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Title: PALAEOENVIRONMENTAL RECONSTRUCTION OF THE ALLUVIAL LANDSCAPE OF NEOLITHIC ÇATALHÖYÜK, CENTRAL SOUTHERN TURKEY: THE IMPLICATIONS FOR EARLY AGRICULTURE AND RESPONSES TO ENVIRONMENTAL CHANGE

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Abstract: Archaeological discussions of early agriculture have often used the Neolithic village of Çatalhöyük in central southern Turkey as a key example of the restricting effect of environment on agricultural production and organization. Central to these discussions is the palaeoenvironmental reconstruction of the landscape surrounding the site. This paper presents an important new dataset from an intensive coring programme undertaken between 2007 and 2013 in the immediate environs of the site, designed to improve significantly the spatial resolution of palaeoenvironmental data. Using sediment analyses including organic content, magnetic susceptibility, particle size, total carbon and nitrogen contents and carbon isotope analysis, coupled with 3D modelling, we are able to present a new reconstruction of the palaeotopography and sedimentary environments of the site. Our findings have major implications for our understanding of Neolithic agricultural production and social practice.
We present four phases of environmental development. Phase 1 consists of the final phases of regression of Palaeolake Konya in the later parts of the Pleistocene, dominated by erosion due to wind and water that created an undulating surface of the marl deposited in the palaeolake. Phase 2 occurs in the latest Pleistocene and early Holocene, and indicates increased wetness, probably characteristic of a humid anabranching channel system, in which there are localized pockets of wetter conditions. In Phase 3a, this infilling continues, producing a flatter surface, and there are fewer pockets being occupied by wetter conditions. The fluvial régime shifts from humid to dryland anabranching conditions. The earliest period of occupation of the Neolithic East Mound coincides with this phase. Phase 3b coincides with the shift of occupation to the West Mound in the Chalcolithic, when there is evidence for a very localized wetter area to the southeast of the West Mound, but otherwise a continuation of the dryland anabranching system. Finally, Phase 4 shows a shift to the pre-modern style of fluvial environment, modified by

channelization. This reanalysis demonstrates the importance of extensive spatial sampling as part of geoarchaeological investigations.
With this new evidence we demonstrate that the landscape was highly variable in time and space with increasingly dry conditions developing from the early Holocene onwards. In contrast to earlier landscape reconstructions that have presented marshy conditions during the early Holocene that impacted agriculture, we argue that localized areas of the floodplain would have afforded significant opportunities for agriculture closer to the site. In this way, the results have important implications for how we understand agricultural practices in the early Neolithic.

**Highlights (for review)

- A four phase palaeoenvironmental reconstruction of the area surrounding Çatalhöyük
- Data reveals Neolithic landscape not as wet as previously thought
- Results have significant implications for models of early agriculture
- Fluvial régime was a dryland anabranching system

Dear Prof. Rehren,

We would like to thank you and the reviewers for their time and helpful suggestions on ways in which to improve the submitted manuscript. In response to the comments of Reviewer 2 and 3 we would like to document how we have addressed the issues raised by each below. Please note that we have numbered the suggestions from Reviewer 3 (their original text in italics) below for clarity. On the manuscript, reference is made to the Reviewer who made the comment (either R2 or R3) and the numbered comment to which the alteration of the text responds. Hopefully this will make it easier for you to assess how we have responded to their helpful suggestions to improve the text.

Reviewer 2:
We have made all typographical amendments to the text as indicated in the annotated manuscript that was provided. Please see the corrections and comments on the manuscript for indication where this has happened.
In response to the request to reduce the amount of raw data within the text, we have decided to maintain what was originally presented in order to render clear our observations and the conclusions we have drawn from them. We have included however the raw data in supplementary tables to accompany the manuscript as suggested.

We have also included a further photographic log of a representative core to illustrate the sedimentary sequence (the new Figure 3) (this was also requested by Reviewer 3 below).

Reviewer 3:

(Comment 1)* *The discussions of palaeoclimate and palaeoenvironment (p2 and p4 lines 174-6) could be expanded and include more recent data and interpretations based on lake-cores and speleothems in the region and Turkey more widely (e.g. Gokturk et al. 2011; Charles et al. 2014; Roberts 2014; Roberts 2001; Woldring & Woldring 2001;) to add to the syntheses of data referred to in this paper (Fortugne et al. 1999; Kuzuguoglu et al. 1999). Importantly, these more recent studies suggest that the climate 10,500 to 9400 BP was more humid than today and that during the occupation of the site 'in the period from 9400-8200 BP there are indications of a further increase in moisture availability'(Charles et al. 2014, 71). The wording in the abstract contradicts this, stating that there were 'increasingly dry conditions from the early Holocene (p1, line 53) (meaning 'after the early Holocene'?), and a previous sentence states that in Phase 2 in the latest Pleistocene and early Holocene there are indications of 'increased wetness' (line 42). Suggest that the climate descriptions at the base of p2 line 102 differentiate more clearly between current climate observations and palaeoclimate reconstructions.*

We have added references and discussion as appropriate in the text, and reworded the abstract so that it is consistent with the wording in Charles et al.

(Comment 2) * *The discussion of vegetation, task-scapes and animal movements (p3, and in the discussion/conclusions) could refer more to debates and data in Charles et al. 2014, Bogaard et al. 2015), although this will require considerable interdisciplinary research beyond the scope of this article. Note some grazing is attested on the plain today.*

We agree that this is an interesting line of research but to address it directly here would require a significant increase in the length of the text, which is already beyond the word limit of the journal, and would require a significant amount of extra analysis, which would dilute the focus from this paper, which is about the geoarchaeological interpretation of the landscape. We have added references to the work of Bogaard and of Charles et al., although these papers were cited in the original manuscript.

(Comment 3) * *There could perhaps be further justification/statements supporting the focus of coring within 1-1.6km, as this raises several questions and issues:*
a) farmers are known ethnographically to tend regularly fields up to 1 hour's walking distance from their home base (4-5km), the intensive sampling could be balanced by consideration of the wider geographical region, perhaps by greater consideration of and correlation with cores across Konya Plain by Roberts et al. (Boyer et al. 2006).

We have included further justification of the focus of the coring to the immediate surrounding of the tell and added reference to Boyer et al 2006 work further afield and indicated how the coring programme fits into discussion of recent agricultural models (Bogaard and Isaakidou 2010).

b) The cores are all very close to the site and are likely to be in a landscape impacted by the large settled community. There is little consideration of anthropogenic agencies in the arguments presented in this paper e.g. on the varied topography around the site, as this is likely to be impacted not only by wind and water erosion, but also brick-pits (Doherty 2013 (not referred to in this article); Charles et al. 2014). The KOPAL excavations identified and recovered a wide range of anthropogenic material and activities close to the site, which could be considered in interpretations of the analytical data in this paper. Is there scope in discussion of Nitrogen levels (on pages 10-11) for considering anthropogenic input from such activities within this zone and from animals, known to have been proximate and penned on mound during its occupation? Is there also scope for evaluation of any anthropogenic impacts on magnetic susceptibility data?

We have added a reference to the potential of anthropic agencies impacting on the topography through reference to the brick pits as well as the nitrogen levels as an indicator of penning. In terms of the interpretation of the magnetic susceptibility readings reflecting anthropogenic impact, upon review we did not see enough of a variation to justify this so we have refrained from drawing this conclusion. We note in the text that care needs to be taken in drawing more detailed interpretations of these points until further analyses are made.

(Comment 4) * *Figure 1 needs a contour height*

Figure 1 is a representation of the coring locations and does not have contour lines. The two tells are outlined for reference as stated in the figure caption. Possibly the reviewer has interpreted these outlines as contour lines? We have amended the caption to this Figure to clarify.

(Comment 5) * *Future research could consider including more recent methods of sediment description than Wentworth 1922 (line 208). Some photo-logs of the cores would perhaps be helpful.*

We used Wentworth (1922) only in regards to particle-size classes and have added a reference to the descriptive methods used. We have included the photo-log of Core14 as a representative example of the sequence (as suggested also by R2), which is the new Figure 3.

(Comment 6) * *It would be helpful if each core in Figure 2 had absolute heights added for each core. In addition, the core sequences could be aligned according to these to show the variation in topography and facies in relation to one another (e.g. Roberts et al. 1999, Fig. 2.12), or the decision not to do this justified/stated. Absolute heights could perhaps also be provided in discussion of stratigraphic facies instead of depths below ground surface e.g. line 283. A small-scale 3-D fence diagram is presented in Figure 4, however. Does line 308 'the dark grey or black clay layer is also found at higher points in the Lower Complex' mean in absolute heights or above other sediment facies allocated to the Lower Complex, if so what are these and why? The key and descriptors for Figure 2 could be explained and justified more, e.g. little mention of colour for example.*

Figure 2 has been redrawn and the text modified as suggested.

(Comment 7)**As the authors conclude, there is both a need to consider, and evidence for, considerable spatial and temporal variation in environments and sequences (lines 167-8, 425). It is perhaps advisable to reword some sections, to avoid statements that suggest particular layers were the same across the entire area sampled e.g. line 275 'all locations are capped by a marl layer that varies in thickness' (line 281 suggests this marl was used as a marker for the top of the basal sequence). In addition, all dark clays seem to be classified as a single facies type 'Dark Clay' (line 251 'the fine dark clay'; line 322 'the dark clay'; lines 357, 364 'the Dark Clay'; line 419 'the Dark Clay' and 422 - whilst stating that this layer is much later and at the same time critiquing (I think erroneously) previous research for suggesting that the 'Dark Clay' was 'a continuous, chronological marker' (374-379).*

We would like to thank the reviewer for pointing out the potential circularity of the definition. The text has been clarified as suggested to avoid this issue. As for the comment that the Dark Clay is referred to as a single facies type, we would suggest that this definition does not in any way imply anything about chronology and hence we stand beside our critique of the previous research stating that it was a continuous chronological marker. We have also added closer referencing in the text of where previous research has made this assumption.

The text, however, does discuss the variation in these clays e.g. line 314 'the dark and grey clays' [make up 15% of the described units' how measured?], and concludes the 'the Dark Clay is not a single deposit' (line 378). It would be helpful to discuss this variation within the dark and grey clays more and to provide clearer indicators of which facies are being referred to within this group, to help the reader. It would also perhaps be helpful if correlations with some of Roberts identifications could be suggested and variation highlighted. Roberts et al. distinguished between an early discontinuous very dark 'organic clay', and a later grey clay ('lower alluvium'/'backswamp' clay').

The value of 15 % of described units was measured as a proportion of defined units rather than of relative thickness of those units, and this point is now clarified in the text.
The definitions of these deposits by Roberts et al. are inconsistent in the different publications where they are presented, and therefore we have not attempted the correlations that are here suggested. We have highlighted this appropriately within the text.

I suggest page references be added to the lines 424-6 that assert that previous researchers argued for 'a continuous, marshy environment' or these statements be qualified (see comments below on Boyer et al. 2006 Fig 7b). The sandy deposits could perhaps also be more clearly classified and different types more clearly identified, including colour, e.g. to support the point that 'sandy deposits in the Lower complex' suggest that 'the breach did in fact occur much earlier' (lines 493-4).

The suggested references have been included and information on the sandy deposits has been included in the supplementary tables.

(Comment 8)* *Would it be helpful to add descriptors to the classifications Basal, Lower, and Upper Complex, to enable reference to more than just relative positions, especially as there may be complex spatial and temporal variation in sequences?*

We accept that the classifications seemed problematic to both reviewers, however, the three ‘complexes’ demonstrate such a degree of variability that makes assigning simple descriptors impossible – hence our use of the term “Complex”. Furthermore, the terminology is based on the relative chronological relationship between the Basal, Lower and Upper complexes, which becomes apparent as you read further into the analysis, but the nature of the presentation of the results means that this information is not available to the reader until later in the paper. An alternative would be to start the paper by calling them Complexes 1-3 and then defining them as Basal, Lower and Upper, respectively later on, but we feel that this would only add to the potential for confusion. Our preference has been to provide an explanation at the end of the Discussion section in order to make the distinction absolutely clear to the reader once all of the information is available to make that distinction.

(Comment 9)* *Field photos of the cores or a photolog might help to support observations.*

This has been included as the new Figure 3.

(Comment 10)* *It would be helpful if, to support the text, there were tables and graphic representations of spatial and temporal variation in the particle size, mag sus, organic content data, for example data (e.g. (Roberts et al. 1996 Fig. 2.6), and of the correlations between the different data sets for the core analysed in greater detail (2013/14); and arguably statistical analyses of the data.*

The statistical analysis of the data was already included at the appropriate points in the text. To help further, we have included graphs of the data as suggested in the supplementary material.

(Comment 11)* *The model proposed could be strengthened by more 14C dates, as the four phases identified in the research have not been fully dated, and are not presented with bracketing dates. Of the seven dates provided 5 are earlier than Catalhoyuk. Table 1 could include a column indicating which Phase the samples dated are from and a description of this, to aid correlation with the text and discussion. There could perhaps also be more discussion/correlation, if possible, of how the sediment facies and Phases identified compare to dates and phases from previous research previous research (Roberts et al. 1996 and Boyer et al. 2006), e.g. in a table? The early dates in Figure 5 could be examined more. Are there insufficient dates to support the complex model? No age-depth models are considered to examine rates of deposition*

We do agree entirely with the reviewer that more ^{14}C dates would be preferable, however as is already stated in the text (line 380), we have dated all available material at present. We hope to find other opportunities to improve on the dating of the sequence in the future. In response to R2's suggestion to discuss the dating of the shell deposits we respond also to the comment here to expand discussion of the early dates in Figure 5. We have already incorporated Roberts' and Boyer's dates here and feel that in doing so there is enough evidence to support the three-phase model. We

feel that we have pushed the available evidence as far as is possible and would prefer not to infer more into it as there is no justification.
In reference to the age-depth models used to examine the rates of deposition, we fell that due to the heterogeneity of the sequence it did not make sense to have an age-depth model as one would for example in a model of lacustrine deposition.

We have also modified Table 1 as requested.

(Comment 12)* *There has arguably been an oversimplification of the original arguments and interpretations presented by Roberts and Boyer et al. in a range of other publications (e.g. Charles et al. 2014) as in this article. Boyer et al. 2006, Fig. 7b, for example illustrate a very complex topography, with discontinuous 'marsh clay' and raised hummocks, which closely resembles those described in this and other subsequent articles. The new research has certainly added to earlier data and models, but arguably builds more on previous research than is acknowledged here and more widely. Similarly p4- the palaeochannel has always been dated as post-Neolithic, as it cut the Neolithic deposits and was 14C dated as mid-Holocene (e.g. Roberts et al. 1996, p37), contra lines 156-8. It was proposed by Roberts et al. 1996 that there may have 'distributary' of the Carsamba close to the site, and that this required further fieldwork and radiometric dating (Roberts et al 1996, 37), it was not asserted that there was 'a meandering single channel' as suggested in this article (Line 170). There also arguably needs to be greater recognition in this and other articles of the large-scale excavations conducted by Roberts (10x10m) and analyses of long field-sections and the large-scale sections and features that these identified in plan and in section, in addition to cores.*

We have inserted the appropriate references which highlight previous arguments asserting the presence of a 'meandering single channel' and have included direct reference to the previous KOPAL excavations conducted by Roberts (1997 and 1999 KOPAL trench). We would like to point out that a 'distributary channel' in a terminal dryland system is not the same as an anabranching system as we are proposing.

(Comment 13) * *P12 line 509 is there a possibility that some of the sands and gravels could be from deltaic deposition in or at the edge of a lake system? Further discussion on the spatial and temporal distribution of these, and their defining characteristics would help the reader here. There could be clarification of the statement 'Phase 1 is the hiatus between the top of the Basal Complex and the start of the Lower Complex' (line 511). There could be more supporting data on the May Cay discussions line 487.*

We accept this point from the reviewer and have amended the text as suggested.

(Comment 14)* *There is no explicit discussion of the Younger Dryas, which would be of wider interest, and could be considered as four of the seven radiocarbon dates are from this period: 11,000-10,000 BCE.*

We think this is a useful suggestion to be taken up in further work. However, at this stage, we believe that to extrapolate a narrative based on four dates in a relatively restricted area would not be a helpful contribution to the literature on the topic.

(Comment 15)* There could perhaps be some discussion of the research conducted by Liverpool at Boncuklu, 9km to the north as this is also likely to have a bearing on the wider regional dynamics. It could be stated how this research relates to that in Doherty 2013 (which is not cited) and Charles et al. 2014. There could also perhaps be suggestions for future research in the conclusions, e.g. phytolith analyses as pollen is not well-preserved.

At present, none of the palaeoenvironmental work from Boncuklu has been published as far as we have been able to ascertain. We are aware of the work done at Boncuklu, but feel it would not be appropriate to cite what we have seen from conference presentations.

Detail of Doherty (2013) has been added.

(Comment 16) * *The language could be a little more technical/scientific in places e.g. line 150 'followed' could be replaced with 'supported/concurred with'; line 159 'was found' change to 'was identified'; line 163 'seen in Greenland ice cores'; line 178 'the current project set to investigate'; sampling intervals are best expressed in cm rather than metres to two decimal places e.g. line 193 and throughout; line 263 'divided into three groups'; line 378 change 'either' to 'neither'; lines 408-9 ?change 'rises' to 'increases'; 421 'late pockets of development in some places' [of what?]; 430 'moving up through the sequence'.*

The language noted has been changed but we report sampling intervals in m (and not cm), which is the relevant SI unit and thus the most appropriate way to present technical/scientific data.

PALAEOENVIRONMENTAL RECONSTRUCTION OF THE ALLUVIAL LANDSCAPE OF NEOLITHIC ÇATALHÖYÜK, CENTRAL SOUTHERN TURKEY: THE IMPLICATIONS FOR EARLY AGRICULTURE AND RESPONSES TO ENVIRONMENTAL CHANGE

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Abstract

Archaeological discussions of early agriculture have often used the Neolithic village of Çatalhöyük in central southern Turkey as a key example of the restricting effect of environment on agricultural production and ~~organisation~~organization. Central to these discussions is the palaeoenvironmental reconstruction of the landscape surrounding the site. This paper presents an important new dataset from an intensive coring programme undertaken between 2007 and 2013 in the immediate environs of the site, designed to improve significantly the spatial resolution of palaeoenvironmental data. Using sediment analyses including organic content, magnetic susceptibility, particle size, total carbon and nitrogen contents and carbon isotope analysis, coupled with 3D modelling, we are able to present a new reconstruction of the palaeotopography and sedimentary environments of the site. Our findings have major implications for our understanding of Neolithic agricultural production and social practice.

We present four phases of environmental development. Phase 1 consists of the final phases of regression of Palaeolake~~the~~ Konya ~~palaeolake~~ in the later parts of the Pleistocene, dominated by erosion due to wind and water that created an undulating surface of the marl deposited in the palaeolake. Phase 2 occurs in the latest Pleistocene and early Holocene, and indicates increased wetness, probably characteristic of a humid anabranching channel system, in which there are localized pockets of wetter conditions. In Phase 3a, this infilling continues, producing a flatter surface, and there are fewer pockets being occupied by wetter conditions. The fluvial régime shifts from humid to dryland anabranching conditions. The earliest period of occupation of the Neolithic East Mound coincides with this phase. Phase 3b coincides with the shift of occupation to the West Mound in the Chalcolithic, when there is evidence for a very localized wetter area to the southeast of the West Mound, but otherwise a continuation of the dryland anabranching system. Finally, Phase 4 shows a shift to the pre-modern style of fluvial environment, modified by channelization. This reanalysis demonstrates the importance of extensive spatial sampling as part of geoarchaeological investigations.

With this new evidence we demonstrate that the landscape was highly variable in time and space with increasingly dry conditions developing from the early Holocene onwards. In contrast to earlier landscape reconstructions that have presented marshy conditions during the early Holocene that impacted agriculture, we argue that localized areas of the floodplain would have afforded significant opportunities for agriculture closer to the site. In this way,

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the results have important implications for how we understand agricultural practices in the early Neolithic.

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Introduction

The site of Çatalhöyük (*c.*7400–6000 cal BCE: Bayliss et al. 2015, Cessford 2001) in central southern Turkey~~Anatolia~~ has played a pivotal rôle in on~~-~~going discussions regarding Neolithic settlement and the onset of agriculture. The environmental reconstruction of the surrounding landscape of Çatalhöyük has been at the centre of evolving archaeological debates about early agricultural communities and their adaptation to environmental change (Sherratt 1980; Roberts 1991; Bogaard et al. 2014; Charles et al. 2014). Central to the palaeoenvironmental reconstruction of the past landscape is the characterisation of the alluvial landscape in the vicinity of the site. The modern Çarşamba River flows close to the edge of the site and extends southwards until the termination of the Konya Plain at limestone hills that border the Taurus Mountains (Figure 1). Previous geoarchaeological research has characterized the alluvial plain as a very marshy environment subject to significant seasonal flooding (Roberts et al. 1999; Boyer et al. 2006; Roberts and Rosen 2009) which has driven models of land use (Fairbairn 2005; Roberts and Rosen 2009). In particular, Roberts and Rosen (2009) have suggested that agriculture during the Neolithic phases of the site would have been constrained by the marshy conditions and could only have been undertaken upon the well-drained foothills up to 12 km from site, which has significant implications for social and economic nature of settled life (see also Rosen and Roberts 2005). These palaeoenvironmental models have been based on sedimentological data derived from nine coring locations and trench sections near the tells as well as the investigation of 16 archaeological sites (four of which date from the Palaeolithic to Bronze Age) further away in the area of Palaeolake~~the~~ Konya ~~palaeolake~~ (Boyer 1999: 63; Boyer et al. 2006: 684; Boyer et al. 2007). Recent interpretations of land use and *taskscapes* have attempted to integrate the sedimentological data with on-site evidence, including but not limited to archaeobotanical and faunal remains, as well as clay sourcing (Charles et al. 2014). At times this on-site environmental evidence fits well within the model that suggests a dominantly wet landscape contemporary with the Neolithic settlement, but there is increasing on-site palaeobotanical evidence that is beginning to challenge the pervasiveness of the marsh environment (Bogaard et al. 2014; Charles et al. 2014).

As a consequence of these apparently conflicting interpretations of the Neolithic landscape, a further campaign of geoarchaeological research was undertaken between 2007 and 2013, with the specific aim of resolving these conflicts, using both more intensive and extensive sampling protocols. This research provides an important body of data that raises significant questions about the validity of these earlier palaeoenvironmental models and established ideas about early agriculture derived from them, which would have required extensive time away from site for large numbers of the population to tend fields. In this paper we provide data from a coring programme undertaken that targeted a further 29 coring locations within a radius of up to 1.6 km of Çatalhöyük to provide a more nuanced approach to landscape reconstruction. The combination of sediment with isotope analysis and 3D modelling of the stratigraphic sequence ~~(detailed below)~~ enables us to construct a more refined understanding of the

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Comment [GA2]: Coring locations are visible on Fig. 1. Reviewer 2 suggested their version of the figure was incomplete.

hydrology and resulting dynamic topography of the low-lying alluvial plain around this crucial time of early agricultural society in the near East. This high-resolution environmental reconstruction provides direct evidence of the Neolithic alluvial landscape from which we can advance archaeological discussions of cultural response to environment and environmental change.

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Regional Setting

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Çatalhöyük is located in the Çumra District on the Konya Plain (Figure 1). The current climate is defined by the Köppen-Geiger classification as BSk (de Meester 1970, 5; Kuzucuoğlu et al. 1999), or cold semi-arid/steppe climate, having hot, dry summers and cold, wet winters. The majority of rainfall at Çumra occurs between December and May, with an average annual precipitation of 350 mm, and there is a considerable seasonal temperature range of over 20°C between the warmest and coolest months. The climate regime can also be seen to include a three-month period of drought between July and September, and throughout the year the winds in the basin come mainly from the north (Fontugne et al. 1999).

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The surface of the plain is fairly flat, with shoreline terraces and beaches rising up to 30 m above the margins of the plain, suggesting that a fairly shallow, albeit expansive lake (>400 km^2) occupied this basin at its maximum extent. The basin has not been tectonically active in radiocarbon history, and so recent stratigraphic sequences remain *in situ* (Roberts 1995).

Soil surveys by de Ridder (1965) and de Meester (1970), revealed that the basin is in places infilled with in excess of 400 m of Quaternary marl sediments, testifying to the lengthy presence of a lake in this location. More recently with greater water management the plain has dried, and three marshy depressions within the basin, the Yarma marshes, the Konya marshes and the Hotamiş Lake, have become desiccated leaving only the seasonal Sultaniye Lake and permanent Akgöl Lake as water-holding depressions in the basin (Fontugne et al. 1999).

The plain today is dominated by irrigation agriculture, yet studies have shown that in recent history *Artemisia* steppe and Chenopodiaceae were the chief plants present, with the volcanic soils having open forests of *Quercus*, and limestone soils containing forests of *Pinus* and *Juniperus* (Kuzucuoğlu et al. 1999; Fontugne et al. 1999). Further analysis of the palaeovegetation sequence is hindered by limited palynological investigations in the Konya basin, which have been confined to deposits collected from the Yarma and Akgöl basins, allowing few long vegetation sequences to be created, and none locally to the Çarşamba fan (Bottema and Woldring 1984; Kuzucuoğlu ~~–~~et al. 1999; Woldring and Bottema 2003; Roberts et al., 2016). Traditionally, pastoral grazing of sheep on the plain has been crucial to the livelihoods of local populations which has undoubtedly controlled the development of vegetation. Today though, grazing has moved onto the higher slopes surrounding the plain (Russell and Martin, 2005).

Previous Palaeoenvironmental Research in the Konya Basin

The Konya Basin is a closed pluvial basin that has actively responded to changes in climate and precipitation. Projects such as the KOPAL (*KO*nya basin *PAL*aeoenvironmental research) programme ~~utilised~~ utilized a variety of radiometric dating techniques to try to constrain the ages of different deposits and in doing so create a chronostratigraphic sequence for the basin (Boyer 1999; Boyer et al. 2006; Boyer et al. 2007; Roberts et al. 1999).

Çatalhöyük is located to the east of the present course of the Çarşamba ~~river~~River, but the river has been heavily channelized for the last fifty years and so can no longer adjust to changing conditions. It previously debouched from a relatively confined section to the south of Çumra to form an extensive, low-angled fan and in the last century consisted of a single-branched channel which previously passed between the East and West Mounds. The Çarşamba fan has been subject to a variety of interpretations, in part because of its ~~shallowly~~ low angle sloped deposits, with its form being described as "more akin to an alluvial floodplain than an alluvial fan environment" (Roberts 1995: 209). Initially, de Meester (1970: 86) described the entry of the river to the basin as deltaic, and it was suggested that the Neolithic soils found upon it were formed under "semi-lacustrine marsh" conditions. The KOPAL project ~~followed~~ concurred with de Meester's (1970) assessment of soil formation. Roberts et al. (1999: 624) identified a dark, organic clay deposit that began to form just prior to the foundation of Neolithic Çatalhöyük (*c.* 7400 cal BCE: Bayliss et al. 2015), as representative of a marsh or backswamp deposit. Above it, another dark-grey-brown silt-clay, described as the first truly alluvial deposit (termed the Lower Alluvium) was dated as forming coevally with the occupation of Çatalhöyük (from *c.* 7000 cal BCE), in a seasonally flooding environment, due to its high organic content and lack of coarse sediment (Roberts et al. 1999: 625). The coarser grain size and increased carbonate content in the overlying Upper Alluvium was interpreted as indicative of the catchment area changing between the early and late Holocene (Roberts et al. 1999: 627). In addition, a palaeochannel of the Çarşamba River ~~river~~ was ~~found~~ identified that contained a variety of coarse-grained sediments and freshwater shells, and, at 42.5 m wide, led the

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authors to conclude that a large meandering river system rather than a deltaic system was in place on the fan. Later research by Roberts and Rosen (2009) sought to constrain the end of the alluvial flooding phase seen in the ~~upper~~ Upper ~~alluvium~~Alluvium, suggesting that it may have ceased with the arrival of the 8.2 ka event (i.e. c.6200 cal BCE) ~~seen~~ identified in Greenland ice cores, which they interpreted regionally as a short, relatively arid and cool interval, and which seemed to have coincided with the abandonment of Çatalhöyük East mound and occupation of the smaller West mound (Roberts and Rosen 2009, 399; Alley and Ágústsdóttir 2005; Gasse 2000).

Dryland environments are inherently heterogeneous (Parsons and Abrahams 2009; Müller et al. 2013). Care therefore needs to be taken in making extensive spatial and temporal interpretations of landscape reconstruction based on a small number of samples. The review of the evidence from the palaeochannel would indicate that the interpretation of the meandering single channel is not directly dated to the occupation of either mound, as the OSL dates on the fill are much later, in the Chalcolithic (Boyer et al. 2006), while the review of the bioarchaeological evidence by Charles et al. (2014) points to incompatibility of the onsite material with this interpretation. Similarly, there is insufficient chronological detail to allow an interpretation of sedimentation changes in relation to the 8.2 ka event that has been ~~identified~~suggested as being represented in Turkish spelaeothem sequences (Göktürk et al 2011:2444) and lake cores (Roberts et al. 2011 and references therein; Roberts et al. 2016:357). Even at the regional scale, the interpretation of aridity is based on a hiatus of sedimentation, which according to Fontugne et al. (1999) lasted for 1,100 to 1,300 years, and potentially as long as 1,500 years. Evidence for a short event is thus lacking. In view of these discrepancies driven by sampling as well as analytical constraints, the current project ~~set~~ attempts to investigate the landscape through a much higher resolution, intensive sampling programme in which more extensive sediments were sampled in more detail to try to add information into the interpretation, especially the periods immediately preceding and contemporaneous to the occupation of the mounds.

Materials and methods

Field sampling and sub-sampling

A total of 29 sediment cores were taken in 2007-2013 to provide this higher resolution data (**Figure 1**) by focusing on the immediate environment surrounding the two tells. Previous coring programmes (Boyer et al 2006) had made lower~~-~~-resolution correlations between relatively few coring locations close to the site with those in larger landscape. The coring programme of 2007-2008 instead focused on an area within 1 km of the site which recent work has suggested would have been more than adequate for supplying the agricultural needs of the site (Bogaard and Isaakidou 2010) and related taskscapes (Charles et al. 2014). The ~~with~~ coring locations ~~spread out~~were distributed in order to

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Comment [GA9]: Reviewer 3, comment 3a ensure representation representative sampling of potentially varied microenvironments. The purpose of the first two seasons of renewed coring (2007-2008) was to address an immediate inconsistency between the KOPAL wetland model and changing mudbrick compositions. Heavy mudbricks (hundreds required per house) would have been made from raw materials close to the site and borehole locations were constrained accordingly, while also including a few distant control points. As part of larger holistic review of all aspects of clay-based material culture at Çatalhöyük, Doherty (2013) used the sequence of mudbricks as proxies for changing sediment availability immediately around the mound.

All cores were extracted with a percussion corer. The cores in 2007 were taken in discontinuous 0.5--m sections while in 2008, a system of coring parallel sets of overlapping cores 1-2 m apart was employed to ensure that a continuous sequence was recovered. A total of 21 coring locations of 3 to 5 m depth were extracted in 0.5-m sections, described and photographed in the field, wrapped in cellophane and placed in plastic guttering for transportation back to the UK where they were refrigerated prior to analysis. Subsampling for sediment was carried out at 0.05-m intervals on the 2007 cores, while sampling was focused on the identified lithological units on 2008 and 2013 cores instead. In the summer of 2013, a further eight coring locations were sampled from an area *c.* 2 km^2 centred around the Çatalhöyük settlement mounds, using transects that concentrated on areas that had not previously been sampled. At each location a parallel set of overlapping cores were taken 2-3 m apart to a depth of 5 m (8 × 4.50 m from each borehole; the top 0.5 m was discarded due to considerable modern reworking of sediments by agriculture since the Hellenistic-Byzantine period) (Boyer et al. 2006). Following transportation, all cores were then refrigerated to prevent degradation before analysis (Tirlea et al. 2014).

Sediment analyses on core lithology

The lithology of the cores was described, in particular the colour, sediment type, and grain size. Munsell soil colour charts were used to precisely log the colour of sediments (Munsell Color Company 1994; Melville and Atkinson 1985). Particle size was noted using a slightly modified Wentworth (1922) description for clastic sediments, and structures within the cores such as transitions and artefacts (e.g. macrofossils) were recorded (Tucker 2011) (Wentworth 1922). Any missing or damaged sections were also documented. All cores were analyzed for magnetic susceptibility in a Bartington Instruments MS2 meter, with a continuous loop at 0.02-m intervals. In addition, 443 bulk samples were sub-sampled and measured with a dual frequency sensor type MS2B with a low frequency sensor, following Gale and Hoare's method for measurement at normal sensitivity (1991, 223-229) to provide estimates of volumetric magnetic susceptibility. Loss on ignition of 350 discrete samples was conducted at 550°C and 950°C following Nelson and Sommers (1996) for organic matter

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content and $CaCO_3$ equivalent. Approximately 3 grams of sediment were sub-sampled from the same 350 discrete samples tested for LOI for Particle Size Analysis (PSA) using laser diffractometry. Samples were disaggregated and sieved down to 2 mm and weighed. For fractions <2 mm, the methodology followed the HORIBA LA-950 machine protocol, and Gale and Hoare (1991), for the removal of plant organic matter before PSA through wet digestion with hydrogen peroxide prior to disaggregation through the addition of 10 ml of sodium hexametaphosphate 0.1% solution. These observations were then mapped and logged using RockWorks™ v16 software. Individual lithological units were condensed into a series of lithostratigraphic units identifiable across the site, and 2D boreholes were used to visualize the cores. These units were projected onto transects as a fence diagram, showing the locations of the cores relative to one another, allowing changing depositional environments across the site to be identified.

Geochemical and isotopic analyses

Core 2013/14 was chosen for more detailed analysis as it produced the most complete and representative sequence of sediments. Subsamples were analyzed to establish the total carbon and nitrogen contents, as well as bulk-sediment carbon-isotope ratio ($\delta^{13}C$) analysis along with organic carbon-nitrogen (C/N) ratio. This geochemical analysis was carried out to evaluate the source and nature of organic material preserved in the sediments and nature of the vegetation and moisture in the landscape (Chmura et al. 1987; Meyers 1994; Yu et al. 2010), given that previous attempts to extract pollen or diatoms from the sediments had failed. A series of 36 samples were sub-sampled from core 2013/14 for total carbon and total nitrogen measurement with sampling resolution ranging from 0.2 m to 0.02 m depending on lithology sampled (more closely sampled across the Dark Clay layer). From this initial sample set 17 levels were selected for more detailed total organic carbon and nitrogen analysis (used for C/N) and subsequently bulk organic $\delta^{13}C$ analysis. All samples were dried and ball milled before measurements of total carbon and total nitrogen were made using a Carlo Erba CHN Elemental Analyser. The 17 sub-samples from this initial set were then acidified to remove carbonate ($CaCO_3$), using a modified method from Brodie *et al.* (2011). The samples were then left in a drying cabinet at 40°C for 48 hours before again being milled. Samples were then sent to the BGS laboratories in 5 ml glass bottles with tin lids to prevent plastic contamination, where the total organic carbon, total nitrogen and $\delta^{13}C$ isotope ratio were measured using a Carlo Erba Elemental CHN Analyser on-line to a Carbon Isotope VG Triple Trap and Optima dual-inlet mass spectrometer. Measurements from the BGS laboratory of the weight ratio of organic carbon to total nitrogen were then used to calculate a final C/N ratio.

Dating

Nine samples were selected from the 2013 cores for Accelerator Mass Spectrometer (AMS) radiocarbon dating. Eight samples were from bulk organic material from the fine dark clay sediments, the other sample was from shell fragments (Table I). Radiocarbon dates were carried out by Beta Analytic. Radiocarbon calibration was performed using OxCal 4.2 (Bronk Ramsey 2009) using the IntCal13 calibration curve (Reimer et al. 2013).

Results

Cores taken in 2007 penetrated to a depth of 7.47-8.03 m, while those in 2008 and 2013 were limited to a depth of 5 m (Figure 2). The 2007 and 2008 cores were only extracted every alternate metre, but visual analysis of the intervening sediments was made in the field. The 2013 cores were extracted continuously. Based on changes in texture, colour and magnetic susceptibility as well as stratigraphic position, the sedimentary units described have been divided into three groups (Figure 2).

Basal Complex

The lowest part of the sequence is made up of marl, and sands with gravel. The sands and gravels tend to be moderately to well sorted, and in units of 0.1 – 0.5 m in thickness. Locally, there are poorly sorted layers containing mixed granules of different lithologies derived from the local limestone bedrock and surrounding sand ridges, as well as from igneous and other bedrocks from further upstream in the Çarşamba catchment (up to small pebbles of 5 mm). Granules and sands are all subrounded to rounded. There was no evidence of structures, although this lack may simply be due to the restricted diameter of the cores. These sands and gravels are typically light brown in colour (2.5Y5/2 or 2.5Y6/2), although locally are darker brown (10YR4/2 or 10YR5/3). There is much lateral variation in texture at equivalent elevations across the landscape. At locations 2007/1-3, 6 and 10, the sands are interbedded with marls and clays which occur in units of 0.05 – 0.5 m in thickness. All locations sampled are capped by a marl layer that varies in thickness from 0.01 m (core 2007/7) to 1.04 m (2013/12). The marl is predominantly light grey (2.5Y1-6/1-2) to white (10YR8/1), and with a clay texture in the lower parts of the section and silty-clay texture towards the top of the

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Comment [GA11]: Identifiable from the dark colour of the sediment which is already stated in the same sentence, and further confirmed by the bulk sampling mentioned above and presented in the Results below. Reviewer 2.

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Comment [GA12]: Summary tables of this information have been included in the supplementary files as requested by R2.

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complex. Core 2013/12 also contains a laminated Dark Clay layer (see further discussion of the Dark Clay below) 1.1 m below the marl, and another thin Dark Clay layer in between two marl units.

Because of its ubiquity, The the upper part of this complex was taken as the uppermost appearance of marl in the core, and thus its elevation varies between locations. At its deepest (core 2007/6), the upper boundary is at 6.33 m below the modern ground surface, and at 1.65 m at its shallowest (core 2007/4). The upper surface tends to be lower between and immediately to the south of the mounds, but it also undulates in a N-S and E-W direction between cores (Figure 4). In the shorter cores, this complex is absent from 2008/8 and 9 and 2013/4.

The marls in this complex have a mean organic content of 4.65 ± 0.23 % (SE), $CaCO_3$ content of 45.94 ± 1.71 %, and a mass-specific magnetic susceptibility of 27.99 ± 4.28 × 10^{-8} m^3 kg^{-1}. The clastic sediments have a mean organic content of 3.75 ± 0.35 %, $CaCO_3$ content of 29.18 ± 1.70 % and a mass-specific magnetic susceptibility of 111.87 ± 13.31 × 10^{-8} m^3 kg^{-1}.

Two dates were obtained from core 2013/12. A level of laminated dark clay (2.5Y2.5/1) at a depth of 3.865-3.88 m produced a date of 27,617-27,011 cal BCE (2σ) on bulk organics. At a depth of 3.82-3.83 m, a date of 44,666-42,555 cal BCE (2σ) on large (up to 20 mm), angular shell fragments was obtained (Table I; Figure 2).

Lower Complex

The Lower Complex is dominated by silts, silty clays and clays with some reworked fragments of marl in places (Figure 2). In a number of places (cores 2008/1-3, 2013/17 and 18), the marl at the top of the basal complex is directly overlain by a dark grey or black (10YR2/1-4/1, 10YR3/3 or 2.5Y2.5/1) clay (subsequently called Dark Clay). Elsewhere, Dark Clay is absent the lower complex starts with lighter coloured silts and clays (cores 2007/5-10, 2008/5, 2013/4, 2013/14-16 and 2013/19: ranging from light greyish brown 2.5Y6/2 to grey 10YR5/1), or in the case of core 2007/10, a gravel with silty matrix (2.5Y6/2 [light brownish grey]). In core 2007/4 there is a transitional boundary of 0.04 m with the Basal Complex characterised by a mix of marl and the silt. The upper contact of the marl at the top of the Basal Complex was not observed in the other 11 cores. Boundaries are abrupt

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and smooth or occasionally wavy, suggesting erosional contacts. The dark grey or black clay layer is also found at higher points stratigraphically in the Lower Complex in cores 2007/1-3, 2007/7, 2007/8 and 2007/10, 2013/4, 2013/14, 2013/15 and 2013/19, but elsewhere (2013/16) it is absent. The ~~dark~~ Dark ~~clay~~ Clay varies from 1-mm thick (2008/3) to between 5-15 mm thick (2007/5 and 9, 2008/1 and 2, 2013/12, 2013/15 and 2013/18) and is made up of coarse clay to fine silt. It often contains small, white $CaCO_3$ nodules, and has an organic carbon content of 2-10 %, 2-26 % $CaCO_3$ content, and mass-specific magnetic susceptibility of 13-46 × 10^{-8} m^3 kg^{-1}. The dark and grey clays make up 15 % (by number) of the described units in the lower complex from the 2007-2013 cores.

Of the remaining units in the lower complex, 43 % are made up of silty-clays or silts, and a further 11 % of clays. However, there are also a range of sands, granules and gravels, occasionally with silt matrices. For example, in 2013/15, there is a coarse, mixed lithology sand of subangular to angular grains from 1.73-1.94 m in depth. In core 2013/4 there is a fining-upwards sequence from poorly sorted granules (4.64-4.97 m) to coarse sand (4.56-4.64 m) then medium sand with intermixed clays (4.24-4.56 m), and then silty clays or silts (3.7-4.24 m), capped by the dark clay noted above. Colours are dominantly in the range 10YR4-6/1-4 (dark grey/grey to light yellowish brown).

The mean organic content of the Lower Complex is 6.13 ± 0.20 % (SE), $CaCO_3$ content is 30.90 ± 1.03 %, and a mass-specific magnetic susceptibility is 67.02 ± 3.78 × 10^{-8} m^3 kg^{-1}. All three variables show a significant difference from the values measured in the Basal Complex ($p<0.05$).

Dates were obtained on bulk organic carbon from sediments from seven samples of the Dark Clay layer. The dates (all 2σ) range from 11,113-10,841 cal BCE to 5,720-5,631 cal BCE (Table I; Figure 2).

Upper Complex

The transition to the upper complex also occurs at a wide range of depths. Although it dominantly occurs at 1.5-2.5 m below the modern surface, it varies from 0.74 to 4.07 m. The units are dominantly (51 %) silty-clays or silts, followed by 11 % of clays. Coarse sands are less frequent than in the Lower Complex, but there are still relatively frequently recorded poorly sorted granules (10 %) or sandy silts (15 %). There is a slight tendency for the Upper

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Comment [GA19]: Reviewer 2: The dates were done on the bulk organic sediments without further differentiation. As recommended by the appropriate Beta Analytic protocol, we have reported this as noted. No further information is available.

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Complex sediments to be lighter than Lower Complex sediments (more 10YR4-6/1-4 (dark grey/grey to light yellowish brown) and fewer 10YR2-3/1-2 (black to very dark greyish brown). In all locations, the Upper Complex grades up into the modern ploughsoil in the upper 0.5 m or so. The most distinguishing characteristics of this complex are the combination of colour change from the grey to brown expressions of hue and the lower frequency of coarser material (sand and granule fractions).

The mean organic content of the Upper Complex is 6.06 ± 0.23 % (SE), $CaCO_3$ content is 30.69 ± 1.07 %, and a mass-specific magnetic susceptibility is 73.28 ± 2.51 × 10^{-8} m^3 kg^{-1}. None of these variables is significantly different (at p=0.05) from the values recorded in the Lower Complex. It was not possible to identify any unit with sufficiently concentrated bulk organics to provide a radiocarbon date.

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Geochemical and isotope analyses

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Detailed geochemical and isotope analyses were completed from selected samples across the Basal, Lower and Upper Complexes in core 2013/14 (Figures 3 and 4). The top of the marl marking the top of the Basal Complex is at a depth of 3.3 m. The top of the Lower Complex is represented at 1.87 m by a marked rise in mass-specific magnetic susceptibility from 33.5 to 65.0 10^{-8} m^3 kg^{-1}. Total nitrogen (TN) values are low (<0.1 %) from 5 m to 3 m (Figure ~~3~~4). There is a slight increase to 0.17 % at 2.98 m, which is midway through the Dark Clay. Immediately above the Dark Clay, at a depth of 2.92 m, TN peaks at 3.39 %, then declines exponentially to oscillate around 0.6 % from 2.5 – 1.55 m. There is a further peak of 2.45 % at a depth of 1.40 m.

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Total carbon (TC) is highest in the gravel at the base of the core at 4.9 m (7.06 %), then decreases to plateau at c. 2.5 % in the sands and silts between 4.8 – 3.8 m. In the two marl units (3.54 – 3.82 m and 3.32 – 3.44 m) values peak at around 6 %, with a dip in TC in the interleaved silty-clay layer (3.55 – 3.44 m). Values then decrease over the Dark Clay with only minor peaks in this layer at 2.11 % and 2.27 %. TC then rises to remain around 3.0 % to the surface. Conversely, the C/N ratio is lowest in the Dark Clay with values close to 7. The highest values (15.5 – 15.9) are seen lower in the section in the silty-clay sediment at 4.38 – 3.82 m. Above the Dark Clay, the ratio plateaus at c. 10 in silty-clay sediments above 2.7 m.

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Values of $\delta^{13}C$ are c. 24 ‰ immediately below the Dark Clay, within which values decrease, reaching a minimum of 26.1 ‰ at 3.0 m. The values steadily increase above the Dark Clay, again reaching about 24 ‰ from 2.7 to 1.4 m in depth.

Discussion

Previous reconstructions of the palaeoenvironment surrounding Çatalhöyük have emphasized the importance of the Dark Clay in the earliest post-lake levels as a continuous, chronological marker, and as a basis for interpreting the landscape as having been dominantly humid (Boyer 1999; Boyer et al. 2006:685; Roberts and Rosen 2009:394). However, the higher resolution coring since 2008 has demonstrated that the Dark Clay is not a single deposit, neither stratigraphically nor chronologically. To have a more refined interpretation of the deposits, it is important first to revisit the nature of lacustrine deposition and drying.

Lacustrine sediments preserved in the sequences recorded here are characterized by marl and clay deposits with the coarser sands and gravels diagnostic of fluvial deposition. Core 2013/12 shows earlier lake deposition was interrupted in MIS3-2 by local fluvial deposition before returning to lake deposition. The apparently anomalous date of 44,666-42,555 cal BCE (2σ) on shells a few centimetres above the level of laminated dark clay dated to 27,617-27,011 cal BCE (2σ) could be explained by the reworking of older shelly deposits. This interpretation is consistent with the fragmentary nature of the shells, or it may relate to the inclusion of old carbon in the shells, taking the date close to the limit of radiocarbon. This core suggests a series of frequent shifts in fluvial deposition within the Basal Complex, before a return to lacustrine deposition in the upper part of the core (marl deposits from 3.0 – 1.52 m: Figure 2c). Although there is no direct date on this final lacustrine deposition, it is likely to relate to the final parts of MIS2. At the latest, the date of 11,113-10,841 cal BCE (2 σ) in core 2013/15 suggests the end of lake deposition in this part of the Konya Basin in the later Pleistocene. However, Boyer (1999) provides an OSL date on a sandy loam in a palaeochannel cut into the upper marl at site 95PC2 dated to 13,319 ± 2050 BCE by OSL. This date would suggest early fluvial activity in the latest Pleistocene, and a hiatus before deposition of the Dark Clay or other deposits at the base of the Lower Complex.

In the 2007-2013 cores, the top of the marl varies from 6.33 m to 1.33 m below the modern ground surface, which corresponds to elevations of 1002.5 – 1005.5 m asl. However,

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Comment [GA22]: This is correct, Reviewer 2 had misunderstood the sentence – 2007 is the earliest season when we had permission to undertake coring, but it was only at relatively low resolution. The higher resolution coring did indeed commence in 2008 and further detail on the rationales for the different coring campaigns is provided in the methods

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including elevations from cores and sections in Boyer (1999), the range is 999.73 – 1006.14 m asl. Thus, local variation in the upper surface of the marl is significant, and what is seen is a highly undulating surface reflecting processes of wind deflation and surface water erosion (e.g. the development of local, low-relief "badlands") as well as later incision by channels (Figure ~~4~~5). As the lake retreated aeolian deflation of sediments may also have occurred, caused by strong winds across the basin evidenced by high wave cut notches above the palaeobeaches of the late Pleistocene Lake Konya~~, dated to the late Pleistocene period~~ (Naruse et al. 1997). Without the cover of the palaeolake, this process could have led to quarrying of surface deposits. The magnetic susceptibility of the cores, an indicator of surface erosion (Dearing et al. 1981), is seen to ~~rise~~ increase slowly in sediments from this point, although sizeable rises in magnetic susceptibility do not occur until later in the sequence. These processes would have been in operation during the time of the hiatus in deposition, noted above, before the formation of the Dark Clays. Thus, the later Pleistocene reflects the development of drier conditions and accelerated local erosion, possibly relating to poor initial colonization of the marl surface by vegetation (see discussion in Fontugne et al. 1999). This local erosion produced a ground surface surrounding the site that would have fallen from east to west, and south to northwest, which would have constrained subsequent river activity as seen in the deposits of the Lower Complex in the area of, or to the west of, the study area (Figure ~~4~~5; see also Boyer et al. 2006, Figure 7b). Excavations in the immediate vicinity of the east tell have also identified pits dug into the marl and led to interpretations of quarrying the marl near the tell for the production of mudbrick (Roberts et al 2007, Doherty 2013). Doherty (2013) concluded that the observed mudbrick transition resulted directly from a combination of the deep extraction of reddish Pleistocene clay beneath the marl and of large qualities of distal colluvium accumulating in exposed former mudbrick pits. The ability to dig far below the marl and the complete absence of either erosion or of flood deposits in one met~~er~~re-plus sections of consistently fine-grained colluvium were taken to indicate an absence of seasonal floods. Instead, from a combination of the geomorphological setting, the observed sedimentary structures (or absence of, e.g. lev~~e~~ées) and in particular the sediment composition (predominantly clay aggregates), this clay-centric study argued for an alternative alluvial system at Neolithic Çatalhöyük (small channels; very infrequent and low magnitude flooding) (Charles et al, 2014): a re-interpretation that resolves the clay-digging contradictions of the KOPAL model and is also consistent with all aspects of observed clay use at Neolithic Çatalhöyük, and consistent with the interpretation based on the detailed sedimentological analysis herein.

Comment [GA25]: R2 has commented that this might raise questions regarding the Boyer OSL date, however the date is "on a sandy loam in a palaeochannel cut into the upper marl", so it does not date the exact point of lacustrine deposition, simply provides a *terminus ante quem* for it. Thus, there is no implication for the reliability of the Boyer date.

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The Lower Complex thus began to deposit and infill this undulating surface. Where the Dark Clay is present, most samples predate the occupation of the East Mound (which starts between 7150-7100 cal BCE according to Bayliss et al. 2015; Figure ~~5~~6). However, there are also late pockets of development of the Dark Clay in some places, as suggested by the sample from 2013/4. The Dark Clay in 2013/4 is contemporary with dates from the West Mound (5,720-5,631 cal BCE compared to c.6150 to 5,500 cal BCE based on dates in Higham et al. (2007) (Figure ~~4~~5). All of the dating evidence suggests that the Dark Clay is both spatially and temporally discontinuous, refining previous ~~as opposed to previous~~ interpretations of a ~~continuous,~~ marshy environment in all of the low points of the landscape solely in the Early Holocene (Boyer 1999). Boyer et al (2006:683) suggests the ubiquity of this dark clay directly overlying the marl although this interpretation is contradicted by their Figure 7b, in which it only occurs in some of the lower points in the landscape. Furthermore, Boyer et al (2006: 685) suggests that deposition of the dark organic clay is from 7850-7450 cal BCE (1 sigma), however they were only able to date the material directly at Kızıl höyük and Avrathanı höyük~~–~~, which are approximately 6-8 km to the northeast and northwest, respectively, of Çatalhöyük. Five of our dates belong to the period 11113 – 9218 cal BCE (2σ), so predate the "broadly contemporaneous deposition" (Boyer et al. 2006: 685) suggested based on correlation. One date of 8223 – 7948 cal BCE (2013/19 to the north of Çatalhöyük) overlaps the dates of Boyer et al. at 2σ (their dates correspond to 8198-7083 cal BCE when calibrated to 2σ using OxCal 4.2), but our dates from both much earlier and much later suggest that the facies is more likely to relate to local conditions rather than regional ones.

The Lower Complex is a mix of both coarse and fine sediments – including the Dark Clay – with significant lateral and vertical variability. This pattern of facies is consistent with deposition from an anabranching river system. As there is a tendency for there to be fewer Dark Clays and fewer coarser deposits ~~moving up throughg~~at higher positions in the sequence, there is a suggestion that there may have been a shift from more humid to dryland anabranching conditions, following the definitions of Nanson and Knighton (1996) and North et al. (2007) (Figure ~~6~~7). Dryland anabranching rivers have variable morphology and sedimentary behaviour, but one such sub-system, the mud-dominated system, seems to fit the current data for the Lower Complex very well. Under this model (Type 1c of Nanson and Knighton 1996), the mud (silt and clay)-dominated system is characterized by a low-~~sloped~~

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gradient floodplain, ~~with~~ which has a low rate of aggradation ~~on the floodplain~~, and a very slight difference between the nature of the deposits in channel and on the floodplain thus not presenting the classic fluvial indicators such as sand-filled channel bodies, lag conglomerates, current ripples and dunes, and fining-up units (North et al. 2007, 930, their Table 2). As a dryland anabranching system, new channels would form via obtrusion, which North et al. (2007: 930) define as a much more gradual process than channel change by ~~as opposed to~~ avulsion. While avulsion is an energetic and rapid process, that requires the channel to cut through solid, vegetation-strengthened channel embankments in a humid river system, in a dryland system, new channels face less resistance to avulsion and are therefore formed more "gradually and incrementally" (North et al. 2007: 930). The frequent sands and silts present in the Lower Complex (cores 2007/1, 2, 3, 6, 7, 10; 2008/8&9, 10&11; and 2013/14 and 15), would indicate the distribution of these anabranching palaeochannels between the undulations in the marl as opposed to episodic fluctuation of flow. This interpretation is in contrast to the laterally continuous and extensive deposition of "backswamp clay" (Boyer 1999; Boyer et al 2006: 685; Roberts and Rosen 2009:394). Dating evidence suggests that the Lower Complex brackets the occupation of East Mound and at least some of the West Mound (Figure ~~5~~6). It is possible that the late Dark Clay in core 2013/4 formed as a result of a local hydrological blockage as the development of the West Mound started to cause diversion of pre-existing channels. Most deposition of the Lower Complex is in the southern and western parts of the study area, suggesting a progressive infilling of the landscape (Figure ~~4~~5).

Bi-plots of $\delta^{13}C$ against C/N ratios in core 2013/14 relative to measured values for freshwater algae, C_3 and C_4 plants and various soils (Figure ~~7~~8) can be used to interpret potential sources of organic material (Meyers 1997, Yu et al~~,~~. 2010). In comparisons with the measured soil samples from Yu et al. (2010), samples within the silt unit underlying the Dark Clay (>3.1 m depth) fall within the riverbank soil range, and samples above the Dark Clay (<2.76 m) are also most closely clustered around the lower range of riverbank soil (Figure ~~7~~8). The silty-clay unit immediately above the Dark Clay (2.92 – 2.76 m) has a broad range of values close to, or within the range of riverbank soils. Samples from the Dark Clay have low $\delta^{13}C$ and C/N ratios, clustering close to and within the freshwater algal field indicating significant proportions of freshwater algal organic material. The sediments in core 2013/14 both underneath and immediately above the Dark Clay suggest drier conditions than during the Dark Clay. Despite the low organic matter contents, the Dark Clay is probably representative of localized marshy or channel cutoff conditions with periods of standing water, as reflected

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Comment [GA32]: Although questioned by Reviewer 2, we prefer to keep this term as it is the correct usage as defined in the literature. We have summarized that definition here for clarity.

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by the high algal content. Thus, the inherited, undulating environment provided areas that were relatively stable and (at least seasonally) dry during the initial occupation of Çatalhöyük. Indeed, while there is substantial evidence for the presence of wetlands in the archaeozoological and archaeobotanical record at Çatalhöyük (Atalay and Hastorf, 2006), organic matter content in the sedimentological record is quite low, there are no buried peat deposits, and pollen preservation, which is common in anoxic and acidic wetland deposits (Moore et al. 1991), is largely absent here. Wetlands present in the vicinity of Çatalhöyük are likely to have been limited, marked by flowing water with limited standing water, and seasonally desiccated which may help explain the low organic readings in the dark clay layers. These wetter areas are likely to have been more common to the west, with drier conditions more dominant to the east of the site, based on the palaeotopography.

Nitrogen levels rise significantly immediately following the Dark Clay in Core 2013/14 (Figure ~~3~~4). A possible explanation is that regular deflation can cause increases in nutrient concentration, and so increase total nitrogen concentration (Scholz et al. 2002). Study of soils has shown that drying and rewetting causes increased nitrogen levels due to microbial death, causing nitrate and ammonia to form, and although some of this is flushed with rewetting, a proportion remains fixed in soil (van Gestel et al. 1991). This response has been seen as an increased concentration in nitrogen in the floodwaters from ephemeral basins following desiccation (Scholz et al. 2002). Alternatively, nitrogen from a geological origin could indicate a changing river input, which would be supported by the fact that the increase in nitrogen is accompanied by a decrease in total carbon content in the core. ~~The May River flows through Mesozoic limestone bedrock geology, which would be expected to give this river's discharge a higher carbon content than that of the Çarşamba, although Boyer et al. (2006) concluded that it did not contribute to the deposits seen on the Çarşamba.~~ Contrary to the suggestion of Boyer et al. (2006) that the Çarşamba did not break through the sand spit at Çumra formerly bordering ~~palaeolake~~ Palaeolake Konya until about 7,000 cal BCE, the presence of sandy deposits in the Lower Complex here suggests that the breach did in fact occur much earlier. This interpretation is consistent with the dated sandy loam in Boyer's (1999) section 95PC2, which is part of a channel fill cut into marl dated to 13,319 ± 2050 BCE by OSL. The nitrogen data are thus also consistent with the interpretation of increasing desiccation in the fluvial environment. Further to this it is also possible that anthropogenic additions in the form of penning, manuring or middening coming from the settlement could also have impacted upon the nitrogen levels from the time of occupation (Vaiglova et al

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2014, Fraser et al 2011), although caution is required with this interpretation until more data are available from cores elsewhere in the landscape.

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The Upper Complex is more difficult to date, as none of the 2007-2013 cores contain dateable material. There is some evidence for a change in style of deposition, with more fine material than in the Lower Complex, although there continues to be some lateral variability reflecting the palaeotopography. Boyer (1999) suggests that the onset of this phase can be estimated from an OSL date in section 95PC1, of 3548 ± 1337 BCE. Thus, it postdates the occupations of both mounds at Çatalhöyük.

In summary, we propose that the palaeoenvironmental evolution of the area surrounding the Çatalhöyük tells, up to the period of their occupation, can be illustrated as four phases (Figure ~~8~~9). Following the retreat of Palaeolake Konya towards the end of the Pleistocene, Phase 1 consists of dominant erosion due to wind and water that created an undulating surface of marl. The topography of the study area would have varied by about 7 m by the end of this phase. Sands and gravel provide possible evidence of early fluvial activity, although near-shore deltaic deposits cannot be excluded because of the lack of observed sedimentary structures. Within the sequences demonstrated by the 2007-2013 cores, Phase 1 is the hiatus between the top of the Basal Complex and the start of the Lower Complex. Phase 2 occurs in the latest Pleistocene and early Holocene, and indicates increased wetness, probably characteristic of a humid anabranching channel system, in which there are localized pockets of wetter conditions, relating to local hollows or cutoffs in the channel system. The undulating topography is starting to infill during this phase. In Phase 3a, this infilling continues, producing a flatter surface, and there are fewer pockets being occupied by wetter conditions. The fluvial régime shifts from humid to dryland anabranching conditions, which are more concentrated in the west of the study area. The earliest period of occupation of the East Mound coincides with this phase. This interpretation is more consistent with the archaeological evidence from the site for a mosaic of both dry and wet conditions. Phase 3b coincides with the shift of occupation to the West Mound, when there is evidence for a localized wetter area to the southeast of the mound, but otherwise a continuation of the dryland anabranching system. Phases 2 and 3 represent deposition in the Lower Complex. Finally, Phase 4 (not illustrated) – representing deposition in the Upper Complex – shows a shift to the pre-modern style of fluvial environment, modified by channelization as demonstrated by Boyer (1999) and Boyer et al. (2006). Finally, to clarify the terminology developed here, the Basal Complex is defined as the late Pleistocene deposition in fluvial and

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lacustrine environments, ending in a widespread erosional phase in the basin. The Lower Complex commences in the final part of the Pleistocene and is broadly parallel to the Lower Alluvium in previous studies. The Upper Complex is parallel to the Upper Alluvium. In all cases, there is significant vertical and lateral variability in facies, hence our preference for the term "Complex".

Conclusions

Contrary to the palaeoenvironmental reconstruction based on the geoarchaeologial work that situated Çatalhöyük within a palaeolandscape dominated by wet conditions (Roberts 1996, 1999; Boyer 1999, Boyer et al. 2006), the high-resolution coring carried out since 2007 has been able to demonstrate that the landscape was highly variable and has shown evidence of increasingly dry conditions from the early Holocene. While earlier work identified the general sedimentary sequence, the intensive coring programme (adding a further 29 coring locations to the previous nine) and subsequent 3D modelling has identified important localised variability of the alluvial landscape, particularly around the site. Moreover, the inclusion of the geochemical and isotope analysis and further dating of the sediments has enhanced our understanding of the fluvial regime and the degree of wetness around the site during occupation of the Eastern Tell occupied during the Neolithic.

This new evidence forces us to review the established landscape model and related interpretations of Neolithic land use at the site. The earlier idea that a large single channel flowed past the site in a high-energy meandering river system (Roberts and Rosen 2009:395-6, 399, and their Figure 2b; Roberts et al 1996: 39 but *cf* ibid p, 37; Boyer 1999: 97, and his figure 4.19 but note he firmly places the date as later in the Calcolithic) has had a lasting impact on the interpretation of the site especially on discussions of early farming practice. Rosen and Roberts (2005) argued that the territory around the site was so heavily affected by seasonal flooding that areas of viable agriculture were available only in the highlands at a distance of 12 km from the site (and see Roberts et al. 1996, 1999; Roberts and Rosen 2009; Rosen and Roberts 2005; Fairbairn et al. 2002; Fairbairn 2005). We argue that the river system contemporaneous with the settlement was anabranching which means that the large-

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scale overbank flooding envisaged in previous analyses (Boyer et al. 2006) is of limited application for the archaeological interpretations of the occupation of Çatalhöyük and human responses to changing environmental circumstances. This interpretation is also consistent with the lack of levées observed (Roberts, *pers. comm.*, Roberts et al. 1997:39), which would provide evidence of such overbank flooding, even on the palaeochannel that postdates the settlement. Thus, the Neolithic landscape is likely to be one of mosaics both in space and in time, which is reflected in the variability of the sedimentary sequence. Bogaard et al. (2014) used isotopic work on both faunal and botanical evidence that has proposed relatively local, small-scale herding and farming took place during the Neolithic; such a model is consistent with our new interpretation of the landscape contemporary with the occupation of the site.

This study has shown that while rigorous, the previous palaeoenvironmental model based on a limited number of data points near the site coupled with assumptions derived from the investigation of widely distributed (spatially and chronologically) coring locations failed to pick up the variability of the dynamic landscape which would have presented itself to the Neolithic inhabitants. Furthermore, the data produced a model of Neolithic *taskscapes* which now requires revision. There is a broader implication for geoarchaeological practice, in that sampling needs to reflect the nature of the environment being studied and its variability. Where there is significant heterogeneity as here, and in dryland environments in general, palaeoenvironmental reconstruction needs to be carried out using as high spatial and temporal resolutions as is possible.

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List of Tables

Table I Radiocarbon-dated materials from the cores sampled in 2013. Radiocarbon calibration was performed using OxCal 4.2 (Bronk Ramsey 2009) using the IntCal13 calibration curve (Reimer et al. 2013).

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Mound); and d. Phase 3b (continuation of dryland anabranching channel and shift to occupation of the West Mound).

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Table I Radiocarbon-dated materials from the cores sampled in 2013. Radiocarbon calibration was performed using OxCal 4.2 (Bronk Ramsey, 2009) using the IntCal13 calibration curve (Reimer *et al*., 2013).

Sample core – depth [m]	Material dated	Uncalibrated AMS age years bp	Calibrated age cal BCE 2σ	Laboratory code	Stratigraphic context*	Notes
2013/4 3.43-3.44	Bulk organics	6770 ± 30	5720 – 5631	Beta – 427866	LC	
2013/12 3.82-3.83	Shell fragments	42150 ± 570	44666 – 42555	Beta – 427864	BC	Shell fragments presumably reworked based on date on bulk organics above them
2013/12 3.865-3.88	Bulk organics	25220 ± 100	27617 – 27011	Beta – 427863	BC	
2013/14 2.98-3.00	Bulk organics	10390 ± 30	10456 – 10142	Beta – 427861	LC	
2013/15 3.29-3.31	Bulk organics	11060 ± 50	11113 – 10841	Beta – 427862	LC	
2013/18 1.78-1.79	Bulk organics	10720 ± 40	10781 – 10644	Beta – 427859	LC	This sample and Beta – 427860 are from the same unit but sampled in different core segments
2013/18 2.15-2.165	Bulk organics	10490 ± 30	10611 – 10300	Beta – 427860	LC	
2013/19 1.65-1.66	Bulk organics	9760 ± 30	9289 – 9218	Beta – 436099	LC	This sample and Beta – 427865 are from the same unit but sampled in different core segments
2013/19 2.05-2.06	Bulk organics	8880 ± 30	8223 – 7948	Beta – 427865	LC	

*BC = Basal complex; LC = Lower complex. As noted in the text, it was not possible to obtain datable material from the Upper Complex

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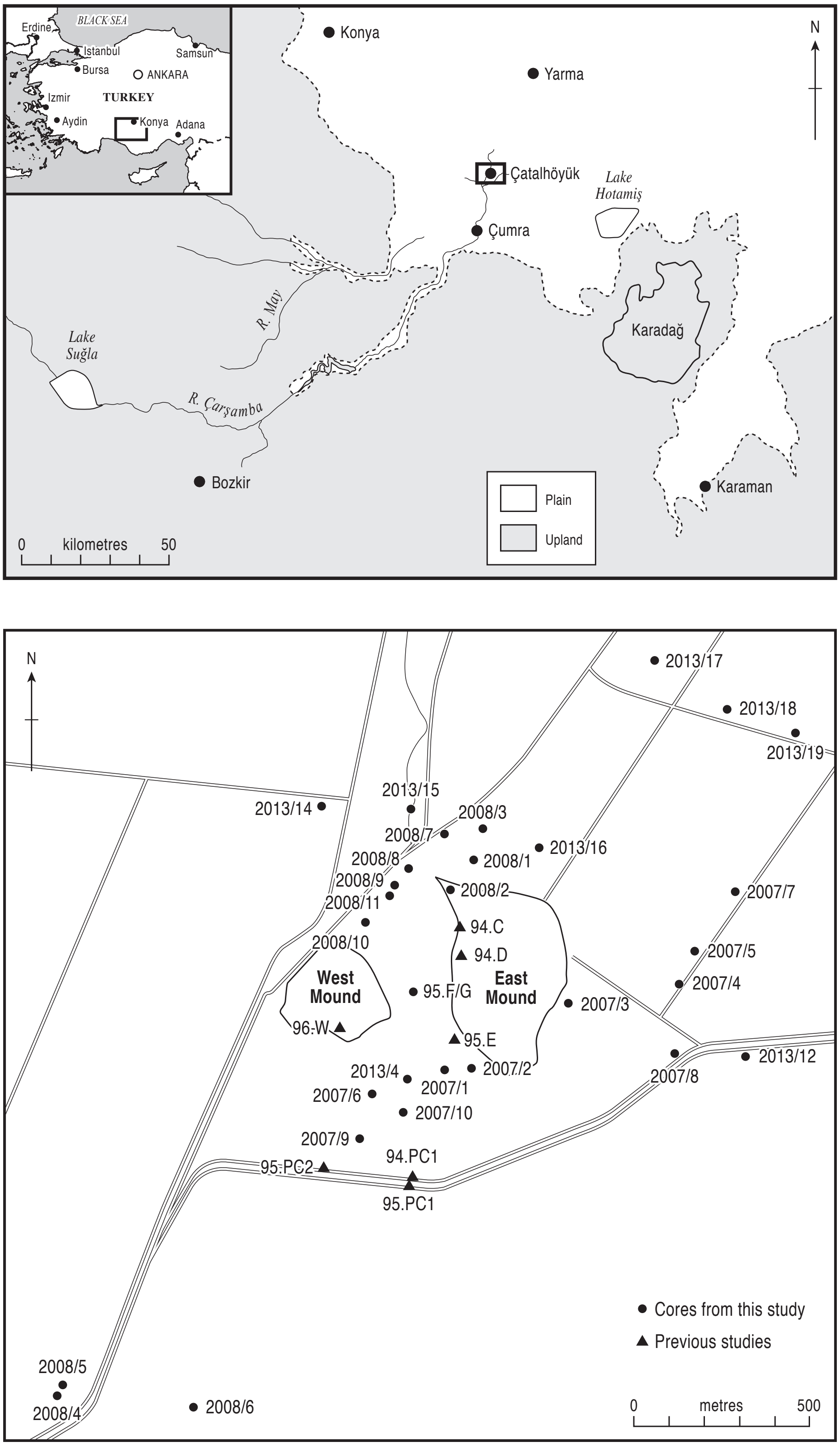
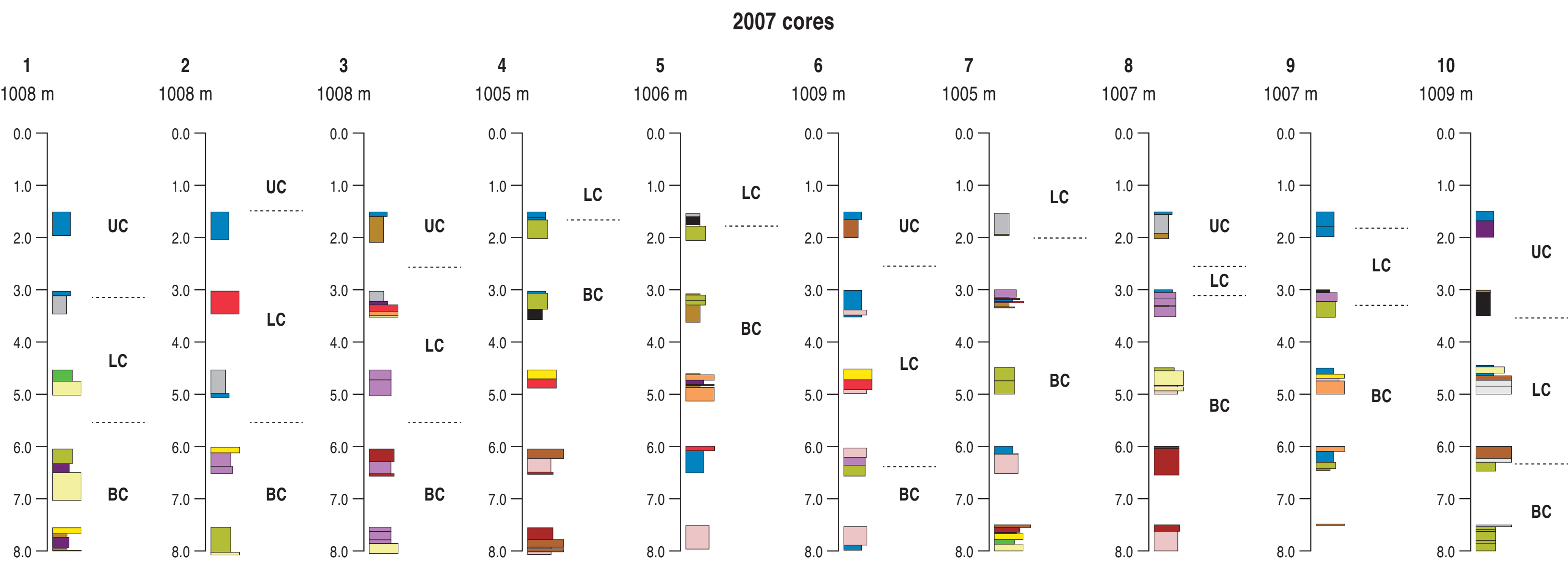
Figure

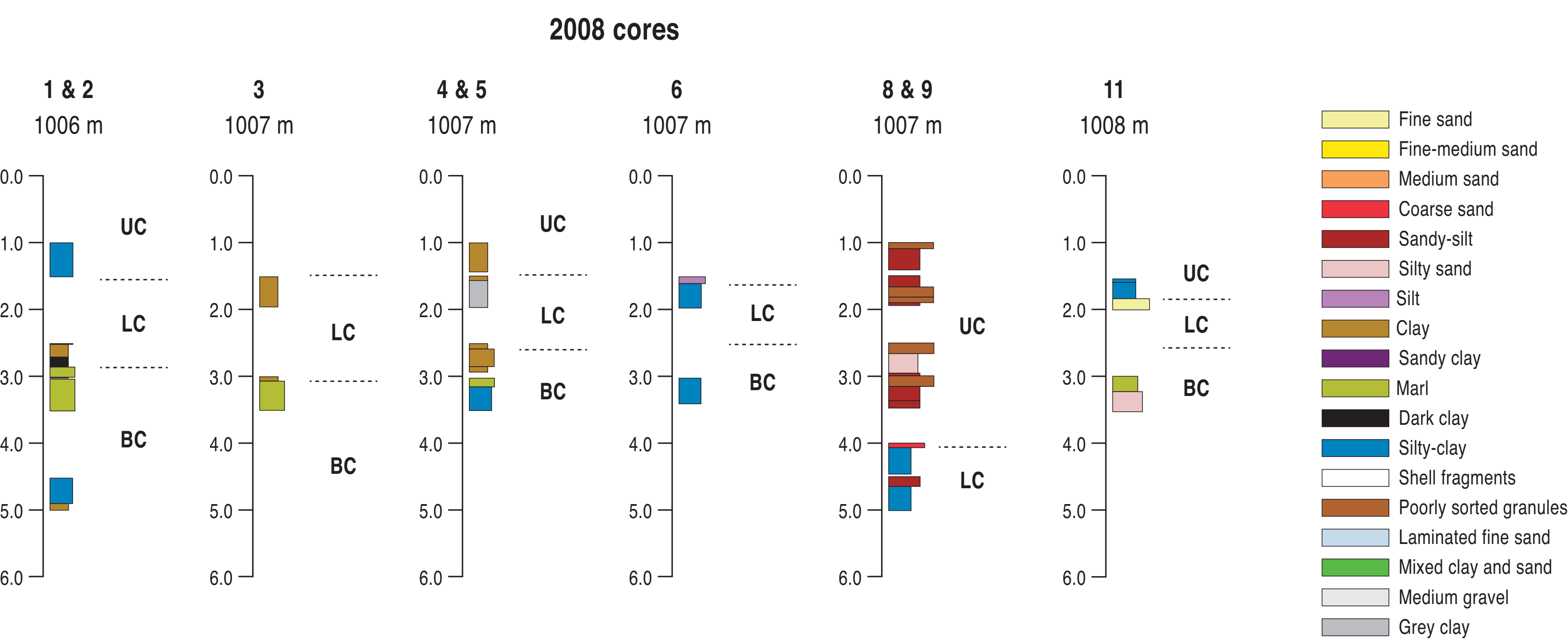


BLACK SEA
Erdine
Istanbul
Samsun
Bursa
ANKARA
Izmir
TURKEY
Aydin
Konya
Adana
Konya
Yarma
N
Çatalhöyük
Lake
Hotamiş
Çumra
Karadağ
R. May
Lake
Suğla
R. Çarşamba
Bozkir
Karaman
Plain
Upland
0
kilometres
50
N
2013/17
2013/18
2013/19
2013/15
2013/14
2008/3
2008/7
2013/16
2008/8
2008/1
2008/9
2008/2
2007/7
2008/11
94.C
2008/10
94.D
2007/5
West
Mound
East
Mound
2007/4
95.F/G
2007/3
96.W
95.E
2013/4
2007/2
2013/12
2007/1
2007/8
2007/6
2007/10
2007/9
94.PC1
95.PC2
95.PC1
Cores from this study
Previous studies
2008/5
2008/4
2008/6
0
metres
500

Figure

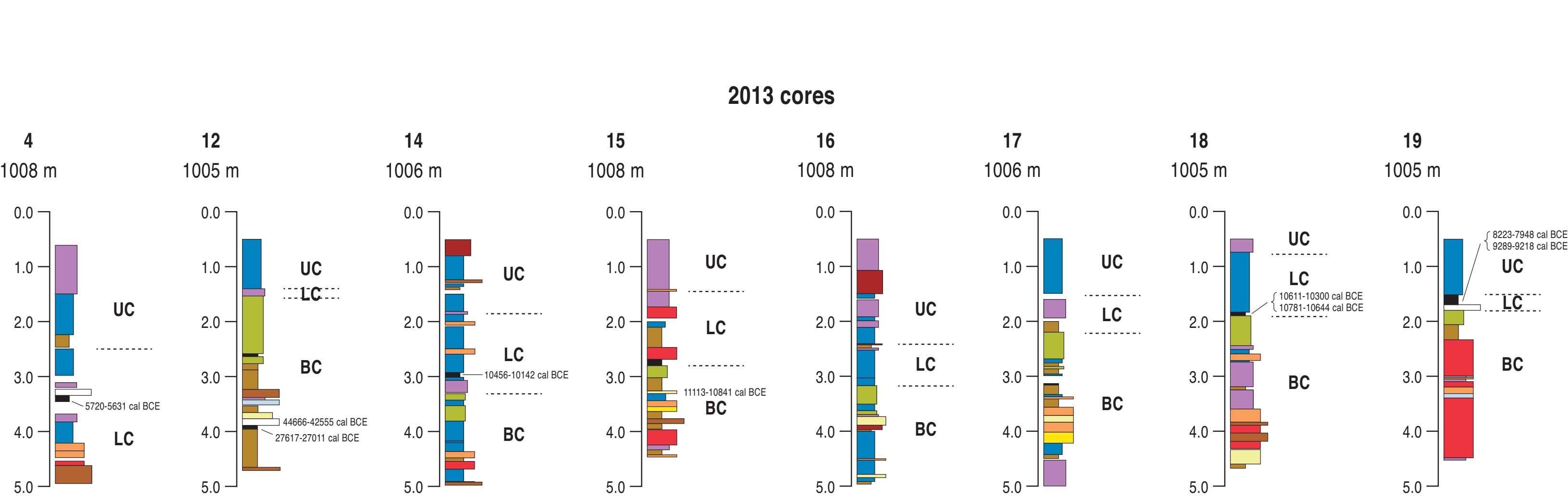

2007 cores
1
1008 m
2
1008 m
3
1008 m
4
1005 m
5
1006 m
6
1009 m
7
1005 m
8
1007 m
9
1007 m
10
1009 m
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
UC
LC
BC

Figure

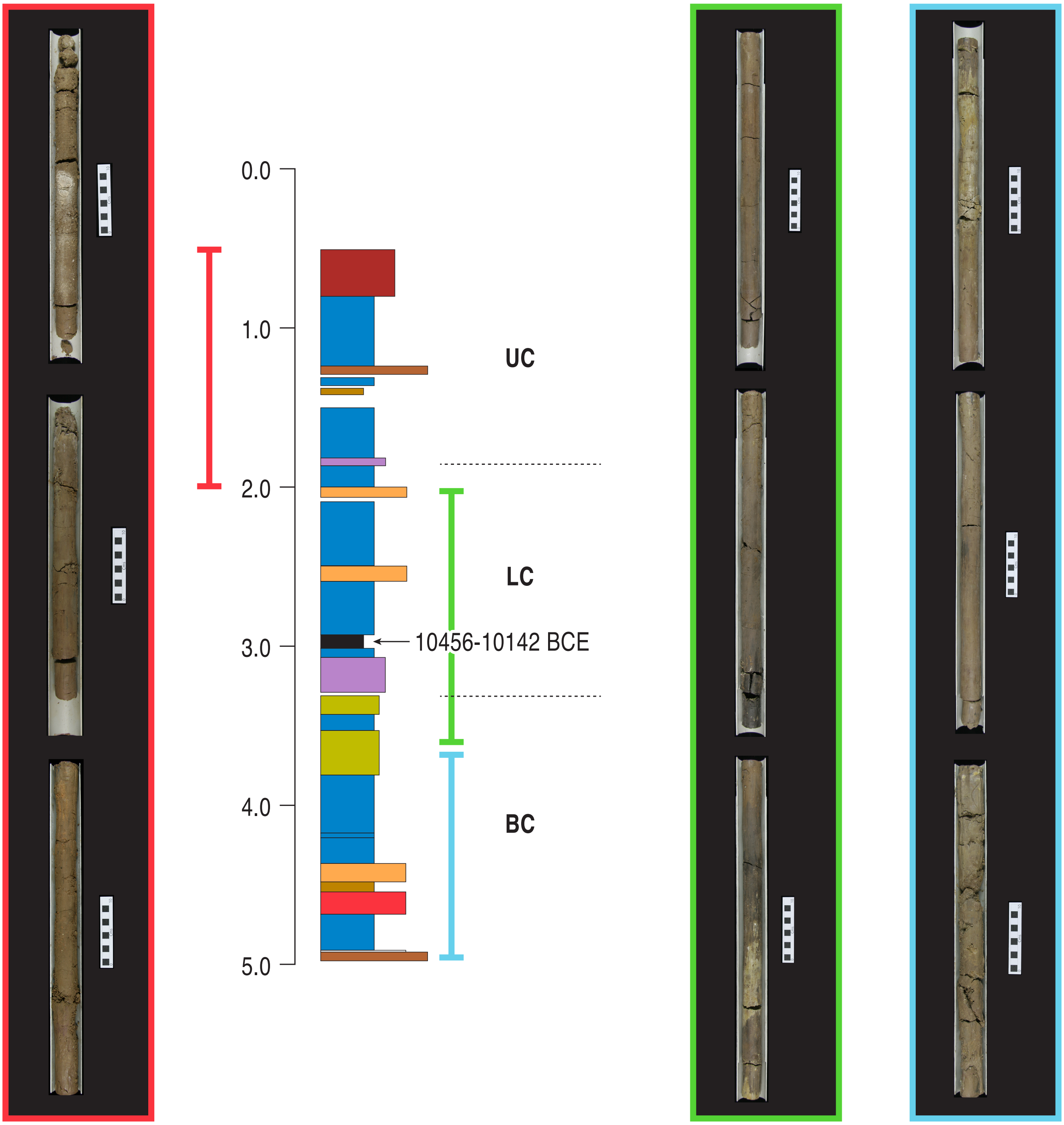


2008 cores
1 & 2
1006 m
3
1007 m
4 & 5
1007 m
6
1007 m
8 & 9
1007 m
11
1008 m
0.0
1.0
2.0
3.0
4.0
5.0
6.0
UC
LC
BC
Fine sand
Fine-medium sand
Medium sand
Coarse sand
Sandy-silt
Silty sand
Silt
Clay
Sandy clay
Marl
Dark clay
Silty-clay
Shell fragments
Poorly sorted granules
Laminated fine sand
Mixed clay and sand
Medium gravel
Grey clay

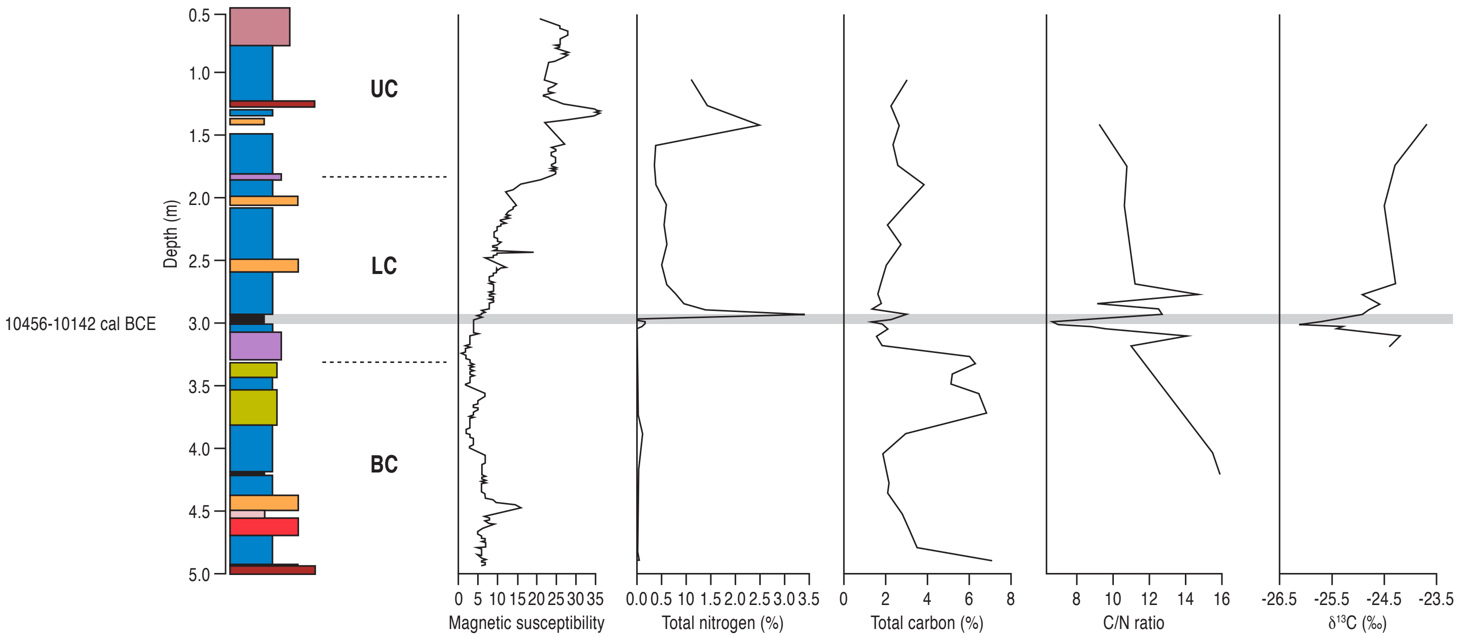
Figure


2013 cores
4
1008 m
UC
5720-5631 cal BCE
LC
12
1005 m
UC
LC
BC
44666-42555 cal BCE
27617-27011 cal BCE
14
1006 m
UC
LC
10456-10142 cal BCE
BC
15
1008 m
UC
LC
11113-10841 cal BCE
BC
16
1008 m
UC
LC
BC
17
1006 m
UC
LC
BC
18
1005 m
UC
LC
10611-10300 cal BCE
10781-10644 cal BCE
BC
19
1005 m
8223-7948 cal BCE
9289-9218 cal BCE
UC
LC
BC
0.0
1.0
2.0
3.0
4.0
5.0

Figure

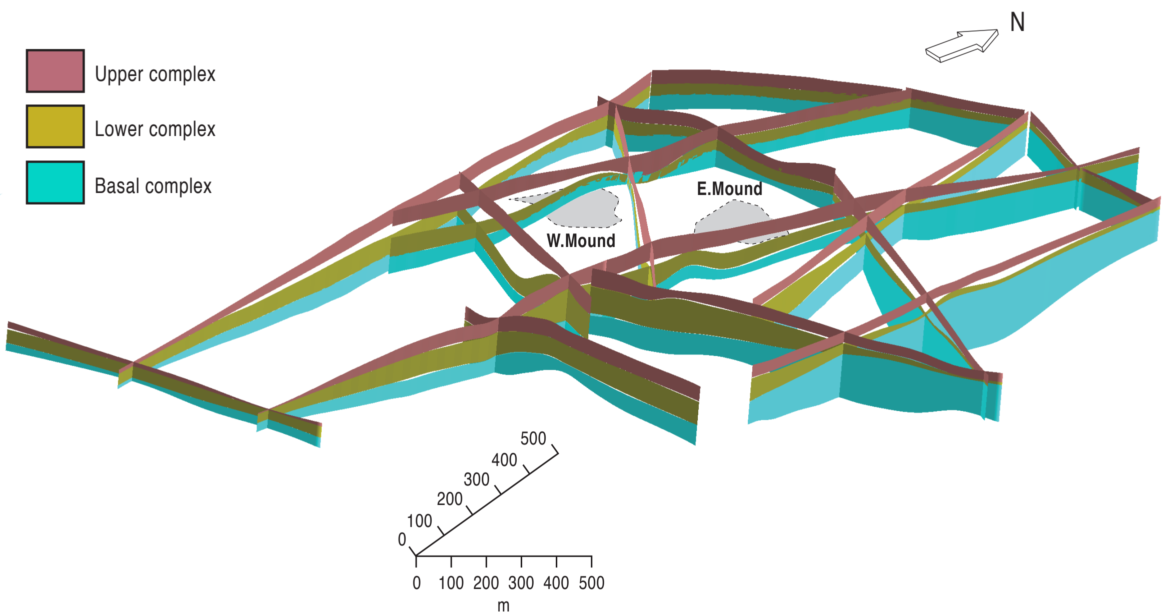


Figure



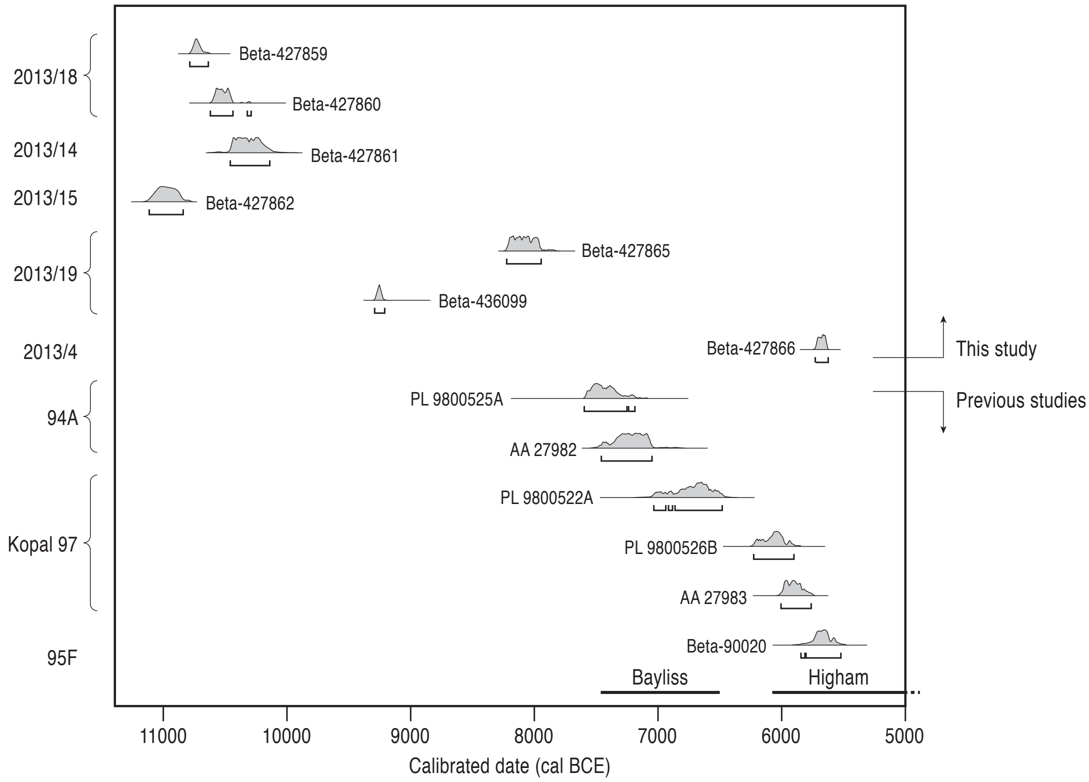
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Depth (m)
10456-10142 cal BCE
UC
LC
BC
0 5 10 15 20 25 30 35
Magnetic susceptibility
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Total nitrogen (%)
0 2 4 6 8
Total carbon (%)
8 10 12 14 16
C/N ratio
-26.5 -25.5 -24.5 -23.5
δ13C (‰)

Figure



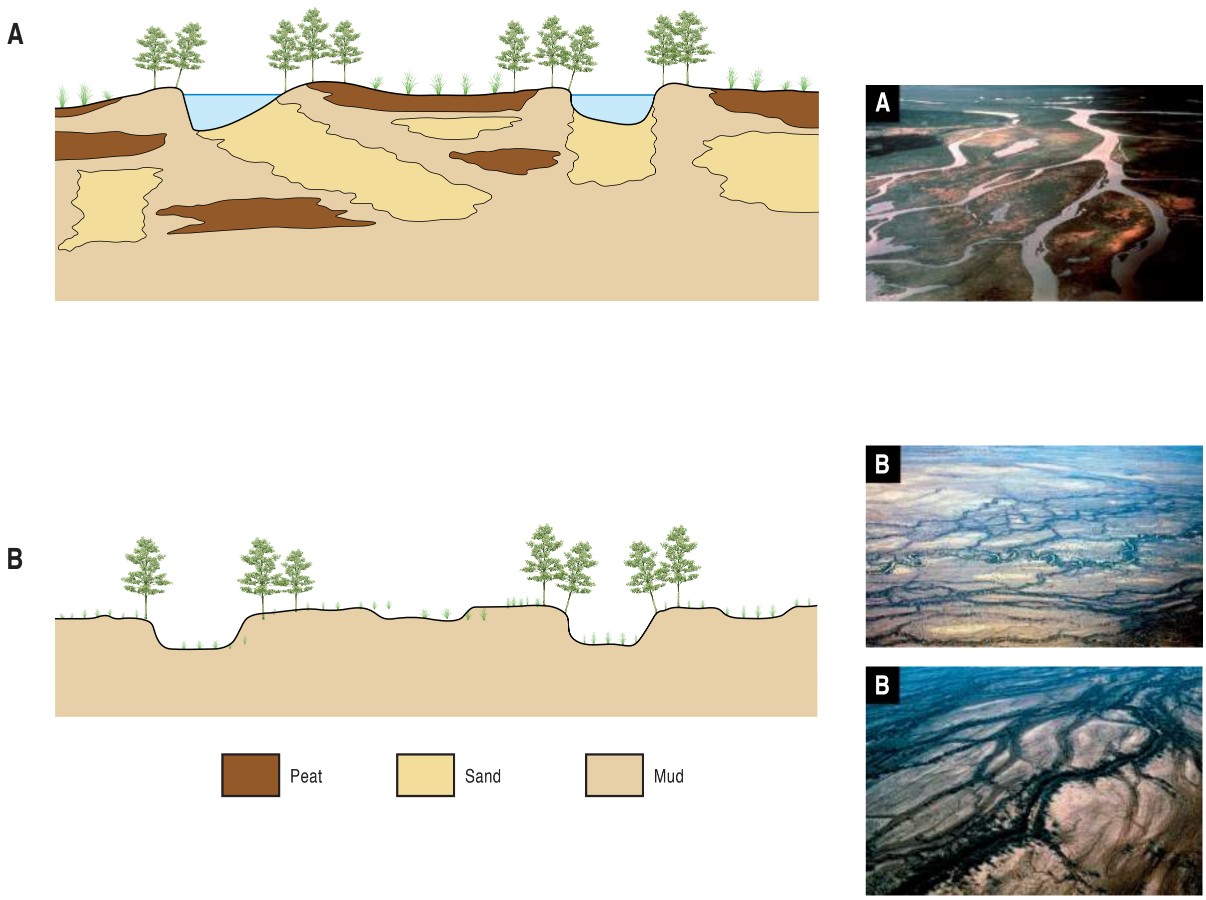
Upper complex
Lower complex
Basal complex
N
E.Mound
W.Mound
500
400
300
200
100
0
0 100 200 300 400 500
m

Figure



2013/18
Beta-427859
Beta-427860
2013/14
Beta-427861
2013/15
Beta-427862
2013/19
Beta-427865
Beta-436099
2013/4
Beta-427866
This study
94A
PL 9800525A
Previous studies
AA 27982
Kopal 97
PL 9800522A
PL 9800526B
AA 27983
95F
Beta-90020
Bayliss
Higham
11000
10000
9000
8000
7000
6000
5000
Calibrated date (cal BCE)

Figure



Figure
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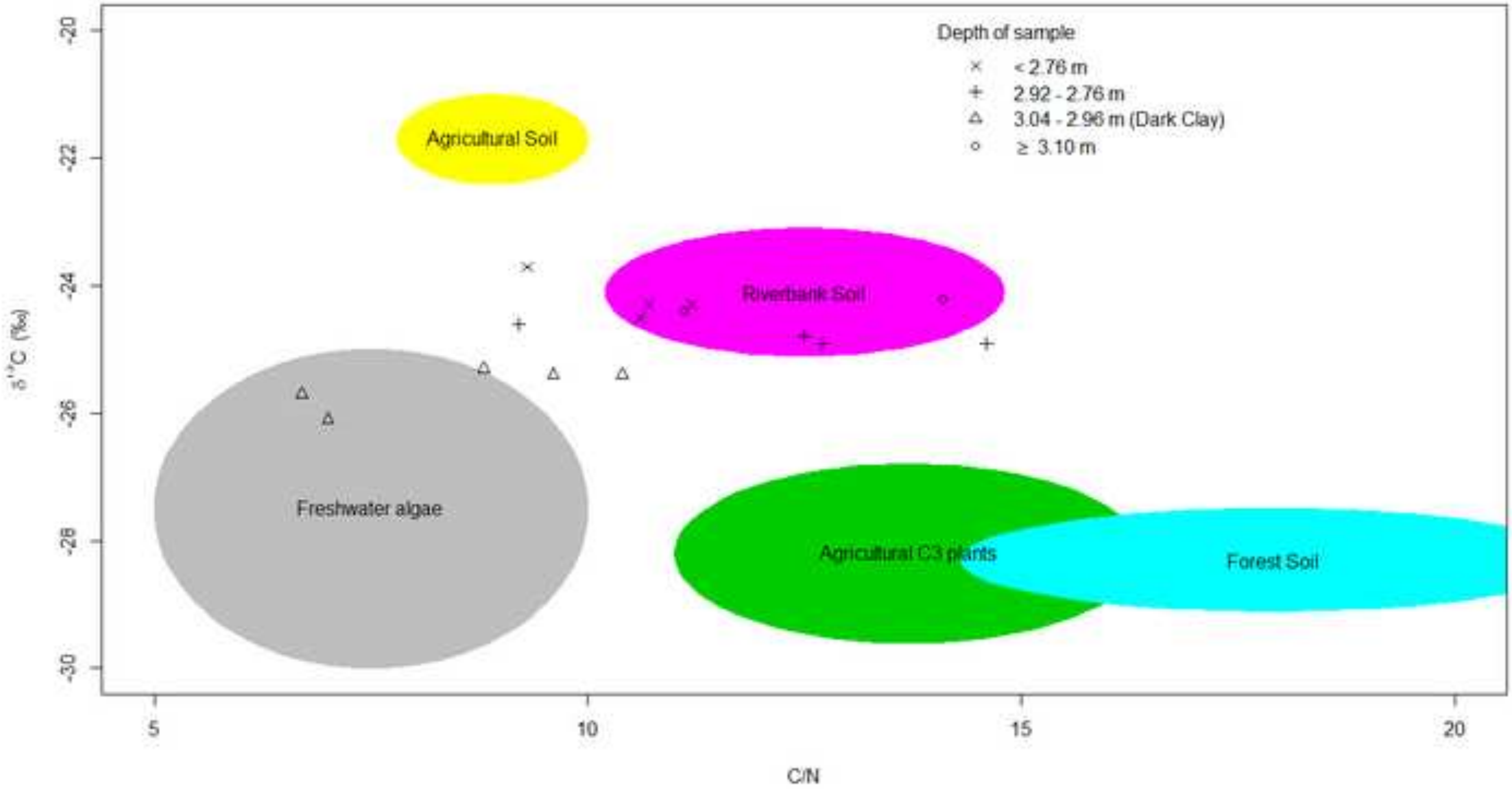

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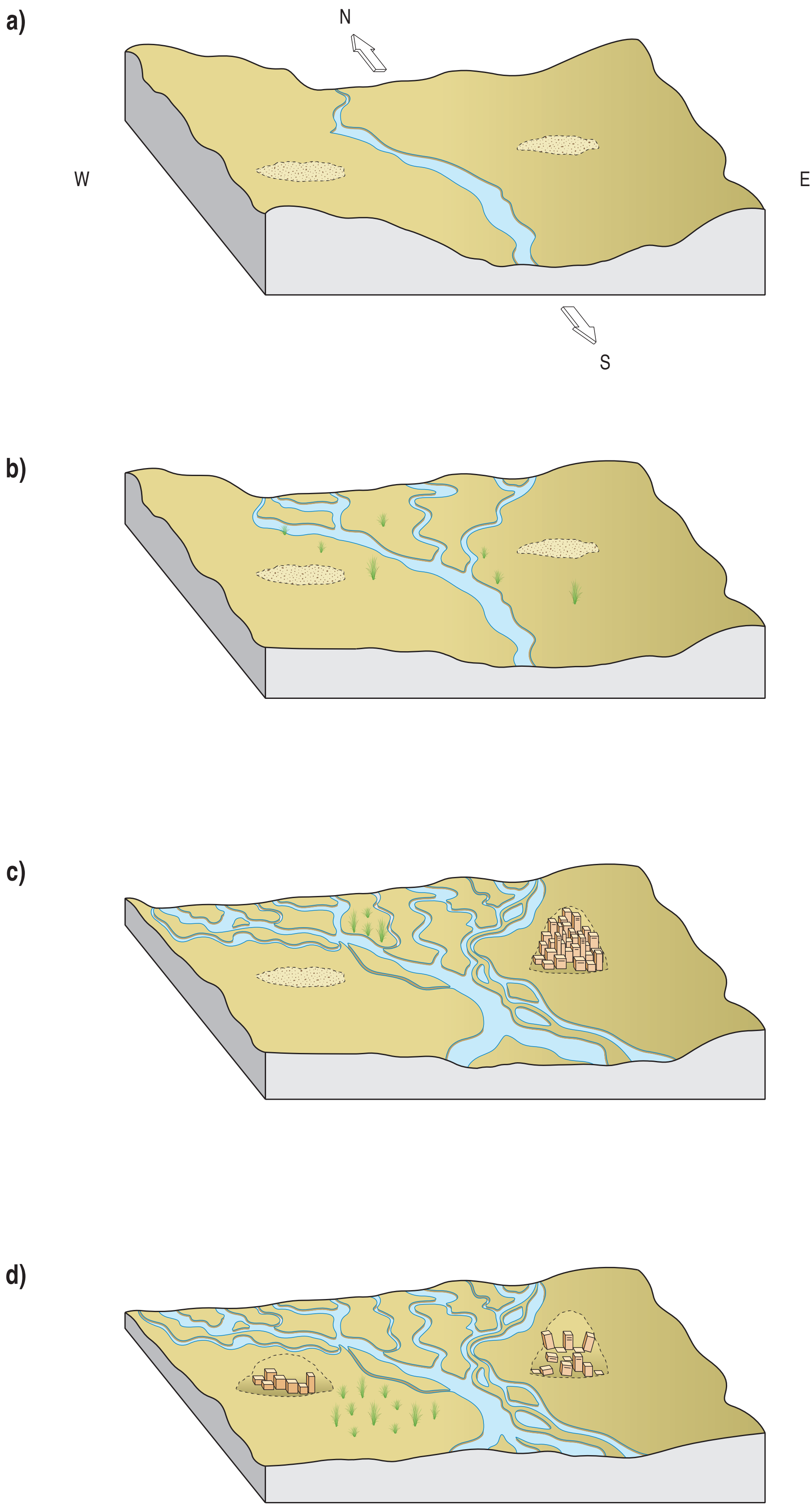

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