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Holocene fluvial and anthropogenic processes in the region of Uruk in southern Mesopotamia

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ABSTRACT

For decades, it has been unclear as to how the world's first cities, in southern Mesopotamia, not only arose in a fluvial environment but also how this environment changed. This paper seeks to understand the long-term fluvial history of the region around Uruk, a major early city, in relation to water-human interactions. This paper applies geomorphological, historical and archaeological approaches and reveals that the Uruk region in southern Mesopotamia had been under the influence of freshwater fluvial environment since the early Holocene. It further demonstrates how canals and long-term human activities since the mid Holocene have been superimposed on the natural river channel patterns. Fieldwork has been conducted to ground-truth features identified applying remote sensing techniques. Five sediment cores were analysed to elucidate palaeoenvironmental changes. Radiocarbon ages for organic samples suggest that the oldest sediment layers, at a depth of 12.5 m, are from the Early Holocene, while results from diatom analyses imply that the whole sediment column was deposited in a freshwater environment. Intensive networks of palaeochannels and archaeological sites within the study area have been reconstructed and these networks have been divided into four different time intervals based on changes in channel courses. The first is from the early 4th to the late 1st millennium BCE; the second is from the late 1st millennium BCE to the middle 2nd millennium CE; the third lasted from after the Islamic period until the 1980s; the fourth is from the 1980s until the present. Key results include evidence for freshwater environments and favourable settlement conditions had already formed by the 8th millennium BCE. The favourable settlement environment resulted in stable (long-lived) canals between the 4th millennium BCE and 1st millennium CE. A significant settlement and irrigation expansion occurred in the early 1st millennium CE. Major abandonment ensued in the late 1st millennium CE and lasted until the mid 2nd millennium CE.

1. Introduction

In the present study, we discuss changes in the riverine landscape in an area around the archaeological site of Uruk, often considered the world's first city, established in the 4th millennium BCE (Adams, 1981). The site and region are located in southern Mesopotamia, modern-day southern Iraq (Fig. 1). Despite the significance of this site, very little is known about the long-term hydrology of the area and the interactions between societies and their environment in the region that helped shape the rise and continuity of the city. This work shows how human impact has played a leading role in governing both the ancient and more recent geomorphology of the region around Uruk. The results are also used to show how the landscape has imposed changing conditions on the development of a major urban centre in southern Mesopotamia. The data collected also provide a perspective on the nature and

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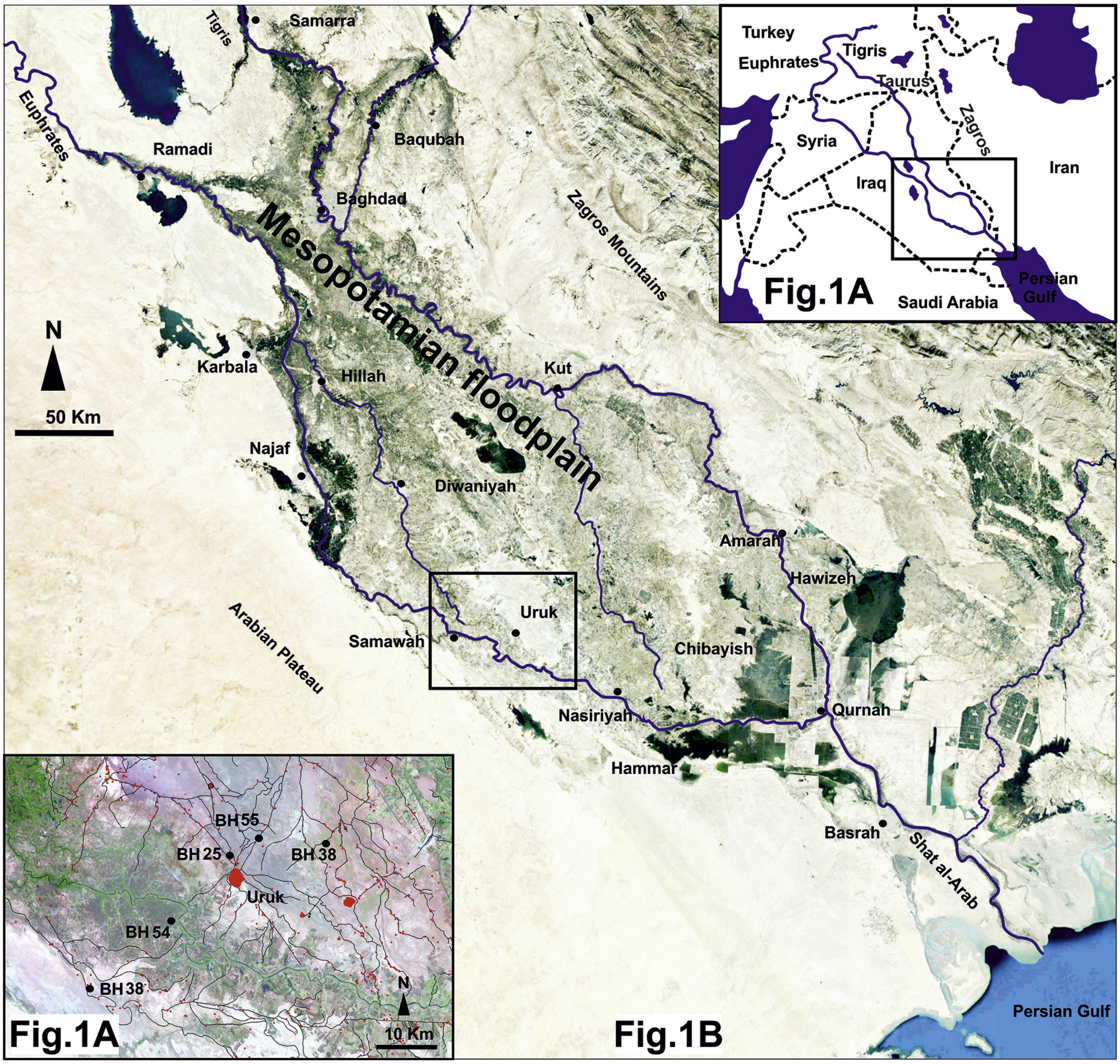

Fig. 1. Location map showing the Uruk region within the floodplain of the Tigris and Euphrates of Southern Mesopotamia.

upstream extent of the mid Holocene transgression in Iraq.

The issues discussed in this paper centre around two main themes: first, the depositional environment – whether it is a riverine freshwater or saltwater tidal depositional environment; second, the role of human activities in the Mesopotamian floodplain that affected the stability or instability of settlement and environment in this region during the investigated periods, spanning from the 4th millennium BCE until the present.

2. Geology of the southern Mesopotamian floodplain

The Mesopotamian region represents the foreland basin to the Zagros belt (Baltzer and Purser, 1990; Garzanti et al., 2016), with the Tigris and Euphrates rivers as axial drainage systems passing along this basin from northwest to southeast (Fig. 1). Both rivers originate in Turkey, where they receive a large supply of water from rainfall and snowmelt from the Taurus Mountains. The Euphrates rises out of the mountains of north central Turkey; the Tigris drains the mountains of eastern Turkey, northwest Iran and northern Iraq (Fig. 1). The two rivers then meander through valleys in Turkey, Syria and Iraq until they enter the Mesopotamian floodplain (Fig. 1). The Tigris mainly occupies the eastern part of the floodplain while the Euphrates occupies the western side. They converge in the marshland area north of Basrah to form the Shatt-al-Arab, which then enters the Persian Gulf (Fig. 1). The upper catchment has a Mediterranean climate with hot, dry summers and cold, wet winters. Rainfall decreases gradually towards the south from about 1000 mm/yr in the Taurus Mountains to about 300 mm/yr near the Syrian–Turkish border, 150 mm/yr in Syria, and only 75 mm/yr in southern Iraq (Bozkurt and Sen, 2011).

The discharge of both rivers fluctuates from year to year, depending on the amount of precipitation and meltwater, whilst also being subject to an annual cycle, with the highest monthly discharge during April and May at the time of peak snowmelt

(Bozkurt and Sen, 2011). According to the Iraqi Ministry of Water Resources (IMWR), the average annual discharge of the Euphrates in the floodplain from 1970 to 2003 was 19.68 billion cubic metres (IMWR, 2005), although there has been a general decline in discharge during the last few decades as a result of dam construction, increased water consumption for irrigation and climate change (Jones et al., 2008; Chenoweth et al., 2011). The Euphrates transports about 21 million tons of suspended sediment per year through the Hindiyah area near Karbala (Fig. 1; IMWR, 2005), although most of the sand and silt is deposited in the former marshes of southern Iraq before the confluence at Qurnah (Fig. 1); only clay passes down to the Shatt-al-Arab (Fig. 1; Philip, 1968).

Since about 12000 BP, the Tigris and Euphrates have been depositing their load in the floodplain and building a large delta before entering the Persian Gulf (Pournelle, 2003; Pirasteh et al., 2009; Yacoub, 2011). Consequently, the morphology of the modern floodplain has been mostly constructed by normal alluvial deposition of meandering and braided rivers, with resulting landforms such as levees, scroll-bars, oxbow lakes, crevasse splays, distributary channels, inter-distributary bays and marshes. However, critical to the development of the Mesopotamian landscape is the presence of substantial ancient and modern human activity in the form of canals and settlements, which have substantially reorganized and reshaped the natural system (Verhoeven, 1998; Wilkinson, 2003; Yacoub, 2011; Ertsen, 2016). It is worth to mention here that uplift and other neotectonics movements have not been investigated in the present study.

3. Methods

In this case study, we integrated data from a variety of methods to reconstruct the palaeo-hydrology and geoarchaeology of this part of the southern Mesopotamian floodplain (Fig. 1), an area which has never before been sufficiently described or understood. Remote sensing techniques were used in combination with archaeological site data to identify and date possible palaeochannels, while historical and archaeological approaches have been carried out to understand the role of human activity in the geomorphology of the region. Fieldwork in the form of auger drilling was conducted to ground-truth features identified using remote sensing techniques and to provide a further perspective on the overall succession of landscapes within the region, with samples analysed using diatoms (Table 2) and dated using radiocarbon methods.

The work done incorporates remote sensing techniques, mainly to identify possible palaeochannels, relevant archaeological sites and regions of sampling; fieldwork consisted of field observations and auguring on identified palaeochannels. We also dated our samples, where possible, and conducted diatom analysis to understand the sedimentary environment and water conditions. These methods are further described below.

3.1. Remote sensing

Remote sensing has been supporting archaeological surveys since the early 20th century and since that time, the technique has rapidly developed and has been enhanced to become an essential step in any archaeological survey or landscape study (Watanabe et al., 2017). In the present study, satellite imagery, including CORONA and QuickBird, have been utilized (Fig. 2). Additionally, digital topography analysis using the Shuttle Radar Topography Mission (SRTM; 3 arc second dataset) has also been carried out (Fig. 3). The method of employing different types of satellite images and digital topography, where these results are then integrated in standard GIS packages, such as ArcGIS or QGIS, to visualize and assess them, has become a common and productive method in landscape archaeology studies (Hritz, 2010; Ur, 2013; Jotheri and Allen, 2017). Palaeochannels, levees and archaeological sites can be recognized in the SRTM digital elevation model, as they are relatively highly elevated with respect to the surrounding area (Fig. 3) (Hritz and Wilkinson, 2006; Chen et al., 2017).

In the present study, SRTM has been used in the beginning of the investigation process to recognize the main palaeochannels. Once the main palaeochannels were identified, QuickBird images were used to recognize other minor channel branches. ASTER elevation data were not used in the present study since QuickBird imagery was sufficient to identify geomorphological features and suitable places for auger sampling.

As CORONA images were taken by the United States from 1959 to 1972, they are mainly useful for identifying locations of palaeochannels and archaeological sites, since that period was prior to the major cultivation and urban expansion of modern-day Iraq (Fig. 2; Philip et al., 2002; Hu et al., 2017).

3.2. Archaeological and historical data

Archaeological and historical data have been used in the present study to locate palaeochannels, suggest dates for their existence and provide a perspective on changing human use and impact on the geomorphology of the floodplain. Ancient palaeochannels have been located and dated based on the existence of settlements of known occupation age along their length. Due to the generally arid climate in the Mesopotamian floodplain, human settlements depend on the availability of water for irrigation. This has led to the assumption that the ages of archaeological settlements are closely linked to the periods of active channels (e.g., Adams, 1981; Wilkinson et al., 2015). For hydrological reconstruction of more recent times, Arabic texts from the 9th to 14th century CE such as Ibn-Alatheer (2003), Ibn-Alfuwati (1938) and Ibn-Aljozi (1992), ancient maps from the Ottoman period and travel reports from the last century are useful (e.g., Ooghe, 2007; Walstra et al., 2010).

A perspective on past human management of the landscape can be approached through the study of the cuneiform tablets on which

Table 1
Results of the radiocarbon dating for samples from the study area.

Borehole no.	Coordinates	Depth from surface to sample (m)	Laboratory code	Calibratedage 14C (yr BCE-CE)	Dated material/Species
M38	31°22′46.98″N	0.75	Beta- 439491	1290 to 1410 (95%)	Organic sediments
	45°48′50.66″E	0.75	Beta −439490	945 to 1020CE (95%)	Shells/Corbiculafluminea
		1.0	Beta-349662	760 to 690 BCE (95%)	Shells/Corbiculafluminea
		5.0	Beta-349663	3980 to 3940 BCE (95%)	Shells/Corbiculafluminea
		7.0	Beta-349668	4900 to 4860 BCE (95%)	Shells/Corbiculafluminea
		12.5	Beta-417654	7750 to 7600 BCE (95%)	Shells/Corbiculafluminea
BH38	31° 9′ 14.44″N 45° 21′ 8.92″E	0.25	Beta-379037	45 BCE to 75 CE (95%)	Shells/Corbiculafluminea
M25	31° 21′23.12″N 45° 38′5.78″E	5.0	OxA-31984	4219+/-30 BCE (95%)	Shells/Corbiculafluminea

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Table 2
Planktonic diatom in samples from borehole number M38.

Daitom species	Life form		Salinity			pH			Eutrophication			Depth[†Depth†]							
	Planktonic	Benthic	Freshwater	Brackish	Marine	Acidophilous	Circumneutral	Alkaliphilous	Oligotrophic	Mesosaprobous	Eutrophic	8	8.5	10	11.5	12	12.5	13	13.5
Amphora libyca Ehrenb.Amphora libyca Ehrenb.		*	*	*				*		*				*		++	++	++	+
Aulacoseira crassipunctata KrammerAulacoseira crassipunctata Krammer		*															+		
Aulacoseira granulata (Ehrenb.) SimonsenAulacoseira granulata (Ehrenb.) Simonsen	*		*					*		*	*						+		
Aulacoseira sp.Aulacoseira sp.	*																	++	
Campylodiscus sp. ?Campylodiscus sp. ?		*		*	*													*	
Cocconeis placentula Ehrenb.Cocconeis placentula Ehrenb.		*	*					*		*							*		
Cymbella cistula (Ehrenb.) O.KirchnerCymbella cistula (Ehrenb.) O.Kirchner		*	*					*	*										+
Cymbella neocistula KrammerCymbella neocistula Krammer		*	*					*	*						++				
Diploneis sp.Diploneis sp.		*	*									+	+						
Encyonema silesacum (Bleisch) D.G.MannEncyonema silesacum (Bleisch) D.G.Mann		*	*				*		*						++				
Epithemia adnata (Kütz.) Bréb.Epithemia adnata (Kütz.) Bréb.		*	*					*	*	*		+			++				
Epithemia turgida (Ehrenb.) Kütz.Epithemia turgida (Ehrenb.) Kütz.		*	*					*	*	*									*
Fragilaria radians (Kütz.) Williams & RoundFragilaria radians (Kütz.) Williams & Round		*																++	
Lindavia sp.Lindavia sp.	*		*						*								+		
Navicula notha Wallace		*	*			*	*		*							+			
Nitzschia liebetruthii Rabenh.		*	*					*		*							+		
Pinnularia divergens W.Sm.		*	*				*		*									+	
Staurosira construens Ehrenb.		*	*					*	*							++	++	++	
Stephanodiscus cf. lucens	*																+		
Stephanodiscus sp.	*		*													+			
Tabellaria fascculosa (Roth) Kütz.		*	*	*		*			*	*							++	++	

† ++: complete frustule (preserved more 2/3), two or more individulals, +: complete frustule, one individual, **: many fragment, *: one fragment.

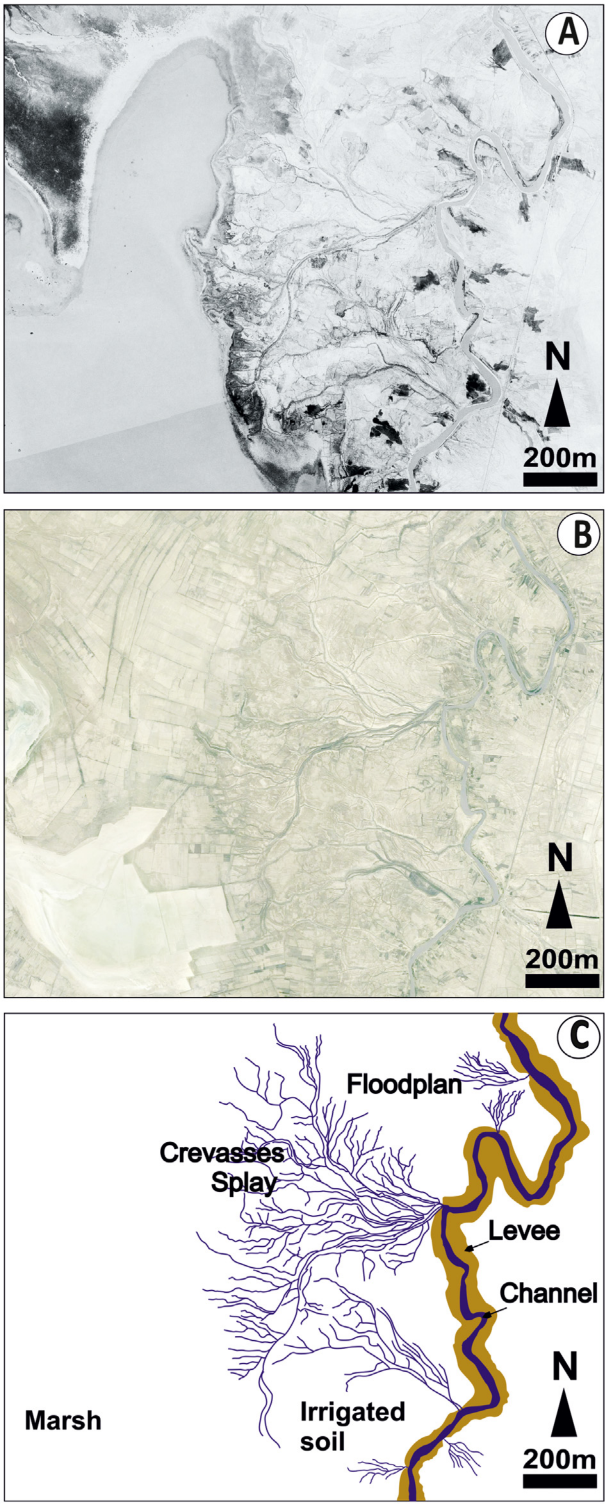

Fig. 2. The six common types of riverine sub-environment (channel, levee, crevasse splay, floodplain, marshes and irrigated soil or palaeosols) in the Mesopotamian floodplain. (A) CORONA and (B) QuickBird satellite images respectively for an area located on the active Tigris near Kut. (C) Sketch of these images showing the six typical sub-environments.

the ancient people of Mesopotamia recorded their activities relating to the rivers, such as the digging and cleaning of irrigation or trading canals (Gibson, 1972; Adams, 1981). Furthermore, archaeological investigations and their results at the site of Uruk and other sites in the region have been undertaken since the 1910s (Adams, 1981; Boehmer, 1991; Finkbeiner and Becker, 1991; Crüsemann, 2015).

3.3. Sediment auger coring and dating

To ground-truth the results of the remote sensing and historical data analyses, samples of sediment columns were collected from boreholes dug using a sediment auger. Cored samples were taken from each sedimentary facies starting from the surface. When changes in sedimentary facies were not recognized, cored samples were taken each metre for more detailed sediment descriptions in the laboratory, including grain composition, grain size and microfossil observations under the microscope. Organic matter (charcoal, shell, etc.) was separated for radiocarbon dating when available.

In the Mesopotamian floodplain, riverine environments are the main depositional environment that formed the Holocene sediments of the floodplain, covering its current surface (Yacoub, 2011). Previous works regarding this floodplain (e.g., Buringh, 1960; Heyvaert and Baeteman, 2008; Jotheri et al., 2016; Wilkinson et al., 2015) have discussed a variety of sub-environments of river deposits and their effects on the inhabitants. However, in the present study, six types of riverine sub-environment have been identified. They are: channel, levee, crevasse splay, floodplain, marshes and irrigated soil or palaeosols (Fig. 2C). As the deposits are heterogeneous, the recognition of these sub-environments was mainly according to their field properties in outcrops or core samples such as lithology, colour, sedimentary structures, macrofossils and preliminary facies. In addition, they could be identified by their visual criteria in satellite images (e.g., tone, height, etc.; see above) (Fig. 3). Here are the general field descriptions for each sub-environment.

Channel deposits (Figs. 2 and 3) are the main stream of the river confined by river levees, mainly filled with coarse grain deposits as the result of the river leaving that course. Their dimensions roughly reflect the depths of the original channels and widths of the channel belts. They can be recognized by the weakness of bedding and lamination, greyish colour, coarser grain size (medium to fine sand), variable sorting of sand and the existence of shells and shell fragments.

Levee deposits (Figs. 2 and 3) are commonly laminated and layered, smaller in grain size compared with channel deposits, fining upwards and showing the existence of lenses of silts. The coarser particles are deposited alongside the channels, forming small elevated banks, while the lighter particles are deposited a long way from the channel, forming the floodplain (for example see Mohrig et al., 2000).

Crevasse splay deposits (Figs. 2 and 3) are characterized by very fine sand to fine silt, in a thin-bedded structure. These deposits occur close to the channel, in time becoming a feature of high elevation, but lower than the channel levees (Bristow et al., 1999). It has been claimed that crevasse splays were the first sub-environment which ancient people chose to dig canals through to divert water to form farms and then settlements.

Floodplain deposits (Figs. 2 and 3) are the most frequent facies in the area (i.e., they cover most of the surface of southern Mesopotamia) and consist of massive to blocky clay and silt, brown in colour and of solid homogeneous texture. In the present day, most of the floodplain area is well drained and irrigated as it represents the main farming area.

Marsh deposits (Figs. 2 and 3) are clay to silty clay deposits, easily recognizable compared with other facies because they are greenish to charcoal in colour, rich in bioturbation, roots and vegetation fragments, with the presence of gastropod shells. They are marshy areas which form when water spreads out from levees: a result of floodwaters overflowing the banks. This sub-

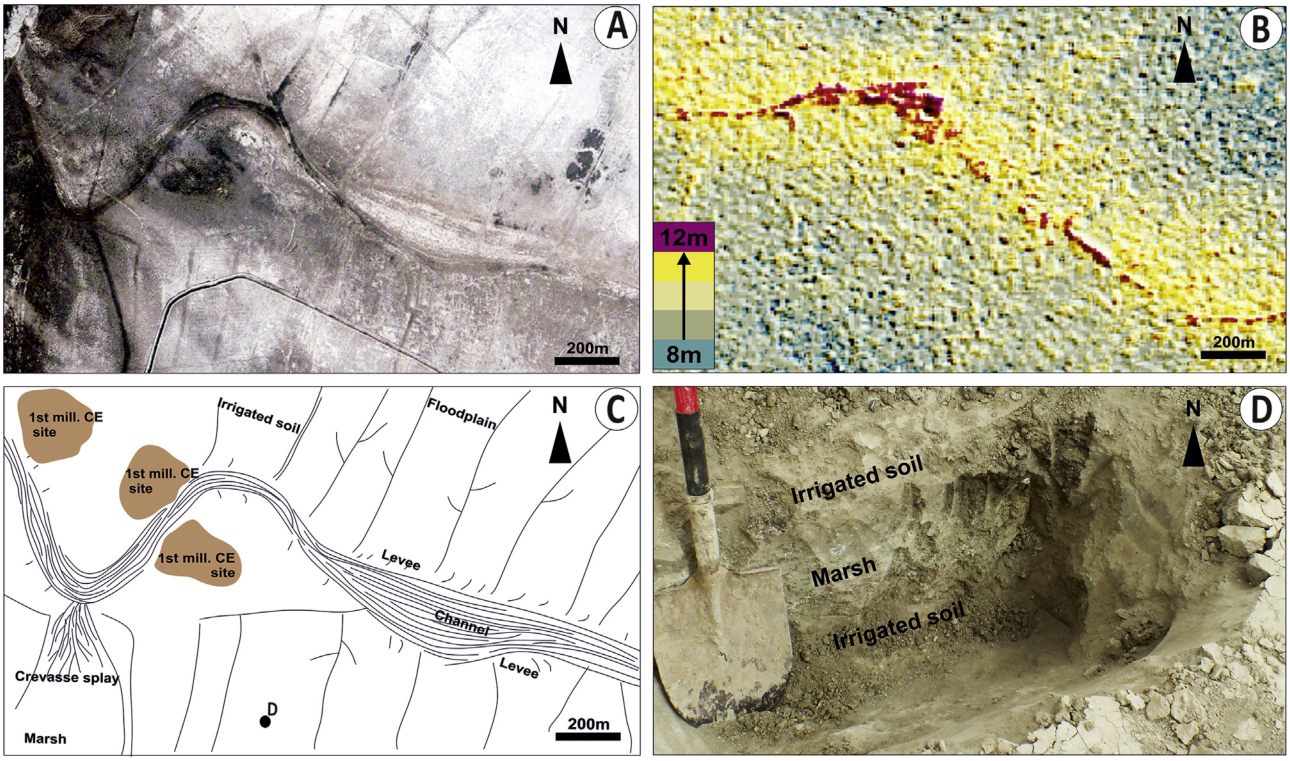

Fig. 3. An example of using (A) QuickBird images of year 2006 (B) SRTM data to identify palaeochannels and archaeological sites in the Uruk region. (C) Sketch of the study area (A, B) showing riverine sub-environment; channel, levee, crevasse splay, floodplain, marshes and irrigated soil. (D) A shallow pit showing marshes and irrigated soil deposits.

environment is rich in natural resources such as freshwater, reeds, fish, birds, pigs and other marsh animals.

Irrigated soils or palaeosols (Figs. 2 and 3) are mostly silty clay, grey-brown in colour, of blocky structure, containing freshwater gastropods and small fragments of ceramics mixed in as a result of cultivation. Palaeosols occur before and after avulsion, representing periods of exposure and low deposition conditions. Irrigated soils occur not far from river levees, as only gravity-fed irrigation is possible (i.e., the levees form slopes as a result of aggradation flow from the river to the land when water-lifting devices are used).

3.4. Diatom analysis

Diatoms were sampled by extracting them from the sediments of the auger samples. The samples were prepared at the National Museum of Nature and Science in Tsukuba, Japan. About 1–3 g of clay and silt powders were placed into disposable glass centrifuge tubes. About 2 ml of concentrated hydrochloric acid was added to each tube and the tubes were left to stand 20 min. Additionally, 15 ml of concentrated nitric acid was added to each tube and heated on a hot plate (HPR-4030, As One, Japan) until it boiled. Each tube was heated about 10 min and this reduced the quantity of total liquid to 10 ml. After boiling, each treated material was washed five times with filtered tap water using a centrifuge. After final washing, the treated materials were kept in 70% ethanol. Finally, the disaggregated samples were mounted in a ZRAX medium and examined by light microscopy (Axiophoto, Zeiss, Germany).

3.5. AMS dating

Accelerator mass spectroscopy (AMS) dating was used on shell and organic samples. Seven samples were sent to Beta Analytic in Miami, USA and one sample to the Oxford Radiocarbon Accelerator Unit in Oxford University (ORAU). The results have been calculated as calibrated ages with a 2-sigma error range in calendar years BP (Table 1).

4. Results

4.1. Geomorphological observation

Geomorphological features in the present study have mainly been created by channel processes, including the formation of levees, floodplains, crevasse splays and marshes. The area is generally flat, but the locations of the levees are higher than the surrounding floodplain by about 2–5 m. The directions of channels follow the general slope of the area which is from the northwest towards the southeast The archaeological sites also appear as a series of small mounds associated with these levees (Fig. 4).

The ancient channels and archaeological sites are distributed over the whole of the study area and there is no clear difference in density (Fig. 4). However, it seems that the current location of the Euphrates has no ancient channels or archaeological sites; this might be because either the modern Euphrates has covered those ancient channels and sites, or because the location was already a desert or deep marshes in ancient times and so was not occupied like other sites (Fig. 4).

It seems that the ancient channels in the south of the modern Euphrates are different from those to the north of it. The main difference is that the channels in the northern network are interconnected such that it is extremely difficult to distinguish the main channel from its branches. Conversely, the channels of the southern network are not interconnected – there is one main channel with several branches extending from it. The connection between these two channel systems is intensive except in the southeastern part of the study.

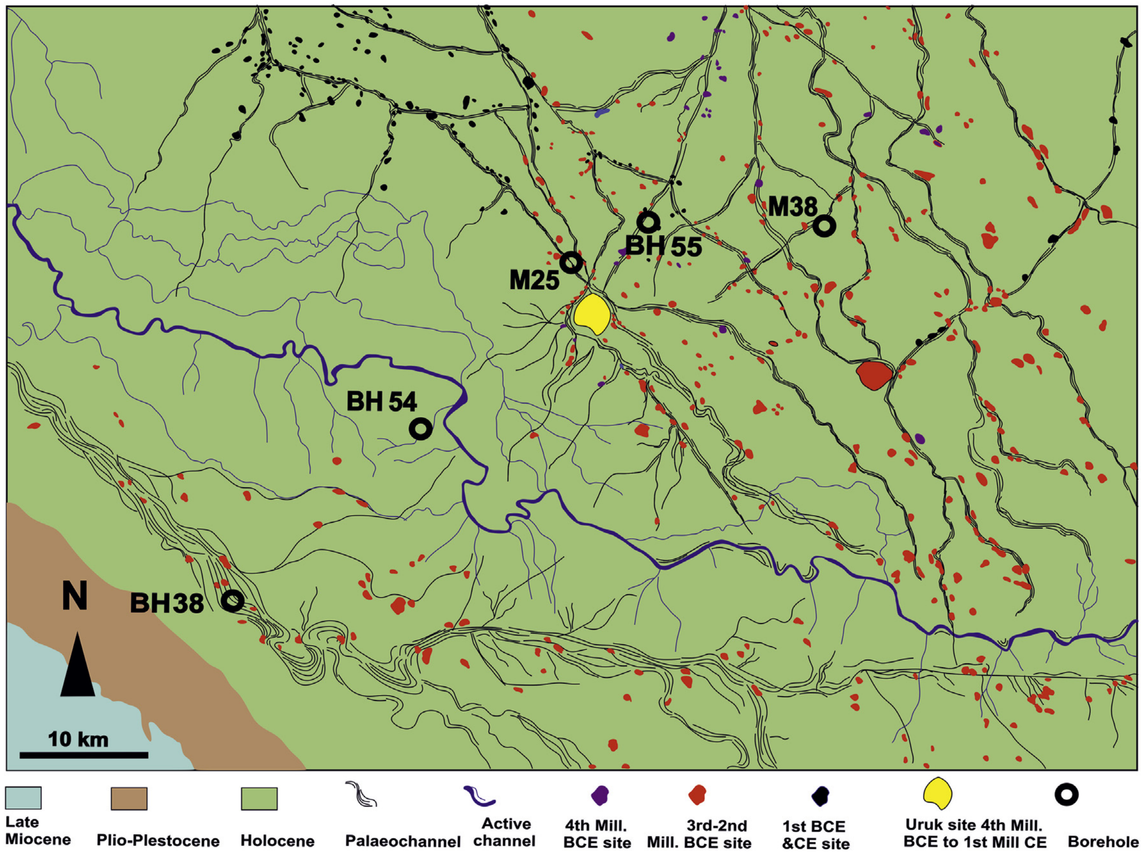

Fig. 4. The identified channels and archaeological sites in the present study (see also Fig. 1).

4.2. Borehole sedimentary facies and depositional ages

In this section, sedimentary facies, depositional environments and ages for the five boreholes (BH38, BH54, M25, BH55 and M38), from west to east (Fig. 5), are discussed. Fluvial sedimentary environments were principally identified according to geomorphological and geological observations in the field, but also using criteria described by others (Buringh, 1960; Heyvaert and Baeteman, 2008; Jotheri et al., 2016; Wilkinson et al., 2015). Fine-grained sediments in the floodplain are generally abundant as calcite grains and include tests (exoskeletons) of marine nanofossils derived from the Phanerozoic limestone upstream. Siliciclastic grains are mostly composed of continental grains (quartz, plagioclase, biotite, zircon, etc.). Absolute age determination by radiocarbon has been carried out for seven freshwater bivalve (*Corbicula fluminea*) samples and one charcoal sample via AMS (Table 1). At one interval (M38–0.75 in Table 1), the shell sample yielded a slightly older age compared to the charcoal sample from the same marsh deposit. This could be attributed to a reworking of the shell, or to the older carbon effect on the shell (Zhou et al., 2015; Philippsen, 2013) as a result of dissolved CO_2 that comes from erosional products of geological formations (Törnqvist et al., 2015). Since it was difficult to collect sufficient charcoal sample using the employed method, and shells were more frequently observed in the cores, we used shell ages in the following argument. By carefully choosing autochthonous shells from marsh deposits, we avoided the risk of measuring reworked fossils. Five radiocarbon ages on shells obtained from the deep borehole (M38 in Table 1), decreasing in age from bottom to the top, support the reliability of the employed method. Other information for depositional ages was obtained from artificial inclusions such as ceramic fragments. The age data are incorporated into the following borehole descriptions. The change in sedimentation rate is calculated from depths and the ^{14}C ages listed in Table 1.

Borehole BH38 (Fig. 5) is a 5 m-deep hole dug from the surface at 11 m above mean sea level (msl), at approximately 10 km southwest of the modern Euphrates (Fig. 1, inset) near the margin of the Arabian plateau. The top 2 m of the hole were composed of olive brown clay to silty clay, grading downward to silt and to sandy silt. This sediment is rich in charcoal and contains freshwater shells and fragments of sponge spicules. The interval between 2 m and 3 m below the surface was composed of very fine grey sand that can be interpreted as a natural levee deposit. The bottom 2 m were composed of grey fine to very fine sand with the rare occurrence of shells. Abundant charcoal and freshwater shells in clay to silt-size top sediments are indicative of a marsh environment, whereas we interpreted the charcoal-free sand-size sediments with rare occurrence of shell in the bottom 3 m to be channel deposits. As the top marsh sediment has been radiocarbon dated to between 45 BCE and 75 CE, the Parthian period, the date of the channel deposit can be assumed to be prior to that. It is clear that this succession reflects a river avulsion process in terms of a primary channel that has been abandoned and then covered by the marsh sediments of the migrated river.

Borehole BH54 (Fig. 5) is located at about 20 km southwest of Uruk within 1 km southwest of the modern Euphrates. BH54 is 5 m deep from the surface which is 10 m above msl. The first 0.5 m consists of reddish pure clay and corresponds to current floodplain deposit. The next 0.5 m consists of sandy silt and fine sand with some ceramic fragments, implying irrigated soil. The following

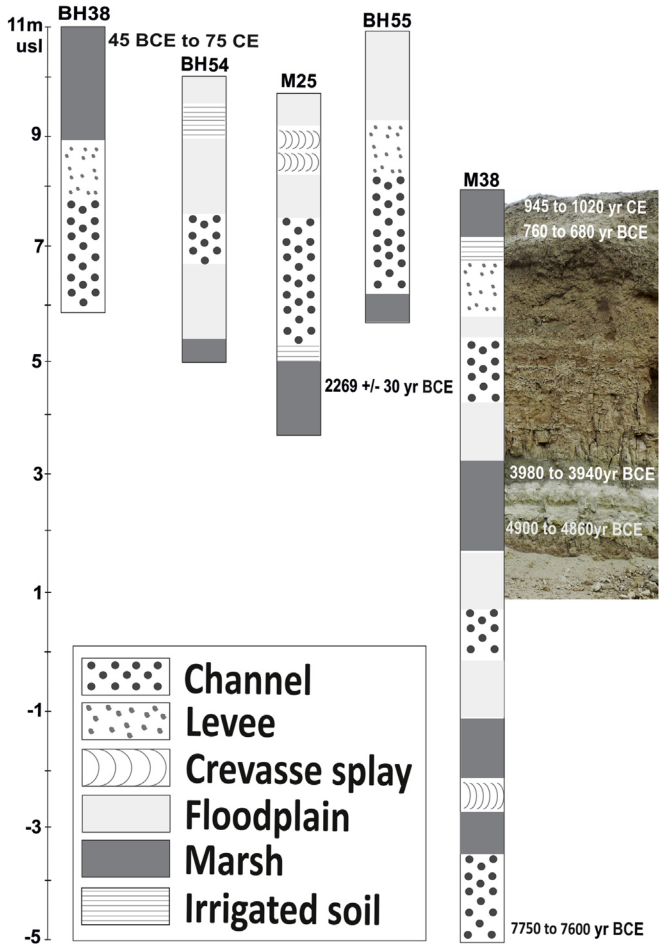

Fig. 5. Lithologies of boreholes BH38, BH54, M25, BH55 and M38 of the present study and location of the dated samples by radiocarbon analysis. The vertical scale is metres above mean sea level (msl).

1.25 m is reddish clay to silty clay, with no shells. This bed is underlain by 1.0 m of fine to very fine sand channel deposit, rich in ceramic fragments that might come from river erosion of previous sites. The next bed is 1.5 m-thick reddish clay to silty clay bed. The changes in the grain size of these beds from clay to ceramic-bearing sand, and then from sand to clay in a shell-free environment, imply a migrating channel that resulted in changes in depositional environment from channel to floodplain. The bottom of BH54 is composed of 0.5 m silt to sandy silt rich in shells and charcoal that can be interpreted as marshes. The ceramic fragments in the lower channel deposit were from the Sasanian period, while the ceramic fragments in the irrigated soil were dated as being from the Islamic period. Thus, the marshes at the bottom could predate the Sasanian period.

Two borehole samples (M25 and BH55 in Fig. 5) were obtained only a few kilometres upstream from the city of Uruk. M25 is a 6 m-deep hole that was dug from about 9.5 m above msl. The first 0.5 m of M25 is floodplain deposit composed of reddish clay, followed by 0.5 m of sandy silt to fine sand and 0.5 m of reddish clay to silty clay. We interpreted the sandy deposit as a crevasse splay deposit interbedded in floodplain deposits because it is thinly laminated. There are then 2.5 m of channel deposits consisting of greyish, fine to very fine sand with some ceramic fragments covering a 0.25 m-thick silty clay blocky structure (palaeosols) followed by 1.5 m of marsh deposits consisting of charcoal silt to silty clay rich in shells. The age of the marsh deposits in the bottom of the section was 2269 ± 30 years BCE, i.e. from the Ur III period. It seems that this section represents a cycle of river avulsion; the marshes were invaded by a new channel running through and, as it migrated, the channel deposit was covered by floodplain and crevasse splay sediments.

Borehole BH55 (Fig. 5) was dug from about 11 m above mean sea level (msl) and total of 5 m of sediment section was observed. The top of the section is composed of 1.5 m-thick floodplain deposits consisting of massive, pure reddish clay. The bed was underlain by 1 m of levee deposit composed of very fine and laminated greyish sand. A 2 m-thick channel deposit, composed of greyish, very fine to medium sand underlies the levee deposit. The bottom 0.5 m of this hole consists of charcoal-bearing silt to sandy silt, rich in shells and interpreted as a marsh deposit.

Borehole M38 (Fig. 5) is the deepest borehole (at 13.0 m) in the present study and was also well-dated using radiocarbon techniques. It was dug from the surface 8 m above msl and reached to 5 m below msl. Shells of *Corbicula fluminea*, a freshwater bivalve, were collected from five intervals down to 12.5 m below the surface. The top metre of the section is marsh deposit composed of dark greyish charcoal silt, rich in shells. Two radiocarbon dating processes were carried out for the marsh sediment, and both indicate the Islamic period; the lower one is 760 to 650 years BCE while the upper one is 945–1020 years CE. This deposit is underlain by 0.5 m of irrigated soil (palaeosols) and then 1.0 m of laminated greyish fine sand interpreted here as a levee deposit. This bed covers a 1.0 m-thick reddish clay floodplain deposit, underlain by 1.0 m of greyish medium sand of channel deposit. A 1.0 m-thick floodplain deposit composed of reddish clay and a 2.0 m-thick marsh deposit consisting of greyish charcoal silt to sandy silt, rich in shells, underlie the channel deposit. The bottom of this marsh facies was dated to 4900 to 4860 years BCE (Ubaid period), while the top was dated at 3980 to 3940 years BCE (Uruk period). There is then 1.0 m of floodplain clay covering 1.0 m of channel deposit, grey fine sand. The subsequent facies is 1.0 m of floodplain clay. The next facies are 0.5 m of charcoal silt, rich in shells, marsh bed covering 1.0 m of crevasse splay, grey, fine sand, followed by 1.0 m of marsh bed consisting of charcoal silt, rich in shells. The 1.5 m-thick bottom bed is channel deposit greyish fine sand with some shells dated to 7750 to 7600 years BCE (i.e., Neolithic). This borehole has shown two clear and complete cycles of river avulsion, each cycle starting and ending with marsh deposits. The first avulsion started in the Neolithic period and ended in the Uruk period; the last one began after the Uruk period, continuing until the Islamic period.

4.3. Planktonic diatoms

Many freshwater planktonic diatom species (Table 2) were observed in the samples from −4.0, −4.5 and −5.0 m from msl (Fig. 5) in the M38 borehole suggesting a deep water environment and/or water coming from a freshwater lake. Several benthic diatom taxa were frequently found in these samples. One marine-brackish water benthic species was discovered at a depth of about −5 m msl, but just as a fragment, while other species, which were observed in abundant numbers at the same depth, were both benthic and planktonic freshwater species. Most of the taxa are indicator species of freshwater, and are alkaliphilous and oligotrophic to mesosaprobous environments, which are common for unpolluted upper stream areas. A sample from −3.5 m includes *Cymbellaneocistula*, *Encyonemasilesiacum* and *Epithemiaadnata*. These species are benthic diatoms and indicate freshwater, and are alkaliphilous and oligotrophic to mesosaprobous environments. Planktonic species were not found at this depth, potentially indicating an environment with running water. Samples from 0.0

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to −2.0 m include a very limited number of benthic diatoms. These could be secondary fossils from deeper sediments. An environment such as fast sedimentation and/or high alkaline and low concentration of silica may cause the very limited number of benthic diatoms. Overall, given the data obtained at −4.5 m, this indicates that by the 8th millennium BCE, a freshwater habitat had emerged in the region of Uruk. This freshwater environment seems consistent with a riverine environment that lasted between 9750 (7750–7600 BCE) to 6860 BP (4900–4860 BCE).

4.4. Channel courses

Using the multidisciplinary methods outlined above, intensive networks of palaeochannels and archaeological sites within the study area have been reconstructed (Fig. 6). According to the periods of occupation, archaeological sites can be divided into two main occupation groups. The main group consists of more than 400 sites occupied from the 4th millennium to the late 1st millennium BCE (Chalcolithic (Uruk) to Hellenistic/Parthian periods; Fig. 6-A), while the smaller group is fewer than 150 sites, occupied from the late 1st millennium BCE to the middle of the 2nd millennium CE (end of the Islamic period; Fig. 6-B) (the dates are based on Adams, 1981). Accordingly, the palaeochannel networks can also be divided into the same two groups of occupation, assuming that the ages of the channels are close to the ages of the associated sites as mentioned earlier. After the end of the Islamic Period (about 13th century CE), the channel network can be divided into two periods using historical maps and texts. One period is from the 13th century until the 1980s (Fig. 6-C); the other is from the 1980s until the present (Fig. 6-D).

4.4.1. From the early fourth to the late first millennium BCE

There are more than 400 archaeological sites that date to this 4000-year span, with the majority of these associated with palaeochannels. Uruk is the only site that was occupied for most of this period, including occupation lasting into the 1st millennium CE. The palaeochannel network of this period seems to have an anastomosing pattern whereby multiple interconnected channels that enclose flood-basins separate and rejoin downstream (Twidale, 2004).

4.4.2. From the late first millennium BCE to the middle of the second millennium CE (end of the Islamic period)

In the present study, about 150 sites were occupied during this period – most of them associated with channels. The main channel that these sites are associated with enters from the northwest and reaches Uruk and then passes the site to the south. Jotheri et al. (2016) suggest that the upstream part of this channel is anthropogenic and was dug during the Sasanian period. Associated archaeological sites and radiocarbon dating support the idea of the channel having been dug in this period, and it was then abandoned after the end of the Islamic period. In the present study, a borehole was dug in this canal. The first 3 m of the sample were found to contain shattered pottery, possibly older than the first millennium BC period. The bottom of the borehole is marshland deposits made during the third millennium BCE, as radiocarbon dating shows. This

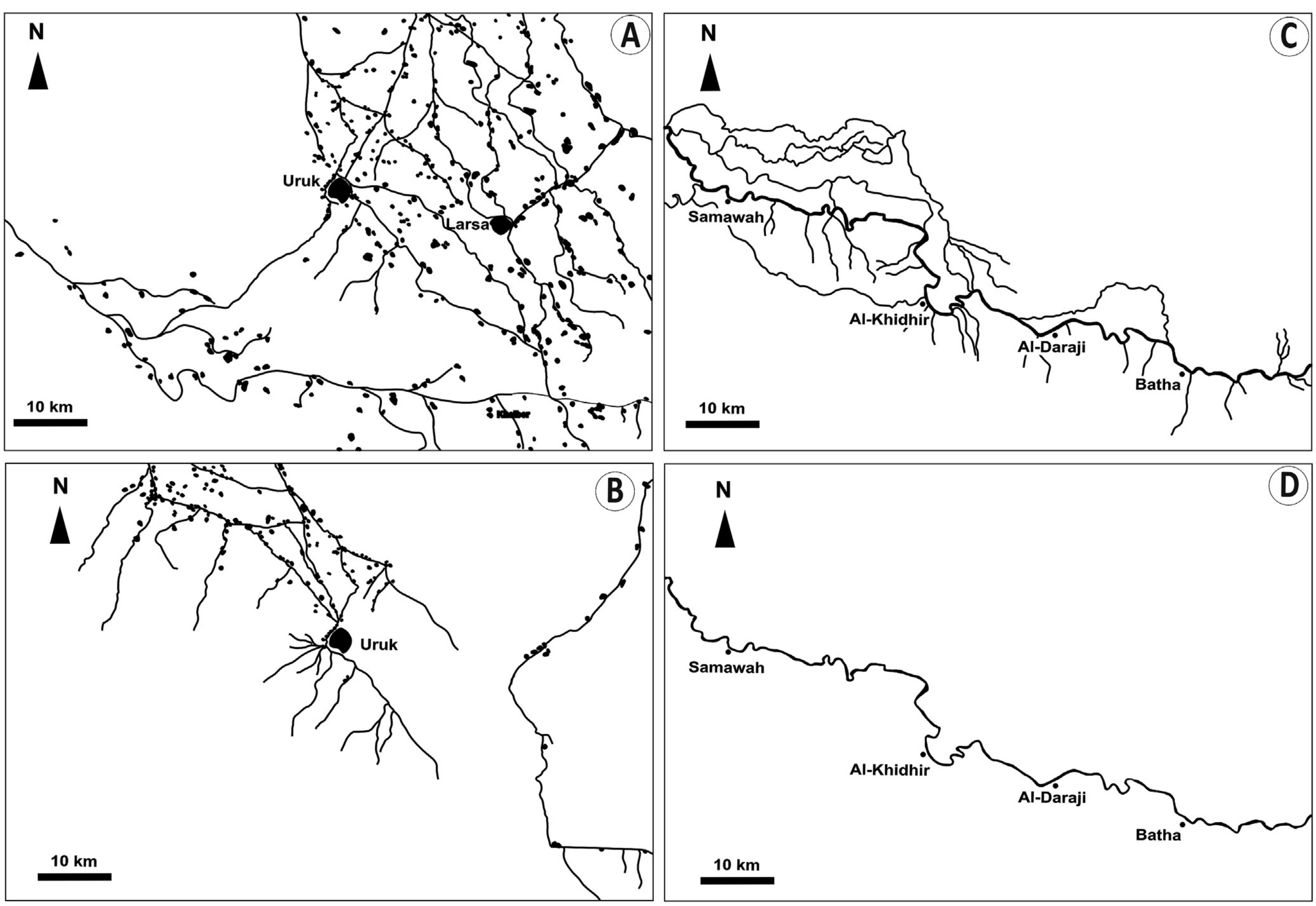

Fig. 6. Channel networks of the Uruk region at different time intervals. (A) From the early fourth to the late first millennium BCE. (B) From the late first millennium BCE to the middle of the second millennium CE (end of the Islamic period). (C) After the Islamic period until the 1980s. (D) From the 1980s until the present.

is interpreted as a flooded area that was marshy. It is noteworthy that the 400 sites mentioned above were not occupied during this time. Thus, it can also be assumed that their channel network was abandoned.

4.4.3. From the Islamic period to the 1980s

According to Islamic historical texts by authors such as Ibn-Alatheer (2003), Ibn-Alfuwati (1938) and Ibn-Aljozi (1992), the strip area between Uruk and the Arabian plateau, i.e., where the modern Euphrates now runs, was covered by large marshes during the late Islamic period. The area of these marshes increased after the Islamic period, mainly as a result of the failure of the irrigation system, especially dams and barrages, possibly when Mongols invaded Baghdad in the 13th century CE (Susa, 1948). Marshes cannot be formed unless there are relatively high topographic features that act as barriers to confine the floodwater and prevent it from flowing towards lower land. Consequently, in the present study, the highly elevated palaeochannel levees cover the entire area except the strip area along the modern Euphrates. This means that the inherited levees acted as a barrier or highland area, where floodwater followed the gradient and accumulated in the confined lowland area to form marshes. Furthermore, floodwater from the irrigation system continued to flow and increased after the Mongol invasion, leading to a new river taking on an anastomosing channel pattern, as the area is at a relatively low gradient with low discharge. This area has been described by several Western travellers (e.g., Willcocks, 1912) and also on Ottoman maps and texts (e.g., Husain, 2014, 2016), as being subject to frequent flooding, and its banks commonly have crevasse splay activity and are not high enough to retain water inside the channel throughout the year.

4.4.4. From the 1980s until the present

According to IMWR (2005), at the beginning of the 1980s, the modern Euphrates was chosen as the main river reaching this area and was maintained frequently while other branches were ignored, with barriers and a dike being constructed to prevent water running into them. By this time, it seems that there had been a settled degree of aggradation in the chosen reach of the Euphrates, which has resulted in a highly elevated levee that is able to prevent water from overflowing the banks. This means that this reach was subjected to floods in the past but the aggradation of river levees through time led to silting up of the crevasse splays, thus reducing flooding. Consequently, the Euphrates pattern in this area has become meandering rather than anastomosing, as the reach has changed to a single-thread channel and has been accompanied by highly elevated levees, a sinuous meander belt, point bars at each curve, cohesive banks and generally fine-grained floodplain sediments (Twidale, 2004; Peakall et al., 2007).

4.5. Rise and fall of uruk in archaeological and historical data

Previous archaeological studies around the site of Uruk (Adams, 1981; Boehmer, 1991; Finkbeiner and Becker, 1991; Crüsemann, 2015) suggested that Uruk was occupied by the 5th millennium BCE, becoming a major urban centre in the mid 4th millennium BCE, reaching a size of more than 200 ha by the second half of that millennium (Adams, 1981; Finkbeiner and Becker, 1991). Thus, Uruk is often referred to as the world's first city (Crüsemann, 2015). In the late 4th millennium BCE, some of the world's earliest known writing was developed, and large temple/administrative complexes were established in the heart of the city. By the 3rd millennium BCE, the site continued to expand to about 400 ha, reaching a size that almost no other pre-Iron age site ever reached. Uruk was largely abandoned at around 1600 BCE, but was reoccupied in the second half of the 2nd millennium BC (c. 1400 BCE). It was abandoned again by about 1200 BCE. Before the site was reoccupied in the early 1st millennium BCE through to the first half of the 1st millennium CE, it reached major town status at about 50 ha or more in the late 1st millennium BCE. By the late 1st millennium CE, the site was again abandoned.

This intensity of occupation roughly mirrors the development of suburban sites immediately around Uruk, where settlement increases substantially from the 4th–3rd millennium BCE, then declines by around 1600 BCE, then increases again in the late 2nd millennium BCE. Another abandonment phase occurred at around 1200 BCE. Settlement once again increased in the early 1st millennium BCE. By the early 1st millennium CE, substantial settlement is evident in the area; however, by the late 1st millennium CE, occupation is once again substantially diminished (Adams, 1981).

5. Discussion

5.1. Holocene transgression limits relative to uruk

It has been claimed by many researchers that earlier in the Holocene the shoreline of the Persian Gulf in southern Mesopotamia was significantly further north of its current location (Fig. 1), as a result of the changing position of sea level (Hudson et al., 1957; Aqrawi, 1995; Heyvaert and Baeteman, 2007). Most of the studies have suggested that initial transgression, followed by regression and the formation of the Holocene Mesopotamian river delta occurred around 6000–5000 BP (e.g., Cooke, 1987; Sanlaville, 2000; Aqrawi, 2001; Pournelle, 2003; Kennett and Kennet, 2007). Recent studies carried out by Bogemans et al. (2016, 2017), aiming to understand the depositional evolution and date the transgression and regression in the head of the Persian Gulf using radiocarbon analysis, have suggested a more protracted process: the transgression have started around ca. 7700–7900 BP, whereby an estuarine environment persisted for 2000–2500 years, before progradation occurred ca. 4850–5000 BP to form the present riverine environment. The transgression/tidal influence was restricted to the channels (no general flooding), Bogemans et al. (2016). Different locations for the point of maximum transgression have been posited: Cooke (1987) suggests the sea reached the location of Diwaniayh and Kut; Hritz and Pournelle (2015) suggest Samawah, while Aqrawi (1995, 2001; Fig. 1) suggests Nasiriyah and Amarah. From the aggradation history and sea level curve alone (Fig. 6), marine to brackish water environments could have occurred at the elevation of Uruk (changing through history because of the cumulative sedimentation) between 8000 and 5000 BP, since the sea level maxima took place during this period. It is even possible that a fully marine environment could have existed, if a transgression of about 3 m is assumed during the Hypsithermal period (thick dotted line in Fig. 6).

However, the evidence collected in the present study instead implies a fully freshwater depositional environment at the location of Uruk throughout the Holocene. The frequent occurrence of freshwater molluscs (including *Corbicula fluminea*) and charcoals, together with sedimentary facies from the boreholes, suggest fresh water.

Furthermore, the presence of both planktonic and benthic freshwater diatoms from the deepest part of borehole M38 suggests the existence of deep fresh water in this location from the early Holocene until around 9500 BP at the level of −4 m from present msl. The lack of freshwater planktonic diatoms in the overlying interval suggests that the deep lake had disappeared and changed to a running water environment by around 9000 BP (at −3.5 m present msl). Between 8500 and 7000 BP, the limited occurrence of benthic diatoms implies fast sedimentation and/or low concentration of silica in the running water. Overall, therefore, our data

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obtained from borehole M38 indicate that a riverine environment continued throughout the Holocene, and there is no evidence for tidal influence or for penetration of marine water in the region of Uruk.

5.2. Shifting channel patterns: natural and human impact

Through time the channel patterns on the Mesopotamian floodplain have changed significantly. In some cases, shifts have been driven by a variety of interconnected natural drivers, while in many other instances the channels have been modified directly or indirectly by human action.

Initially, the anastomosing channels observed from the early 4th millennium BCE are likely the result of a combination of several factors: a) rapid base-level rise due to relatively faster rates of sea level rise; b) higher than present rates of sediment supply as a result of greater precipitation in the headwaters (Wick et al., 2003); c) the existence of a cohesive floodplain rich in fines. A combination of high sediment supply and faster base-level rise results in high rates of in-channel aggradation (and the sedimentary fluvial record demonstrates this), while cohesive fines inhibit lateral river mobility. Together, this tends to produce an anastomosing pattern of river distributaries (Jerolmack, 2009; Jerolmack and Mohrig, 2007; Pennington et al., 2016), and an associated dynamic landscape comprising narrow levees, extensive flood basins and frequent crevassing and avulsion. These landscapes were probably in existence in the area for a substantial period earlier than the dating information provided by the settlement patterns in the current study (Pennington et al., 2016). Borehole M38 shows that fine-grained riverine sediments have been being deposited in the area since at least 7750–7600 BCE; these sediments would have forced low rates of lateral migration and, in tandem with high rates of relative sea level rise, this could have given rise to an anastomosing channel pattern from at least this date.

Basin irrigation agriculture likely originated from the management of frequent natural crevasse splays within this anastomosing network (Adams, 1981; Morozova, 2005; Wilkinson et al., 2015); it was from within this landscape that the world's first city, Uruk, emerged. Following the establishment of this city and its surrounding satellites, there was increased human management of the natural landscape. Dams and barrages were constructed to manage the irrigation system (George, 2009; Jansen, 1980), which, in addition to providing management and diversion of water resources, would have also had the effect of reducing avulsion frequency. There are also situations where people deliberately break channels and flood the surrounding area; the most common reasons for manually breaking levees is to use water as a weapon of war (Chen, 2013) or to irrigate reed farms (Postgate, 1994).

Historical texts can also provide further insights into irrigation patterns during the 3rd millennium BCE, since references to irrigation systems and projects are found in administrative texts and royal inscriptions from the Early Dynastic Period (2900–2350 BCE) onwards. Rulers of the early city-states, such as Urnanshe from Lagash, note the construction of canals and hydraulic devices in their inscriptions as notable accomplishments. Urnanshe, for example, claims to have built no less than seven primary canals (Schrakamp, 2017), while Ur-Namma, the founder of the Third Dynasty of Ur, also claims to have constructed seven overland canals (Flückiger-Hawker, 1999; Sallaberger, 1999; Rost, 2015). Unfortunately, none of these inscriptions provides any information on the size of the canals and hydraulic devices, and there has always been considerable debate on the magnitude of these undertakings. However, given the relatively low population density at this time compared to later periods, these projects must have been fairly limited. Considering the new archaeological evidence of an anastomosing river regime, it makes these royal claims of constructing a large number of canals much more plausible, as it most likely entailed modifying an existing web of anastomosing river channels, a simpler task than digging a multitude of new canals. The cuneiform record suggests that the irrigation system remained fairly simple, with short primary canals arranged in a herringbone pattern, until the 2nd millennium BCE. Changing river systems and the silting up of major water arteries led to greater intervention from local rulers, such as Hammurabi (1792–1750 BCE), to redirect water flow to major urban centres (Rost, 2017).

The major reorganization of settlement patterns around the late 1st millennium BCE appears contemporaneous with a shift in channel pattern from an anastomosing system to a network with fewer (larger) channels in the area (the shift from A to B in Fig. 6). This shift in channel pattern could potentially be the later, downstream expression of a natural change that seemed to occur across much of the Mesopotamian floodplains around 2000 BCE (Adams and Nissen, 1972; Pennington et al., 2016; Verhoeven, 1998), related to a natural decrease in aggradation rates. However, in this area the shift is much more likely to be a result of changing patterns of human management of the channel networks. Several new, long channels were initiated at this time (including the main channel in the area – see above) along with new dams and barrages (Jotheri et al., 2016; Wilkinson et al., 2015; Rost, 2015), resulting in a reorganization of channel patterns. This shift towards increased intensity of land management may be related to a significant development in digging technology (whether developed inside southern Mesopotamia or imported from elsewhere) or a desperate need to increase cultivatable land as a result of population increase.

The next shift in channel pattern (B to C in Fig. 6) probably came about as a result of decreased human investment in the channel network following the Mongol invasion. Regular channel maintenance prior to this time involved the removal of vegetation and sediment to ensure water flow and navigability, and the subsequent dumping of such excavated material on the channel margins. This continual redistribution of sediment would have acted to inhibit river migration, and reduce natural channel formation by avulsion. Following the Mongol invasion in the 13^{th}century CE, such investment in channel maintenance was reduced; there was also a failure of barrages and dams (Susa, 1948). This would have resulted in the reversion of the river network to a more ‘natural’ character, with natural avulsions creating a mosaic of new channels in the area. Finally, the shift to a single-thread meandering pattern (C to D in Fig. 6) came about solely as a result of human management of the landscape, as described in Section 4.4.4.

This study has also shown that channel criteria (such as patterns, duration of running, flooding, aggradation and time of abandonment) can be directly or indirectly affected by human activities present since the mid Holocene in the southern Mesopotamian floodplain. It should also be stressed that the degree and effect of this intervention varies from one period to another and from one place to another. Although the present study has discussed the issue of human activity on fluvial features and geomorphology in the Uruk area, other parts of the Mesopotamian floodplain have also likely been affected. In the present study, the dating of channels using the periods of the associated settlement sites alongside with radiocarbon dating can give a good age estimation of channel changes through time.

5.3. River and marsh alternation

The main process of floodplain construction in Mesopotamia is avulsion, a natural river process whereby an established river channel diverts to a new course on the adjacent floodplain (Slingerland and Smith, 2004). Several studies carried out in the

Mesopotamian floodplain have proven that avulsions were a common and frequent process during the Holocene (e.g., Morozova, 2005; Heyvaert and Baeteman, 2007; Jotheri et al., 2016), while regular modern-day avulsions have necessitated the construction of several barrages and regular river cleaning (IMWR, 2005). Consequently, avulsion belt deposition should reflect the avulsion process (Slingerland and Smith, 2004), in that the stratigraphic succession of the ancient channel should give an indication of the scenario and history of deposition. In the present study, the clear alternation between marsh and channel environments observed in the sediments suggests that the rivers were subject to frequent avulsions in this area, and thus the floodplain was likely aggrading quickly.

6. Conclusions

Several conclusions about the region of Uruk can be suggested as a result of carrying out the present study. The main conclusion is that the region had been under a riverine environment since the early Holocene, which continued throughout the Holocene, and that there was no tidal influence or invasion of the Persian Gulf in the region. Therefore, geomorphological features in the present study have mainly been created by channel processes, including the formation of levees, floodplains, crevasse splays and marshes.

Another conclusion is that the sedimentation rate was unstable – faster in the Early Holocene and slower in the late Holocene – as a result of increasing aridity during that time. Therefore, the people of the region constructed more canals to cope with climate change.

In terms of channel patterns in the region, it can be concluded that they underwent significant changes during the Holocene. In the Early to middle Holocene, changes were driven by a variety of interconnected natural drivers, while from the middle to late Holocene, human actions were directly or indirectly behind the changes.

In relation to channel avulsions in the region, it also can be concluded that the repeated avulsions led to an alternation between marsh and river environments in the area. As a result of this, this area has relatively more aggradation than the south (Nasiriyah–Amara line) which prevented the Persian Gulf from invading the region during the Holocene transgression.

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