Holocene avulsion history of the Euphrates and Tigris rivers in the Mesopotamian floodplain

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Holocene avulsion history of the Euphrates and Tigris rivers in the Mesopotamian floodplain

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Durham University

Department of Earth Sciences
Durham University
June 2016

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By Jaafar Jotheri

Abstract

The present study deals with reconstruction of the ancient courses of the Tigris and the Euphrates in the Mesopotamian floodplain, which covers most of the central and southern parts of Iraq. The focus is on tracing palaeochannel courses, determining when these palaeochannels were active, and understanding the patterns of avulsion and its impact on human settlements of ancient civilisations.

The research was carried out using a combination of geological, geomorphological, remote sensing, historical and archaeological approaches. Fieldwork included "groundtruthing" of the remote sensing work. A total of thirty seven boreholes were dug, sedimentary and geomorphologic documentation has been carried out, and twenty five shell samples were collected, and analysed by radiocarbon dating.

This study has reconstructed palaeochannels and archaeological sites within the area of southern Mesopotamia; intensive networks of palaeochannels and archaeological sites within the study area have been identified. More than eight thousand archaeological sites have been plotted during this study, and most of them show a location and alignment consistent with an identified palaeochannel.

Eleven major river avulsions and their nodes have been identified, five for the Euphrates and six for the Tigris. It has been found that these avulsions contributed to the shaping, formation and aggradation of both the ancient and present–day landscapes of the floodplain. Two kinds of avulsion have taken place in the floodplain, re-occupational and progradational. In the first of these types of avulsion, the major flow diverted into a previously existing channel. In contrast, the progradational avulsion began by inundating a large section of the floodplain between elevated ridges, producing prograding deposits that filled topographic lows of the floodplain.

These avulsions have affected the distribution, flourishing and degradation of human settlements of the southern Mesopotamian civilisations. The present study has demonstrated how human impact played a leading role in distribution of sediments across the floodplain and shaping both the Holocene and the recent landscapes of the Mesopotamian floodplain. By using periods of human occupation of archaeological sites to date associated palaeochannels, we can get acceptable accuracy on their timing and duration, and can give clear indications about the activity of a given channel.

Contents

List of Figures

List of Tables

Declaration

I declare that this thesis, which I submit for the degree of Doctor of Philosophy at Durham University, is my own work and not substantially the same as any which has previously been submitted at this or any other university.

Jaafar Jotheri
Durham University
June 2016

Acknowledgments

Undertaking this PhD has been a really life-changing knowledge for me and it would not have been possible to do without the support and guidance that I received from many people.

First, I would like to express my genuine appreciation to my enthusiastic supervisors Prof. Mark Allen, Prof. Tony Wilkinson and Prof. Graham Philip for their continuous support, patience, motivation, and enormous knowledge. Their guidance helped me in throughout my research and the writing of this thesis. I am deeply saddened that Tony Wilkinson died during my third year of study, but I celebrate his achievements in landscape archaeology, and his contributions to the study of Mesopotamia.

I gratefully acknowledge the funding received towards my PhD from the Iraq Ministry of Higher Education and Scientific Research. Special mention goes to my fieldwork team, the archaeologist Amer Alzubaidi and the technician Mohamed Almansori, for going far beyond the call of duty.

I am also grateful to all those who I met or contacted and provided me with their feedback throughout my work, especially Dr. Galina S. Morozova, Prof. Jamie Woodward, Prof. Gary Huckleberry, Prof. McGuire Gibson, Dr. Mark Altaweel, Dr. Abdulameer Al-Dafar, Dr. Stephane Rost, Dr. Wendy Matthews, Dr. Jennifer Pournelle, Dr. Adnan Aqrawi, Dr. Dan Lawrence, Dr. Louise Rayne, Dr. Carrie Hritz, Dr. Cecile Baeteman, Dr. Vanessa Heyvaert, Prof. Jason Ur, and Dr. Maurits Ertsen. I would also like to take this opportunity to thank Professor Roger Matthews and Professor Stuart Jones - my viva examiners, for their very helpful comments and suggestions.

Finally, but by no means least, I would like to thank my family: my parents, my lovely wife, my brothers and sister for supporting me spiritually throughout writing this thesis and my life in general.

This thesis dedicated to my father, who has been dreaming for so long about my future doctorate.

Jaafar

1. Introduction

1.1 Rationale

The Mesopotamian floodplain (Fig. 1.1) has formed from Holocene sediments of the Tigris and the Euphrates rivers (Yacoub, 2011) (Fig. 1.2). It is both a very important region in Iraq and also well-known around the world. It was the location of the world's first complex society, and contains some of the largest hydrocarbon reservoirs in the Middle East. It has the most fertile agricultural soil in the region. At present, two-thirds of the Iraqi population are settled in this part of Iraq (Mansoori, 2012). Due to the generally arid climate in the Mesopotamian floodplain (annual precipitation <200 mm), human settlements rely totally on the availability of water for irrigation (Adams, 1981; Matthews, 2003; Wilkinson, Rayne & Jotheri, 2015). Therefore, the Tigris and Euphrates rivers are and were the main control on the life of humans, animals and plants in this region of Iraq. Here, these rivers have been continuously subjected to changes in their courses as a response to a wide range of autogenic, allogenic and human processes. These changes created, and are creating, problems for human lives, such as flooding, desiccation, desertification, and damage to the irrigation system.

Considerable efforts have been made by the Mesopotamian people since early Holocene times to use, control and sustain the water for their requirements. As a result, an intensive network of channel structures was formed over time throughout the landscape of this region. This anthropological palimpsest, just part of the Holocene in this region of Iraq (Fig. 1.2) contains records for decisive episodes of human history (Fig. 1.3).

1.2 Thesis aims

Despite the importance of the Mesopotamian floodplains as explained above, only limited geological, geomorphological and archaeological survey studies have been carried out in this region. Unfortunately, the continuous political issue, ongoing since the middle of the last century, has prevented local and foreign researchers from conducting appropriate investigations. Therefore, little is known about the formation of this floodplain.

Various research efforts have been carried out in the Mesopotamian floodplain in order to reconstruct, date and identify river avulsion, as it will be discussed in the previous work section. Most of these studies covered only a part of the present study area, while others only used remote sensing or surveys of archaeological sites. No study has yet integrated archaeological, geological and geomorphological surveys in the research area. Therefore, the main aims of this research are:

1.6.1 To reconstruct the palaeochannel networks in the study area and then to understand the style and period of avulsion of each main course. In other words, to identify the time, style and causes of river avulsion in the whole Mesopotamian floodplain during the Holocene and its roles in the development of the Mesopotamian floodplain aggradation during that period. Data are more available for the second half of the Holocene, so that is the main focus of the thesis.

1.6.2 To determine the impact of river avulsion on the pattern (the distribution and survival) of human settlements of ancient civilizations, as well the possible effects of future avulsions of the modern channel in the floodplain on surface water management.

1.6.3 To discuss how the anthropogenic activities played its parts on the forming, reshaping and controlling of palaeochannels and fluvial processes in the Mesopotamian floodplain.

1.6.4 To understand the geo-archaeological development of the major palaeochannels levees in southern Mesopotamia and also reveal when these levees began to aggrade so that benefiting from their levee slopes for irrigated agriculture became possible.

1.6.5 To find out how palaeochannels and settlements can be recognized amongst other natural and anthropogenic surface features, according to their visual characteristics.

1.3 Terminology

A number of terms will be used frequently in the present study and it is useful to define them here because they may have different meanings in other literature.

Mesopotamia: The term “Mesopotamia” was first used by the ancient Greeks to refer to the land that hosted the world’s first civilization lying between the Tigris and the Euphrates. As generally used, the term covers Iraq, northeastern Syria, southeastern Turkey and the lowlands of southwestern Iran. However, in the present study, only the floodplain of South Mesopotamia, referring to the alluvial plain of the Tigris and the Euphrates and their distributaries which covers most of the central and southern parts of Iraq, is considered. The area of this floodplain (Figs. 1.1 and 1.2) is approximately 116,000 km^2 in which the local economy was / is based upon channel-fed agriculture, while North Mesopotamian communities were reliant upon rain-fed agriculture.

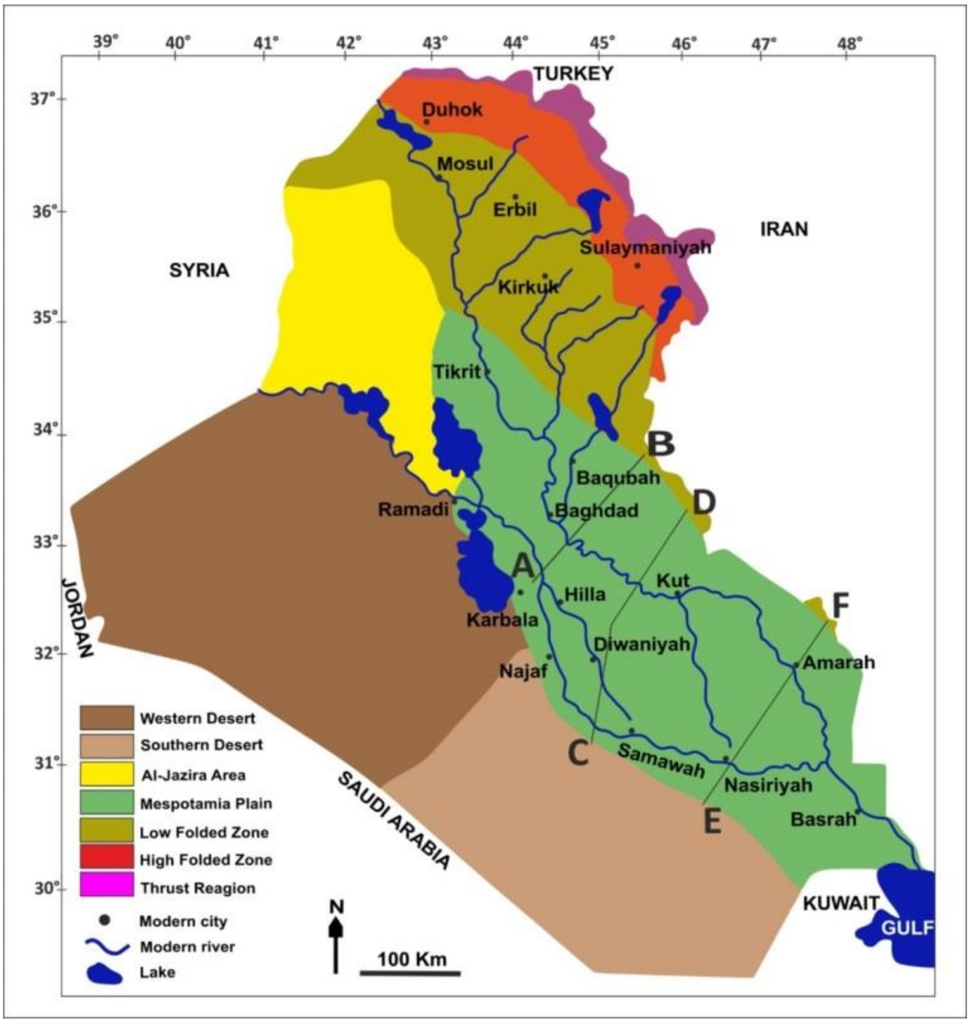

Figure 1.1: General tectonic map of Iraq showing location of the Mesopotamian floodplain amongst others tectonic regions. Modified after Yacoub (2011).

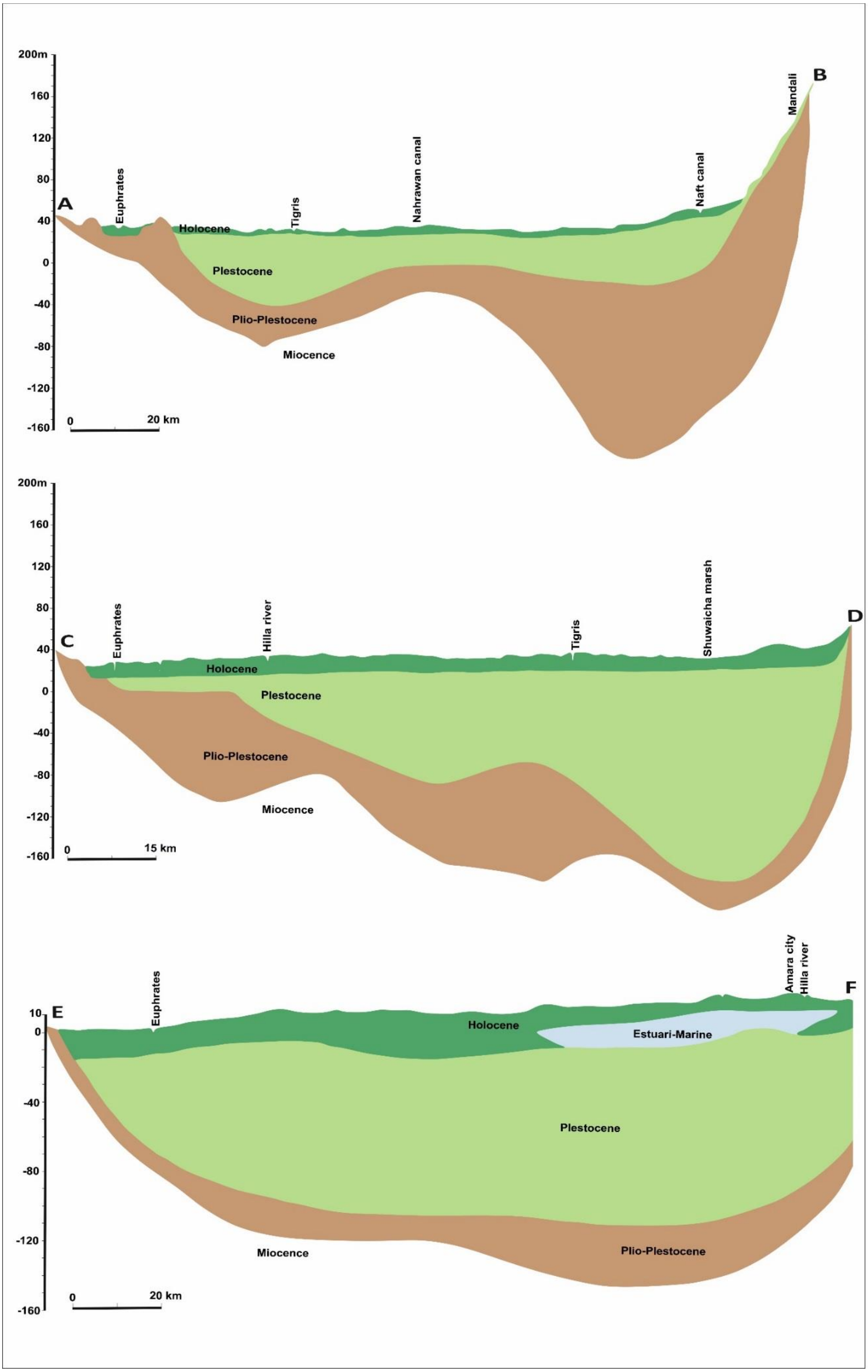

Figure 1.2: Regional geological cross sections in the Mesopotamian floodplain showing thicknesses of the Pliocene, Pleistocene and Holocene sediments. All of the channels and archaeological sites are located within the top few metres of the Holocene. Modified after Yacoub (2011).

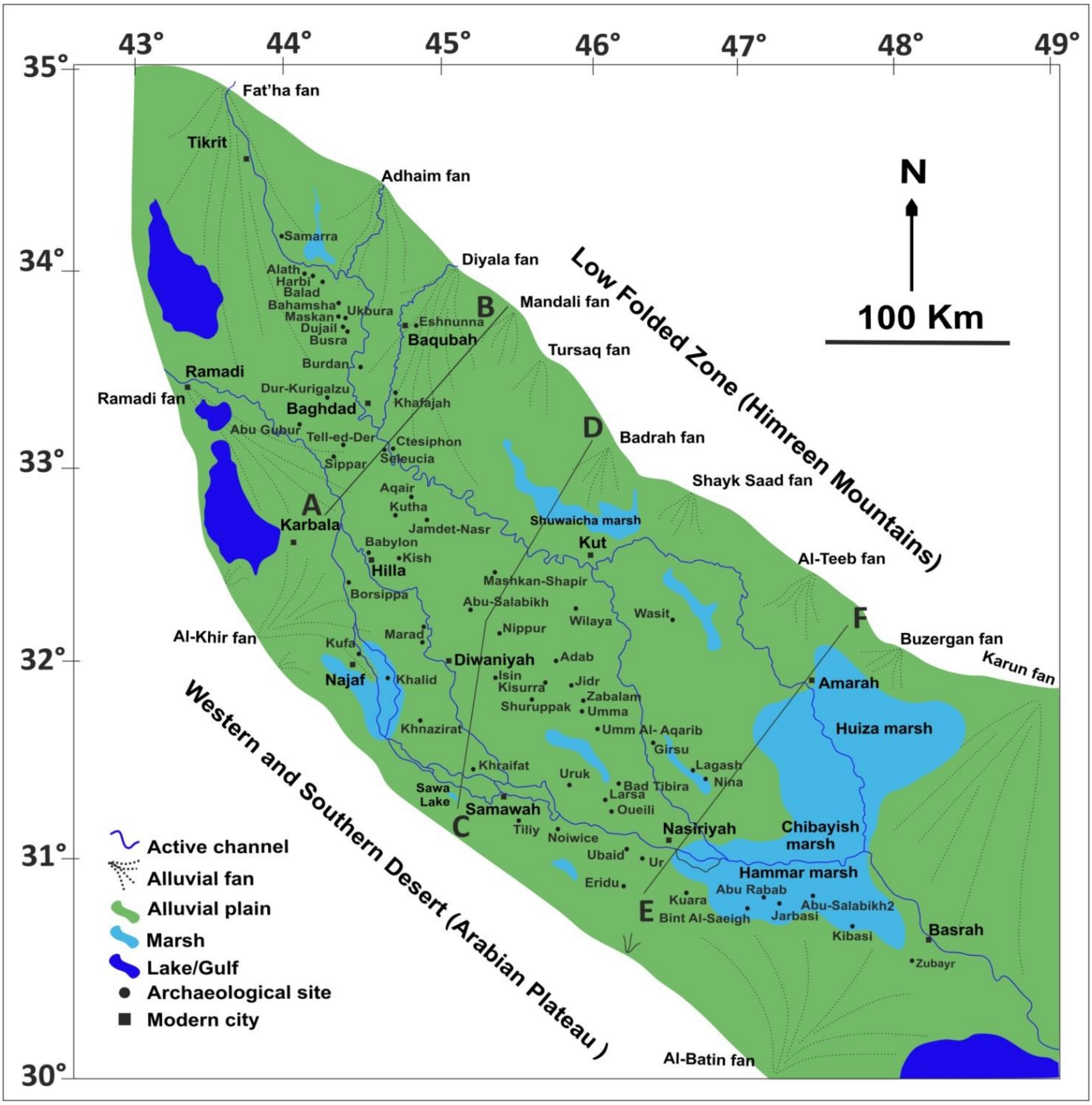

Figure 1.3: A map showing how the Mesopotamian floodplain is bounded by several alluvial fans and the archaeological sites are distributed alongside it.

Palaeochannel: This term will be used in this study to refer to any abandoned or relict channel (whether it was an anthropogenic canal or a naturally formed river) that can be dated to the Ottoman period or earlier (i.e. older than 1918 AD).

Archaeological site: This term will be used in this study to refer to the remains of any human settlement formed in/or before the Ottoman period (i.e. older than 1918 AD) that can be distinguished by the existence of anthropogenic materials (artefacts and/or features) such as any exposed or buried houses, palaces, cemeteries, temples or forts.

Confined river meanders: Those meanders that are incapable of fully developing the meander belt geometry of free meanders, because their lateral migration is forced by the walls of the relatively narrow valleys through which they flow (Fig. 1.4).

River avulsion: The avulsion, the abandonment of all or part of a meander belt in favour of a new course, is controlled by both autogenic and allogenic processes (Allen, 1965). Autogenic factors include river meandering and the vertical accretion of deposits. Allogenic factors are those such as climate change, tectonics, sea-level change, and human interference (Smith, 1989; Stouthamer and Berendesn, 2007). Two kinds of avulsion could have taken place in the floodplain (Morozova, 2005): re-occupational and progradational. In the first of these, the major flow diverted into a previously existing channel (Fig. 1.5). In contrast, the progradational avulsion began by inundating a large section of the floodplain between elevated ridges producing prograding deposits that filled topographic lows of the floodplain (Fig. 1.6).

The Chronology of Lower Mesopotamia: In the present study, the archaeological timescale of southern Mesopotamia adopted refers to the periods of occupation of archaeological sites as well as the formations, flooding, avulsion and desiccation of channels and marshes. Although there is some ongoing debate about the duration of a number of periods or the dates when they began or ended, generally, the commonest time-scale divides the chronology of this region into eighteen periods. (Table 1.1).

Period	Date B.C. /A.D.
Ottoman	1500–1918 A.D.
Islamic	637–1500 A.D.
Sasanian	226–637 A.D.
Parthian	125 B.C.–226 A.D.
Seleucid	331–125 B.C.
Achaemenid	Late first millennium BC
Neo-Babylonian	Early first millennium BC
Early Neo-Babylonian	
Post-Kassite	Late second millennium BC
Kassite	
Old Babylonian	Early second millennium BC
Isin-Larsa	
UR III	Late third to early second millennium BC
Akkadian	Late third millennium BC
Early Dynastic I–III E	Early third millennium BC
Jemdet Nasr	Fourth millennium BC
Uruk	
Ubaid	Late sixth to late fifth millennium BC

Table 1.1: The Chronology of Lower Mesopotamia (Matthews, 2003; Carter and Philip, 2010)

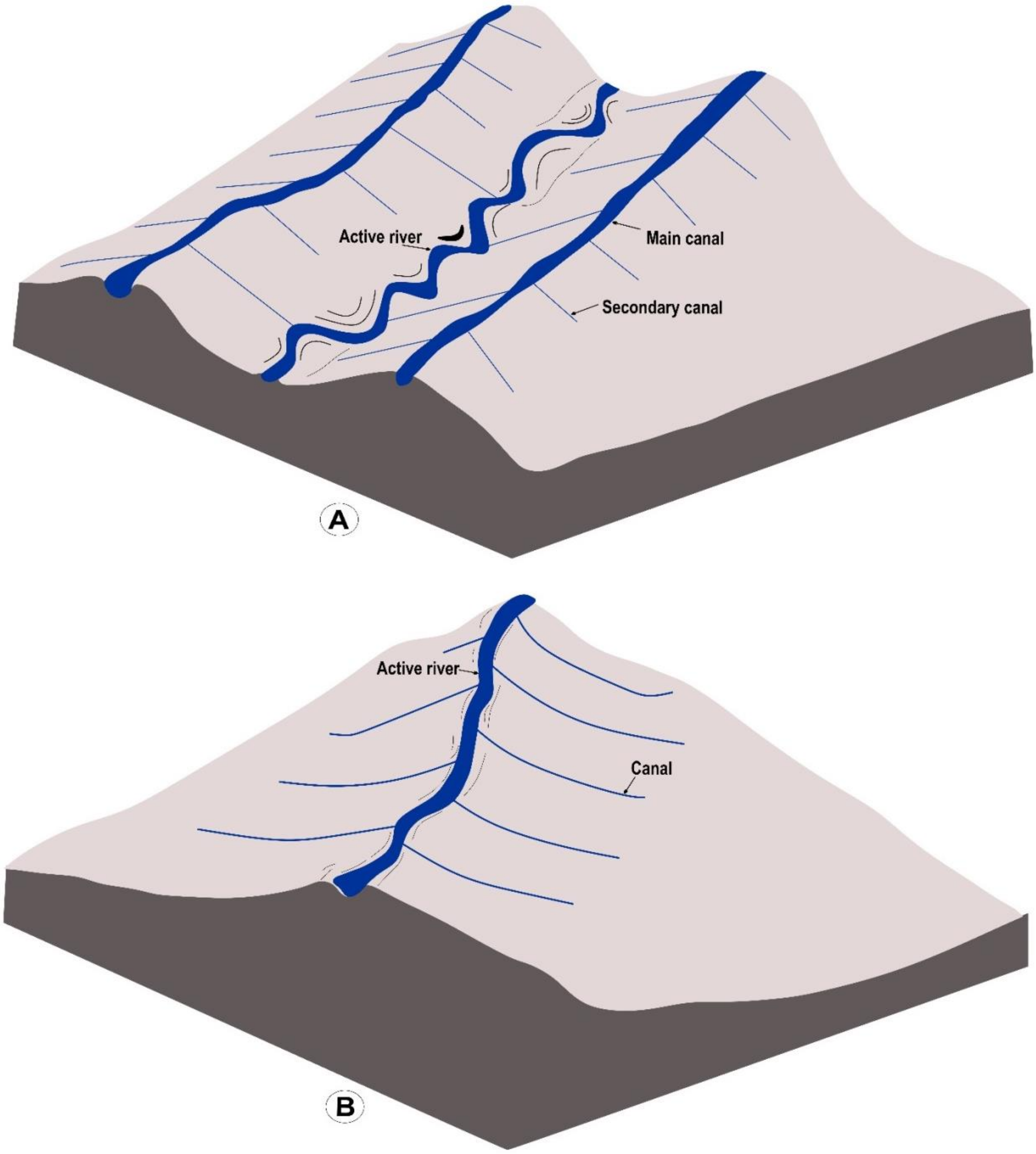

Figure 1.4: Sketch showing the differences between the common rivers meander belt in the Mesopotamian floodplain (A) a river running in a confined meander belt and (B) a river running in an unconfined meander belt. The latter is more likely to avulse in comparison with the former.

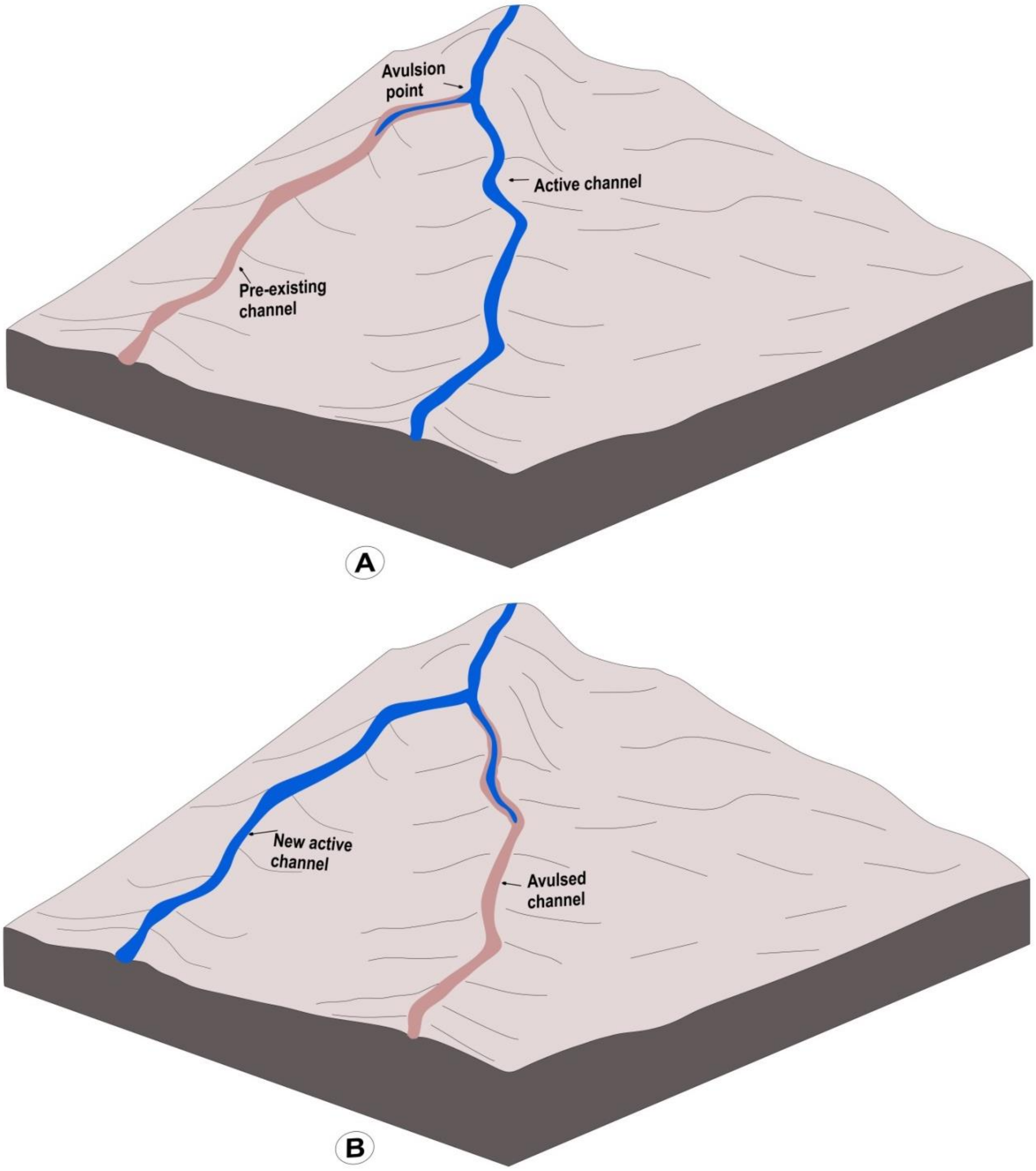

Figure 1.5: Sketch showing the mechanism of re-occupational river avulsions. (A) Water starts running in a pre-existing channel at the avulsion point. (B) Water completely turns to the pre-existing channel, to become the active one while the original one becomes abandoned.

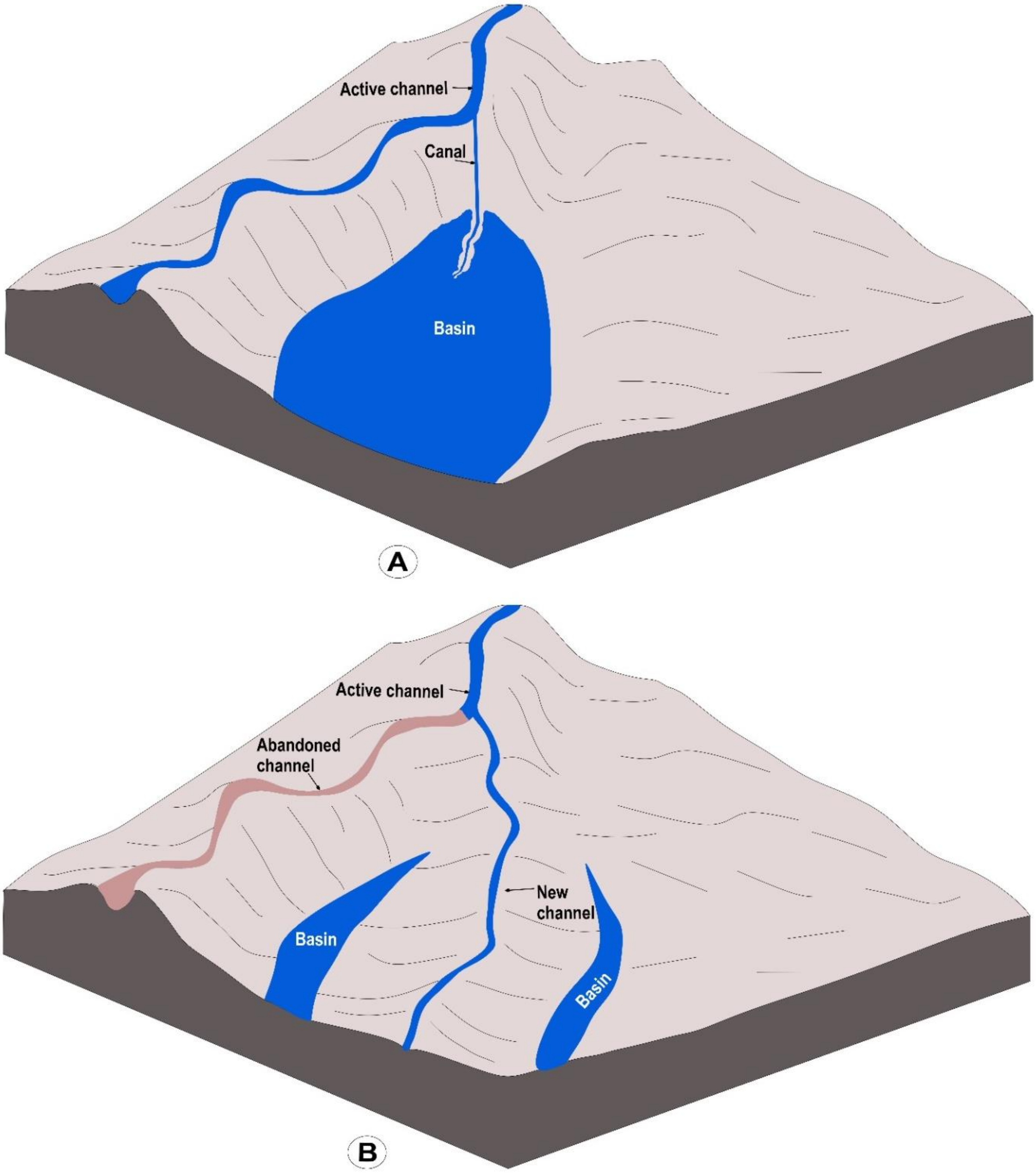

Figure 1.6: Sketch showing the mechanism of progradational river avulsions. (A) Water starts running in a relatively lowland area (basin, marsh etc.). (B) Water completely turns to the lowland area, a channel starts forming and filling the area while the original one becomes abandoned.

1.4 Geology and geomorphology of the Mesopotamian floodplain

Geologically, the Mesopotamian region (Figs. 1.1) represents the foreland basin to the Zagros fold-and-thrust belt (Baltzer and Purser, 1990; Allen *et al.*, 2013), and the Tigris and Euphrates rivers are axial drainage systems passing along this basin from northwest to southeast. The Mesopotamian floodplain was mainly built by the Holocene sediments of the Tigris and the Euphrates rivers (Pournelle 2003; Pirasteh *et al.,* 2009).

According to the Iraqi Geological Survey (Yacoub, 2011) (Fig. 1.2), the Holocene deposits are about 15 - 20m thick, composed of several greyish floodplain sediments alternating between fine and medium sand of a channel belt, and fine sand to silty sand of a crevasse splay, and finally a silty clay to clay flood basin. These sediments were deposited in a climate that was warming up after the last phase of the pluvial conditions of Pleistocene. The Plio-Pleistocene sediments are about 50-150m thick, composed of poorly sorted sand, sandstone and gravels of igneous rock representing a fresh water environment of fluvial to deltaic sedimentation in an extensive sheet, probably large old alluvial fans. The Pleistocene sediment is about 10-15m thick, composed of reddish and pinkish brown course to pebbly coarse grained sands deposited as an alluvial fan and sheet in a run-off environment in relatively wet climatic conditions.

The landscape of the Mesopotamian floodplain is mainly structured by channel processes, including the formation of levees, meanders, scrollbars, oxbow lakes, crevasse splays, distributary channels, inter-distributary bays and marshes. Moreover, several human-made features also organize and shape this landscape, such as canals and both modern and ancient settlements on scales from villages to cities (Verhoeven, 1998; Wilkinson, 2003; Yacoub, 2011).

This floodplain (Figs. 1.3) has clearly defined physiographic boundaries with Al-Jazira Highland and the Low Folded Zone from the northwest and northeast respectively, and the Western and Southern Deserts, in the west and southwest, respectively. As the rivers have been continuously subjected to changes in their courses in this region, redirection of river flow in the Mesopotamian floodplain had a direct impact on the geomorphology of the Mesopotamian floodplain area and the continued existence of ancient settlements (Cole and Gasche 1998; Heyvaert and Baeteman, 2007).

As these settlements include some of the oldest urban sites and long-lasting centres of human settlement such as Ur, Uruk and Babylon, (Fig. 1.3) the controls on their locations and periods of occupations are subjects of great interest for archaeologists, historians, and geoscientists. Conversely, the historical and archaeological records of settlement patterns and their relation with changes in fluvial activity, allow insights into fluvial processes on spatial and temporal scales that are not commonly available, in particular through reconstruction of the ancient courses of the Euphrates and Tigris rivers. The area still contains numerous urban and rural communities, whose existence depends in large part on the behaviour of the regional drainage systems. A better understanding of temporal changes in these systems will have benefits for the present occupants of these landscapes.

1.5 General geomorphology of the modern Tigris and Euphrates in the study area

The morphological form and behavioural characteristics of channels mainly depend on the relationships among several variables such as channel gradient, degree of channel confinement, catchment hydrology and flood history, sediment character and supply, riverside vegetation, climate change, sea level change and human impacts (Schumm, 1981; Blum, 2000; Twidale, 2004;Reinfelds *et al.* , 2004; Peakall, 2007).

It is normal that when channels enter their floodplain downstream these variables change as gradients decrease, discharges increase, confinement decreases, human intervention is intensified and the sedimentation rate increases. Channels in the floodplain are more changeable and subject to major shifting or avulsion (Reinfelds *et al.,* 2004).

In this section, several geomorphological and sedimentological criteria and features including discharge, sediments calibre, gradient, sinuosity, pattern and crevasse splay of the modern channels in the Mesopotamian floodplain will be briefly described. It is worth emphasising that most of these channels or reaches had been affected directly or indirectly by ancient and/or recent anthropogenic activities that led to the forming and reshaping of the channel. However, these effects, which will not be mentioned in this section, will of course be demonstrated in detail in the forthcoming chapters.

1.5.1 Discharge

Both the Tigris and the Euphrates start in Turkey where they rise and receive a large supply of water from rain and melted ice from the Taurus Mountains. The Euphrates rises out of the mountains of north central Turkey while the Tigris drains the mountains of eastern Turkey, northwest Iran and the north of Iraq. The Tigris and the Euphrates meander through valleys in Turkey, Syria and Iraq until they enter the Mesopotamian floodplain (Figs.1.1 and 1.7) where they deposit their sediments through which the floodplain is formed. The Tigris mainly occupies the eastern part of the floodplain while the Euphrates occupies the western side. These two rivers meet at Qurnah in the marshland area to form one river called the Shatt-al-Arab, which reaches the Arabian-Persian Gulf.

The region of the Tigris and the Euphrates (Fig.1.7) has a Mediterranean climate, with hot dry summers and cold wet winters. The rainfall decreases gradually towards the south from about 1000 mm/yr in the 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 assessment of discharge for these two rivers has been accurately recorded since the 1960s. The average over the last 60 years shows that the Tigris has a 40% higher annual discharge than the Euphrates. The average annual discharge of the whole Tigris basin is about 50 billion cubic metres (bcm) while that of the Euphrates is about 32 bcm (Kibaroglu and Unver, 2000).

More than 40% of the Tigris' water resources are generated within Turkish territory, while 51% derive from inside Iraq and 9% from the Zagros Mountains in Iran. In terms of the Euphrates, more than 90% of its water is produced in Turkey and the rest comes from Syrian land. The inflow added to the Euphrates in Iraq along the western desert valleys is of little significance (Kibaroglu and Unver, 2000; Partow, 2001).

The discharge fluctuates from year to year, depending on the amount of the precipitation and the melt water. Moreover, the discharge also changes over the same year. The highest discharge of both rivers is during April and May as it is the peak time for snow to melt in this area (Bozkurt and Sen, 2011).

However, there has been a general decline in the discharges of the Tigris and the Euphrates during the last few decades as a result of dam construction, increased water consumption for irrigation, and climate change (Jones, 2008; Chenoweth, 2011). The discharge calculations from 1970 to 2003 according to IMWR (2005) to the river where it enters the floodplain show that the Euphrates annually discharged approximately 19.68 bcm at Ramadi while the Tigris at Fat'hah discharged about 45.4 bcm. The Adhaim and Diyala tributaries of the Tigris (Fig. 1.7) annually discharge 0.70 bcm and 5.86 bcm in Adhaim and Mansuriyah respectively.

1.5.2 Sediments calibre

In terms of the quantity of suspended sediments, the Tigris carries more than 50% more sediment than the Euphrates. The Tigris in Baghdad (Fig.1.7) transports about 30 million tonne of sediment per year (Abbett & McCarty 1953) while the Euphrates transports about 21 million tonne per year through the Hindiyah area (IMWR, 2002). Most of the sand and silt calibres are deposited in the marshland area before the confluence of the two rivers at Qurnah (Fig. 1.7), while only clay passes down to the Shatt-al-Arab (Philip, 1968). In the marshland area the Euphrates is essentially empty of suspended load whereas the Tigris carries a heavy load of suspended material, and so the suspended sediment calibre of the Shatt-al-Arab River more closely resembles the sediment of the Tigris than that of the Euphrates (Berry et al, 1970). I will discuss the fluctuation of sedimentation rate according to the present study in chapter four.

1.5.3 Gradient

In present study, the gradient of channels within the Mesopotamian floodplain (Fig.1.7) has been measured (Table 1.2) and broadly the results showed that the gradient of significant each reaches of river. Notably, the whole Tigris flows over a higher gradient than the whole Euphrates. For the Tigris, the general gradient from Fat'hah to Qurnah is about 17.24 cm/km. As regards the Euphrates, from Ramadi to Qurnah it is about 9.25 cm/km. Adhaim has the highest gradient at 68.18 while Shatt-al-Arab has the lowest at 1.2.

1.5.4 Sinuosity

It is the ratio of channel distance to down valley distance in other words the ratio between channel length and valley length as the channel length is determined along the channel between two points on a river, and valley length is the straight line distance between the same two points (Williams, 1986). In the present study, the sinuosity of the main channels has been measured (Table 1.2) and the results varied from one river to another and from reach to reach of the same river (Fig.1.7 and 1.9) (Table 1.2) but generally it was comparatively higher in the Tigris and its tributaries than in the Euphrates. In any case it does not exceed 1.80, the maximum, in Diyala and 1.11 in Shatt-al-Arab. (Fig.1.7)

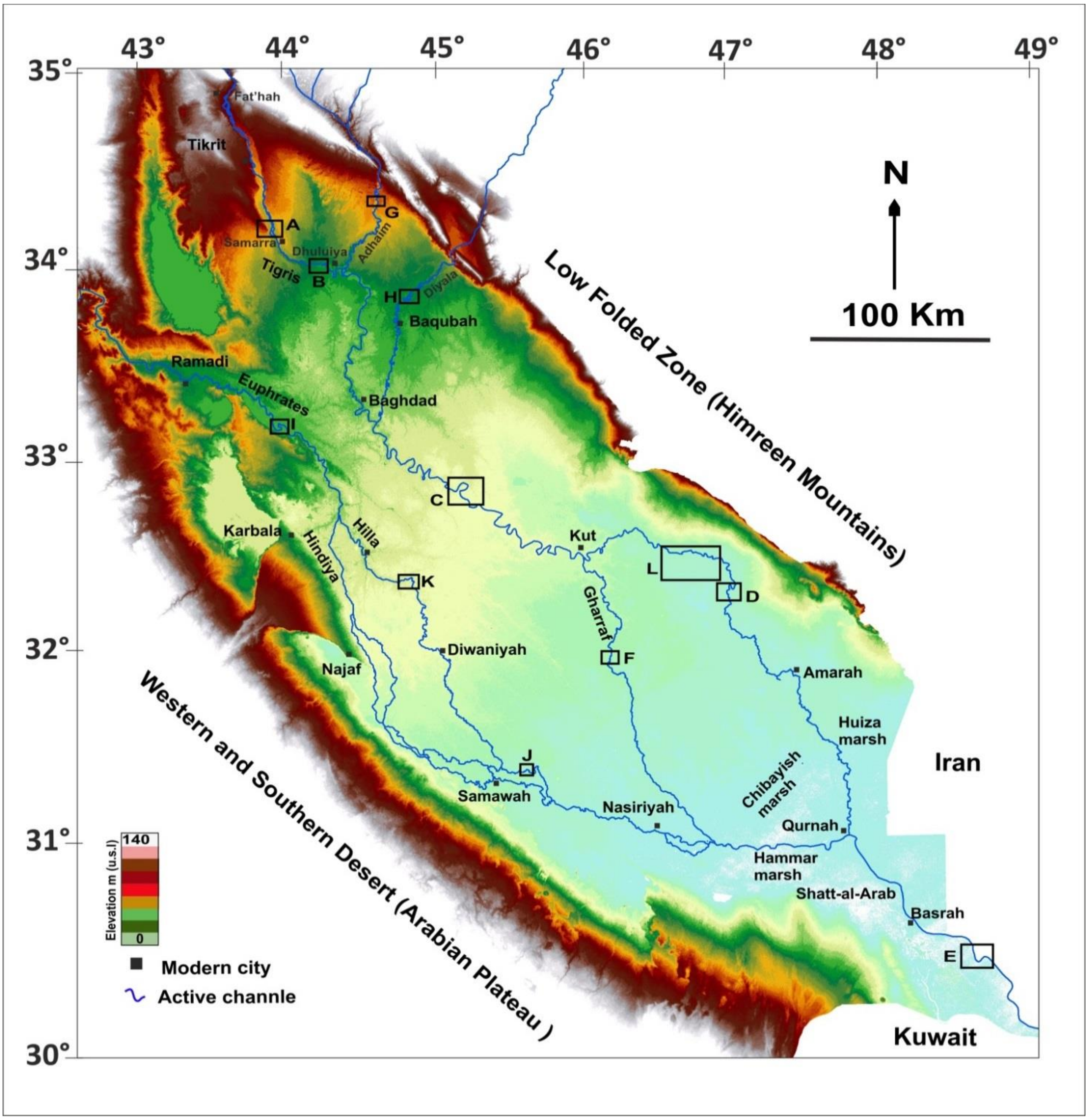

Figure 1.7: SRTM DEM showing the modern channels in the Mesopotamian floodplain.

Channel	Discharge (bcm)	Gradient (cm/km)	Sinuosity	Pattern	Figure No.
Tigris from Fat'hah to Qurnah	45.94	17.24	1.58	-	
Tigris from Fat'hah to Samara	45.94	54.45	1.14	Braided	1.9A
Tigris from Samarra to Dhuluiya	32.34	33.33	1.51	Anabranching	1.9B
Tigris from Dhuluiya to Kut	31.31	7.91	1.72	Meandering	1.9C
Tigris from Kut to Qurnah	30.76	9.00	1.52	Meandering	1.9D
Shatt-al-Arab	6.37	1.20	1.11	Meandering	1.9E
Tigris' Gharraf branch	5.97	8.2	1.32	Meandering	1.9F
Diyala, Tigris' distributary	5.86	33.01	1.80	Meandering	1.9G
Adhaim, Tigris' distributary	0.70	68.18	1.78	Braided	1.9H
Euphrates from Ramadi to Qurnah	19 .68	9.25	1.32	-	
Euphrates from Ramadi to Shinifiyah	19.68	12.30	1.29	Meandering	1.9I
Euphrates from Shinifiyah to Qurnah	14.92	6.07	1.35	Anastomosing	1.9J
Euphrates' Hilla branch	4.5 0	13.06	1.33	Meandering	1.9K

Table 1.2: shows the channels and their discharges, gradients, and sensuosities. The discharge measurement is after the IMWR (2005) while the gradient and sinuosity have been calculated in the parent study. Generally, the Tigris river is higher than the Euphrates in discharge, gradient, and sinuosity. The Dhuluiya to Kut reach has the greatest combination of sinuosity and gradient in relation to other reaches in the river, while the reach from Fat'hah to Samara has the lowest sinuosity and the largest discharge. The Shinifiyah to Qurnah is the most sinuous reach, while the Diyala channel is the most sinuous channel in the whole floodplain. The Shatt-al-Arab has the lowest gradient and sinuosity. The Adhaim channel has the highest gradient and the second highest sinuosity after the Diyala, but the lowest discharge.

1.5.5 Patterns

Several classifications or terminologies have been used over time by geomorphologists to describe channel shapes in floodplains. In the present study, the classification that divides channel behaviours into four patterns is used, namely, meandering, braided, anabranching and anastomosing (e.g. Knighton and Nanson,1993; Twidale, 2004).

As a result, the channels and reaches have been classified as presented in Table 1.2 It can be clearly noticed that the Tigris behaves as braided and meandering while the Euphrates behaves in a meandering and anastomosing fashion. For the Tigris, from Fat'hah to Samarra the pattern is braided while from Samarra to Amara it is meandering. From Amara to Qurnah, it is also meandering but starts to branch when entering the marshland area. For the Euphrates, from Ramadi to Shinifiyah it is meandering, while from Shinifiyah to Qurnah it is anastomosing (Figs. 1.7&1.9).

1.5.5.1 Braided pattern

A braided channel pattern, where several channels that split off and re-join each other to form a braided shape, usually occurs when a channel transfers coarse-grained sediment on a steep gradient and with a high water discharge (Schumm, 1981; Piegay *et al.* , 2009) (Fig 1.8). This pattern is generally characterised by common lateral shifts, frequently totally reshaped by sizable floods, no levees, and non-cohesive banks (Miall, 1977). Consequently, the braided pattern of the Tigris occurs to the north of Samarra (Figs. 1.7&1.9), because of the relatively higher discharge and steeper gradient of the river in this region (Table 1.2). Moreover, the coarse sediments of this reach (Berry et al, 1970) also led to the formation of this pattern.

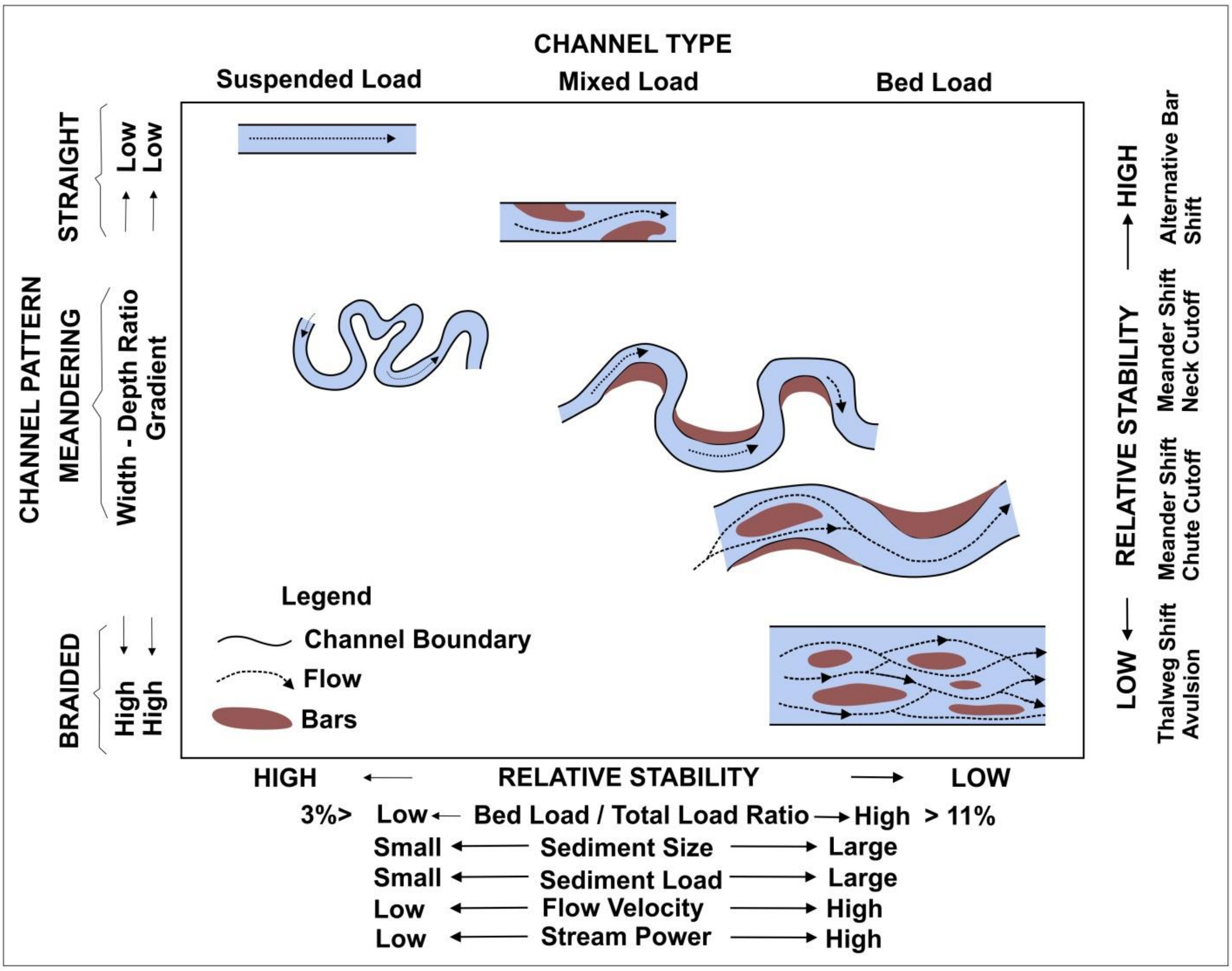

Figure 1.8: Classification of channel based on pattern and type of sediment load with associated variables and relative stability (redrawn from Schumm, 1981)

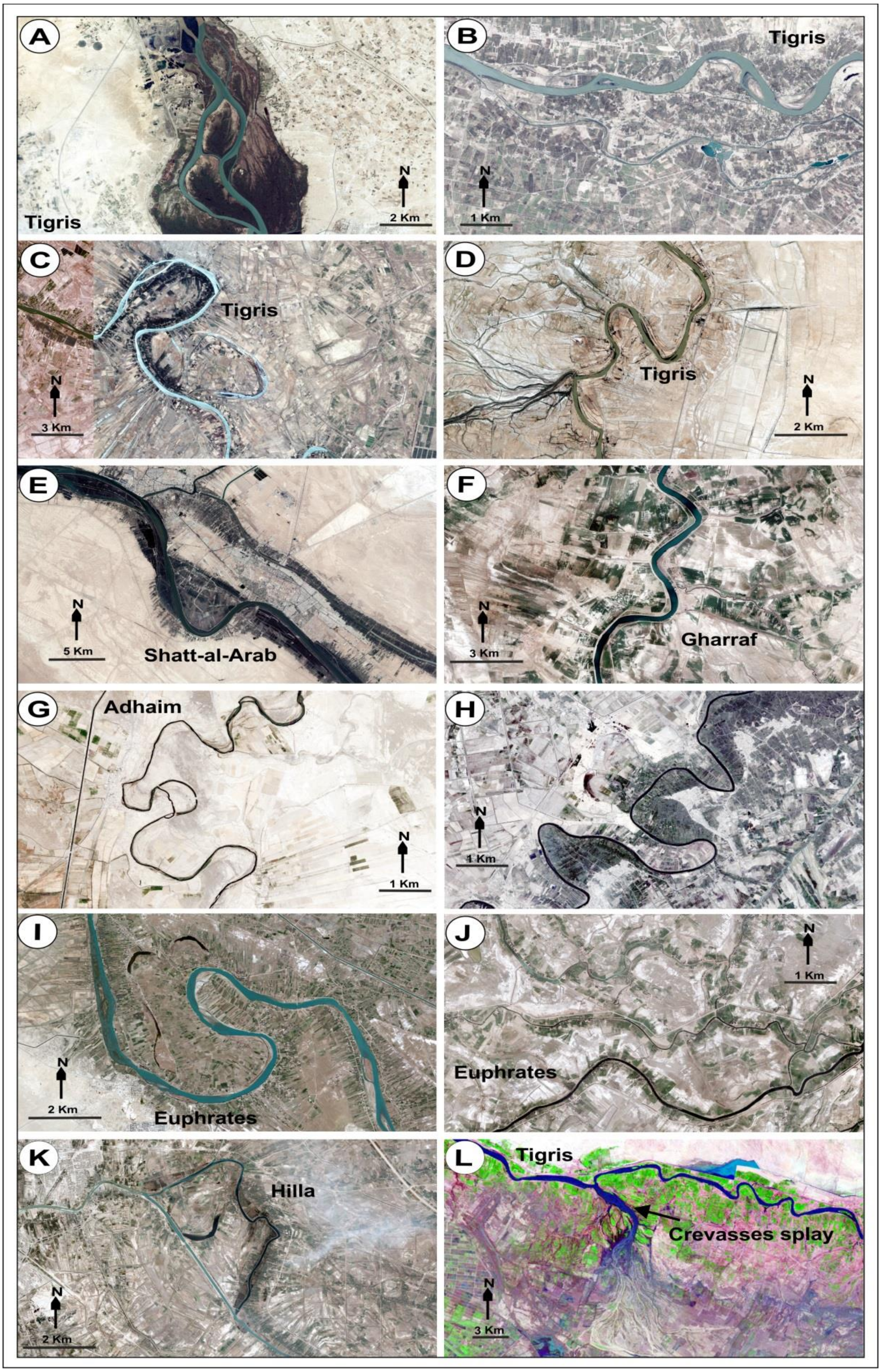

Figure 1.9: (A-K) QuickBird images 2000 and (L) Landsat showing examples of patterns of the modern channels in the Mesopotamian floodplain. See Table 1.2 for more details and Figure 1.1 for location.

1.5.5.2 Meandering pattern

For a given reach of a channel, the patterns mainly reflect the degree of gradient, amount of discharge and particle size of the load (Schumm, 1981; Twidale, 2004) (Fig 1.8). Meanders occur as a result of the deposition and erosion process in the channel where sediments are eroded at the outer banks of channel bends and are deposited in the inner banks.

Usually this meandering process ends when cut-offs occur and the old meander is abandoned and forms an oxbow lake (Hooke *et al.,* 2011). The meander pattern channel is usually a single-thread channel and accompanied by highly elevated levees, a sinuous meander belt , point bars in each curve, cohesive banks, and generally fine-grained floodplain sediments (Twidale, 2004; Peakall, 2007).

In the present study, this pattern is the most common type as most of the reaches and channels have been named ‘meandering’ (Table 1.2). These reaches are the Tigris from Dhuluiya to Kut, the Tigris from Kut to Qurnah, Shatt-al-Arab, the Tigris’ Gharraf branch, the Tigris’ Diyala distributary to the Euphrates from Ramadi to Shinifiyah and the Euphrates’ Hilla branch (Figs. 1.7&1.9).

In all the reaches mentioned above, except for the Gharraf branch of the Tigris’ and the Shatt-al-Arab, there are several visible oxbow lakes associated with the channel. Notably, sinuosity and the number of oxbow lakes decrease gradually downstream until it nearly disappears. The reduction of sinuosity downstream usually reflects a declining gradient (Burnett and Schumm, 1983).

1.5.5.3 Anastomosing pattern

An anastomosing channel pattern is where multiple interconnected channels that enclose flood-basins, separate and re-join downstream (Twidale, 2004). Such a channel pattern is reflected in the low gradient and flood-dominated regimes and is usually characterised by a low-energy flow, cohesive banks, and a stable deposition environment favourable for the accumulation of organic material, together with rapidly aggrading channels and adjacent wetlands caused by a rising local base level downstream (Smith and Putnam, 1980; Makaske, 2001).

In the present study, the reach of the Euphrates from Shinifiyah to the marshland area shows an anatomising pattern, as the reach has a relatively lower gradient and lower discharge than the upstream reaches as some of it is carried in other channels. (Figs. 1.7 & 1.9).

1.5.5.4 Anabranching pattern:

This pattern is similar to the anastomosing pattern in terms of occurrences in flood-dominated situations, cohesive banks and the containment of multiple channels separated by vegetated semi-permanent alluvial islands, eradicated from a floodplain or formed by within-channel or deltaic accretion (Nanson and Knighton, 1996). However, it differs from the anastomosing pattern in its need for a high gradient and a coarser calibre (Nanson and Knighton, 1996; Twidale, 2004).

In the present study, the Tigris reach from Samarra to Dhuluiya is behaving in an anabranching pattern, as it has a high gradient, high discharge (Table 1) and coarser calibre (Philip, 1968). Therefore it is completely different from the anastomosing pattern of the Euphrates reach from Shinifiyah to the marshland (Figs. 1.7&1.9).

1.5.6 Crevasse splays

These are sheetflood deposits with fan- or lobe-shaped features. They are formed by subsidiary river channels where the levee of a channel has been broken, and the flow is fed directly onto the floodplain through a crevasse channel, as a result of point failures of the channel levee – they usually form after times of flooding (e.g. Bristow *et al.,* 1999; North and Davidson, 2012). Crevasse splay activity in a given channel depends on whether this channel is subjected to flooding or not and also whether the channel has reached a settled degree of aggradation that has built a highly elevated levee, able to prevent water from overflowing the banks (Bristow *et al.,* 1999).

In the present study, it was found that the Tigris reach from Kut to Qurnah has several active crevasse splays, while other reaches and branches, mentioned in chapters 3 and 4, have abandoned, ancient examples. This reach is frequently subject to flooding and its banks are not high enough to keep water inside the channel throughout the year (Figs. 1.7& 1.9).This means that the other reaches were subjected to flood in the past but, the aggradation of river levees throughout the time led to silting up of crevasses splays and then reducing flooding.

1.6 Previous studies

This section reviews previous work carried out on the Mesopotamian floodplain, which dealt directly with the palaeochannels.

In term of the palaeochannels, from an archaeological point of view it has been argued that periods of activity of the channels can be established by dating the associated archaeological settlements and most of the identified ancient settlements were established near active channels. (Adams, 1957, 1965, 1972, 1976 and 1981; Gibson, 1972; Wilkinson, 1990; Wright, 1981; Matthews, 1989).

This argument was deployed for the first time in 1937, when Thorkild Jacobsen undertook a field survey of the Diyala area (Jacobson, 1960) (Fig.1.10). From his survey, he identified archaeological sites with different periods of occupations in the study area (from the Ubaid to the Islamic period) and dated the various palaeochannel networks depending on the dates of the sites along them.

1.6.1 Susa (1948)

He discussed the main palaeochannels in the Samarra, Diyala and Kut areas, using limited groundtruthing in certain areas (Fig. 1.10). He suggested dates for these palaeochannels in accord with associated archaeological sites and Islamic historical texts. However, later detailed

excavations, surveys and investigations in these areas have revised his work in terms of dating and reconstructing the channels.
This methodology was applied later by several researchers when they did similar field surveys in other areas in the Mesopotamian floodplain (such as Adams, 1957, 1965, 1972, 1976 and 1981; Gibson (1972); Wilkinson, 1990; and Wright, 1981) (Fig. 1.10). They also found a variety of periods at the archaeological sites and suggested dates for the watercourses based upon settlement data.

1.6.2 Adams (1957 and 1958)

He conducted field survey in the centre of Iraq in an area called the Akkad region, located to the south of Baghdad (Fig. 1.10). Then, focussing on the main palaeochannels, he proposed that the Tigris and Euphrates rivers ran together as one river during the fifth millennium BC, beginning to divide into three main branches somewhere to the north of the Tell Ed-Der site (Fig. 1.10). The first branch passed Sippar and Kish, the second branch passed Sippar and Kutha, while the third passed Tell Ed-Der and Jemdet Nasr. He also suggested that during the fourth millennium BC, the Tigris shifted to the east and separated from the Euphrates to run to the east of the Tell Ed-Der Jamdet Nasr branch. He further claimed that there was another shift of the Euphrates to the west during the first half of the second millennium BC.

1.6.3 Jacobsen (1960)

He used the same methodology, suggested that the Tigris, in the fifth to the third millennium BC, ran to the east of its modern course while the main branch of the Euphrates ran from Tell Ed-Der to Jemdet Nasr and then to the east of Mashkan Shapir and Wilaya (Fig. 1.10).
Interestingly, Adams also continued his survey strategy to cover a wider area of the Mesopotamian floodplain with some more highly developed techniques such as the use of British ordnance survey maps and aerial photographs to identify more sites. Therefore, he was able to survey the Diyala region (Adams, 1965) and then the Uruk region (Adams, 1972), and finally, he completed a wide (but fairly low intensity) survey of the area in the south of Iraq (Adams, 1981) and Wright (1981) (Fig. 1.10).

1.6.4 Northedge, Wilkinson and Falkner (1990)

They excavated the Samarra archaeological sites and were able to conduct a preliminary reconstruction of palaeochannels in the region using aerial photographs and limited groundtruthing (Fig. 1.10). As a result, the researchers partially reconstructed the Nahrawan and Dujail canals as well as the two ancient Tigris courses in this area. Wilkinson (1990) carried out a field survey at the Abu-Salabikh site, which included digging auger boreholes up to 5.4m in depth across the site. He identified several visible channels as well as a buried channel, arguing that some of these channels belonged to the ancient Euphrates (4th – 2nd millennium BC) as Adams had (1981), while other were from the Sasanian periods. He also presented a method of studying the landscape archaeology of the Near East by integrating geomorphological, sedimentological and archaeological analysis based on a geographical information system (Landscapes of irrigation in Wilkinson, 2003). This method was and is widely adopted by several scholars when attempting to practice landscape archaeology (Ur and Ertsen, 2015).

1.6.5 Cole and Gasche (1998) and Gasche *et al.* (2002)

They reconstructed palaeochannel courses in the northwest part of the Mesopotamian floodplain including at the Babylon, Kish, Kutha, Sippar and Tell-Der archaeological sites, and west of Baghdad as far as Ramadi. They integrated geomorphology and textual sources with Adams' (1981) survey (Fig. 1.10) and they suggested the locations of the Euphrates and the Tigris in that region, describing them as follows: from about the third and the second millennium BC, the Euphrates ran from the modern Falluja, and then somewhere to the north of Sippar it divided into three main branches, the Irina, the Purattum and the Arahtum. The Irina branch ran to the east and met the ancient Tigris somewhere south of modern Baghdad. The Purattum ran to the east to meet the ancient Tigris somewhere further south of present day Baghdad. The Arahtum ran south and then split into the Babylon, Kish and Kutha branches. Regarding the ancient Tigris, it ran from Samarra to the west of the modern Tigris and then passed the location of modern Baghdad and continued to the south.

1.6.6 Al-Sadoun (2000)

He studied the ancient course of the Tigris during the Abbasid period from Samarra to Baghdad (Fig. 1.10), focusing on the morphometric analysis of the geomorphological features of the river and its floodplain. He used Landsat images and fieldwork groundtruthing to construct the channel, and he also used the evidence of the associated archaeological sites to date the channel using the two general atlases of sites of Iraq, General Directorate of Antiquities (GDA) (1970) and GDA (1976), both of which deal with the location and the main occupation periods of archaeological sites. However, he was not able to get access to high resolution satellite images nor CORONA images, so he was not able to determine the whole course in greater detail or accuracy.

1.6.6 Steinkeller (2001)

He used textual sources from the UIII period taken from Umma. Most of these tablets describe human activities in terms of the irrigation network and river trading. Therefore he was able to suggest the location of the Tigris and its branches in the Umma region during the third millennium BC based on Adams' (1981) data and the information in the Ur III texts from Umma.

1.6.7 Pournelle (2003)

She integrated remote sensing data, such as CORONA images, SPOT images, with Adams' archaeological survey work (1957, 1965, 1972, 1976 and 1981), and that of Gibson (1972), Wilkinson (1990) and Wright (1981) (Fig. 1.10), already digitized by Hritz (2005) to discuss the importance of the marshes, and their relation to urban resilience in the Mesopotamian floodplain. She argued that the marsh resources in the southern area of the floodplain, especially Uruk, and the Umma downstream regions, along with farming and grazing livestock, provided a stable economy and aided the evolution of the early Mesopotamian Civilisation.

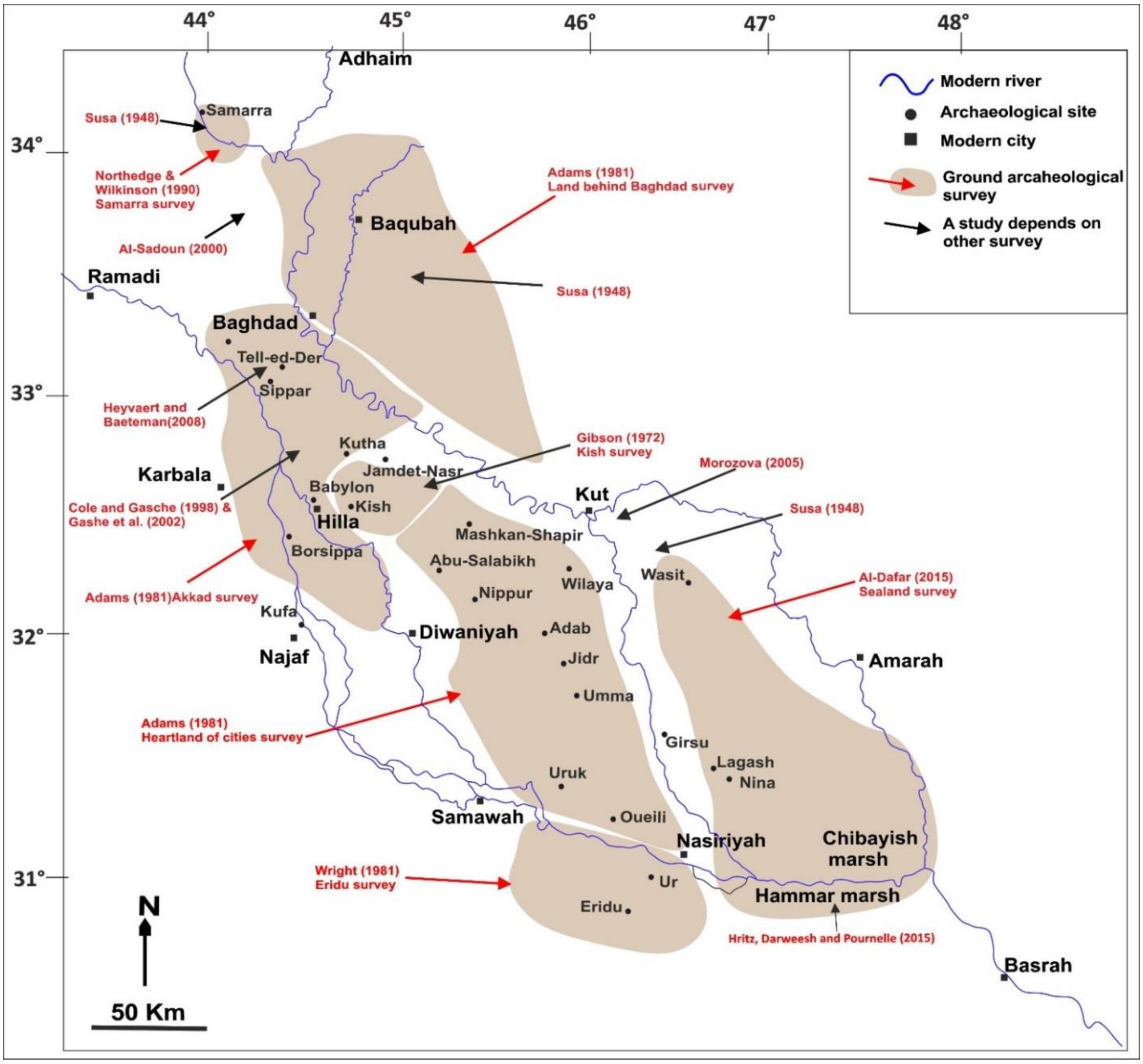

Figure 1.10: Map of the Mesopotamian floodplain showing the location of the previous archaeological sites and palaeochannel surveys.

Pournelle explained the reason behind the existence of significant layers of marsh sediments in the lithological section of the lower part of the floodplain, stating that in her view this region was subjected to seasonal flooding and marsh formation during the fourth millennium BC as a result of the variations in the monsoon track that brought more rainfall to the east and southwest of the Mesopotamian floodplain. Moreover, Pournelle (2012) and Pournelle and Algaze (2014), using remote sensing, geomorphological, and archaeological data, suggested that the presence of rich marsh resources gave the southern regions (i.e. Uruk, and the Umma downstream regions of the floodplain) a great advantage in the emergence of complex societies during the 4th millennium BC in comparison with the northern region of the floodplain.

1.6.8 Morozova (2005)

She did not reconstruct or date palaeochannels but discussed the river avulsion in the Mesopotamian floodplain by analysing previous archaeological, geomorphological and cuneiform texts, maps, satellite images, and geological work. She selected an area within the Kut region in southern Iraq (Fig. 1.10), concluding that two kinds of avulsion could have taken place in the floodplain: re-occupational and progradational. The issues of avulsion location, style and mechanism are a focus for the present study.

1.6.9 Heyvaert and Baeteman (2008)

They analysed the excavation and geological borehole data of the Belgian-Iraqi excavation of Tell Ed-Der and Sippar (Fig. 1.10) carried out in the 1970s and partially analysed by Paepe, (1971); Paepe and Baeteman, (1978); Paepe *et al.* (1978) and Baeteman, (1980). They integrated geological, archaeological and textual data (cuneiform texts of the third millennium BC) to identify the ancient course of the Euphrates in the area. They argued that the ancient Euphrates, which is called the Purattum according to textual resources, had already existed before Sippar was founded during the Uruk period. They estimated that this course avulsed and was completely abandoned in the first millennium BC.

1.6.10 Hritz (2005, 2007 and 2010), Hritz and Wilkinson (2006), Hritz, Pournelle and Smith (2012)

They made huge efforts in terms of identifying archaeological sites and palaeochannels in several parts of the Mesopotamian floodplain. She integrated varied data sources such as the archaeological survey work of Adams (1957, 1965, 1972, 1976 and 1981), Gibson (1972), Wilkinson (1990) and Wright (1981) (Fig. 1.10) along with maps, CORONA satellite images, digital elevation models (SRTM), and aerial photographs. As a result, she plotted 3146 archaeological sites identified by past archaeological surveys and 2129 that were newly identified using remotely sensing investigation (and therefore of uncertain date). She also suggested that the ancient Tigris was located in the Diyala fan and continued to the west of the modern Gharraf channel until the late First Millennium BC. The reason behind her suggestion was that there were linear arrangements of archaeological sites. However, despite her integrated work she was also not able to do fieldwork or undertake groundtruthing. She was also uncertain about several parts of the floodplain that had not been covered by previous surveys, including parts of the Najaf and Kut areas. As a result, she was not able to identify the roles and the history of river avulsions (the Euphrates, the Tigris, the Adhaim, and the Diyla) in the Mesopotamian floodplain.

1.6.11 Yacoub (2011)

He discussed the general geomorphology of the Mesopotamian floodplain based on data collected from several field geological surveys and remote sensing interpretation carried out by the Iraqi Geological Survey Company. As a result, however, he made little mention of the geomorphology of the ancient courses of the rivers in the floodplain, nor did he attempt to identify, date or explain the history of palaeochannels.

1.6.12 Hritz, Darweesh and Pournelle (2015)

They reconstructed the lower part of the Euphrates in the marshland area in the south of Iraq (Fig. 1.10). They pursued remote sensing techniques such as QuickBird (0.5m resolution, taken in 2006), groundtruthing and they used associated archaeological sites, OSL dating and radiocarbon dating analysis to date the reconstructed channel, concluding that it dates from about the third millennium BC. They also suggested that the river was shifted towards the marsh away from the Al-Batin fan as a result of neo-tectonic movement of the subsurface folds.

1.6.13 Al-Dafar (2015)

He undertook an archaeological field survey of the southern marshes of Iraq (Fig. 1.10) in order to discover and date the archaeological sites in this area. He used these data together with textual, ethnographic and ethno-historical data to reconstruct the ancient landscape of the area. As a result, he suggested that the area was covered by marshes and was first settled when a dynasty called the "Sealand Dynasty" ruled the area between 1739-1340 BC. He also suggested the locations of the Euphrates and the Tigris at that time in this area: the Euphrates ran west of Uruk to the south, passing Eridu, adjacent to the Al-Batin fan. The Tigris ran close to Nippur, Adab, Girsu, Lagash and Nina, to disappear into the marsh.

Several geomorphological studies of the modern Tigris and Euphrates rivers in the floodplain were carried out by Iraqi scholars, but the majority of these studies dealt with the morphometric analysis of the rivers rather than the history of their formation or avulsions. For example, Al-Khafaji (2003) discussed the morphometric properties of the Euphrates river in the south of Samawa (Fig. 1.10) without any attempt to date or understand its formation. Another example is Hussein (2007), when he discussed the geomorphology of the Gharraf branch of the Tigris (Fig. 1.10), he stressed that he was not able to cover the date or the style of formation of this river as there were insufficient data to analyse this issue in his project. The final example is Rzoqi (2012) who studied the Tigris river south of Kut (Fig. 1.10), and was also not able to address the issue of the date or the mechanism of the formation of the river, dealing with the morphometry of such features as meanders, channels, oxbow lakes, crevasse splays.

No comprehensive study comparable with the current thesis has been attempted to investigate river avulsions in the whole area of the Mesopotamian floodplain.

1.7 Thesis outline

Following this introductory chapter, structure of the thesis is as follows:

Chapter 2**:** This chapter explains the methods that were implemented to achieve the aims of the present study, which is a combination of geological, geomorphological, remote sensing, historical, and archaeological approaches.

Chapter 3**:** This chapter is devoted to presenting the course of the Euphrates by dividing the area into three sub-areas (Fig. 1.11), which are: first, the Najaf area which covers the northeastern part; second, the Ur area, covering the central eastern part, and third, the marshland area covering the southern part of the floodplain.

Chapter 4**:** This chapter is dedicated to presenting the courses of the Tigris by dividing its area into five sub-areas (Fig. 1.11) which are as follows: first, the Samarra area where the main Tigris runs, in the northern part; second, the Adhaim area where the Adhaim tributary runs and joins the Tigris; third the Diyala area where the Diyala tributary runs and joins the Tigris; fourth, the Baghdad area with the Tigris running in the central part of the floodplain, and the fifth is the Kut area where the Tigris runs and joins the Euphrates in the south.

Chapter 5**:** This chapter presents the discussion, conclusions and subjects and ideas for possible future research, building on the results of this thesis.

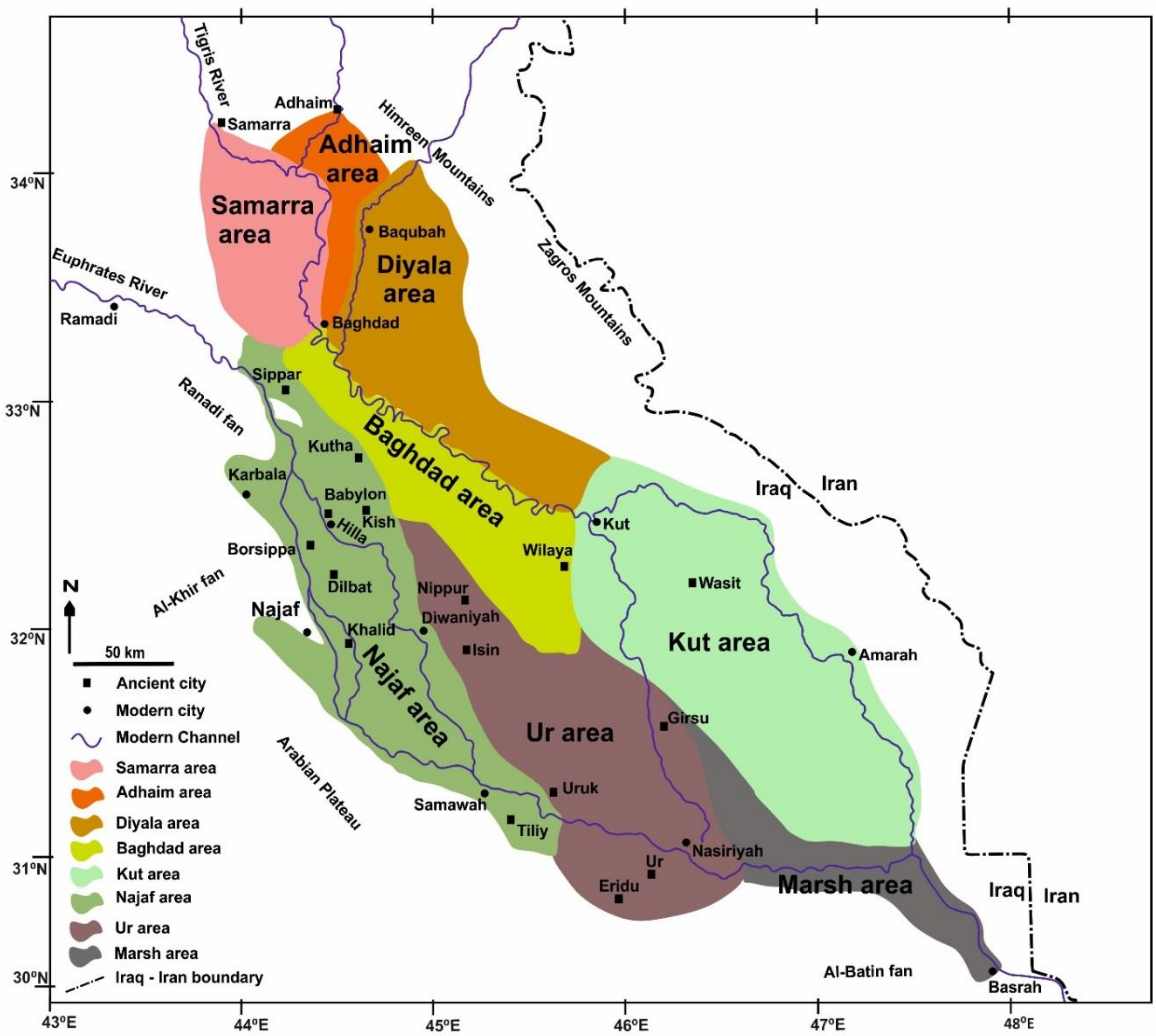

Figure 1.11: Map of the Mesopotamian floodplain showing how the study area has been divided into several subareas in the present study.

2. Methodology

The research was carried out using a combination of geological, geomorphological, remote sensing, historical and archaeological approaches. Fieldwork included “groundtruthing” of the remote sensing work, drilling boreholes (up to 7m in depth), sedimentary and geomorphologic documentation and the collection of samples for radiocarbon dating.

2.1 Remote sensing

Note: this description of remote sensing methods forms the basis for the following paper:
Jotheri, J. and Allen, M.B., in press. Recognition of ancient channels and archaeological sites in the Mesopotamian floodplain using satellite imagery and digital topography. In: Lawrence, D., Altaweel, M. and Philip, G. (eds.), *New agendas in remote sensing and landscape archaeology in the Near East: Studies in Honour of T.J. Wilkinson*. The Oriental Institute of the University of Chicago, Chicago, Illinois. I wrote the text and prepared the figures. Mark Allen commented on the text and provided supervision.

2.1.1 Preface

The main aim of using remote sensing in the present study is to recognize ancient channels and archaeological sites in the Mesopotamian floodplain. Satellite images and digital elevation models, including SRTM (Shuttle Radar Topographic Mission), ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), CORONA and QuickBird data, are examined in this study. Several aspects of visual interpretation are discussed, including elevation, tone or colour, texture, pattern, shadow, shape, size, and situation. Many archaeological sites and ancient channels have been recognized using these types of images.

Examination of satellite imagery and digital topography has become an increasingly important tool for geologists, geomorphologists and archaeologists, because this method integrates information drawn from multiple sources and provides accurately calibrated physical locations (Hritz 2010). The use of such techniques to identify palaeochannels and ancient settlements has increased in recent times the study of the Middle East region (e.g. Pournelle, 2003, Hritz, 2010, Scardozzi, 2011 and Ur, 2013).

ArcGIS version 10 was used to examine CORONA and QuickBird images, and SRTM and ASTER digital elevation data. But, the specific GIS platform and datasets are perhaps less important than the methodology, and the understanding of what signals in the data are important. I do not attempt to review all available topographic and satellite image platforms and datasets, but instead focus on some of the generic features of sites and landforms in the Mesopotamian plain that can be identified and interpreted using such imagery (Fig. 2.1). The next sections briefly review data sources.

We stress the physical appearance of features of interest, and have not paid detailed attention to processing multispectral data for image enhancement. In part this is because such techniques are not applicable to the high resolution panchromatic data used. Additionally, such techniques are not always required for the identification and interpretation of key features. The high spatial resolution of both panchromatic datasets and digital topography is the critical parameter.

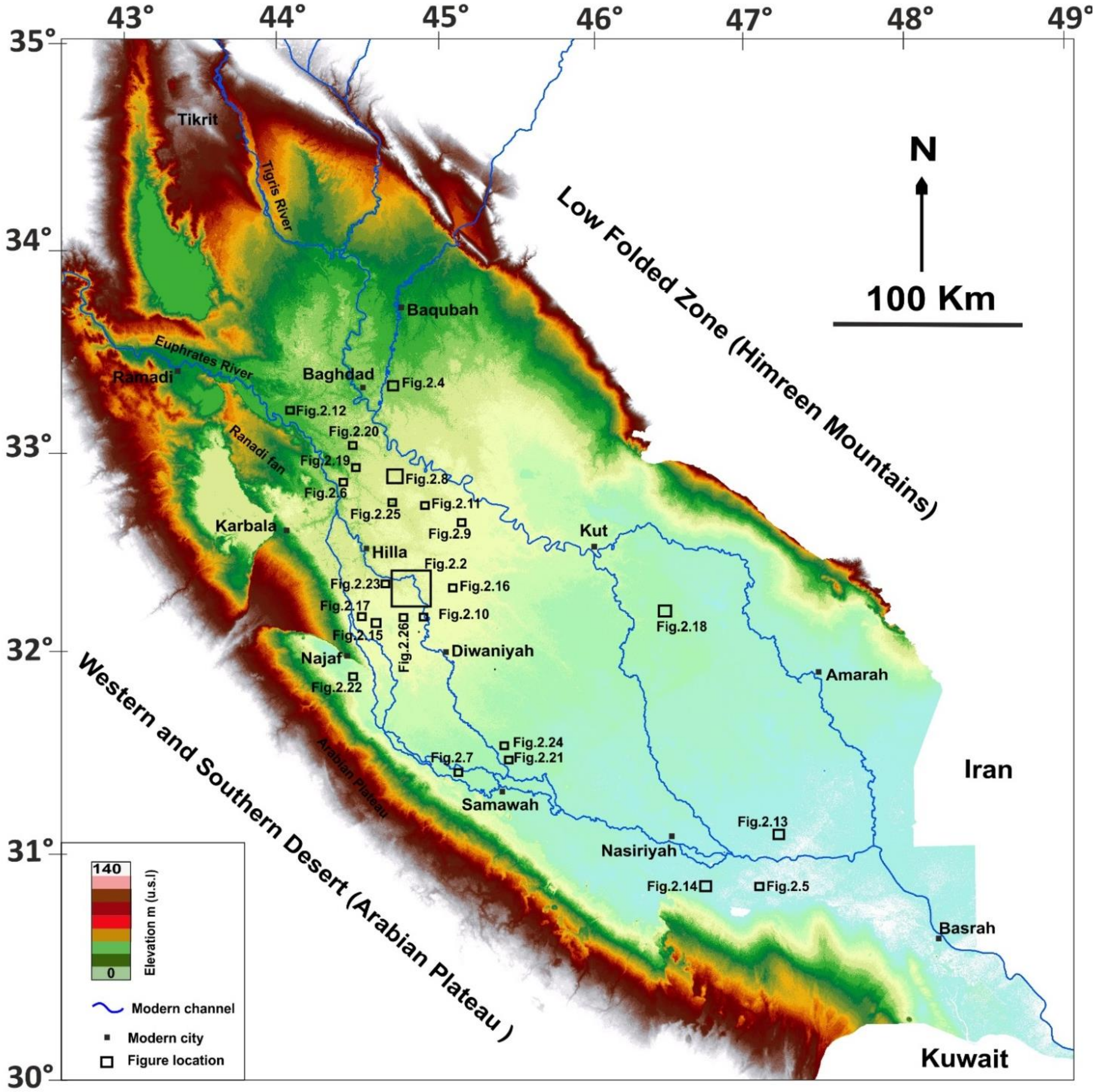

Figure 2.1: Location map of the study area, highlighting major modern river channels.

2.1.2 Remote sensing data

2.1.2.1 Digital topography (SRTM and ASTER)

SRTM data were acquired via a radar system that flew on board the Space Shuttle Endeavour in 2000, with the objective of producing elevation data for most parts of the globe. Imagery is available for Iraq with the standard 90m pixel size, and it can be freely downloaded online from the Consortium for Global Agricultural Research (CGIAR) website.

ASTER data have a pixel size of 15 m, and include data in 14 spectral bands, from the visible to the thermal infrared wavelengths. A stereo viewing capability has made it possible to create digital elevation models, which are now also available (referred to as ASTER GDEM). Data and

more specific information on ASTER and its various instruments are found at NASA website (Rexer and Hirt, 2014).
Most geomorphologic features of the palaeochannels and archaeological sites in the Mesopotamian floodplain have a relatively high topographic elevation with respect to the surrounding area; this phenomenon can make these features easy to identify in both SRTM and ASTER data (Altaweel,2005 and Hritz and Wilkinson, 2006), i.e. digital elevation data may be more useful than either panchromatic or multispectral satellite imagery, even if the spatial resolution is lower, because the crucial element in identifying features is their relative height. Conversely, some palaeochannels and archaeological mounds with low elevation and small dimensions cannot be identified by SRTM or ASTER because their resolution and accuracy are not sufficient to allow the recognition of certain features (Rexer and Hirt, 2014).

In this chapter I demonstrate how to use the visual expression of objects that are detectable in QuickBird and CORONA satellite images to recognize palaeochannels and archaeological sites, as well as how to recognize these features by examining SRTM and ASTER topography.
Interestingly, channels in the Mesopotamian floodplain are characterized by their levees, created by the cumulative process of sediments deposition following each annual flood. Over time, this process creates a strip of sediments at an elevation some way above the level of the floodplain. SRTM and ASTER data can be used to examine and quantify topographic values of the surface features in several ways, such as cross-profiles of river levees (Hritz & Wilkinson, 2006). Simple topographic maps can, at times, be sufficient to show raised levee systems where such features are not clear on multispectral or panchromatic satellite imagery.

In practice, not all ancient rivers are detectable in the topography data, for example, in the case of levees that have been destroyed by cultivation or quarrying, or where the levee has a relatively low relief with respect to the surrounding area. Standard GIS packages are able to present and process SRTM and ASTER data, with colour scale manipulation and artificial shading among the tools routinely employed to assist in the identification of levees and site features.

2.1.2.2 CORONA Imagery

CORONA images were derived from a United States intelligence program of satellite reconnaissance. They were used from 1959 to 1972 and then declassified by the American Government in 1995. The data have been publicly available since 1998. These images can be searched and ordered via the Internet through the United States Geological Survey website or downloaded from the Arkansas University website (Casana, and Jackson, 2013). CORONA images are particularly useful for the reconstruction of ancient landscapes because they provide a valuable archival record of many surface features that have been destroyed by urban development or large-scale agricultural development projects, undertaken since the 1960s. As the original platform was high resolution photography the images can be considered as panchromatic (greyscale) data (Philip *et al.,* 2002).

Many natural surface features can be clearly identified in CORONA images because of the high spatial resolution of the imagery. The best ground resolution for different CORONA missions is quoted as from ~13 to 2 m (Ur, 2013). Examples include river scrolls and crevasse splays. Levees and archaeological sites can also be identified by the clear shadow they cast because of their relatively high elevation in relation to the surrounding area (Ur, 2013). In fact, analysis of CORONA images has revealed several ancient river channels that cannot be identified using other examined images.

2.1.2.3 QuickBird Imagery

DigitalGlobe is a commercial company founded in 1994 that provides high resolution satellite images to governments and to companies such as Google. In 2009 it started to sell QuickBird satellite images to the public. The imagery is very high resolution: 61 cm for panchromatic data and 2.44-1.61 m for multispectral data. In 2007 the Iraqi Government purchased QuickBird images from 2006 for the whole of Iraq with resolutions of 0.6m and with Natural Colour; these images were used in the present study. QuickBird imagery has proven to be useful in both verifying results and locating potential geomorphological features that cannot be easily distinguished using other satellite data. Note that images derived from QuickBird (and other sources) derived from the Google Earth platform are subject to copyright arrangements.

2.1.3 Useful Characteristics

Recognizing palaeochannels and archaeological sites and observing the differences between these features and their backgrounds involves a comparison of different features based on one or more of the visual elements of height, tone, texture, pattern, shape, shadow, size and situation **(**Joseph, 2005; Lillesand et al, 2008)**.** Visual interpretation of QuickBird and CORONA images using these elements is the best way to identify these features, especially when SRTM and ASTER data analysis is of limited value, because of scale (resolution) issues.

2.1.3.1 Relative height

Relative height refers to the difference amongst several features. As noted above, the tendency of both natural and human landforms to have relative height differences means that digital topography can be used for their identification and interpretation. SRTM (Fig. 2.2) and ASTER (Fig. 2.3) data are used in the examples in conjunction with analysis of historical literature of the region and original fieldwork. The specific workflow involved initial location of palaeochannels and archaeological sites from the literature, followed by manipulation of the SRTM and ASTER data to produce maps with elevation scales that highlight the features of interest, followed by targeted fieldwork to sample material for radiocarbon dating. Note that the resolution of SRTM and ASTER data is sufficient in these examples to allow levees on distributary channels and canals to be mapped.

It is not easy to distinguish between palaeochannels and active or recently abandoned channels because both appear as ridges relatively higher than the surrounding area. However, in some cases, modern channels can be identified because their two banks are high enough to be recognisable in relation to the channel itself (Fig. 2.2). In contrast, the palaeochannels appear as one levee, i.e. “one ridge”, because the two levees have been eroded over time and the channel bottom has filled, thus forming a single ridge (Fig. 2.3). It has been noted in the present study that some of the Sasanian channels have a convex topographic profile i.e. two well identified levees with a channel between them because the older channels have infilled to a greater extent than the Sasanian ones. The topographic profiles of older channels (Babylonian or earlier), however, have a relatively smooth and concave profile.

2.1.3.2 Tone

Tone refers to the relative brightness i.e. strength of reflectance and colour of objects in an image. Palaeochannel levees (Fig. 2.4) and the isolated islands of archaeological mounds (Fig. 2.5 and Fig. 2.6) can be recognized in QuickBird images because of their differences in tone and colour. In QuickBird imagery, the essential element for distinguishing between different objects or features is the colour of the objects (Fig. 2.7A), whereas in CORONA, in the negative format, it is the brightness of the objects (Fig. 2.7B). In several cases it is difficult to recognize palaeochannels in QuickBird images (Fig.2.7A) because there is not enough relative brightness. Therefore CORONA images (Fig. 2.7B) proved better to trace the feature (Fig.2.7C and7D). However, in some places, the advantage of cultivation of the land is evident, leading to changes in the tone of the irrigated land and producing archaeological mounds, which become more recognisable as the farmer develops the area around the site, making it easy to see the anomalies, such as mounds and levees in other images.

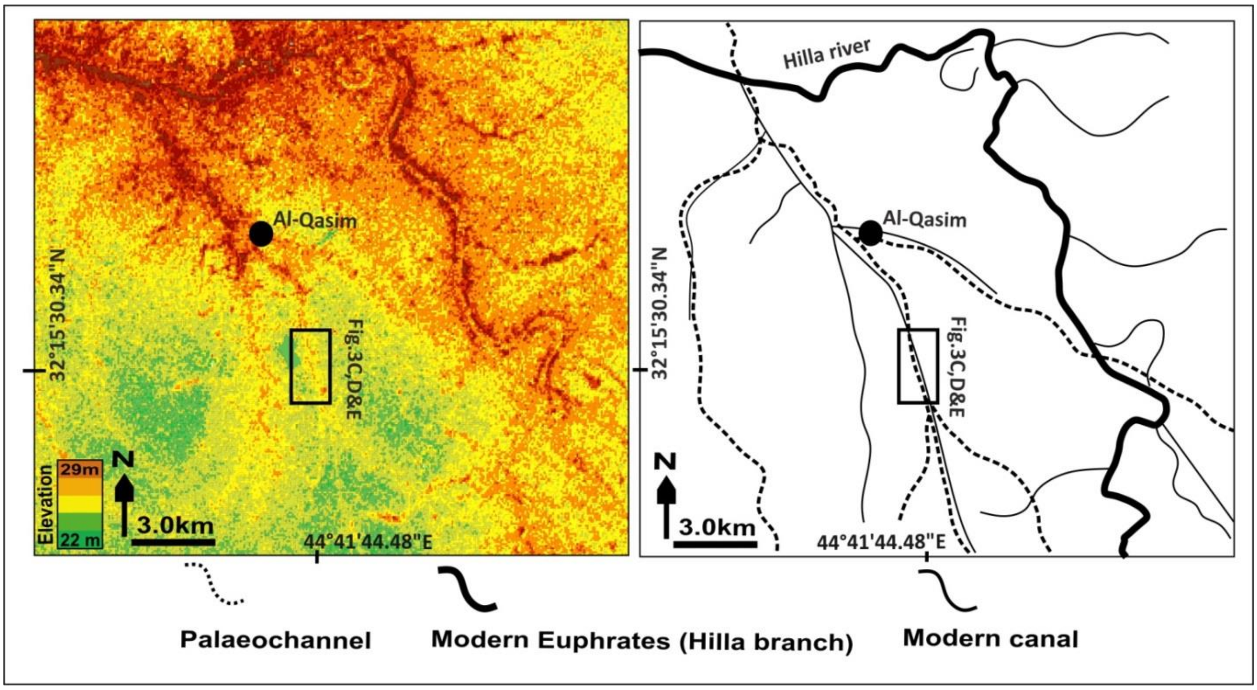

Figure 2.2: Example of elevated topography associated with a palaeochannel from an area to the south of Hilla, as it appears in SRTM data.

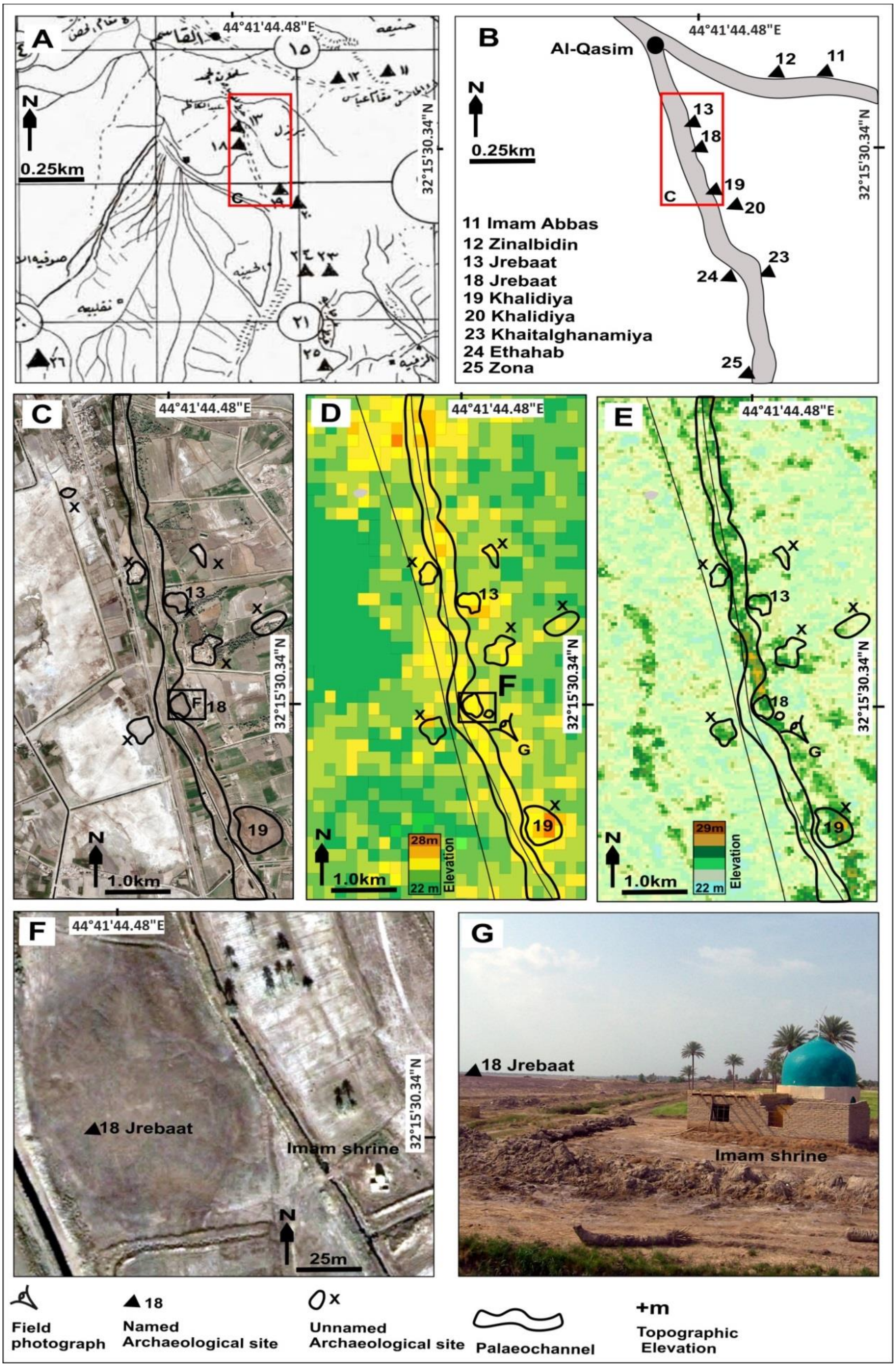

Figure 2.3: Tracing palaeochannel and archaeological sites using different datasets. (A) General Directorate of Antiquates (GDA, 1970) map showing the location of archaeological sites and palaeochannels in Al-Qasim city in Babylon province. (B) Sketch showing palaeochannels and archaeological sites from Figure 2.3A (C) QuickBird image covering part of Figure 2.3A. (D) SRTM data covering the same part of Figure 2.3A. (E) ASTER GDEM data covering the same part Figure 2.3A. (F) QuickBird image covering Jrebaat site (number 18). (G) Field photograph showing the Jrebaat site and Imam Shrine.

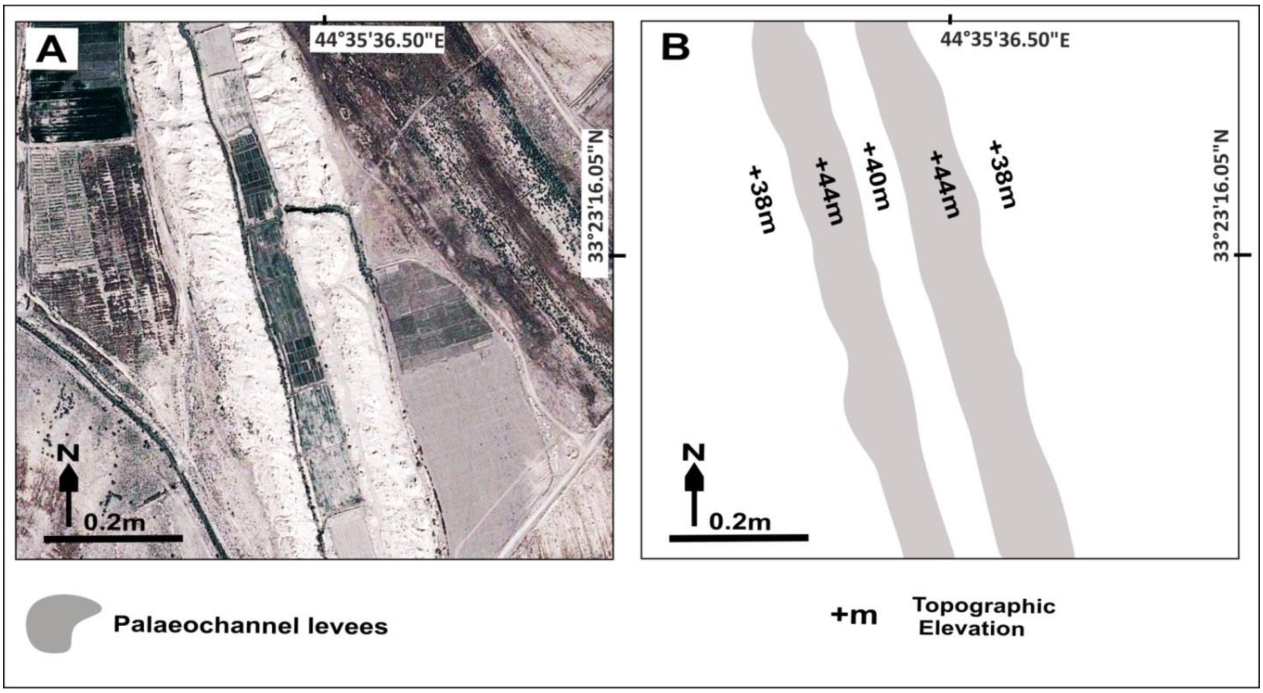

Figure 2.4: Example of a palaeochannel to the south of Baqubah City (Fig. 1), highlighted by its tone in QuickBird imagery.

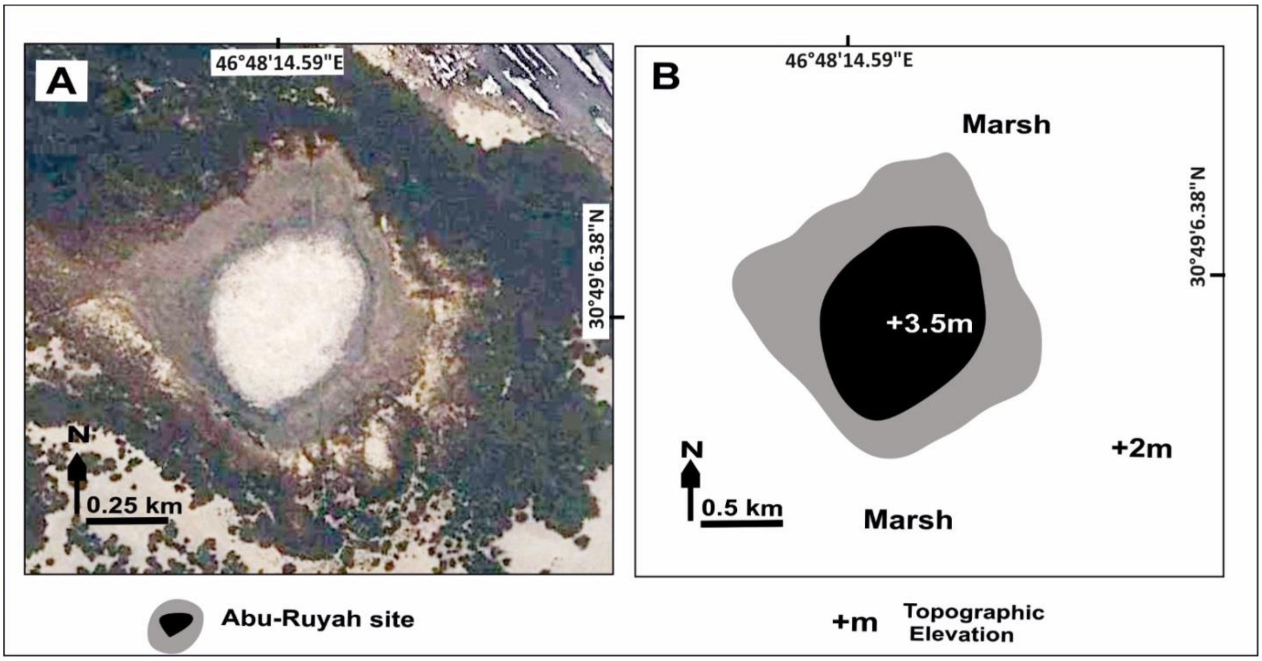

Figure 2.5: Example of an archaeological mound surrounded by marsh south of Iraq, utilising its tone in QuickBird imagery.

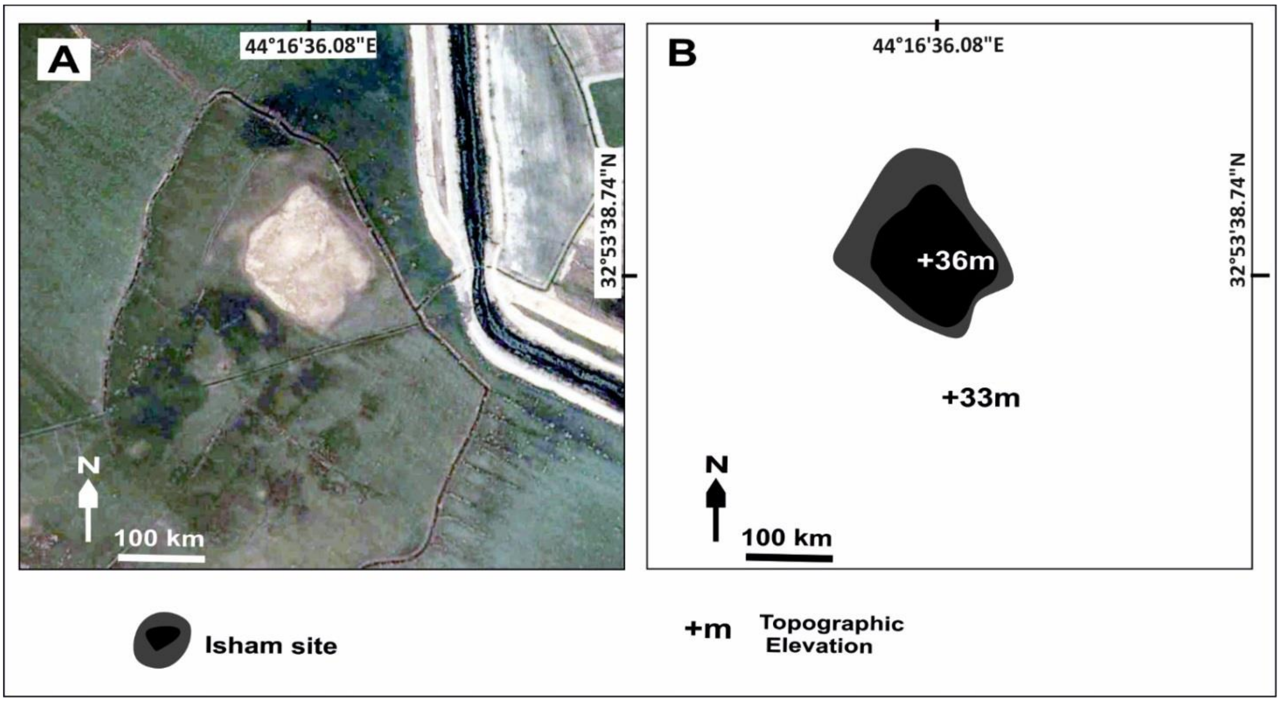

Figure 2.6: Example of an archaeological mound to the north of Hilla city, utilising its tone in QuickBird imagery.

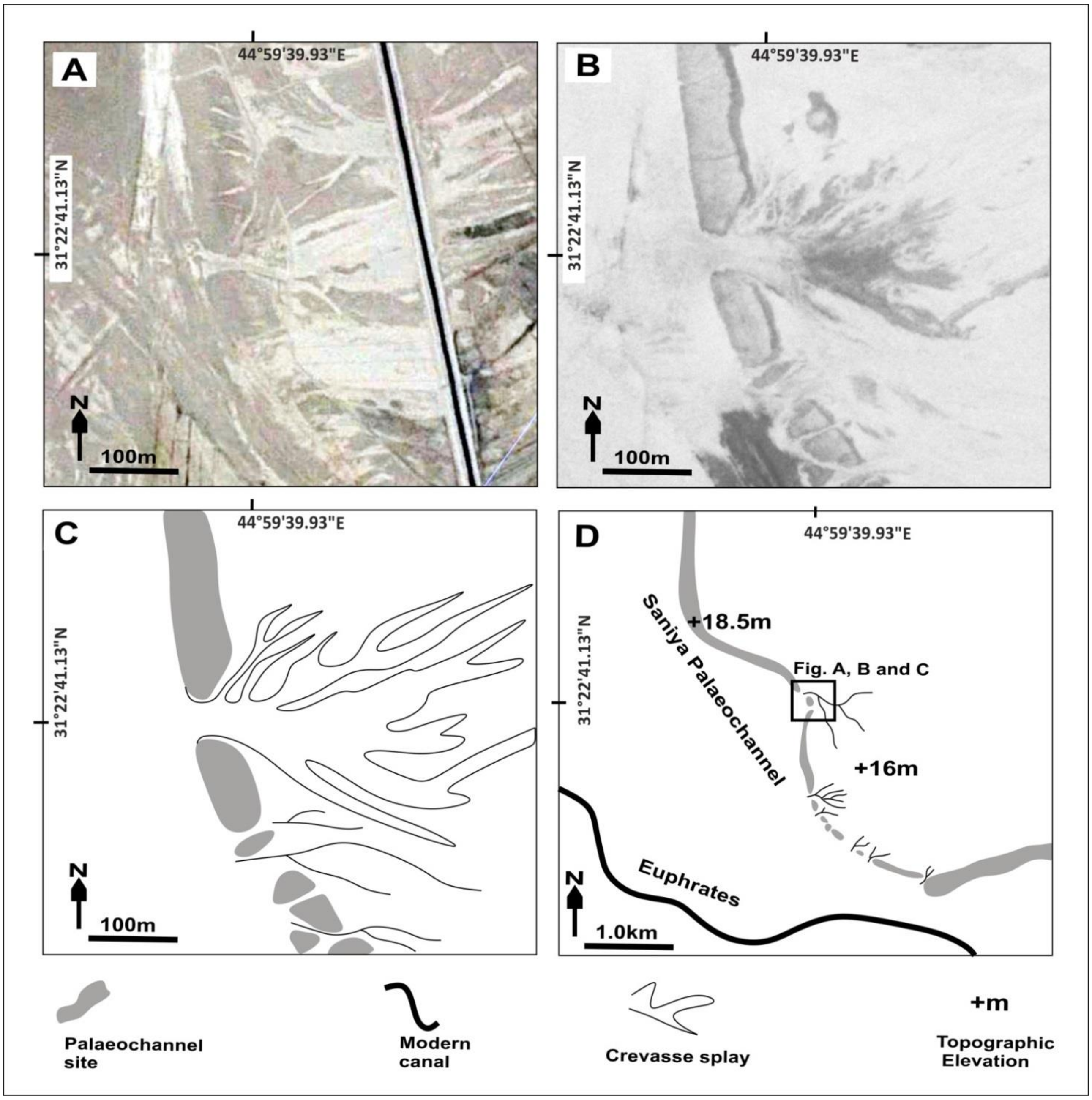

Figure 2.7: Example of a crevasse splay alongside a palaeochannel to the northeast of Samawah city, identified by their tone. (A) QuickBird image. (B) CORONA image. (C) and (D) Sketch showing tracing of the palaeochannel and crevasse splay.

2.1.3.3 Texture

Texture refers to the arrangement and frequency of tonal and colour variation in specific areas of an image. Palaeochannel scrollbar features (ridges and swales) are usually formed as a result of lateral migration of rivers, leading to the formation of parallel and systematic lines of ridges and swales. The present study revealed that this feature can occur as an associated feature of palaeochannels everywhere within the Mesopotamian floodplain. Therefore, this feature can be used as an indicator for the identification of palaeochannels in high resolution satellite images, such as QuickBird (Fig. 2.8, 2.9 and 2.10) and CORONA (Fig. 2.11A). The method works because there is a relative difference in topographic elevation between ridges and swales, and also because ridge sediments are coarser than swale sediments, as a result of natural sedimentation of river in the meandering are, thereby forming a relative difference in tone and colour.

This feature is always associated with natural rivers (Fig. 2.10); it is limited in the case of anthropogenic canals. Although, in a few cases, such canals can meander over time so that scrollbars are formed, it will be across a smaller area in comparison with natural rivers (see Fig. 2.18). The scrollbars of natural channels can occasionally be discovered because they were covered by more recent human-made canals, associated with natural river levees or removed as a result of later cultivation projects. Most human settlements were built close to channel levees, so in the case of lateral river migration, new human settlements are built close to the new location of the channel. For this reason, human settlement patterns tend to follow the shape of these levees or scrollbars (Fig. 2.10).

2.1.3.4 Pattern

Pattern refers to the spatial arrangement of features by repetition of similar tones or colours or textures. Many archaeological mounds have natural radial drainage (Fig. 2.12) as a result of rain water running over the mound surface, which, over time, can become wider and longer and can easily be seen in QuickBird images, giving a good indication of the existence of archaeological mounds. However, the size of these drainage gullies clearly reflects how the site has been affected by erosion. It can be seen that sites that are wide and high tend to have the gullies that are wider and deeper, than those of smaller sites. Consequently, the size of these drainage gullies may give an indication of the height of the site i.e. the greater the length of the guilles, the higher the mound is likely to be.

There are several mounds located in marshland areas, in the southern region of the Mesopotamian floodplain (Fig. 2.13 and 2.14), that have been surrounded and partially covered by water. Most of these mounds are archaeological sites and were identified after the southern marshes dried up in the 1990s, however, some of these mounds have recently been used as a base to build human settlements because of the low risk of flooding or because it is the only dry land in the marsh area (Ur and Hamdani, 2014). These mounds can be seen clearly in QuickBird images but cannot be identified by SRTM and ASTER because of their low elevations (generally less than 2m above to the surrounding marshes). It is worth highlighting the fact that most of these mounds are characterised by radial features, “linear hollows”, which are a good indication of existing archaeological sites in the marsh (Fig. 2.15). According to Pournelle (2003) and Ur and Hamdani (2014), these features are the result of a combination of boat and buffalo traffic in and out of the marshes, and they are preserved as soil and vegetation marks resulting from their micro-topography and variation in organic content and hydration level as compared with their surroundings. These features have also been recorded in northern Mesopotamia where they are termed ‘hollow ways’ and have been interpreted as the remains of tracks that were used to reach fields and outlying pastures (Wilkinson, 1993). However, a limited number of cases have been observed in the present study where some of these features look like channels, i.e. there is water running between two banks and connected with a modern channel.

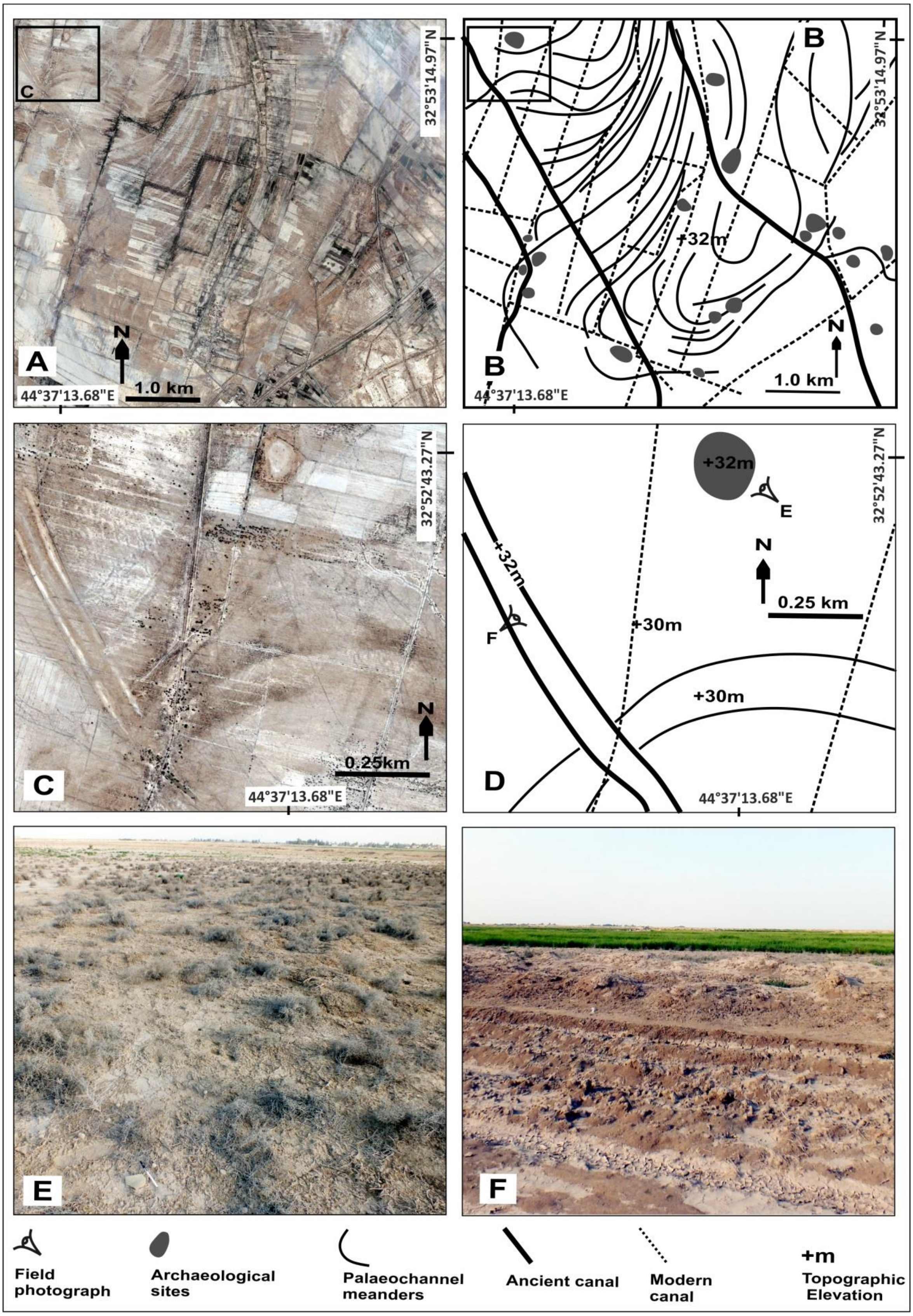

Figure 2.8: Recognition of palaeochannels and archaeological sites according to their texture in QuickBird images. (A) QuickBird image showing palaeochannel and archaeological sites located to the south of Baghdad. (B) Sketch showing the identified palaeochannel and archaeological sites of the image in (A). (C) QuickBird image showing the palaeochannel and an archaeological site in part of the image in (A). (D) Sketch showing the identified palaeochannel and archaeological sites of the image in (C). (E) Field photograph showing site of the image in (C). (F) Field photograph showing Sasanian canal visible in image (C).

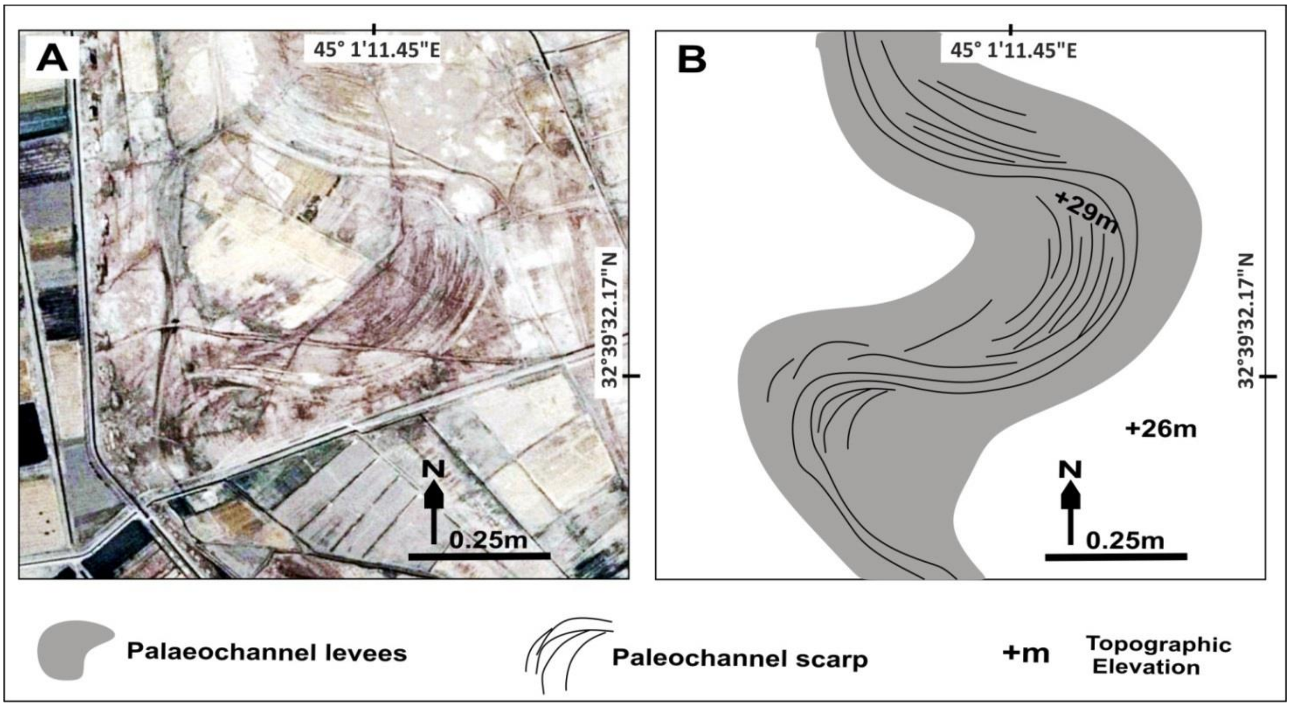

Figure 2.9: Recognition of palaeochannel and archaeological sites according to their texture. (A) QuickBird images showing palaeochannel meanders north of Kut City. (B) Sketch showing the identified palaeochannel meanders.

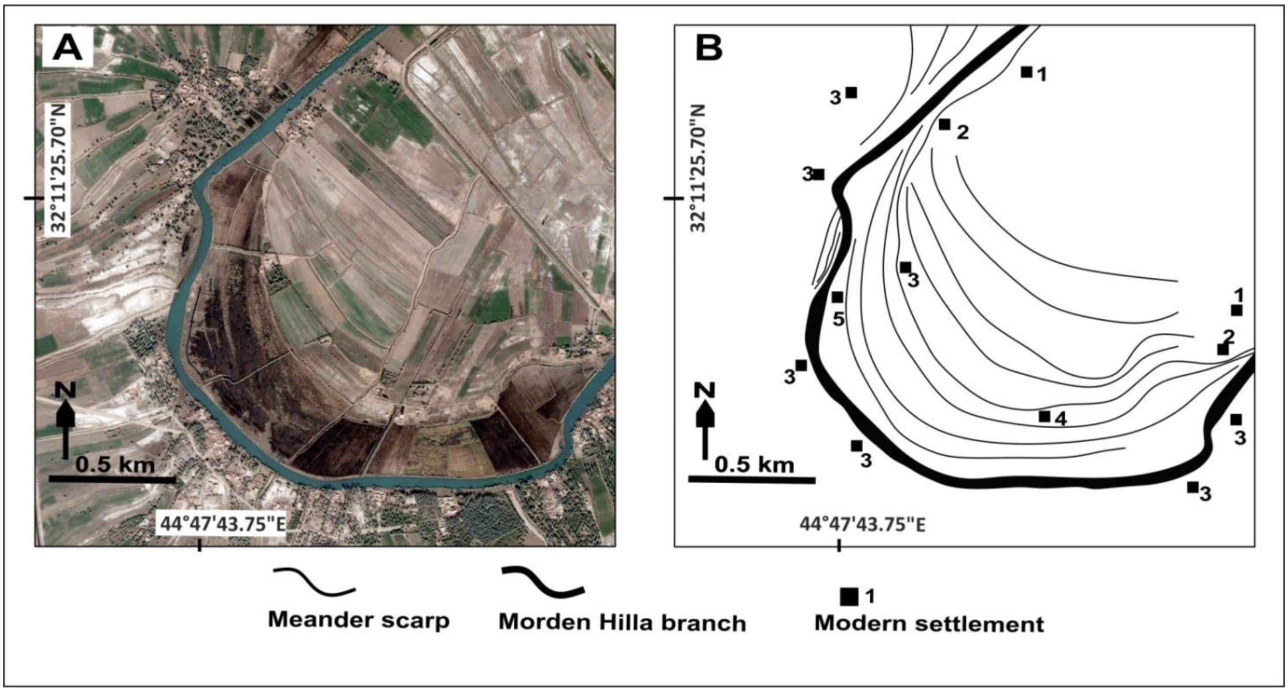

Figure 2.10: Recognition of gradual and lateral “combing” of the river meander by their texture. (A) QuickBird images showing modern river meanders of the Hilla, north of Diwaniya city. (B) Sketch showing the identified meander lines and the relative ages of the houses (numbered); the oldest house was built close to the oldest meander line.

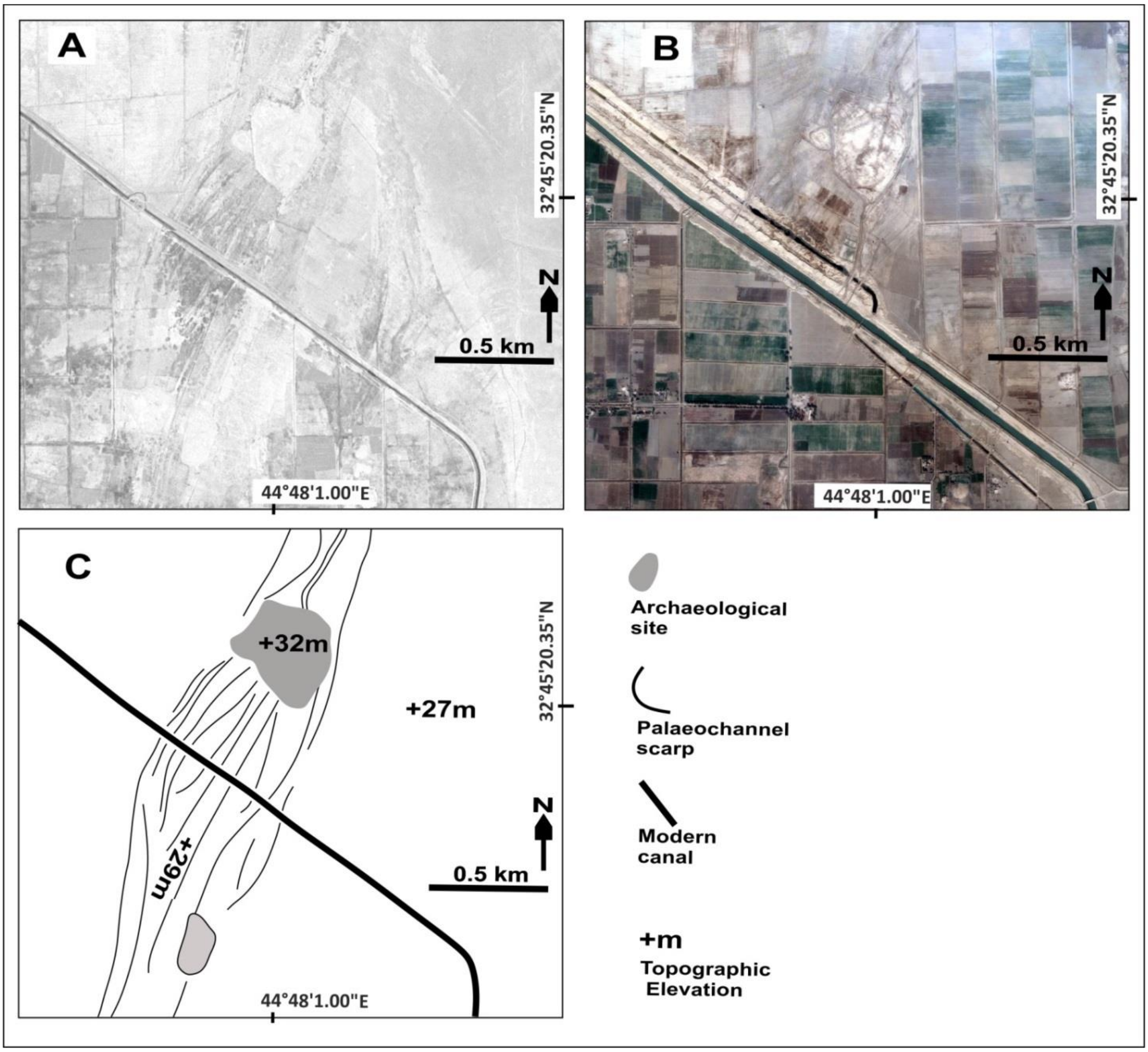

Figure 2.11: Recognition of palaeochannel meander scarps according to their texture. (A) CORONA image showing palaeochannels and archaeological sites, west of Hilla city (B) QuickBird image for the same area; note it is difficult to see the palaeochannel scarp, emphasizing the extent of landscape change since the late 1960s, and its impact upon the preservation of archaeological and geomorphological evidence.. (C) Sketch showing the identified palaeochannel and archaeological site.

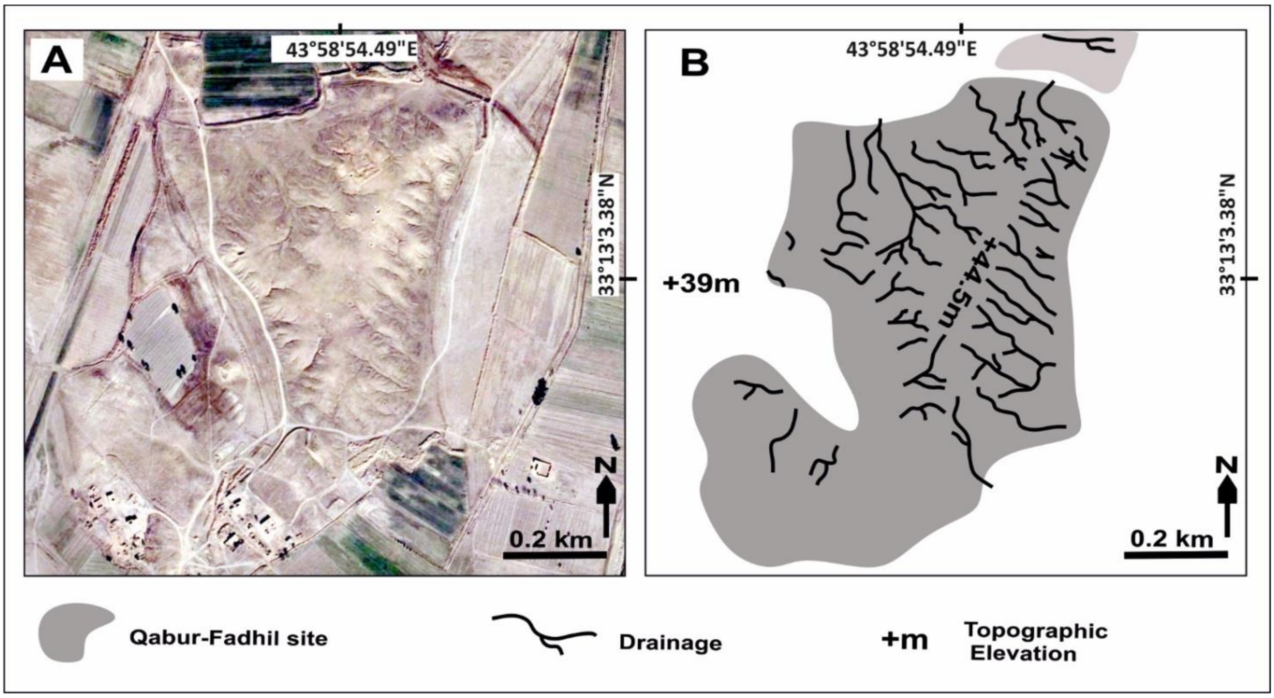

Figure 2.12: Recognition of an archaeological site according to its drainage pattern. (A) QuickBird image showing drainage pattern on a site mound, west of Baghdad (B) Sketch showing the identified drainage pattern on the archaeological site.

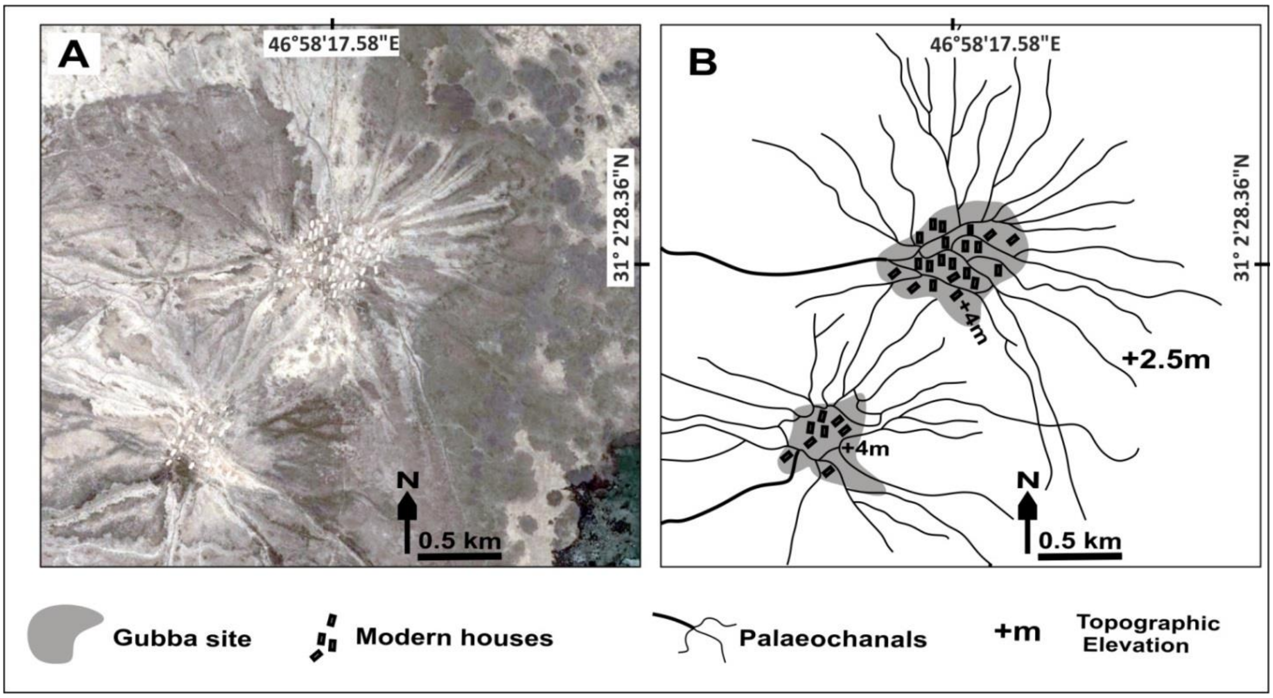

Figure 2.13: Recognition of an archaeological site according to drainage pattern around it. (A) QuickBird image showing drainage pattern around the site mounds, east of Nasiriya, formerly covered Chibayish marsh. (B) Sketch showing the identified palaeochannel and archaeological site.

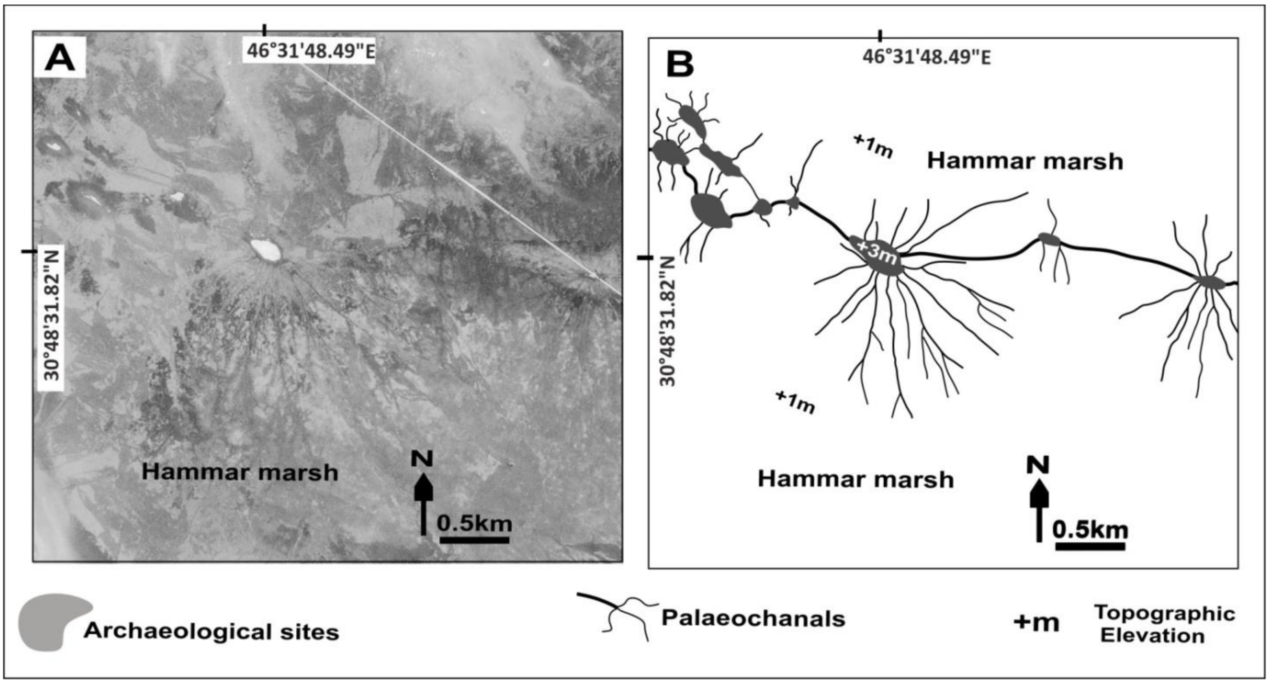

Figure 2.14: Recognition of an archaeological site according to drainage pattern around it. (A) CORONA image showing drainage pattern around the site mounds south of Nasiriya, covered by Hammar marsh. (B) Sketch showing the identified palaeochannel and archaeological sites.

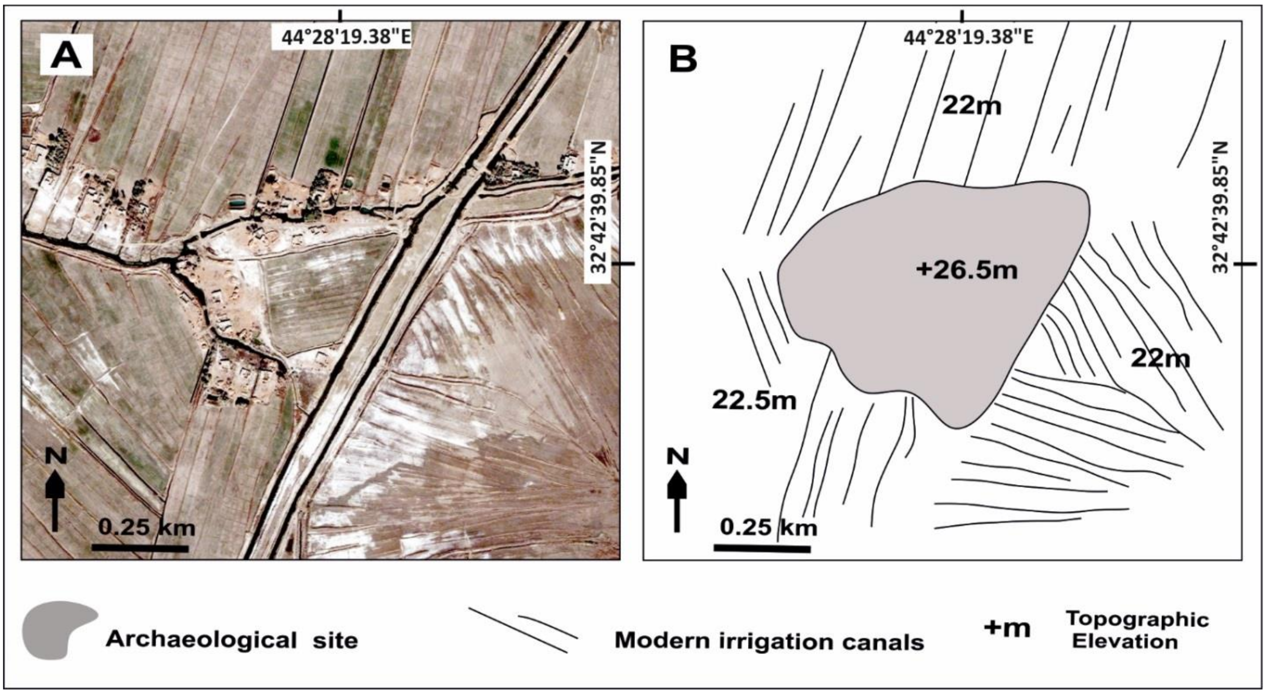

Figure 2.15: Recognition of an archaeological site according to drainage pattern around it. (A) QuickBird image showing drainage pattern around a site mound North of Najaf city. (B) Sketch showing the identified archaeological sites.

2.1.3.5 Shape

Shape refers to the general form, outline or structure of individual objects. There are several common shapes for archaeological sites that can be used as key indicators, such as the geometrical shape of walls or building foundations (Fig. 2.16 and 2.17), the division of mounds into two parts by a palaeochannel (Fig. 2.18) and the deviation of modern canals where they encounter a mound (Fig. 2.19A). Interestingly, we found in the present study that the commonest shapes of an archaeological mound, as can be seen in the imagery are elongated ellipsoid shapes and always parallel to the associated channel (e.g. fig. 2.19 C). The shape of the site, one way or another, reflects the shape of the archaeological buildings such as "castle or temple foundations" which are generally rectangular. In fact, this point can be used to determine the channel when several sites are found.

2.1.3.6 Shadow

Shadow refers to a dark area shaped by relatively high features that block light. The impact of shadow depends a lot of upon the time of day that the image was taken. In fact, there are several sites that can typically be marked by shadow, especially, those sites where the remains are distinctly above the ground-surface such as ziggurats, castles and shrines. Most palaeochannels and buried archaeological sites are not sufficiently high or, suitably shaped to create shadows, but in some cases shadows can give an indication of the height of the object associated with the archaeological site, such as trees (Fig. 2.20) and shrines or mosques (Fig. 2.21).

2.1.3.7 Size

The size of features is a function of scale in an image. There are several classes of object that look like palaeochannels while others resemble archaeological sites; for example, unpaved roads look like palaeochannels but are smaller. There are two features that look like archaeological sites; seed winnowing (Fig. 2.22) and human-made mounds for specific purposes e.g. building material (Fig. 2.23). They have the same shape, colour and elevation as an archaeological site, but are usually not of the same size.

2.1.3.8 Situation

Situation considers the relationship between other recognizable objects or features near to the target of interest. There are several objects or features that are normally associated with palaeochannels and/or archaeological sites, for example, the location of holy shrines (Fig. 2.21), because the building of shrines as graves for people of significances is a common Islamic custom in the Mesopotamian floodplain. Most of these shrines were built on relatively elevated areas in order to avoid flooding and groundwater. Therefore, they were built on channel levees or archaeological mounds. Most of these shrines can be recognized in QuickBird images and they can give a good indication for the identification of palaeochannels and archaeological sites. Distinct signals exist for looting, in the form of pock-marks on the site (Fig. 2.24). Some sites are surrounded or part-surrounded by modern urban areas (Fig. 2.25), which leads to one relationship between the ancient and modern settlement. In contrast, there are instances of small, isolated modern sites of population on larger ancient sites.

A natural example of situation being an important parameter is the occurrence of crevasse splays (Fig. 2.26) adjacent to the main channel (Wilkinson *et al.* 2015). Seen in isolation, such splays may be mis-identified as other kinds of channel; their relationship to the trunk stream makes their identification easier.

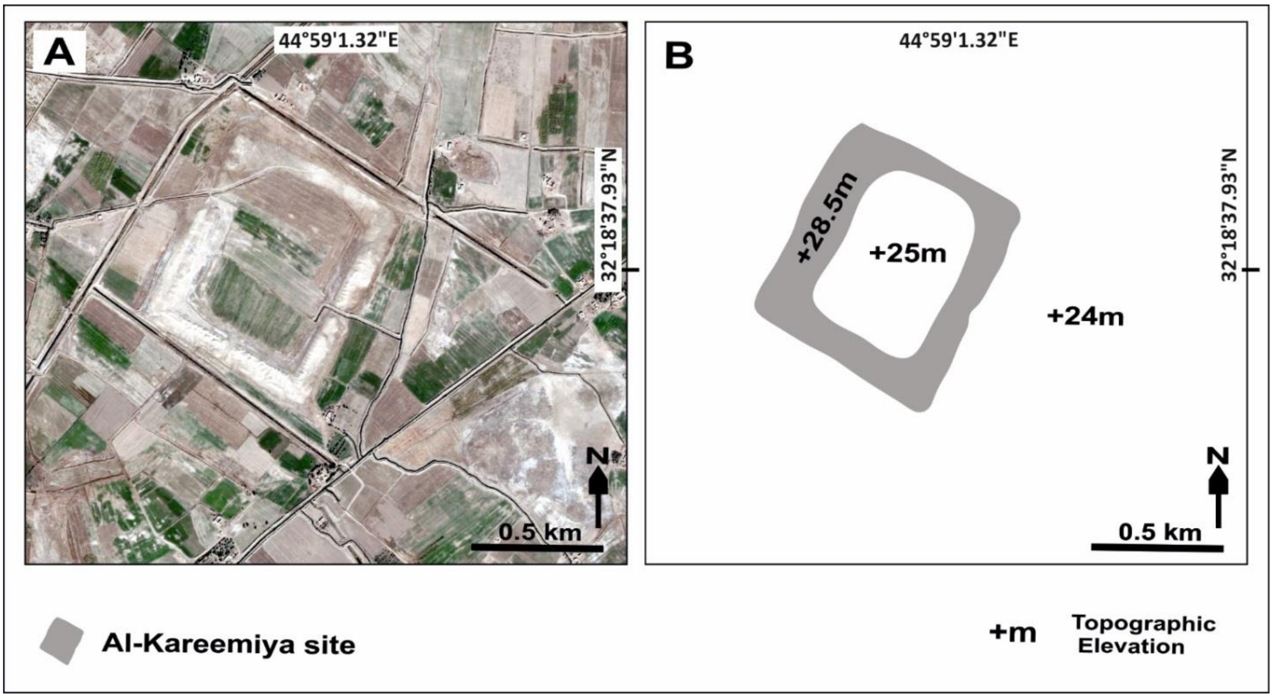

Figure 2.16: Recognition of an archaeological site according to its shape. (A) QuickBird image showing a typical rectangular earthen rampart with an internal area that is lower in absolute height than the wall around it of an archaeological site south east of Hilla city. (B) Sketch showing the identified archaeological sites.

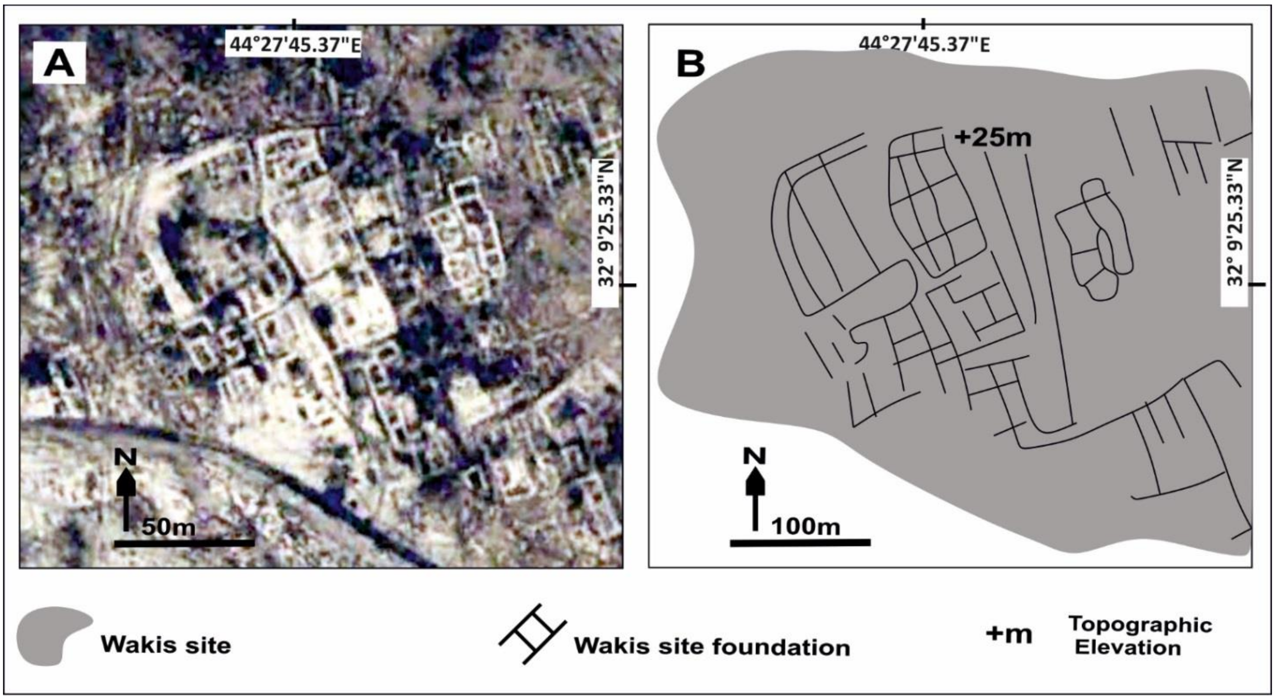

Figure 2.17: Recognition of an archaeological site according to its shape. (A) QuickBird image showing foundations of archaeological site north east of Najaf city. (B) Sketch showing the identified archaeological site.

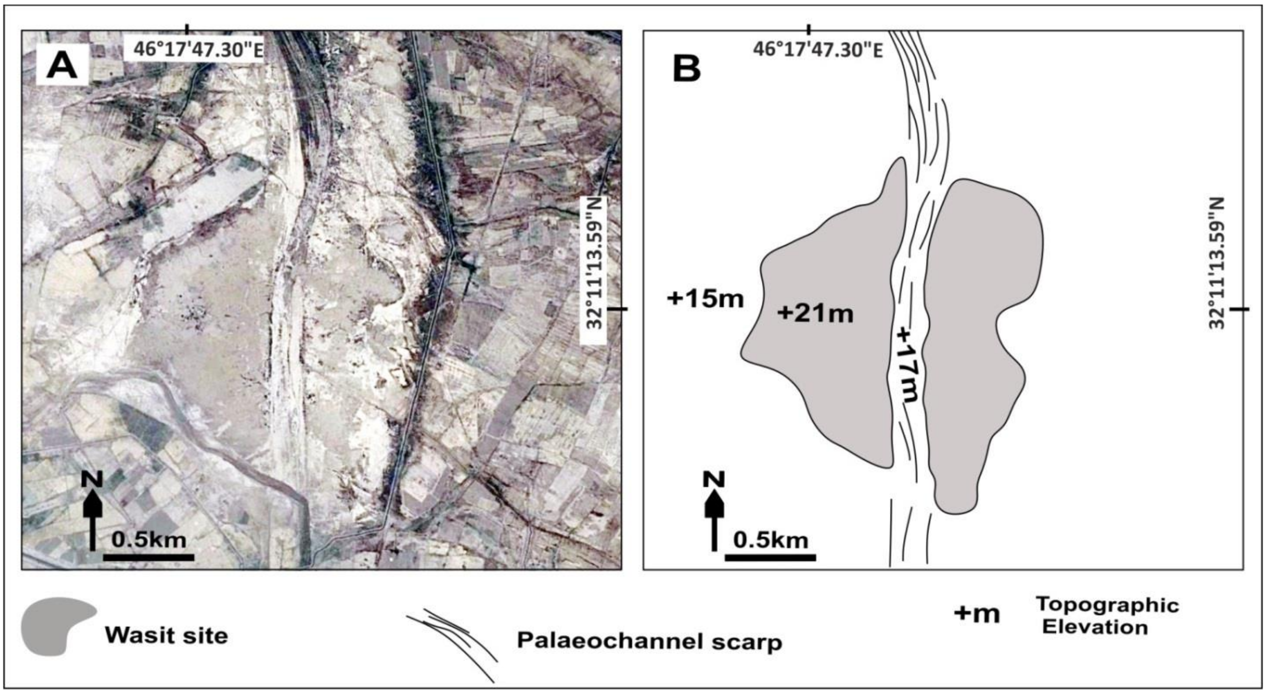

Figure 2.18: Recognition of an archaeological site according to its shape. (A) QuickBird image showing two loops of archaeological mound divided by palaeochannel south east of Kut city. (B) Sketch showing the identified archaeological site.

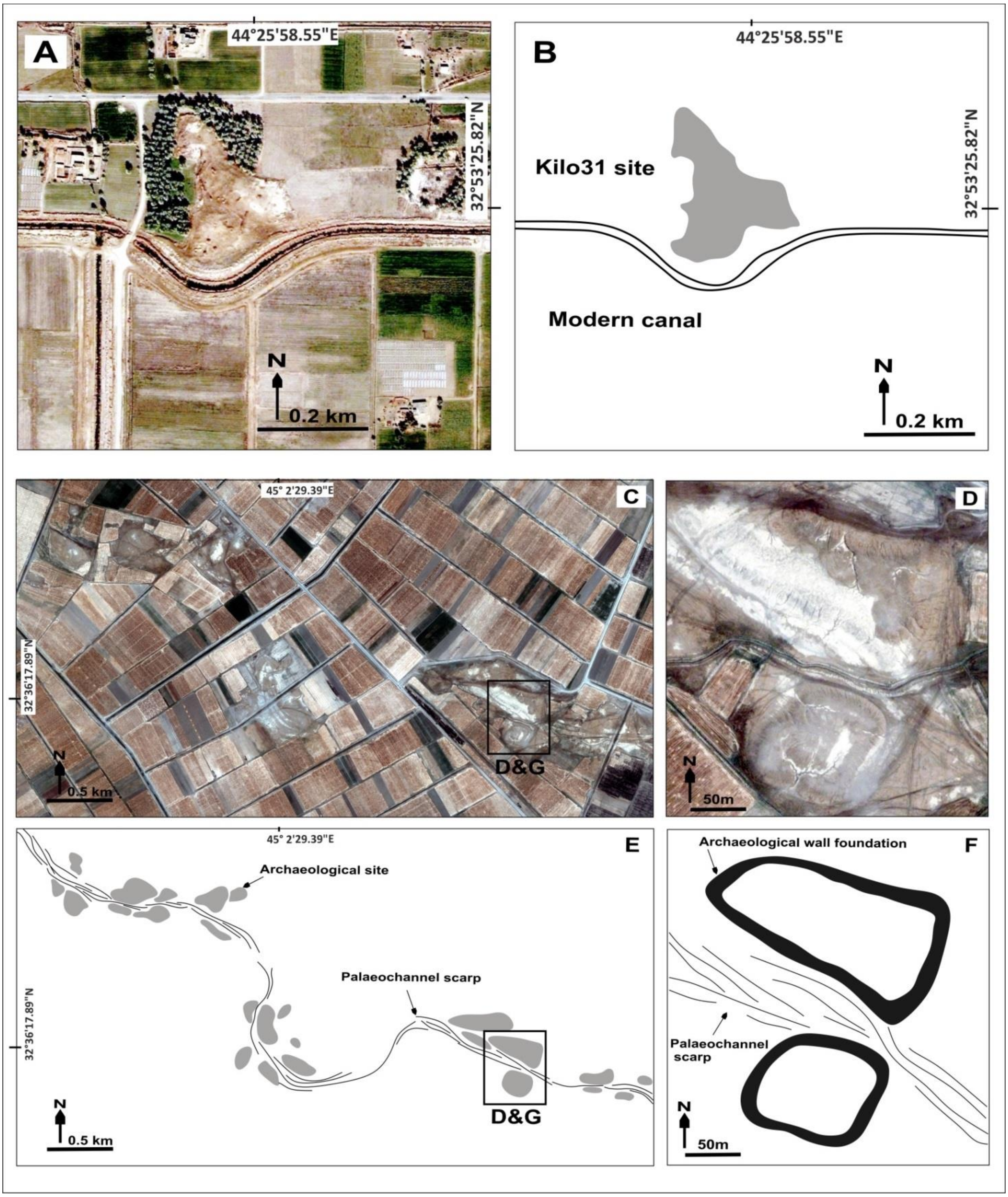

Figure 2.19: Recognition of an archaeological site according to its shape. (A) QuickBird image showing deviation of modern canal close to the archaeological mound south of Baghdad. (B) Sketch showing the identified archaeological site. (C and D) QuickBird image showing archaeological sites associated with palaeochannel when the shapes of the associated sites are elongated ellipsoid shapes and arranged parallel to the channel (E and F) Tracing of surface features including palaeochannel levees, scars and archaeological sites of the image.

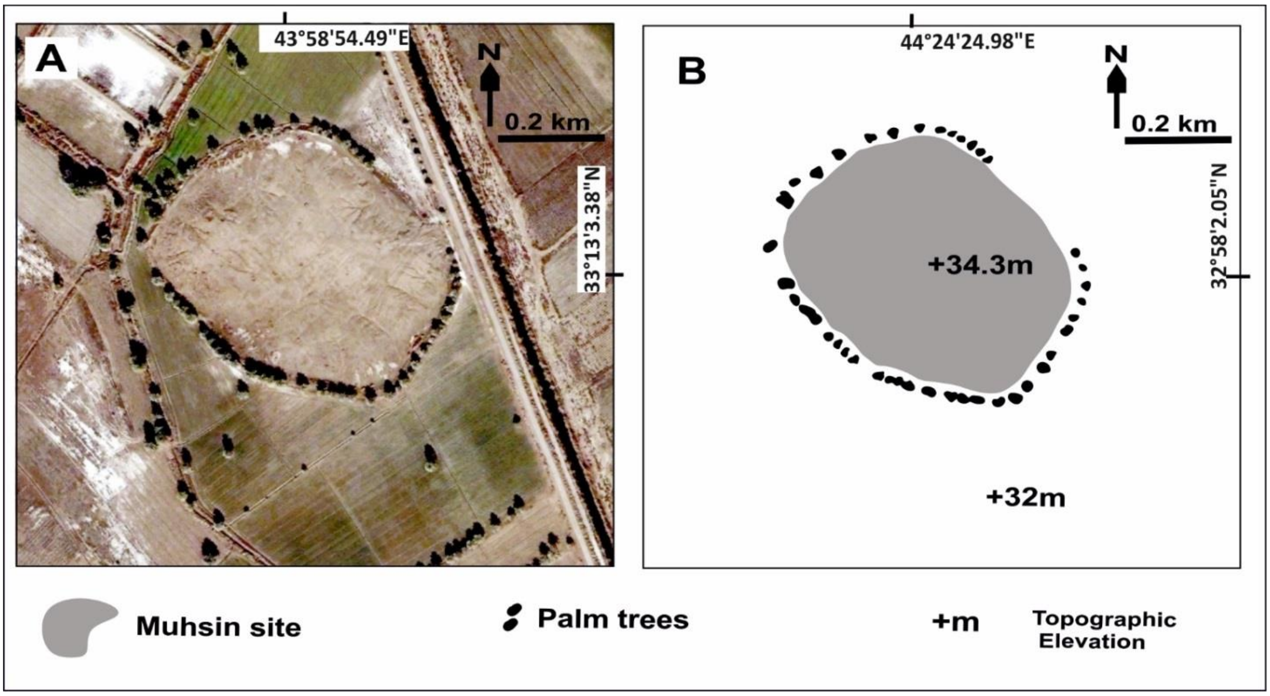

Figure 2.20: Recognition of an archaeological site according to shadow. (A) QuickBird image showing high trees around an archaeological site South of Baghdad. (B) Sketch showing the identified archaeological site.

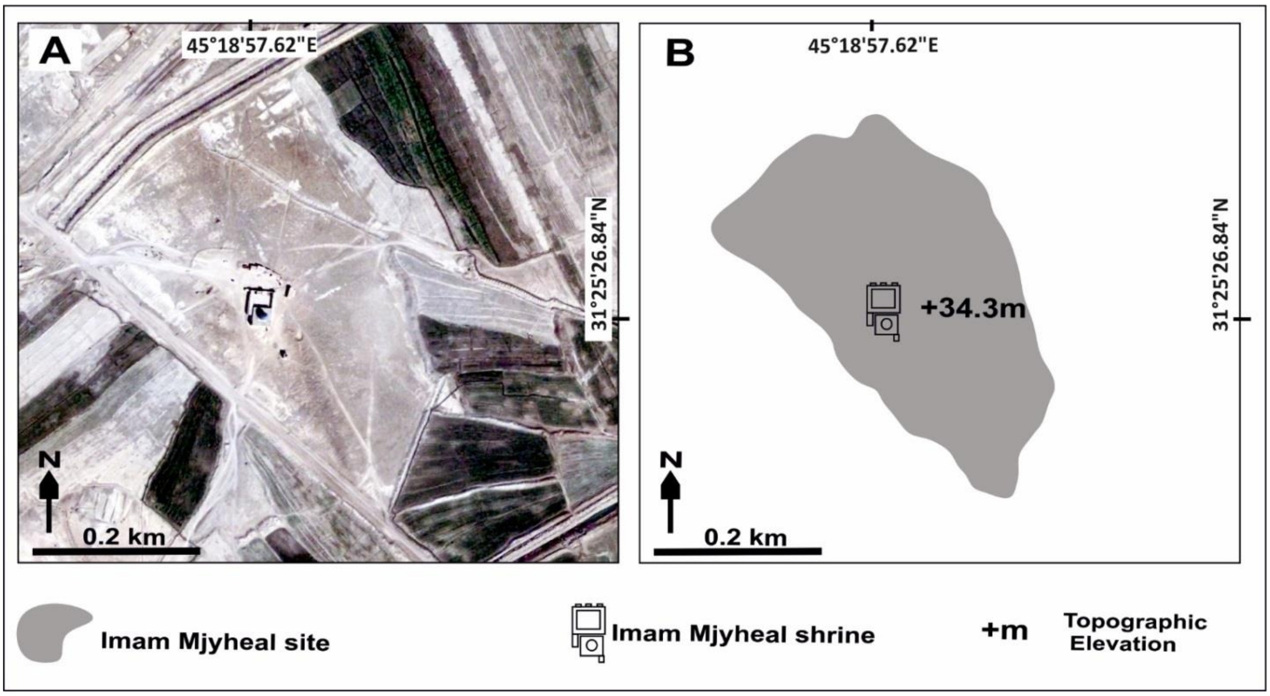

Figure 2.21: Recognition of an archaeological site according to shadow. (A) QuickBird image showing a shrine over an archaeological site South of Diwaniya city. (B) Sketch showing the identified archaeological site.

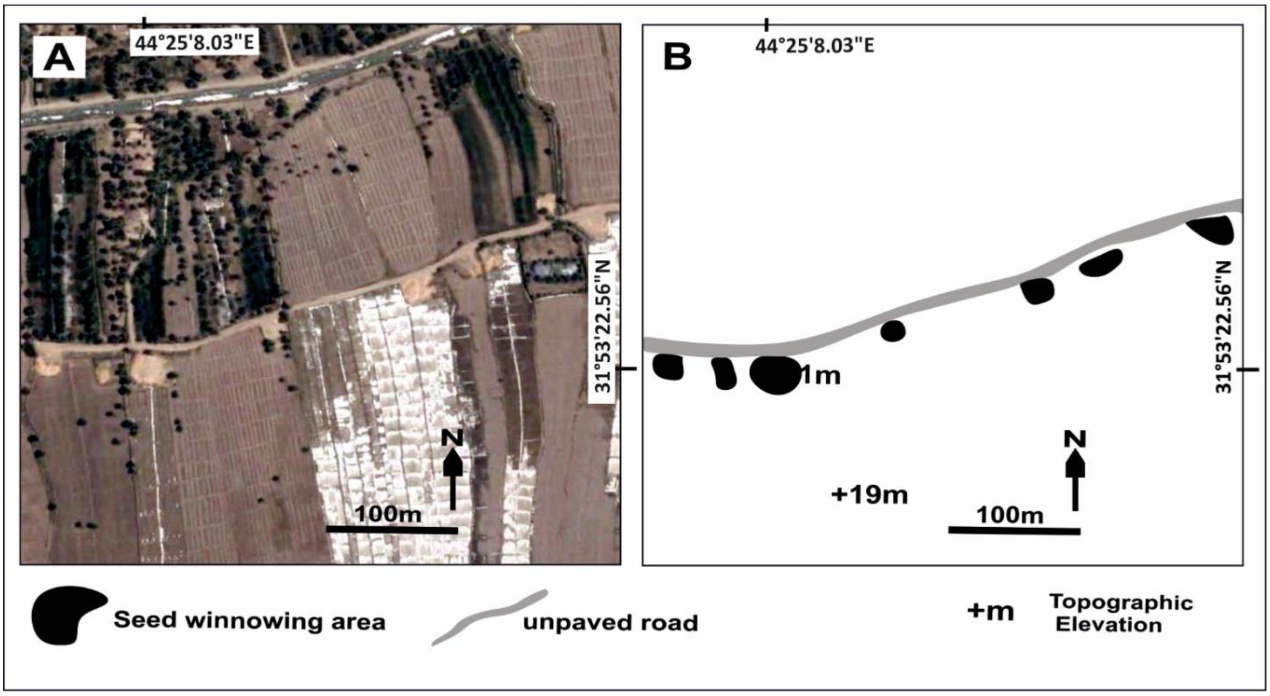

Figure 2.22: Potential pitfalls in the recognition of an archaeological site according to its size. (A) QuickBird image showing a seed winnowing area associated with an unpaved road south west of Najaf city. It is not an archaeological site associated with a palaeochannel. (B) Sketch showing the identified features.

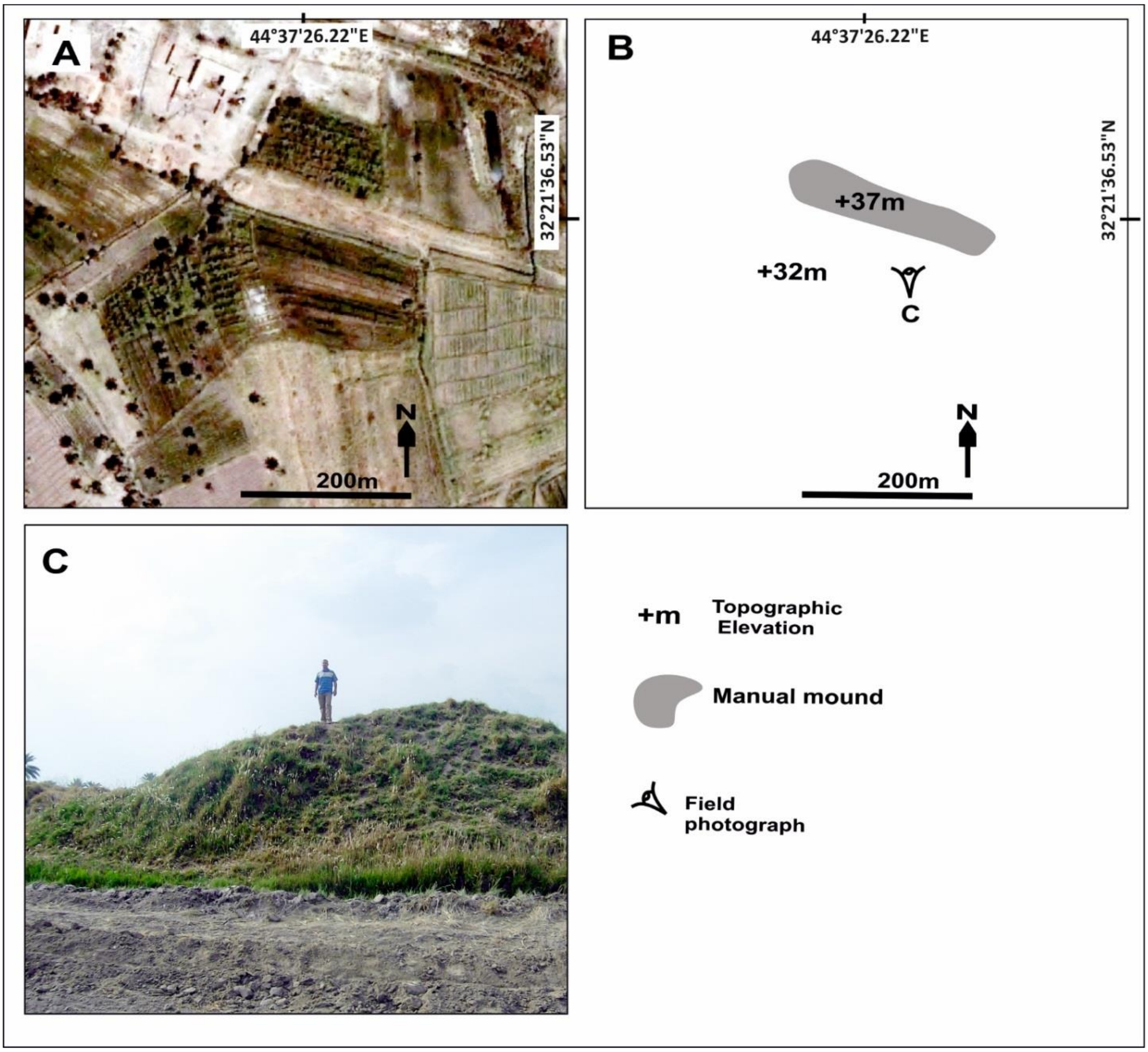

Figure 2.23: Potential pitfalls in the recognition of an archaeological site according to its size. (A) QuickBird image showing recent manually-dug mound south of Hilla city. It is not an archaeological site and this is where comparing recent imagery with Corona images is valuable, as it will highlight things that are present in recent imagery but which are not indicated on Corona and so are probably modern features. (B) Sketch showing the identified mound. (C) Field photograph showing the mound.

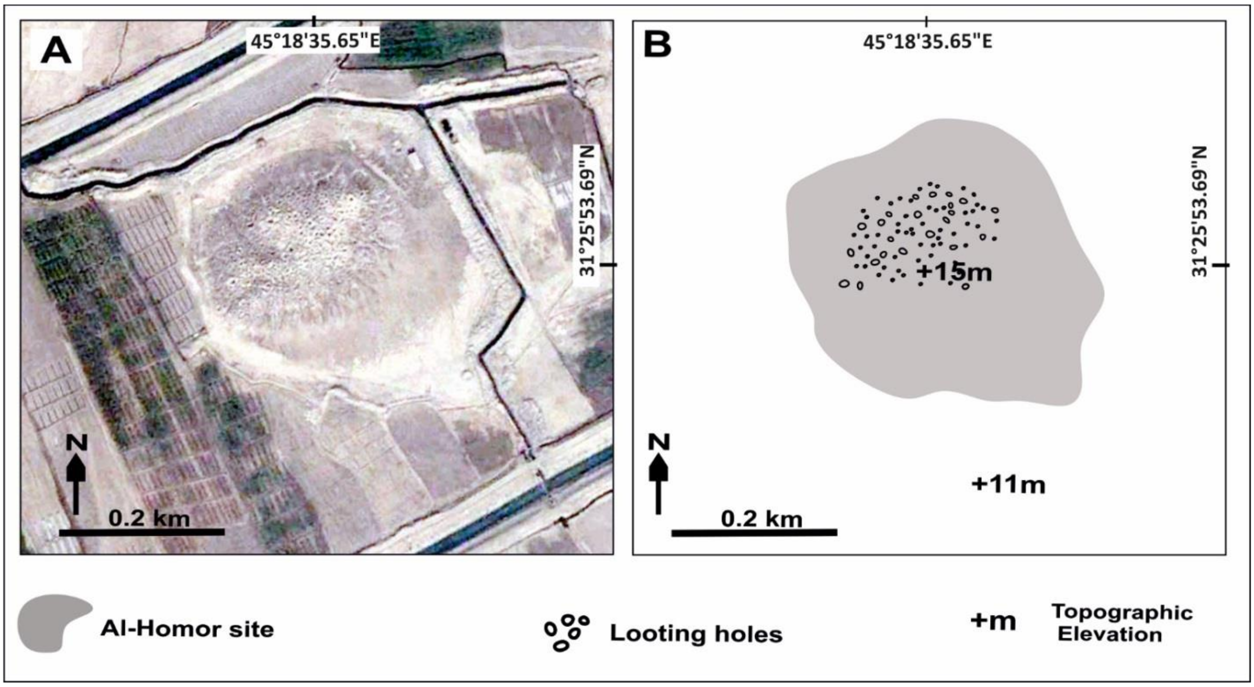

Figure 2.24: Recognition of an archaeological site according to situation. (A) QuickBird image showing relatively recent looting holes on an archaeological site North of Samawah city. (B) Sketch showing the identified mound.

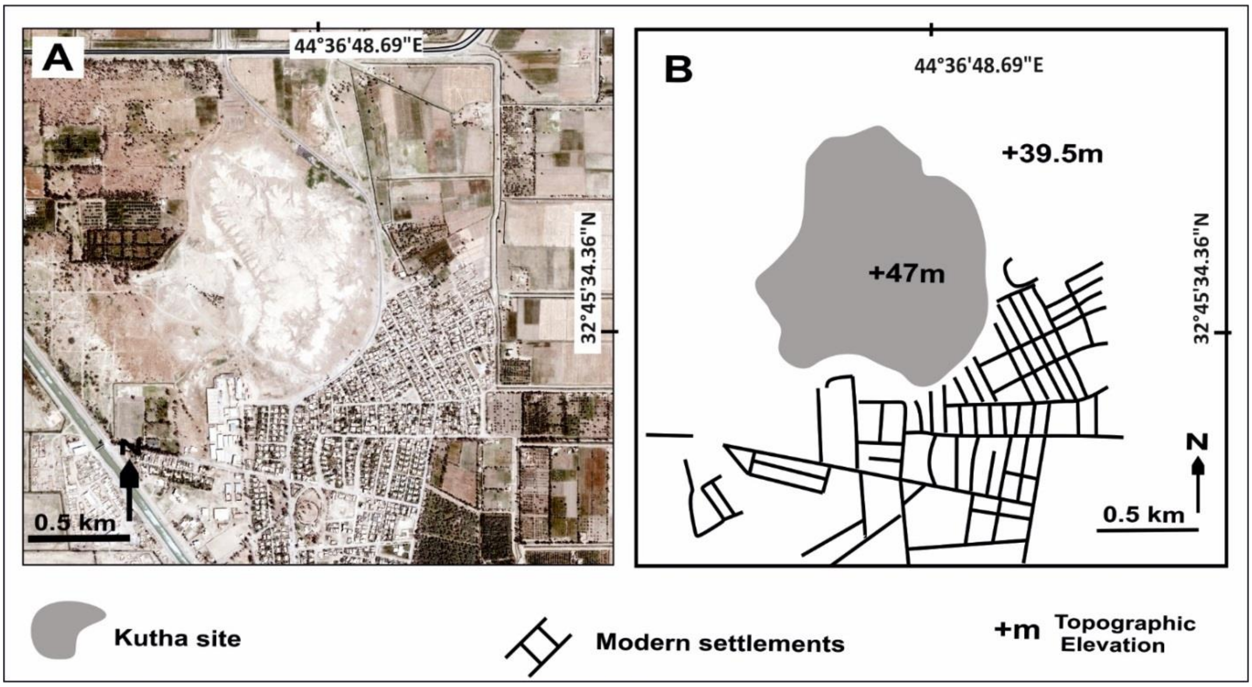

Figure 2.25: Recognition of an archaeological site according to situation. (A) QuickBird image showing modern urban development around an archaeological site north east of Hilla city. (B) Sketch showing the identified mound.

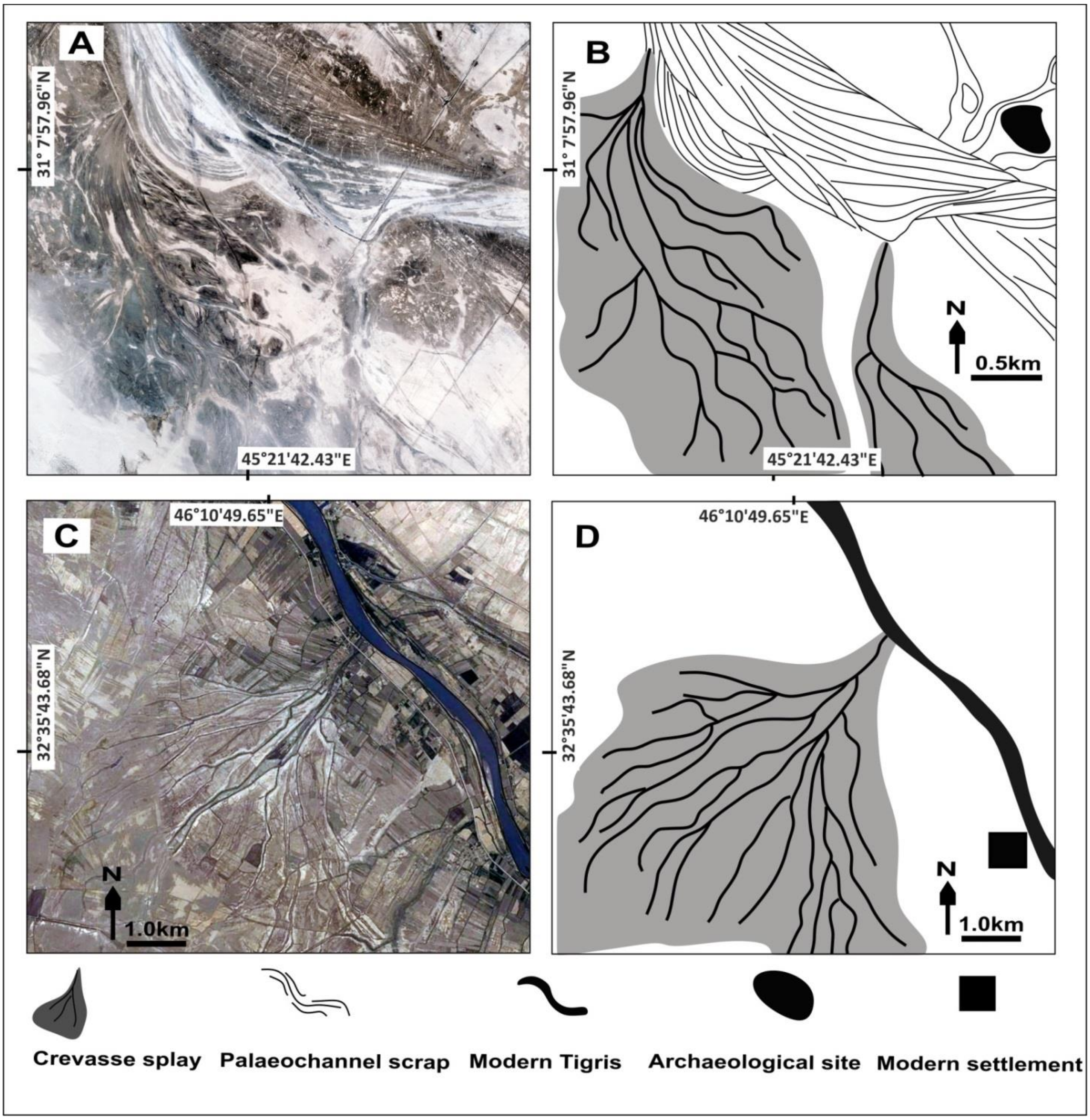

Figure 2.26: Recognition of palaeochannel according to situation. (A) QuickBird image showing crevasses splay associated with a palaeochannel west of Samawa city. (B) Sketch showing the identified features. (C) QuickBird image showing a crevasse splay associated with the modern Tigris River near Kut city. (D) Sketch showing the identified features.

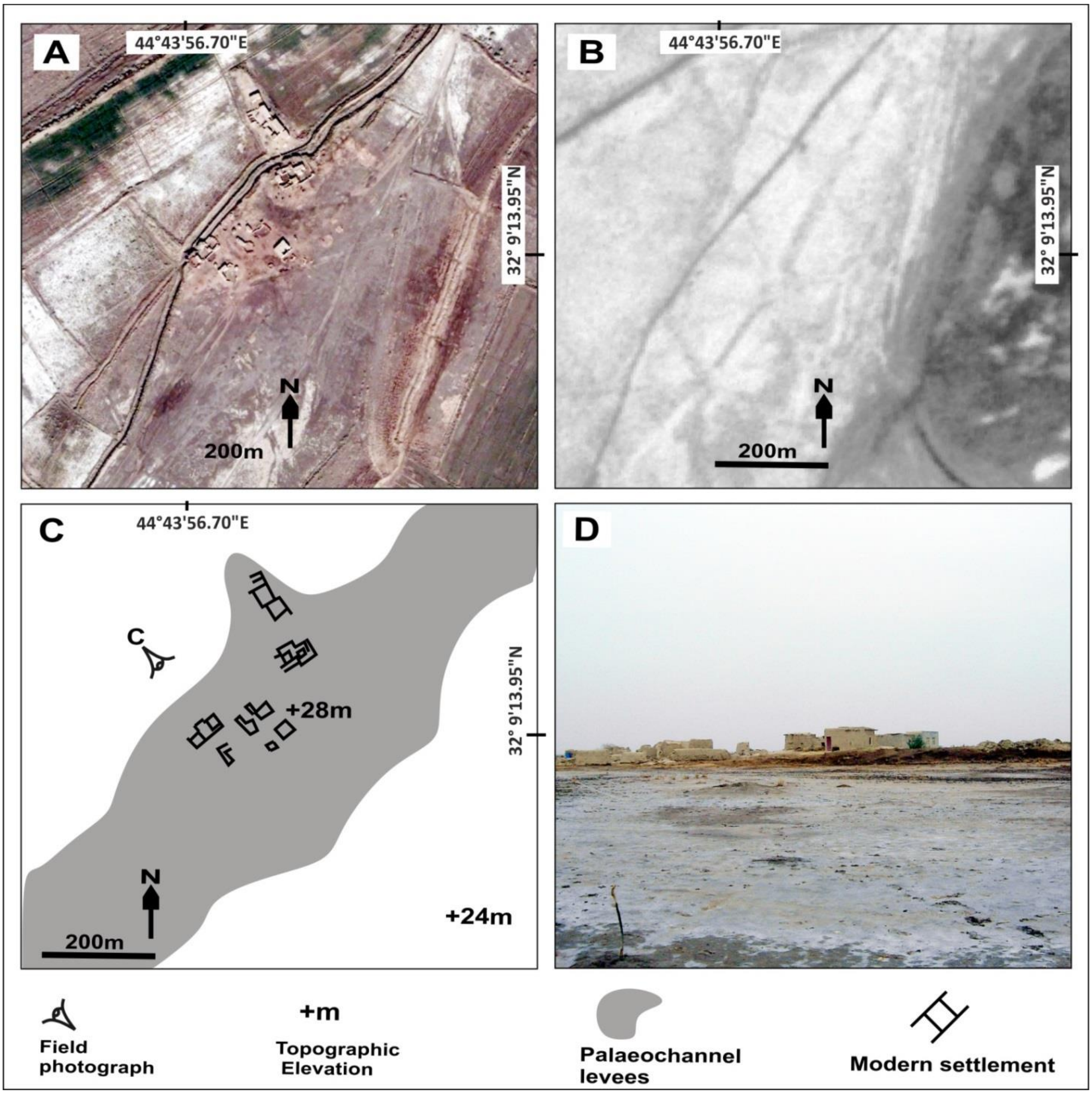

Figure 2.27: Recognition of an archaeological site according to situation. (A) QuickBird image showing modern development over palaeochannel levees north of Diwaniya city. (B) CORONA image for the same location before the houses were built. (C) Sketch showing the identified levee. (D) Field photograph showing part of this village and the palaeochannel levee.

2.1.4 Results summary

Intensive networks of palaeochannels (Fig. 2.28) and archaeological sites (Fig. 2.29) within the Mesopotamian floodplain have been identified in this study. More than eight thousand archaeological sites (Fig. 2.29) have been plotted during this study and most of them show an alignment consistent with an identified palaeochannel (Fig. 2.30). This total obviously includes many sites previously identified (e.g. there are ~6000 sites in the work of Hritz (2005)), but there are at least ~2000 new sites plotted in Fig. 2.29, identified using the methods and protocols described in this chapter.

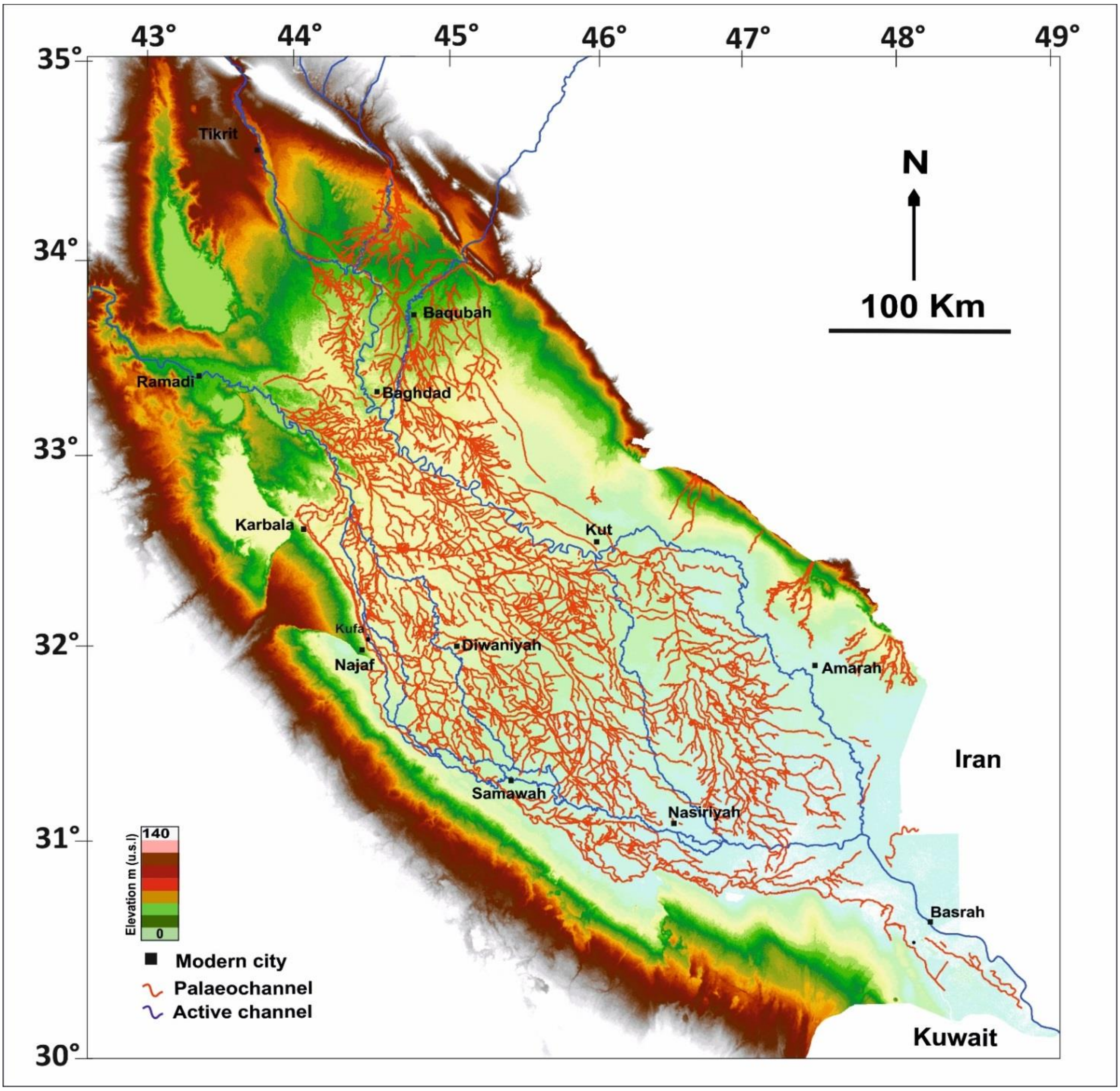

Figure 2.28: SRTM map of the Mesopotamian floodplain showing all the identified palaeochannels in the present study.

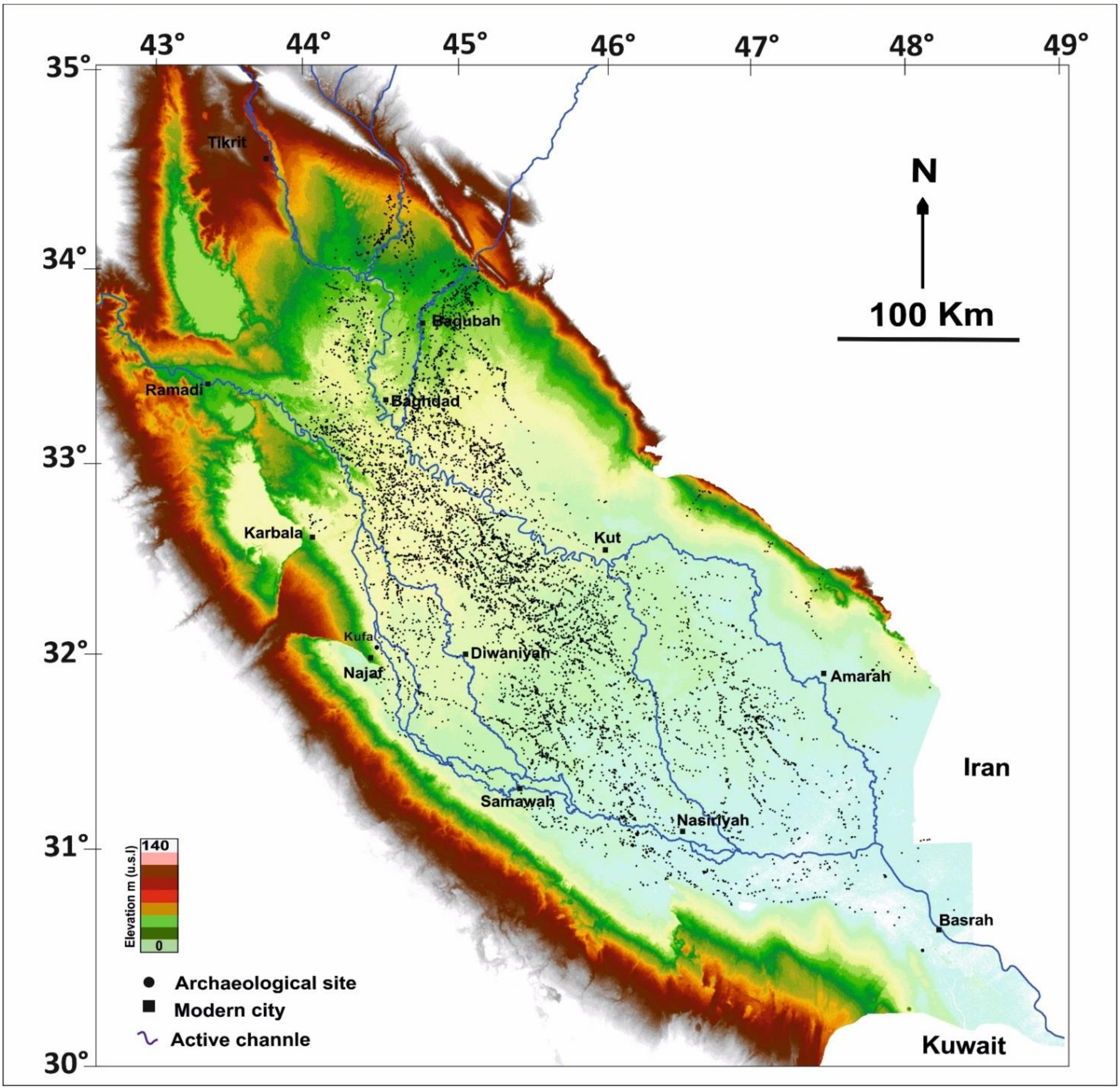

Figure 2.29: SRTM map of the Mesopotamian floodplain showing all the ~eight thousand identified archaeological sites in the present study.

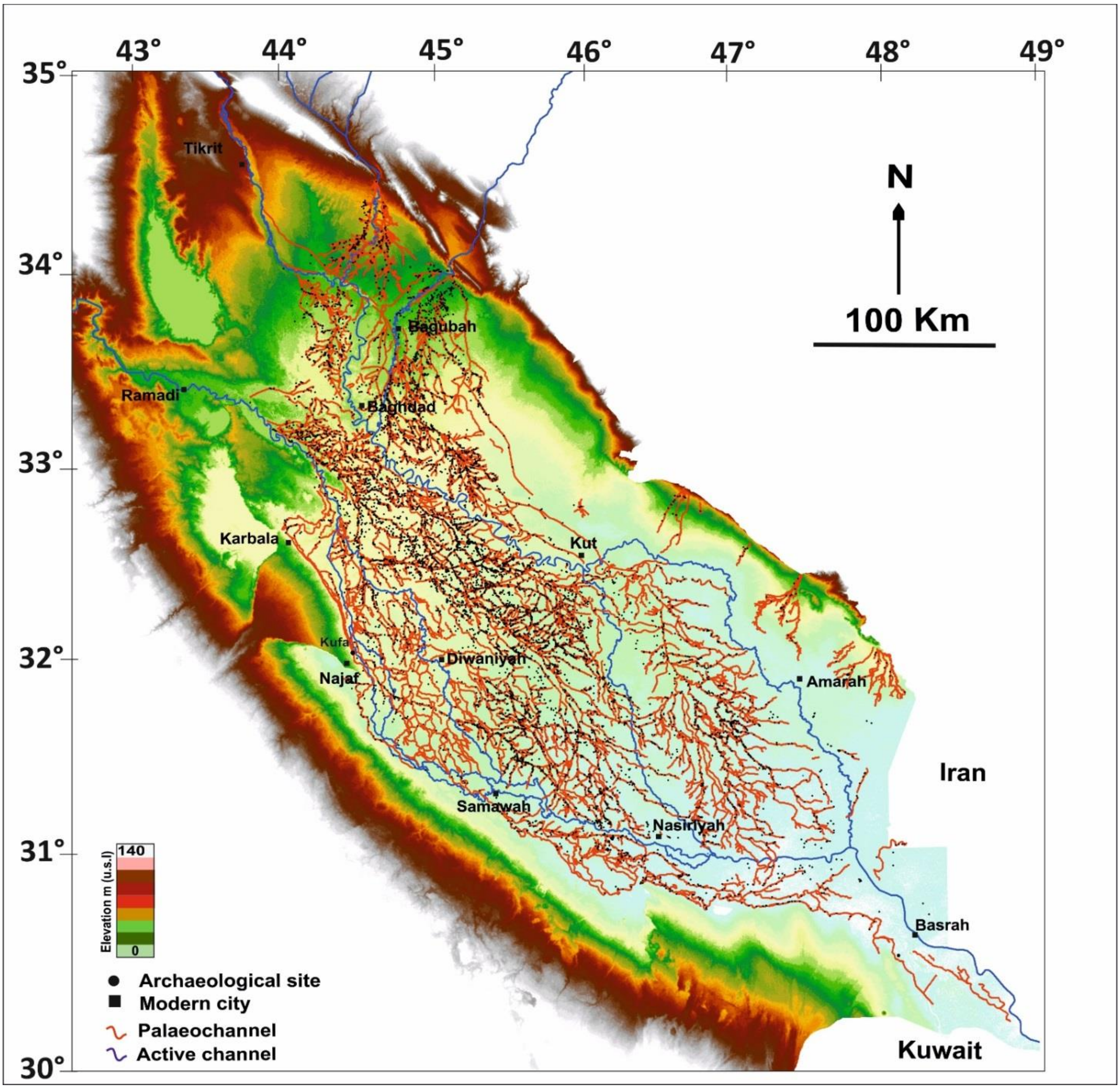

Figure 2.30: SRTM map of the Mesopotamian floodplain showing all the palaeochannels and the archaeological sites palaeochannels in the present study.

2.2 Cuneiform tablets and historical documents

Several cuneiform tablets have made direct reference to activities associated with rivers, such as the digging of new irrigation channels, the annual cleaning of a certain river or using the river to transport goods from one city to another (Gibson, 1972; Wilkinson *et al.,* 2015). These texts are useful to determine the locations and periods of existence of rivers, particularly when some texts refer to specific sites (Cole, 1994).

Certain events have attracted historians and geographers throughout time in the Mesopotamian floodplain such as tracking the waterways of the Tigris and the Euphrates, digging or cleaning irrigation canals, flooding, and the collapse of barrages or dams. The works of many of these classical Islamic scholars have been re-published in recent years. Such historical documents (texts and/or maps) are valuable in reconstructing the ancient landscape.

In the present study, a number of Arabic texts from the 9th to 14th century AD (Table 2.1) have been reviewed as they give a general idea about a river's course and its associated settlements during or before the time of writing (Ooghe, 2007; Walstra *et al.*, 2010). Here key texts are listed below with brief explanations as to their contribution.

Al-Yaqoobi (died in 897 AD) wrote a number of books such as "*Al-Boldan*" (The homelands) and "*Kitab Al-Buldan*" (The homelands book). He described the pre-Islamic (Sasanian) and the early Islamic periods. In relation to the Mesopotamian floodplain area, he documented several floods, constructions of irrigation canals and barrages, annual cleaning of some canals and the drying out of some channels.

Ibn-Khurdadhabih (died in 912 AD) wrote author of "*Al-Masalik wa Al-Mamalik*" (The roads and the kingdoms) described the location of most human settlements (cities, town and villages) in the early Islamic period. In relation to the Mesopotamian floodplain, he named human settlements associated with rivers and canals in the region.

Ibn-Rista (died in 912 AD) wrote "*Al-Alaiq Al-Nafessa*" (The valuable objects) describing several lands (both urban and rural areas) of the Islamic Empire. He mentioned in some detail the canals and cultivated lands in the Mesopotamian floodplain.

Ibn-Hawqal (died in 978 AD) collated and discussed a number of previous geographical books and then he wrote his own, entitled "*Surat Al-Ardh*" (The picture of the earth). He preferred to draw maps to illustrate the geographical distribution of towns, rivers and seas, for example the first complete map of Iraq covering the whole of the Mesopotamian floodplain and showing the Tigris and the Euphrates, their distributaries and the main associated towns.

Ibn-Aljozi (died in 1116 AD) wrote several books on different topics including "*Al-Muntadham fe Tareekh Al-Mulook wa Al-Umum*" (The organized book of the kings and nations history) relating to the geography and history of the Mesopotamian floodplain. It describes the history of states (during Sasanian and Islamic periods) that ruled the region and also mentions changes in the rivers and construction of irrigation projects.

Ibn-Alatheer (died in 1223 AD) author of "*Al-Kamil Fi Al-Tareekh*" (The perfect book for history) dealt with the ancient history and geography of the region, including the Islamic period. He used an annual documentation system, writing the main event for each year including flooding and other irrigation projects.

Al-Hamawi (died in 1225 AD) wrote a number of books concerning several Islamic regions, one of the most famous of which is "*Muaajim Al-Buldan*" (The homeland index). In this book, in effect a gazetteer, he listed names and locations of most towns and lands in the Mesopotamian floodplain.

Ibn-Alfuwati (died in 1323 AD) wrote "*Al-Hawadith Al-Jamiayh wa Al-Tajarib Al-Nafia*" (The comprehensive events and the beneficial experiences) featuring a number of major events in the Islamic region of that time. He also mentioned some irrigation and river projects in the Mesopotamian floodplain.

Ibn-Abdulhaq (died in 1338 AD) discussed and summarised several previous historical and geographical books as well as a book entitled "*Maracid Al-Itila'a*" (The observations of acquaintances). He made mention of the distribution of rivers and irrigation projects in the Mesopotamian floodplain.

In addition to the Arabic sources, European travel literature from the 16th to the early 20th century AD provides information on subsequent changes in river courses, especially the more recent shifts (Selby *et al.,* 1885; Ooghe 2007; Heyvaert *et al.,* 2012).

2.3 Fieldwork

Fieldwork for the present study was undertaken over six weeks during February and March 2013. Security issues prevented free access across the whole of the Mesopotamian floodplain. Nevertheless, there was successful access to key locations on both the Tigris and Euphrates, identified by initial remote sensing study in Durham.

2.3.1 Groundtruthing

General observations were made at several locations (Fig. 2.31), the main purpose of which was to ensure that there was agreement between what was identified in the remote-sensing work and what existed on the ground. I stress the importance of fieldwork, which should be used jointly with remote sensing studies. Fieldwork can permit "groundtruthing" of observations made initially from satellite imagery and digital elevation models, and allows the collection of samples for dating and other analytical techniques. Alternatively, re-examination of imagery after fieldwork allows a regional-scale perspective on local features of interest identified in the field. However, in some cases, the geomorphological surface features, such as ancient crevasse splays, cannot be identified in the field although they are very recognisable in satellite imagery.

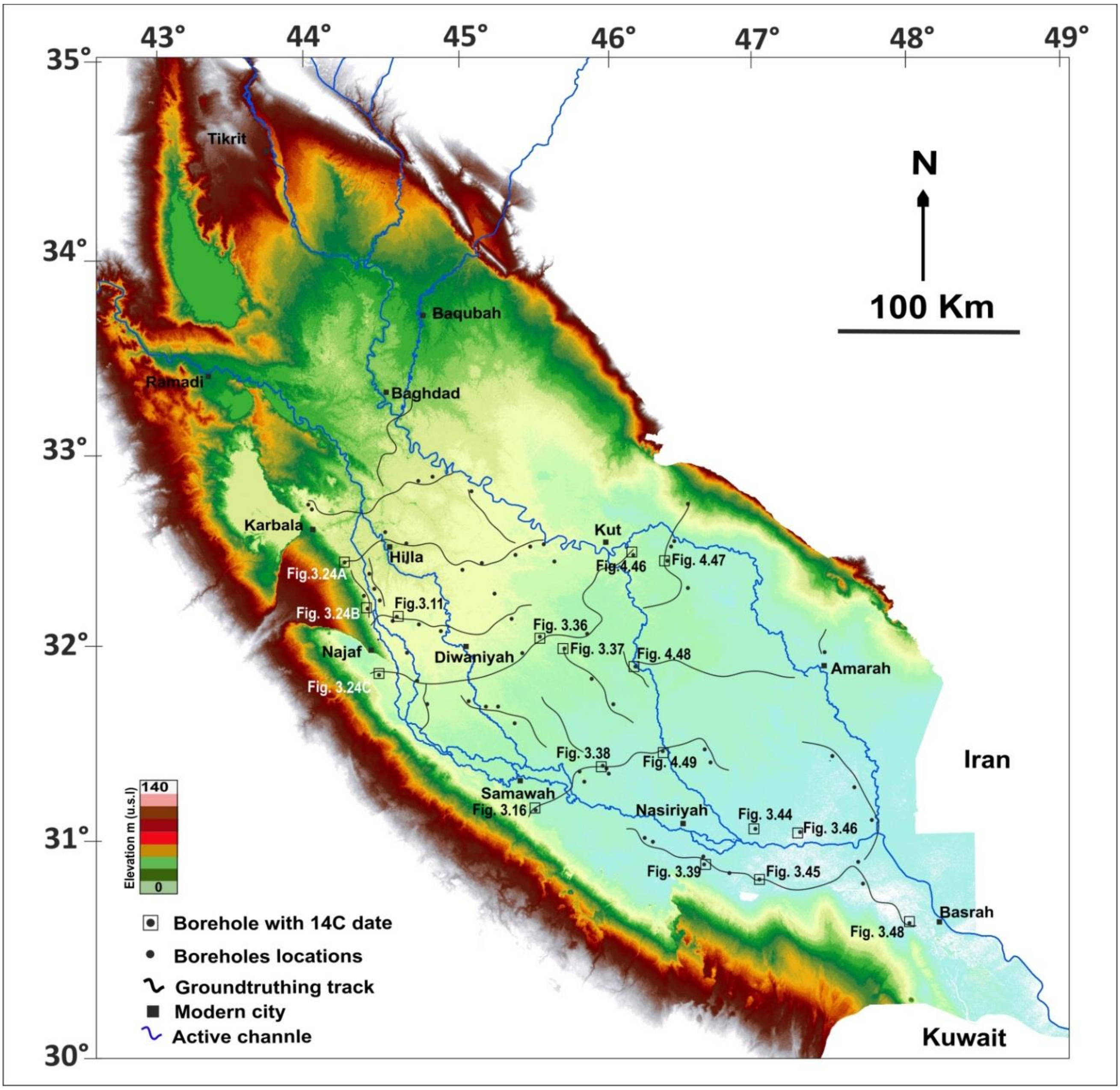

Figure 2.31: SRTM location map of the Mesopotamian floodplain showing the boreholes and the groundtruthing tracks that have been carried out in the present study.

2.3.2 Cross-sections

Sixty six cross-sections were made on selected palaeochannel reaches (Fig. 2.31); the elevations of the cross-sections were obtained using levelling and theodolite equipment during the 2013 field surveys. Boreholes were dug to depths up to 7 m using a hand-auger, designed to collect disturbed samples. Two auger kit types were used. For mud sediments, an auger with very narrow blades was used, the advantage being that they meet with little resistance. For sandy sediments, an auger with broader blades was used, to keep the sample inside. The length of each kit (the head of the auger) was 50 cm so the digging interval space was 50 cm, meaning sediments could be recovered every half metre.

Sediments from each borehole were primarily distinguished based on their macroscopic properties, including grain size, colour, texture, root penetration, macrofossils, ceramic fragments, shells and charcoal. The grain size estimations were made in the field with a hand lens and well-log cards. The interpretation of sedimentary environments of each facies of the deposits was performed drawing on Buringh (1960), Heyvaert and Baeteman (2008), and Wilkinson and Jotheri (2015).

Six different environments were identified during fieldwork, utilising borehole samples and adopting approaches described in Buringh (1960), Heyvaert and Baeteman (2008), and Wilkinson and Jotheri (2015).

Crevasse splay deposits: these are coloured from tan to brown, of very fine sand and coarse to fine silt, with massive to thin-bedded structure.

River levees: these commonly consist of several layers of different sediments with thick layers of fine to medium sand usually fining upwards, followed by thin layers or lenses of silts.

Floodplain deposits: these are compact homogeneous brown clay to silty clay; accumulation commenced with blocky, clayey silt.

Marsh deposits: this range in colour from greenish to light black, clay to silty clay with bioturbation, rooted with vegetation fragments, and containing gastropod shells.

Channel post-abandonment deposits: these have weak to no bedding, variable sorting, clay to sand, charcoal and shells, colluvium (bank failure sediments).

Irrigated soils: these consist of grey-brown blocky silty clay to sandy silts containing freshwater gastropods and small fragments of ceramics mixed by cultivation.

2.4 Radiocarbon dates

Sixteen palaeochannel reaches were selected for radiocarbon age dating (Fig. 2.38 and Table 2.2). In the present study we have used the principles of Morozova and Smith (2000) to date ages of channel avulsion (Figs. 1.5 & 1.6).

Gastropod and bivalve shells are powerful chronological tools (Plaziat and Younis, 2005; Hritz *et al.,* 2012; Gabor *et al.,* 2014), and they are the most common organic materials in the sediments of the study area. Other organic materials are very rare in the boreholes. The samples (Table 2.2) were from freshwater mollusc fossil shells, including both *Melanoides tuberculata* gastropods and *Pseudodontopsis* bivalves. For more details about river molluscs in the study area, see Salman (2011). The samples of the present study were shells analysed by Beta Analytic, using a combination of Accelerator Mass Spectrometry (AMS) radiocarbon and conventional radiometric dating. The calibrated dates are given with a 2-sigma error range and presented in calendar AD-BC. Reimer *et al.* (2013) was used to convert 14C dates into calendar years.

Radiocarbon dating of shell material can yield erroneous ages due to the "hard-water" effect (Xu *et al.* 2011; Zhou *et al.* 2015). Tthis issue will be discussed in Chapter 5.

2.5 Archaeological data

Most archaeological studies which have been carried out in the Mesopotamian floodplain, such as Jacobsen (1960), Adams (1981), Matthews (1987), Cole and Gasche (1998), have assumed that periods of active channels are closely linked to the ages of archaeological settlements, and that most of the identified ancient settlements were established near active channels. In other words, the archaeologists' premise whereby human settlement in ancient Mesopotamia could only occur along river waterways, thus being spatially constrained, has guided Mesopotamian studies ever since it was propounded. Adams (1981) put forward the suggestion that if all mounded sites in the region were systematically mapped, with examination of pottery visible on the surface for dating purposes (Ceramic Surface Survey), and if the mounds were plotted on maps by chronological period, emerging linear patterns would represent the major routes of ancient palaeochannels.

Consequently, this study focuses on only two characteristics of archaeological sites: periods of occupation (Tables 1.1 & 2.3) and geographical locations, i.e. the existence of settlements in certain areas is a good indication of the probability of the existence of a channel close to the site and vice versa. The dates ascribed to settlements, generally on the basis of surface finds, suggest the time when a particular river channel was active. In such a way, the spatial distribution of tells could be used to suggest the locations of channels and canals that were no longer visible (or only in part) on the ground, and for which no excavation evidence, was available.

In the present study, the Mesopotamian floodplain has been divided into eight sub-areas of study (Fig. 1.11), and each area will be discussed separately. The areas of the Euphrates are: Najaf, Ur and Marsh, while the areas of the Tigris are: Samarra, Adhaim, Diyala, Baghdad and Kut (Fig. 1.11).

Author's name	Year of author's death AD
Al-Balatheri	829
Al-Yaqoobi	897
Ibn-Khurdadhabih	912
Ibn-Rista	912
Ibn-Jaafar	948
Ibn-Hawqal	978
Ibn-Aljozi	1116
Ibn-Alatheer	1223
Al-Hamawi	1225
Ibn-Alfuwati	1323
Ibn-Abdulhaq	1338

Table 2.1: Authors of the historical texts of the present study

Borehole no.	Figure no.	Depth from surface to sample (m)	Coordinates	Beta Laboratory code	2 Sigma Calibrated age 14C (yr BC-AD) (%95)	Dated material/ Species	Facies in the stratigraphic profile
BH8	3.17A	5.5	32° 9' 19.36"N 44° 27' 40.60"E	Beta - 349656	2860 BC to 2810 BC	Shells /*Melanoides tuberculata*	River levee deposits
BH38	3.17B	0.25	31° 9' 14.44"N 45° 21' 8.92"E	Beta - 379037	45 BC to 75 AD	Shells / *Corbicula fluminea*	Channel post-abandonment deposits
BH36	3.28A	2.75	32° 27' 19.39"N 44° 10' 40.11"E	Beta - 349669	340 BC to 320 BC	Shells / *Melanoides tuberculata*	Marsh deposits
BH10	3.28B	2.0	31° 53' 12.01"N 44° 24' 34.10"E	Beta -349657	910 BC to 810 BC	Shells/ *Melanoides tuberculata*	Marsh deposits
BH34	3.28C	0.3	32° 15' 29.30"N 44° 18' 6.60"E	Beta - 349664	420 AD to 570 AD	Shells / *Corbicula fluminea*	River levee deposits
BH39	3.36	3.75	32° 3'34.52"N 45°24'10.16"E	Beta - 349670	4330 to 4230 BC	Shells / *Corbicula fluminea*	River levee deposits
BH41	3.37	0.5	31°54'57.30"N 45°35'38.19"E	Beta - 379038	1410 to 1445 AD	Shells /*Melanoides tuberculata*	Marsh deposits
BH41	3.37	3.0	31°54'57.30"N 45°35'38.19"E	Beta - 379039	4040 to 3955 BC	Shells / *Corbicula fluminea*	River levee deposits
BH33	3.38	1.0	31°22'46.98"N 45°48'50.66"E	Beta - 349662	760 to 690 BC	Shells / *Corbicula fluminea*	Marsh deposits
BH33	3.38	5.0	31°22'46.98"N 45°48'50.66"E	Beta - 349663	3980 to 3940 BC	Shells / *Corbicula fluminea*	Marsh deposits
BH33	3.38	7.0	31°22'46.98"N 45°48'50.66"E	Beta - 349668	4900 to 4860 BC	Shells / *Corbicula fluminea*	Marsh deposits
BH33	3.38	12.5	31°22'46.98"N 45°48'50.66"E	Beta - 417654	7750 to 7600 BC	Shells / *Corbicula fluminea*	Marsh deposits
BH30	3.39	0.7	30°51'42.68"N 46°24'3.48"E	Beta - 349667	770 to 900 AD	Shells /*Melanoides tuberculata*	Marsh deposits
BH30	3.39	4.5	30°51'42.68"N 46°24'3.48"E	Beta - 349660	5840 to 5710 BC	Shells / *Corbicula fluminea*	Marsh deposits
BH30	3.39	6.0	30°51'42.68"N 46°24'3.48"E	Beta - 349661	8170 to 8110 BC	Shells / *Corbicula fluminea*	Marsh deposits
M32	3.44	5.0	30°59'59.28"N 46°57'1.80"E	Beta - 413642	3695 to 3635 BC	Shells / *Corbicula fluminea*	Marsh deposits
M35	3.45	5.0	30°47'7.62"N 46°44'37.38"E	Beta - 413643	1390 to 1335 BC	Shells / *Corbicula fluminea*	Marsh deposits
M35	3.45	3.0	30°47'7.62"N 46°44'37.38"E	Beta - 414466	395 to 540 AD	Shells / *Corbicula fluminea*	Marsh deposits
M28	3.46	2.5	31° 0'53.01"N 46°42'51.80"E	Beta - 413641	360 to 170 BC	Shells / *Corbicula fluminea*	Marsh deposits
M28	3.46	3.5	31° 0'53.01"N 46°42'51.80"E	Beta - 413640	790 to 730 BC	Shells / *Corbicula fluminea*	Marsh deposits
BH32	3.47	1.25	30°30'10.55"N 47°37'35.11"E	Beta - 379036	2470 to 2285 BC	Shells / *Corbicula fluminea*	Marsh deposits
BH26	4.46	2.7	32°29'16.47"N 45°58'12.40"E	Beta - 349658	920 to 970 AD	Shells /*Melanoides tuberculata*	River levee deposits
BH28	4.47	5.0	32°29'10.55"N 46°13'46.49"E	Beta - 349666	810 to 760 BC	Shells / *Corbicula fluminea*	Marsh deposits
BH42	4.48	4.0	31°55'27.09"N 45°57'19.94"E	Beta - 349665	Cal AD 1280 to 1400	Shells /*Melanoides tuberculata*	River levee deposits
BH29	4.49	2.4	31°31'12.18"N 46° 6'7.01"E	Beta - 349659	430 to 580 AD	Shells /*Melanoides tuberculata*	Marsh deposits

Table 2.2: Radiocarbon dates employed in the present study.

Archaeological Sites	Periods of occupations (earliest – latest)	Archaeological Sites	Periods of occupations (earliest – latest)
Abu Salabikh	Uruk - Early Dynastic	Shuruppak	Jamdet Nasr – U III
Abu Salabikh2	Neo Babylonian	Sippar	Uruk - Parthian
Adab	Early Dynastic- Ur III	Suryfon	Sasanian - Islamic
Alath	Sasanian - Islamic	Tell Aqair	Ubaid – Jamdet Nasr
Babylon	Akkadian - Sasanian	Tell Ed-Der	Ur III - Islamic
Bad Tibira	Uruk – Isin Larsa	Tiliy	Uruk - Parthian
Bahamsha	Islamic	Ubaid	Ubaid - Early Dynastic
Balad	Islamic	Ukbura	Sasanian - Islamic
Bikasi	Old Babylonian – Sasanian	Umm Al-Aqarib	Ubaid – Ur III
Bint Al-Saeigh	Isin Larsa - Islamic	Umma	Early Dynastic – Old Babylonian
Bizughi	Sasanian - Islamic	Ur	Ubaid - Achaemenid
Borsippa	Ur III - Islamic	Uruk	Ubaid – Sasanian
Burdan	Old Babylonian - Islamic	Wasit	Sasanian - Islamic
Busra	Islamic	Wilaya	Early Dynastic – Old Babylonian
Ctesiphon	Sasanian- Ottoman	Zabalam	Jamdet Nasr – Akkadian
Dilbat	Akkadian - Islamic	Zubayr	Islamic
Dujail	Islamic	Abu Gubur	Akkadian – Achaemenid
Dur-Kurigalzu	Kassite – Neo Babylonian	Khafajah	Jemdet Nasr-Early Dynastic
Eridu	Ubaid - Old Babylonian	Asaker	Jemdet Nasr-Early Dynastic
Eshnunna	Early Dynastic - Old Babylonian	Samar	Old Babylonian
Girsu	Early Dynastic- Parthian	Qubur Al- Mishahda	Parthian - Islamic
Harbi	Old Babylonian - Islamic	Kissar Al-Faris	Parthian - Islamic
Isin	Ubaid – Post Cassite	Ukbura	Parthian - Islamic
Jamdet Nasr	Jamdet Nasr – Early Dynastic	Dhibai	Old Babylonian - Islamic
Jerbasi	Kassite – Neo Babylonian	Sakir	Old Babylonian
Jother	Old Babylonian	Qabir Muhammed	Neo Babylonian
Khalal	Uruk - Parthian	Fasiyah	Old Babylonian - Islamic
Khalid	Old Babylonian – Sasanian	Ghazal	Sasanian - Islamic
Khnazirat	Uruk - Parthian	Ieeth	Sasanian - Islamic
Khraifat	Uruk - Parthian	Janab	Sasanian - Islamic
Kibashi	Islamic	Abdhulaij	Sasanian - Islamic
Kish	Jemdet Nasr – Sasanian	Thahuba	Sasanian - Islamic
Kisurra	Early Dynastic	Tell Harmal	Akkadian – Old Babylonian
Kuara	Ubaid - Islamic	Shuruppak	Jemdet Nasr
Kufa	Islamic		
Kutha	Early Dynastic- Sasanian		
Lagash	Uruk – Old Babylonian		
Larsa	Ubaid - Parthian		
Marad	Early Dynastic- Sasanian		
Marad	Early Dynastic – Parthian		
Mashkan Shapir	Uruk – Old Babylonian		
Maskan	Sasanian - Islamic		
Muzrafa	Sasanian - Islamic		
Nippur	Ubaid - Islamic		
Nowaywees	Uruk - Parthian		
Ona	Seleucid - Islamic		
Oueili	Ubaid		
Qaism	Neo Babylonian – Islamic		
Samarra	Ubaid - Islamic		
Seleucia	Seleucid - Islamic		
Shmid	Uruk		

Table 2.3: Periods of occupations of some key archaeological sites in the present study (Adams, 1981 and General Directorate of Antiquates, 1976)

3. The Euphrates River

In this chapter, a study reconstructing the ancient courses of the Euphrates in the Mesopotamian floodplain is presented. The focus is on tracing palaeochannel courses, determining when they were active, and understanding the patterns of avulsion. In this study, the Euphrates River has been divided into three areas of study (Fig. 1.11), and each area will be discussed separately. The areas are: Najaf, Ur, and Marshland. It is significant that fieldwork has been done in all these three areas, therefore, the research was carried out using a combination of geological, geomorphological, remote sensing, historical and archaeological approaches as explained in Chapter Two.

3.1 Euphrates River in the Najaf area

Note: this section of the thesis formed the basis for a paper:

Jotheri, J., Allen, M.B., and Wilkinson, T.J., 2016. Holocene avulsions of the Euphrates River in the Najaf area of western Mesopotamia: impacts on human settlement patterns. Geoarchaeology, 31, 175-193, doi 10.1002/gea.21548. I analysed and interpreted the data (with the exception of radiocarbon ages analysed by Beta Analytic as outlined in Chapter 2), wrote the text and prepared the figures. Mark Allen and Tony Wilkinson commented on the text and provided supervision.

The Najaf area is located in the northwest of the Holocene Mesopotamian floodplain, and includes several modern cities, such as Hilla, Karbala, Najaf, Diwaniya and Samawah as well as famous ancient cites such as Sippar, Babylon, Borsippa, Kish, and Dilbat (Fig.3.1). It is bordered from the west by the Arabian Plateau, the Al-Khir alluvial fan and the Ramadi alluvial fan (Fig. 3.1). The present course of the Euphrates enters the study area from the north and spreads distributaries over the floodplain in the study area. There are two branches for the present Euphrates: the Hindiya and the Hilla (Fig. 3.1).

Compared with rest of the Mesopotamian floodplain, the Najaf region has largely been neglected, with the exception of Brinkman (1984), who mentioned the probability of several important archaeological sites associated with the ancient Euphrates in the south of ancient Babylon. Cole (1994) and Cole and Gasche (1998) reconstructed palaeochannel courses in the present study area based on geomorphology and cuneiform texts, but only north and northeast of Babylon. Ur and Hamdani (2013) mentioned the ancient Euphrates from the Ur region towards the north, but they did not trace its course, and stopped their description near Samawah i.e. to the south of Najaf area (Fig. 3.1).

As with palaeochannel reconstructions, archaeological surveys in the Najaf region have been limited with the exception of a few sites well excavated by international and local teams, such as Tell Ed-Der , Sippar, Babylon, Borsippa, Kish, Dilbat, Bikasi and Khalid (Fig. 3.1). Other sites have been dated by local archaeological teams who carried out preliminary investigation of pottery and buildings of archaeological sites. The main archaeological resources of the present study are from the two general atlases of sites of Iraq, General Directorate of Antiquities (GDA) (1970) and GDA (1976), both of which deal with the location and the main occupation periods of archaeological sites.

Results

More than 200 archaeological sites are more recent than the Neo-Babylonian period (after the mid-first millennium BC), most indicate occupation in the Parthian, Sasanian and Islamic periods (Ur and Hamdani, 2013), while 17 sites (Table 1.2) contain evidence of periods of occupation prior to this (but after the late fourth millennium BC) (GDA, 1970 and 1976).

Five main courses of the Euphrates, in five different periods have been identified, described and mapped, and summarised by time slices in this area (Fig. 3.2-3.7). From oldest to the youngest, the main courses

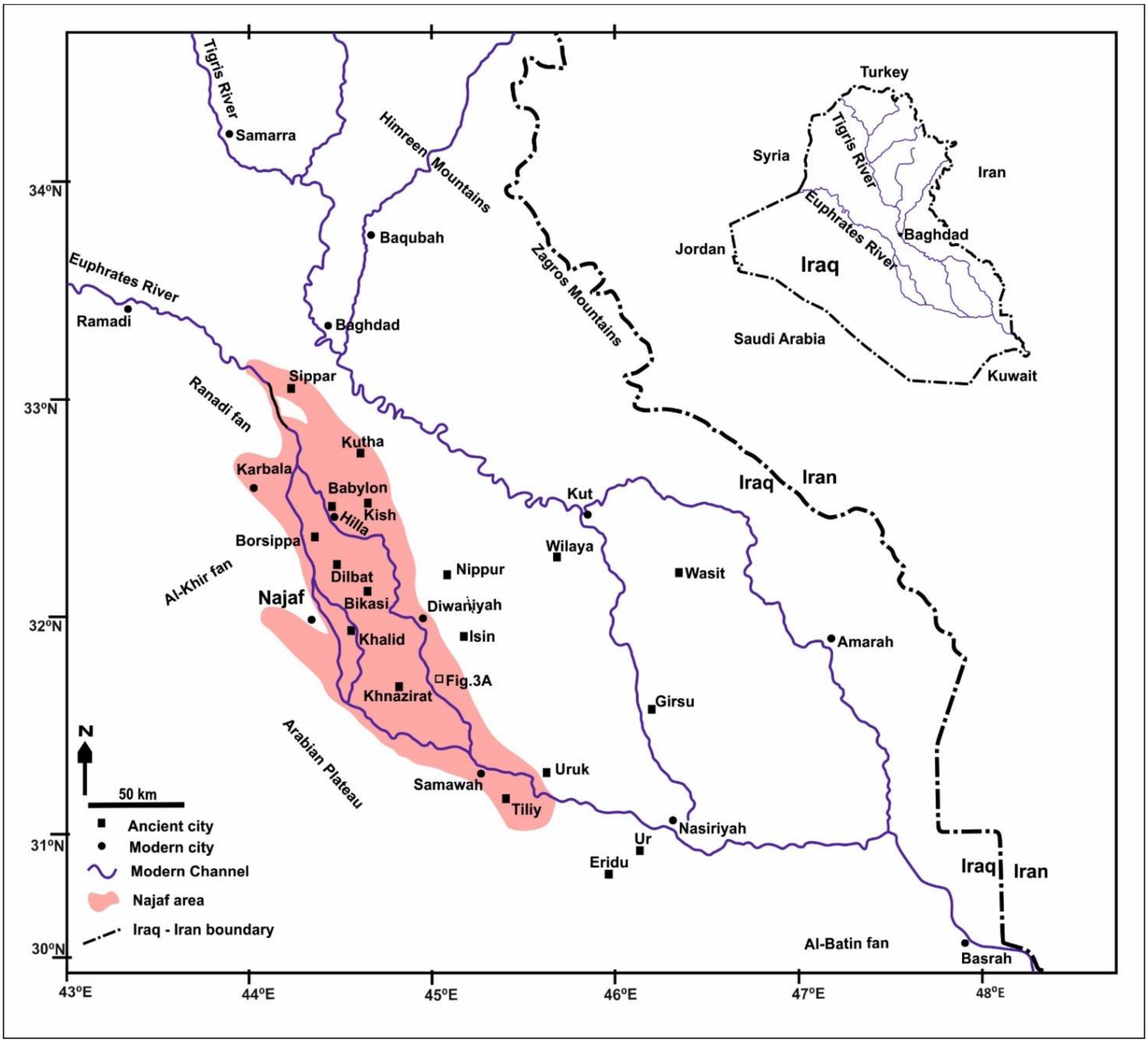

Figure 3.1: Location map showing the Najaf area.

are the Purattum Course (the fourth to the first millennium BC) (Fig. 3.2), the Arahtum Course (from the early to the late first millennium BC) (Fig. 3.3), the Sura Course (from the early first millennium BC to the thirteenth century AD) (Fig. 3.4), the Hilla Course (from the 13^{th} to the 19^{th} century AD) (Fig. 3.5), and the Hindiya Course (from 19^{th} to 20^{th} century AD) (Figs. 3.6 & 3.7). Additionally, there was a major channel in the west of the study area, the Pallukkatu channel, which was occupied from ~the middle first millennium BC to ~the thirteenth century AD, i.e. overlapping several of the main channel periods. The oldest group of archaeological sites (i.e.

after the late fourth millennium BC) continued to be occupied during the Purattum and the Arahtum. Members of the youngest group of archaeological sites (i.e. dating after the middle first millennium BC) were mainly established during Parthian and Sasanian periods and continued to be occupied during the Islamic period.

Specific examples of palaeochannel features, of the type used to build up the reconstruction of the five palaeocourses (Figs. 3.2 – 3.7) are located in Fig. 3.8.

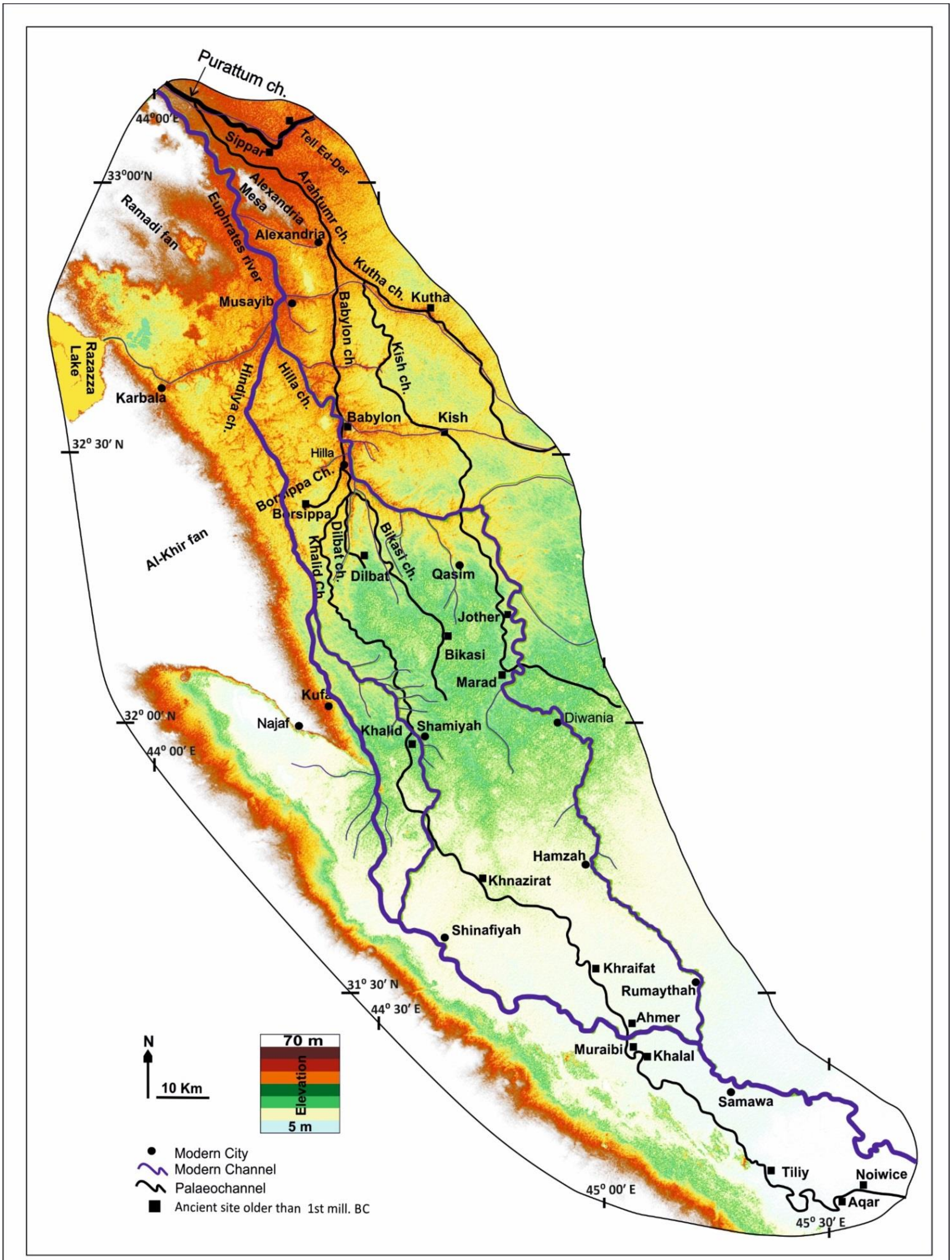

Figure 3.2: The Purattum Course (the fourth to the first millennium BC). The general gradient of Najaf area palaeochannels is about 15cm/km.

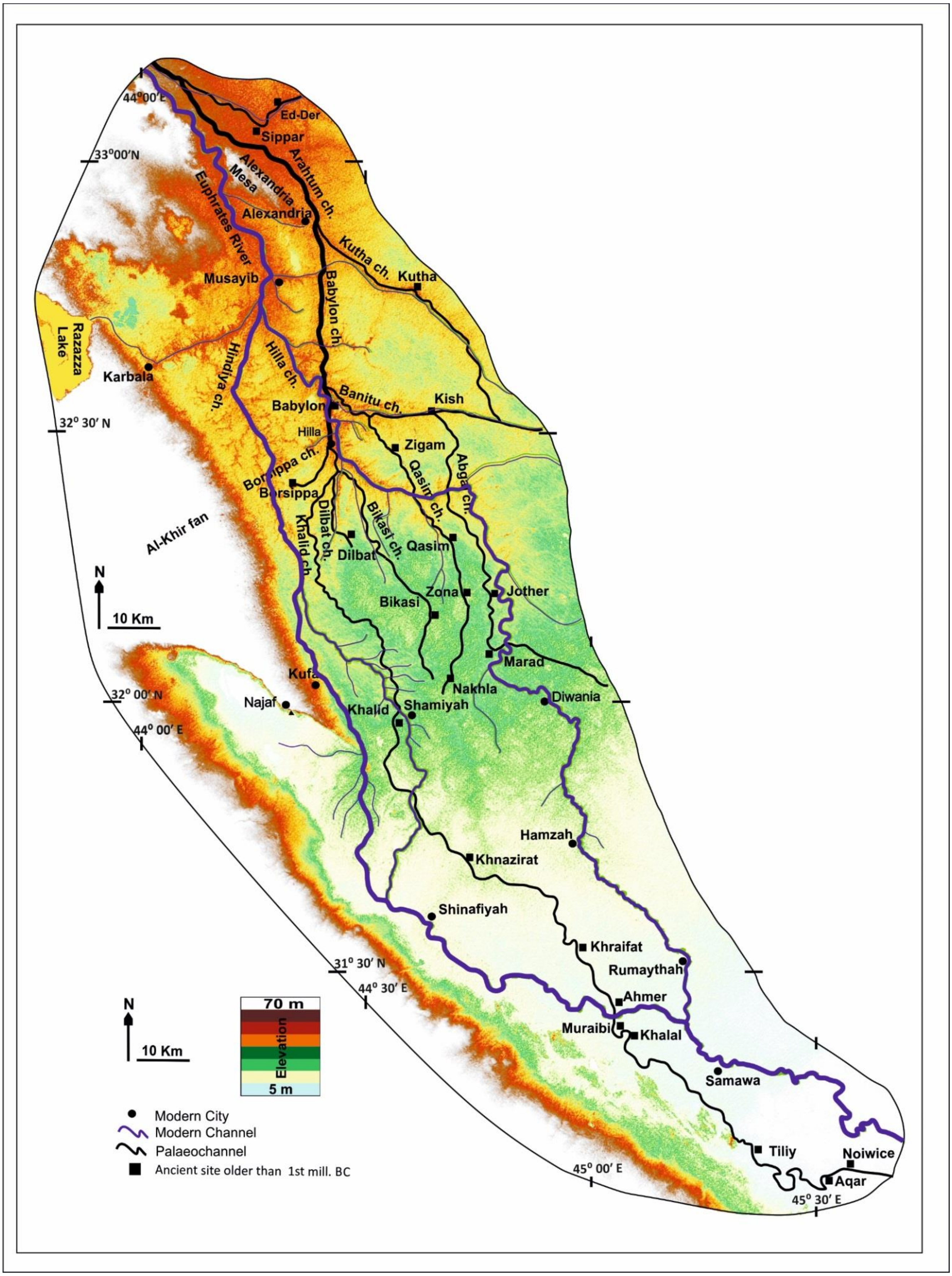

Figure 3.3: Arahtum Course (from the early to the late first millennium BC).

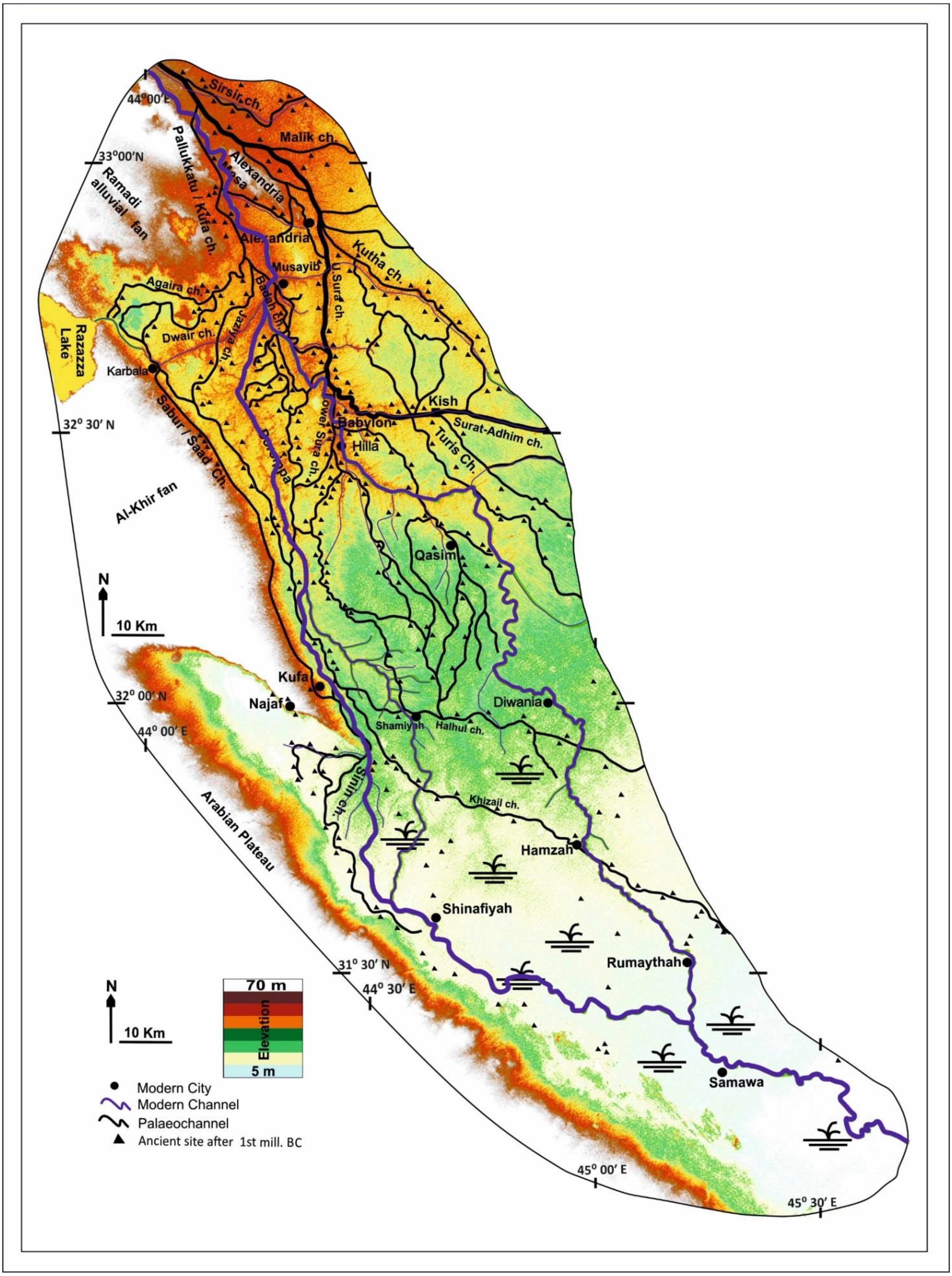

Figure 3.4: The Sura Course (from the early first millennium BC to the thirteenth century AD)

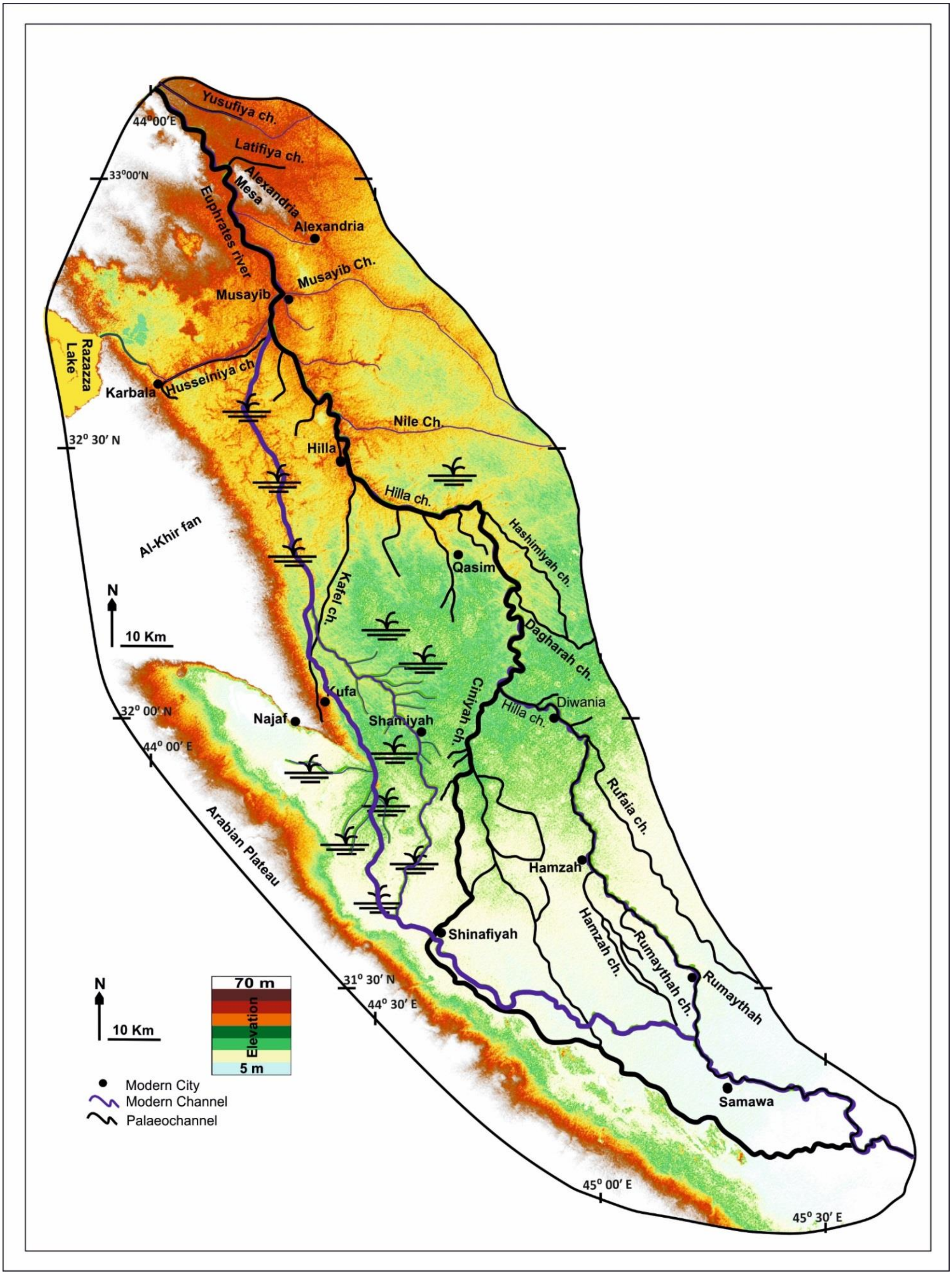

Figure 3.5: The Hilla Course (from the 13th to the 19th century AD)

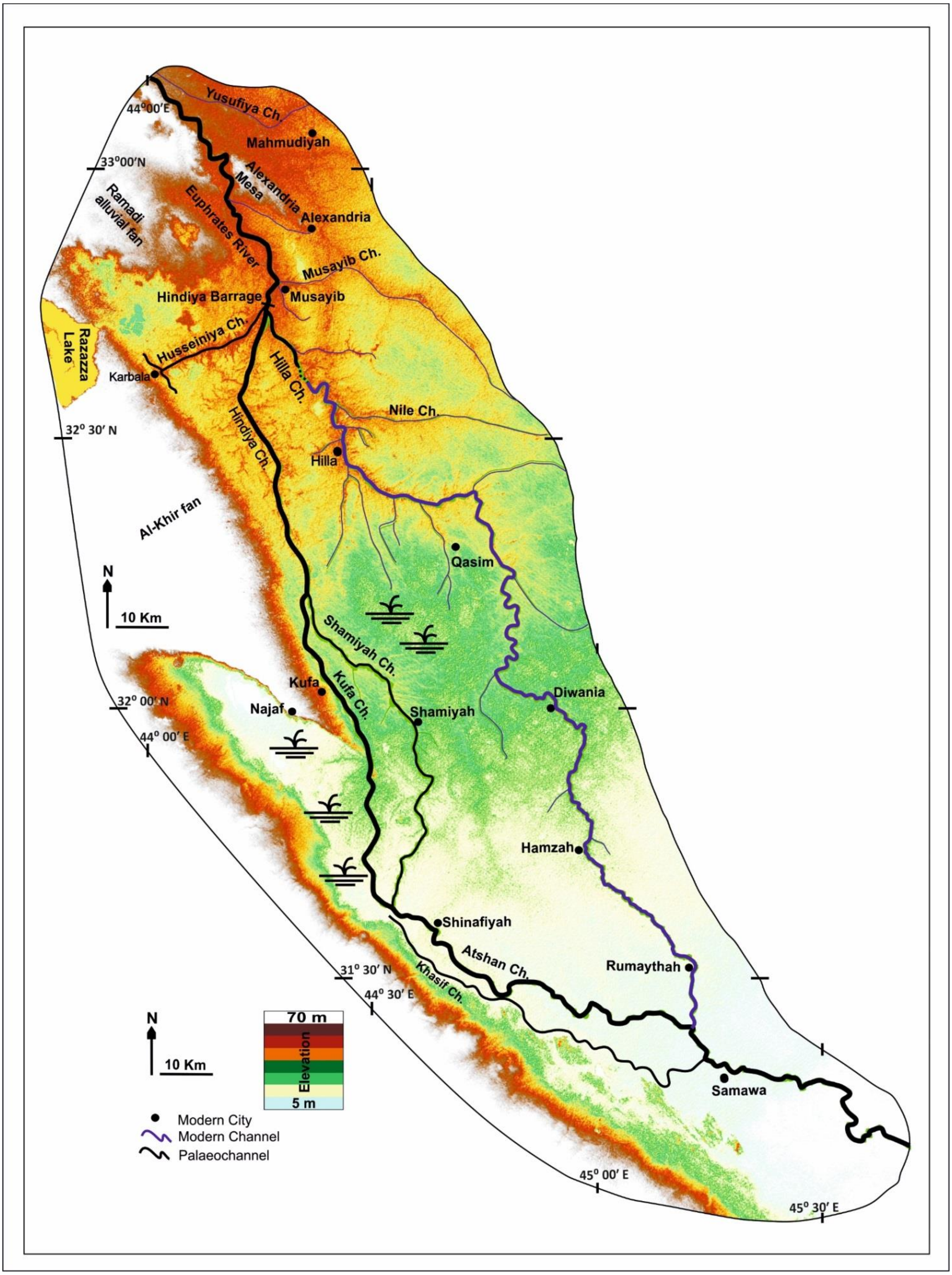

Figure 3.6: Start of avulsion from Hilla to Hindiya course.

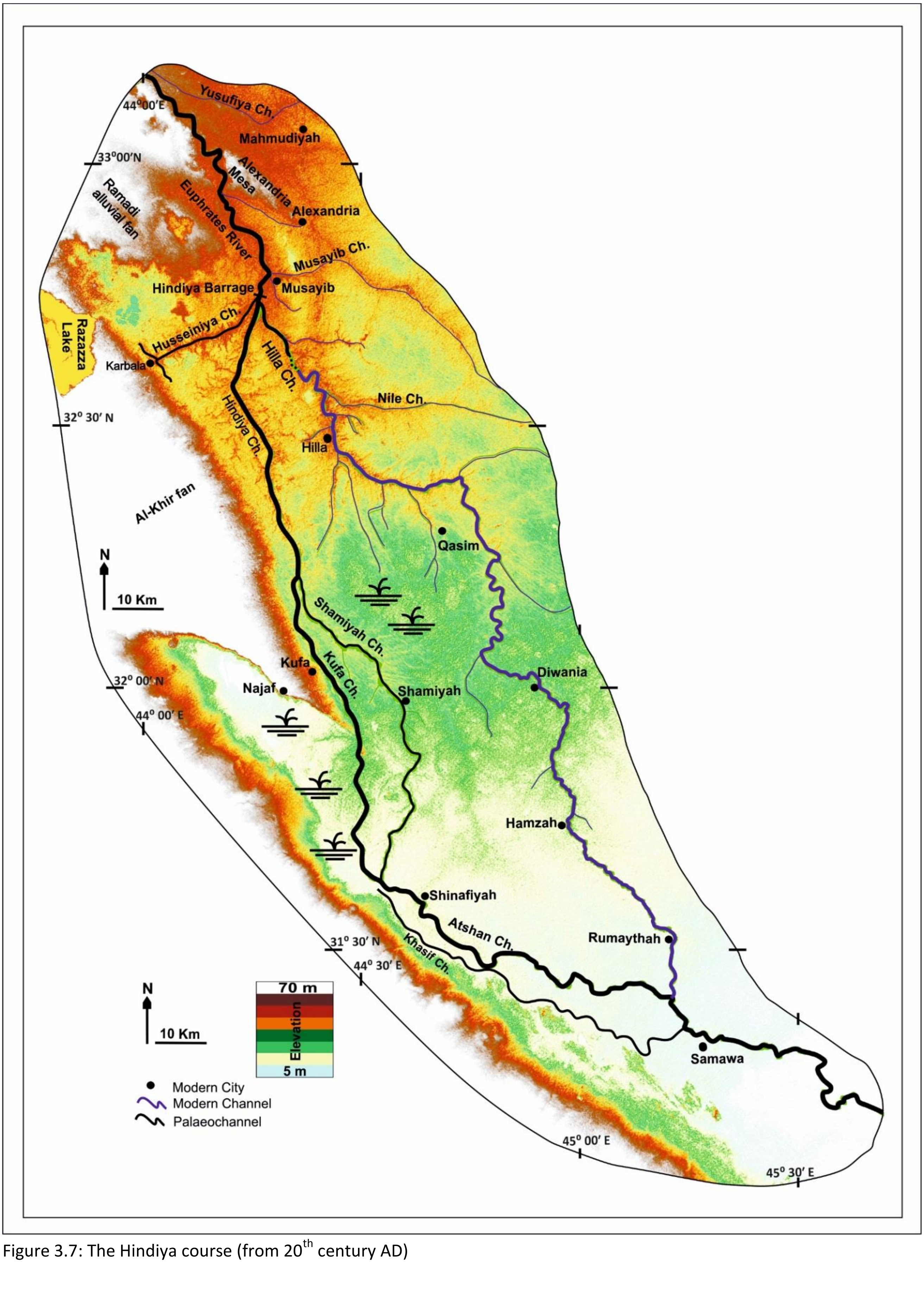

Figure 3.7: The Hindiya course (from 20th century AD)

3.1.1 The Purattum Course (the fourth to the first millennium BC)

This course (Fig. 3.2 and 3.9) was identified and dated by Heyvaert and Baeteman (2008) based on the integration of geological, historical and archaeological data. Most of the route of the proposed main channel is to the east of the present study area, joining with the ancient Tigris to the south of Baghdad (Fig. 3.1). Heyvaert and Baeteman (2008) assumed, on the basis of borehole survey results and archaeological excavations that the main Purattum course already existed before the foundation of Sippar during the Uruk period (Table 1.1). They estimated that the end of the period of this meander belt occurred in the first millennium BC because they identified several archaeological sites from this period that were founded on earlier Sippar palaeochannel sediments. Cole and Gasche (1998) also identified and dated several palaeochannels belonging to this course, based on ancient documentary sources, and concluded that this course was active during the first half of the second millennium BC, was called the Purattum, and was the main Euphrates channel until the first millennium BC.

The present study has found geomorphic evidence for distributary channels to the south of Babylon (Figs. 3.10 to 3.16). The Babylon channel bifurcated into four channels: Borsippa, Khalid, Dilbat, and Bikasi (Fig. 3.10). There is no firm evidence to prove whether they were all active at the same time or whether they represent different avulsions in the downstream part of the Arahtum/Babylon system. However, the existence of archaeological sites from the same period, i.e. the fourth to the first millennium BC, on these channels suggests that they were active at the same time. Brinkman (1984) carried out research on cuneiform tablets found during excavation at the site of Borsippa, and found that there were channels mentioned in these tablets that were located near the site and southwards (Figs. 3.1 and 3.2), and that these channels were necessary for river trade between Babylon and the downstream sites (Fig. 3.2). The Kutha channel also bifurcated into two parts, named Kutha and Kish; the Kish channel continued toward the south to pass near the Kish, Jother and Marad sites (Fig. 3.2). As the Kutha archaeological site was occupied from the Early Dynastic period i.e. 2900 – 2350 BC (Table 1.1), it may suggest that the formation of the Kutha branch predated the Early Dynastic period. Researchers such as Gibson (1972) and Cole and Gashe (1998) have suggested that the Kish branch was formed before the late 4th Millennium BC as the excavation at this site did not reach the virgin soil. The Khalid channel continued towards the south, to pass through Khnazirat, Khraifat, Ahmer, Muraibi, Khalal, Tiliy, Aqar and Nowaywees sites (Fig. 3.2, 3.14 and 3.16). The sites associated with the Khalid channel generally have a similar occupation period, to those associated with theBabylon channel (i.e. before the late 3rd Millennium BC) as the Khalid site was occupied during this period (Mansoori, 2012). This presumably means that the channel was active in the same channel belt.

Two radiocarbon dates were obtained on shells taken from the Khalid channel (Figs. 3.11, 3.16 and 3.17). Fig. 3.17A shows one locality which is dated 2860 to 2810 BC; Fig. 3.17B shows the other, which is dated as 45 BC to 75 AD. We suggest that the first locality represents the age of lateral movement of the channel within the meander belt because the location of the borehole (Fig. 3.11) is rather far away from the channel/levees visible on the satellite imagery and the shell sample was taken from the beginning of a fining-up succession of sediments (Fig. 3.17A). The second locality may represent the final stage of channel abandonment, because the shell sample was taken from the end of the fining-upward succession (Fig. 3.17B) and the location of the borehole (Fig 3.16) is close to the channel/levee.

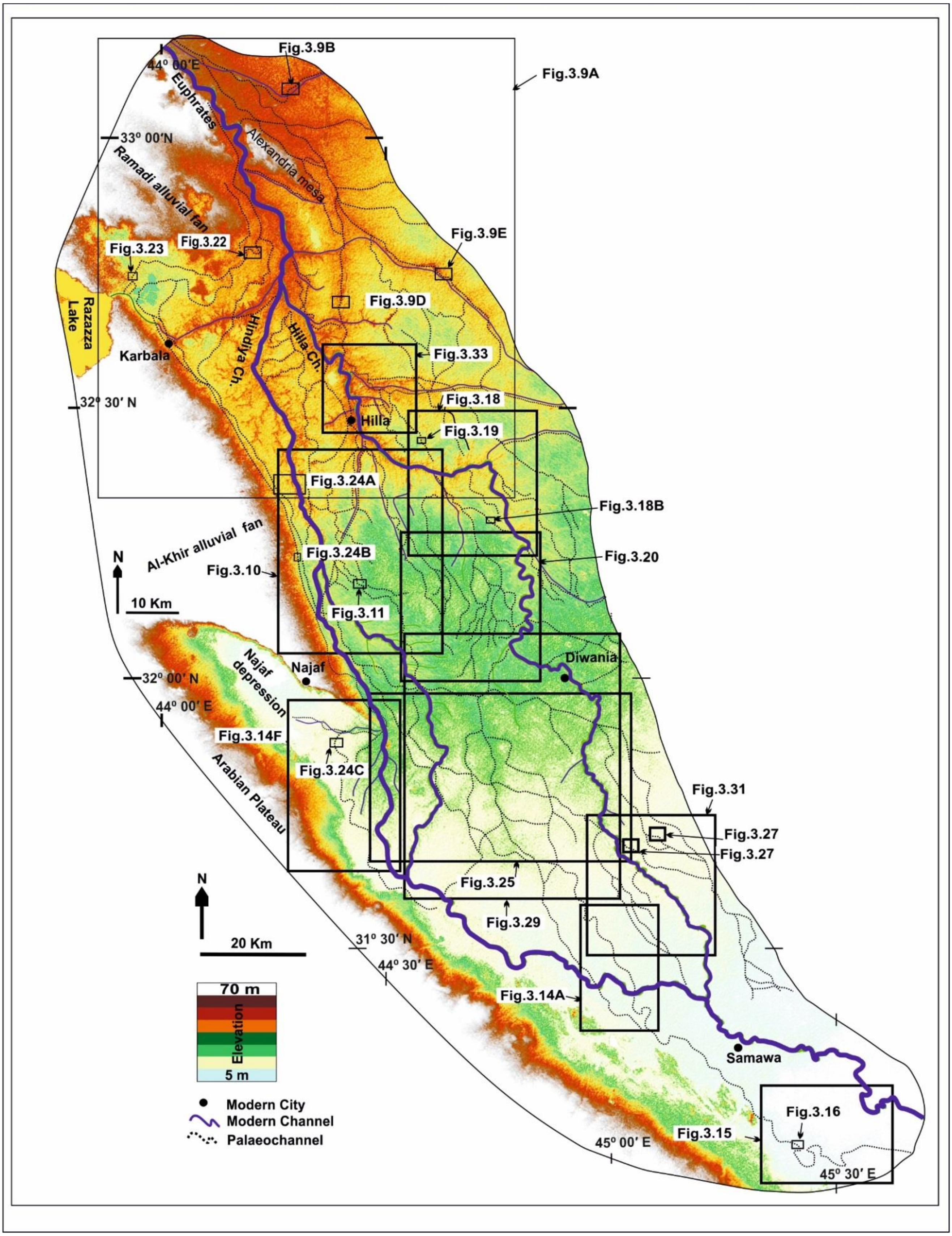

Figure 3.8: SRTM location map showing the detailed figures of the Najaf area.

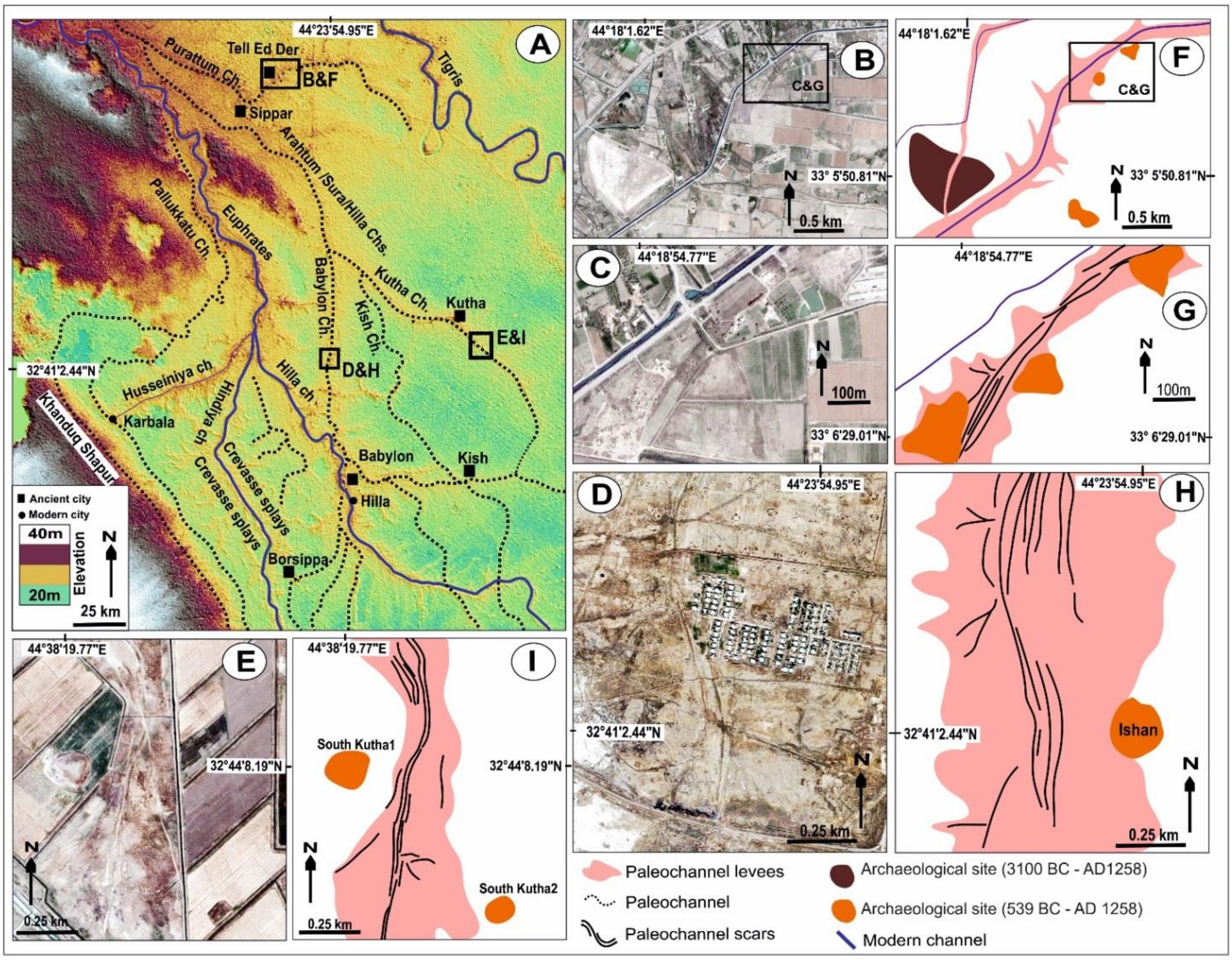

Figure 3.9: SRTM data (A) for the north part of the present study (see Figure 3.8 for location) showing how palaeochannel levees are elevated in relation to the surrounding floodplain. Main modern channels are indicated by solid lines; palaeochannels by dotted lines. QuickBird images (B-E) and interpretations of features on these images (F-I), respectively. The QuickBird images show selected examples of relict channel meander loops and a series of human settlements, which are evidence that the channel was present at the time of settlement.

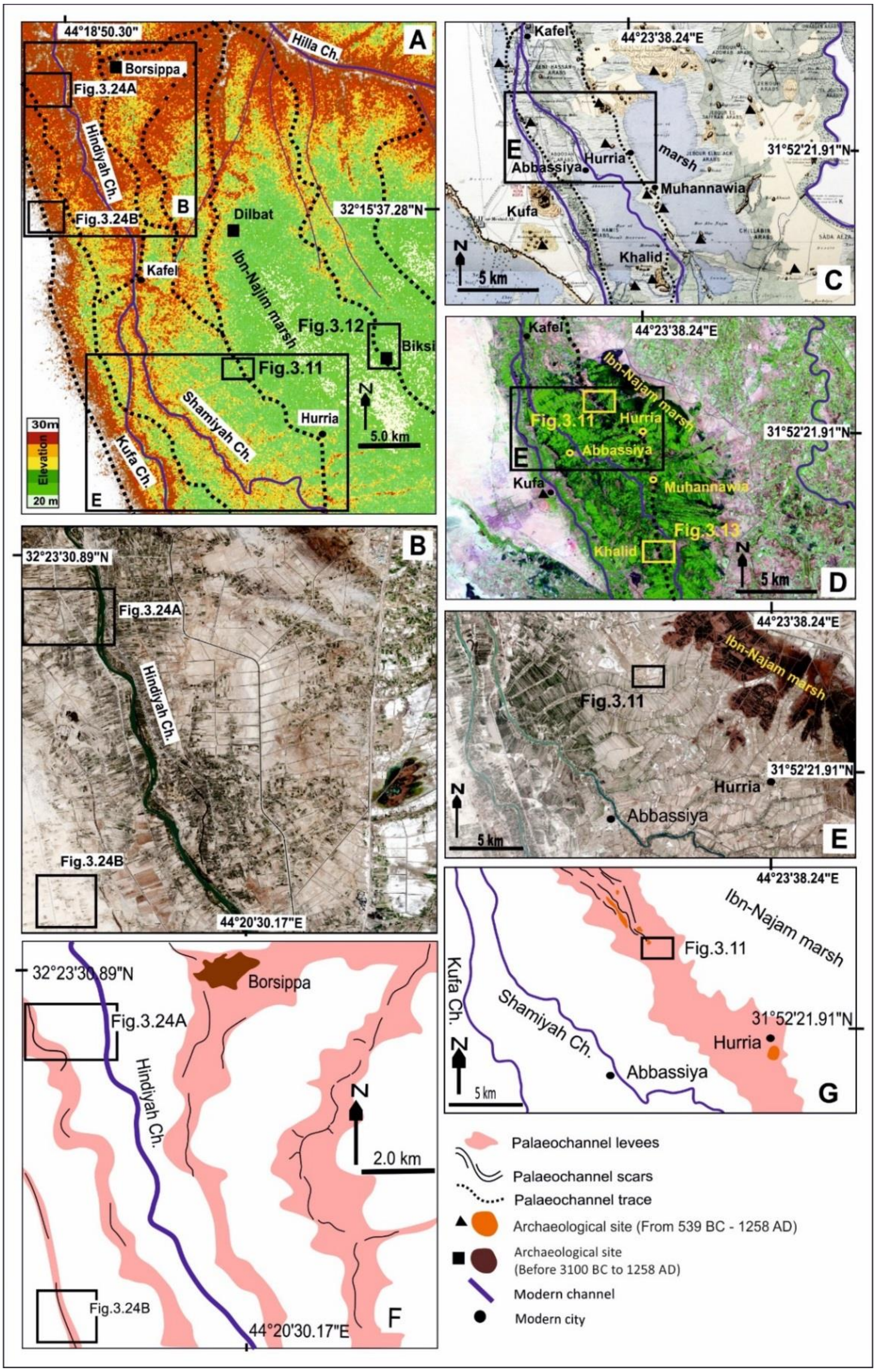

Figure 3.10 :(A) SRTM data of the middle part of the present study showing palaeochannel levees that have relatively high topographic elevations in relation to the surrounding floodplain. (B) QuickBird images (2006) show the locations of palaeochannel levees. (C) Later historical map (Selby et.al, 1885) showing palaeochannel levees covered by marshes and the growth of the Shamiyah and Kufa distributary channels. (D) Landsat ETM (2000) image showing palaeochannel levees covered by younger marshes and modern settlements. (E) QuickBird images (2006) showing the palaeochannels after most of the marshes dried up. (F)Tracing of surface features including palaeochannel levees, scars and archaeological sites of the image B. (G) Tracing of surface features including palaeochannel levees, scars and archaeological sites of the image E.

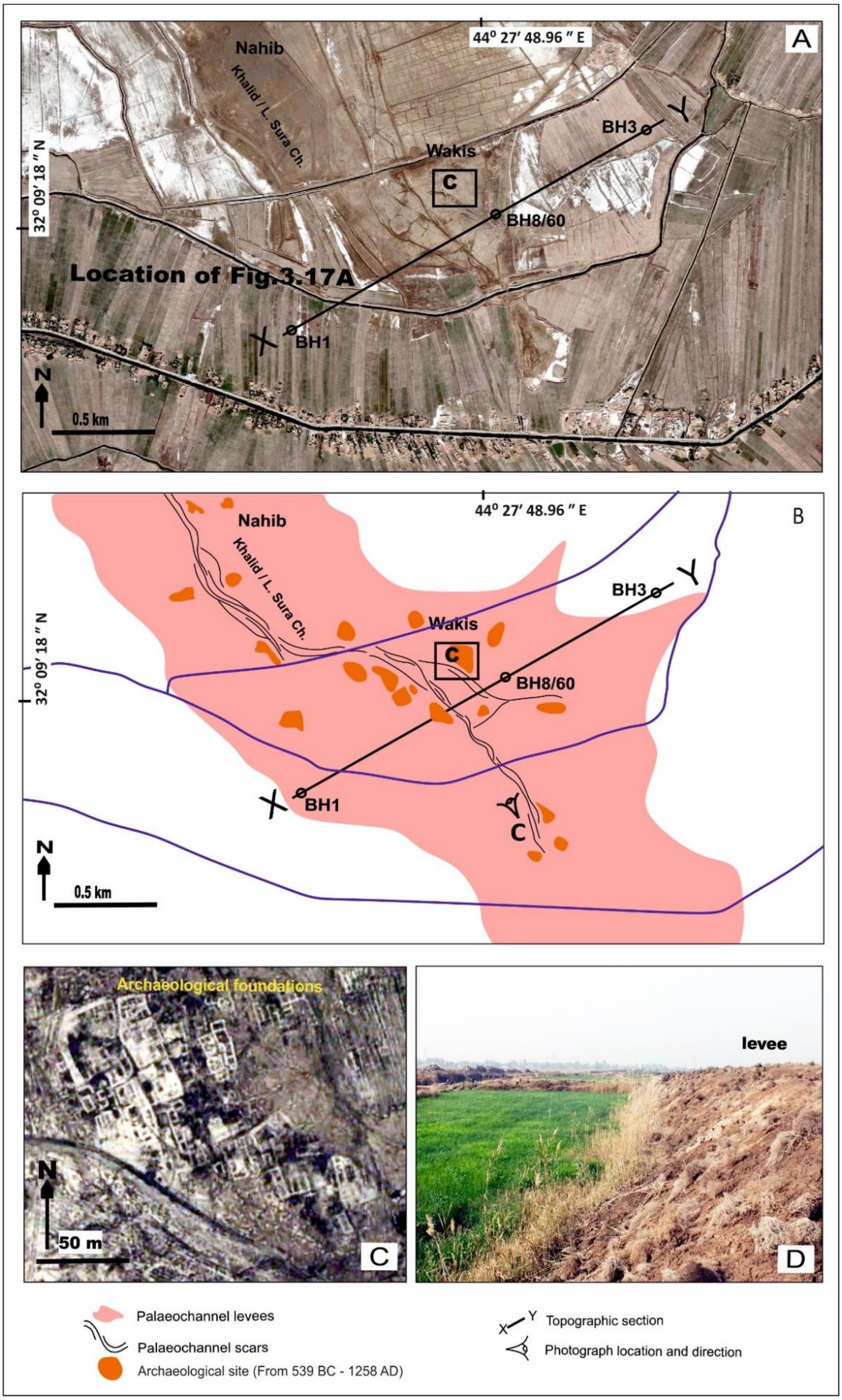

Figure 3.11: (A) QuickBird image showing the Khalid and one of the Lower Sura distributary palaeochannels. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Archaeological foundations from the Parthian period to the Islamic period. (C) Field photograph showing the palaeochannel levees. (D) Topographic cross-section through the palaeochannel, showing the lithologies of the BH1, BH8/60, and BH3 boreholes.

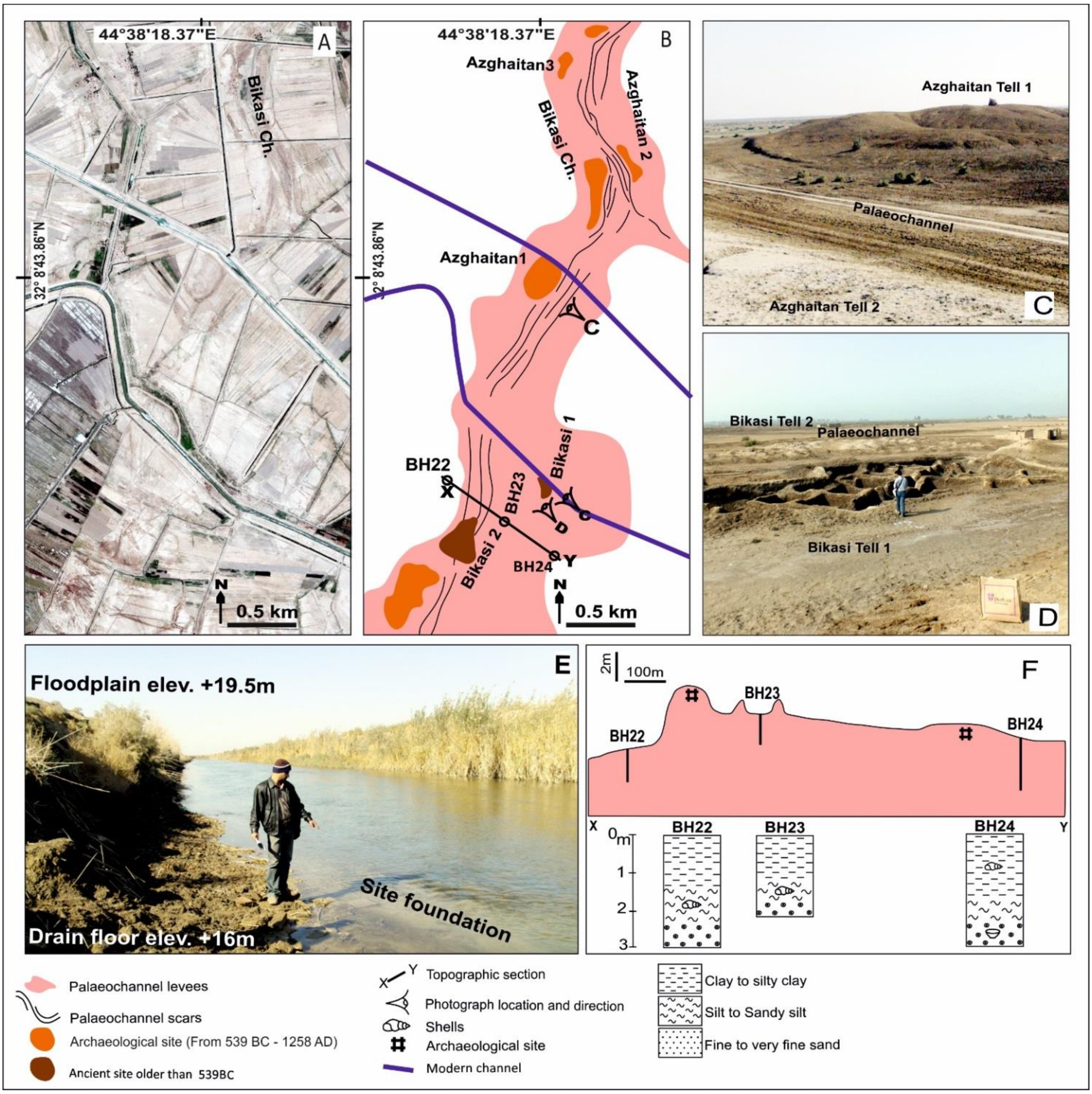

Figure 3.12: (A) QuickBird image showing the Bikasi palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph showing a palaeochannel between two loops of a site. (D) Field photograph showing the Bikasi palaeochannels. (E) Field photograph showing buried foundation belong the Bikasi site. (F) Topographic cross-section through the palaeochannel, showing the lithologies of the BH22, BH23, and BH24 boreholes.

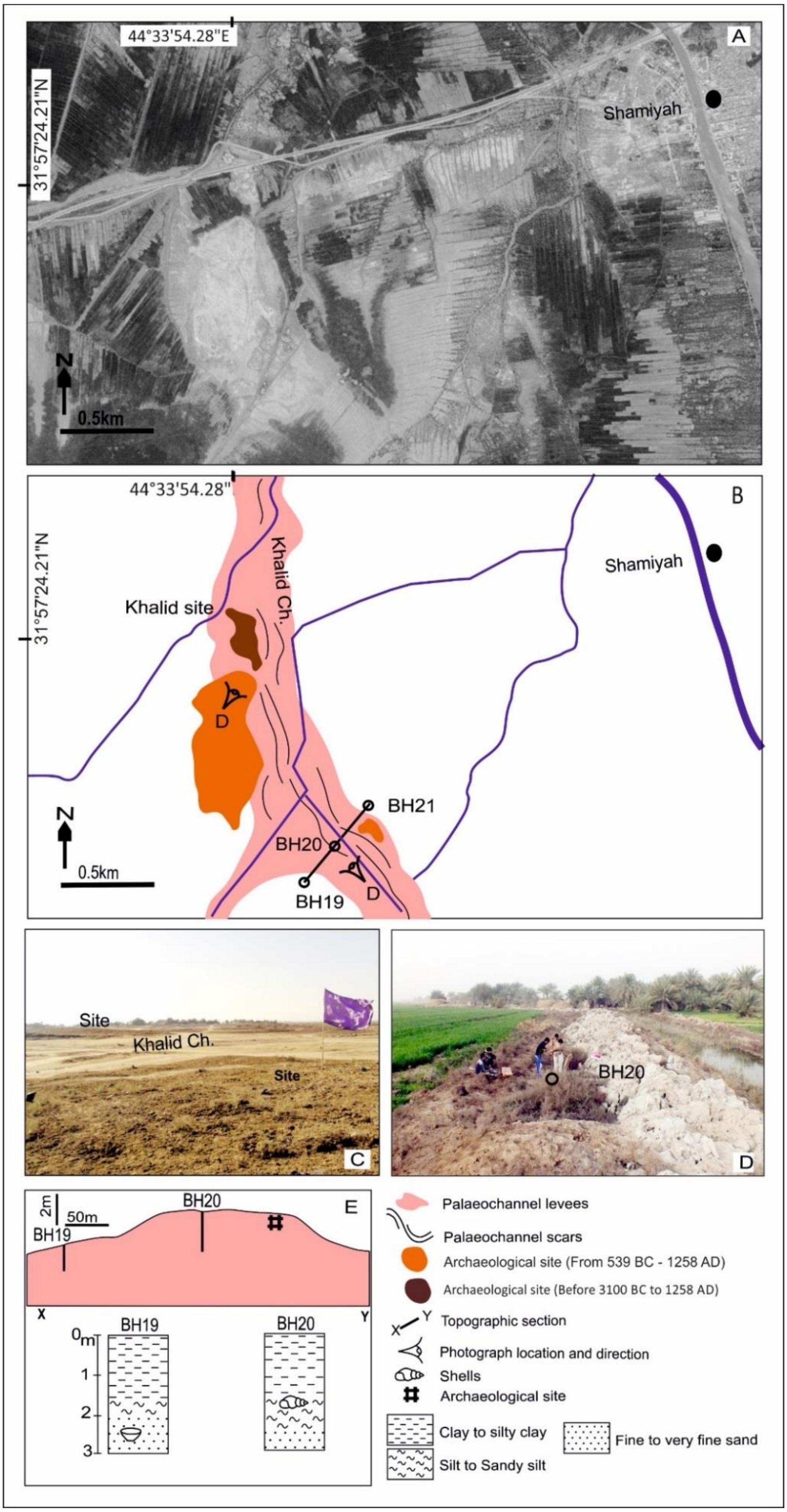

Figure 3.13: (A) CORONA image showing the Khalid palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph showing a palaeochannel between two loops of a site. (D) Field photograph showing the Khalid palaeochannel levees and the location of BH20. (E) Topographic cross-section through the palaeochannel, showing the lithologies of the BH19, BH20, and BH21 boreholes.

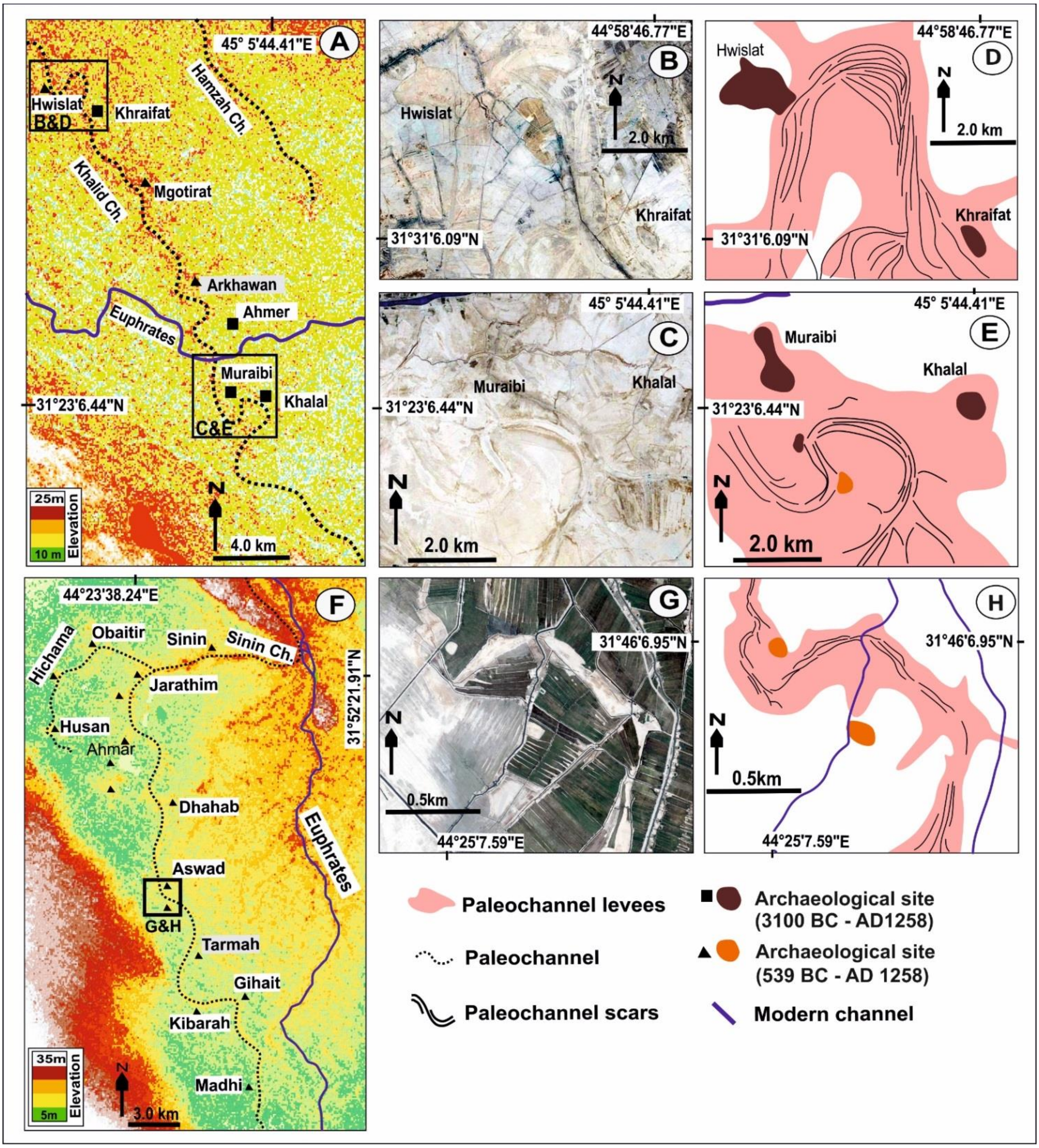

Figure 3.14: SRTM data (A) for the south part of the study area showing how palaeochannel levees are elevated in relation to the surrounding floodplain. QuickBird images (B & C) and interpretations of surface feature (D & E), respectively. SRTM data (F) for the west part of the study area showing palaeochannel levees. QuickBird image (G) and interpretations of the surface features (H).

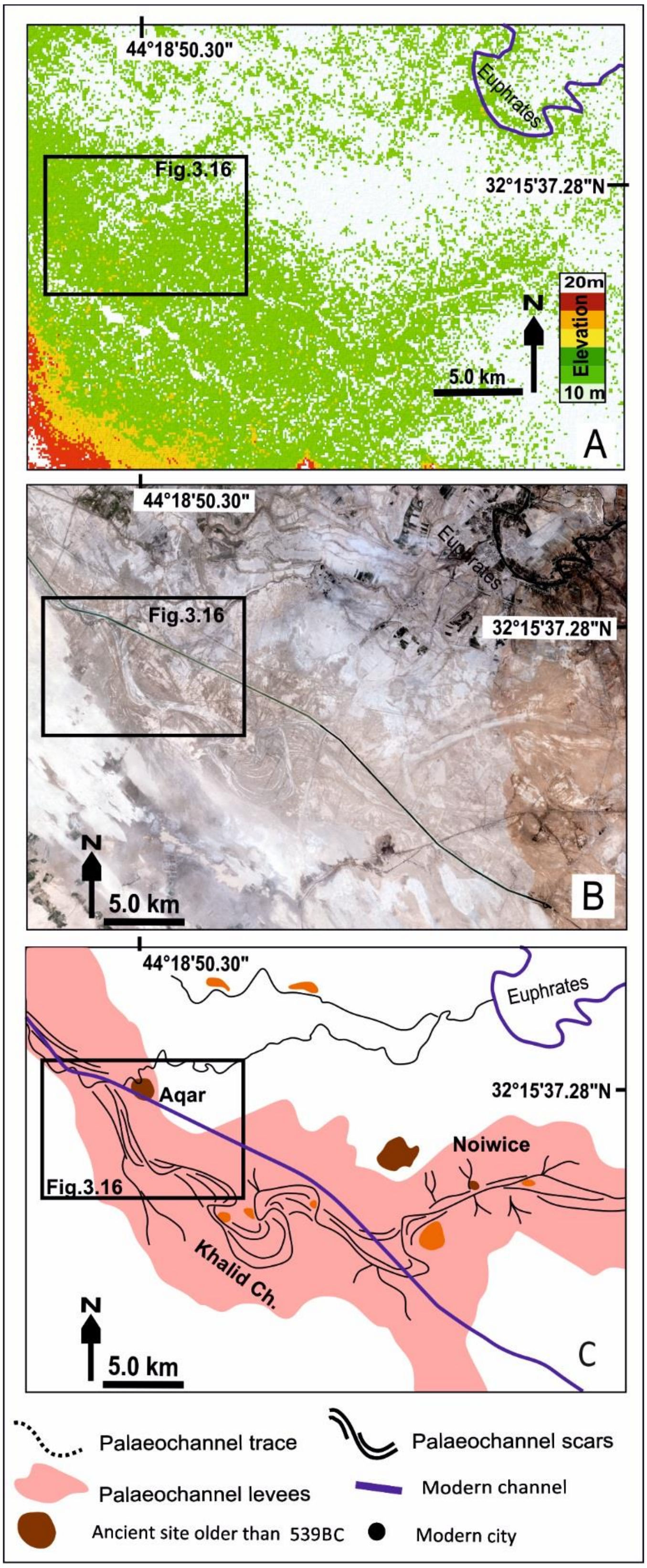

Figure 3.15: (A) SRTM data map of the southern part of the study area showing how Khalid palaeochannel levees have a relatively high topographic elevation in relation to the surrounding floodplain. (B) QuickBird image (2006) of the same area to show archaeological sites associated with Khalid palaeochannel. (C) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

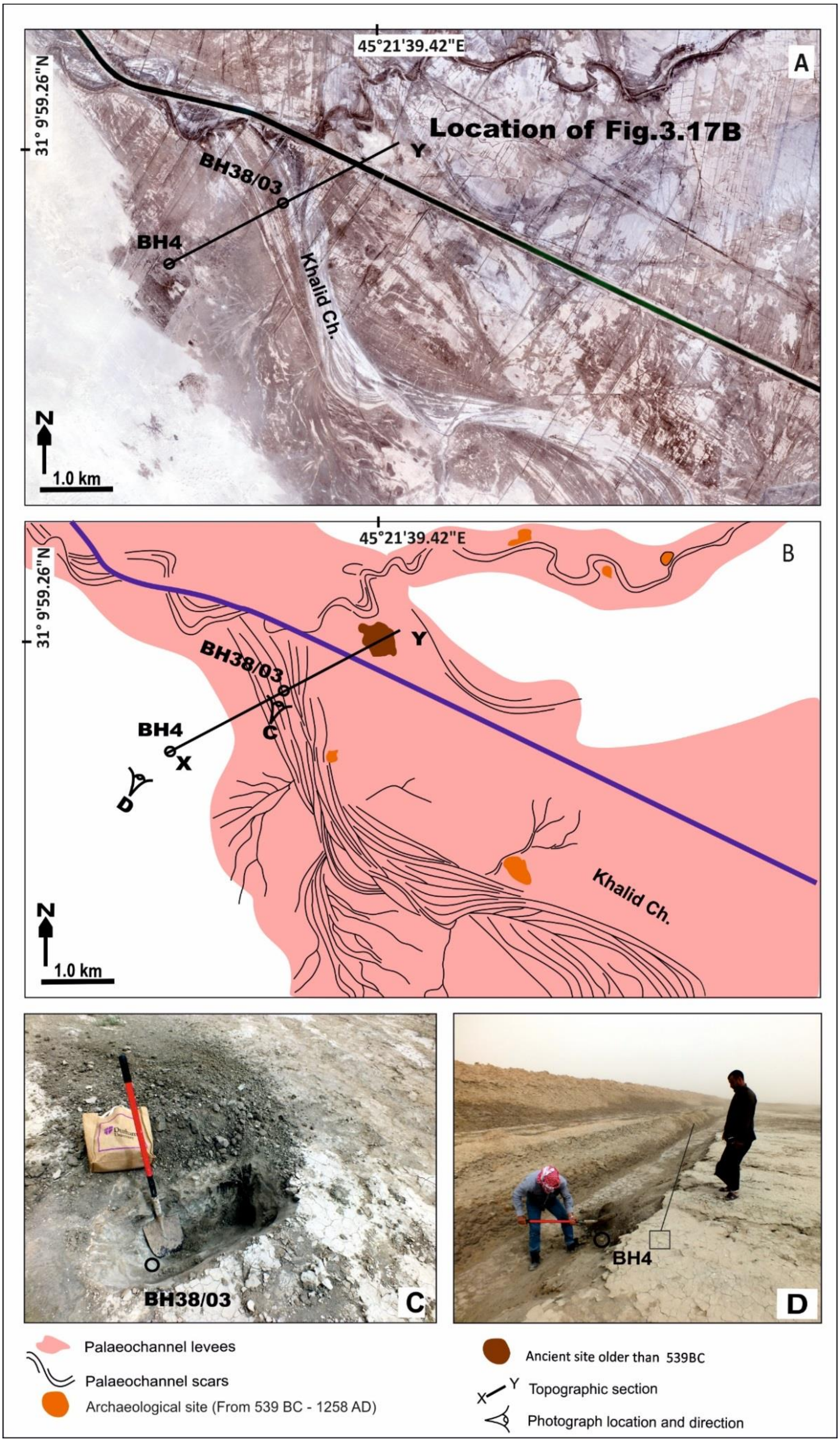

Figure 3.16: (A) QuickBird image showing the Khalid palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph showing the location of BH38/03. (D) Field photograph showing the location of BH4.

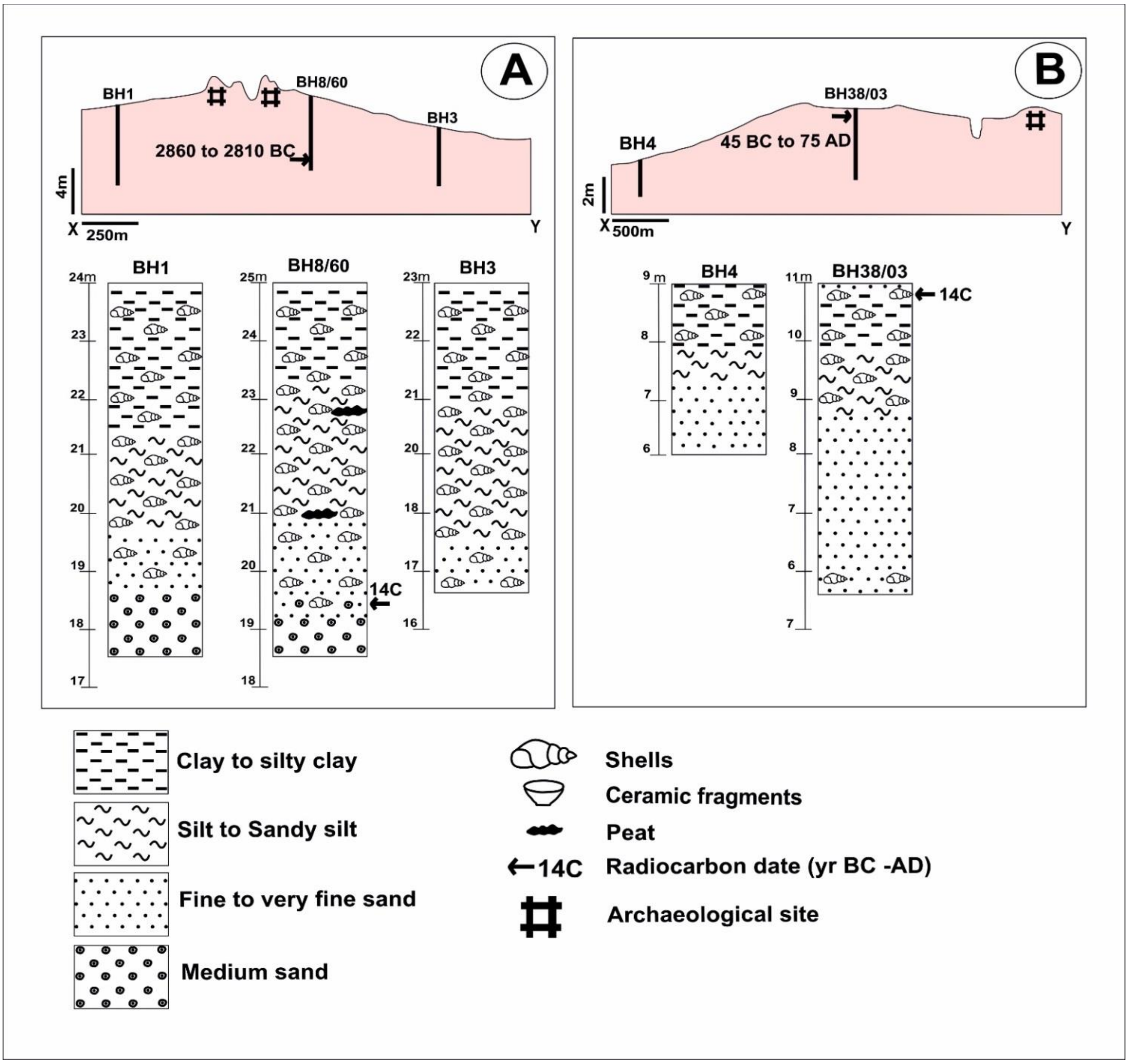

Figure 3.17: Topographic cross-sections through palaeochannels, showing the locations of the augured boreholes, radiocarbon samples, and associated archaeological sites. (A) and (B) shows radiocarbon ages of shells from the Khalid Channel (Purattum and Arahtum courses).

3.1.2 Arahtum Course (from the early to the late fist millennium BC)

This course (Fig. 3.3) has been suggested by Cole and Gasche (1998) on the basis of archaeological material and textual data, as having been the largest channel in the first half of the first millennium BC, They also reported that previously, at the time of the Purattum, the Arahtum (Fig.3.3) was a distributary channel branching off the main course, and that there were two secondary distributaries branching from Arahtum (Fig. 3.3): the Babylon and the Kutha (Figs. 3.3 and 3.9). They suggested that the Kish channel was larger and older than the others. Cole and Gashe (1998) did not, however, study the geomorphic traces of these channels downstream of Babylon.

The avulsion node for the Arahtum is located ~20 km northwest of Sippar (Figs. 3.3 and 3.9). Cole and Gasche (1998) documented several differences from the previous course, including the abandonment of the Kish channel, and establishment of a new channel called the Banitu (Figs.

3.3 and 3.9). According to textual evidence, Cole and Gasche (1998), the Banitu channel was dug during the Neo-Babylonian period to take water from the Arahtum (Babylon) course to the site of Kish, with the formation of a new channel (referred to here as the Qasim), which passes the Zigam, Qasim, Zona, and Nakhla sites (Figs. 3.18 , 3.19,3.20 and 3.21)
All of these palaeochannels have been recognised in remote sensing investigations and confirmed by original fieldwork in this study (Figs. 3.18, 3.19, 3.20 and 3.21). It is not clear which route the Arahtum course took downstream of Hilla to reach the sea, but the Khalid channel is a likely candidate because of settlements of the right age such as Khalid, Khnazirat and Tilly (Mansoori, 2012) (Fig. 3.3).

3.1.3 The Pallukkatu channel (from the middle first millennium BC to the thirteenth century AD AD)

According to Susa (1948), Cole (1994), Cole and Gasche (1998), Verhoeven (1998) and Ooghe (2007), there was an active channel from the Achaemenid to Seleucid periods called the Pallukkatu (Fig. 3.4). They did not trace it, but suggested its location was west of the ancient sites of Babylon and Borsippa, and that it took water from the west bank of Arahtum course and ran to the west of the Alexandria Mesa (Fig. 3.9). The Pallukkatu channel does not represent a wholesale re-organisation of the Euphrates, and so is not treated here as a separate course in the same category as the Purattum and Arahtum etc. Nevertheless, it merits attention, as it was a major channel.
Susa (1948) and Cole (1994) suggested that the Pallukkatu channel was of human origin, i.e. it was dug adjacent to the desert from the west bank of the main Euphrates, over the west side of the Alexandria Mesa and continued southward. They assumed the reasons behind digging this canal were (1) to irrigate the area close to the desert, (2) to protect the farms and villages from invasion by nomads from the Arabian Desert, and (3) to drain excess water from the Arahtum channel during the flood season. According to Ibn-Alatheer (2003), in the Islamic period the Pallukkatu was called the Kufa or sometimes Al-Alqami. These authors added that although this palaeochannel was documented and described by cuneiform texts, no study had succeeded in reconstructing its route south of the Alexandria Mesa. Therefore our observations, summarised and represented by Fig. 3.4, are the first geomorphic evidence for the location of the Pallukkatu palaeochannel in this region (Figs. 3.22 to 3.27). The Pallukkatu channel was cut (from around the Neo-Babylonian period) through the eastern tip of the Ramadi fan; from that time the Alexandria Mesa, which is part of the Ramadi fan , became isolated (Fig. 3.9). The avulsion node for the Pallukkatu is located ~15 km northwest of Sippar (Fig. 3.9). Also, it appears that the Pallukkatu channel turned to the southeast near Karbala, and flowed along the toe of the Al-Khir fan at least as far as Kufa and trend to southeast passing Hamzah site (Figs. 3.22 to 3.27). There is a canal called Khandug Shapur (Shapur Trench) which has been widely mentioned in historical texts such as Ibn-Alatheer (2003) (Table 2.1) as it is the western frontier of the Sasanian Empire. This canal has been clearly identified and traced in the present study (Fig. 3.4 & 3.9), and it runs perpendicular to the main gradient towards the flood basin at the toe of the Al-Khir fan (Fig. 3.4, 3.9 and 3.24), and is a downstream continuation of the Pallukkatu system (Fig. 3.4).

In the present study the main Sura palaeochannel and its distributaries have been clearly identified and traced in the satellite imagery and digital topography (Figs. 3.22 to 3.27). Confirmation that these features are from the Sura course time i.e. from the early first millennium BC to the thirteenth century AD, comes from radiocarbon dating and periods of archaeological sites occupations. Three radiocarbon dates have been obtained from channels from this course (shown from north to south as Figs. 3.24, 3.28 and Table 2.2). The oldest one (Fig. 3.28A) is from marsh deposits before formation of the Sinin channel which is dated 910 to 810 year BC cal. The second sample (Fig. 3.28B) is from marsh deposits before formation of Pallukkatu/Kufa (Fig. 3.4) which is dated 340 to 320 year BC; the third sample (Fig. 3.28C) is from the levee deposits of the Khandug Shapur channel, which is dated 420 to 570 year AD cal. The Sinin channel could be related to both Sura and Pallukkatu systems; it is not clear because of its downstream position. But given the new radiocarbon age, we suggest that Sinin is more likely related to Pallukkatu system.

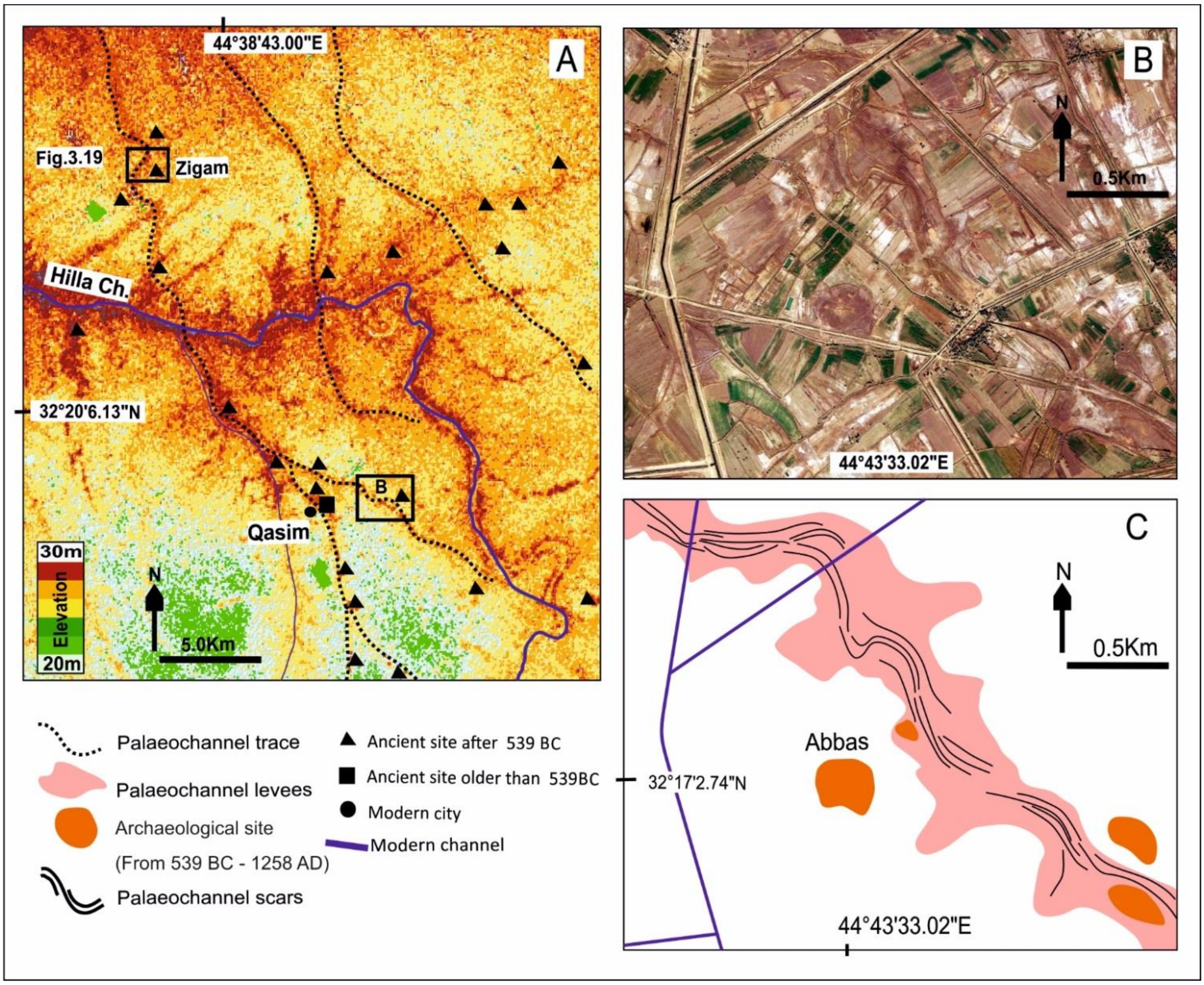

Figure 3.18: (A) SRTM data showing how palaeochannel levees have a relatively high topographic elevation in relation to the surrounding floodplain in Qasim area. (B) QuickBird image (2006) showing the Qasim palaeochannel. (C) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

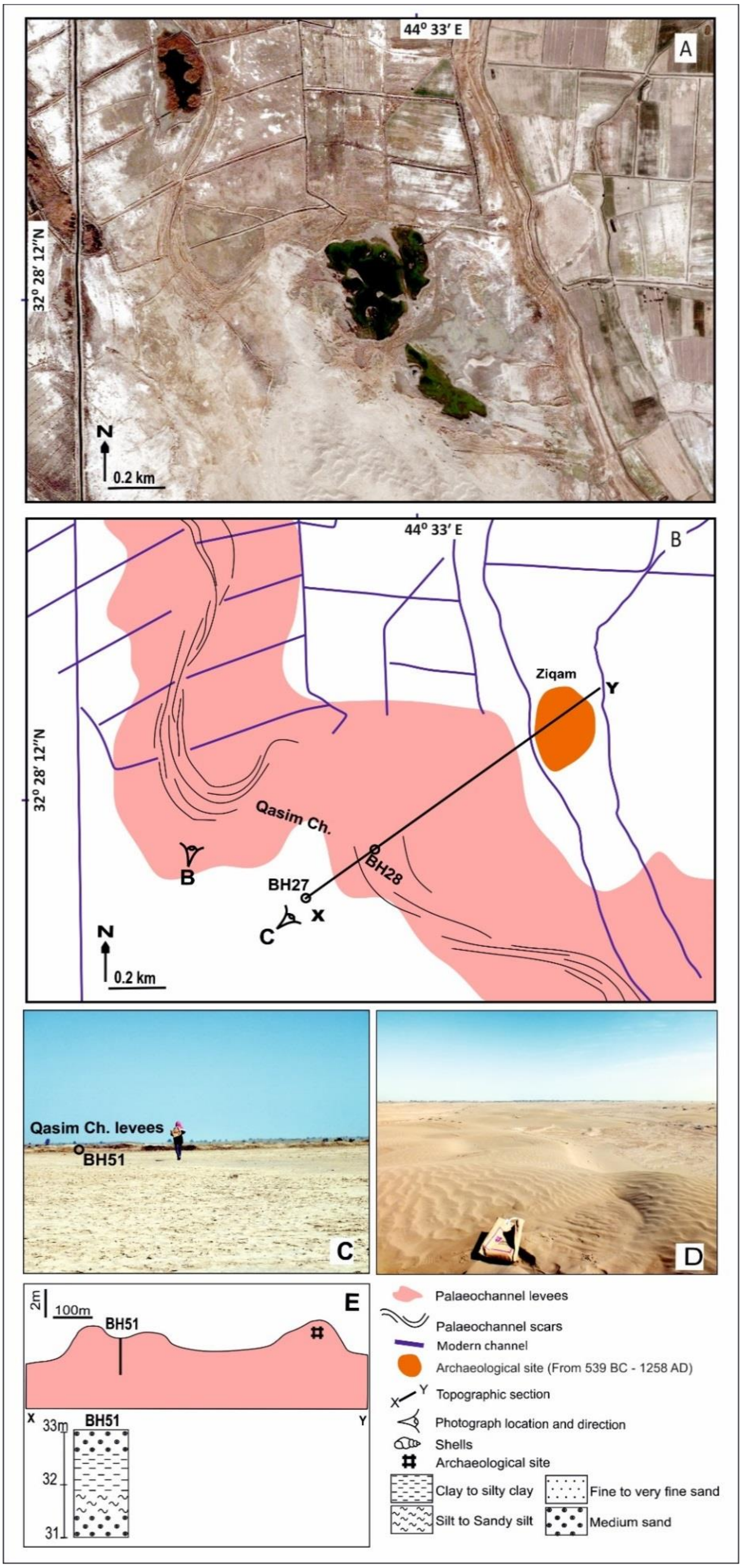

Figure 3.19: (A) QuickBird image showing the Qasim palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph showing the Qasim palaeochannel levees and BH27. (D) Field photograph showing the location of BH28. (E) Topographic cross-section through the palaeochannel, showing the lithologies of the BH27and BH28 boreholes.

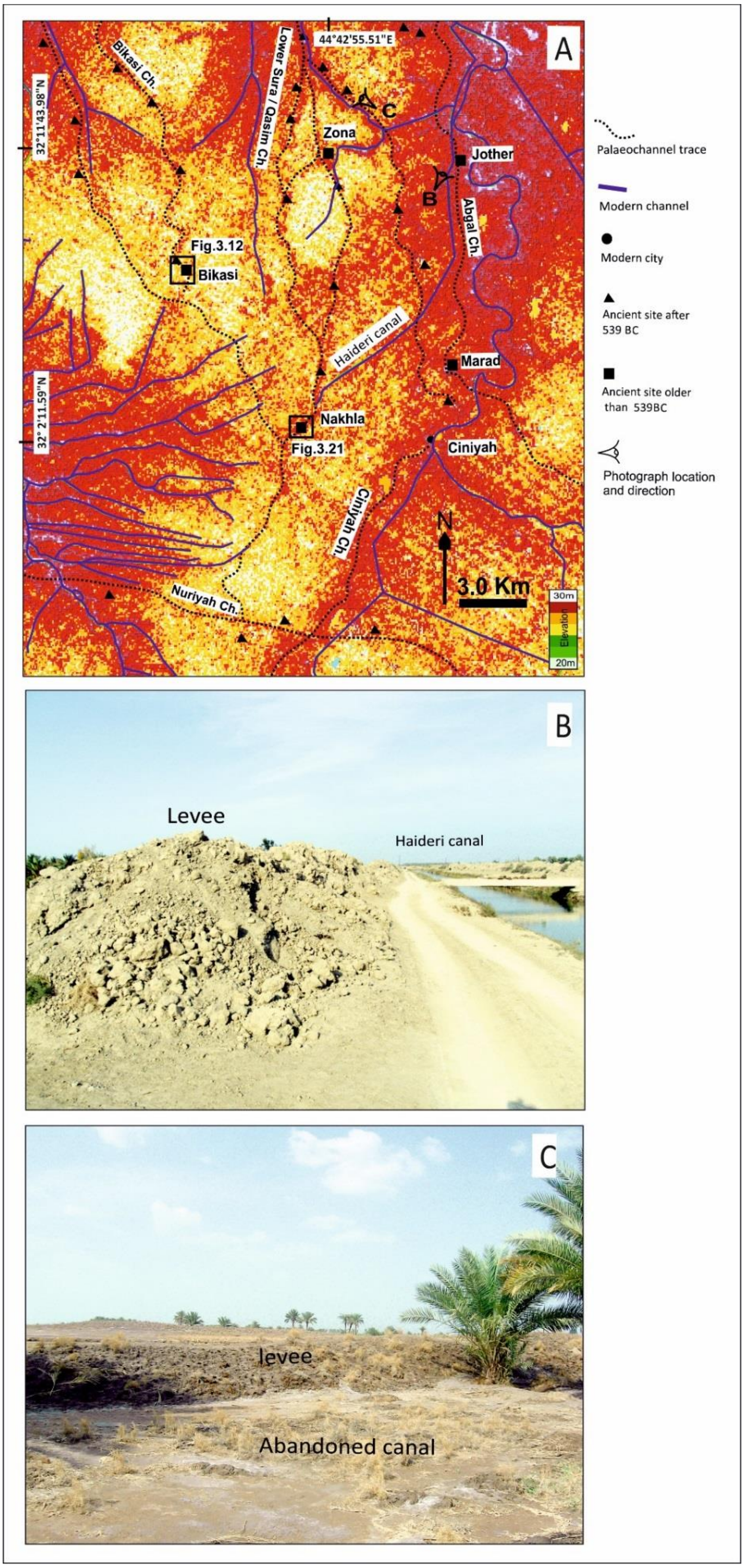

Figure 3.20: (A) SRTM data of the middle part of the study area showing how palaeochannel levees have a relatively high topographic elevation in relation to the surrounding floodplain. (B) Field photograph showing the Haideri irrigation canal. (C) Field photograph showing the Lower Sura /Qasim palaeochannel.

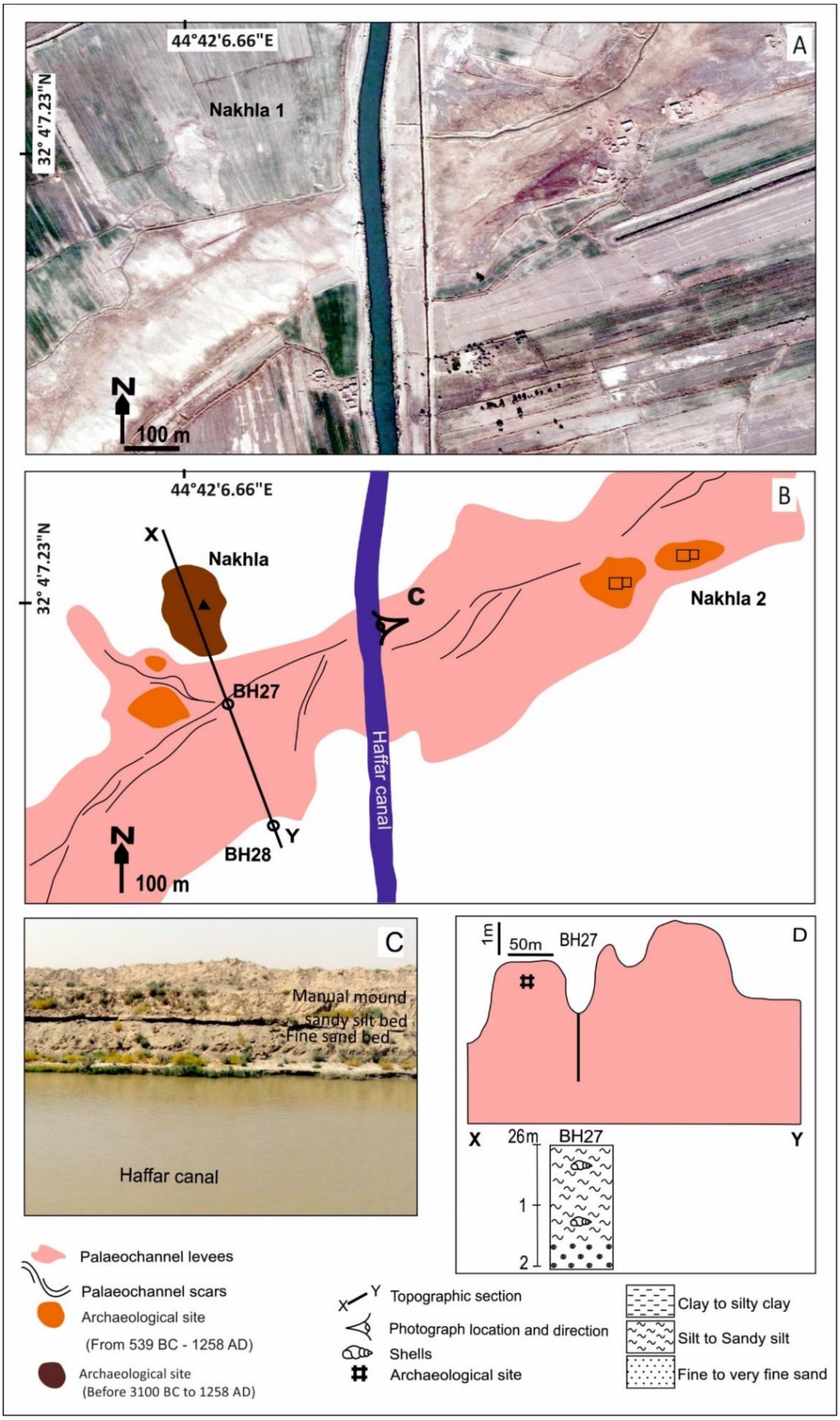

Figure 3.21: (A) QuickBird image showing the Qasim palaeochannel levees and the Nakhla site. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph of the Qasim palaeochannel levees. (D) Topographic cross-section through the palaeochannel, showing the lithologies of the BH27 and BH28 boreholes.

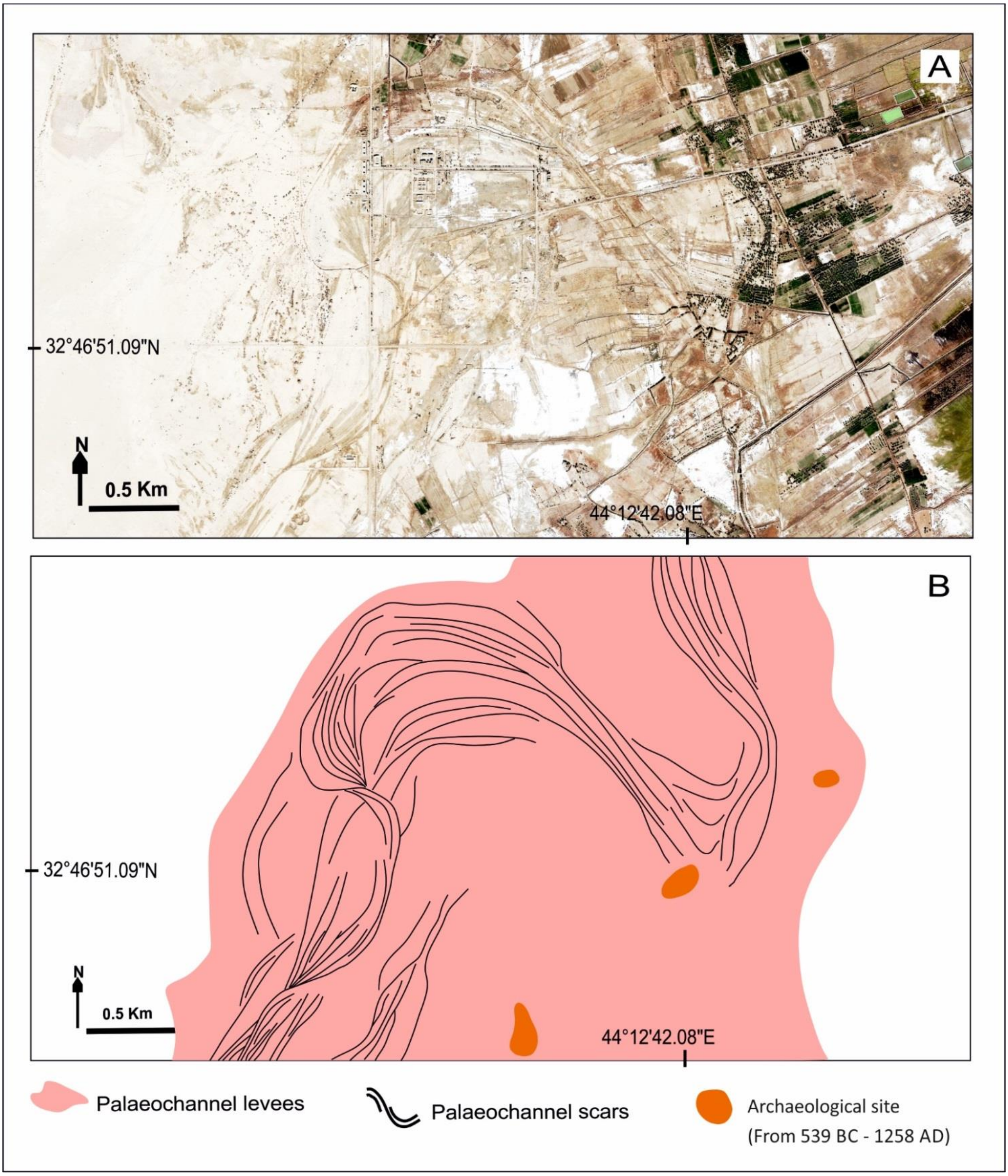

Figure 3.22: (A) QuickBird image showing the Pallukkatu/Kufa palaeochannels and how canals can meander over time so that scrollbars are formed. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

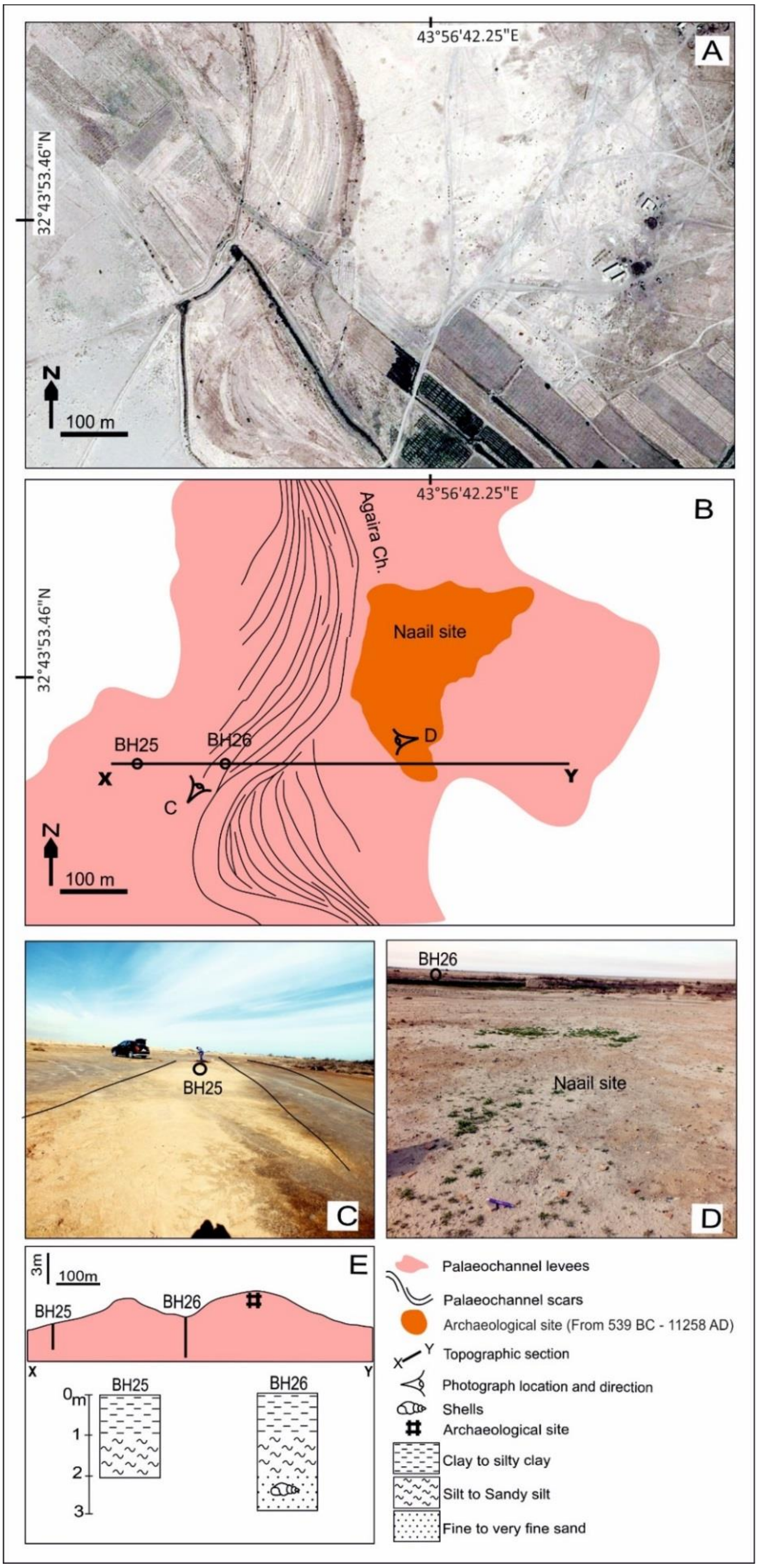

Figure 3.23: (A) QuickBird image showing the Agaira branch (Pallukkatu/Kufa palaeochannels). (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph location of the BH25 borehole. (D) Field photograph showing the Naail site, the Agaira palaeochannel and the location of the BH26 borehole. (E) Topographic cross-section through the palaeochannel, showing the lithologies of the BH25 and BH26 boreholes.

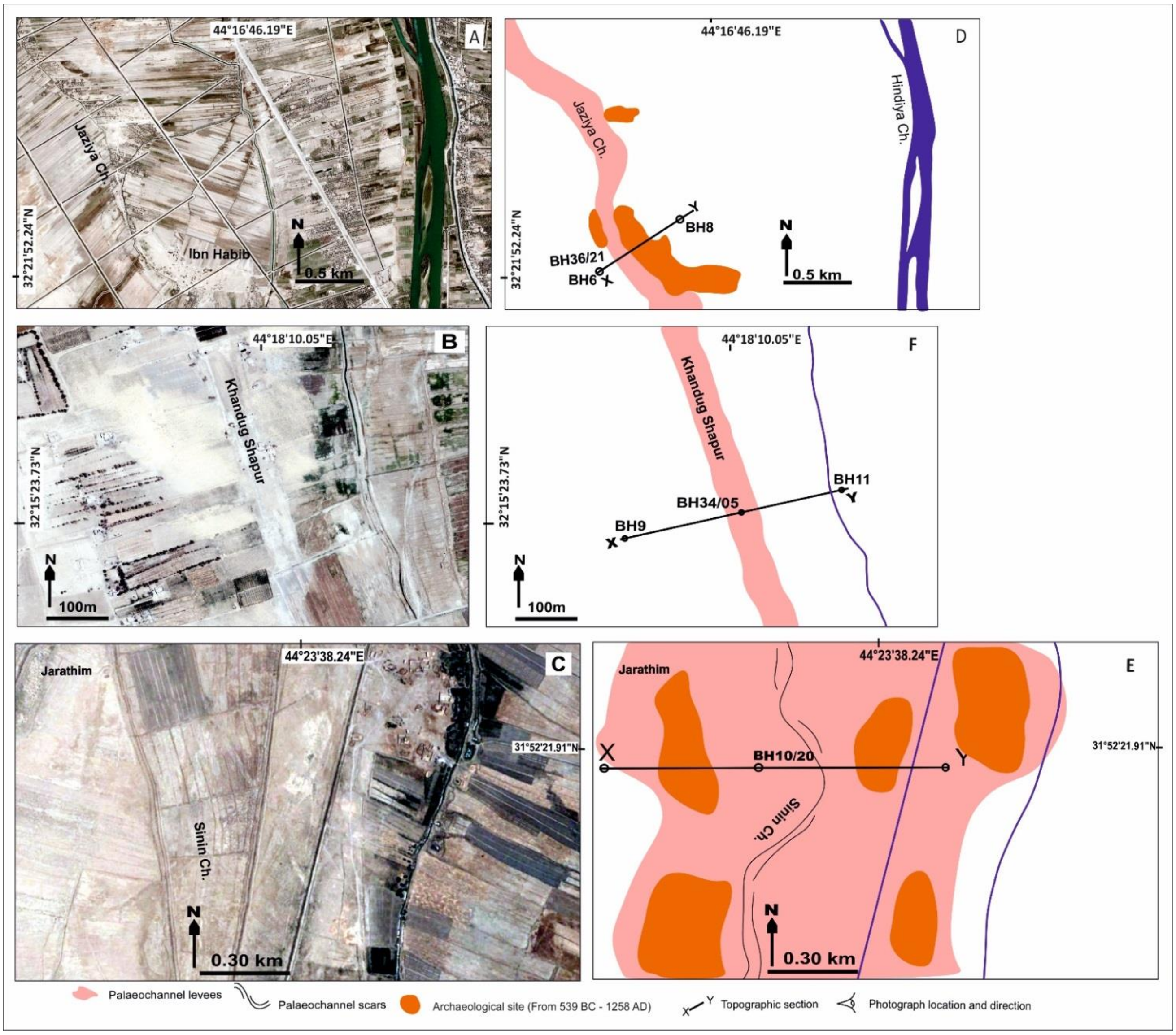

Figure 3.24: (A) Quickbird image showing the Jaziya branch one of the Pallukkatu/Kufa palaeochannels. (A) Quickbird image showing the Sinin branch one of the Pallukkatu/Kufa palaeochannels. (C) Quickbird image showing the Khandug Shapur canal branch on the Pallukkatu/Kufa palaeochannels. (D, E, and F) are tracing of surface features including palaeochannel levees, scars and archaeological sites of these images.

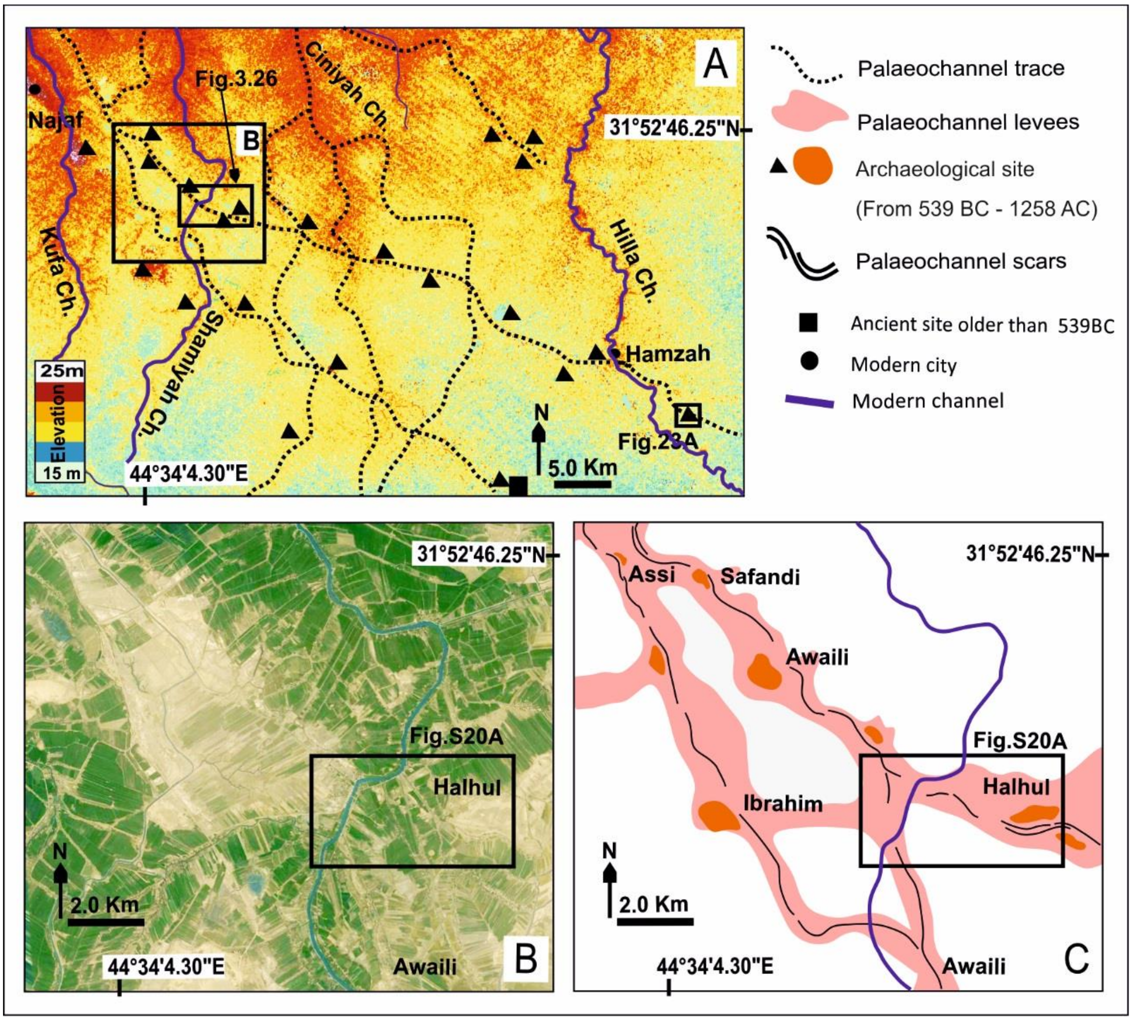

Figure 3.25: The Halhul palaeochannel of one of the Pallukkatu/Kufa palaeochannels. (A) SRTM, (B) QuickBird image and (C) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

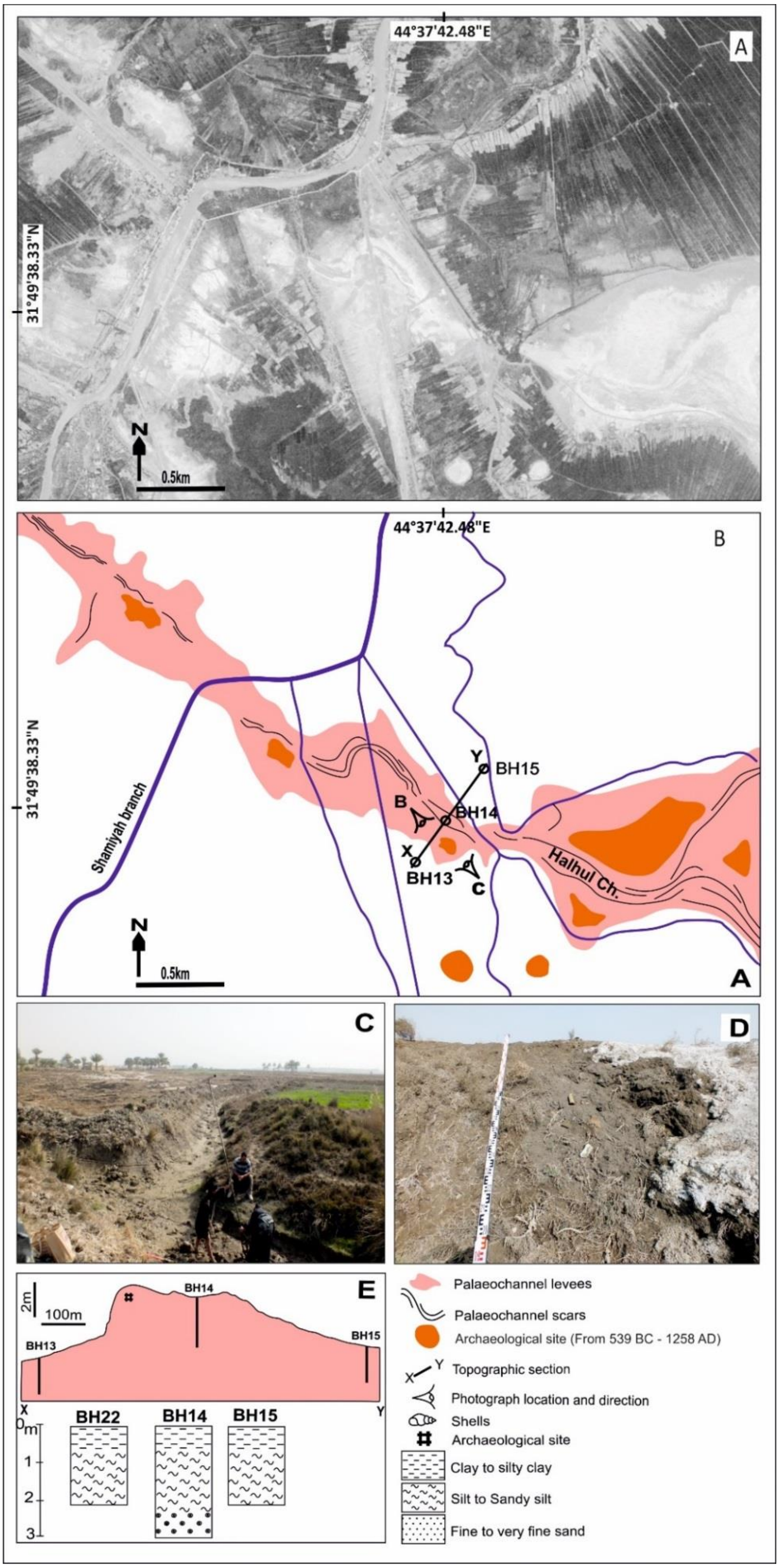

Figure 3.26: (A) CORONA image showing the Ciniyah palaeochannel. (B) Tracing of surface features including palaeochannel levees and scars. (C) Field photograph showing the locations of BH14 and BH29 (D) Field photograph showing archaeological site (E) Topographic cross-section through the palaeochannel, showing the lithologies of the BH22, BH13, and BH15 boreholes.

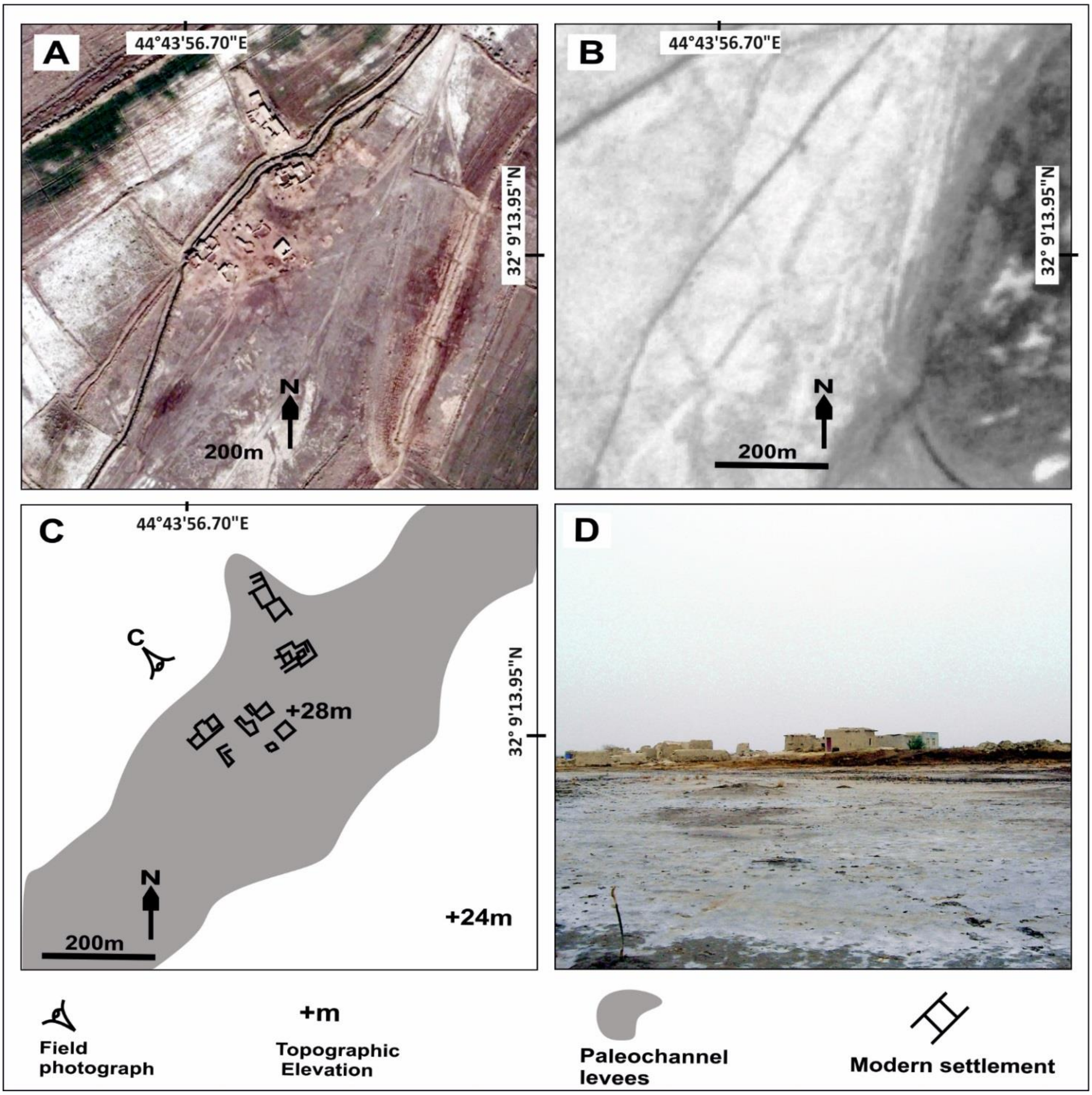

Figure 3.27: (A) QuickBird image showing the Khizail palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph showing the Khizail palaeochannel. (D) Field photograph showing a section inside the Khizail palaeochannel. (E) Field photograph showing sand and shell of the palaeochannel.

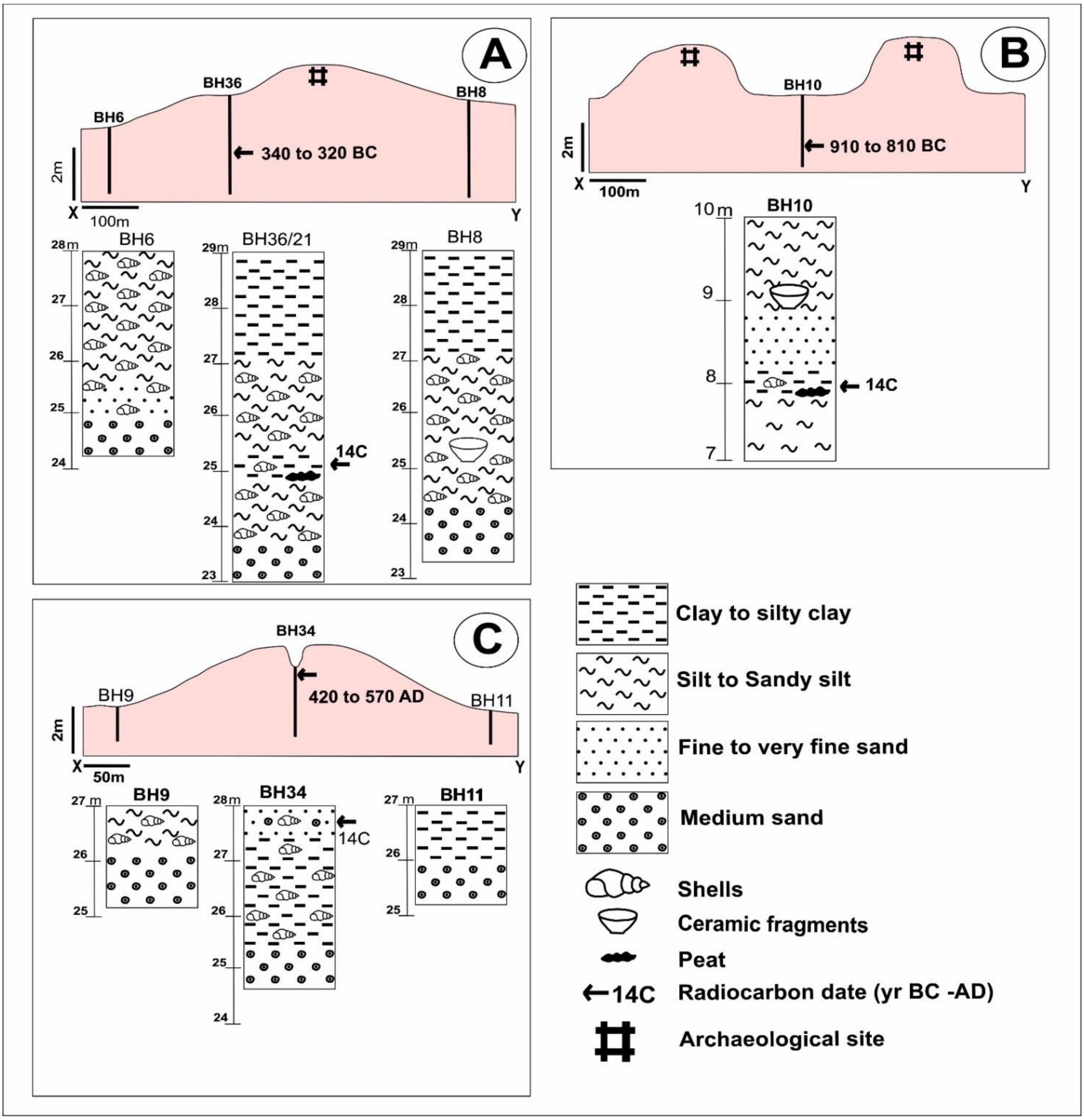

Figure 3.28: Topographic cross-sections through palaeochannels, showing the locations of the augured boreholes, radiocarbon sample (A, B, and C) show location of radiocarbon shell samples from the Pallukkatu, Khandug Shapur, and Sinin channels (Sura Course).

3.1.4 The Sura Course (from the early first millennium BC to the thirteenth century AD AD)

Several historical texts such as Ibn-Alatheer (2003), Ibn-Alfuwati (1938), and Ibn-Aljozi (1992) have mentioned this course (Fig. 3.4) as the main Euphrates channel during these periods, i.e. from about 125 BC to the late Islamic period, and it was largely in the same location as the previous course i.e. the Arahtum channel (Fig. 3.3). In other words the upstream part of the Arahtum did not cease to exist, but the Sura is the new name used for the same channel, with the avulsion node north of Babylon (Fig. 3.4). This study has identified a new channel route of this age, just north of Babylon (Fig. 3.4), where the river turns abruptly east and flowed towards the Tigris, here called the Surat-Adhim branch, after Islamic historical texts such as Ibn-Alatheer (2003), Ibn-Alfuwati (1938), and Ibn-Aljozi (1992). This channel utilised the man-made Banitu canal (Cole and Gasche, 1998) (Fig. 3.3); it is not recorded whether there was a human intention behind the diversion of the main stream of the river. There are several distributary channels (Fig. 3.4) that bifurcated from this course such as the Sirsir, the Malik, the Kutha, the Surat Al-Adhim, the Turis, and the Lower Sura (Fig. 3.4). The Malik channel seems to be newly formed, and bifurcated from the unchanged upstream part of the Arahtum channel because all the associated archaeological sites are from Parthian and later, while the others are continuations or reoccupations of earlier channels as their associated site were occupied from older than Parthian. The timing of the end of the Sura channel seems to have been abrupt (Susa, 1983), perhaps related the collapse of the maintenance and irrigation system at the time of the Mongol invasion in the thirteenth century AD. We further suggest that this was the time of the switch from the Sura channel to the Hilla channel (Figs. 3.4 and 3.5).

3.1.5 The Hilla Course (from the 13th to the 19th century AD)

This course (Fig. 3.5) is largely the same as the Hilla branch of the present Euphrates (Fig. 1). There is no specific mention in historical texts about when or how the main course of the Euphrates switched from being the Sura channel to the Hilla River (Fig.3.4) (Ooghe, 2007). This seems to be the first time that the main channel of the Euphrates ran west of the Alexandria Mesa (Fig. 3.9). The avulsion node for this course cannot be precisely located but it is approximately located to the northwest of the Alexandria Mesa (Fig. 3.5).

There is geomorphic evidence, confirmed by fieldwork (Figs. 3.29 to 3.33) that the ancient city of Hilla, which was founded in 1012 AD (Mansoori, 2012), is located on the Lower-Sura channel (Fig. 3.4 and 3.5), i.e. a distributary channel of the main Sura channel, while the modern city of Hilla is located on the modern Hilla river. Therefore, during the time of the ancient Hilla city, the present Hilla course presumably did not exist and the Lower-Sura channel was active. Although the lateral shift involved is small (≤3 km; Fig. 3.3, 3.4 and 3.33), it is distinct, with a line of settlements from the Parthian, Sasanian and Islamic periods along the Lower Sura channel (Mansoori, 2012).

It is possible that the Hilla branch started building its belt gradually in the low-lying flood basin. There are Ottoman documents and maps (Mansoori, 2012, Husain, 2014 & 2016) that show that the area of south Hilla (i.e. south of Hilla city) was swamp, either seasonal or permanent, and the modern Hilla river prograded its belt gradually into it, cutting across the route of earlier north-south palaeochannel ridges of the Sura period (Fig.3.4). This indicates that by the time that the Hilla system prograded southward, the Sura channels in this region provided no favourable gradient, otherwise these channels would probably have been reoccupied. Therefore it seems likely that the Sura channels were fully abandoned and had silted-up at this time.

Several cities were established in this region during the 16th century AD, such as Diwaniya and Samawa (Mansoori, 2012) (Fig. 3.5). This timing may mean that the modern Hilla river was established between the 13th and 15th century AD. It is clear from the Mansoori (2012) maps that the main Hilla channel during the 17th century AD was to the west of Alexandria Mesa, except a small branch going to Yusufiya and Latifiya channels which are continuations of the Sirsir and Malik palaeochannels respectively.

South of 32° N, the Hilla Channel at this time presumably had two major branches (Fig. 3.5): the Ciniyah and the Hilla (Fig. 3.29). The Ciniyah branch was the main distributary during this period (Mansoori, 2012), running to the southwest and then turning to the southeast and passing the modern city of Shinifiyah. However, there were also several smaller branches such as the Hindiya, the Kafel, the Dagharah and the Hamzah. Maps and texts also identified a large area of marshes to the west of the Hilla channel and adjacent to the western desert (Mansoori, 2012). During the late 17th century AD, the Ciniyah branch was completely dry (Selby *et al.*, 1885).

3.1.6 The Hindiya Course (from 19th to 21st century AD)

During the 19th century there were two significant changes. The first one was the weakening of the Hamzah branch, at the same time as other branches begun to weaken, such as the Kafel and the Dagharah. The second change was the growth and development of the Husseiniya and Hindiya canals (Fig. 3.6). According to several historical documents, reviewed by Iraqi Ministry of Water Resources (IMWR) (2002), the Hindiya canal did not exist before the 19th century and was dug manually during this period and developed two branches; the Shamiyah and the Kufa. The Khasif channel (Fig. 3.6) at that time, worked also as a drain for additional water coming from the upstream marshes and flowed roughly adjacent the Arabian plateau. The Atshan channel crossed the levees of the Ciniyah palaeochannels in Shamiyah town (Fig. 3.6). Shamiyah and Kufa channels joined Khasif channel and made the Euphrates.

The effect of the Hindiya canal was to lower the discharge in the Hilla channel, so the Hindiya barrage was built in 1830 at the junction of the canal and the Hilla channel (Fig. 3.7). The barrage collapsed in 1854 and again in 1880. It was rebuilt again in the same year, but it collapsed once again in 1885 (IMWR, 2002). In 1905 the Hilla channel became completely dry (Fig. 3.7) and all its water flowed into the Hindiya canal, which became the main channel of the Euphrates (Cadoux, 1906) (Fig. 3.10C). The barrage was rebuilt again in 1889 and finally completed in 1913, so that water returned to the same Hilla channel, but with the Hindiya having higher discharge (Susa, 1983). During the 1960s and later, the channel network has generally been stable: there is no significant different between the location of channels on the CORONA and Quickbird imagery which have been used in the present study.

Regular maintenance, i.e. cleaning as well as construction, is essential to keep the water flowing or to avoid silting up and abandonment of the canals. In Qasim city (Fig. 3.7), a series of irrigation canals is now useless, having gradually become abandoned, as they were not cleaned for three years. Sediments also accumulate along the sides of canal levees, rendering cleaning more difficult each year. Thus, sediments from the bottoms of the canals have to be removed and spread over the levees. Alternatively, these deposits can be taken some distance away to avoid their returning to the canals. As both of these processes are hard work, farmers often choose to dig a new canal next to the old abandoned one, such as downstream of the Hilla branch in 1958, where two new canals were dug to take the place of two old, silted-up ones. Government agencies now take care of the Euphrates branches and irrigation systems, as water distribution is a critical issue, and maintain these channels, with a complex series of barrages, including dams, and discharges. Such discharges decrease if the canals are not cleaned, causing higher levels of water in the main Euphrates branches, adding to the risk of flooding, as in 1991 (the year of the first Gulf War). During that year, the government did not clean many irrigation canals. The risk of the Hilla flooding and bursting its banks in various places was considerable, prevented only by increasing the height of the natural levees.

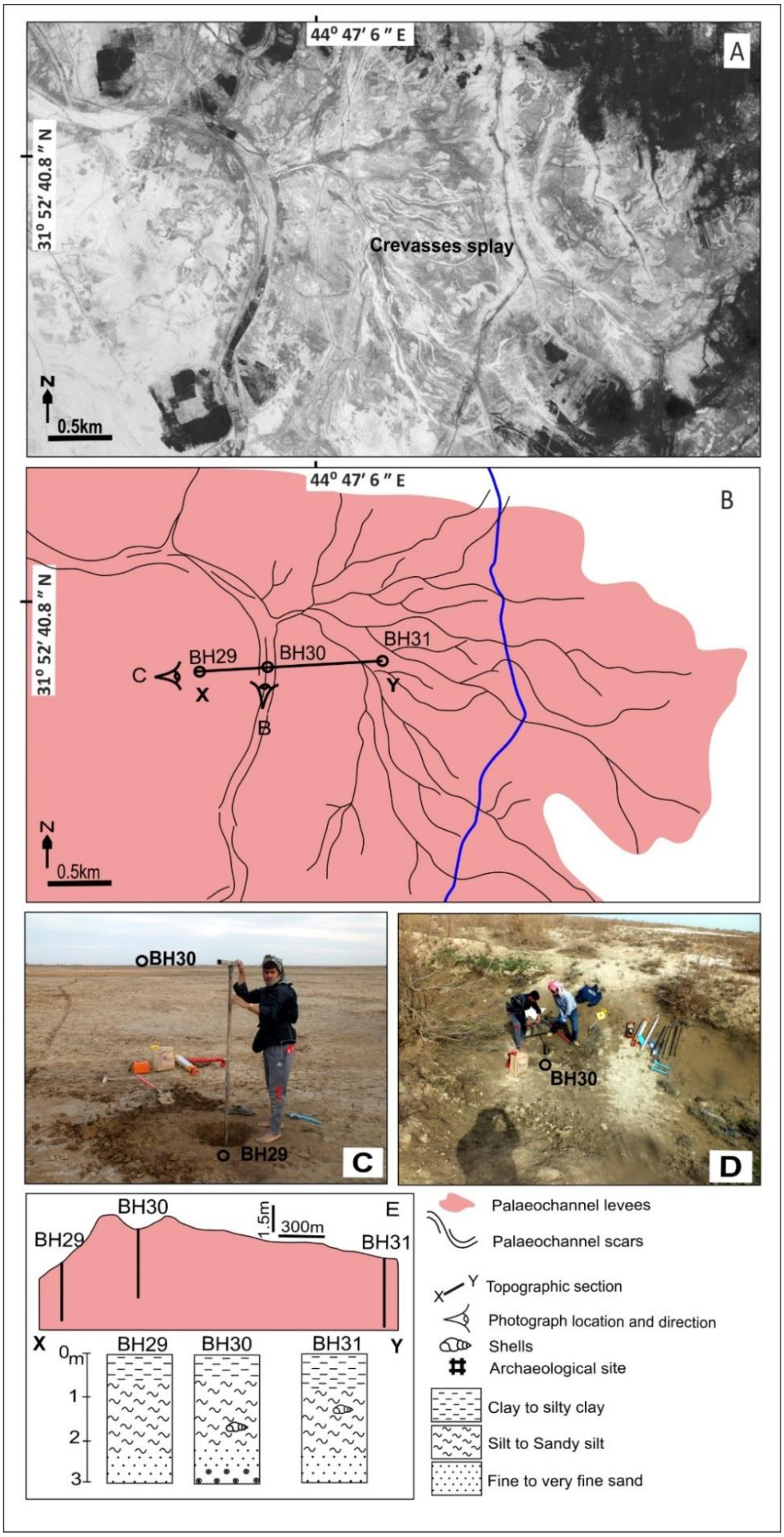

Figure 3.29: (A) CORONA image showing the Ciniyah palaeochannel. (B) Tracing of surface features including palaeochannel levees and scars. (C) Field photograph showing the locations of BH30 and BH29 (D) Field photograph showing the location of BH30. (E) Topographic cross-section through the palaeochannel, showing the lithologies of the BH29, BH30, and BH31 boreholes.

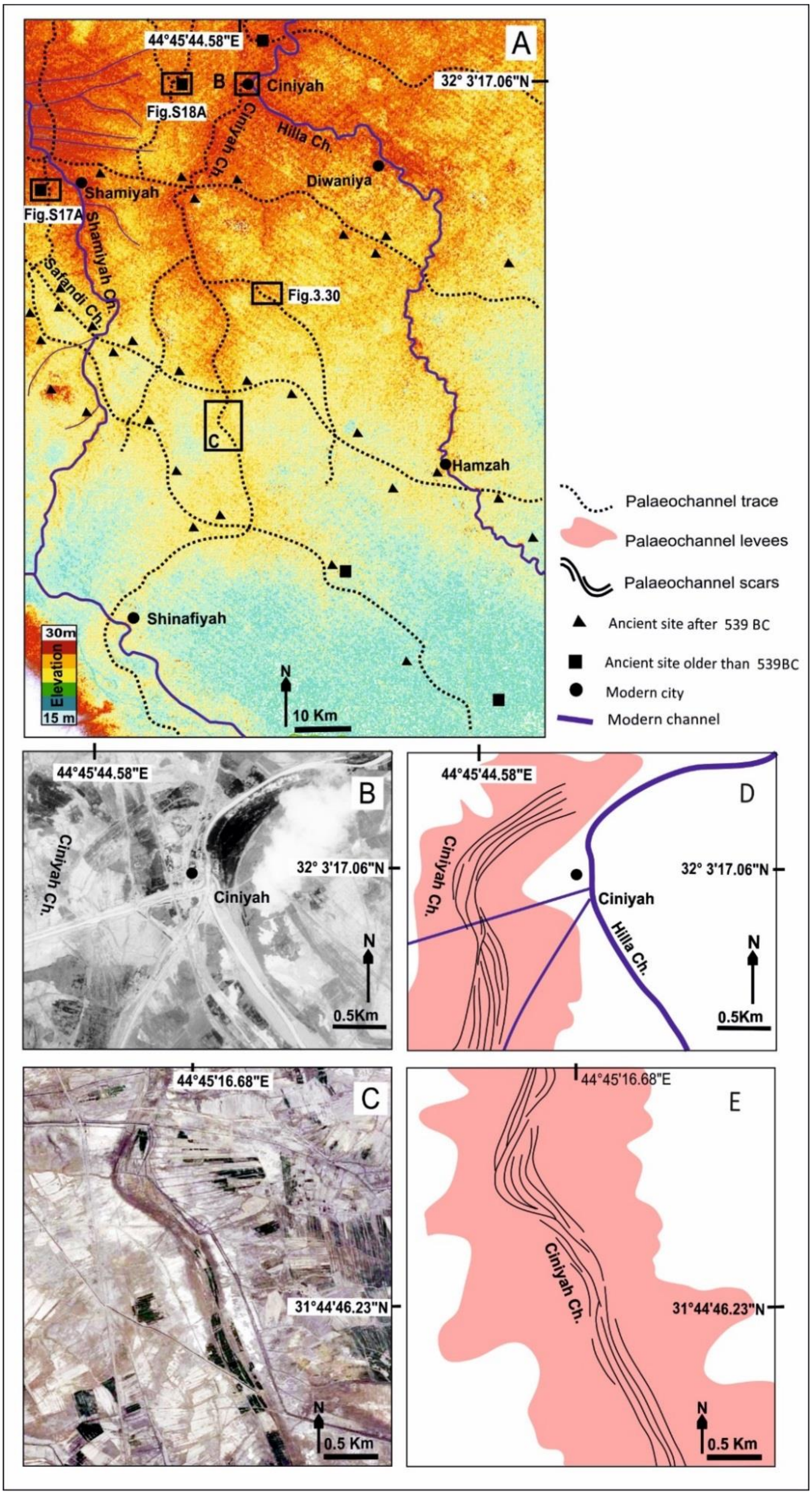

Figure 3.30: (A) SRTM data map of south east part of the study area showing how palaeochannel levees have a relatively high topographic elevation in relation to the surrounding floodplain. (B) CORONA images (1968) showing the avulsion node of the Ciniyah avulsed channel. (C) QuickBird image (2006) as an example to show the relict meander loops and scars of Ciniyah palaeochannel levees. (D and E) Tracing of surface features including palaeochannel levees, scars and archaeological sites of the images B and C respectively.

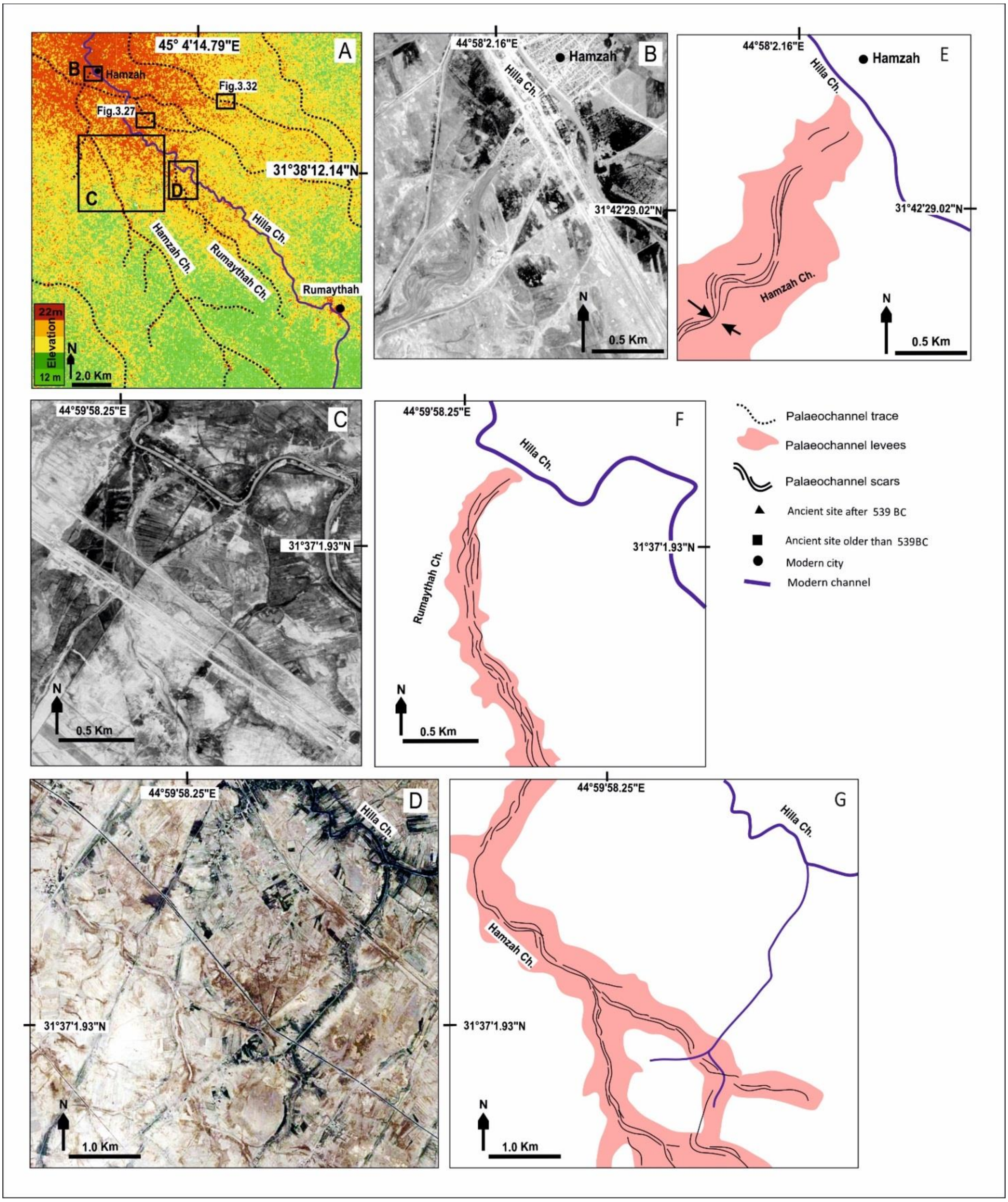

Figure 3.31: (A) SRTM data map of the Hamzah palaeochannel showing how palaeochannel levees have a relatively high topographic elevation in relation to the surrounding floodplain. (B) CORONA images showing the avulsion node of the Hamzah avulsed channel. (C) and (D) QuickBird image showing Hamzah palaeochannel levees. (E, F and G) Tracing of surface features including palaeochannel levees, scars and archaeological sites of these images respectively.

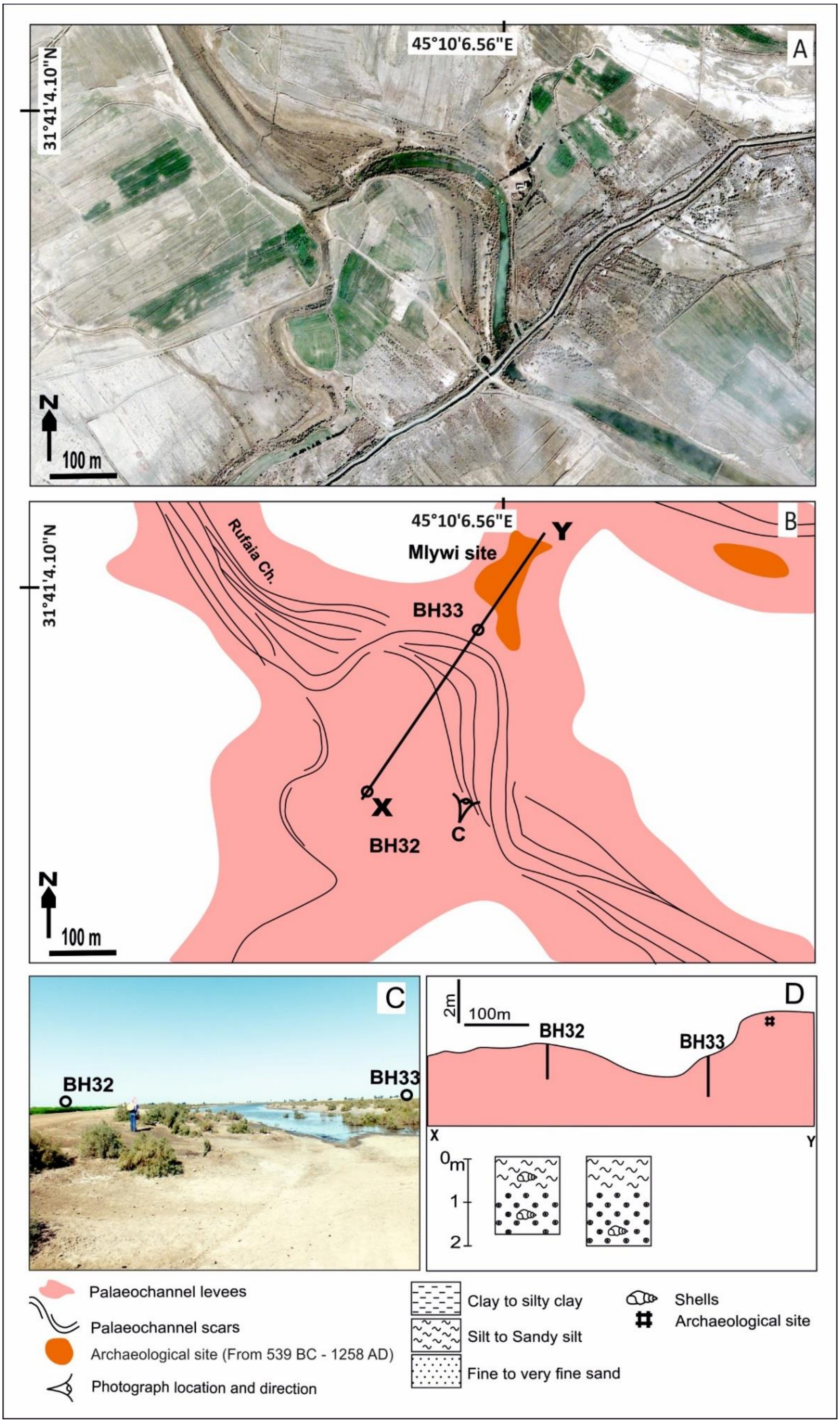

Figure 3.32: (A) QuickBird image showing the Rufaia palaeochannel. (B) Tracing of surface features including Palaeochannel levees, scars and archaeological sites. (C) Field photograph of the meander of the Rufaia palaeochannel. (D) Topographic cross-section through the palaeochannel, showing the lithologies of the BH32 and BH33 boreholes.

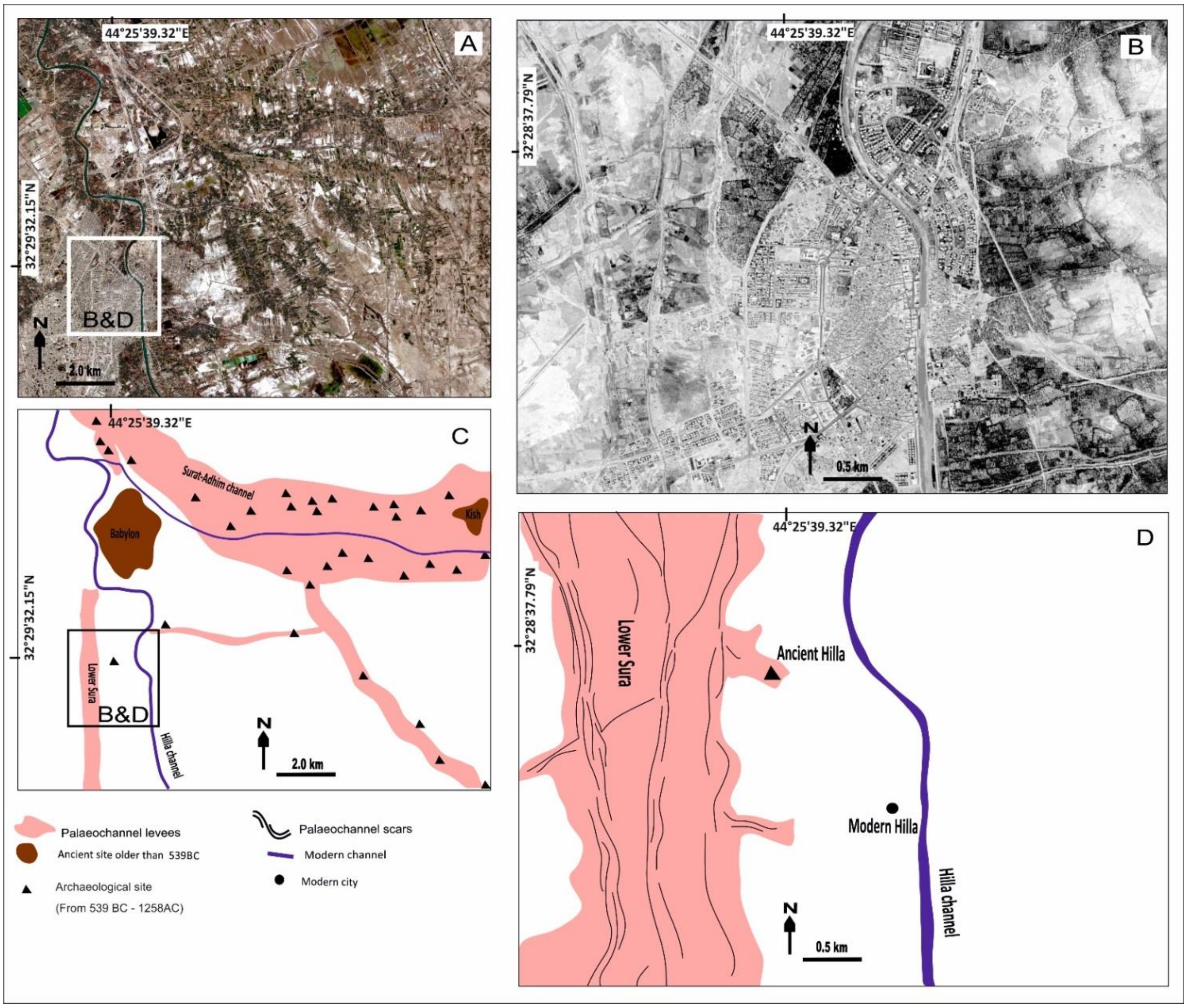

Figure 3.33: (A) QuickBird image showing the modern Hilla channel (B) CORONA image showing the modern Hilla channel and levees of the lower Sura palaeochannel (C) and (D) are tracing of A and B respectively .

3.2.4 Discussion

Our study presents the changing courses of the Euphrates as a series of timeslices (Fig. 3.2-3.7), which could be argued, over-simplifies the changing dynamics of the river system during each timeslice. This may be especially true of the older periods for which less resolution is available, and which are of longer duration than each of the final three periods (Fig. 3.5-3.7). But, our study emphasises the rule of human impact on river avulsion, which is particularly well-documented for the changes in the thirteenth century AD and 1905 AD. Diversions took place at discrete avulsion nodes (whether progradational or reoccupational avulsion, (Figs. 1.5 & 1.6)), rather than gradual and lateral "combing" of the river system (e.g. von Suchodoletz, 2016) over 100s of km, as is seen in other modern river systems such as the Yenisei in Siberia (Allen and Davies, 2007). There is a closer comparison with the behaviour of the Yellow River (Huang He) in China, which has a recorded 26 major and abrupt changes in course in 2550 years (Shu and Finlayson, 1993). Some of these shifts involve lateral migrations of the mouth of the Yellow River of over 400 km, each taking place following a virtually instantaneous breach of the levee system.

There are five main avulsion cycles of Euphrates palaeochannels in the Najaf region which have been identified in this study by a combination of remote sensing, fieldwork and radiocarbon dating: the main courses are the Purattum Course (the fourth to the first millennium BC) (Fig. 3.2), the Arahtum Course (from the early to the late first millennium BC) (Fig. 3.3), the Pallukkatu channel (from the middle first millennium BC to the thirteenth century AD AD) (Fig. 3.4), the Sura Course (from the early first millennium BC to the thirteenth century AD AD) (Fig. 3.4), the Hilla Course (from the 13th to the 19th century AD) (Fig. 3.5), the Hindiya Course (from the 19th to 20th century AD) (Fig. 3.6 and 3.7). Although many sections of these major channels have previously been identified (e.g. Cole and Gasche, 1998), this study presents new evidence for the timing, location and style of migration between the different channel periods.

Here follows a summary of the development of the Najaf area by the five courses of the Euphrates.

After around the late fourth millennium BC, the Purattum was the main channel of the Euphrates while the Arahtum channel was a small distributary (Fig. 3.2). Therefore the area of Arahtum, which is located to the south of Sippar, and all regions to its south, received a lower water and sediment supply than the Purattum area, which is located to the east of the site of Sippar and toward the Tigris and the middle of the Mesopotamian floodplain.

Gradually, and especially for some time after the early first millennium BC, the Arahtum became the main channel as the Purattum silted up and became lower in discharge (Fig. 3.3). The marshes and distributaries of the Arahtum in the Najaf area started to receive higher levels of water and sediments. Therefore, and as a consequence of turning the main course from the Purattum to the Arahtum, several new channels were formed, such as the Qasim channels, and several new settlements were also established, such as Zigam, Qasim, Zona, and Nakhla (Figs. 3.18, 3.19, 3.20 and 3.21). As a result of the Arahtum continuing to be the main course there was a decrease in the marsh area compared with an increase in the canalized area north of Babylon. This means that progradation of the river and marshes spread toward the south. Several new canals were dug to sustain human settlements that faced avulsion or silting up, such as Borsippa (Cole, 1994).

The Arahtum was still the main channel of the Euphrates in the Najaf area, but near the site of Babylon it turned to the east, rather than to the south, heading toward the Tigris in around 125 BC, and defining the start of what is referred to in this study as the Sura course (Fig. 3.4). During this time there was a significant increase in the number of new channels formed by natural or human activity, such as the Pallukkatu. New settlements were associated with these channels. Most of the marshes to the west of the Babylon and Borsippa sites were buried as a result of prograding Pallukkatu channels (Susa, 1984 and Cole, 1994) and its distributaries such as the Agaira, Dwair, Jaziya, and Badadh channels (Fig. 3.4). To the south of Babylon there was also a dense network of channels such as the Lower Sura and Turis channels.

During the Sura period, there were fewer channels and sites to the south of Kufa than to the north. Only three major channels were present in this area at that time: Halhul, Khizail, and Sinin (Fig. 3.4, 3.24 and 3.25). Most of the Islamic historical texts, such as those written by Ibn-

Khurdadhabih (1889) and Ibn-Alatheer (2003), described the area of south Kufa as a marshland area that extended to the south and joined the Gulf during the Islamic period (i.e. after 656 AD).

After the Mongol invasion and the collapse of the Islamic state in the thirteenth century AD and the destruction of the barrages and irrigation systems, the Hilla channel was formed. This course started as highly bifurcated typical for a natural prograding avulsion belt and had a significant number of distributaries covering the middle and south of the Najaf area, and, of course, several new marshes were formed as well (Mansoori, 2012). Over time, and as a result of the sediment supply, the Hilla channel and its distributaries gradually started to silt up and most of the marshes dried up (IMWR 2002). The silting up problem can affect the stability of modern channels in this region, and channels face the risk of abandonment as a result of silting up unless they are cleaned manually. The Hindiya channel became the main branch of the Euphrates during the 20th century, which led to the formation of new channels and marshes from Karbala that passed Kufa and led southward, adjacent to the western desert, which was relatively lower in elevation than the Hilla channel area. At the present time, most of these marshes have dried up and the Hindiya channel area and its distributaries have started progradation and the building-up of their levees.

According to Morozova (2005) there are two kinds of avulsion which take place in the Mesopotamian floodplain: reoccupational avulsion and progradational avulsion. In the case of reoccupational avulsion, the major flow diverts into a previously existing channel. In contrast, the progradational avulsion begins by inundating a large section of the floodplain between elevated ridges; this stage forms prograding deposits filling in the topographic lows of the floodplain (Smith and Perez-Arlucea, 2008). It is hard to find a pre-established channel for the switch from the Sura to the Hilla channels (i.e. from Fig. 3.4 to 3.5) and from the Hilla to the early stage of the Hindiya (Figs. 3.5 to 3.6); these avulsions therefore appear to be progradational. We suggest that the lower Hilla branch formed after the Mongol invasion, i.e. after the thirteenth century AD, when control of the channels was lost and most of barrages were destroyed (Susa, 1984; Longrigg, 1999; Butzer, 2012). Apparently as a result of this collapse in channel system management, several low elevated areas were flooded and several channels became abandoned (Susa, 1984). Likewise, the upper part of the Hindiya channel appeared to form in a region previously occupied by swamp, before avulsion of the Hilla channel into this region in the 19th century AD (Fig. 3.5 and 3.6). The other avulsions appear to be reoccupational. The Arahtum channel was in existence before it became the main channel (Figs. 3.2 and 3.3); the Banitu channel existed in Arahtum times before it became the main route of the Sura channel (Figs. 3.3 and 3.4); the Hindiya channel existed before the Hindiya barrage diverted the main route of the modern Euphrates into it (Figs. 3.6 and 3.7). Therefore three of the five avulsions appear to be reoccupational and two progradational, noting that the reoccupied channels were active distributary channels and not completely abandoned just before they became the main channels (i.e. a slightly different scenario to that envisaged by Morozova, 2005).

This study focusses on the Najaf area, which is only one part of the Mesopotamian region. It is hoped in the future that there will be the opportunity to complete similar studies across other areas of Mesopotamia, and apply a wider range of dating techniques, such as Optically Stimulated Luminescence (OSL). In time, it may be possible to produce an overview of the entire floodplain of the Euphrates and Tigris rivers, understanding their relationships with human settlement over the Holocene.

3.2 The Euphrates River in the Ur area

The Ur area (Fig. 1.11 and 3.34) contains several archaeological sites considered important religious or political centres, such as Ur, Uruk, Larsa, Umma, Lagash, Nippur and Adab (3.35). For this reason, many archaeological excavations, surveys and studies have been carried out in this area since the last century. In terms of reconstruction of palaeochannels of this area, several researchers such as Jacobsen, (1960); Adams, (1981); Wilkinson, (1990); Steinkeller, (2001); Pournelle, (2003); Hritz, (2010); Hritz, Darweesh and Pournelle, (2015) and Al-Dafar, (2015), attempted to trace such palaeochannels. As a result of these earlier works, hundreds of archaeological sites and palaeochannel reaches have been mapped intensively.

In the present study, the Ur area has been covered, applying the full range of survey and investigation methods as for other areas of the floodplain such as Najaf (section 3.1). In other words, remote sensing and fieldwork techniques have been utilised to identify and date the area's archaeological sites and the palaeochannels (Fig. 3.35).

As a result of this study, there is no indication of the existence of any river avulsion at major nodal points, and it is suggested that in Ur there are three main downstream reaches that can be continued with the upstream main river courses of the Najaf area, which were informally named the Kutha, Kish and Khalid palaeochannels i.e. the same names as the channels of the Najaf area (Fig. 3.35). This suggestion arose from tracing the identified highly elevated levees associated with the archaeological sites (Fig.3.34).

Adams puts forward two proposals: first, Babylon's growth into a major centre during the old Babylonian period was a consequence of these changes, and second, cities in the centre of the plain, such as Nippur, went into decline and a period of abandonment due to a lack of water. Further, Adams was able to plot a growing number of artificial canals planned to cut across the topography of the plain and bring water back to the dehydrated cities, arguing that this reflected a deep, basic change in the human-channel relationship. Prior to the second millennium, even with artificial irrigation, settlements were tied to the rivers themselves, and inhabitants had to move if a channel moved. In this time, despite drastic changes in channel paths, the developing technology of engineering canals meant that settlements could remain and a constant water supply was assured.

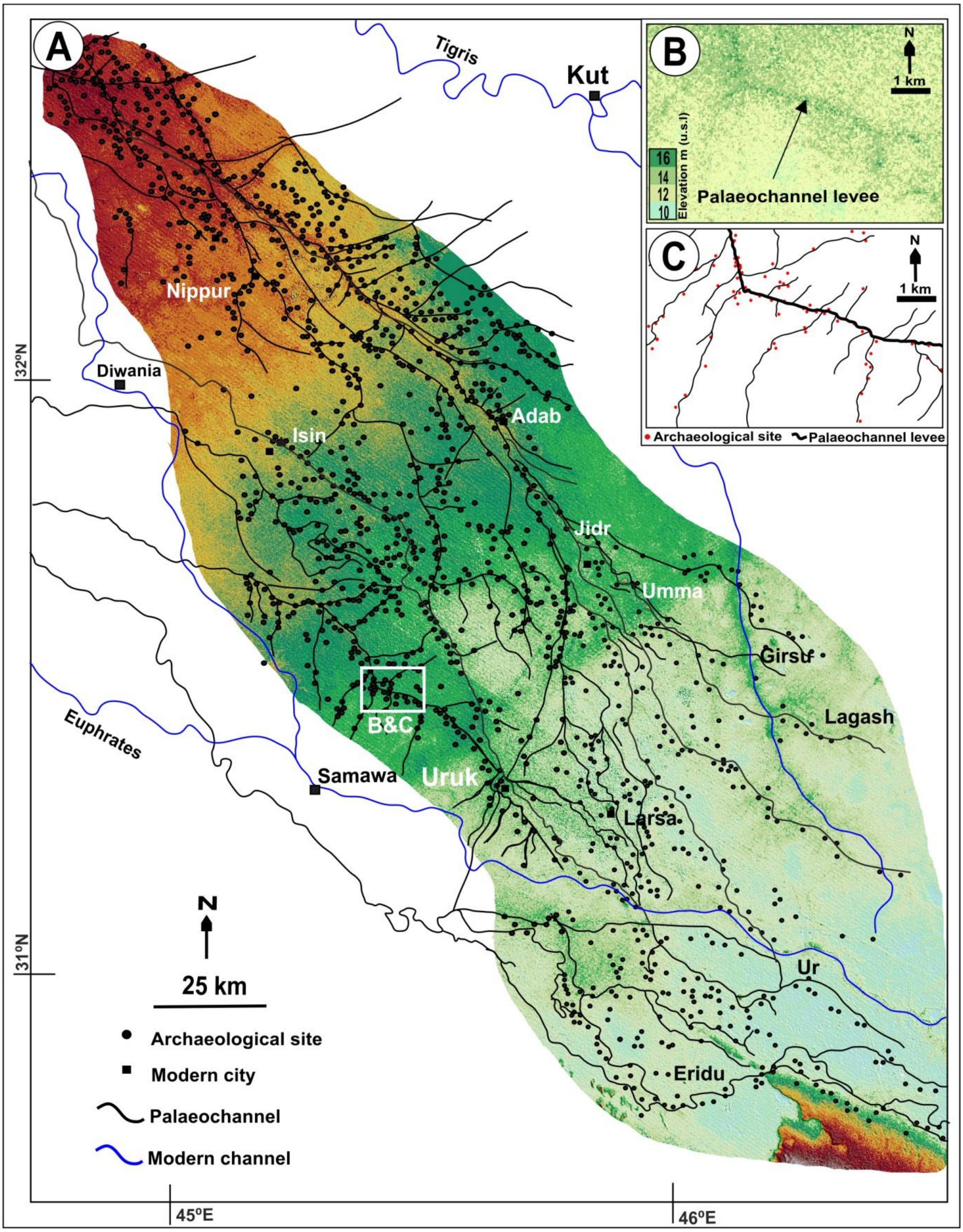

Figure 3.34: (A) General SRTM data for the Ur area showing all the identified archaeological sites and palaeochannels and how palaeochannel levees are elevated in relation to the surrounding floodplain. The archaeological sites identified by previous work such as GDA (1976), Adams (1981) and Wright (1981). The palaeochannels has been identified in the present combined with the previous work of study and some of Adams (1981) and Wright (1981). (B and C) An example of SRTM data showing elevated levees. The general gradient of Ur area palaeochannels is about 10cm/km.

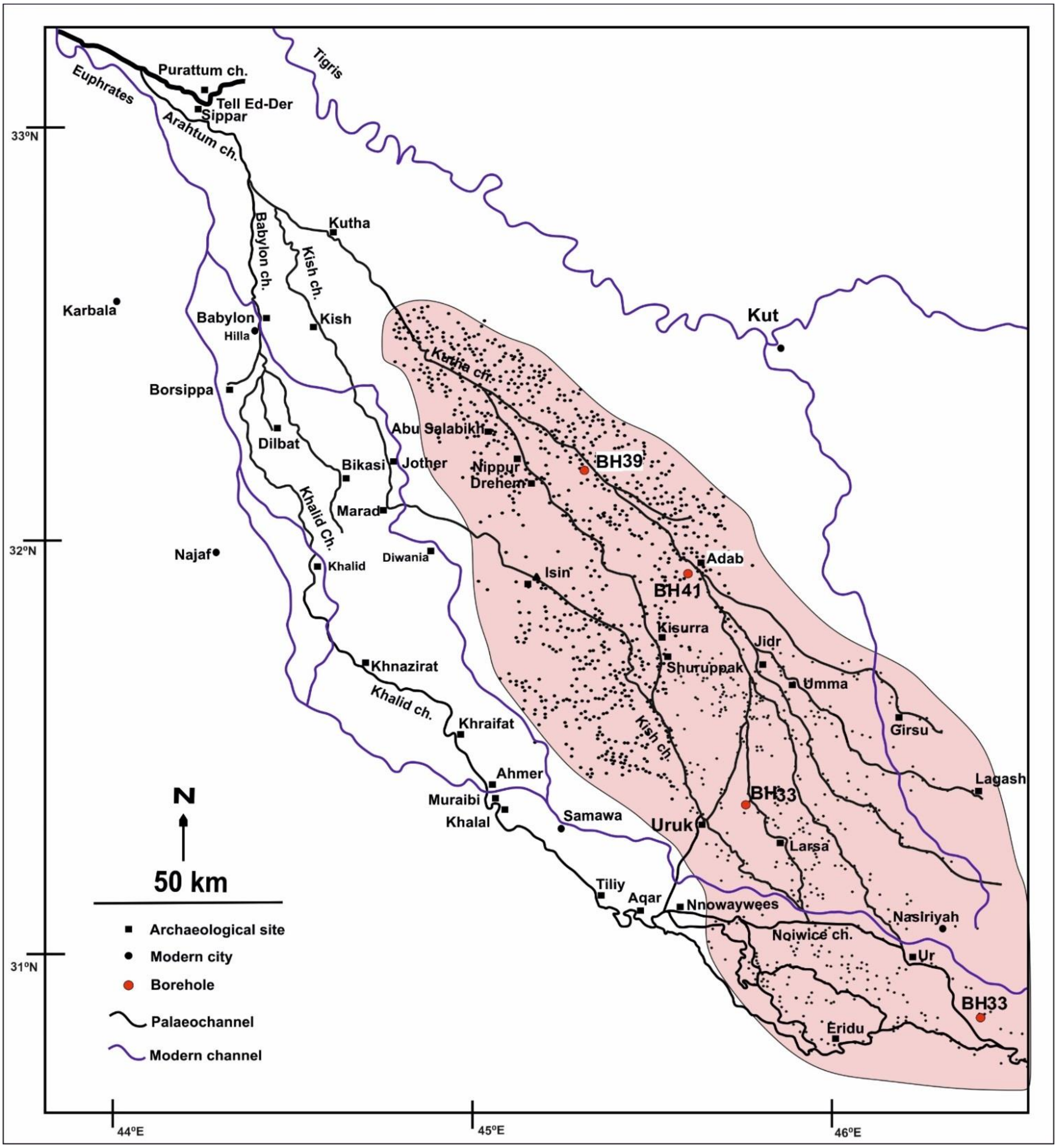

Figure 3.35: Map showing how the main palaeochannels of Najaf area were continued in Ur area.

3.2.1 The Kutha palaeochannel (from the fourth millennium BC to the first millennium AD)

Note: the Kutha palaeochannel work forms part of a paper: Wilkinson, T.J. and Jotheri, J. (2016). The Origins of Levee and Levee-Based Irrigation in the Nippur Area. In: Altaweel, M. and Hritz, C, (eds.), *Cycles and Stages in Jeeps and Passats: Studies in the ancient Near East in honor of McGuire Gibson.* Oriental Institute, University of Chicago: Chicago. All of the observations and text presented in this thesis are by myself and are not from this paper.

When the Kutha palaeochannel left the Najaf area it bifurcated into the eastern branch, going to the Adab site while the western branch went to the Nippur site (Fig.3. 35). The Adab branch also divided, into five branches, those of the Girsu, Lagash, Jidr, Ur, Larsa and Uruk site (Fig.3.35). The

Nippur branch went to Kisurra, Shuruppak and then the Uruk site. In accordance with the age of the associated archaeological sites of this area (GDA, 1970 and 1976; Adams, 1981; Wilkinson, 1990; Al-Dafar, 2015), the Kutha palaeochannel has been dated as lasting from the fourth millennium BC to the first millennium AD.

Four boreholes were dug in the Ur area in order to date the Kutha palaeochannels; these boreholes are BH39 (Fig.3.36), BH41 (Fig. 3.37), BH33 (Fig.3.38) and BH30 (Fig.3.39). All these boreholes showed a significant similarity in lithology, succession, and alternation between river and marsh sediments. The general succession of these boreholes can be summarized as follows: the lowest bed appears to represent the floodplain deposit of an early Holocene river. The overlying bed is interpreted as the bedload sand of a river which was gradually abandoned before the Mid-Holocene, as the area was flooded to form marsh. Subsequently this marsh was covered by low-energy deposits interpreted as the floodplain or deposits of the low-energy distal part of a levee bed. These sediments represent the course of a new river which accumulated after the Mid-Holocene. At this time the area was again flooded to form marsh. Finally, these marshes dried out to became desert, until the area was reclaimed for modern agriculture as represented by the uppermost soil.

Boreholes BH39, BH41 and BH33 are similar to each other (Figs. 3.36, 3.37 and 3.38). The lowest floodplain deposits are undated, but the overlying marsh deposits are dated 4330 - 4230 BC, 4040 - 3955 BC and 4900 - 3940 BC respectively. All sets of marsh deposits are covered by channel and floodplain deposits. In borehole BH41 (Fig. 3.37) the river sediment was in turn covered by a marsh deposit dated 1410 - 1445 AD. In borehole BH33 (Fig. 3.38) the river sediment was covered by a marsh deposit which accumulated in 760-680 AD. Borehole BH30 (Fig. 3.39) is somewhat different to the other three described above. The lowest deposit is the Hammar Formation deposit of early Holocene age, dated as beginning in 8170-8110 BC, with the accumulation ending in 5840 to 5710 BC. It was followed by a floodplain deposit. After this, the river deposit was covered by a marsh deposit dated 770-900 AD. The radiocarbon dates clearly show that the floodplain and channel deposits were sustained over 4000 - 5000 years.

3.2.2 The Kish palaeochannel (from the fourth millennium BC to the first millennium AD)

When this palaeochannel passes Marad in the Najaf area, it goes to Isin and then meets the Nippur branch to form one channel before reaching the Uruk sites (Fig.3.35). Several small channels branch from the Kish palaeochannel, especially from the eastern bank towards the Nippur channel. In accordance with the age of the associated archaeological sites of this area (GDA, 1970 and 1976; Adams, 1981; Wilkinson, 1990; Al-Dafar, 2015), the Kish palaeochannel has been dated from the fourth millennium BC to the first millennium AD.

3.2.3 The Khalid palaeochannel (from the fourth to the first millennium BC)

There are two branches of this palaeochannel when it passes Nowaywees in the Najaf area, the Nowaywees channel going to the Ur sites and the Eridu channel going to the Eridu site (Fig.3.35). The Nowaywees channel meets the Uruk, Larsa and Ur channels to become one channel passing Ur to meet the Eridu channel to then form one channel heading to the Gulf, as will be explained later on, in the Marshland area. In accordance with the age of the associated archaeological sites of this area (GDA, 1970 and 1976; Adams, 1981; Al-Dafar, 2015), the Khalid palaeochannel has been dated from the fourth millennium BC to the first millennium BC. There are no recognisable abandoned channels in the Ur area except the abandonment of the Khalid palaeochannel from the south of the site of Khalid to the south of Ur (Fig.3.40), which occurred during the 1st millennium BC, as there are no associated sites from this period, according to Adams (1981).

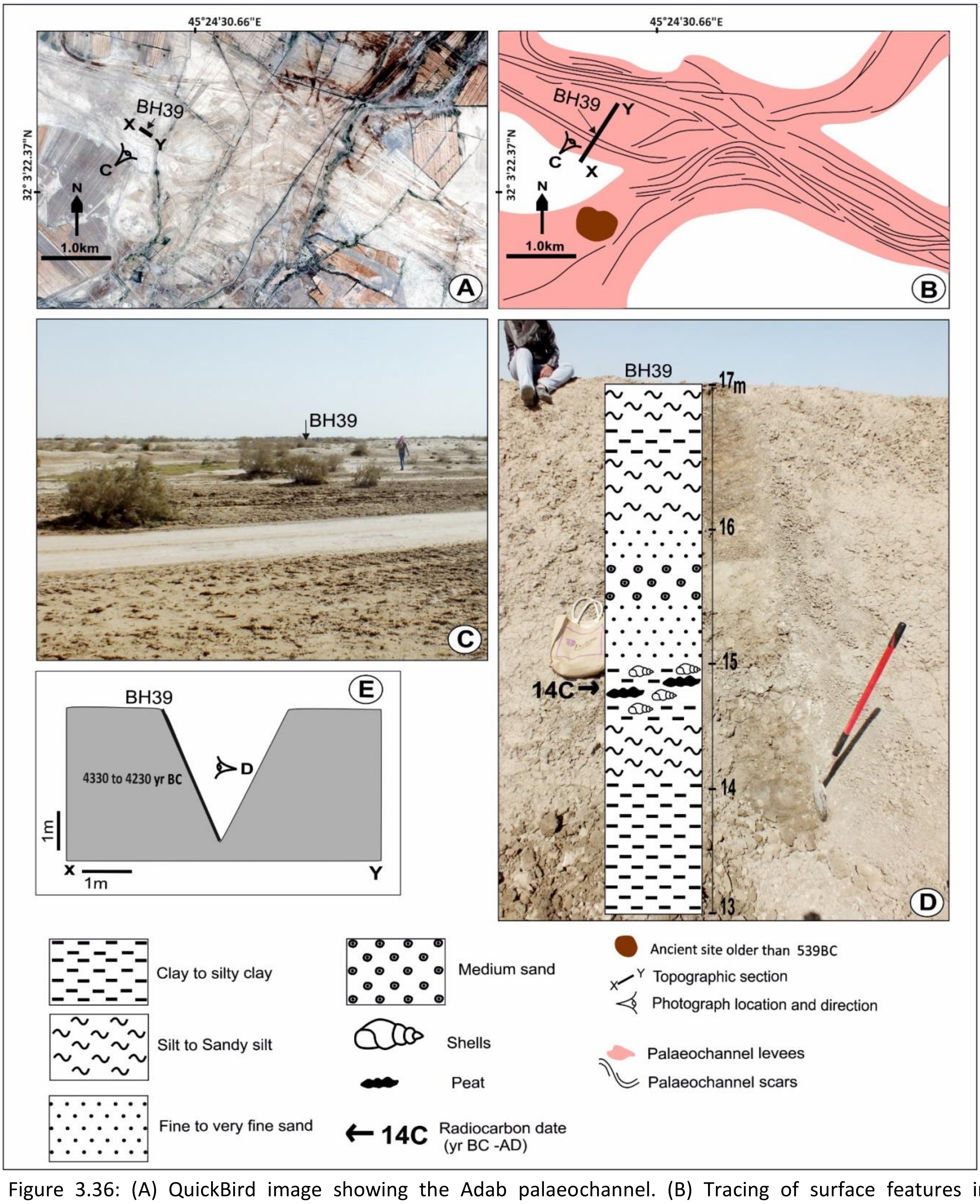

Figure 3.36: (A) QuickBird image showing the Adab palaeochannel. (B) Tracing of surface features including Palaeochannel levees, scars and archaeological sites. (C) Field photograph of the meander of the Adab palaeochannel. (D) Field photograph and section through the palaeochannel, showing the lithologies of the BH39 and location of the radiocarbon sample (E) Sketch showing a modern canal was constructed on the Adab palaeochannel and the location of the BH39.

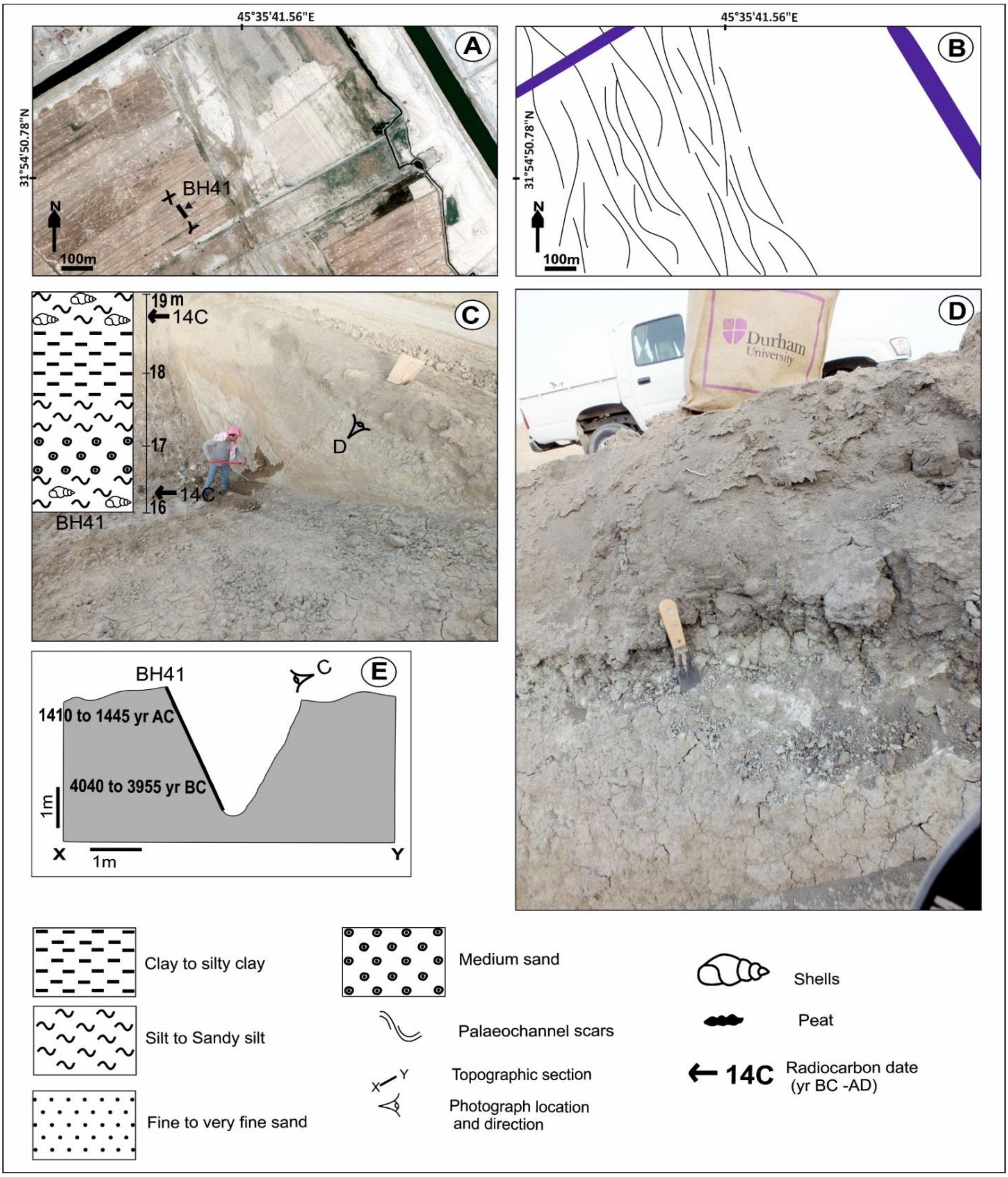

Figure 3.37: (A) QuickBird image showing the Adab palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph and section through the palaeochannel, showing the lithologies of the BH41 and location of the radiocarbon samples (D) Field photograph and section through the palaeochannel (E) Sketch showing a modern canal was constructed on the Adab palaeochannel and the location of the BH41.

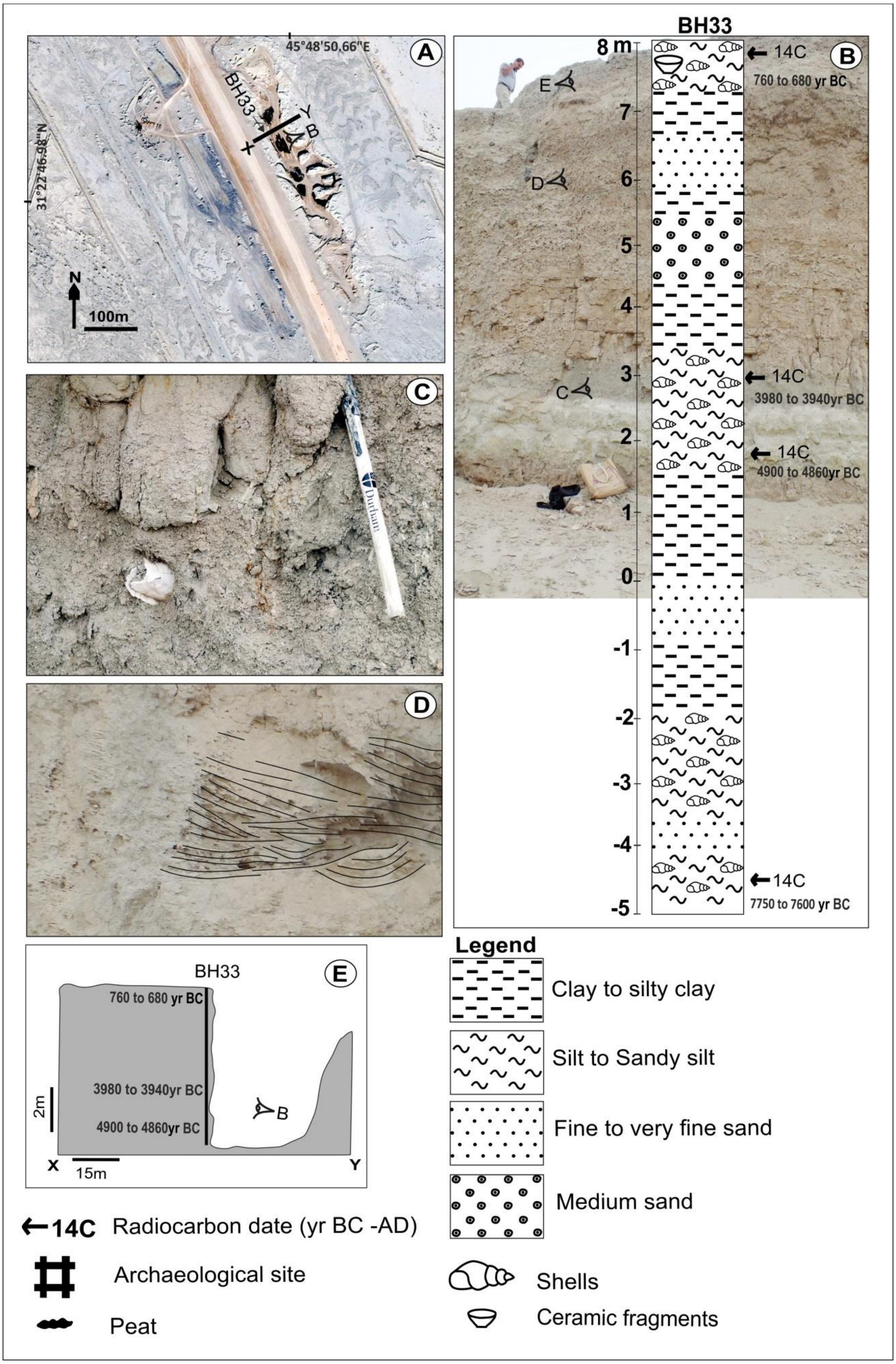

Figure 3.38: (A) QuickBird image showing the location of the quarry and the BH33 close to Larsa palaeochannel. (B) Field photograph and section through the palaeochannel, showing the lithologies of the BH33 and location of the radiocarbon samples (C) Field photograph showing shell sample (D) Field photograph showing cross bedding in a sand bed (E) Sketch showing the modern quarry and location of the BH33.

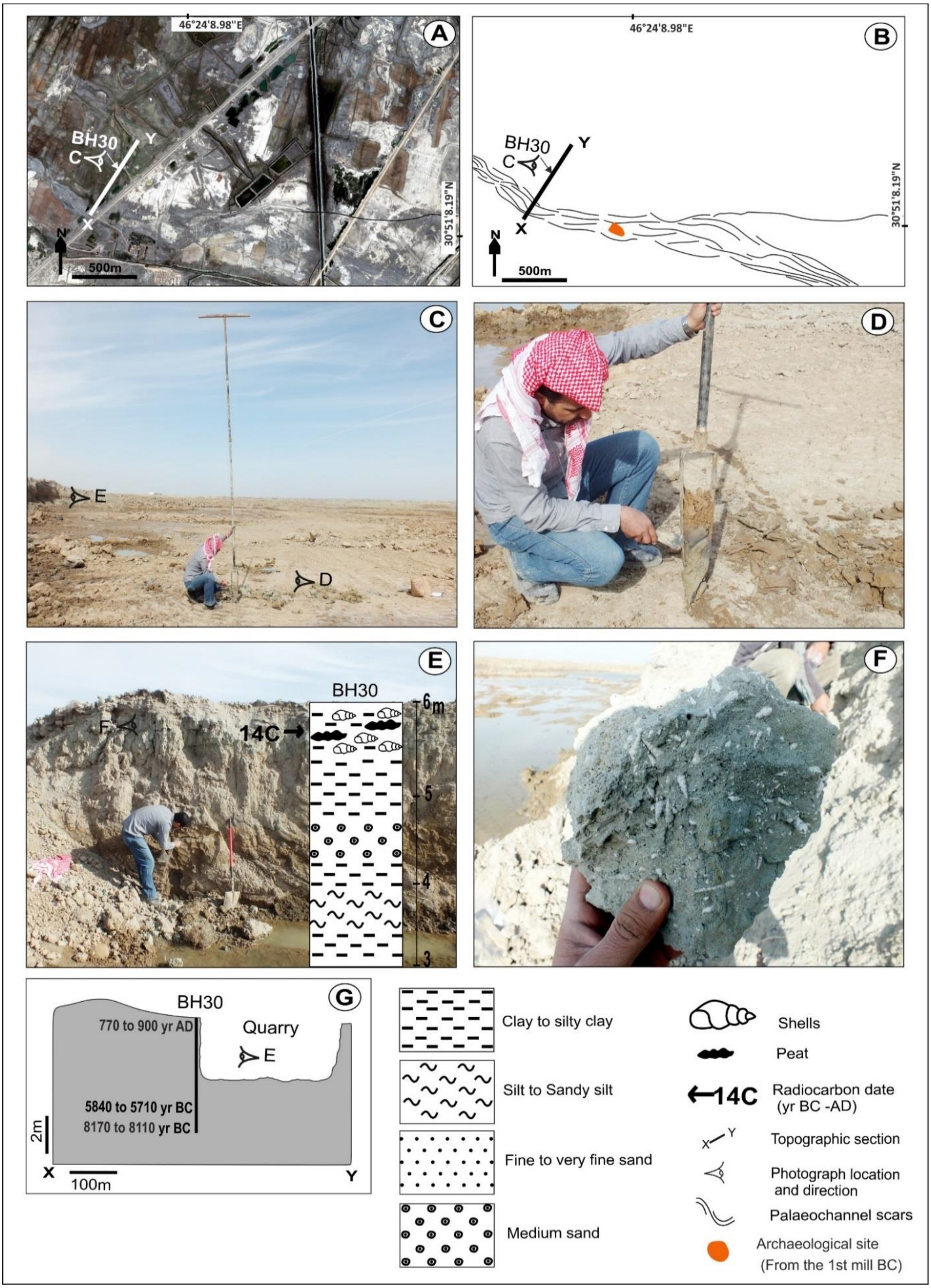

Figure 3.39: (A) QuickBird image showing the BH30 close to the Ur palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph showing the auguring process of the BH30 (D) Field photograph showing auger sample in 4.5 m depth of the BH30 (E) Field photograph and section through the quarry where the BH30 dug. (F) Field photograph showing sample taken from the marsh sediments in 0.7m depth of the BH30.

3.2.4 Discussion

As noted earlier, the Ur area is unlike the other areas in the Mesopotamian floodplain in terms of a lack of river avulsion points. A fundamental difference between the Ur region and the Najaf area described in section 3.1 is that most of the palaeochannels of the Ur area were canalised and used over a long period. Archaeological sites were occupied during multiple stages from the fourth millennium BC until the Islamic period.

During these periods, economic and political stability could only be achieved through control of the Euphrates channels and their tributaries. This ensured long-distance trade, boat travel for people, animals and goods, and extensive irrigation agriculture. Maintaining a stable channel system and meeting the needs of growing cities and their populations necessitated widespread human modifications of the naturally branching channels (Adams, 1981). Jacobsen (1960) suggested that the branches of the Euphrates divided and re-joined as they made their way towards their delta in the southern marshes. Also, he came to understand the basic stability in the channel system, from cuneiform texts.

As a result, the landscape of palaeochannels in this area resembles an anastomosing channel pattern, i.e. multiple interconnected channels that enclose flood-basins, separate and re-join downstream (Twidale, 2004). Such a channel pattern is reflected in the low gradient and flood-dominated regimes and is usually characterised by a low-energy flow, cohesive banks, and a stable deposition environment favourable for the accumulation of organic material, together with rapidly aggrading channels and adjacent wetlands caused by a rising local base level downstream (Smith and Putnam, 1980; Makaske, 2001). Interestingly, the shape of the palaeochannels in the Ur area is generally straight, which might be support the idea that these channels were intensively regulated by human intervention. A good example of human intervention in river shape is that of the people of the Netherlands, who started cutting off river meanders and constructing groynes on the Waal River in the 1830s. In time, the river was converted from its original low, sinuous meandering shape to its present-day, straight form (Geerling *et al.*, 2008).

3.3 The Euphrates River in the Marshland area

Marshes played a significant rule in the evolution of early Mesopotamian Civilization as they all have the natural resources required for sustainable human occupation (Pournelle, 2003). The marshes were widely mentioned in cuneiform tablets and historical texts as an important area for living, hunting and escaping from organised states. They were first settled when a dynasty called the “Sealand Dynasty” ruled the area between 1739 -1340 BC (Al-Dafar, 2015). However, Al-Dafar’s study is the first record that we have of settlement, there could be earlier occupation that simply has not yet been found.

This area is located in the southern part of the Mesopotamian floodplain where the modern Tigris and Euphrates meet to the north of the Persian Gulf (Figs. 3.41, 3.42 and 3.43). In terms of archaeological surveys of this area, several studies have been carried out such as those by Hritz, Darweesh and Pournelle (2015) and Al-Dafar (2015). Both studies traced the palaeochannels and the archaeological sites. In the present work, archaeological sites and palaeochannels have been also traced, using remote sensing data, groundtruthing and new boreholes, as described in Chapter Two. Radiocarbon dating was employed to date the palaeochannel and the marsh sediments. As a result of this study, there is no indication of the existence of any river avulsion. However, independently of previous work, the reconstructed reaches of palaeochannels in the present study can be categorised into three main palaeochannels, - the Lagash, Kuara and Zubayr palaeochannels.

3.3.1 The Lagash Palaeochannel (from the fourth to the first millennium BC)

This channel is the same channel as in the Ur area. When it passes Lagash, it continues running to the southeast until reaching the Nina archaeological sites before disappearing under the later sediment of the Dujaila palaeochannel (Fig.3.43). In the present study, the M32 borehole was dug in the channel to the southeast of the Nina site and a radiocarbon sample was taken, which dates the palaeochannel sediment at between 3695 and 3635 BC (Fig 3.44). This sample represents the date of the channel sediment at the depth of 5m, but the channel sediment is deeper, which might mean that the Lagash channel is older than the 4th millennium BC. The channel sediment was followed by a marsh deposit. Data from borehole M28 (Fig. 3.46) indicate that the marsh deposit accumulated before 790-730 BC and was covered by a channel deposit after 360-170 BC. This means that the area of the Jidr palaeochannel was covered by marsh and channels during the Partisan, Sasanian and Islamic periods, as will be discussed in relation to the Kut area in the following chapter.

3.3.2 The Kura palaeochannel (from the fourth millennium BC to the first millennium AD)

When the Khalid channel and the Ur channel meet to the south east of the Ur site they form a channel running eastwards, adjacent to the Al-Batin i.e. to the southern shore of the modern Hammar marsh. Several archaeological sites are associated with this channel, dating from the 4th millennium BC until Islamic periods. For example, Kura, Banat Al-Saeigh, and Abu Salabikh2 have been occupied since the 4th, 3rd and 1st millennium BC respectively (Ur and Hamdani, 2014). This channel will be named informally the Kura palaeochannel (as it passes the Kura archaeological sites).

In accordance with the age of the associated archaeological sites of this area (GDA, 1970 and 1976; Al-Dafar, 2015), the Kura palaeochannel has been dated from the fourth millennium BC to the first millennium AD.

Borehole M35 (Fig. 3.45) was dug in the marshland associated with the Kura palaeochannel. Unfortunately, issues connected with obtaining permission prevented digging in the channel levees. However, this borehole provides evidence that marsh sediments 3m deep were deposited between 395 and 540 AD and at a depth of 6m in the borehole there were marsh sediments. Sediments at a depth of 5m dated from 1390 to 1335 BC (Fig. 3.45), so the marshes could have been formed before the second millennium BC.

3.3.3 The Zubayr palaeochannel (from the first millennium BC to the fist millennium AD)

This channel is a branch from the Kura channel, from the right bank near Bint Al-Saeigh and continuing south, passing the Zubayr site and then ending in the Gulf (Fig. 3.43). This channel is associated with several archaeological sites occupied between Sasanian and Islamic periods - there is no associated site that is known to be older than these periods (Ur and Hamdani. 2014). Therefore, it can be argued that this channel dates from the Sasanian through to the Islamic period. Moreover, borehole BH32 (Fig. 3.48) was dug in the Zubayr palaeochannel in order to date it, providing evidence that the lowest bed is a marsh deposit dated 2470- 2285 BC followed by a channel deposit. This means that the area was covered with marsh during the late 3rd millennium BC and there was no flowing channel at that time - it was formed much later, i.e. in the Sasanian period.

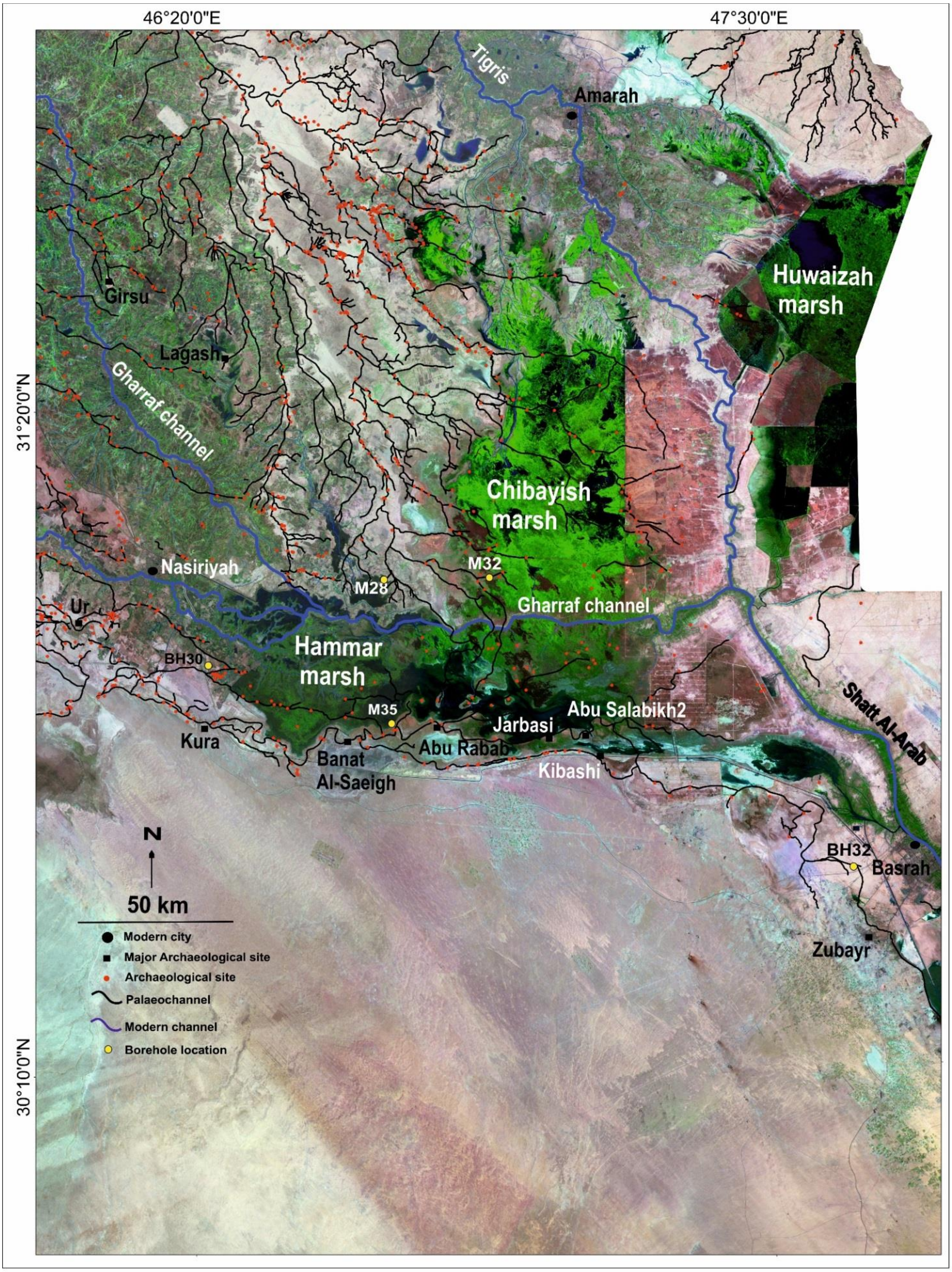

Figure 3.41: Landsat (2000) showing the identified archaeological sites and palaeochannels in the Marshland area.

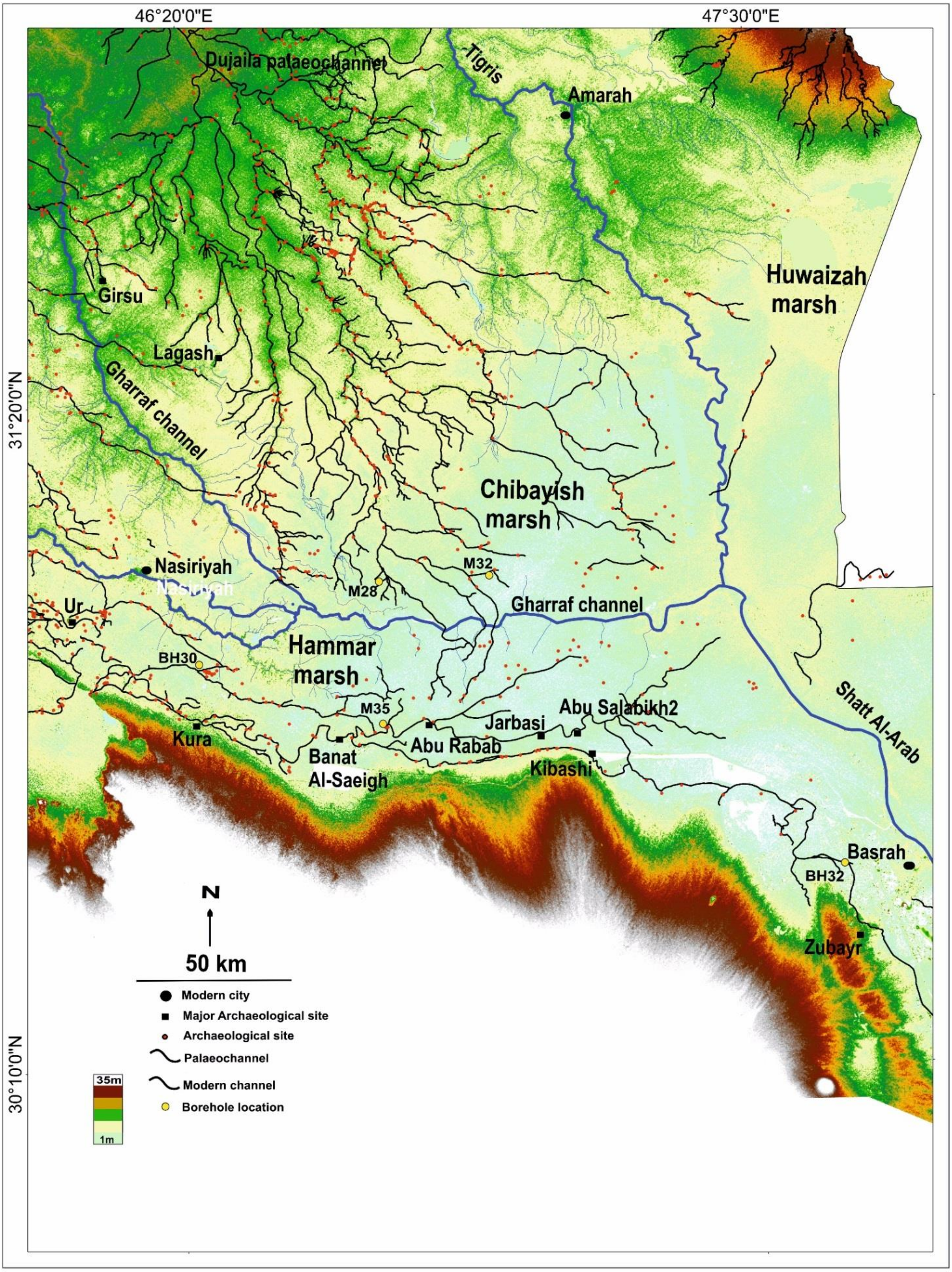

Figure 3.42: SRTM showing the identified archaeological sites and palaeochannels in the Marshland area.

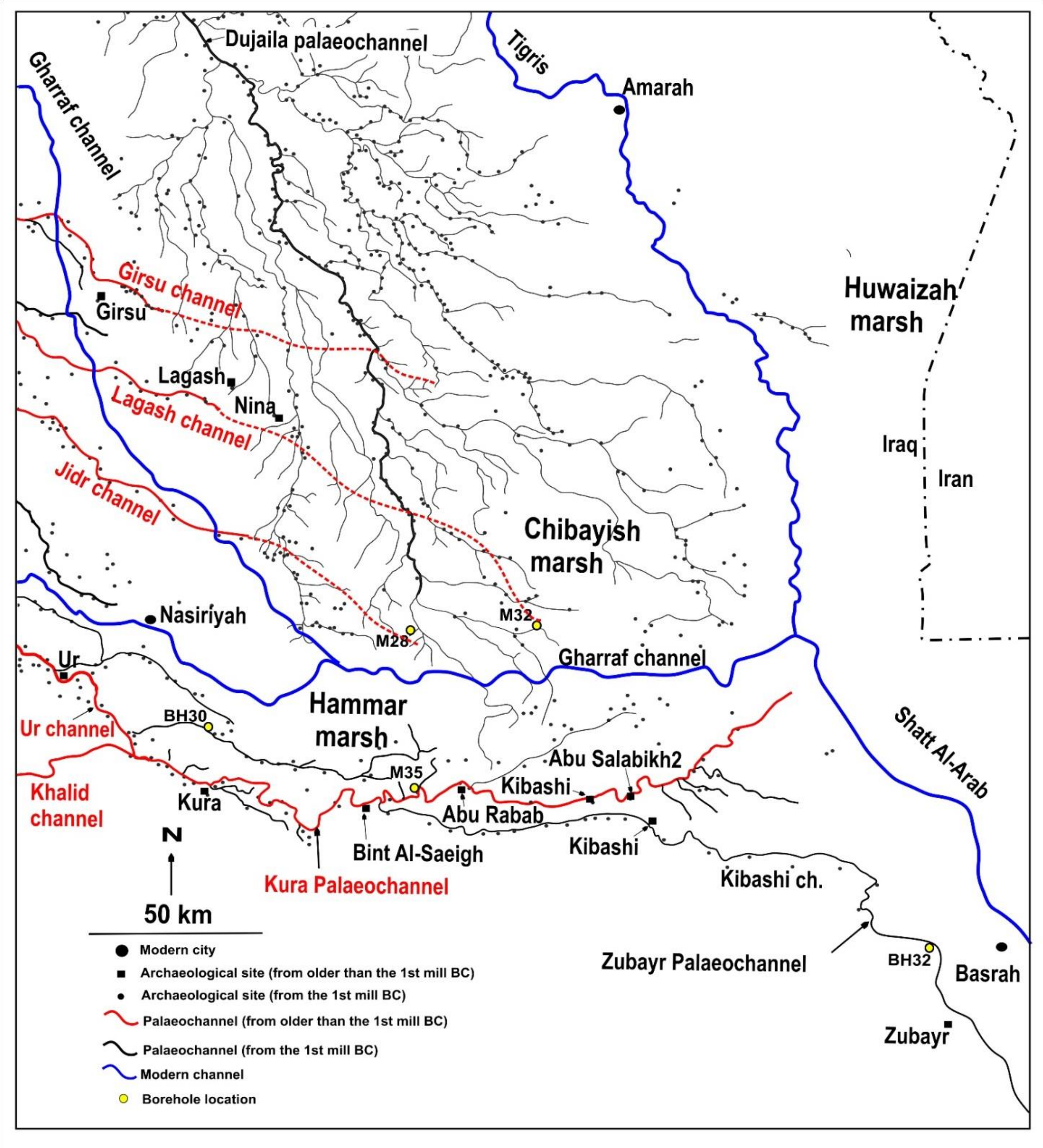

Figure 3.43: The identified archaeological sites and palaeochannels in the Marshland area. The extrapolated eastern continuations of the Girsu, Lagash and Jidr channels are based on the new identification of channel deposits in the boreholes M32, M28 and M35. Note the implications for the presence on a single, continuous "sealand" across this area at the time of channel deposition, as discussed in the text.

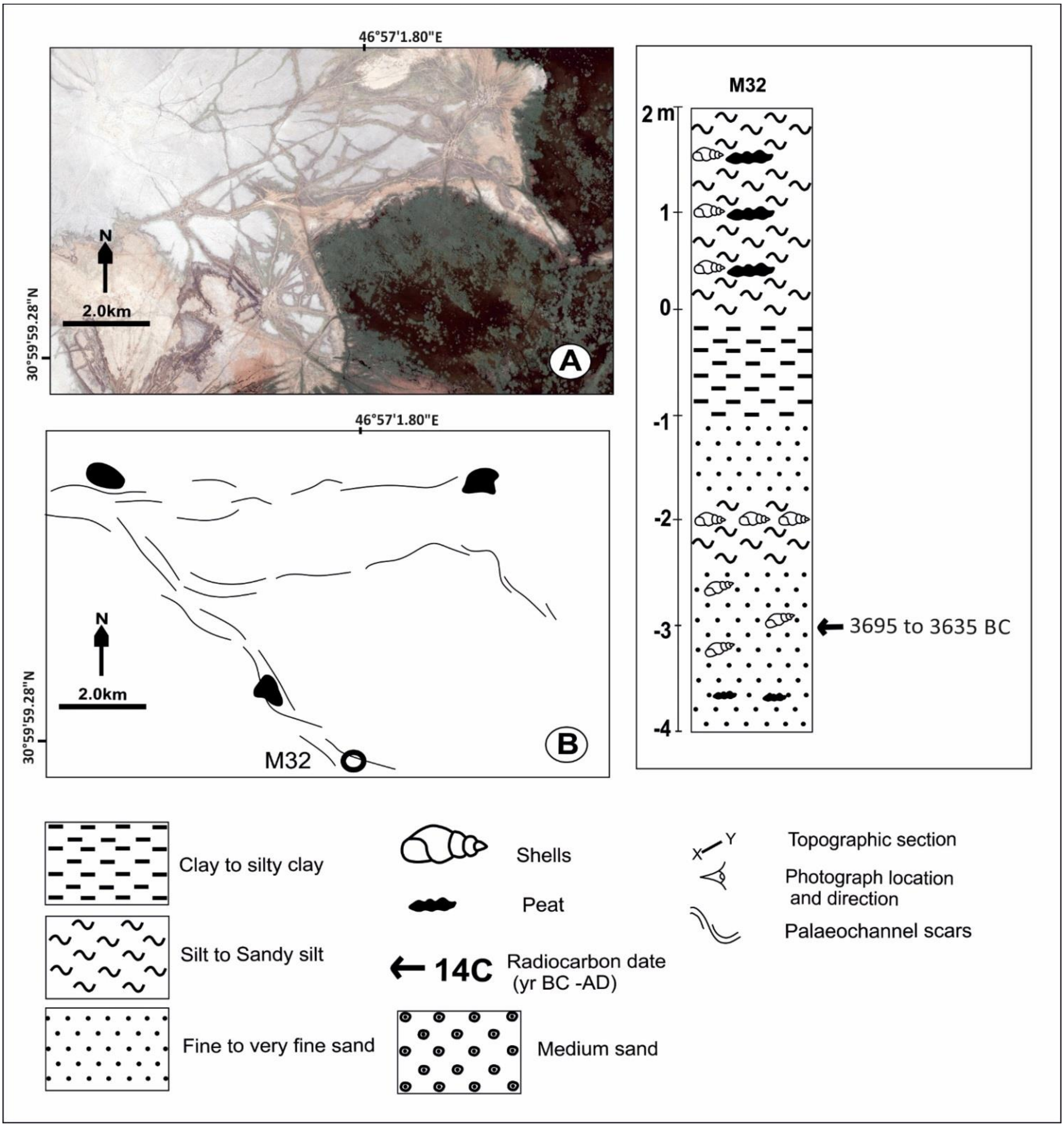

Figure 3.44: (A) QuickBird image showing the borehole M32 on to the Lagash palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Section through the palaeochannel, showing the lithologies of the borehole M32 and the location of the radiocarbon sample.

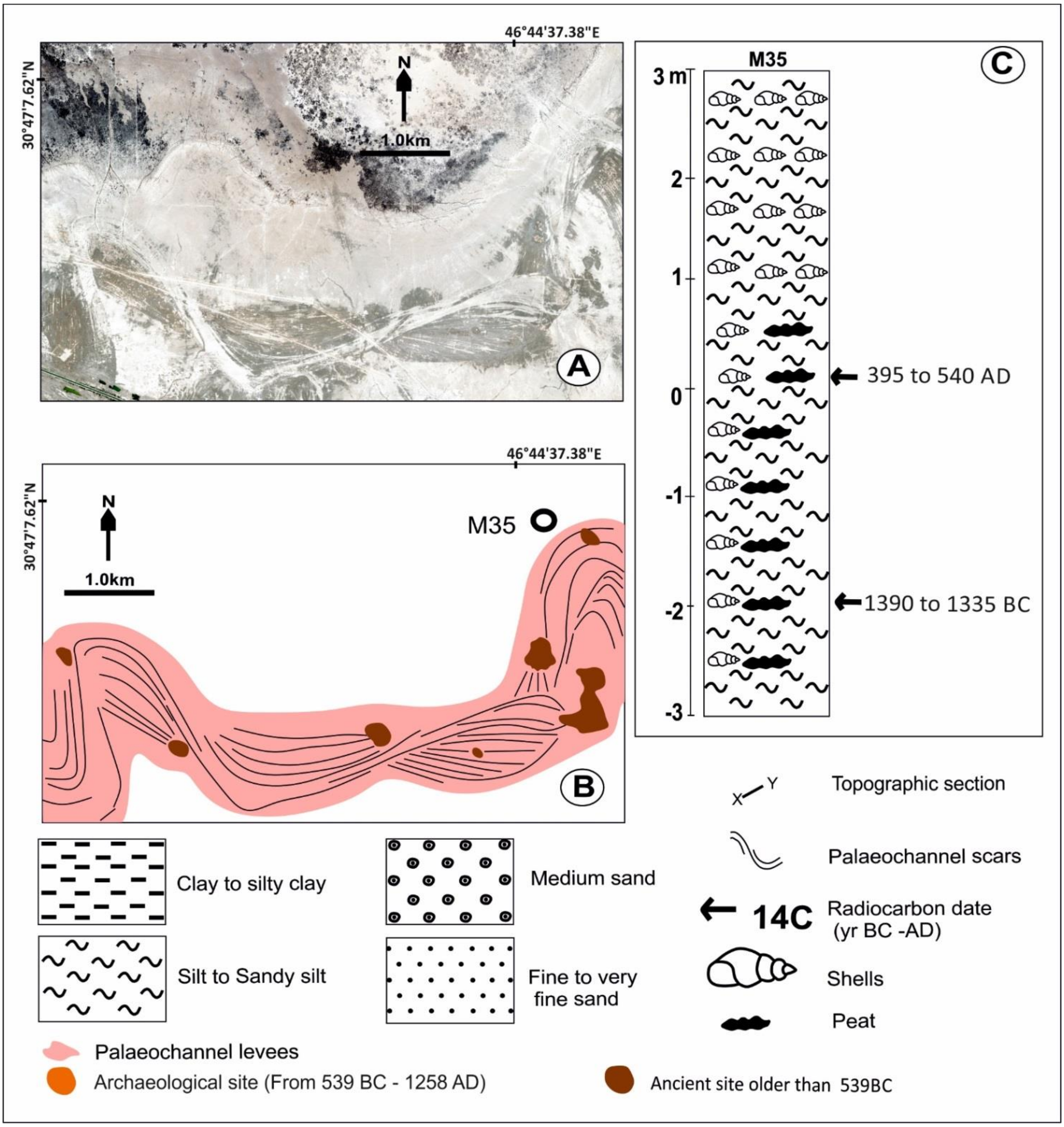

Figure 3.45: (A) QuickBird image showing the borehole M35 on to the Kura palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Section through the palaeochannel, showing the lithologies of the borehole M35 and the location of the radiocarbon samples.

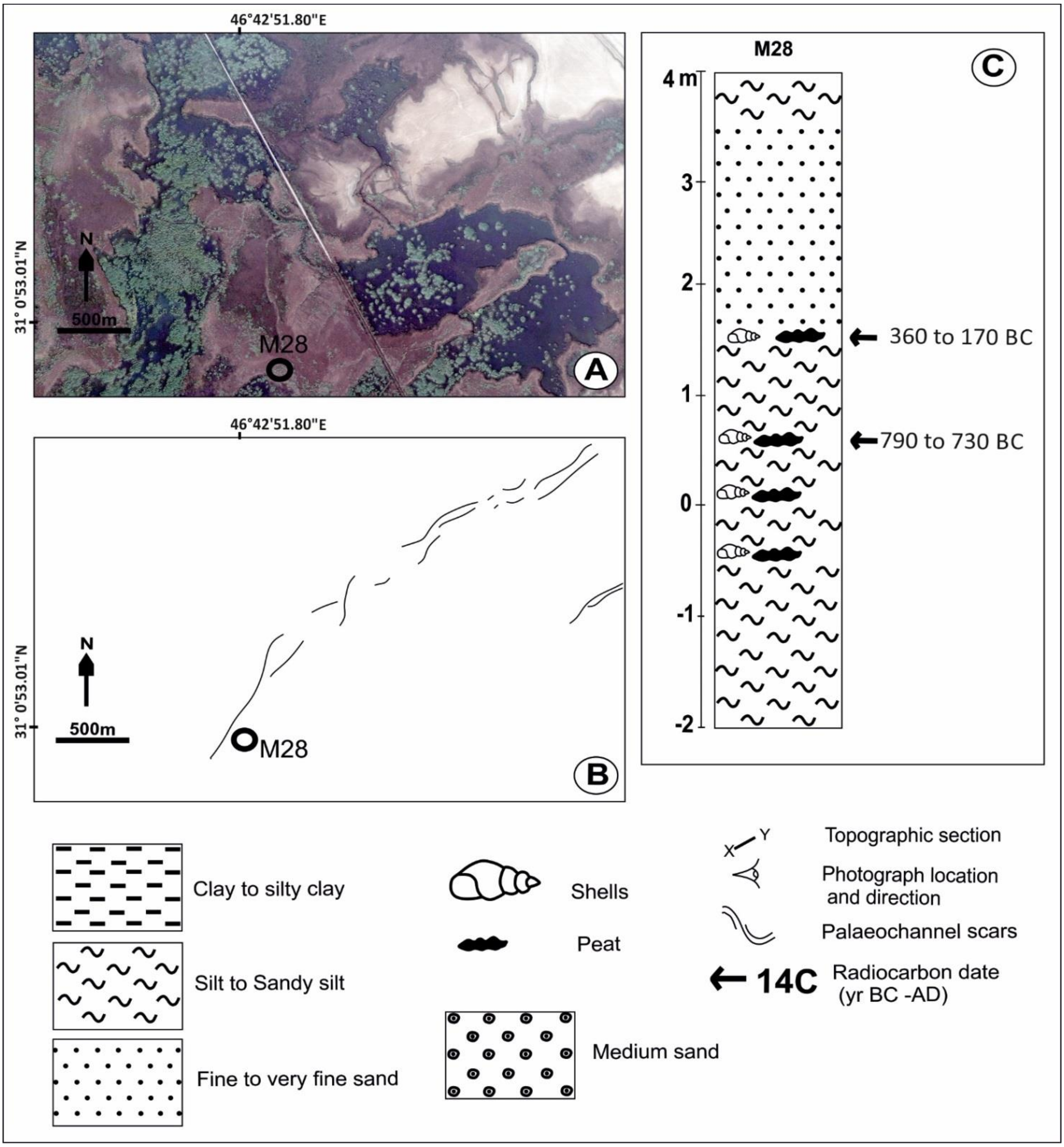

Figure 3.46: (A) QuickBird image showing the borehole M28 on to the Jidr palaeochannel. (B) Tracing of surface features including palaeochannel levees and scars. (C) Section through the palaeochannel, showing the lithologies of the borehole M28 and the location of the radiocarbon samples.

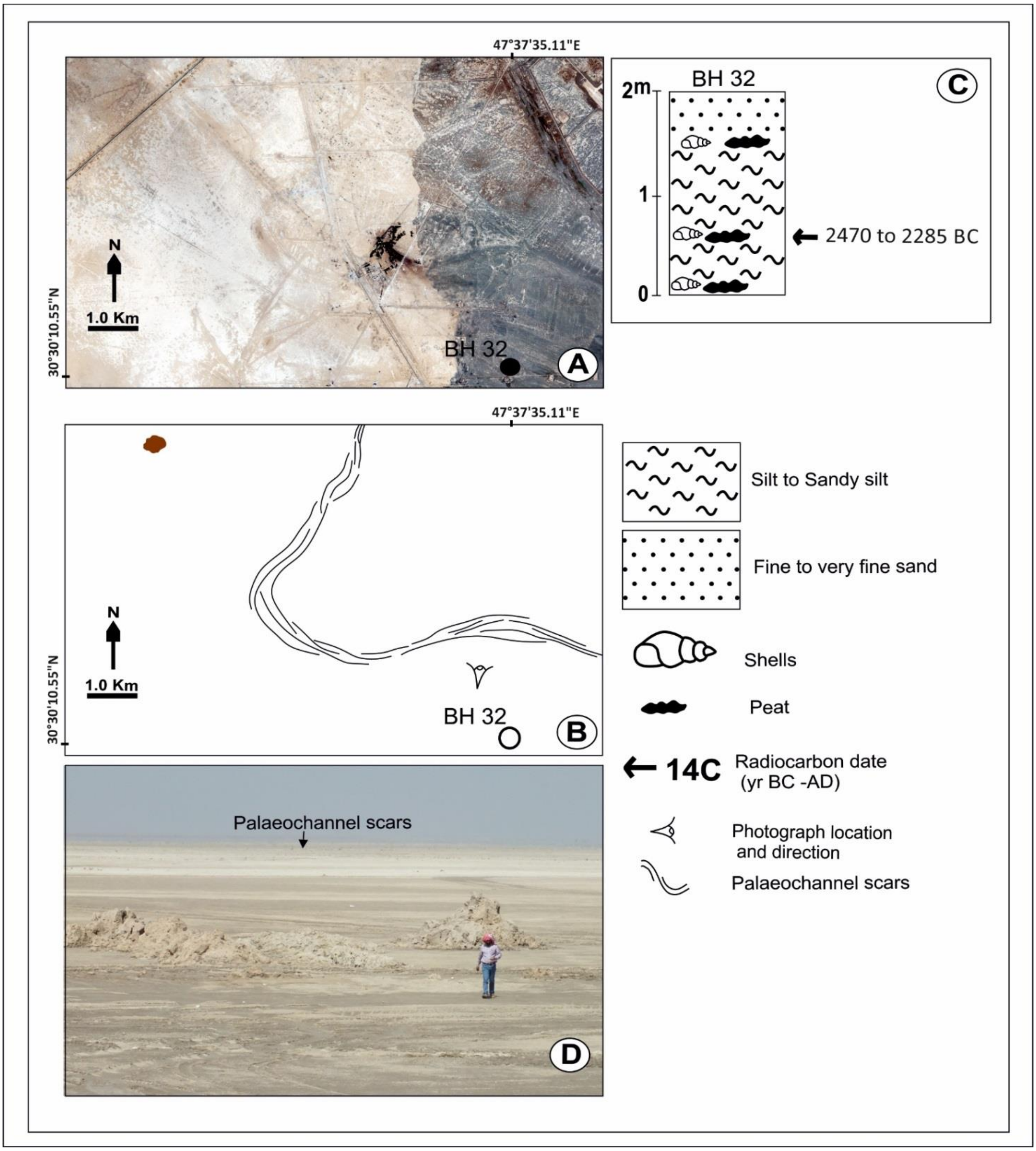

Figure 3.47: (A) QuickBird image showing the borehole BH32 on to the Zubayr palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Section through the palaeochannel, showing the lithologies of the borehole BH32and the location of the radiocarbon sample. (D) Field photograph showing the Zubayr palaeochannel levee.

3.3.4 Discussion

Marshes, lakes and seasonal swamps can be formed everywhere in the Mesopotamian floodplain and not only in the southern part of the floodplain. For example, there was a sustainable marshland located to the west of Babylon (Cole, 1994) (see figures of Najaf area, for example, Fig. 3.3). There are several ancient maps from the 19th and early 20th centuries AD (e.g. Willocks, 1912) showing several areas of marshes distributed thought the Mesopotamian floodplain, see for example Aqarquf marsh to the north of Baghdad. In addition, according to the environmental and lithological interpretation of the boreholes that have been drilled in the present study, there was a clear alternation between river and marsh sediments.

Marsh needs only two conditions for its formation in an area: water overflow from channel banks and barriers to trap the water in a basin. The wetland area cannot be formed unless there are relatively high topographic features that act as a barrier to confine the flooded water and prevent it from flowing towards lower land. The size and the depth of the wetland area depend generally on the amount of the flooded water, the size of confined basin or lowland area, and the elevation of the confining structure, and evaporation rates.

In terms of the barriers, there are five types of barriers have been identified in the present study: palaeochannel levees, contemporary channel levees, alluvial fans, the Arabian Plateau and artificial dykes. Examples of marshes contained by these types of barriers are: the Najaf marsh, confined by the Arabian Plateau from the west and the Ciniyah palaeochannels from the east (Fig. 3.4); the Hammar marsh, confined by the Al-Batin fan from the south and the modern Shatt al- Arab levees from the east (Fig. 4.39); the Chibayish marsh, confined by the modern Euphrates levees from the south and the modern levees of the Tigris from the east (Fig. 4.39); Shuwaicha Lake, confined by the modern Tigris levee from south and the Teab fan (Fig. 4.39); Dalmaj Lake, confined by palaeochannel levees from the east and the west, and a constructed dyke from the south (Fig. 3.1).

Suggestions of past marsh locations should account for the locations, dimensions and types of the confining barriers for completeness. This point is relevant to the wide and continuous body of water (sealand) that was suggested by (Hritz and Pournelle, 2015; Al-Dafar 2015): what type and size of barrier existed to form such a marsh. Arguably this “sealand” could have consisted of several marshes, separated by channel levees, which acted as natural barriers for each marsh, such as the down steam levee of Kura palaeochannel that help to make marsh to the north and north west of the Kura levee (Fig. 3.43).

4. The Tigris River

This chapter presents a study reconstructing the ancient courses of the Tigris in the Mesopotamian floodplain. The focus is on tracing palaeochannel courses, determining when they were active, and understanding the patterns of avulsion. In this study, the Tigris River has been divided into five areas of avulsions, and each area will be discussed separately. The areas are: Samarra, Adhaim, Diyala, Baghdad and Kut (Fig. 1.11). It is significant that no fieldwork has been done in this study in the first three areas i.e. Samarra, Adhaim and Diyala because of political and security issues in these regions. Therefore, the research was carried out using a combination of geological, geomorphological, remote sensing, historical and archaeological approaches only, while in the other two areas i.e. Baghdad and Kut, fieldwork has been undertaken. In terms of the recognition and dating of palaeochannels and archaeological sites in the first three areas of Tigris, for the identification of the surface geomorphological features, the same remote sensing methods were applied as explained in Chapter Two to determine the age of the associated archaeological sites and to date the palaeochannels.

4.1. Samarra area

The Tigris river goes through the Hamrin Mountains and enters the Mesopotamian floodplain in Fat'hah city (Fig. 4.1), building a large fan called the Fat'hah fan which continues as far as the north of Baghdad (Fig. 4.1). The Tigris runs south in a confined river belt within the Fat'hah alluvial fan until it reaches Samarra, where it starts running in a relatively wide, open river belt (Figs. 4.1 & 4.2). According to the present examination of the remote sensing data, it is clear that there is no indication of any notable surface features of palaeochannels and/or archaeological sites in the area from Fat'hah to Samarra, while the area to the south, south west and south east of Samarra is relatively intensively populated with palaeochannels and archaeological sites (Figs. 4.3 & 4.4). This area, i.e. the area of well-developed palaeochannels floodplain, will be termed in this work 'the Samarra area' (Figs. 4.1- 4.4). The Samarra area attracted several researchers, such as Buringh (1960) and Susa (1948), who conducted geomorphological and archaeological studies, but unfortunately few attempts were made to discuss the Tigris River in this area in terms of river avulsion processes and their effects on the pattern of human settlements, which the present study has undertaken.

In the present study, three main courses of the Tigris River (Fig. 4.4) in three different periods have been mapped within the Samarra area, namely, from the Pleistocene to the early fourth millennium BC period, from the early fourth millennium BC period to the Islamic period, and from the Islamic period to the present.

4.1.1 The west Balad Mesa course (from the Pleistocene to the Mid-Holocene)

This course is located to the west of the Balad Mesa and involves a wide area of numerous oxbow lakes and levees; this course is named in the present study as the "west Balad Mesa course". According to geological surveys of this area carried out by Buringh (1960) and Yacoub (2011), this area is the oldest part of the Tigris River in the Samarra area, and formed during the late Pleistocene to the middle Holocene (Fig. 4.5). It is hard to identify one continuous levee of this course in this part, because of the high degree of interference amongst the large number of oxbow lakes and levees mentioned (Fig. 4.6). However, its starting point can be located to the north of the Balad mesa, i.e. the location of the avulsion node where the present channel originates (Fig. 4.5). There is no mention of this course in any historical texts and also no archaeological site has been established in this terrace, either in the present study or in any previous work.

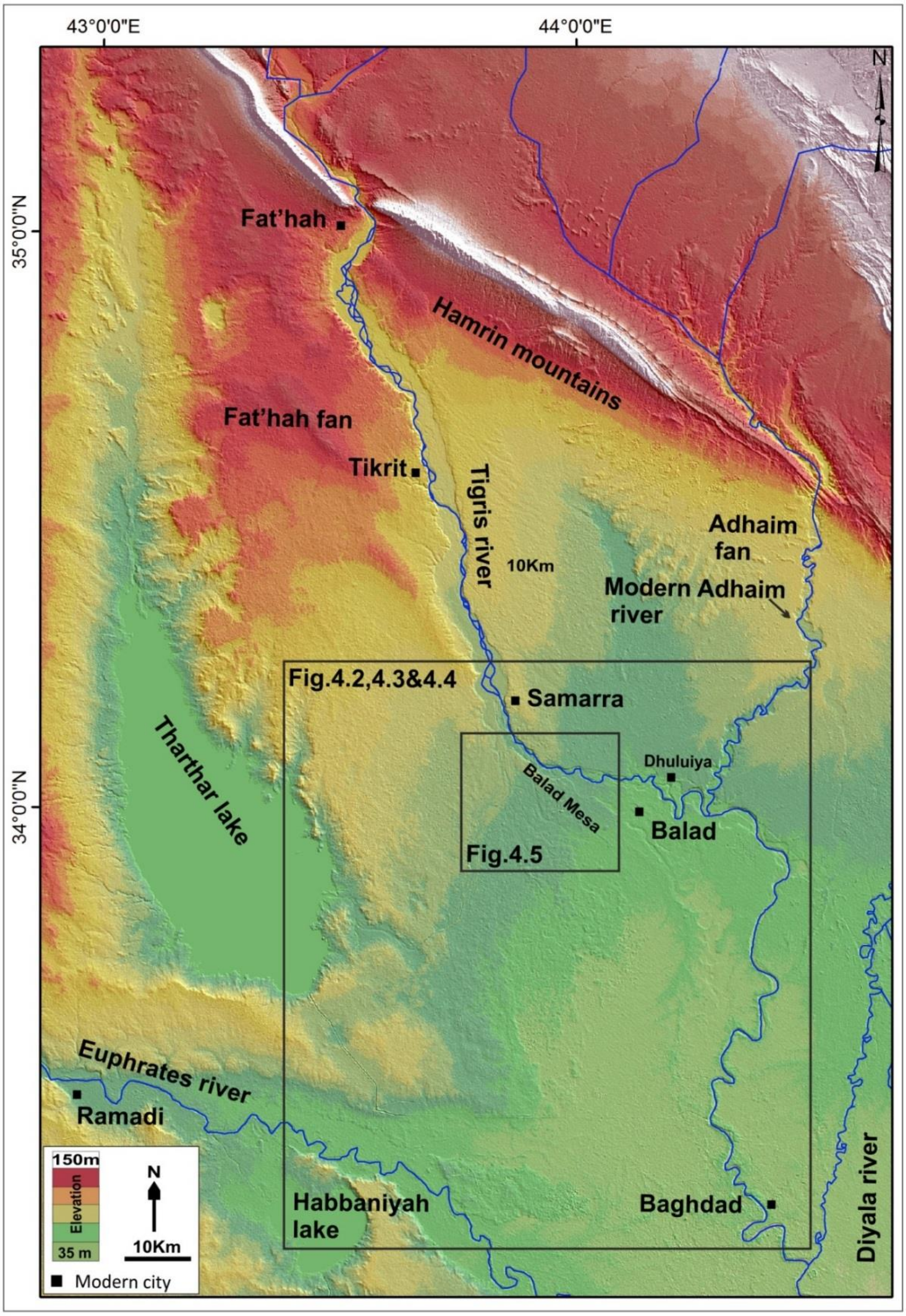

Figure 4.1: SRTM map showing Fat'hah fan.

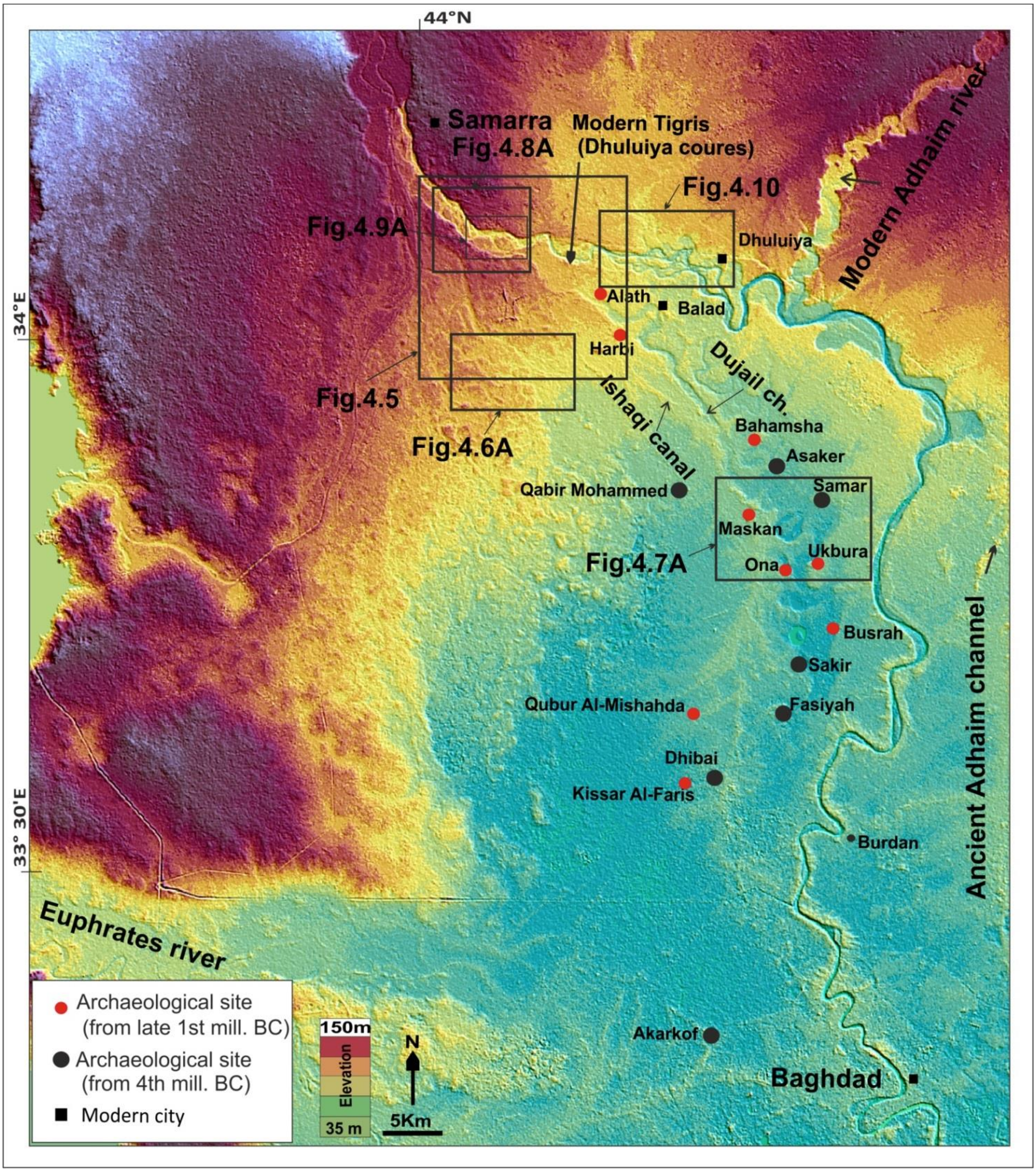

Figure 4.2: SRTM map showing the Samarra area which is located to the south of the Fat'hah fan and the most important archaeological sites.

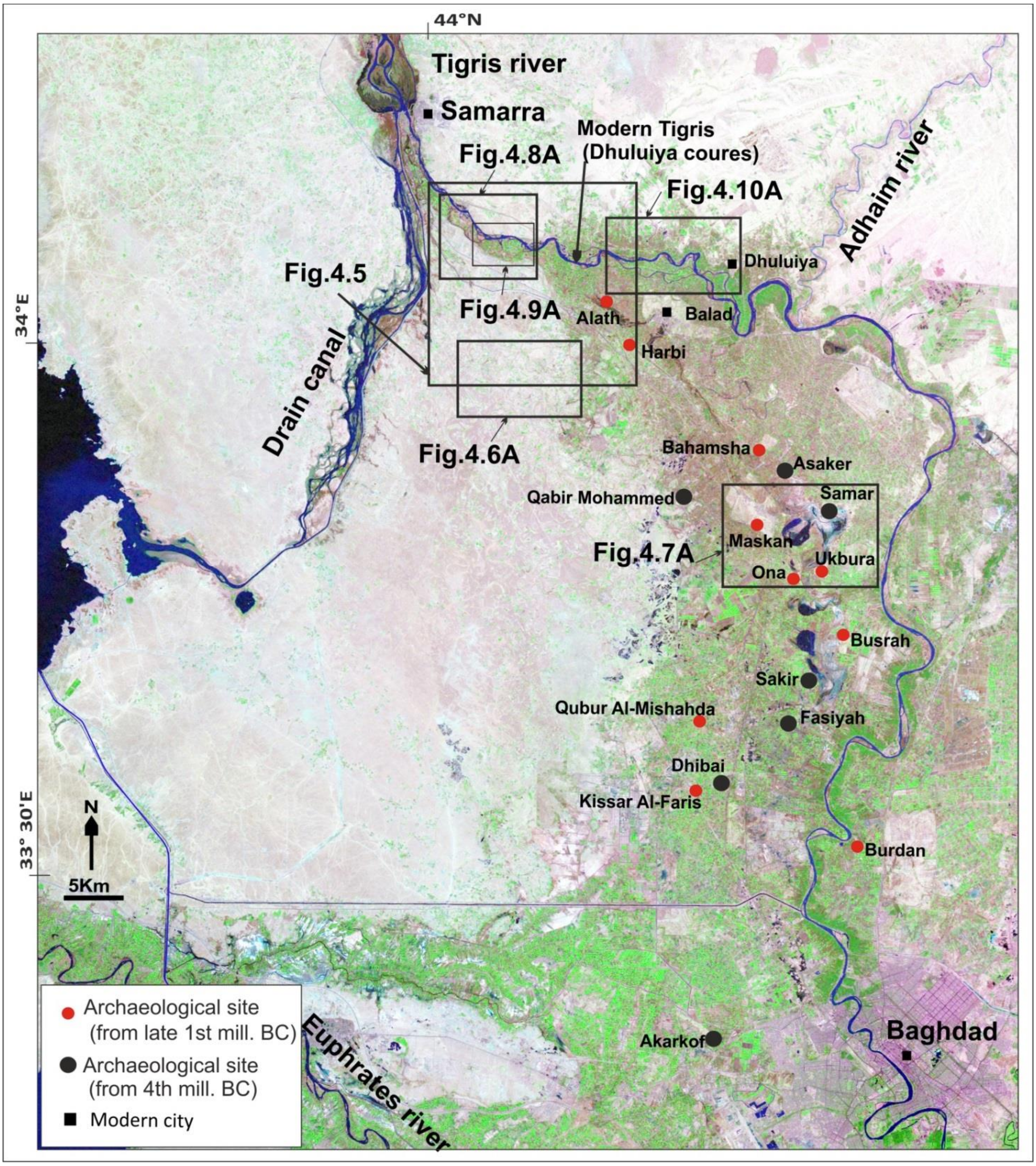

Figure 4.3: Landsat image (2000) showing the Samarra area and the most important archaeological sites.

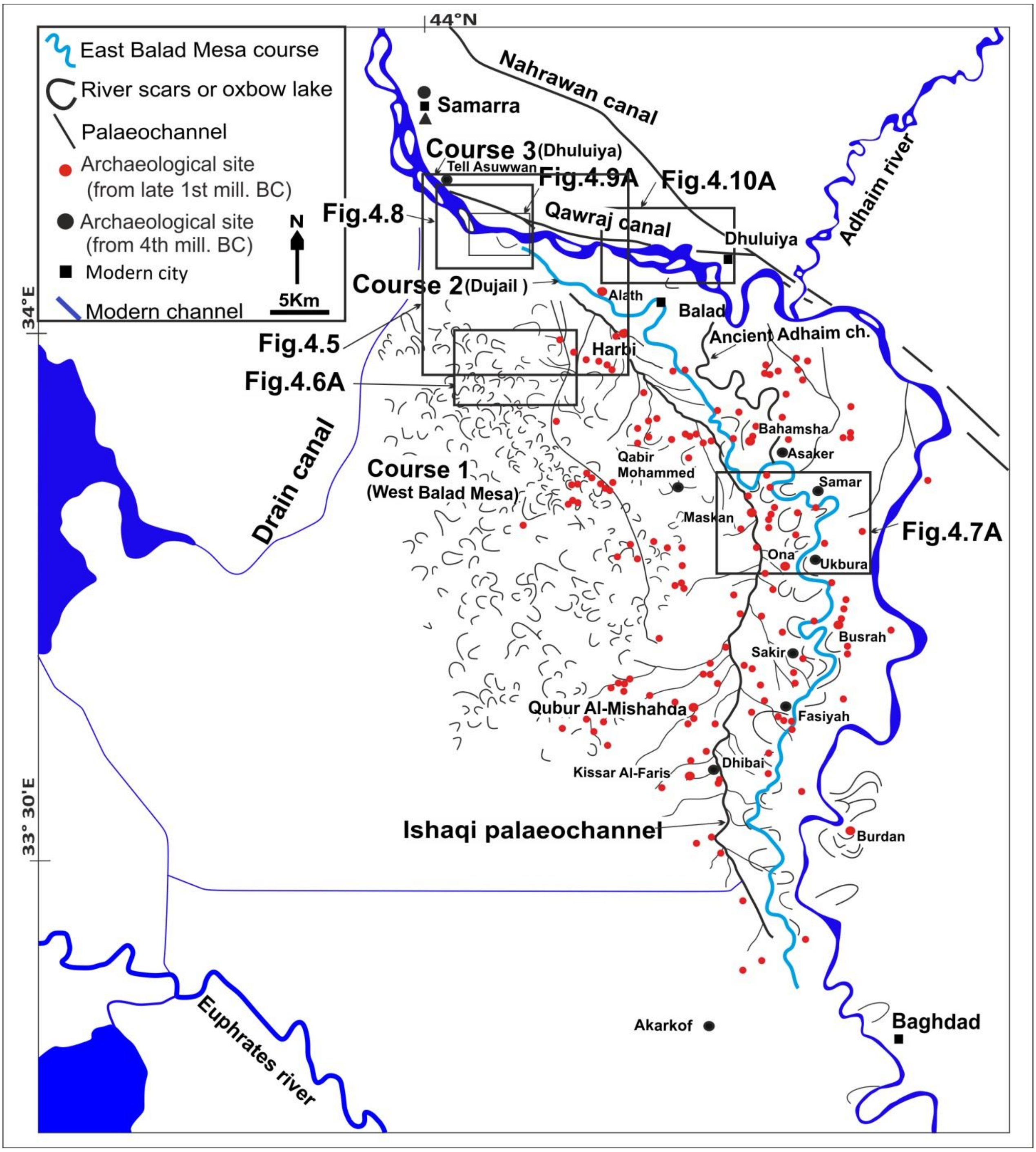

Figure 4.4: All the reconstructed Palaeochannels and archaeological sites in the Samarra area in the present study.

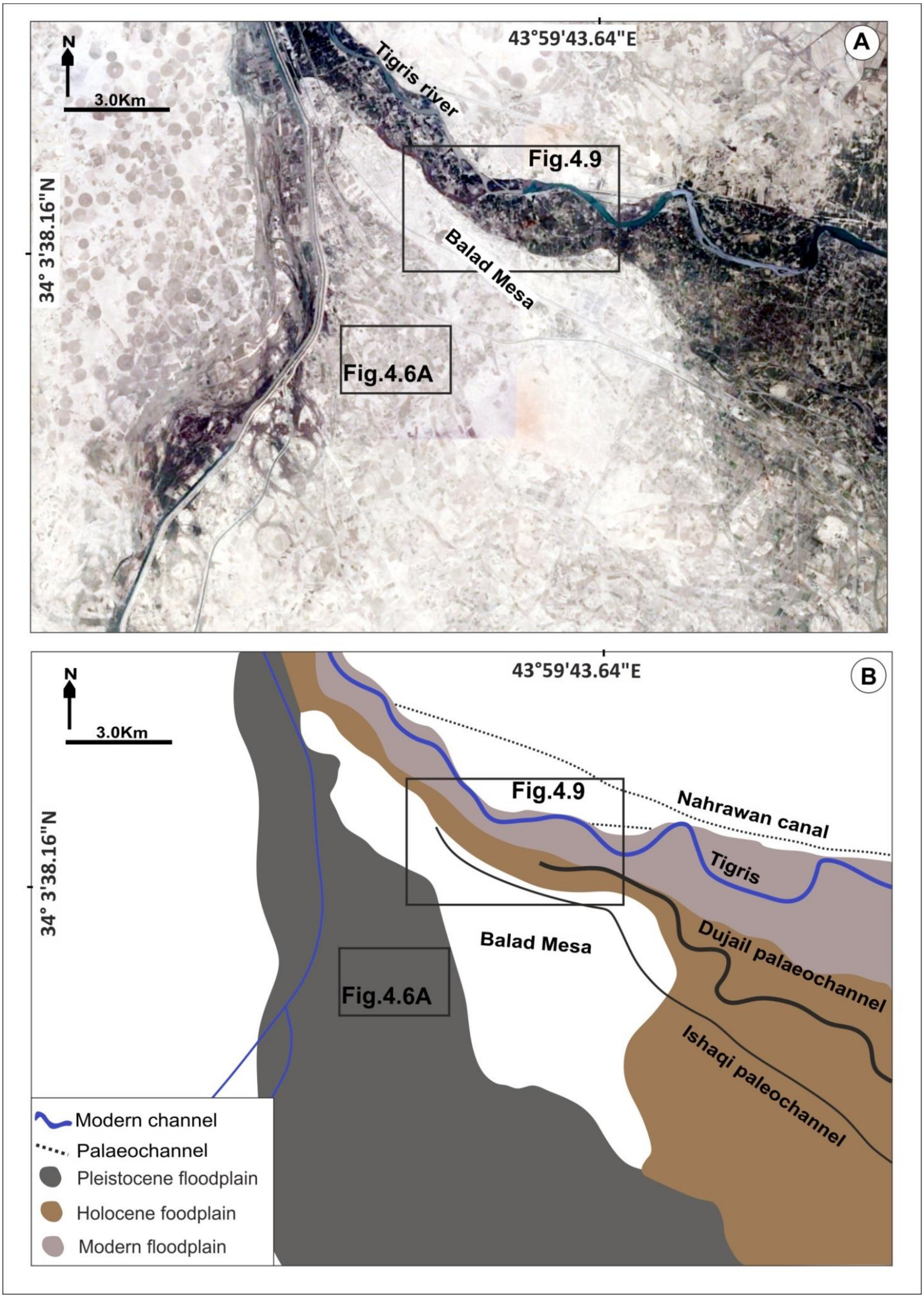

Figure 4.5: (A) QuickBird image showing the Balad Mesa (B) Sketch showing the floodplains of the palaeochannels to the west and east of the Mesa.

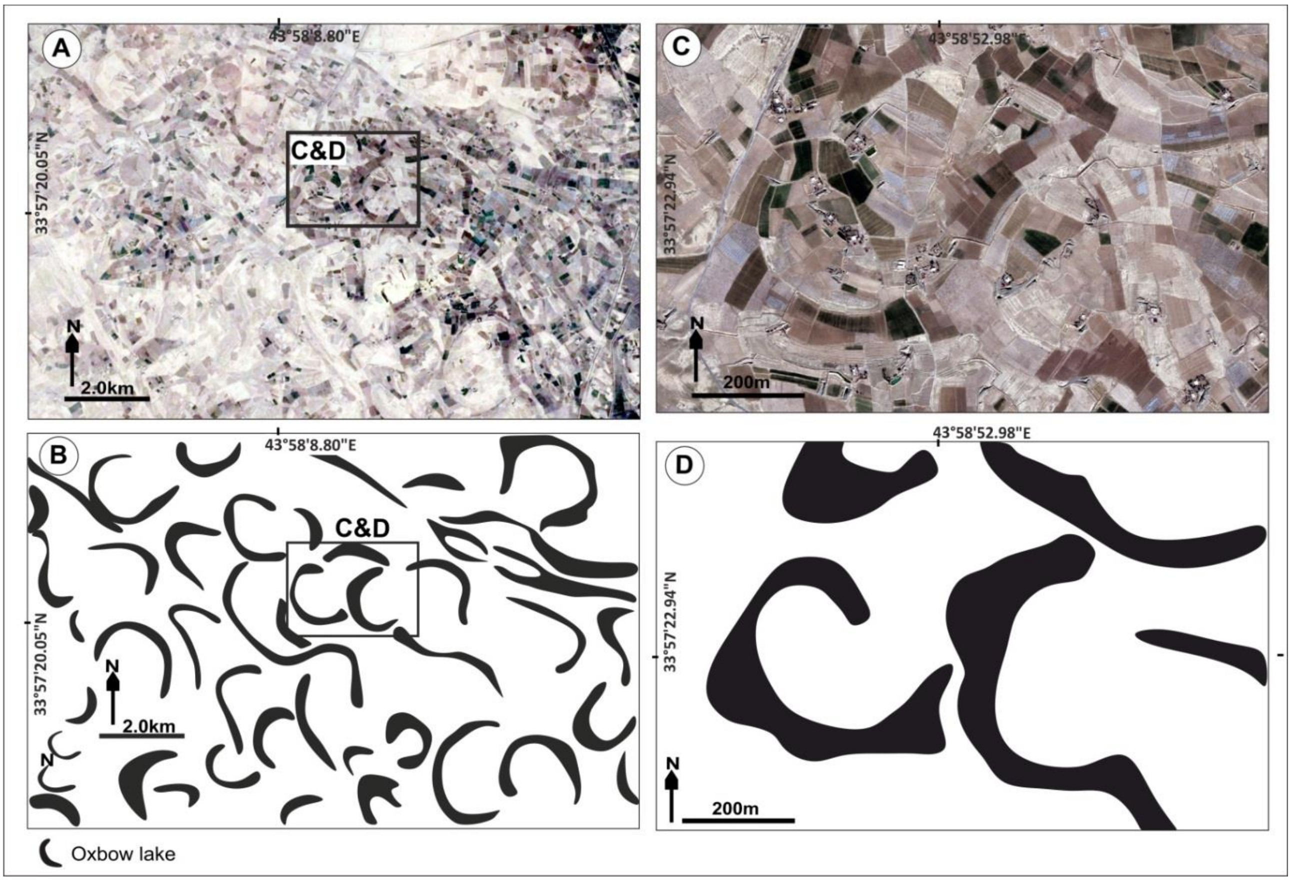

Figure 4.6: Intensive oxbow lakes in the Pleistocene floodplain of Samarra area. (A and B) QuickBird images. (C and D) tracing of the oxbow lakes of the A and B images respectively.

4.1.2 The east Balad Mesa course (from the Mid-Holocene to the thirteenth century AD)

This course started from the avulsion node to the north of the Balad Mesa, running to the south between the west Balad Mesa course and the Adhaim alluvial fan (Figs. 4.1 and 4.5), forming a new floodplain of the Tigris river in the Samarra area. According to the geological survey of this area carried out by Buringh (1960) and Yacoub (2011), this area represents the Holocene floodplain of the Tigris in the Samaraa area. Archaeological sites, levees, relict oxbow lakes and meanders of this course are well-preserved and clearly identifiable using remote sensing data (Figs. 4.4 & 4.7). More than 200 sites are associated with this course and its canals and the majority of these sites, such as Alath, Harbi, Bahamsha, Maskan, Ukbura, Busra, Qubur Al-Mishahda, and Kissar Al-Faris, were occupied from the late first millennium BC to Islamic times (GDA, 1970, 1976; Adam, 1981; Northedge, Wilkinson and Falkner, 1990) (from 539 BC to 1500 AD) (Figs. 4.2 - 4.4). However, there are only six sites occupied from the Ubaid period to the late first millennium BC: Samar, Sakir, Asaker, Qabir Muhammed, Fasiyah and Dhibai (Figs. 4.2 - 4.4). Consequently, it can be assumed that this course existed before the Ubaid period as a result of the avulsion of the Pleistocene course of the Tigris. The archaeological sites, irrigation canals, floods, and dams related to this course have been widely mentioned in historical texts (e.g. Ibn Alfuwati, 1938; Ibn Aljozi, 1992). A barrier on this course was suggested by Willocks (1912) and Susa (1948), as during their surveys they found massive masonry rubble in the north east of the Balad Mesa (Figs. 4.4, 4.5 & 4.8). However, they did not describe barrage remains in detail. In addition, several field surveys covered this area such as Northedge, Wilkinson and Falkner (1990), and Yacoub (2011) but they did not mention any location of remains for this barrage. Although there is no mention in these Babylonian texts of digging canals to benefit the building of the Nimrod dam, the later Islamic texts such as Ibn Alfuwati (1938) and Ibn Aljozi (1992) documented that there were two main canals diverted from the Tigris in this area: the Nahrawan canal on the left bank, and the Is'haqi canal leading to the right bank (Figs. 4.4, 4.5 & 4.9). According to Willock (1912), Susa (1948), and Northedge, Wilkinson and Falkner (1990), both of these canals were highly developed during the Sasanian period. However, there has been no modern archaeological survey or excavation of these two canals to determine the exact age of their construction.

The Alath dam partially blocked the natural flow of the Tigris and diverted the water into the Is'haqi and Qawraj (Fig. 4.4), located on both sides of the Tigris (Ibn Alfuwati, 1938; Ibn Aljozi, 1992). The Nahrawan extends for more than 250 kilometres, ending in the Tigris near Kut, while the Is'haqi extends for more than 70 kilometres, ending in the Tigris just to the north of Baghdad. Although there were previous attempts to trace these two canals and their associated sites, including Susa (1948) and Adams (1981), in the present study I did my own identification and tracing using remote sensing techniques as described in the methodology chapter of the present study. The canal estimated measurements are up to 100m wide and 5m deep. This course and its canals ran during the Sasanian and Islamic periods until the thirteenth century AD as most of the archaeological sites that associated with these channels were occupied from Sasanian and Islamic periods according to Adam (1981), as will be discussed below.

4.1.3 The Dhuluiya course (from the thirteenth century AD to the present)

This is the modern course of the Tigris river in Samaraa area and is named informally here as the "Dhuluiya course", from the modern Dhuluiya city that is associated with it (Fig. 4.4). The Dhuluiya course is located to the east of the east Balad Mesa course, and runs close to the route of the Qawraj canal (Figs. 4.4, 4.9 & 4.10. The avulsion node is also located to the east of the Balad Mesa in the area where the east Balad Mesa course and the Qawraj canal meet (Figs. 4.4 & 4.8). There is no archaeological site associated with Dhuluiya course itself (GDA, 1970, 1976; Adams, 1981; Northedge, Wilkinson and Falkner, 1990). There is no mention of the course in the historical texts. Al-Hamawi (1977) and Ibn-Abdulhaq (1992) do mention a number of events such as flooding, migration of people and the drying out of a river course that led in the end to the diversion of the Tigris from the east Balad Mesa course to the modern one.

Al-Hamawi (1977) and Ibn-Abdulhaq (1992) also stated that:
"During 1228 AD, there were a number of towns such as Aukbura and Alath associated with the east side of the Tigris flourishing during this period as this river was used to irrigate their farms and gardens. In the same year, the Qawraj canal, which was dug by Khosrow I in 555 AD, was receiving large discharges from the Tigris, which led to several floods in the east of Baghdad".

Ibn Aljozi (1992) reported the effect of the abandonment of the Tigris thus: *"During 1009 AD the Caliph Al-Qadir made an order to clean up the Tigris river and remove sediment from the channel to avoid flooding by keeping the water running between the river levees rather than over the levees and farms."*

Ibn-Abdulhaq (1992) reported that: *"the Aukbura town was located on the east bank of the Tigris but, after 1338 AD it became located on the west bank of the new Tigris. The ancient Tigris was partially abandoned and farmers left their land and moved to live in the Tigris towns, so the Caliphate ordered that a canal be dug from the Tigris, which was already located to the west of the ancient Tigris, to feed the town".*

Ibn Alfuwati (1938) described the flooding of Baghdad as a result of diverting water from the Tigris to the Qawraj canal, saying that "*a number of floods happened in Baghdad because of flooding in the Qawraj canal and the silting up of the main Tig*ris".

Susa (1948), who did a primary field survey in the Samarra area, found that the elevation of the bottom of the Qawraj and the elevation of the bottom of the abandoned Tigris (i.e. the east Balad Mesa channel) were apparently the same, which is one of the conditions of an avulsion. Consequently, it can be suggested that the modern Tigris (Dhuluiya) course was the result of a complete avulsion after the Mongol invasion, i.e. after 1258 AD, when control of the channels was lost, when the management and maintenance of the channel system ceased and most barrages were destroyed (Susa, 1948; Longrigg, 1999; Butzer, 2012). It is likely that the Qawraj canal is an indication of the role of human activity as a trigger for avulsion, as farmers breached the banks and dug irrigation canals to irrigate farms on low elevations, the result was that this new channel (canal) became the main course of the Tigris in this region.

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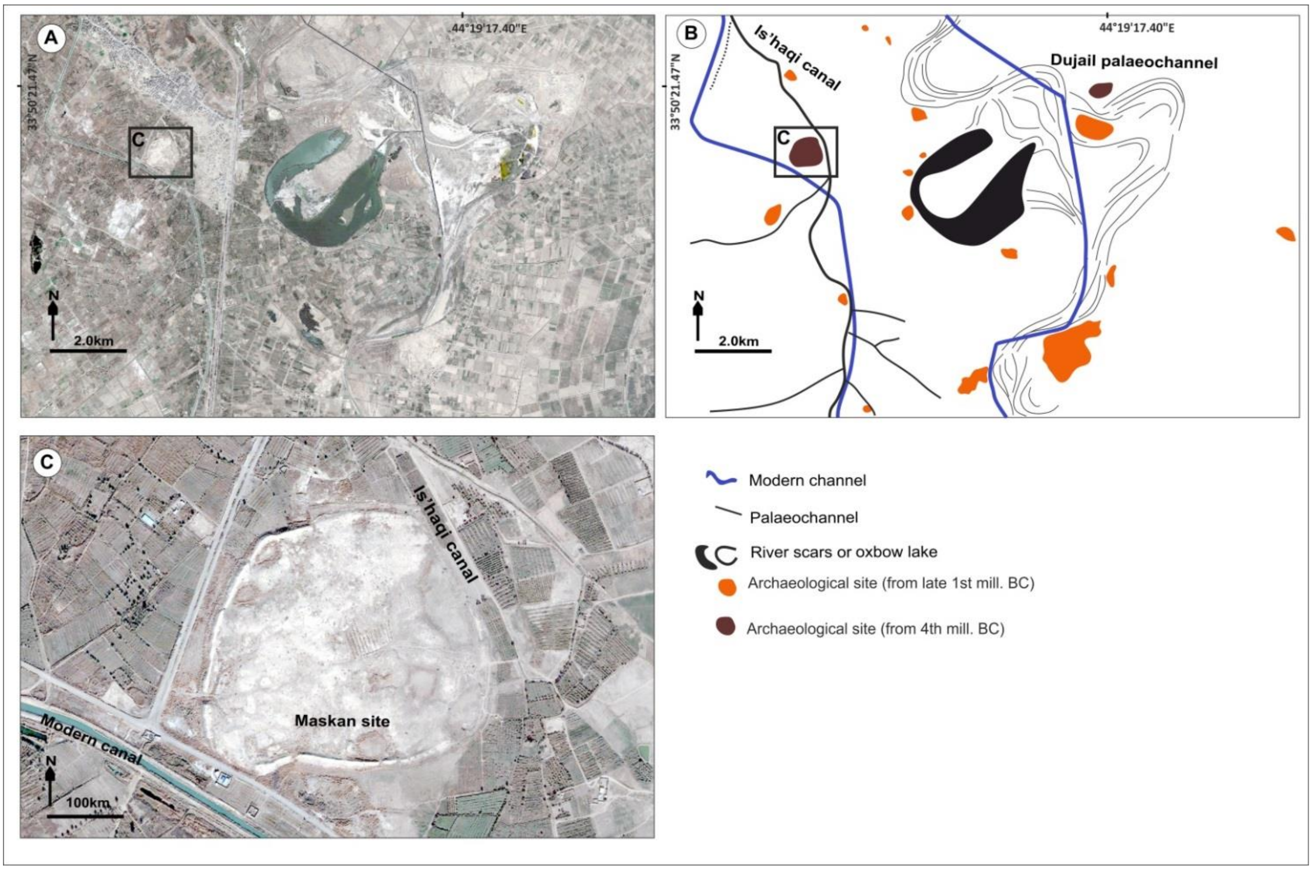


Figure 4.7: QuickBird image showing where Nahrawan and Is'haqi canal taking water from Tigris (B) Dujail palaeochannel (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) QuickBird showing Is'haqi canal and Maskan site.

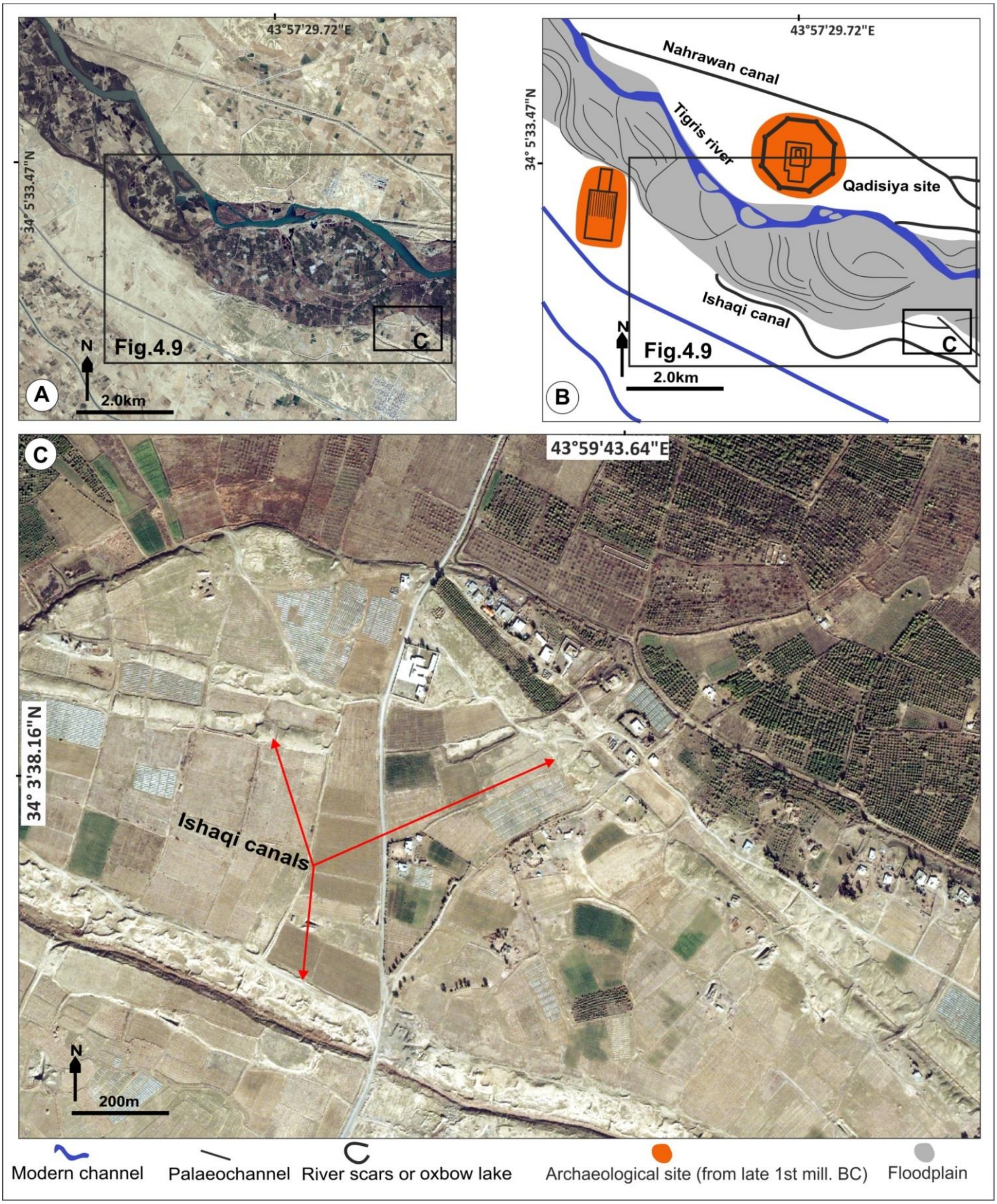


Figure 4.8: (A) QuickBird image showing Nahrawan and Is'haqi canals in the Samarra area. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) QuickBird images showing Is'haqi canal.

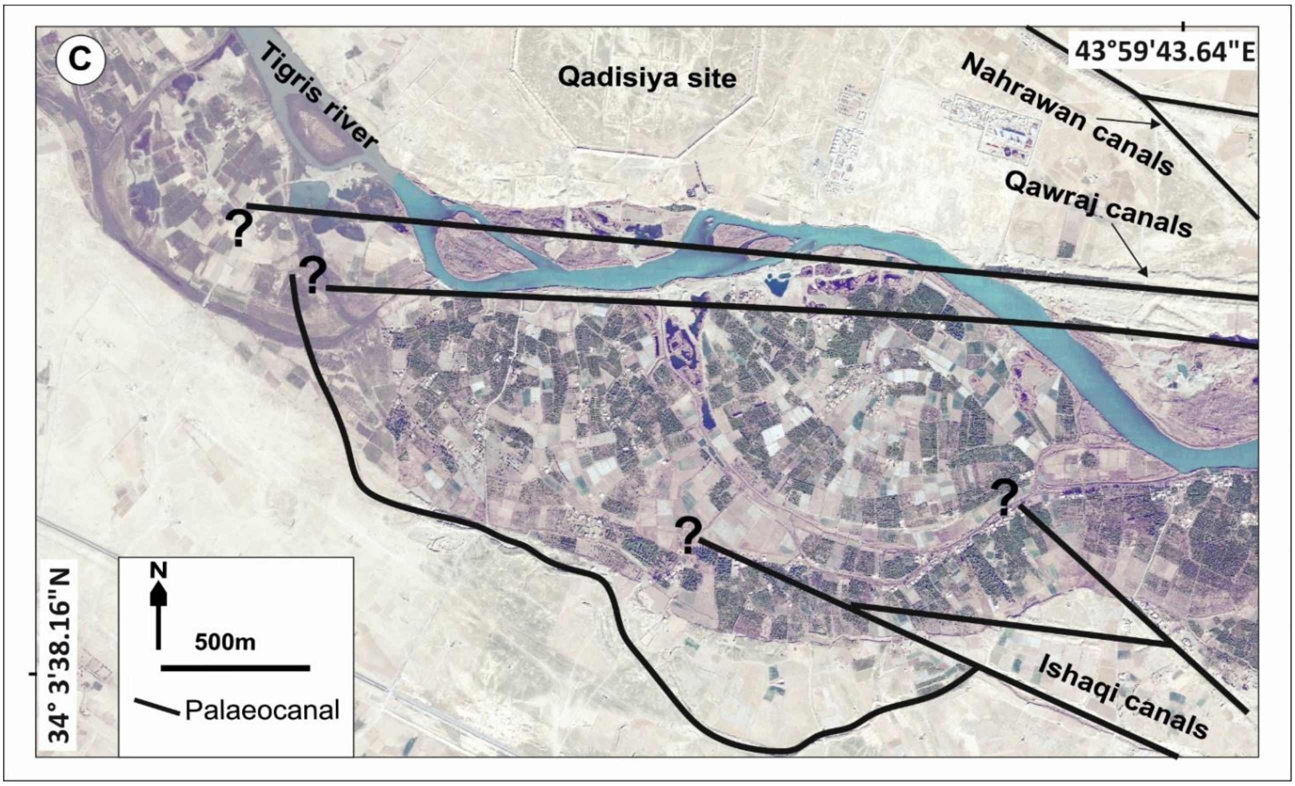


Figure 4.9: QuickBird image showing Nahrawan, Qawraj, and Is'haqi canals in the Samarra area.

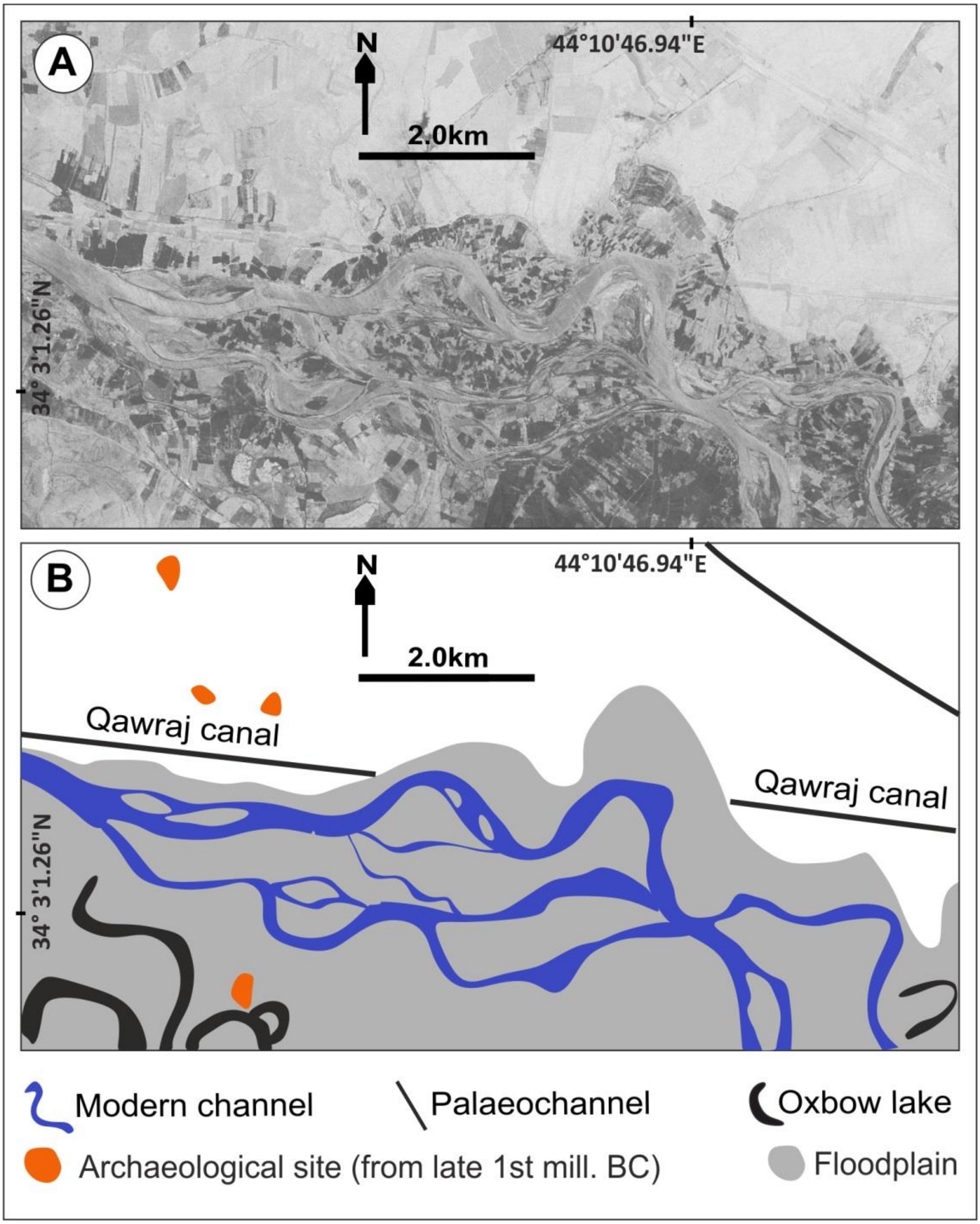


Figure 4.10: (A) CORONA image showing Qawraj canal and the modern Tigris river. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

4.2. Adhaim area

The Adhaim river goes through the Hamrin Mountains and enters the Mesopotamian floodplain in Adhaim city, building an alluvial fan called the Adhaim fan (Figs. 1.11, 4.11 and 4.12). This area was not covered by the surveys of Jacobsen (1960) or Adams (1981). However, the surveys of the GDA (1970, 1976) and Sulaiman (2014) have been used in the present study to date the archaeological sites and their associated channels. Two main courses of the Adhaim river have been identified in this fan in the present study, which are the ancient Adhaim course and the modern course. There is no previous study of the distribution of the archaeological sites or avulsion of the Adhaim river in this area.

4.2.1 The ancient Adhaim (Pre-first millennium BC)

This course can be seen clearly in the remote sensing data as continuous abandoned meanders and levees starting from the centre of the Adhaim fan and running to the southeast until it disappears under the modern Diyala River channel (Figs. 4.13 - 4.14). There is no mention of this course in reviewed historical texts, and there is no archaeological site associated with it. However, this course can be dated as pre-first millennium BC because the Batt canal that is dated as the first millennium BC, as will be discussed later, was constructed over the course (Figs. 4.15 and 4.16).

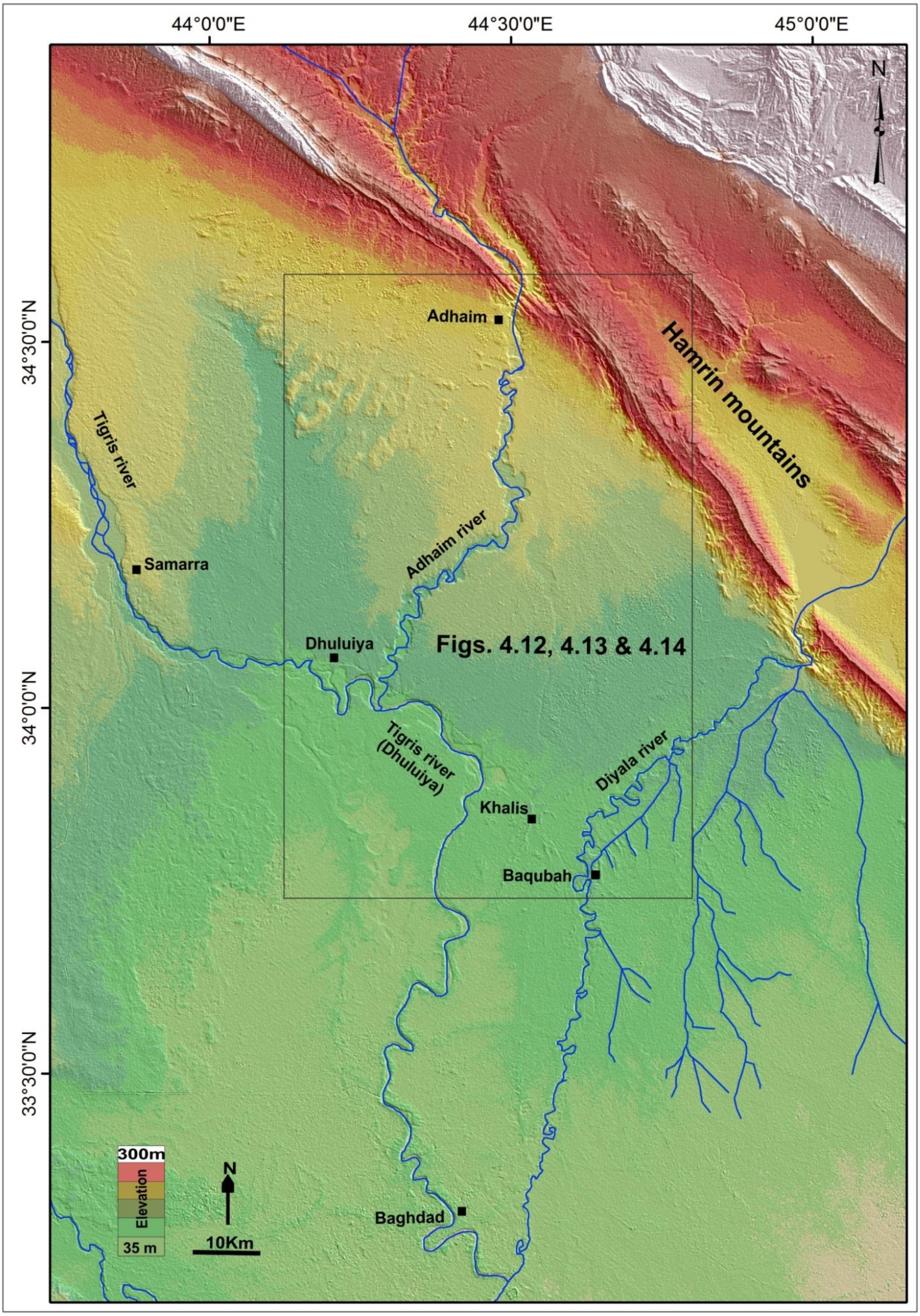


Figure 4.11: SRTM map showing the location of Adhaim alluvial fan.

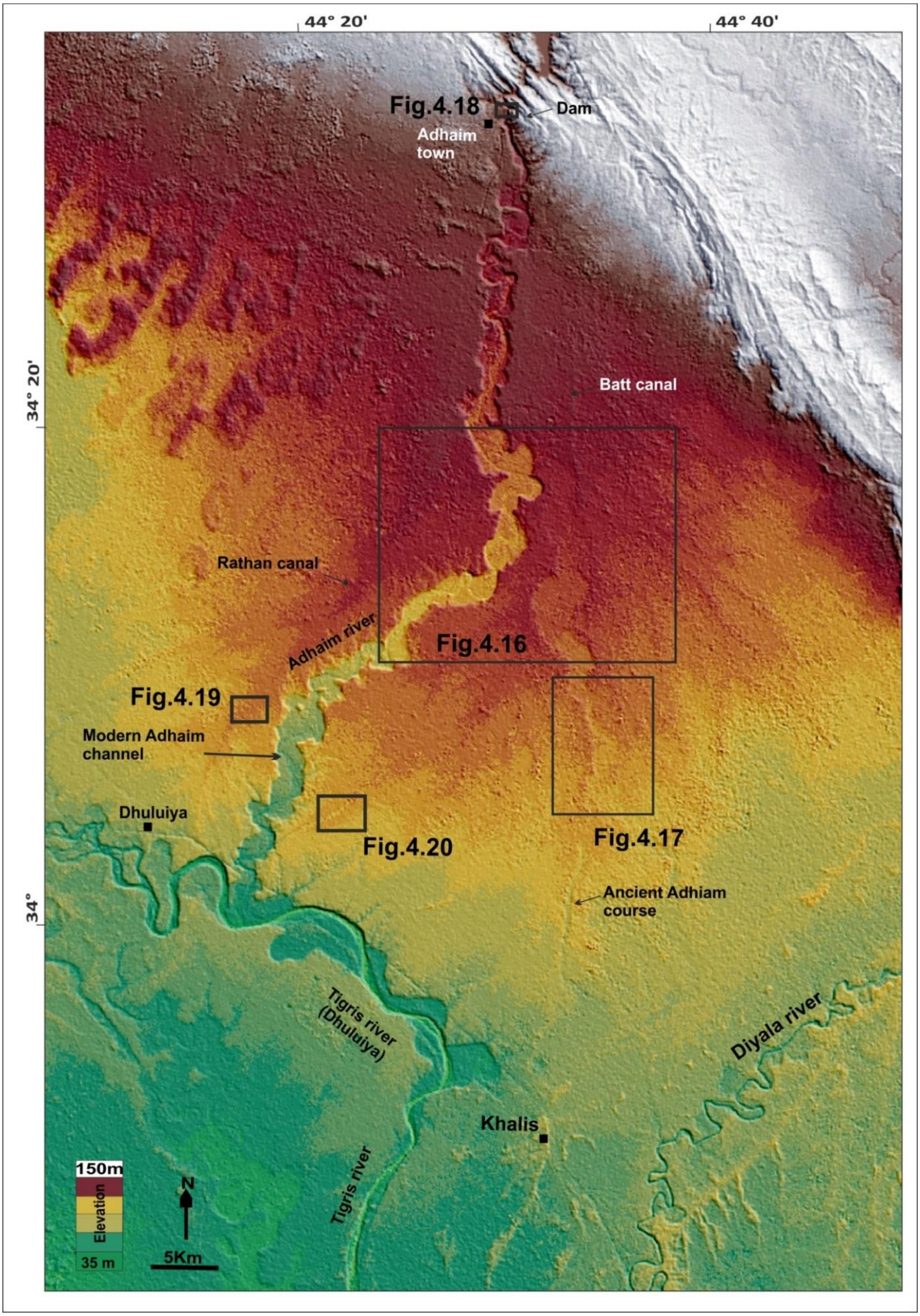


Figure 4.12: SRTM map showing the location of the ancient and the modern courses of the Adhaim river in the Adhaim area.

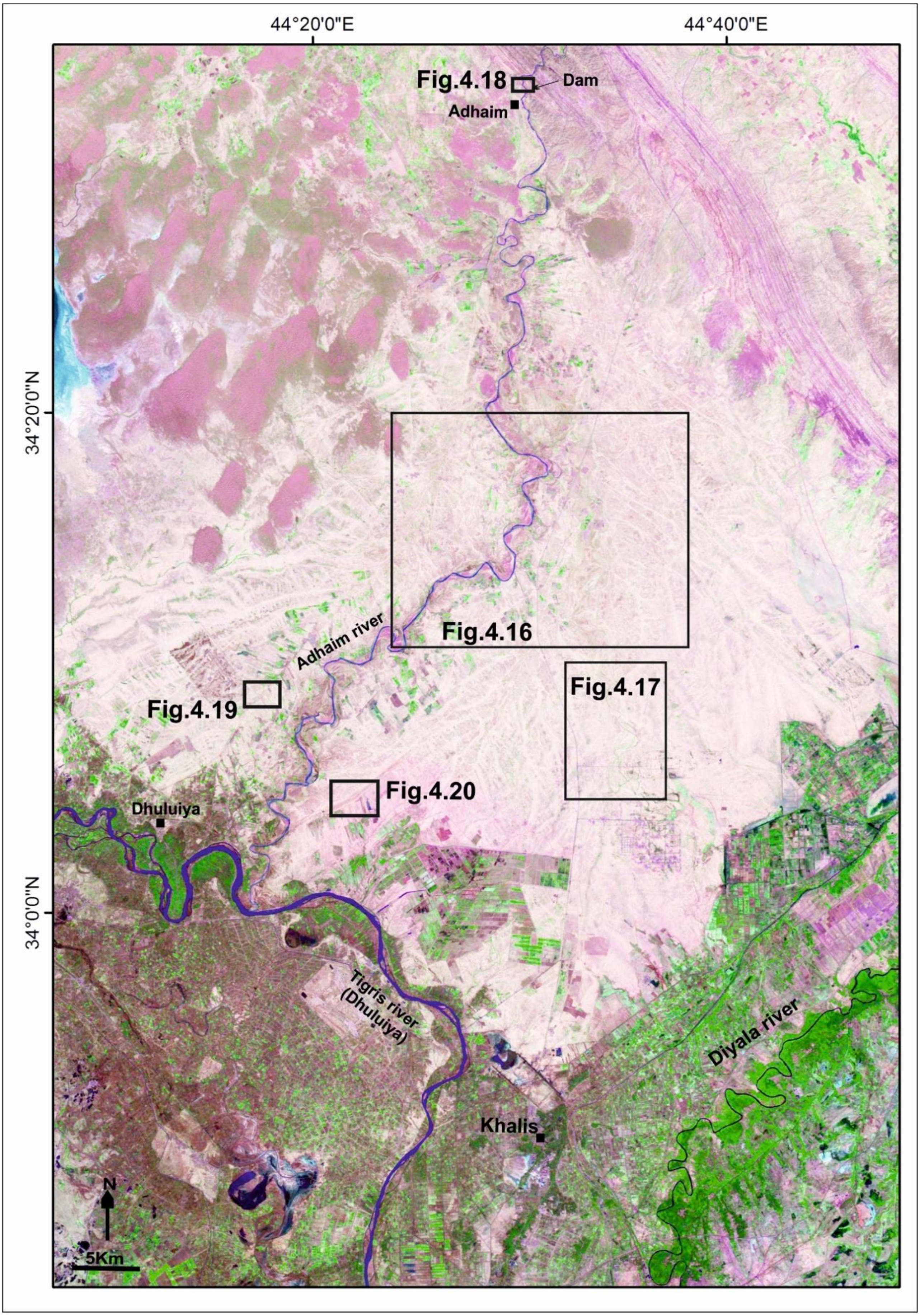


Figure 4.13: Landsat image (2000) showing the Adhaim area.

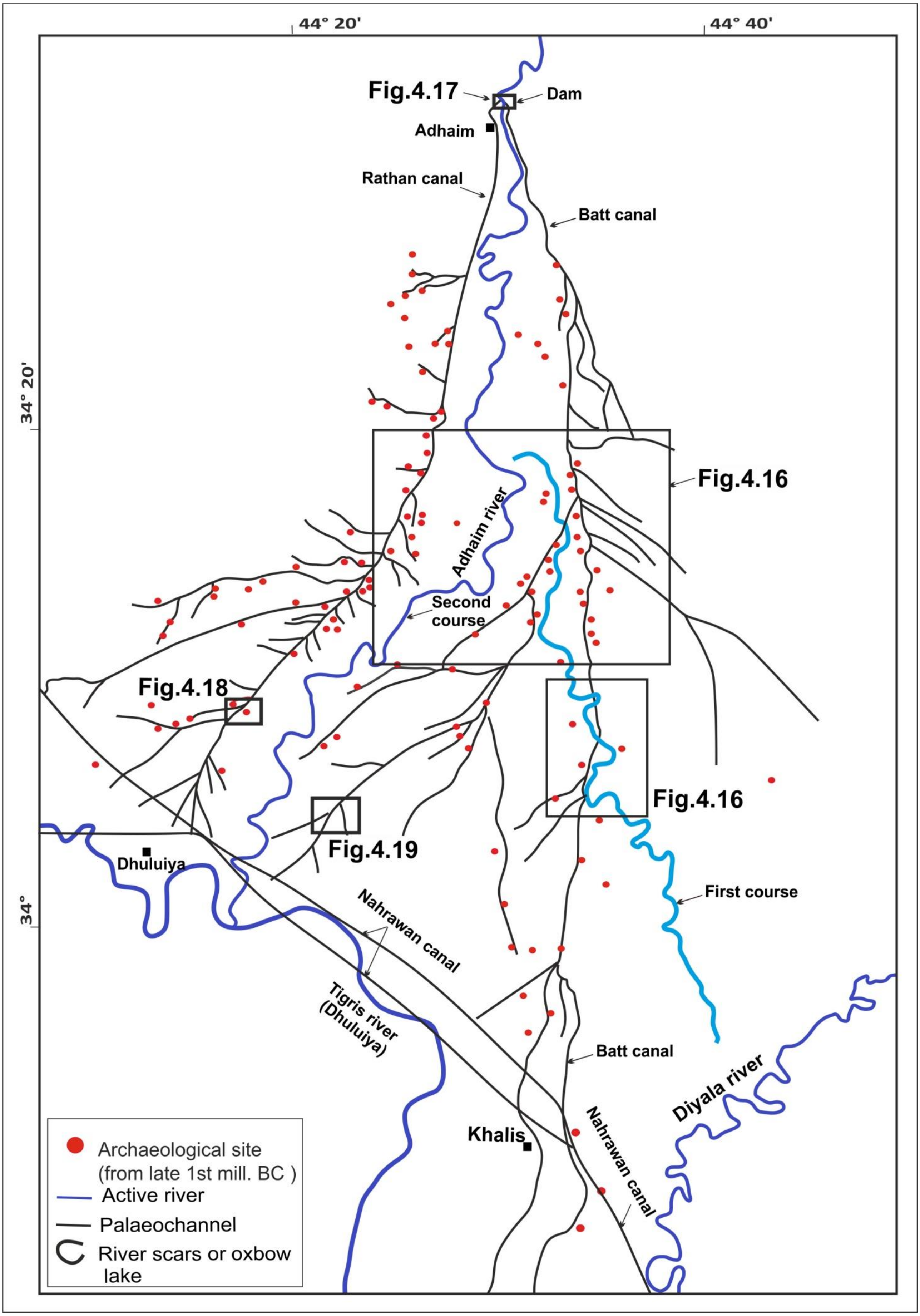


Figure 4.14: All the identified palaeochannels and archaeological sites in Adhaim area.

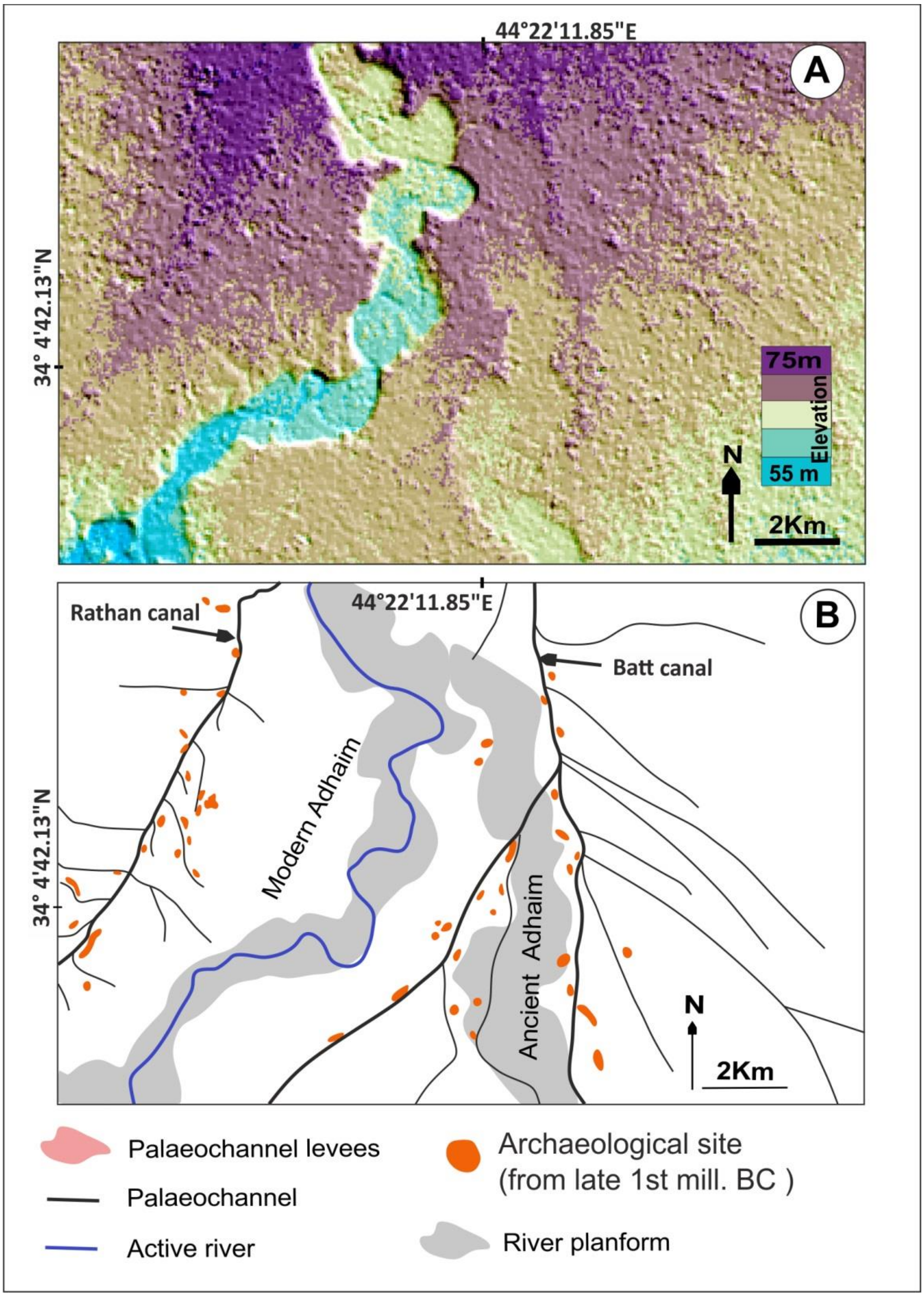


Figure 4.15: The reconstructed palaeochannels and archaeological sites in the avulsion node area in Adhaim area.

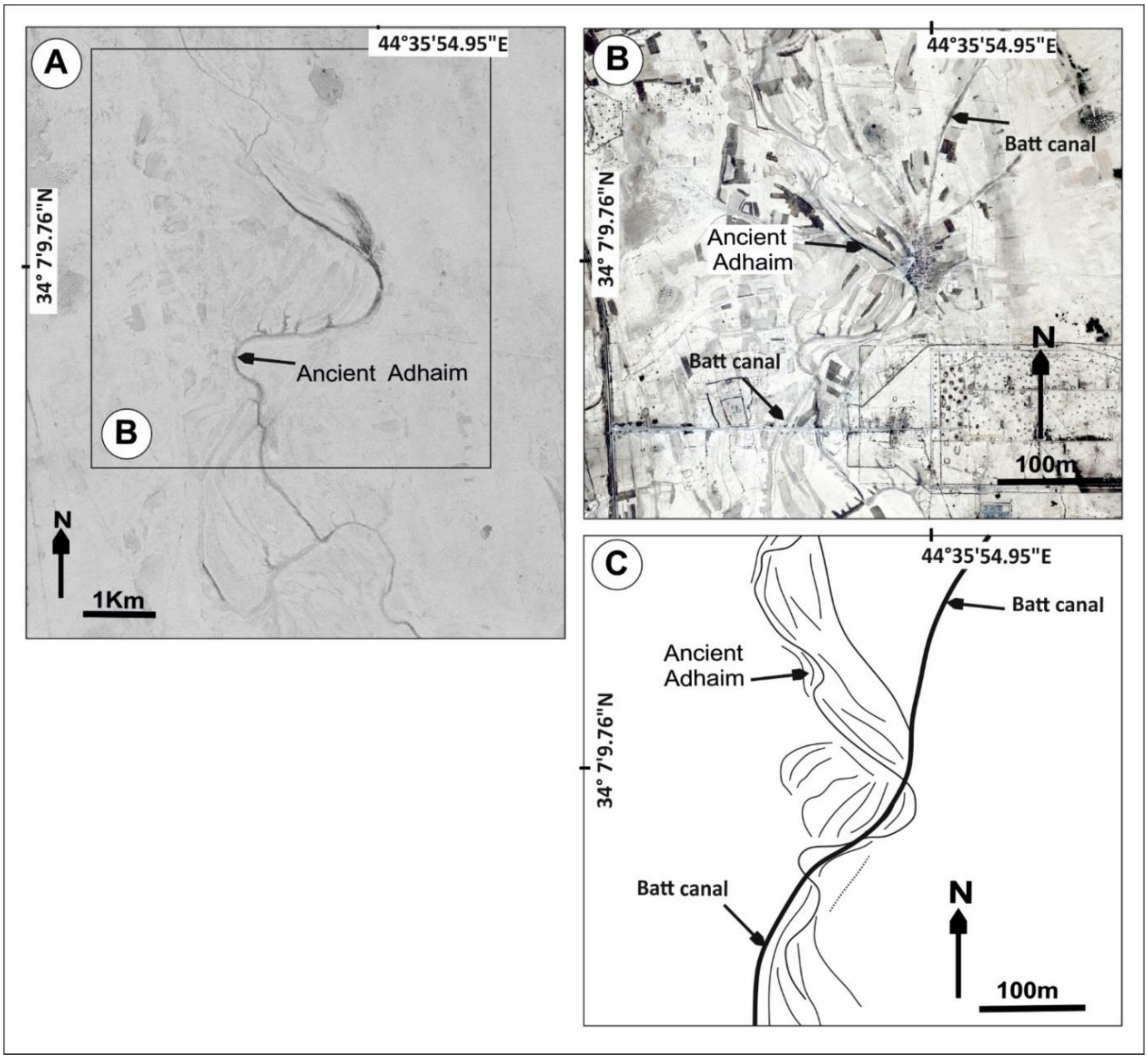


Figure 4.16: (A) CORONA image showing the ancient Adhaim channel. (B) QuickBird images showing the ancient Adhaim and the Batt canal. (C) Tracing of surface features including palaeochannel levees and scars.

4.2.2 The modern Adhaim course (from the late first millennium BC to the present)

This course started from Adhaim city in the same location as the first course but this course avulsed to the southwest from a node located in the middle of the fan (Figs. 4.15-4.17). This course was mentioned in historical texts, for example Al-Hamawi (1977) described the irrigation in this region thus: "*during the Sasanian period, there was a masonry dam on the river in this area for diversion into two canals: the Rathan canal from the right and the Batt canal from the left to irrigate farms on both sides of the Adhaim*". Moreover, Sulaiman (2014) excavated the Adhaim dam and argued that it was established during the Sasanian period. Both the Rathan and the Batt canals extended from the Adhaim dam (Fig. 4.17) for about 60 km until they joined the Nahrawan canal at a regulator made of masonry (Susa, 1948). In the present study, more than 100 associated sites have been traced for each canal and all these sites date from Parthian to Islamic times (GDA, 1970, 1976)(Figs. 4.14, 4.18 & 4.19).

There are several canals dug on both sides of the first course. Presumably the second course channel was among these canals.

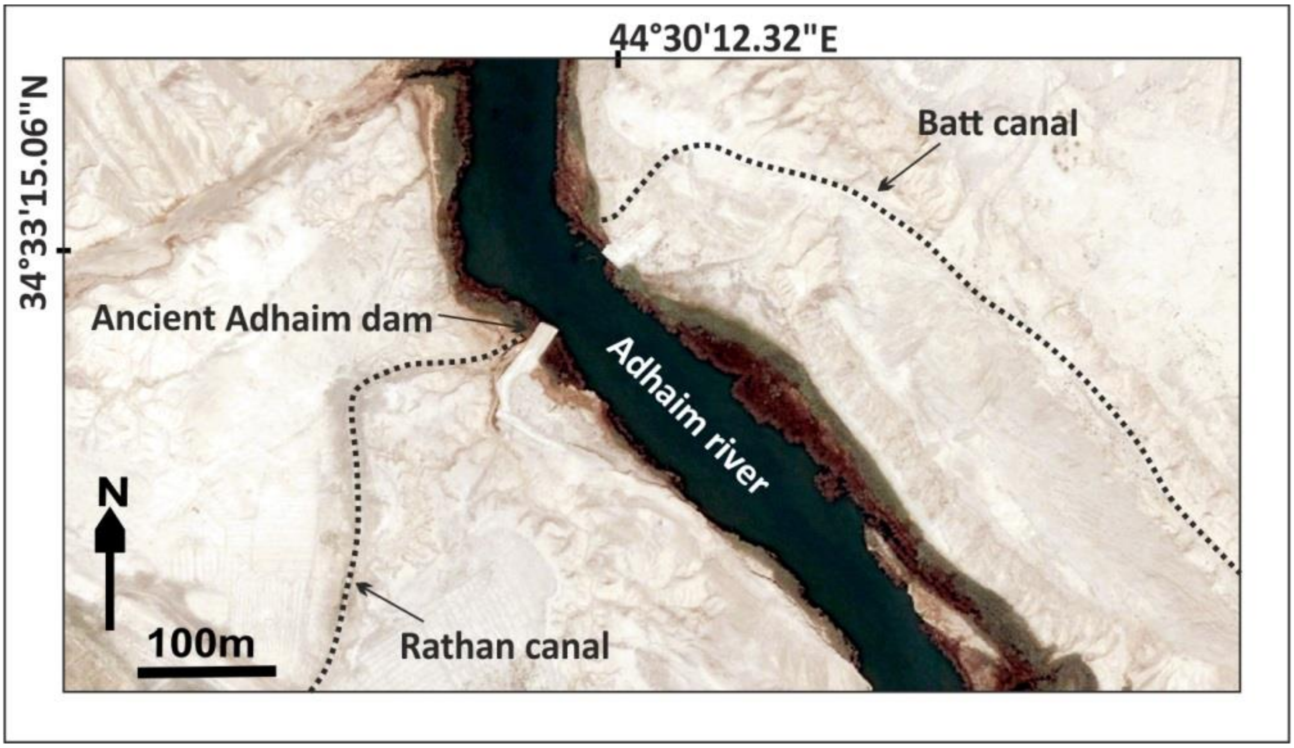


Figure 4.17: QuickBird image showing location of the ancient Adhaim dam.

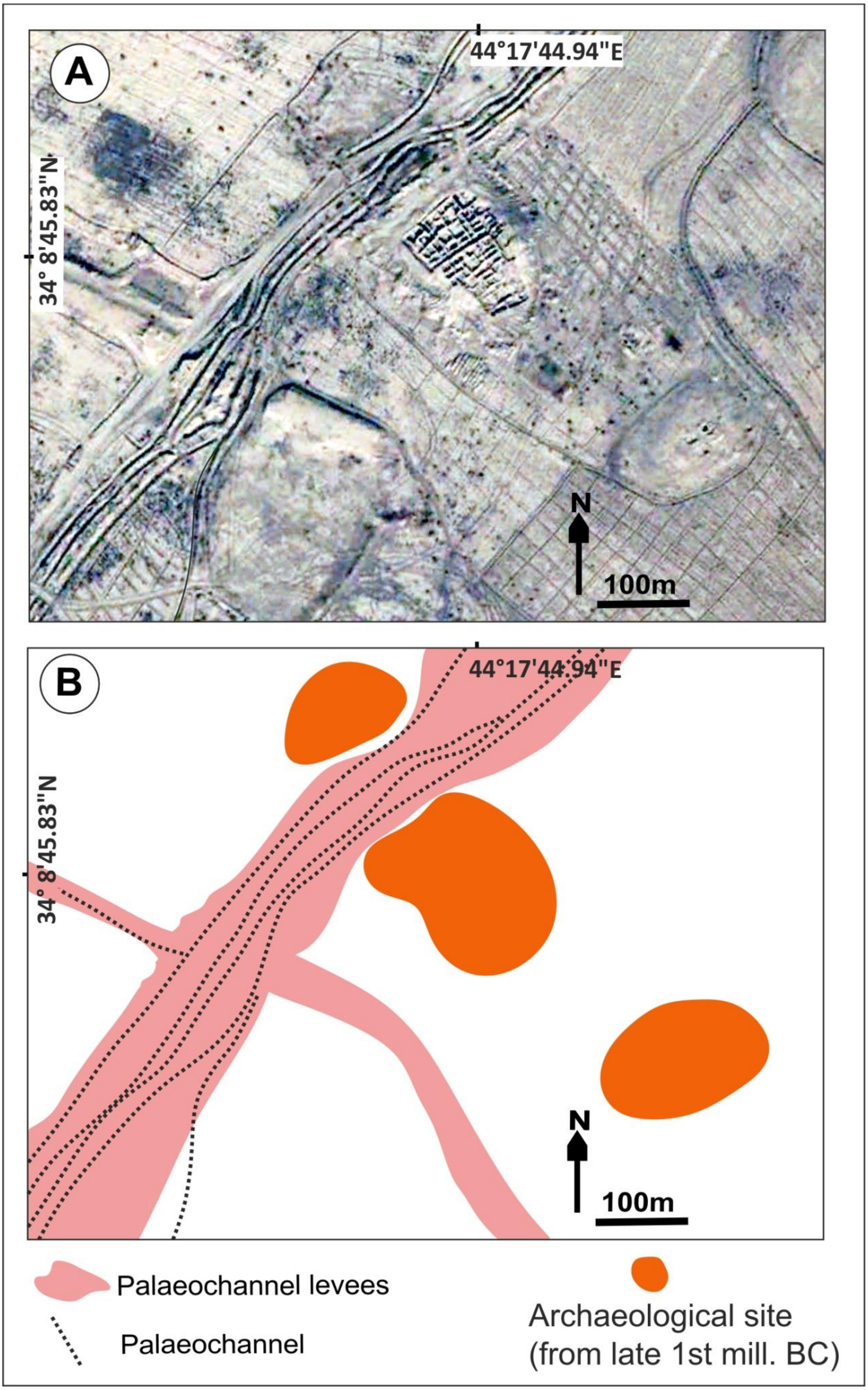


Figure 4.18: QuickBird image showing Rathan Palaeocannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

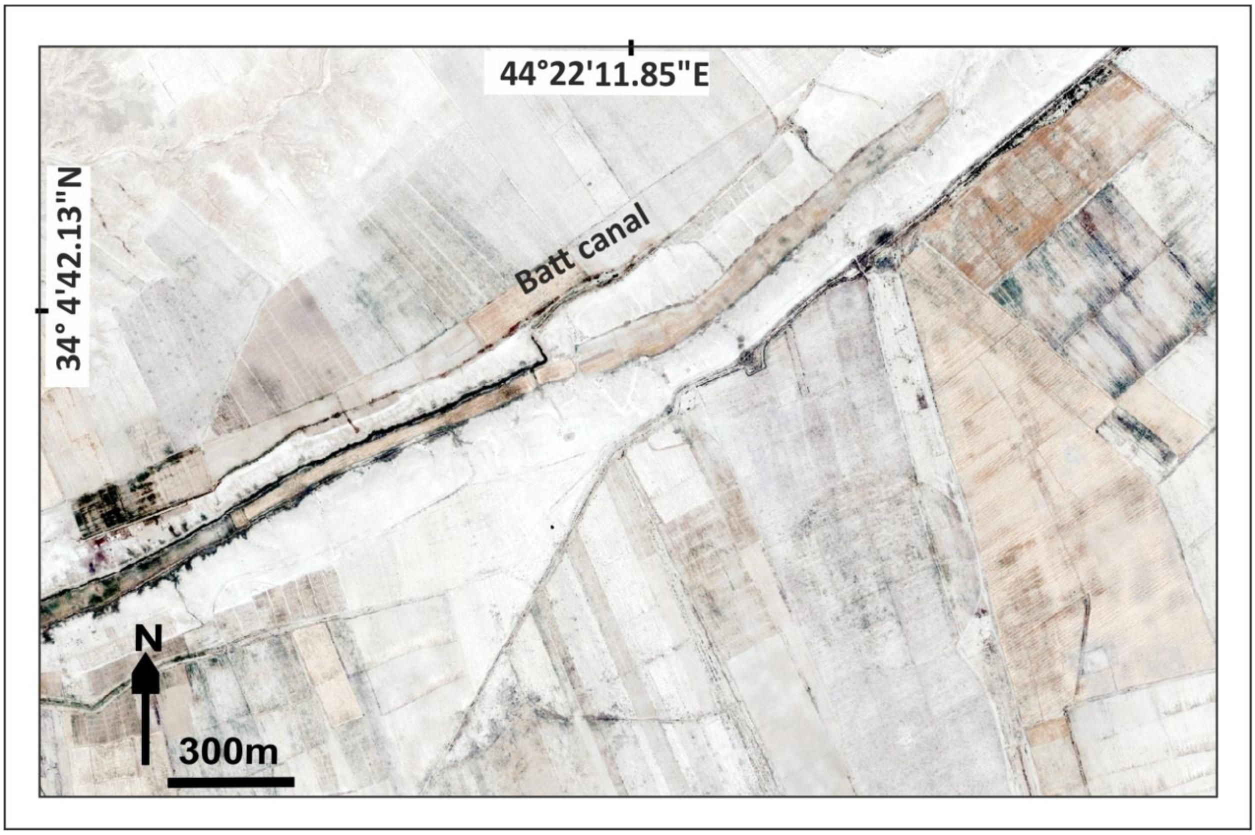


Figure 4.19: QuickBird image showing Batt palaeocanal.

4.3. The Diyala river area

The Diyala River goes through the Hamrin ridge (an active anticline) and enters the floodplain in the Mansuriyah area to form a fluvial fan, called the Diyala fan, which extends northeast of Baghdad (Figs. 4.20 – 4.23). The archaeological sites of this region were surveyed in detail by Adams (1965) and Jacobson (1982). Unfortunately, they were not linked to the ancient course of the Diyala River in the reconstruction of the watercourse. It is worth mentioning here that although Adams' dating of pottery is widely accepted and was adopted by several studies to date sites, a number of more recent studies have refined his ceramic dating. For example his work in the Diyala region (i.e. Adams, 1965) has been slightly revised by Wells (2015) who concludes that the dating of the stratigraphic levels at Tell Abu Sarifa could be changed by 100-150 years. In other words, whilst Adams' original dating indicated that the aggregate settlement area peaked at about 600 AD and declined slightly thereafter, Wells found that the new applied dating indicated that the peak in the settled area occurred between 700 and 750 AD. This puts peak settlement in the early Islamic period, rather than Sasanian and this has important implications for economic and political history.

The present study has identified two main courses of the Diyala river, which can be dated using the age of the associated archaeological sites. These are, firstly, a course from the early fourth millennium BC to the late first millennium BC, and secondly, a course from the late first millennium BC to the present (Fig. 4.23).

4.3.1 The ancient Diyala course (from the Mid-Holocene to late first millennium BC)

This course started in an area of about 20 km downstream of the Modern Diyala dam (Fig. 3.23), running towards the southwest until it reached the northeast of Baghdad (Figs. 4.23, 4.25 and 4.28). There is no mention to this course in the reviewed historical texts. In terms of archaeological sites, those sites dating to the fourth millennium BC are associated with the southern part of the channel while they are less well-aligned with the middle and the north parts. On the other hand, those sites that date to the late first millennium BC are not associated with the channel at all, but with canals that were running alongside it or even across it. Therefore, it might be argued that this course is older than the first millennium BC.

4.3.2 The modern Diyala course (from the late first millennium BC to the present)

The modern course also flows from the Mansuriyah area, where the avulsion node is located, running within the fan until it meets the Tigris to the south of Baghdad (Fig. 4.23). This course and its dams and canals were widely mentioned in historical texts, for example, according to Smith (1920), Herodotus mentioned that during the late first millennium BC period an earth dam was built on this river. Where the river goes through the mountains and enters the floodplain, diversion works were created for irrigation and more than thirty canals were dug to irrigate the farmland .The Islamic historical texts such as Ibn-Abdulhaq (1992) also support this idea, stating that "*there was a dam on the Diyala river during the Sasanian period, continuing in the Islamic period, to irrigate the area that is located in the north east and east of Baghdad*". Consequently, several canals were dug on both sides of the first course and presumably the second course channel was among these canals. Unfortunately, there is no surveying evidence for this dam.

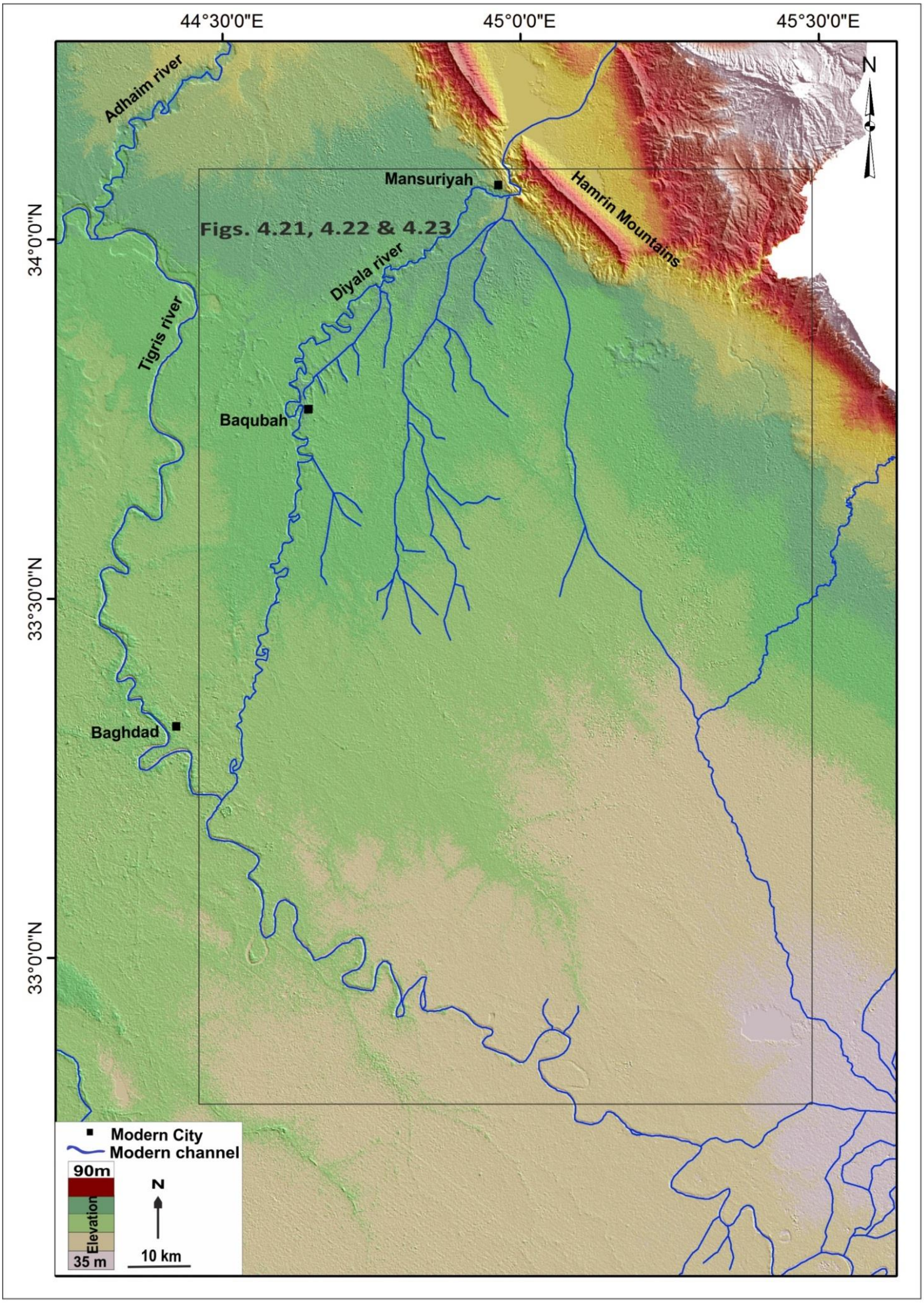


Figure 4.20: SRTM map showing the location of Diyala alluvia fan.

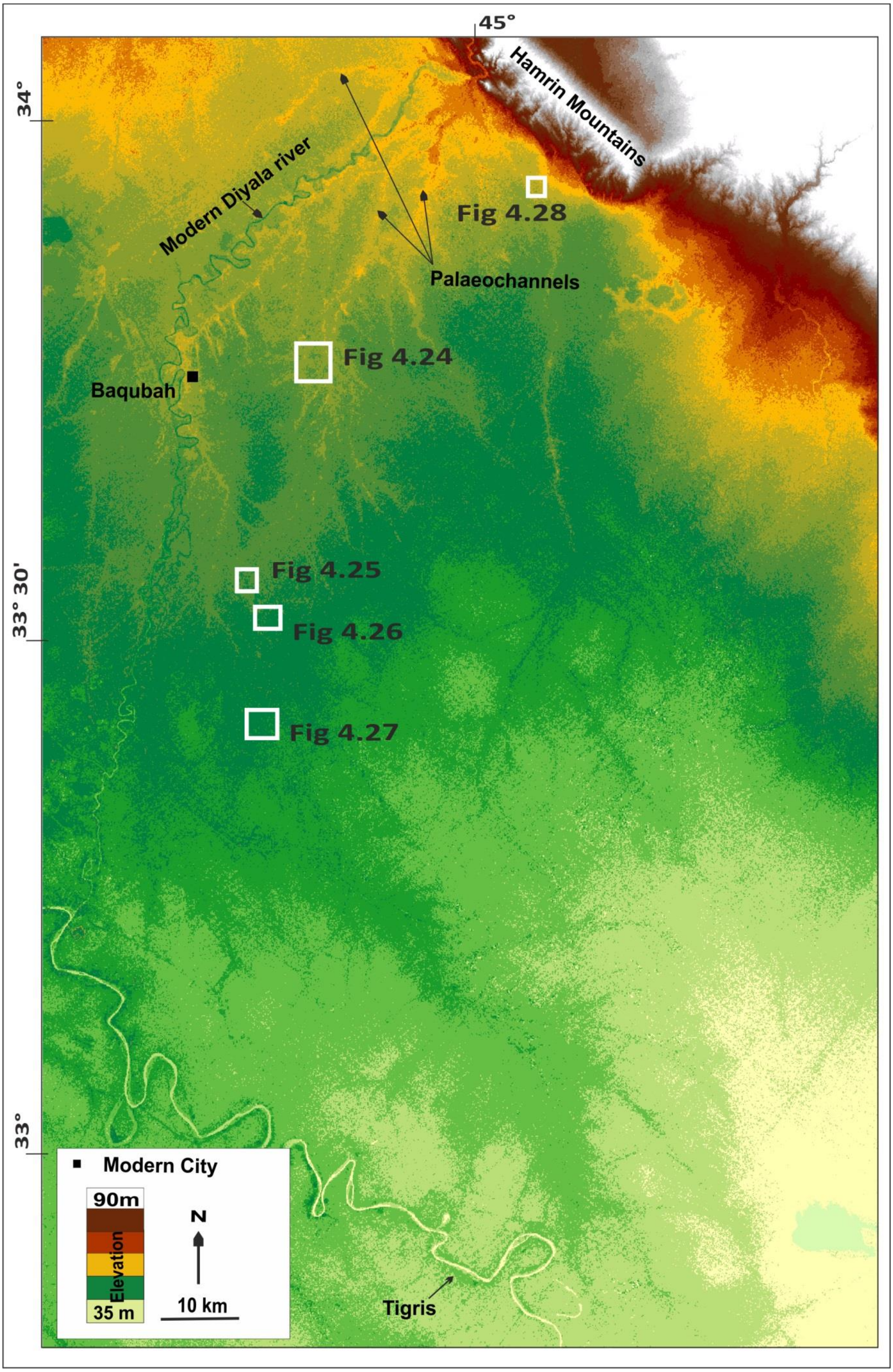


Figure 4.21: SRTM map showing more details of Diyala alluvial fan.

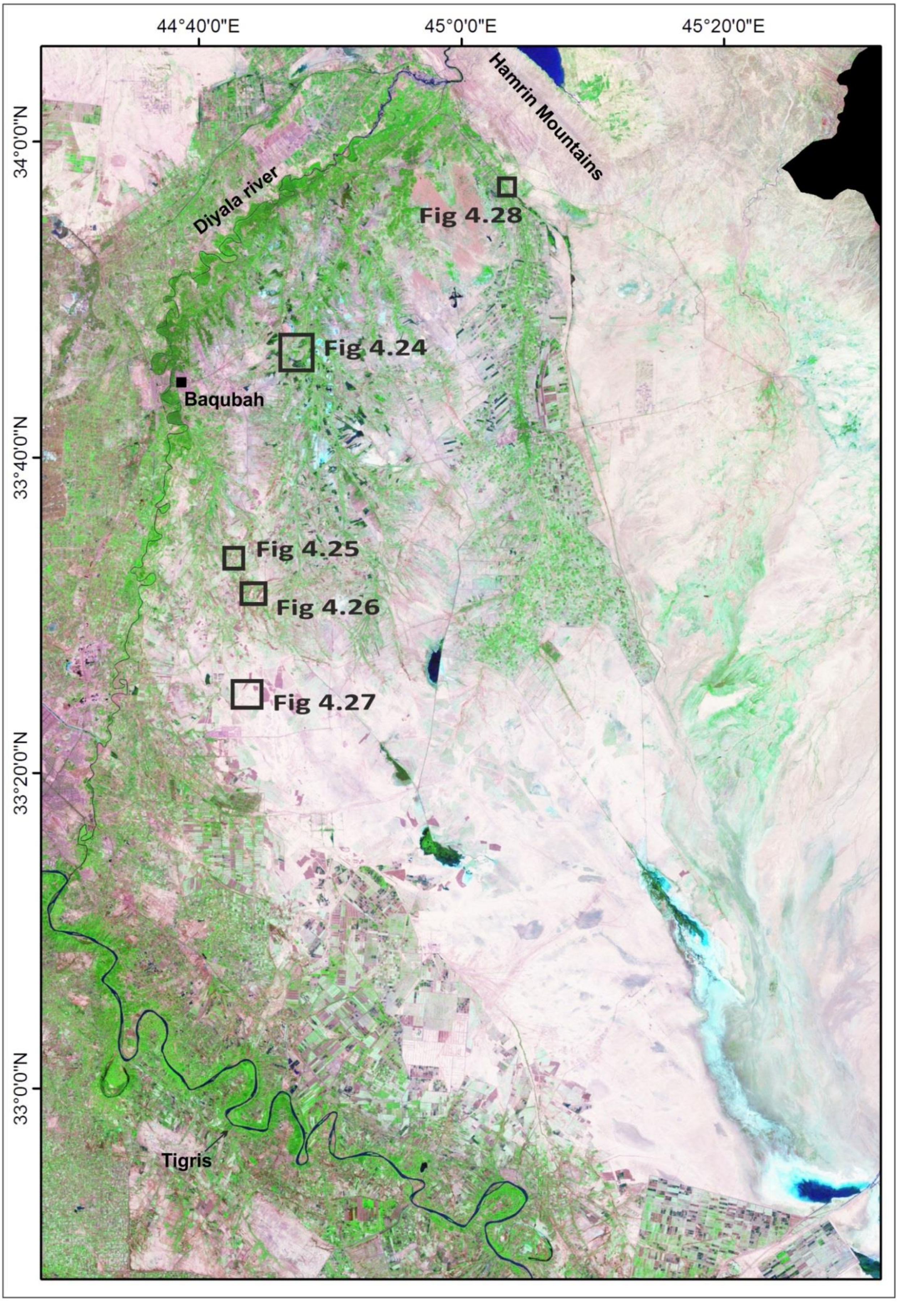


Figure 4.22: Landsat image (2000) showing more details of Diyala alluvial fan.

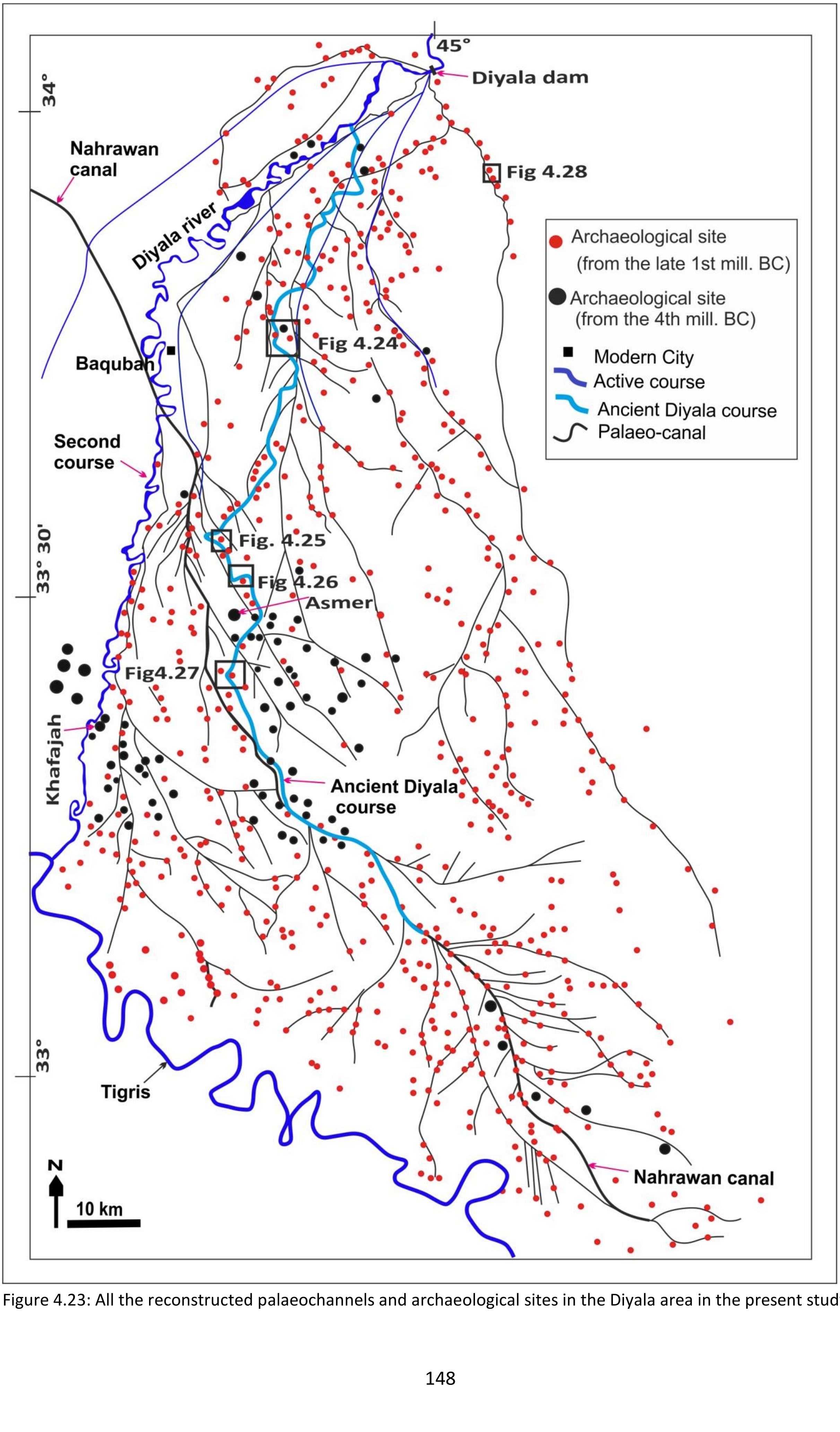


Figure 4.23: All the reconstructed palaeochannels and archaeological sites in the Diyala area in the present study.

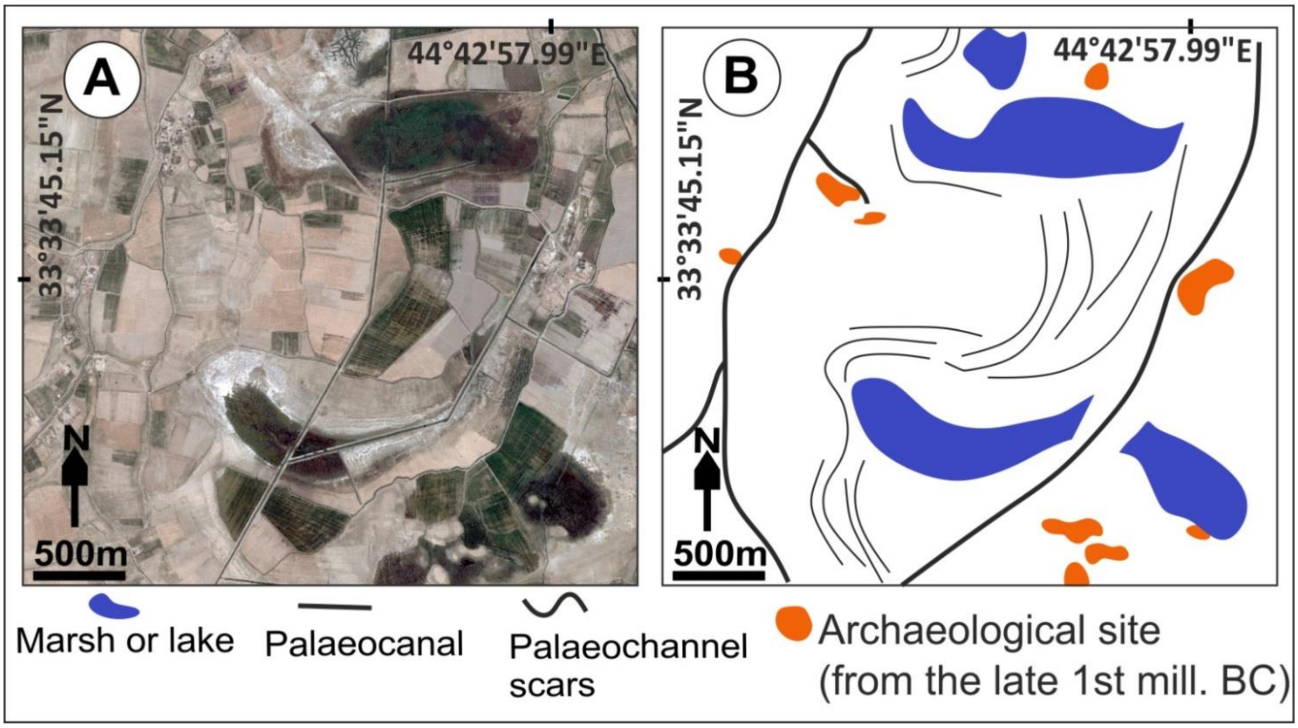


Figure 4.24: QuickBird image showing scars of the ancient course of Diyala river. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

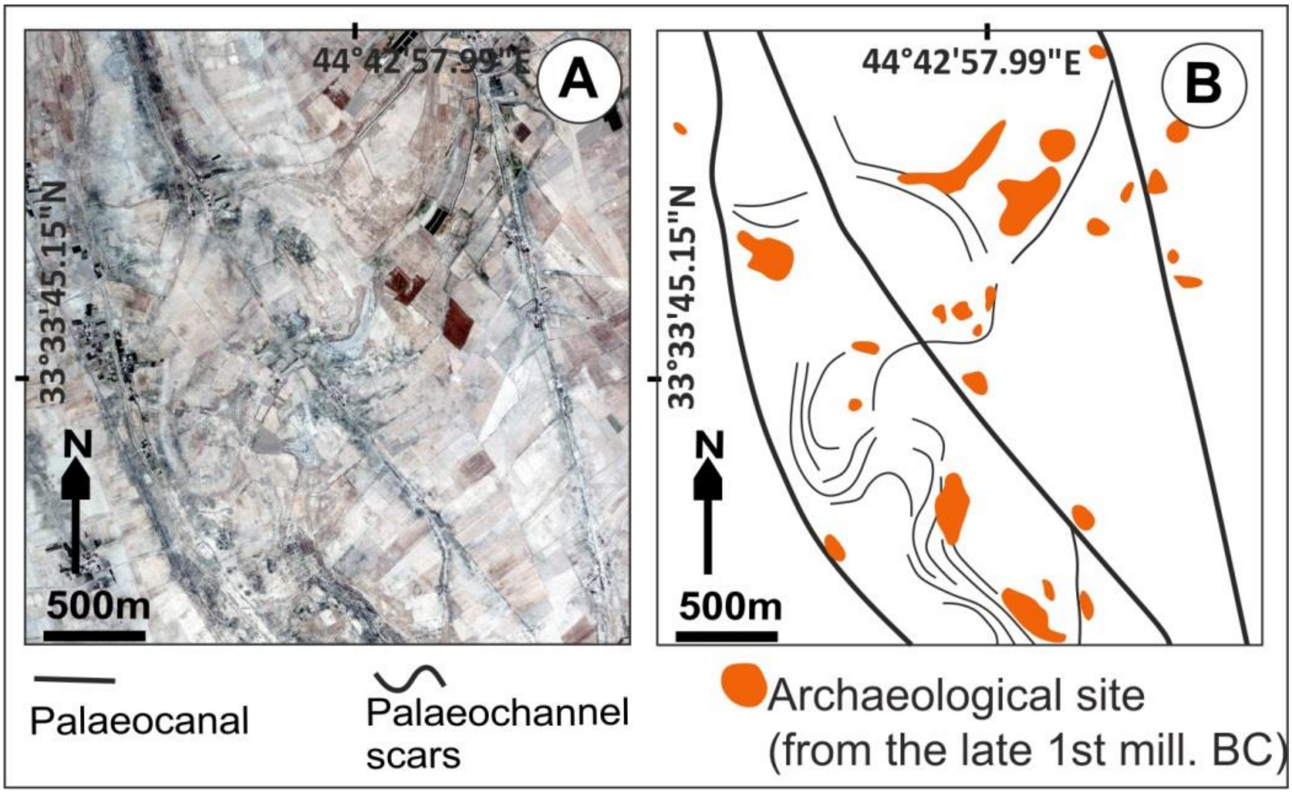


Figure 4.25: QuickBird image showing scars of the ancient course of Diyala river. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

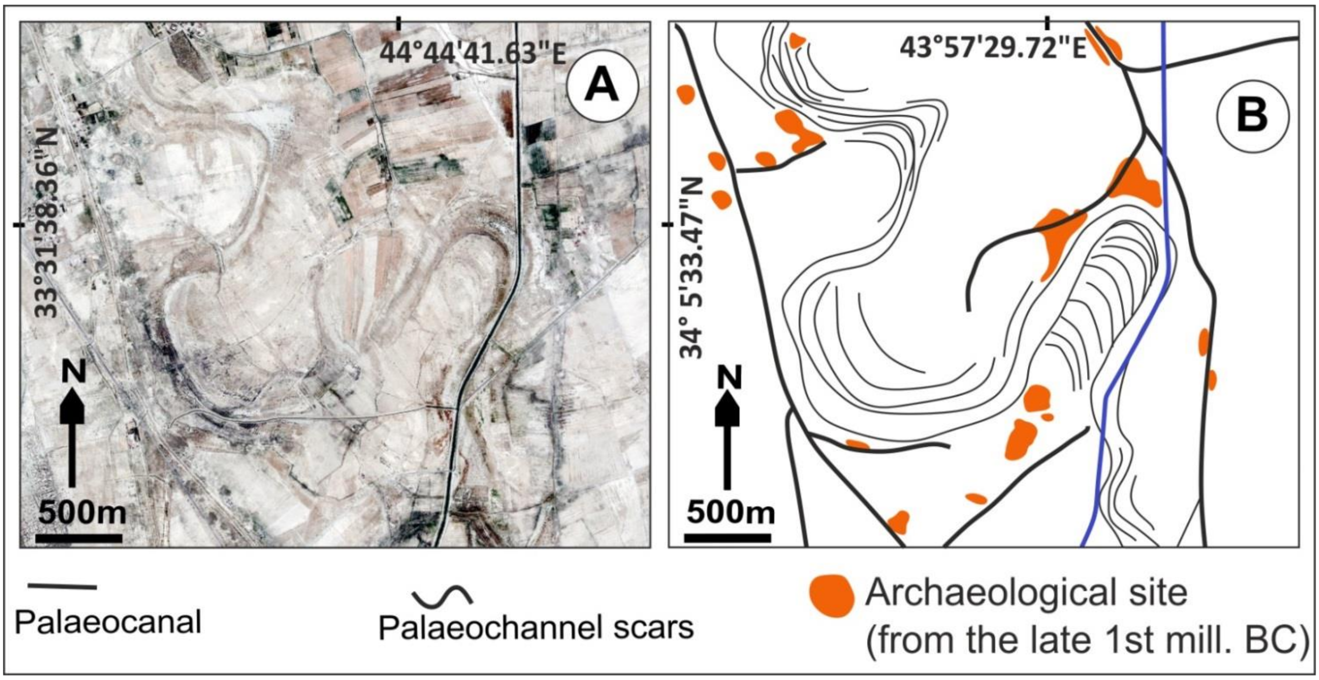


Figure 4.26: QuickBird image showing scars of the ancient course of Diyala river. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

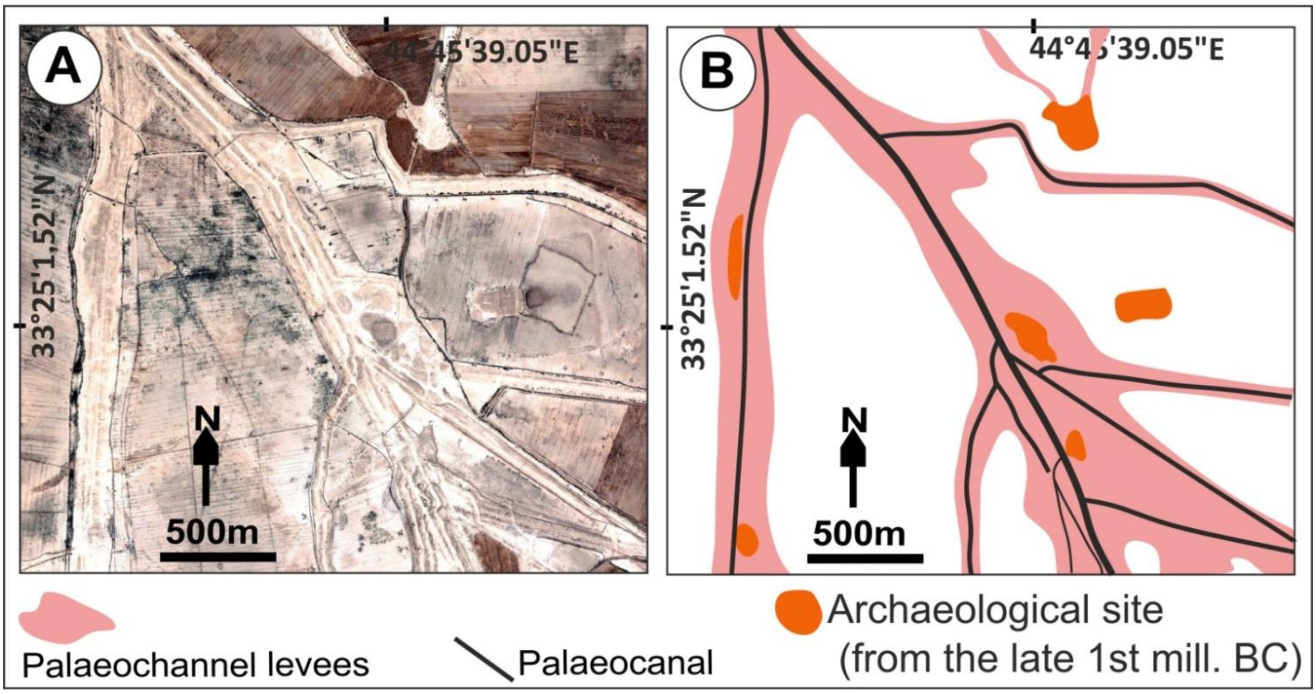


Fig. 4.27: QuickBird image showing scars of palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

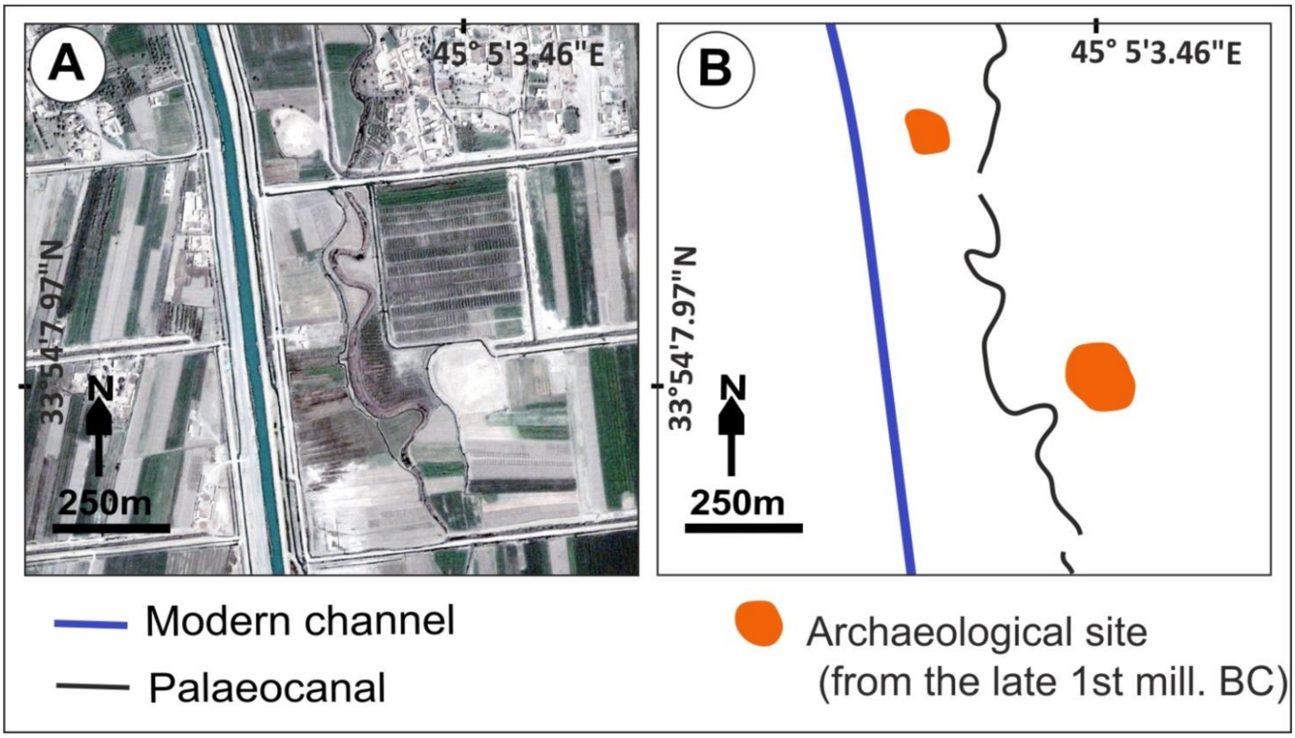


Figure 4.28: QuickBird image showing scars of palaeochannel (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

4.4 The Tigris river in the Baghdad area

In the present study, two courses have been identified in the area southeast of Baghdad (Figs. 4.30 - 4.32): first, a course dating from the Mid-Holocene to the early second millennium BC, This channel will be named informally here as "the Dalmaj course" (as it passes the modern Dalmaj Lake) and second, a course dates from the early second millennium BC period to the present. This channel will be named informally here as "the Baghdad course" (as it passes the modern Baghdad city).

4.4.1 The Dalmaj course (from the Mid-Holocene to the early second millennium BC)

This course is the same as that of the east Balad course in the Samarra area (Fig. 4.4). When it reaches Baghdad it is covered by the built-up area of the present-day city, but it can be identified once more to the south (Figs. 4.33 - 4.36). The course goes to the west of the modern Tigris, passing several important sites, by running to the east of Jamdet Nasr, to the west of Mashkan Shapir, and to the east of Nippur, and to the east of Adab, and then it disappears under the sediments of the modern Gharraf channel (Figs. 4.30 - 4.32). This course met the Euphrates Purattum course southeast of Baghdad as mentioned before. It has been suggested that this course was the ancient Tigris by a number of Mesopotamian archaeologists such as Adams (1957) and Stone (2012) but they did not fully trace the line of this channel on a map. However, Adams (1981) estimated the date of this course as being Mid-Holocene and concluded that, according to various cuneiform texts, there are several sites associated with this course. Moreover, Rost (2015) and Al-Dafar (2015) argued that according to cuneiform textual evidence, the main channel that was used for irrigation and riverboat trading in the Umma region during the third millennium BC was the Tigris river.

Furthermore, archaeologists such as Armstrong (1989), Wilkinson (1990), Adams (1981), Steinkeller (2001), Stone (2003) and Hritz and Wilkinson (2006), have estimated that the ancient Tigris course ran across the centre of the floodplain (from Baghdad to Dalmaj Lake) until the Old Babylonian period, when it avulsed to the northeast, i.e. close to the present-day location of the Tigris. Their suggestion is based upon cuneiform texts that mentioned desertification and silt accumulation in this period, and also because many human settlements were abandoned in this specific period.

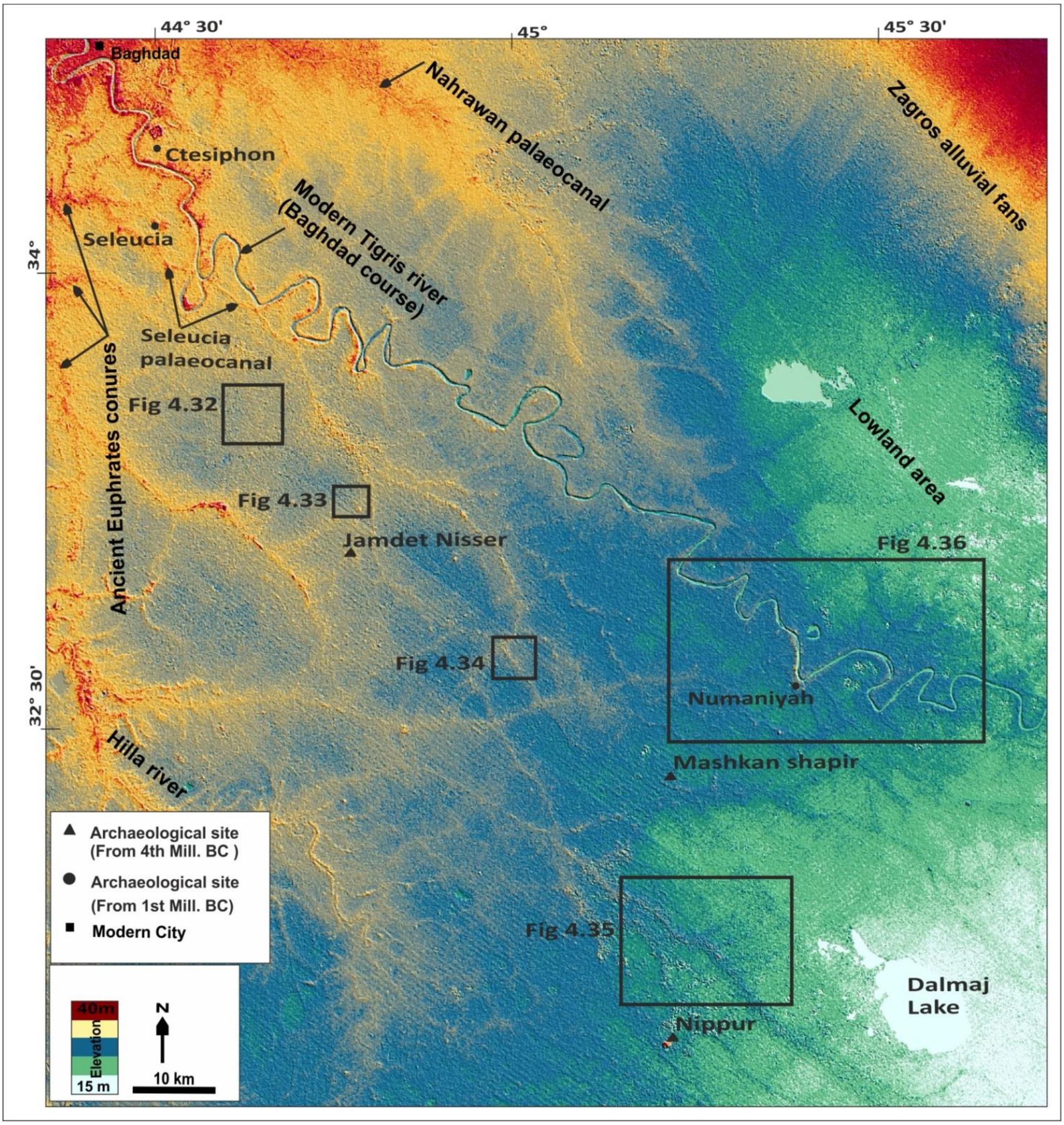


Figure 4.29: SRTM map showing the location of Baghdad area in the present study.

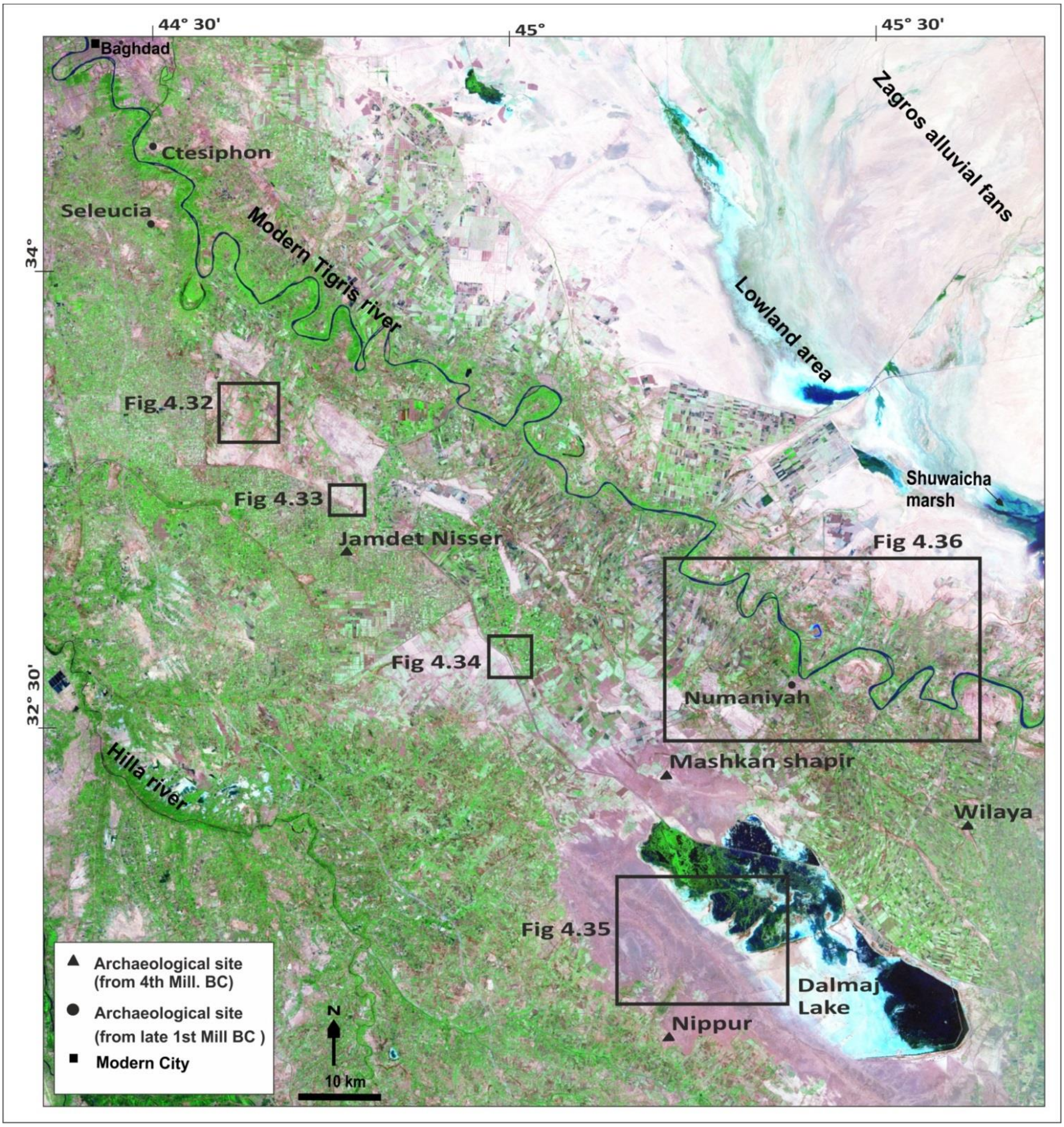


Figure 4.30: Landsat (2000) showing the location of Baghdad area in the present study.

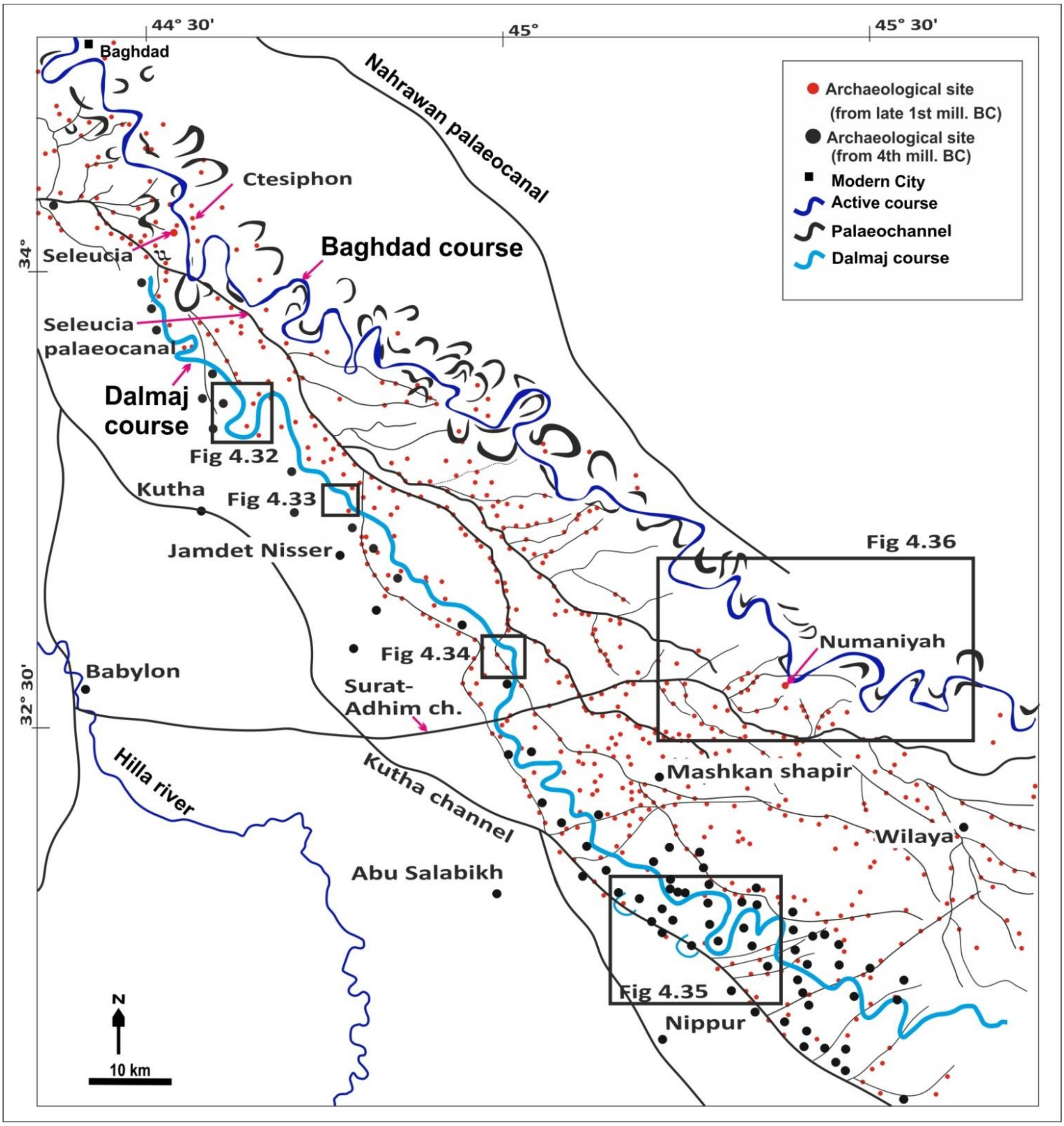


Figure 4.31: All the identified reconstructed palaeochannels and archaeological sites of Baghdad area in the present study. (the periods of sites are after Adams (1981).

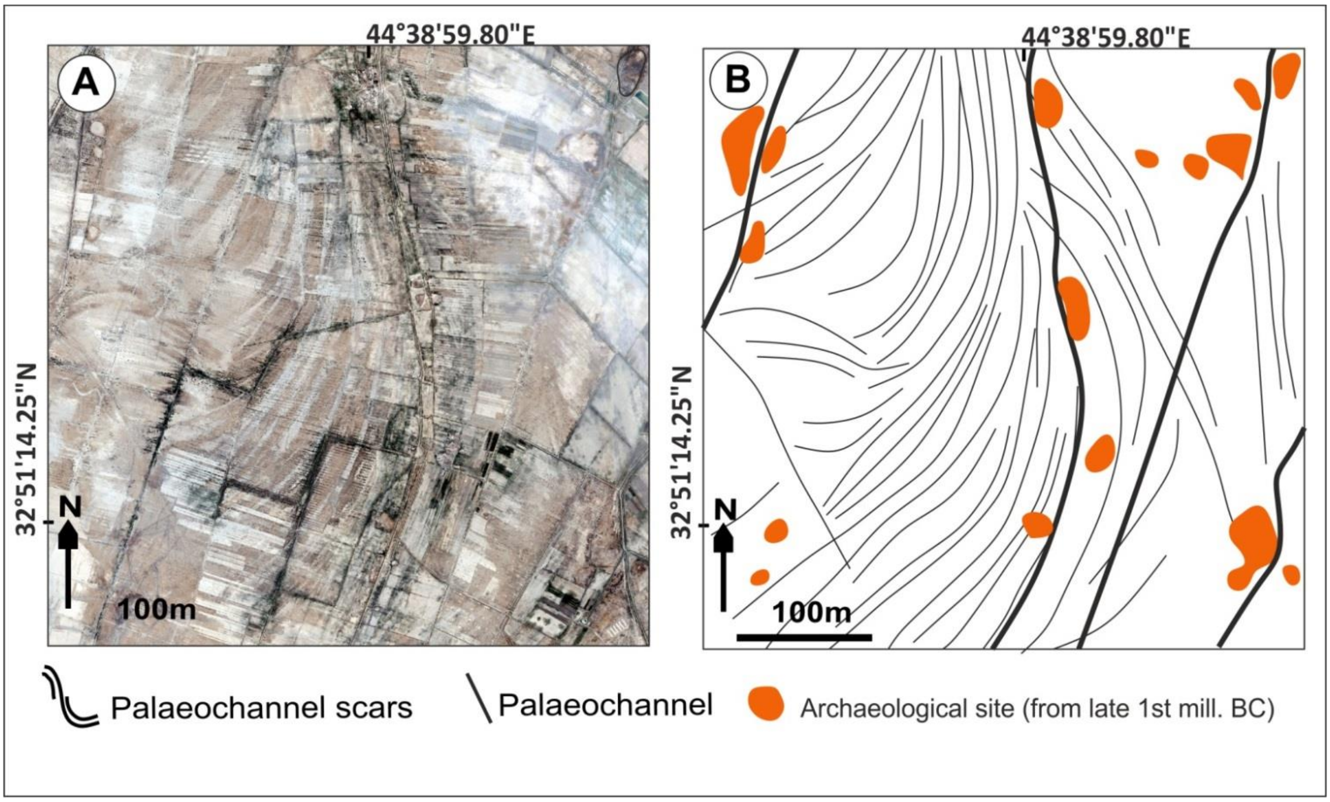


Figure 4.32: (A) QuickBird image showing dalmaj course scars. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

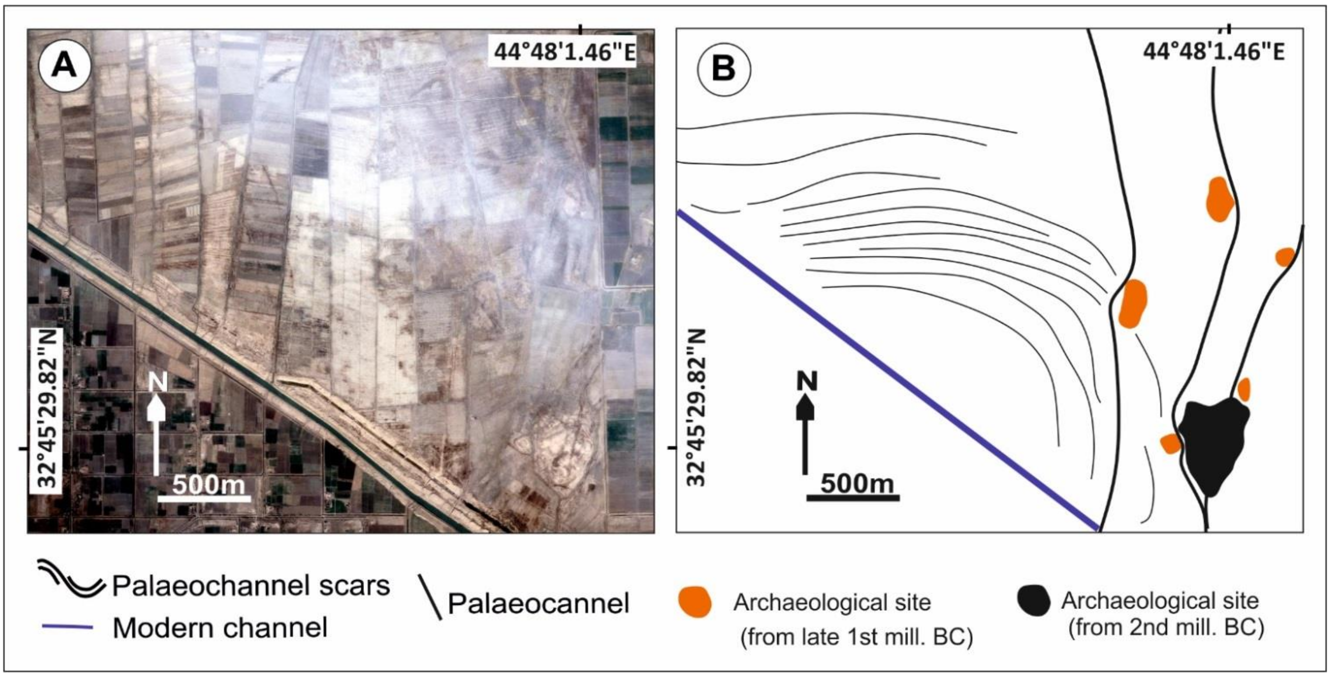


Figure 4.33: (A) QuickBird image showing Dalmaj course scars. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

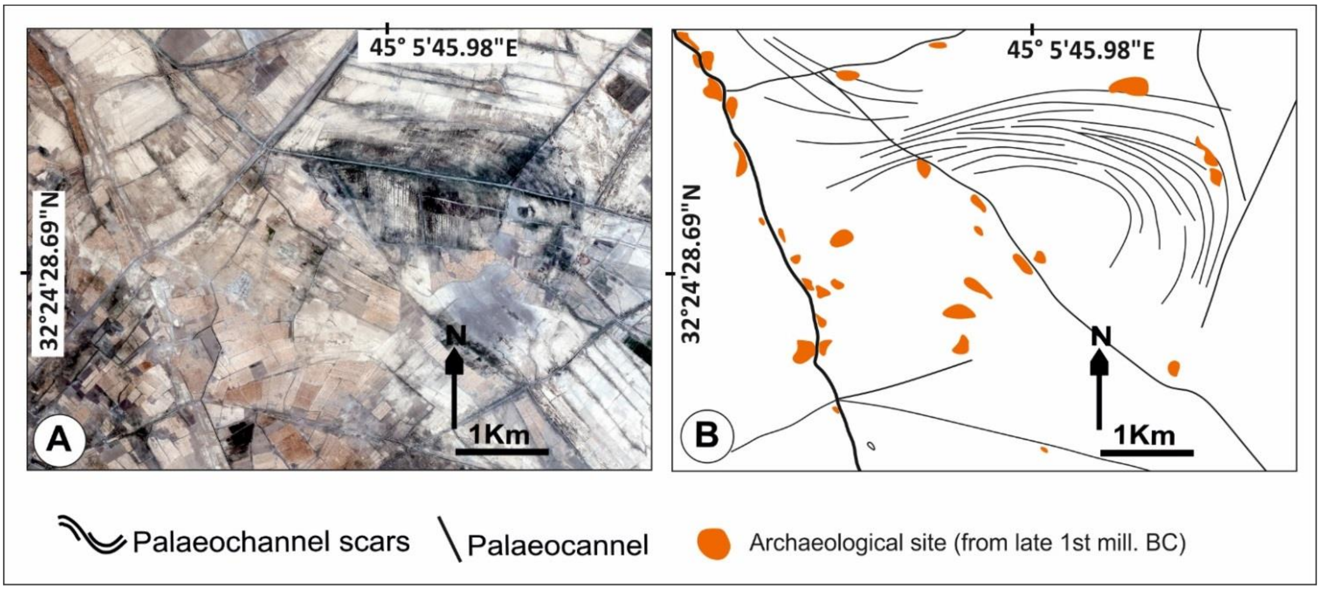


Figure 4.34: (A) QuickBird image showing dalmaj course scars. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites.

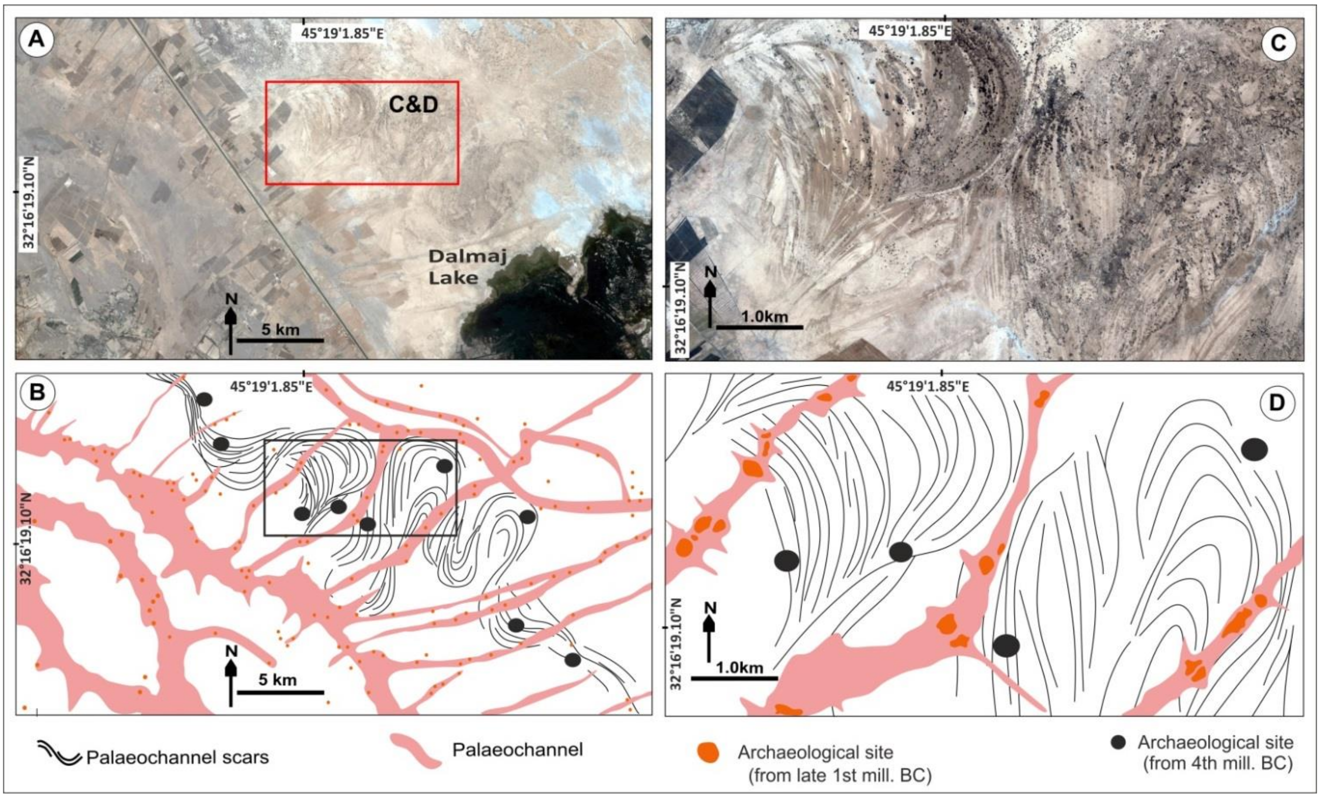


Figure 4.35: (A and B) QuickBird images showing Dalmaj course scars. (B and C) Tracing of surface features including palaeochannel levees, scars and archaeological sites respectively.

4.4.2 The Baghdad course (from the early second millennium BC period to the present)

This is the modern course of the Tigris (Figs. 4.30 - 4.32), formed when the first course avulsed south of Baghdad. It is widely mentioned in historical texts such as Ibn-Rista (1893) and Ibn-Hawqal (1992) and there are several archaeological sites associated with it, such as Seleucia, Ctesiphon, Baghdad and Numaniyah (Figs. 4.30 - 4.32). There are numerous relict oxbow lakes on both sides of this course until it reaches Kut (Figs. 4.32 & 4.37). Both banks of this course were well irrigated by developed canal networks. The right bank of a canal took water from the Euphrates while the left bank took water from the Nahrawan canal, as the water-level within the Tigris channel is lower than that of the surrounding plain, at least north of Kut. A number of canals were dug on both sides of the first course and presumably the second course channel was started as a canal among these other canals, then becoming the main channel.

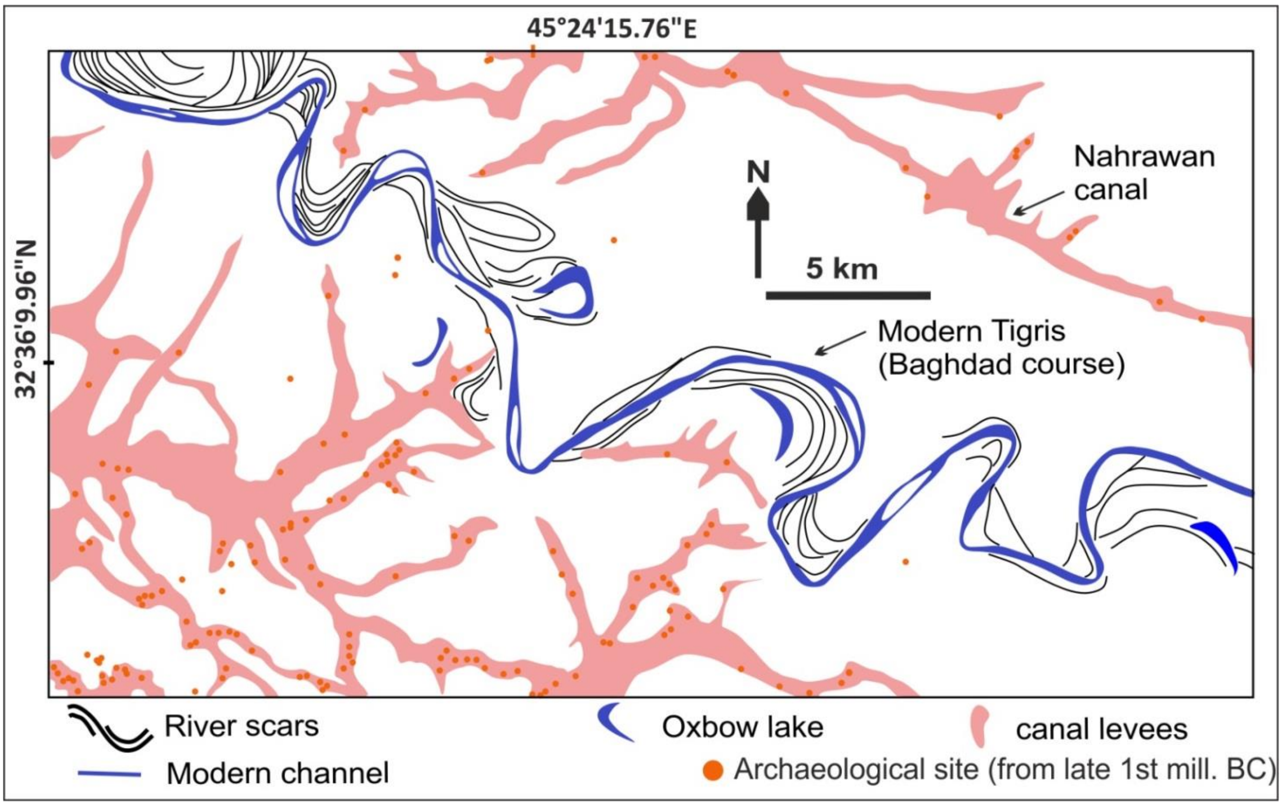


Figure 4.36: Map showing how the modern Tigris is bounded by the relatively high elevated levee (see Fig.4.29 for location and elevation).

4.5. The Tigris river in the Kut area

There are four main courses of the Tigris River recognised east and south of Kut in this study: first, from before the late first millennium BC to the Islamic period, secondly from the Sasanian to the Islamic period, thirdly from the Islamic period to the present, and fourthly from the Ottoman period to the present (Figs. 4.37 - 4.39). Obviously, these periods overlap: more than one channel was active at times.

4.5.1 The Dijla-Alaoura course (from the first millennium BC to the first millennium AD)

The abandoned meanders of this course can be seen from Kut city continuing to the west of the modern Tigris and then disappearing under a modern Tigris river crevasse splay (Fig. 4.40). This course has been widely mentioned in historical texts and was known as "Dijla-Alaoura". For example, Ibn-Rista (1893) and Ibn-Hawqal (1992) affirmed that at the beginning of the Sasanian period or earlier, settlements and farms were located on the west bank of the Dijla-Alaoura, irrigated by canals drawing water from the Euphrates. Some of these canals drained into the Tigris in this region. The oldest settlements associated with these canals in this region date from the Parthian period (Susa, 1948; Al-Rekaby *et al.*, 2013). This means that this course pre-dated the Parthian period. Radiocarbon dating of organic materials taken from the ancient Tigris channel was carried out as part of this study with a view to establishing when this channel first started to form, which the results show as between 810 and 760 Cal BC and 680 and 670 Cal BC (Fig. 4.47) (Table 2.2).

These historical texts also note that during the Sasanian period the water level of the Tigris approached the level of the banks, which led to the flooding of farms and the formation of crevasse splays, surface evidence of which exists on both sides of the course. These are good indications of the water level approaching that of the banks, allowing water to spill over of its own accord (Wilkinson *et al.*, 2015). According to the historical text this course began to be abandoned in the early Islamic period and for this reason it was known as the Dijla-Alaoura (the Tigris blind river) and the present site database confirms that.

4.5.2 The Dujaila course (from the fist millennium BC to the first millennium AD)

This course is the large remaining one in this region, covering the entire area of the west Tigris, extending to the Hammar Marsh (Figs. 4.37 - 4.39). It was widely mentioned in historical texts and there are more than 200 Sasanian and Islamic archaeological sites associated with it (Figs. 4.39 and 4.41 - 4.44). The farms in this region were irrigated by a channel called the Dujaila (the miniature Tigris) during the Sasanian and Islamic periods and several canals of this course were dug and cleaned manually (Ibn-Jaafar, 1981; Al-Balatheri, 1987). This region, which used to be irrigated by canals drawing from the Euphrates as mentioned above, faced drought during the late Parthian and early Sasanian periods, causing some areas to turn into desert (Ibn-Rista, 1893; Ibn-Hawqal, 1992). According to historical texts, such as Ibn-Rista, 1893; Ibn-Jaafar, 1981; Al-Balatheri, 1987; and Ibn-Hawqal, 1992, Wasit, the most important Islamic settlement in this area, was founded in 702 AD on a relatively elevated mound associated with the Dujaila channel. The texts also added that Dujaila had several distributaries, including the Sasi, Gharaaf, Daqla, Jaafar, Misan, Hovery and Hamama channels. Between 723 and 742 AD, the Dujaila channel gradually reduced its discharge to less than that of the Tigris and the Tigris banks flooded several times during the period (Ibn-Jaafar, 1981).

It is clear now that, according to the texts mentioned above, the Dujaila channel was established during the Sasanian period and continued to be active into the Islamic period. Two radiocarbon dateswere carried out on organic materials taken from the Dujaila channel as part of this study. These established that the channel first started to form between 430 and 580 Cal AD (Fig. 4.49) and that the channel dried up between 780 and 900 Cal AD and 920 and 970 Cal AD (Fig. 4.46) (Table 2.2)

4.5.3 The Shayk-Saad course (from the first millennium AD to the present)

There is no mention in historical texts of when or how the modern Tigris (Shayk-Saad) and the Gharraf channels were established and neither are any archaeological sites associated with these channels (Fig. 4.39) (Al-Dafar, 2015). However, historical texts (e.g. Ibn-Rista, 1893) mentioned that during the late Sasanian and the early Islamic periods, several crevasse splays started running from the west of the Tigris, where the Dujaila channel drew water from the Tigris. The farmers of the Wasit area tried unsuccessfully to build a dam across the Tigris near the Khaizuran site to keep water running in the Dujaila channel (Ibn-Jaafar, 1981) (Figs. 4.37, 4.38 and 4.39). This suggests that a new Tigris river had formed as a result of these crevasse splays. Moreover, the modern settlements that are now associated with these channels were established during or after the Ottoman period; the sites of Kut and Amarah (Fig. 4.39) were all established during the nineteenth century (Al-Rekaby *et al.*, 2013), for instance. Furthermore, the modern Tigris now cuts across the Nahrawan canal, and as this was dug during the Parthian period and abandoned in 937 AD (Ibn-Rista, 1893), it means that the Tigris is younger than the Nahrawan canal.

4.5.4 The Gharraf course (the thirteenth century AD period to the present)

The Gharraf channel is the modern branch of the Tigris (Figs. 4.37, 4.38 and 4.39). A radiocarbon dating test was carried out on organic materials taken from the Gharraf channel as part of the study. These tests set the age for the formation of this channel at between 1280 and 1400 Cal AD (Fig. 4.48). Therefore, the author suggests that this channel was formed after the Mongol invasion, i.e. after 1258 AD, when control of the channels was lost and most of the barrages were destroyed. This channel may have started as a crevasse splay, which then developed into channels following the formation of banks. Channels in this group flowed in a general northeast to southwest direction, i.e. in the same direction as the second group.

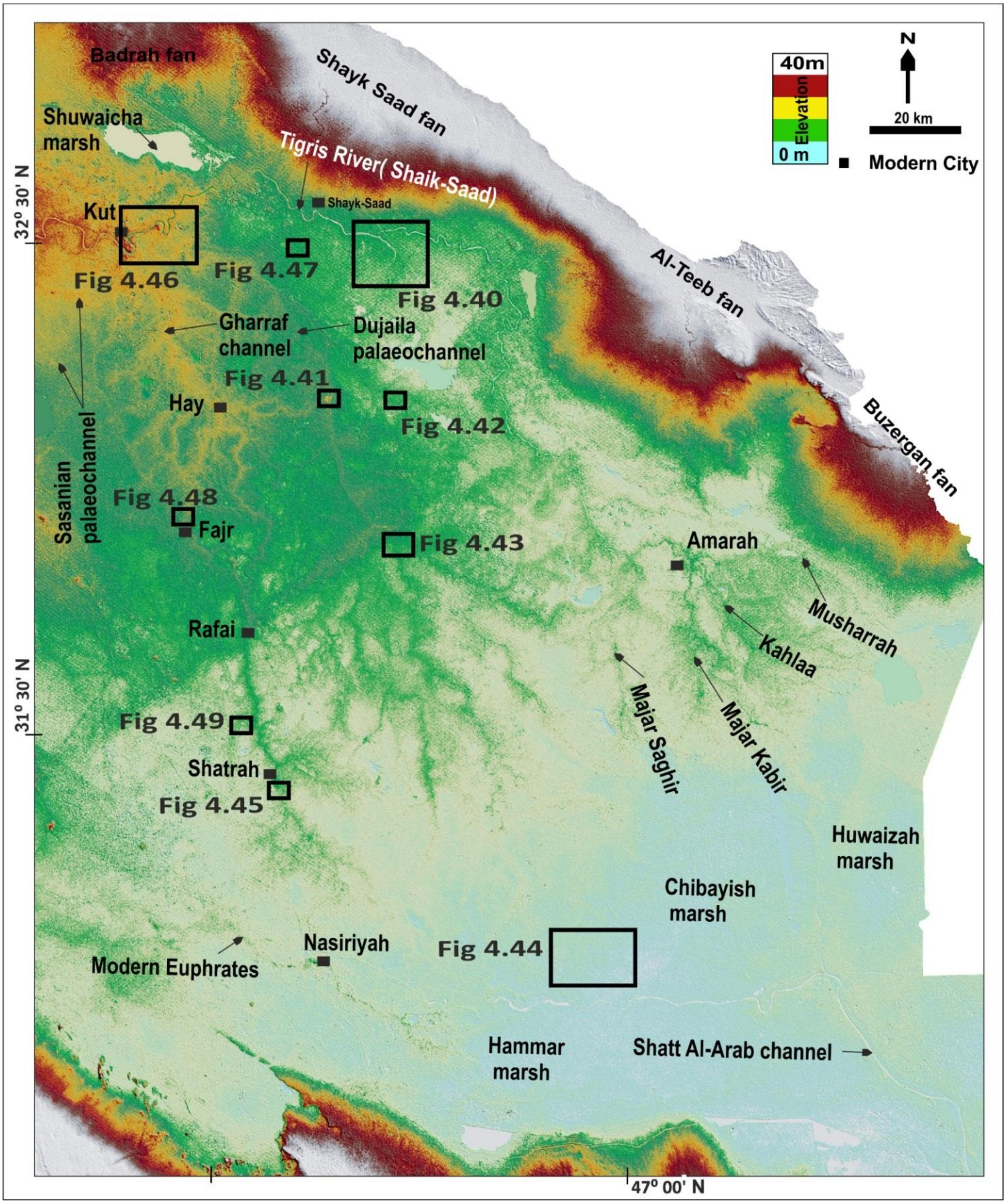


Figure 4.37: SRTM map showing the location of Kut area in the present study.

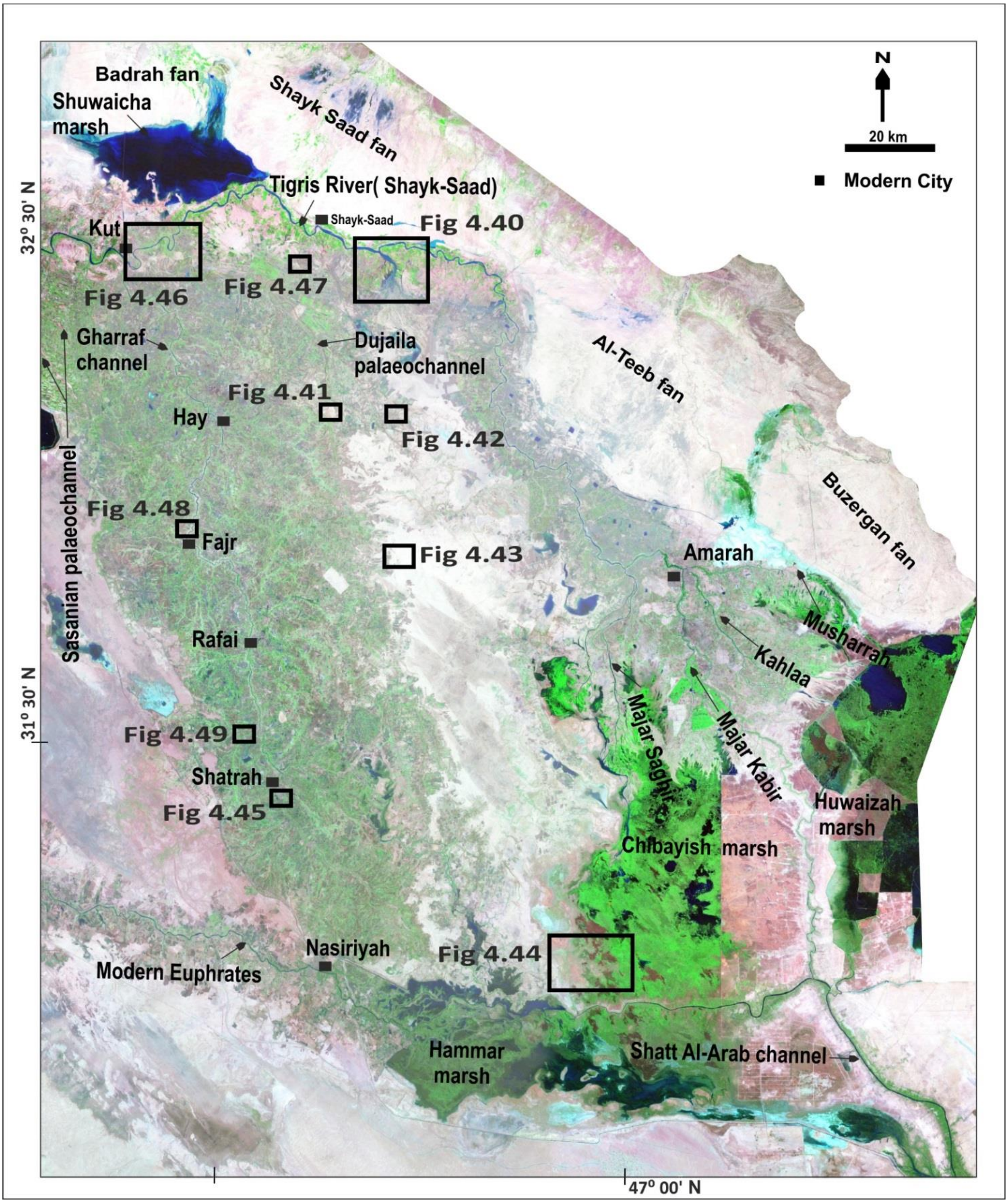


Figure 4.38: Landsat image (2000) showing the location of Kut area in the present study.

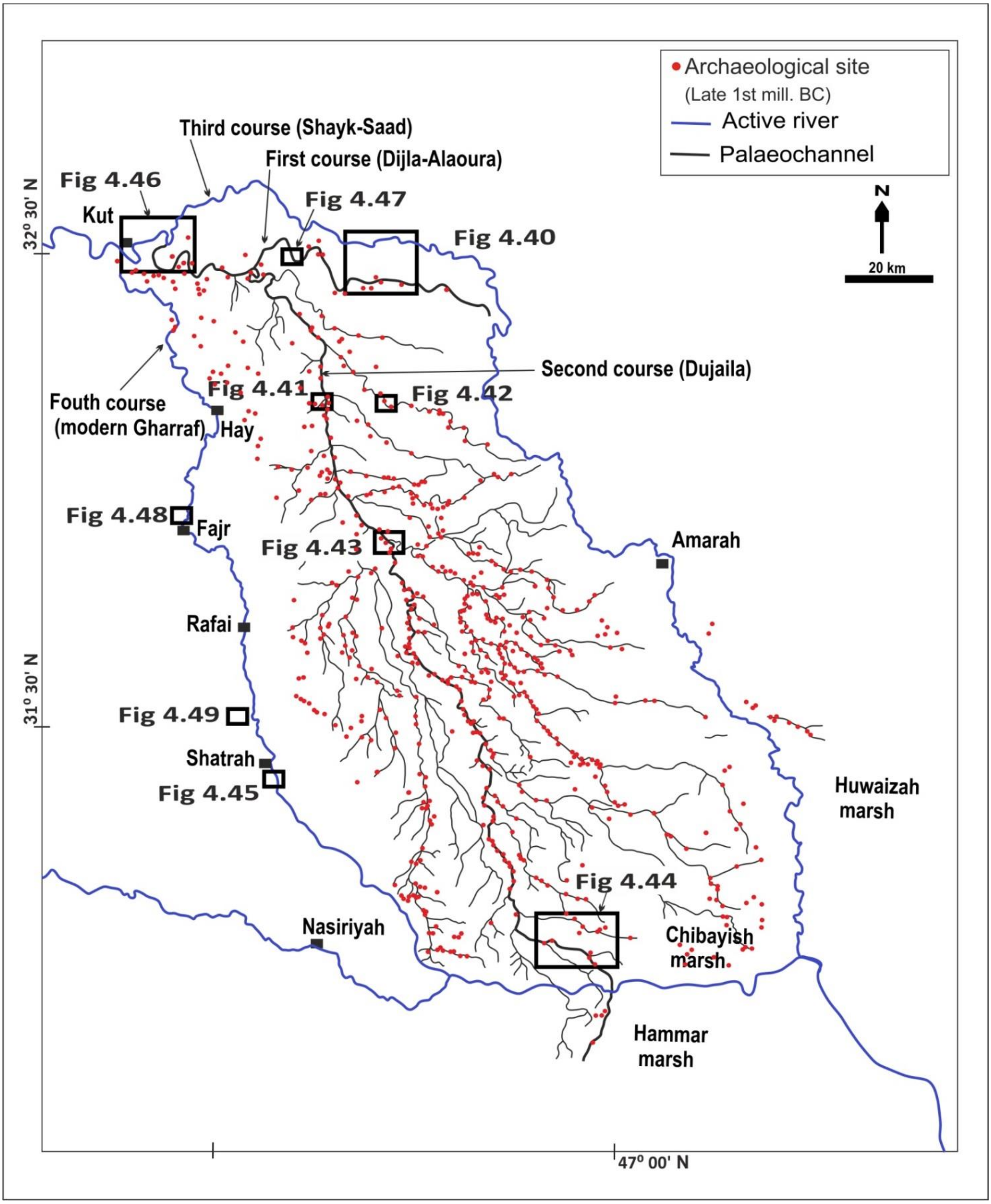


Figure 4.39: All the reconstructed palaeochannels and archaeological sites of the Kut area in the present study.

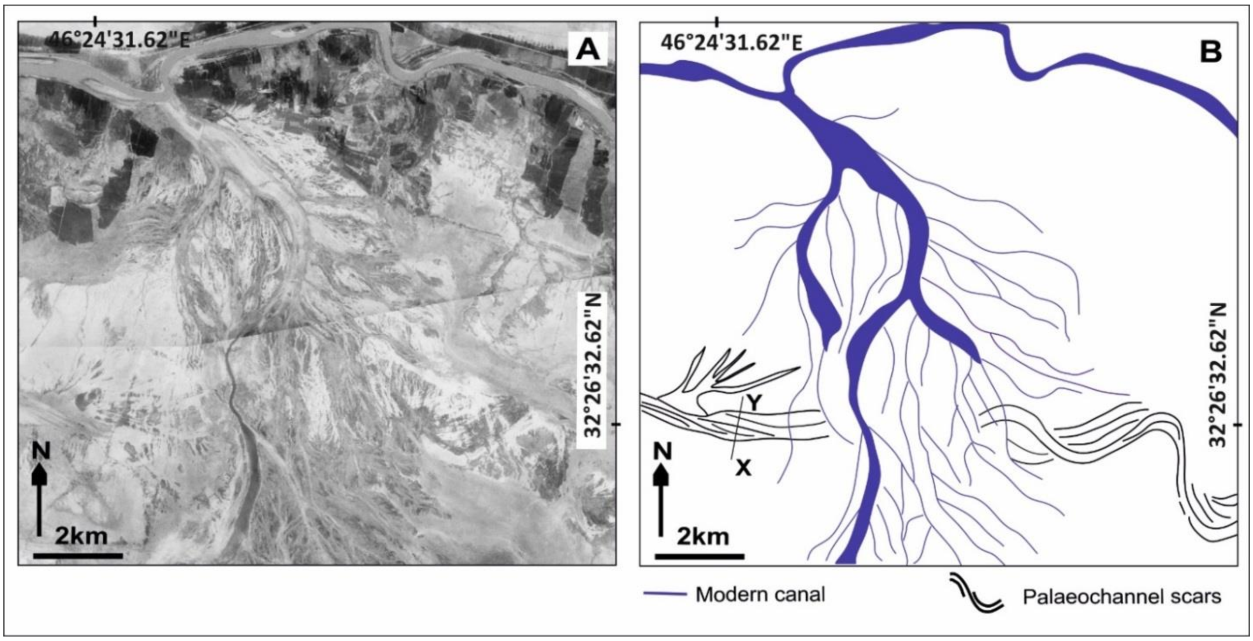


Figure 4.40: (A) CORONA image showing the Dijla-Alaoura channel. (B) Tracing of surface features including palaeochannel levees and scars.

Figure 4.41: (A and B) Field photograph showing the Dujail palaeochannel levee and the Wasit archaeological site.

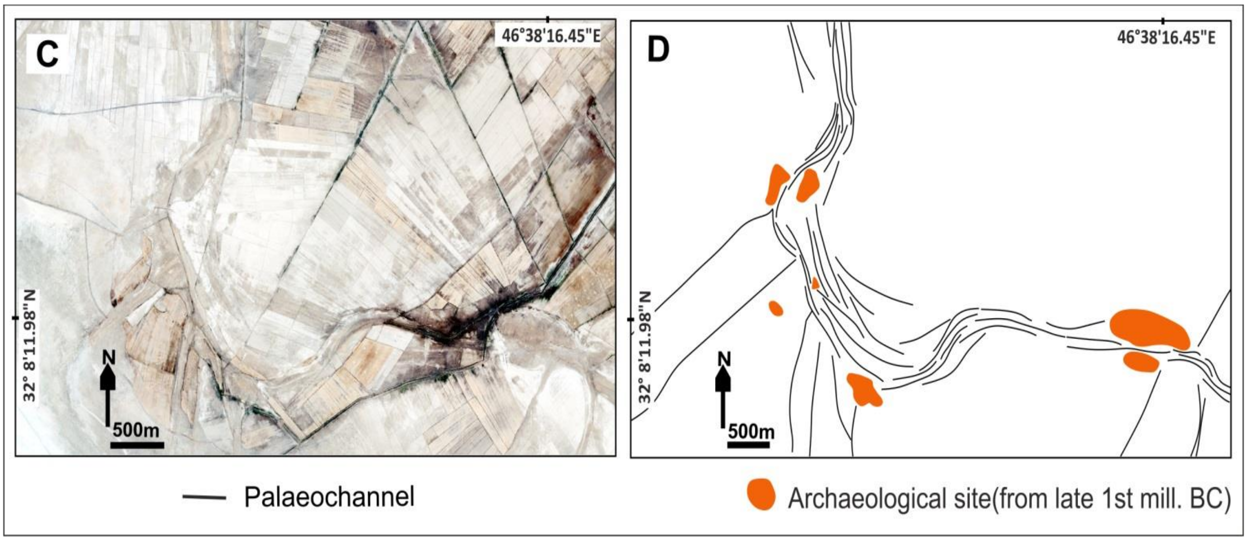


Figure 4.42: (A) QuickBird image showing the scars of Dujaila channel. (B) QuickBird images showing the ancient Adhaim and the Batt canal. (C) Tracing of surface features including palaeochannel levees and scars.

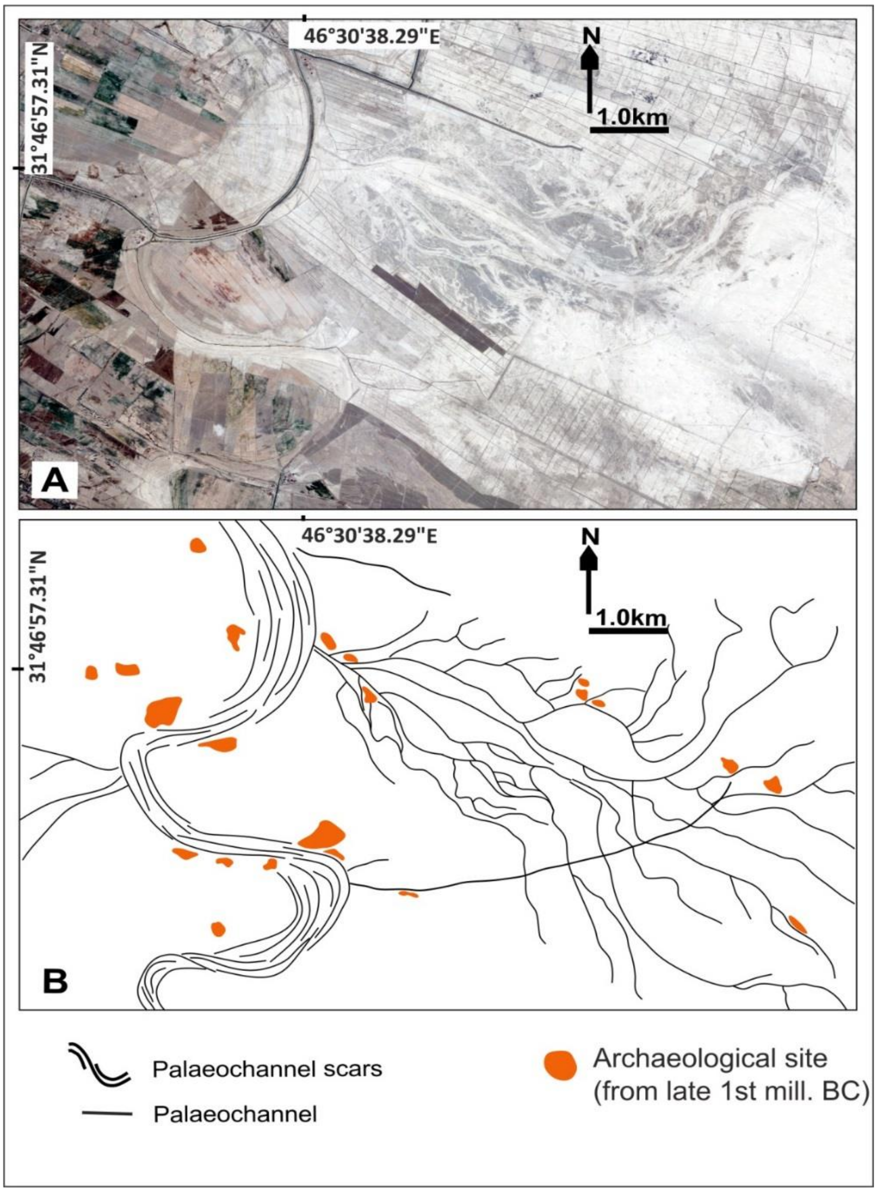


Figure 4.43: (A) QuickBird image showing the scars of Dujaila channel. (B) QuickBird images showing the ancient Adhaim and the Batt canal. (C) Tracing of surface features including palaeochannel levees and scars.

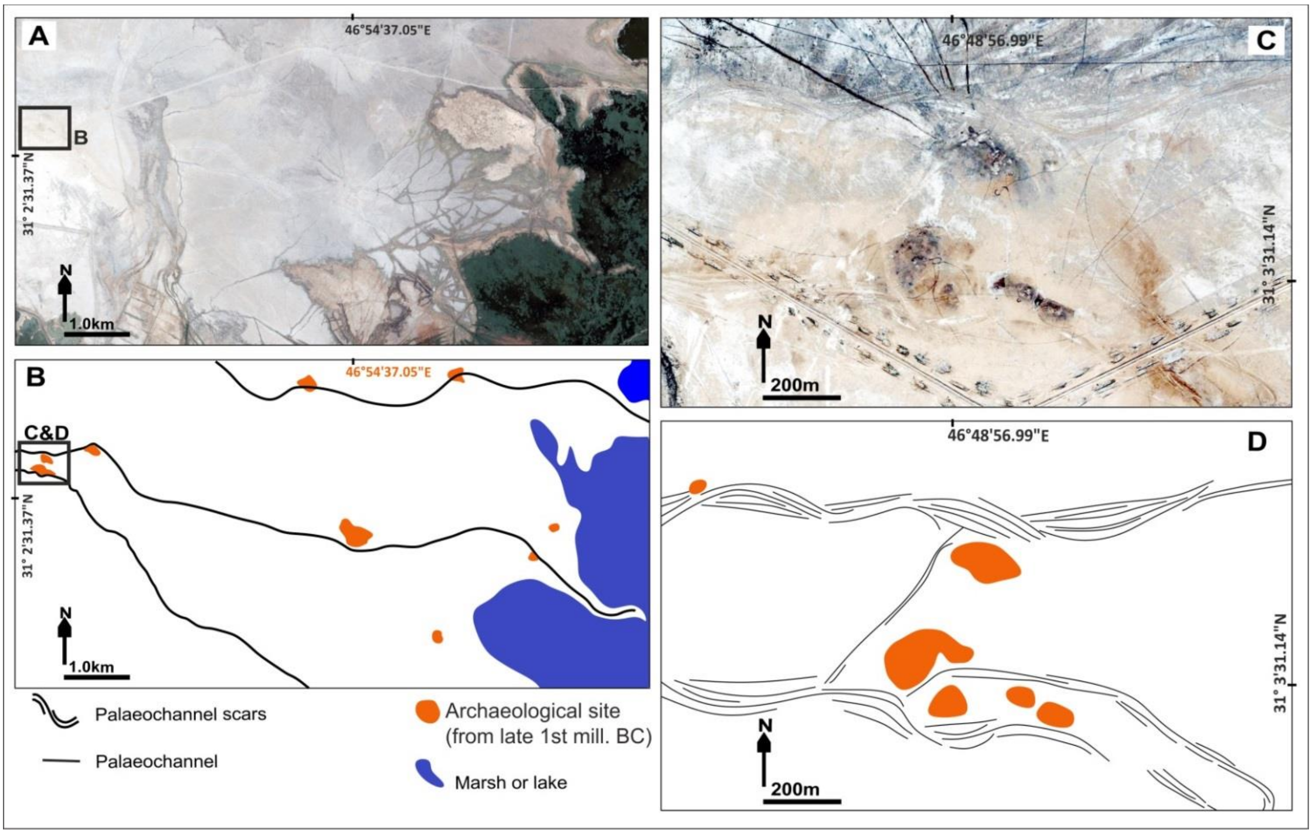


Figure 4.44: (A) QuickBird images showing the scars of Dujaila channel. (B) Tracing of surface features including palaeochannel levees and scars. (C) QuickBird images showing the scars of Dujaila channel. (D) Tracing of surface features including palaeochannel levees and scars.

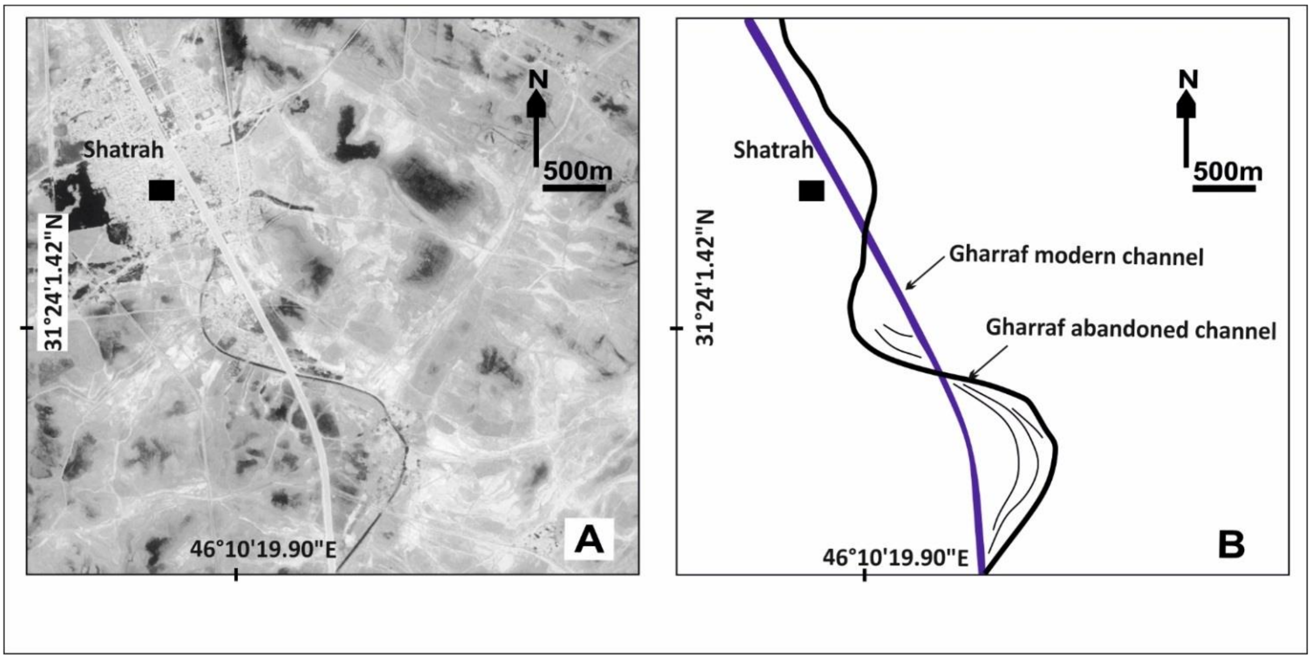


Figure 4.45: (A) CORONA image showing the Gharraf channel. (B) Tracing of surface features including palaeochannel levees and scars.

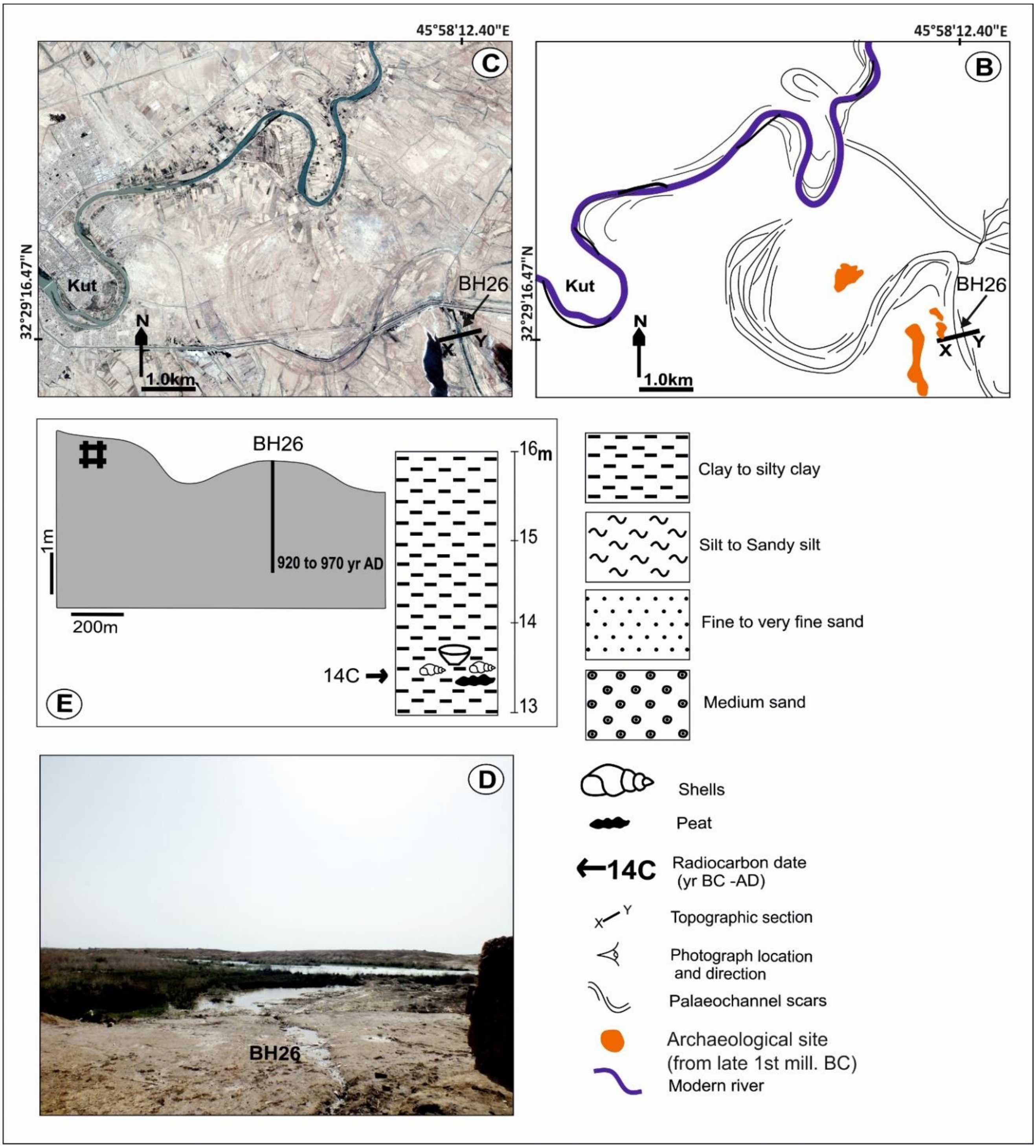


Figure 4.46: (A) QuickBird image showing the borehole BH26 on to the Dujaila palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Cross-section through the palaeochannel, showing the lithologies of the borehole BH26 and the location of the radiocarbon sample. (D) Field photograph showing the Dujaila palaeochannel levee.

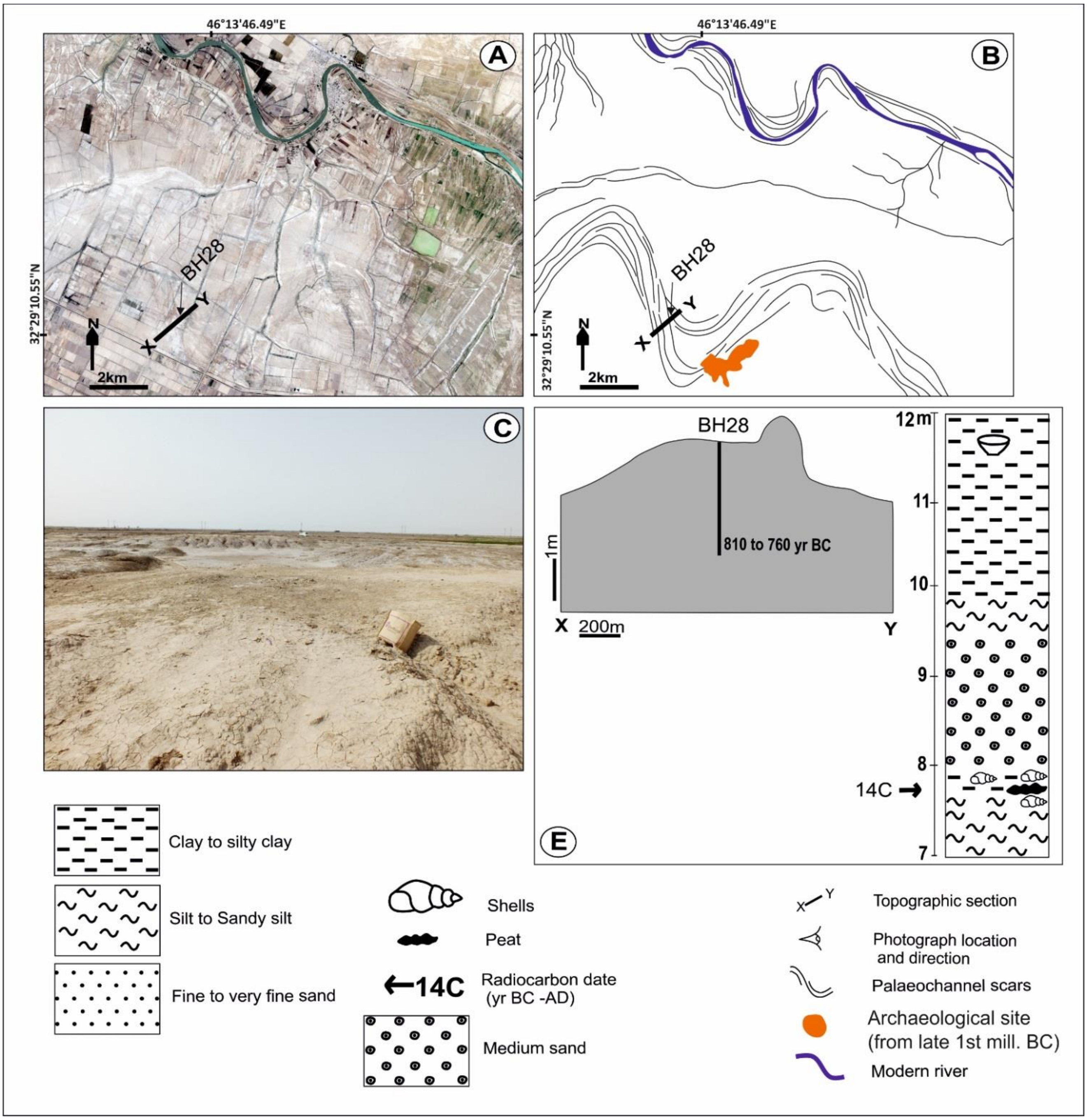


Figure 4.47: (A) QuickBird image showing the borehole BH28 on to the Dujla Alora palaeochannel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph showing the Dujaila palaeochannel levee (D) Cross-section through the palaeochannel, showing the lithologies of the borehole BH28 and the location of the radiocarbon sample.

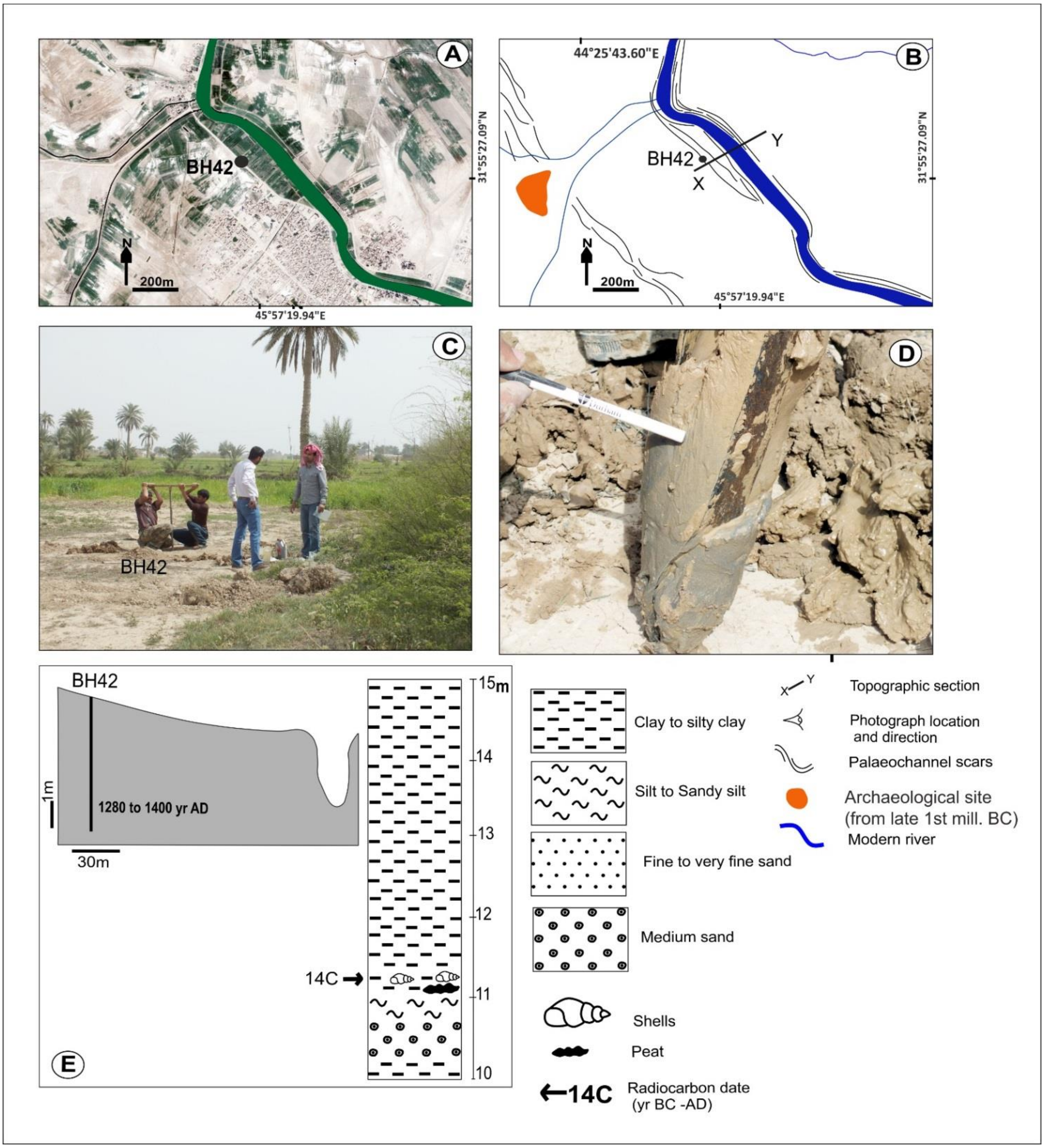


Figure4. 48: (A) QuickBird image showing the borehole BH42 on to the modern Gharraf channel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph showing the Gharraf channel levee (D) Field photograph showing auger sediment of the borehole in 4m depth (E) Cross-section through the palaeochannel, showing the lithologies of the borehole BH28 and the location of the radiocarbon sample.

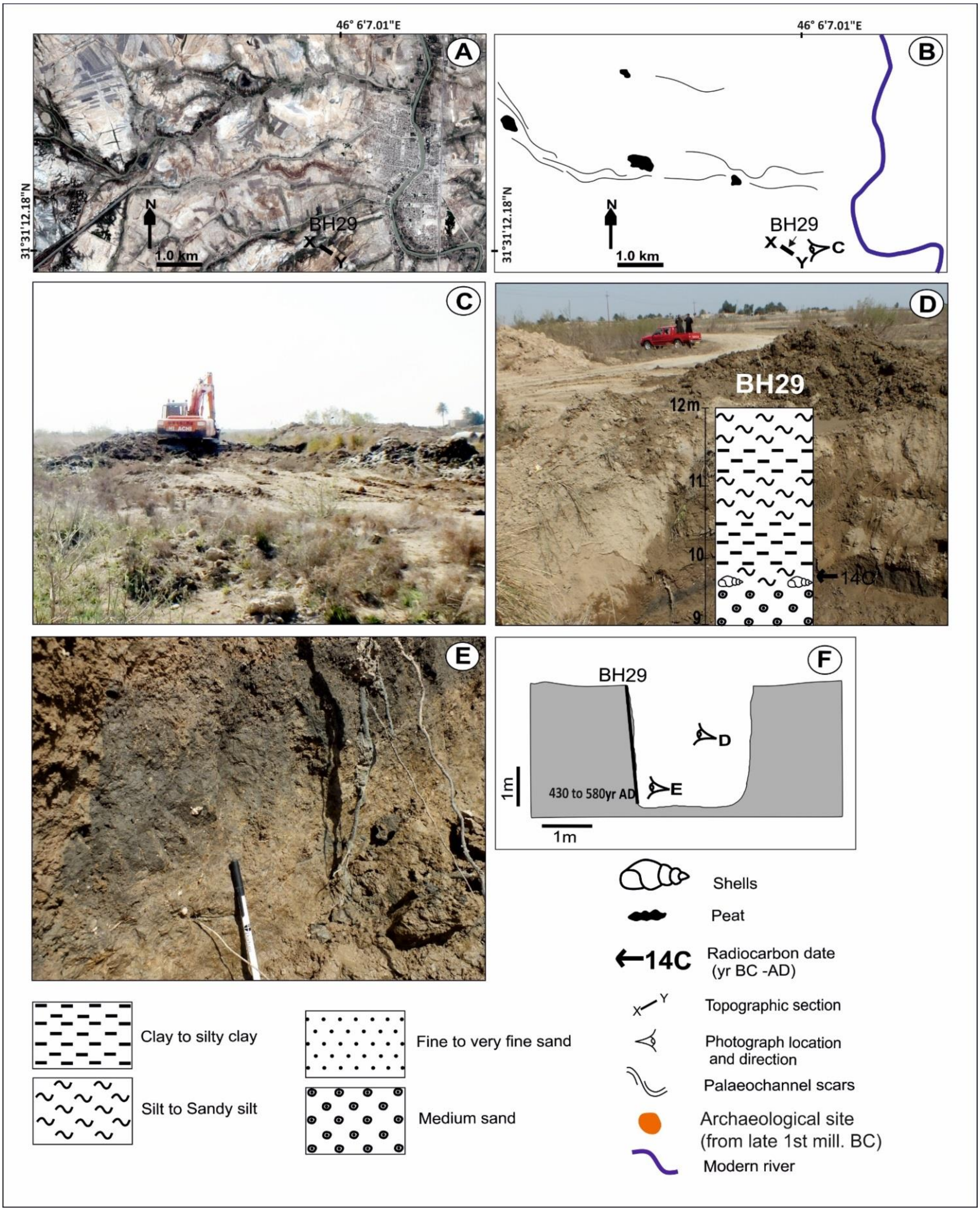


Figure 4.49: (A) QuickBird image showing the borehole BH29 close to the modern Gharraf channel. (B) Tracing of surface features including palaeochannel levees, scars and archaeological sites. (C) Field photograph showing use of the excavator to dig the borehole (D) Field photograph showing cross-section through the palaeochannel, showing the lithologies of the borehole BH29 and the location of the radiocarbon sample. (E) Field photograph showing the marsh sediments in 2m depth (F) Sketch showing the excavated hole of the Borehole BH29.

5. Discussion and conclusions

5.1 Discussion

This section presents a discussion of several aspects of the geomorphology and archaeology, arising from the material presented in chapters 3 and 4.

5.1.1 The northern shoreline of the Persian/Arabian Gulf

There has been considerable discussion and debate about the location of the shoreline of the Persian/Arabian Gulf during the Holocene, and its relation with the Tigris and Euphrates rivers (Fig. 5.1). The first example of these studies to use fieldwork was Hudson *et al.* (1957) who studied the sediments of a borehole dug by the Iraqi Oil Company in the Hammar Marsh, identifying for the first time a 30m thick marine unit in the marsh, and calling it the Hammar Formation. The lower part of this unit consists of coarse to very coarse sand, while the upper part consists of grey clay. The formation is rich in marine fauna such as gastropods (*Minolta edyma, Hinia idyllia*) and lamellibranchs (*Itar bekheri,Brachidontes variabilis, Corbula sulculosa, Abra cadabra*). Hudson *et al.* (1957) found this marine bed covered by about 6m of alluvial sediments with ostracods.

The second example is Aqrawi (1995 and 2001). During his studies of the area as part of his PhD thesis, he did fieldwork in Hammar Marsh and dug 12 boreholes, also using data and samples taken from 6 boreholes previously drilled by the Iraqi Geological Survey Company during 1980-1997. The main aim of his study was to address environmental change in the marsh using petrological, geochemical, palaeontological and radiometric analyses of the samples. He suggested, according to radiocarbon dates, that the Gulf transgressed to reach Nasiriya and Amara during the mid-Holocene (Fig. 5.1), depositing marine/brackish water sediments. After about two thousand years the Gulf receded and deposited tidal flat sediments.

The third example is Heyvaert and Baeteman (2007) who reconstructed the paleogeography of the Lower Khuzestan plain and the northern area of the Arabian/Persian Gulf for different points in time between 8000 and 450 cal BP. They carried out a fieldwork survey on the Iranian side of the Gulf and used a hand auger to dig 52 boreholes (up to 10m deep) in different locations in the area, identifying four Holocene sedimentary environments: brackish tidal flat, clastic coastal sabkha, brackish–freshwater marsh and fluvial plain. They used radiocarbon analysis to date the sediments. They concluded that during the early and middle Holocene, the Gulf had covered the plain, as the sediments were from a brackish tidal flat environment. There was also a sea-level regression after about 3500 BC indicated by the coastal sabkha environment sediments. There followed a progradation of the coastline from around 500 BC, as the fluvial sediments environment was found.

It is worth mentioning here that several archaeological researchers studied the marshland area of the southern region and carried out fieldwork investigation but without digging boreholes, using archaeological data instead, textual resources, ethnographic and remote sensing analysis and groundtruthing to estimate the paleogeography of this region. As an example of these studies, Hritz and Pournelle (2015) as mentioned earlier, suggested that before the mid-Holocene, the area that extends from the location of Samawa, Uruk, Umma and Amara southward to the Gulf was covered by water, merging with the Persian/Arab Gulf and that since that time the Tigris and Euphrates delta has been in aggradation until reaching the modern Gulf shoreline. Another example is Al-Dafar (2015) as mentioned earlier, who supported Hritz and Pournelle's hypothesis and added that the area to the far south of the region was called "Sealand" and was firstly occupied by a sealand Dynasty between 1739 -1340 BC.

Jassim *et al.* (1984), as a part of the geological survey of Iraq, dug 11 boreholes as a section between Barsa and Amara, to a depth between 25 and 35m. They found that there were four recognizable units accumulated above the Late Miocene formation, from the bottom to the top: Pleistocene fluvial clay, rich in secondary gypsum; Early Holocene sand of fluvial environment; Mid-Holocene silty clay from estuarine to marine settings, and Late Holocene sand to silty clay from a fluvial environment. The thickness of each unit is between 3 and 15m. They did not apply any absolute date in their study and they suggested these units were deposited after the Late Miocene sediment.

In summary, regarding the shoreline location (Fig. 5.1), researchers argued in previous geological studies (Hudson *et al.*, 1957; Jassim *et al.*, 1984; Aqrawi, 1995 and 2001; Heyvaert and Baeteman, 2007) that before the Mid-Holocene (i.e. approximately before the fifth millennium BC) there was a Gulf transgression to create the shoreline north of the present location of Amara and Nasiriya cities, followed by regression and fluvial delta aggradation after that time. In contrast, the researchers carrying out archaeological studies (Hritz and Pournelle, 2015; Al-Dafar 2015) pursued remote sensing techniques together with textual resources and argued that the marsh water body during the Mid-Holocene was further to the north, from Samawa to Amara.

It is clear now that little is known about the locations and dates of rivers that deposited the fluvial sediments that covered the marine sediments (Hammar Formation) in the marsh area and also whether these marine sediments existed in the area of the body of marsh water suggested by the archaeologists. The present research has attempted to address this issue.

In the present study, based on the borehole lithologies and radiocarbon dating results of BH33 and BH30 (presented in Figs. 3.38 and 3.39 and located on Fig. 5.3), it can be argued that the mid Holocene shoreline of the gulf was near the location of modern Nasiriya city in the west and Amara in the east of the floodplain (Fig. 5.1). The regression started in the Middle Holocene. Therefore, this study (Figs. 5.1 and 5.2) supports the geological works of Hudson *et al.* (1957) and Aqrawi (1995 and 2001), rather than the conclusions of Hritz and Pournelle (2015) and Al-Dafar (2015) in their estimation that the shoreline was located further to the north, reaching the location of Samawa and Kut.

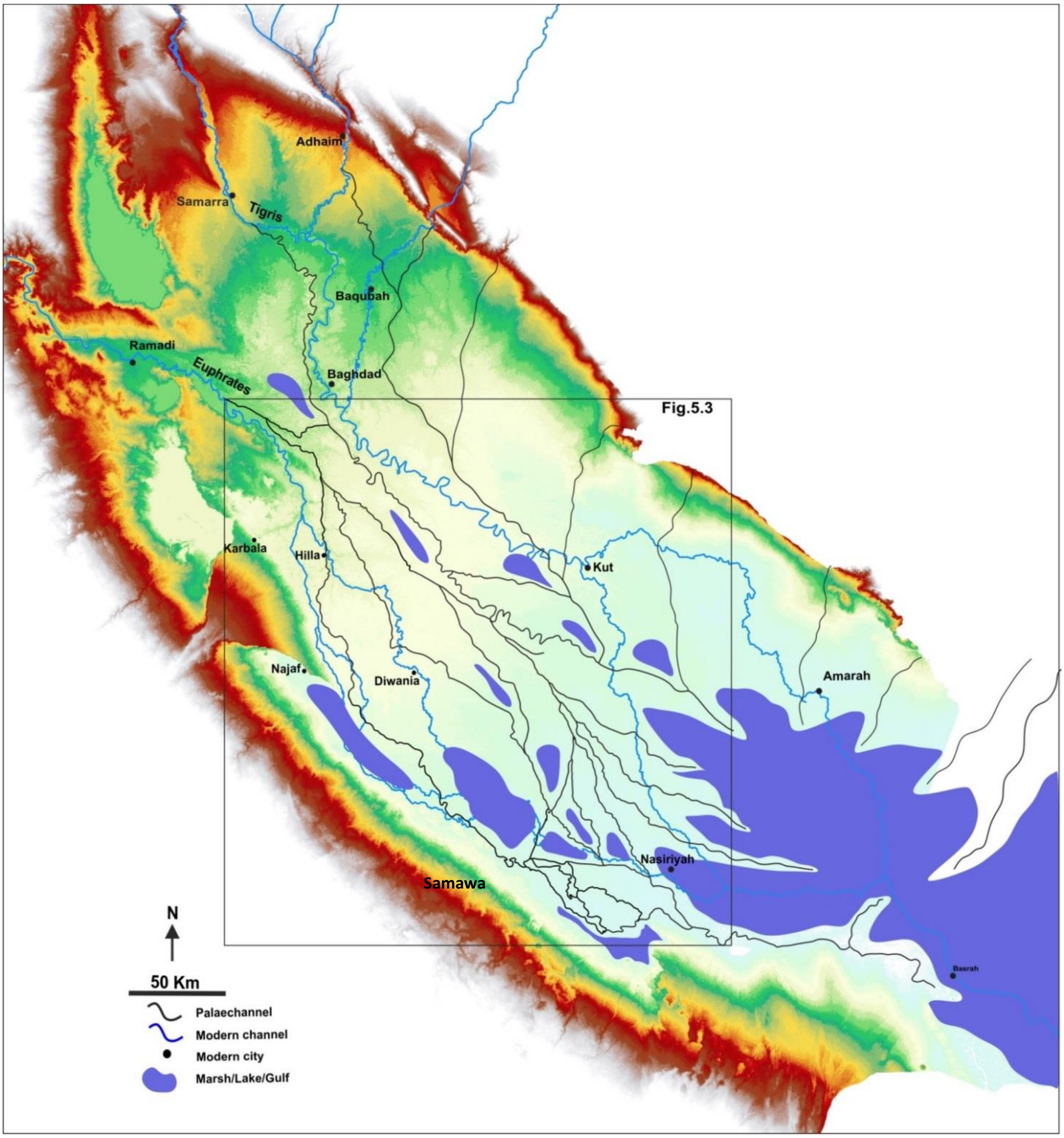


Figure 5.1: The palaeochannels, lakes, marshes and the northern shoreline of the Gulf during the Mid-Holocene, based on a combination of geological, geomorphological, remote sensing, textual, radiocarbon dating and archaeological approaches.

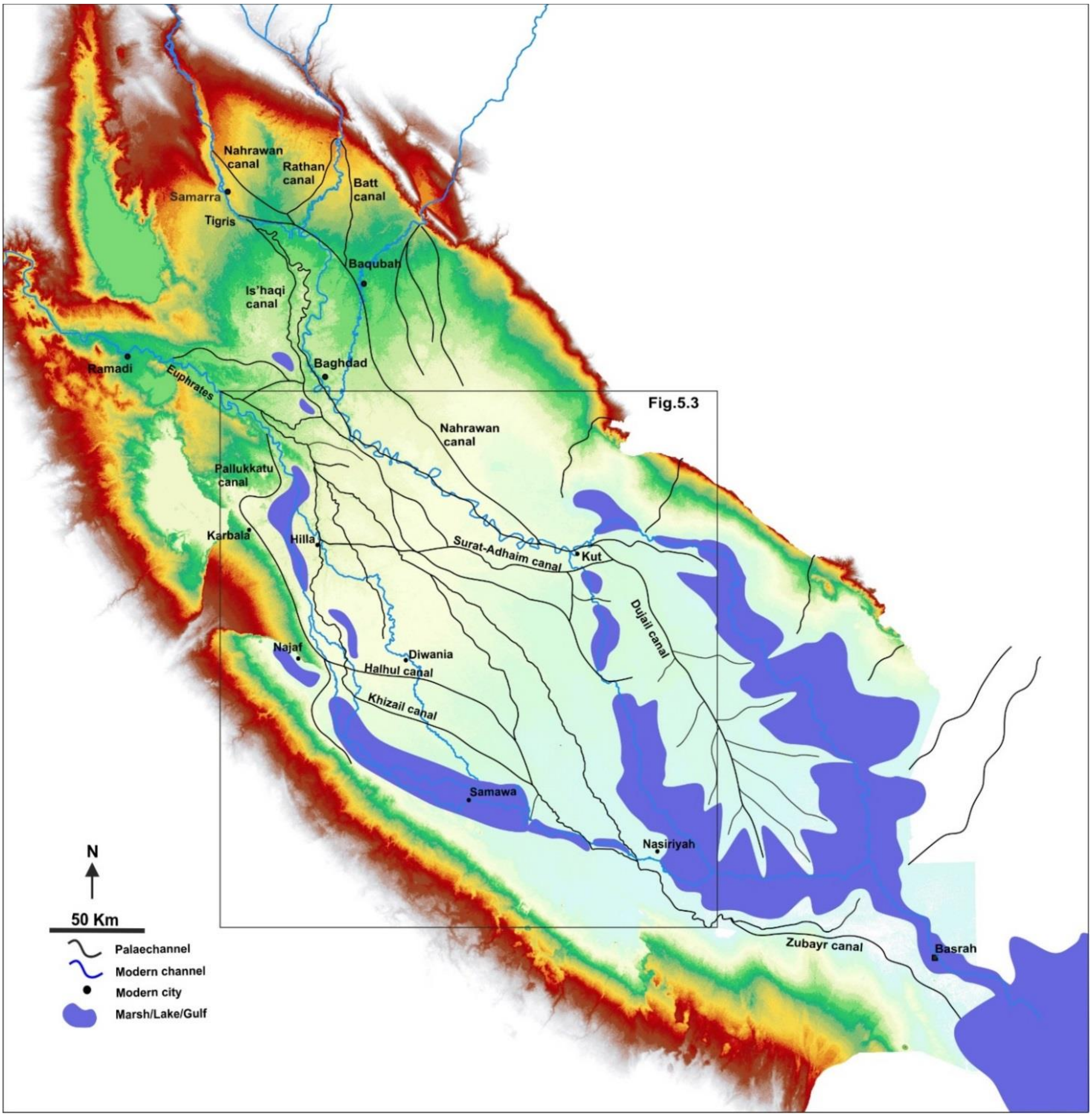


Figure 5.2: The palaeochannels, lakes, marshes and the northern shoreline of the Gulf during the late Holocene (around Parthian, Sasanian and Islamic periods) based on a combination of geological, geomorphological, remote sensing, textual, radiocarbon dating and archaeological approaches.

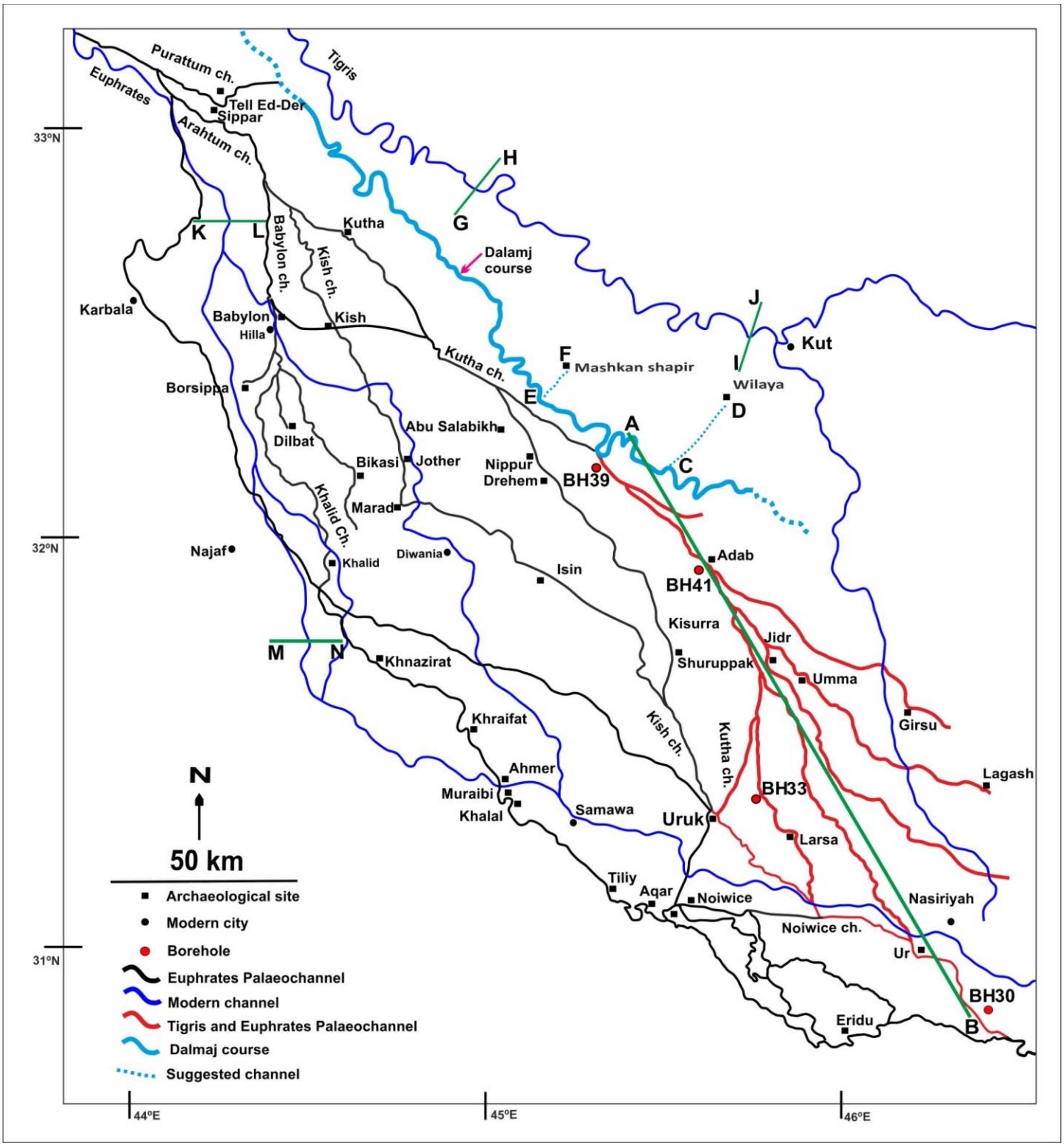


Figure 5.3: Coexistence of the Tigris and the Euphrates during the fourth and third millennium BC.

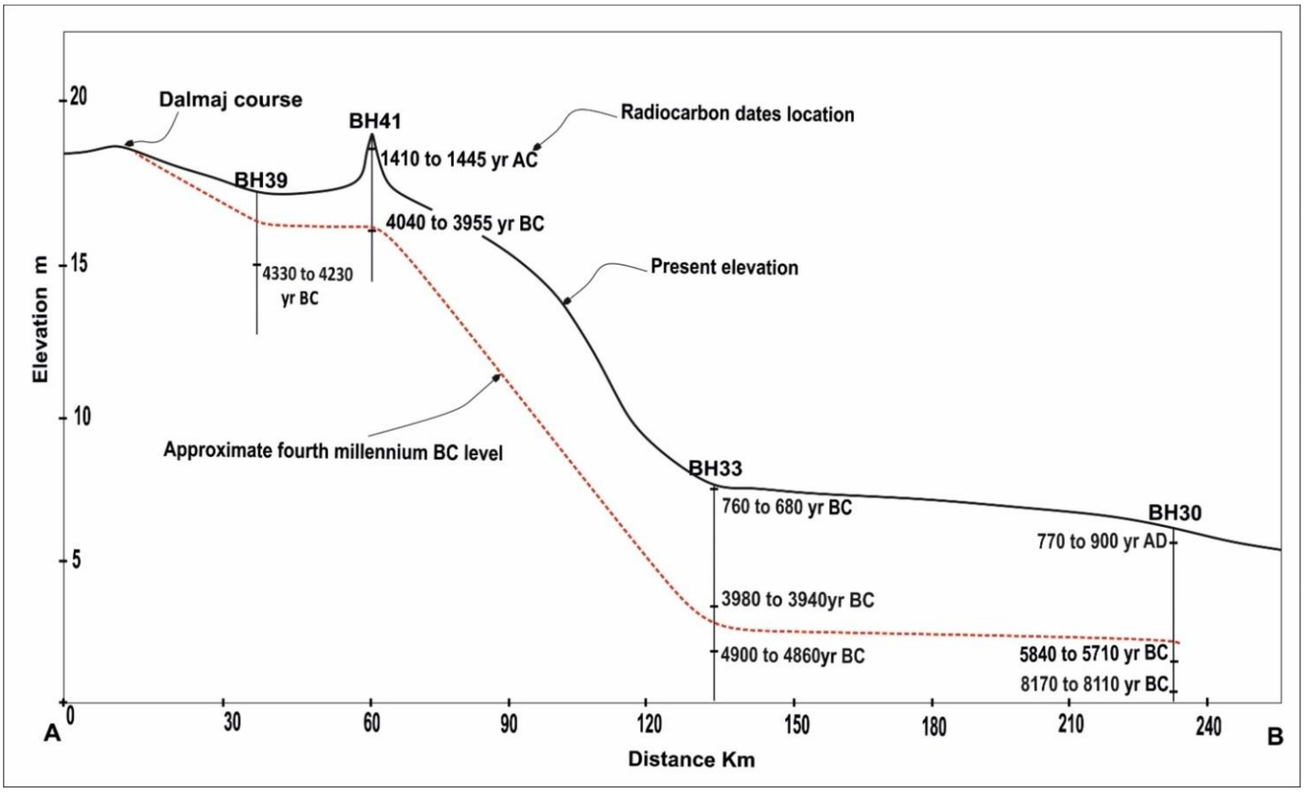


Figure 5.4: General Cross-section showing the approximate 4th millennium BC level (see Fig. 5.3 for location).

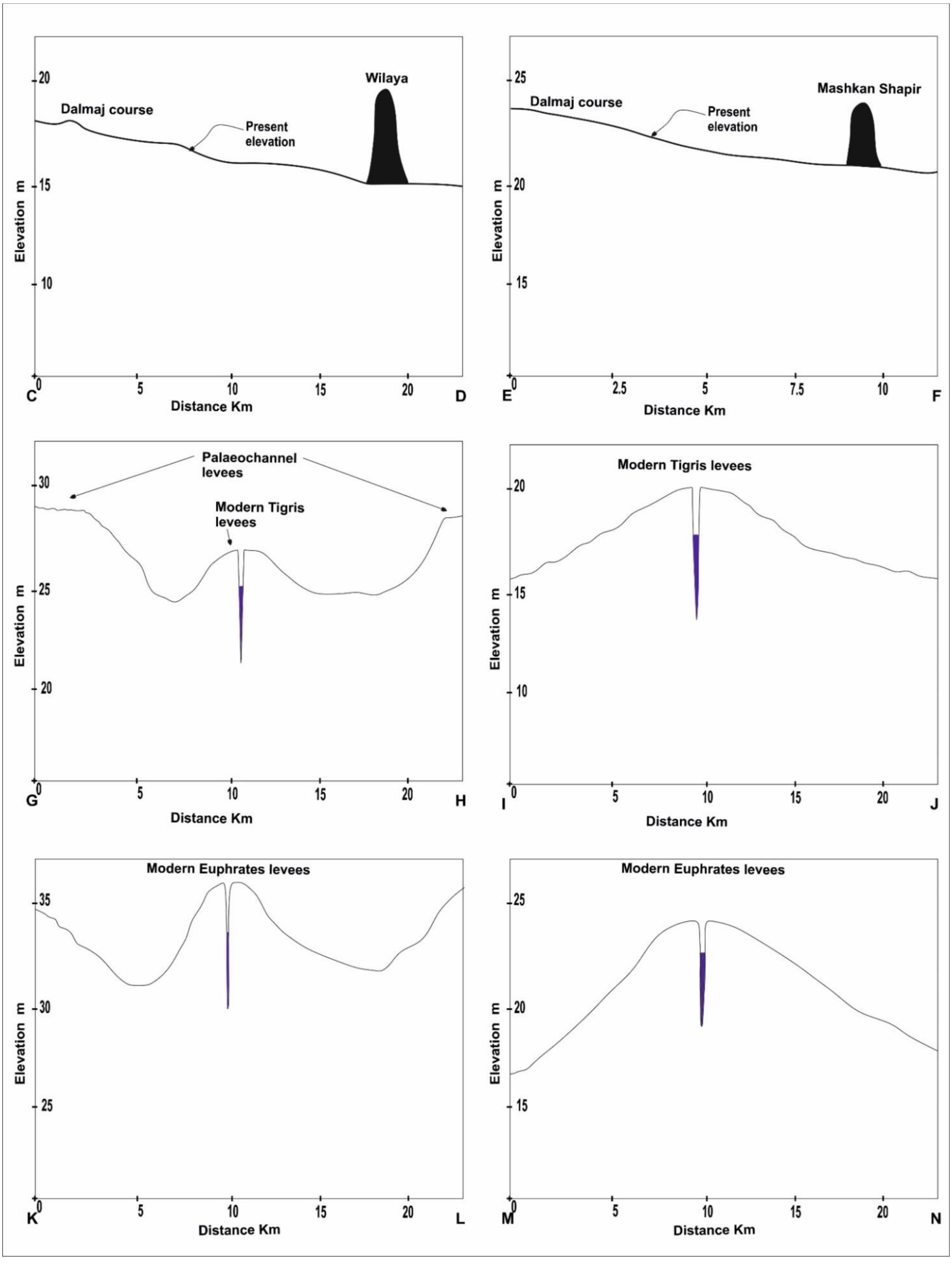


Figure 5.5: Topographic profiles (see Fig. 5.3 for location). Section (C-D) showing possibility of irrigation Wilaya from the Dalmaj course. Section (E-F) showing possibility of irrigation Mashkan-Shapir from the Dalmaj course. Section (G-H), (I-J),(K-L) and (M-N) showing the confined and unconfined river meander belt for Tigris and Euphrates.

5.1.2 Human intervention in river avulsions

Channel avulsion requires destabilization by a trigger, which is the actual event that initiates the process of flow redirection, such as sudden flooding or human disturbance. When channel beds become level with or higher than the surrounding floodplain, the channel is unstable and sensitive to any trigger that might initiate the avulsion process (Mohrig *et al.*, 2000). There are several examples around the world that illustrate the role of human activity in changing rivers. For example, the people of Ucayali village on the Amazon River dug a small channel connecting an oxbow lake side and served for travel during the flood season, this canal was barely wide and deep enough to be crossed by boat at flood stage, but few years later it has become the main course of the Ucayali River (Abizaid, 2005). Another example of human intervention in river avulsion is the Tagus river in Portugal in 1550 AD when people asked the King to shift the river to the northeast due to flooding, so, in one month, workers dug a straight canal and diverted the river, and within few years this became the main course (Azevedo, 2007). Finally, the people of the Jarrahi fan of southwest Iran maintained the distributary channel network of the fan, therefore crevasse splays are transformed into rapid prograding irrigation lobes, and avulsions are prevented (Walstra, Heyvaert, and Verkinderen, 2010).

In the present study, the human activities that related directly or indirectly with river avulsions or stability can be summarized by the following eight types. It might be worth mentioning that I have personal experience, as I grew up in an agricultural family in the Hilla area, and I worked myself on a primary style of irrigation system until 2003.

5.1.2.1 Construction of irrigation canals

Digging an irrigation canal is the most effective human interference in the landscape, well developed throughout time. It is started by digging a canal few meters in length, which might have been originally developed from a crevasse splay (Wilkinson, Louise and Jotheri, 2015) and eventually becomes the construction of a large canal with a length extending to tens of kilometres and a width of tens of metres, such as the Nahrawan canal (Fig. 5.2). Many of the canals constructed in the past were probably started in a relatively straight form and then developed into a sinuous river with high elevated levees.

For example, the number of irrigation canals and human settlements decreases during the thirteenth century AC when Hilla and Hindiya courses formed (Figs. 3.3 and 3.4), perhaps reflecting the collapse in population of Mesopotamia after the Mongol invasion (Susa, 1984; Longrigg, 1999; Butzer, 2012). This is a significant indication of the role of human activity as a trigger for avulsion, as farmers break the banks and dig irrigation canals to irrigate low elevation farms, resulting in this new channel (canal) becoming the main waterway. A specific example was the digging of the Pallukkatu Canal west of the Alexandria Mesa (Figs. 3.3) which later became an independent course. Another example is digging of the Hindiya Canal, which became later the main course of the present Euphrates. Both of these examples have favourable gradient advantages in the flood basin, i.e., they are an example of autogenic control.

In the present study, it can be argued that the Dalmaj course of the Tigris was feeding the downstream area of the Kutha palaeochannel and the meeting point between these two courses is near the location of borehole BH39 (Fig. 5.3). There are four items of evidence to substantiate this argument. First, according to the lithology of boreholes BH39, BH41, BH33 and BH30, the elevations of the fourth millennium BC sediment are 17m, 19m, 8m and 6m (AMSL) and the present elevation of the Dalmaj course levees is about 2m (AMSL) (Fig. 5.3). Therefore, it is normal from the point of view of gradient that water can run naturally from the Dalmaj to the Kutha and its downstream distributaries, i.e. the Adab channel and its five branches, those of the Girsu, Lagash, Jidr, Ur, Larsa and Uruk sites (Fig. 5.3). It is worth mentioning that the current top elevations of the Kutha channels are higher than the Dalmaj course levees. This is because the Kutha channel was subjected to aggradation processes as it was used for irrigation for more than four thousand years (Wilkinson and Jotheri, 2016), while the Dalmaj course seems to have been abandoned since avulsion during the Old Babylonian period (Adams, 1981). Second, it is not possible from a gradient point of view for the Dalmaj course to join the Kutha palaeochannel in an area to the north of the location of borehole BH39 because this area had a higher elevation than the Dalmaj channel. In other words, there is a change in the slope in this area, indicating there were already several palaeochannels during the fourth millennium BC running from the northwest towards the southeast such as the Kish and the Abu Salabikh channels. In contrast, there were several palaeochannels running from the northeast towards the southwest, downstream from the Kutha and Dalmaj channels. Third, there are several relict meanders in the area of borehole BH39, partially covered by the Kutha palaeochannel. They might belong to the Kutha palaeochannel when it joined the Dalmaj course, i.e. before it started aggrading and became manually canalised after the avulsion during the Old Babylonian period. Fourth, no Mesopotamian archaeologists have reported that the archaeological sites located to the west of the Kutha palaeochannel above the area of borehole BH39, such as at Abu Salabikh and Nippur, relied on ancient Tigris water. In contrast, most of the sites associated with the Kutha palaeochannel were reported as depending on the Tigris for water.

Regarding the eastern branches of the Dalmaj course, previous scholars such as Stone (2012) have argued that the archaeological site of Mashkan Shapir was associated with the ancient Tigris, according to textual evidence of the Akkadian and Ur III periods. Stone (2012) suggested that the location of the ancient Tigris was to the east of the Maskan Shapir site, according to her interpretation of satellite images. However, in the present study, it has been found that the main Dalmaj course is located to the west of the site (Fig. 5.3), and the palaeochannels that pass the site could be eastern branches of the Dalmaj course (Figs. 5.3 and 5.5). With respect to the Wilaya region palaeochannel, this channel had not been reconstructed before, nor in the present study, because the Wilaya region is now completely covered by a dense Sasanian and Islamic palaeochannel network (Figs. 5.3 and 5.5). However, it can also be suggested that there should be a channel taking water from the east bank of the Dalmaj course and feeding the Wilaya region before the Old Babylonian avulsion. The reasoning behind this suggestion is that the region was at a lower elevation, especially before the dense Sasanian and Islamic palaeochannel.

It has long been argued that Euphrates has relatively high elevated levees with respect to the surrounding floodplains, therefore ancient framers used this character to irrigate their farms by breaching the levee, with a little effort, so the water flowed down slope. In contrast, it has been argued that the Tigris water level is lower than the surrounding area, so that farmers were not able to use Tigris for irrigation as they needed technology to lift the water (for example Postgate, 1994; Susa, 1984).
However, this study has not found this difference as we will explain it later on, and argues that any given channel levees can be breached and water can flow without lift unless the channel was running in a confined meander belt (Fig. 1.5A). In other word, the issue of having channel with highly elevated levees was not enough for farmers to break the levees and watering their land when this channel running in a confined meander belt because the surrounding agricultural area in the confined meander belt case is still relatively higher than the water level inside the channel.

Therefore, for each reach of a river, it is possible to have, or not have, the water flow irrigation technique and that completely depends on whether the reach is running in a confined meander belt or not and no matter whether it belongs to the Euphrates or Tigris. For example, the modern Tigris south of Baghdad (Fig. 5.3 and Fig. 5.4 section G-H) is running in an unconfined meander belt , so it is easy to irrigate the surrounded floodplain without water lift, while the Tigris north of Kut is confined by palaeochannels (Fig. 5.3 and Fig. 5.4 section I-J), so water lift is needed. In the modern Euphrates, The Hindiya channel reach is running in a confined meander belt (Fig. 5.3 and Fig. 5.4 section K-L) while Kufa and Shamiyah reaches are running an unconfined meander belt (Fig. 5.3 and Fig. 5.4 section M-N), therefore the farms alongside Hindiya cannot be irrigated without lift while it is possible in the Kufa and Shamiyah cases.

5.1.2.2 Construction of a trading canal

Numerous canals were dug not mainly for irrigation but also to improve river transportation. For example, to join the boats trading between Euphrates and the Tigris, a canal was dug during the late Islamic period from Surat-Adhaim channel to the Tigris in Numaniyah city (Fig.4.31) (Ibn-Rista, 1893 and Ibn-Hawqal, 1992). This canal has been identified in the present study, and there are several Islamic archaeological sites associated with it. Therefore, there is a high probability that there are other trading canals that were dug when and where needed throughout the floodplains, and of course, some of them developed and changed the landscape.

5.1.2.3 Cleaning up the channels

Authorities usually invested in labour to remove vegetation and widen and maintain the channels. The benefits of their efforts were improvements in river transportation and increased safety for river travel for goods and people. Canals should be cleaned regularly to remove the materials such as sediments or plants which choke the channel, to ensure that the water flows and properly discharges, and also to allow use of the channel as a water way for boat transport. However, as a result of this cleaning process, the channel will meander less and it will have stable levees.

A significant issue with channels, either anthropogenic or natural, is that of choking by accumulation of sediments. These deposits form part of the alluvial zone, as a result of aggradation within the river belt, whereby the levee becomes higher and the risk of flooding increases. Therefore, cleaning and removal of the sediment is essential to guarantee a smooth flow of water. For example, according to the IMWR (2002), the Hindiya, Hilla, Shamiyah and Kufa channels need cleaning every five years due to accumulations of sediment. Distribution canals used by farmers for irrigation need cleaning every year due to accumulations of sand, silt, and vegetation; smaller field laterals are cleaned of silt and clay every planting season. An example is the Haideri irrigation canal where over one meter of sediment within the channel is extracted by the government agency every year (Fig.3.20).

5.1.2.4 Breaching channel levees

There are cases where people deliberately break channels and flood the surrounding area. Therefore, a channel might be avulsed completely and a new channel might be made in the flooded area, or the flooded area will silt up and the farms will be destroyed. The most common reasons for manually breaking levees is to use water as a weapon of war against a village or farmers living in the area surrounding the channel (Chen, 2013) or maybe trying to irrigate reed farms (Postgate, 1994). However, doing this without taking into account how to control the breaking levees, will of course lead to worse outcomes that were probably never anticipated. There is one example in my personal experience, when farmers in my village Jother (see its location in Fig. 3.3) tried to breach the Hilla river levee by themselves without permission or supervision from the Iraqi Water Agency during the Second Gulf War in 1991. They dug a small canal to feed the original canal that had desiccated. When they had finished digging the small canal and joined it to the original one, water started flowing rapidly in the small canal and the erosion on its banks increased, widening the canal and increasing the discharge. The water overflowed the banks and the downstream area of the small canal flooded. The farmers tried to close the canal with sand bags but the situation became uncontrollable. Finally, they managed to fill the opening of the small canal by using an excavator truck.

5.1.2.5 Desiccation of marshes

Marshes can be desiccated by farmers or authorities for several reasons, such as creating new fertile land for growing grains or gardens and also marshes - usually a place where rebels or criminal groups can hide and occasionally settle so government tend to desiccate the marsh when it possible (Taher, 1998). Therefore marshes were subjected to drying up in the past including the 20th century when the Iraqi government executed a new irrigation project leading to the drying up of the southern marsh of Iraq (Abd al-Jabbar, 1994). The methodology of drying a marsh might involve digging canal to drain the water to land of relatively low elevation and also strengthening the banks of the channel that supplies water to the marsh. So, both of these drying methods would lead to changes in the landscape of the area. These two methods were applied in the Islamic period (Taher, 1998) and in the 20th century (Abd al-Jabbar, 1994). In the modern-day village of Jother, when farmers try to reclaim the fertile land of the marsh, they always construct a clay barrier between the river bank and the associated marsh to prevent water from overflowing its bank and feeding the marsh. This method, of course leads to the strengthening of the river levees.

5.1.2.6 Flood-control techniques

A variety of ways have been tried to avoid river floods. These ways directly or indirectly affected the landscape of the present study. The methods included using ponds, lowland areas, flood basins and wetlands as local water storage by digging canals to join the main channel, already higher than the surrounding floodplain, to these lowland areas (Postgate, 1994). However, the lowland areas were subject to silting up as a result of receiving extra sediments transported from the main channel over time.

However, these linking canals had to be well controlled by humans, especially during periods of flooding, otherwise they could develop and become enlarged, or uncontrollable, which could then allow the main channel to divert to the linking canal, thus forming a new channel flowing through these lowlands. The best example about this case is in Najaf area, where the Sura course turned to Hilla course (Figs. 4.4 and 3.5) as a result of digging a drain canal from Sura courses to the lowland area as we mentioned earlier.

5.1.2.7 Construction of dams and barrages

Dam / barrage construction technique is common in the ancient / present Mesopotamian floodplain to manage the irrigation system (Jansen, 1980) for example, during Old Babylonian period (George, 2009), and the Adhaim (Fig. 4.14) and Alath (Fig. 4.4) dams, where there is a need to raise the water level and divert it to the left and right sides of the river. Barrages such as the Dujaila (Fig. 4.32) (Ibn-Khurdadhabih, 1889) and Hindiya barrages (Fig.3.7) in the Najaf area (IMWR, 2002) were needed to divide or share water between two channels. Building a dam would lead to decreased discharge in the main channel, and the little water that escaped from the dam and ran into the main channel was not enough for silting up or aggradation of the channel so there was a tendency to incision, such as the modern Adhaim and Diyala channels. The present channel network of the Mesopotamian floodplain, including main and minor river channels, irrigation canals, and drain channels, is controlled by different sizes and types of dams and barrages, otherwise, avulsions would take place more frequently. It is clear now that many of the distributary channels are utilized as canals, for flood control and irrigation, and may have originated as anthropogenic canals, such that the whole architecture of the river would have looked significantly different without this human intervention.

5.1.2.8 Building settlement next to a channel

As the Mesopotamian floodplain climate is generally arid, human settlements rely totally on the availability of surface water and people built houses or public buildings close to channels (Adams, 1981). Consequently, these buildings could be considered as embanking or strengthening factors in the river banks. It is worth highlighting that the avulsion nodes identified in this study were located in reaches where no settlements were associated with the channel, as settlements possibly help channel stability.

5.1.3 Neotectonic factors

Scholars such as Yacoub (2011) and Hritz, Darweesh and Pournelle (2015) have suggested that some of river changes might be because of neotectonic activities of subsurface geological structures in the Mesopotamian floodplain. Their claims were based upon published tectonic and structural studies that suggested the existence of subsurface geological structures such as Jassim and Goff (2006) and Aqrawi (2010). However, these studies were not able to describe precisely the locations, dimensions, depths and types of these bodies, nor the probability of their continued tectonic activities. However, in the present study, I was not able to address this issue in greater detail due to the lack of accurate information about the subsurface geology of the floodplain. Above all, the present study has shown how the wide range of human interventions, effective silting up processes, local differences in gradients within the floodplain and frequent floods have led to channel changes occurring, regardless of neotectonic movements.

5.1.4 Climate change

No direct study inside the Mesopotamian floodplain has been conducted in order to determine the Holocene climate change of the region. In fact, most of the research that mentions the palaeo-environment of southern Mesopotamia was carried out in neighbouring areas and not within the floodplain. For example, the most recent attempt to address the climate of the Mesopotamian floodplain was carried out by Flohr *et al.* (2016) and Clarke *et al.* (2016) as part of a study addressing a large area of the Middle East. They examined terrestrial and marine records in published literature related to climate change in the Near East and Eastern Mediterranean during the early and mid-Holocene. When an attempt was made to address the climate of southern Mesopotamia, no published dedicated study about this matter was available, so, the researchers adapted several records of published archaeological data and tried to use them as an indication of the palaeo-environment. The conclusion was reached that there was a harsh wet winter during the period of 8000 to 4500 BC, especially in the Fertile Crescent, i.e. north Syria, south-eastern Turkey and northern Iraq. They also added that this stability in climate prompted the organisation of agricultural work and led to cultural continuity in the Levant and the Mesopotamian floodplain. The researchers were aware that the linkage between this data and south Mesopotamia was pretty tenuous.

Another example of indirect study of the climate of the Mesopotamian floodplain is that by El-Moslimany (1994) who analysed remnants from early Holocene lakes in the Rub' Al-Khali (Empty Quarter) of Saudi Arabia: pollen data, plant remains in archaeological deposits, and freshwater deposits buried beneath the Arabian-Persian Gulf. She concluded that the region had been subjected to monsoon rainfall during the early-mid Holocene. However, Pournelle (2003), and Pournelle and Algaze (2014) adapted the work of El-Moslimany (1994) to suggest that southern Mesopotamia was a wet environment during the mid-Holocene and that this led to the deposit of thick marsh sediments at that time. In the present study, however, the borehole sections and the radiocarbon dates show that there are several thick marsh sediments from different periods and not from the mid-Holocene. This means that the existence of marshland cannot be used as an indication of a high rainfall climate, because the flow comes from the rivers, and the determinant for their flow is rainfall in eastern Turkey, not in southern Iraq itself. However, in the Mesopotamian floodplain, attention should be paid when using archaeological data such as rapid increases or decreases in human settlements because river changes have a direct impact on the local environment (Matthews, 2003).

5.1.5 Possible human occupation before the 6th Millennium BC in the Mesopotamian floodplain

It has long been suggested that the Ubaid period is the age of the oldest human occupation in the Mesopotamian floodplain, as no evidence has been found thus far of existing archaeological sites older than this (Adams, 1981). The chronology of the Ubaid period is a debatable issue, however, with suggestions that the oldest dates from the 6th millennium BC (Oates, 1960). Additionally, the oldest organic materials found at an archaeological site and dated using radiocarbon dating techniques was a carbonised stem, fragments of which were found at the Oueili site (Fig. 1.3), dating from 4700-4200 BC (Neef, 1991). The northern part of Mesopotamia was occupied for several millennia before the southern part. For example, human settlements from the 9th millennium BC have been recorded (see, for example, Philip, 2002). Several research projects such as that by Clarke *et al.* (2016) suggest that the marine transgression of the Arabo-Persian Gulf prevented humans from settling in southern Mesopotamia.
However, in the present study, it can be suggested that there is a possibility of human settlement existing before the Ubaid period. The evidence behind this claim is that the alternation between the riverine and the marsh environment that has been clearly found in the BH33 borehole (Fig.3.38) at 13m depth showed four marsh beds and three floodplain beds alternating in the lithological section. The oldest marsh bed accumulated between 7750 and 7600 BC. In other words, there was a suitable environment for rivers, floodplains and marshes. Therefore a very suitable environment for hunter-gatherer populations and possibly similar to the one of the 5th and 4th millennium BC, especially, when the shoreline of the Gulf did not overtake Ur, as mentioned later.

5.1.6 Sedimentation rate

One attempt was carried out by previous researchers to estimate the sedimentation rate of palaeochannels in the Mesopotamian floodplain. When Wilkinson *et al.* (2015) conducted two cross-sections of the Kutha palaeochannel to the north of Adab, he determined the age of beds using the dating of archaeological objects ("clay sickles and goblets") to identify the early-late 3rd millennium BC level, and pottery sherds to identify the Sasanian Early Islamic level. Accordingly, he estimated that the sedimentation rate was between 0.73 to 0.51 mm per year for the palaeochannels in this area.

In the present study, not all the boreholes dug were suitable for estimating the sedimentation rate. The boreholes that have been selected for this purpose were only those where accumulations has been dated both of the start and the end of sediments. Both of the dating methods (the radiocarbon or the archaeological site) were adopted to date the beds and then to estimate the sedimentation rate of the palaeochannel. Accordingly, boreholes BH41, BH30, BH10, BH39, BH8, BH36, BH28, BH42 and BH26 were used to estimate the sedimentation rate while the rest were ignored.

The results show that the sedimentation rate fluctuated between the lowest, of 0.5 mm/year, and the highest, 7.4 mm/year. They also show that in the modern Gharraf channel, the sedimentation rate of channel levees is higher (5.5 mm/year) than the channel floodplain (1.4 mm/year). Jacobsen (1958) concluded the same as these results in connection with the sedimentation rate, but did not measure them, during their survey in the Diyala area. They described it by saying "*the rate of deposition is not uniform. It is most rapid along the major rivers and canals, and their broad levees slope away to interior drainage basins where accumulated runoff and difficult drainage have led to seriously leached soils and seasonal swamps* ".

However, it seems that the sedimentation rate in the Ur area channels was relatively the lowest as it was less than 1.6 mm/year, approximately. In contrast, the Kut area channels had the highest rate of more than 2.6 mm, reaching 7 mm/year. This might be because the Tigris (from Baghdad to Kut) had been flowing since the 1st millennium BC in a confined meander belt in a single, meandering pattern but when it reached the Kut area, it started running across an open meander belt . Therefore it bifurcated and deposited the greatest amount of its load of sediment as a result of losing of energy to transport these sediments.

Therefore, it is clear now why the accumulation of sediments in the Kut area has increased since the 1st millennium BC. It might be because the Kut area became a favourite place for human settlements as new fertile land was forming there. At the same time, downstream from the Ur area channels started to be abandoned and was therefore covered by the sediments of the Kut area.

Borehole No.	Date of the older bed (year BC/AD)	Date of younger bed (year BC/AD)	Distance between the two dated beds (mm)	Duration of sedimentation (year)	Sedimentation rate (mm/year)	Figure
BH41	4040 BC	1410 AD	2500	5450	0.5	3.37
BH30	5840 BC	700 AD	5000	6540	0.8	3.39
BH10	910 BC	700 AD	2000	1610	1.3	3.28B
BH29	430 AD	2013 AD	2250	1583	1.5	2.4
BH39	3980 BC	760 BC	5000	3220	1.6	3.36
BH8	2860 BC	700 AD	6000	3560	1.7	3.17A
BH36	340 BC	700 AD	2500	1040	2.4	2.27
BH28	810 BC	700 AD	4000	1510	2.7	4.47
BH42	1280 AD	2013 AD	4000	733	5.5	4.48
BH26	920 AD	1258 AD	2500	338	7.4	4.46

Table 5.1: Sedimentation rate of the presents study.

5.1.7 Choking of channels

One of the most significant issues that faced and still faces channel sustainability in the Mesopotamian floodplain is choking, mostly by deposits of channel sediments and sometimes freshwater weed. People frequently clean and maintain the channels, but in some stages, the channels become choked to such a degree that there is no alternative to dealing with it but to leave it and choose between digging new one or leaving the settlements entirely.

The present channel network of the area under study, including major and minor river channels, irrigation canals, and drain channels, is controlled by differing sizes and types of dams and barrages. Otherwise, avulsions would take place more frequently.

However, as the gradient of the floodplain is relatively low in the southern part, from the Samawah – Kut downstream as far as the marshland area (Figs. 1.3), people there tended to dig new canals in the case of choked channels, rather than abandon settlements and migrate to others. Interestingly, in this region, no main channel avulsions except those of the Tigris river in the Kut area have been reported. The reasons for the lack of avulsion in this regions are: first, it is a low gradient area so that the channel beds cannot become level with or higher than the surrounding floodplain, a pre-condition to the initiation of the avulsion process; secondly, it is a marsh area bounded by natural barriers so that even if the channel levees were breached, water would flow slowly and merge with the marsh, offering no opportunity for the formation of a new channel.

5.1.8 Reservoir effect on shells

It has frequently been reported that two reservoir effects are applicable to the radiocarbon dating of shells and lead to obtaining apparently differing ages: the hard water effect and the marine effect. These two effects must be calculated in order to achieve more accurate shell ages (Bowman, 1990).

The marine effect is a consequence of both the delay in exchange rates between atmospheric carbon dioxide and ocean bicarbonate, and the dilution effect caused by the mixing of surface waters with upwelled deep waters (Stuiver *et al.*, 1998). The marine effect can be determined, for example, by comparing the results of dating both of plant material such as charcoal and marine shells situated in the same bed (Facorellis *et al.*, 1998).

The hard water effect is the existence of calcium ions that result from the dissolution of older CaCo3 dissolved into the freshwater source from materials such as limestone through which the lake or streams move (Philippsen, 2013). This effect can be calculated in several ways, such as dating living shells in the same area to see if they yield current results or older results (Zhou *et al.*, 1999), dating known-age shells of the same species from the same locality that were collected before nuclear weapons testing ("pre-bomb") of the 1950s and 1960s (Rea and Colman, 1995) and dating organic material such as a seed or twig in close context with the shell, and then assuming the 14C age difference between them is the reservoir effect for that time period (Facorellis *et al.*, 1998; Zhou *et al.*, 1999; Philippsen, 2013).

In the present study, none of the mentioned analyses has been applied because 1) pre-bomb shells from the Mesopotamian floodplain are not available and 2) living shells have already been affected by nuclear weapons testing. Unfortunately, the quantity of plant materials (such as peat, charcoal and twigs, seeds) that were sampled was not enough to yield a radiocarbon date; therefore the test was considered a failed test during the analysis process.

However, in the present study, it can be assumed that the shells from the freshwater of Mesopotamian floodplain were not greatly affected by hard water. This assumption might be supported by the following points:
First, several shell radiocarbon dating samples have revealed good dates equivalent to some known-age sediments. These are:

1. The Khandaq Shapur canal (borehole BH34, see Fig. 3.28C) which is well known, from the Sasanian period (226-637 AD) with a radiocarbon date of 420 AD to 570 AD.
2. The Modern Gharraf channel (borehole BH42, see Fig. 4.48) formed during the 13th century AD and with radiocarbon dates of Cal AD 1280 to 1400.
3. The Dujaila canal (borehole BH26, see Fig. 4.46), active during the Sasanian period and began to be abandoned, silting up during the late Islamic period - the Medieval Period of Islam (900-1500 AD) with radiocarbon dates of 920 to 970 AD.
4. The marsh that covered the south west area of southern Mesopotamia during the Medieval Period of Islam (900-1500 AD) the radiocarbon dates for which marsh sediments are 770 to 900 AD (borehole BH30, see Fig. 3.39).
5. The marsh that covered the centre of southern Iraq during the Ottoman period (1500-1918 AD) (e.g. Husain, 2014 & 2016) with radiocarbon dates for related samples from this marsh being 1410 to 1445 AD (borehole BH41, see Fig. 3.37).

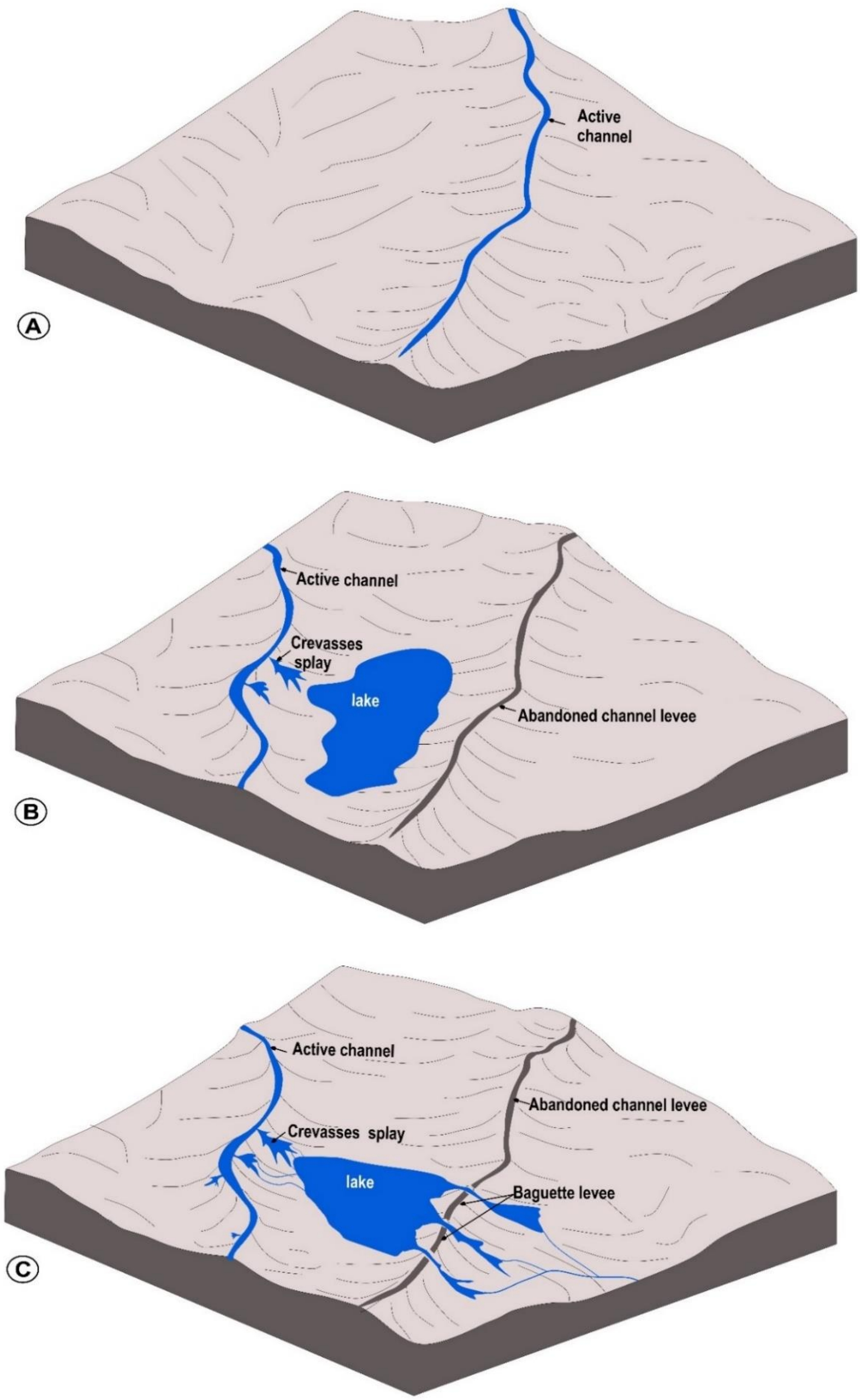
It is clear from the cases mentioned that it would be not sensible to suggest that hard water can provide ages thousands of years older than the current age result, because if we added several hundred years to the current radiocarbon ages, their dates would be closer to recent time rather than to the past.
Second, all the radiocarbon dates in the present study have shown sequential dates and there is no overlap among the results in the same borehole i.e. the lowest shell is the oldest. These results are the four date samples for borehole M38 (Fig. 3.38), the two dates for borehole M35 (Fig.3.45), the two dates for borehole M28 (Fig. 3.46) and the two dates for borehole BH41 (Fig. 3.37). There are some examples, such as Zhou *et al.* (1999) where the hard water effect was found to be significant, thus yielding overlapping dates: i.e. the lower shell sample yielded a later date than the upper sample from the same borehole.
Third, in the present study, the shell sample dates that have been taken from channel sediments have shown good matches with the archaeological sites associated with the channel. This also means that the hard water might not have that effect. It is worth mentioning the work of Hritz *et al.* (2012) who collected shell samples from inside several archaeological sites in southern Mesopotamia and used AMS to date the shells. They did not apply the hard-water effect correction when they dated the shell samples from southern Mesopotamia, as these samples were from freshwater environments and limestone outcrops were some distance away from the sample locations. They also demonstrated good matches between shell radiocarbon ages and associated archaeological sites.

5.1.9 Baguette levees

There are cases across the Mesopotamian floodplain of palaeochannel levees where the levee has the *baguette* form. This is a new term defined by the author and initially summarised in

Jotheri et al (2015). The term describes a geomorphological feature formed when relatively high-elevation levees show, in specific reaches, a series of breakdowns or transversal gaps across the levees (Fig. 5.6). The aerial view of these gaps, readily apparent in satellite imagery, resembles a baguette loaf (see for example figs. 5.7 to 5.12).
The interpretation of this feature is that is can be formed when the older channel levees are cut by flooding of the younger channel. In other words, when the relatively elevated palaeochannel levee initially acts as a barrier to the active channel water (flood or crevasse splay), water may eventually crosses the palaeochannel levee at several locations during a time of high river discharge. Over the duration of the flood period these locations become entrenched and form waterways, transferring water to the other side of the barrier (levee) (Fig. 5.6). Over time, discharge settles into a new pattern, with one main channel cutting across the palaeolevee, and the other channels becoming abandoned and left as relict features in the landscape. Figure 5.8 shows a particularly clear example of this evolution, where a branch of Pallukkatu palaeochannel was cut by the modern Euphrates channel. This interpretation offers an explanation of the otherwise odd geometry seen commonly across the Mesopotamian floodplain, whereby an ancient levee system is cut across by a younger channel.

The presence of baguette levees across the Mesopotamian floodplain (Fig. 5.7) indicates that no special conditions are needed for their formation. It is anticipated that more examples will be discovered in other river systems of similar discharge, gradient and meander belt geometry to the Euphrates and Tigris.



Figures 5.6: Sketches showing mechanism of forming a baguette levee. (A) Active channel is running in the floodplain and building up levees. (B) By the time, for one reason or other, it became abandoned and other channel started running close to the previous one. Water spills over-bank and assemblage in a lowland area between the new and the abandoned channel during the flooding time or as a result of breaking levees. (C) Water runs over the abandoned levees when exceed the lowland capacity and cutting the levees in different places.

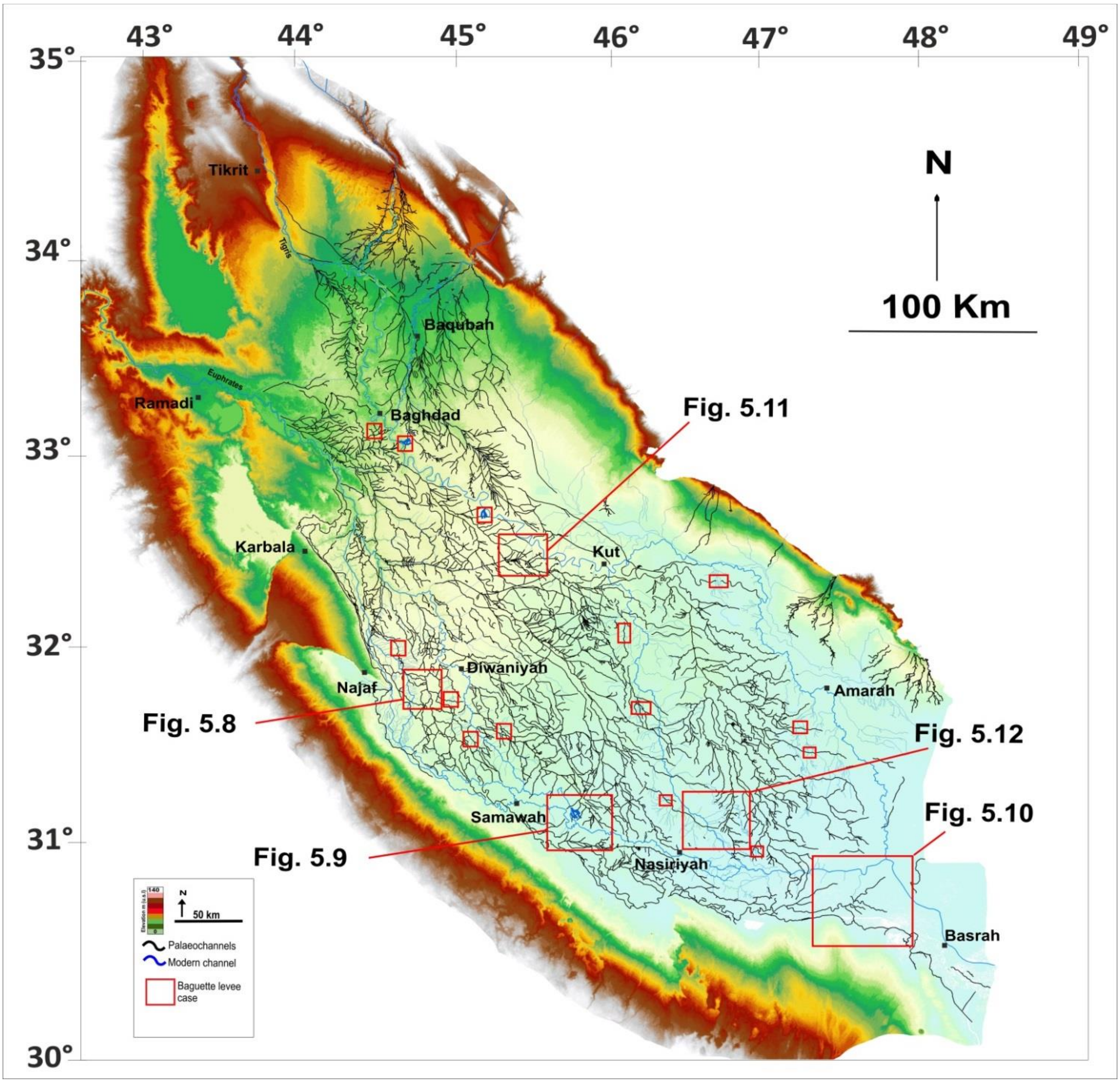


Figure 5.7: Location map of the Mesopotamian floodplain showing the nineteen reported baguette levees in the present study.

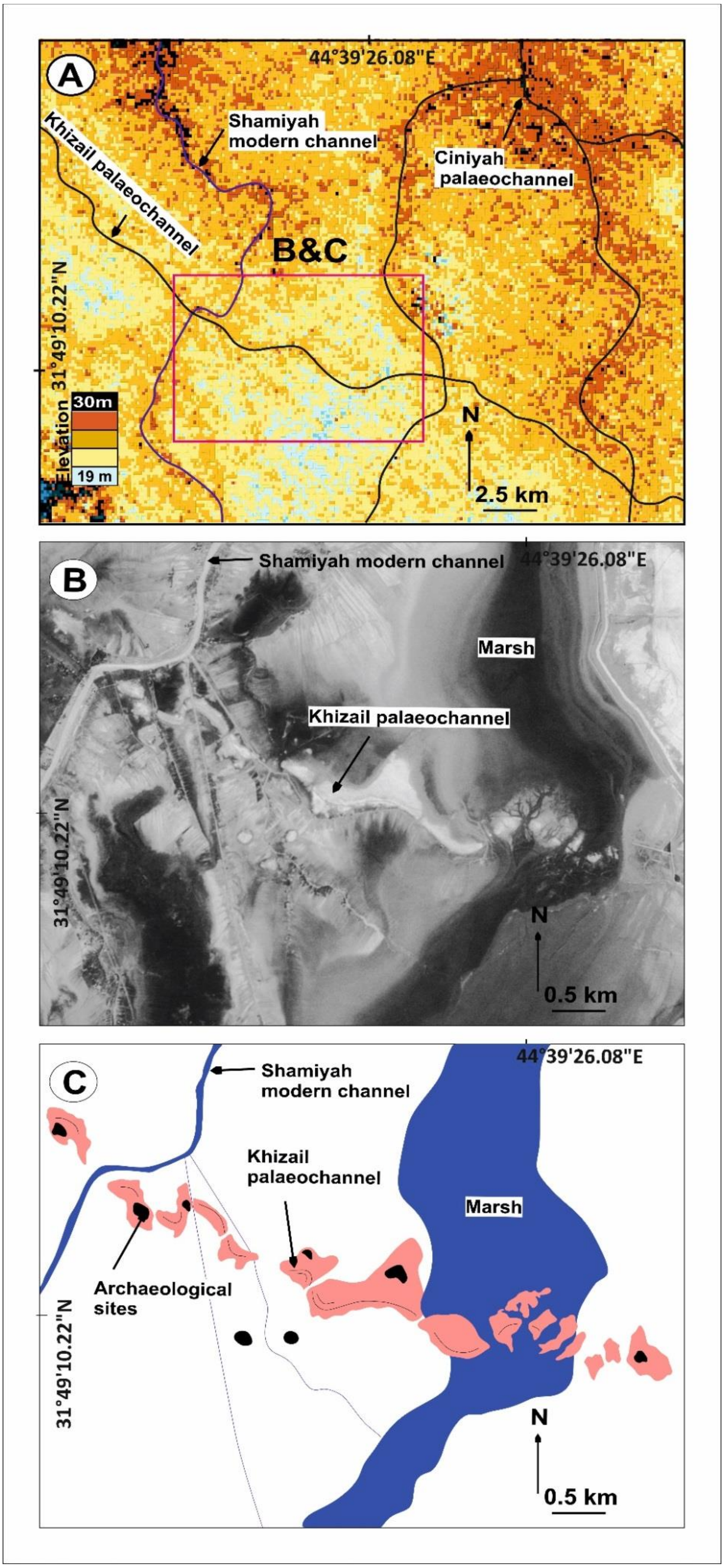


Figure 5.8: An example of baguette levee located to the south east of Najaf showing how the relatively high elevated abandoned levee of Khizail palaeochannel which was cut by the modern Shamiyah channel water. (A) SRTM map, (B) CORONA image and (C) Sketch showing the identified feature in the A and B.

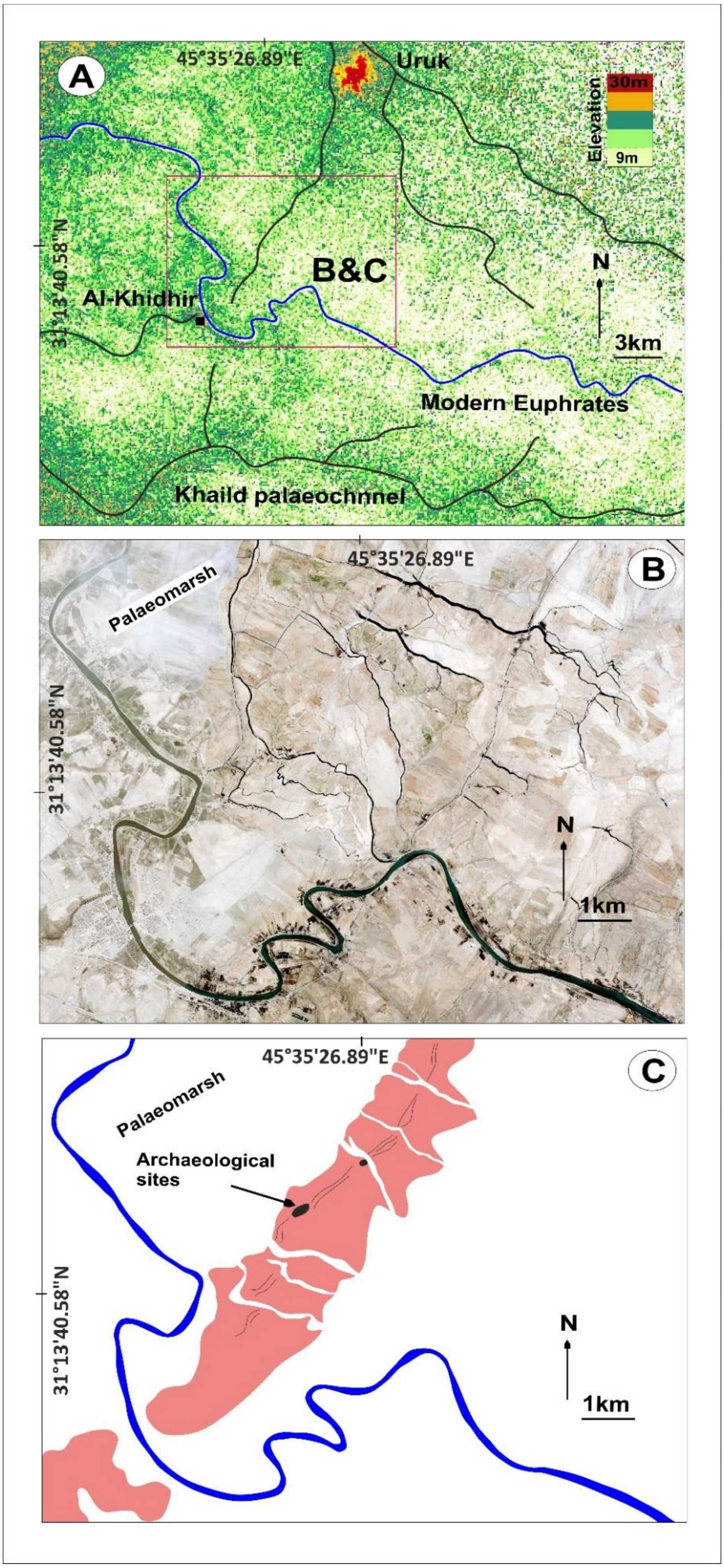


Figure 5.9: An example of baguette levee located to the north east of Samawah showing how the relatively high elevated abandoned levee of a branch of Pallukkatu palaeochannel was cut by the modern Euphrates channel water. (A) SRTM map, (B) QuickBird image and (C) Sketch showing the identified feature in the A and B.

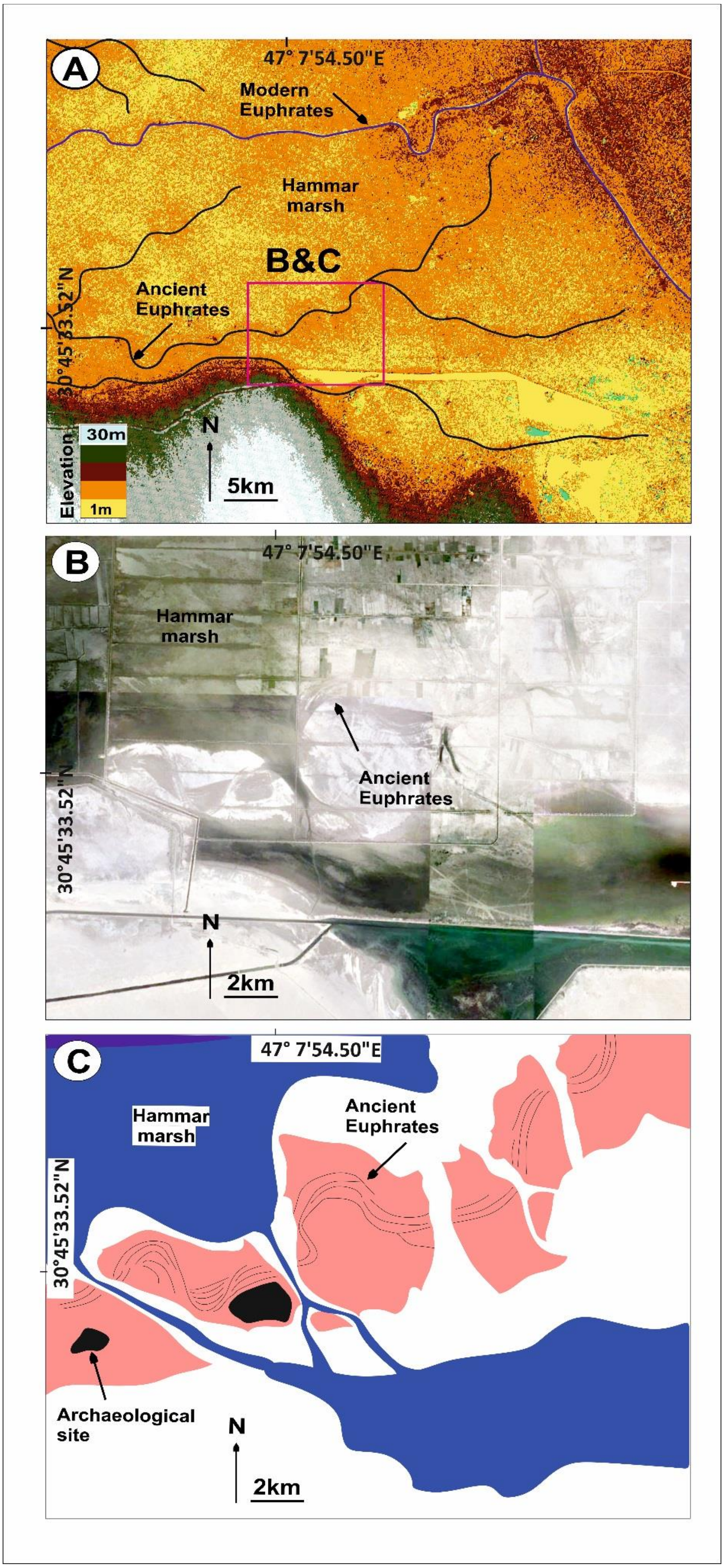


Figure 5.10: An example of baguette levee located to the north west of Basra showing how the relatively high elevated abandoned levee of the ancient Euphrates which was cut by the modern Euphrates channel water. (A) SRTM map, (B) QuickBird image and (C) Sketch showing the identified feature in the A and B.

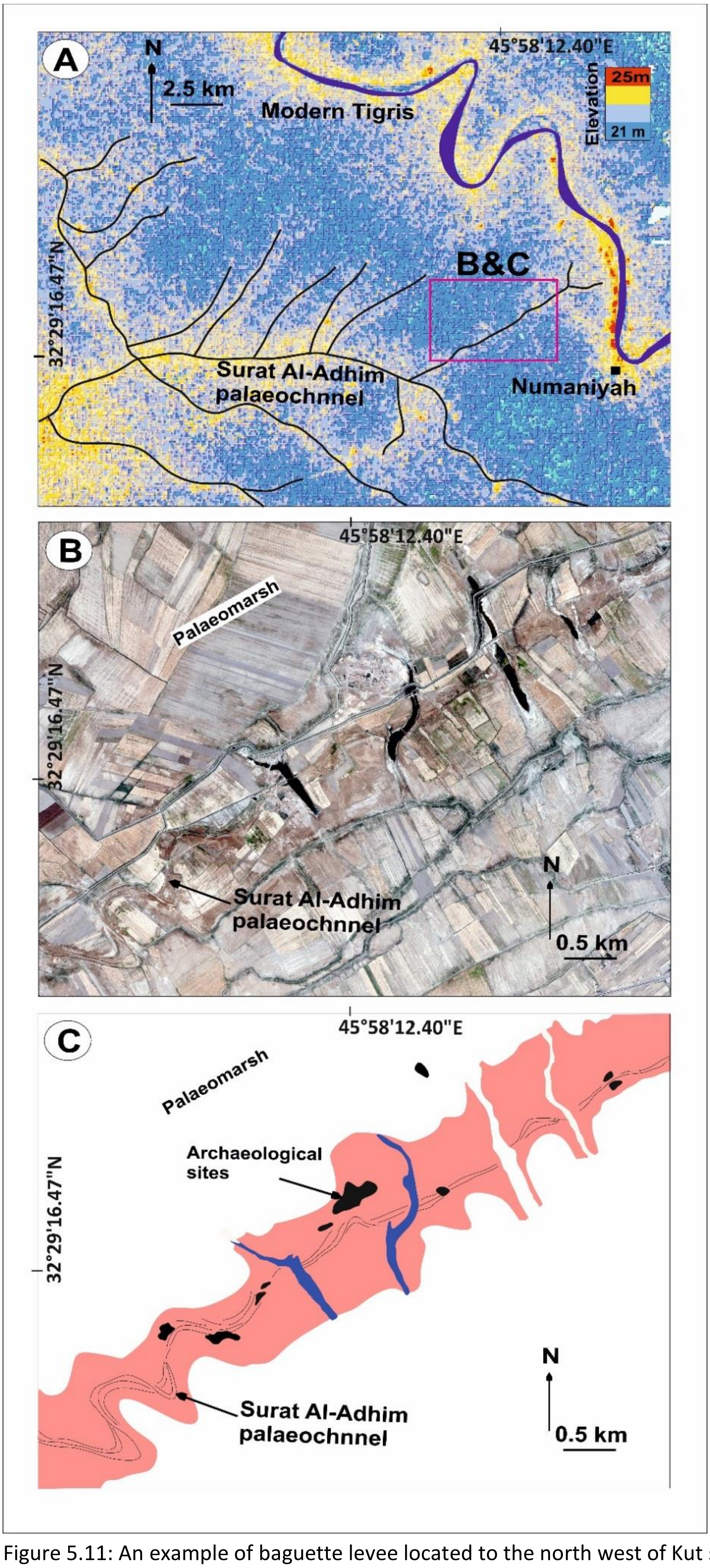


Figure 5.11: An example of baguette levee located to the north west of Kut showing how the relatively high elevated abandoned levee of the Surat Al-Adhim palaeochannel which was cut by the modern Tigris channel water. (A) SRTM map, (B) QuickBird image and (C) Sketch showing the identified feature in the A and B.

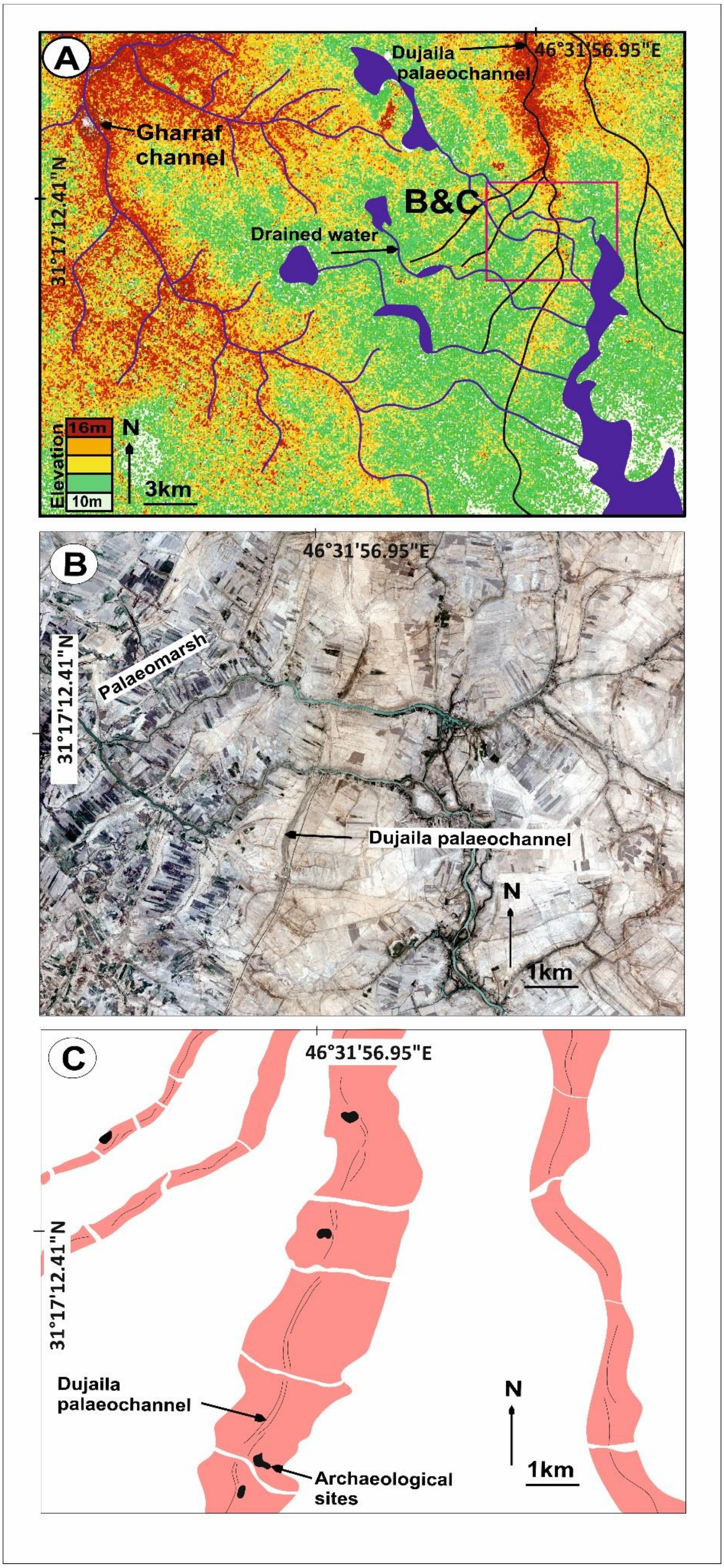


Figure 5.12: An example of baguette levee located to the east of Nasiriya showing how the relatively high elevated abandoned levee of the Dujaila palaeochannel which was cut by the modern Tigris channel water. (A) SRTM map, (B) QuickBird image and (C) Sketch showing the identified feature in the A and B.

5.2 Conclusions

Several conclusions can be highlighted as a result of the present study and can be summarized by the following points:

5.2.1 River avulsions

This study has reconstructed all the visible palaeochannels and archaeological sites within the area of southern Mesopotamia. The periods when each of these palaeochannels were active, avulsed and desiccated was determined. Only two main river avulsions had been reported in previous works, such as those by Heyvaert (2008) and Morozova (2005), while in the present paper nine more avulsions are reported. Therefore, it is argued that eleven main river avulsions have happened in the entire floodplain since the Middle Holocene.

These avulsions can be summarized in the following table (Table 5.1) and Figure (Fig. 5.13). It is proposed that these avulsions contributed to the shaping, forming and aggrading of both the ancient and present–day landscapes of the floodplain. Moreover, these avulsions have affected the distribution, flourishing and degradation of human settlements of the southern Mesopotamian civilisation.

River	Original course	Avulsed course	Type of avulsion	Estimated date of avulsion
Euphrates	Purattum	Arahtum	Re-occupational	The early 1st millennium BC
	Arahtum	Sura	Re-occupational	The late 1st millennium BC
	Sura	Hilla	Progradational	The 13th century AD
	Hilla	Hindiya	Progradational	The early 20th century AD
Tigris	West Balad Mesa	The Balad course	Re-occupational	The 5th millennium BC
	Balad course	Dhuluiya	Re-occupational	The 13th century AD
	Dalmaj	Baghdad & Dijla-Alaoura	Progradational	The early 2nd millennium BC
	Dijla Aloura	Dujaila	Re-occupational	The early 1st millennium AD
	Dujaila	Shayk-Saad	Progradational	The 13th century AD
Adhaim	The Adhaim palaeochannel	Modern Adhaim	Re-occupational	The late 1st millennium Bc
Diyala	The Diyala palaeochannel	Modern Diyala	Re-occupational	The late 1st millennium Bc

Table 5.2: All the identified channel main avulsions in the present study (see Fig. 5.13)

5.2.2 Coexistence of the Tigris and the Euphrates

It had been long thought that the ancient Tigris and Euphrates, after they entered the floodplain separately, met near Baghdad and ran as one course to the south (e.g. Susa, 1948; Adams, 1981; and Al-Sadoun 2000). However, the present investigation suggests that they have run separately in the floodplain, at least since the Middle Holocene, but since this period, the western distributors of the Euphrates drained their water into both the Tigris courses, the first branch was the Purattum (Fig.3.2), during the 4^{th} millennium BC, and the other was the Surat-Adhaim (Fig.3.4), until the 13^{th} century AD.

5.2.3 Dating of palaeochannels

This study shows that using periods of human occupation of archaeological sites to date associated palaeochannels provides acceptable accuracy, and can give clear indications about the activity of a given channel, i.e. human occupation should run parallel with the channel when the channel is operating. The reason behind this argument is that there are good matches between the radiocarbon dating of shells taken from palaeochannels and the periods of archaeological sites associated with the said channel.

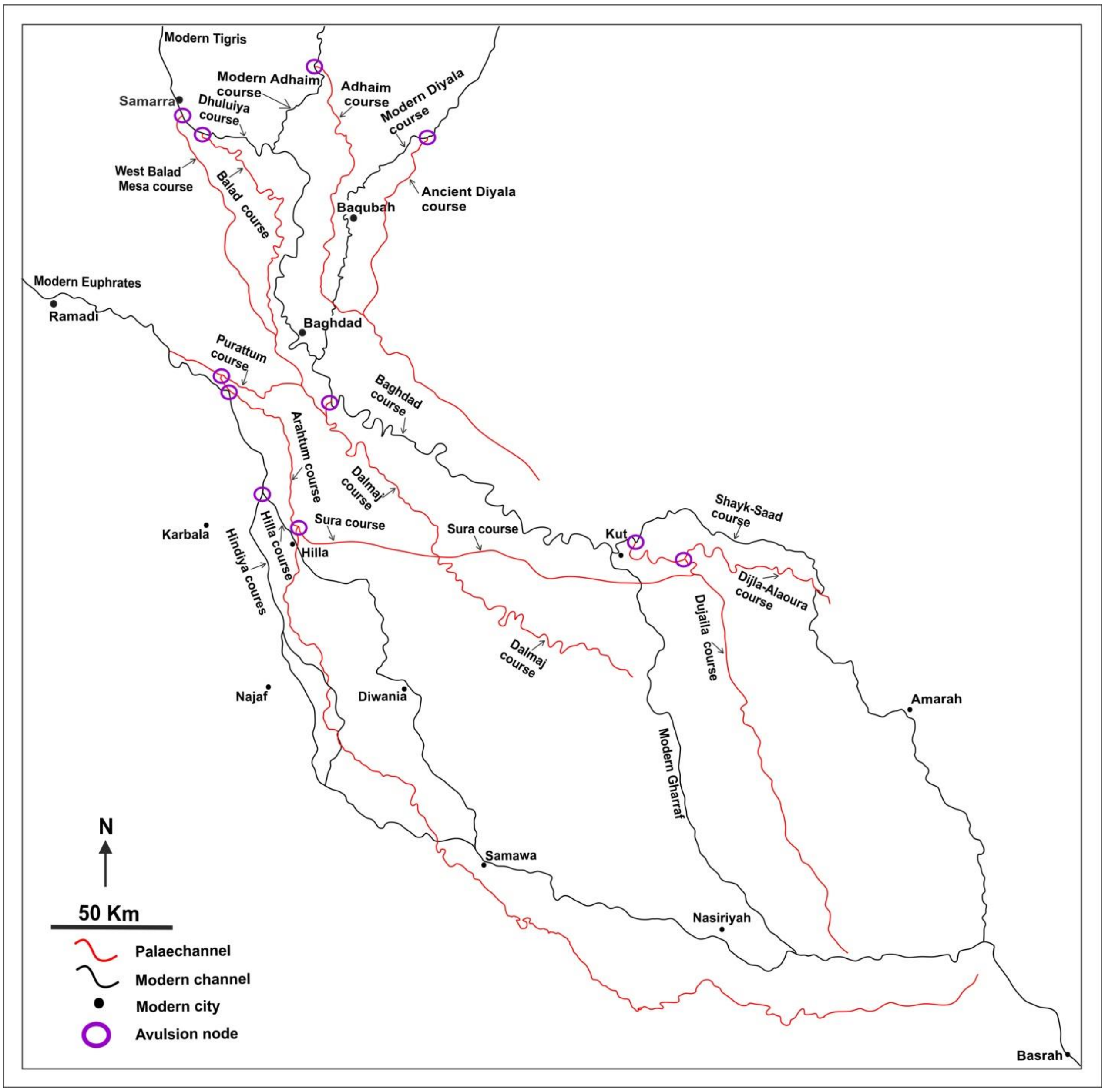


Figure 5.13: All the identified channel main avulsions in the present study.

5.2.4 Human impact on river geomorphology

For a long time, there has been considerable ignorance of the role of human impact on the river geomorphology of the Mesopotamian floodplain, especially among local Iraqi archaeologists, geologists and geomorphologists. However, the present study has showed how human impact has played a leading role in shaping both the ancient and the modern landscapes of the Mesopotamian floodplain, as people dug large canals, diverted rivers and dried out marshes. In fact, several reaches of modern rivers were originally dug as canals in the past. Therefore, it might possibly be argued that anthropogenic factors have been the most influential aspect in river geomorphology in comparison to other factors such as tectonics, natural flooding or climate change.

5.2.5 The ancient shoreline of the Persian Gulf

According to the borehole lithology and radiocarbon dating results, it can be argued that the ancient shoreline of the gulf was near the location of modern city of Nasiriya in the west and Amara in the east of the floodplain. The regression started in the Middle Holocene. Therefore, in this conclusion, I support the geological works of Hudson *et al.* (1957) and Aqrawi (1995 and 2001). In contrast, I disagree with the conclusions of Pournelle (2003) and Al-Dafar (2015) in their estimation that the shoreline was further to the north, reaching the location of Uruk and Wilaya.

5.3 Future research

5.3.1 Fieldwork

There has been no fieldwork or ground-truthing in the areas of Samarra, Adhaim, Diyala and the area north of Baghdad. Furthermore, sufficient geological data are not available to establish the river courses in the floodplain before the Middle Holocene, which would of course help to understand the area. However, it is hoped that the opportunity will arise to complete similar studies across these areas of the region, applying a wider range of dating techniques, such as optically stimulated luminescence (OSL).

5.3.2 Eastern alluvial fans

Several fans are located to the east of the Mesopotamian floodplain including Mandali, Tursaq, Badrah, Shayk Saad, Al-Teeb and Buzergan fans (Fig. 1.3). Each one of these fan contained number of palaeochannels and archaeological sites that have been noticed clearly during the remote sensing investigation of the present study, but the issues of channel avulsions and human irrigation activities have not been discussed. Therefore, it is worth studying the channel geoarchaeology in these alluvial fans, because primary indications suggest that they were intensively manually irrigated in the past.

5.3.3 Eridu region

In the present study, no boreholes were dug in the ancient reach of the palaeochannels that extend from the Nowaeess to the Eridu sites (Fig.3.35). This reach meanders, is less canalised and used to run across an unconfined meander belt. Therefore digging several boreholes in this area and dating the organic materials for each reach might determine possible river avulsions and could provide some more details about the geoarchaeology in this area.

5.3.4 Climate change

In Southern Mesopotamia, Holocene climate change has not been studied directly yet, although it can be suggested that Sawa Lake (Fig. 1.3) is the best location to study sedimentation records and determine the climate change during the Holocene. The lake is located in the mid-western part of the floodplain, i.e. between the floodplain and the Arabian Plateau. It was originally a topographic depression, and has been filled with spring water since the Pleistocene (Jassim and Goff, 2006). Therefore, a full record from the Pleistocene to the recent era exists. Moreover, the fossil pollen and spores accumulated at archaeological sites can also be studied to determine past environments, in terms of humidity and common kinds of plants. Therefore, the alternation of riverine, marshy and desert environments that has been found clearly in the borehole sections of the present study can also be found in the sites, thus increasing the certainty regarding the environment common to each archaeological occupation. For example, such analysis can be carried out to determine the environment in the marshland area and prove whether it was constantly covered by marsh or if it was also subjected to riverine or desert changes.

5.3.5 Palaeo-sol analysis

It has been widely argued that anthropological soil, i.e. the soil that has been used for occupation or production in the past, has unique chemical fingerprints, different from natural soil. For example, Oonk *et al.* (2009) argued that phosphorus (P) and in some cases calcium, potassium, sodium, magnesium, copper and zinc are predominant in anthropological soil when it is subjected to planting, livestock waste, ashes and sewage. Therefore, identifying the pasture and arable land associated with palaeochannels or archaeological sites would help in discovering human activities in the past. For example, such analysis could be applied in the Ur area, as it has long been occupied and not covered completely by modern sediments.

These are the main conclusions and suggestions of the present study. It is clear now that the main questions of the present study have been answered as a result of employing geoarchaeological data, remote sensing and ancient texts. The time, style and causes of river avulsion during the Holocene have been identified. The impact of river avulsion on the distribution and survival of human settlements of ancient civilizations has been discussed. The role of the anthropogenic activities on the forming, reshaping and controlling of palaeochannels and fluvial processes have been determined. The geo-archaeological development of the major palaeochannels levees has been addressed and finally the recognition and documentation of palaeochannels and archaeological sites has been carried out demonstrated in details.

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