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The Marco Gonzalez Maya site, Ambergris Caye, Belize: Assessing the impact of human activities by examining diachronic processes at the local scale

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Abstract

Research at the Maya archaeological site of Marco Gonzalez on Ambergris Caye in Belize is socio-ecological because human activities have been a factor in the formation and fluctuation of the local marine and terrestrial environments over time. The site is one of many on Belize's coast and cayes that exhibit anomalous vegetation and dark-coloured soils. These soils, although sought for cultivation, are not typical 'Amazonian Dark Earths' but instead are distinctive to the weathering of carbonate-rich anthropogenic deposits. We tentatively term these location-specific soils as Maya Dark Earths. Our research seeks to quantify the role of human activities in long-term environmental change and to develop strategies, specifically Life Cycle Assessment (LCA), that can be applied to environmental impact modelling today.

1. Introduction

1.1 Scale, context, and aims of the research

Understanding socio-ecological processes at a scale at which individuals can make a difference is problematic when environmental and social questions are articulated at macro-scale levels of analysis, such as 'climate change'. How, then, can we envision what we have recognised at a macro-scale—in our case, long-term environmental change—at a level at which we can not only ask the right questions but also articulate them so that our answers will have some impact on human decision-making today? At the Maya site of Marco Gonzalez on Ambergris Caye, Belize (Fig. 1.1), long-term environmental change is evidenced in dark surface soils that could not have formed naturally from local soil parent materials. If we keep the frame of analysis at the macro scale, we would ask what the Maya did to *cause* (produce) dark-coloured soils. To mitigate the danger of conflating hundreds of years of social and ecological factors into a macro-question, however, we instead view the dark soils as an *association* (Graham 2006: 58-62). We are attempting to reconstruct the long and complex history of soil formation processes at the site by studying the details of sequent human occupation and the effects over time. In this way we hope to 'capture' the management of human actions at a level of analysis that, because it is not structured causally by what we know to have been the long-term result, should help in addressing decisions that have to be made concerning human behaviour today. Beyond recycling, which is a short-term concern, long-term environmental impact is not something that people generally feel empowered to change. Rather than battling to change human behaviour, it may be possible to exploit it.

The activities associated with occupation at Marco Gonzalez—which reflect a social group, and at times a true community (Hegmon 2002)—comprise house construction, house destruction, land modification, resource procurement, rubbish deposition, shoreline fill, burying of the dead, production and manufacturing, and the deposition of excreta. Although we sometimes refer to the ‘Marco Gonzalez community’, there is no doubt that the people and the nature of the social group changed through time, a period of over 2,000 years. The aim of the preliminary research we describe here is not to elucidate the rationale, in an emic sense, behind the human behaviour involved in depositional activity—except insofar as details help us to gauge intensity and timing. In fact, the evidence from Marco Gonzalez so far suggests that the soil enrichment represented by the modern dark earths was inadvertent. Our aim is to determine the successive *effects* of past behaviour. The idea that soils on the planet have been enriched by activities for which humans have been the catalyst is widely acknowledged in Amazonian Dark Earth (ADE) research (Arroyo-Kalin 2008, 2014a). In the Maya area, dark earths have not received much attention, mainly owing to the rarity of evidence of ADE-level enrichment (Beach et al. 2015: 18). The degree of enrichment at Marco Gonzalez is, however, significant enough (Beach et al. 2009) to warrant extending studies of the distribution of anthropogenic dark soils of Precolumbian origin to this region of the Neotropics (Arroyo-Kalin 2014a: 174; Graham 2006).

A key methodological issue in the study of anthropogenic soils and sediments is the 'need to establish adequate baselines to assess anthropogenic modification' (Arroyo-Kalin 2014b: 282). In the caye environment, it is simpler than it would be on the mainland to: 1) identify the natural soil parent materials and distinguish what would be expected to be natural soil formation processes; and 2) identify an area that was not occupied or altered or utilised by the ancient Maya. The dark-coloured soils and vegetation at Marco Gonzalez are not what one would expect to find on an island where the soil parent materials are derived from coral and Pleistocene limestone of the Belize Barrier Reef (Gischler and Hudson 2003).

1.2 Study area

The Belize Barrier Reef (BBR) complex runs N-S, paralleling Belize’s Caribbean coastline, and marks the rim of a carbonate platform or shelf (Fig. 1.2), although the 'barrier' reef becomes a ‘fringing' reef in northern Belize and adjoining Yucatan (Gischler and Hudson 2004: 223; James and Ginsburg 1979: 1). The BBR was established from □ 8.26 to 6.68 ky BP on Pleistocene reef limestones. At 250km long, it is the largest reef complex in the Atlantic and extends from the Yucatan Peninsula to the Gulf of Honduras (Gischler and Hudson 2004:223; James and Ginsburg 1979: 1). It includes—in addition to the islands or ‘cayes’ along the reef edge, of which Ambergris Caye is the largest—three atolls: Glovers Reef, Lighthouse Reef, and Turneffe Islands. The elevation of the Pleistocene limestone that underlies the majority of the reef varies from about 1m above sea level on Ambergris Caye in the north to □ 25mbelow sea level at the southern end (Gischler and Hudson 2004: 223-225; Purdy 1974). The high elevation of the ‘reefstone’ (our term for the Pleistocene limestone) on Ambergris Caye facilitated its use in construction by the Precolumbian Maya.

According to Gischler and Hudson (2004: 225), knowledge of the late Quaternary development of the BBR is limited (although see James and Ginsburg 1979) but research is being carried out to address the existing lacunae (Gischler and Hudson 2004; Gischler et al. 2000). As regards the Maya environment and available resources, the reef as we know it today was established by the Holocene and has been subject to similar processes since Pleistocene times—that is, there has been no major uplift of Pleistocene limestones, and the shelf lagoon between the BBR and the mainland in the north was already inundated by 5.6 ky BP; sea levels have, however, risen, and there has been late Quaternary subsidence along offshore fault-blocks underlying the reefs, and some karst dissolution (Dunn and Mazzullo 1993; Gischler and Hudson 2004: 232-234; Gischler et al. 2000; James and Ginsburg 1979). The shelf behind the reef south of Belize City receives clastic input from the Maya Mountains, which includes siliciclastic sedimentary rocks and granites, whereas the northern Belize Tertiary and Cretaceous limestones provide negligible input (Gischler and Hudson 2004: 234). The presence of siliciclastic sediments at Marco Gonzalez can therefore be assumed to be anomalous.

The span of human occupation at Marco Gonzalez paralleled the last phase of Holocene sea level rise. Coastal stabilisation, sea-level rise, and back-barrier sedimentation are recorded in the stratigraphy of the southern end of the caye, where Marco Gonzalez is situated, by a transgressive sequence of high-energy beach deposits, lagoonal/inter-tidal muds and mangrove peats overlying an irregular surface of Pleistocene karst limestone (Dunn and Mazzullo, 1993). The stratigraphic (and topographic) feature of occupation is an irregular mound (ca. 3.5m a.s.l.) formed by decaying masonry structures, artefacts, 'Anthrosol' and colluvium which interstratifies with peripheral mangrove and back-barrier wetland sediments. The vegetation that characterises the mound is topographically anomalous, and a discrete boundary can be observed with forest trees rising above the surrounding mangrove to heights of 12-15 m (Fig. 1.3). These features are characteristic of other parts of the Belize coast and cayes where areas of dark earth support distinctive vegetation in a zone of mangal associated with Maya sites (Graham 1994: 18-27; 1998: 130; 2006: 75, 76).

1.3 Previous research and chronology

The site of Marco Gonzalez has yet to be extensively excavated (Fig. 1.4), and there is much to resolve concerning the character of occupation through time. The excavations carried out in 1986, 1990, and 2010, however, yielded a broad range of data with which to build a framework of cultural and environmental change (Graham 1989; Graham and Pendergast 1989; Pendergast and Graham 1987; Simmons and Graham 2015). The chronological sequence is derived from historical sources, relative stratigraphy and typological dating of ceramics recovered from successive strata, with emphasis placed on ceramics from primary deposits such as burials and caches (e.g., Pendergast 1979). Dates for Maya ceramics are known by reference to burial and cache sequences based on archaeological associations with inscribed monuments with absolute calendar dates (Smith 1955; Martin and Skidmore 2012). Radiocarbon dates also contribute to the Maya lowlands sequence (Kennett et al. 2013). No radiocarbon dates have yet been run for Marco Gonzalez archaeological samples; however, identities and similarities with ceramics from other coastal sites, such as the Colson Point sites (Graham 1994) and Lamanai, where radiocarbon dates have been run (Graham 1989: 154; 2007), support the Marco Gonzalez chronology (Fig 2.1).

Like other sites on the island of Ambergris Caye (Guderjan 1995; Guderjan and Garber 1995; Guderjan and Williams-Beck 2001; Guderjan et al. 1988; Guderjan et al. 1989; Mazzullo et al. 1994; Weinberg et al. 2003), Marco Gonzalez has supported occupation and activity since Late Preclassic times (ca. 300 B.C.). Because the earliest deposits are below the modern water table, we have yet to reach initial occupation levels at the site, but sherds from shell midden below the table support a date of c. 300 B.C. to A.D. 1.

We infer from a combination of relative stratigraphy and ceramics that Marco Gonzalez first saw intensive use during the Terminal Preclassic period (ca. A.D. 1-250) (Fig. 1.5). Test pits have revealed platform and floor construction during the Early Classic (A.D. 250-550) along with shell midden accumulation and a lively trade in polychrome pottery. Large numbers of crudely made, roughly standardised vessels (Coconut Walk ware)—thought to have been used in salt production—began to appear sometime in the 6th century. Sherds recovered from charcoal and ash layers indicate that brine was probably heated in the vessels to drive water off and ready the salt for shipment (Reina and Monaghan 1981). We do not know whether this final step was preceded by other practices that might have helped to concentrate the salt, such as evaporation of sea water in salt pans. Based on the evidence to date, after the water was driven off from the brine, the vessels were broken and the charcoal residues from the wood fuel, as well as the vessel fragments and ash, were collected and swept aside and dumped, which resulted in deposition of pyrogenic carbon.

Islanders seem to have focused largely on the shipment of salt during the Late Classic period (ca. A.D. 600-750). Production tailed off towards the end of the 8th century A.D. just prior to the time of the Maya collapse (Demarest et al. 2008). There is no evidence at Marco Gonzalez, however, of the collapse that depopulated a number of mainland sites between ca. A.D. 750 and 1000. Instead, the site's occupants constructed buildings of local reefstone and wood over salt production debris, expanded the settlement, and buried their dead (as is Maya practice) beneath the floors of successive structures. Widespread trade and exchange activity flourished during this period and set the stage for the seaborne commerce which so impressed Spanish conquerors in the 16th century (Graham 2011:105-124). Most of the 49 structures ('mounds') identified at Marco Gonzalez (Fig. 1.4) were constructed between about A.D. 750 and 950 (Late to Terminal Classic). Occupation of most of the structures continued into the Early Postclassic (A.D. 950 to ca. 1200) but with modifications to terrace facings and significant changes in material culture. About A.D. 1200-1250 inhabitants began to drift away from the area, owing to mangrove encroachment and coastal sedimentation (Dunn and Mazzullo 1993), probably shifting just north to the site of San Pedro. Less intensive and apparently intermittent occupation continued through the Middle and Late Postclassic (A.D. 1200 to 1500) and early Historic periods (A.D. 1500-1650) as indicated by the ceramics recovered from residential remains, surface scatter, and from offerings in a late addition to the stair of Str. 12, a probable residential building (Graham and Pendergast 1989). We do not yet know exactly when the present dark soils and vegetation developed, but given stratigraphic evidence to date, the process probably began in the late 13th or early 14th century A.D. when Marco Gonzalez ceased to be densely settled.

2. Method and theory

2.1 The theoretical framework

Concern with the earth as transformed by human action (Marsh 1864; Thomas 1956; Turner et al. 1990) is by no means new, but the consequences of human impact are viewed as largely negative: soil erosion, land degradation, pollution, biodiversity loss, and greenhouse gas production (Goudie 2006). That humans can improve soils through additives is acknowledged, but the idea that unintentional consequences of human depositional activity can result in soil enrichment receives less attention. The reasons for researchers' low level of interest in the inadvertent consequences of human activity include limited awareness of the intensity of human activity in the deep past (Crutzen and Stoermer 2000; Willis et al. 2007:176); assumptions that areas of the earth's surface covered in plants and trees are representative of what is 'natural' rather than managed (Balée 1994; Chase et al. 2011; Graham 1998, 1999); the idea that progress can only be made by considering humans as a unique force in nature (Steffen et al. 2011); and the high priority ascribed to intentionality in past human action (Glaser and Birk 2012: 39).

Amazonian Dark Earth (ADE) or *terra preta* studies have contributed most to the idea that long-term human impact can be measured positively rather than negatively (Arroyo-Kalin

2012; Glaser and Woods 2004; Lehmann et al. 2003). In the ADE context, the role of unintentional consequences of human activity in soil enrichment is increasingly recognised (Arroyo-Kalin 2014a). The connection between humans and ADEs, made in the Amazon in the 19th century, was not widely accepted in scientific circles until the latter part of the 20th century (Sombroek 1966; Woods 2003:3). The English term 'dark earth' was coined in Britain in 1912, but it is only since 1973 that the phenomenon has been recognised—specifically through soil micromorphological studies—as a product of decay of the built environment (Macphail et al. 2003). Because many European dark earths, including those in Britain, are buried by later cultural deposits, the dark earths are studied for what they can reveal about the past rather than for their cultivability. Nonetheless, understanding what sorts of human activities led to dark earth formation is a critical first step in revealing the sources of fertility (Macphail 2010; Macphail et al. 2007), and there is growing interest in Europe in the persistence of dark earths (Verslype et al. 2008). Plaggen soils—an intentionally created dark earth the management of which goes back to the late Bronze Age—have long been recognised for their fertility (Blume and Leinweber 2004). We here identify an anthropic soil formed in a locus of Precolumbian Maya settlement, which we are tentatively calling a Maya Dark Earth.

To understand the complexities of soil-formation processes influenced by a component that increases fertility, studies of the constructive environmental effects of human activities need to expand beyond the Amazon basin. Fertile cultivable soils are associated with many lowland Maya sites in Mesoamerica. In the Puuc Hills, for example, the Yukatek term *kakab* refers to soils associated with ruins (Beach et al. 2015: 18; Dunning 1992: 33-58). Given the extensive knowledge that has accumulated on Maya civilisation, attention to such apparently anomalous soils is almost certain to help address basic questions regarding the formation and persistence of dark earths, *sensu lato*.

The Marco Gonzalez archaeological data point to a long and complex pedogenetic history that cannot be tied to a single episode of intentional management. Therefore we do not assume that the Maya were adjusting over the short term to fluctuating conditions by consciously guarding against species loss or land degradation, thereby effecting long-term adaptation. There is little doubt, however, that lowland Maya communities—in the past and present—developed resource practices that were adaptive (e.g., Beach and Dunning 1995; Beach et al. 2002; Dunning and Beach 1994, 2004a; Dunning et al. 2009; Luzzadder-Beach and Beach 2006, 2009); and the body of literature on Maya soil knowledge and on impacts of agricultural practices continues to grow (e.g. Beach et al. 2006; Beach et al. 2013; Dunning 1992; Dunning and Beach 2004b). If episodes of intentional management existed at Marco Gonzalez, this will come to light through further investigation. At the analytical level at which we are modelling our approach, however, what matters is whether the cumulative effects of human activities played a significant role in shaping the soils and landscape over time. For the present, our methodological strategy avoids the question of 'intent' to focus on quantifying the physical and chemical characteristics of soils and sediments that current land use and archaeological evidence suggest reflect a critical type of interaction, or series of interactions, between the residues of human activity and the environment (Arroyo-Kalin 2014b; Graham 1998: 121; Graham 2006.).

Quantification of soil and sediment characteristics as input is merely an exercise unless it can contribute to discriminating the effects that these characteristics have had in the formation of the modern landscape. Models for quantifying environmental impact in this manner have been developed for modern industrial contexts; Life Cycle Assessment, for example, is a standard technique used to measure impact over the entire 'life cycle' of a product or process (Finnveden et al. 2009). On the premise that ancient activities such as Maya salt production can be analysed as we would analyse a modern industry, LCA is being applied in our study. There are important distinctions, however, between modern and ancient application of LCA. In modern applications, the inputs and outputs of an operating process are well quantified and characterised, whereas inputs and outputs are difficult to quantify or even characterise in an application that is only accessible archaeologically. It is also the case in modern applications that environmental impacts of a process are quantified as surrogate ‘mid-point indicators’ (i.e., proxies) and short-term impacts, because the long-term impacts can only be conjectured. In our archaeological application, the environmental impacts have actually taken place and are measurable. Although the extent of measurability from ancient times to the present is subject to the constraints typical of archaeological investigation (i.e., degradation processes over time obscure earlier environmental impact data), the final, current state of the local environment is accessible and can be assessed.

Our workplan is aligned with the standard LCA framework agreed by various organisations (e.g., European Commission 2009), and comprises:

- Identification/selection of physical boundaries that define the system, the time frames in which activities and environmental impacts have occurred, the activities related to production to be included, the relevant inputs and outputs for each of these activities, and the environmental impacts of interest
- Collection of data about the inputs and outputs in connection with production activities (inventory analysis)
- Quantification of selected environmental effects resulting from the inputs and outputs of the production process (impact assessment)
- Interpretation

At the current stage of investigations and as the preliminary archaeological application of LCA, our analysis is highly localised, reflecting our focus on surface soil formation at the specific locations at which diachronic change is accessible through stratigraphic exposure, via excavation units, of sediments that have accumulated over time. The detailing required for an excavation unit approach (identifying the nature of the stratigraphic deposits and the material character of contexts in each sounding, converting archaeological data to measurable inputs/outputs, and determining the relevance of each dataset) will allow us to test the appropriateness of LCA. This process will help us to identify the potential for upscaling once more excavation data are available.

2.2 The present study

Structures 8, 14, and 19 (Fig. 1.4) served in 2013 as test pit sites from which the samples reported on here were derived. 'Structures' are identified by the presence of mounds 30 cm to ca. 7-8 m tall. The mounds represent the ruins of single or multiple-phase constructions, usually masonry platforms built of reefstone that supported perishable superstructures. Three test pits, measuring ca. 1.5 x 1.5m, were laid out, one on the summit of each structure (Fig. 2.1, Fig. 2.2, Fig. 2.3). The presence of burials, which we did not excavate, forced reduction of pit size at depth, hence the varying widths represented in the section drawings. Structures rather than flat areas were selected because features such as platform floors or terrace faces serve to protect underlying deposits. As strata, sub-strata, and features were excavated, they were assigned lot/context numbers (e.g., MG 201, MG 202).

The construction efforts date largely to the 9th through 12th centuries (Graham and Simmons 2012; Simmons and Graham 2015). Str. 14 was partially excavated in 1990 and had had the bulk of its dark soil surface layers removed; it was selected, however, because it exhibited the full occupation sequence, and the dates represented by the strata are known. Str. 19, like Str. 14, exhibited a full stratigraphic sequence but had not previously been excavated and retained the dark earth surface soil stratum. Str. 8 was selected as an example of a locale at the site periphery; intensive mixture of deposits afforded few datable contexts, but the section drawing is included (Fig. 2.3) to show the effects of land crab burrowing.

The excavation, coring, and sampling that produced the results described herein were undertaken in August of 2013; the vegetation survey was carried out in July and August of 2014. The fieldwork and the ongoing analyses are geared to assess the nature of the task as well as to test methods of investigation; the results will be applied to more extensive research at Marco Gonzalez and possibly at other ‘dark earth’ sites along Belize’s coast. We devised approaches to assess both the factors that can affect soils and the contexts in which soils change over time. Our approaches include, in addition to archaeological methods to obtain cultural and chronological information:

- Soil micromorphology and bulk analyses to assess the character of the sediments over time: What materials comprise the sediments, and what are their sources? Are the deposits natural, cultural, mixed? What post-depositional processes (pedogenetic?) have or are affecting the deposits?
- Coring of sediments to obtain information on local environmental changes: What was the environment prior to human habitation? What effects on the environment can be attributed to human activities?
- Macrobotanical studies of both plant and woody material recovered from archaeological deposits to obtain information on people and the environment over time: What plants were available? Are imported species present? What fuel choices were made? Did human activities affect the ecology?
- Identification of modern vegetation to begin to assess the relationships between species, patterns of growth, and environmental conditions: What species are present? Do these form recognisable communities that reflect particular conditions of growth? Can vegetation be linked to sub-soil conditions?
- Development of a model, based on LCA: Because we know the impact of long-term human activity, can we quantify inputs, particularly pyrogenic carbon, and the relationship of inputs to output in a way that can inform modern environmental impact assessment?

2.3 Hypotheses to be tested

The approaches described above, their attendant field methods, and their preliminary results are reported below. We do not yet have the data to answer all our questions, but progress made is best measured by the extent to which our original hypotheses are being addressed. These hypotheses are:

H1: That the MG site and its environs have changed over time, and these changes bear some relationship to human activities characteristic of each occupation period.

H2: That charcoal found with sherds from Coconut Walk pottery is spent fuel associated with salt production.

H3: That evidence of salt production exists in the form of salt pans, residues, and/or peripheral chemical changes in soils or ceramics brought about by high salt concentrations.

H4: That fuel was obtained on the island.

H5: That the MG dark earths reflect interaction between residues of human behaviour and environmental processes over time.

H6: That variation in vegetation species types, richness, and diversity will reflect anthropogenic influence/impact on local environmental conditions.

H7: That principles of interaction will be established with implications for modern practices in relation to both resource-efficient management of wastes and future land use.

3. The character of sediments over time: bulk soil analyses and micromorphology

3.1 Sampling

Once the excavations were terminated and the sequence determined, monoliths for micromorphological analyses were removed: 3 monoliths were removed from Str. 8 (Op 13-3); 7 from Str. 14 (Op 13-1) (Fig. 3.1), and 4 from Str. 19 (Op 13-2) (Fig. 3.2); the east and west faces of the Str. 14 test pit were sampled. In addition, charred and fresh termite nests and two lime plaster floor fragments from Str. 8 were collected as reference material. Sampling included modern surface soils at 1.770m asl at Str. 19; at 2.150m asl at Str. 14; and stratified anthropogenic deposits as deep as -0.050m asl at Str. 14. Below this depth, sediments were too wet to collect intact. The upper 10cm of surface soils, including leaf litter, were also collected at Strs. 18, 19, and 25. Bulk soil samples were collected in the field, and small bulk samples were removed from specific layers of the monoliths for XRF element study (in progress).

3.2 Methods

Monoliths were examined at the Institute of Archaeology, University College London, U.K. by R. MacPhail. Bulk soil analyses were carried out by J. Crowther at Trinity St David's, University of Wales, Lampeter. The soil micromorphology and bulk study methods were chosen following the experience of studying UK intertidal sediments and ancient coastal salt working (Avery, 1990; Boorman et al., 2002; Macphail, 2009; Macphail et al., 2010; Macphail et al., 2012). Subsampling for bulk samples and resin-impregnation of intact monolith material for thin section production followed protocols (Courty et al., 1989; Goldberg and Macphail, 2006).

Bulk analyses involved the testing of 39 samples for organic matter (LOI @ 375°C), carbonate (LOI @ 950°C) and total P, pH, specific conductance ('salinity') and magnetic susceptibility (χ, χ_{max} and %χ_{conv})(e.g. heating effects of climate and burning), and 10 samples for particle size (Avery and Bascomb, 1974; Scollar et al., 1990; Tite, 1972; Tite and Mullins, 1971).). Specifically, LOI (loss-on-ignition) and carbonate content were determined by sequential ignition: at 375^{o}C for 16 hrs (Ball, 1964)—previous experimental studies having shown that there is normally no significant breakdown of carbonate at this temperature—and at 950^{o}C for 2 hours; for a separate surface soil mapping study, a temperature of 550°C for 2 hours was employed for LOI (Heiri et al., 2001). Phosphate-Pi (inorganic phosphate) and phosphate-Po (organic phosphate) were determined using a two-stage adaptation of the procedure developed by Dick and Tabatabai (1977) in which the phosphate concentration of a sample is measured first without oxidation of organic matter (Pi), using 1N HCl as the extractant; and then on the residue following alkaline oxidation with sodium hypobromite (Po), using 1N H2SO4 as the extractant. Phosphate-P (total phosphate) has been derived as the sum of phosphate-Pi and phosphate-Po, and the percentages of inorganic and organic phosphate calculated (i.e. phosphate-Pi:P and phosphate-Po:P, respectively).

Out of a total of 44 thin-sections, SEM/EDS (Energy Dispersive X-Ray Spectrometry) (Weiner, 2010) was carried out on specific features in 6 thin sections. Thin sections were described, ascribed soil microfabric types (MFTs) and microfacies types (MFTs), and counted according to established methods (Bullock et al., 1985; Courty, 2001; Courty et al. 1989; Macphail and Cruise, 2001; Stoops 2003; Stoops et al., 2010).

3.3 Bulk soil results (Table 3.1)

Loss-on-ignition (LOI), which reflects a combination of soil organic matter and/or charcoal in the contexts analysed, displays very marked variability (range: 2.02–28.1%). As would be expected, the highest values were recorded in the two surface soil samples, from Structures 8 (LOI, 28.1%) and 19 (26.9%). Soil micromorphology indicates that in both cases these high values appear to be attributable both to a high soil organic matter content and to the presence of micro-charcoal, unlike most of the underlying stratified archaeological layers in which charcoal, rather than soil organic matter, is the dominant organic material. The surface soils are particularly organic-rich for a tropical soil in which high rates of organic decomposition would be anticipated.

All samples contain high or very high proportions of *carbonate* (range: 33.5–75.0%), with the majority containing ≥ 50.0%. All samples analysed also display very marked variability in *specific conductance*. Two of the lowest values were recorded in the two surface soil samples from Structures 8 and 19, with values of 455 and 477 μS, respectively. The values suggest that the upper horizon of the soils is subject to some degree of leaching. The majority of the samples, in contrast, are much more saline (≥ 2500 μS), with seven having values ≥ 5000 μS (maximum: 5700 μS). Although it seems likely, in this near-coastal environment, that the salts are largely of natural origin (saline groundwater), it should be noted that six of the seven samples with the highest salinity levels contain ash, charcoal and/or burnt residues.

Given these findings, *pH* analyses expectably found that the samples are all alkaline, with pH values ranging from 7.9–9.1. The lowest values were recorded for the two surface soil samples from Structures 8 and 19 (7.9 and 8.0, respectively), which is consistent with their notably lower carbonate content and salinity. The majority of the remaining samples have exceptionally high pH values of ≥ 8.5. This is likely largely to reflect the saline nature of many of the samples, but there does not appear to be a consistent relationship between pH and specific conductance. The most striking anomaly is sample xMRef3 (Lot MG 376), which has the highest pH (9.1) but only a relatively low specific conductance (1090 μS).

Phosphate-P concentrations are highly variable, with some samples exceptionally enriched. At the lower end, 19 samples have concentrations in the range 1.09–4.50 mg g^{-1}; soil micromorphology indicates that these are often layers rich in burnt intertidal sediment fragments. The remaining 20 samples, which have concentrations ≥ 5.00 mg g^{-1}, are therefore interpreted as displaying some degree of phosphate enrichment. Values ≥ 10.0 mg g^{-1} are rarely encountered in archaeological contexts and are usually associated with bone-derived phosphate (either actual bone fragments or residual phosphate from the decomposition of bone which has been ‘fixed’ within the soil). Two of the samples have concentrations of 10.0–19.9 mg g^{-1}, classified as ‘strongly enriched’ (Table 3.1), and nine have concentrations of ≥ 20.0 mg g^{-1} (‘very strongly enriched’), with a maximum of 36.5 mg g^{-1}. As is generally the case when very high concentrations of phosphate-P are recorded, a very high proportion of the phosphate present is in an inorganic form (Crowther, 2014). The nine very strongly enriched samples, for example, have Pi:P ratios of 96.8–99.0%. This suggests significant enrichment from inorganic sources (e.g. bone or and/or the accumulation of residual phosphate derived from the decomposition [mineralisation] of organic phosphates such as cess or midden materials, possibly fixed in colluvial, fine, bone-rich, calcium carbonate-rich, ash-dominated layers, i.e. in the x4 (lowermost Structure 14) and x13 and x14 (lowermost Structure 19) sample sets that show very strong enrichment (*n*=8).

Particle size analysis proved problematic owing to the large quantities of carbonate present (Crowther 2014). Only the surface soil from Structure 8 and sample x13c at Structure 19 stand out as having rather more substantial and coarser carbonate-free sand fractions (~14-

16% sand); x13c is a weathered colluvial layer at the top of ash-dominated deposits (MG 391).

Magnetic susceptibility analyses demonstrated that the χ values are extremely variable, ranging from 4.8–641 x 10^{-8} m^3 kg^{-1}. Unusually, the χ_{max} values exhibit a similar range (14.8–714 x 10^{-8} m^3 kg^{-1}) and the resulting χ_{conv} values are exceptionally high ($\geq$ 37.4%), with nine samples having values $\geq$ 100.0% (i.e. $\chi \geq \chi_{max}$). These findings are anomalous, but have been encountered before in the study of three tropical African and Mediterranean sites (Crowther 2014). In the published χ_{max} and χ_{conv} data from sites in Britain, natural levels of susceptibility enhancement in soils/sediments resulting from microbial ‘fermentation’ processes tend to be relatively small compared with enhancement caused by burning. In a review of more than 1000 samples of natural soils/sediments and archaeological contexts from mostly British sites (Crowther, 2003), relatively few χ_{conv} values exceeded 25.0%, with the maximum recorded in Britain being 61.1%. Tite and Linington (1975) report generally higher natural χ_{conv} values in Mediterranean soils, which they attribute to more active fermentation activity, and in such environments enhancement through localised burning is likely to be less significant. The present results from Marco Gonzalez confirm that χ_{conv} data are problematic from such warm environments. In these circumstances, the χ data clearly need to be interpreted with caution, as it cannot be assumed that higher values are necessarily indicative of heating/burning; they could equally reflect a higher Fe content and/or degree of fermentation.

The restrictions on the interpretation of these data are discussed below in relationship to the soil micromorphology. For example, low values do not necessarily reflect an absence of burning. A relatively pure ash deposit is likely to have a low Fe content and correspondingly low χ value (cf. sample x13b, χ: 17.8 x 10^{-8} m^3 kg^{-1}), whereas deposits including burnt ferruginous sediment inclusions show anomalously high χ_{conv} values (>100%; Table 3.1) (Crowther, 2014). In the case of deposits that include burnt ferruginous sediment inclusions, the combined effects of 1) fermentation in exposed tidal mudflats (see below), where enhancement potential could become naturally close to 'saturation', and 2) the burning of such sediments (where they are found as inclusions within lime plaster floors and within the Late Classic processing deposits) may be responsible. The suggested strong effects of fermentation may therefore make indications of heating/burning less evident in both χ and χ_{conv} data. Further discussion of the LOI, carbonate, phosphate, specific conductance (salinity) and magnetic susceptibility appears below.

3.4 Soil micromorphology results

Sixty microstratigraphic layers were identified and analysed with a maximum of 6 microstratigraphic layers in a single thin section (a series of lime plaster floors alternating with occupation-trampled spreads in MG 384, Str.19, Op 13-2, assessed as associated with Late Classic salt working). The layers are described according to the activities they represent, in chronological order (see Table 3.2 for summary).

- Terminal Preclassic (AD 100-250?)/Early Classic (AD 250-550/600) settlement activities and landscape development
- Early Classic lime plaster floor constructions (AD 250-550/600)
- Late Classic intensive processing and associated occupation features (AD 550/600-700/760)
- Terminal Classic to Modern activities, deposit weathering and ‘dark earth’ formation (AD 760/800-Present Day)

3.4.1 Terminal Preclassic (AD 100-250?)/Early Classic (AD 250-550/600) settlement activities and landscape development

The lowermost sediments—that is, the lowermost accessible deposits before groundwater made sample recovery impossible—as sampled in Op 13-1, Str. 14 (MG 383) (Fig. 3.1) are composed of microlaminated (or burrow homogenised) compact calcitic ash in which there are very abundant small bone inclusions; many inclusions are fish bones, including vertebrae (Fig.3.3). Notably, in Op 13-2, Str. 19 (MG 391) (Fig. 3.2), a very similar sediment type is present. At both locations, some bones are pale yellow to almost colourless and are probably poorly preserved ('partly digested') coprolitic bone, whereas orange-coloured and white calcined bones were probably heated and burned, respectively (Macphail and Goldberg 2010). EDS analyses (M4D, MG 383) indicate that coprolitic bones are depleted in Ca and P compared to burnt bone (coprolitic bone: 36.6-37.7% Ca, 15.6-17.5% P; burned bone: 39.0-39.3% Ca, 17.1-18.7% P). The amount of bone overall is consistent with Contexts MG 383 and MG 391 having some of the highest phosphate concentrations at Marco-Gonzalez (22.5-28.1 mg g^{-1} phosphate-P, n=7; see above). As two areas of the ashy matrix material were found by EDS to contain 1.99-3.36% P, phosphate in general could be “fixed” in this calcareous environment (see above). It is also possible that MG 383 and MG 391 are waterlaid colluvial sediments, and within thin section M4C there is a 25 mm-thick coarse lens containing gravel-size plaster, potsherds, shell, and bone, including 5 mm-size, charcoal and bioclastic limestone within the uppermost part of MG 391 (Fig. 3.4). This is a higher energy colluvial gravel within otherwise low energy colluvium. Other bulk analyses (x4a and x4b; x13c-x14d) confirm the presence of only small amounts of fine charcoal/charred organic matter by having a relatively low LOI (3.30-5.51%). It is possible that coarser charcoal could have floated away, a phenomenon recorded at a number of coastal occupation sites, such as Mesolithic Goldcliff, Gwent and Neolithic “The Stumble,” Essex (Bell et al., 2000; Macphail et al. 2010; Wilkinson et al. 2012). As noted earlier, the high $\%\chi_{conv}$ of such calcareous ashy deposits is difficult to understand fully, but clearly burnt non-calcareous mineral material associated with this ash is likely to show magnetic susceptibility enhancement. Lastly, these lowermost sediments have a high specific conductance which, as noted earlier, is probably related to salts within the unweathered ash and also to saline groundwater effects.

The presence of waterlaid and waterlogged sediments is consistent with suggested lower base levels during the initial Maya occupation of the island, with subsequent rise in sea level (Dunn and Mazzullo, 1993). The sediments also record Terminal Preclassic activities which produced large amounts of ash, bone—both heated and strongly burnt as well as coprolitic bone, with much of the bone from fish. These ash and bone-rich occupation deposits were then subject to erosion by seasonal (?) rainstorms, with ensuing colluviation infilling low ground within and around the areas of occupation and into the proximal estuarine/developing mangrove site margins. This implies high occupation concentrations during the Terminal Preclassic period.

At both Op 13-1 (Str. 14) and Op 13-2 (Str, 19) the waterlaid ash sediments were biologically worked, marking a period of exposure and minor weathering (“soil ripening”). Whereas in Op 13-1 the biologically worked surface was sealed by a series of lime plaster floors (see below—dated to the Early Classic), in Op 13-2, the uppermost biologically worked ashy 'soils' record midden remains (Fig. 3.5). Upwards (MG 389-386, and probably into Early Classic levels here) there is a 200 mm-thick series of compact ash and trampled occupation floor layers that are extremely rich in heated and more strongly burnt fish bones that are often horizontally oriented. This amount of bone is consistent with the highest phosphate measurement at the site, for example (x13b – 36.5 mg g^{-1} phosphate-P).

3.4.2. Early Classic lime plaster floor constructions

At Op 10-1, Str. 14, the biologically worked surface formed in waterlaid ashy sediments is dated to the Early Classic period, because constructed lime plaster floors (base of MG 382) (Figs. 3.6, 3.7) stratigraphically sealed two cached Early Classic basal-flange bowls (MG 390) (Fig. 3.8). In fact, there are two distinct layers of horizontally oriented lime plaster floor concentrations involving 5mm to 25mm-thick and 25-35mm-long fragments, with ~25mm-thick trampled occupation deposits between the turbated remains of the constructed floors. The trampled deposits include typically horizontally oriented coarse anthropogenic materials. The lime plaster floors are tempered with large amounts of fine to coarse-size isotropic, and often siliceous, microfossil-rich sediment clasts, some of which are iron-stained examples that show strong rubefication from being burned. These sometime diatomaceous sediments can be described generically as typical fine tidal flat sediments (Reineck and Singh, 1986: 451). Their microlaminated character with oxidised (ferruginised) remains of detrital plant material (e.g., seaweed) is also consistent with intertidal sedimentation (Macphail, 2009; Macphail et al., 2010), as found in European salt marsh environments (Boorman et al., 2002). The lime matrix is often rich in fine burnt bone and charcoal, with thin charcoal frequently embedded in plastering layers. Pure lime plastering laminae could possibly be ash-rich in origin. Lime manufacture seems to have included the burning of siliceous sediments and background bone-rich midden material, whether by design or accidentally. The floors do not seem to include burnt shell, as found commonly in the overlying Late Classic lime plaster floors, whereas large amounts of shell, bioclastic limestone, bone and charcoal are ubiquitous in the trampled occupation deposits. The burnt inclusions are typical of lime plasters in general (Karkanas, 2007), although as regards acid-insoluble materials, the absence of quartz and the presence of large amounts of isotropic siliceous 'clay' seem to suggest some possible differences between these floors and examples from Guatemala, probably owing to the materials available at Marco Gonzalez's marine location. The 'chaotic texture, however, with a highly random aggregate particle size' seems to be a ubiquitous characteristic (Hansen et al., 1996).

3.4.3 Late Classic intensive processing and associated occupation features

In Op 13-1, Str. 14, the layers reflecting intensive processing (salt?) were examined from ca. 2.075-1.070 m asl (MG 359-377) (Fig. 3.1) on the east face above the masonry platform (MG 382 in Fig. 3.1). On the west face, the layers had subsided into a gap within the rock platform (Monolith 5) so that they extended downwards to 0.530 m asl (MG 377 within MG 382). A range of layer types can be described. These are:

a) little disturbed and sometimes totally *in situ* ashy combustion zones,
b) *in situ* lime plaster floors,
c) chaotically mixed burned sediment clast layers, with various proportions of ash and coarse charcoal present, and
d) trampled occupation surfaces showing minor weathering features and bone-rich midden waste.

a) Totally in situ *ashy combustion zones.* These ashy hearth/combustion zone layers, including massive cemented ash and little-weathered ash layers, also display horizontal ash layers thinly interbedded with charcoal (*in situ* hearths) (Figs. 3.9, 3.10). For example, at the base of MG 374, small *in situ* fires with 0.5-1.5 mm-thick ash and charcoal layers are present; it is suggested that these represent fuel layers that were originally ca. 75-225 mm thick (Courty et al., 1989). One such series of small fires reddened (rubefied) the uppermost 15mm of the 40mm-thick lime plaster floor that capped MG 377 (Figs. 3.1, 3.11) (see below). Such small fires would have produced low-temperature heating consistent with boiling brine.

b) In situ lime plaster floors In Op 13-2, Str. 19, an extensive sequence of lime plaster floors, with trampled occupation soils between, occurs above 1.085 m asl (MG 386) (Fig. 3.2). In Op 13-1, Str. 14, a similar sequence begins at a depth of 1.070 m asl (MG 377 to MG 364) (Fig. 3.9). At both locations, the floors include very large amounts of shell tempering, as well as burnt shell of presumed burnt lime origin. As in the Early Classic floors, a major component is clasts of tidal flat sediments rich in siliceous microfossils. As noted above, in Op 13-1, Str. 14, it is clear that there are examples of lime floors on which small fires were lit (Fig. 3.10). In Op 13-2, Str. 19, however, the sampled floor sequence seems also to record occupation trample between the floors (see below), perhaps indicating domestic activities and not exclusively processing (salt-working?) activities, as indicated in Op 13-1, Str. 14.

c) Chaotically mixed ashy and burned sediment clast layers

At both Structures 14 and 19 there are >1-2m thick layers of pink lime plaster floors alternating with mixed ash and burnt sediment-rich layers (see Figs. 3.1, 3.2). They are alkaline (pH 8.9) and highly saline (specific conductance [μS] of ~3000-5000), with apparently strongly enhanced high magnetic susceptibility values (see above). On the other hand, they often have relatively low amounts of phosphate (unlike midden occupation floors – see below). In addition to charcoal and ash, their other chief component consists of sediment clasts. The clasts are composed of 1) calcareous and often fossil-rich sediments and 2) much higher quantities (than the calcareous sediments) of isotropic and siliceous microfossil (diatom)-rich sediment materials, which, as suggested above, can be described as tidal flat sediments (Figs. 3.12 to 3.15). When the siliceous sediment clasts include iron-staining features, they are markedly rubefied, which indicates subjection to heat or fire; other burnt iron-stained diatomaceous clay fragments occur within lime plaster floors. The rubefication is indicative of temperatures around 300-400°C (Dammers and Joergensen, 1996), especially as no more strongly altered or vitrified mineral material was found at the site (Berna et al, 2007). The ubiquity of these burnt intertidal sediments is also consistent with the magnetic susceptibility and specific conductance data. As noted previously, the exposure of tidal flat sediments and the resulting concentration of salt are also probably linked to fermentation and a naturally strongly enhanced magnetic susceptibility consistent with a sub-tropical climate. Why is this burned sediment here, however? As a further consideration, we note that whereas most sherds from the excavations show only a loose coating of background matrix material, two large pottery fragments from processing contexts, MG 374 and MG 377 (Fig. 3.2), retain coatings on their interiors formed of the siliceous, microfossil-rich salt flat sediment (Fig. 3.11), which suggests an association between the heating of the vessels and the tidal-flat sediments.

d) Trampled occupation surfaces showing minor weathering features and bone-rich midden waste. These surfaces were detected in the west face of Op 13-1 and seem to be processing debris (MG 377 within MG 832, not apparent in Figs. 2.1, 3.1) that was either dumped, spread, or left exposed owing to a shift in the active processing locale. The deposits here are often compacted and finely fragmented, with horizontal fissuring and horizontally oriented coarse inclusions, which typifies such trampled surfaces (Cammas et al., 1996; Courty et al., 1994). The layers include shell, heated and strongly burnt bone, with much fish bone and some fine cess fragments in places, producing marked phosphate enrichment (x5b: 18.7 mg g^{-1} phosphate-P) (Fig. 3.13). Of note is the occurrence of coarse shell fragments that enclose calcitic, fossiliferous sands of presumed coral beach origin (Fig. 3.17). This suggests that molluscs such as conchs were processed and then the shells dumped at site peripheries, where coral sand was washed into them; the shells were later collected for various purposes (construction, lime making) and became incorporated in occupation deposits above the beach line.

3.4.4 Weathering and 'Maya dark earth' formation

Weathered deposits and dark earth soils are encountered in increasing amounts upwards in both Ops 13-1 and 13-2 (Strs. 14, 19). We infer from the fragments of the lime plaster floors (referred to as YB, W or GB in the section drawings, which are designations for degrees of staining) that the processing levels were once thicker--that is, there was more accumulation than is now visible in the sections--but have been heavily disturbed. Disturbance (beyond roots, crabs and other non-human interference) first took place towards the end of the 8th century, when the standing accumulation of processing debris served as the core of platforms faced by reefstone that supported pole-and-thatch buildings. These are the structures shown in Fig. 1.4, although many of them were added to and modified up to the 13th century, followed by intermittent use or alteration through modern times.

As if the actual construction activities were not enough disturbance, the Maya practice of burying their dead beneath the floors of buildings served very well in intruding into and heavily mixing the processing levels. Less than half of Str. 14 has been excavated (in 1990 and 2010), yet the area (c. 12 m^2) produced 38 burials. The Op 13-2 test pit (Str. 19) and Op 13-3 (Str. 8), neither of which had been excavated before 2013, produced a minimum of three relatively coherent burials each plus random skeletal parts. Because the Maya disturbed older burials in the process of excavating new graves, it is common to find interments with bones from several burials; crab activity then helps to scatter bones throughout deposits (Fig. 2.3). How deeply the ancient burial activity intruded is difficult to say because it depended in part on how long the building was occupied, but in Op 13-2 (Str. 19) the burial disturbances seem to diminish at about 70cm below the ground surface.

Once the locale was no longer the site of an active trading community, ca. A.D. 1200/1250, land crabs (*Cardisoma guanhumi*), which must always have been active, increased their activities. Much of the disturbance visible in the sections is attributable to land crab burrowing. The crabs burrow down to the water table and in the process bring artefacts, sediment, and material up to the surface. When they abandon their burrows, the walls collapse and material is carried downward. From the point of view of someone interested in how soil horizons can change and develop, they are important agents in mixing deposits and may be key factors in the wide distribution of remains such as pyrogenic carbon.

In addition to Maya construction and inhumations and crab activity, there is the ubiquitous perturbation from roots, insects and other invertebrates. Thus dark earth is found to penetrate deeply into extant stratified deposits. One of our ultimate goals is to estimate the 'normal' depth of weathering and dark earth formation, but a great deal of surface soil has been removed by locals for gardening purposes, and we need to know more about the site's history in order to develop a strategy that will yield reasonably accurate results.

For the present, we are focusing on the recognisable pedological processes affecting the archaeological layers. The most obvious post-depositional processes affecting the site are fragmentation and partial dissolution of ashy and lime plaster floor remains, which can be observed as 'ghost' layers (e.g. MG 359, Op 13-1, Str. 14) (Figs. 3.1), especially in burrows and other disturbances. Heavy fragmentation and dissolution of floor remains are characteristic of Op 13-3, Str. 8 (see Fig. 2.3). We cannot be certain, but it appears that the salt processing deposits were either exposed for a long period before construction of Str. 8, or construction was less substantial and afforded less protection from the elements.

In any case, where once stratified deposits occurred, a generally calcareous (carbonate rich) and moderately humic soil formed, characterised by thin to broad organo-mineral excrements of small invertebrate mesofauna. The pH is still alkaline, but leaching seems to have greatly reduced specific conductance in Op 13-2, Str. 19, some 30cm below the modern topsoil (e.g. as low as 184 μS in sample x12a). In Op 13-1, Str. 14, because ca. 1 m (surface soil, burials, building floors) had been removed before 2013, and plastic had been laid down to mark the level at which the excavations ceased, specific conductance shows less leaching (697 μS in sample x1a), while the remains of burnt debris and lime plaster containing burnt material allow maintenance of an enhanced magnetic susceptibility.

The weathering effects on ash and lime-based construction materials and deposits can readily be compared to the breakdown of Roman stratified levels, where ash and lime-based construction materials were common. Such processes have been modelled since the 1980s (Cammas, 2004; Macphail, 1983, 1994). More recently, the weathering of limestone and stucco (lime plaster and mortar) at Late Classic Maya sites in the Yucatan Peninsula (Río Bec and Dzibanché) have been investigated (Straulino et al., 2013). Of note is the common observation of carbonate dissolution and ensuing secondary recrystallisation of calcite. At Marco Gonzalez, plaster surfaces within the dark earth (and sometimes lower down in the sequence) often show total dissolution of the $CaCO_3$ matrix, whereas only a few mm below these same surfaces, recrystallisation in the form of micrite had occurred. In other words, the floor layer is characterised by a narrow topzone of dissolution below which is recrystallised calcite, which gives the lime plaster floors a banded appearance (Fig. 3.10). The soils associated with the weathered levels are dark because they are characterised not only by increased amounts of surface soil humus but also by high concentrations of very fine charcoal (rather than so-called highly residual ‘black carbon’ [Sørensen, 2007]), presumably owing to relict charcoal-rich layers within the processing contexts (Fig 3.11). The colour of European dark earth has exactly the same character. London dark earth has much higher amounts of cations—producing cation-humus complexes—compared to the local natural soils and sediments. This is probably the case at Marco Gonzalez, although in bulk-measured amounts, the dark earth and surface soils contain less Ca and NaCl compared to the underlying well-preserved levels (Courty et al., 1989, 261-268, fig 15.2b; Macphail and Courty, 1985).

Surface soil (0-5cm) examples from Ops 13-3 and 13-2 (Strs. 8 and 19 respectively) are characterised by broad humic organo-mineral and extremely thin organic excrements (Table 3.2), which together produced the highest organic content (26.9-28.0% LOI, including amorphous humus and ageing plant remains of roots and leaf litter, Mull horizon) (Table 3.1, 0-5cm samples). They also demonstrate strongest decarbonation and leaching of saline salts (combining to produce some of the lowest $CaCO_3$ [35.1% carbonate], pH [7.9] and specific conductance [455-477μS] at the site) (Table 3.1, 0-5cm samples). Furthermore these surface soils often have the greatest amount of acid-insoluble quartz sand (~8-14%) compared to the underlying archaeological levels. Quartz sand deposits do not occur on the caye; the nearest source of quartz is mainland northern Belize, although here the quartz is confined to deposits of reworked and redeposited old alluvium along drainage systems (Howie 2012: 69). Farther south, quartz is a component of the sediments deposited by younger alluvium associated with the Maya Mountains (see sources in Howie 2012: 60-8). Given that many of the ceramics found at Marco Gonzalez are tempered with quartz sand--or are made of non-local clays with naturally occurring quartz (Teal 1984; Ting 2013), the presence of quartz is likely to be the result of the weathering of anthropogenic materials such as the pottery, although quartz as an additive may have been used in other materials, such as floors, ovens, or daub. Phosphate enrichment of surface soils is possibly complicated both by the amount of relict bone from midden activity and decomposition of so many inhumations.

4. Local environmental change: sediment coring

4.1 Sampling, methods

Sediment coring was undertaken in 2013 to investigate the extent and nature of anthrosol-derived material in the coastal margin of the site (Fig. 4.1). As sea level during the earliest known occupation phase, c. 2000 B.P., was approximately 0.3 m below present level and activities such as salt production are assumed to have occurred close to or within the inter-tidal zone, a series of short (1-2m) cores on a 150m transect extending out from the site were collected for detailed stratigraphic analysis. Additionally, in the search for a continuous off-site depositional record of environmental change at Marco Gonzalez, a sediment core was collected from a pool found at the SE edge of the site (Fig. 4.1). A short core was also collected from a distant, uninhabited and recently formed back barrier sand bar with colonising vegetation (lon-87.869122º, lat 18.187373º) to assess compositional changes seen in an undisturbed carbonate to estuarine mud sequence analogous to pre-mangrove conditions at Marco Gonzalez.

To assist in understanding the relationship between occupation, soil development, and inputs of anthrosol into marginal wetland sediments, surface soil samples (5cm-10cm depth) were collected from across the archaeological site for multi-element geochemical analysis. Samples (n=85) were collected from locations chosen by randomly generated coordinates, although this system was influenced by ground conditions and GPS signal. A random sampling strategy was applied to avoid influence of preconceived differences between soil composition and proximity to structures, vegetation types, and elevation.

Although full-profile analyses are preferred in assessing broad soil development, near-surface samples are viable for measuring and mapping geochemical differences in heterogeneous soils influenced by anthropogenic contamination (Johnson & Ander, 2008). Mixing of deep and surface soil at the site is a result of collapse and weathering debris from structures, excavation and looting pit spoil, and bioturbation from tree-throw heave and land crab burrows. Near-surface soil (upper 0-5 cm) was removed from the samples to minimise large uncertainties resulting from measurement of recent soil, leaf litter and fire ash. As well as assessment of compositional differences, a specific enquiry is whether elevated concentrations of metals reflect past Maya occupation activities at the site (Cook et al. 2006).

4.2 Preliminary coring results

Stratigraphies of cores collected from the distal and marginal ends of the coring transect show contrasting depositional histories. In the mangrove core (MG01) (Fig. 4.2) approximately 100m from the southern edge of the site, a transition between lagoonal, tidal sandy muds and mangrove colonisation is recorded in 1m of sediment. Below 1m, water-saturated shelly muds impeded collection, although samples of compact white silty carbonate mud were retrieved between 1.6 and 1.7 m below surface. A levelling survey revealed that the mangrove surface is approximately at sea level (+0.1m).

Mangrove 1 [MG1]: (Figs. 4.1, 4.2) Measurement of dry weight, organic and carbonate content of the sediment intervals shows a gradual transition from carbonate sandy mud (pre-3000 BP) through finer-grained lagoonal mud to mangrove mud and peat. The greatest extent and occupation of MG span this transition. Sherds and worked conch fragments were not found in this core. Mangrove systems are efficient trappers of inter-tidal sediment, and hence the observed transition to more terrestrial elements may be a response to broader Classic-period climate, erosion, and sediment transport into Chetumal Bay (Beach et al. 2008).

Mangrove 4 [MG4: (Figs. 4.1, 4.2) This core proximal to the site comprises an 0.8 m sequence of silty, relatively low organic content mud packed with waste products of coastal resource use and occupation, i.e. ceramic sherds, conch shell, fish vertebrae, and chert microliths. At 0.8 m to 1.3 m below the surface is a matrix of coral sand and large (ca. 5 cm) fragments of ceramic and processed conch. This basal deposit reflects early occupation of the site and either direct dumping or short-distance transport in a coastal setting during rising sea levels (before c. 2000 yrs BP). The upper unit appears to represent the transgressive lagoon/estuarine fill following stabilised sea levels and Classic period Maya occupation of the site. Although only metres distant from current mangrove, the core yielded evidence in the upper 10 cm of organic-rich mangrove mud. More detailed geochemical analysis of this core is underway. Evidence from cores logged between the two ends of the transect shows that the lower coarse anthropogenic waste unit extends an additional c. 30m distance. This apron of buried waste material is unlikely to extend out uniformly around the site but it is a significant extension to the area for archaeological investigation.

Plaza Cores [P1-3]: (Fig. 4.1) Exploratory pits dug in the east-facing depression north of Strs. 12 and 14 revealed a 0.5-0.6m thickness of artefact-rich colluvium above saturated shelly/coral sands. The position and stratigraphy suggest that this area may have been an open embayment during occupation.

Preliminary stratigraphic results from the sediment sequence collected from the open-water east of the site are comparable to the changes seen in MG1: lower carbonate sandy muds replaced by abundant organic and terriginous-element muds. Fragments of conch and ceramics were not found in the 0.6 m-deep core. This core is being used for palaeoecological analyses (diatoms and pollen) to provide more offsite palaeoenvironmental evidence and is also being used to investigate recent geochemical and contaminant fluxes. ^{210}Pb dating provides a well constrained chronology of the last 100 years in the upper cm of the pool sediment.

Preliminary results from surface soil survey of Marco Gonzalez: (Fig. 4.1) Surface soil samples have been measured for organic content (LOI @ 550°C for 2 hours [Heiri et al. 2001]), magnetic susceptibility, and bulk geochemistry (XRF). All samples have been freeze-dried and sieved at 125 micron prior to measurement and milling for XRF analysis.

The organic content of the soils was measured by LOI as a precursor to geochemical analysis because many elements are strongly associated/adsorbed into organic matrices. The organic content of the surface soil is noticeably higher (>20%, max 40% LOI) in the central area of the site where the majority of the structures are located, but also where leaf-litter is abundant. Lowest values occurred in non-vegetated areas, often with an abundance of surface sherds. Owing no doubt to the significant effect of recent plant matter, the organic content (LOI h15 mean=18.2) of the surface soils is higher than in dark earth soils encountered in the Amazon (<12% LOI) (Arroyo-Kalin, 2010), in the Maya lowlands (<16% LOI) (Beach et al. 2005), and in archaeological contexts at depth at MG (<10% LOI). Identification of a soil, perhaps incorrectly, as a dark earth by its increased ‘organic’ content alone, especially as measured by LOI, is highlighted by charcoal-prolific contexts from Str. 14 that only generated an LOI <20%. Significantly higher magnetic susceptibility values are also concentrated in the central area, possibly associated with leaf litter/topsoil bacterial redox processes, but also the presence of fired ceramics and burnt soil matter.

5. People and the environment: macro-botanical studies

5.1 Sampling, methods

Archaeobotanical samples were gathered through flotation of sediment samples from across the 2013 excavations as well as via water screening (1/2, 1/4, 1/8 in. mesh), and retrieved by hand through excavation. Both woody and non-woody macrobotanicals were collected for identification and to quantify the density of pyrogenic carbon in the deposits. Flotation followed the manual, decanting, bucket flotation method (Fuller 2007: 197; Pearsall 2010), whereby the sediment sample and water are agitated and the floating material is decanted through a cloth sieve; the process is repeated until no further charred material is recovered. Approximately 20 litres were sampled from each context and floated in 2-litre subsamples, passing the flot through a 250-micron mesh. The heavy fraction, which was observable in the bucket but did not float, was poured through a 1mm mesh to ensure maximisation of recovery. Dried flots were sieved using 4mm, 2mm, 1mm and 500 micron geological brass sieves before sorting. Charred material was first separated from other organics to allow volume and mass measurements for pyrogenic carbon in each deposit. Identifications are being undertaken using reference material collected at Lamanai and Ambergris Caye during the 2014 season. Additional reference materials are available at UCL, the Royal Botanic Gardens, Kew, and the Royal Botanic Garden Edinburgh.

With regard to wood charcoal content, flotation samples are sorted in the lab to recover all fragments of the absolute minimum size (>2mm) required for identification. Microscopic analysis of the wood charcoal follows standard procedures (Hather 2000). Quantification of the charcoal macro-remains proceeds through presence/absence analysis (Popper 1988). At present, there is no comprehensive single resource dedicated to the anatomy of woods from Belize or Neotropical Central America as a region. To determine the identity of the woods present, reference will therefore be made to: 1) the existing atlas of woods from adjacent regions (Uribe 1988); 2) internet identification resources, specifically the NCSU Libraries' 'InsideWood' database (InsideWood); and 3) direct comparison with thin-section and charcoal reference material, including that collected during the 2014 field season.

5.2 Preliminary results

With regard to non-woody macrobotanicals, only contexts from Op 13-2 (Str. 19) (Figs. 2.2, 3.2) have been analysed to date; the preliminary results from the lowest levels of Op 13-2 support the initial soil micromorphology findings, which suggest different activity phases. The two lowermost Terminal Preclassic to Early Classic samples (from MG 393 and MG 391/392) contain a large number of *Zea mays* (maize) cupules and *Byrsonima* sp. (craboo or nance) seeds that are absent in the overlying late Early Classic and Late Classic levels (MG 386 and MG 375 respectively). Neither of these species grows naturally in coral sand environments and both are believed to have been imported. *Zea mays* and *Byrsonima* sp. are well known Maya subsistence items (e.g. Miksicek 1991), and their presence is consonant with the midden and hearth contexts identified through soil micromorphological analysis, together with the excavated evidence of fish bone, net sinkers, and pottery sherds.

The overlying stratum MG 386 (separated from MG 391 by a hard-packed surface or floor, MG 389) is dominated by wood charcoal, which suggests a shift from the kinds of domestic food-processing activities reflected in Terminal Preclassic and Early Classic levels (A.D. 1 to c. 550) to a fuel-intensive, larger-scale processing activity (c. A.D. 550-760). MG 386 and 389 correspond to the phosphate-rich series of compact ash and trampled occupation floors identified by soil micromorphology, with strong evidence of heated and burnt fish bones. Further analysis of these and the remaining 2013 contexts is anticipated in the coming year, and it is hoped that the results will shed additional light on the nature of occupation and the sources of pyrogenic carbon in the soils.

6. Modern vegetation and conditions of growth

6.1 Sampling, methods

The aim of this initial part of the project was to provide baseline data on the current species composition at Marco Gonzalez. Investigations of patterns of within-site variation in species richness and composition were also begun, based on differences in soil depth and localised substrate characteristics. Vegetation sampling was addressed in two ways. First, sampling proceeded along four transects (north-south; east-west; north east-southwest; north west-southeast), all of which pass through the central (highest/deepest) part of the site to the periphery. This allowed recording of variation in soil profile depth, while allowing for the possible confounding influence of aspect (direction, e.g., leeward- or windward-facing) (Fig. 6.1). Second, non-linear sampling involved recording abundance of plant species within 45 randomly positioned 10 by 10 m plots (Fig. 6.2).

6.2 Preliminary results

Sixty-four plant species were identified from Marco Gonzalez. The forest at the centre of Marco Gonzalez is characterised by tree species such as *Bursera simaruba*, *Coccoloba diversifolia*, *Metopium brownei*, *Pouteria campechiana* and *Citharexylum caudatum*. *Thrinax radiata* is ubiquitous in the understory alongside *Picramnia antidesma*, although it has perhaps been encouraged by clearing of the site to allow for excavations in 1986 (Graham and Pendergast 1989). There is a stand of *Cocos nucifera*, which is thought to be of plantation origin, although it is currently restricted to small patches. At the woodland periphery, there is a higher proportion of more salt-tolerant plants in a transition to the mangrove swamp. The woodland periphery is represented by a slightly different community, characterised by *Pithecellobium keyense*, *Sideroxylon americanum* and *Hyperbaena winzerlingii*, with monospecific patches of Gulf Cordgrass (*Spartina spartinae*) or Swamp Flatsedge (*Cyperus ligularis*) in the lowest-lying areas that are not dominated by mangrove trees. The gradient in vegetation type from the higher areas in the centre of the site to the lower-lying periphery follows ecologically reasonable expectations and indicates that plant community composition may be related to soil depth. More detailed contour mapping as well as expanded excavation is necessary, however, to yield information on the nature of the subsurface deposits, which can then be related to surface vegetation.

The current species composition at Marco Gonzalez reflects complex factors, conditions, and history. Several factors add complexity to the historical interpretation of current species composition; amongst these are: a) The time that has passed since the site was intensively occupied (c. A.D. 1200/1250) is long enough to have accommodated several generations of forest trees and the period of generational turnover is probably shortened by the site’s exposure to hurricanes; b) Intensive occupation ceased about 700 years ago but intermittent occupation continued at least until the historic period. Recent human introductions (e.g. *Cocos*, *Terminalia catappa*) and modifications (clearance, extracting soil) are likely to have altered the structure and composition of modern vegetation; c) The environment of Marco Gonzalez, owing to the site’s coastal location, differs substantially from the mainland Maya sites that have undergone botanical survey, and therefore findings from mainland studies on the effects of Maya settlement and resource exploitation may not be strictly applicable to Marco Gonzalez.

Plant communities at coastal Maya sites (*sensu stricto*) in Belize remain largely un-circumscribed. There is no existing description of a specific type of plant community associated with coastal Maya sites on anthrosols in the region, which means that there is nothing, at least at present, with which to compare the site. Furthermore, the plant communities cannot reasonably be expected to match those of the mainland. However, species presences at Marco Gonzalez ordinate well amongst the ‘Cay forest’ classification of Murray and colleagues (1999) and *Cay Broadleaf Forest* (Stoddart 1962). Characteristic species described in these studies, although relevant to Turneffe Atoll, include *Bursera simaruba*, *Metopium brownei*, *Cordia sebestana*, *Coccoloba uvifera*, *Thrinax radiata*, *Pouteria campechiana* and *Pithecellobium keyense*, all of which occur in abundance at Marco Gonzalez. Where these habitats are described (in Murray et al. 1999), it is in the context of naturally developed forest rather than that of land husbandry. These descriptions were, however, made as part of a broad geographical circumscription and investigators may well have overlooked the influence of anthrosols, especially considering that Maya sites have been reported both from Turneffe Atoll (MacKie 1963) and Glovers Reef Atoll (Graham 1997,1998).

The survey reported here constitutes a pilot approach to vegetation description of the habitat type in the context of dark earth soils. Anecdotal comparisons, derived from walkthrough survey at another Maya site on Ambergris Caye (Chac Balam, N18.17829 W87.86796 NAD 27 Central) (Guderjan 1995; Guderjan and Garber 1995) reveal further consistencies in composition and physiognomy and suggest that longer-term studies may reveal patterns in the association between dark earths and the ‘cay forest’ system. Elsewhere on Ambergris Caye, vegetated parts of the island that were not occupied by mangrove and which displayed no archaeological evidence exhibited soils that were observed to be too thin and sandy to accommodate forests; the vegetation in these conditions forms thickets of drought-adapted shrubs.

The mainland Maya are well known as pioneers of sustainable forest management under a forest garden or *Pet kot* system (Ford and Nigh 2015; Gómez-Pompa 1987), which aims to maintain high levels of diversity of species which have many uses in a domestic setting. Associations of Maya sites in mainland Yucatan and the wider Maya region with forests that contain high representation of useful species is a well-recognised phenomenon (Puleston 1968, Gómez-Pompa 1987, Rico-Gray and García-Franco 1991, White and Hood 2004, Ford 2008, Ross 2011). Prevalence of domestically useful trees in these forests has given rise to a concept of the ‘Maya tropical forest’ (Nations 2010), uniformly abundant in useful species and which has persisted owing to positive anthropic selection.

The extent to which this recognized diversity represents persistent regeneration of initially favoured trees has been called into question, as abundance of useful species may reflect ecological characteristics which enable survival in niches created, purposefully or otherwise, by human modification of the environment (Rico-Gray and Garcia-Franco 1991). Therefore the presence of diversity of species, many of which are considered useful, in mature forest communities in the Maya region is best envisioned as a function of ecological characteristics, independent of whether or not species were introduced in the first place by the Maya in the past. A well-known example is the association of *Brosimum alicastrum* (ramon nut tree) with the edges of limestone structures high in exchangeable C and Mg (Lambert & Arnason 1982), which conflicts with previous assertions that the abundance of ramon at Maya sites was related to its use as a food crop (Puleston, 1968).

Physically, as regards structural characteristics, forests at Maya sites may include sparser distribution of much larger trees than untended woodland, which generally exhibits structural complexity and greater variation in age and sizes of individuals (White and Hood, 2004). The pattern of scattered distributions of very old trees (few, large individuals) is consistent with the structure of historically managed wooded landscapes in Europe, such as pasture woodlands (Vera 2000, Rackham 2009). However, another reason for development of this open structure at Maya sites could be that continued management has aimed to preserve archaeological features by ‘bushing’ or selective clearing (White and Hood, 2004).

7. LCA modelling

7.1 Sampling and methods

At this early stage we are in the process of determining the appropriate time frames for LCA sub-systems (e.g., A.D. 550/600 to 760/800 for salt production); defining the sectors of activity relevant to the specific excavation locations (domestic activity, interments, caching, brine boiling); distinguishing the relevant inputs and outputs for each sector (wood charcoal, lime, human waste, midden accumulation, organic and mineral waste); and describing surface soil characteristics and vegetation suites as the indicators of environmental impacts.

Excavation, wet screening, and flotation (with wet-sieving) enabled capture of materials (inventory) to be quantified as inputs, and in some cases outputs, for the model. Recovered materials include: ceramics, bone (e.g. human, fish, mammal, reptilian), shell, conglomerates, coral, foreign stone (e.g., chert, granite, obsidian), macrobotanical plant remains, and black carbon. The materials that are comminuted are in the process of becoming sedimentary deposits, but methods are being devised for their quantification so that both large and small-fraction measurements can be included in the model. LCA requires quantification of the material flows (inputs and outputs) of systems and sub-systems to allow an overall assessment of environmental impact. The density of materials in each stratum, as outputs of cultural processes, is being calculated using volumes and masses of the water-screened samples and also the pyrogenic carbon from the archaeobotanical flots. In addition, chemical and mineralogical characterisation data from the soil micromorphological investigation are being used to develop estimates of large-scale material quantities that have contributed to soil composition at the microscopic level.

7.2 Results

At the present time, we are at the stage of distinguishing and measuring the material inputs, as described above. We now have base-line information on the site’s environmental history, and information on the current state of the environment such as the vegetation suite and surface soil characteristics. Impacts are in the process of being characterised via mid-point indicators that will be used to suggest the potential impact from ancient activities and their material residues. For example, the presence of pyrogenic carbon can be used as a proxy for increased soil fertility, as the association has been suggested in Amazonian research (e.g. Arroyo-Kalin et al. 2009, 113-114, 119). From the quantified outputs in the inventory analysis, we are moving towards being able to define the availability of materials and chemicals, which can then be compared to information about the current environment to determine if outputs could be the source of recognised impacts. For example, the density of fish bone is being calculated for a given context, the composition of which can then be approximated (e.g, Toppe et al. 2007); this will provide estimates for the availability of elements such as calcium, phosphorous and iron, all of which can affect soil fertility. This availability can then be compared to surface soil chemistry to pinpoint potential origins for surface soil signatures.

8. Conclusions and future research

8.1 Addressing the hypotheses

H1: That the MG site and its environs have changed over time, and these changes bear some relationship to human activities characteristic of each occupation period.

Data on addressing H1 have come from sediment coring, bulk soil and micromorphological studies, and marcobotanical remains. Distinct stratigraphic changes revealed in sediment cores record transgressive sedimentation, mangrove development and incorporation of human detritus, all of which indicate that throughout human occupation, a dynamic coastal system prevailed. Both the dynamic conditions and the evidence for long-term occupation tell us that occupants would have been required to adjust to the changing coastal landscape and seascape.

The location (southern end of the caye with access to both windward and leeward maritime travel), surface elevation, and sediments (produced by Holocene coastal changes) generated the initial conditions for occupation and utilisation of resources (Dunn and Mazzullo 1993). After initial settlement, the site developed as a result of varying degrees and combinations of intended and unintended consequences. Waste, such as discarded shells from processing conch, was deposited as near to production locales as possible without immediately affecting working/living at the time, but it is also possible that such deposition was known to encourage expansion of areas above the tidal limit (by fine-grained sedimentation). Preliminary geochemical data in cores show a distinct transition from carbonate-dominated muds and sands to mineral, non-coral-origin muds and sands. The presence of artefacts below and throughout this transition suggests coincidental human activity during deposition. Indications so far point strongly to humans as a major factor in creating the geochemical changes measured.

Both the bulk soil analyses and the soil micromorphological studies combine with Dunn and Mazzullo's (1993) characterisation of the site before settlement to make clear the extent to which the topography and stratigraphic build-up of deposits at Marco Gonzalez are the results of human activity. Outside of the ongoing natural processes of post-abandonment surface soil accumulation, sub-surface deposits reflect a range of human endeavours from domestic activity (refuse and waste accumulation) to resource procurement such as fishing and shellfish collecting, inhumations, construction, lime production from shells, and intensive processing (probably salt production) and fuel use. Construction and salt production involved the importation to the site of local tidal mudflat sediments, which must have affected the shoreline morphology and made a significant contribution to ground-raising of the island. Deposits have also been affected by plants and animals attracted to the site by the human presence. The large population of hermit crabs (*Coenobita sp.*), for example, is attributable to the availability of thousands of conch shells left behind by the Maya. Construction activity and the build-up of land surfaces through conch deposition have also improved drainage and increased the surface area and elevation of dry land. The results of the bulk soil and micromorphological analyses support the hypothesis that the Marco Gonzalez site, and by implication its soils and vegetation, reflect the long-term accumulation of deposits generated by human activities. Initial results also add support to the hypothesis that local environmental changes are connected to human activities.

The presence of maize (*Zea mays*) and craboo (*Byrsonima* sp.) in Terminal Preclassic to Early Classic deposits suggests strongly that the community at the site was engaged in exchange activities. Neither of these species grows naturally under conditions in which coral sand forms the soil parent material, and imported food had to be stored. Both of these factors suggest that networks of exchange were regular and wide-ranging. A regular influx of imported goods combines with the extensive fish and shellfish remains to point to the potential for significant environmental impact not simply from land alteration as the result of processing and discard but also from changes in ecological relationships brought about by fauna and flora (imported foods) attendant both directly and indirectly on human occupation. *Zea mays and Byrsonima* sp. are notably frequent in the Terminal Preclassic to Early Classic levels but absent in the later wood-dominated ashy levels, which supports the notion of a shift from a focus on domestic or food production to a specialised production activity.

H2: That charcoal found in deposits with sherds from Coconut Walk pottery is spent fuel associated with salt production.

H2 cannot yet be addressed on present evidence; work on charcoal identification only began in November of 2014. In some instances the creation of charcoal is the specific aim of an anthropogenic fire; in most instances, however, the creation of charcoal is an entirely incidental phenomenon arising from intentional or unintentional fire events. At present there is no evidence to suggest that the wood charcoal recovered from Marco Gonzalez derives from the purposeful creation of charcoal. The presence of *in situ* hearth or fireplace features indicates that some of the charcoal macro-remains recovered from deposits (although not necessarily all) are the by-product of wood used as fuel. The contextual association of charcoal and hundreds of Coconut Walk pottery fragments does suggest that there is a link between the presence of charcoal and mass production of some kind. It is the presence of burnt tidal flat sediments in association with the lime plaster surfaces, ash and charcoal layers that points to salt production, although more work, particularly excavation, needs to be carried out to explore the strength of this connection. In any case, the association of charcoal and ash layers with lime plaster surfaces indicates intensive processing of some kind, and the charcoal in these cases is likely to be spent fuel.

H3: That evidence of salt production exists in the form of salt pans, residues, and/or peripheral chemical changes in soils or ceramics brought about by high salt concentrations.

Six of the seven bulk soil samples with the highest salinity levels contain ash, charcoal and/or burnt residues and are derived from the processing levels. Because unweathered ash deposits and tidal flat sediments, which are present as burnt clasts, inevitably contain soluble salts, it seems likely that the variability in salinity recorded across the various samples reflects a combination of enrichment through natural processes with anthropogenic activity, namely the collection of saline sediments. Thus, in addition to the presence of crude pottery believed to be associated with the heating of brine to drive off water to produce salt, there is some indication from soil chemistry to support the hypothesis that the processing levels reflect salt production.

The exact process for salt working at Marco Gonzalez remains obscure, but given the findings thus far, sleeching may have been practiced, in which naturally salt-enriched sediments were utilised. In various reviews of U.K. and worldwide salt-working methods, Biddulph and colleagues (2012, 13-15, 80-82) suggest that ‘sleeching’ was one method that could produce large amounts of burnt intertidal sediment waste, termed ‘redhills’ in Essex, U.K. (Macphail et al., 2012). It is noteworthy that the same U.K. salt-working deposits had both enhanced specific conductance and magnetic susceptibility. Using Biddulph and colleagues’ 2012 findings, it seems plausible that at Marco Gonzalez, tidal flat sediments of upper salt marsh character, which are the most saline owing to evaporation, were employed by mixing the sediments with sea water to produce brine. This mixture, which was discovered adhering to some sherds, was heated over small fires lit on or within the now-pink (heated) lime plaster features, which are the remnants of hearths or fireplaces. If collection of sediments for salt production was a seasonal activity, dry season evapotranspiration and/or sediment fermentation (see magnetic susceptibility) would have increased the salt content of upper tidal flat sediments. If so, this model may help to explain the layered lime plaster and burnt salt-making debris deposits. Some of the tidal flat sediment clasts are ferruginous, hence their rubefication and enhanced magnetic susceptibility qualities; experimental studies on newly formed tidal flat sediments at Wallasea Island, Essex, UK, have shown that ferruginisation was recorded after only 2 years of exposure, suggesting that at Marco Gonzalez such iron staining could have been a very rapid process indeed (Macphail et al., 2010). Concurrent subaerial exposure under tropical conditions may also have enhanced the sediment's magnetic susceptibility naturally (see Table 3.1), before any burning took place during salt processing.

Lastly, it may be possible to estimate a minimum number of salt-processing episodes by counting lime plaster floors at Structures 14 and 19, for example, with some levels recording 6 plaster floor sequences per ca. 30cm. 1.00-2.00 m of salt-working levels does not, however, exactly correlate to 20-40 salt-working events, because within these industrial layers are occasional trampled occupation floors.

Identification of the processing activity may seem at first to be important only from an archaeological point of view and not from the perspective of soil-formation processes. However, because driving off water from brine requires large amounts of fuel, it is critical to make the connection between the processing activity and salt production (or to discover what, if not salt, was being produced) in order to develop a good understanding of the nature of fuel use, and temperature and firing conditions. We also need to explain the presence of particular raw materials such as quartz sand, which seems to be the essential tempering material for the standardised ceramics subjected to heating. The presence of quartz in sediments improves drainage, and the presence of pyrogenic carbon is instrumental in dark earth formation.

H4: That fuel was obtained on the island.

Because the analysis of the charcoal samples has only recently begun, this hypothesis cannot yet be addressed. Given the quantities of unexpected exotic materials—e.g., chert nodules (rather than finished flakes or preforms) that were imported and flaked on site—we are keeping an open mind regarding the sources of the fuel used so intensively in salt processing.

H5: That the MG dark earths reflect interaction between residues of human behaviour and environmental processes over time.

The macro/micro and chemical nature of the soils across the site is locally distinct but variable owing to the collective effect of human activities and environmental change. Human-derived detritus (conch piles, sherd scatters, combustion products) has become incorporated into the active soil horizon. Initial statistical analysis and mapping of element values show two main clusters: soil samples located at the periphery of the site with elevated Ca and Sr, and interior samples with elevated concentrations of minerogenic elements owing to the degradation of imported ceramics (or possibly in some cases, ceramics made with imported temper). Within the cluster of interior samples with concentrations of minerogenic elements, results show elevated concentrations of trace metals in defined areas of the site and in proximal sediments that suggest anthropogenic enhancement.

The high LOI values in the surface soils are attributable to high soil organic matter and the presence of micro-charcoal. The surface soils are also notably organic-rich for a tropical soil in which high rates of organic decomposition would be anticipated. Overall, indicators are strong that that the surface soils have been enriched in a way that implicates anthropogenic activity. Macrobotanical remains occur as pyrogenic carbon, but further work is necessary to determine whether or not: a) the quantity of microcharcoal is greater than what would be expected in areas where forest is simply cleared and burned for farming (*milpa*); and b) a significant proportion of the micro-charcoal can be traced to charcoal in buried deposits as its source.

H6: That variation in vegetation species types, richness, and diversity will reflect anthropogenic influence/impact on local environmental conditions.

No specific claims can yet be made to support the hypothesis that detectable variation within the site reflects anthropogenic factors. Analysis has begun on species composition in relation to elevation, but a detailed contour map is needed—one that excludes the tradition (for archaeologists) of schematic representation of structures displayed in Fig. 2.2—to enable the plotting of vegetation against elevation. The vegetation is very different from the surrounding area, as described above, and anthropogenic factors are strongly implicated, but the way in which individual species or vegetation communities might reflect growth conditions that result from anthropogenic input remains to be studied.

H7: That principles of interaction will be established with implications for modern practices in relation to both resource-efficient management of wastes and future land use.

At this stage in the research, analyses of the basic datasets are ongoing and no principles of interaction have been identified. Direct, causal connections between deposits and impacts are not intended, however; instead, we can establish potentials for impact, suggest the relative contributions of different occupation phases, and initiate an alternative approach to understanding anthropogenic impact.

8.2 Future directions

One of the next essential steps is to undertake extensive excavations at Marco Gonzalez to: 1) provide further information on the nature of the 9th through 12th-century occupations (Terminal Classic to Early Postclassic), including their effects on the sealing of the carbon deposited in the late 6th through mid-8th centuries (Late Classic); 2) produce extensive exposure of the layers of carbon, pottery, and lime plaster surfaces/features associated with the Late Classic salt production; and 3) create deeper soundings to gather further information on Preclassic and Early Classic activity and its relationship to the environment prior to human occupation. To widen our knowledge of the relationship of dark earths and human activity, it is important to investigate other dark earth sites along the Belize coast and cayes, particularly in areas such as the Stann Creek District, where the soil parent materials are the granites and metasedimentary rocks of the Maya Mountains and where carbonate-rich deposits are believed to be absent.

The vegetation at Marco Gonzalez is now recorded, and the next step to undertake is detailed contour mapping in order to determine whether or not there are associations between particular communities and subsurface deposits. The mangrove vegetation surrounding the site should be examined for indications of former locations of salt pans. Finally, and not least important, the invertebrate communities, both insects and crustaceans, warrant study to examine the extent to which they contribute to disturbance and perturbation of deposits.

Our ultimate goal is to apply the results of our work in two ways. The first is to steer modern landfill practices away from the idea of ‘sealing’ residual waste (and separating out organic waste) towards managing the chemistry of discarded material in the context of planning for optimal long-term decomposition. The second is to influence the way in which agricultural soil viability is conceptualised by those who measure soil fertility. As matters stand, surface soil viability tends to be depicted as synchronic—understandably in the case of assessments of fertility for short-term cultivation. Where diachronic processes form the context of understanding, soils are described as the product of parent materials or rocks with components comprising minerals, organic materials, organisms, water and air, all of which have origins in the natural environment; people enter the picture as users—which can sometimes be beneficial—or as degraders (Balée, 1998; Soils, 2015). We argue that deposits associated with human occupation (buildings, rubbish, waste, as detailed above) should be considered as parent materials or components that have a role in soil formation. Our study is taking the initiative not only to identify and measure the products and processes involved but also to apply the results in developing a model with the potential to inform environmental impact assessments in today's world.

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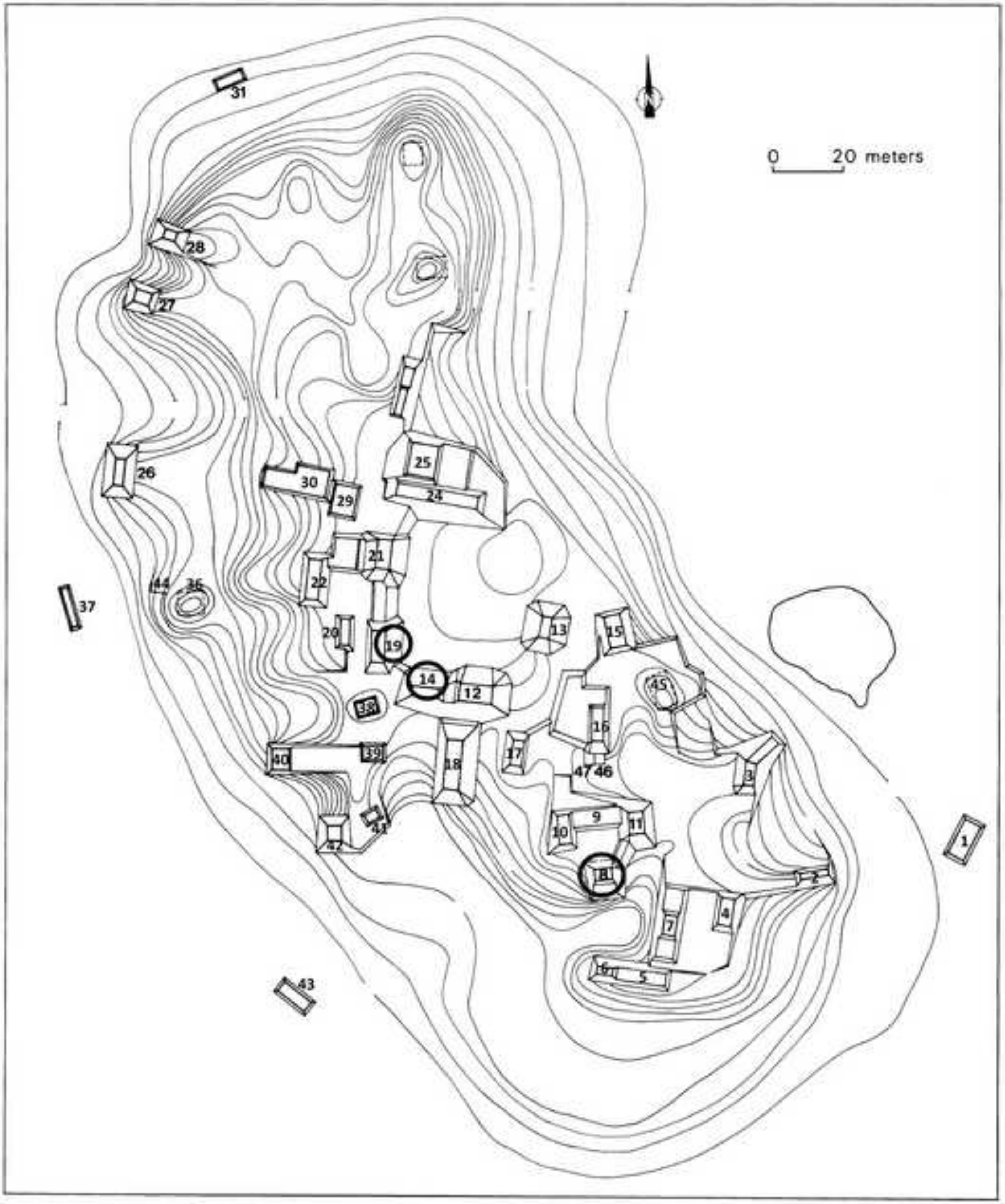
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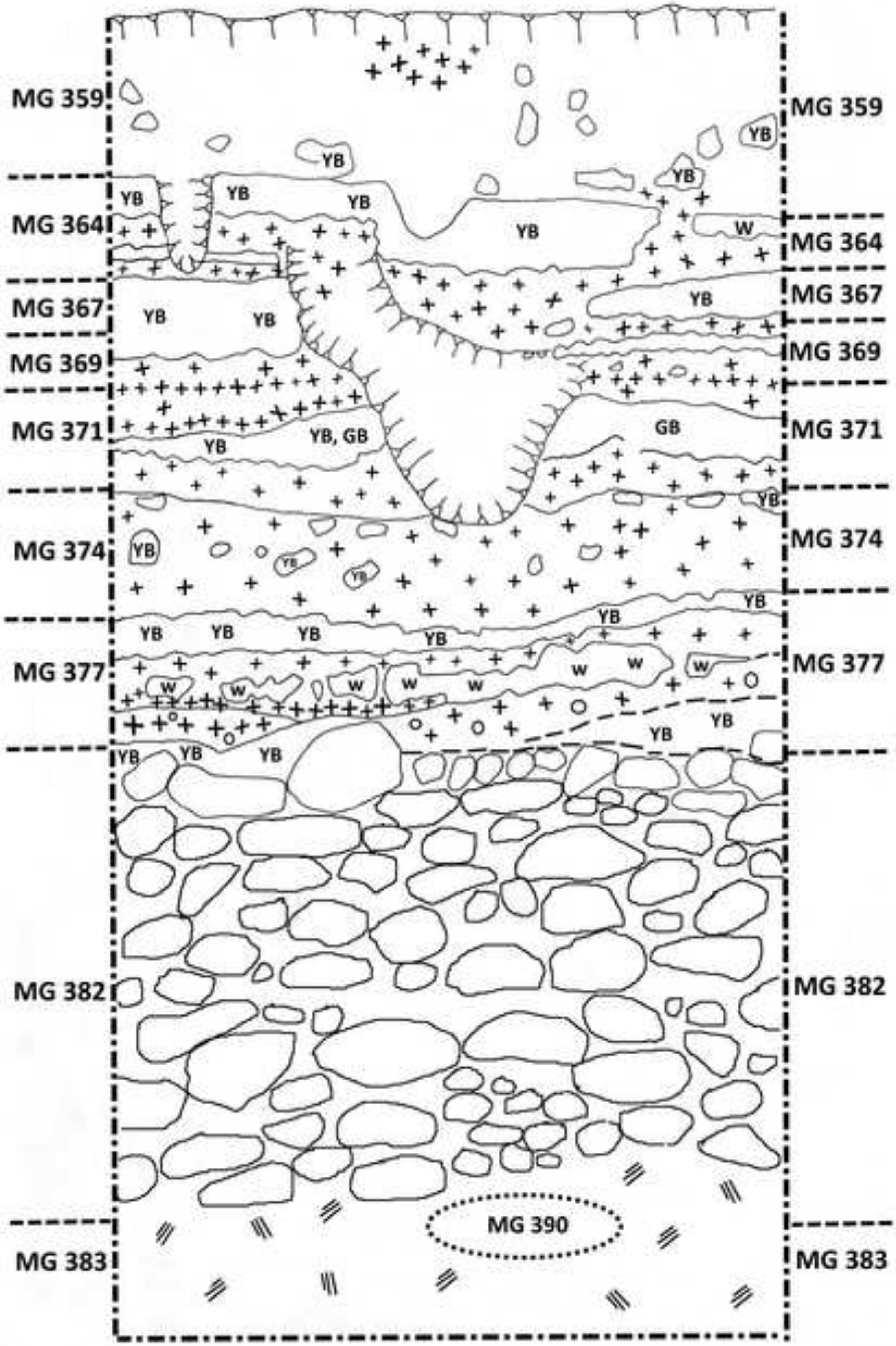
Figure

MARCO GONZALEZ CHRONOLOGY IN CONTEXT

Period	Time	Activity
Modern	1981 – present	Independent nation of Belize
Late British colonial	1964 – 1981	Self-governing Crown Colony
British colonial	1862 – 1964	Belize becomes a British Crown Colony
Early British colonial	1660s – 1862	British become firmly established on the mainland; Belize known at this time as the Bay of Honduras; evidence of British occupation largely from San Pedro
Late Spanish colonial	1648 – 1708	Diminished Spanish activity in Belize after mainland Maya rebel; some Spanish pottery from San Pedro.
Early Spanish colonial	1544 – 1648	Major period of activity in Belize with *encomiendas* established at Lamanai and Tipu on the mainland; cache dated to this period from MG Str. 12
Terminal Postclassic	1492 – 1544	Coastal incursions by European seafarers affected all coastally oriented communities but no direct evidence from MG.
Late Postclassic	1350 – 1492	Special-purpose platforms at NW site periphery of MG possibly built at this time; random house platforms
Middle Postclassic	1200/1250 – 1350	Mangrove encroachment at MG; inhabitants probably move north to San Pedro, which displays intensive trade activity at this time and in the Late Postclassic
Early Postclassic	960/1000 – 1200/1250	Additions to standing buildings at MG, possibly those with “giant riser stairs,” as well as continued trade and exchange
Terminal Classic	750/800 – 960/1000	Construction of buildings at MG comprising a small town engaged in trade and exchange
Late Classic	600 – 750/800	Among other activities at MG, lime production and salt processing
Early Classic	250 – 600	MG trading in polychrome pottery, chert, obsidian and a range of products
Terminal Preclassic	A.D. 1 – 250	Evidence from lowest accessible levels at MG indicating dense occupation, households, fishing, processing
Late Preclassic	300 B.C. – A.D. 1	Evidence at MG in the form of sherds from shell midden below water level
Middle Preclassic	600 – 300 B.C	No evidence as yet from MG, although pottery of this date has been recovered from one of the Colson Point sites and Placencia in southern Belize.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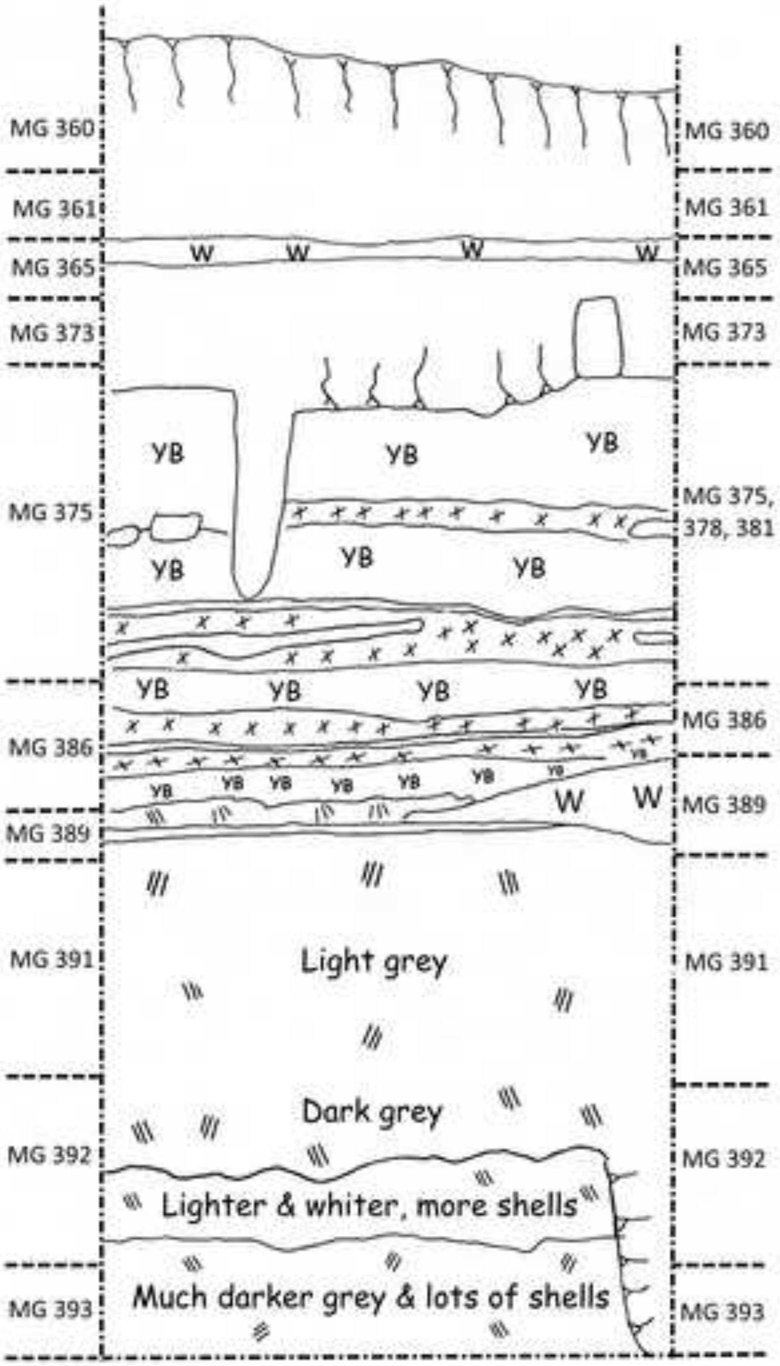

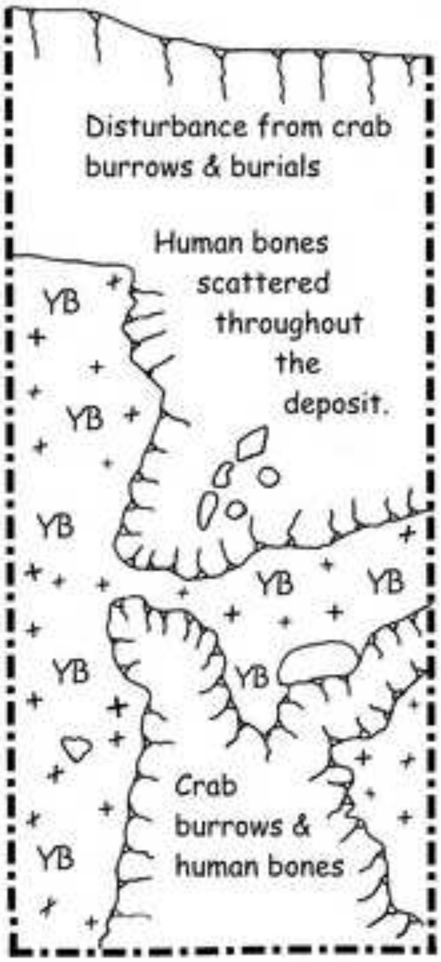
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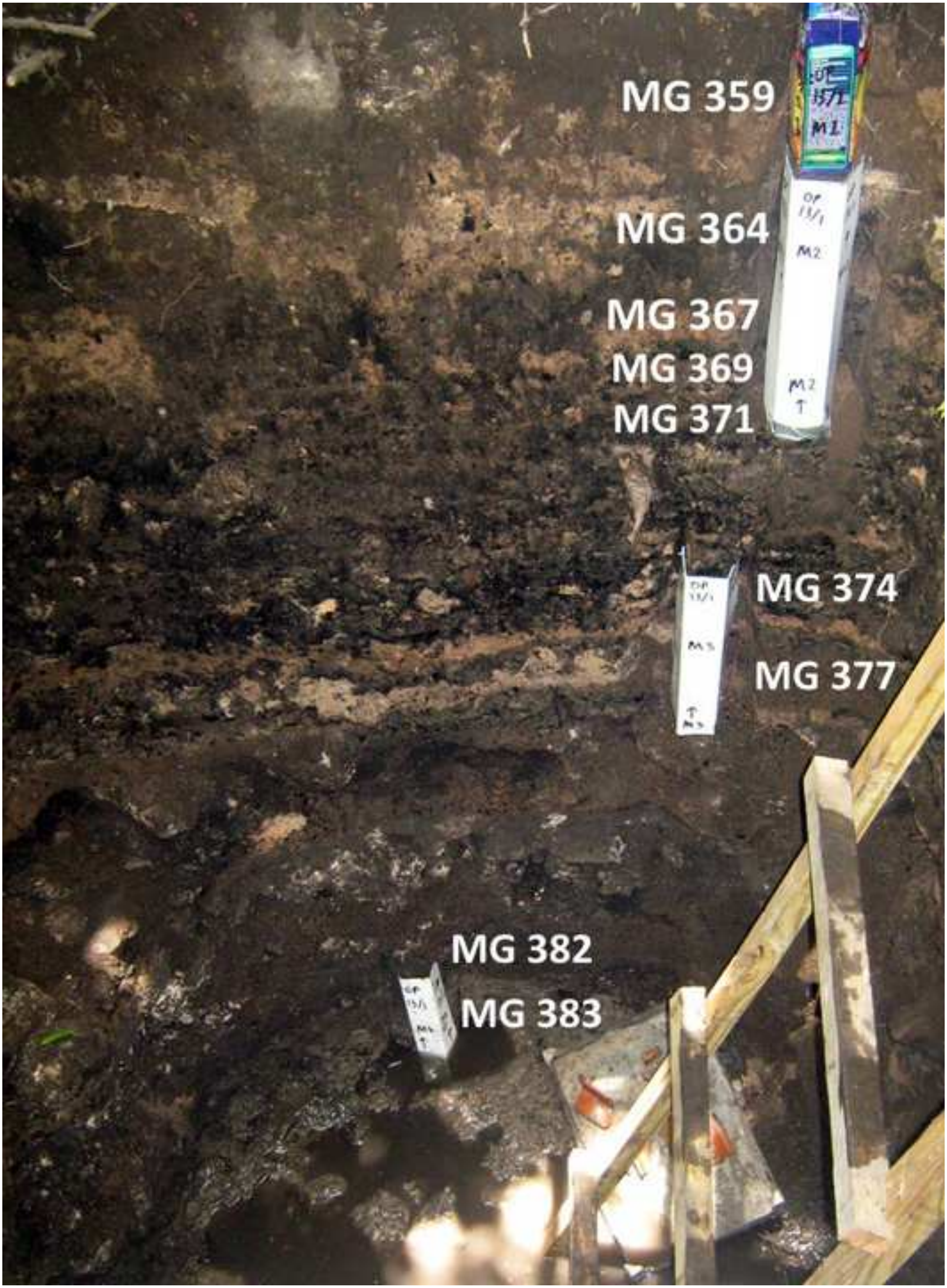
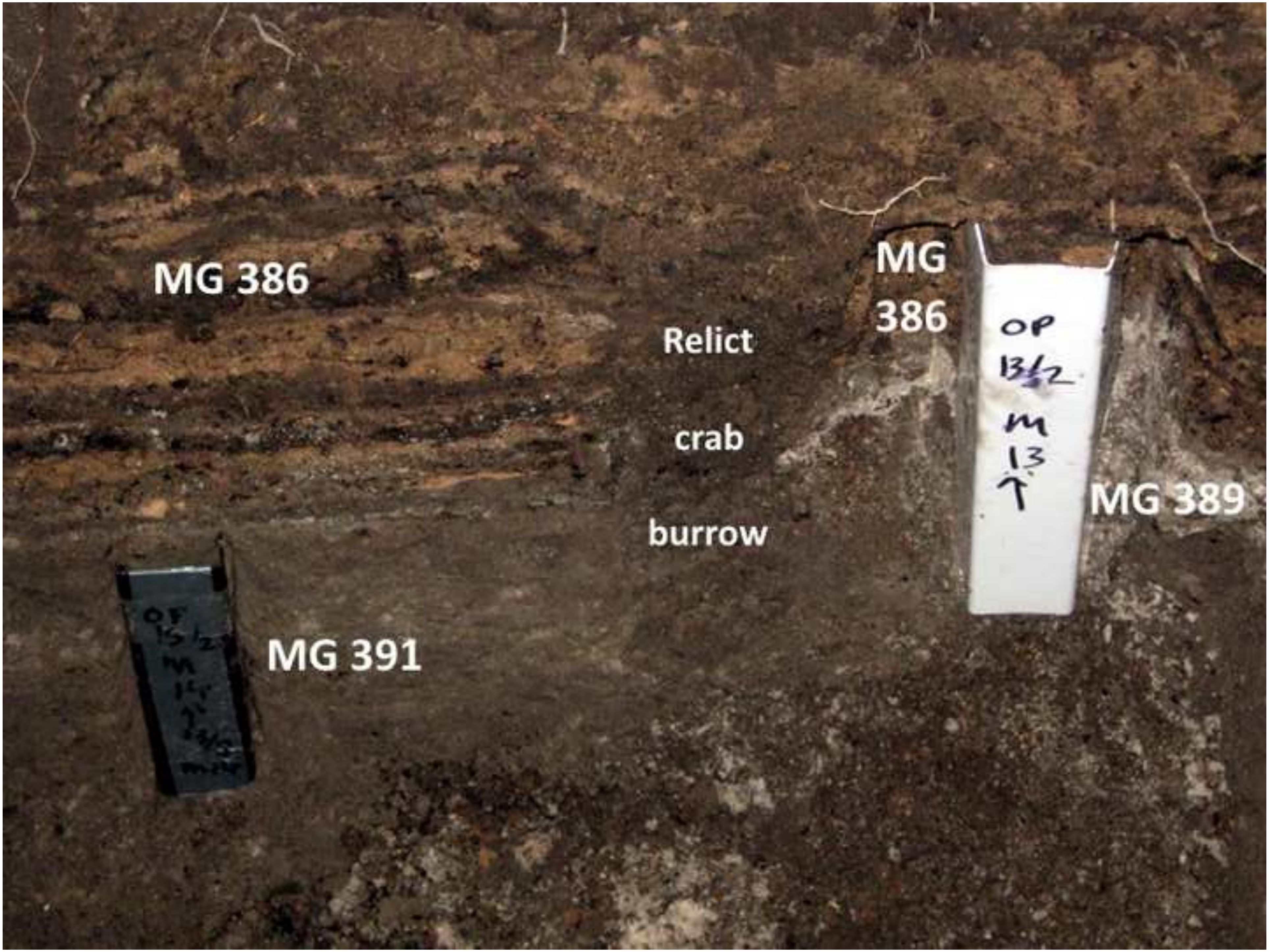
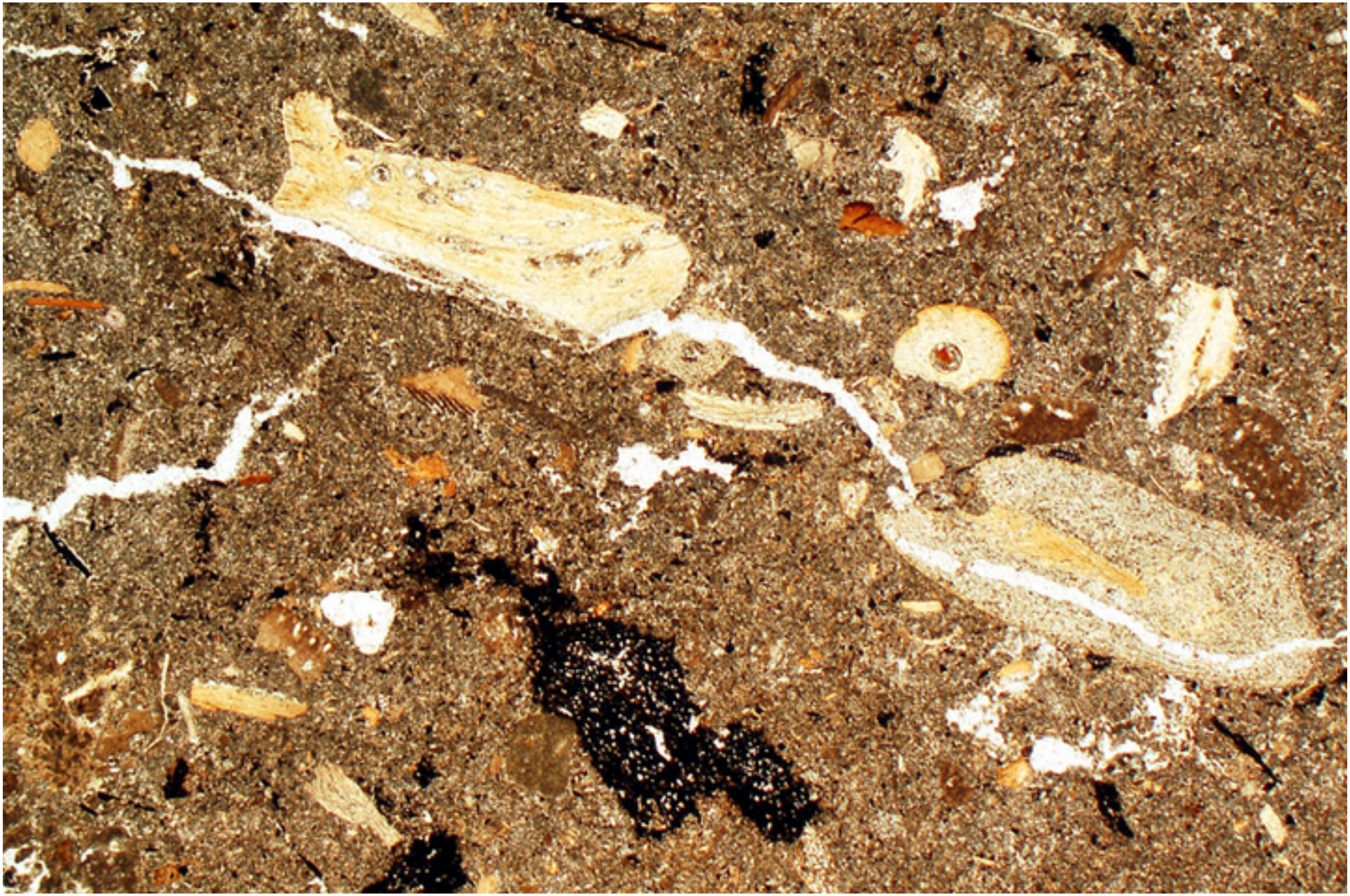
Crab burrows & human bones


MG 359
MG 364
MG 367
MG 369
MG 371
MG 374
MG 377
MG 382
MG 383


MG 386
Relict
crab
burrow
MG
386
OP
13½
M
13
↑
MG 389
MG 391

Figure



Figure

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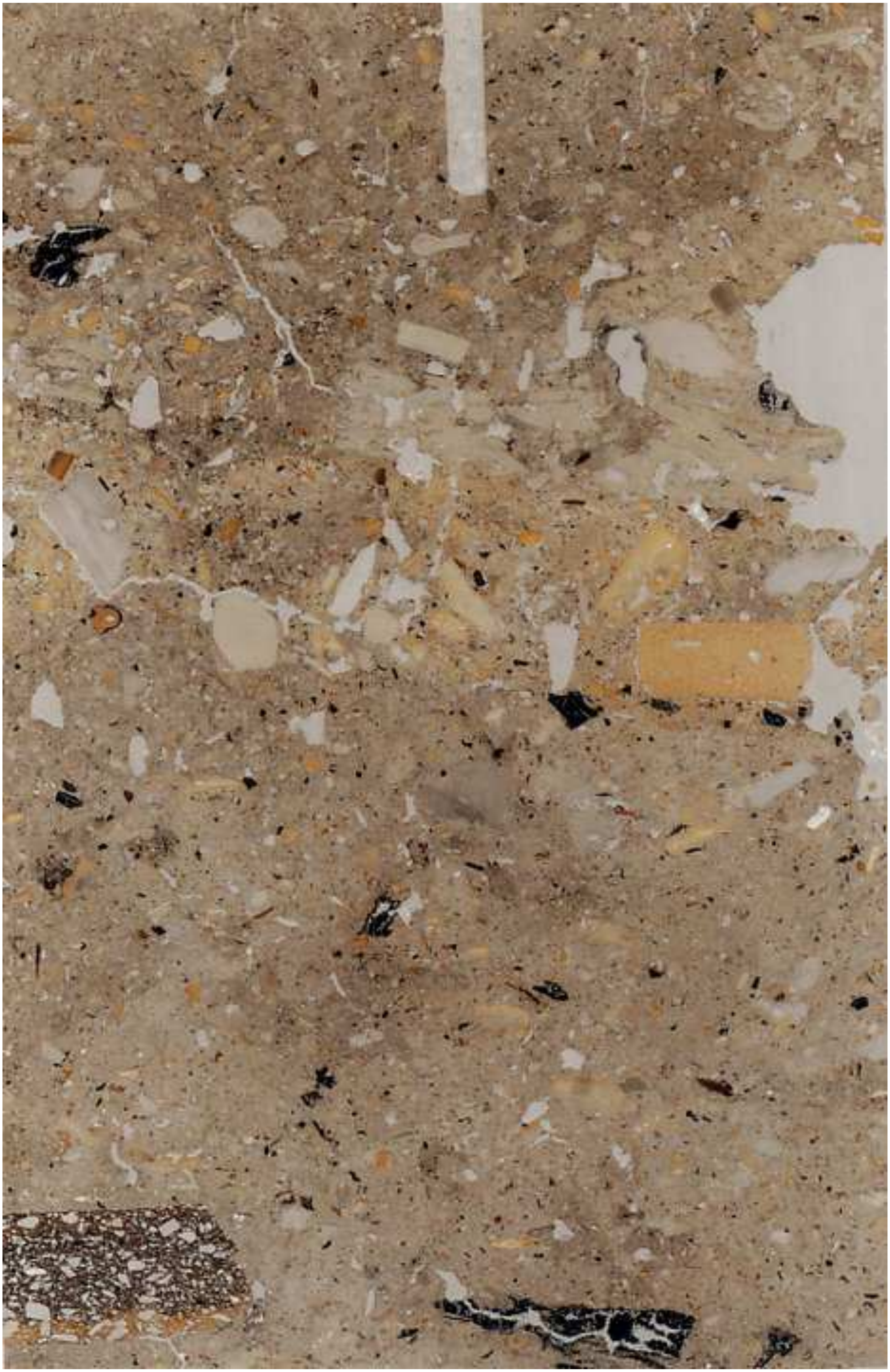

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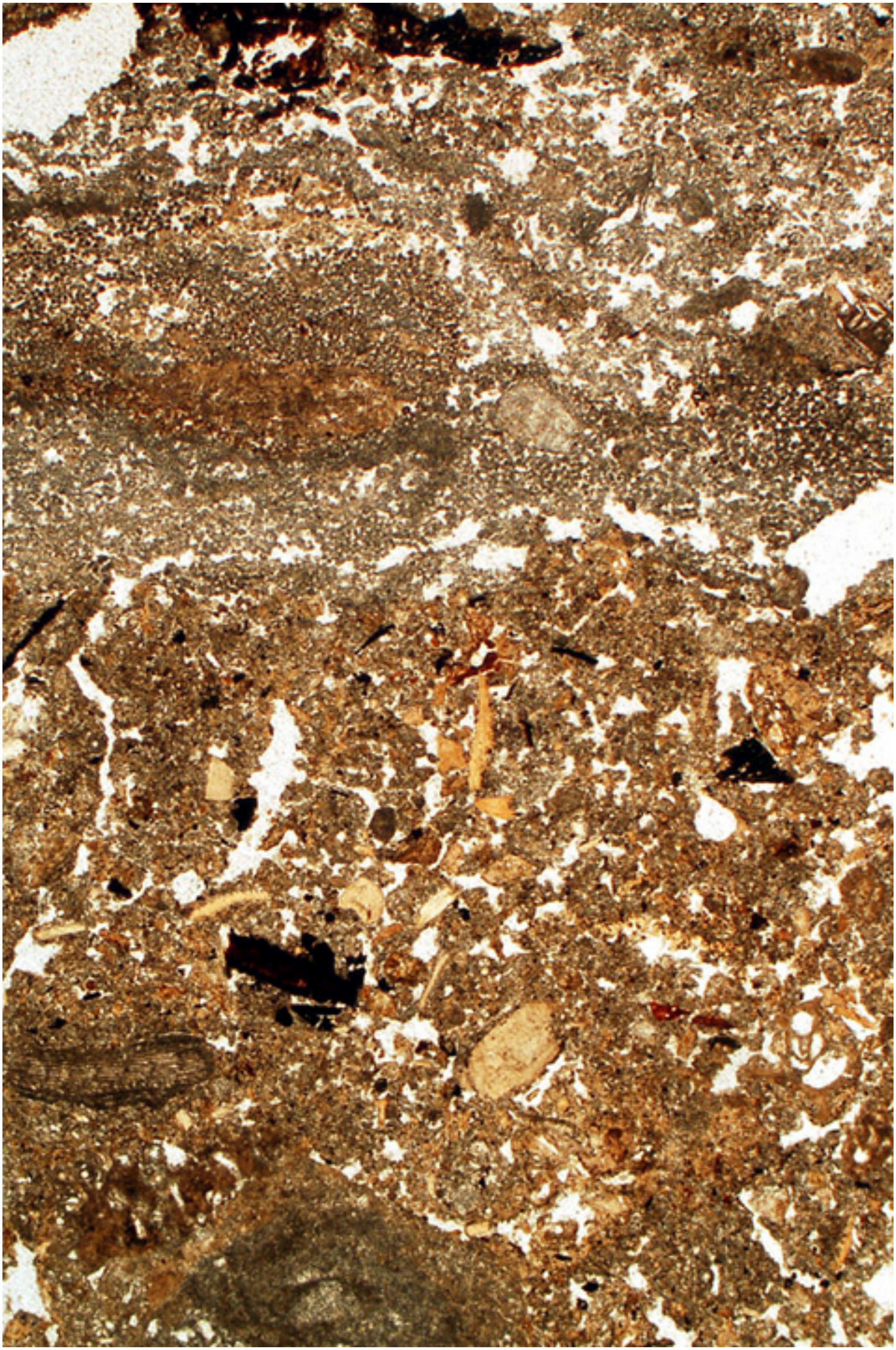

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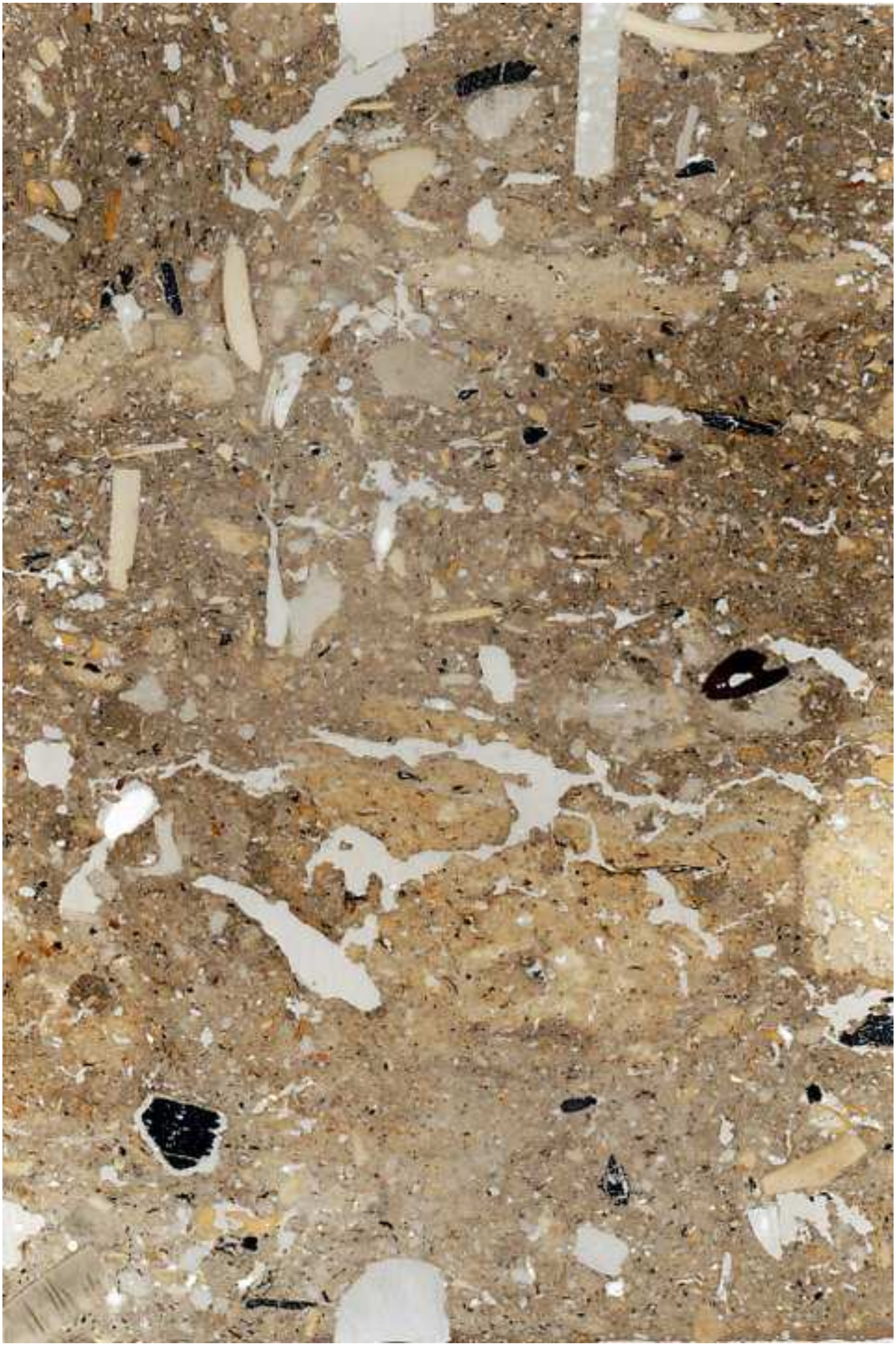

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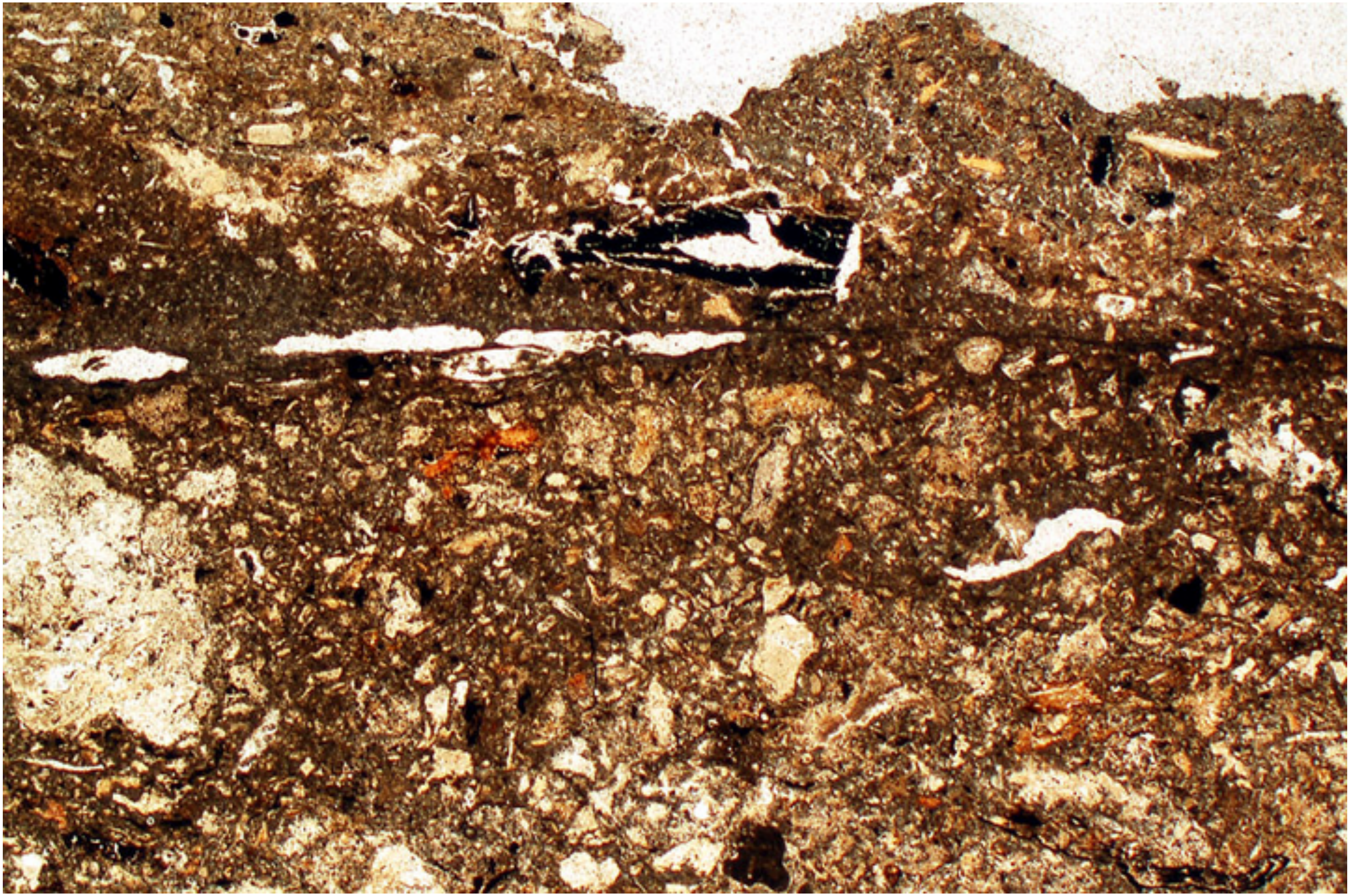
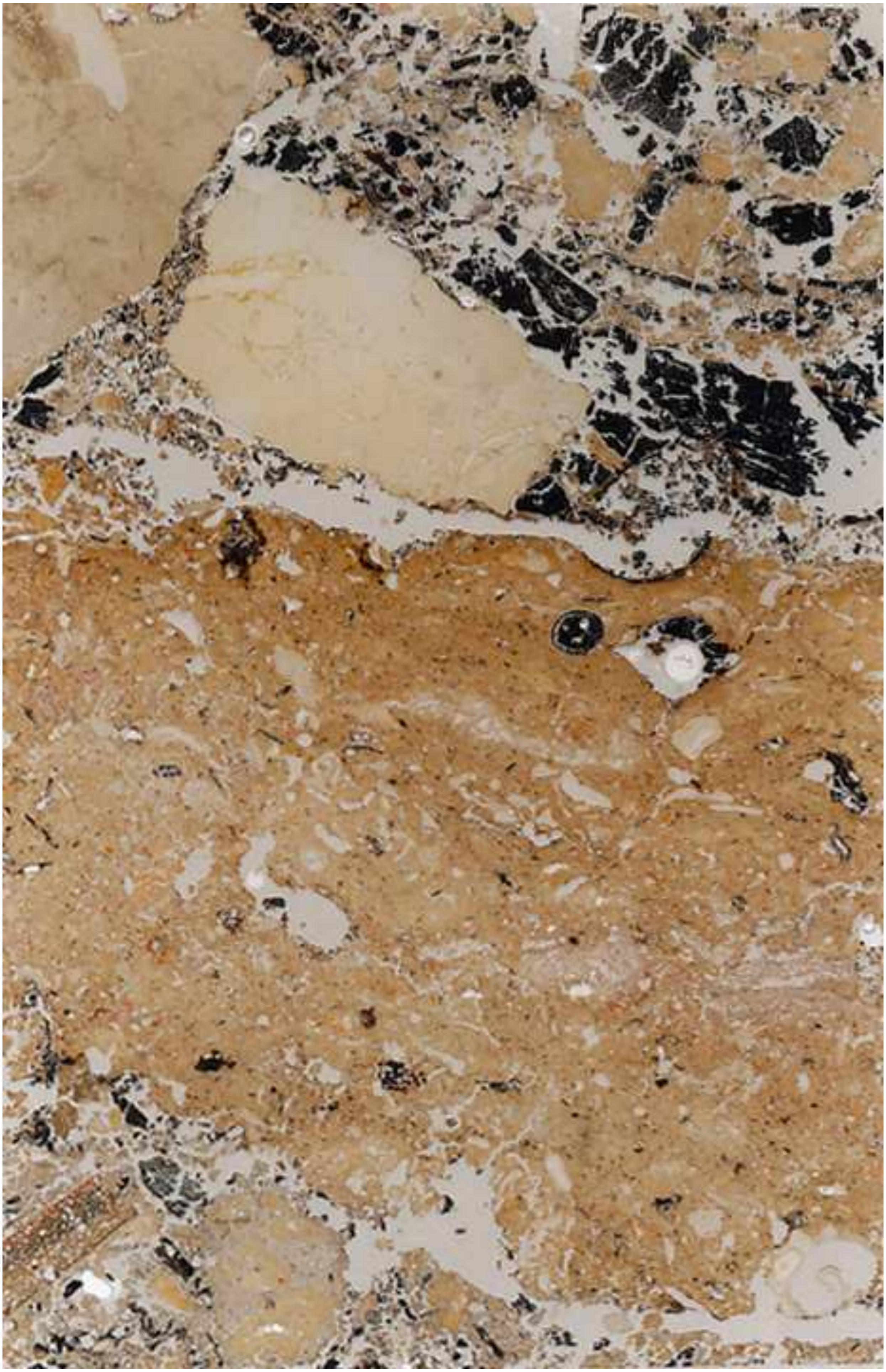
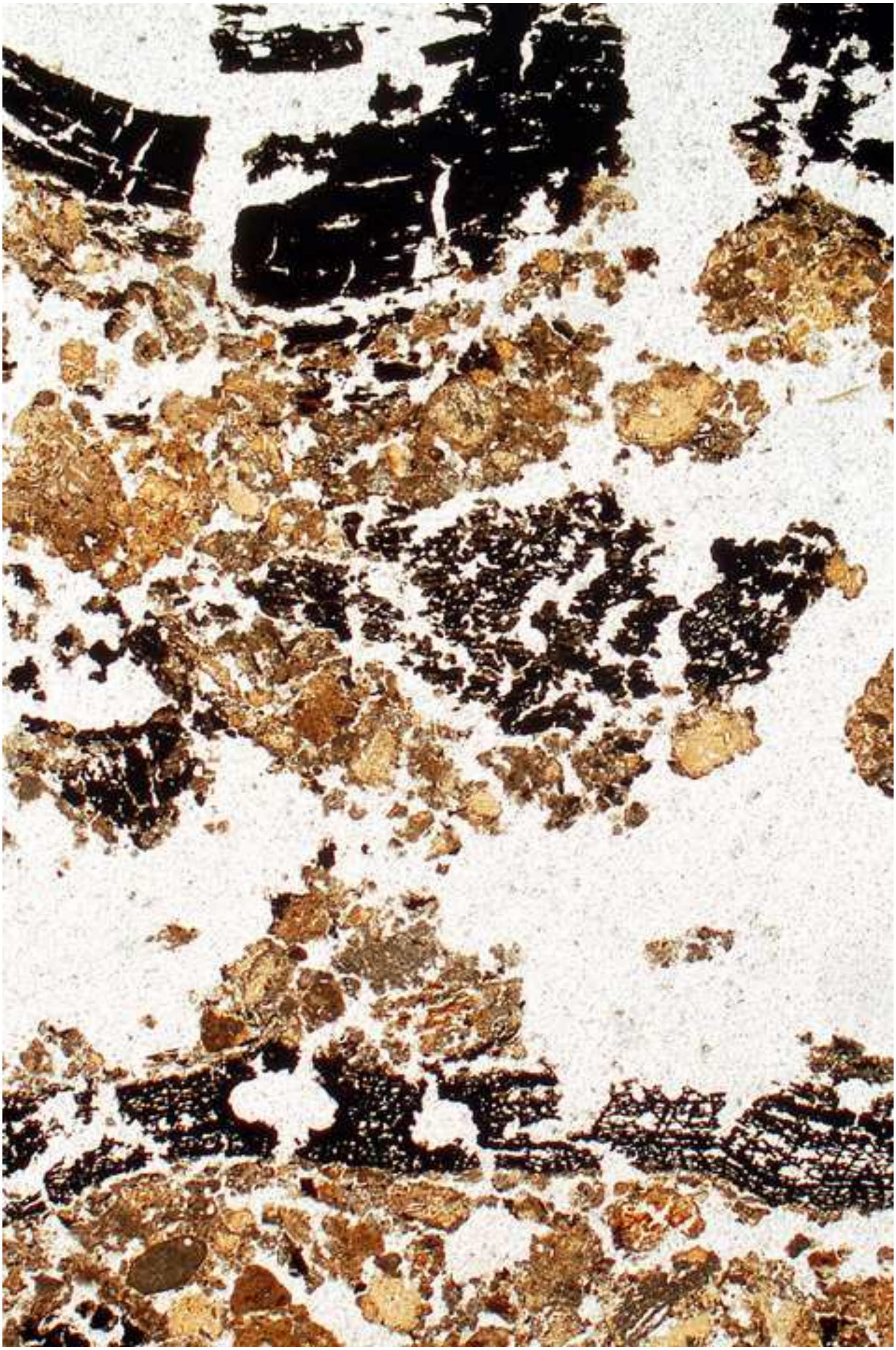
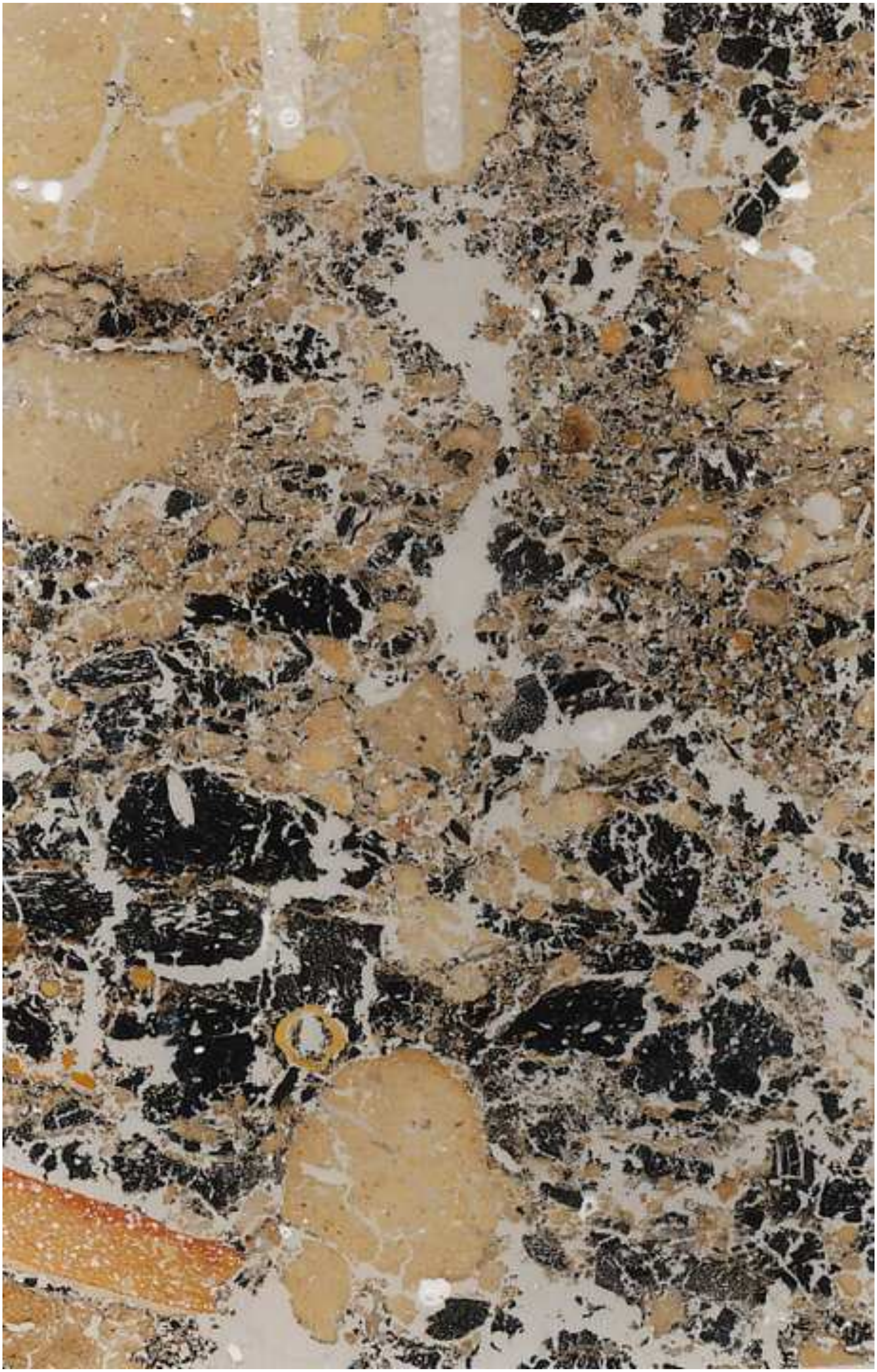


Figure

Figure







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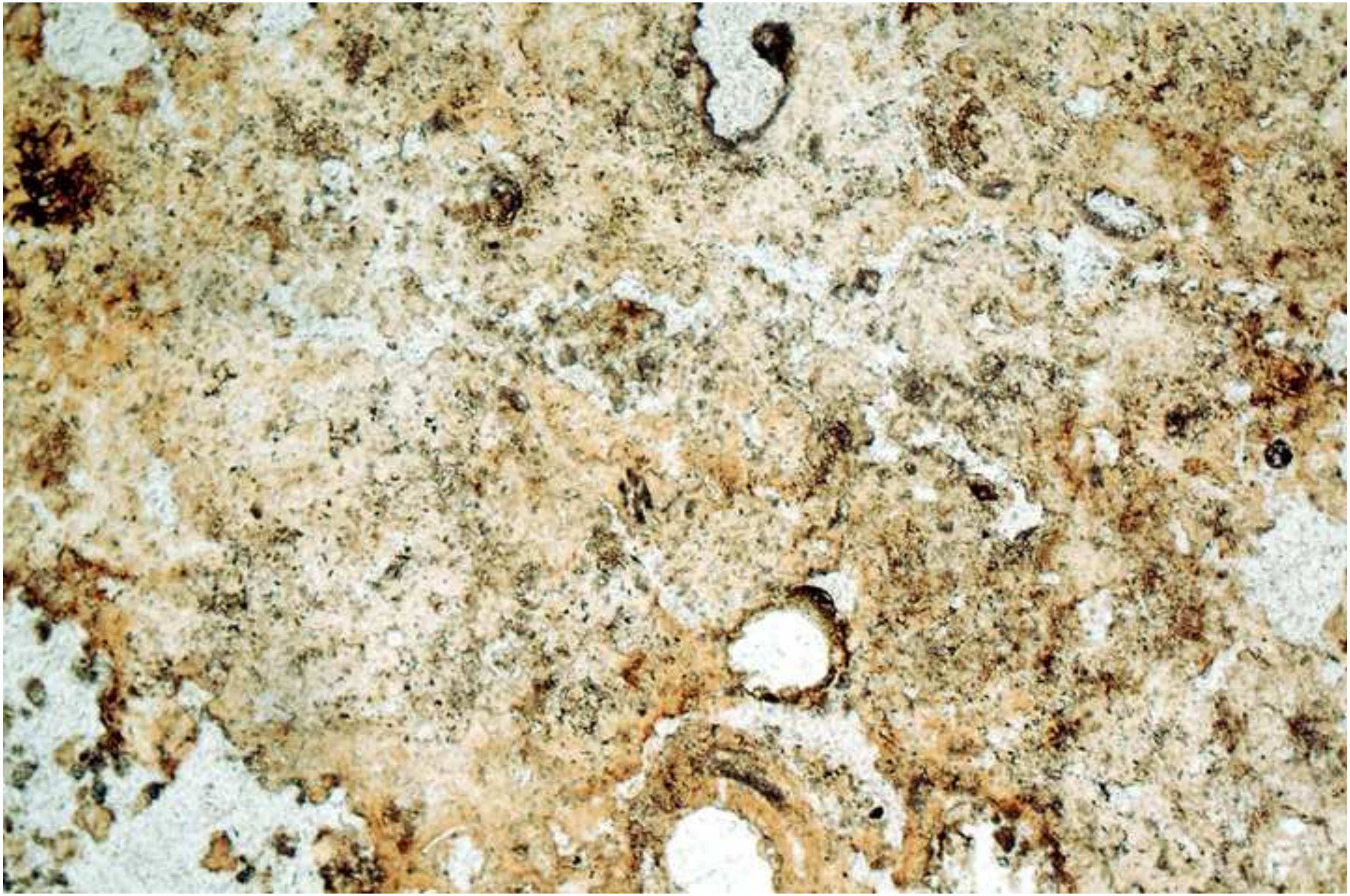

Figure

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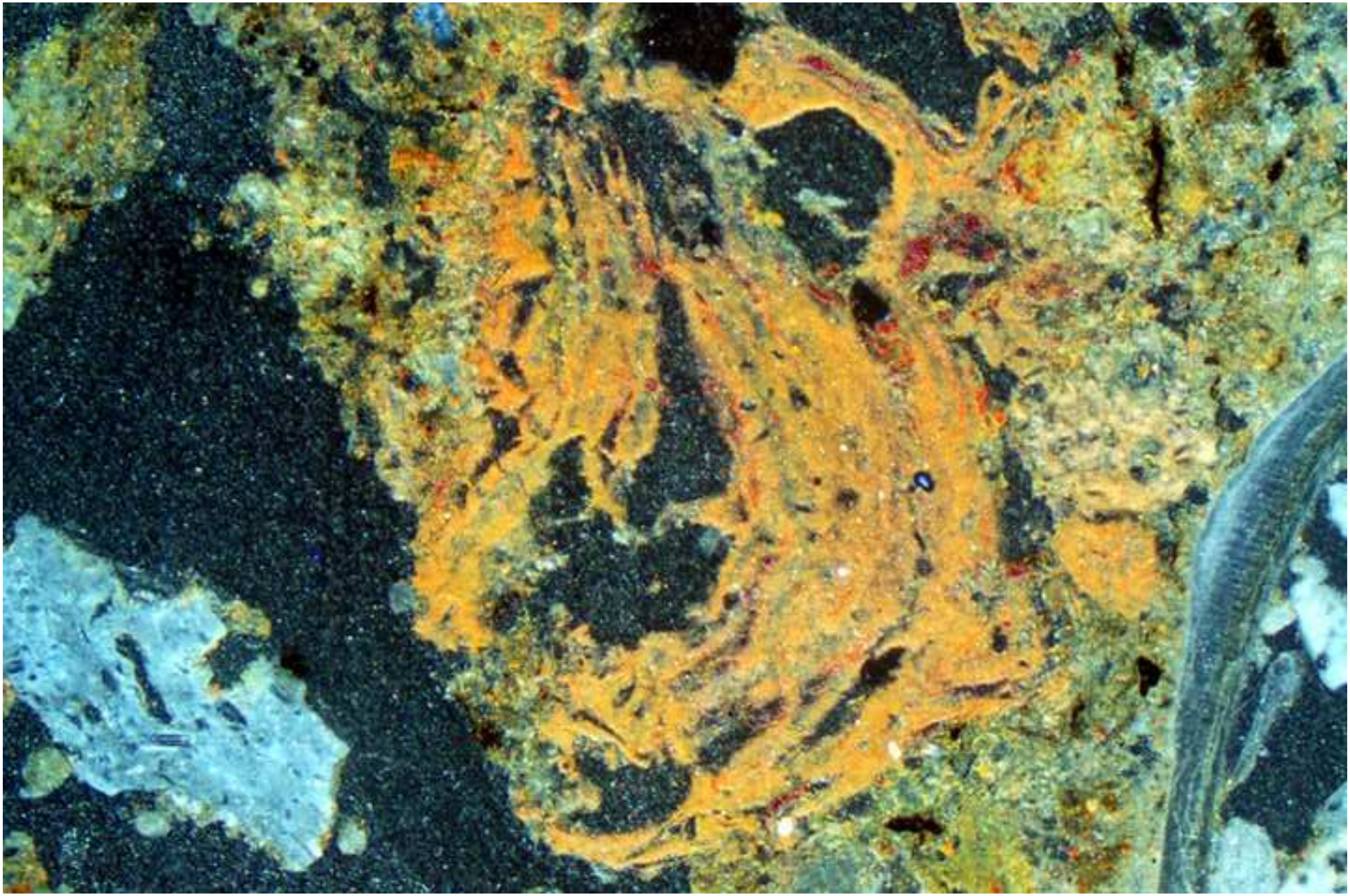

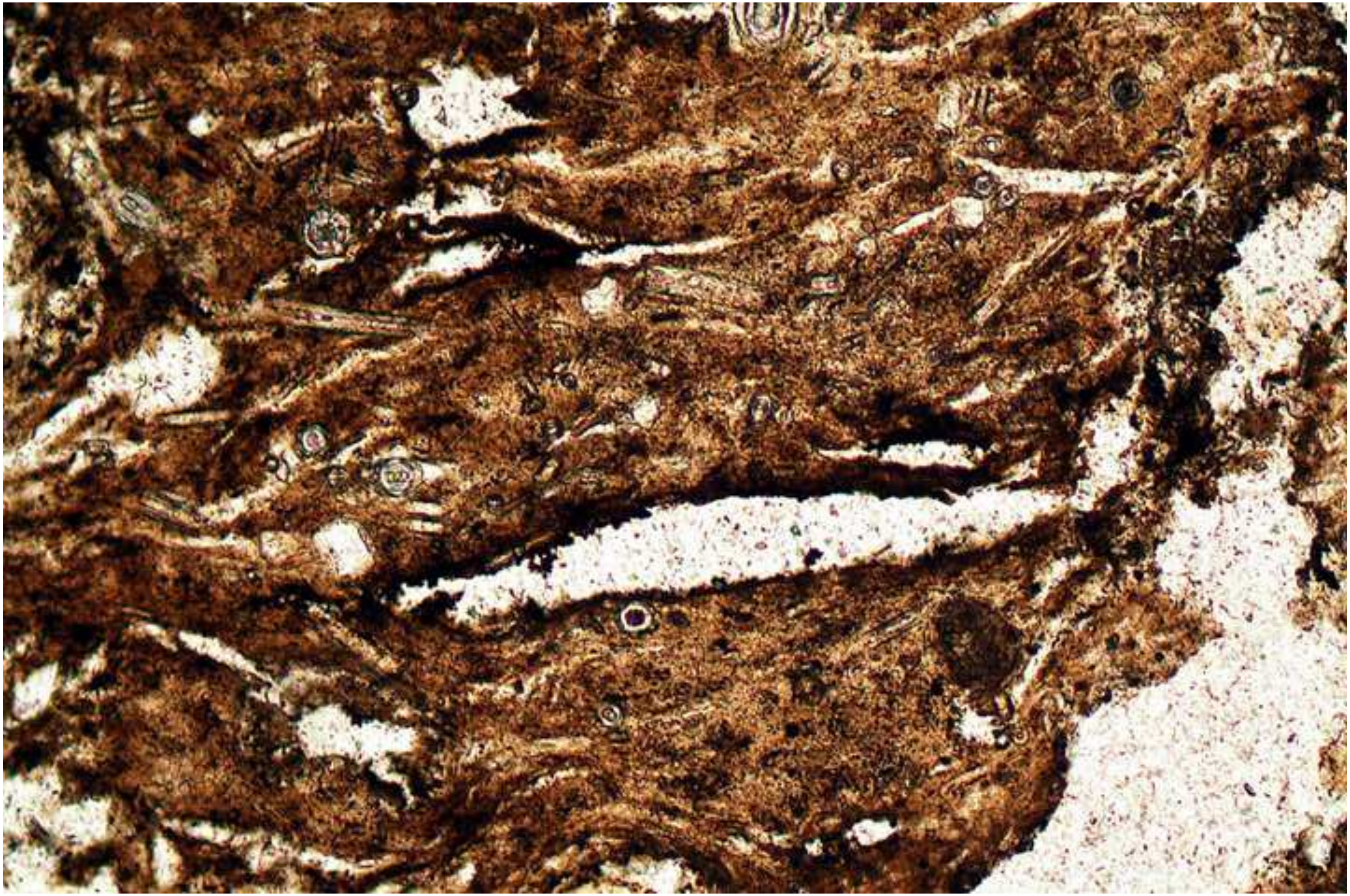

Figure

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Figure

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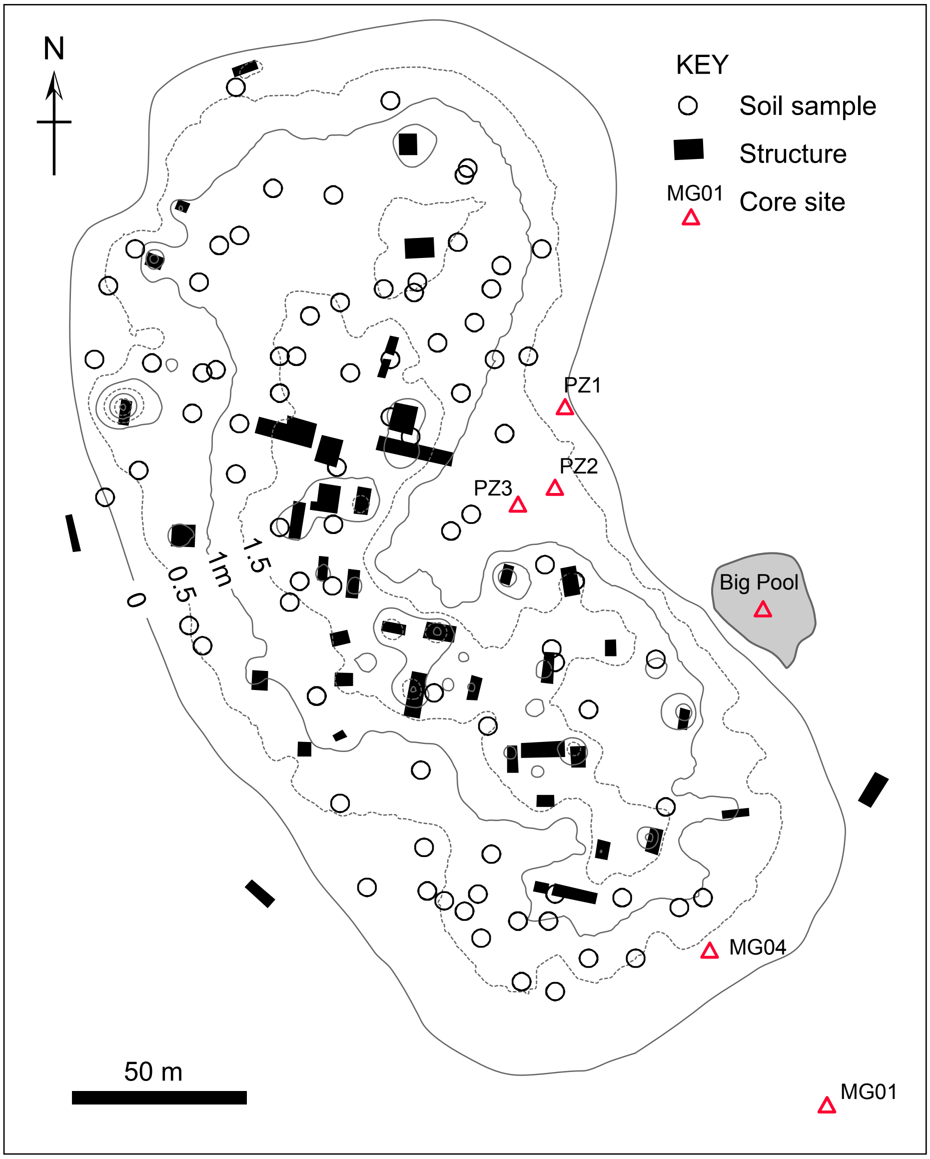
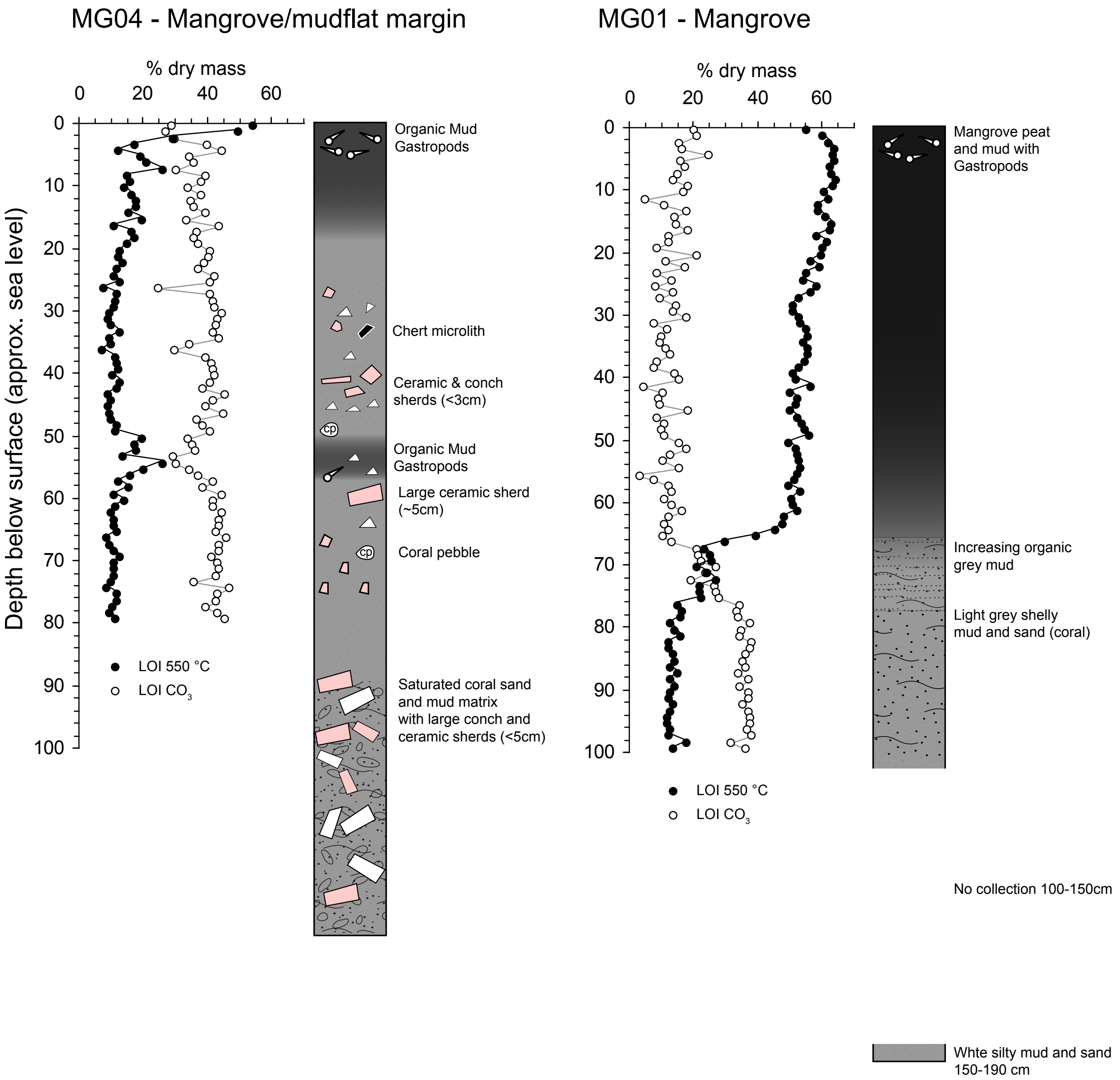
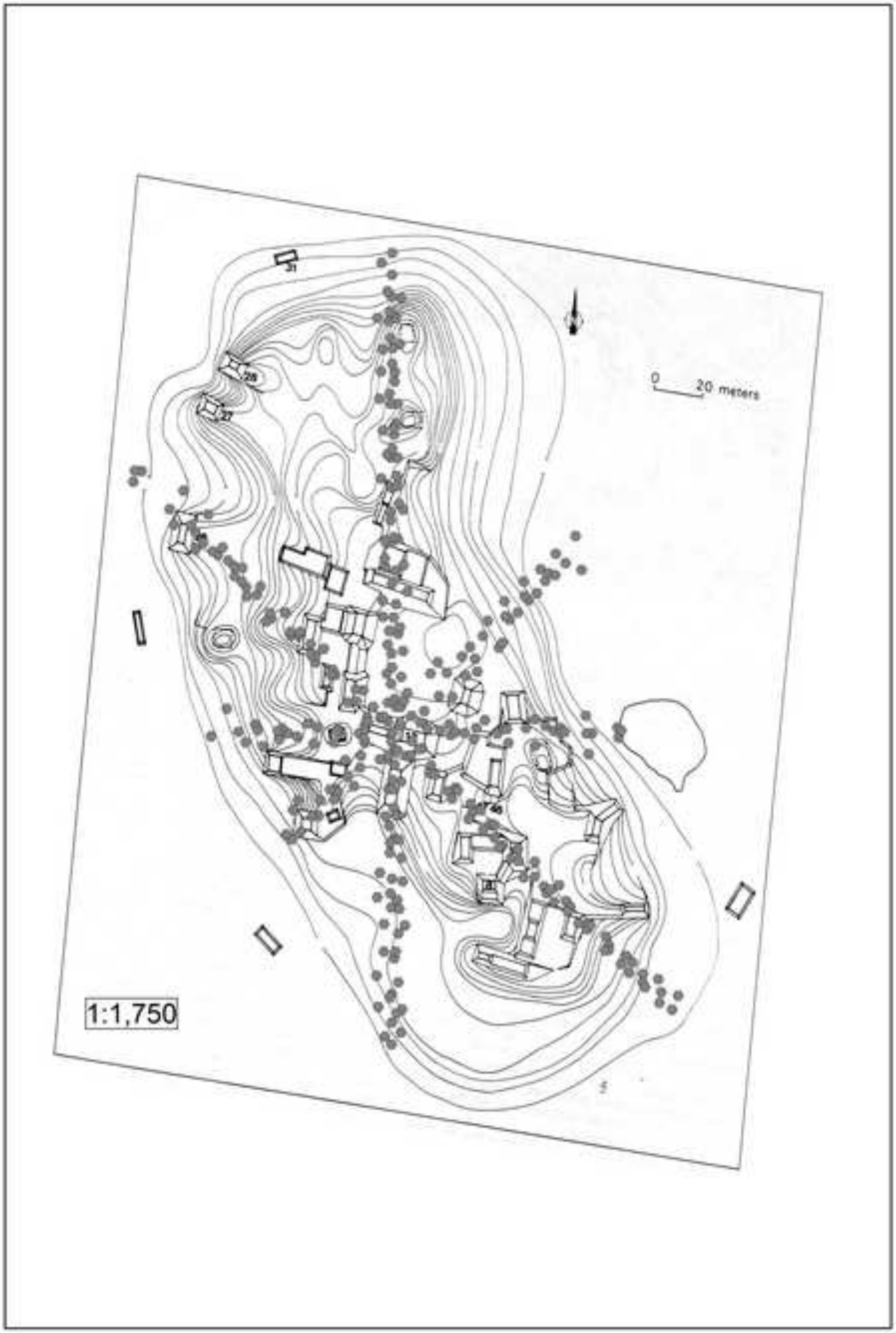
Figure

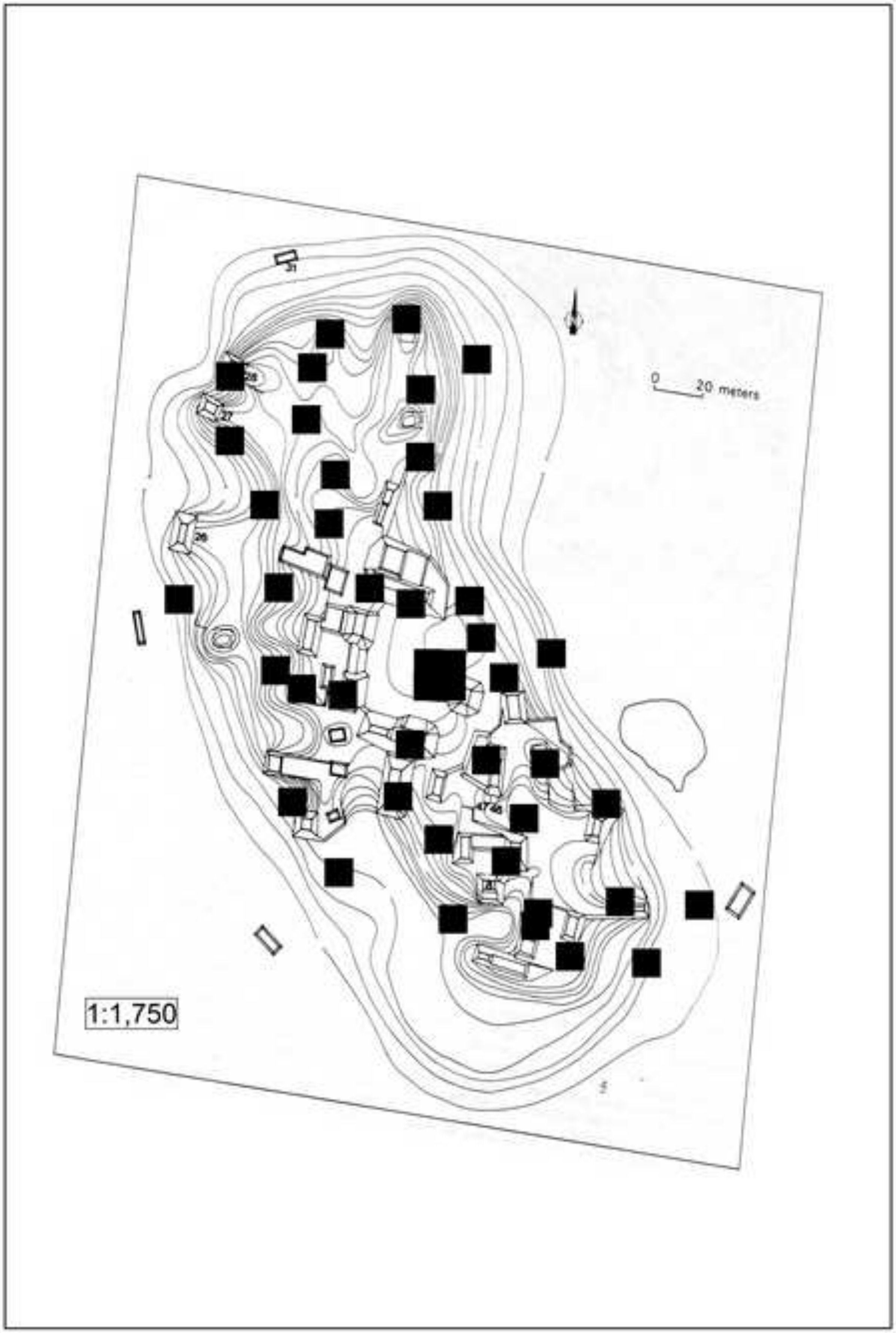

N
KEY
○ Soil sample
Structure
MG01
Core site
PZ1
PZ2
PZ3
Big Pool
MG04
MG01
0
0.5
1m
1.5
50 m

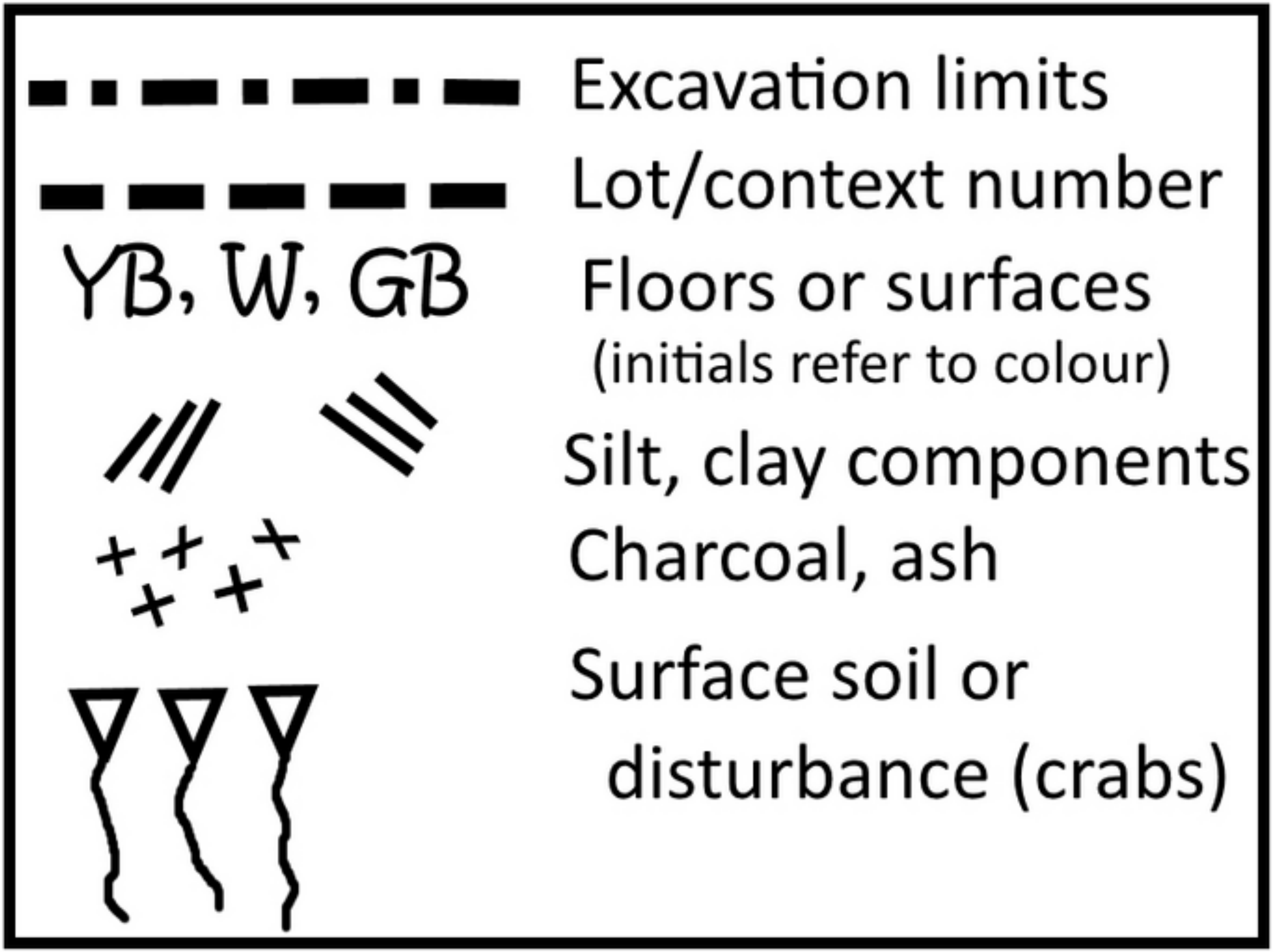
Figure


MG04 - Mangrove/mudflat margin
% dry mass
0
20
40
60
Depth below surface (approx. sea level)
0
10
20
30
40
50
60
70
80
90
100
● LOI 550 °C
○ LOI CO$_3$
Organic Mud
Gastropods
Chert microlith
Ceramic & conch
sherds (<3cm)
cp
Organic Mud
Gastropods
Large ceramic sherd
(~5cm)
Coral pebble
Saturated coral sand
and mud matrix
with large conch and
ceramic sherds (<5cm)
MG01 - Mangrove
% dry mass
0
20
40
60
0
10
20
30
40
50
60
70
80
90
100
● LOI 550 °C
○ LOI CO$_3$
Mangrove peat
and mud with
Gastropods
Increasing organic
grey mud
Light grey shelly
mud and sand (coral)
No collection 100-150cm
Whte silty mud and sand
150-190 cm

Figure




31
28
27
26
47 46
8
5
0 20 meters
1:1,750


Excavation limits
Lot/context number
YB, W, GB
Floors or surfaces
(initials refer to colour)
Silt, clay components
Charcoal, ash
Surface soil or
disturbance (crabs)

List of Figures and Figure Captions

Figure 1.1
Map of northern Belize showing the location of Marco Gonzalez.

Figure 1.2
Belize coast, barrier reef and atolls. NASA Visible Earth, Yucatan.A2003342.1645. Jacques Descloitres, MODIS Rapid Response Team NASA/GSFC, 8 December 2003. visibleearth.nasa.gov/view.php?id=69512.

Figure 1.3
Marco Gonzalez from the air, looking ESE.

Figure 1.4
Map of Marco Gonzalez showing structure numbers.

Figure 1.5
Chronology of occupation at Marco Gonzalez in the context of Belize history.

Figure 2.1
Section drawing, Str. 14, Op 13-1, E face. Width of test pit 1.30m

Figure 2.2
Section drawing, Str. 19, Op 13-2, W face. Width of test pit 0.90m

Figure 2.3
Section drawing, Str. 8, Op 13-3, S face. Width of test pit 0.70m.

Figure 3.1
Str. 14, Op 13-1, E face, showing Monolith samples 1-4. Monolith 1: ‘dark earth’ and lime plaster floor ghosts; Monoliths 2-3: Late Classic processing levels (probably salt-working) including solid pink lime plaster floors; Monolith 4: Early Classic sediments and overlying floors, with cached Early Classic vessels below floors. Note that below -0.050 m asl at the base of Monolith 4, deposits were too wet to retrieve. Monoliths on the East Face sampled Early Classic (Monolith 6) and Late Classic (monoliths 5 and 7) deposits.

Figure 3.2
Str. 19, Op 13-2, S face, Monoliths 13, 14. Upper Monolith 13: Late Classic processing levels (probably salt-working),, top at 1.130m asl; Lower Monolith 13: Early Classic compact ash; Monolith 14: Terminal Postclassic sediments as low as 0.058m asl. Above, and out of view, are Monoliths 12 (‘dark earth’ formed in/of Early Postclassic and Late Classic-Terminal Classic levels; top at 1.770m asl) and Monolith 11 (surface soil at 2.070m asl).

Figure 3.3
Photomicrograph of M4D (MG 383). Compact waterlain ash with fine and very fine charred organic matter, and very abundant pale yellow to colourless coprolitic bone and orange-coloured heated bone. Plane polarised light (PPL), frame width is ~4.62mm.

Figure 3.4
Photomicrograph of M4C (MG 391) showing 25mm-thick coarse lens containing gravel-size plaster, potsherds, shell, bone, including 5mm-size charcoal and bioclastic limestone.

Figure 3.5
Photomicrograph of M13D (uppermost MG 391, lowermost MG 389). MG 391 is a biologically worked and slightly weathered soil formed in ash- and exceptionally bone-rich kitchen midden deposits (x13b – 36.5 mg g^{-1} phosphate-P) proposed to date to the transition to the Early Classic period. This soil was sealed by very pure ash layers. Size of ash crystals suggest a wood fire. PPL, frame height is ~4.62mm.

Figure 3.6
Scan of M4B (MG 382) showing the remains of two lime plaster floors and trampled charcoal-rich occupation deposits in between. Lime floors are mainly tempered with isotropic siliceous microfossil-rich tidal flat sediments. Frame width is ~50mm.

Figure 3.7
Photomicrograph of M4B, Op 13-1 (MG 382) detailing plaster layers, with “chaotic” textures involving tempering with clasts, which include isotropic siliceous microfossil-rich tidal flat sediments of various size ranges. Note pure lime plaster surface layer with horizontal voids in this micritic calcite layer. PPL, frame width is ~4.62mm.

Figure 3.8
Lower of the two Early Classic basal-flange bowls (MG 390-1) from Cache 14/6, Op 13-1.

Figure 3.9
Scan of M3B, Op 13-1. The junction between burned lime plaster floor (uppermost MG 377) and overlying burned layer (lowermost MG 374). MG 374 is composed of mixed coarse burned limestone, tidal flat sediments and charcoal, but also contains relict horizontal ash and thinly interbedded charcoal layers from small, low temperature *in situ* fires, conceivably used for boiling brine in salt making. The uppermost 15mm of the lime plaster floor is rubefied from the effect of fires, suggesting that such floors acted as hearths. Frame width is ~50mm.

Figure 3.10
Photomicrograph of M3B (burned debris layer at the base of MG 374, Op 13-1) showing six thin layers of alternating ash and charcoal, recording a series of small fires located on a lime plaster floor (see Fig. 15). PPL, frame height is ~4.62mm.

Figure 3.11
Scan of M3A (MG 377, Op 13-1), a typical chaotically mixed ashy, charcoal and burned sediment clast layer, with coated ceramic fragment (Coconut Walk pottery associated with salt production). Such deposits accumulated rapidly. Frame width is ~50mm.

Figure 3.12
Photomicrograph of M7B (MG 377, Op 13-1). OIL view of probably weakly burned calcareous sediment containing fossils. Frame width is ~4.62mm.

Figure 3.13
Photomicrograph of M7B (MG 377, Op 13-1). Detail of typical isotropic, siliceous microfossil-rich tidal flat sediment clast showing pale colors and minor rubefication from being heated. PPL, frame width is ~2.38mm.

Figure 3.14
Photomicrograph of M7B (MG 377). Example of burned (rubefied) laminated tidal flat sediment clast found in processing layers; clast is isotropic owing to its high siliceous fossil content. The exposed tidal flat sediment was affected by iron staining as exposed detrital organic matter, such as seaweed, became oxidised. This can be typical of high salt marsh intertidal environments. OIL, frame width is ~4.62mm.

Figure 3.15
Photomicrograph of M7B (MG 377). Another example of burned microfossil-rich tidal flat sediment clast. Detail of relict microlaminated, once-humic, fine sediment rich in microfossils such as diatoms. PPL, frame width is ~0.90mm.

Figure 3.16
Photomicrograph of M5A (MG 377 within 382). Trampled occupation layer within processing levels with heated (rubefied) bone and darkened ash showing weak weathering from exposure; layer can be characterized as bone and cess-rich with strong phosphate enrichment (18.7 mg g^{-1} phosphate-P). PPL, frame width is ~4.62mm.

Figure 3.17
Photomicrograph of M5A (MG 377 within 382). Fragment of shell sealing fossiliferous coral sands. Presence of coral sand suggests that shells of molluscs originally collected for food were discarded on nearby beaches and later collected to be reused in construction or lime making. This example was found in a trampled occupation floor (see Fig. 22). PPL, frame width is ~4.62mm.

Figure 4.1
Map of location of cores and soil samples, Marco Gonzalez.

Figure 4.2
Cores MG04 and MG01.

Figure 6.1
Marco Gonzalez, vegetation transects.

Figure 6.2
Marco Gonzalez, location of 10 X 10m vegetation plots.

Table 3.1
LOI, carbonate, PH, conductance, phosphate-P and magnetic susceptibility data

Table 3.2
Details of bulk samples analysed.

Table 3.2
Summary of soil micromorphology, bulk soils findings, and other information.

Table

Table 3.1: LOI, carbonate, pH, conductance, phosphate-P and magnetic susceptibility data

Bulk sample	Thin sections	LOI[a] (%)	Carbonate[b] ($CaCO_3$ equiv, %)	pH[c]	Specific conductance[d] (μS)	Phosphate-P[e] (mg g^{-1})	χ[f] (10^{-8} m^3 kg^{-1})	χ_{max}[f] (10^{-8} m^3 kg^{-1})	χ_{conv}[f] (%)
x0-5cm Str8	(Topsoil)	28.1***	35.1	7.9	455	11.4**	70.3	188	37.4
x8a	M8A-B	12.0**	50.5*	8.6*	1900*	7.25*	87.3	167	52.3
x8b	M8A-B	8.67*	54.8*	8.7*	2220*	6.26*	88.1	157	56.1
x8c	M8C-D	6.24*	59.1*	8.8*	2240*	3.66	127*	145	87.6
xMRef3	MRef3	4.41	58.8*	9.1*	1090*	2.32	212*	225	94.2
x9a	M9A	5.41*	57.9*	8.9*	2620**	4.50	139*	158	88.0
x9b	M9B-C	5.36*	59.3*	8.7*	2880**	2.42	209*	209	100
x9c	M9B-C	5.34*	60.9*	8.6*	4080**	1.88	206*	191	>100
xMRef2	MRef2	2.02	75.0**	9.0*	2340*	1.15	59.4	57.3	>100
x10a	M10A-B	5.24*	57.6*	nd	nd	1.82	203*	197	>100
x10b	M10A-B	3.28	61.7*	nd	nd	1.92	164*	155	>100
x1a	M1A	7.22*	52.1*	8.9*	697	5.42*	197*	214	92.1
x1b	M1C	6.51*	43.4	8.8*	1420*	2.00†	444*	440	>100
x2a	M2A-B	2.61	60.1*	nd	nd	3.12†	77.8	92.3	84.3
x2b	M2A-B	12.6**	47.7	8.7*	2500**	2.00†	144*	166	86.7
x2c	M2C-D	8.12*	44.0	8.7*	2930**	3.65†	362*	348	>100
x2d	M2C-D	18.4**	45.4	nd	nd	1.62	105*	144	72.9
x3a	M3A-B	19.9**	49.7	8.5*	5260***	1.09	163*	244	66.8
x3b	M3A-B	5.89*	33.5	8.7*	5220***	2.10†	641*	714	89.8
x3c	M3C-D	14.4**	56.0*	8.6*	5700***	1.19†	110*	198	55.6
x3d	M3C-D	7.28*	53.0*	8.8*	4900**	6.67*	257*	303	84.8
x3e	M3C-D	3.72	63.8*	8.8*	3340**	1.37	96.4	189	51.0
x3f	M3C-D	6.99*	48.6	8.8*	5070***	5.66*	374*	402	93.0
x5a	M5A-B	5.39*	48.9	8.9*	5010***	5.52*	286*	323	88.5
x5b	M5A-B	5.84*	54.9*	8.9*	3980**	18.7**	85.4	159	53.7

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Bulk sample	Thin sections	LOI^a (%)	Carbonate^b (CaCO$_3$ equiv, %)	pH^c	Specific conductance^d (μS)	Phosphate-P^e (mg g^{-1})	χ^f (10^{-8} m^3 kg^{-1})	χ_{max}^f (10^{-8} m^3 kg^{-1})	χ_{conv}^f (%)
x5c	M5A-B	9.21*	55.1*	nd	nd	5.43*†	158*	205	77.1
x6a	M6	4.65	65.8*	nd	nd	21.2***	4.8		
x0-5cmStr19	(Topsoil)	26.9***	39.4	8.0	477	8.09*	120*	194	61.9
x12a	M12A-B	5.42*	58.3*	8.4	184	3.91	86.2	137	62.9
x12b	M12A-B	8.65*	50.0*	nd	nd	3.26†	132*	175	75.4
x13a	M13A-B	5.87*	48.0	8.5*	5020***	7.03*	388*	451	86.0
x13b	M13C-D	2.70	59.4*	8.8*	3620**	36.5***	17.8	16.3	>100
x13c	M13C-D	4.02	58.8*	8.7*	3560**	25.3***	76.3	99.4	76.8
x14a	M14A-B	3.85	56.6*	nd	nd	26.9***	62.4	81.3	76.8
x14b	M14A-B	3.91	63.4*	8.8*	3680**	22.4***	16.5	21.0	78.6
x14c	M14C-D	3.30	67.1*	8.8*	3040**	24.5***	16.1	26.8	60.1
x14d	M4C-D	3.36	65.0*	8.8*	3480**	28.1***	13.1	20.4	64.2
x4a	M4A-B	5.51*	60.5*	8.7*	5580***	22.5***	121*	111	>100
x4b	M4C-D	3.66	70.2*	8.9*	3540**	23.2***	8.6	14.8	58.1

[a] **LOI:** values highlighted indicate notably higher LOI values, which reflects the amount of organic matter and/or charcoal present: * = 5.00–9.99%, ** = 10.0–19.9%, *** ≥ 20. 0%.

[b] **Carbonate:** values highlighted indicate higher carbonate concentrations: * = 50.0–74.9%, ** ≥ 75.0%.

[c] **pH:** values highlighted indicate pH ≥ 8.5; nd = not determined because of insufficient sample.

[d] **Specific conductance:** values highlighted indicate higher values: * = 1000–2440 μS, ** = 2500–4990 μS, *** ≥ 5000 μS; nd = not determined because of insufficient sample.

[e] **Phosphate-P:** † indicates that phosphate-P was determined on residual samples from the LOI analysis (see ~~footnote of Table 3~~Crowther 2014); values highlighted indicate likely phosphate-P enrichment: * = 'enriched' (5.00–9.99 mg g^{-1}), ** = 'strongly enriched' (10.0–19.9 mg g^{-1}), *** = 'very strongly enriched' (20.0–39.9 mg g^{-1}).

[f] **Magnetic susceptibility:** data are difficult to interpret (see text); χ values ≥ 100 x 10^{-8} m^3 kg^{-1} are highlighted

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Comment [A1]: In my original report, I included (as Table 1) details of each of the samples analysed. Without this, these are just 'random numbers' and the reader has no idea how the table is organised, where these samples are taken from or what their significance is - as only a few are explicitly referred to in the text. I'd be grateful if some thought could be given to this. Thanks.

Table 3.3 Summary of soil micromorphology and bulk soil findings and other information

Period/Contexts	Soil micromorphology and bulk soil data interpretations	Other findings
Surface soil Structures 8 and 19 Dark earth Structures 8, 14 and 19	Most organic (highest LOI), and least alkaline layer, with biologically mixed humic mineral soil and litter (L) layer of typical Mull humus horizon. Relatively high phosphate levels may result from relict bone and possible effects of decomposition of inhumations (also likely influencing character of dark earth). Typified by total biological microfabric of very fine charcoal-rich soil – hence dark colour – containing relict clasts of resistant burned sediment, ash nodules and calcined bone, for example, while lime plaster floors and fragments show dissolution and sometimes recrystalisation of calcite (micrite), and can occur as 'ghost' layers. Leaching has caused marked reduction specific conductance (salinity).	Deposits above salt-working layers cannot be clarified by small excavation units owing to extent of perturbation by either Terminal Classic burial activity or land crab burrowing, as well as modern removal of dark earth. Extensive excavation of Str. 14 revealed that the floors here are associated with Terminal Classic and Early Postclassic structures.
Late Classic Str. 14 - MG 359-377 Str. 19 - MG 386	Salt working deposits formed of mainly layered: a) little disturbed and sometimes totally *in situ* ashy combustion zones, b) *in situ* lime plaster floors, c) chaotically mixed burned marine sediment clast layers (with high specific conductance and magnetic susceptibility), with various proportions of ash and coarse charcoal present, and d) occasional trampled occupation surfaces showing minor weathering features and bone-rich kitchen midden waste; presence of shells which had 'trapped' fossiliferous beach sands. Findings suggest use of tidal flat sediments (probably 'upper salt marsh' environment) for source of concentrated salt, which when mixed with sea water produce a strong brine; this was heated on small low temperature fires located on lime plaster floors which acted as the hearth base. Mainly siliceous fossil-rich fine tidal flat sediment was employed – as also found coating sand-tempered Coconut Walk pot fragments. Some mollusc shells, once processed for food, and which were discarded on the beach, were sometimes recycled for constructions or lime burning.	Very little datable pottery is present aside from the Coconut Walk vessels used in salt production. Clearly represents a change in focus of activity from earlier times.

Early Classic Str. 14 - MG 382 Str. 19 - MG 389-386	Construction of a series of lime plaster floors (for example over a cached Early Classic bowl), tempered with isotropic siliceous microfossil rich tidal flat sediment clasts of various sizes (silt to gravel size), and incorporating charcoal and fine burned bone, with pure micritic lime plastered surfaces, conceivably of ash(?) origin. Upwards, 391 is sealed by a series of ash layers (389-386) – some ‘wetted’ and recemented – with an interbedded series of thin trampled deposits, which can be extremely rich in heated/burned bone (mainly fish bone) and for example record the highest phosphate content at Marco-Gonzalez. In this ‘domestic’ occupation area, these are presumed fireplaces used for food preparation which may have included low temperature cooking/smoking of fish.	Indications of substantial Early Classic construction (at least one metre-high platform); also faunal remains, ceramics, a range of foreign stone. Preliminary archaeobotanical results suggest increase in proportion of woody to non-woody remains compared to earlier levels.
Terminal Preclassic Str. 14 – MG 383 Str. 19 – MG 391 (389?)	Rainstorm erosion of putative ash-rich hearths, with associated burned bone (cooking), heated bone (low temperature cooking - food processing – smoking?) and human waste (coprolitic bone), all including fish bone, producing waterlain ashy sediments in low ground. High energy colluviation resulted in coarse lens composed of gravel-size lime plaster, pot, bone, bioclastic limestone and charcoal. Exposure and short period of stasis led to weak weathering effects and biological working of the uppermost sediments at both locations. At Structure 19 these were composed of shell- and bone-rich kitchen midden deposits at the top of Context 391.	Coring data suggest such ‘early’ ash-rich sediments were widespread (see Section 4), which implies high occupation concentrations. Ceramics and skeletal material, both human and faunal remains, are all well preserved but fragmented. *Zea mays*, *Byrsonima* sp. are present.