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PUBLIC PROVISIONS FOR DRY SEASONS: THE HYDRAULIC SYSTEM OF UXUL AND ITS RELEVANCE FOR THE SURVIVABILITY OF THE SETTLEMENT

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Abstract

As palaeoclimatic studies indicate, the water supply of the Central Maya Lowlands during the Classic period, was as challenging as it is today. One of the goals of the Uxul Archaeological Project is the identification of the adaptation strategies, which guaranteed the site its water supply. The archaeological investigation of the site's two big artificial reservoirs (Aguada Oriental and Aguada Occidental) and a sophisticated feeding canal demonstrate that these hydraulic features had been the result of costly labor investment and that their construction had been carefully planned. All results obtained indicate that Uxul's pre-Hispanic inhabitants were well aware of the fatal risk of an ebbing water supply and therefore modified the natural landscape in order to increase the local watersheds. This paper will introduce the formation and function of Uxul's hydraulic features, analyze the social system in which they emerged and will furthermore examine how the challenge of water supply was managed at other sites of the Central Lowlands.

Resumen

Como los estudios paleoclimaticos nos indican, el abastecimiento de agua en las Tierras Bajas Mayas durante el Clásico Tardío, fue un desafío similarmente grande como hoy en día. Una meta del Proyecto Arqueológico Uxul es la identificación de las estrategias que garantizaban el abastecimiento de agua en el sitio. La investigación arqueológica de los dos depósitos de agua artificiales (Aguada Oriental y Aguada Occidental), así como un canal de afluencia indican que estos rasgos hidráulicos son el resultado de una gran inversión de trabajo y que su construcción había sido planificado cuidadosamente. Todos los resultados obtenidos indic an que los habitantes prehispánicos de Uxul estaban conscientes del riesgo mortal de una falla del abastecimiento de agua y que consecuentemente modificaron el paisaje natural para aumentar las cuencas hidrográficas locales. Este artículo va introducir la formación y la función de los rasgos hidráulicos de Uxul y analizar el sistema social en el cual surgieron. Últimamente, se examinará como el reto del abastecimiento de agua fue acometido en otros ciudades de la Tierras Bajas Centrales.

INTRODUCTION

Since the inception of Maya studies, the issue of water supply in Maya polities of the Central Lowlands during the Classic period has been a matter of controversial debate. Due to the familiar and annually recurring dry and rainy seasons, the availability of water during the dry period is and has always been problematic. In the light of these conditions it is highly astonishing, that the ancient Maya were able to found, develop and maintain prospering urban centers over surprisingly long periods. While the ancient Maya had evidently developed effective adaptation strategies for survival in this landscape, these strategies are largely unknown today and these remain a little-studied research focus. Due to this circumstance we lack an exact explanation as to how a constant water supply could have been ensured in Classic Maya polities. This article presents the results of the archeological investigations of three hydraulic features within the site of Uxul, Campeche, Mexico. These investigations were planned and carried out with the objective of developing a functional model of water supply for this settlement.

Within the first part of this paper I will address the ecological and cultural reasons for the complexity of water supply as well as the key points of research history and the theories relating to water management. Thereafter, the location, composition and functionality of Uxul's hydraulic features shall be clarified. he final section of the paper will illustrate the relevance of these hydraulic features for the survivability of the settlement. In order to introduce the site of investigation, the Uxul Archaeological Project is first presented.

Uxul is a medium-sized Classic Maya City in the extreme south of Campeche (see Figure 1). The site is located within the Calakmul Biosphere, 34 km southwest of Calakmul and 4 km north of the border separating Mexico and Guatemala (Grube *et al.* 2012). Over the course of the past four years (2009-2012) the Uxul Archaeological Project of the University of Bonn, Germany, has conducted archaeological surveys and excavations at the site. The project is carried out under general direction of Nikolai Grube and Antonio Benavides Castillo and in collaboration with Mexico's Instituto Nacional de Antropología e Historia (INAH). Funding for the project is provided by the German Science Foundation (DFG). The site was discovered, examined and mapped in 1934 during the Third Carnegie Institution of Washington expedition to Campeche (Ruppert and Denison 1943: 74). The scientific rediscovery of Uxul took place in 2005, after Iván Šprajc had identified the site on aerial photos (Šprajc 2008: 13). Thorough mapping of the area once occupied by the city began in 2007 in preparation for the current archaeological research project. The goal of the project is to investigate the expansion and disintegration of hegemonic power in the Maya area, concentrating in the core area of the Maya Lowlands (Grube and Delvendahl 2011: 66; Grube *et al.* 2012).

Thus far, a total of 614 structures have been mapped within the site. Based upon this result, a population of approximately 5 000 people can be estimated at present. The site's occupation began in the late Middle or Late Preclassic and persisted into the initial portion of the Terminal Classic (Grube *et al.* 2012).

THE CHALLENGE OF WATER SUPPLY IN THE CENTRAL MAYA LOWLANDS

A significant prerequisite for the funding and growth of all human settlements, is an assured and constant water supply for all of its inhabitants. However, the general availability of water in the Central Maya Lowlands is highly problematic. Essentially this problem is caused by two basic factors:

- First, the Yucatan Peninsula consists of a permeable limestone shelf that is almost entirely devoid of surface water (Dunning *et al.* 2006: 82; Wahl *et al.* 2007: 214).

- Second, the climate of this region is marked by the pronounced seasonality of rainfalls, which manifest themselves in the distinctly separated rainy season and dry-season (Scarborough 1991: 125).

Currently, this combination of highly seasonal precipitation, as well as the general absence of surface water represent a challenge for all dwellers within this habitat (Weiss-Krejci and Sabbas 2002: 343; Wilk 1985: 48). In order to comprehend the current perceptions and ideas on Maya water management practices, the most significant benchmarks of the research history will be addressed below.

Figure 1. Map of the Yucatán Peninsula (this and all other figures by Nicolaus Seefeld unless otherwise specified).

KEY POINTS OF RESEARCH HISTORY ON THE ISSUE OF WATER SUPPLY

The problems deriving from this specified water scarcity had already been recognized at the very beginnings of scientific examinations of prehispanic Maya Culture. Thus John Lloyd Stephens (1843, II: 165) already observed that “Among the wonders unfolded by the discovery of these ruined cities, what made the strongest impression on our minds was the fact that their immense population existed in a region so scantily supplied with water”.

Despite such early and self-evident conclusions, a resolution of this issue was not pursued before the beginning of the 1970ies. Prior to this time, the issue of water supply was frequently diluted by the assumption, that climatic conditions during the Classic period had been much more favorable. This vision was essentially based on a hypothesis by Charles Wythe Cooke, who claimed that the contemporary seasonal *bajos* would have constituted perennial bodies of freshwater as shallow lakes or big reservoirs during the Preclassic and Classic periods (Cooke 1931). Although none of these assumptions had been sustained by empirical data, this vision was widely accepted (Turner and Harrison 1983: 265). Most regrettably, it was even actively diffused by the majority of the scientific community, causing it to be treated as common consensus (Leyden 2002: 93; Siemens 1982: 216; Adams 1980: 211).

A serious investigation of the issue of water supply was not furthered before the early 1980ies, when the first pollen diagrams were extracted within the Central Lowlands (Turner and Harrison 1983: 251; Dunning *et al.* 2006: 85). While these pollen-diagrams had initially been extracted quite sporadically, they have experienced a much wider application during the last three decades (Folan *et al.* 1995: 312; Gunn *et al.* 1994, 1995). During this process an extended corpus of pollen-diagrams were developed. Many of the resulting climate-reconstructions suggested that conditions during the Late Classic period had been comparable with contemporary conditions in the majority of the regions, and especially in the Central Lowlands (Shaw 2003: 160; Beach *et al.* 2003; Gunn *et al.* 2002: 298).

The resulting scenario indicates that water supply within the Central Lowlands during the Late Classic period was as challenging a task as nowadays (Dunning *et al.* 2006: 85). To this day we are still lacking an exact explanation as to how the prehispanic Maya, with scarce water resources, were able to sustain extended settlements. Although the interest in Maya water management practices on the part of the archaeologists has markedly increased since the emergence of palaeoclimatic studies, and particularly during the last decade (cf. Geovannini Acuña 2008; Beach *et al.* 2008; Brewer 2007; Crandall 2009; Davis-Salazar 2003; Dunning *et al.* 2010; Johnston 2004; Thomas 2010; Weiss-Krejci and Brandl 2010), a clear elucidation of adaptation strategies is still lacking for the majority of Maya sites.

REQUIREMENTS FOR A CONSTANT WATER SUPPLY

In order to focus an understanding of these adaptation strategies, the author’s archaeological research within the Uxul Archaeological Project was planned and carried out with the objective of developing a functional model of water supply for the settlement, which would be able to explain the apparent incompatibility of scarce water-sources and high settlement densities. Since the ancient Maya survived and flourished for many centuries at Uxul and other polities faced the very same challenges, they evidently must have developed effective strategies of water supply. However, this task, apart from the aforementioned constraints conditioned by the landscape and environment, was further complicated by the fact, that this habitat was lacking animals that could be used as beasts of burden (Crandall 2009: 14). Due to such additional constraints, water could not be transported over long distances since all loads needed to be carried by human bearers. For trading lighter goods such as jadeite, obsidian and even food crops, a transport by human carriers was demonstrably practicable, even for longer distances (Tourtellot and Sabloff 1972: 132; Drennan 1994: 210). In contrast, water imports soon would have become inefficient after few kilometers, because the carriers had to consume considerable amounts of the transported water themselves (Drennan 1985: 891). Therefore, water imports from sources more than a couple of kilometers from the settlement-center would be inefficient.

Consequently, Maya polities could not be supplied by sources of water from the hinterlands. Accordingly, regional models of water supply that have been developed for ancient civilizations of the Old World, as well as the New World, surely cannot be applied for the Maya civilization (Wheeler 1969; Scarborough 2003: 145; Prasad *et al.* 1987). In fact, one is compelled to develop a local model, since the water supply of each settlement inevitably had to be locally motivated and organized. Thus, it can be stipulated that each settlement needed to ensure, that the local water sources permitted a sufficient provision for each inhabitant during the entire year.

The key to such a provision rests in the application of rainwater harvesting. By utilizing the landscape and collecting some amount of the precipitations of the rainy season, the development of a water storage for the dry season would have been possible (Dunning *et al.* 1999: 656; Geovannini Acuña 2008: 87). Rainwater harvesting aims to collect a maximum of precipitations before they seep into the bedrock. Within the landscape of the Central Lowlands, the inhabitants therefore had to make use of natural surface depressions and extend their natural catchment area. For this purpose, one could artificially increase the capacity of existing reservoirs and alter the course of seasonal streams (*corrientales* and *arroyos*) (Scarborough *et al.* 1995: 100). Essentially, rainwater harvesting involves landscape modifications of varying scales. Artificial reservoirs could be created either by increasing the size or impermeability of natural depressions or through more labor intensive "constructions" of new reservoirs. Growing interest in the water management practices of the Maya has shown the wide prevalence of this technique in sites such as Edzna (Matheny 1976, 1978; Matheny *et al.* 1983), La Milpa (Scarborough *et al.* 1995: 101) and Tikal (Silverstein *et al.* 2009; Dunning *et al.* 2010). The self-evident application of that technique becomes obvious in the fact, that it still could be observed by Fray Diego de Landa, who described, that "those Indians who are living close to the mountains tend to dig cavities into the bedrock, in order to collect precipitations, because of the low-lying groundwater-level" (de Landa 1993: 155).

Since most of these documented applications of rainwater harvesting involved large-scale landscape modifications, they necessarily required the recruitment of a large workforce. Historically, discussions of Maya water management practices always considered their origin, functionality as well as their impacts on society and political structure. In order to develop a functional model of water supply, the existing theories pertaining to the social relevance of water-management likewise needs to be taken into consideration.

THEORIES ON THE SOCIAL RELEVANCE OF WATER-MANAGEMENT

The theory, that the development of hydraulic systems within the Maya Lowlands would have been an essential, if not the central driving factor for the formation of the Classic Maya society, is fundamentally based upon Wittfogel's (1957) model of hydraulic societies and Karl Marx' Asiatic production model (Kunen 2006: 100). This concept was originally drafted by Karl Marx in the theory of a hydraulic (*Oriental* or *Asiatic*) society (Marx and Engels 1957-1968: 13: 9) and subsequently adopted by Wittfogel (1957: 61). In 1957 Wittfogel devised his extended theory of hydraulic societies, in his opus magnum "*Oriental Despotism: A Comparative Study of Total Power*", in which he examined big hydraulic systems on a regional level (see also Scarborough 1991: 123). According to his conception, despotic bureaucracies constituted the consequences of large-scale irrigation systems in arid, or semi-arid regions, which had to be supplied with water from far-off sources by the use of canals (see also Seefeld 2008: 21). These attempts at irrigation led to the centralization of resource control and triggered the uneven relation between managers and consumers, which subsequently manifested itself in a strictly defined social stratification (Scarborough 1991: 123). His work of 1957 referred to the first hydraulic societies in southern Mesopotamia, China, Egypt and the Indus-Valley, but later on Wittfogel (1972) developed a model adapted to Mesoamerica. Basing themselves upon Wittfogel's models, some Mayanists speculated that the installation of hydraulic systems initially provoked the development of social stratification, which ultimately resulted in the manifestation of a centralized and authoritarian government during the Late Classic period (Adams 1991: 632; Puleston and Puleston 1971: 336; Palerm 1955). Dunning and colleagues (2006: 96) as well as Scarborough (1983: 720, 1998) believe that this process took place in several stages:

Initially, the Central Lowlands were sparsely settled during the Early and Middle Preclassic period (2000-300 B.C.) (Dunning *et al.* 1997: 93). From the early Classic on, the dry seasons would have forced the Maya to construct modified *aguadas* at the margins of seasonal *bajos* (Scarborough and Gallopin 1991: 661; Scarborough *et al.* 1994: 104; 1995: 109). According to this hypothesis, reservoirs would have developed into integral parts of the urban landscape in which such artificial water sources would have represented "foci of urbanization" (Dunning *et al.* 2006: 92-96). Scarborough (1991: 135) is convinced, that the construction of artificial reservoirs would have caused the gradual emergence of a centralized water resource control through local elites. These developments ultimately would have given rise to the centralization and stratification of land ownership (Dunning *et al.* 2006: 96). According to Scarborough's (1991: 106) belief, hydraulic structures, contrary to usual public architecture, required a more intensive planning and maintenance, and therefore constituted more suitable indicators for the power of elites (Kaplan 1963: 404). Based upon this idea, Pyburn (2003: 127) claims, that the generally poor state of preservation of hydraulic features could be attributed to the fact, that the small groups that populated the Central Lowlands after the collapse had been unable to assemble sufficient labor in order to maintain them (Scarborough 1994: 198; Turner and Harrison 1983: 248).

Those disputing the model of hydraulic societies criticize its claimed universality (Kunen 2006: 100). Weiss-Krejci and Sabbas (2002: 343), for instance, do not recognize hints for a centralized organization of water sources. According to these authors, there was no necessity for centrally controlled constructions of hydraulic features since the numerous natural and artificial water sources such as reservoirs, *aguadas*, small depressions or *chultunes* would have assured a sufficient water supply of the entire population (Weiss-Krejci and Sabbas 2002: 343). They advocate taking alternative and un-centralized water sources into consideration before claiming the preponderance and even necessity of centralized water resource control.

After this brief outline of the existing models on the origin, development and social relevance of Maya water management practices, I shall outline the methodology applied in the investigation of Uxul's hydraulic system.

ARCHAEOLOGICAL INVESTIGATION OF UXUL'S HYDRAULIC SYSTEM

Regardless of the predominating government or societal structure, the application of rainwater harvesting necessarily required landscape modifications, which nowadays can be still identified in the settlement landscape. In order to comprehend the adaptation strategies of Uxul's inhabitants, two basic research methods were applied during the last four field seasons (2009-2012):

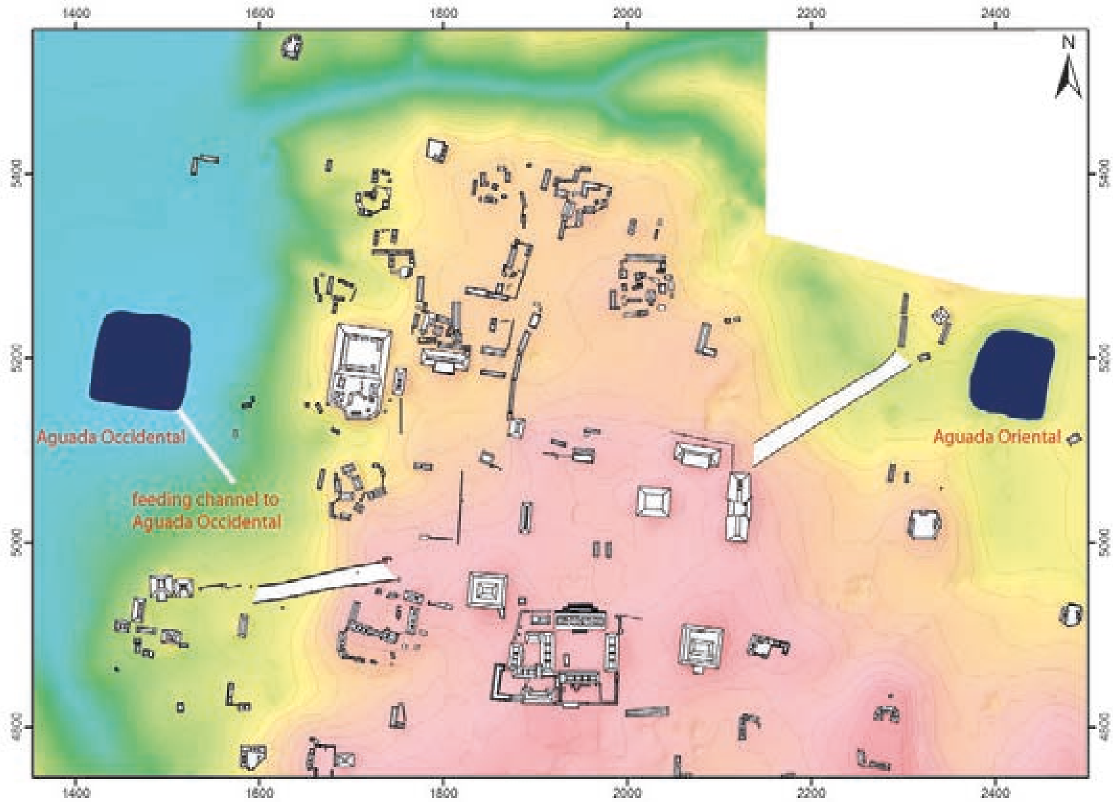

Figure 2. Map of Uxul's Hydraulic Features.

1) A topographic survey of the settlement landscape, in order to locate landscape modifications, which serve to divert and accumulate precipitations.

2) An archaeological investigation of these landscape modifications/hydraulic features, in order to obtain data on the technology, chronology, as well as the social implications of these modifications.

The settlement of Uxul is situated on elevated terrain close to a large *bajo*, with structures spreading over a group of adjacent flat hilltops with elevations fluctuating between 250 and 270 m above mean sea level (Grube *et al.* 2012). Seasonal streams, known locally as *corrientales* cut the relatively level surface of these hilltops and drain emerging runoff towards low-lying areas (Figure 2). In the landscape surveyed to date, three major hydraulic features could be identified: 1) the Aguada Occidental, 2) a feeder channel to the Aguada Occidental and 3) the Aguada Oriental (Figure 2). The two aguadas are situated to the west and east of the site core. Astonishingly, these reservoirs do not only share the same form and extent, but are also the same basic dimensions. Furthermore, it appears as though the two reservoirs served to demarcate the eastern and western boundaries of the site's epicenter since the density of structures markedly drops off to the west of the Aguada Occidental and to the east of the Aguada Oriental. Although size and form of the two reservoirs are nearly identical, they are located in differing topographic surroundings.

The Aguada Occidental, which was discovered and mentioned by Ruppert and Denison (1943) lies to the west of the central hilltop of Uxul, in a naturally low-lying area, which merges into a *bajo* further to the west. During the survey work of 2007, as well as during the 2012 field season, a standing water-surface was still visible during the dry season. Due to its low elevation, the Aguada Occidental exhibits an extensive catchment area and is fed with substantial amounts of run-off through numerous *corrientales*.

In contrast, the Aguada Oriental, which was discovered by the author in March 2009, is situated upon the crest of an elevated plain within the northeast of the settlement. Due to this location, it exhibits a water catchment area of at most 4 ha. Owing to these factors, water could only be observed during the exceptionally rainy field season of 2012. An interesting peculiarity of the Aguada Oriental is a linear depression of 15 m length in the middle of the southern bank, which obviously served to direct rainfall from the southern catchment area to the interior. As the map also clearly indicates, the reservoir is formally connected with the site core by a raised causeway, or *sacbe* (Figure 2).

In order to determine, if the two reservoirs constituted natural depressions, cultural modifications of natural depressions, or entirely new constructions, a systematic excavation schedule was developed: initially after its discovery, a 2 x 4 m trench was excavated at the very center of Aguada Oriental, in order to obtain a first impression of the soil types and general stratification (Figure 5). After exposing a highly complex base modification in the center, a 2 x 2 m trench was subsequently excavated near the northern bank on the same north-south axis.

The particularly dry field season of 2010 enabled the archaeological investigations in the Aguada Occidental. During that field season, a 2 x 4 m trench was excavated in the center of the reservoir (Figure 3).

Since the investigation of Aguada Oriental in 2009 had still left a number of open questions in regard to the construction methods, as well as the extension of base-modifications, the entire field season of 2011 was dedicated to the excavation of that reservoir. Fortunately, anticipating further explorations, the trenches dug in 2009 had been positioned in such a way, that future extensions towards the south would also intersect the clearly discernible feeding channel. This strategy enabled the seven new excavation units to be positioned upon the same axis as the 2009 trenches, so that the profiles of each individual trench could be merged to a nearly uninterrupted profile of the reservoir (Figure 5). The main purpose of excavating such a “complete profile” was to provide a foundation for the calculation of the reservoir’s total water holding capacity (Figure 9).

The canal feeding the Aguada Occidental had initially been observed in 2010. Essentially, this feeder canal at first consisted of two simple, but parallel stone alignments, which crossed the camp of the archaeological project. In order to assess their function, two trenches, one measuring 2 x 5 m and another measuring 1,5 x 12 m, were excavated in the middle of the camp. When these trenches revealed that these stone alignments constituted the top edges of two parallel lateral retaining walls, forming part of a sophisticated canal construction, a third 2 x 8 m trench was positioned near the southwestern edge of the Aguada Occidental, in direct extension of the course of the walls (Figure 4).

Owing to the intensive investigation of these hydraulic features, their structural composition, as well as the function of the individual constructional elements can be explained fairly well. Since, the process of construction is evident, the exposed features need not be presented in the same sequence, in which they were documented. In order to clarify the composition and function of each constructional element, these features will be presented in the sequence of the reconstructed building-history.

CONSTRUCTION HISTORY OF UXUL'S HYDRAULIC SYSTEM

Current excavation results indicate that the earliest constructions of Uxul began near the Aguada Occidental during the late Middle or Late Preclassic period (Grube *et al.* 2012). This outcome can be attributed to the fact, that the earliest settlers were necessarily dependent on a natural water source for the founding of a permanent settlement.

Aguada Occidental

The Aguada Occidental features a roughly rectangular shape and measures approximately 100 m on a side. The immediate topographic surroundings and the proximity to a *bajo* environment indicate, that this reservoir mainly constitutes a modification of an already existing natural *aguada*.

When this natural surface depression no longer provided sufficient water supply for an increasing population, the inhabitants decided in the first half of the Late Classic period, to increase its capacity artificially. To this end, the constructors initially removed the *aguada*'s natural alluvial sediment down to the natural underlying marl (known locally as *sascab*). In this process, a 3 m deep, rectangular basin with an artificially flattened ground area and uniformly sloped embankments was excavated (Figure 3).

During the subsequent construction stage, a pavement was assembled of unworked limestone slabs. The mostly rounded stones exhibit very uneven dimensions and are irregularly distributed. Moreover this pavement, which was documented at a depth of 170 cm, exhibits numerous gaps. This basal modification was apparently laid down in order to prevent water seepage and to potentially ensure the storage of large water quantities for the critical dry-season.

Feeder Canal to Aguada Occidental

During the second half of the Late Classic period, when the modifications to Aguada Occidental no longer adequately served to store sufficient water for the entire dry season, Uxul's inhabitants chose to reduce the seepage of precipitation by connecting the catchment area between Groups A and B and the reservoir's southeastern corner via a feeder canal (Figures 2 & 4). The canal's central element consists of a highly compact 2.80 m wide pavement of limestone-slabs, which feature a uniform height of 8 cm and had been processed particularly for this purpose. On both sides, the pavement was subsequently delimited by two vertical, 50 cm high walls of upright stone clabs (Figure 4). Thereupon, these vertical facings were enclosed by embankments of stones, measuring 80 cm wide and 40 cm high, in order to reinforce them laterally. Finally these embankments were themselves delimited on both sides by low stone facings (Figure 4). The highly quality of the pavement, in conjunction with the lateral veneers, accelerated the flow-rate and thereby impeded water-seepage effectively. By means of this canal, it became possible to extend the reservoir's catchment area and thereby increase the amount of stored water. Owing to the construction of a logging-road in the 1980ies, the canal's origin in the elevated terrain between Groups A and B has become obliterated. Currently, the canal can be seen to run a length of c. 50 m (Figure 2).

Aguada Oriental

The Aguada Oriental also measures approximately 100 m on a side and features a nearly perfectly rectangular form. Overall, the location of this reservoir appears strange in regard to the immediate topography, where no other natural depressions occur – especially when taking into account that a natural catchment area is almost entirely lacking (Figure 2). Excavations revealed that this reservoir definitely does not represent a modification of a previously existing natural depression. Instead, this location in the "high bush" (or *selva alta*) was rather consciously selected for the creation of a new

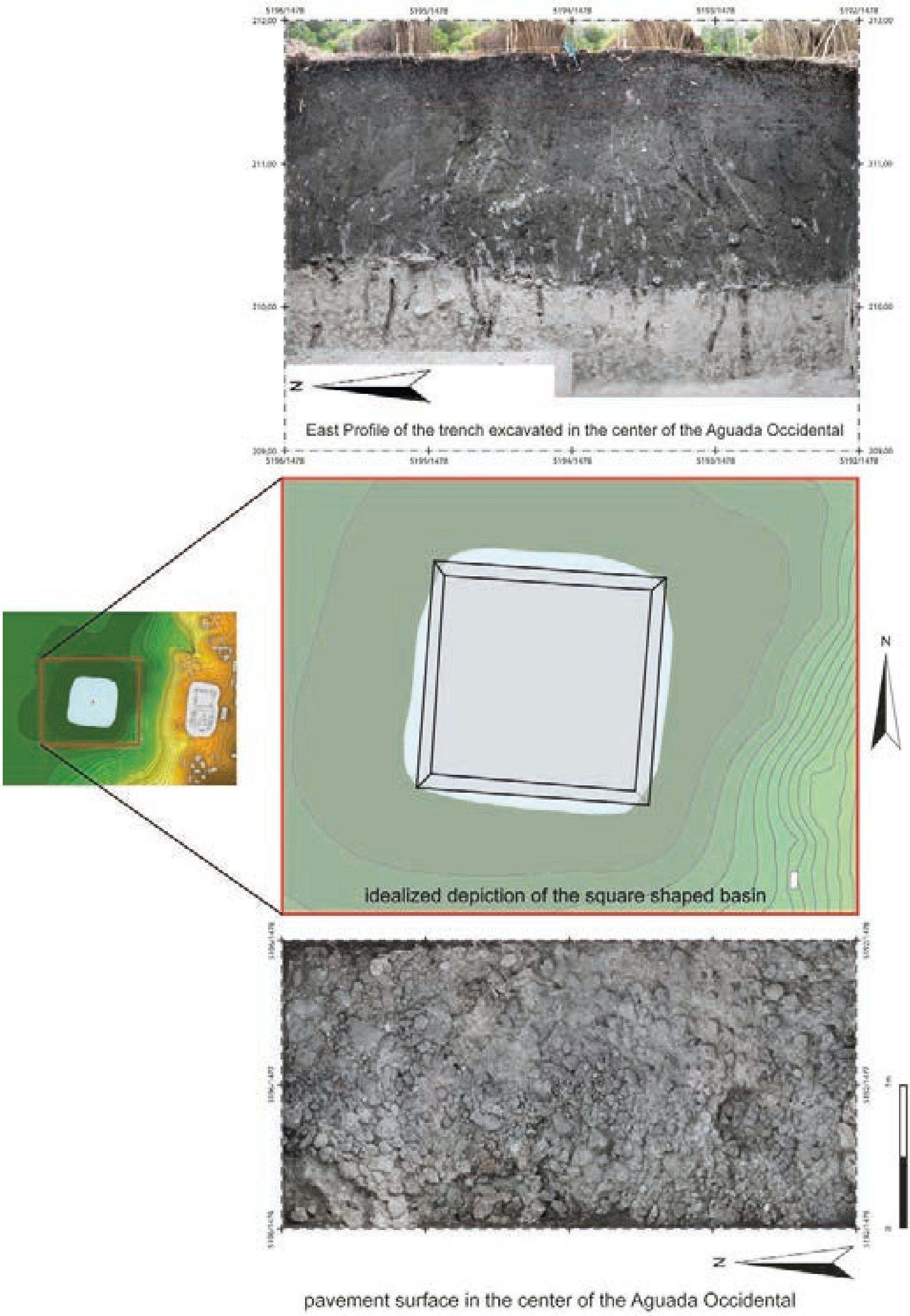

Figure 3. Base modification of the Aguada Occidental.

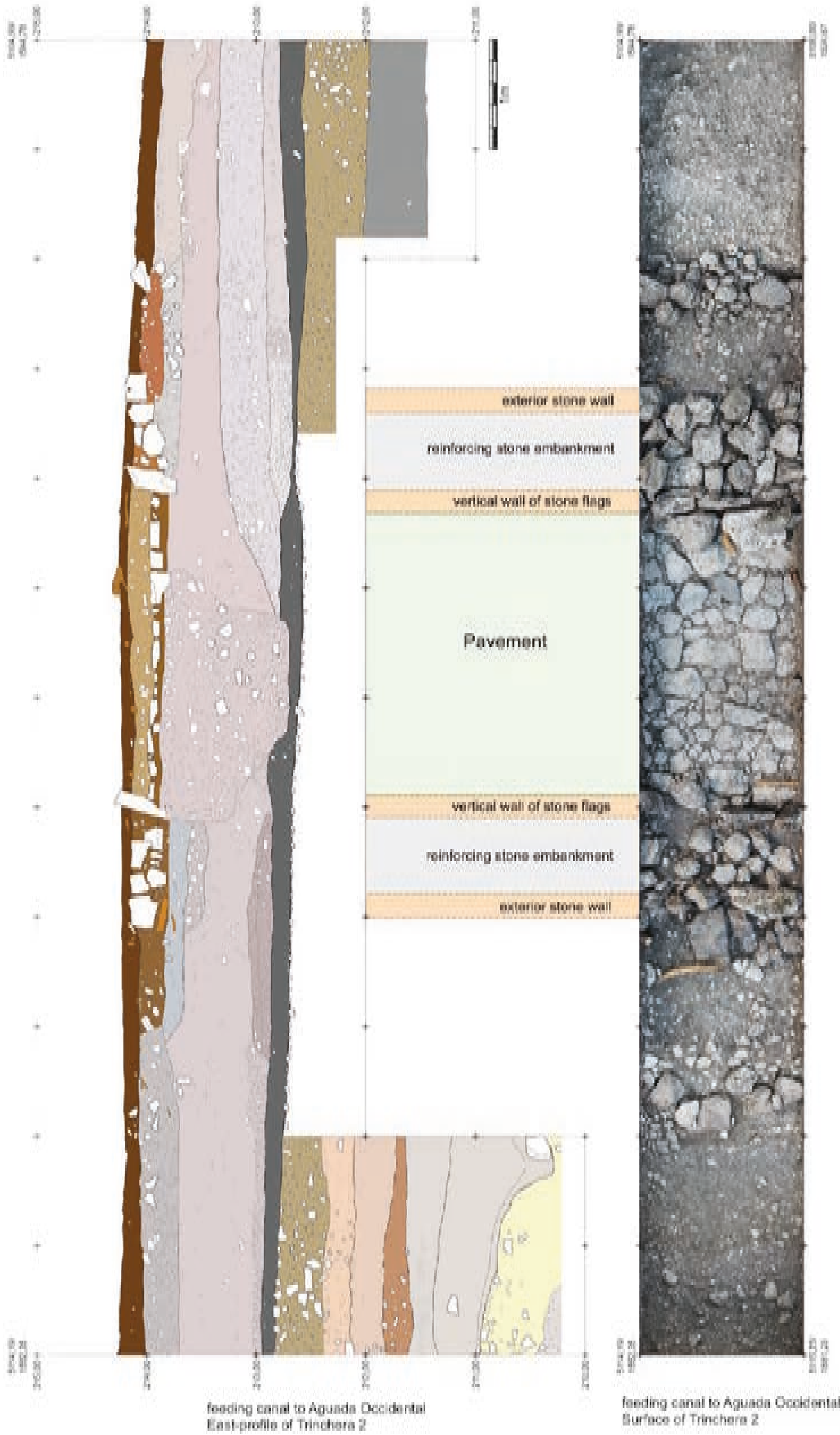

Figure 4. Structural composition of the feeding canal to the Aguada Occidental.

reservoir, which was constructed with great investments of logistics and labor. The dating of the ceramic material from the Aguada Oriental indicates, that this construction process took place during the second half of the Late Classic period (Sara Dzul, pers. comm. 2012).

During the first construction stage, a rectangular basin with a depth of 2.5 m was cut into the bedrock, with 3 m wide sloping embankments, of even angles, on all sides. The effects of this construction stage can still be observed in all of the nine trenches, which were excavated in this reservoir (Figure 5). During this process, a 4 m wide and 15 m long, semicircular depression, which was positioned exactly in the middle of the southern embankment, was likewise cut into the bedrock (Figure 5). At the northern end of this canal, a 0.4 m high and 4 m wide pedestal of bedrock was left standing, while the rest of reservoir was quarried out. Upon this pedestal, large, but carefully cut limestone-rocks were assembled into a wall measuring 1.20 m in height and consisting of four courses. This wall also partially blocked the canal's northern end (Figure 6). The lowest alignment of facing stones was anchored into cavities in the bedrock pedestal, which had been cut especially to receive these blocks. Furthermore, the basin's ground area was so carefully leveled, that the bedrock surface finally exhibited only minute height differences from the center to edge of the reservoir's construction (Figure 10).

During the following construction stage, several thousand ceramic sherds of plates and shallow basins were accurately and tightly bonded upon this finely leveled bedrock surface (Figure 7). These discarded vessels had obviously been collected during a long period and stored for this specific purpose since the constructors had evidently selected sherds of ceramic vessels with low heights and wide mouths. Apparently, the reservoir's engineer(s) had purposefully assembled these specific fragments, in order to assemble them into a mosaic-like ceramic-layer with an even surface. A close examination of this exposed feature shows that many of the partial vessels were deliberately fragmented *in situ*. The archaeological documentation process showed, that each sherd had deliberately been placed upon the artificially leveled bedrock surface, since not a single fragment was superimposing each other (Figure 7).

During the next working stage, a pavement of flat limestone slabs was placed upon this ceramic layer (Figure 8). These limestone slabs, which were presumably produced during the excavation of the bedrock, were cut to a uniform height of 5-7 cm and feature dimensions of 8 x 10 cm and up to 28 x 40 cm. In order to create a solid surface, they were carefully assembled to form a very homogenous pavement. Remains of this pavement were documented in all of the excavated trenches. Excavations revealed that the pavement of the *aguada*'s base precisely begins at the transition from the slope to the even base-surface of the reservoir (Figure 8). The pavement shows neither gaps in the surface, nor differences in form and size of the individual stone slabs. A more detailed examination of these documented surfaces also shows that all the gaps between the individual stone slabs had been filled up with a surprisingly hard stucco binder (Figure 8). Due to this accurate layout, this final construction unit minimized water-seepage and could be documented in its nearly intact state.

Through its position within the installation the retaining wall feature can easily be identified as a "filter-wall", which served to purify the rainwater, of the southern catchment area that streamed in via the southern influx channel from sediment and ensured a decontaminated reservoir north of this barrier. The elevated position of the retaining wall supposedly facilitated the deposition of sediment and other impurities. If these particles would have been removed on a regular basis, this construction element clearly would have improved that reservoir's overall potability.

That the entire construction of the Aguada Oriental was formally connected with the settlement's center by a *sacbe*, points out the desire to integrate it into the urban architecture (see Figure 2). Due to the spatial relationship of the *sacbe* between the aguada and the epicenter it stands to reason that this sacbe was built after the completion of the reservoir.

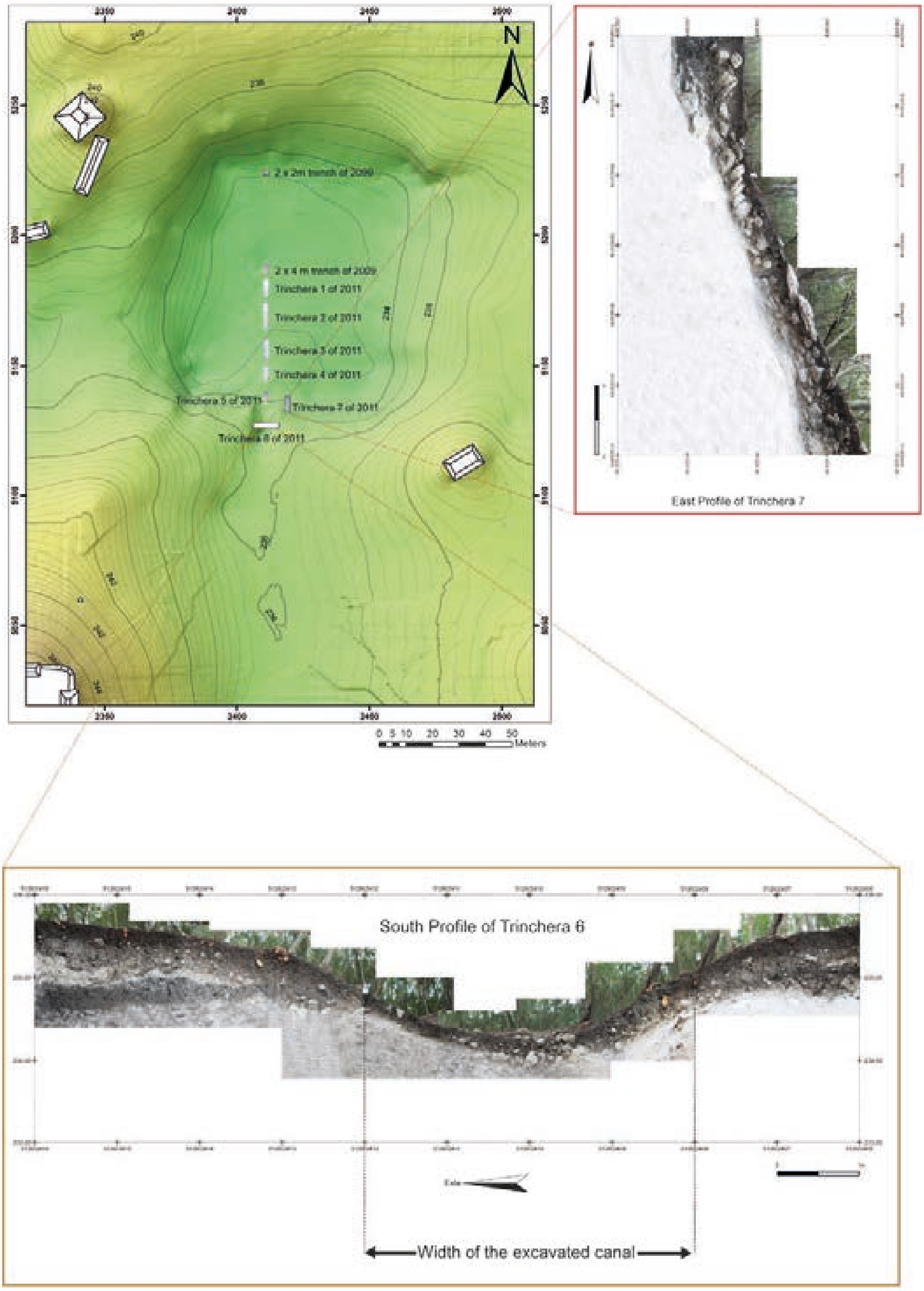

Figure 5. Bedrock modifications during the construction of the Aguada Oriental.

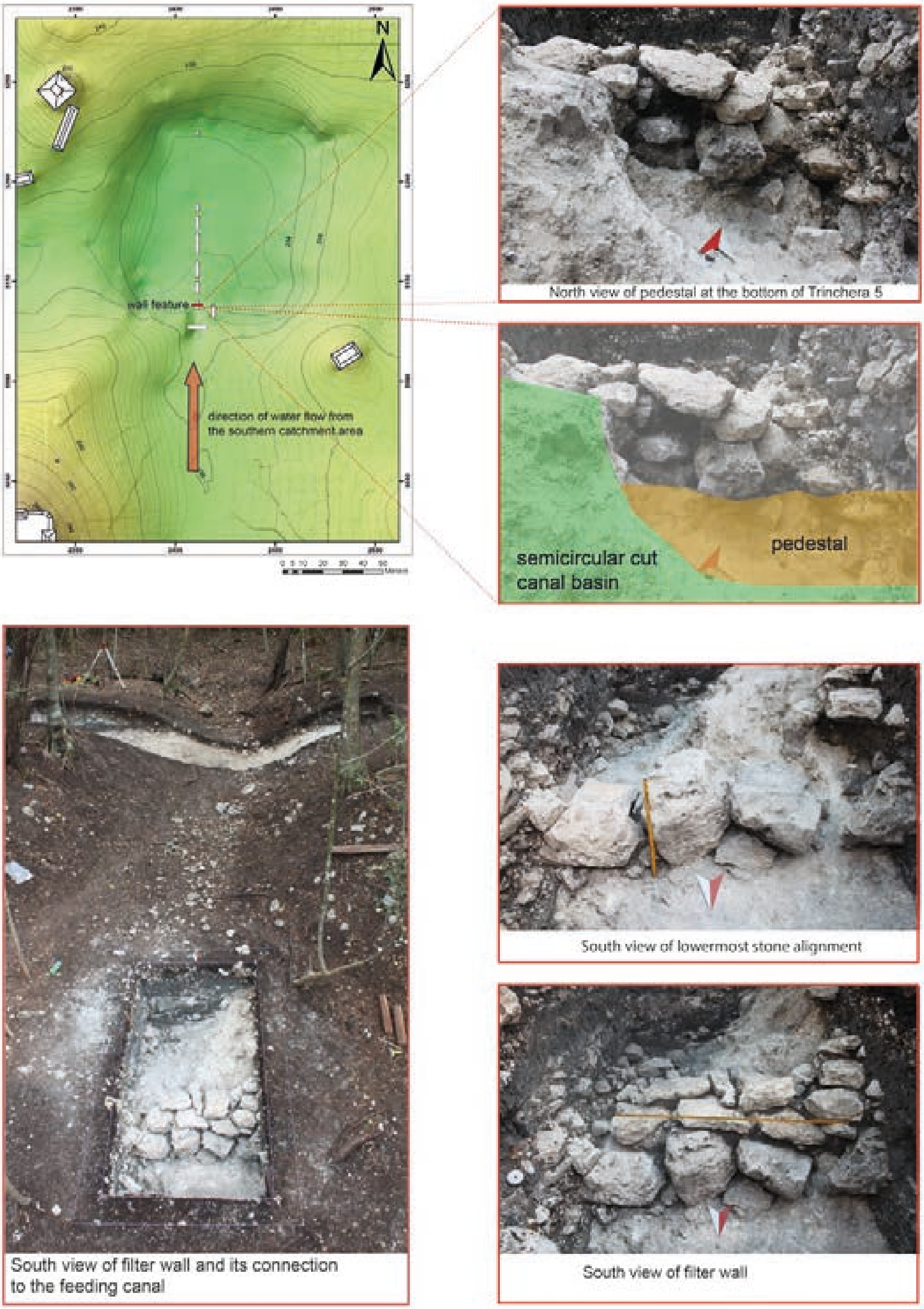

Figure 6. Composition of the filter-wall within the Aguada Oriental.

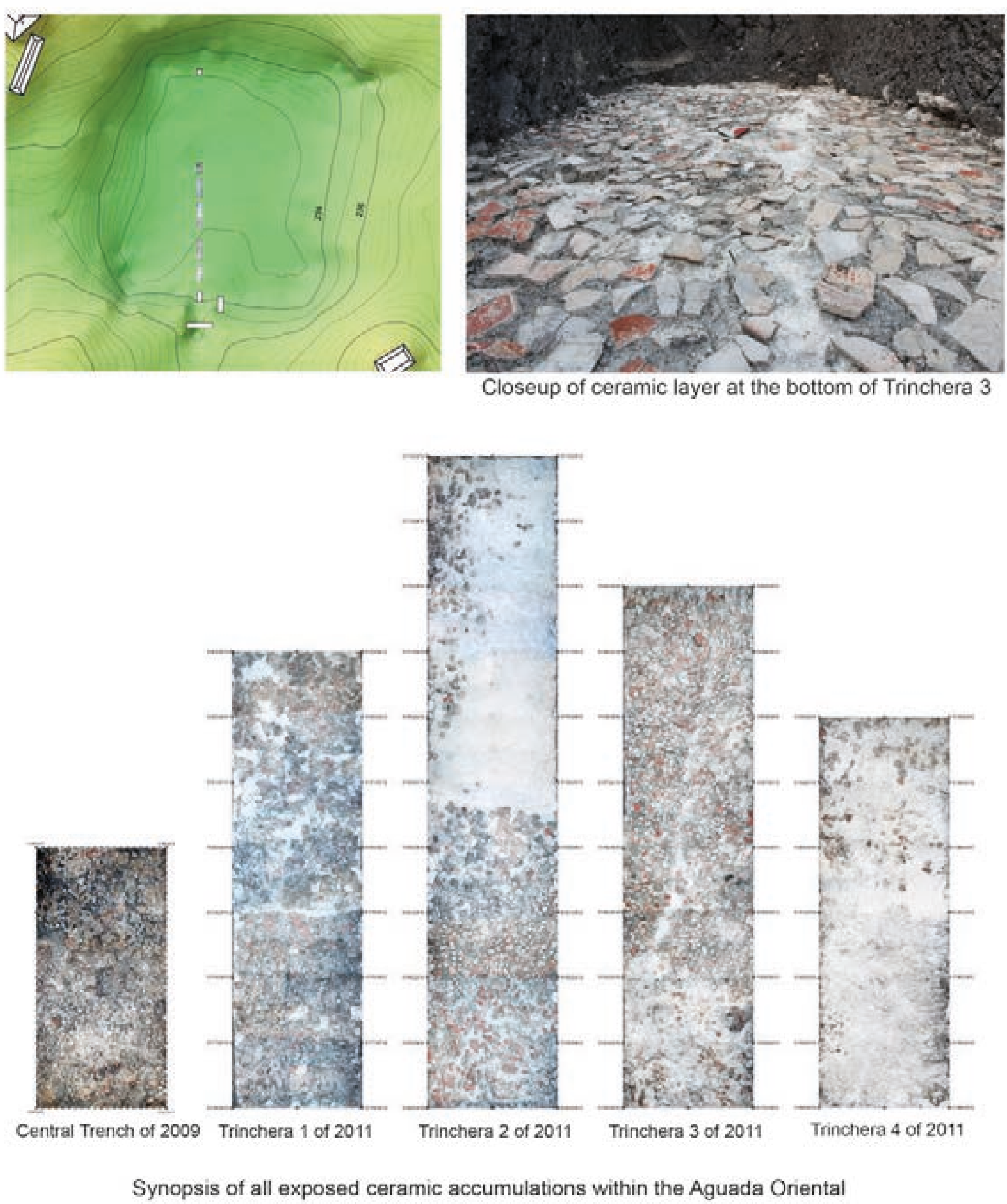

Figure 7. Ceramic layer of the Aguada Oriental.

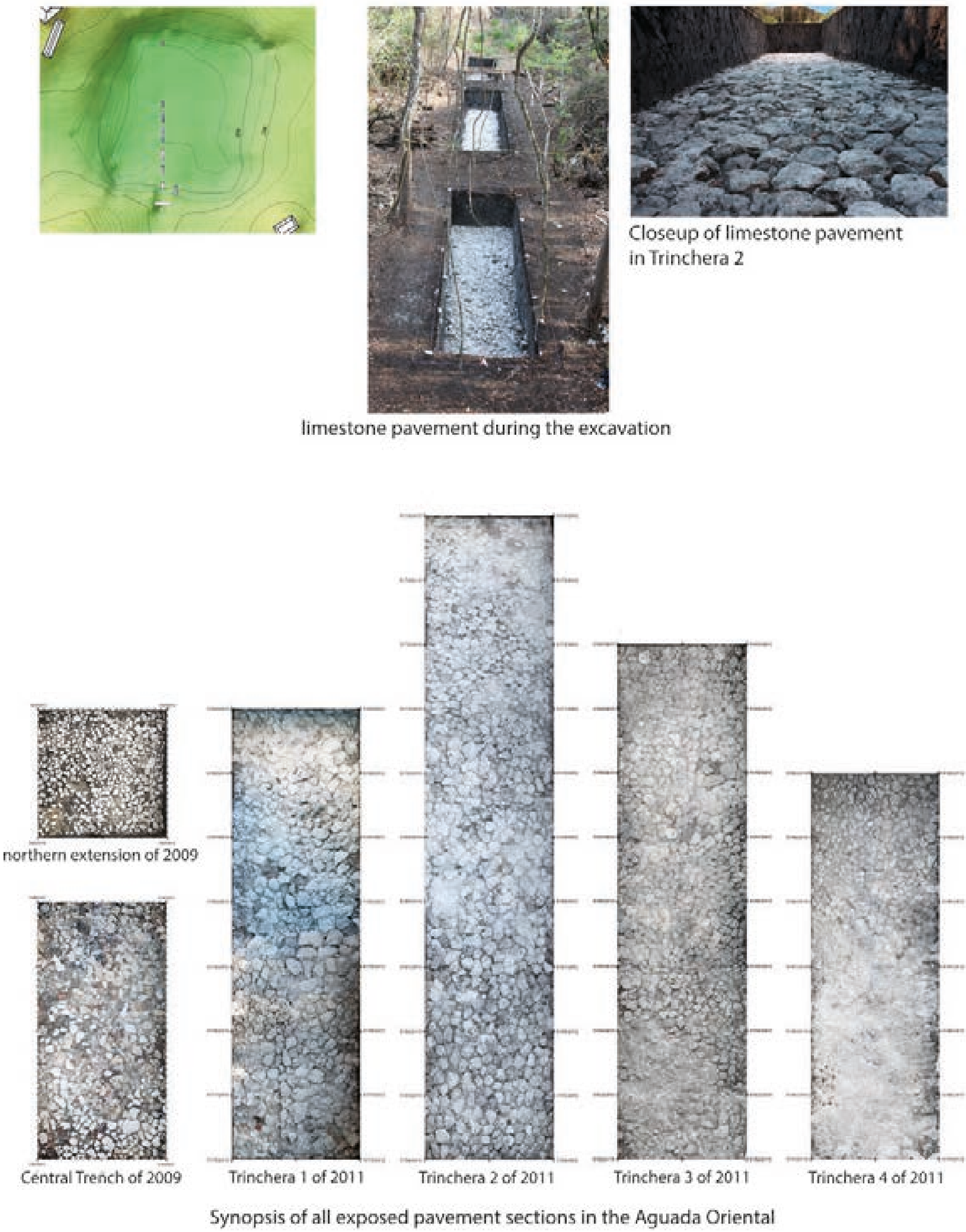

Figure 8. Pavement of the Aguada Oriental.

Figure 9. *Bukte'* at the bottom of the Aguada Occidental.

Apart from the observed integration of both central reservoirs into the epicenter of the site, the construction of a feeding channel and the application of rainwater harvesting on the natural landscape no further hydraulic features have been documented to date. In fact, the next archaeologically documented transformation of the hydraulic system showed its disintegration and deliberate destruction. During the documentation of the limestone pavement at the bottom of the Aguada Occidental, a small, circular depression with a diameter of 40 cm in the southeast of the pavement could be observed (Figure 3). After excavating a cross section through the center of this feature it became evident, that this depression had been excavated after the initial construction of the pavement (Figure 9). While the pavement obviously rests upon a stratum of *sascab*, this depression was deliberately hollowed out down until a depth of 60 cm, until the bedrock was encountered. The only explanation for this feature is the desire for extracting small quantities of water through the creation of a small well. Since the excavation of the documented *bukte'*, or small well, involved the partial destruction of the previously intact pavement, this operation in all likelihood took place during the Terminal Classic, when the site was already partially abandoned and the public architecture evidently was no longer maintained.

FUNCTIONALITY OF THE HYDRAULIC FEATURES

An essential notion, resulting from the archaeological investigation of Uxul's hydraulic system is, that these features needed to be planned in all details prior to the actual construction works. Due to the evident adaption to the local landscape, its tactical composition, but particularly due to its finely coordinated construction elements, the sum of the individual elements can even be defined as a complex hydraulic system (Gunn *et al.* 2002: 298; Matheny *et al.* 1983). All of the height values and constructional elements had to be previously established. The accuracy of these constructions suggests some amount of experience in the layout of such features, which might reflect a lengthier learning process with a long history. The specific models or predecessors that might have influenced and facilitated the scheduling and construction of Uxul's hydraulic system cannot be accurately identified, since only few hydraulic features are known and were investigated in the immediate vicinity of the site. Nonetheless, some elements of Uxul's hydraulic system resemble other such features, documented in the Maya Lowlands. In order to illustrate the potential interaction between the different construction elements, the functionality of each element shall be exemplified. In this process, comparable hydraulic features will be drawn upon, in order to illustrate similar configurations and operation modes.

FUNCTION OF THE FEEDER CANAL TO AGUADA OCCIDENTAL

The canal construction that was documented in the archaeological camp of Uxul is a very concrete example of the collection of rainwater in this landscape (Figure 4). By considering the local topography in the current map, it becomes obvious that those who constructed this feature had evidently observed their environment very carefully, since the canal is aligned towards the course of a natural *corriental*, which already existed prior to the construction (Figure 2). In constructing the canal, the natural water flow was channeled, accelerated and directed towards the Aguada Occidental. The erection of the two lateral stone walls, framing the central pavement strongly indicates, that the emerging flow of the stream must have been considerable, since these faced retaining walls reach a height of 50 cm (Figure 4). That the water flow and the involved pressure towards the sides was substantial, is furthermore substantiated by the reinforcements that each of these raised retaining walls exhibit on their exterior faces (Figure 4). These architectural elements clearly served to provide mass in order to compensate for the water pressure exerted onto the sides.

Similar examples of canal features have been documented at numerous sites in the Central Lowlands. Of all hydraulic features, canals experienced the most intensive and systematic investigation (Seefeld 2008: 29). These features have also been assigned a central role by Wilken (1971), especially considering their function in intensified irrigation agriculture (Healy *et al.* 1983: 399). In general, canal-systems can be subdivided into 1) irrigations-canals (Culbert *et al.* 1991: 11; Jacob 1995: 177) and 2) drainage canals (Pope and Dahlin 1989: 100; Fedick and Ford 1990: 22). Since irrigation canals are distinct indicators for intensified agriculture, they were investigated much more systematically than drainage canals (Olson 1974; Puleston 1977: 455; Antoine *et al.* 1982: 234; Siemens 1982: 219, Siemens *et al.* 2002: 120). Technically, the documented construction within Uxul can be characterized as a drainage-canal. Other drainage-canal features were documented at Río Azul (Culbert *et al.* 1991: 119), Calakmul (Domínguez Carrazco 1993: 42; Folan *et al.* 1995: 311; Geovannini Acuña 2008: 89, Fig. 6.5), Kinal (Scarborough 1994: 197, Fig. 3), Baking Pot (Conlon and Powis 2004; Bevan *et al.* 2013: Fig. 1, 2380), Nohmul (Pyburn *et al.* 1998: 43), La Milpa (Scarborough and Valdez 2003: 10; Scarborough *et al.* 1995: 115, Fig. 10) and Chau Hiix (Pyburn 2003: 124, Fig. 4). In terms of the technical design however, the nearest analogy to the feeding canal of Uxul is the drainage-system that was documented in connection with Calzada Blom (Hermes and Ramos 2004: 610, figs. 2-13) and Calzada del Lago (Hermes *et al.* 1998) within Yaxha. In both cases, the causeways were bordered by raised retaining walls, which were constructed in order to retain the causeways and canalize precipitation into nearby reservoirs.

FUNCTION OF THE LIMESTONE-PAVEMENTS IN AGUADA ORIENTAL AND AGUADA OCCIDENTAL

The most extensive and most important element of the basal modification in Aguada Oriental and Aguada Occidental is the pavement of limestone slabs. Particularly in the case of the Aguada Oriental, the size of the modified surface can be calculated fairly well. The fact that the limestone pavement at the northern end of Trench 7 begins precisely at the transition from the slope to the reservoir's leveled zone exemplifies, that the entire base had been covered with limestone-slabs (Figure 8). For the calculation of the basal area, this surface was reduced to a simplified rectangle, measuring 68 by 86 m. Consequently, it can be deduced, that the Aguada's limestone-pavement had a surface area of almost 6 000 m^2.

During the documentation of this pavement became obvious, that the respective stone slabs feature almost identical dimensions: All of the documented slabs from different trenches feature a uniform height of 5 to 7 cm, which suggests, that they were produced especially for this purpose. Due to their accurate size and form, they could be assembled to form a closed pavement, which constituted a level surface. The stucco binder mentioned earlier was documented in many spaces between and at times upon the stone slabs. Remarkably this binder was extremely hard, suggesting that it served as an important element for the sealing of the pavement.

A similar limestone pavement lining the bottom of an aguada has been documented at nearby Calakmul. Excavations in Aguada No. 4 revealed several faced stone slabs (30 x 50 cm and 5-10 cm thick) at a depth of 2.3 m, which Domínguez Carrazco and Folan (1996: 176, Fig. 15) interpreted as the paving to the floor of the aguada. During excavations within Aguada No. 6, a similar pavement of limestone slabs was also documented (Domínguez Carrazco and Folan 1996: 176, Fig. 14).

FUNCTION OF THE CERAMIC LAYER IN AGUADA ORIENTAL

The function of the ceramic layer at the bottom of Aguada Oriental was more difficult to determine. The dense concentration of ceramic sherds could only be observed in the central trench of 2009 and in Trenches 1 through 4 of 2011 (Figure 7). However, this layer features numerous and sometimes fairly spacious gaps in all of the excavated trenches and in some quadrants, sherds are entirely lacking.

Whereas it is difficult to account for the gaps and the absence of sherds in some areas, since only 70% of the Aguada's level base is lined with ceramic sherds, it seems unlikely that the sherds served as a sealing element. It is also evident from every trench, that the builders deposited these sherds only on even surface areas. Therefore such sherds are entirely lacking in the northern extension of 2009 and could not be identified in the southern half of Trench 4 that exhibits a slight inclination (Figure 7).

On the basis of these observations, this immense amount of specially selected, flat ceramic sherds seems to have been employed as a leveling layer between the underlying bedrock and the limestone-pavement serving to resist water pressure. Up to this point, no similar example of a comparable ceramic feature has been documented or reported.

FUNCTIONALITY OF THE FILTER-WALL AT THE BOTTOM OF AGUADA ORIENTAL

Due to its good state of preservation and its position within the reservoir, the function of the retaining wall at the bottom of Trench 5 within the Aguada Oriental is readily understood. Surprisingly, two other examples of retaining walls, at the margins of reservoirs and within streambeds have already been discovered and described in the Central Lowlands. In both cases, they were identified as filtration walls or as dam features and can be used as examples due to their resemblance.

The first example is a “dam-wall”, which stretches across a 10 m wide streambed near the logging camp of Blue Hole Camp, in the Cayo District of Belize (Healy 1983: 149, Fig. 3). Much like the wall at the bottom of Aguada Oriental, the lowest facing stones are tightly fixed in the bedrock. At the base of the dam, Healy (1983: 15) documented a clearly visible opening with an extension measuring 30 x 70 cm, which he interpreted as a drain for the slowed and controlled release of water.

Within the Copan Valley of Honduras, Turner and Johnston (1979: 301, Fig. 2) documented a 4 m long and 1,45 m high dam wall that was constructed out of carefully worked stone blocks. The individual blocks likewise had been anchored into cavities within the bedrock. A 23 cm deep and 50 cm wide slot in the upper middle of that wall was interpreted as a spillway (Turner and Johnston 1979: 301).

At Kinal, Scarborough *et al.* (1994: 102, Fig. 10) documented a “silting tank”, having the form of a small trough that was situated at the margin of a reservoir. According to their interpretation it served as a filter by collecting debris, submerged by a drainage-canal, and thereby kept the reservoir in a clean and potable state. In order to conclude this study, in the following section I will dwell on the relevance of the documented hydraulic features for the survivability of the settlement.

RELEVANCE OF THE HYDRAULIC FEATURES FOR THE SETTLEMENT’S SURVIVABILITY

As the presented hydraulic structures clearly indicate, the prehispanic inhabitants of Uxul had evidently experienced drastic water scarcities during the dry seasons that forced them to develop a sophisticated hydraulic system in order to satisfy the needs of an extant and growing population. In this process, the collection of rainwater was the most crucial strategy, which the inhabitants skillfully applied to the local landscape. That the available water sources were apparently sufficient to supply a population of almost 5 000 inhabitants during the Late Classic, raises the question as to what degree these modifications increased the amount of available water or how much water the two central reservoirs were able to store. Related to these questions, the investigations within the Aguada Oriental produced a thorough foundation for the calculation of its total capacity. To these ends, the data of the topographic survey were used in order to extend the line of the excavated trenches towards the north and the south. By uploading the same east-value out of the total station dataset, an exact representation of today’s landscape could be developed (Figure 10). On the basis of all the excavated trenches, which compose 40% of the reservoir’s total width, the profile of the entire pavement was reconstructed. Subsequently, the course of this pavement was used in order to determine the possible water-level. The resulting figure shows, that retaining a water level of 2 m would technically have been possible (Figure 10). In order to avoid uncertainties in the calculation of the sloping embankments, these areas were entirely omitted for the calculation of the storing capacity. By the omission of these areas, the north-south distance was limited to 76 m. Subsequently, this distance was multiplied with the previously determined width of the pavement (68 m). At a water level of 2 m, this would result in a volume of up to 10 000 m^3.

Due to its frequently inundated state, the Aguada Occidental could only be investigated with one single trench in 2010. Although the data pertaining to this reservoir are not as good as in the case of the Aguada Oriental, its slightly larger area (Figure 2), deeper excavation, and its connection with several sources of runoff indicate, that its storage capacity was even larger. On the basis of these results, it seems reasonable to estimate, that these two artificial reservoirs had a total capacity of a least 20 000 m^3.

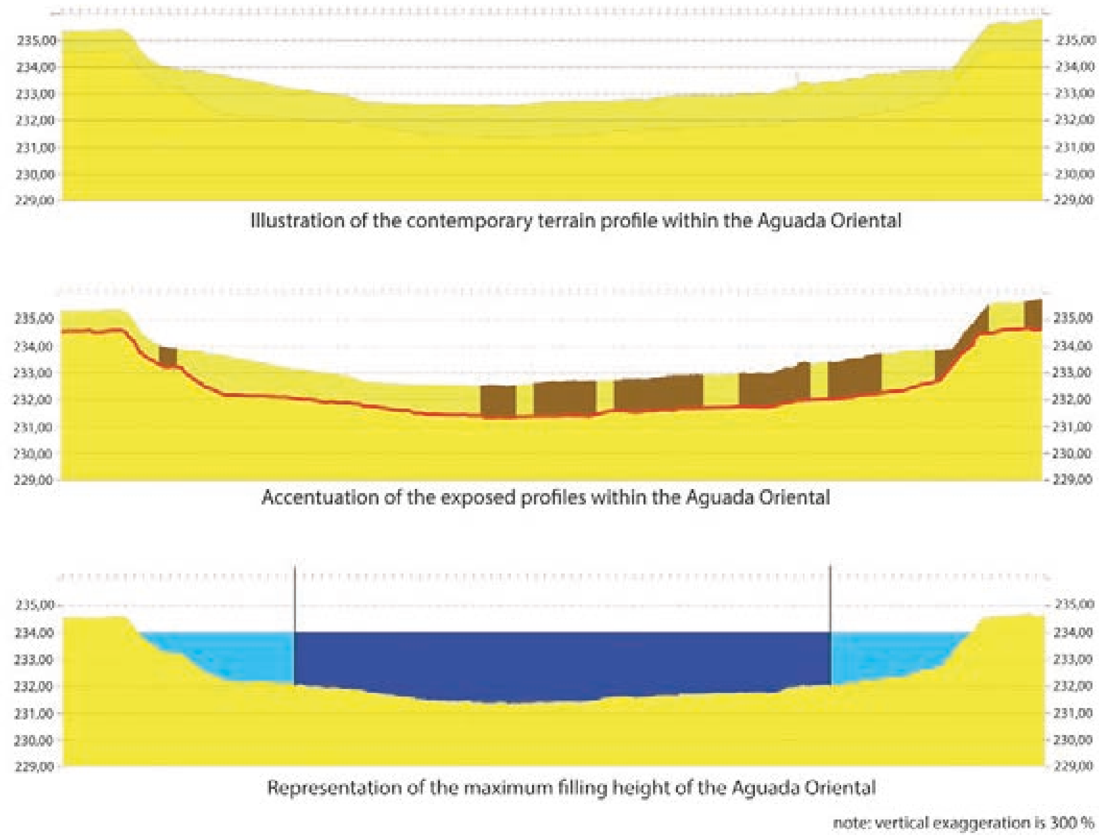

Figure 10. Procedures during the calculation of Aguada Oriental's Catchment Capacity.

In this context should be stressed, that this figure is only meant to give an approximate idea, of how much water could potentially have been stored under optimal conditions. It is impossible to determine, if precipitations would ever have been sufficient to fill up the reservoirs to their maximum height, or how effective the base modification were in serving to impede water seepage, and how much water evaporated.

Relating to the construction process of the hydraulic system, the manifest scale of landscape modifications necessarily raises the old question of the form of society, in which these features were planned and realized.

It is the author's belief that the construction of hydraulic features indicates: 1) a drastic public need for reliable water sources prevailed during the Late Classic period. The author further supposes that 2) the sophistication of the hydraulic system reflects a centralized power for the accomplishment of the construction. 3) Furthermore, the apparent input in public architecture leads the author to the hypothesis that the indemnification of water supply was among the ruler's responsibilities.

The extent and severity of water scarcity during the dry season is clearly apparent in each of the described hydraulic features. In this case, the apparent expenditure of work itself bears testimony to the relevance of these features for the survivability of the settlement and moreover demonstrates that the climatic conditions during the Late Classic period cannot have been more favorable than today. Among these features, the small and hurriedly excavated well that was exposed at the bottom of the Aguada Occidental (Figure 9) displays the gravity of water scarcity at its extreme. The desperate search for water obviously motivated the population to accept the partial destruction of an intact pavement in order to extract small quantities of water in the short-term.

The most essential indicator for the necessity of a central power for the design, realization and maintenance of the hydraulic system is once again the extent of the construction works. This, however, does not constitute evidence that the installation of hydraulic systems triggered the emergence of social stratification and central governance (Adams 1991: 632; Puleston and Puleston 1971: 336; Palerm 1955). Nevertheless, household communities or smallholder groups would have been incapable of planning, constructing and maintaining a hydraulic system of that scale. The documented public construction works, especially the recruitment of labor required, the centralized supervision and a higher hierarchical authority. Still, the layout of the three investigated hydraulic features shows that each individual constructional element, including its exact position, had to be planned in all details prior to the actual construction works. Reflecting upon the excavation results of these hydraulic features and considering its finely coordinated constructional elements, points out, that they formed part of a construction program designed for the long-term. Crucial is not only the mere construction process, but also the need and the availability of both specialists and unskilled laborers for the construction as well as the regular maintenance and cleaning. Since the strategy of rainwater collection was so skillfully applied to the local landscape, it stands to reason that the Uxul's rulers were well aware of the fatal risk of dwindling water supplies in this environment. Therefore, a considerable portion of the labor at the disposal of the ruling elite, was set to work to ensure a constant water supply. The presumed diligence, which was ascribed to these tasks is apparent in every constructional element documented in the various hydraulic systems. Although each of the three delineated features was erected in one single construction phase, they cannot be attributed to a single ruler. In fact one should envision the development of this hydraulic system as a highly dynamic and responsive process. New water-storage features were obviously constructed when a demographic stress had overstrained previous constructions. Nevertheless, each ruler always had to consider the essential factor of water supply during the development of new building programs. The profile of the documented hydraulic system gives reason to believe, that the effective implementation of the rainwater collection was given preference during the planning phases of new building programs. Previous results attested, that the entire landscape in the immediate vicinity of the Aguada Occidental was subordinated to the collection of rainwater and the Aguada Oriental was architectonically integrated into the site's epicentre by means of a *sacbe*. It therefore seems reasonable to presume, that watershed maximization also played a prominent role in the layout of the central hilltop. However, this interpretation should not convey the idea that rainwater collection was the central or decisive factor in the settlement planning of Uxul.

Apart from severe water scarcity, the necessity of a central power for the implementation of construction and the liabilities of the ruler, the hydraulic system allows further inferences on the society of Uxul during the Late Classic and Terminal Classic periods. In this connection, the small well-like depression, or *bukte'* (Figure 9), at the bottom of Aguada Occidental, which was hastily excavated in order to extract minute water quantities in the short-term and thereby required the partial destruction of a previously intact pavement is of particular relevance. Considering the amount of labor recruited, it seems highly unlikely, that the local elites, who had supervised their construction, were still exerting power, when the well was excavated. The stratigraphic position of that well indicates, that it was excavated during the Terminal Classic, at a time, when Uxul already was largely abandoned. It is thus reasonable to state, that a hierarchical society and the ruling of a central power was integral to the development and maintenance of such a sophisticated hydraulic system. Scattered inhabitants of the

Terminal Classic were evidently not able to build additional artificial reservoirs and were furthermore lacking the social cohesion to protect the infrastructure that had originally enabled a constant and florescent survival in this environment. This correlation indicates, that a form of interdependency between rulers and commoners may have prevailed at Uxul. Within such a putative relationship, a ruler had to satisfy the basic needs of his subordinates, enabling his privileged position. Despite these privileges, a ruler was therefore not in a position of "total power" (Wittfogel 1957). At the same time, commoners were dependent on the authority of a centralized ruler, whose position enabled to design, enforce and supervise the construction of the vitally important infrastructure. The relationship of interdependency between rulers and commoners and the relevance of public infrastructure for the survival of the society might help to explain, why the process of the collapse had evolved so rapidly. The neglected maintenance of existing infrastructure, as well as the lacking of new constructions, would have caused a domino effect, which accelerated and aggravated the process of collapse.

SIGNIFICANCE OF THE DOCUMENTED STRUCTURES FOR THE HYDROLOGY OF THE CENTRAL MAYA LOWLANDS

In order to conclude this paper, it needs to be stresses out, that the factor of water-management for the development of building programs or even the general form of society should not be overestimated. However, it is highly enjoyable, that the question of water supply and potential adaptation strategies actually experienced such a gaining interest in the course of the past decade. Due to these intensified archaeological investigations of water management features in the Central Maya Lowlands, we have gained a more profound understanding of the basic adaptations and strategies to a constant water supply. The investigation of Uxul's hydraulic system, which was carried out under the objective of developing a functional model of water supply for this settlement has shown, that the fundamental adaptation strategy was the practice of rainwater harvesting. Furthermore it revealed new constructional methods and forms of hydraulic structures, whose scale and accurate execution elucidate the importance, which was attributed to them. Moreover, the possible interdependence between rulers and commoners, which might be expressed in the formation and demise of public infrastructure of Uxul, bears an interesting potential for ongoing research since it might help to explain, why the process of the collapse could elapse so rapidly.

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