

Research Article

LiDAR analyses in the contiguous Mirador-Calakmul Karst Basin, Guatemala: an introduction to new perspectives on regional early Maya socioeconomic and political organization

Richard D. Hansen^a , Carlos Morales-Aguilar^b , Josephine Thompson^c, Ross Ensley^d, Enrique Hernández^e, Thomas Schreiner^f, Edgar Suyuc-Ley^f and Gustavo Martínez^{e,f}

^aDepartment of Anthropology, Idaho State University, Pocatello, Idaho, and Foundation for Anthropological Research and Environmental Studies (FARES), Idaho, United States; ^bDepartment of Geography and the Environment, University of Texas, Austin, United States, and Laboratoire ArchAm, UMR8096-CNRS, Paris, France; ^cMirador Conservation Fund, Redwood City, California, United States; ^dTerra Geo Solutions, Houston, Texas, United States; ^eEscuela de Historia, Universidad de San Carlos, Guatemala City, and Proyecto Cuenca Mirador, Guatemala City, Guatemala and ^fFARES Foundation/Mirador Basin Project, Guatemala City, Guatemala

Abstract

LiDAR coverage of a large contiguous area within the Mirador-Calakmul Karst Basin (MCKB) of northern Guatemala has identified a concentration of Preclassic Maya sites (ca. 1000 B.C.–A.D. 150) connected by causeways, forming a web of implied social, political, and economic interactions. This article is an introduction to one of the largest, contiguous, regional LiDAR studies published to date in the Maya Lowlands. More than 775 ancient Maya settlements are identified within the MCKB, and 189 more in the surrounding karstic ridge, which we condensed into 417 ancient cities, towns, and villages of at least six preliminary tiers based on surface area, volumetrics, and architectural configurations. Many tiered sites date to the Middle and Late Preclassic periods, as determined by archaeological testing, and volumetrics of contemporaneously constructed and/or occupied architecture with similar morphological characteristics. Monumental architecture, consistent architectural formats, specific site boundaries, water management/collection facilities, and 177 km of elevated Preclassic causeways suggest labor investments that defy organizational capabilities of lesser polities and potentially portray the strategies of governance in the Preclassic period. Settlement distributions, architectural continuities, chronological contemporaneity, and volumetric considerations of sites provide evidence for early centralized administrative and socio-economic strategies within a defined geographical region.

Resumen

La cobertura LiDAR de una gran área contigua dentro de la Cuenca Kárstica Mirador-Calakmul (CKMC) del norte de Guatemala, ha permitido la identificación de una concentración de antiguos sitios mayas preclásicos (ca. 1000 a.C.–150 d.C.) conectados por calzadas elevadas, formando una red de implicaciones sociales, políticas y económicas. Hasta la fecha, se han identificado 775 asentamientos mayas antiguos dentro del CKMC, así como cientos más en el sistema geomorfológico circundante, que comprende al menos 417 sitios que formaban ciudades, pueblos y aldeas antiguas. Se propone una jerarquía de sitios de asentamientos de al menos seis niveles de distintos tamaños, área de superficie, configuraciones arquitectónicas y volúmenes de relleno, con una mayoría que data de los períodos preclásico medio y tardío. La arquitectura monumental, los formatos arquitectónicos consistentes, los límites y unificaciones de sitios específicos, las instalaciones de gestión y recolección de agua y más de 177 km de calzadas elevadas preclásicas sugieren inversiones laborales que desafían las capacidades organizativas de entidades políticas menores y representan las estrategias de gobierno en los períodos preclásicos. Las distribuciones de los asentamientos, las continuidades arquitectónicas, la contemporaneidad cronológica y la organización jerárquica de los sitios, brindan evidencia de una administración centralizada temprana y estrategias socioeconómicas, dentro de una región geográfica definida en las tierras bajas mayas.

Corresponding author: Richard D. Hansen, email: hansric2@isu.edu

Cite this article: Hansen, Richard D., Carlos Morales-Aguilar, Josephine Thompson, Ross Ensley, Enrique Hernández, Thomas Schreiner, Edgar Suyuc-Ley, and Gustavo Martínez (2022). LiDAR analyses in the contiguous Mirador-Calakmul Karst Basin, Guatemala: an introduction to new perspectives on regional early Maya socioeconomic and political organization. *Ancient Mesoamerica* 1–40. <https://doi.org/10.1017/S0956536122000244>

“States were originally defined by anthropologists and political scientists, but archaeologists can now identify the skeletons of their institutions” (Flannery 1998:16).

“Because the early state must have been ... a regional phenomenon, methodological control over regional analysis must be emphasized in the study of the transition phenomenon” (Jones and Kautz 1981:34).

Introduction

This article presents one of the largest, contiguous, regional LiDAR studies published to date in the Maya Lowlands, revealing more than 775 ancient Maya settlements within the Mirador-Calakmul Karst Basin (MCKB), and 189 more in the surrounding karstic ridge that comprise the geomorphological borders of the geographical area, together forming 964 archaeological settlements. A “settlement” is defined as a grouping or independent cluster of architecture, but when a group of settlements can be demonstrated as related via intrasite causeways or other architectural affiliations, such as shared logistics facilities like reservoirs or marshes, we suggest they can be defined as a “site” or “polity.” A single settlement can also be a site, depending on the quantity of public or residential architecture, as determined by the volumetrics of contemporary construction fill. The settlements that demonstrate a strong political/social/geographical relationship with other settlements within the basin via intrasite causeways have allowed us to suggest a condensation of “settlements” into at least 417 centralized site hierarchies forming ancient cities, towns, and villages (defined below in Settlement Distribution) with specific boundaries, such as *bajo* or *arroyo* edges or large areas of uninhabited terrain. A preliminary settlement and administrative hierarchy of at least six tiers is proposed for sites based on surface area, numbers, and densities of monumental architecture, and volumetric calculations of architecture extracted from surface-mapping measurements and LiDAR data. The approximate volumetric assessments were conducted in each site of what appeared to be the civic center of an area 1 km², with monumental architecture and specific architectural configurations dating to the Middle and Late Preclassic periods, as determined by extensive regional archaeological testing by the Mirador Basin Project in 56 sites, consisting of test pits, archaeological salvage of looters’ trenches, and broad horizontal architectural exposure of structures, as well as morphological characteristics of architecture (e.g., Mejía 2008, 2012; Mejía et al. 2007, 2010). Monumental architecture, consistent architectural formats, specific site boundaries, water management and collection facilities, and more than 177 km of elevated Preclassic causeways suggest labor investments that defy organizational capabilities of lesser polities and portray the strategies of governance by uniting major sites in a network in the Middle and Late Preclassic periods.

Mesoamerica is one of the ideal areas of the world where the process of cultural, political, and economic complexity can be critically evaluated (Clark 2016; Love and Guernsey 2022; Rosenswig 2021a; Traxler and Sharer 2016). The wide range of natural resources and variant cultures within a limited geographical framework permitted social, political, and economic interactions via emulation, adaptation, and/or independent innovation. Data relevant to site formation and complexity are more readily available, due to the duration and consistency of archaeological research and new technologies such as LiDAR (light detection and ranging), which have been conducted in the Mirador-Calakmul Karst Basin (MCKB; Ensley et al. 2021;

Force and Dohrenwend 2008, 2021) of northern Guatemala and southern Campeche, Mexico (Figures 1 and 2; Table 1; see also Supplementary Figure 1). Multidisciplinary research over the past four decades in the area of the MCKB by the Foundation for Anthropological Research and Environmental Studies (FARES) and the Mirador Basin Project has resulted in the field mapping and excavations in 56 separate archaeological sites of varying sizes, providing a ground-truthing of LiDAR and GIS analyses. Many of these studies have been published in annual symposium volumes in the National Museum of Anthropology and Ethnology of Guatemala (<https://www.asociaciontikal.com>), in scientific papers (e.g., <https://www.researchgate.net/profile/Richard-Hansen-3>), and in technical reports provided to the Government of Guatemala. LiDAR studies of a contiguous area of the southern MCKB have provided new information that, when combined with systematic archaeological research, suggests that a more adequate and improved interpretation of the cultural process can be obtained via improved archaeological methodologies, a greater utilization of multidisciplinary approaches, application of more advanced technologies, improved chronometric methods, and archaeological investigations conducted on a regional scale (Hansen 2016b:333). Long-term, comprehensive regional investigations have the advantage of broader, multidisciplinary perspectives based on multiple lines of evidence and allow testing of hypotheses, identification of multi-causal factors, and alternative models for the rise of complexity within specific regions (Clark 2016; Rosenswig 2021a; Sharer and Sedat 1987; Sharer et al. 2006). This study uses airborne LiDAR data to demonstrate how complex societies organized their infrastructure to reflect their socio-economic organization and political power, conforming to a proposed incipient kingdom/state during the Preclassic period in the Maya Lowlands.

These data are relevant to the cultural development within the Mirador-Calakmul region, a karst basin defined by hydrological and geomorphological features, groundwater flow, and natural boundaries (Ensley et al. 2021; Force and Dohrenwend 2008, 2021). Over recent years, LiDAR data have been acquired that cover 85.8 percent of the southern, or Guatemalan, MCKB. These data have unveiled a remarkable density of Maya sites (Table 2), many of them linked by a network of elevated causeways. Using a GIS and remote-sensing methodology, we have identified and are proposing a six-tiered settlement and administrative hierarchy of sites, with monumental ceremonial architecture, that were present during the Preclassic period, based on archaeological data, density of architecture, superficial areas, calculated volumetrics of architectural fill of contemporaneously constructed or occupied architecture, consistent or similar architectural or artistic traits, and geographical characteristics. A similar study was suggested for the region between Yaxuna and Coba by Stanton and colleagues (Stanton et al. 2020), with architectural densities, surface areas, and architectural volumes to be considered in settlement pattern research. Extensive monumental architecture in the MCKB has been mapped, including E-Groups, triadic complexes, ballcourts, causeways, and

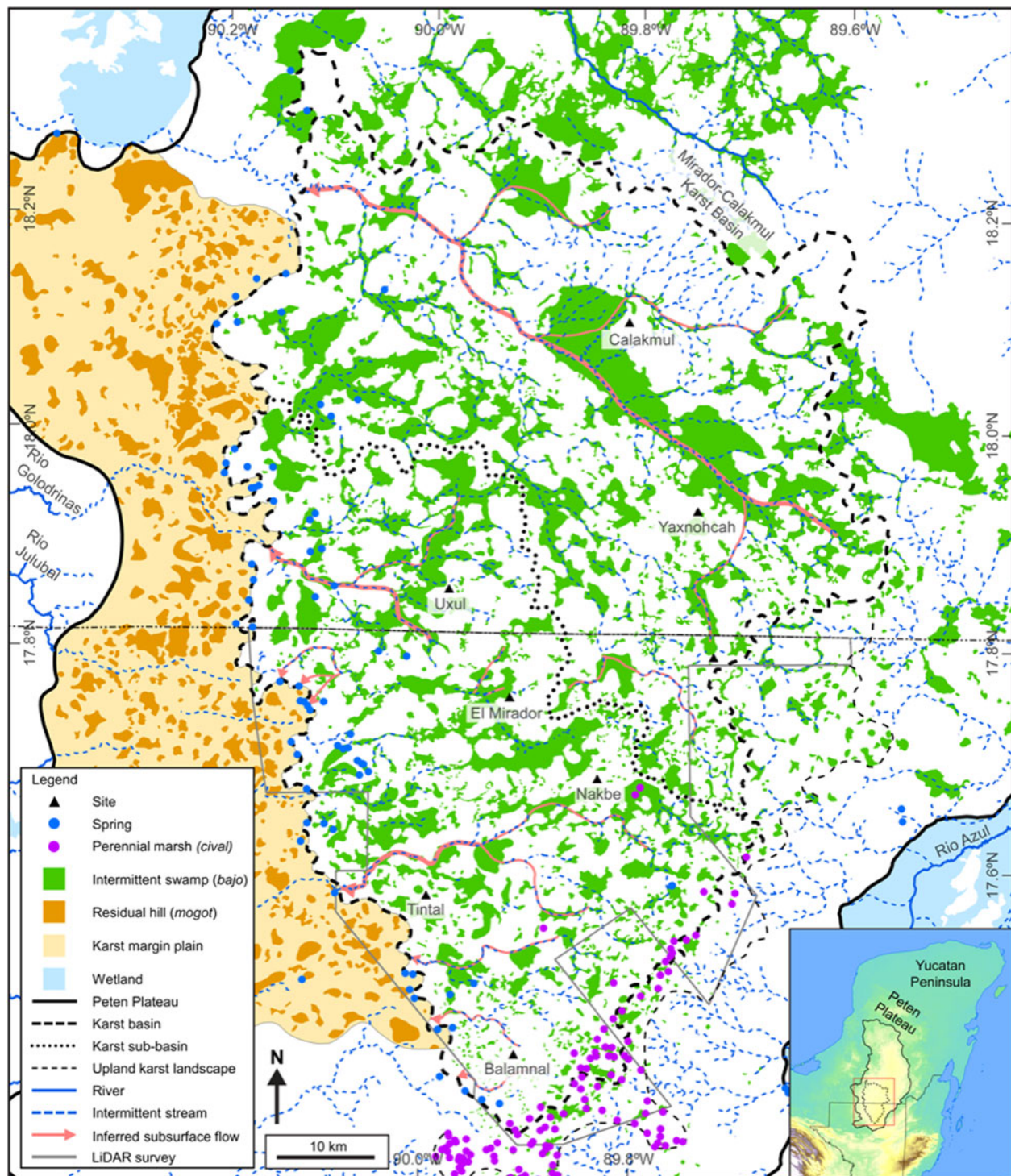


Figure 1. Drainage map of the MCKB in the southern Peten Plateau, which is a fluviokarst landscape dominated by seasonally inundated *bajos* and intermittent streams. Numerous *civales* occur in the southeast MCKB, and springs exist at the base of low hills punctuated by dry karst valleys at the edge of the karst basin. Over time, the west karst margin border and plain have eroded, leaving residual hills, or *mogotes*. Modified after Ensley et al. (2021).

reservoirs throughout the basin. Collectively, we argue that the development of infrastructure demonstrates the presence of complex societies with strong levels of socio-economic organization and political power during the Middle and Late Preclassic periods.

The Mirador-Calakmul Karst Basin

The Mirador-Calakmul area is a Neogene fluviokarst landscape (Gates 1992, 1999), located on the southern Peten Plateau and defined by its geomorphological features (Ensley 2018; Ensley et al. 2021:Figure 1; Folan et al. 2001;

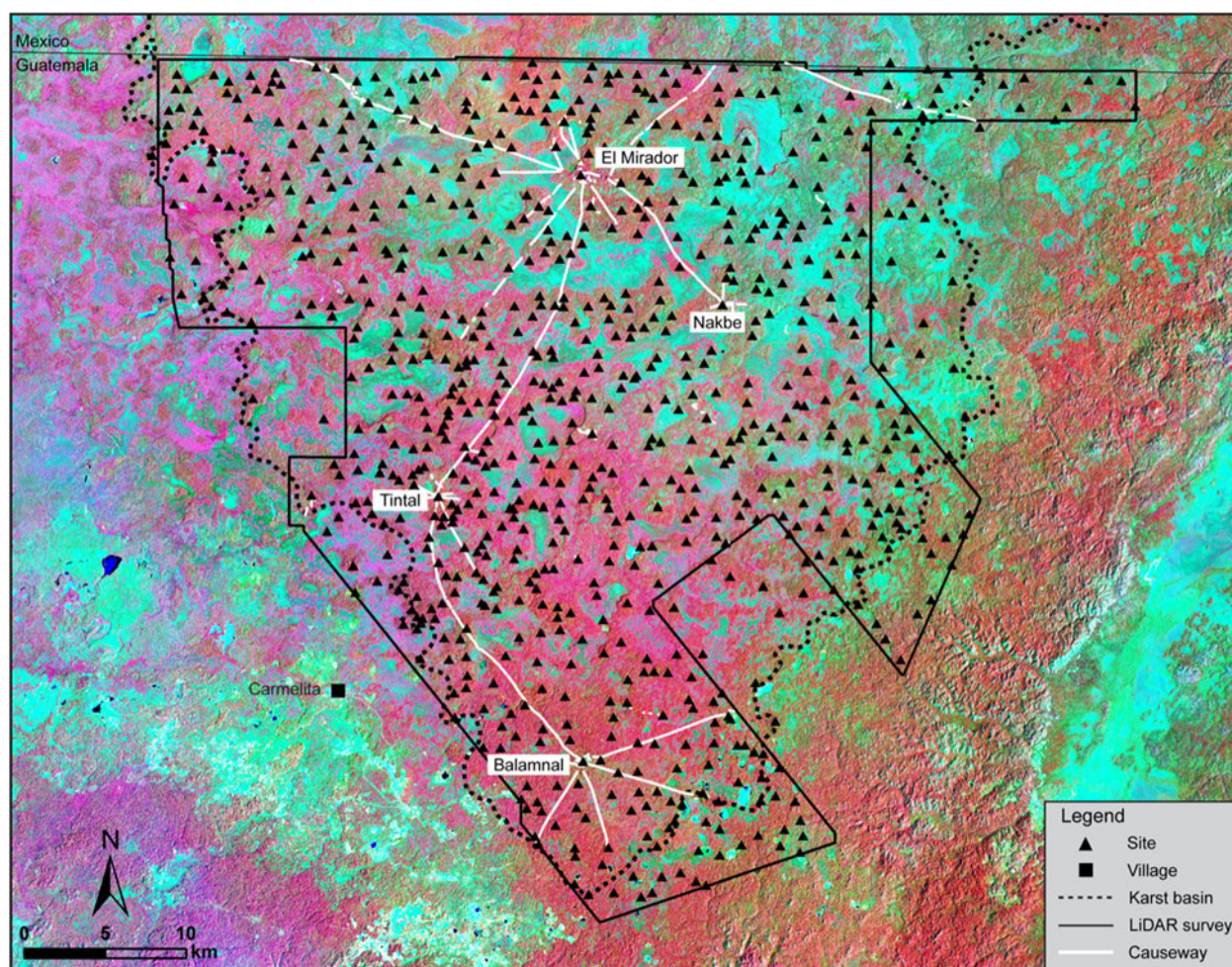


Figure 2. Site map of the southern MCKB. The concentration of sites and causeways in the MCKB demonstrates the likely economic and political cohesion of the area. The background near-infrared image indicates the vegetation types with lowland, or bajo, vegetation in blue-green and upland vegetation in red. Causeways do not extend beyond the natural borders of the basin, suggesting an enclosed centralization associated with settlement nucleation in the Middle and Late Preclassic periods. Sentinel-2 multispectral data: <https://earthexplorer.usgs.gov>.

Force and Dohrenwend 2008; Gunn and Folan 1992; see also Figure 1). The area is dominated by low-lying seasonal swamps, known as *bajos*, where water collects from the surrounding karstic upland hills that form the natural borders (Ensley 2018; Ensley and Hansen 2020; Ensley et al. 2021:20; Gunn and Folan 1992; Hansen 2012a, 2012b, 2016a, 2016b, 2017; Hansen et al. 2002). The area is particularly visible on infrared satellite images, first published in 1992 (Supplementary Figure 1), due to the dominant, stunted *bajo* vegetation (blue in infrared color) that varies from tropical forests in more elevated areas (red in infrared color; Stuart 1992; see also Hansen 2016b:340, 2017:308).

The MCKB exhibits hydrological features common to drainage basins, in addition to inferred groundwater flow routes and defined boundaries (Ensley et al. 2021:20; Quinlan and Ewers 1989:66; Ray 2001:236; Taylor and Greene 2008:81; White 1988:112–113, 153–155). Regional visualization and hydrogeological interpretation of the basin and its surrounding landscapes used satellite-derived elevation data recorded by the Japan Aerospace

Exploration Agency (Takaku et al. 2014, 2016), and was confirmed by LiDAR data covering much of the southern portion of the basin. Borders of the MCKB drainage basin are delineated by the Mirador Anticline on the southeast, the Calakmul Anticline to the northeast, a northern line of karst hills that denotes the divide between the Calakmul and Desempeño drainages, and the line of low, residual hills interrupted by karst valleys along the west. Like the western flank of the Mirador Anticline, the eastern flank is part of the upland karst landscape (Ensley et al. 2021:19–20) and has a similar karst geomorphology, dominated by numerous perennial marshes known as *civales*.

Karst landscapes form a periphery surrounding the MCKB. To the southeast, the basin is bounded by a rugged polygonal karst landscape (e.g., Ensley et al. 2021:17–19, Figure 3) that is a geomorphologically defined buffer zone (Adams 1999:Figures 1 and 2; Adams and Jones 1981: Figure 2; Gunn et al. 2019: Figure 11.5) flanked by the Buenavista Escarpment. On the west side, a karst margin plain is a seasonally flooded alluvial plain with residual

hills (Figure 1) which constrains the basin. North of Calakmul, the basin is bounded by a range of hills that separates two fluviokarst drainages, the Desempeño to the northwest and the Escondido to the northeast. The area is believed to be an important water source for much of the Yucatecan shelf (Bauer et al. 2011).

Materials and methods of LiDAR exploration of the MCKB

The MCKB contains some of the largest ancient Maya cities, and the antiquity of many, if not most, of the sites dates to the Middle and Late Preclassic periods (ca. 1000 B.C.–A.D. 150), with a more modest occupation of the area during the Late Classic period (A.D. 600–900; Clark and Hansen 2001; Clark et al. 2000; Hansen 1998, 2001, 2005, 2012a, 2012b, 2016a, 2016b, 2017; Hansen and Suyuc-Ley 2016; Hansen et al. 2008; Morales-Aguilar 2010, 2021). Previous archaeological mapping in the southern MCKB surveyed the sites of Nakbe, La Florida, El Mirador, and Tintal with Total Station laser technology, allowing 3-D capability. The success of LiDAR in the archaeology of tropical forests in the Maya Lowlands of Belize (Chase et al. 2011, 2014; Ford et al. 2014; Prufer et al. 2015; Weishampel et al. 2011), Mexico (Fernandez-Diaz et al. 2014; Hare et al. 2014; Hutson and Welch 2014; Rosenswig et al. 2013), and Angkor, Cambodia (Evans et al. 2013) prompted the pioneering use of LiDAR in the northern Peten of Guatemala by the Mirador Basin Project. Starting in 2015, the project recorded two large-scale aerial LiDAR surveys within the southern half of the MCKB, covering an area of 1703 km² (Figure 2), making it one of the largest contiguous LiDAR surveys recorded for archaeological research in the Maya Lowlands to date. Our review of over 150 publications and unpublished reports, which detail the use of LiDAR data in Maya Lowlands, has documented 26 individual surveys designed for archaeological research that constitute 18 contiguous regions of 100 km² or greater (Table 1; see also Canuto et al. 2018; Inomata et al. 2021), demonstrating the importance of regional-scale surveys in Maya archaeology. In these regional studies, LiDAR has facilitated mapping of settlement observations and cultural features, and enabled detailed environmental, geological, geomorphological, and hydrological interpretation.

Eagle Mapping conducted the LiDAR survey of the southern MCKB, under contract with FARES, in two phases (Phase I: 2015; Phase II: 2018), using the Riegl LMS-Q1560 system and a Riegl LMS Q780 scanner at nominal altitudes of 550 m and 650 m. The Riegl systems used a scan angle of 58 degrees. The light-beam divergence was 0.25 mrad and the nominal pulse density was 20 pulses/m². Because of weather conditions, the Phase II survey was recorded at lower levels, requiring more flight lines, at a lower pulse density of 15 pulses/m². The swath width was 513–741 m, with an overlap of 55–70 percent. The average density of total returns (including vegetation) was 48.39 points/m² in Phase I and 39.64 points/m² in Phase II, while the ground return density (Grtn) was 2.18 points/m² in Phase I and 2.95 Grtn/m² in Phase II. The LiDAR point data were

delivered to FARES in LAS 1.2 in 500 m² tiles. Post processing of the Phase I survey with Rapidlasso's LASTools software provided a ground density return of 5.2 Grtn/m². The overall accuracy of both surveys is ± 15 cm horizontal and ± 30 cm vertical. QuickTerrain Modeler was used to create bare-earth digital elevation model (DEM) and digital terrain models (DTM) with a 0.5 m resolution. Once the LiDAR-derived DEM was generated, we produced different surface and visualization models to interpret archaeological features, including hillshade with different light positions. Hillshade models have been widely applied in archaeology in tropical environments to enhance, detect, and define cultural remains (A.S.Z. Chase et al. 2017; Chase et al. 2014; Dunning et al. 2019; Evans et al. 2013; Golden et al. 2021; Horn and Ford 2019; Rosenswig and López-Torrijos 2018; Šprajc et al. 2021; Thompson 2020). To generate visualizations and interpret archaeological features, we used several software programs, including RVT, ArcMap, GlobalMapper, Quick Terrain Modeler, and QGIS.

Settlement distribution

The LiDAR survey revealed an extraordinary density and distribution of Maya sites concentrated in the MCKB, many of them linked directly or indirectly by a vast causeway network (Figure 2). Using hillshade models derived from a LiDAR DEM, at present 775 ancient Maya settlements (defined as an architectural cluster) have been identified within the southern lowland MCKB, of which 581 are unnamed (Figure 3, Table 2). An additional 189 ancient Maya settlements of varying sizes were identified within the geomorphological borders of the southern MCKB, including the upland karst landscape along the Mirador Anticline, for a total of 964 settlements (of all periods), of which 645 are unnamed as yet. An additional 52 known sites are located on the Campeche side, but without the benefit of contiguous LiDAR, with the exception of dispersed areas in Campeche, Mexico (see Brewer et al. 2017; Reese-Taylor 2017; Schroder et al. 2020; Šprajc 2020; Šprajc et al. 2021). Varying scales and structural densities are dependent partially on the *bajo* landscapes (see also Canuto 2021). A settlement that was thought to be relatively small, on a small elevation surrounded by large *bajos*, has proven to be much larger in size when direct links, such as intrasite causeways, dams, dikes, canals, common reservoirs, and common *bajo* utilizations, were detected between the site center and its dependent peripheries. When settlements are determined to be dependent peripheries of larger polities, and defined by *bajo* borders or *arroyos* with contemporary occupation and architecture, then a total of at least 417 centers, consisting of cities, towns, and villages with demarcated boundaries, have been identified to date within the MCKB polygon (Figure 3; Supplementary Figure 2). The definition of these terms is a thorny issue, and scholars have attempted to define them for years (e.g., Smith 2016, 2020), with wildly variant results for population and settlement distributions based on definition and numbers of residences, the contemporaneity of structures, and family sizes per residence (Rice and Puleston 1981:144). A Mesoamerican “city” has been

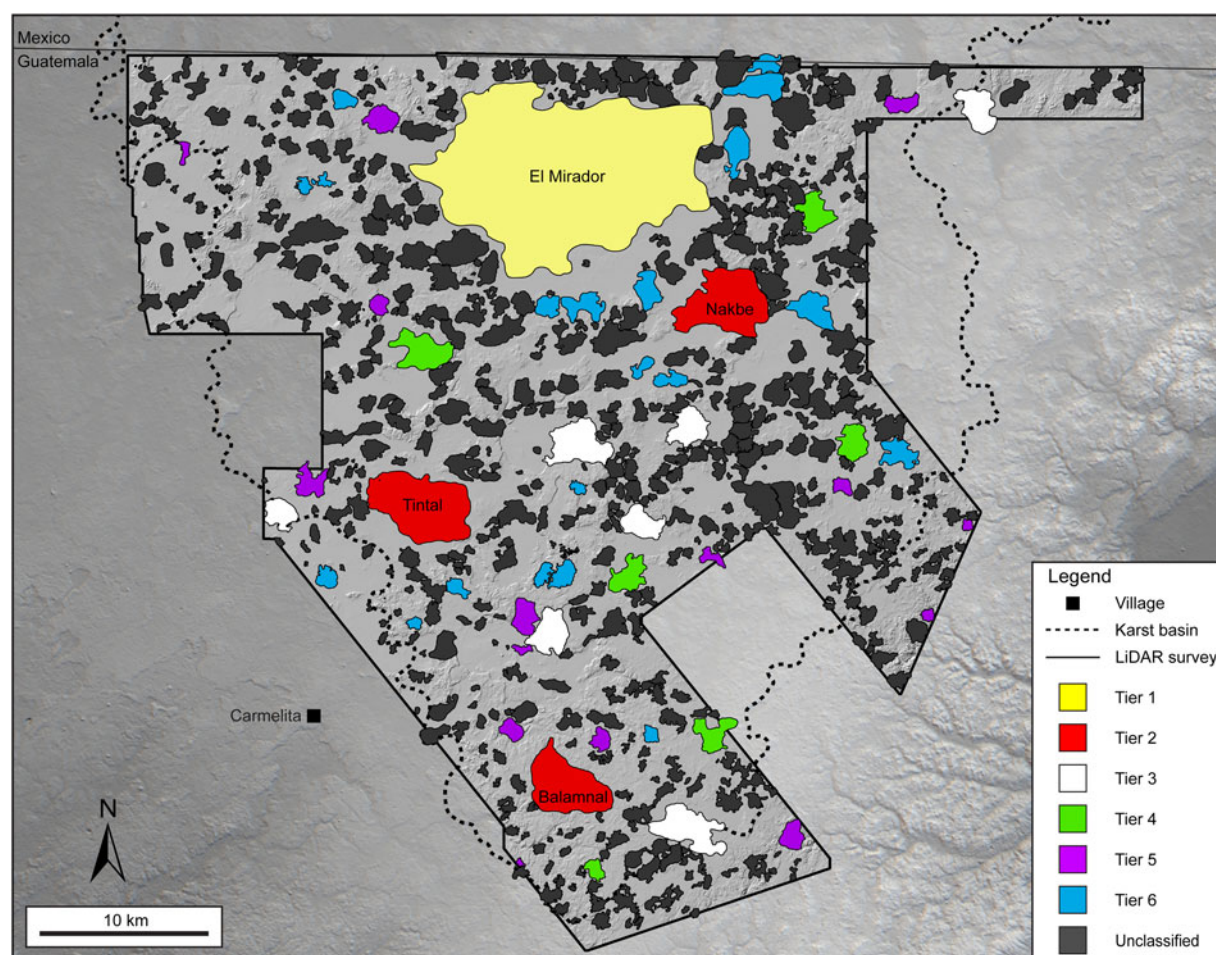


Figure 3. Site center map of the southern MCKB. Polygons represent cohesive site centers identified through GIS analyses of LiDAR, near-infrared data, and ground surveys throughout the southern half of the MCKB. Individual centers may consist of several settlements as suburbs or peripheral sites that are closely affiliated. Polygon colors are proposed tier levels. Digital elevation: ALOS World 3D (AW3D30), Japan Aerospace Exploration Agency (<https://www.eorc.jaxa.jp/ALOS/en/aw3d30/>), and FARES LiDAR.

previously defined as “a semi-urban center of at least 4000–5000 people” (Clark 2016:124). A “town” could be considered as a conglomerate of residences and public structures that would have had 1000–3000 inhabitants, while a “village” would be less than 1000 inhabitants. Architecturally, a “city” would be represented by large groups of residential and public architecture, while a “town” would be a much sparser collection of residences and reduced public/ceremonial architecture, and a “village” is defined as a social grouping of residences with at least one or less ceremonial/public structure.

To further complicate issues, the Mirador Basin Project has identified an astonishing presence of “invisible” house mounds, with packed earthen floors, postholes, and Preclassic pottery in situ, but with no surface indications of architecture (Johnston et al. 2015; Paine 2019, 2020; Paine and Hansen 2018; Paine et al. 2018a, 2021; see also Chase 1990; Pyburn 1990). We are unprepared to tackle this issue until enough sampling has been conducted to provide a statistically valid algorithm that would allow a refinement of Preclassic population estimates in the MCKB. In this

article, we have preferred to define site sizes as “tiers” with specific spatial qualities, numbers of monumental structures, and volumetrics of contemporary buildings and/or platforms. Larger sites, most of which are contemporaneous based on test excavations, are linked by an extensive causeway network that establishes a premise for early sophistication of socio-economic processes that gave rise to cultural complexity (Hansen 2016a, 2016b, 2017; Hansen et al. 2020; Hernández-Salazar 2021; Hernández et al. 2013, 2016; Morales-Aguilar and Castanet 2017). All the causeways previously detected with surface exploration mapping, testing and trenching excavations, and, later, with LiDAR were plotted in different bare-earth models to better understand how the Maya built their causeway system to consolidate a powerful state-level society during the Middle and Late Preclassic periods (see Causeways, below).

Years of field mapping, combined with LiDAR data and decades of archaeological research, have revealed a hierarchy of contemporaneous Preclassic settlements in sites with ceremonial characteristics, large, monumental architecture, and residential densities within the MCKB

Table 1. Selected large-scale LiDAR surveys in the Maya Lowlands. Included are contiguous surveys greater than 100 km² in size, designed for Maya archaeological research. Not included in this list are very large, but low-resolution surveys recorded in Mexico, primarily for terrain analysis, environmental studies, and emergency planning (Inomata et al. 2021; Instituto Nacional de Estadística, Geografía e Informática 2022). Also not included is the G-LiHT survey, a set of discontinuous profiles across the Yucatan Peninsula and Chiapas recorded by NASA and designed for the analysis of terrestrial ecosystems (Cook et al. 2013; Hutson et al. 2021; Inomata et al. 2021; Schroder et al. 2020).

Survey	Acquisition year	Survey area (km ²)	Contiguous area (km ²)	Resolution (m)	Total returns (points/m ²)	Ground returns (points/m ²)	Primary sources
Mirador Phase I	2015	645.0	1703.2	0.5	48.39	2.18	Ensley et al. 2021:9
Mirador Phase II	2018	1087.0		0.5	39.64	2.95	Ensley et al. 2021:9
Caracol	2009	199.7	1256.7	1.0	21.43	1.35	Chase et al. 2014a:212; Hightower et al. 2014:10721
West-Central Belize	2013	1057.0		1.0	15.00	2.80	Chase et al. 2014a:215; Moyes and Montgomery 2019:7
Aguada Fenix	2019	~260.0	~545.0	0.5	18.50	10.40	Inomata et al. 2021:1489; Inomata 2019:217
Zaragoza	2019	~170.0		0.5	18.50	10.40	Inomata et al. 2021:1489; Inomata 2019:219
Santa Elena	2019	~115.0		0.5	18.50	10.40	Inomata et al. 2021:1489; Inomata 2019:221
El Ceibal	2015	470.0		0.5	15.00	2.84	Inomata et al. 2019:3–5; Chase et al. 2016: Table 1
Yaxuna/Coba	2017	394.6	461.4				Stanton et al. 2020:3–4
Chichen-Itza/Yaxuna	2014	66.8		2.0	18.80	1.90	Magnoni et al. 2016:235; Rohrer and Stanton 2019:28
Uaxactun	2016	160.0	460.6	1.0		1.1–5.3	Bundzel et al. 2020:5–6; Stanton et al. 2020:3
Tikal	2016	146.9		1.0	99.46	2.07	Canuto et al. 2018: Table 1
El Zotz	2016	143.7		1.0			Canuto et al. 2018: Table 1; Garrison et al. 2019:137
La Corona	2016	431.7		1.0	28.58	2.65	Canuto et al. 2018: Table 1; Canuto and Auld-Thomas 2021:6
Homul	2016	308.6		1.0	26.87	1.00	Canuto et al. 2018: Table 1
Rio Bravo	2016	274.6		0.5	40.10		Beach et al. 2019:21471; McFarland and Cortes-Rincon 2019:50
Buenavista	2019	~160.0	~240.0	0.5	18.50	10.40	Inomata et al. 2021:1489; Inomata 2019:223

(Continued)

Table 1. (Continued.)

Survey	Acquisition year	Survey area (km ²)	Contiguous area (km ²)	Resolution (m)	Total returns (points/m ²)	Ground returns (points/m ²)	Primary sources
Moral-Reforma	2019	~80.0		0.5	18.50	10.40	Inomata et al. 2021:1489; Inomata 2019:225
Puuc	2017	237.2		0.5	39.00	10.60	Ringle et al. 2021:6–7
Chactún	2016	230.0		0.5	73.00	12.80	Šprajc et al. 2021:2–3
Yala	2016	172.3		1.0	26.10	1.92	Canuto et al. 2018: Table 1
Naachtun	2016	135.3		1.0	27.10	1.46	Canuto et al. 2018: Table 1; Morales-Aguilar and Castanet 2017
Uxbenka	2011	132.0		1.0	20.10	2.72	Thompson 2020:4; Prufer et al. 2015:4–5
Xultun	2016	124.0		1.0	27.63	1.11	Canuto et al. 2018: Table 1
Mosquitia	2012	122.8		1.0	36.64	0.71	Fisher et al. 2016:7; Fernandez Diaz et al. 2014:9953
Yaxnohcah	2014	100.0		0.5	20.51	1.30	Reese-Taylor et al. 2016:317; Dunning et al. 2019:130

(Figures 4 and 5; Table 3). Others have attempted the identification of a tiered site hierarchy based on plaza counts, house styles, palaces, platforms, and surface area (e.g., Adams 1990; Adams and Jones 1981; Wright and Johnson 1975:270, 281). Additional tiers of sites, not noted in this article, include residential groups with no ceremonial or “public” architecture, such as that noted previously by Hammond in his identification of the nine tiers of Late Classic Belize (Hammond 1975). The various settlement tiers in the MCKB were identified by variations in (1) the surface area of sites with monumental architecture larger than 12 m high; (2) the presence, consistent sizes, and numbers of ceremonial/public architecture, such as pyramids, E-Groups and triad groups; (3) the volume of artificial contemporaneous constructions within a 1 km² area identified as a site or civic center with volumetrics, a concept previously

suggested (Adams and Jackson Adams 2003), but not applied (but see Stanton et al. 2020); (4) the presence of intrasite and intersite causeways; (5) the number of Preclassic residence platforms; (6) the presence of ballcourts; (7) logistics facilities, including reservoirs and terrace systems; and (8) the presence of defensive constructions.

The diachronic changes in site rank and status reveal changes of the political, economic, and social status of sites through time. The largest sites varied chronologically: Nakbe, Wakna, El Pesquero, Xulnal, El Mirador, Kunal, Yaxnohcah, and Balamnal have a strong presence in the Middle Preclassic period (ca. 900–400 B.C.). Sites such as El Mirador, Tintal, Nakbe, and Balamnal became even more dominant by the early Late Preclassic period (ca. 300 B.C.), indicating fluctuating fortunes of various centers through time (Hansen et al. 2020; Morales-Aguilar 2021; Reese-Taylor et al. 2016).

Table 2. Settlement density in the southern MCKB.

Polygon	Area (km ²)	Number of settlements	Number of unnamed settlements	Settlement density (sites/km ²)
LiDAR survey	1703.2	748	535	0.44
Southern MCKB	1720.8	775	581	0.46
Karst landscapes bordering MCKB	2016.8	216	119	0.11

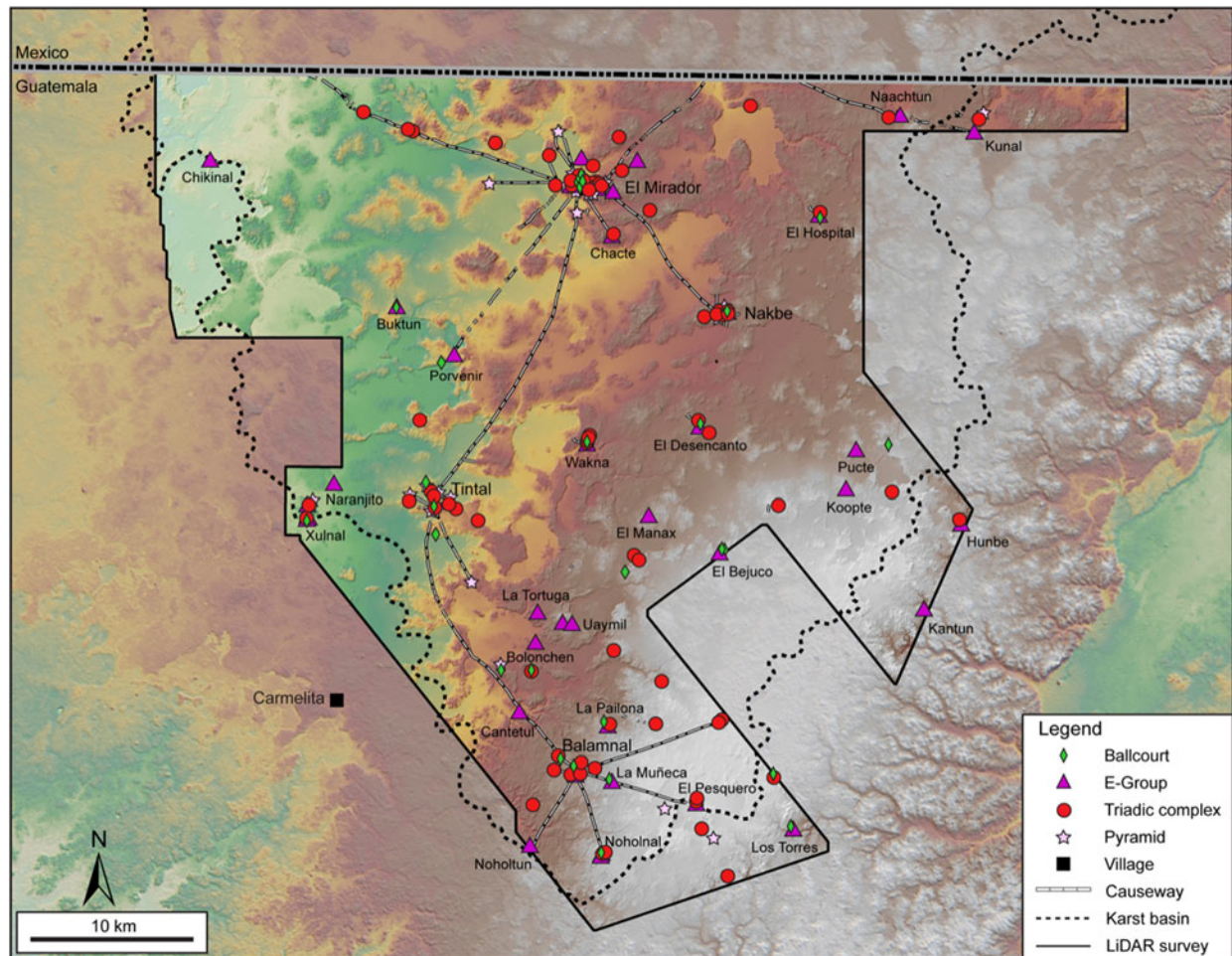


Figure 4. Monumental architecture map of the southern MCKB with ballcourts, E-Groups, triadic complexes, causeways, pyramids, and modern villages. Background color represents terrain elevation with lowest elevations in light blue-green, gradually increasing to higher elevations in browns, and highest elevations in white. Digital elevation data: ALOS World 3D (AW3D30), Japan Aerospace Exploration Agency (<https://www.eorc.jaxa.jp/ALOS/en/aw3d30/>), and FARES LiDAR.

By the late Middle Preclassic and early Late Preclassic periods, El Mirador became the dominant site, with monumental platforms, pyramids, agricultural terraces, water collection mechanisms, raised fields, E-Group and triadic architectural constructions, massive causeways, and a high demographic density as part of a network of allied sites with a nucleated power structure throughout the geographical confines of the MCKB (see Hansen and Guenter 2005). The civic center of the site, together with its subordinate suburbs, populated affiliated *bajos*, residential architecture, and monumental architecture, covers 132 km², making it the largest center in the basin, comparable to the post-LiDAR area of sites such as Caracol, at 177–317 km² (e.g., Chase and Cesarette 2018; Chase and Chase 2017; Chase et al. 2014a:214–216, 2016) or pre-LiDAR data at Tikal, at 120 km² (Culbert et al. 1990) to 165 km² (Lentz et al. 2015:287). The surrounding terrace systems, *bajo* field systems, and outlying residential compounds would make El Mirador even larger, but the natural borders of *bajos*, plus the structural format of sites in the basin, suggests a certain autonomy under the overall hegemony of El Mirador.

Part of this area includes several adjacent *bajos*, which were incorporated specifically in the site size because of extensive ancient modifications, including the presence of residential architecture (Dahlin et al. 1980), raised fields, “chinampa-like” structures, canals, and other artificial modifications within the *bajo* areas directly affiliated with the civic center (see below). LiDAR revealed similar modifications in the *bajos* of adjacent areas (e.g., Beach et al. 2019).

LiDAR site definitions and boundary identifications

LiDAR remote sensing in tropical forests has become a useful tool for detection of archaeological remains through the application of a GIS-based approach (Canuto et al. 2018; Chase et al. 2011, 2014b; Evans et al. 2013; Ford et al. 2014; Garrison et al. 2019; Inomata et al. 2019, 2020, 2021; Rosenswig and Lopez-Torrijos 2018; Rosenswig et al. 2013). Our extensive previous archaeological surveys carried out before LiDAR acquisition were used to support our interpretation of archaeological features observed on LiDAR data. One of the common problems in Lowland Maya archaeology

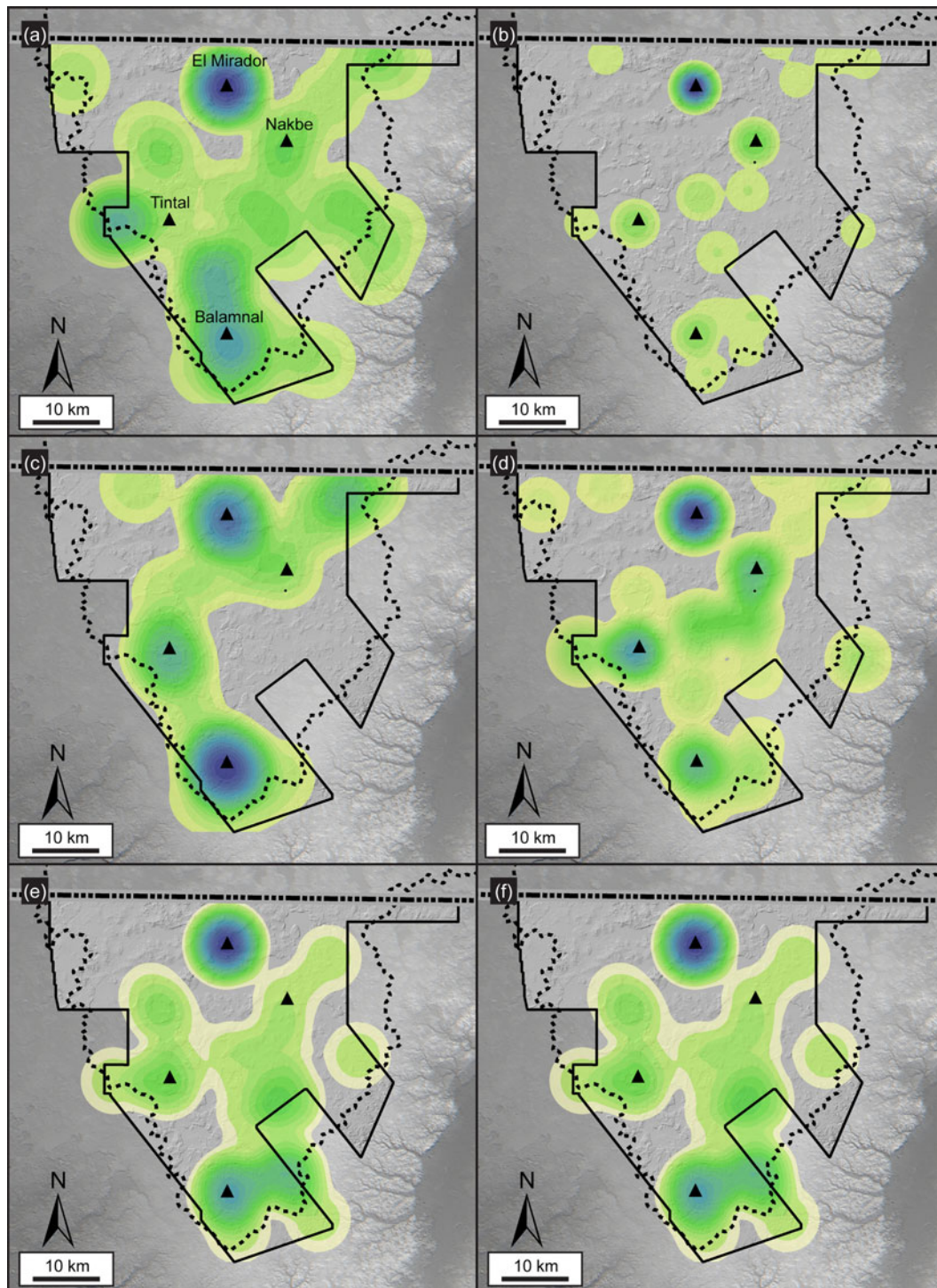


Figure 5. Density analyses of monumental features in the southern MCKB, showing (a) E-Groups, (b) triadic complexes, (c) intersite causeways, (d) intrasite causeways, (e) ballcourts, and (f) large reservoirs. The density scale shows low architectural density in yellow, varying moderate density in shades of green, and high architectural density in blue. Digital elevation: ALOS World 3D (AW3D30), Japan Aerospace Exploration Agency (<https://www.eorc.jaxa.jp/ALOS/en/aw3d30/>), and FARES LiDAR.

has been the identification of site boundaries and borders (Adams and Jones 1981:301; Culbert et al. 1990; Drápela et al. 2016). LiDAR data covering the contiguous area in the southern MCKB have offered the opportunity to refine these details. For example, our criteria for site definitions

consisted of individual settlements that were found to have intrasite causeways, contemporaneous architecture of consistent forms, and/or shared subsistence facilities or constructions which articulated with a site homogeneity that was absent with other sites. In this study, remote-

Table 3. Surface area of Preclassic sites and monumental metrics for randomly selected sites in Tiers 1–6 in the MCKB.

Tier	Site	Surface area (km ²)	E-Groups	Triadic complexes	Intersite causeways	Intrasite causeways	Ballcourts	Large reservoirs	Carved monuments	Non-carved monuments	Defensive features
Tier 1	El Mirador	132.00	8	48	5	12	7	7	19	26	Yes
Tier 2	Tintal	19.00	1(?)	7	3	8	2	3	2		Yes
	Nakbe	15.00	2(?)	11	1	6	1	2	4	11	No
	Balamnal	13.00	3	7	5	6	3		?	?	No
Tier 3	El Pesquero	7.70	1	1	1	2					No
	Wakna	7.36	1	4		4	1			7	No
	Uaymil	4.60	2			1					No
	Kunal	4.00	1(?)	1	1	1					Yes
	El Desencanto	3.90	1	2		4	1				No
	El Manax	3.50	1								No
	Xulnal	2.70	3	1		3	2			2	Yes
Tier 4	Porvenir	5.50	1(?)		1	1	1	2			No
	El Civalon	3.20		2			1				No
	El Hospital	3.00	1			1	1				Yes
	La Union	3.00		2		1	3				No
	Pucte	3.00	1								No
	Noholnal	1.02	2	2	1	1	1		?	?	Poss. wall
Tier 5	El Limon	2.50		1	2					2	No
	La Tortuga	2.45	1								No
	Naranjito	2.39	1								No
	Los Torres	1.80	1				1				No
	Naachtun	1.60	1	1	2	1		1			No
	Cantetul	1.30	1		1						No
	La Pailona	1.20	1(?)	1			1				No
	Buktun	1.00	1				1				No
	El Bejuco	0.80	1			1	2				No
	Koopte	0.80	1								No

(Continued)

Table 3. (Continued.)

Tier	Site	Surface area (km ²)	E-Groups	Triadic complexes	Intersite causeways	Intrasite causeways	Ballcourts	Large reservoirs	Carved monuments	Non-carved monuments	Defensive features
	Chikinal	0.50	I			I			?	?	No
	Kantun	0.40	I								No
	Bolonchen	0.40	I								No
	Hunbe	0.30	I	I		2					No
	Noholtun	0.16	I		I						No
Tier 6	Chicanticanal Sur	3.90		I		I				3	Yes
	La Ciudadela	3.66									No
	Ikmal	3.04								I	No
	La Zumbadora	2.70					I				No
	Las Terrazas	1.70				I					No
	Las Ilusiones	1.50									No
	La Naranjita	1.50			I						No
	Xulbil	1.40									No
	Paixban	1.30		I	I	I					No
	Petencito	1.30									No
	Uucnal	1.03									No
	La Ceibita	1.00			I						No
	El Chiquero	0.92							I		No
	Hunal	0.70		I							No
	La Isla	0.70			I				2	I	No
	El Karstico	0.60									No
	El Bajon	0.50									No
	La Florida	0.50							I	(?)	No
	Tamazul	0.50							I		No
Total		277.53	44	95	28	59	30	15	30	53	

sensing methods have been applied to determine site limits using geographical characteristics. This was combined with the natural topography of the area to provide identifiable circumscribed borders, such as *bajos*, *civales*, or *arroyos*, to settlements which appear now to have been part of the same site. This allowed surface area determinations of specified sites with chronological similarities, and many have been confirmed by mapping survey, salvage of looters' trenches and test pits, and horizontal architectural excavations at 56 separate sites conducted on a regional scale by the Mirador Basin Project.

Using LiDAR data and analyses, combined with surface mapping and archaeological excavations, we propose a six-tiered settlement hierarchy for sites with monumental architecture established by the Middle Preclassic and Late Preclassic periods (Figure 6). This six-tiered settlement hierarchy is consistent with the use of four-tiered settlement data elsewhere in the world to suggest the existence of a more complex or "state-level" governance (Wright and Johnson 1975). This hierarchy was derived by the surface area of the site epicenters, the associated number of major buildings, platforms, plazas, and agricultural and hydraulic features, as determined by archaeological data and calculations of the volume of the built environment of contemporaneous architecture (construction and/or utilization). The selected examples are not comprehensive, but indicative of site sizes (Figure 4). The presence of dense settlements and centers of varying sizes within the MCKB and its surrounding natural frame indicates a prodigious growth and development in the Middle and Late Preclassic periods of Maya occupation (Figures 2 and 3). The tiered layers of sites were established through the analysis of topography for natural site boundaries, as well as the concentration and distribution of Preclassic structures, numbers and sizes of plazas, public and residential structures, platforms, intrasite causeways, E-Groups, ballcourts, the number of dominant triadic structures, chronological contemporaneity, and architectural volumetrics (Figures 5a–5f; Tables 3 and 4). In addition, the uniformity of the testing strategy for tier identification which could be applied to any Maya site would be to identify an area of 1 km² and determine the volumetrics of construction fill of contemporaneous architecture within the area. Based on those criteria, we suggest that the largest site in the MCKB is El Mirador, which represents Tier 1, covering an area of 132 km², with monumental architecture greater than 15 m high. This area included several surrounding *bajos* because of the presence of low residential architecture throughout them (e.g., Dahlin et al. 1980; Hernández et al. 2019), and the extensive raised fields immediately associated with the civic center in the Bajo La Jarilla (Hansen et al. 2018a, 2018b; Figure 7). It is even possible that the *civales/bajos* within the civic center of El Mirador were densely populated with "stilt" communities, or elevated wooden residential platforms, judging by the presence of Preclassic slipped and utilitarian ceramics found in numerous test pits throughout the *bajos* (e.g., Dahlin et al. 1980; Hernández et al. 2019; Jacob 1994; Johnston et al. 2015; Paine et al. 2018a, 2018b). Even excluding the *bajos* within

Table 4. Sample of volumetric evaluations of a 1 km² area for selected sites. Global Mapper was the program used for the majority of volumetrics in this article.

Site	Tier	Structure volume (m ³)	Max. str. height (m)/km ²
El Mirador	1	4,306,867	55
Nakbe	2	922,393	48
Tintal	2	776,621	50
Balamnal	2	905,738	22
Wakna	3	207,063	24
Kunal	3	203,145	21
El Limon	4*	194,189	17
Noholnal	4	156,601	18
Hospital	4	137,469	16
El Pesquero	5*	85,093	16
Cantetul	5	68,625	10
La Ceibita	6*	94,997	22
Hunal	6	33,266	20
Total		8,092,066	

* Volumetrics, architectural morphology, and site surface area require additional testing for confirmation of tier category.

the confines of the site (37.93 km², or 28.64 percent), the upland area with Preclassic monumental and residential architecture is 94.51 km², or 71.36 percent of the suggested site area. El Mirador is also composed of a periphery with large areas of residential structures connected by a causeway network. The associated *bajos* were highly exploited by the Maya during the Preclassic period. Raised fields, large reservoirs, and canals were constructed in the wetland system and were key elements in Preclassic agrarian and water management strategies. Large numbers of E-Groups, triadic pyramids, and other complexes at El Mirador, in addition to the presence of carved monuments depicting rulers (see Table 3; e.g., Hansen 2012a:155, 2016b:382, 386, 394–397, 409; Hansen and Guenter 2005; Hansen et al. 2018a:160; Justeson and Mathews 1983), represent a high concentration of political power in the Maya Lowlands during Preclassic times. Combined architectural mass in a 1 km² sample of our Tier 1 site civic center was calculated in two ways: (1) computer generations of volume, using programs of ArcGIS Pro, Global Mapper, and QGIS; (2) geometrical mathematical calculations using total station contour measurements for platform volumes, and truncated and pointed pyramidal superstructures which amounted to a calculated minimum of 4,809,310 m³ of construction fill for contemporaneous structures for the 1 km² of the West Group of El Mirador. Calculations of the mass of architecture using three separate programs provided an approximate volumetric estimate of approximately 4,306,867 m³ (Global Mapper), in the selected 1 km² at the site.

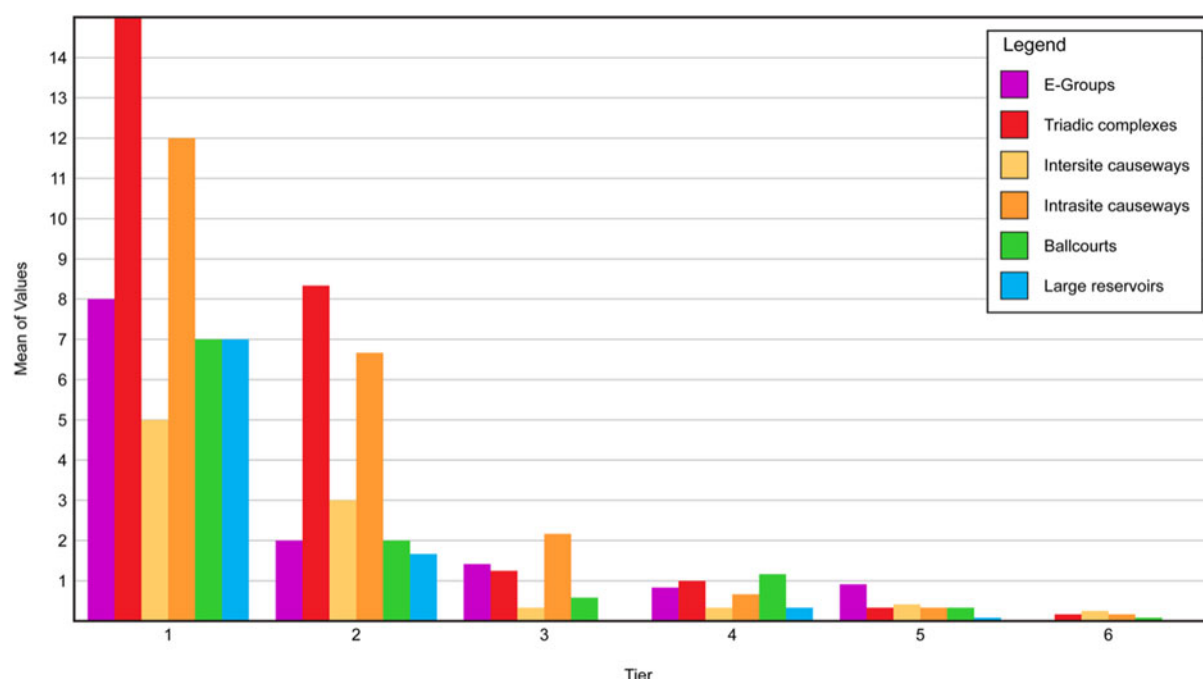


Figure 6. Graph of the monumental architectural features in the southern MCKB showing the various normalized levels of consistency of settlement hierarchies.

The Tier 2 sites, such as Tintal, Balamnal, and Nakbe, have a surface area ranging between 13 and 19 km² (Figure 8), but some of the features described above are less frequent or absent. The presence of fewer large reservoirs and carved monuments suggests a different level of political organization. Nevertheless, all of the Tier 2 sites show monumental architecture up to 50 m in height and causeway networks. Tier 2 sites have a 1 km² mass of contemporaneous artificial construction, ranging from 922,392 m³ (Global Mapper) to 945,678 m³ (QGIS) at Nakbe, 776,620 m³ (Global Mapper) to 781,645 m³ (QGIS) at Tintal, and 905,737 m³ (Global Mapper) to 941,633 m³ (QGIS) at Balamnal.

Tier 3 sites include centers such as El Pesquero, Wakna, Porvenir, Uaymil, Xulnal, and others with civic centers with surface areas ranging between 2.7 and 8.0 km² (Figure 9). Tier 3 sites are smaller in surface area than Tier 2 sites, but differ from Tier 4 sites because of the larger size and greater abundance of monumental architecture, with at least five structures ranging from 8 to 20 m in height within the civic centers. All Tier 3 sites have E-Groups, but the sizes and scales of the eastern platforms are 150–200 m in length. All Tier 3 sites have intrasite causeways which link architectural complexes within the civic centers, indicating an administrative and settlement distribution hierarchy. Computer volumetrics of Tier 3 sites range between 200,000 and 300,000 m³/km², based on Global Mapper calculations.

Tier 4 sites include centers such as Noholnal, El Civalon, La Union, and El Hospital, with an average surface area between 1.01 and 4 km² (Figure 10). These sites differ from Tier 5 sites in that they generally have more triadic structures (2+), usually at least one ballcourt, and intrasite causeways to link various architectural groups with the

civic centers. Computer-generated volumetrics estimated these tiers at between 137,000 m³ (Hospital), 156,000 m³ (Noholnal), and sites up to approximately 200,000 m³ of contemporaneous constructions within the 1 km² selected.

Tier 5 sites include La Tortuga, Naranjito, Los Torres, Cantetel, and La Pailona, with a surface area of 1.2–3.04 km² (Figure 11). All Tier 5 sites have E-Groups, in spite of the diminished surface area of the civic centers of the sites and computer-generated volumetrics (Global Mapper) of 68,000 m³ (Cantetel) to about 100,000 m³ (El Pesquero).

Examples of Tier 6 sites include Las Ilusiones, La Ceibita, Hunal, El Karstico, La Florida, Hunbe, and Noholtun, with surface areas between 0.16 and 1.5 km² (Figure 12). Only one of the Tier 6 sites has an E-Group, but all of these sites have at least one monumental structure that exceeds 12–22 m in height. Sites such as Oxkinlal, located on the western margin of the MCKB consists solely of an E-Group. Sites such as La Ceibita and Hunal have a massive single pyramid, with a volume of about 33,000–95,000 m³, but no other monumental buildings. Randomly selected examples of site hierarchies are listed in Table 3, with a sample of volumetrics listed in Table 4.

We applied a Kernel density method in ArcGIS Pro to analyze the spatial patterns of E-Groups, triadic complexes, intersite causeways, intrasite causeways, ballcourts, and large reservoirs (Figure 5). As a result, six different models show hotspots of concentration of these features. The main hotspot is located at El Mirador, representing the largest cityscape in the southern MCKB. Another important hotspot is represented at Balamnal, demonstrating its sociopolitical influence in the region during the Preclassic period.

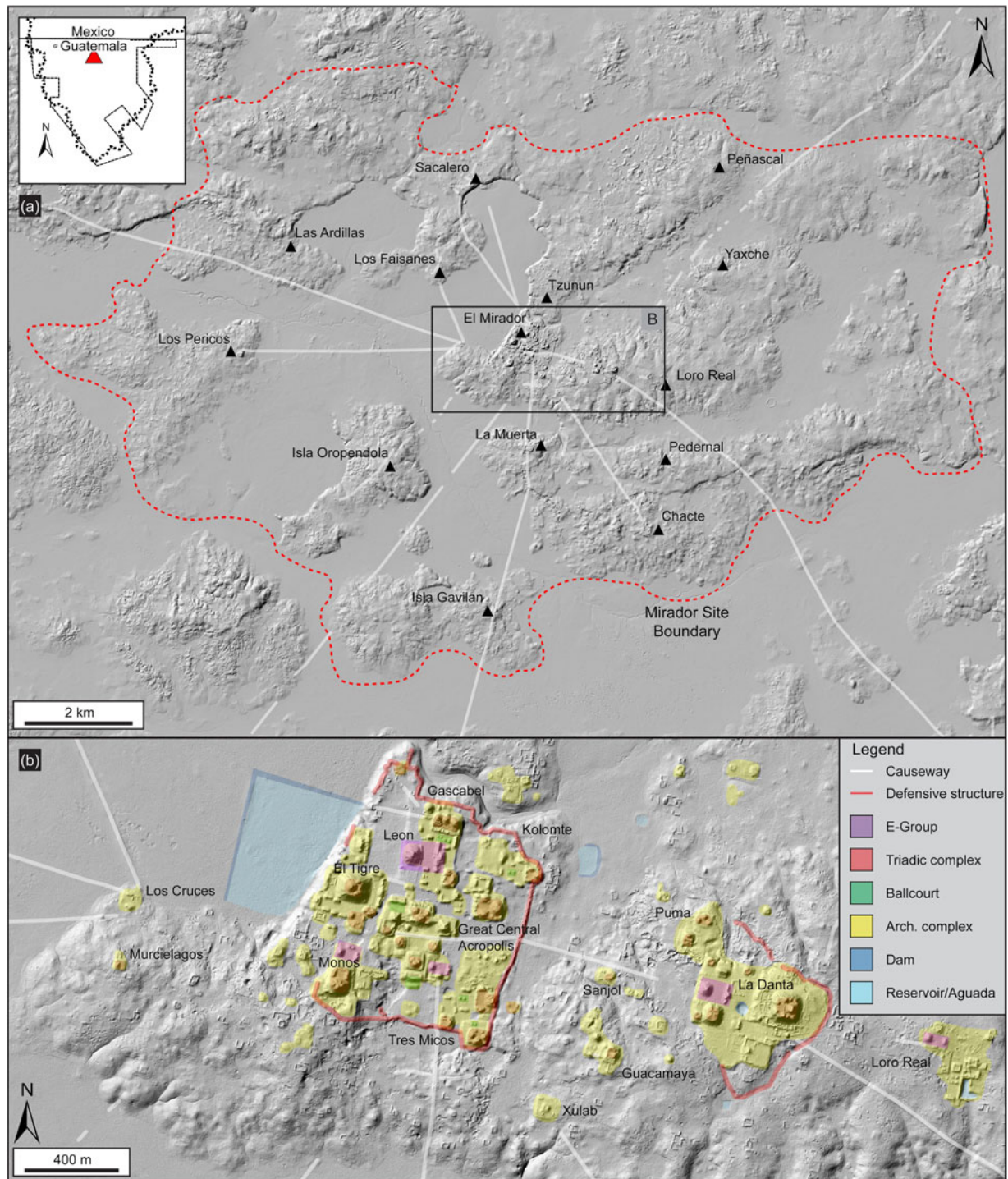


Figure 7. (a) Example of a Tier I site center, El Mirador. Structures range between 15 and 72 m high in the areas indicated. The area of the site is indicated by the dotted red line and associated suburbs of the city are connected by intrasite causeways. Monumental architecture and intrasite causeways indicate that the site covers an area of 132 km². (b) The volumetrics of 1 km² of the civic center, consisting primarily of the walled West Group of the site, exceed 4,000,000 m³.

New perceptions of the MCKB settlements via LiDAR

Our documentation of hundreds of archaeological sites in the MCKB of northern Guatemala challenges the old notion of sparse early human occupation in the Maya Lowlands, particularly in the Preclassic period (Fox 1977:40; Fry 1969; Haviland 1965:19; Sanders and Webster 1988; Thompson

1954:50). The presence of dense settlements within the natural confines of the MCKB indicates prodigious growth and unusual cultural dynamics in the Middle and Late Preclassic periods of Maya occupation. Our preliminary six-tiered settlement and administrative hierarchy of ceremonial sites in the Preclassic period, as identified by excavations

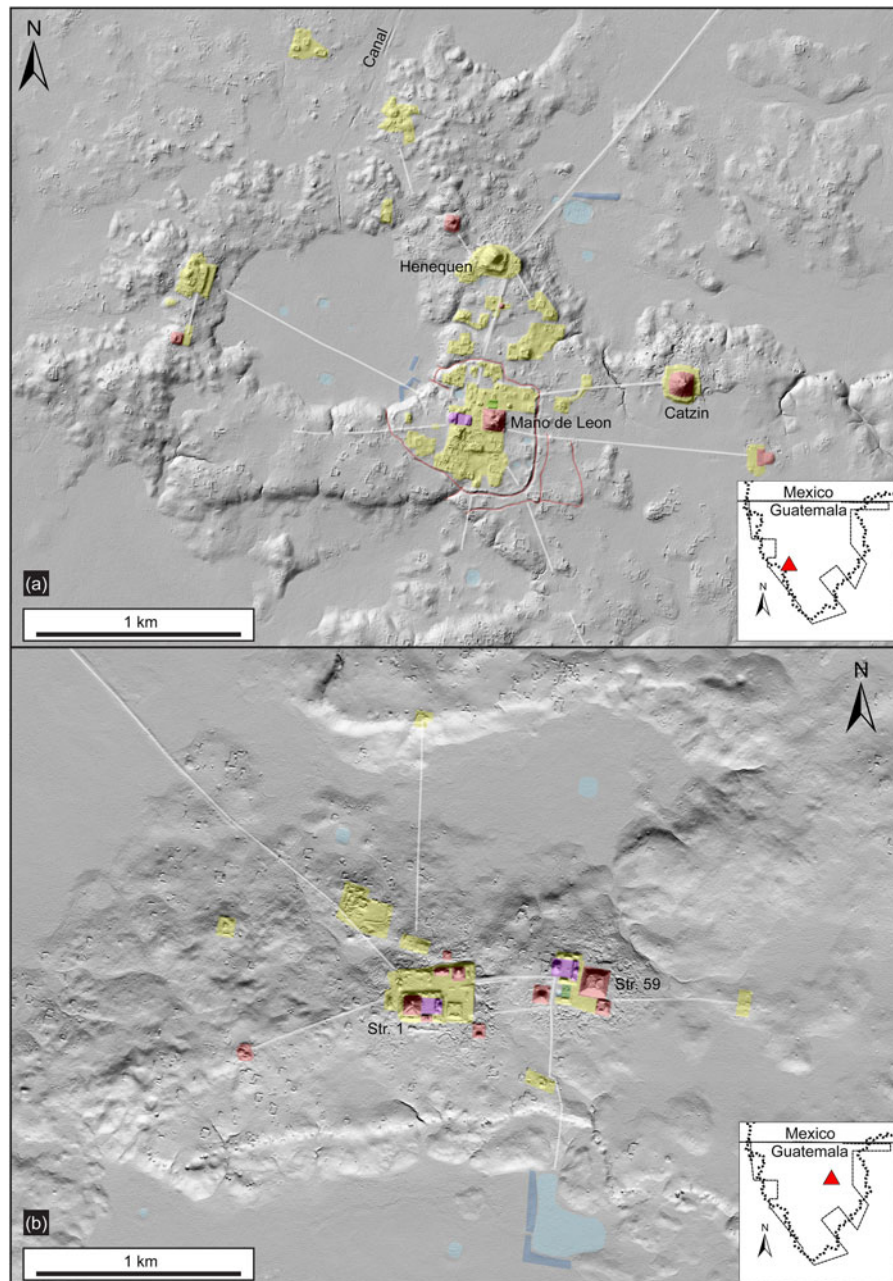


Figure 8. LiDAR images of example Tier 2 sites: (a) Tintal, with structures between 20 and 50 m high, numerous platforms, and intersite and intrasite causeways; and (b) Nakbe, with a surface area of 13–19 km², and volumetrics of a 1 km² sample exceeding 906,000 m³. Color codes for the shaded image are provided in the legend shown in Figure 7b.

conducted over several decades in the MCKB (Figure 5) is indicative of a general uniformity of site morphology in this region. While the Late Classic (A.D. 600–900) presence in the southern MCKB is limited to smaller residential settlements, with the exception of the sites of Naachtun, Porvenir, Tamazul, La Pailona, and Lechugal (on the Guatemalan side), and Uxul, Calakmul, and Pared de los Reyes on the Mexican side, a wider range of tiered hierarchy seems to be found in the Preclassic sites. The consistency of architectural forms and patterns, ceramics, sculptural art, architectural patterns, and unifying causeway constructions within a specified geographical territory suggests a centralized political, social,

and economic organic solidarity among the occupants (Hansen and Suyuc-Ley 2011). This is not to imply either the reduced or enhanced political importance of the centers, however, since sites like Xulnal are located in Tier 3 due to the restricted area of the civic center surrounded by large *bajos*. Clearly, it was an important social and economic hub, based on the number of E-Groups (three), with at least three intrasite causeways, large early architecture, and defensive or restricted access moats. It is also one of the few sites in the basin with a north–south orientation, while most other early sites have an east–west orientation.

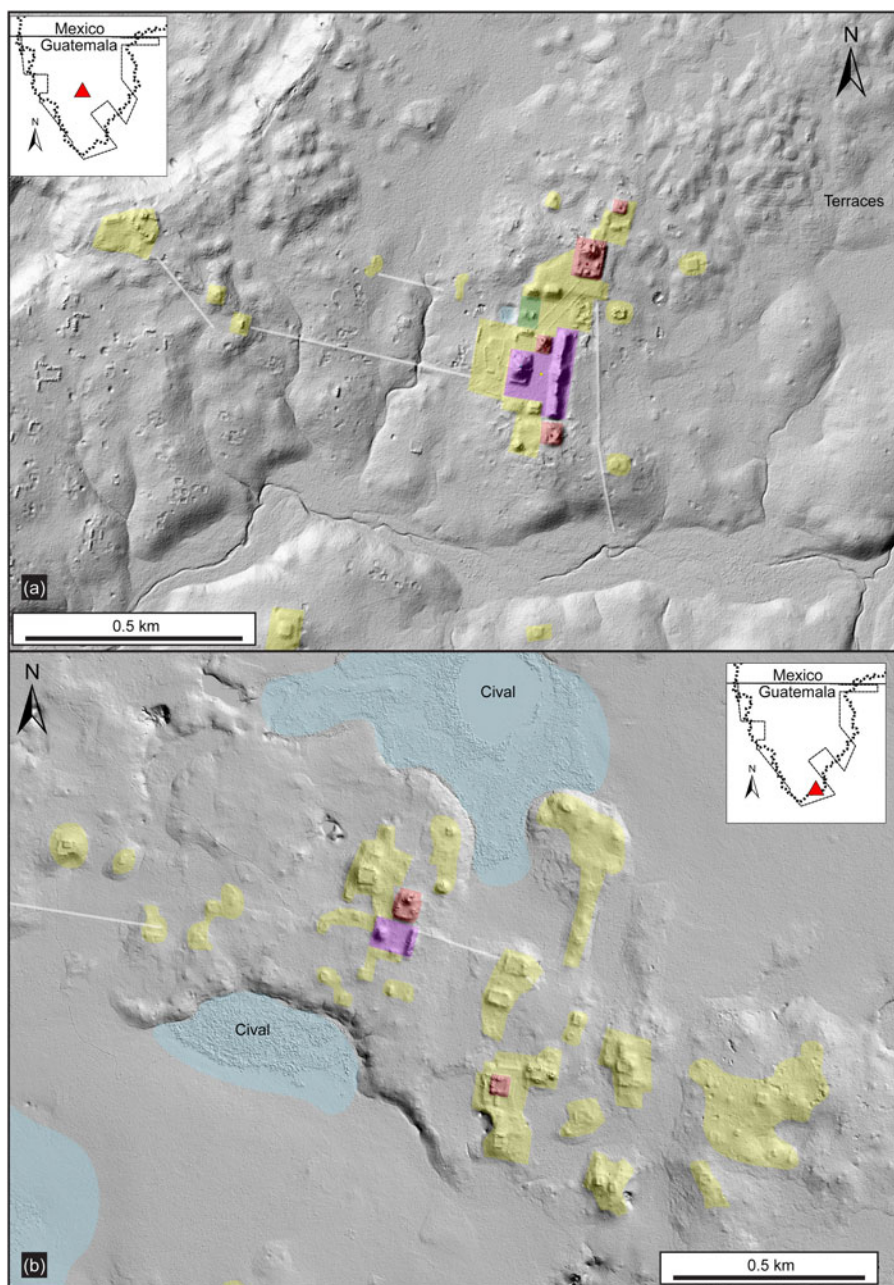


Figure 9. LiDAR images of example Tier 3 sites: (a) Wakna, with a surface area of 7.4 km²; and (b) El Pesquero, with a surface area of 7.7 km² and at least five structures that exceed 12 m in height. However, El Pesquero has volumetrics of 81,516 m³ of construction fill, which could place it as a Tier 5 site, pending additional investigation. Color codes for the shaded image are provided in the legend shown in Figures 6 and 7b.

The magnitude of the labor in the construction of massive platforms, palaces, dams, causeways, and pyramids dating to the Middle and Late Preclassic periods throughout the MCKB suggests a power to organize thousands of workers and specialists, ranging from lime producers, mortar and quarry specialists, lithic technicians, architects, logistics and agricultural procurement specialists, and legal enforcement and religious officials, all operating under a political and ideological homogeneity. The social, economic, and ideological branches of cultural complexity within a demarcated geographic territory are suggested by differential

causeway accessibility. The varied sites within the MCKB are a testament to regional public programs, such as E-Groups, monumental ceremonial architecture, including triadic complexes, intersite causeways, intrasite causeways, ballcourts, reservoirs, dams, canals, terraces, and raised fields (Figures 4–6). Residential architecture within large sites demonstrates a marked inequality of size and sophistication of architecture and the presence, or lack, of imported commodities (e.g., Hansen 2016b:362–369).

The consistent architectural construction techniques (stone, mortar, stucco, and architectural art), and both

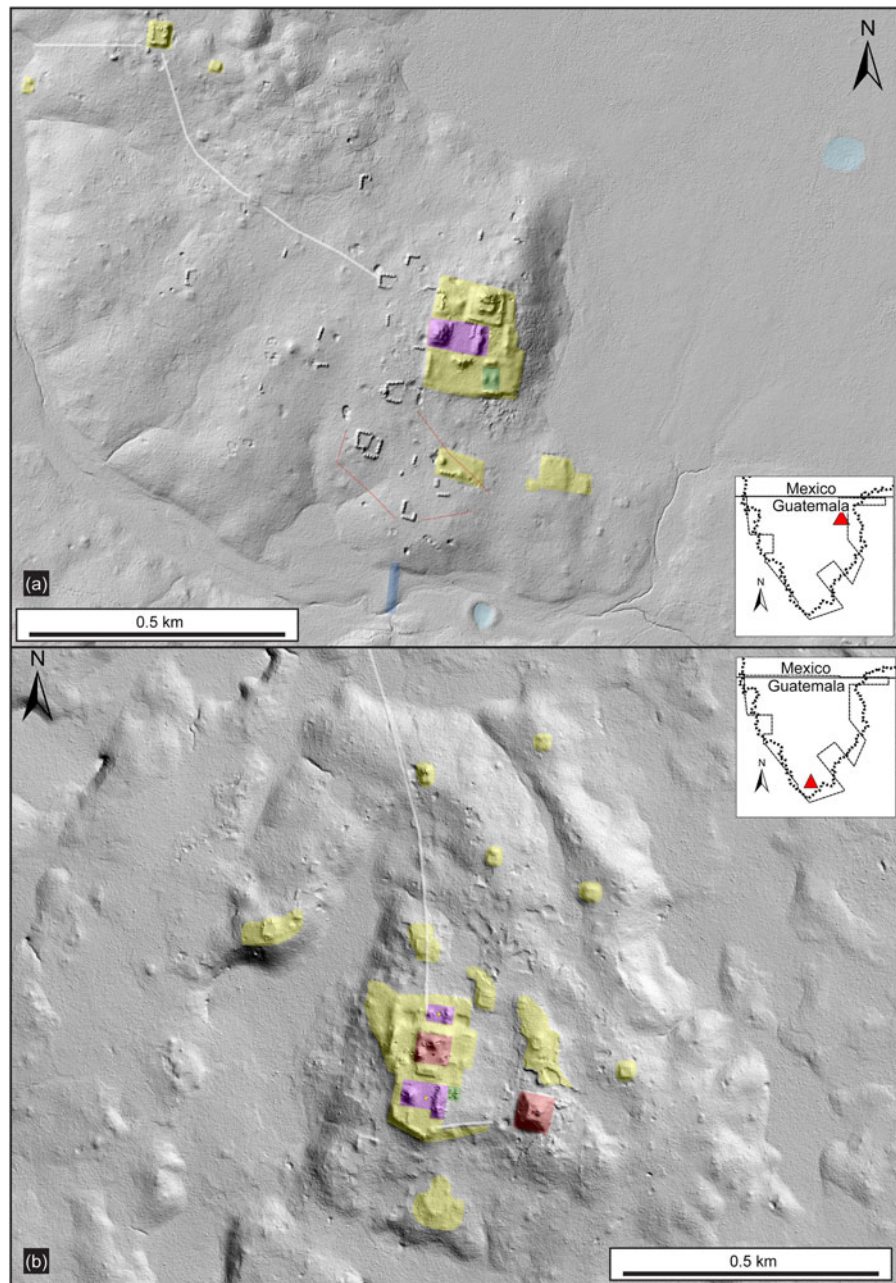


Figure 10. LiDAR images of examples of Tier 4 sites: (a) El Hospital, with an area of 3 km² and a 1 km² architectural volumetrics of 137,469 m³; and (b) Noholnal, with an area of 3 km² and a 1 km² structural volume of 156,601 m³. These tiers have sophisticated, large Preclassic complexes, platforms, and causeways. Color codes for the shaded image are provided in the legend shown in [Figures 6 and 7b](#).

utilitarian and ceremonial artifacts in the Middle Preclassic period, plus the innovation of large triadic architecture throughout the area by the beginning of the Late Preclassic period, imply a formation and institutionalization of a unified religious ideology (Coe 1981; Durkheim 1915; Keatinge 1981; Weber 1956). We have yet to identify gridded sites, such as the Middle Preclassic site of Nixtun Ch'ich' (Pugh and Rice 2017; Pugh et al. 2019), which suggests the independent nature of the formation of sociopolitical complexity by this early period. Agricultural terracing has been identified by LiDAR and surface excavations in nearly all areas of the southern MCKB, similar to the Classic period terracing

identified at Caracol, Belize (Chase and Chase 1998; Chase et al. 2014a:214ff.) and Naachtun (Morales-Aguilar, personal communication 2021), as well as the Preclassic terraces at Nakbe and El Mirador (Hansen 2012a, 2016b, 2017; Hansen et al. 2002, 2018a, 2018b; Martínez Hidalgo et al. 1999). Terraces and sites appear to decrease near the natural borders of the basin, but it may be possible to determine the effects of such extensive populations in the Preclassic on subsequent populations and contemporary rainforest canopy (Hightower et al. 2014). The agricultural and logistical capacity to accommodate large Preclassic populations required a marshalling of labor, on an industrial scale perhaps, for the

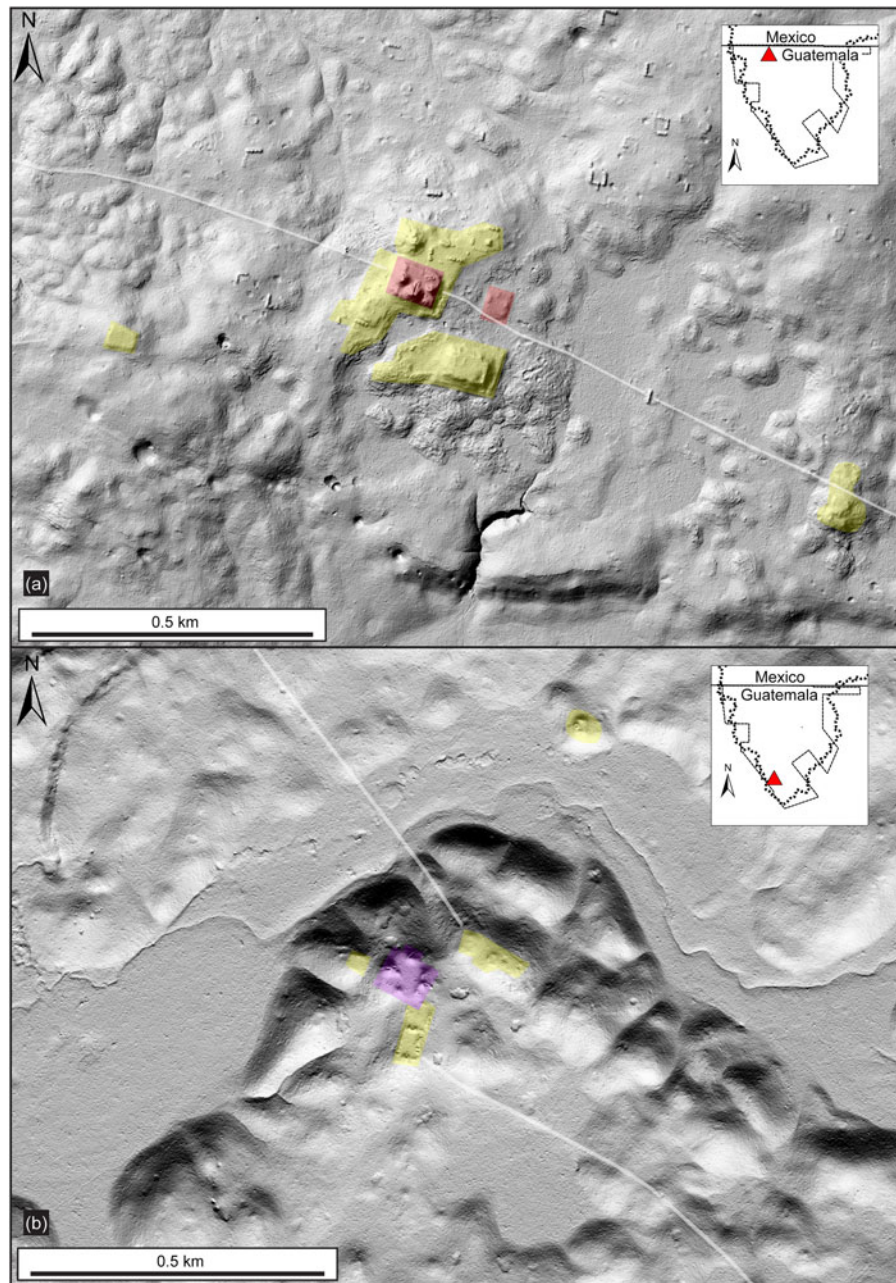


Figure 11. LiDAR images of examples of Tier 5 sites: (a) El Limon covers an area of 2.5 km², but has volumetrics of 194,189 m³/km², making it a candidate for a Tier 4 classification, pending further investigations; (b) the site of Cantetel covers an area of 1.30 km², with volumetrics of 68,224 m³/km². Color codes for the shaded image are provided in the legend shown in Figures 6 and 7b.

architectural construction, planting, weeding, watering, and harvesting of the terrace crops.

The monumental architecture, major platforms, complexes known as E-Groups (see below), and associated causeways (see below) were formed by the late Middle Preclassic period, and subsequent constructions were built with up to 1.5 million–2.8 million m³ of fill in a single structure in the Late Preclassic period (Hansen 2012a, 2016b; Hansen et al. 2018a; Suyuc-Ley and Hansen 2013). Massive triadic pyramidal structures, such as the pyramid of Tigre at El Mirador, measuring 145 × 150 × 55 m has similar counterparts in at

least 12 major sites in the southern MCKB, and similar constructions are noted at Yaxnohcah, Calakmul, and probably Balakbal in Campeche, indicating the magnitude of the contemporaneous labor conscription. Estimates for the construction of Danta are between 6 and 10 million person-days of labor, depending on the volume that might be affected by an undulating bedrock surface (Hansen et al. 2018a:185). The quantity and density of contemporaneous constructions in the MCKB allow an understanding of the labor, ideological consistency, and uniformity of construction materials invested in, and on, the monumental architecture

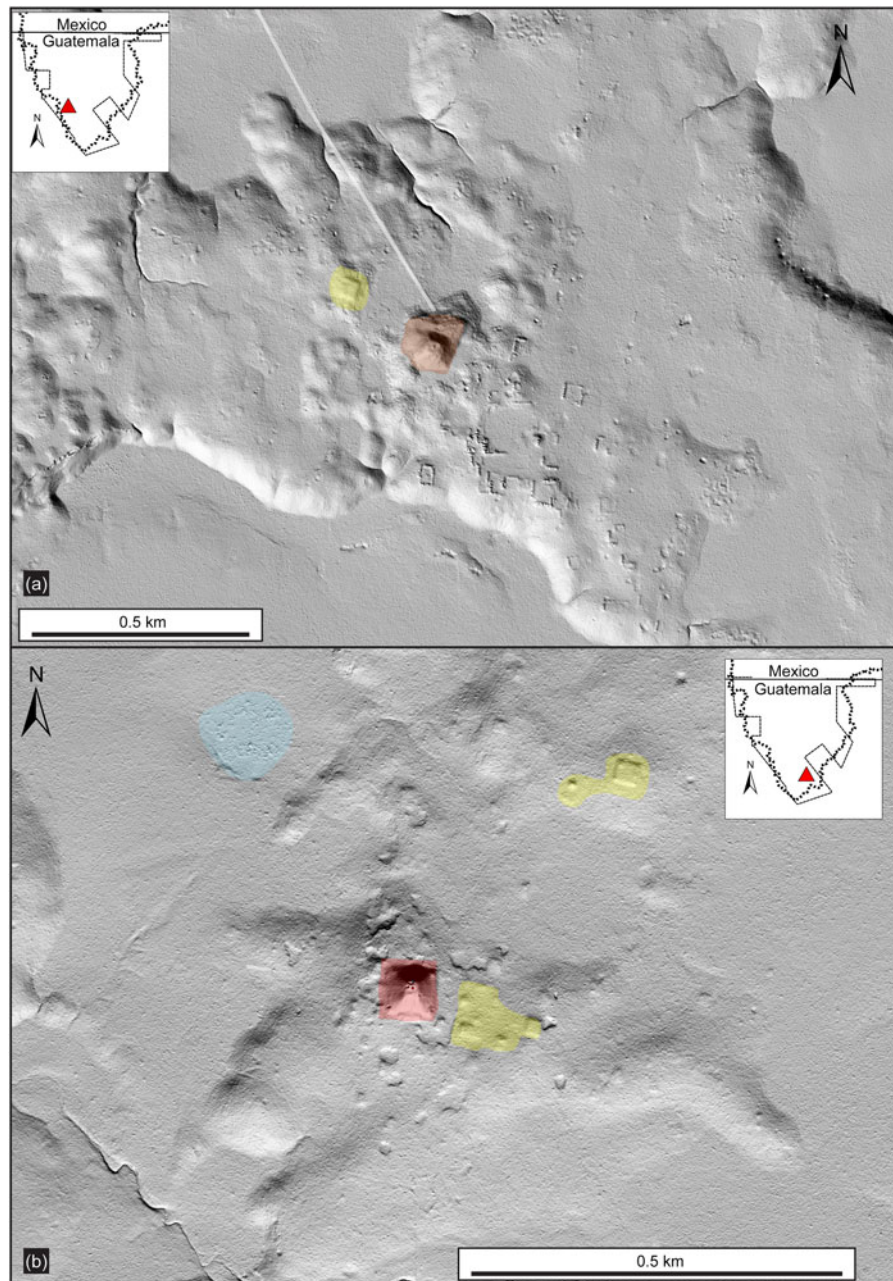


Figure 12. LiDAR images of examples of Tier 6 sites: (a) La Ceibita, which covers an area of 1.0 km², but has volumetrics of 94,997 m³, which could place the site in a Tier 5 category, pending further investigation. Several residential groups at the site were not included in calculations because of inconsistent contemporaneity with the larger architecture; (b) Hunal, which covers 0.7 km² and has volumetrics of 33,265 m³/km². Note the single monumental structures at each site, of 22 m and 20 m high, respectively, with little additional associated architecture. Color codes for the shaded image are provided in the legend shown in Figures 6 and 7b.

(E. Hansen et al. 1995, 1996, 1997; Hansen et al. 2020; Schreiner 2001, 2002, 2009, 2021).

The evidence for complex social, economic, and political organizations and the emergence of a hierarchical sociopolitical structure with institutions of kingship allow the testing of models and hypotheses (Hansen 2016b, 2017). The formation of such hierarchical power structures has anthropological implications that are best observed via diachronic and synchronic perspectives on a regional basis (Haas 1982:216).

Monumentality of ritual and religious architecture, ballcourts, causeways, and water collection systems

E-Groups

Primary sites of the MCKB have structures built for ceremonial or religious ideology (e.g., Demarest and Conrad 1992). LiDAR analyses have facilitated the identification of more structural complexes known as E-Groups. These architectural complexes are of a consistent form, with a dominant pyramid on the west and an elongated north-south platform on the

east of a plaza group, and were purported to be associated with solstice and equinox alignments, as first identified in Group E at Uaxactun in the 1920s (Blom 1924:218; Doyle 2012; Freidel 1981; Freidel et al. 2017; Hansen 1998:63–70; Ruppert 1940:222). However, these assessments are not reliable (see Aveni and Hartung 1989; Šprajc 2021a, 2021b). They had important ritual and ceremonial functions in early Maya and Mixe-Zoque sites and are the earliest consistent architectural group format in the Maya Lowlands (Chase and Chase 1995, 2017:32; Hansen 1998:63–64; Inomata 2017; Inomata et al. 2013, 2020). While there is debate over the origins of E-Groups (see Clark and Hansen 2001; Hansen 2005:55; Inomata 2017), there is no doubt that this architectural format was developed and utilized in the Middle Preclassic period throughout the Maya Lowlands (Doyle 2012, 2013; Estrada-Belli 2017; Estrada-Belli et al. 2003a, 2003b; Hansen 1992, 1998, 2000; Morales-Aguilar 2021). E-Groups are common throughout the MCKB (e.g., Hansen 1998:69–70; and Figures 4 and 13), but vary in quantity and size. Analysis of LiDAR imagery has located at least 30 centers in the southern MCKB, which altogether have 42 E-Group complexes (Figure 13). A Tier 1 site such as Mirador has eight E-Groups, while Tier 2 sites like Balamnal have at least two E-groups, and “end of the road” tertiary sites such as Noholnal and Noholtun, located to the south and southwest of Balamnal, have two and one E-Group complexes, respectively. The size of the site, though, seems to be irrelevant, since E-Groups are found in all identified tiers of site size. Some Tier 6 sites like Oxkinah consist of little other than the structures of an E Group. While El Mirador has perhaps the largest western structure of any E-Group in the Basin, with the Leon structure at 33 m in height (Figure 13a), the elongated eastern structure at Wakna is probably the largest, at 210 m in length (Figure 13f). The E-Group complex in the East Group at Nakbe (Figure 13b) is among the earliest in the MCKB, with construction and occupation dating from 900–600 B.C. (Figure 14). Ceramics from excavations at El Pesquero, Balamnal, Wakná, Kunal, Xulnal, and El Mirador suggest that those E-Groups are contemporaneous.

Triadic architecture

The vast majority of the largest architecture throughout the MCKB is a triadic configuration, a “dominant structure flanked by two, inward-facing smaller mounds” (Figures 15a–15f; see Freidel 1979; Graham 1967:45–46; Hansen 1990:171ff., 1998:77–78, 2000, 2016a, 2016b, 2017). While no triadic structures are yet known from the Middle Preclassic period, the format appears suddenly and ubiquitously throughout the entirety of the MCKB by the early Late Preclassic period (ca. 350–300 B.C.). The triadic pattern is possibly related to an early cosmology of “three hearth stones of Maya creation” (Tedlock 1996:236, n72). The Late Preclassic Tigre pyramid in the West Group at El Mirador (Figure 16a) was estimated, based on replication experiments by the Mirador Basin Project and others, to have been constructed at a minimum of 2,803,595–5,000,000 person days of labor (Erasmus 1965; Hansen 1982, 1984, 1990:215; Hansen et al. 2018a; Sidrys 1978:159).

The pyramid of Danta (Figure 16b) located on the east side of the civic center of El Mirador consists of three continuous elevated platforms, with a major triadic group on the summit of the third platform and measures $600 \times 320 \times 72$ m in height, and a possible volume of $2,816,016 \text{ m}^3$ of fill, pending additional excavations in the primary platform of the structure (Hansen and Suyuc-Ley 2011; Hansen et al. 2018a:184; Suyuc-Ley and Hansen 2013). Based on our calculations, the building has a surface covering of 205,508 limestone blocks at an average size of $1.30 \times 0.45 \times 0.40$ m, requiring 158 workers continually for five years to quarry the stones, based on our detailed experiments in the field (Hansen et al. 2018a:182–186; Woods and Titmus 1994, 1996). Depending on the natural configurations of the bedrock below the structure, the entire building could have had as much as 6,000,000 to 10,000,000 person-days of labor, exceeding the capacity of polities of lower hierarchical political and economic status, and suggesting a high level of organization as the sociopolitical and economic patron of such prodigious growth (Hansen et al. 2018a:185). This is consistent with the patterns of Preclassic platforms and monumental constructions, as identified in other areas of the Maya Lowlands (Inomata et al. 2013, 2020, 2021). Inomata and colleagues (2013, 2020, 2021) have argued that such monumental constructions at Aguada Fenix and Carmelita in Tabasco, Mexico may have been constructed by societies with less complexity compared with the Olmec neighbors of San Lorenzo and La Venta. We suggest that such observations may be premature. There are reasons to suspect that the early sites of Tabasco may not be Maya, and they may be more aligned politically and economically with the Olmec (see also Rosenswig 2021b). Extensive experimental data conducted by the Mirador Basin Project suggests that the labor requirements for the construction of Preclassic Maya monumental architecture were also high, requiring a greater diversity and specialization, especially in constructions with quarried limestone blocks, lime cement, sascab quarries, mortar preparation, water collection and utilization, and quarried limestone fill (Hansen 2016b; Hansen et al. 2018a; Schreiner 2001, 2002, 2009, 2021; Woods and Titmus 1994, 1996).

Ballcourts

The sites in the MCKB have a combined total of at least 30 ballcourts that are scattered throughout the system (Figure 4), with 26 associated with Middle and Late Preclassic architecture. Several excavated examples, such as the one at Tintal, is one of the larger ballcourts in the MCKB, but the final version dates to the Late Classic period (Balcárcel et al. 2021). The ballcourts located in the MCKB show two parallel structures, often in a north–south axis, and are approximately 10–20 m long. The site of El Mirador has seven presumed ballcourts, consisting of four small ones and three possible larger courts in the Great Central Acropolis at the site. The presence of a royal throne, specialized ceremonial sunken plazas, elaborate cosmological iconography, reservoirs and hydraulic systems, and massive platforms and constructions suggests that the Great Central Acropolis may have been the seat of power of Preclassic rulers at the site (Hansen 2016b:397–400).

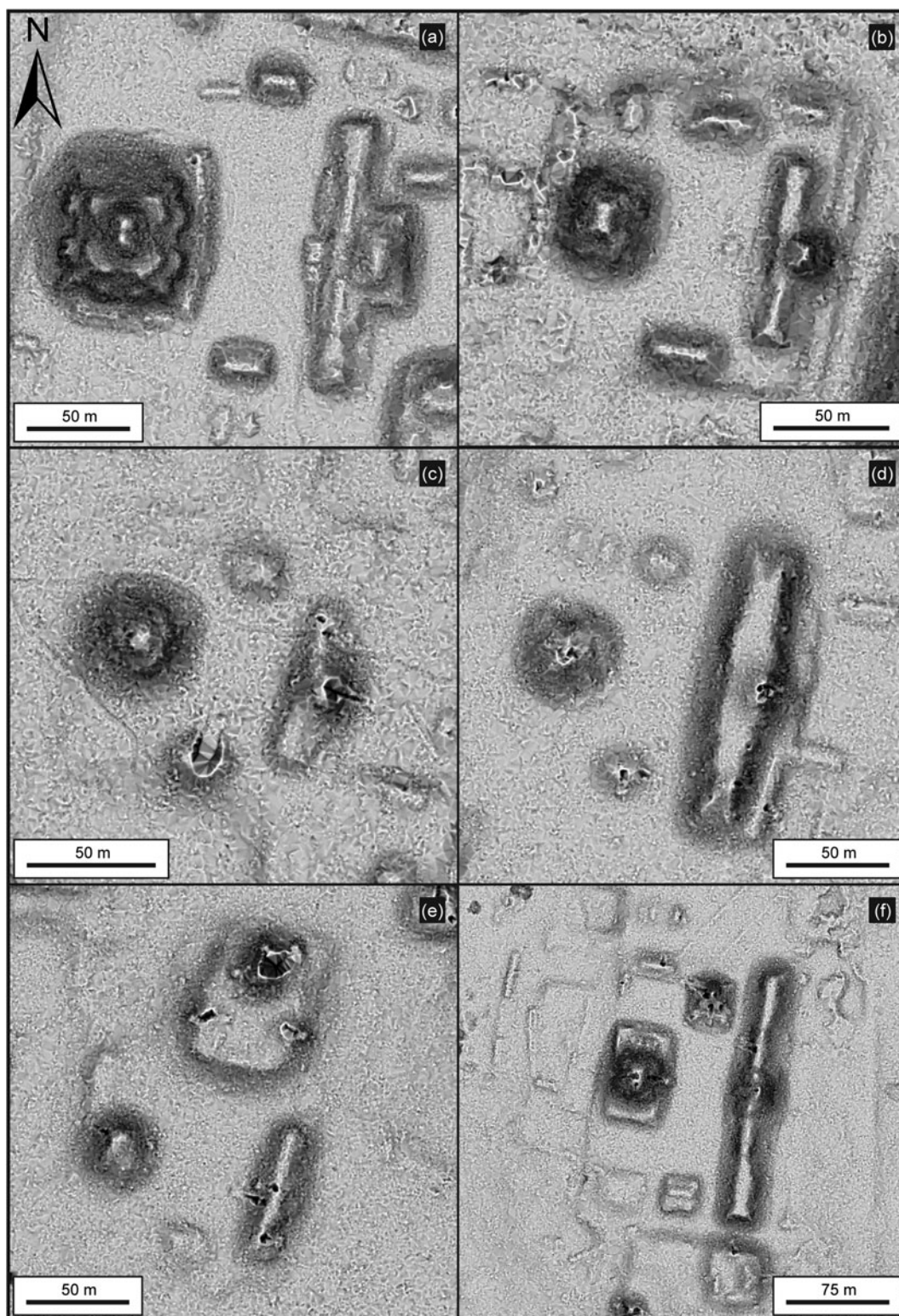


Figure 13. LiDAR images of selected E-Groups in the MCKB: (a) Leon Group, El Mirador; (b) Nakbe, Grupo Oriental; (c) Group A, Xulnal; (d) Group A, Balamnal; (e) Group A, El Pesquero; and (f) Zapote Group, Wakna.

Causeways

One of the crowning achievements of the Middle and Late Preclassic Maya was the construction of a dendritic system

of causeways throughout the entirety of the MCKB (Hansen et al. 2020; Hernández 2008; Hernández-Salazar 2021; Hernández and Schreiner 2006; Hernández et al. 2007, 2013, 2016, 2019; and Figures 17 and 18). While causeways were

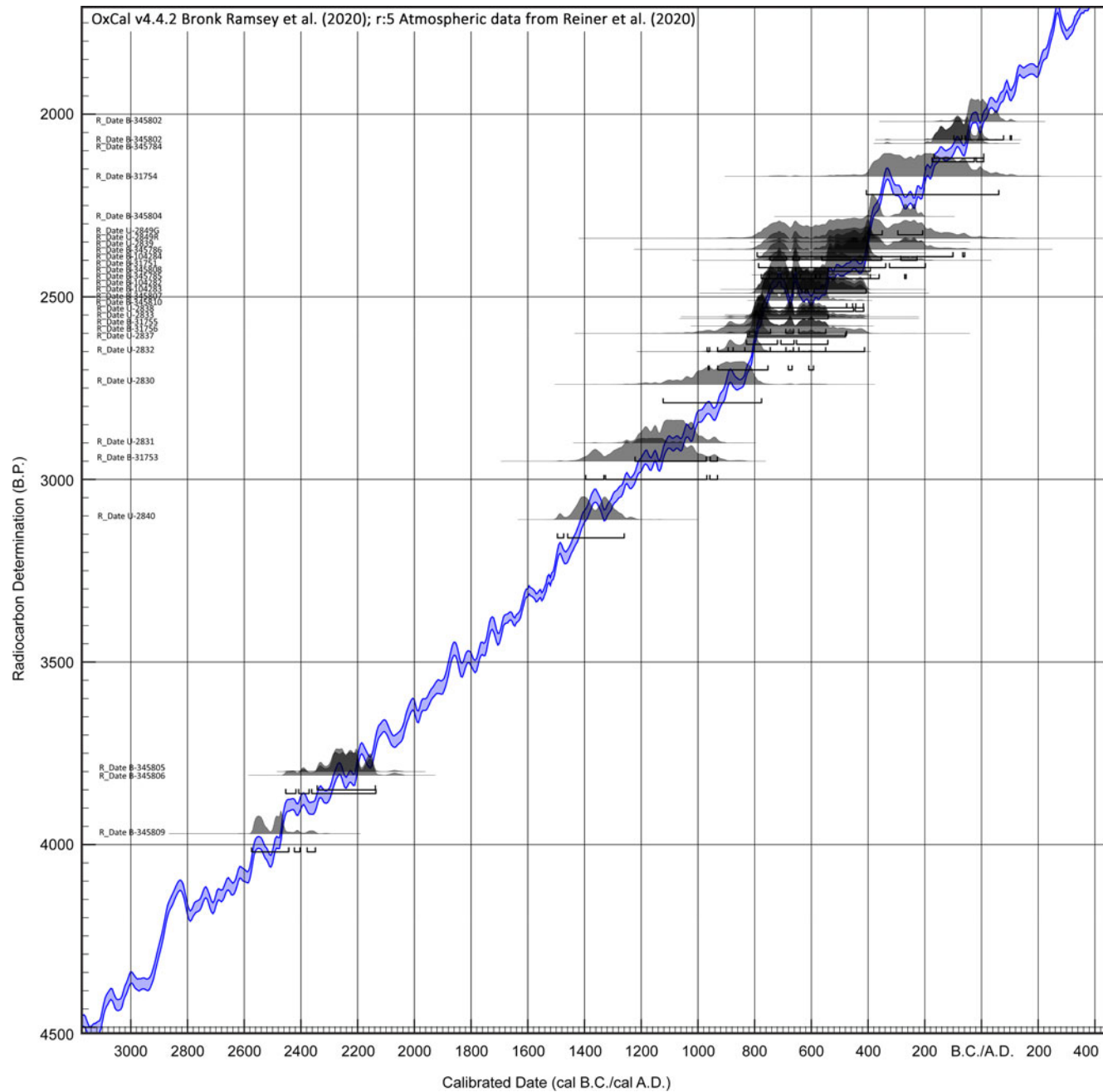


Figure 14. Graph of radiocarbon C-14 dates stratigraphically aligned in a Bayesian scale associated with Operation 51 C, a major excavation at the base of Structure 51, an E-Group in the East Group at Nakbe, with a heavy cluster of dates between ca. 1200 and 500 B.C. in a 2-sigma range. The earliest dates are from burned posts in postholes in the bedrock in front of the structure and are consistent with early dates from the cores extracted from lakes on the western edge of the MCKB (OxCal v. 4.4.2, Bronk Ramsey et al. 2020; atmospheric data: Reimer et al. 2020).

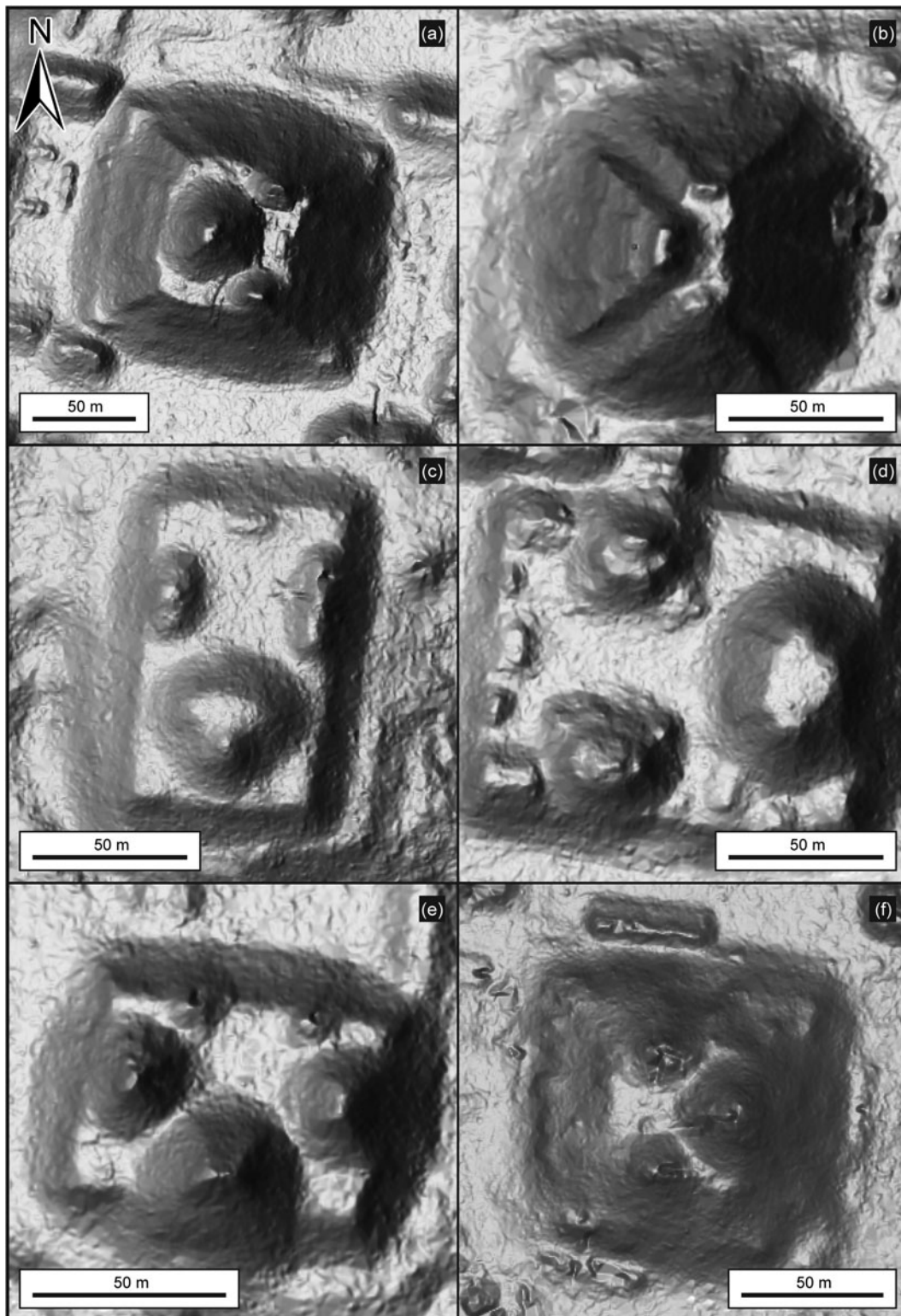


Figure 15. LiDAR images of selected triadic monumental structures in the MCKB: (a) Tigre Pyramid, El Mirador; (b) Structure I, Nakbe; (c) Xulnal, South Acropolis; (d) Grupo Chicharras, El Mirador; (e) Tres Micos, El Mirador; and (f) El Pavo, Tintal.

known to have existed throughout the Maya area (e.g., Benavides-Castillo 1981; Bennett 1930; Chase and Chase 2001; Cobos and Winemiller 2001; Folan 1991; Gómez 1996; Hutson and Welch 2021; Kurjack 1977; Maldonado-Cárdenas

1979; Shaw 2001, 2008; Villa 1934) and the MCKB (e.g., Graham 1967:41–47), the scope and scale of the features are now fully evident with the airborne LiDAR, supported by satellite imagery and GIS software.

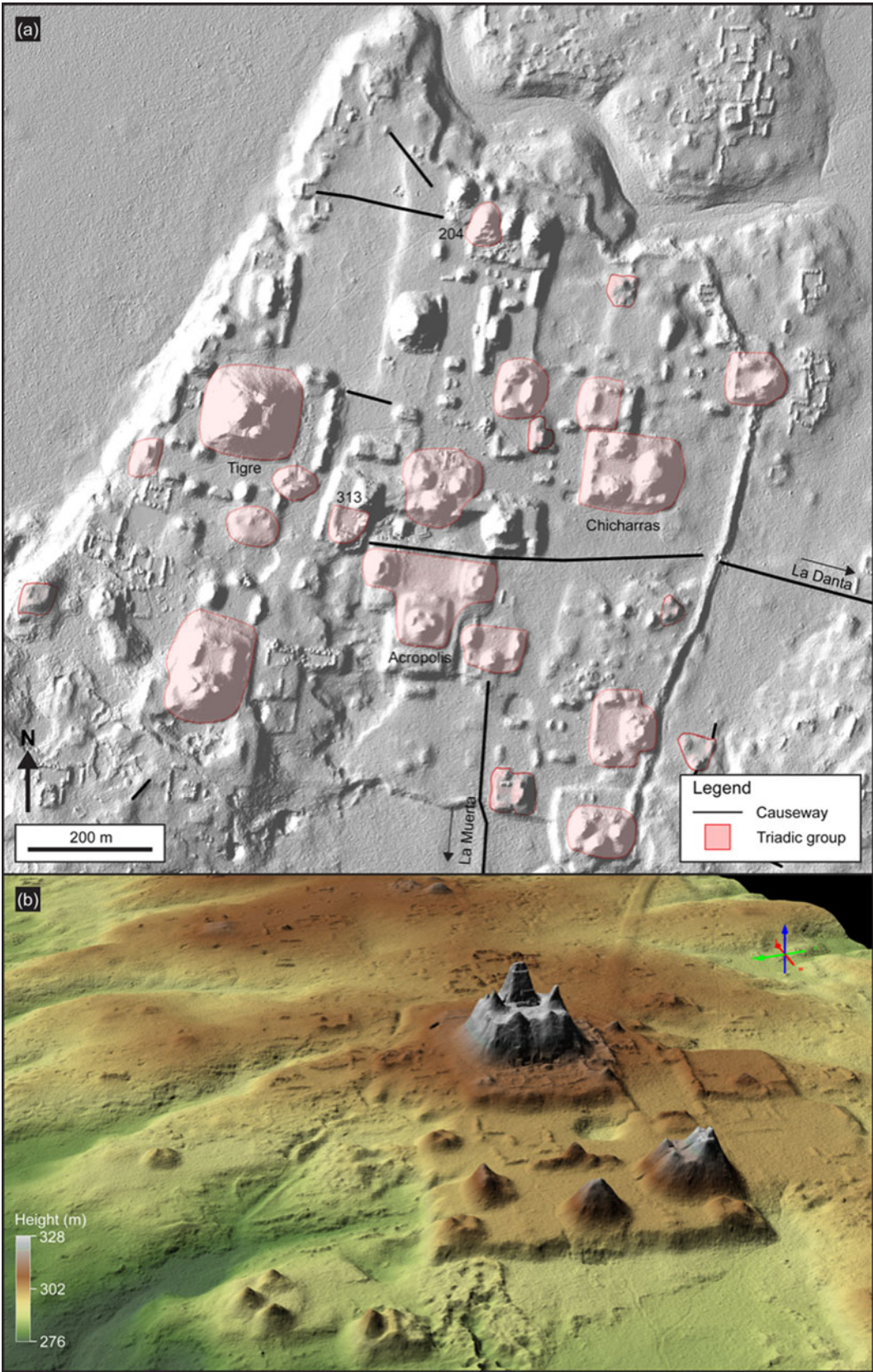


Figure 16. Triadic structures in El Mirador: (a) LiDAR image showing triadic structures in the civic center of El Mirador (Tigre pyramid is the largest in this section of the city); (b) LiDAR 3D view showing the pyramidal complex of La Danta, located on the east side of the civic center at El Mirador.

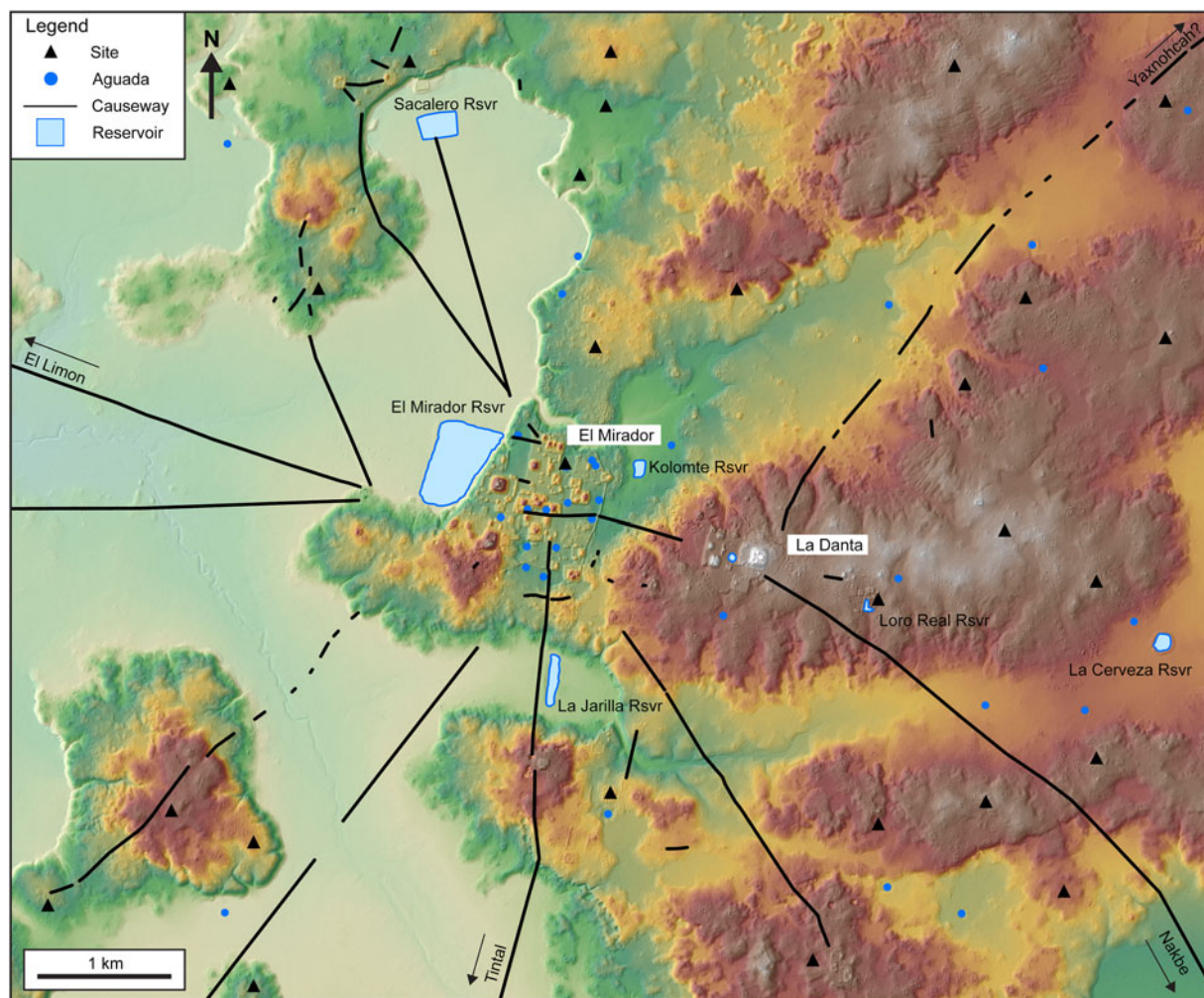


Figure 17. Digital elevation map of El Mirador with causeways and reservoirs. Major causeways from the civic center of El Mirador show the extent and nature of the vast intrasite and intersite networks. Primary causeways extend from Danta pyramid northeast into Campeche, Mexico (Yaxnohcab?), and southeast to Nakbe. Other intersite causeways extend from the Central Acropolis south to Tintal, and from the Las Cruces Group northwest to El Limón and Paxbán. Intrasite causeways connect the civic center to neighboring suburbs of Sacalero, Los Faisanes, Chacté, Los Pericos, La Muerta, Yaxché, Las Ardillas, and others. Background color represents terrain elevation with lowest elevations in light blue and gradually increasing to highest elevations in browns and white.

LiDAR mapping in the southern MCKB has revealed a network of at least 133.22 km of intersite and 38.23 km of intrasite Preclassic *noh be* (“big road”) or *chibal be* (“large lineage road”) causeways (Bolles and Folan 2001). An additional 3.89 km could be added if the site destination platforms are included. The mapped Preclassic intrasite causeways indicate intracommunity connectivity and integration. Preclassic causeways are easily distinguished from Classic period causeways by the width of the features and the lack of low stone walls or parapets along the edges. All Late Classic causeways are defined by the presence of low parapets on each side of the causeway. Only 12.13 km of Classic period causeways are found throughout the entirety of the Southern Basin, and none of them are intersite, indicating the vast differences in demographic density and administrative process between the two periods. The majority of Preclassic causeways have a locus at El Mirador, with 12 intrasite causeways and five major intersite

causeways. The intrasite causeways measure 9–40 m wide, while the intersite causeways range from 28 to 40 m wide. There are at least 11 suburban residential areas (dense groups in the peripheral regions), directly linked by intrasite causeways to the civic center of El Mirador (Hansen et al. 2020; Hernández-Salazar 2021:23; Morales-Aguilar et al. 2015; and Figure 17). Large intersite causeways include the Paixban causeway, which extends to the northwest of Mirador to the sites of El Limón and Paixban. This causeway is 30–40 m wide and 2–4 m high, and extends 21 km before reaching the limits of our LiDAR survey. Another previously undetected causeway (Campeche causeway) extends from Danta pyramid to the northeast for more than 12 km, and crosses into the state of Campeche, Mexico. This feature is 30–40 m wide and 2–4 m high, and extends 7.4 km to a semi-rectangular aperture in the terrain of the natural topography before continuing on another 2.3 km to the northeast Mexican border. There is a likely possibility that this



Figure 18. Photographs of several MCKB intersite causeways: (a) edge of the Mirador–Nakbe causeway; (b) the Mirador–Tintal causeway, showing the relative heights normal for the elevated intersite causeways; (c) the Jade causeway in Tintal is 40 m wide, typical of the Preclassic causeways in the MCKB.

causeway extends towards Yaxnohcah or Chicanticanal in Campeche, and not Calakmul, as purported earlier (Folan et al. 2001:296–297). At present, there is no indication on LiDAR data of a causeway between El Mirador and Calakmul, which is logical considering the differences in contemporaneity of the sites, even though Calakmul does have some Preclassic occupation and at least one monumental substructure.

An important causeway (Mirador–Nakbe causeway) extends from the southeast corner of the second platform of Danta pyramid, 13 km to the site of Nakbe. This causeway varies between 0.5 m and 5 m in height (Figure 18a) and is

35–40 m in width. Another, the Tintal–Mirador causeway, extends to the southwest of El Mirador and is 40 m wide, 1.0–4.5 m in height, and 24 km long to Tintal (Figures 18b and 18c). It unites the Central Acropolis at Mirador with the Henequen and Mano de Leon Groups at Tintal. Furthermore, it has a mid-course directional change to the west from the original line of sight on the large pyramid at the site of La Ceibita, suggesting that the construction origin of the causeway was from El Mirador. Excavations on this causeway revealed a series of C-14 dates (Table 5), ceramics, and a consistent sequence that places the initial construction possibly as early as the late Middle Preclassic

Table 5. C-14 dates from the Tintal–Mirador Causeway (Hernández 2021:152–154). Radiocarbon years were calibrated to calendar years using Calib 7.0 (Stuiver and Reimer 1993) and the IntCal13 dataset (Reimer et al. 2013).

Sample name	Lab no.	Material	d ¹³ C	Radiocarbon age (C-14 yr. B.P.)	Age range 2s (cal A.D./B.C.)	Median age (cal A.D./B.C.)
Sacb.500C.06.11	Beta-345793	Wood charcoal	–24.6‰	2010 ± 30	90 cal B.C. to cal A.D. 65	10 cal B.C.
Sacb.500A.08.17	Beta-345790	Wood charcoal	–24.6‰	2030 ± 30	155 cal B.C. to cal A.D. 50	30 cal B.C.
Sacb.500A.07.14	Beta-345789	Wood charcoal	–24.5‰	2200 ± 30	365 to 185 cal B.C.	285 cal B.C.
Sacb.500B.04.05	Beta-345791	Wood charcoal	–23.3‰	2450 ± 30	755 to 410 cal B.C.	580 cal B.C.

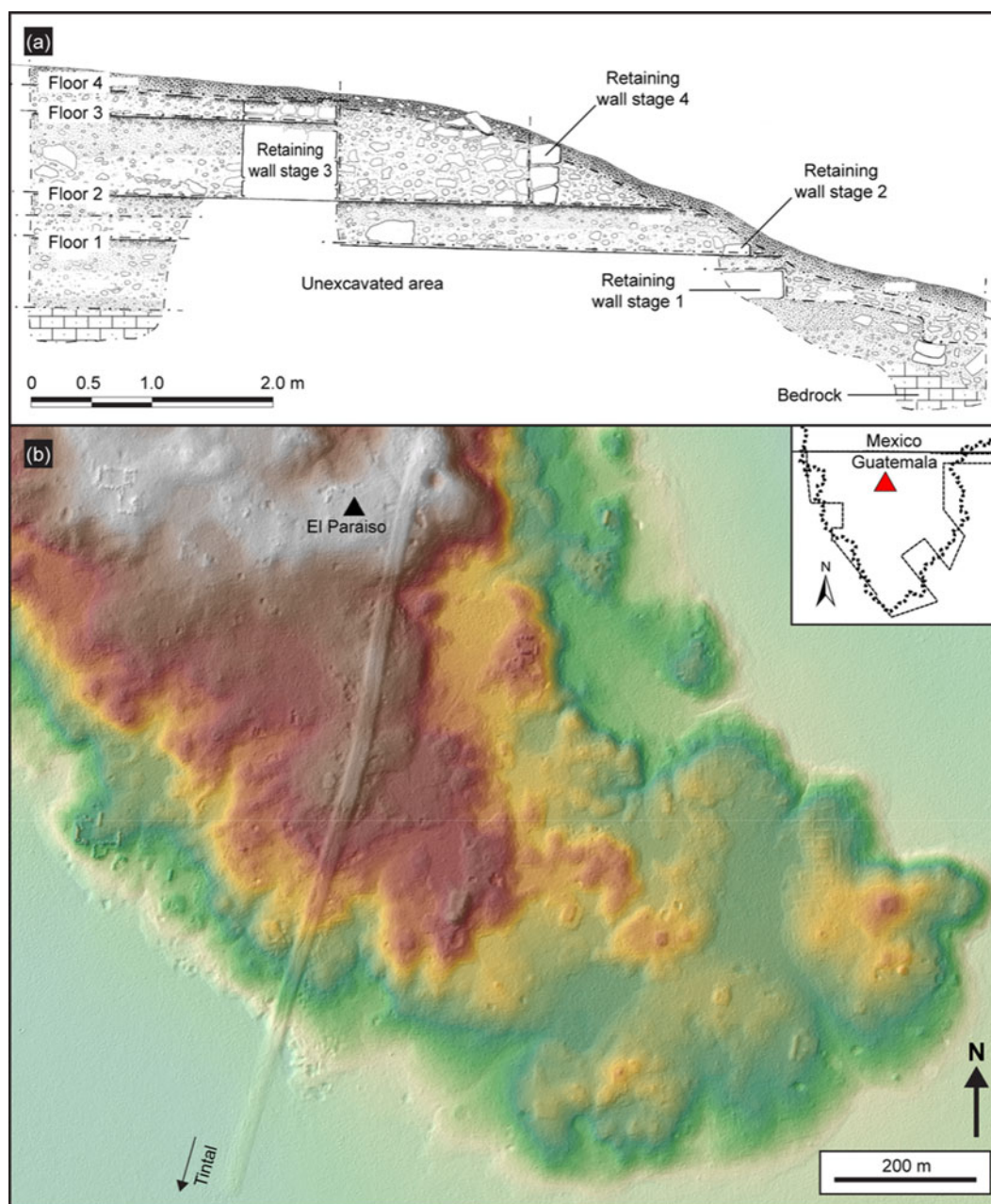


Figure 19. Detailed LIDAR image of the Mirador–Tintal causeway: (a) profile of Op. 500-A, excavation of the Mirador–Tintal causeway, showing the stratigraphic sequences of the construction phases with four floors (after Hernández-Salazar 2021:129; Hernández et al. 2013:950); (b) LiDAR image of Gavilan “El Paraiso” Island in the Bajo Carrizal, located south of El Mirador, showing the large Preclassic causeway. Background color represents terrain elevation with lowest elevations in light blue and gradually increasing to highest elevations in browns and white.

period, but certainly by the beginning of the Late Preclassic period (Figure 19; Hernández-Salazar 2021:152–154, 60 ff.; Hernández et al. 2016; Schreiner and Hernández 2009; Schreiner et al. 2015).

Calculations of the volume of the Tintal–Mirador causeway, based on excavations, determined that the Preclassic Maya used as much as 10,000 m³/km of lime plaster and lime reinforced fill for elevated sections of the causeway. Schreiner and Hernández also determined that up to 40,000 m³/km of *tzaal* stone (a soft, porous limestone of

nearly pure calcium carbonate, with 2 percent montmorillonite clay) was used on the combined volume of the four sequential renovations of the causeway (Hansen 2012b:263–264; Hansen et al. 2018a; Schreiner 2001, 2002, 2021; Schreiner and Hernández 2008, 2009; Schreiner et al. 2015). Such consumption required the burning of great amounts of limestone and wood, with large labor requirements to make the quicklime for the lime plaster of the surfaces and substrate materials (Hansen 2012b; Hansen et al. 2018a, 2020; Hernández et al. 2013, 2016; Schreiner

2001, 2002, 2021). On wetland stretches, the causeway lime use was closer to 5000 m³/km, with the technical innovation of lime and clay mixtures that controlled moisture-induced heaving of available expansive clay base substrates (Schreiner 2021).

The Tintal–Mirador causeway diverged at the site of Tintal to form another important causeway (Tintal–Ceibita causeway), 25–30 m wide, which extended 5 km to the southeast from the site, connecting directly to the monumental pyramid at the site of La Ceibita (Hernández-Salazar 2021:72). The primary causeway (Tintal–Balamnal causeway) continued from Tintal in a southerly direction for approximately 3 km before curving to the southeast and running parallel with the natural karst border of the MCKB for 17 km, to the site of Balamnal (Figure 20). It is clear from the size, distribution, and quantity of major structures that Balamnal was one of the most important centers in the MCKB, with dominant E-Groups in the center of the site, and a series of elevated intrasite and intersite causeways, 15–20 meters wide, that extended to lower tiered sites in a dendritic format (Hansen et al. 2020; see Chase and Chase 2001:276–280 for a similar Classic period system at Caracol). The primary causeway (Tintal–Balamnal causeway) comes from Tintal to the northwest. Another elevated causeway, the Noholtun causeway, extends 5 km to the

southwest to the site of Noholtun. The Noholnal causeway extends 5.5 km from Balamnal to the south to the site of Noholnal. The Pesquero causeway extends 7.5 km to the east and southeast to the site of El Pesquero, and yet another, the Union causeway, extends 9.5 km to the northeast to the site of La Unión. The smaller outlier sites may have served as frontier stations for the MCKB, and no causeways have yet been observed that extend beyond the Mirador Anticline on the north, east or southeast or the low, residual karst hills on the west that form the natural borders of the basin.

Excavations at both Balamnal and El Pesquero have located up to seven sequential floors in the plazas of the E-Group complexes, with the lower levels dating to the Middle Preclassic period (Mejía 2008, 2012; Mejía et al. 2007, 2010). The unification of these sites, directly and indirectly, with the Tier 1 site of El Mirador via the causeway network suggests an administrative centralization and an autochthonous development of economic and political power indicative of a complex authority at kingdom (and state) level.

Water management: Reservoirs

The LiDAR survey in the MCKB system has provided new insights into the control of water. The MCKB has no

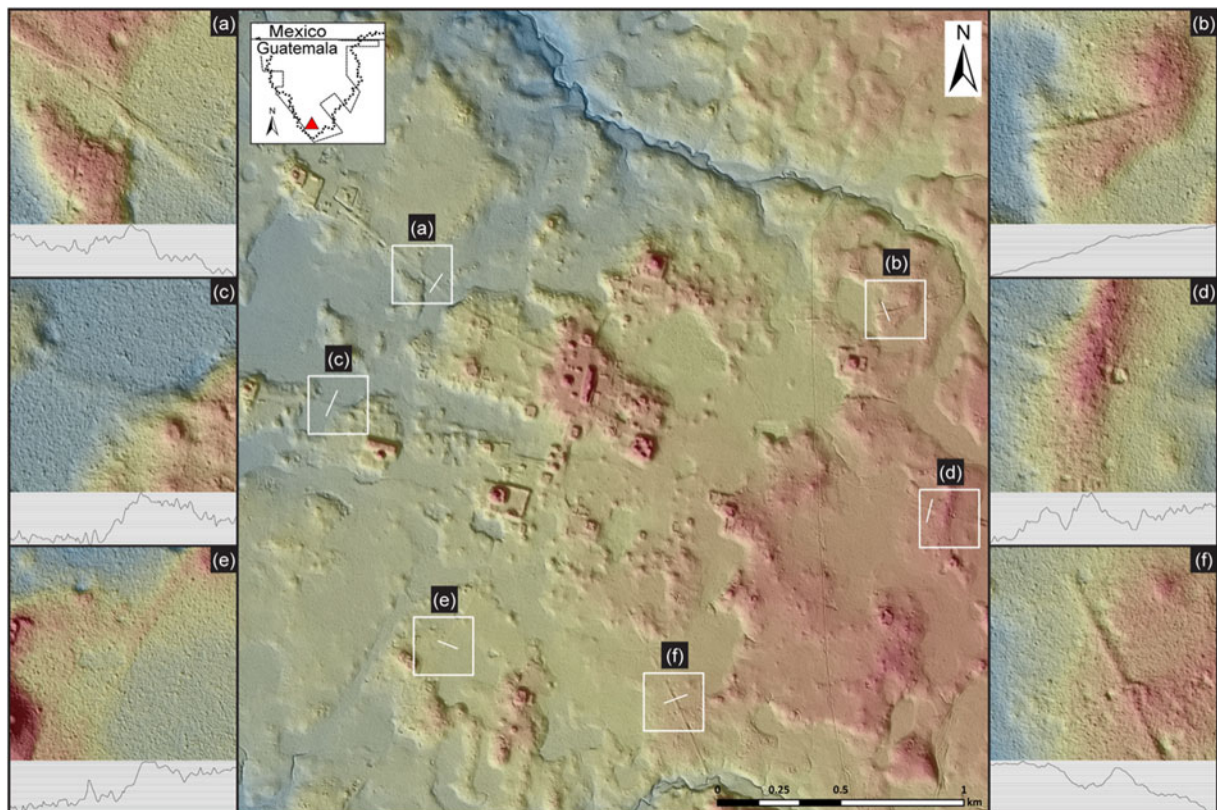


Figure 20. LiDAR images of the newly discovered site of Balamnal. Background color for the map and the six insets represents terrain elevation with lowest elevations in blue and gradually increasing to highest elevations in reddish brown. Six causeways extend outwards from the site center: (a) a primary intersite causeway from Tintal; (b) intersite causeway to the site of La Unión; (c) an intrasite causeway connects a palace compound with the site center; (d) causeway to the site of El Pesquero; (e) intersite causeway to the peripheral site of Noholtún; (f) intersite causeway to the site of Noholnal.

perennial rivers or lakes, aside from mature marshes on a small scale (*civales*), requiring the ancient Maya to construct large reservoir systems for water collection and rainwater management (see Chase and Cesaretti 2018 for similar observations in Caracol and Tikal, as well as Nakum; Żrałka and Koszkul 2015). LiDAR data located 195 artificial water reservoirs (termed *aguadas* by locals, although naturally occurring *aguadas* are rarely found in the basin) and a series of monumental reservoir systems designed for large water capture and control in the southern half of the MCKB. Other scholars have contributed to understanding water management strategies within the MCKB (Brewer 2017; Brewer et al. 2017; Parry 2007; Seefeld 2013, 2017) and such studies can be substantially refined with LiDAR. Strategies at El Mirador between 300 and 100 B.C. included the conversion of sunken ceremonial plazas into water collection reservoirs, such as those in the Great Central Acropolis at El Mirador and the construction of lime cement pools for water capture (Argyle 2008, 2009, 2010; Argyle and Hansen 2010, 2015, 2016:135–140). Subsistence strategies included the construction of a variety of reservoirs and the construction of dams and canals by the Middle and Late Preclassic periods (Hansen et al. 2002; Hernández et al. 2013, 2019:462–463; Morales-Aguilar et al. 2015; Schreiner et al. 2015), all of which exceeded the capacities of lower administrative levels. The Preclassic reservoir system at the base of the escarpment in the West Group at El Mirador held an estimated 336,653 m³ of water in a defined area of 224,435.41 m². Four other major reservoirs at the site (excluding *aguadas*) had a combined estimated capacity (via Hydrology Toolset) of an additional 374,490.53 m³ (Table 6). The volume of reservoirs was calculated with ArcGIS Pro Hydro tool. Storage Capacity, Fill, and Pixel Editor tools were performed using LiDAR DEM with an arbitrary depth of 1 m (based on prior excavations) to obtain the volumetrics of the reservoirs.

The primary dam for the Bajo La Jarrilla was constructed across a narrow stretch of *bajo* between the civic center of El Mirador and the suburb of La Muerta, measuring more than 400 m long, 3 m high, and 50 m wide in its current state, forming a reservoir containing at least 166,468 m³ of water (Figure 21). The Mirador–La Muerta causeway was directly

attached to the dam along its western edge. Excavations of the dam recovered 184 ceramic sherds, 97 percent dating to the Middle Preclassic (ca. 600–400 B.C.) period (Hernández et al. 2019:462). A calibrated carbon sample (wood charcoal) from the lower levels of the causeway associated with the dam provided a possible 2σ date of 2450 ± 30 B.P. (δ¹³C = −23.3‰; 775–410 cal B.C.) with a median age of 580 cal B.C. (Beta 345791). Similar monumental water collection systems were located at the southern border of the Palma causeway at Nakbe, where a rectangular walled enclosure allowed capture and access of water.

Final observations

The formation of a unified “kingdom” in the MCKB may have emerged as smaller entities were absorbed into a larger hegemony, an alternative model to that proposed by Clark for the Middle Preclassic kingdoms of the Western Maya Highlands (Clark 2016). According to Clark, the “critical competition facing Middle Preclassic rulers was ... nurtured ... within the boundaries of their own domains” (Clark 2016:223, editing Hansen). In the case of El Mirador, extraordinary economic, political, and social power was wielded at least by the Middle Preclassic period to form the networking of contemporaneous sites, welded together by an extraordinary web of large, dendritic causeway systems, a unified and homogeneous religious and political ideology, as portrayed first in E-Group compounds dating to the Middle Preclassic period, and modified by about 350–300 B.C. to include the large repertoire of triadic architectural complexes throughout the MCKB. We concur with Chase et al. (2009:181) that Mesoamerican polities seem to have been defined by relationships with the ruler, but in the MCKB the region seems to have included a territorial framework, since none of the large causeway systems extend beyond the natural borders of the Basin. The expansion and control of labor for such massive, contemporaneous monumental architectural groups suggests a unified power that could draw on labor and resources from throughout the entirety of the MCKB. Furthermore, the monumentality evident in the architecture of the MCKB is also found in contemporary cultures or antecedent societies in the Western Maya Lowlands or Gulf Coast areas (Inomata et al. 2021; see also Rosenswig 2021b).

Contiguous, regional LiDAR studies of this southern half of the MCKB area have presently revealed 964 archaeological sites. Many of these settlements demonstrate a political/social/geographical relationship with other nearby settlements, which has resulted in the consolidation into at least 417 ancient cities, towns, and villages with identifiable site boundaries. A settlement and administrative hierarchy of at least six tiers is proposed for sites, based on surface area of the sites, numbers and densities of monumental architecture, and volumetric calculations of architecture extracted from geometric calculations and LiDAR data. The approximate volumetric assessments of construction fill within the civic center of a 1 km² area with contemporary monumental architecture allows similar methodology to be applied in other areas of the Maya Lowlands, as a

Table 6. Formal reservoir areas and capacities at El Mirador, Nakbe, and Tintal.

Reservoir name	Area (m ²)	Capacity (m ³)
El Mirador	224,235	336,653
Sacalero	48,927	97,204
La Cerveza	11,520	23,736
Kolomte	9,361	20,035
La Jarrilla	24,249	63,990
Isla Ramón	60,523	90,784
Nakbe	76,718	115,077
Tintal	91,599	137,398

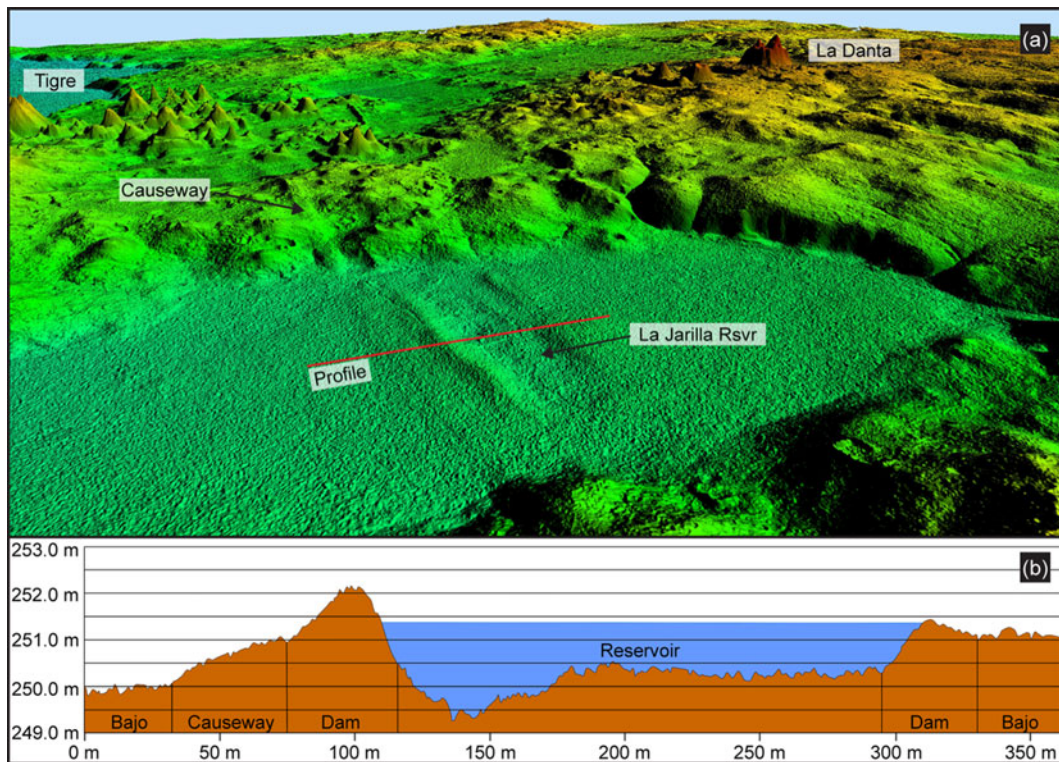


Figure 21. Illustrations of the La Jarilla reservoir: (a) LiDAR 3D view of the Mirador–Tintal causeway and dams in the Bajo La Jarilla between the suburb of La Muerta and the civic center of El Mirador; (b) west–east profile of the La Jarilla reservoir, showing the dikes on both sides and the causeway. The reservoir, possibly constructed by 580 B.C. according to exclusive Middle Preclassic ceramics, and a single C-14 date may have been among the earliest such features in the MCKB.

means of determining the sociopolitical and economic prowess of sites. Large-scale monumental architecture, consistent architectural formats, specific site boundaries, water management and collection facilities, and more than 177 km of elevated Preclassic causeways suggest a social and economic cohesion that exceed those of lesser polities during these periods and portray the strategies of governance in incipient kingdom-/state-like formation in the Middle and Late Preclassic periods of the MCKB.

The complex societies that emerged in the MCKB organized infrastructure to promote and reflect socio-economic organization and political power during the Preclassic period of Maya history. The peculiarity of dense demographic regions in the wetland *bajos* bolsters the hypothesis that an incipient state-level kingdom had been formed by these periods in an area that today would have been considered inhospitable for demographic and architectural expansion. This was a sequentially defined process that evolved to a tiered hierarchy of sites within a specific territorial area, possibly as an autochthonous process, but that may have been inspired by competitive ideologies, peer polity interactions, or other influences by other Highland or Lowland societies. The adoption and adaptation of “important ingredients to contemporaneous Mesoamerican social and political identities” provided the cultural foundations for later Maya and Mesoamerican states (Hansen 2016b:330). The contemporary and consistent architecture connected by the dendritic network of causeways within a geographically

defined, congruent, natural, socio-economic, and political region is suggestive of a centralized political, economic, and/or ideological authority, which we believe to have emerged at El Mirador by the Middle Preclassic period and expanded by the beginning of the Late Preclassic period. Later patterns of dendritic networks of causeways elsewhere in Mesoamerica, such as Chichen Itza, Caracol, and the Basin of Mexico, suggest that the political and economic integration may have had antecedents such as those found in the MCKB. Major new cities have been found by this research, such as the great site of Balamnal, with archaeological excavations placed in the site (also known as “El Cedro”) by the Mirador Basin Project in 2008 and 2009 (Mejía et al. 2010), which was part of the unified settlements and causeways in the basin. New site boundaries and architectural group integrations (as noted by intrasite causeways) were identified, amplified, or modified due to LiDAR analyses as well.

LiDAR analyses have demonstrated the presence of dense concentrations of new and previously unknown contemporaneous sites, massive platform and pyramid constructions, including triadic groups, numerous E-Group complexes, causeway networks, ballcourts, and reservoirs that required vast amounts of labor and resources, amassed by a presumably centralized organization and administration. The skeleton of the ancient political and economic structure as a kingdom-state in the Middle and Late Preclassic periods has a tantalizing presence in the Mirador-Calakmul Karst Basin.

Acknowledgments. Appreciation is extended to the Ministerio de Cultura y Deportes of Guatemala (MICUDE, Contract DAJ 270-2018), the Dirección General del Patrimonio Cultural y Natural, and the Instituto de Antropología e Historia de Guatemala (IDAEH) for the authorizations and permits to carry out this research. Fieldwork in the southern Mirador-Calakmul Karst Basin was accomplished as part of the ongoing Mirador Basin Project, directed by Richard D. Hansen under the auspices of the Department of Anthropology of the University of Utah and the Department of Anthropology at Idaho State University, with financial assistance from many other private and public donors. We are thankful to the Dirección General de Aeronáutica Civil de Guatemala (Contracts DGAC/FA 1-2009, 016-2014) for the necessary flight permits and authorizations. ALOS Global Digital Surface Model (AW3D) digital elevation data, used for interpretation of the terrain and large-scale geological features, were provided by the Japan Aerospace Exploration Agency. Sentinel-2 multi-spectral data, including near-infrared bands, used for interpretation of hydrological features, were provided by the European Space Agency and the National Centre for Space Studies (CNES). LiDAR data were provided by FARES, the Mirador Conservation Fund, the National Geographic Society, and Eagle Mapping. We extend our appreciation to Jody Hansen, Dr. Robert Rosenswig and five anonymous reviewers for their comments and suggestions for improving this article. We extend our appreciation to the thousands of workers from the communities who have participated in the collection of much of these data and who have fostered a keen interest in the conservation of their unique cultural heritage. We appreciate and give thanks to the entire staff and personnel of the Mirador Basin Project, without whom none of this would have been possible.

Supplementary Material. To view supplementary material for this article, please visit <https://doi.org/10.1017/S0956536122000244>

Competing Interests. All authors have contributed to this article, and there are no competing or conflicts of interest among the authors.

Funding Statement. Funding for the research noted in this article was provided by the FARES Foundation, FARES-Guatemala, Pettit Foundation, Mirador Conservation Fund, Global Conservation, Mammel Foundation, Global Heritage Fund, Rosalinde and Arthur Gilbert Foundation, NAISA, Wolf Creek Foundation, Morgan Family Foundation, Moon Family Foundation, Jay I. Kislak Foundation, Peace, Love and Happiness Foundation, Selz Foundation, APANAC-Guatemala, Fundaserva Guatemala, National Geographic Society (Grant # SP 08-15 and SP-Garcia 18), U.S. Department of the Interior International Affairs Program, Victoria Earl-Mion Trust, Harry and Roberto Salter Foundation, Robert Berry, John Paul DeJoria, Dr. Nancy Furlotti, Adam and Chontal Green, John and Pat Hansen, Linda Pierce, Jeff Morgan, Joanna Miller, Darin Moon, Pitch and Cathy Johnson, Spencer Kirk, Francois and Nini Berger and family, Francois DuBois and family, Jose Maria Kong, Barby Pickett, and Peter Smith.

References

- Adams, Richard E.W.
1990 Archaeological Research at the Lowland Maya City of Rio Azul. *Latin American Antiquity* 1:23–41.
1999 *Rio Azul: An Ancient Maya City*. University of Oklahoma Press, Norman.
- Adams, Richard E.W., and Jane Jackson Adams
2003 Volumetric and Stylistic Reassessment of Classic Maya Sites in the Peten, Rio Bec, Chenes, and Puuc Hills. *Ancient Mesoamerica* 14:139–150.
- Adams, Richard E.W., and Richard C. Jones
1981 Spatial Patterns and Regional Growth among Classic Maya Cities. *American Antiquity* 46:301–22. <https://doi.org/10.2307/280210>.
- Argyle, J. Craig
2008 Investigación de los sistemas de recolección de agua en El Mirador, Operación 610 A-L. In *Informe final de investigaciones 2007: Investigación y conservación en los sitios arqueológicos de la zona cultural y natural Mirador*, edited by Nora Lopez, Richard D. Hansen, and Edgar Suyuc-Ley, pp. 487–497. Report filed with the Departamento de Monumentos Prehispánicos y Coloniales, Instituto de Antropología e Historia, Ministerio de Cultura y Deportes, Guatemala City.
- 2009 Manejo de agua en el período preclásico en El Mirador, Petén, Guatemala: Operación 610 O, 2008. In *Investigaciones multidisciplinarias en El Mirador: Informe final de la temporada 2008*, Vols. 1 & II, edited by Héctor Mejía, Richard D. Hansen, and Edgar Suyuc-Ley, pp. 586–612. Report filed with the Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Departamento de Monumentos Prehispánicos y Coloniales, Guatemala City.
- 2010 Los paneles y rasgos asociados al manejo de agua en la Gran Acrópolis de El Mirador: Operación 610-O. In *Exploraciones arqueológicas en la Cuenca Mirador, 2009*, edited by Héctor E. Mejía, Richard D. Hansen, and Edgar Suyuc-Ley, pp. 539–556. Report filed with the Instituto de Antropología e Historia, Guatemala, Departamento de Monumentos Prehispánicos y Coloniales, Guatemala City.
- Argyle, J. Craig, and Richard D. Hansen
2010 La cosmovisión de estuco: Los paneles estucados del sistema hidráulico del Mirador. In *La cosmovisión a través del tiempo: Tres mil años de historia maya*. III Convención Mundial de Arqueología Maya, 2010. Casa Convento Concepción, Antigua Guatemala, June 18–20, 2010.
- 2015 Excavaciones de la Plaza Hundida Oeste, Gran Acrópolis Central, El Mirador: Operaciones 610 KK, 610 LL, 610 MM, 610 NN, 610 OO. Temporada de Campo 2014. In *Investigaciones en la Cuenca Mirador, Temporada 2014*, edited by Richard D. Hansen and Edgar Suyuc-Ley, pp. 154–171. Report presented to the Instituto de Antropología e Historia, Ministerio de Cultura y Deportes, Guatemala City.
- 2016 El friso preclásico de la Gran Acrópolis Central en El Mirador: Distribución de recursos y mitos relatados en estuco / The Preclassic Frieze of the Great Central Acropolis at El Mirador: Resource Allocation and Myth Recounted in Stucco. In *Mirador: Research and Conservation in the Ancient Kaan Kingdom*, edited by Richard D. Hansen and Edgar Suyuc-Ley, pp. 131–152. Foundation for Anthropological Research and Environmental Studies (FARES), Corporación Litográfica, Guatemala City.
- Aveni, Anthony F., and Horst Hartung
1989 Uaxactun, Guatemala, Group E and Similar Assemblages: An Archaeoastronomical Reconsideration. In *World Archaeoastronomy*, edited by Anthony F. Aveni, pp. 441–461. Cambridge University Press, Cambridge.
- Balcárcel, Ana Beatriz, Richard D. Hansen, Carlos Morales-Aguilar, and Juan Luis Velásquez
2021 Games or Prehispanic Rituals? The Ball Courts of the Mirador Basin. Paper presented at the 86th Annual Meeting of the Society for American Archaeology, San Francisco.
- Bauer-Gottwein, Peter, Bibi R.N. Gondwe, Guillaume Charvet, Luis E. Marin, Mario Rebolledo Vieyra, and Gonzalo Merediz-Alonso
2011 Review: The Yucatán Peninsula Karst Aquifer, Mexico. *Hydrogeology Journal* 19:507–524. <https://doi.org/10.1007/s10040-010-0699-5>.
- Beach, Timothy, Sheryl Luzzadder-Beach, Samantha Krause, Tom Guderjan, Fred Valdez, Juan Carlos Fernandez-Diaz, Sara Eshleman, and Colin Doyle
2019 Ancient Maya Wetland Fields Revealed under Tropical Forest Canopy from Laser Scanning and Multiproxy Evidence. *PNAS* 116:21469–21477. <https://doi.org/10.1073/pnas.1910553116>.
- Benavides-Castillo, Antonio
1981 *Los caminos de Cobá y sus implicaciones sociales*. Instituto Nacional de Antropología e Historia, Centro Regional del Sureste, Colección Científica, Mexico City.
- Bennett, Robert R.
1930 *The Ancient Maya Causeway in Yucatan*. Indian Notes VII(3). Museum of the American Indian, Heye Foundation, New York.
- Blom, Franz
1924 Report on the Preliminary Work at Uaxactun, Guatemala. *Carnegie Institution of Washington Year Book* 23:217–219.

- Bolles, David, and William J. Folan
2001 An Analysis of Roads Listed in Colonial Dictionaries and their Relevance to Pre-Hispanic Linear Features in the Yucatan Peninsula. *Ancient Mesoamerica* 12:299–314.
- Brewer, Jeffrey L.
2017 *A Landscape Archaeology Approach to Understanding Household Water Management Practices of the Ancient Lowland Maya*. Ph.D. dissertation, Department of Geography, College of Arts and Sciences, University of Cincinnati.
- Brewer, Jeffrey L., Christopher Carr, Nicholas P. Dunning, Debra S. Walker, Armando Anaya Hernandez, Meaghan Peuramaki-Brown, and Kathryn Reese-Taylor
2017 Employing Airborne LiDAR and Archaeological Testing to Determine the Role of Small Depressions in Water Management at the Ancient Maya Site of Yaxnohcah, Campeche, Mexico. *Journal of Archaeological Science: Reports* 13:2291–2302.
- Bronk Ramsey, Christopher, Timothy Heaton, M. Blaauw Blackwell, Paula J. Reimer, Ron W. Reimer, and Marion Scott
2020 Statistical Approaches and Tools for IntCal20. *EGU General Assembly*: EGU2020–9336. <https://doi.org/10.5194/egusphere-egu2020-9336>.
- Bundzel, Marek, Miroslav Jašćur, Milan Kováč, Tibor Lieskovský, Peter Sinčák, and Tomáš Tkáčik
2020 Semantic Segmentation of Airborne LiDAR Data in Maya Archaeology. *Remote Sensing* 12(22):3685. <https://doi.org/10.3390/rs12223685>.
- Canuto, Marcello A., and Luke Auld-Thomas
2021 Taking the High Ground: A Model for Lowland Maya Settlement Patterns. *Journal of Anthropological Archaeology* 64:101349. <https://doi.org/10.1016/j.jaa.2021.101349>.
- Canuto, Marcello, Francisco Estrada-Belli, Thomas G. Garrison, Stephen D. Houston, Mary Jane Acuña, Milan Kováč, Damien Marken, Philippe Nondédéo, Luke Auld-Thomas, Cyril Castanet, David Chatelain, Carlos R. Chiriboga, Tomáš Drápela, Tibor Lieskovský, Alexandre Tokovinine, Antolín Velasquez, Juan C. Fernández-Díaz, Ramesh Shrestha
2018 Ancient Lowland Maya Complexity as Revealed by Airborne LiDAR Scanning of Northern Guatemala. *Science* 361(6409). <https://doi.org/10.1126/science.aau0137>.
- Chase, Adrian S.Z., and Rudolf Cesaretti
2018 Diversity in Ancient Maya Water Management Strategies and Landscapes at Caracol, Belize, and Tikal, Guatemala. *WIREs Water* 6(2):e1332, 1–13. <https://doi.org/10.1002/wat2.1332>.
- Chase, Adrian S.Z., Diane Z. Chase, and Arlen F. Chase
2017 LiDAR for Archaeological Research and the Study of Historical Landscapes. In *Sensing the Past: From Artifact to Historical Site*, edited by Nicola Masini and Francesco Soldovieri, pp. 89–100. Springer, New York.
- Chase, Arlen F., and Diane Z. Chase
1995 External Impetus, Internal Synthesis, and Standardization: E Group Assemblages and the Crystallization of Classic Maya Society in the Southern Lowlands. In *The Emergence of Lowland Maya Civilization: The Transition from the Preclassic to the Early Classic*, edited by Nikolai Grube, pp. 87–101. Acta Mesoamericana 8. Anton Saurwein, Möckmühl.
- 1998 Scale and Intensity in Classic Period Maya Agriculture: Terracing and Settlement at the “Garden City” of Caracol, Belize. *Culture and Agriculture* 20:60–77.
- 2001 Ancient Maya Causeways and Site Organization at Caracol, Belize. *Ancient Mesoamerica* 12:273–281. <https://doi.org/10.1017/S0956536109990095>.
- 2017 E Groups and the Rise of Complexity in the Southeastern Maya Lowlands. In *Maya E-Groups: Calendars Astronomy, and Urbanism in the Early Lowlands*, edited by David A. Freidel, Arlen F. Chase, Anne S. Dowd, and Jerry Murdock, pp. 31–71. University Press of Florida, Gainesville.
- Chase, Arlen F., Diane Z. Chase, and Michael E. Smith
2009 States and Empires in Ancient Mesoamerica. *Ancient Mesoamerica* 20:175–182. <https://doi.org/10.1017/S0956536109990095>.
- Chase, Arlen F., Diane Z. Chase, John F. Weishampel, Jason B. Drake, Ramesh L. Shrestha, K. Clint Slatton, Jaime Awe, and William E. Carter
2011 Airborne LiDAR, Archaeology, and the Ancient Maya Landscape at Caracol, Belize. *Journal of Archaeological Science* 38:387–398. <https://doi.org/10.1016/j.jas.2010.09.018>.
- Chase, Arlen F., Diane Z. Chase, Jaime J. Awe, John F. Weishampel, Gyles Iannone, Holley Moyes, Jason Yaeger, and M. Kathryn Brown
2014a The Use of LiDAR in Understanding the Ancient Maya Landscape. *Advances in Archaeological Practice* 2:208–221. <https://doi.org/10.7183/2326-3768.2.3.208>.
- Chase, Arlen F., Diane Z. Chase, Jaime J. Awe, John F. Weishampel, Gyles Iannone, Holley Moyes, Jason Yaeger, M. Kathryn Brown, Ramesh L. Shrestha, William E. Carter, and Juan Fernandez Diaz
2014b Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey. *Remote Sensing* 6:8671–8695. <https://doi.org/10.3390/rs6098671>.
- Chase, Arlen F., Kathryn Reese-Taylor, Juan C. Fernandez-Diaz, and Diane Z. Chase
2016 Progression and Issues in the Mesoamerican Geospatial Revolution. *Advances in Archaeological Practice* 4:219–231. <https://doi.org/10.7183/2326-3768.4.3.219>.
- Chase, Diane Z.
1990 The Invisible Maya: Population History and Archaeology at Santa Rita Corozal. In *Prehistoric Population History in the Maya Lowlands*, edited by T. Patrick Culbert and Don S. Rice, pp. 199–213. University of New Mexico Press, Albuquerque.
- Clark, John E.
2016 Western Kingdoms of the Middle Preclassic. In *The Origins of the Maya States*, edited by Loa P. Traxler and Robert J. Sharer, pp. 123–224. University of Pennsylvania Museum, Philadelphia.
- Clark, John E., and Richard D. Hansen
2001 The Architecture of Early Kingship: Comparative Perspectives on the Origins of the Maya Royal Court. In *Royal Courts of the Ancient Maya, Vol. 2: Data and Case Studies*, edited by Takeshi Inomata and Stephen D. Houston, pp. 1–45. Westview Press, Boulder, Colorado.
- Clark, John E., Richard D. Hansen, and Tomas Perez
2000 La zona maya en el preclásico. In *Historia Antigua de México*, 2nd ed., edited by Linda Manzanilla and Leonardo López Luján, Vol. 1, pp. 437–510. Instituto Nacional de Antropología e Historia, Coordinación de Humanidades, Instituto de Investigaciones Antropológicas, Mexico City.
- Cobos, Rafael, and Terance L. Winemiller
2001 The Late and Terminal Classic Period Causeway Systems of Chichen Itza, Yucatan, Mexico. *Ancient Mesoamerica* 12:283–291. <https://doi.org/10.1017/S0956536101122066>.
- Coe, Michael D.
1981 Religion and the Rise of Mesoamerican States. In *The Transition to Statehood in the New World*, edited by Grant D. Jones and Robert R. Kautz, pp. 157–171. Cambridge University Press, Cambridge.
- Cook, Bruce D., Lawrence A. Corp, Ross F. Nelson, Elizabeth M. Middleton, Douglas C. Morton, Joel T. McCorkel, Jeffrey G. Masek, Kenneth J. Ranson, Vuong Ly, and Paul M. Montesano
2013 NASA Goddard's LiDAR, Hyperspectral and Thermal (G-LiHT) Airborne Imager. *Remote Sensing* 5:4045–4066. <https://doi.org/10.3390/rs5084045>.
- Culbert, T. Patrick, Laura J. Kosakowsky, Robert E. Fry, and William R. Haviland
1990 The Population of Tikal, Guatemala. In *Precolumbian Population History in the Maya Lowlands*, edited by T. Patrick Culbert and Don S. Rice, pp. 103–121. University of New Mexico Press, Albuquerque.
- Dahlin, Bruce R., John E. Foss, and Mary Elizabeth Chambers
1980 Project Alcalches, Reconstructing the Natural and Cultural History of a Seasonal Swamp at El Mirador, Guatemala: Preliminary Results. In *El Mirador, Peten, Guatemala: An Interim Report*, edited by Ray T. Matheny, pp. 37–57. Papers of the New World Archaeological Foundation 45. Brigham Young University, Provo.
- Demarest, Arthur A., and Geoffrey W. Conrad (editors)
1992 *Ideology and Pre-Columbian Civilizations*. School of American Research Advanced Seminar Series. SAR Press, Santa Fe.
- Doyle, James
2012 Regroup on “E-Groups”: Monumentality and Early Centers in the Middle Preclassic Maya Lowlands. *Latin American Antiquity* 23:355–379. <https://doi.org/10.7183/1045-6635.23.4.355>.

- 2013 Early Maya Geometric Planning Conventions at El Palmar, Guatemala. *Journal of Archaeological Science* 40:793–798. <https://doi.org/10.1016/j.jas.2012.08.006>.
- Drápela, Tomáš, Milan Kováč, Tibor Lieskovský, Jakub Straka, and Robert Peschl
 2016 Nuevos sitios mayas en el centro y noreste de Petén: Recorridos del equipo SAHI entre la frontera norte del Parque Tikal hasta la frontera de México (2009–2015). In *XXIX Simposio de Investigaciones Arqueológicas en Guatemala*, edited by Bárbara Arroyo, Luis Méndez Salinas, and Gloria Ajú Álvarez, pp. 357–370. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal Guatemala. Electronic document, <http://www.asociaciontikal.com/wp-content/uploads/2020/09/29-Drapela-et-al.pdf>.
- Dunning, Nicholas P., Armando Anaya Hernández, Timothy Beach, Christopher Carr, Robert Griffin, John G. Jones, David L. Lentz, Sheryl Luzzadder-Beach, Kathryn Reese-Taylor, and Ivan Šprajc
 2019 Margin for Error: Anthropogenic Geomorphology of Bajo Edges in the Maya Lowlands. *Geomorphology* 331:127–145. <https://doi.org/10.1016/j.geomorph.2018.09.002>.
- Durkheim, Émile
 1915 *The Elementary Forms of the Religious Life*. Allen & Unwin, London.
- Ensley, Ross A.
 2018 Karst Landscapes of the Petén Plateau. Paper presented at the Mesoamerican Conference, November 16–17, 2018, Salt Lake City. Electronic document, https://www.researchgate.net/publication/344157824_Karst_landscapes_of_the_Peten_Plateau, accessed September 30, 2022.
- Ensley, Ross, and Richard D. Hansen
 2020 El paisaje cárstico de la Cuenca Mirador-Calakmul. In *Investigaciones multidisciplinares en la Cuenca Mirador: Informe final de la temporada 2019*, edited by Richard D. Hansen, Edgar Suyuc-Ley, Carlos Morales-Aguilar, and Beatriz Balcárcel-Villagran, pp. 591–654. Ministerio de Cultura y Deportes, Dirección General del Patrimonio Cultural y Natural, Departamento de Monumentos Prehispánicos y Coloniales, Instituto de Antropología e Historia, Guatemala City.
- Ensley, Ross, Richard D. Hansen, Carlos Morales-Aguilar, and Josie Thompson
 2021 Geomorphology of the Mirador-Calakmul Karst Basin: A GIS-Based Approach to Hydrogeologic Mapping. *PLoS ONE* 16(8): e0255496. <https://doi.org/10.1371/journal.pone.0255496>.
- Erasmus, Charles J.
 1965 Monument Building: Some Field Experiments. *Southwestern Journal of Anthropology* 21:277–301. <https://doi.org/10.1086/south-janth.21.4.3629433>.
- Estrada-Belli, Francisco
 2017 The History, Function, and Meaning of Preclassic E-Groups in the Cival Region. In *Maya E-Groups: Calendars, Astronomy, and Urbanism in the Early Lowlands*, edited by David A. Freidel, Arlen F. Chase, Anne S. Dowd, and Jerry Murdock, pp. 293–327. University Press of Florida, Gainesville.
- Estrada-Belli, Francisco, Jeremy Bauer, Molly Morgan, and Angel Chavez
 2003a Symbols of Early Maya Kingship at Cival, Petén, Guatemala. *Antiquity Project Gallery* 77(298): http://www.antiquity.ac.uk/projgall/estrada_belli298/
- Estrada-Belli, Francisco, Nikolai Grube, Marc Wolf, Kristen Gardella, and Claudio Lozano Guerra-Librero
 2003b *Preclassic Maya Monuments and Temples at Cival, Petén, Guatemala*. *Antiquity*. Electronic document, <http://www.antiquity.ac.uk/projgall/belli296>, accessed July 2015.
- Evans, Damian H., Roland J. Fletcher, Christophe Pottier, Jean-Baptiste Cheavance, Dominique Soutif, Boun Suy Tan, Sokrithy Im, Darith Ea, Tina Tin, Samnang Kim, Christopher Cromarty, Stéphane De Greef, Kasper Hanus, Pierre Bâty, Robert Kuszinger, Ichita Shimoda, and Glenn Boornazian
 2013 Uncovering Archaeological Landscapes at Angkor Using LiDAR. *PNAS* 110:12595–12600. Electronic document, <https://www.pnas.org/content/pnas/110/31/12595.full.pdf>, accessed September 30, 2022.
- Fernandez-Diaz, Juan Carlos, William E. Carter, Ramesh L. Shrestha, and Craig L. Glennie
 2014 Now You See It ... Now You Don't: Understanding Airborne Mapping LiDAR Collection and Data Product Generation for Archaeological Research in Mesoamerica. *Remote Sensing* 6:9951–10001. <https://doi.org/10.3390/rs6109951>.
- Flannery, Kent V.
 1998 The Ground Plans of Archaic States. In *Archaic States*, edited by Gary M. Feinman and Joyce Marcus, pp. 15–57. School of American Research, Santa Fe.
- Folan, William J.
 1991 Sacbes of the Northern Maya. In *Ancient Road Networks and Settlement Hierarchies in the New World*, edited by Charles D. Trombold, pp. 222–229. Cambridge University Press, New York.
- Folan, William J., Jacinto May Hau, Joyce Marcus, W. Frank Miller, and Raymundo González Heredia
 2001 Los caminos de Calakmul, Campeche. *Ancient Mesoamerica* 12:293–298. Cambridge University Press. <https://doi.org/10.1017/s0956536101122017>
- Force, Eric, and John Dohrenwend
 2008 Geologic and Geomorphologic Analysis of the Area of the Mirador Cultural and Natural System. Unpublished report presented to the Foundation for Anthropological Research and Environmental Studies (FARES), Idaho. Electronic document, <https://miradorbasin.com/wp-content/uploads/2017/06/Force-and-Dohrenwend-2008-Geologic-Geomorphologic-analysis-Mirador.pdf>, accessed September 30, 2022.
- 2021 Análisis geológico y geomorfológico del área del Proyecto Arqueológico Cuenca Mirador. In *Investigaciones multidisciplinares en la Cuenca Mirador: Informe de los trabajos del laboratorio 2020*, edited by Richard D. Hansen, Edgar Suyuc-Ley, and Gustavo Martínez, pp. 570–577. Report presented to the Ministerio de Cultura y Deportes, Dirección General del Patrimonio Cultural y Natural, Departamento de Monumentos Prehispánicos y Coloniales, Instituto de Antropología e Historia, Guatemala City.
- Ford, Anabel, Hugo Bihl, and Paulino Morales
 2014 Usando métodos vanguardistas LiDAR en El Pilar, Guatemala-Belize: Cambiando la arqueología en la selva maya. In *XXVII Simposio de Investigaciones Arqueológicas en Guatemala*, edited by Bárbara Arroyo, Luis Méndez Salinas, and Andrea Rojas, pp. 805–812. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City. Electronic document, <http://www.asociaciontikal.com/wp-content/uploads/2017/07/Simp27-65-Ford-Bihl-y-Morales.pdf>, accessed September 30, 2022.
- Fox, Richard G.
 1977 *Urban Anthropology: Cities in their Cultural Settings*. Prentice-Hall, Englewood Cliffs.
- Freidel, David A.
 1979 Culture Areas and Interaction Spheres: Contrasting Approaches to the Emergence of Civilization in the Maya Lowlands. *American Antiquity* 44:36–54.
- 1981 Civilization as a State of Mind: The Cultural Evolution of the Lowland Maya. In *The Transition to Statehood in the New World*, edited by Grant D. Jones and Robert R. Kautz, pp. 188–227. Cambridge University Press, Cambridge.
- Freidel, David A., Arlen F. Chase, Anne S. Dowd, and Jerry Murdock (editors)
 2017 *Maya E Groups: Calendars, Astronomy, and Urbanism in the Early Lowlands*. University Press of Florida, Gainesville.
- Fry, Robert E.
 1969 *Ceramics and Settlement in the Periphery of Tikal, Guatemala*. Unpublished Ph.D. dissertation, University of Arizona, Tucson, Arizona.
- Garrison, Thomas G., Stephen Houston, and Omar Alcover Firpi
 2019 Recentering the Rural: LiDAR and Articulated Landscapes among the Maya. *Journal of Anthropological Archaeology* 53:133–146. <https://doi.org/10.1016/j.jaa.2018.11.005>.
- Gates, Gary R.
 1992 Fisiografía, geología e hidrología. In *Programa de manejo de la Reserva de la Biósfera Calakmul, Campeche*, edited by William J. Folan, Jose M. García Ortega, and Maria C. Sánchez Gonzáles, pp. 22–27. Campeche, México.
- 1999 Fisiografía, geología e hidrología. In *Naturaleza y cultura en Calakmul, Campeche*, edited by William J. Folan, María Consuelo

- Sánchez Gonzáles, and Jose M. García Ortega, pp. 31–39. Universidad Autónoma de Campeche, Campeche.
- Golden, Charles, Andrew K. Scherer, Whittaker Schroder, Timothy Murtha, Shanti Morell-Hart, Juan Carlos Fernandez Diaz, Socorro Del Pilar Jiménez Álvarez, Omar Alcover Firpi, Mark Agostini, Alexandra Bazarisky, Morgan Clark, G. Van Kollias, Mallory Matsumoto, Alejandra Roche Recinos, Joshua Schnell, and Bethany Whitlock
- 2021 Airborne LiDAR Survey, Density-Based Clustering, and Ancient Maya Settlement in the Upper Usumacinta River Region of Mexico and Guatemala. *Remote Sensing* 13(20):4109. <https://doi.org/10.3390/rs13204109>.
- Gómez, Oswaldo
- 1996 Calzadas mayas: Un estudio desde el sureste del Petén. In *IX Simposio de Investigaciones Arqueológicas en Guatemala, 1995*, edited by Juan Pedro Laporte and Héctor L. Escobedo, pp. 115–129. Museo Nacional de Arqueología y Etnología, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City. Electronic document, http://www.asociaciontikal.com/wp-content/uploads/2016/11/09.95_-_Oswaldo.pdf, accessed September 30, 2022.
- Graham, Ian
- 1967 *Archaeological Explorations in El Petén, Guatemala*. Middle American Research Institute Publication 33. Tulane University, New Orleans.
- Gunn, Joel D., and William J. Folan
- 1992 Clima. In *Programa de manejo de la Reserva de la Biosfera Calakmul, Descripción*, Vol. 1, pp. 34–55. Secretaría de Desarrollo Social, Centro de Investigaciones Históricas y Sociales, Universidad Autónoma de Campeche, Campeche.
- Gunn, Joel D., William J. Folan, Nuria Torrescano-Valle, Betty B. Faust, Helga Z. Geovannini-Acuña, and Alfred H. Siemens
- 2019 From Calakmul to the Sea: The Historical Ecology of a Classic Maya City that Controlled the Candelaria/Chapotón Watersheds. In *The Holocene and Anthropocene Environmental History of Mexico*, edited by Nuria Torrescano-Valle, Gerald A. Islebe, and Priyadarsi D. Roy, pp. 209–248. Springer Press, Cham. https://doi.org/10.1007/978-3-030-31719-5_11.
- Haas, Jonathon
- 1982 *The Evolution of the Prehistoric State*. Columbia University Press, New York.
- Hammond, Norman
- 1975 Maya Settlement Hierarchy in Northern Belize. In *Studies in Ancient Mesoamerica, II*, edited by John A. Graham, pp. 40–55. Contributions of the University of California Archaeological Research Facility 27. University of California, Archaeological Research Facility, Berkeley. Electronic document, <https://escholarship.org/uc/item/8fc5f0wr>, accessed September 30, 2022.
- Hansen, Eric F., Richard D. Hansen, and Michele F. Derrick
- 1995 Los análisis de los estucos y pinturas arquitectónicas de Nakbe: Resultados preliminares de los estudios de los métodos y materiales de producción. In *VIII Simposio de Investigaciones Arqueológicas en Guatemala, 1994*, edited by Juan Pedro Laporte and Héctor L. Escobedo, pp. 543–560. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City.
- Hansen, Eric F., Carlos Rodríguez-Navarro, and Richard D. Hansen
- 1996 Incipient Maya Burnt-Lime Technology: Characterization and Chronological Variations in Preclassic Plaster, Stucco, and Mortar at Nakbe, Guatemala. In *Materials Issues in Art and Archaeology V*, edited by Pamela B. Vandiver, James R. Druzik, John F. Merkel, and John Stewart, pp. 207–216. Materials Research Society, Vol. 462. Materials Research Society, Pittsburgh. <https://doi.org/10.1557/PROC-462-207>.
- Hansen, Eric F., Arie Wallert, and Michele R. Derrick
- 1997 An Organic Colorant Found in the Ancient Maya Architectural Sculpture at Nakbe, Peten, Guatemala. In *Materials Issues in Art and Archaeology V*, edited by Pamela B. Vandiver, James R. Druzik, John F. Merkel, and John Stewart, pp. 287–300. Materials Research Society, Vol. 462. Materials Research Society, Pittsburgh. <https://doi.org/10.1557/PROC-462-287>.
- Hansen, Richard D.
- 1982 Excavations in the Tigre Pyramid Area, El Mirador, Guatemala: A New Evaluation of Social Process in the Preclassic Maya Lowlands. In *Abstracts of the 44th International Congress of Americanists*. University of Manchester, Manchester. (Summarized in *Past and Present in the Americas: A Compendium of Recent Studies*, edited by John Lynch, 1984, pp. 133–134. Manchester University Press, Manchester.)
- 1984 Excavations on Structure 34 and the Tigre Area, El Mirador, Petén, Guatemala: A New Look at the Preclassic Lowland Maya. Master's thesis, Department of Anthropology, Brigham Young University, Provo.
- 1990 Excavations in the Tigre Complex, El Mirador, Petén, Guatemala. Papers of the New World Archaeological Foundation 62. Brigham Young University, Provo.
- 1992 *The Archaeology of Ideology: A Study of Maya Preclassic Architectural Sculpture at Nakbe, Petén, Guatemala*. Ph.D. dissertation, Department of Archaeology, University of California, Los Angeles. University Microfilms, Ann Arbor.
- 1998 Continuity and Disjunction: The Pre-Classic Antecedents of Classic Maya Architecture. In *Function and Meaning in Classic Maya Architecture*, edited by Stephen D. Houston, pp. 49–122. Dumbarton Oaks Research Library and Collection, Washington, D.C.
- 2000 Ideología y arquitectura: Poder y dinámicas culturales de los mayas del período preclásico en las tierras bajas. In *Arquitectura e ideología de los antiguos mayas: Memoria de la segunda mesa redonda de Palenque*, edited by Silvia Trejo, pp. 71–108. Instituto Nacional de Antropología e Historia, Consejo Nacional para la Cultura y las Artes, Mexico City.
- 2001 The First Cities: The Beginnings of Urbanization and State Formation in the Maya Lowlands. In *Maya: Divine Kings of the Rain Forest*, edited by Nikolai Grube, pp. 50–65. Könemann, Cologne.
- 2005 Perspective on Olmec–Maya Interaction in the Middle Formative (Preclassic) Period. In *New Perspectives on Formative Mesoamerican Cultures*, edited by Terry G. Powis, pp. 51–72. BAR International Series 1377. Archaeopress, Oxford. Electronic document, <https://miradorbasin.com/wp-content/uploads/2017/06/OlmecMayainteraction.pdf>, accessed September 30, 2022.
- 2012a Kingship in the Cradle of Maya Civilization. In *Fanning the Sacred Flame: Mesoamerican Studies in Honor of H.B. Nicholson*, edited by Matthew A. Bost and Brian Dervin Dillon, pp. 139–171. University Press of Colorado, Boulder.
- 2012b The Beginning of the End: Conspicuous Consumption and Environmental Impact of the Preclassic Lowland Maya. In *An Archaeological Legacy: Papers in Honor of Ray T. Matheny*, edited by Joel Janetski, Deanne Gurr, and Glenna Nielson-Grimm, pp. 241–285. Brigham Young University Press, Provo.
- 2016a The Mirador-Calakmul Cultural and Natural System: A Priceless Treasure in Guatemala and Mexico / El sistema cultural y natural Mirador-Calakmul: Un tesoro invaluable en Guatemala y México. In *Mirador: Research and Conservation in the Ancient Kaan Kingdom*, edited by Richard D. Hansen and Edgar Suyuc-Ley, pp. 9–36. Foundation for Anthropological Research and Environmental Studies, Corporación Litográfica, Guatemala City.
- 2016b Cultural and Environmental Components of the First Maya States: A Perspective from the Central and Southern Maya Lowlands. In *The Origins of Maya States*, edited by Loa P. Traxler and Robert J. Sharer, pp. 329–416. University of Pennsylvania Press, Philadelphia. <https://doi.org/10.9783/9781934536087-013>.
- 2017 The Feast before Famine and Fighting: The Origins and Consequences of Social Complexity in the Mirador Basin, Guatemala. In *Feast, Famine or Fighting? Multiple Pathways to Social Complexity*, edited by Richard J. Chacon and Reuben Mendoza, pp. 305–335. Springer, New York. https://doi.org/10.1007/978-3-319-48402-0_12.
- Hansen, Richard D., and Edgar Suyuc-Ley
- 2011 L'émergence de l'État dans le monde maya: Une vue du bassin de Mirador. In *Maya: de l'aube au crépuscule, Collections nationales de Guatemala*, edited by Dominique Michelet, pp. 32–37. Somogy Editions d'art, Musée de quai Branly, Paris.
- Hansen, Richard D., and Edgar Suyuc-Ley (editors)
- 2016 *Mirador: Research and Conservation in the Ancient Kaan Kingdom*. Foundation for Anthropological Research and Environmental Studies (FARES), Corporación Litográfica, Guatemala City.
- Hansen, Richard D., and Stanley P. Guenter
- 2005 Early Social Complexity and Kingship in the Mirador Basin. In *Lords of Creation: The Origins of Sacred Maya Kingship*, edited by

- Virginia M. Fields and Dorie Reents-Budet, pp. 60–61 Los Angeles County Museum of Art, Scala Publishers, Los Angeles.
- Hansen, Richard D., Steven Bozarth, John Jacob, David Wahl, and Thomas Schreiner
- 2002 Climatic and Environmental Variability in the Rise of Maya Civilization: A Preliminary Perspective from Northern Petén. *Ancient Mesoamerica* 13:273–295. <https://doi.org/10.1017/S0956536102132093>.
- Hansen, Richard D., Wayne K. Howell, and Stanley P. Guenter
- 2008 Forgotten Structures, Haunted Houses, and Occupied Hearts: Ancient Perspectives and Contemporary Interpretations of Abandoned Sites and Buildings in the Mirador Basin, Guatemala. In *Ruins of the Past: The Use and Perception of Abandoned Structures in the Maya Lowlands*, edited by Travis W. Stanton and Aline Magnoni, pp. 25–64. University Press of Colorado, Boulder.
- Hansen, Richard D., Donald W. Forsyth, James C. Woods, Eric F. Hansen, Thomas Schreiner, and Gene L. Titmus
- 2018a Developmental Dynamics, Energetics, and Complex Economic Interactions of the Early Maya of the Mirador Basin, Guatemala. In *Pathways to Complexity: A View from the Maya Lowlands*, edited by George Bey and Katherine Brown, pp. 147–194. University Press of Florida, Gainesville. <https://doi.org/10.5744/florida/9780813054841.003.0007>.
- Hansen, Richard D., Carlos Morales-Aguilar, Thomas Schreiner, and Enrique Hernández
- 2018b El uso de LIDAR en la identificación de los antiguos sistemas agrícolas mayas de la Cuenca Mirador. In *XXXI Simposio de Investigaciones Arqueológicas en Guatemala, 2017*, edited by Bárbara Arroyo, Luis Méndez-Salinas, and Gloria Ajú-Álvarez, pp. 583–590. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City.
- Hansen, Richard D., Edgar Suyuc-Ley, Stanley P. Guenter, Carlos Morales-Aguilar, Enrique Hernández, and Beatriz Balcárcel
- 2020 Economic Interactions and the Rise of Sociopolitical Complexity in the Maya Lowlands: A Perspective from the Mirador-Calakmul Basin. In *The Real Business of Ancient Maya Economies: From Farmers' Fields to Rulers' Realms*, edited by Marilyn A. Masson, David A. Freidel, and Arthur A. Demarest, pp. 317–339. University Press of Florida, Gainesville. <https://upf.com/book.asp?id=9780813066295>
- Hare, Timothy, Marilyn Masson, and Bradley Russell
- 2014 High-Density LiDAR Mapping of the Ancient City of Mayapán. *Remote Sensing* 6:9064–9085. <https://doi.org/10.3390/rs6099064>.
- Haviland, William A.
- 1965 Prehistoric Settlement at Tikal, Guatemala. *Expedition* 7:14–23.
- Hernández-Salazar, Enrique
- 2021 Investigaciones arqueológicas en el Sacbé Tintal-Mirador, Petén, Guatemala. Unpublished licenciatura thesis, Escuela de Historia (Arqueología), Universidad de San Carlos, Guatemala City.
- Hernández, Enrique
- 2008 Sitios asociados a la calzada Tintal-Mirador: Sitio arqueológico El Arroyón. In *Informe final de investigaciones 2007: Investigación y conservación en los sitios arqueológicos de la zona cultural y natural Mirador*, edited by Nora Lopez, Richard D. Hansen, and Edgar Suyuc-Ley, pp. 1084–1103. Report filed with the Departamento de Monumentos Prehispánicos y Coloniales, Instituto de Antropología e Historia, Ministerio de Cultura y Deportes, Guatemala City.
- Hernández, Enrique, and Thomas Schreiner
- 2006 Exploraciones y excavaciones del Sacbé Tintal-Mirador, Petén, Guatemala. In *Investigación y conservación en los sitios arqueológicos El Mirador, La Muerta, Wakná, El Porvenir, El Guiro, La Iglesia, La Sarteneja, Chab Ché y la Ceibita: Informe final de la temporada 2005*, edited by Edgar Suyuc-Ley and Richard D. Hansen, pp. 318–357. Foundation for Anthropological Research & Environmental Studies, Idaho State University, Pocatello.
- Hernández, Enrique, Thomas Schreiner, and David Wahl
- 2007 The Tintal-Mirador Causeway: A Monumental Prehispanic Sacbe in the Mirador Basin, Guatemala. Paper presented at the 72nd Annual Meeting of the Society for American Archaeology, Austin.
- Hernández, Enrique, Thomas Schreiner, and Carlos Morales-Aguilar
- 2013 Uso público, uso privado y mitos asociados a las calzadas y sacbeob de El Mirador. In *XXVI Simposio de Investigaciones Arqueológicas en Guatemala, 2012*, edited by Bárbara Arroyo and Luis Méndez Salinas, pp. 939–950. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City.
- Hernández, Enrique, Thomas Schreiner, Richard D. Hansen, Carlos Morales-Aguilar, Edgar Ortega G., and Douglas Mauricio
- 2016 Las calzadas y sacbeob de la Cuenca Mirador / The Causeways and Sacbeob of the Mirador Basin. In *Mirador: Research and Conservation in the Ancient Kaan Kingdom*, edited by Richard D. Hansen and Edgar Suyuc-Ley, pp. 219–254. Foundation for Anthropological Research and Environmental Studies, Corporación Litográfica, Guatemala City.
- Hernández, Enrique, Thomas Schreiner, Carlos Morales-Aguilar, and Richard D. Hansen
- 2019 Resultados de las investigaciones arqueológicas en el reservorio, dique, y calzada del bajo La Jarrilla, El Mirador, Petén. In *XXXII Simposio de Investigaciones Arqueológicas en Guatemala 2018*, edited by Bárbara Arroyo, Luis Méndez Salinas, and Gloria Ajú Álvarez, pp. 459–468. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City.
- Hightower, Jessica N., A. Christine Butterfield, and John F. Weishampel
- 2014 Quantifying Ancient Maya Land Use Legacy Effects on Contemporary Rainforest Canopy Structure. *Remote Sensing* 6:10716–10732. <https://doi.org/10.3390/rs6110716>.
- Horn, Sherman W., and Anabel Ford
- 2019 Beyond the Magic Wand: Methodological Developments and Results from Integrated LiDAR Survey at the Ancient Maya Center El Pilar. *Science and Technology of Archaeological Research* 5 (2):164–178. <https://doi.org/10.1080/20548923.2019.1700452>.
- Hutson, Scott R., and Jacob A. Welch
- 2014 Sacred Landscapes and Building Practices at Uci, Kancab, and Ucanha, Yucatan, Mexico. *Ancient Mesoamerica* 25:421–439. <https://doi.org/10.1017/S0956536114000285>.
- 2021 Roadwork: Long-Distance Causeways at Uci, Yucatan, Mexico. *Latin American Antiquity* 32:310–330. <https://doi.org/10.1017/laq.2020.98>.
- Hutson, Scott R., Nicholas P. Dunning, Bruce Cook, Thomas Ruhl, Nicolas C. Barth, and Daniel Conley
- 2021 Ancient Maya Rural Settlement Patterns, Household Cooperation, and Regional Subsistence Interdependency in the Río Bec Area: Contributions from G-LiHT. *Journal of Anthropological Research* 77:550–579. <https://doi.org/10.1086/716750>.
- Inomata, Takeshi
- 2017 The Isthmian Origins of the E Group and its Adoption in the Maya Lowlands. In *Maya E Groups: Calendars, Astronomy, and Urbanism in the Early Lowlands*, edited by David A. Freidel, Arlen F. Chase, Anne S. Dowd, and Jerry Murdock, pp. 215–252. University Press of Florida, Gainesville.
- Inomata, Takeshi, Daniela Triadan, Kazuo Aoyama, Victor Castillo, and Hitoshi Yonenobu
- 2013 Early Ceremonial Construction at the Site of Ceibal, Guatemala and the Origins of Lowland Maya Civilization. *Science* 340 (1126):467–471.
- Inomata, Takeshi, Daniela Triadan, Flory Pinzón, and Kazuo Aoyama
- 2019 Artificial Plateau Construction during the Preclassic Period at the Maya Site of Ceibal, Guatemala. *PLoS ONE* 14(8):e0221943. <https://doi.org/10.1371/journal.pone.0221943>.
- Inomata, Takeshi, Daniela Triadan, Verónica A. Vázquez López, Juan Carlos Fernandez-Díaz, Takayuki Omori, María Belén Méndez Bauer, Melina García Hernández, Timothy Beach, Clarissa Cagnato, Kazuo Aoyama, and Hiroo Nasu
- 2020 Monumental Architecture at Aguada Fénix and the Rise of Maya Civilization. *Nature* 582:530–533. <https://doi.org/10.1038/s41586-020-2343-4>.
- Inomata, Takeshi, Juan Carlos Fernandez-Díaz, Daniela Triadan, Miguel García Mollinedo, Flory Pinzón, Melina García Hernández, Atasta Flores, Ashley Sharpe, Timothy Beach, Gregory W.L. Hodgins, Juan Javier Durón Díaz, Antonio Guerra Luna, Luis Guerrero Chávez, María de Lourdes Hernández Jiménez, and Manuel Moreno Díaz

- 2021 Origins and Spread of Formal Ceremonial Complexes in the Olmec and Maya Regions Revealed by Airborne LiDAR. *Nature Human Behaviour* 5:1487–1501. <https://doi.org/10.1038/s41562-021-01218-1>.
- Instituto Nacional de Estadística, Geografía e Informática
2022 Relieve continental. Electronic document, <https://inegi.org.mx/temas/relieve/continental/>, accessed April 25, 2022.
- Jacob, John
1994 Evidencias para cambio ambiental en Nakbe, Guatemala. VII *Símpoio de Investigaciones Arqueológicas en Guatemala*, edited by Juan Pedro Laporte, Héctor L. Escobedo, and Sandra Villagran de Brady, pp. 275–280. Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Museo Nacional de Arqueología y Etnología, Guatemala City.
- Johnston, Kevin, Richard Hansen, Beatriz Balcárcel, and Carlos Morales-Aguilar
2015 Non-Mounded Architecture, Invisible Housemounds, and the Problem of Settlement Identification and Demographics in the Mirador Basin. Paper presented at the Society for American Archaeology, 80th Annual Meeting, San Francisco.
- Jones, Grant D., and Robert R. Kautz
1981 Issues in the Study of New World State Formation. In *The Transition to Statehood in the New World*, edited by Grant D. Jones and Robert R. Kautz, pp. 3–34. Cambridge University Press, Cambridge, London, and New York.
- Justeson, John S., and Peter Mathews
1983 The Seating of the Tun: Further Evidence Concerning a Late Preclassic Lowland Maya Stela Cult. *American Antiquity* 48:586–593.
- Keatinge, Richard W.
1981 The Nature and Role of Religious Diffusion in the Early Stages of State Formation: An Example from Peruvian Prehistory. In *The Transition to Statehood in the New World*, edited by Grant D. Jones and Robert R. Kautz, pp. 172–187. Cambridge University Press, Cambridge.
- Kurjack, Edward B.
1977 Sacbeob: Parentesco y desarrollo del estado maya. In *Los procesos de cambio en Mesoamérica y áreas circunvecinas: XV Mesa Redonda de la Sociedad Mexicana de Antropología*, pp. 217–230. Sociedad Mexicana de Antropología, Guanajuato.
- Lentz, David L., Nicholas P. Dunning, and Vernon L. Scarborough
2015 *Tikal: Paleoecology of an Ancient Maya City*. Cambridge University Press, Cambridge, London, and New York.
- Love, Michael, and Julia Guernsey (editors)
2022 *Early Mesoamerican Cities: Urbanism and Urbanization in the Formative Period*. Cambridge University Press, Cambridge.
- Maldonado-Cárdenas, Rubén
1979 Los sacbeob de Izamal-Aké y Uci-Cansacab en el noroeste de Yucatán. *Antropología e Historia* 27:23–29.
- Martínez Hildalgo, Gustavo, Richard D. Hansen, John Jacob, and Wayne K. Howell
1999 Nuevas evidencias de los sistemas de cultivo del preclásico en la Cuenca Mirador. In *XII Símpoio de Investigaciones Arqueológicas en Guatemala*, edited by Juan Pedro Laporte, Héctor L. Escobedo, and Ana Claudia M. de Suasnavar, pp. 327–336. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City.
- Mejía, Héctor E.
2008 Desarrollo y estructura de las ciudades al sur de El Mirador, Petén. In *XXI Símpoio de Investigaciones Arqueológicas en Guatemala*, 2007, edited by Juan Pedro Laporte, Bárbara Arroyo, and Héctor E. Mejía, pp. 543–564. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Fundación Arqueológica del Nuevo Mundo, Guatemala City.
2012 Caminando bajo la selva: Patrón de asentamiento en la Cuenca Mirador. In *XXV Símpoio de Investigaciones Arqueológicas en Guatemala*, 2011, edited by Bárbara Arroyo, Héctor L. Escobedo, Olga de Hazard, Juan Carlos Melendez, and Zoila Rodríguez Girón, pp. 85–96. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City. Electronic document, http://www.asociaciontikal.com/wp-content/uploads/2017/03/008_Mejia_2.pdf, accessed September 30, 2022.
- Mejía, Héctor, Gendry Valle, Francisco Castañeda, and Enrique Hernández
2007 Sobreviviendo a la selva: Patrón de asentamiento en la Cuenca Mirador. In *XX Símpoio de Investigaciones Arqueológicas en Guatemala*, edited by Juan Pedro Laporte, Bárbara Arroyo, and Héctor E. Mejía, pp. 241–264. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Fundación Arqueológica del Nuevo Mundo, Guatemala City. Electronic document, http://www.asociaciontikal.com/wp-content/uploads/2017/01/19.06_-Mejia_et_al.06_-www.pdf, accessed September 30, 2022.
- Mejía, Héctor, Boris Aguilar, Julio Cotom, Hiro Iwamoto, and Antonio Portillo
2010 Rescate arqueológico en El Pesquero: Un sitio de rango intermedio en el límite sur de la Cuenca Mirador. In *XXIII Símpoio de Investigaciones Arqueológicas en Guatemala*, 2009, edited by Bárbara Arroyo, Adriana Linares Palma, and Lorena Paiz Aragón, pp. 567–582. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City. Electronic document, http://www.asociaciontikal.com/wp-content/uploads/2016/12/43.09_Mejia_et_al.pdf, accessed September 30, 2022.
- Morales-Aguilar, Carlos
2010 Patrones de asentamiento en el área central de El Mirador, Petén, Guatemala durante el período clásico tardío (600–850 d.C.). Unpublished licenciatura thesis, Escuela de Historia, Área de Arqueología, Universidad de San Carlos, Guatemala City.
2021 *La ocupación maya del norte de Petén (Guatemala) en el clásico (150–950 d.C.) y su estructuración sociopolítica*. Unpublished Ph.D. dissertation, Institut d'art et d'archéologie, Ecole doctorale d'archéologie, (ED112) Université Paris 1, Panthéon-Sorbonne, Paris.
- Morales-Aguilar, Carlos, and Cyril Castanet
2017 Análisis preliminares de la imagen LiDAR de la micro-región de Naachtún. In *Proyecto Petén-Norte Naachtún 2015–2018: Informe de la Sexta Temporada de Campo 2016*, edited by Philippe Nondédéo, Dominique Michelet, Julien Hiquet, and Lilian Garrido, pp. 53–82. Instituto de Antropología e Historia, Guatemala City, and Université Paris 1 Panthéon-Sorbonne, Paris.
- Morales-Aguilar, Carlos, Douglas Mauricio, Richard Hansen, and Enrique Hernández
2015 Los suburbios de la antigua ciudad de El Mirador, Petén, Guatemala. In *XXVIII Símpoio de Investigaciones Arqueológicas en Guatemala*, 2014, edited by Bárbara Arroyo, Luis Méndez Salinas, and Lorena Paiz, p. 497–510. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City. Electronic document, <http://www.asociaciontikal.com/wp-content/uploads/2017/07/Simp28-40-Morales-Aguilar-et-al.pdf>, accessed September 30, 2022.
- Paine, Richard R.
2019 Excavaciones en residencias no visibles, El Mirador: Operaciones 118 E, 118 F, 118 G, 118 H, 118 J, 118 N, 118P, 118Q, 118 R, 118 S, y 118T. In *Investigaciones multidisciplinarias en la Cuenca Mirador: Informe final de la temporada 2018*, edited by Richard D. Hansen, Carlos Morales-Aguilar, Edgar Suyuc-Ley, and Beatriz Balcárcel-Villagran, pp. 39–56. Report presented to the Ministerio de Cultura y Deportes, Dirección General del Patrimonio Cultural y Natural, Departamento de Monumentos Prehispánicos y Coloniales, Instituto de Antropología e Historia, Guatemala City.
- 2020 Investigaciones en estructuras no visibles en El Mirador, Temporada 2019: Operaciones 119A-D, K, L, M, P, Q, R, S, T. In *Investigaciones multidisciplinarias en la Cuenca Mirador: Informe final de la temporada de campo 2019*, edited by Richard D. Hansen, Edgar Suyuc-Ley, Carlos Morales-Aguilar, and Beatriz Balcárcel, pp. 118–141. Report presented to the Ministerio de Cultura y Deportes, Dirección General de Patrimonio Cultural y Natural, Departamento de Monumentos Prehispánicos, Instituto de Antropología e Historia, Guatemala City.
- Paine, Richard R., and Richard Hansen
2018 Ancient Demographics of the Mirador Basin: The Problem of Invisible Structures. Paper presented at the 2018 Mesoamerican

- Conference of the University of Utah: A Symposium in Honor of Dr. Norman Hammond and Dr. Ray T. Matheny. Department of Anthropology, University of Utah, and Natural History Museum of Utah.
- Paine, Richard R., Andrea Brunelle, and Benjamin Marconi
 2018a Sondeos arqueológicos y registros pedológicos en Tzunún, El Mirador: Operaciones 117H, 117I, 117J, 117Z, 117AA, 117AB, 117AC, y 117AD. In *Investigaciones multidisciplinarias en la Cuenca Mirador: Informe final de la temporada de campo 2017*, edited by Richard D. Hansen, Carlos Morales-Aguilar, Edgar Suyuc-Ley, and Beatriz Balcárcel-Villagran, pp. 129–148. Report presented to the Ministerio de Cultura y Deportes, Dirección General del Patrimonio Cultural y Natural, Departamento de Monumentos, Guatemala City.
- Paine, Richard R., Richard Hansen, Carlos Morales-Aguilar, and Kevin Johnston
 2018b Issues Reconstructing the Ancient Population of El Mirador Guatemala. Paper presented at the 83rd Annual Meeting of the Society for American Archaeology, Washington, D.C.
- Paine, Richard R., Kevin Johnston, Enrique Hernández, and Richard Hansen
 2021 Hidden Structures at El Mirador: Challenges and Prospects. Paper presented at the 87th Annual Meeting of the Society for American Archaeology, Chicago.
- Parry, Roberta G.
 2007 *Maya Water Management: Excavations in the Reservoir at Naachtún, El Petén, Guatemala*. Master's thesis, Department of Archaeology, University of Calgary, Alberta.
- Prüfer, Keith M., Amy E. Thompson, and Douglas J. Kennett
 2015 Evaluating Airborne LiDAR for Detecting Settlements and Modified Landscapes in Disturbed Tropical Environments at Uxbenká, Belize. *Journal of Archaeological Science* 57:1–13. <http://dx.doi.org/10.1016/j.jas.2015.02.013>.
- Pugh, Timothy W., and Prudence M. Rice
 2017 Early Urban Planning, Spatial Strategies, and the Maya Gridded City of Nixtun-Ch'ich', Petén, Guatemala. *Current Anthropology* 58:576–603.
- Pugh, Timothy W., Evelyn M. Chan Nieto, and Gabriela W. Zygadlo
 2019 Faceless Hierarchy at Nixtun-Ch'ich', Petén, Guatemala. *Ancient Mesoamerica* 31:248–260.
- Pyburn, Anne
 1990 Settlement Patterns at Nohmul: Preliminary Results of Four Excavation Seasons. In *Prehistoric Population History in the Maya Lowlands*, edited by T. Patrick Culbert and Don S. Rice, pp. 183–197. University of New Mexico Press, Albuquerque.
- Quinlan, James F., and Ralph O. Ewers
 1989 Subsurface Drainage in the Mammoth Cave Area. In *Karst Hydrology: Concepts from the Mammoth Cave Area*, edited by William B. White and Elizabeth L. White, pp. 65–103. Van Nostrand Reinhold, New York. https://doi.org/10.1007/978-1-4615-7317-3_3.
- Ray, Joseph A.
 2001 Spatial Interpretation of Karst Drainage Basins. In *Geotechnical and Environmental Applications of Karst Geology and Hydrology: Proceedings of the Eighth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karsts*, edited by Barry F. Beck, and J. Gayle Herring, pp. 235–244. Balkema, Lisse.
- Reese-Taylor, Kathryn V.
 2017 Founding Landscapes in the Central Karstic Uplands. In *Maya E-Groups: Calendars, Astronomy, and Urbanism in the Early Lowlands*, edited by David A. Freidel, Arlen F. Chase, Anne S. Dowd, and Jerry Murdock, pp. 480–513. University Press of Florida, Gainesville.
- Reese-Taylor, Kathryn, Armando Anaya Hernández, Atasta Flores Esquivel, Kelly Monteleone, Alejandro Uriarte, Christopher Carr, Helga Geovannini Acuña, Juan Carlos Fernandez-Díaz, Meaghan Peuramaki-Brown, and Nicholas Dunning
 2016 Boots on the Ground at Yaxnohcah: Ground-Truthing LiDAR in a Complex Tropical Landscape. *Advances in Archaeological Practice* 4:314–338. <https://doi.org/10.7183/2326-3768.4.3.314>.
- Reimer, Paula J., Edouard Bard, Alex Bayliss, J. Warren Beck, Paul G. Blackwell, Christopher Bronk Ramsey, Caitlin E. Buck, Hai Cheng, R. Lawrence Edwards, Michael Friedrich, Pieter M. Grootes, Thomas P. Guilderson, Haflidi Haflidason, Irka Hajdas, Christine Hatté, Timothy J. Heaton, Dirk L. Hoffmann, Alan G. Hogg, Konrad A. Hughen, K. Felix Kaiser, Bernd Kromer, Sturt W. Manning, Mu Niu, Ron W. Reimer, David A. Richards, E. Marian Scott, John R. Southon, Richard A. Staff, Christian S. M. Turney, and Johannes van der Plicht
 2013 IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. *Radiocarbon* 55:1869–1887. http://dx.doi.org/10.2458/azu_js_rc.55.16947.
- Reimer, Paula J., William E. N. Austin, Edouard Bard, Alex Bayliss, Paul G. Blackwell, Christopher Bronk Ramsey, Martin Butzin, Hai Cheng, R. Lawrence Edwards, Michael Friedrich, Pieter M. Grootes, Thomas P. Guilderson, Irka Hajdas, Timothy J. Heaton, Alan G. Hogg, Konrad A. Hughen, Bernd Kromer, Sturt W. Manning, Raimund Muscheler, Jonathan G. Palmer, Charlotte Pearson, Johannes van der Plicht, Ron W. Reimer, David A. Richards, E. Marian Scott, John R. Southon, Christian S. M. Turney, Lukas Wacker, Florian Adolphi, Ulf Büntgen, Manuela Capano, Simon M. Fahrni, Alexandra Fogtmann-Schulz, Ronny Friedrich, Peter Köhler, Sabrina Kudsk, Fusa Miyake, Jesper Olsen, Frederick Reinig, Minoru Sakamoto, Adam Sookdeo, and Sahra Talamo
 2020 The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon* 62:725–757. <http://dx.doi.org/10.1017/RDC.2020.41>.
- Rice, Don S., and Dennis E. Puleston
 1981 Ancient Maya Settlement Patterns in the Peten, Guatemala. In *Lowland Maya Settlement Patterns*, edited by Ashmore Wendy, pp. 121–156. SAR. University of New Mexico Press, Albuquerque.
- Rosenswig, Robert M.
 2021a Reconstructing Sovereignty on Ancient Mesoamerica's Southern Pacific Coast. *American Anthropologist* 123:370–388.
 2021b Early Mesoamerican Monumentality. *Nature Human Behaviour* 5:1469–1470.
- Rosenswig, Robert M., and Ricardo López-Torrijos
 2018 LiDAR Reveals the Entire Kingdom of Izapa during the First Millennium b.c. *Antiquity* 92:1292–1309. <https://doi.org/10.15184/aqy.2018.166>.
- Rosenswig, Robert M., Ricardo Lopez-Torrijos, Caroline E. Antonelli, and Rebecca R. Mendelsohn
 2013 LiDAR Mapping and Surface Survey of the Izapa State on the Tropical Piedmont of Chiapas, Mexico. *Journal of Archaeological Science* 40:1493–1507. <http://dx.doi.org/10.1016/j.jas.2012.10.034>.
- Ruppert, Karl
 1940 A Special Assemblage of Maya Structures. In *The Maya and their Neighbors*, edited by Clarence L. Hay, Ralph L. Linton, Samuel K. Lothrop, Harry L. Shapiro, and George C. Vaillant, pp. 222–223. D. Appleton-Century Company, New York and London.
- Sanders, William T., and David Webster
 1988 The Mesoamerican Urban Tradition. *American Anthropologist* 90:521–546.
- Schreiner, Thomas
 2001 Fabricación de cal en Mesoamérica: Implicaciones para los mayas del preclásico en Nakbé, Petén. In *XIV Simposio de Investigaciones Arqueológicas en Guatemala*, edited by Juan Pedro Laporte, Ana C. de Suasnavar, and Bárbara Arroyo, pp. 405–418. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala City. Electronic document, <http://www.asociaciontikal.com/wp-content/uploads/2016/11/25.00.pdf>, accessed September 30, 2022.
- 2002 *Traditional Maya Lime Production: Environmental and Cultural Implications of a Native American Technology*. Unpublished Ph.D. dissertation, Department of Architecture, University of California, Berkeley.
- 2009 Excavaciones y prospección arqueológica en el Sacbé Tintal-Mirador: Excavación en el Bajo Carrizal, Op. 500 F y La Naranjita Op. 500 G. In *Investigaciones multidisciplinarias en El Mirador: Informe final de la temporada 2008*, Vols. 1 & II, edited by Héctor Mejía, Richard D. Hansen, and Edgar Suyuc-Ley, Vol. II, pp. 217–242. Report filed with the Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Departamento de Monumentos Prehispánicos y Coloniales, Guatemala City, and FARES Foundation, Idaho State University, Pocatello.

- 2021 Production and Use of Lime for Preclassic Architecture and Causeway Construction in the Mirador Karstic Basin. Paper presented at the Society for American Archaeology, Session 48: Recent Multidisciplinary Investigations in the Mirador Basin, Guatemala.
- Schreiner, Thomas, and Enrique Hernández
- 2008 Investigaciones en el Sacbe Tintal, Mirador y Naranjita, 2008. In *Informe preliminar temporada 2008: Investigación y conservación en los sitios arqueológicos de la zona cultural y natural Mirador 2008*, edited by Nora Lopez, Richard Hansen, and Edgar Suyuc-Ley, pp. 120–123. Report filed with the Instituto de Antropología e Historia, Monumentos Prehispánicos y Coloniales, Ministerio de Cultura y Deportes, Guatemala City.
- 2009 Excavaciones y prospección arqueológica en el Sacbé Tintal-Mirador: Excavación en el Bajo Carrizal, Op. 500 F y La Naranjita Op. 500 G. In *Investigaciones multidisciplinarias en El Mirador: Informe final de la temporada 2008*, Vols. 1 & II, edited by Héctor Mejía, Richard D. Hansen, and Edgar Suyuc-Ley, Vol. II, pp. 217–242. Report filed with the Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Departamento de Monumentos Prehispánicos y Coloniales, Guatemala City.
- Schreiner, Thomas, Enrique Hernández, David Wahl, and Richard Hansen
- 2015 Preclassic Causeways of the Mirador Basin, Guatemala. Paper presented at the 80th Annual Meeting of the Society for American Archaeology, San Francisco.
- Schroder, Whittaker, Timothy Murtha, Charles Golden, Armando Anaya Hernández, Andrew Scherer, Shanti Morell-Hart, Angélica Almeyda Zambrano, Eben Broadbent, and Madeline Brown
- 2020 The Lowland Maya Settlement Landscape: Environmental LiDAR and Ecology. *Journal of Archaeological Science: Reports* 33:102543. <https://doi.org/10.1016/j.jasrep.2020.102543>.
- Seefeld, Nicolaus
- 2013 Public Provisions for Dry Season: The Hydraulic System of Uxul and its Relevance for the Survival of the Settlement. *Contributions in New World Archaeology* 5:57–84.
- 2017 *The Hydraulic System of Uxul: Origins, Functions, and Social Setting*. Ph.D. dissertation, Institut für Archäologie und Kulturanthropologie (IAK), Philosophische, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn. Electronic document, <https://bonndoc.ulb.uni-bonn.de/xmlui/handle/20.500.11811/7058>, accessed September 30, 2022.
- Sharer, Robert J., and David W. Sedat
- 1987 *Archaeological Investigations in the Northern Maya Highlands, Guatemala: Interaction and the Development of Maya Civilization*. University Museum Monograph 59, University of Pennsylvania, Philadelphia. <https://doi.org/10.2307/280812>.
- Sharer, Robert J., Andrew K. Balkansky, James H. Burton, Gary M. Feinman, Kent V. Flannery, David C. Grove, Joyce Marcus, Robert G. Moyle, T. Douglas Price, Elsa M. Redmond, Robert G. Reynolds, Prudence M. Rice, Charles S. Spencer, James B. Stoltman, and Jason Yaeger.
- 2006 On the Logic of Archaeological Inference: Early Formative Pottery and the Evolution of Mesoamerican Societies. *Latin American Antiquity* 17:90–103. <https://doi.org/10.2307/25063038>.
- Shaw, Justine M.
- 2001 Maya Sacbeob: Form and Function. *Ancient Mesoamerica* 12:261–272. <https://doi.org/10.1017/S0956536101121048>.
- 2008 *White Roads of the Yucatan: Changing Social Landscapes of the Yucatec Maya*. University of Arizona Press, Tucson. Electronic document, <https://uapress.arizona.edu/book/white-roads-of-the-yucatan>, accessed September 30, 2022.
- Sidrys, Raymond
- 1978 Megalithic Architecture and Sculpture of the Ancient Maya. In *Papers on the Economy and Architecture of the Ancient Maya*, edited by Raymond Sidrys, pp. 155–183. Monograph VIII, Institute of Archaeology, University of California, Los Angeles.
- Smith, Michael E.
- 2016 How Can Archaeologists Identify Early Cities: Definitions, Types, and Attributes. In *Eurasia at the Dawn of History: Individualization, Urbanization and Social Differentiation*, edited by Manuel Fernández-Götz and Dirk Krausse, pp. 153–168. Cambridge University Press, Cambridge, London, and New York.
- 2020 Definitions and Comparisons in Urban Archaeology. *Journal of Urban Archaeology* 1:15–30.
- Šprajc, Ivan
- 2020 *Lost Maya Cities: Archaeological Quests in the Mexican Jungle*. Texas A&M University Press, College Station.
- 2021a Equinoctial Sun and Astronomical Alignments in Mesoamerican Architecture: Fiction and Fact. *Ancient Mesoamerica*, 1–17. <https://doi.org/10.1017/S0956536121000419>.
- 2021b Astronomical Aspects of Group E-Type Complexes and Implications for Understanding Ancient Maya Architecture and Urban Planning. *PLoS ONE* 16(4):e0250785. <https://doi.org/10.1371/journal.pone.0250785>.
- Šprajc, Ivan, Nicholas P. Dunning, Jasmina Štajdohar, Quintin Hernández Gómez, Israel Chato López, Aleš Marsetič, Joseph W. Ball, Sara Dzul Góngora, Octavio Q. Esparza Olguín, Atasta Flores Esquivel, and Žiga Kokalj
- 2021 Ancient Maya Water Management, Agriculture, and Society in the Area of Chactún, Campeche, Mexico. *Journal of Anthropological Archaeology* 61:101261. <https://doi.org/10.1016/j.jaa.2020.101261>.
- Stanton, Travis W., Traci Ardren, Nicolas C. Barth, Juan C. Fernandez-Diaz, Patrick Rohrer, Dominique Meyer, Stephanie J. Miller, Aline Magnoni, and Manuel Pérez
- 2020 “Structure” Density, Area, and Volume as Complementary Tools to Understand Maya Settlement: An Analysis of LiDAR Data along the Great Road between Coba and Yaxuna. *Journal of Archaeological Science: Reports* 29:102178. <https://doi.org/10.1016/j.jasrep.2019.102178>.
- Stuart, George E.
- 1992 Maya Heartland Under Siege. *National Geographic* 192(5):94–107.
- Stuiver, Minze, and Paula J. Reimer
- 1993 Extended 14C Data Base and Revised CALIB 3.0 14C Age Calibration Program. *Radiocarbon* 35: 215–230.
- Suyuc-Ley, Edgar, and Richard D. Hansen
- 2013 El complejo piramidal La Danta: Ejemplo del auge en El Mirador. In *Millenary Maya Societies: Past Crises and Resilience*, edited by M. Charlotte Arnaud and Alain Breton, pp. 217–234. Electronic document, http://mesoweb.org/publications/MMS/14_Suyuc-Hansen.pdf, accessed September 30, 2022.
- Takaku, Junichi, Takeo Tadono, and Ken Tsutsui
- 2014 Generation of High-Resolution Global DSM from ALOS Prism. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL-4:243–248. <https://doi.org/10.5194/isprsarchives-XL-4-243-2014>.
- Takaku Junichi, Takeo Tadono, Ken Tsutsui, and Mayumni Ichikawa
- 2016 Validation of “AW3D” Global DSM Generated from ALOS Prism. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* III-4:25–31. <https://doi.org/10.5194/isprsannals-III-4-25-2016>.
- Taylor, Charles J., and Earl A. Greene
- 2008 Hydrogeologic Characterization and Methods Used in the Investigation of Karst Hydrology. In *Field Techniques for Estimating Water Fluxes between Surface Water and Ground Water*, edited by Donald O. Rosenberry and James W. LaBaugh, pp. 71–114. U.S. Geological Survey Techniques and Methods 4-D2. Electronic document, <https://pubs.usgs.gov/tm/04d02/>, accessed September 30, 2022.
- Tedlock, Dennis
- 1996 *Popol Vuh: The Definitive Edition of the Mayan Book of the Dawn of Life and the Glories of Gods and Kings*. Touchstone, Simon & Schuster, New York and London.
- Thompson, Amy E.
- 2020 Detecting Classic Maya Settlements with LiDAR-Derived Relief Visualizations. *Remote Sensing* 12(17):2838. <https://doi.org/10.3390/rs12172838>.
- Thompson, J. Eric S.
- 1954 *The Rise and Fall of Maya Civilization*. University of Oklahoma Press, Norman.
- Traxler, Loa P., and Robert J. Sharer (editors)
- 2016 *The Origins of the Maya States*. University of Pennsylvania Museum, Philadelphia.
- Villa R., Alfonso
- 1934 *The Yaxuna-Coba Causeway*. Contributions to American Archaeology 9. Carnegie Institution of Washington Publication 436, Washington, DC.

- Weber, Max
1956 *The Sociology of Religion*, translated by Ephraim Fischhoff. Beacon Press, Boston.
- Weishampel, John F., Jessica N. Hightower, Arlen F. Chase, Diane Z. Chase, and Ryan A. Patrick
2011 Detection and Morphologic Analysis of Potential Below-Canopy Cave Openings in the Karst Landscape around the Maya Polity of Caracol Using Airborne LiDAR. *Journal of Cave and Karst Studies* 73:187–196.
- White, William B.
1988 *Geomorphology and Hydrology of Karst Terrains*. Oxford University Press, Oxford.
- Woods, James C., and Gene L. Titmus
1996 Stone on Stone: Perspectives of Maya Civilization from Lithic Studies. *Eighth Palenque Round Table*, 1993, edited by Merle Greene Robertson, Martha J. Macri, and Jan McHargue, pp. 479–489. Pre-Columbian Art Research Institute, San Francisco.
- Woods, James C., and Gene L. Titmus
1994 Piedra en piedras: Perspectivas de la civilización maya a través de los estudios líticos. In *VII Simposio de Investigaciones Arqueológicas en Guatemala*, 1993, edited by Juan Pedro Laporte and Héctor L. Escobedo, pp. 349–368. Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Museo Nacional de Arqueología y Etnología, Guatemala City. Electronic document, <http://www.asociaciontikal.com/wp-content/uploads/2016/11/28.93-Woods-y-Titmus.pdf>, accessed September 30, 2022.
- Wright, Henry T., and Gregory A. Johnson
1975 Population, Exchange, and Early State Formation in Southwestern Iran. *American Anthropologist* 77:267–289.
- Żralka, Jarosław, and Wiesław Koszkul
2015 Archaeological Evidence for Ancient Maya Water Management: The Case of Nakúm, Peten, Guatemala. *Antiquity* 39:397–416.