GROUND-PENETRATING RADAR SURVEY
BANTEAY CHHMAR, CAMBODIA.

For the Global Heritage Fund

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EXECUTIVE SUMMARY

Till Sonnemann of the Archaeological Prospection Group (University of Sydney) was commissioned by the Global Heritage Fund to undertake a remote sensing (Ground-penetrating radar) survey to identify potential sub-surface buried Angkorian water management features and structures in proximity of the temple site of Banteay Chhmar, Banteay Meanchey Province, Cambodia. The ground penetrating radar (GPR) and surface survey of the site was conducted on Wednesday, December 14-15, 2009. 41 transects and a small grid in the temple enclosure were conducted.

Several estimated Angkorian water management features were detected with the GPR. There is evidence for remains of a road that connected the main temple and the eastern gate.
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BACKGROUND INFORMATION

Banteay Chhmar was founded and built under the rule of Jayavarman VII. A large water management system was constructed to fill the *baray* and the moat of Banteay Chhmar to support the area population’s need for water.

Figure 1: Overview of Banteay Chhmar with areas where GPR profiles were conducted.

STUDY AREA

Due to the limited time, several areas visible in *Figure 1* were chosen for the survey where a positive outcome of the GPR was regarded as most promising. This included Area A1 at the temple enclosure of Banteay Chhmar to investigate the relationship of the temple enclosure and the gate in the east. Areas A2-A4 were chosen to search for water management features in the *baray* embankment and to investigate the interior of the *baray* east of the enclosure. GPR-Profiles in Areas A5 and A6 were supposed to understand better the role of the distributor channels, while A7 and A8 were conducted to detect potential inlets/outlets of the enclosure moat. 41 profiles of varying length were conducted. The profiles are presented in order of conduction.

A grid that was intended to cover most of the void area between the eastern side of the temple and the gate was unfinished due to equipment failure. Therefore only 50m x 15 m were covered.
GROUND PENETRATING RADAR

Ground Penetrating Radar (GPR) is a non-destructive and non-invasive geophysical survey method widely used in archaeological prospection to locate and indicate the depth of subsurface features, such as building foundations, buried structures, graves and service lines. Ground Penetrating Radar works on the basis of VHF pulses being directed into the earth’s surface.

The GPR instrument consists of an antenna and a processing unit. The antenna slides over the ground sending every few centimetres an electromagnetic signal into the subsurface. Whenever the signal hits a layer or an object of different electromagnetic character than the layer above, part of the signal is reflected and sent back (Snell’s law). The signal is received by a second antenna and the time elapsed (travel time) is measured in nanoseconds [ns], while the velocity for electromagnetic signals is displayed in meters/ nanoseconds [m/ns].

The sum of all transmitted signals of one survey line is called radargram. With knowledge of the composition of the subsurface (i.e. dry concrete, dry sand ~ 0.15 [m/ns], wet sand ~ 0.055 [m/ns]) the travel time can be translated into depth of the object from which the signal has been reflected, which allows the creation of an electromagnetic image of the subsurface. Knowledge from excavations in the Angkor area is the only possible information about the true depth of features, it is assumed in this study that 10ns is about 0.6 – 0.8 metres depth. Tree roots and strong electrical/magnetic fields such as from power lines can also influence results.

The depths and resolution of the survey depends on the ground composition and the antenna type used. For archaeological prospection a frequency range of 250-500 MHz antenna is normally used. For this survey a 250 MHz shielded antenna on a Mala X3M GPR system was utilized.

To survey an area a grid is set up, and the GPR is run over in parallel lines with a spacing of usually 0.5 m, a process similar to lawn mowing, to cover the total area. Grids have to be a certain size to make the results interpretable (should not be smaller than 5 m by 5 m), so the goal is to make the grids as large as possible with minimum obstacles in the path of the GPR. Using the travel time/depth information, computer programs can take the data from each line in the grid and produce a travel time—and therefore depth—dependent three-dimensional map of the area. The map can be viewed as horizontal slices, layer by layer defined by the depth, known as time-slices. For the current survey all data was post-processed using GPR Slice imaging software.
Interpretation of Results were carried out by adding the GPS information of the profiles into a GIS environment (Map information WGS 84, Universal Transverse Mercator (UTM) Projection, Zone 48N) and then relating the measured anomalies with Geoeye Satellite Imagery (provided by Damian Evans). The interpreted anomalies are here categorized as

- **linear feature (red)**: apply to lateritic or sandstone bases, such as foundations, buried bridges or modern metal covers,
- **channel (green)**: concave anomalies that are either engineered channels or ponds.
- **disturbance (yellow)**: strong disturbances of the subsurface, usually related to water saturated soil or former natural rivers.

**RESULTS AND INTERPRETATION**

**AREA A1: CONNECTION BETWEEN THE TEMPLE STRUCTURE AND THE GATE**

![Figure 2: Area A1 – GPR-Profiles east of the temple](image)

The location east of the moat was chosen to survey for an exit channel out of the moat at the east side of the moat. The profiles (BC_DAT_0001 and BC_DAT_0002) show no clear evidence which support this assumption. The strong reflection at BC_DAT_0002 (2-4m) is presumably a metal cover.
Profile BC_DAT_0003 which runs over the causeway shows a reflection at 15-35 m (at about 1-1.5m depth), as it is visible throughout part of the radargram, it could be the water table below the saturated causeway and presumably no structure. A line representing the extension of the temple causeway to the east shows the direction of the original causeway. The long reflection in BC_DAT_0003 could in some way correspond to this alignment; the reflection though is not very strong to represent any form of rock like laterite, but could be a clay surface.

Figure 4: Profile BC_DAT_0003 (E->W) over the moat.
The remaining profiles in this area were conducted to investigate a potential road between the temple in the west and the gate. DAT_0004 – 0007 were conducted in a lower area, about 0.5 m lower than the platform where DAT_0008 - 0011 were conducted. While BC_DAT_0004 and 0005 do not show significant results, a very strong horizontal reflector was detected in BC_DAT_0006, and can be assumed to be a laterite/sandstone surface. Disturbances are also visible in BC_DAT_0007 through BC_DAT_0008 which are close to the line that displays the extension of the temple axis. This would speak for a partly still existing alignment between the two gates. Nevertheless a laterite road would have definitely been detected more clearly. An interpretation would be that in certain areas the laterite is still in place, while in other parts it had been removed.
The Grid, which unfortunately was not finished due to equipment failure, is too short in east-west direction to interpret much, though there are 2 linear features, at y=20 and y=30 m length that are visible in several time slices (especially A7). As they are in alignment with the gates, this could be of importance. Another linear feature is visible at y = 44 m, this coincides with the northern one of the three gates of the temple and the Dharmasala north of the central axis. The strong (red) reflection visible at the right at 27-30 m is a sand mount from a former excavation.
Figure 7: Setting up the grid west of the temple. Time slice A7 (Depth: 0.66-0.78 m).
Figure 8: GPR-Grid time slices of the unfinished Grid.
Area A2, A3 and A4: The Baray

At the baray the main intention for a GPR survey was to find out more about a potential outlet, expected to be situated here through a canal leaving the baray into southeastern direction. Another task was to investigate if laterite could be detected under the surface in the baray. As the complete baray embankment is covered by cut laterite to the inside, it is presumed that the stone comes from close by. Several profiles were conducted parallel to the embankment. Three transects were conducted south of the embankment, two inside the baray and five on the embankment, to find clues about a potential outlet.

Figure 9: Area A2. Profiles BC_DAT_0012 – BC_DAT_0021
Disturbances and strong reflection in the profiles south of the *baray* embankment, in line with the canal feature to the south, suggest that there was a channel, although a clear defined channel feature (especially visible in BC_DAT_0012, 37-43m) cannot be readily distinguished from the results.
The profiles in the *baray*, and here especially BC_DAT_0016 which was taken further inside the *baray* display a strong reflector at about 1 m depth. As the southern *baray* embankment was raised at its construction over the original surface, the reflection of the original soil could be visible as a strong anomaly, though considering the distance to the embankment and its depth this is rather unlikely. Usually ground water displays a similar reflection (displayed as a long horizontal layer), though was the *baray* filled with water when the survey was taken, which neglects this hypothesis too. Therefore it is probably a change in the subsurface, such as a clay layer or a possible lateritic layer. This would have to be investigated further by coring or excavation.

After georeferencing the profiles surveyed on the embankment and correlating it to the extended alignment of the southeastern canal, all profiles, especially BC_DAT_0017 which shows no strong reflection, are clearly situated too far to the west to intercept a straight canal feature. The other profiles on top of the embankment, (BC_DAT_0018 - BC_DAT_0021) display clearly a disturbance at the location where a potential exit could have been. The GPR signal does not penetrate the ground further than 2-2.5 m at this location, but the additional profiles taken to provide a better conclusion at this location, show structural features in the subsurface. Here definitely an excavation would make sense. Unfortunately to the survey, the surveyed area was later found to be too far to the west, and the area where the canal would have reached the embankment was not surveyed.
Figure 13: GPR-Profiles BC_DAT_0017 (W->E), BC_DAT_0018 (W->E), BC_DAT_0019 (E->W), BC_DAT_0020 (W->E) BC_DAT_0021 (E->W). On top of the embankment.
Another survey was conducted at the former visible inlet in the south embankment of the *baray*. If the signal doesn’t disappear due to the combination of soil and water as it is visible In BC_DAT_0022, a similar strong reflector is visible at about 1 m depth, definitely a change in the soil, but difficult to conclude more. Clearly detected was the entry of the visible entry channel coming from the south, where the original surface has been eroded.
Figure 15: GPR-Profiles BC_DAT_0022 – BC_DAT_0024. In the south-east corner of the baray.

Figure 16: Area A5: Along the north embankment

Figure 17: Profile BC_DAT_0025 (E->W). Along the north embankment

A long profile was conducted on the road that runs outside of the baray parallel to the north embankment, but the intended extension of the feature in the south does not appear in the signal. The road also changes in its topography, which influences the signal. Actual mounts appear as channel features in the signal, this makes interpretation very difficult. Although the dirt road rises to the embankment from 350 meters on there is an actual dip / channel feature at 375-390, which runs about 25 m west of the potential extension of the southeastern canal leaving the baray.
AREA A5 AND A6: CHANNELS

Several features were investigated in the region northwest of the temple enclosure. In Area A5 two long transects were conducted to detect possible laterite breaches in the embankments.

Figure 18: Area A5: Concerning the outer moat
Figure 19: Profiles BC_DAT_0026 (E->W) – BC_DAT_0027 (S-N).

BC_DAT_0025 does not show any evidence for breaches in the embankment where the GPR instrument was run. The result of BC_DAT_0027 does not show the channel at the anticipated location, but several large potential channels visible in Fig. 18. As always that does not mean that there has never been a channel, only that the GPR is not able to detect it.
Figure 20: Area A6: Channels in the northwest.

Area A6 is located on the watershed a few kilometres to the northwest of the enclosure. The embankments of one channel parallel to the road are clearly visible. Two small profiles, BC_DAT_0028, (N->S, further west) and BC_DAT_0029 (S-N) display the deposited sediments in the channel. Clear evidence for channel features is visible in the following profiles BC_DAT_0030 (150m) – BC_DAT_0033 (10 m) conducted mainly in North-South direction. The first part of the profiles conducted in the western area display deep channel features. To support the findings, additional transects were conducted to the east, and similar channel features (with about the same size and depth) appear at the anticipated location (BC_DAT_0034, 55m, and BC_DAT_0037 85m), although they vary in form, size and appearance, which prohibits easy correlation with each other. A perpendicular west-> east profile (BC_DAT_0036) does not show any channel features, as expected.
Figure 21: Profiles BC_DAT_0028 – BC_DAT_0034. Western part of the channels.
Figure 22: BC_DAT_0034-BC_DAT_0037. Eastern part of the channels.
Figure 23: Area A7 - Centre of the north enclosure moat

The two profiles parallel to the northern moat perpendicular to the centre walkway were conducted to find evidence for outlet features, close to the northern walkway. While BC_DAT_0038 shows a stronger reflection at 80-90m at the centre of the walkway, which is not for certain a structure or channel, BC_DAT_0039 clearly shows a structural feature at 100-110 m, (1 m depth), in alignment with the northern causeway, probably a laterite continuation of the walkway to the north.

Figure 24: Profiles BC_DAT_0039 (W-E) and BC_DAT_0041 (E-W)
Figure 25: Area A8: Northeast corner of the enclosure moat.

After filtering BC_DAT_0040 a channel like feature appears in the northeast corner of the moat. Due to the heavy lateritic compaction of the road, the data is very noisy, but it can’t be ruled out that the feature actually is an exit channel.

Figure 26: Profiles BC_DAT_0040 (W-E) and BC_DAT_0041 (N-S)
SUMMARY

As Ground-penetrating Radar was able to detect several features that were predicted from aerial images or due to symmetrical reason, it clearly shows the advantages of using geophysical methods at Banteay Chhmar. If no evidence was found this still does not mean that there is no structure/channel. The conclusion here can only be that the instrument has not detected it.

FURTHER SURVEY

Different geophysical methods, such as small scale seismic or resistivity to better understand the subsurface in the baray, or excavations, especially in areas where features were detected will certainly give new clues and improve the understanding of the water management system at Banteay Chhmar. Nevertheless can any Geophysical method not provide the same detailed information which would be received from an archaeological excavation.
REFERENCES


Conyers, L. B. 2004 Ground-Penetrating Radar for Archaeology. Walnut Creek, California: AltaMira Press.


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Ground-penetrating Radar Survey – Banteay Chhmar
## APPENDIX: ANOMALIES

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