EMERGENCE OF CIVILISATION, CHANGES IN FLUVIO-DELTAIC STYLE AND NUTRIENT REDISTRIBUTION FORCED BY HOLOCENE SEA-LEVEL RISE.

<u>THIS IS THE ACCEPTED MANUSCRIPT (FIGURES & TABLES ARE AT THE END). THE FINAL ARTICLE (INCLUDING HIGHER-QUALITY FIGURES) IS PUBLISHED IN GEOARCHAEOLOGY.</u>

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ABSTRACT

During the mid-Holocene, the first large-scale civilisations emerged in lower alluvial systems after a marked decrease in sea-level rise at 7-6kyr. We show that as the landscapes of deltas and lower alluvial plains adjusted to this decrease in the rate of relative sea-level rise, the abundance and location of resources available for human exploitation changed as did the network of waterways. This dynamic environmental evolution contributed to archaeological changes in the three fluvio-deltaic settings considered herein: Egypt, Mesopotamia and the Huang He in China. Specifically, an increase in the scale and intensity of agricultural practice, and the focussing of power towards a single city can be interpreted as responses to these environmental changes. Other archaeological observations, and the cultural trajectories leading to the formation of the Primary States also need to be considered in light of these evolving landscapes.

Keywords: Delta, Holocene, Nutrient, Landscape, Primary States

INTRODUCTION

During the mid-Holocene, significant changes occurred globally in human activity. Along with widespread adoption of agricultural practices, developing social stratification, and division of labour came the initiation of large-scale settlement, construction of monumental architecture and the formation of civilisations such as Sumer, Egypt, China, the Indus Valley, Central America and Peru (Stein, 2001). These changes broadly coincided with a marked decrease in the rate of eustatic sea-level rise (Fleming et al., 1998). Whilst a number of authors (eg. Kennett & Kennett, 2007; Stanley & Warne, 1997) have suggested a possible link between these sea-level changes and the contemporary human events, the subject has never been investigated on a global scale. This current lack of focussed investigation contrasts with the volume of geoarchaeological research into the impacts of climatic fluctuations at this time: changing aridity and temperature have been invoked to explain aspects of mid-Holocene cultural trajectories in a number of studies (Brooks, 2006; Hassan, 2002).

In this paper we examine the geoarchaeology of Egypt, Mesopotamia and the Huang He in China, to determine whether natural remodelling of coastal and fluvio-deltaic environments in response to decreased rates of sea-level rise could have promoted the observed changes in human behaviour and settlement patterns through stimulating changes in the abundances and distributions of nutritional and other resources within the landscape. First, a global fluvial model is developed and applied to these settings in order to understand their bulk landscape evolution. Then, three basic human needs are considered: nutrition, water supply, and a means of transport (all of which are fundamentally derived from the environment) and we explore how patterns of these resources would have evolved in these landscapes. Finally we interpret specific shifts in human behaviour during the mid-Holocene in terms of these environmental and resource changes.

EUSTATIC SEA-LEVEL CHANGE AND DELTAIC LANDSCAPES

In the early Holocene, sea-level rose rapidly as glaciers melted and then slowed around 7,000-6,000 years ago as shown in Figure 1 (Fleming et al., 1998). Whilst meltwater pulses likely provided some additional complexity, world deltas undoubtedly developed in a regime of rapidly rising sea-level in the early Holocene and subsequent slow sea-level rise in the mid-to-late Holocene (Stanley & Warne, 1994). The rate of sea-level rise acts as *the* first-order control on the landscape in both the coastal environment and the fluvial region, as it dictates the rate of creation of accommodation space into which sediments can be deposited. To a first order approximation, landscape changes driven by this decrease in the rate of sea-level rise (decrease in the rate of creation of accommodation space) should be widely observed and near-synchronous globally. Variations in the other controlling parameters of landscape morphology between different regions: climate; tectonic-isostatic regime; subsurface topography; would have caused differences in the timing and magnitude of the landscape change between various settings. Local tectonic or isostatic subsidence, for example, would also also affected the rate of creation of accommodation space, while climatic factors (increased rainfall, for instance) could affect the other side of the volumetric balance by increasing or decreasing the rate of sediment supply.

In order to develop a global model for the broad landscape evolution of fluvio-deltaic settings we look first at the Rhine (Berendsen & Stouthamer, 2001) and Mississippi (Aslan & Autin, 1999) river systems. As they are among two of the best studied fluvial systems in the world, they document a landscape history that might be expected in regions elsewhere. These systems show a strong contrast between their early and later Holocene behaviours, which can be attributed to the decrease in the rate of sea level rise.

Coastal Regions

During the early Holocene and in coastal regions of these deltaic areas, fast rates of sea-level rise and thus a high rate of creation of accommodation space resulted in overall transgression of the sea and retreat of the coastline to a point well inland of its present position. The coastline opened in many places with salt-water incursion into extensive estuarine and tidal-flat environments (Berendsen & Stouthamer, 2001). Delta-lobe formation was initiated at this time (Stanley & Warne, 1994).

In the later Holocene, as the rate of sea-level rise decreased, the coastline began to stabilise and formed a continuous strand including beach-barrier systems, before prograding seaward as the rate of sediment-supply exceeded the rate of creation of accommodation-space and gradually advancing to its present location (Berendsen & Stouthamer, 2001). Fresh water outlets became fixed for longer periods and saltwater inlets scarcer. As a result, the estuarine environment shrank and a clear separation between the fresh water and saltwater domains developed. At the interface, lagoons, and salt marshes became major landscape features (Berendsen & Stouthamer, 2001).

Fluvial Regions

During the earlier Holocene, downstream fluvial regions of these rivers were characterised by high rates of in-channel aggradation, little or no lateral channel migration, multichannel networks, frequent avulsion, continuous crevassing, fast floodplain aggradation, poorly-drained swampy and wetland landscape formation, little or no large-scale soil development, and accumulations of complex flood basin sediments varying substantially both laterally and vertically (Aslan & Autin, 1999; Berendsen & Stouthamer, 2001; Hageman, 1969; Makaske, 1998; Törnqvist, 1993a, 1993b).

These landscape characteristics came about as a direct result of the rapid rate of sea-level rise during the early Holocene. Fast rates of creation of accommodation space would have produced in-channel aggradation by reducing the river gradient, causing a corresponding reduction in energy to transport sediment, and decreased shear stress of the water on the river-bed. Fast in-channel aggradation, in turn, would have led to channel super-elevation (Jerolmack & Mohrig, 2007; Mohrig, Heller, Paola, & Lyons, 2000), since to maintain a constant volumetric flow while the river-bed is silting up, the channel builds its margins above the surrounding flood basin. Super-elevation then would have led to widespread crevassing and frequent avulsion (Jerolmack, 2009; Jerolmack & Mohrig, 2007; Mohrig et al., 2000). Crevasse splays form as a river seeps continually through a break in a levee, forming a splay of small-scale channels diverging locally into the surrounding flood basin where the water eventually drains into the ground. In many cases, avulsions develop from crevasse splays as a river catastrophically abandons one channel to forge or re-occupy another (Slingerland & Smith, 2004). Frequent crevassing and flooding into the basins between channels resulted in fast floodplain aggradation. Ultimately, therefore, fast in-channel aggradation resulted in rapid floodplain aggradation (Kraus, 1996; Kraus & Aslan, 1993; Smith, Cross, Dufficy, & Clough, 1989; Smith & Pérez-Arlucea, 1994; Willis & Behrensmeyer, 1994), which in turn inhibited soil formation, resulting in a wetland criss-crossed with multiple anastomosing narrow channel-belts (Aslan & Autin, 1999). A characteristic length-scale for this environment is given by the width of the channel belts or levees of c.10-100m. This wetland environment, characterised by “large scale crevassing” (Törnqvist, 1993a) is herein referred to as “LSC”, and a representative diagram is given as Figure 2.

In contrast, during the later Holocene, these same rivers displayed lower in-channel aggradation rates, substantial lateral migration of channels through sweeping and point-bar deposition (Jerolmack & Mohrig, 2007), single-channel networks, slow floodplain aggradation, less crevassing, enhanced soil formation, and simpler floodplain sediments, wedging out laterally from the channel (Jerolmack, 2009), creating a landscape herein referred to as “Meandering”. A comparable characteristic length-scale for this environment is an order of magnitude larger than in LSC, c.1km. A diagram showing the “Meandering” river environment is given as Figure 3. The formation of this landscape resulted from the decrease in the rate of creation of accommodation space caused by the lower rate of sea-level rise. Slower in-channel aggradation driven by slower rates of sea-level rise would have reduced channel superelevation and thus reduced the dominance of crevassing and avulsion as landscape processes. Instead, lateral migration of river channels would have been a relatively much more important phenomenon (Jerolmack, 2009; Jerolmack & Mohrig, 2007).

In the Rhine, the spatio-temporal extent of these different river regimes and landscapes has been mapped (Figure 4), and the general features of this figure can be explained by appealing to theory. The LSC facies was initiated at the shoreline once the fine-grained sediments of Sequence III (Stanley & Warne, 1994) were deposited (these fine-grained sediments inhibited lateral migration rates, and thus initially forced high rates of in-channel aggradation (Jerolmack & Mohrig, 2007)). LSC likely then migrated upstream via a diffusion curve (Jerolmack, 2009; Paola, 2000; Paola, Heller, & Angevine, 1992; Swenson, Voller, Paola, Parker, & Marr, 2000) as the river's equilibrium gradient migrated upstream. Once the rate of relative sea-level rise dropped beyond a certain threshold, the LSC facies disappeared and was replaced by Meandering river environments in an event here referred to as the LSC-Meandering Transition.

Corresponding Landscapes of the Nile, Huang He, Mesopotamia and Elsewhere

While no major landscape studies on the scale of those in the Rhine or Mississippi have been carried out on the Nile, the Huang He or in Lower Mesopotamia, numerous individual, isolated landscape studies have been carried out over the last forty years or so. Figs. 5, 6 and 7 bring together the results of many of these studies and demonstrate that the same general pattern of landscape evolution holds in all three settings: an early-mid-Holocene LSC landscape gave way to a later-mid-Holocene Meandering landscape, with the succession of environments in space and time showing the same pattern as in the Rhine and Mississippi. References and a summary of the reasoning behind each data point are given in the figure captions. Table 1 further provides a chronology for the LSC-Meandering Transition.

The differences in timing and upstream extent of the LSC environment between the three settings are attributable to differing local conditions in the river valleys and catchment areas. For example, aggradation rates are higher and the LSC environment is more persistent in both Mesopotamia and the North China Plain than in Egypt, and this may reflect a different isostatic-tectonic regime. While subsidence in the Nile appears restricted to the coastal margin (Stanley & Warne, 1998), the entirety of Mesopotamia sits in an actively subsiding foreland basin (Fouad, 2010) and the North China Plain is likewise composed of a subsiding basin (Ye, Shedlock, Hellinger, & Sclater, 1985). The increased tectonic subsidence in Mesopotamia and China would have acted to increase the rate of creation of accommodation-space at any one point in time, and thus likely sustained the LSC landscape for longer during the period of decrease in sea-level rise. Differing rates of sediment supply likely also contributed to the LSC landscape persisting for longer in Mesopotamia, since the Mesopotamian catchment was more persistently wet for longer than the other two systems, within the overall pattern of diminishing rainfall through the later Holocene (Street & Grove, 1979; Wang, Cheng, & Edwards, 2005; Wick, Lemcke, & Sturm, 2003).

We emphasise that similar landscape changes are likely to have occurred in deltaic systems other than the five settings considered in this paper (Rhine, Mississippi, Nile, Mesopotamia, Huang He). A similar fluvial model to that elucidated herein is likely to be applicable in considering the evolution of many large delta systems in similar tectonic-isostatic settings around the globe.

IMPACT OF CHANGING FLUVIAL REGIME UPON LANDSCAPE RESOURCES

As these landscapes evolved, the availability and distribution of different natural resources would have changed. It is only by understanding this evolving “resource-base” that any causal link between environmental changes and their impact on contemporary events in the human sphere can be suggested. This is not a new idea. Many attempts to establish a link in this way have historically used ideas of “carrying capacity” (Hassan, 1979), or “material and energy flow accounting” (Haberl, Fischer-Kowalski, Krausmann, Weisz, & Winiwarter, 2004) to develop links between subsistence, population, technology and society. In this paper, these relationships are discussed through an appreciation of changing abundances and spatial patterns of nutritional resources, and also changing water-supplies and transport options.

Abundance of Nutritional Resources

The total abundance of nutritional resources in a landscape is the total potential amount of food therein. Humans, as omnivores (Harding & Teleki, 1981), take all their food resources from a landscape by eating parts of the trophic structure: primary producers in part for carbohydrates and higher consumers mainly for protein (which are harvested through hunting, fishing, or pastoral farming (protein), and gathering or arable farming (carbohydrate)). It is thus possible to quantify the total amount of potential food in a particular landscape of a particular size by assessing the total amount of energy flowing through the trophic structure in that landscape. This can be measured as Net Primary Productivity (NPP), the power (per unit area) that supports the food web at its lowermost rung, and thus the maximum amount of nutritional energy that a particular sized patch of the landscape contains (Ajtay, Ketner, & Duvigneaud, 1979; Day, Martin, Cardoch, & Templet, 1997; Giampietro, Cerretelli, & Pimentel, 1992; Odum, 1971). Being a measure of power density, it technically thus has the units W/m^2. While NPP does not consider the entire suite of nutrients necessary for human survival (Brown, Basell, Robinson, & Burdge, 2013), as a "calorie-count" it still provides a first-order model of the nutritional base, and is valuable not least in terms of its simplicity.

Through the LSC-Meandering Transition, the landscape types that existed at different times and in different places each harboured particular ecosystem types and trophic structures, and thus had very different NPP values (Table 2; Figure 8). By mapping the areas of these different landscape types and ecosystems within a region one can therefore describe the changing distribution and abundance of nutritional resources over the entire fluvio-deltaic system (Figure 9) during the transition.

As Figure 9 shows, the LSC-Meandering Transition is accompanied by a drop in the total nutritional abundance of these deltas. The LSC environment itself, composed predominantly of freshwater swamps and freshwater marshes (W/m^2= 1.83), formed a nutritionally rich ecosystem. Coastal zones, characterised by brackish marshes and salt marshes (W/m^2= 2.35) are also very rich landscapes. On the other hand, the Holocene Meandering landscape in these delta systems (W/m^2= 0.48), assumed to have been composed of three different ecosystem types, is not particularly nutritionally rich. Through the LSC-Meandering Transition, the nutrient-rich wetlands characteristic of the early Holocene LSC environment were thus succeeded by dryer landscapes in which nutrients were sparser.

Spatial homogeneity of nutritional resources

The spatial homogeneity, or "scale of distribution", of nutritional resources gives an idea of the maximum size that one food-harvesting activity can cover (e.g. a field of crops, a lake for fishing in, an open stretch of land for hunting). This can be thought of as the horizontal distance over which habitats change, which is essentially the characteristic length scale of any landscape type. Only the LSC and Meandering landscapes are considered in the discussion, as they are the major downstream environments.

The LSC environment would have been characterised by small length-scales for both protein and carbohydrate resources. A myriad of wetland habitats existing in a small geographical area would have resulted in a small characteristic length-scale for protein-based resources; restricted soil development localised to the margins of channels also implies that the scale over which fertile soils were developed continuously is also small. A characteristic length-scale for the landscape would be of the order of 10-100m, as discussed above.

In contrast, the length-scale for resources in the Meandering environment is significantly larger. Similar soils exist (for the most part) continuously over the extensive levees, providing large continuous areas where carbohydrate resources can grow. In terms of protein, the more homogenous floodplain environments support habitats continually over much larger areas, on the order of >1km (see above) Essentially the landscape can be considered to have been “stretched-out”, by a factor of ten or so relative to the LSC regime. This is also shown in Figure 9.

Essentially, the LSC-Meandering Transition would have been accompanied by an overall decrease in the abundance of nutrients, but an increase in the length-scale over which food resources were available.

Other resources

In addition to nutrients, other important resources include water-supply and transport potential.

Once again, only how they would have been different in the LSC and Meandering landscapes is considered.

Securing a reliable water-supply would have been easier in the Meandering landscape than in LSC. The high frequency of avulsions within the LSC landscape meant that a long-term water supply would have only been available at the avulsion nodes. In the Meandering environment, where avulsion nodes are no longer as important a geomorphic feature, the reliability of the water supply would be more similar across the landscape. Of course, annual flooding and meander migration would still occur, contributing to variability in water supply, but these processes would have been more predictable over longer periods of time than the more frequent catastrophic avulsion in the LSC landscape.

Transport potential, on the other hand, would have been greater in the LSC landscape compared with the Meandering one. The multichannel, anastomosing character of the LSC river network would have resulted in waterborne transport opportunities in both a longitudinal and a transverse sense across the floodplain and delta. In the Meandering regime, the tendency for single-channel networks would have caused a loss of the transverse transport potential (Figure 10).

Overall, the LSC environment was a nutritionally rich, varied and heterogeneous wetland environment, while frequent avulsions inhibited long-term water supplies and settlements. Waterborne transport was readily feasible in any direction on the river network due to the availability of many tributaries and river channels.

The Meandering landscape, on the other hand, is more nutritionally homogenous and significantly sparser in resources. The reduction in avulsions means that settlements can persist not only at avulsion nodes; waterborne transport can, however, only be easily accomplished in a longitudinal sense (i.e. parallel to the river).

DISCUSSION OF CONTEMPORARY ARCHAEOLOGICAL CHANGES

During the time periods which correspond to the LSC-Meandering Transition in all three of these locations (Table 1), there are major changes occurring in the social sphere. Three changes that can be explained by the evolution of the physical landscape are as follows: a decrease in the importance of aquatic resources (fish) as a primary source of protein; an increase in the scale of agricultural economies; and a concentration of power at the head of the distributary network. In addition to these specific adaptions, the formation of the State in each case needs to be considered in terms of the dynamic landscape. Figure 11 shows corresponding archaeological periods overlain on the space-time diagram documenting the landscape changes.

Decrease in importance of aquatic resources.

A decrease in the importance of aquatic protein resources through the LSC-Meandering Transition is especially evident in Mesopotamia and Egypt. There is not enough data for a comparison with the corresponding cultures in China. In the prehistoric Nile Delta and Mesopotamia, within the LSC landscape, aquatic resources, and fish in particular, comprised a very important nutritional source. Remains of burnt fish are prevalent at Eridu, Ur, Uruk and Tell Asmar in Mesopotamia (van Buren (1948) in Pournelle, 2007), and in the lower layers of Sais in the Nile Delta (Wilson, Gilbert, & Tassie, 2014). There are also prolific offerings of fish at temples during this time (Kennett & Kennett, 2007), and fish and other aquatic resources are prominent in Uruk proto-cuneiform texts (Englund (1998), p70-71, p88), in contrast to a relative absence of mammals. After the LSC-Meandering Transition at c.4000-3000 BCE in Egypt and c. 2000 BCE in Mesopotamia this is no longer the case. This trajectory can be explained though an appreciation of the landscape evolution: as the wetland areas of the LSC environment reduced in size, aquatic resources such as fish would have become less important due to their increasing relative scarcity.

Increase in the scale of agriculture.

In all three systems, there was undoubtedly agriculture being practised within the LSC environment. However, in all three settings there was significant expansion in the scale of agriculture once the LSC environment disappeared.

In China, the inhabitants of the LSC landscape that persisted between c.5500-2500 BCE were the Houli, Beixin and Dawenkou cultures. For these people, while millet (plus some soybean and rice) was increasingly being farmed, and pigs and chickens were kept, hunting and gathering were still important parts of the subsistence economy (Fuller, Qin, & Harvey, 2006; West & Zhou, 1988; Yuan & Flad, 2002). It was only after the LSC-Meandering Transition, when the Longshan people likely colonised the environment after c.2500 BCE that there was “agricultural intensification evidenced by expansion of anthropogenic habitats and higher densities of crops” (Lee, Crawford, Liu, & Chen, 2007).

In Egypt, the LSC landscape was prevalent from c.5500-3500BCE. Delta settlemenmts probably existed on geziras, stable topographic highs in the landscape, around which grazing, fishing and cereal cultivation were practised (Mączyńska, 2011 p886). Through the later Predynastic and Early Dynastic, after the LSC-Meandering Transition of c.4000-3000 BCE, there was major intensification of agriculture (Dee et al., 2013).

In Mesopotamia, there was also a notable increase in agricultural scale and complexity at the close of the third millennium and beginning of the second millennium – the time of the LSC-Meandering

Transition here. This was manifested by the construction of major branch canals and the expansion of irrigation systems (Adams, 1981 p 164-165; Ur, 2013) .

In these settings, this increase in agricultural complexity and scale across the LSC-Meandering transition can be explained by appealing to both the changes in the nutritional abundance of the landscape, and the scale over which those nutrients were distributed.

The decrease in the nutritional abundance of the landscape through the LSC-Meandering Transition is likely the primary reason behind the increase in agricultural scale in China and Egypt. This decrease in the “amount of food” available for exploitation would have necessitated the appropriation of more efficient food-harvesting methods (increased reliance on agriculture), and rendered untenable less efficient methods of nutrient-collection such as hunting, gathering and fishing, if migration or starvation were to be avoided. It is not that novel agricultural methods were invented at this time – those developments had often already occurred upstream, within the Yangshao culture in China, and in the cultures of Upper Egypt and elsewhere. It is simply that that they were appropriated after the LSC-Meandering Transition – out of necessity.

This decrease in nutritional abundance can be implicated as a driver in Egypt and China but is likely not the primary factor in Mesopotamia, due to the simple fact that hunting, gathering and fishing were likely not as important as they were in China and Egypt. The Late Ubaid and Uruk period settlements existing within the LSC landscape in the southern alluvium of Mesopotamia had already developed a large-scale system of agriculture (Adams, 1981; Wright, 1981) when compared to the situation in China and Egypt, and they relied less on wild resources. As a result it is therefore unlikely that a decrease in NPP in the natural environment would have had as major an effect.

In Mesopotamia, it is instead the decrease in the *scale* over which nutrients are distributed through the LSC-Meandering Transition that was likely the primary reason behind the increase in agricultural intensity. The more homogenous floodplain environments of the Meandering landscape would simply have been more conducive to larger-scale agriculture being practised over larger stretches of land. This would also likely have been a corroborating factor in Egypt and China.

Intriguingly, the reason for the higher intensity of agriculture that was practised by the Ubaid and Uruk settlements within the LSC environment in Mesopotamia (compared to China and Egypt) may be related to increased human modification of the natural LSC environment in Mesopotamia. There is some evidence that the development of irrigation agriculture in this setting may have been related to human attempts at controlling the crevassing (Morozova, 2005).

Shift in Location of Dominant Settlement

The LSC-Meandering transition was accompanied by a shift in location of the dominant settlement to the apex of the distributary network: Memphis in Egypt, Akkad / Babylon in Mesopotamia and Erlitou in China. A simplified diagram summarising these changes is shown in Figure 12. This pattern can also be explained by appealing to the environmental model.

Within the LSC facies, the plethora of transport options from any node in the network to any other node through the large number of interconnected channels meant that there would have been no major trade advantage for a settlement in any position. In this rich, productive landscape it was natural therefore that the larger settlements should be positioned at the interface between the fluvial and the coastal zone: the area with the highest density of nutritional resources. Examples of settlements located in such settings are Uruk and Ubaid in Mesopotamia, and Buto, Minshat Abu

Omar, Tell el-Iswid and others in the Egyptian delta. Other settlements in these deltaic regions were often likely located at nodes in the fluvial network (Morozova, 2005).

After the LSC-Meandering transition, trade of commodities would have become more important due to both the reduction in the total resource-base as well as the decrease in the range of resources available to a single settlement (as a result of the increased homogeneity of the landscape). Coupled with the loss of the transverse transport potential formerly afforded by the many river distributaries there thus would have arisen a “point of power” in the landscape – a node at the apex through which transverse, upstream and downstream trade had to pass. The controlling political centres were established only in these locations once the environmental changes associated with the LSC-Meandering Transition had been completed. In some cases these locations of power persist in the same location even today (Cairo in Egypt and Baghdad in Mesopotamia).

Role of the Environment in the Emergence of the State

In China, the disappearance of the LSC environment likely around 2500BCE is followed by the emergence of the state of Erlitou (Liu, 2009). In Egypt, the LSC-Meandering Transition at 4000-3000 BCE is also followed by the emergence of the world’s first nation state, centred on Memphis (Yoffee, 1997). In Mesopotamia, the first “city states” emerged from within the LSC environment, in the southern alluvium, but the first “nation states” were initiated around the same time as the LSC-Meandering transition, in the form of the empires centred on Akkad and Babylon (Liverani, 1993).

It is tempting to broadly correlate the emergence of the large “nation states” or “empires” with the demise of the LSC environment and the expansion of the more homogenous “Meandering” plains.

However, to do so without significant further work is beyond this paper and likely the currently available dataset. It is not proposed that the LSC-Meandering Transition is the single driver of state formation, and a multi-factor cause is virtually certain. In any case, numerous prerequisites would have been in place in the settings considered in this paper in order for the cultures within them to have undergone the varied social, political and economic transformations that have historically been referred to as hallmarks of “statehood” or “civilisation” (Childe, 1950; Maisels, 1999; Trigger, 1993; Yoffee, 2005). These prerequisites were obviously not in place in other delta systems (for instance, the Rhine), where similar changes in the physical environment were taking place, but there were no such developments in the socio-political sphere.

However, these major changes in the evolving natural landscape do need to be considered within any discussion, not least because of their broad correlation with the archaeological changes, and the impacts they had on the resources available in the landscape. Perhaps a framework by which the evolving environment can be incorporated into the dialogue is by viewing the LSC environment as a “nursery” for civilisations, which later become more archaeologically visible in the LSC-Meandering Transition. During the LSC environment, the resource-rich deltaic and coastal wetlands could have been a natural attractor, with the potential to permit high population density. In these locations, at the interface between numerous landscapes, weather patterns, ecological and marine forces there was an in-built “resilience” to stochastic fluctuations in resources (Pournelle, 2007; Pournelle & Aldgaze, in press), and thus populations in these settings could establish centres of culture if the opportunity arose. This would be offered by – for instance – large pre-existing topographic highs (geziras) within the wetlands. Later, with the shrinkage of the wetland environment during the LSC-Meandering Transition these centres of culture would have been forced to transform and move in order to persist, and they would reposition at the delta apex – the point of power in the new landscape. Perhaps the rich and “resilient” deltaic landscape could have been a factor allowing the creation of centres of culture, while the loss of this landscape could have resulted in the transformation of these cultures into wider, larger systems.

CONCLUSIONS

It is proposed that most fluvio-deltaic systems shared a global underlying unity in their Holocene evolution, characterised by, but not limited to, the development, upstream migration and subsequent disappearance of a Large-Scale Crevassing river environment, accompanied by coastal landscape change. These changes came about as a response to a fall in the rate of sea-level rise.

Since all of the Primary States emerged from within the downstream environment, the formative period of human civilisation needs to be considered in terms of this dynamic and evolving landscape. One way in which geoarchaeologists can analyse the links between the natural and human spheres is to consider the resources the landscape provides: the abundance and distribution of nutrients, transport options, water and continuous stretches of land for agriculture and settlement. Different environments naturally have intrinsically different patterns of resources.

The disappearance of the LSC landscape in the LSC-Meandering Transition is here implicated as a driver of changes in subsistence patterns, land use and settlement hierarchy at these times. The abundance of nutritional resources in the “resilient” LSC environment allowed relatively large stable populations to develop in downstream environments, especially in near-coastal settings. With the LSC-Meandering Transition, power then became concentrated by the reduction in river branches to a point at the apex of the distributary network. Meanwhile, the loss of the nutritional richness of the LSC environment also required a transition to more intensive agricultural techniques, techniques that became possible to appropriate due to the increasing homogeneity of the land as floodplains expanded.

While the demise of the LSC environment is not invoked as a single driver behind the transition in these settings to some form of nation state, the evolving landscape does need to be considered in any discussion. There is a line of reasoning to suggest that the high abundances of resources and inherent "resilience" of populations in the LSC environment can lead to this landscape being thought of as a "nursery" for civilisations, which then relocate and transform in scale during or after the LSC-Meandering Transition. Increased examination of these time horizons and more detailed landscape reconstruction projects (many of which are currently in progress) will lead to further development of these ideas.

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FIGURES

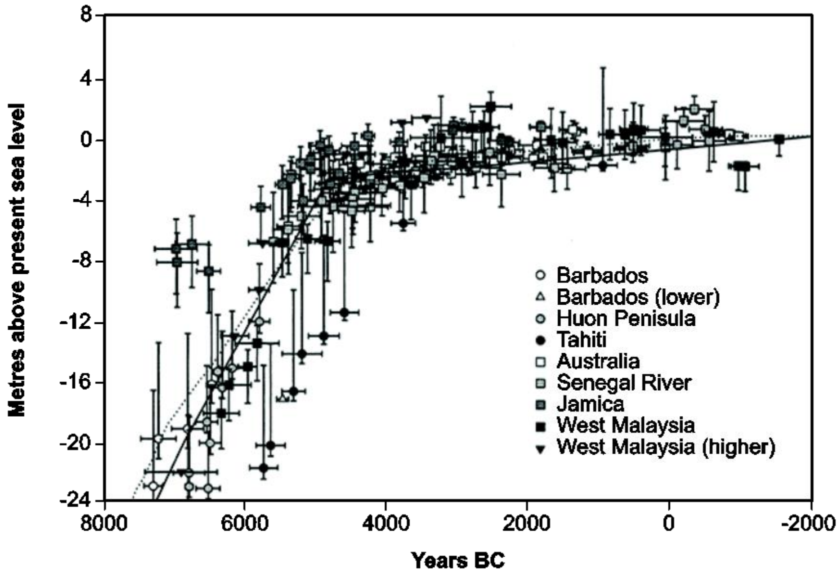

Figure 1. Holocene sea-level rise curve after Fleming et al (1998). Vertical error bars represent uncertainties in elevation relative to sea-level, and horizontal ones represent the error in dating. Note the inflexion point.

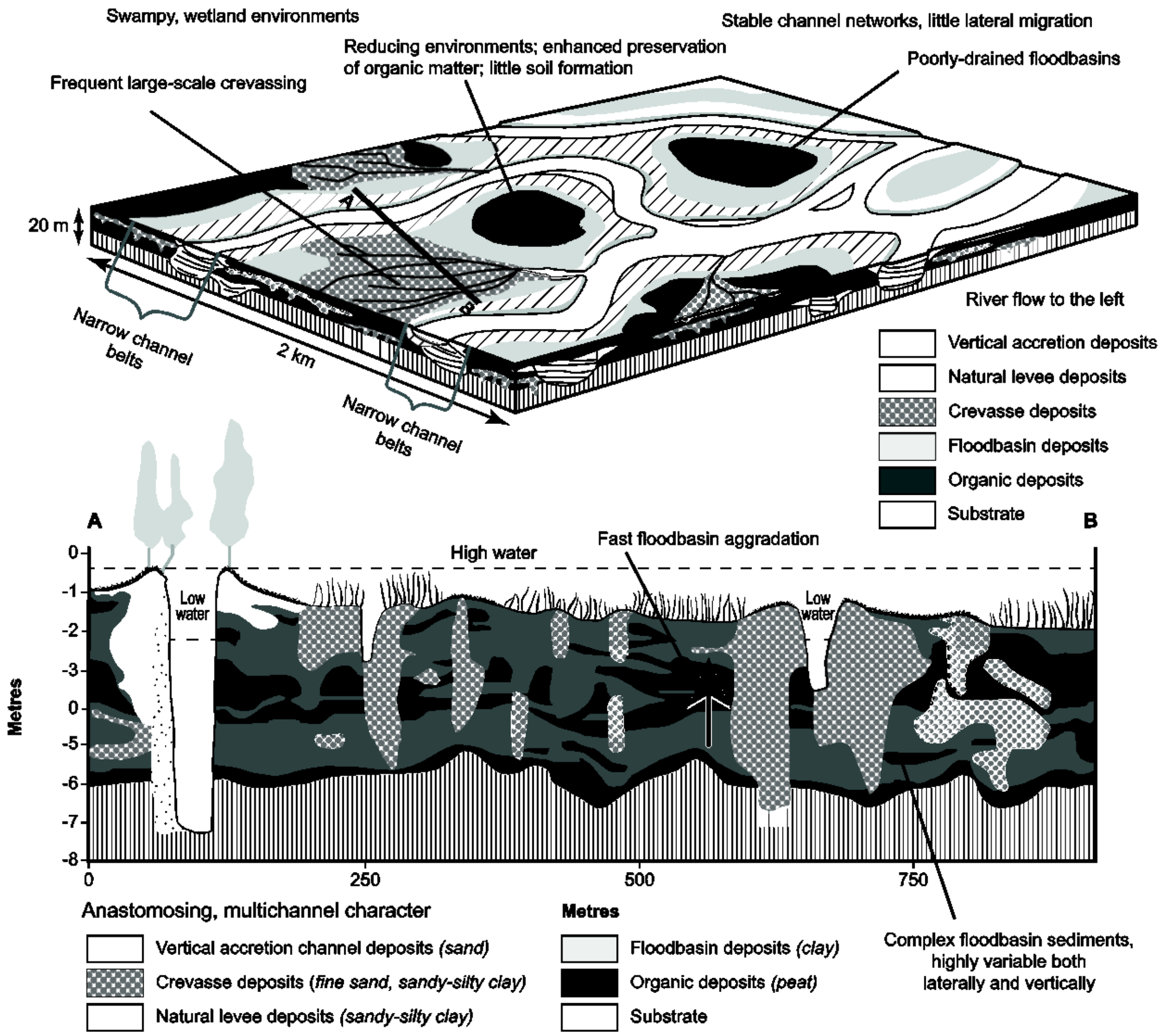

Figure 2. Diagram to show the "LSC" river environment during inundation of deltas by rising sea-level. After Weerts (1996), Berendsen and Stouthamer (2001).

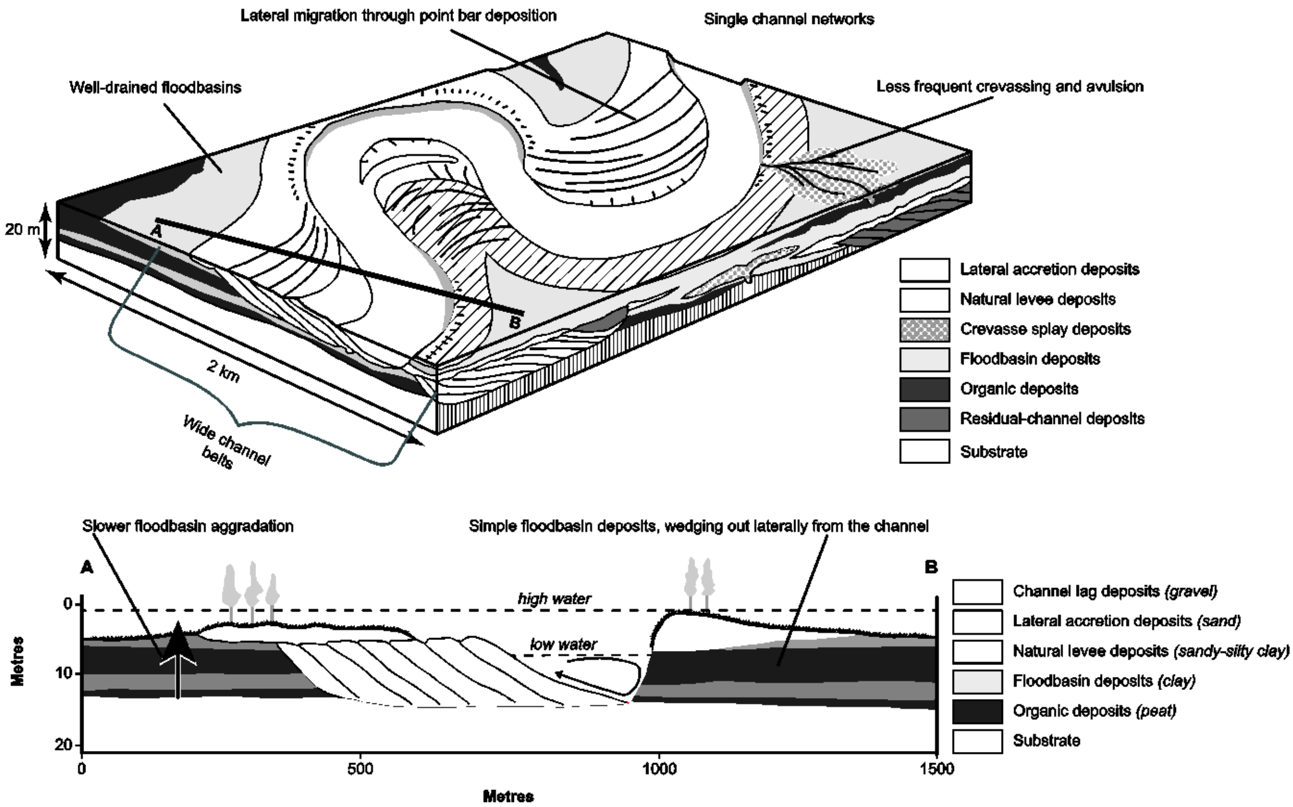

Figure 3. Diagram to show the “Meandering” river environment after the LSC-Meandering Transition. After Weerts (1996), Berendsen and Stouthamer (2001).

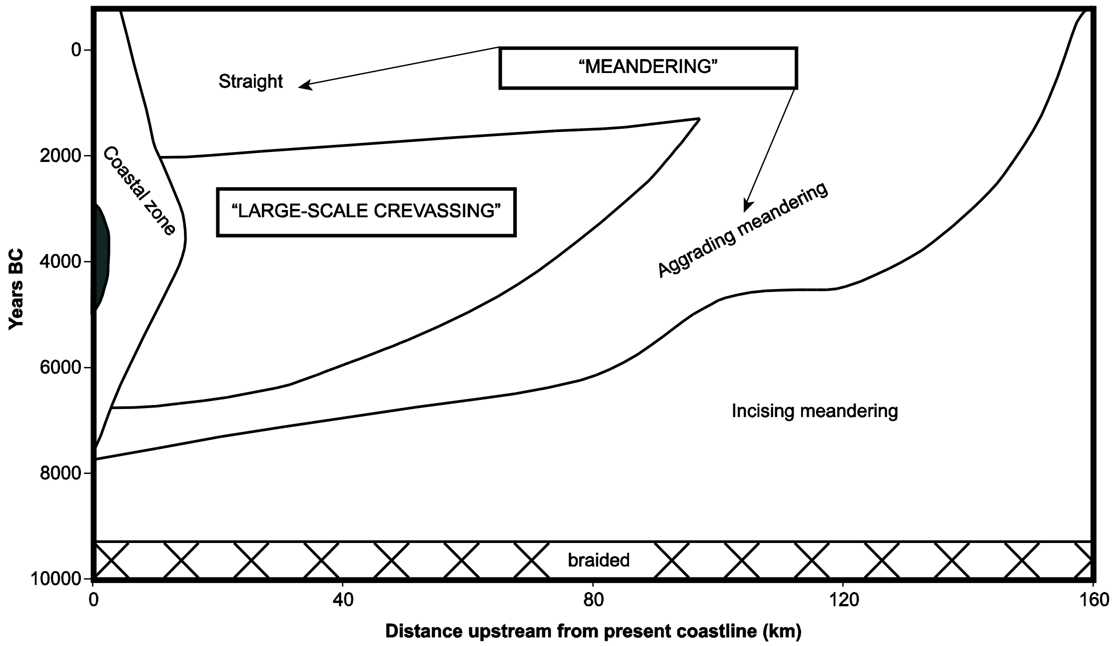

Figure 4. Space-time diagram showing environmental evolution for the lower Rhine River. After Törnqvist (1993a), Berendsen and Stouthamer (2001).

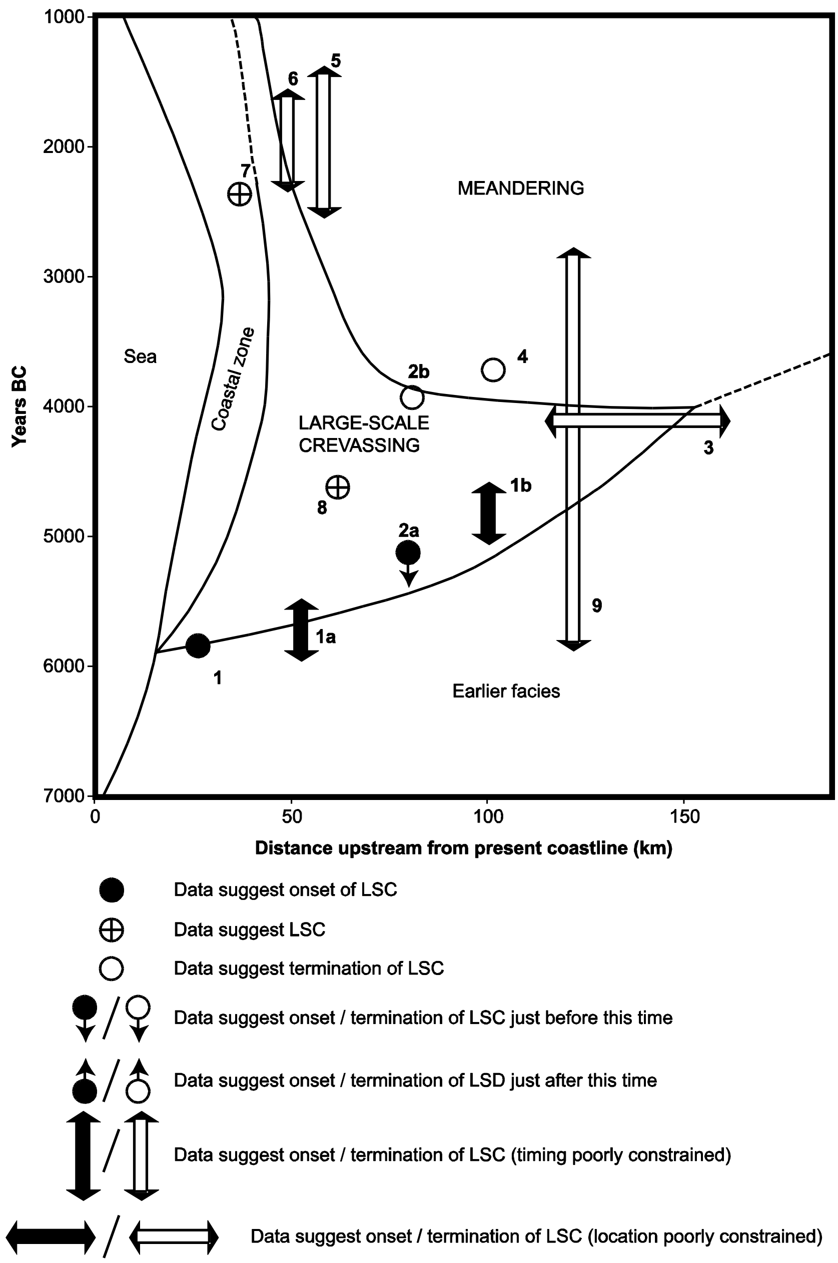

Figure 5.

Space-time diagram showing the distribution of environments in space and time within the Nile Delta. Coastline reconstruction is an average from across the delta (Arbouille & Stanley, 1991; Butzer, 2002; Coutellier & Stanley, 1987). Labelled points represent individual landscape surveys as follows:

1 - Onset of delta lobbing, fine-grained alluvial sedimentation, marsh formation in coastal areas, and proposed start of LSC. (Coutellier & Stanley, 1987; Hassan, 1997; Sneh, Weissbrod, Ehrlich,

Moshkovitz, & Rosenfield, 1986; Stanley & Warne, 1993a; Warne & Stanley, 1993). 1a - Silty deposition likely starts at Minshat Abu Omar. 1b – Earliest dated silty deposits in cores S-86 and S-87 (Z. Chen & Stanley, 1993). 2a - Onset of the "Nile II" facies (de Wit, 1993) characterised by swampy mud deposits, ephemeral stream sediments, and calcareous muds which "alternate rapidly in a lateral and vertical sense". 2b - End of the Nile II facies (de Wit, 1993) and onset of deposition of Nile IB facies. 3 - The maximum number of Nile distributary channels is reached at 6kyr (Stanley & Warne, 1993b (Stanley & Warne, 1993b)), implying furthest upstream avulsion and maximum extent of LSC. 4 - Core S-86 (Z. Chen & Stanley, 1993) has an average aggradation rate of 5.9mm before this date and 1.9mm after. 5 - Smaller distributaries silt up (Andres & Wunderlich, 1992), in an analogous way to the Rhine at the end of LSC (Berendsen & Stouthamer, 2001). 6 - Extensive swamps cease to exist around Minshat Abu Omar (Andres & Wunderlich, 1992). 7 - The ancient Canopic branch of the Nile moved primarily by crevassing and avulsion (Stanley, Warne, & Schnepp, 2004). 8- Sais layer 1a contains an abundance of “remarkable fish bone material… attesting to both shallow water, deep well-oxygenated water, and vegetated marsh environments”, and suggest narrow levee settlement in an LSC environment (Wilson et al., 2014). 9 - Transition from “flood plain, back swamps and crevasse splay” to “flood plain with laterally migrating channel” at Quesna (Rowland & Hamdan, 2012).

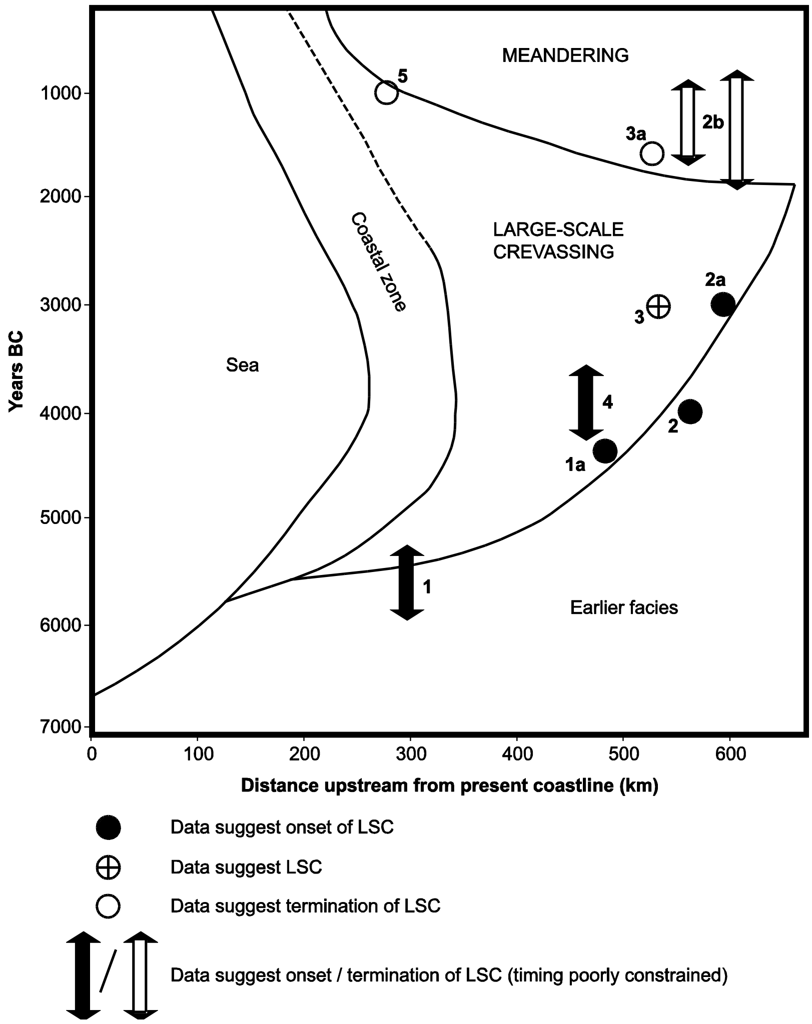

Figure 6. Space-time diagram showing the distribution of environments in space and time within Lower Mesopotamia. Coastline reconstruction based on Sanlaville (1989, 2002); Sanlaville and Dalongeville (2005). Heyvaert and Baeteman (2008) propose the transgression did not extend as far inland. Labelled points represent individual landscape surveys as follows:

1 - Onset of fine-grained sediment deposition and proposed start of LSC. 1a - Onset of fine-grained sediment deposition north of Nippur. (Adams, 1981). 2 - Substantial multi-channel Euphrates network diverges around Sippar (Adams, 1981, p19). 2a - Avulsions start near Fallujah (Morozova, 2005). 2b - Verhoeven (1998) suggests a transition from anastomosing multi-channel networks to a meandering regime around both Sippar and Fallujah. 3 - Heyvaert and Baeteman (2008) see an "avulsion-driven multiple Euphrates channel network" at Tell ed-Der. 3a - Abandonment of this network. 4 - Meander migration is observed north of this point, but inhibited to the south (Adams,

1981, p31). 5 - Major slowing-down of aggradation rates: in general 1-1.8mm/yr before, <0.4mm/yr after (Aqrawi, 1995).

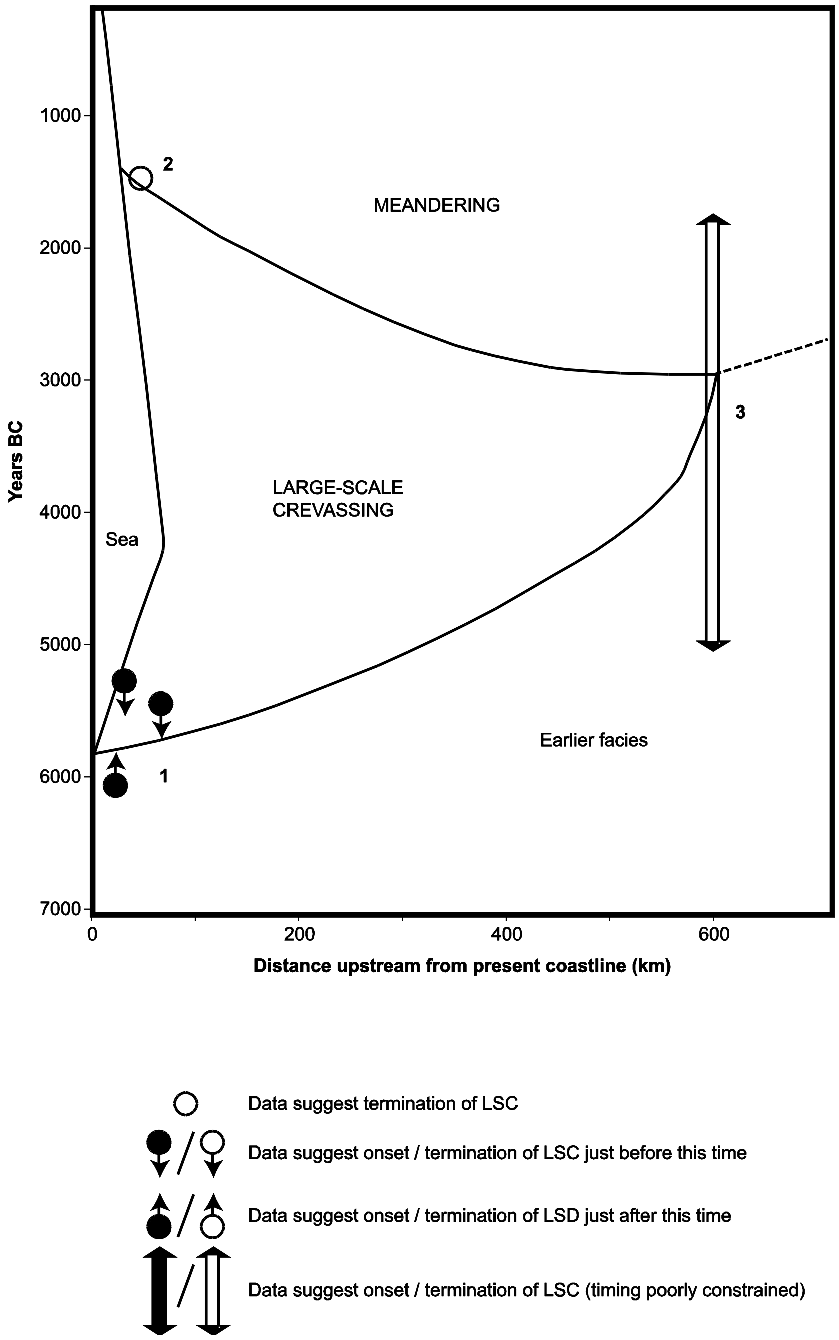

Figure 7. Space-time diagram showing the distribution of environments in space and time within the Lower Huang He. Coastline reconstruction based on Saito, Yang, and Hori (2001); Xue (1993); Yu (2002). Labelled points represent individual landscape surveys as follows:

1 - Onset of deposition of Stage V palaeochannels, and the "palaeoswamp development stage" (W.

Chen, 1996; W. Chen, Qinghai, Xiuqing, & Yonghong, 1996a; W. Chen, Qinghai, Yonghong, & Xiuqing, 1996b; W. Chen, Xuanqing, Naihua, & Yonghong, 1996c; Qinghai, Chen, Xiaolian, & Ningjia, 1996b; Qinghai, Chen, Xuanqing, & Xiaolian, 1996a), with a floodplain composed of black mirey silt, mire with “turf”, reduced clay deposits with autigenic manganese and ferric nodules. At this time "rivers kept within their channels, and... palaeolakes and palaeoswamps developed" (W. Chen, 1996). 2 - Onset of deposition of Stage VI palaeochannels at this point, the floodplain is now composed of loamy soil, fine silt, silt,and sandy clay, and "rivers could change their courses easily". 3 – The landscape changes are seen over the whole Lower Huang He system.

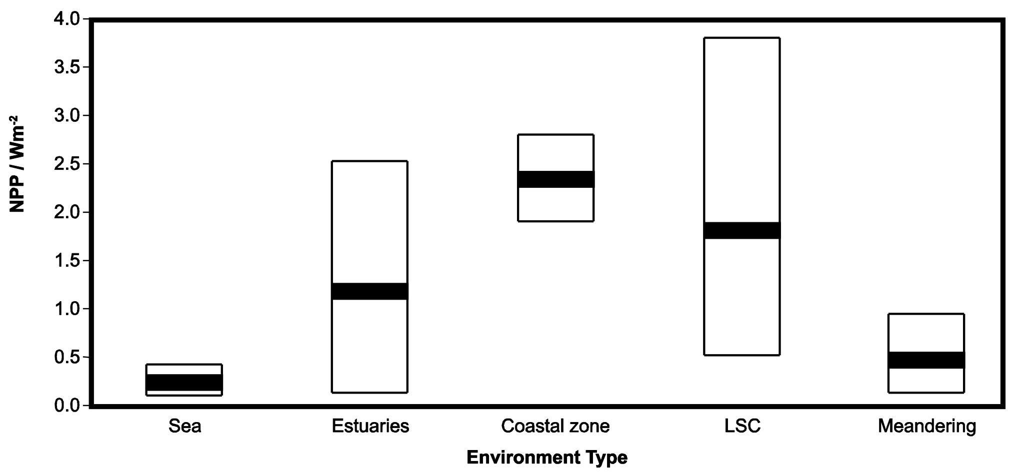

Figure 8. Ranges and averages of suggested NPP values for the different landscape types, from Table 2.

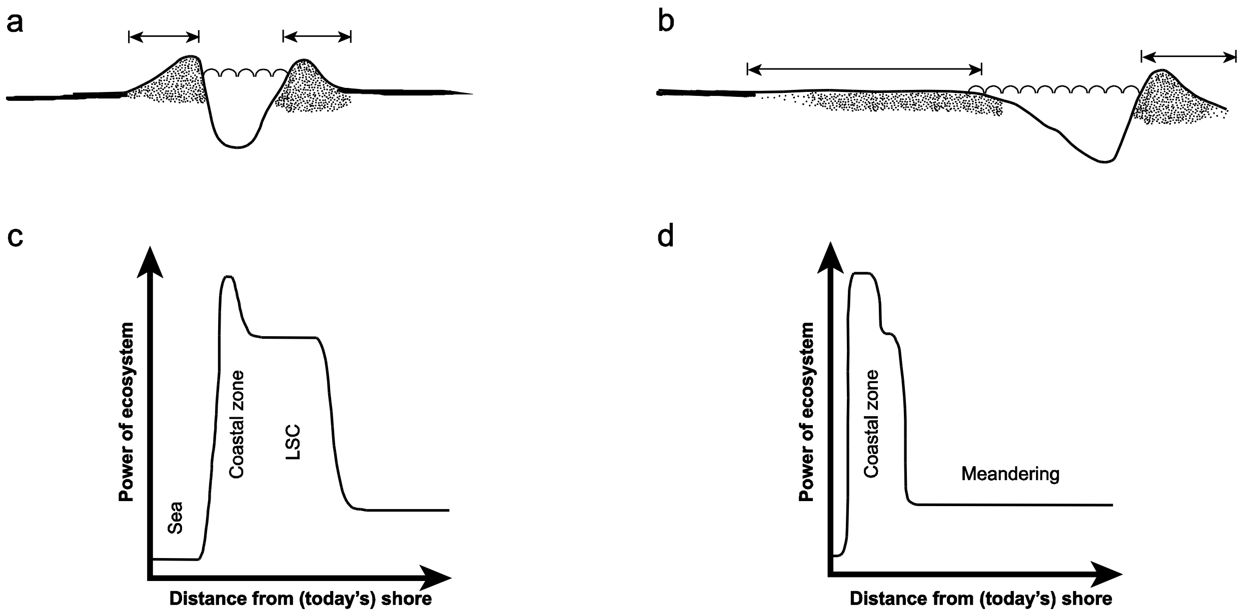

Figure 9. Nutritional differences between the LSC and later Meandering environments. a) and b) show characteristic length-scales for the distribution of nutritional resources, as given by the widths of the river levees. a) Minor levee development in the LSC environment; b) Much more extensive levees in the "Meandering landscape". c) and d) show the nutritional density across a 2D slice of the landscape, by plotting the power of the ecosystem against the distance from the current shore. c) is the graph for when the LSC environment is a major feature of the landscape, while d) represents the time after the LSC facies has disappeared. There is a much greater abundance of nutritional resources in the landscape in c) compared to d).

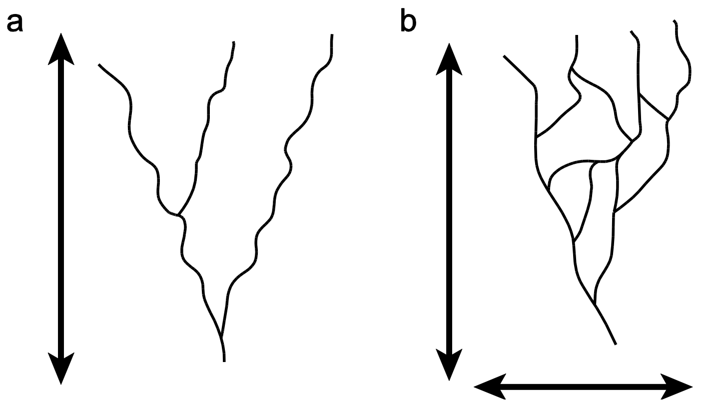

Figure 10. Available transport potential during a) the "Meandering" river regime and b) LSC. Transport in both transverse and longitudinal sense is possible in b) but not in a) due to the lack of cross-branches.

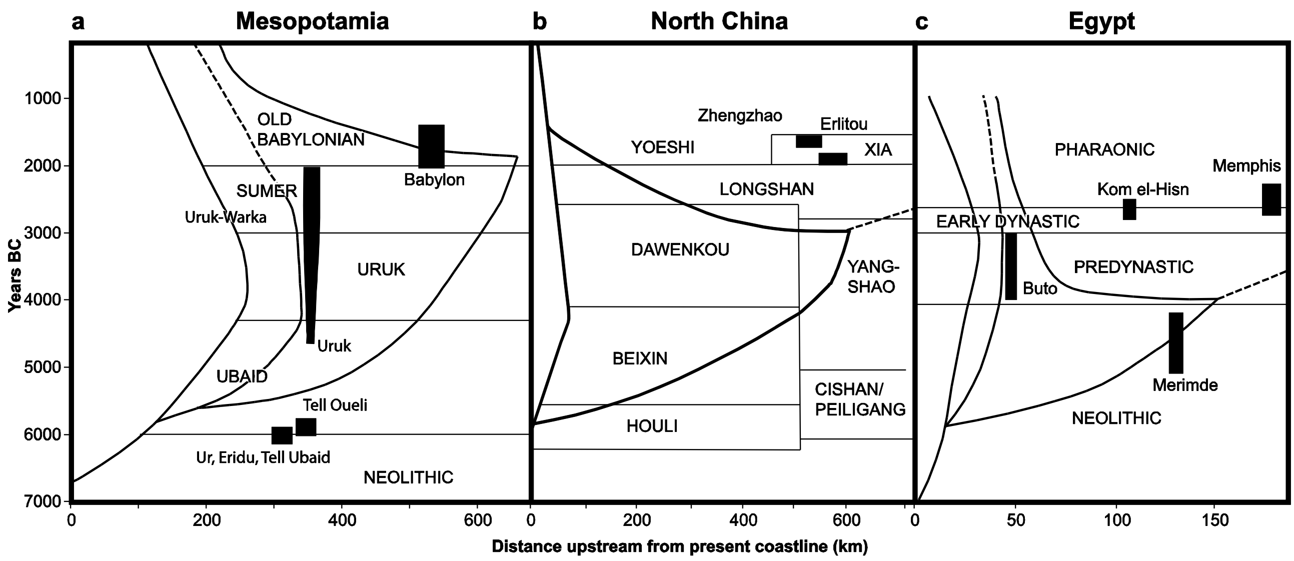

Figure 11. Space-time diagram showing selected sites and archaeological periods overlain on the physical landscape changes for a) Mesopotamia; b) North China; c) Egypt.

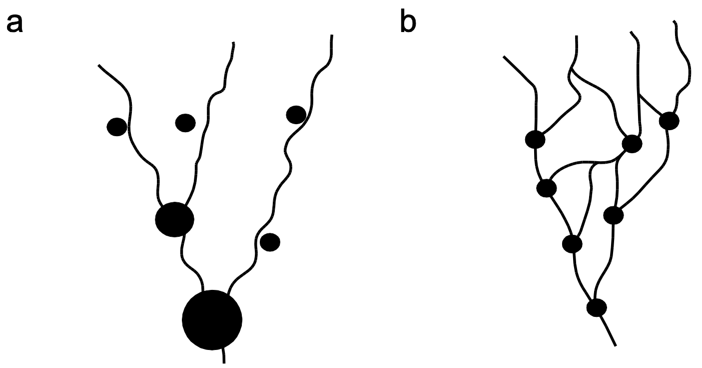

Figure 12. Summary of likely salient and common aspects of settlement patterns across the three regions considered during a) the "Meandering" river regime and b) the LSC regime. During LSC, settlements of similar sizes exist at avulsion nodes, whilst during the "Meandering" regime the settlement at the apex of the distributary network becomes dominant.

REGION	LSC-MEANDERING TRANSITION
Nile	c. 4000-3000 BCE
Mesopotamia	c. 2000-1500 BCE
Huang He	Likely c. 3000-2000 BCE

Table 1. Summary of approximate timings for the LSC-Meandering Transition in each location.

ENVIRONMENT TYPE	ECOSYSTEMS	Average NPP[a] /Wm^{-2}	Range of NPP values /Wm^{-2}
Sea	Continental shelf.	0.24	0.13 – 0.38
Estuary [b]	Estuary.	1.19	0.13 – 2.54
Coastal zone [b]	Brackish marshes, Salt marshes.	2.35	1.90 – 2.79
LSC	Freshwater swamps, Freshwater marshes.	1.83	0.51 – 3.81
Meandering	Woodland, Shrubland, Grassland	0.48	0.13 – 0.95

Table 2. Average NPP values for different landscape types based upon assumed ecosystem types from Day et al. (1997); Ajtay et al. (1979) Lieth and Whittaker (1975); Whittaker and Likens (1973). a) Where values for NPP were presented in kg m^{-2} yr^{-1} dry matter (DM) a conversion was made to W/m^{-2} assuming 1kg DM is equivalent to 20MJ (Haberl, Erb, & Krausmann, 2013; Vitousek, Ehrlich, Ehrlich, & Matson, 1986). Where values for NPP were presented in kg m^{-2} yr^{-1} carbon a conversion was made to W/m^{-2} assuming 1kg C is present in 2.09kg DM (Haberl et al., 2013; Vitousek et al., 1986). While other parameters are excluded from the calculation of NPP the methodology is consistent and the values in the table are correct relative to one another. b) The “coastal zone” of Figs. 4-7 corresponds to both estuarine environments and brackish or salt marshes. It is assumed that before the point of maximum shoreline transgression this area is divided equally between the facies type “Estuary” and “Coastal Zone”, but after the point of max. transgression, closure of the shoreline results in the green facies becoming purely the facies type “Coastal Zone”; the “Estuary” disappears.