not the case.

As for (2), changes in the amount of rainfall, it is known that between the 4th and 12th centuries temperatures rose and rainfall increased in many parts of the world. A number of Angkor researchers share the view that flow volumes in rivers were greater in the days of the Angkor Empire than they are today. But this is not enough to explain certain phenomena; for example, the fact that the lowering of the riverbed in the Siem Reap was far greater than that in the Ou Phaat.

If (3) were true, the flow volume in the Siem Reap would increase as a result of Rajendravarman's weir while that of the Ou Phaat, conversely, would decrease. But in both cases the riverbed has lowered.

Even given the three phenomena in (1), (2), and (3) above, it would still be hard to judge whether riverbed lowering would occur as seen in this site. But if there had been a short cut in the flow course as suggested in (4), this would cause the riverbed to sink.

The course of the Siem Reap has been greatly modified through irrigation works since the days of the Angkor Empire. Its course through the alluvial fan originally featured a succession of gentle bends, but was changed to a straight course through modification works. Let us assume that the course of the Siem Reap, meandering back and forth before reaching the North Baray, was modified to a straight one. If we now measure the change in length using 1:50,000 scale topographical maps, we find that it would be 0.63 times the original length. Minor bends in the course are abbreviated on 1:50,000 topographical maps, owing to limitations on the amount of detail. So the actual rate of contraction would have been even greater.

5) The principle of the Baray system

A major characteristic of the irrigation system in this region is its dependence on massive reservoirs called "Baray". These Baray are all rectangular, with their longitudinal axis in the east-west direction. This means that they run diagonal to the contour lines (with the exception of Indratataaka). At first sight, their rectangular shape and obliqueness to contour lines would appear illogical. The longitudinal Baray requires more earth works and if the long axis of the Baray ran parallel to contour lines, their water storage efficiency would improve.

Some theory claims that, Baray took water from natural rivers through the artificial channel above the embankment from which water was poured in. If such an artificial channel did exist, it would have been more massive than all the other structures, and its remains would be clearly visible in each Baray. In fact, nothing of the sort can be found.

To use water efficiently in areas that have a gentle gradient in a single direction, the water has to flow at the minimum inclination required for the flow to continue, rather than in the direction of the greatest inclination. The water reservoir time is prolonged by making the course as long as possible, and this also helps to maintain the head.

When constructing the city of Angkor, many parallel roads were built running north to south and east to west, with Phnom Bakheng as their central coordinate. These roads were made of mounded earth, and thus also formed embankments. Dwellings are also thought to have existed alongside the roads. Of these roads, those that ran in an east-west direction led water to the southwest as it flowed down from the northeast, and also served to store this water, in combination with the north-south roads. Since these L-shaped Baray used two embankments (roads) to store water, their water storage volume could be increased by lengthening the embankments or raising their height. When the water storage capacity is increased in this way, a C-shaped three-sided reservoir can be produced by adding a third road (embankment) on the north side. If then a further embankment is added on the east side, and the northeastern corner is cut open and then closed off after the maximum volume of water has been collected during floods, more water can be stored. Though lacking conclusive evidence, this would provide a logical explanation to all the issues, including the apparently illogical shape and orientation of the Baray, the flexibility of the construction plans, the ease of the work, and the construction of terraced Baray.