Airborne LiDAR prospection and archaeological investigations at Lovea, an Iron Age moated settlement in central Cambodia

Dougald O'Reilly[1,*], Damian Evans[2] & Louise Shewan[3]

[1] *The Australian National University, School of Archaeology and Anthropology, Canberra, ACT 2601, Australia*

[2] *École française d'Extrême-Orient, Boeung Daun Pa, Slorkram, Siem Reap, Cambodia*

[3] *The University of Melbourne, School of Earth Sciences, VIC 3010, Australia*

[*] *Author for correspondence (Email: dougald.oreilly@anu.edu.au)*

Recent archaeological investigations and technological applications have significantly increased our appreciation of the complexities of pre-Angkorian societal development. The results have revealed a transformative period characterised by increasing socio-political complexity, exchange and technological transfer, differences in burial wealth, growing levels of conflict and variation in site morphology. Among the excavated Iron Age sites in Cambodia, Lovea, near the heart of Angkor, is well placed to provide a greater understanding of these changes in this region. Archaeological excavation and remote sensing confirm that the two moats surrounding Lovea are testimony to the early adoption of water-management strategies. These strategies grew in complexity, culminating in the vast network of canals, reservoirs and tanks that are the hallmarks of the hydraulic society of Angkor.

Keywords: Cambodia, Lovea, Iron Age, LiDAR, water management

Table S1. Location, dimensions and notes on units excavated at Lovea, 2012–2013.

Unit #	Location	Dimensions	Notes
Unit 2	13° 29’ 01.6” N, 103° 42. 47.2 E	3 × 8m	on the mound of Lovea
Unit 3	13° 29’ 00” N, 103° 42’ 56” E	12 × 1.5m	on the inner embankment to the east of the occupation mound
Unit 4	13° 29’ 08.72” N, 103° 43’ 02.36” E	9 × 1.5m	on the outer embankment, western side
Unit 5	13° 29’ 08.72” N, 103° 43’ 01.58” E	12 × 1.5m	on the outer embankment to the west of unit 6
Unit 6	13° 29’ 08.72” N, 103° 43’ 02.14” E	2 × 1.5m	located between units 4 and 5 on the embankment to the west of Lovea
Unit 7	13° 29’ 08.72” N, 103° 43’ 03.06” E	2 × 1.5m	Located on the outer embankment aligned with units 4, 5 and 6 but sitting fArther to the east

LiDAR methodology

The LiDAR acquisition methodology employed at Lovea was generally the same as the one already described in detail by Evans *et al.* (2013), with some key differences. A Leica ALS60 laser system and a 40 megapixel Leica RCD105 medium-format camera were installed within an external pod mounted to the left skid of a Eurocopter AS350 B2 helicopter. The instrumentation included a Honeywell CUS6 Inertial Measurement Unit that registered aircraft orientation at 200Hz. Absolute positional information was acquired by a Novatel L1/L2 GPS antenna attached to the tail rotor assembly and logging positions at 2 Hz. The flight plan was designed so that a cross-hatch pattern would be flown over moderate to heavily vegetated areas to maximise ground returns; flights over open areas, including at Lovea (Figure 5 in main article), were in a single direction (east–west in this case). Flight lines were flown in opposing directions to ensure that overlapping data could be analysed for laser alignment; the single-pass LiDAR swath width averaged 650m with 50 per cent sidelap. A flying height of 800m above ground level and a speed of 80 knots were chosen to give the optimal point densities, providing a field of view of 45^{o} for the laser scanner and a default of 46^{o}for the camera equipped with a 60mm lens. The ALS60 was set at a pulse rate of 105 kHz in regular (single-pulse-in-air) mode with 4 returns recorded per pulse; full waveform data were not acquired at Lovea. Single-pass LiDAR point densities averaged 2–3 points per m^2 and raw photographic images were collected at 80mm resolution.

Position measurements from the aircraft-mounted GPS were post-processed using differential correction data from Trimble R8 GNSS base station receivers installed at surveyed benchmarks at a distance of no more than ~25 km from any acquisition point in the Lovea block, and logging positional information at 1Hz. Prior to the mission, test points were established at two test sites for calibration using an RTK GPS with ~100 points per site; both of these calibration sites were overflown on the (single) aircraft sortie in which we captured the data for Lovea. Project specifications for accuracy were a root-mean-square error (RMSE) of within 150mm compared to surveyed ground control points. All survey measurements were based on the master benchmark for the area, and all data were collected and processed in the WGS84 datum using ellipsoid heights.

The raw laser data were processed against the ground survey data to ensure data quality and conformance with project tolerances for spatial accuracy and precision. The raw data points were then imported into the Terrascan software environment and processed by McElhanney Indonesia, PT using a proprietary ground point identification algorithm. This process divided the data into two separate datasets consisting of 'ground' and 'non-ground' returns. Those outputs were hand-checked by editors, and manually cross-referenced against georeferenced aerial photo data (Evans *et al* 2013). The 'ground' measurements were then post-processed into digital terrain models, hillshade models and local relief models in an ArcGIS software environment (Figure 6 in main article), manually analysed and interpreted, and loaded into hand-held GPS units for systematic field verification of newly-identified features within the Lovea acquisition block by members of our project team.

References

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