BREAKING BARRIERS

Proceedings of the 47th Annual

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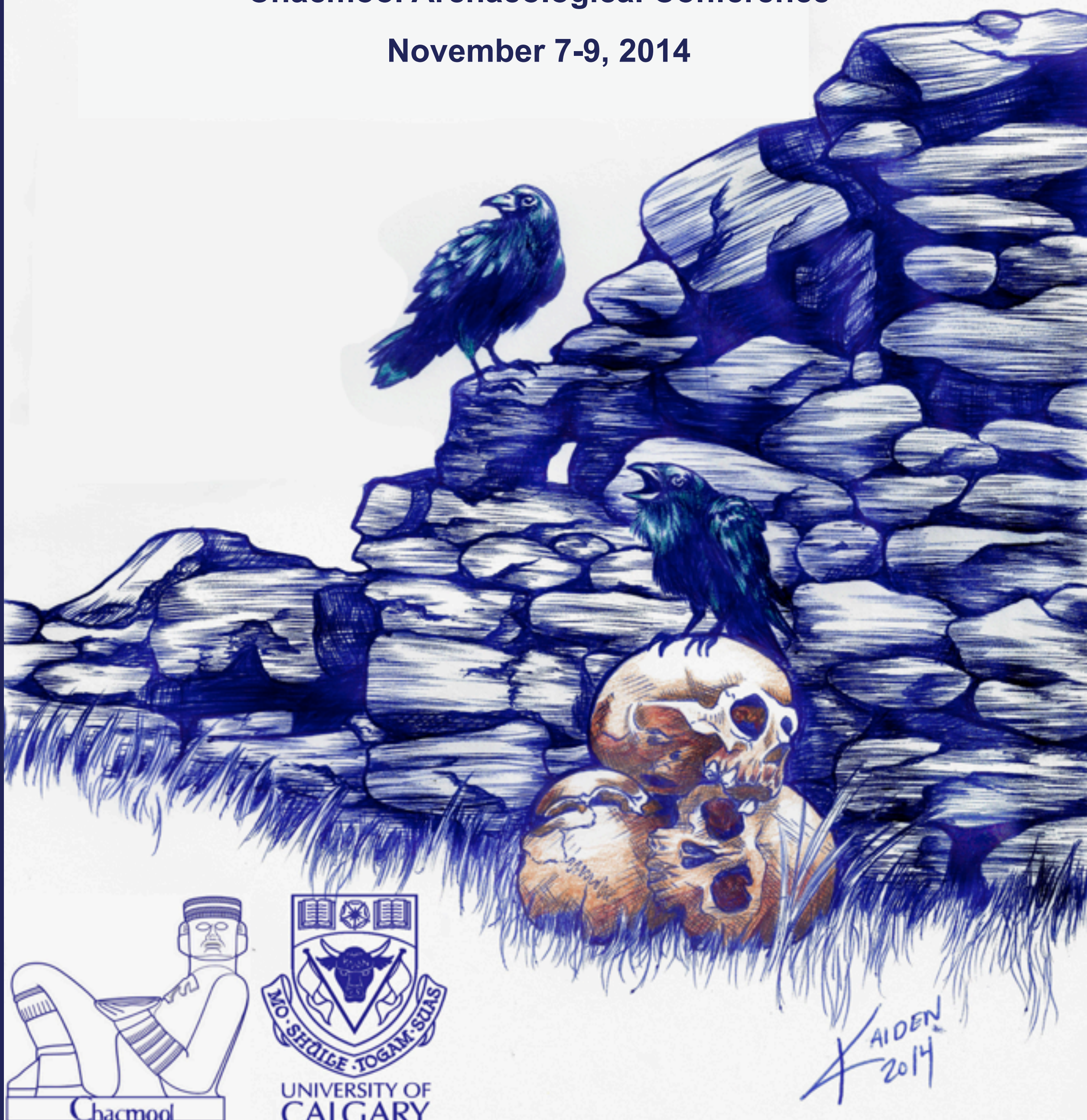
November 7-9, 2014



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Three K'atuns of Pioneering Settlement Research: Preliminary Results of Lidar Survey in the Belize River Valley

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Abstract

In the history of Mesoamerican archaeology, the upper Belize River remains most famous as the sub-region of the Mundo Maya where settlement survey was first introduced by Gordon Willey and his colleagues more than half a century ago. The recent application of Lidar survey to this area once more serves to place the Belize Valley at the vanguard of Maya settlement research. This paper serves to demonstrate how the use of Lidar technology is helping to identify new archaeological sites in the region, how it is providing considerable detail for understanding the ancient Belize Valley landscape, and how its application can contribute significantly to our understanding of the socio-political organization of the area.

In the history of Maya archaeology, the Belize Valley is particularly well-known as the location of Gordon Willey's pioneering settlement research conducted in the 1950's. Indeed, prior to Willey's seminal Belize Valley research, few archaeologists working in the Maya lowlands had ever focused much attention to the study of house mounds (but see Thompson 1931; Wauchope 1934), preferring, instead, to conduct research programs that were primarily aimed at establishing temporal sequences for prehistoric occupation at large elite ceremonial centers. The large systematic survey undertaken by Willey and his colleagues in the Belize Valley brought settlement pattern studies to the forefront of Maya archaeology, transforming research paradigms to encompass households as the basic social and economic unit within ancient Maya society (Chase and Garber 2004:9). The impact of settlement research in the Belize Valley was felt by archaeologists working in other regions of the world as well, where settlement studies increased the awareness of regional diversity in past societies, illustrated the complexity of human adaptations to their natural and social environment, and challenged traditional beliefs about population dynamics (e.g., Chang 1968; Sanders et al. 1979).

Willey and his colleagues also addressed questions concerning the size, distribution, and configuration of settlements in the Maya Lowlands through the Belize Valley survey, which covered multiple sites including Baking Pot, Spanish Lookout, Barton Ramie, and the Melhado Group (Willey and Bullard 1965; Willey et al. 1965). Based on a dual program of survey and excavations at these sites, Willey et al. (1965) proposed a three-tiered model of organization that ranged from residential house mounds at the smallest scale, to mid-level small plazuela groups, and finally large major centers. William Bullard, who collaborated with Willey on the Belize Valley survey and excavated in the Baking Pot site core (Bullard and Bullard 1965), expanded this three-tiered classification system to differentiate between house structures, minor centers, and major centers (Bullard 1960). The new category of minor center was identified by the presence of vaulted architecture, pyramidal structures, stelae, causeways, and/or ballcourts at sites smaller than major centers. The differentiation of sites based on this settlement hierarchy facilitated inter-site comparisons within the Belize Valley and elsewhere in the Maya Lowlands, and helped to answer questions concerning settlement organization and its relationships to social and political organization at multiple scales through time.

Over half a century later, Willey's seminal study continues to impact archaeological investigations in the Maya Lowlands. In the Belize Valley, for example, archaeological projects have continued to make settlement research a strong component of their investigations (Awe 1992; Conlon 1994; Connell 2000; Ehret 1995; Ford 1990; Fedick 1994; Hoggarth 2012; Neff et al. 1995; Peuramaki-Brown 2012; Wyatt and Kalosky 2003; Yaeger 2000, Yaeger et al. 2011). The extensive amount of research in this region has made significant contributions to the study of the ancient Maya, recording a long and continuous history of human occupation from Preceramic times through the Colonial period (Awe 1992; Awe and Helmke 2005; Ball and Taschek 1991; Graham et al. 1989; LeCount et al. 2002; Lohse et al. 2006; Yaeger 2002). More recent settlement studies in the Belize Valley have also served to refine our methods for identifying diversity of site layout and organization. At the regional scale, several models have been developed to understand the spacing of sites. Driver and Garber (2004), for example, have proposed a general spatial pattern where major centers in the Belize Valley are typically located ~10km apart, with minor centers sometimes located between the larger sites. Helmke and Awe (2008, 2013) have built upon this model, integrating archaeological and spatial data with epigraphy. They propose that major centers can be identified by the following characteristics: 1) nucleated monumental epicenters, 2) pyramidal temple structures, 3) eastern triadic temples (such as E-Group-like configurations), 4) royal palatial groups, 5) ballcourts, 6) monuments such as stelae and altars (some of which were carved), 7) intra-site processional sacbeob (causeways) , 8) sacbe termini groups, and 9) in some cases royal tombs (Awe, In Press; Helmke and Awe 2013:60-62). In the Belize Valley, epigraphic evidence suggests that rulers wished to be seen as comparable to rulers of larger centers to the west and south, at least nominally (Helmke and Awe 2008, 2013).

The increased attention paid to minor centers has led to a greater understanding of their organizational diversity (Iannone 2003, 2004). While minor centers are typically smaller (spatially and architecturally) than major centers, they often possess some characteristics of the larger sites, although not all may be present and or are less abundant (Helmke and Awe 2008, 2013). For example, carved (or uncarved) stelae are typically absent from minor centers. Surrounding major and minor centers are domestic plazuela groups, often composed of four or more mounds organized around a central patio.

These groups are thought to house extended family units. House mounds are the smallest unit in ancient Maya settlements, represented by solitary structures lacking adjacent masonry ancillary structures.

The Belize Valley has also been at the forefront of the most recent advances and application of geospatial technologies, which are revolutionizing settlement archaeology in Mesoamerican archaeology and improving our understanding of the relationships between large urban centers and their hinterlands (Chase et al. 2012). Accurate and high-resolution airborne light detection and ranging (Lidar), in particular, has allowed for rapid acquisition of spatial data not previously possible from limited pedestrian survey in areas of heavy vegetation (Chase et al. 2011, 2014, Fisher et al. 2011; Hare et al. 2014, Rosenswig et al. 2013). In this paper, we discuss the results of the West-Central Belize Lidar Survey (Chase et al. 2013) in the Upper and Middle Belize River Valley. Integrating Lidar data with the large regional block survey of the upper to middle Belize Valley (see Hoggarth et al. 2008, 2010) by the Belize Valley Archaeological Reconnaissance project (BVAR) offers new perspectives on the distribution of settlement and its relationship to urban centers in the region (Figure 1). We present new methods for integrating systematic quantitative analysis of Lidar using Geographic Information Systems (GIS) for identifying ecological and cultural features, including previously undiscovered sites as well as constructed agricultural features across the landscape. We argue that more systematic, quantitative Lidar and GIS analyses, coupled with large-scale block settlement surveys, provide an optimal coverage to better understand that size, scale, and organization of settlement patterns. These new advances contribute to the next generation of pioneering settlement archaeology in the Belize River Valley.

Applications of Lidar in the Belize Valley

Accurate and high-resolution airborne light detection and ranging (Lidar) data are becoming increasingly important for the discovery and visualization of prehistoric settlements and agricultural systems in tropical environments (e.g., Hawaii, Ladefoged et al. 2011, McCoy et al. 2011; Southeast Asia, Evans et al. 2013; Mesoamerica, Chase et al. 2011, 2012, 2014, Fisher et al. 2011; Hare et al. 2014; Rosenswig et al. 2013). Airborne Lidar is an active remote sensing system that produces high-resolution three-dimensional spatial data. Within a Geographic Information System (GIS), these spatial data can be used to create "bare earth" (i.e., hillshade) models to visually highlight archaeological and ecological features on the ground in three-dimensions. Recently, archaeologists have been especially active in using Lidar to understand the organization of ancient settlements in Mesoamerica (e.g. Chase et al. 2011, Chase et al. 2012 Rosenswig et al. 2013). For the Belize Valley, our application of this methodology was part of the West-Central Belize Lidar Survey that was designed to provide a detailed model of the local topography and to help plan more efficient, targeted, and cost-effective survey programs in the region. The Lidar survey was flown by the National Center for Air-

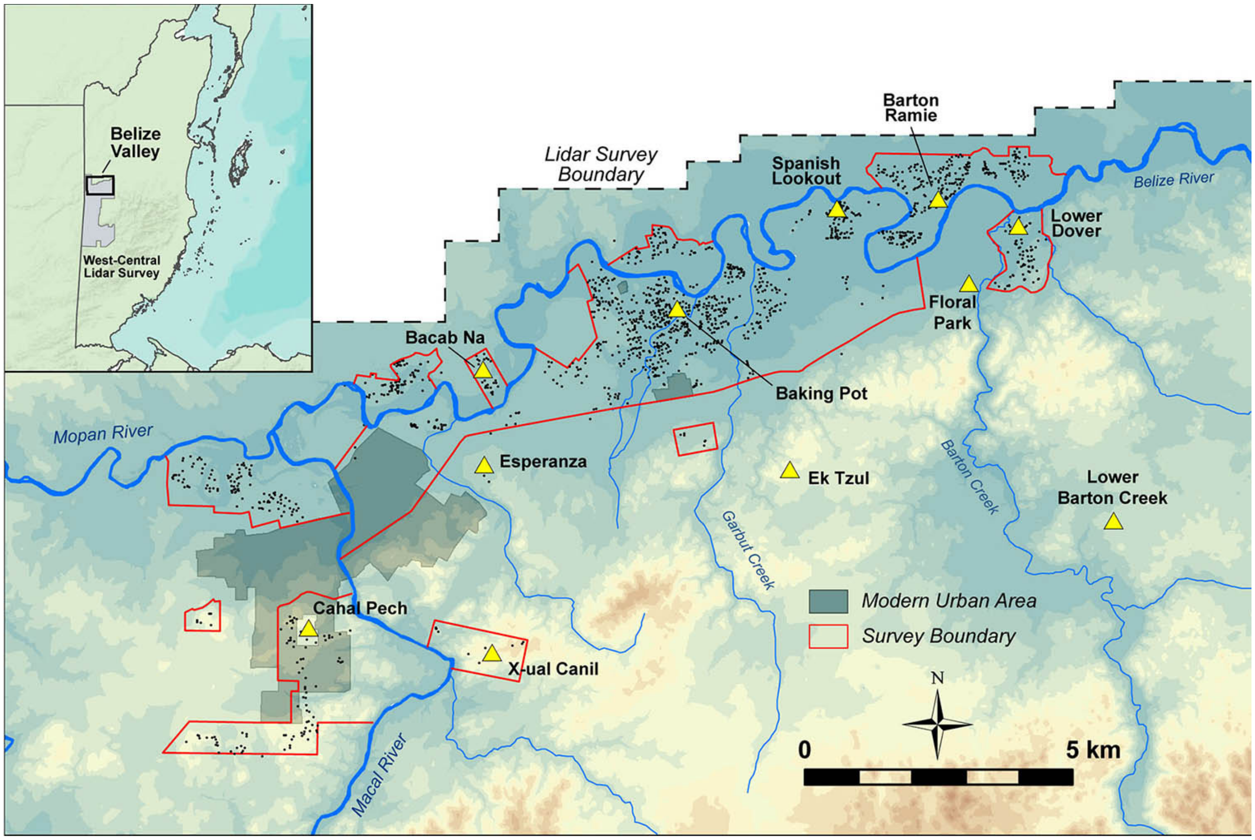

FIGURE 1. Map of Lidar survey in the Belize Valley, with BVAR regional settlement survey (1988-2014) and Barton Ramie survey (Willey et al. 1965) data. Inset shows extent of the West-Central Belize Lidar Survey (Chase et al. 2013). Map by Claire E. Ebert.

borne Laser Mapping (NCALM), and supplements the Caracol survey area (see Chase et al. 2011, 2012) to cover a total of 1257 km2 (Chase et al. 2014). This coverages includes Lidar data for several large centers in the Belize Valley, including the major sites of Baking Pot, Cahal Pech, and Lower Dover which are located in the BVAR permit area.

Compared to other regions documented by airborne Lidar survey (e.g., Caracol in the Chiquibul Forest Reserve; Chase et al. 2011, 2012), the Belize Valley is characterized by high density populations living in modern towns and villages, and by large-scale agricultural farms (Awe et al. 2014). This urban environment has presented a challenge to traditional survey methods, since modern construction and agricultural activities have destroyed ancient ruins and created vegetation patterns (i.e., agricultural fields, dense regrowth) that often hinder survey efforts (Awe 1992; Awe and Brisbin 1993; Ebert 2015; Ebert and Awe 2014). The integration of high-resolution airborne Lidar data into archaeological survey in the Belize Valley helps to eliminate some of these challenges, and has provided vital contributions to our understanding of complex archaeological landscapes in several ways. First, the qualitative visual analysis of hillshade models produced from Lidar data has recorded several previously unknown centers in the region. These include the major centers of Ek Tzul, located approximately 3.6

km south of Baking Pot, and Lower Barton Creek, approximately 5 km south of Lower Dover. The documentation of these new sites, as well as future exploration, will aid in our understanding of social and political developments in the Belize Valley.

Second, Lidar data are a powerful quantitative tool that can be analyzed within a GIS framework to systematically identify and measure archaeological features (Ebert 2015; Ebert and Awe 2014). Lidar research in tropical regions has relied primarily upon visual analyses which can easily distinguish large and medium sized architecture with steeply sloping sides (Chase et al. 2011, 2014, Hare et al. 2013; Rosenswig et al. 2013). However, smaller features, such as mounds and terraces less than 1m in height compose the majority of archaeological features in the Belize Valley and are more difficult to locate through visual analyses alone. Settlement research that integrates visual analysis of Lidar data with quantitative spatial analyses to identify more discrete archeological features has been undertaken at the site of Cahal Pech to document the settlement system around the site (Ebert 2015; Ebert and Awe 2014). Integrative analyses are also being applied to understand agricultural landscapes (Chase et al. 2011, 2014; Ladefoged et al. 2011; Mcoy et al. 2011). These include a water management system at Baking Pot, as well as the remains of ancient agricultural terraces at the site of Lower Barton Creek. Finally, analysis of Lidar data that provide accurate location information may also aid in conservation efforts by pinpointing sites that face destruction from modern activities and giving them high-priority for investigation (Ebert and Awe 2014). Similar issues using Lidar analysis may be encountered at sites located in or near developing urban and agricultural areas elsewhere in the tropics.

Methods

In 2014, BVAR integrated visual and quantitative spatial analysis of Lidar data within the program of settlement survey at Cahal Pech, Baking Pot, and Lower Dover to identify archaeological features including house mounds, ditches, and terraces. Spatial analysis of Lidar data was conducted using the Topographic Position Index (TPI) (Jenness 2006; Weiss 2001). TPI analysis is a simple, repeatable method that is easily performed on spatial data within existing GIS databases (Jenness 2006). TPI analysis has been applied to geospatial studies in geography and geology; landscape, forest, and animal ecology; and climatology (see De Rue et al. 2013). In archaeology, several researchers have used TPI analysis to understand regional settlement patterns in relationship to landform classes (Berking et al. 2010; De Rue et al. 2013; Patterson 2008).

TPI analysis produces a raster composed of equally sized cells with unique values, which reflect differences between the elevation of a cell and its neighboring cells. Patterns in the rasters represent possible archaeological features. High cell values indicate a high point in the local topography, such as a hilltop, house mound, or terrace. While house mounds are represented by a cluster of higher TPI values, terraces are represented by linear patterns of high values. Negative values are associated with areas with lower elevation and less sloping, such as a valley or ditch (Figure 2). TPI analyses are scale-dependent (Weiss 2001). Scale in TPI analysis is determined by the selected search radius size, which defines the number of cells considered in the calculations. Large-scale, regional TPI analyses can be used to identify major landform types across a region (e.g., canyons, ridge lines; Gallant and Wilson 2000; Weiss 2001). Small-scale, site-level TPI analysis, on the other hand, allows for the identification of more detailed topographic features (Jenness 2006). Small-scale TPI studies are especially applicable to archaeological settlement studies since possible mounds may be represented by higher TPI values within localized areas. Pre-processed Lidar point cloud data (Chase et al. 2014) for the Belize Valley was analyzed using ArcGIS 10.2.2 using the LAS data set tools. A high-resolution (1m) DTM for the study area was created from Lidar ground return points. Analyses were performed using an open access TPI extension for ArcGIS v. 9.3-10.2 (Jessness 2006). An annular (doughnut-shaped) search area was used to classify slope position within each sub-sample block, where only cells within 2 and 15 meters were considered in TPI calculations (Ebert 2015). The small search neighborhood can identify subtle variations of topography within each sample block.

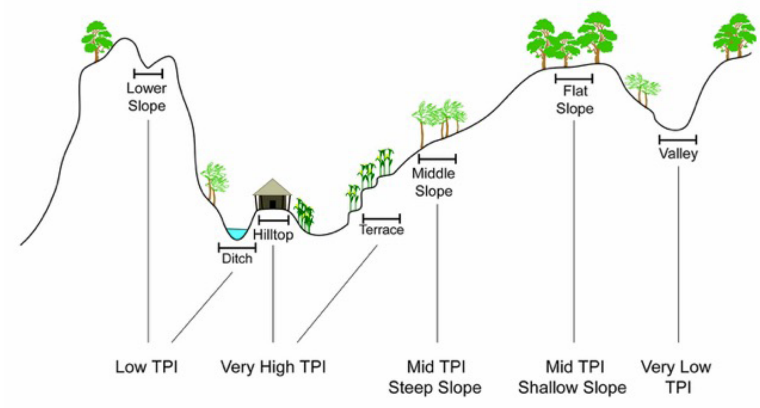

FIGURE 2. Expected Topographic Position Index (TPI) values for natural and constructed features (modified from Weiss 2000).

Lidar and Settlement Survey at Cahal Pech

Cahal Pech is located within the limits of the modern town of San Ignacio, approximately 2 km south of the confluence of the Macal and Mopan Rivers. Archaeological investigation has been active at Cahal Pech since the late 1980's, with ongoing survey and excavations conducted under the auspices of BVAR. Initial settlement survey at the site was undertaken between 1988 and 1992, and focused on documenting large residential settlements immediately south and west of the site core that were threatened by the construction of modern houses (Awe 1992; Awe and Brisbin 1993) (Figure 3). Radiocarbon dating and associated ceramic materials indicate that several large residential groups were founded during the Middle Preclassic (900-600 BC) through the end of the Classic Period (Awe 1992; Cheetham et al. 1993; Ebert 2015; Iannone 1996; Powis 1996). The Cahal Pech settlement survey was extended further south and west of the site core during the 2011 and 2012 field seasons, and documented numerous small residential groups north and south of the Cahal Pech monumental core that were established

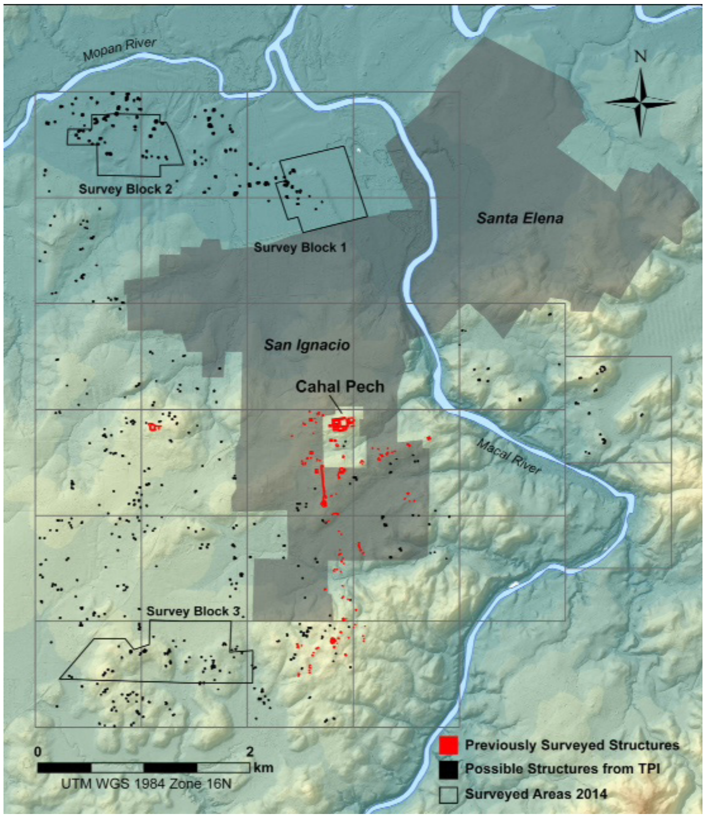

FIGURE 3. Map of BVAR settlement survey at Cahal Pech overlaid onto a hillshade model produced from Lidar ground points, with study area indicated. Settlements documented from previous pedestrian survey (1988-2013) are denoted in red, and possible mounds identified from TPI analysis of Lidar are in black. Ground truthing survey zones are also indicated. Gray shading indicates the extent of the modern towns of San Ignacio and Santa Elena. Map by Claire E. Ebert.

during the Classic Period (Dorenbush 2013).

TPI analysis of Lidar data for a 29 km2 area around Cahal Pech was performed on a high-resolution (1m) DTM incorporated into a GIS to classify the landscape into both slope position and landform category, and to record possible archaeological features for targeted field reconnaissance and mapping (Gallant and Wilson 2000; Weiss 2001). A total of 545 undocumented possible house mounds were located. Analysis of Lidar data at Cahal Pech demonstrates the utility of quantitative spatial analysis for the identification of less prominent architectural features on the landscape. Identification of mounds using the TPI provided precise metrics for possible mounds including location (UTM coordinates), volume, surface area, and height. These attributes were used to identify mounds during survey. These metrics allowed us to eliminate mounds with volumes less than $8m^3$ (Ashmore 1981) or surface areas less than $25m^2$ (Yaeger 2003) from the sample of possible mounds identified through TPI analysis, since they are likely too small to have been residences. These smaller features were often the result of bioturbation and modern activities (e.g., dirt pulled up by tree fall and bull-dozed areas) or locations in the Lidar survey with lower-resolution (Ebert 2015). Approximately half of the mounds were less than 1 m in height, suggesting the ability of quantitative spatial analysis to identify smaller residential features that compose the settlement system at Cahal Pech.

TABLE 1: Results of TPI analysis and ground-truthing survey at Cahal Pech from three survey zones (from Ebert 2015).

Survey Zone 1 - Orchard (0.48 km^2)	TPI Analysis	Survey	% TPI vs. Survey
Number of Mounds	15	15	73%
Average Height (m)	0.70	0.56	
Average Area (m2)	175.20	219.51	
Average Volume (m3)	81.76	35.16	
Average Slope (°)	5°	3°	

Survey Zone 2 - Pasture (0.45 km^2)	TPI Analysis	Survey	% TPI vs. Survey
Number of Mounds	39	22	49%
Average Height (m)	1.2	0.5	
Average Area (m2)	129.7	326.76	
Average Volume (m3)	76.9	102.14	
Average Slope (°)	6°	1°	

Survey Zone 3 - Forest (0.76 km^2)	TPI Analysis	Survey	% TPI vs. Survey
Number of Mounds	49	38	41%
Average Height (m)	1.79	1.05	
Average Area (m2)	60.12	60.73	
Average Volume (m3)	47.67	46.46	
Average Slope (°)	16°	8°	

Our analyses also demonstrate some of the challenges facing spatial analysis of Lidar data. During the BVAR 2014 field season, possible archaeological features identified using TPI analyses were verified through pedestrian survey in three survey zones characterized by different land cover types (orchard, pasture, and forest) to assess the accuracy of TPI analysis based on vegetation cover types (Ebert 2012; Ebert and Awe 2014). The total surveyed area was approximately 1.7 km^2, and 75 structures were documented (Ebert 2015). In orchard and pastured areas (Survey Zones 1 and 2), ground-truthed mounds were often lower and less sloping on average than possible mounds identified through TPI (Table 1). Additionally, some surveyed mounds were leveled by modern construction or agricultural activity so that they were only visible during survey. Areas with less development, such as forested areas characterized by a combination of high canopy and low bushy vegetation (Survey Zone 3), produced even less reliable results, with only 41% of possible mounds located during ground truthing. These results may indicate that Lidar data from heavily vegetated areas, compared to more open spaces like orchards are lower-resolution. The quantitative and qualitative differences between the TPI and survey results and among land cover types indicate that traditional settlement pattern study methods, such as pedestrian survey, remain vital to ground-truthing all types of spatial data.

Documenting Agricultural Landscapes in the Belize Valley with Lidar

A combination of visual analysis and spatial analysis of Lidar data using TPI analysis was also used to understand agricultural landscapes in the Belize Valley (Figures 4 and 5). Previous researchers (Kirke 1980; Conlon and Awe 1995; Conlon and Powis 2004) have noted the presence of ditched field systems in the western periphery of Baking Pot. Intensive agricultural features (agricultural terraces) have also been identified in the area surrounding the newly identified center of Lower Barton Creek. The TPI analysis of the Lidar survey shows that these intensive farming systems are more extensive than previously noted, suggesting that agricultural innovations helped to support large populations in the Belize Valley.

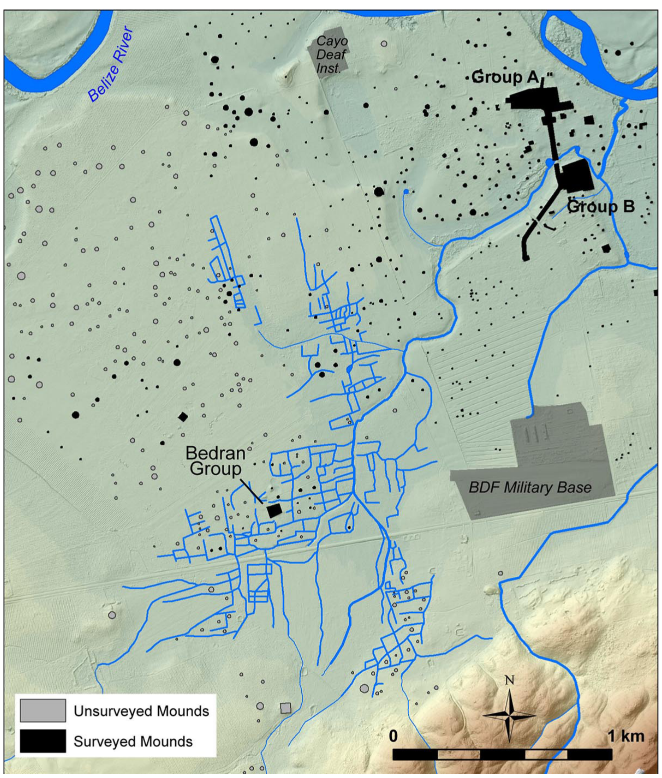

FIGURE 4. Map of water management system in the western periphery of Baking Pot, with ditches documented by TPI from the Lidar survey data. Map by Claire E. Ebert.

FIGURE 5. Map of the newly documented site of Lower Barton Creek, with agricultural terraces documented through TPI analysis of Lidar data. Map by Claire E. Ebert.

The Baking Pot Water Management System

Complex water management systems that served multiple functions (drainage, agriculture) have been identified at sites across the Maya Lowlands (Barthel and Isendahl 2013; French et al. 2012; Scarborough 1998; Wyatt 2014). Settlement survey and excavation have documented a multi-component water management system at the site of Baking Pot both within the site core and in the peripheral settlement. A series of drains in the courtyards of the palace complex at Baking Pot, identified through excavations, may have functioned to feed excess water into the nearby aguadas of Group B (Audet 2005). Survey data also indicates that seasonal streams located around the site directed water into reservoirs that offered drinking water (Hoggarth 2012), and may have also served symbolic purposes (Lucero 2002). These waterways may also have served as buffers that differentiated spatially distinct settlement clusters, or neighborhoods, at the site (Hoggarth 2012; Peuramaki-Brown and Hoggarth 2009).

A system of ditches has also been documented in the southern periphery of Baking Pot. The system was first described by Kirke (1980) based on the analysis of aerial photographs and very limited ground reconnaissance. Kirke noted a lattice system of ditches, with long, straight waterways encompassing rectangular plots between 50 – 120m2 concentrated around the Bedran Group, though he suggested the system likely continued 1 km to the north and south towards the limestone foothills. The ditches that Kirke measured ranged in depth from 20cm to 1m, and were between 1m and 4m wide (Kirke 1980). Conlon and Awe (1995; see also Conlon and Powis 2004) revisited the area in 1994 as part of the Baking Pot settlement survey, during which time they produced a more detailed a plan of the ditches immediately around the Bedran Group. Elevations taken along the ditches indicate that the system flowed from south to north and from west to east (Conlon and Awe 1995). James Conlon and colleagues (Conlon and Awe 1995) conducted test excavations of the ditches and argued that ceramics from those sections suggest that the ditches were constructed sometime during the Late Classic period (Conlon and Powis 2004:79). The location and extent of the system, from the kartstic foothills flowing towards the Belize River, suggests that the primary function of the system may have been drainage, especially during the rainy season when the area is prone to flooding. Similar water management systems dating to the Classic Period have been documented in northern Belize (Beach et al. 2009; Luzzadder-Beach et al. 2012; Siemens and Puleston 1972; Turner and Harrison 1981). Canals were used to drain the waterlogged wetland areas, and perhaps supply water to fields in the dry season. Research in this area suggests that water management features may have become more important during the Classic Period in the face of population increase, anthropogenic degradation of the landscape, and climate change (Beach et al. 2009; Beach and Luzzadder-Beach 2013; Kennett and Beach 2013; Luzzadder-Beach et al. 2012).

Lidar data for Baking Pot have revealed a more extensive system of ditched fields than previously identified, suggesting that the complexity involved in the construction and maintenance of the water system may have required large amounts of labor and energy. A combination of visual analysis and spatial analysis of Lidar data using TPI analysis was used to map the extent of the ditch system at Baking Pot. Ditches were digitized from Lidar data based on the hillshade model and a TPI raster for the site. Approximately 23 km of ditches were visually identified, and an additional 4.25 km was documented by TPI analysis. The TPI also helped to distinguish 270 mounds within a 5 km2 area around the ditched area. Several small residential mounds are interspersed between ditched areas, perhaps indicating plots between ditches that were associated with specific households. The newly identified mounds and ditches will be the focus of ground-truthing and excavation during the 2015 BVAR field season. Research will focus on building an absolute chronology using high-resolution AMS 14C dating for the use of the ditched fields, as well as survey and test excavations to understand their form, function, and water capacity. The region around Baking Pot possesses some of the most productive soils, and the widest extent of the valley floor, in the Belize Valley. These attributes have led some scholars to argue that the site's wealth stemmed from its access to agricultural land (Audet 2006). Exploration of the vast expanse of ditches in Baking Pot's western periphery may offer additional evidence to test this hypothesis.

Lower Barton Creek Agricultural Terraces

Agricultural terraces are another type of intensive farming system that have been documented in the Belize Valley using Lidar. People living throughout the Maya lowlands used terraces to stave off erosion and to stabilize the landscape in contexts of deforestation of tightly packed environments (Beach et al. 2002; Beach and Dunning 1995; Kennett and Beach 2013; Murtha 2002). The vast terrace system at the site of Caracol, for example, was constructed and used during the peak of the sites population, from the middle of the Classic Period (AD 500–600) until the abandonment of the site at the end of the Terminal Classic (Healy et al. 1983; Murtha 2002). The terraces of Caracol were known from pedestrian surveys, but fully documented by Lidar survey (Chase et al. 2011). Terrace systems are also present in the Belize Valley at the site of Lower Barton Creek. Lower Barton Creek is located approximately 5 km south of Lower Dover, and was unknown to archaeologists until the West-Central Lidar survey in 2013. The site core is oriented north south and composed of two primary plazas separated by a ball court. The northern plaza, which is the larger of the two, is bounded by six structures and possess an eastern triadic shrine characteristic of other sites in the Belize Valley (Awe 2008). Several large settlements are located on hilltops around the site core. Visual analysis of a hillshade model as well as TPI analysis of Lidar data identified approximately 11.4 km of agricultural terraces within a 2 km2 area around the site of Lower Barton Creek in the Belize Valley. Terraces are located primarily along the slopes to the west of the site core, but are also present along the slopes of several hill tops with large residential settlements.

Conclusions

Archaeology in the Belize Valley continues to be at the cutting edge of settlement research in the Maya Lowlands. The integration of high-resolution Lidar data into archaeological settlement survey begun by Willey in the 1950's has provided vital contributions to our understanding of complex archaeological landscapes in the Belize Valley, and elsewhere in the Maya Lowlands. Quantitative analysis of Lidar data using GIS allows for the reconstruction of site organization where pedestrian survey, hampered by thick vegetation, has only documented a small sample of settlement. The use of data from the 2013 West-Central Belize Lidar Survey by BVAR led to the discovery of several previously unknown major centers, such as Ek Tzul and Lower Barton Creek, in addition to several smaller sites in the region. Lidar has also provided additional data on the location, size and extent of archaeological features including house mounds, water management systems, and agricultural terraces at several sites throughout the Belize Valley. Equally important is the fact that the incorporation of Lidar into the BVAR settlement research has generated new approaches to archaeological survey and conservation in modern developing urban and agricultural landscapes. Lidar provides accurate location information, which may aid in conservation efforts by pinpointing sites that face destruction from modern activities. Additionally, quantitative analyses using GIS might be applied for the identification and quantification of looting activities. The identification of threatened archaeological features can give them high-priority for investigation. Combined with the BVAR regional survey data from 1988-2014, Lidar data have implications not only for our understanding of the organization of settlements across the Belize Valley, but also the ways in which the ancient Maya modified their landscape in the face of changing social and ecological environments.

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