Chapter 15
The Use of LiDAR at the Maya Site of Caracol, Belize

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Abstract With its ability to penetrate dense tropical canopies, LiDAR is revolutionizing how ancient Mesoamerican landscapes are recorded. Locating ancient sites in the Maya area of Central America traditionally employed a variety of techniques, ranging from on-the-ground survey to aerial and satellite imagery. Because of dense vegetation covering most ancient remains, archaeological documentation of the extent of archaeological sites using traditional means was both difficult and usually incomplete. LiDAR was initially applied to the site of Caracol, Belize in April 2009 and yielded a 200 sq km Digital Elevation Model that, for the first time, provided a complete view of how the archaeological remains from a single Maya site – its monumental architecture, roads, residential settlement, and agricultural terraces – were distributed over the landscape. With the detailed information that can be extracted from this technology, LiDAR is significantly changing our perceptions of ancient Maya civilization by demonstrating both its pervasive anthropogenic landscapes and the scale of its urban settlements.

Keywords Geospatial revolution • Landscape archaeology • Mesoamerica • Remote sensing • Urbanism

15.1 Introduction

Tropical and sub-tropical environments provide some of the most challenging conditions for carrying out archaeological research. For the vegetation-enshrouded Maya area of Central America, the task of documenting the anthropogenic landscapes of ancient sites is particularly problematic. Alternating wet and dry seasons found in these areas hasten the decomposition of archaeological remains and encourage the rapid growth of plants and trees over ruins, making them hard to identify and record. Thus, it can be difficult to analyze ancient occupation areas. While several long-term archaeological projects have attempted to extensively map Maya site

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cores and surrounding areas, generally only partial samples of the remains from any single site can actually be recorded. Thus, exactly how Maya site cores articulate with surrounding landscapes has been open to interpretation – and the scale of Maya settlements is still a topic of debate. Having worked and mapped in the Maya area for some 40 years, it is clear to us that new technologies can resolve some of the issues facing settlement and landscape archaeology in the Maya region.

Surveying in the Maya area has traditionally proceeded by laborious means, requiring lines-of-sight cut by hand with machetes through the jungle undergrowth followed by the lugging of transits and, more recently, electronic distance meters through the karst topography (Chase 1988). Although less effective underneath the forest canopy, today GPS units make this process slightly easier. The carefully measured points taken with all these instruments are limited both in number and extent and rarely capture all of the smaller features on the landscape, largely because their discovery still requires cutting overgrowth, walking transects, and making on-the-ground measurements. Because heavy vegetation generally leads to sampling rather than to the full documentation of sites through survey, the extent and scale of Maya urban settlements and landscape manipulation has been difficult both to establish and to visualize.

Until recently, mapping at Caracol, Belize followed methods that had been utilized by Mayanists for more than a century, resulting in a traditional, 23 sq km rectified plan. Maya ruins are characterized by stone and earth construction of ancient buildings, platforms, reservoirs, and roadways. In most cases, these ancient architectural remains are raised but have lost their form overtime through the effects of vegetation and natural weathering. Both well-constructed stone buildings and the perishable buildings that once formed ancient residential groups appear today as mounds of variable height; roadways are similarly raised above the landscape. In contrast, constructed reservoirs appear as roughly rectangular-shaped depressions into the surface of the land. All of these earth-covered remains are relatively easily recognized and mapped (e.g., Fig. 15.1), if one has the requisite time.

At Caracol, however, the landscape was also covered with lines of stone, recognized as the remains of ancient agricultural terraces, that ranged up to 3 m in height and that appeared in regularized patterns over the site's valleys and hills. Had the site been small, the 23 sq km of area surveyed between 1983 and 2003 might have sufficed to define the city. However, the sampling transects that were cut into the surrounding countryside uncovered Maya settlement well outside of the site epicenter with no clear areas of settlement drop-off. Road systems leading out from the Caracol epicenter were linked to other monumental architecture and plazas some 3–8 km distant; all indications were that residential settlement and agricultural terraces were continuous between these nodes (Chase and Chase 2001). What emerged from conventional mapping at Caracol was a huge urban settlement that did not align well with preconceptions of Maya society based on other data classes. Maya hieroglyphs had been used to reconstruct a landscape populated with numerous small competing polities, each with a royal court (see Chase and Chase 2008) and ancient farmers were still viewed as largely practicing extensive swidden agriculture rather than focusing on more intensive systems.

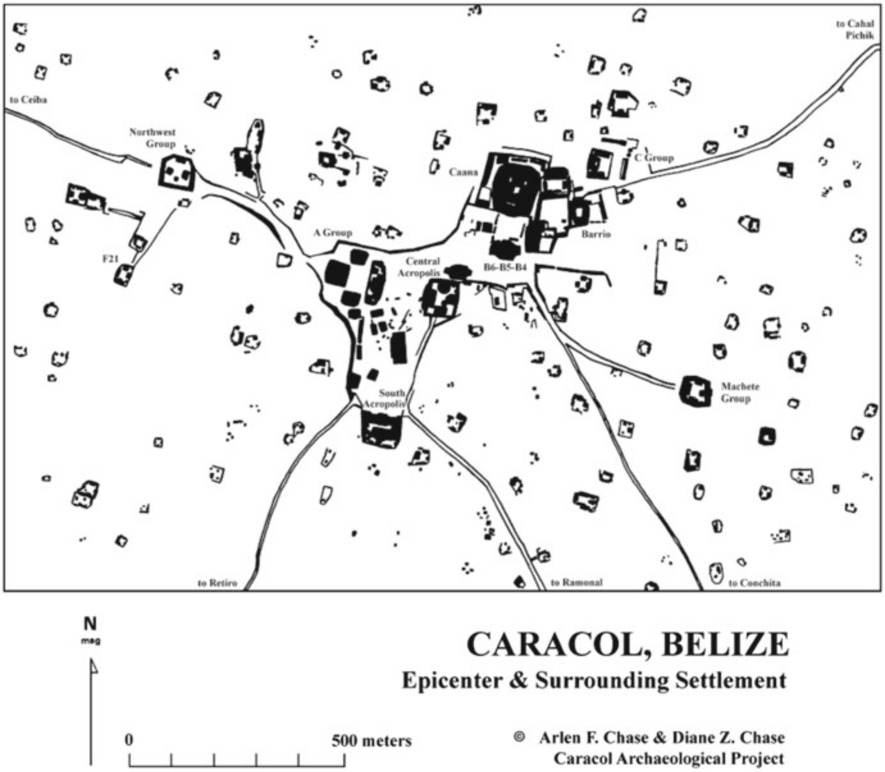

Fig. 15.1 Traditional rectified archaeological map of structural remains in central Caracol created through on-the-ground survey

However, labor-intensive block mapping could not record all of the agricultural terraces that were present at Caracol – simply because there were so many of them and the vegetated understory was too dense to easily accomplish this goal (Chase and Chase 1998). And, neither the full extent of the settlement nor the point of settlement drop-off could be discerned. To remedy this situation and to better understand the totality of the site's settlement, we turned to technology in the form of airborne LiDAR. This geo-spatial technology had not been previously or effectively used at this scale or point density anywhere in Central or South America before this application. The use of LiDAR at Caracol – and subsequently elsewhere in tropical environments – is revolutionizing landscape archaeology and our spatial understanding of past societies (Chase et al. 2012).

15.2 Light Detection and Ranging (LiDAR)

In the early part of the twenty-first century, innovative site documentation efforts were focused on satellite imagery and airborne or satellite-borne radar (Wiseman and El-Baz 2007); however, none of these technologies have the resolution that is necessary to fully identify and document the extent of ancient landscape modifications, especially beneath tree cover. Vegetation covering the ancient remains often covers all but monumental architecture. Thus, neither the identification of the entirety of ancient occupation nor the determination and mapping of architectural forms is possible using these technologies. One of our interdisciplinary research group used LiDAR to image the forest canopies of Costa Rica (Weishampel et al. 2000) and was familiar with the technology and its possibilities. LiDAR had not been previously pursued in the Maya area because earlier archaeological tests of this technology in Costa Rica were not successful (Sheets and Sever 1988).

However, after Hurricane Mitch in Honduras in 1998, LiDAR was flown over coastal areas to assess the damage and a LiDAR image of Copan was published (Gutierrez et al. 2001); although not perfect and aided by undergrowth that had been artificially thinned in the Copan Park, it appeared to demonstrate the potential of this technology to see beneath a jungle canopy. Initial publications also indicated LiDAR's ability to penetrate European forests (Devereux et al. 2005). While less dense than the Maya sub-tropical forest cover, the lasers employed in the European aerial application of LiDAR passed through canopies, returning detailed bare earth information. Thus, given advances in technology, LiDAR presented a potentially viable solution to the issues of scale and visibility that were confronting Maya archaeology.

15.3 The Caracol LiDAR Application

The first large-scale application of airborne LiDAR in Mesoamerica was undertaken at Caracol, Belize in April of 2009 (Chase et al. 2010, 2011; Weishampel et al. 2010). With funding from NASA [NNX08AM11G] and the UCF-UF Space Research Initiative, a 200 sq km area of west-central Belize was overflown by the National Center for Airborne Laser Mapping (NCALM) in a gridded pattern at an elevation of 800 m over the course of 5 days. The sensor was an Optech GEMINI Airborne Laser Terrain Mapper (ALTM) that was flown aboard a twin-engine Cessna Skymaster. The campaign required 25.4 h of flight time and 9.2 h of laser-on time to survey the region. The discrepancy was due to occasional cloud cover below the airplane, which flew nominally 800 m above ground level.

Two billion, three hundred and eighty million laser pulses were fired, resulting in 4.28 billion measurements that constitute a 3D (x,y,z) "point cloud" with approximately 20 points per square meter. Of these, 1.35 points per sq m on average were classified as ground points, yielding a conservatively estimated vertical resolution of 5–30 cm. The ground point density varied as a function of vegetative cover from a few ground points in a 10 by 10 m area for a dense canopy to more than 1,000 points in a comparable treeless area. The classification of ground points is accomplished through a computer intensive process of iteratively building triangulated surface models based on the lowest returns. It involved removing outliers and correlating the measures to elevations of greater than 1,600 check points (i.e., known ground locations which had been previously measured).

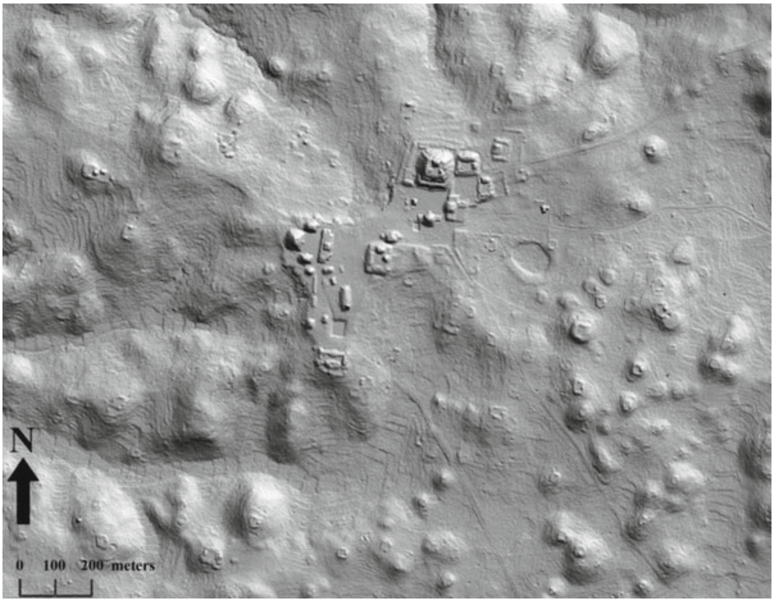

Fig. 15.2 LiDAR bare-earth visualization in 2D of epicentral Caracol. Terraces seen in this figure are not shown in Fig. 15.1 and were not surveyed on the ground due to the difficulty in undertaking traditional mapping in the karst terrain. Approximately 12% of the residential groups that can be identified in this LiDAR image were not recovered through traditional survey methods and some of the mapped groups were not correctly located

The resulting point cloud is the first time that a large number of Maya constructions have been successfully viewed through the encompassing jungle canopy (Fig. 15.2). It is also the first time that the full extent of an ancient Maya city has been visualized in terms of its landscape (Fig. 15.3). For Caracol, the LiDAR analysis conclusively demonstrates that the areal extent of the city was more than 180 sq km. The LiDAR analysis not only recorded thousands of individual residential structures and groups on flat ground, but also recorded almost 5,000 elevated residential groups situated within more than 160 sq km of continuous terracing. Both known and newly discovered causeways that linked outlying monumental plazas to the site epicenter were also easily seen in the Digital Elevation Model (DEM) that was generated from the point cloud data.

Thus, an entire city in the Southern Maya lowlands can be "seen" and its scale appreciated, thus obviating the need for speculation based on a partial sample. Previous investigations serve to "ground-truth" the LiDAR and provide information on time depth and functions for human-made features. Because of 30 years of archaeological research, we know that the settlement visible in the LiDAR-generated DEM dates mostly to the city's Late Classic Period (A.D. 550–900) peak of occupation. At this time, the Caracol settlement was continuous over this landscape and the nodes of larger monumental plazas and architecture (Fig. 15.4) were clearly integrated into a single urban system through the site's causeways (Chase and Chase 2013).

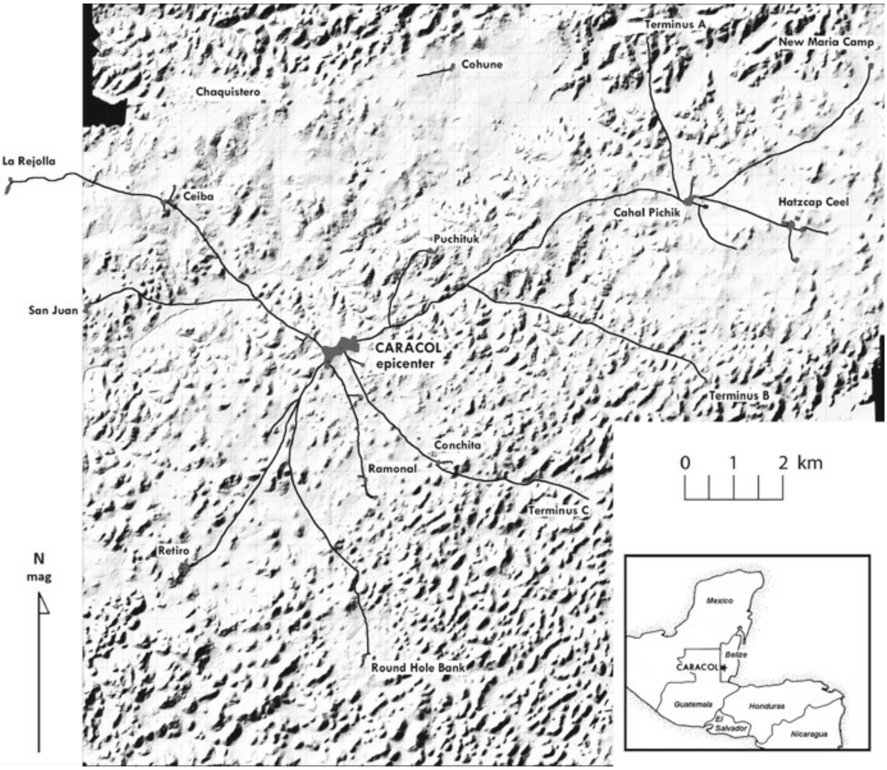

Fig. 15.3 Two hundred sq km hillshaded DEM of Caracol, Belize with the site's road system and termini highlighted. Approximately half the causeways were not recorded through traditional survey. At this reduced scale, no terraces, residential groups, reservoirs, or public architecture are visible; however, most of the landscape is covered with residential groups and agricultural terracing

The LiDAR data from Caracol shed light on a number of issues and data classes related to both ancient and modern agricultural practices. First and foremost, they fully reveal the extent of not only settlement but also agricultural terracing (Fig. 15.5). The LiDAR demonstrates that much of the landscape – some 80% of the 200 sq km DEM – is covered with these terraces, both hillsides and valleys, showing how the Maya of Caracol maintained their large population numbers and size. The vertical control obtainable in the LiDAR data is also sufficiently discriminating to indicate how the terraces changed water flow. Not only do terraces retain water, but also their construction on the landscape created a complex form of water management that largely has precluded erosion of the landscape. Even 1,000 years after being abandoned, the terraces still effectively manage the flow of water on the Caracol landscape. The continued ability of the terraces to retain water has an effect on the height of the canopy; trees on the anthropogenic terraces are approximately 2 m higher than their counterparts that do not occupy these favorable locations (Hightower 2012). The species composition found

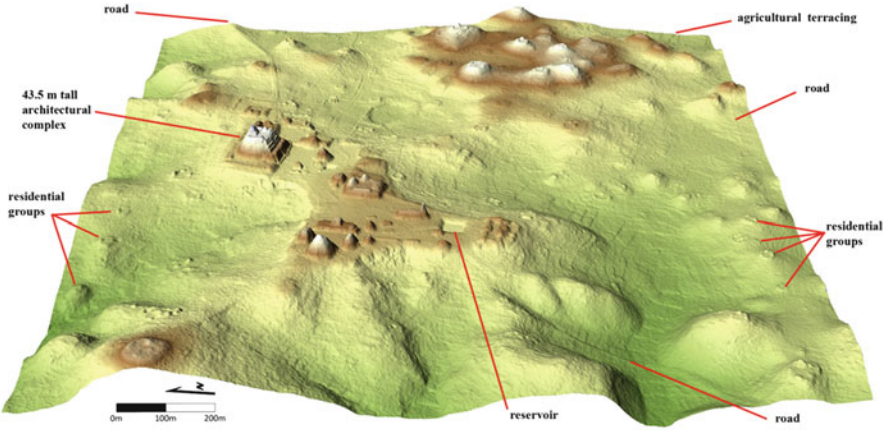

Fig. 15.4 LiDAR bare-earth visualization in 2.5D of central Caracol. Monumental architecture, reservoirs, roads, and residential groups are all visible; some agricultural terraces may be seen in this visualization, but many more are actually present and visible when images are viewed at a larger scale and different hillshade

on the anthropogenic landscape also is significantly different than that found in areas that have not been modified by human agency (Hightower 2012), showing the impact of ancient actions on modern vegetation. LiDAR also provides researchers with a better way to measure the illegal deforestation related to modern agriculture that is currently taking place along Belize's border with Guatemala in the Caracol Archaeological Reserve (Weishampel et al. 2012).

LiDAR elevation data further permit the identification both of deeper sinks/caves beneath the canopy and of shallower depressions that are representative of anciently constructed Maya reservoirs. Some 61 karst depressions or cave openings have been identified within the 200 sq km DEM (Weishampel et al. 2011). The point cloud data provide an uncanny ability to both accurately model the shape of these features and to provide illustrations of the overlying canopy that obscures them. More difficult to identify are the many constructed reservoirs that dot the Caracol landscape. Some ancient reservoirs are quite sizeable (Fig. 15.6), but the vast majority are quite small. However, even these are visible in the point cloud data (as are 1 m wide chultun entrances and looted tombs). Visual inspection of the hill-shaded bare-earth DEMs resulted in the identification of some 271 reservoirs; edge-detection methods, which identify linear features on the landscape, have been applied to portions of the DEM. The results suggest that some 1,400 reservoirs exist in the LiDAR data (Chase 2012). These data have implications for the interpretation of water control by the ancient Maya, suggesting that residential groups controlled their own water sources outside the purview of the Maya elite (Chase 2012).

Perhaps the most significant impact of LiDAR on our view of the Maya landscape is that we can no longer conceive of Maya cities as being small individual "dots" on a map. LiDAR conclusively shows that at least some sites occupied large

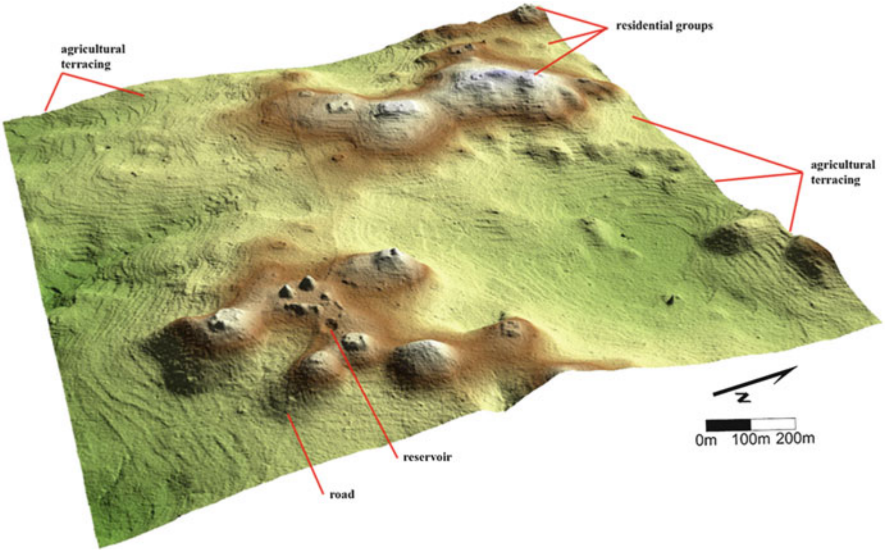

Fig. 15.5 LiDAR bare-earth visualization in 2.5D of Caracol's Ceiba terminus, showing the extent of the terraced landscape. While public architecture, roads, and agricultural terraces are readily visible in this visualization, many of the residential groups cannot be seen due to the reduced scale and hillshade used

areas, in Caracol's case approximately 180 sq km. The size and concentration of this urban settlement is consistent with a form of low-density urbanism found in other tropical parts of the ancient world (Fletcher 2012) and is helping to remove a former theoretical bias among researchers that held that civilizational development was limited within tropical settings. However, it will take more LiDAR covering even larger spatial areas to answer other key questions about ancient Maya polities: How large were they? And, what did borders, boundaries, and frontiers between Maya polities looks like? LiDAR provides a tool that enhances our ability to undertake large-scale spatial research.

15.4 Significance

The successful application of LiDAR at Caracol has had a major impact on Mesoamerican archaeology in that it has helped demonstrate the scale and complexity of ancient Maya city and landscape organization (Chase et al. 2012). For the first time, LiDAR has permitted researchers to view the scale of landscape modification and settlement distribution by the Maya without having to revert to arguments over whether or not the recorded sample is representative. By providing a comprehensive view of the ancient settlement and its distribution over a landscape, LiDAR data are changing forever the ways in which Mesoamerican sites can be mapped and recorded. The full

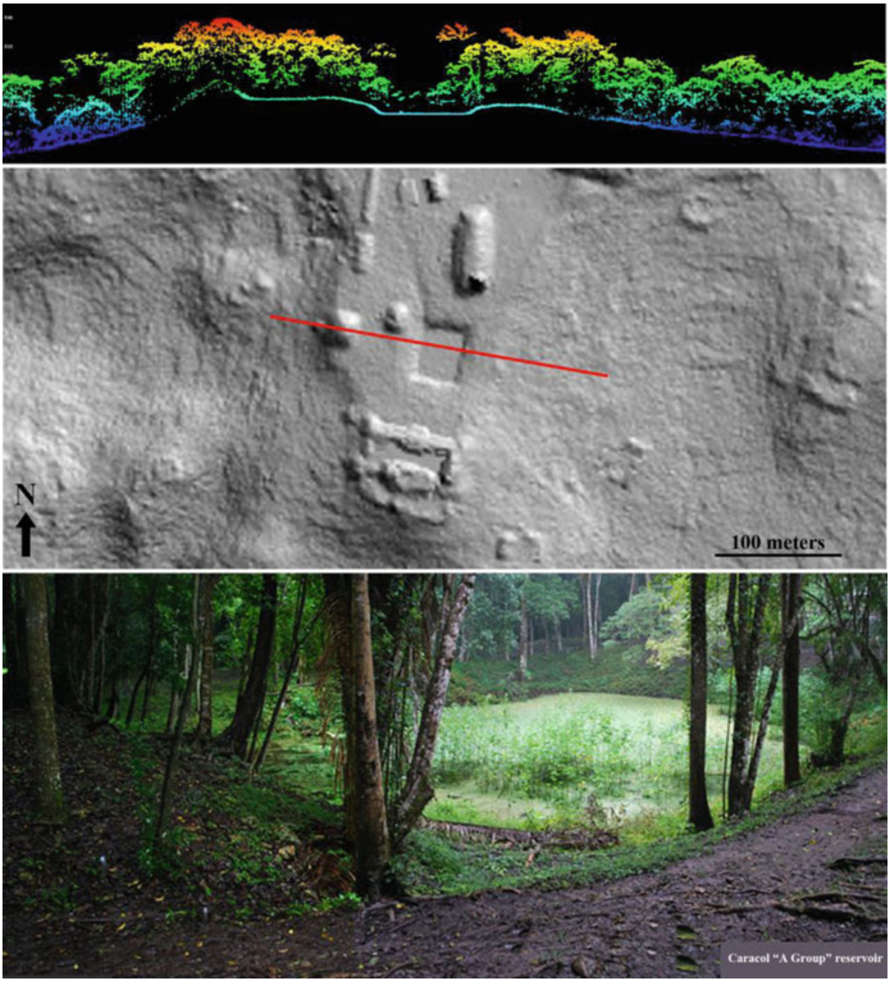

Fig. 15.6 Caracol's "A Group" reservoir (also visible in Fig. 15.4), showing a vertical cross- section of canopy over the reservoir (*top*), a 2D LiDAR bare-earth visualization showing both the reservoir and the position of the cross-section (*middle*); and a photograph of the reservoir looking south (*bottom*)

landscape coverage provided by LiDAR overshadows the data gained from traditional mapping, leading to fuller and more detailed interpretations. Whereas multiple models could compete when societal interpretations were based on limited archaeological sampling of the landscape (as it was with traditional mapping), the totality of the LiDAR data can also provide boundary conditions for the theoretical perspectives that can be correctly applied to ancient Maya civilization during the Classic Period (Chase et al. 2011). When LiDAR can be conjoined with detailed archaeological data, as it can at Caracol, a richer and more nuanced view of the Maya past is gained.

LiDAR is at the forefront of the geospatial revolution that is sweeping through Mesoamerican archaeology. It is changing the way in which landscapes and environments are perceived and will alter our interpretations concerning past human-nature relationships. Ancient Maya societies were not uniform and, as more LiDAR is obtained, the spatial variability that once existed will become better defined. Significantly, however, LiDAR provides the ability to gain a larger, more representative, and detailed sample of a site or a region, providing solid data sets upon which to base further interpretational refinements concerning the scale and integration of ancient Maya land use and manipulation.

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