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,

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

60

Introduction

The site of Çatalhöyük (*c.*7400–6000 cal BCE: Bayliss et al. 2015, Cessford 2001) in central southern Turkey has played a pivotal rôle in ongoing 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 Konya (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 enables us to construct a more refined understanding of the 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.

Regional Setting

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).

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 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, 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 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 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 was identified that contained a variety of coarse-grained sediments and freshwater shells, and, at 42.5 m wide, led the 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 Alluvium, suggesting that it may have ceased with the arrival of the 8.2 ka event (i.e. c.6200 cal BCE) 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 suggested as being represented in Turkish speleothem 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 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 coring locations were distributed in order to ensure 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). 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 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^{TM} 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 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.

298 Because of its ubiquity, the upper part of this complex was taken as the uppermost
299 appearance of marl in the core, and thus its elevation varies between locations. At its deepest
300 (core 2007/6), the upper boundary is at 6.33 m below the modern ground surface, and at
301 1.65 m at its shallowest (core 2007/4). The upper surface tends to be lower between and
302 immediately to the south of the mounds, but it also undulates in a N-S and E-W direction
303 between cores (Figure 4). In the shorter cores, this complex is absent from 2008/8 and 9 and
304 2013/4.

305 The marls in this complex have a mean organic content of 4.65 ± 0.23 % (SE), $CaCO_3$
306 content of 45.94 ± 1.71 %, and a mass-specific magnetic susceptibility of 27.99 ±
307 4.28 × 10^{-8} m^3 kg^{-1}. The clastic sediments have a mean organic content of 3.75 ± 0.35 %,
308 $CaCO_3$ content of 29.18 ± 1.70 % and a mass-specific magnetic susceptibility of 111.87 ±
309 13.31 × 10^{-8} m^3 kg^{-1}.

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

314

315 *Lower Complex*

316 The Lower Complex is dominated by silts, silty clays and clays with some reworked
317 fragments of marl in places (Figure 2). In a number of places (cores 2008/1-3, 2013/17 and
318 18), the marl at the top of the basal complex is directly overlain by a dark grey or black
319 (10YR2/1-4/1, 10YR3/3 or 2.5Y2.5/1) clay (subsequently called Dark Clay). Elsewhere,
320 Dark Clay is absent the lower complex starts with lighter coloured silts and clays (cores
321 2007/5-10, 2008/5, 2013/4, 2013/14-16 and 2013/19: ranging from light greyish brown
322 2.5Y6/2 to grey 10YR5/1), or in the case of core 2007/10, a gravel with silty matrix (2.5Y6/2
323 [light brownish grey]). In core 2007/4 there is a transitionary boundary of 0.04 m with the
324 Basal Complex characterised by a mix of marl and the silt. The upper contact of the marl at
325 the top of the Basal Complex was not observed in the other 11 cores. Boundaries are abrupt
326 and smooth or occasionally wavy, suggesting erosional contacts. The dark grey or black clay
327 layer is also found at higher points stratigraphically in the Lower Complex in cores 2007/1-3,
328 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 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 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.

Geochemical and isotope analyses

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 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.

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. 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.

391

392 ## Discussion

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

400 Lacustrine sediments preserved in the sequences recorded here are characterized by marl and
401 clay deposits with the coarser sands and gravels diagnostic of fluvial deposition. Core
402 2013/12 shows earlier lake deposition was interrupted in MIS3-2 by local fluvial deposition
403 before returning to lake deposition. The apparently anomalous date of 44,666-42,555 cal
404 BCE (2σ) on shells a few centimetres above the level of laminated dark clay dated to 27,617-
405 27,011 cal BCE (2σ) could be explained by the reworking of older shelly deposits. This
406 interpretation is consistent with the fragmentary nature of the shells, or it may relate to the
407 inclusion of old carbon in the shells, taking the date close to the limit of radiocarbon. This
408 core suggests a series of frequent shifts in fluvial deposition within the Basal Complex,
409 before a return to lacustrine deposition in the upper part of the core (marl deposits from 3.0 –
410 1.52 m: Figure 2c). Although there is no direct date on this final lacustrine deposition, it is
411 likely to relate to the final parts of MIS2. At the latest, the date of 11,113-10,841 cal BCE
412 (2 σ) in core 2013/15 suggests the end of lake deposition in this part of the Konya Basin in
413 the later Pleistocene. However, Boyer (1999) provides an OSL date on a sandy loam in a
414 palaeochannel cut into the upper marl at site 95PC2 dated to 13,319 ± 2050 BCE by OSL.
415 This date would suggest early fluvial activity in the latest Pleistocene, and a hiatus before
416 deposition of the Dark Clay or other deposits at the base of the Lower Complex.

417 In the 2007-2013 cores, the top of the marl varies from 6.33 m to 1.33 m below the modern
418 ground surface, which corresponds to elevations of 1002.5 – 1005.5 m asl. However,
419 including elevations from cores and sections in Boyer (1999), the range is 999.73 –
420 1006.14 m asl. Thus, local variation in the upper surface of the marl is significant, and what
421 is seen is a highly undulating surface reflecting processes of wind deflation and surface water
422 erosion (e.g. the development of local, low-relief "badlands") as well as later incision by

channels (Figure 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 (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 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 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 metre-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. levées) 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.

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 6). However, there are

456 also late pockets of development of the Dark Clay in some places, as suggested by the sample
457 from 2013/4. The Dark Clay in 2013/4 is contemporary with dates from the West Mound
458 (5,720-5,631 cal BCE compared to c.6150 to 5,500 cal BCE based on dates in Higham et al.
459 (2007) (Figure 5). All of the dating evidence suggests that the Dark Clay is both spatially and
460 temporally discontinuous, refining previous interpretations of a marshy environment in all of
461 the low points of the landscape solely in the Early Holocene (Boyer 1999). Boyer et al
462 (2006:683) suggests the ubiquity of this dark clay directly overlying the marl although this
463 interpretation is contradicted by their Figure 7b, in which it only occurs in some of the lower
464 points in the landscape. Furthermore, Boyer et al (2006: 685) suggests that deposition of the
465 dark organic clay is from 7850-7450 cal BCE (1 sigma), however they were only able to date
466 the material directly at Kızıl höyük and Avrathanı höyük, which are approximately 6-8 km to
467 the northeast and northwest, respectively, of Çatalhöyük. Five of our dates belong to the
468 period 11113 – 9218 cal BCE (2σ), so predate the "broadly contemporaneous deposition"
469 (Boyer et al. 2006: 685) suggested based on correlation. One date of 8223 – 7948 cal BCE
470 (2013/19 to the north of Çatalhöyük) overlaps the dates of Boyer et al. at 2σ (their dates
471 correspond to 8198-7083 cal BCE when calibrated to 2σ using OxCal 4.2), but our dates
472 from both much earlier and much later suggest that the facies is more likely to relate to local
473 conditions rather than regional ones.

474 The Lower Complex is a mix of both coarse and fine sediments – including the Dark Clay –
475 with significant lateral and vertical variability. This pattern of facies is consistent with
476 deposition from an anabranching river system. As there is a tendency for there to be fewer
477 Dark Clays and fewer coarser deposits at higher positions in the sequence, there is a
478 suggestion that there may have been a shift from more humid to dryland anabranching
479 conditions, following the definitions of Nanson and Knighton (1996) and North et al. (2007)
480 (Figure 7). Dryland anabranching rivers have variable morphology and sedimentary
481 behaviour, but one such sub-system, the mud-dominated system, seems to fit the current data
482 for the Lower Complex very well. Under this model (Type 1c of Nanson and Knighton
483 1996), the mud (silt and clay)-dominated system is characterized by a low-gradient
484 floodplain, which has a low rate of aggradation, and a very slight difference between the
485 nature of the deposits in channel and on the floodplain thus not presenting the classic fluvial
486 indicators such as sand-filled channel bodies, lag conglomerates, current ripples and dunes,
487 and fining-up units (North et al. 2007, 930, their Table 2). As a dryland anabranching
488 system, new channels would form via obtrusion, which North et al. (2007: 930) define as a

much more gradual process than channel change by 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 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 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 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 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 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 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. Contrary to the suggestion of Boyer et al. (2006) that the Çarşamba did not break through the sand spit at Çumra formerly bordering 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 2014, Fraser et al 2011), although caution is required with this interpretation until more data are available from cores elsewhere in the landscape.

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.

555 In summary, we propose that the palaeoenvironmental evolution of the area surrounding the
556 Çatalhöyük tells, up to the period of their occupation, can be illustrated as four phases (Figure
557 9). Following the retreat of Palaeolake Konya towards the end of the Pleistocene, Phase 1
558 consists of dominant erosion due to wind and water that created an undulating surface of
559 marl. The topography of the study area would have varied by about 7 m by the end of this
560 phase. Sands and gravel provide possible evidence of early fluvial activity, although near-
561 shore deltaic deposits cannot be excluded because of the lack of observed sedimentary
562 structures. Within the sequences demonstrated by the 2007-2013 cores, Phase 1 is the hiatus
563 between the top of the Basal Complex and the start of the Lower Complex. Phase 2 occurs in
564 the latest Pleistocene and early Holocene, and indicates increased wetness, probably
565 characteristic of a humid anabranching channel system, in which there are localized pockets
566 of wetter conditions, relating to local hollows or cutoffs in the channel system. The
567 undulating topography is starting to infill during this phase. In Phase 3a, this infilling
568 continues, producing a flatter surface, and there are fewer pockets being occupied by wetter
569 conditions. The fluvial régime shifts from humid to dryland anabranching conditions, which
570 are more concentrated in the west of the study area. The earliest period of occupation of the
571 East Mound coincides with this phase. This interpretation is more consistent with the
572 archaeological evidence from the site for a mosaic of both dry and wet conditions. Phase 3b
573 coincides with the shift of occupation to the West Mound, when there is evidence for a
574 localized wetter area to the southeast of the mound, but otherwise a continuation of the
575 dryland anabranching system. Phases 2 and 3 represent deposition in the Lower Complex.
576 Finally, Phase 4 (not illustrated) – representing deposition in the Upper Complex – shows a
577 shift to the pre-modern style of fluvial environment, modified by channelization as
578 demonstrated by Boyer (1999) and Boyer et al. (2006). Finally, to clarify the terminology
579 developed here, the Basal Complex is defined as the late Pleistocene deposition in fluvial and
580 lacustrine environments, ending in a widespread erosional phase in the basin. The Lower
581 Complex commences in the final part of the Pleistocene and is broadly parallel to the Lower
582 Alluvium in previous studies. The Upper Complex is parallel to the Upper Alluvium. In all
583 cases, there is significant vertical and lateral variability in facies, hence our preference for the
584 term “Complex”.

585

586

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-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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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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853 3b (continuation of dryland anabranching channel and shift to occupation of the West
854 Mound).

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

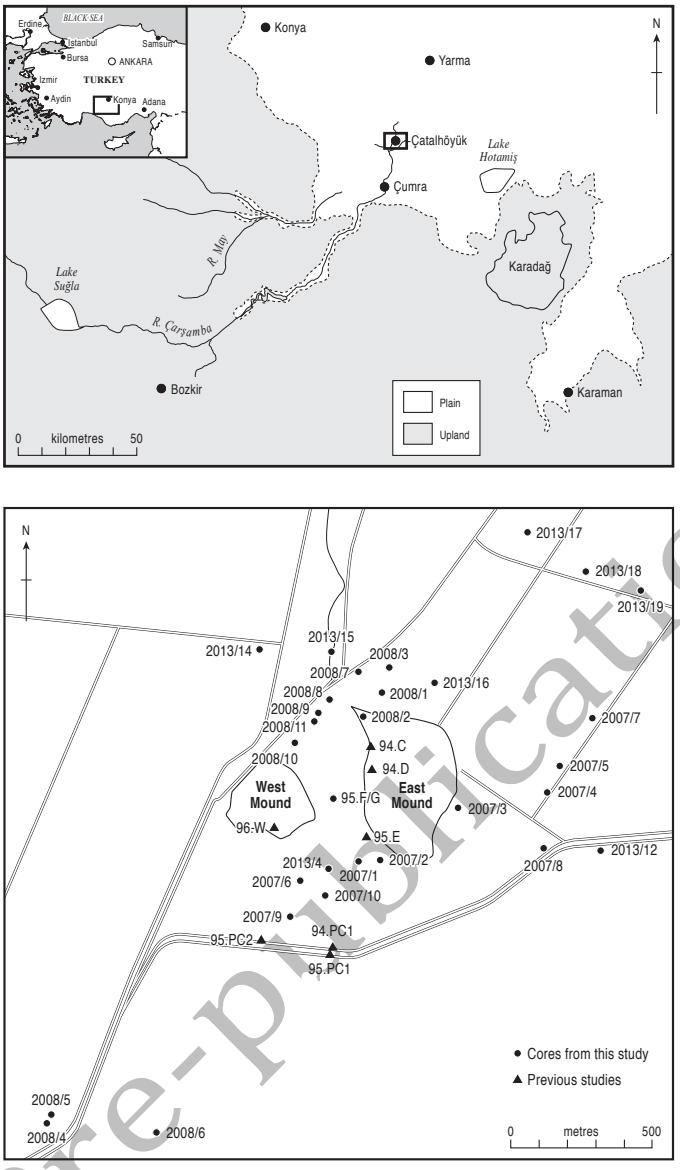

Figure 1.

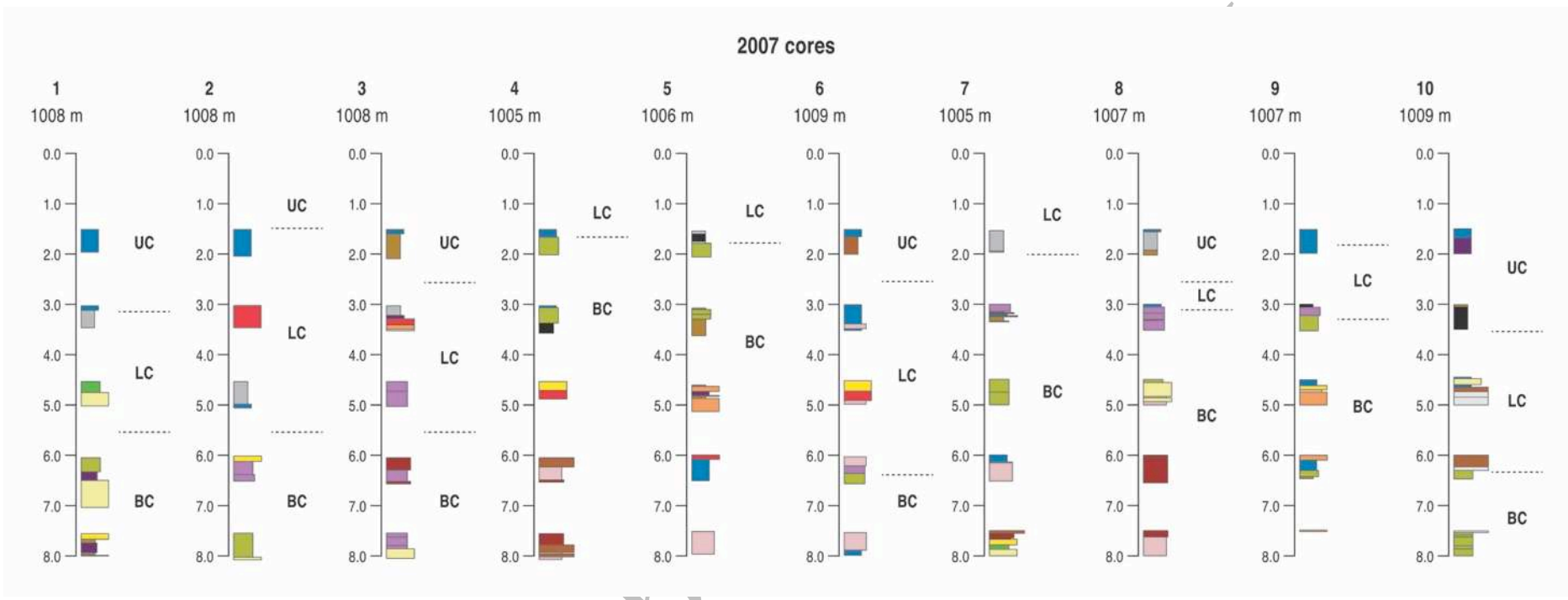

Figure 2a

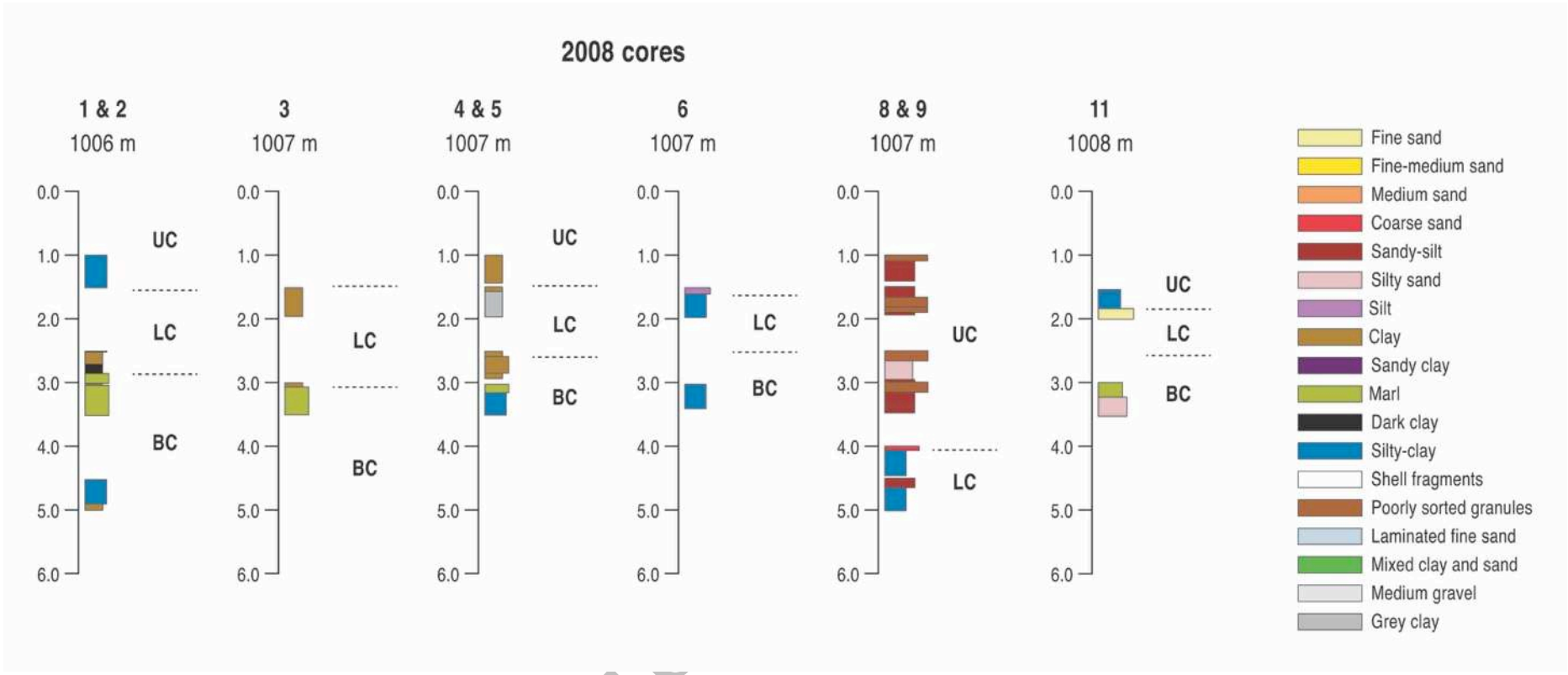

Figure 2b

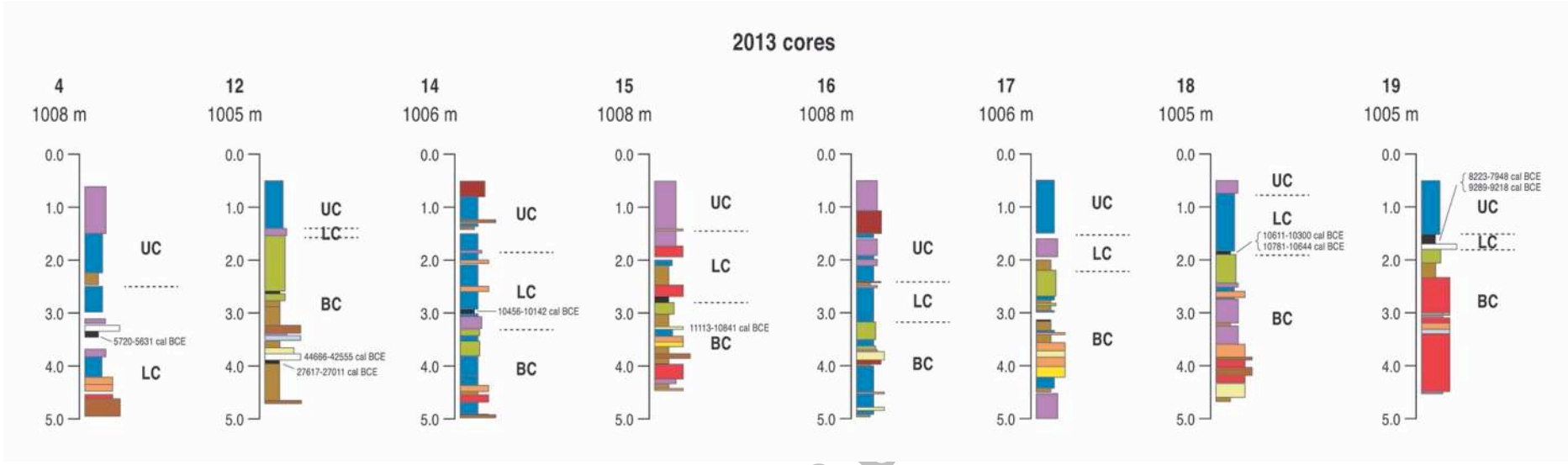

Figure 2c

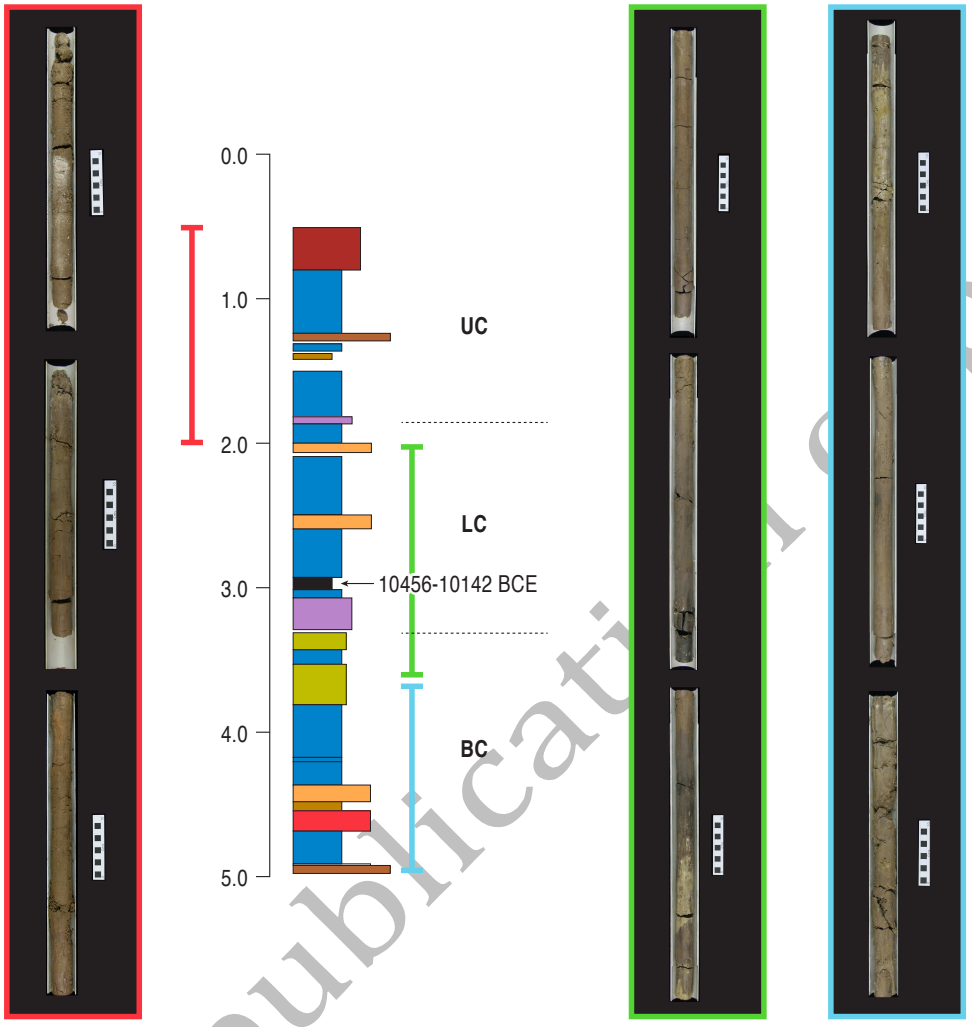

Figure 3

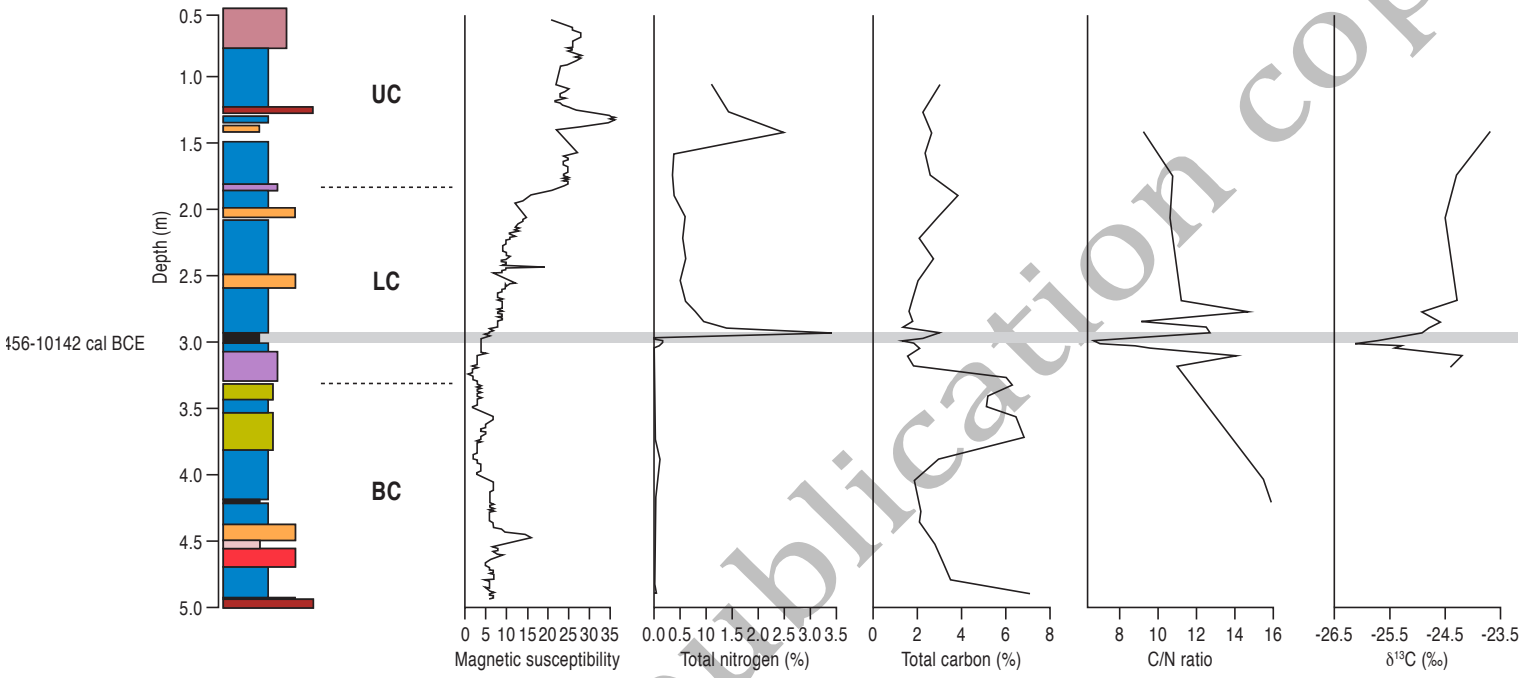

Figure 4

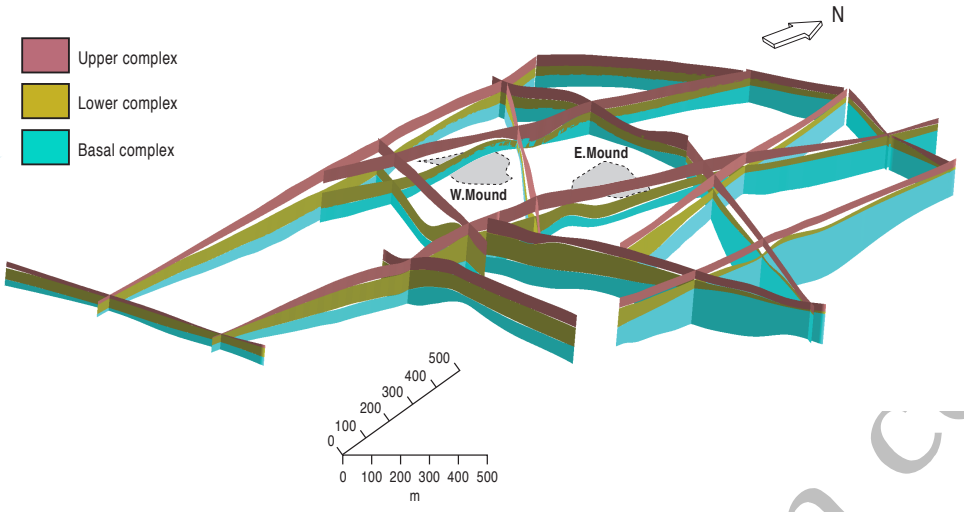

Figure 5

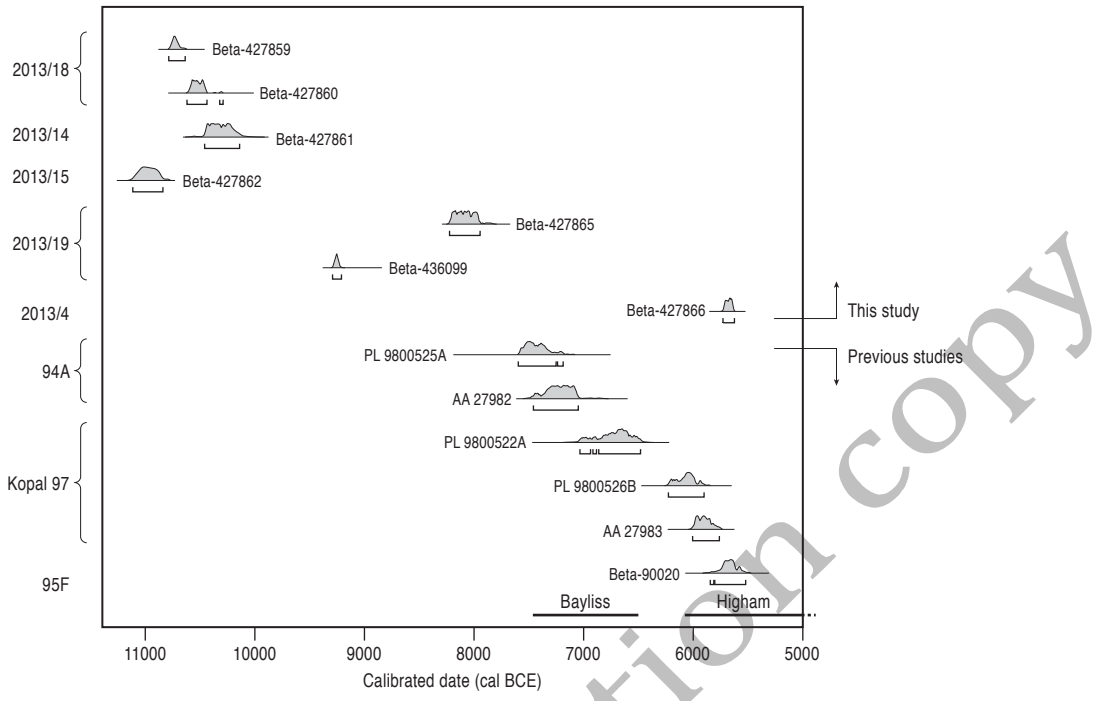

Figure 6

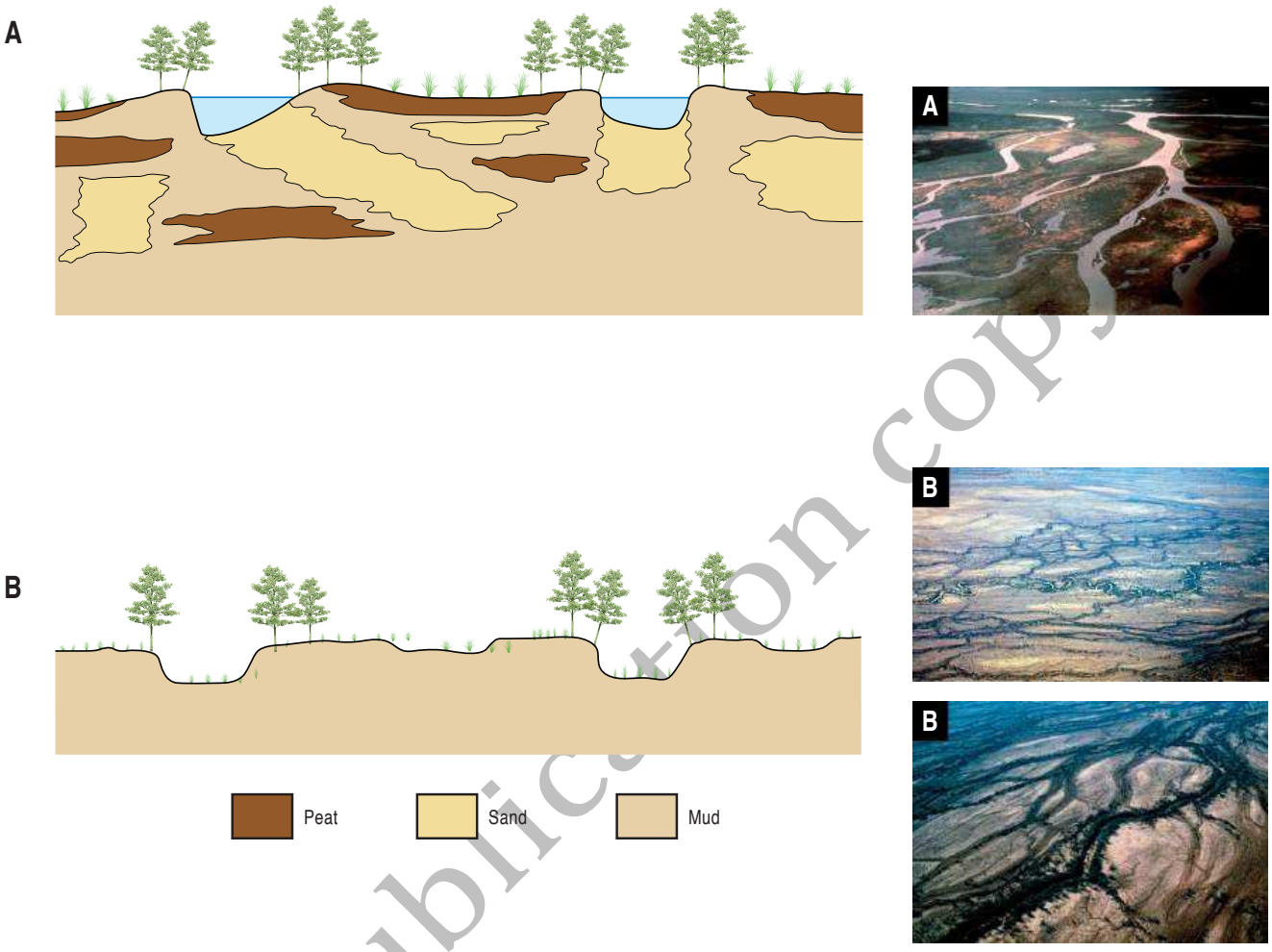

Figure 7

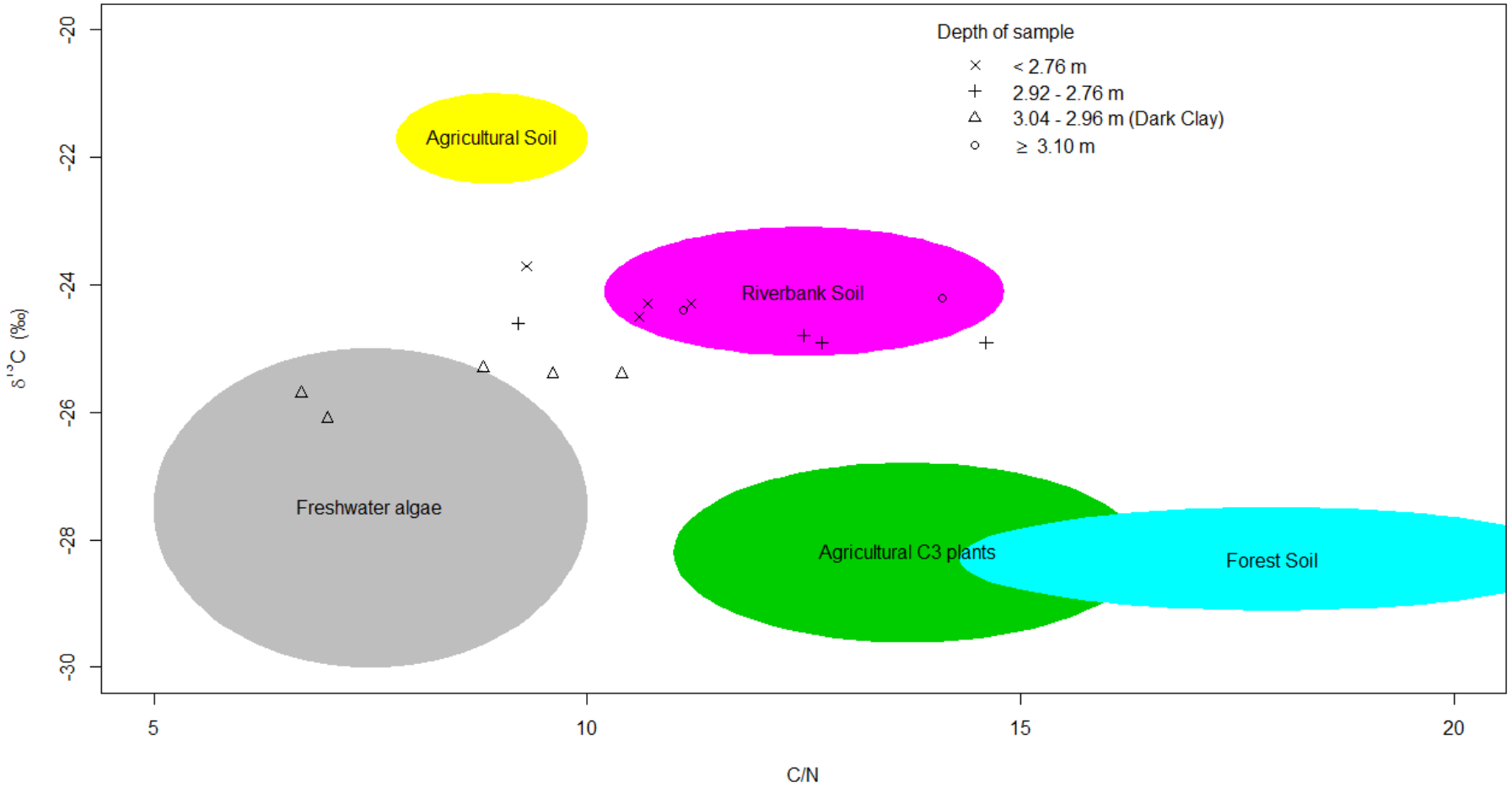
Depth of sample
< 2.76 m
2.92 - 2.76 m
3.04 - 2.96 m (Dark Clay)
≥ 3.10 m
Agricultural Soil
Riverbank Soil
Freshwater algae
Agricultural C3 plants
Forest Soil
δ13C (‰)
-20
-22
-24
-26
-28
-30
5
10
15
20
C/N

Figure 8

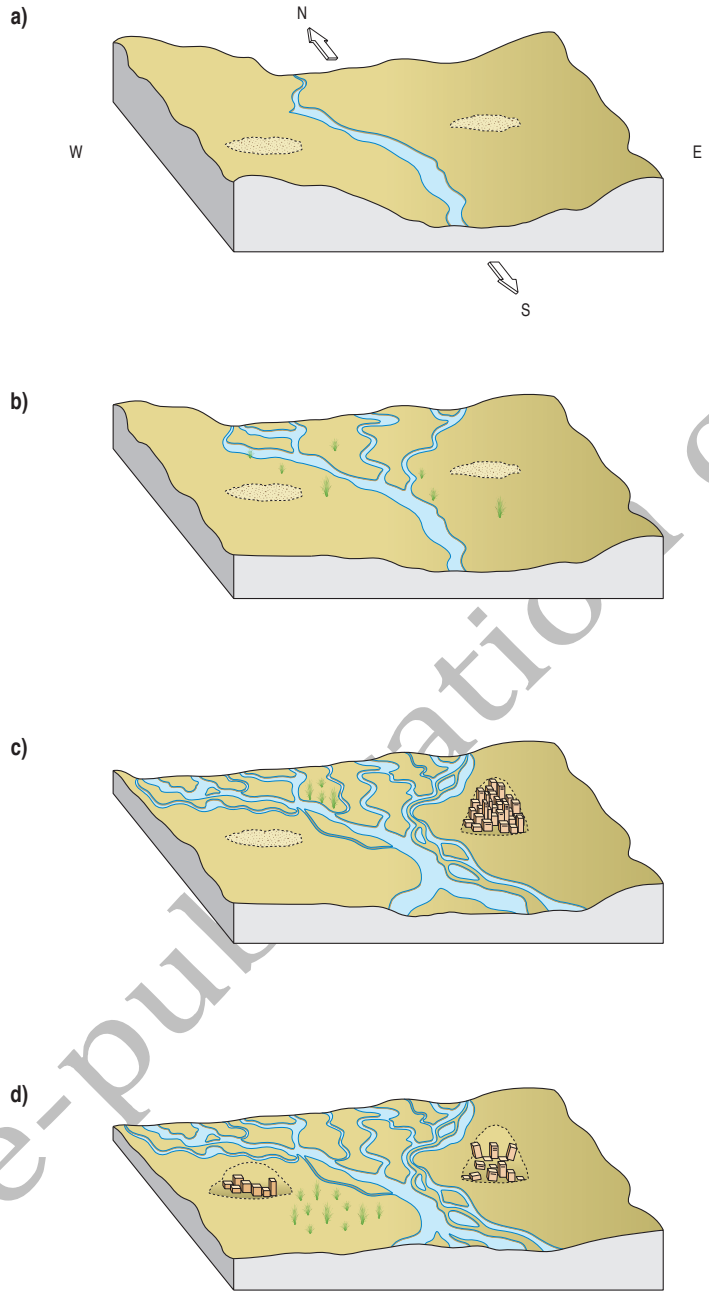

Figure 9