Reconstructing landscape evolution in the Lower Khuzestan plain (SW Iran): Integrating imagery, historical and sedimentary archives

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LANDSCAPES THROUGH THE LENS

AERIAL PHOTOGRAPHS AND HISTORIC ENVIRONMENT

edited by
David C. Cowley, Robin A. Standring and Matthew J. Abicht

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Front cover: Étang de Montady, Languedoc-Roussillon in southern France. A remarkable pattern of field boundaries created in the 13th century on a reclaimed lake photographed on 6 August 1944. Drains converge on the circle which lies at the centre of the former lake, with water then transported out of the shallow basin through a tunnel 1.3km long under the Hill of Malpas. TARA_MAPRW_106G_1960_4175, © Crown Copyright, RCAHMS

Back cover: Erbil, the capital of Iraqi Kurdistan, is a claimant to the title of oldest continuously inhabited settlement in the world. The modern city is still dominated by the ancient tell, recorded here on 22 October 1948 when still a relatively small town. RAF_13A/131_3144, © Crown Copyright, RCAHMS

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11. Reconstructing landscape evolution in the Lower Khuzestan plain (SW Iran): integrating imagery, historical and sedimentary archives

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Introduction

The Khuzestan region had an important role in the development of early civilisations and the great empires of Mesopotamia. Environmental conditions in the upper plains were advantageous for agricultural practices, in particular for the early development of irrigation. The geographical position of Khuzestan was also of strategic significance lying between the lowlands of central Mesopotamia and the highlands of Iran, and near the head of the Persian Gulf (Adams 1962; Alizadeh 1985).

Both in relief and climate, there is a strong contrast between the dry, flat plain of Lower Khuzestan and the Zagros Mountains. The effective rainfall is strongly correlated with elevation, and farming in the lower plains is impossible without irrigation (Kirkby 1977). Consequently, societies have always depended on the position of the major rivers for their economic survival.

Because of an assumption that Lower Khuzestan was too dry to support settled communities without the use of large-scale canal irrigation, there has been a general lack of archaeological interest in the region and only a few limited surveys undertaken (Hansman 1967; Alizadeh 1985; Gasche and Paymani 2005). However, even from this limited information it is clear that since Parthian times (*c.* 160 BC–AD 221) the lower plains were the focus of huge irrigation and settlement programs, resulting from enormous investments and technical innovations. Absence of pre-Islamic sites further south has been attributed to marine influence extending further inland than at present, but could very well be explained by the general lack of archaeological information.

This paper presents a reconstruction of the landscape evolution of the Lower Khuzestan plain, in particular of the Karun River. Past and present landscape elements have been recorded, focussing on alluvial processes, but also accounting for man as an important agent. Given the vast size of the region, and its limited accessibility, the use of remote sensing techniques is crucial for providing a geomorphological context to the information derived from other disciplines, which include archaeological, geological and historical data-sets. The methods used and results obtained in the different research fields will be presented, culminating in an integrated synthesis of the evolution of the Karun alluvial system.

Regional setting

The Lower Khuzestan plain is the south-eastern extension of the Mesopotamian sedimentary basin. In the north and east the plain is bordered by foothills of the Zagros Mountains; in the south by the Persian Gulf, fringed by a large tidal inlet (Figure 11.1). Subsidence of the basin and uplift of the mountains are associated with the collision of the Arabian and Eurasian tectonic plates. The orogenic uplift started during Late Miocene and is still ongoing (Hessami *et al.* 2006). The Zagros Mountains are an important source for the alluvial sediments of the plain.

The plain is extremely flat and dominated by three major rivers – the Karkheh, Karun and Jarrahi. In the northwest, upon entering the plain, the Karkheh River crosses the Ahwaz anticline near Hamidiya. Shortly after, the river splits into two main branches, both ending in the Hawiza Marshes. The Karun River crosses the same anticline in Ahwaz, then meanders southwards through the central plain, and joins the Shatt al-Arab before ending in the Persian Gulf. Just before its confluence with the Shatt al-Arab, the Karun splits into the Shatt al-Haffar and the Shatt Bamishir; the latter debouches into the sea separately. The Karun supplies the bulk of freshwater and suspended sediment load to the Shatt al-Arab estuary (Baltzer and Purser 1990). In the southeast of the plain, the Jarrahi empties into the Shadegan Marshes.

The climate of the study area is hot and arid: in summer temperatures may rise up to 58˚C, while annual rainfall is less than 200mm (Potts 1999). The perennial rivers receive most of their discharge from autumn and winter rains in

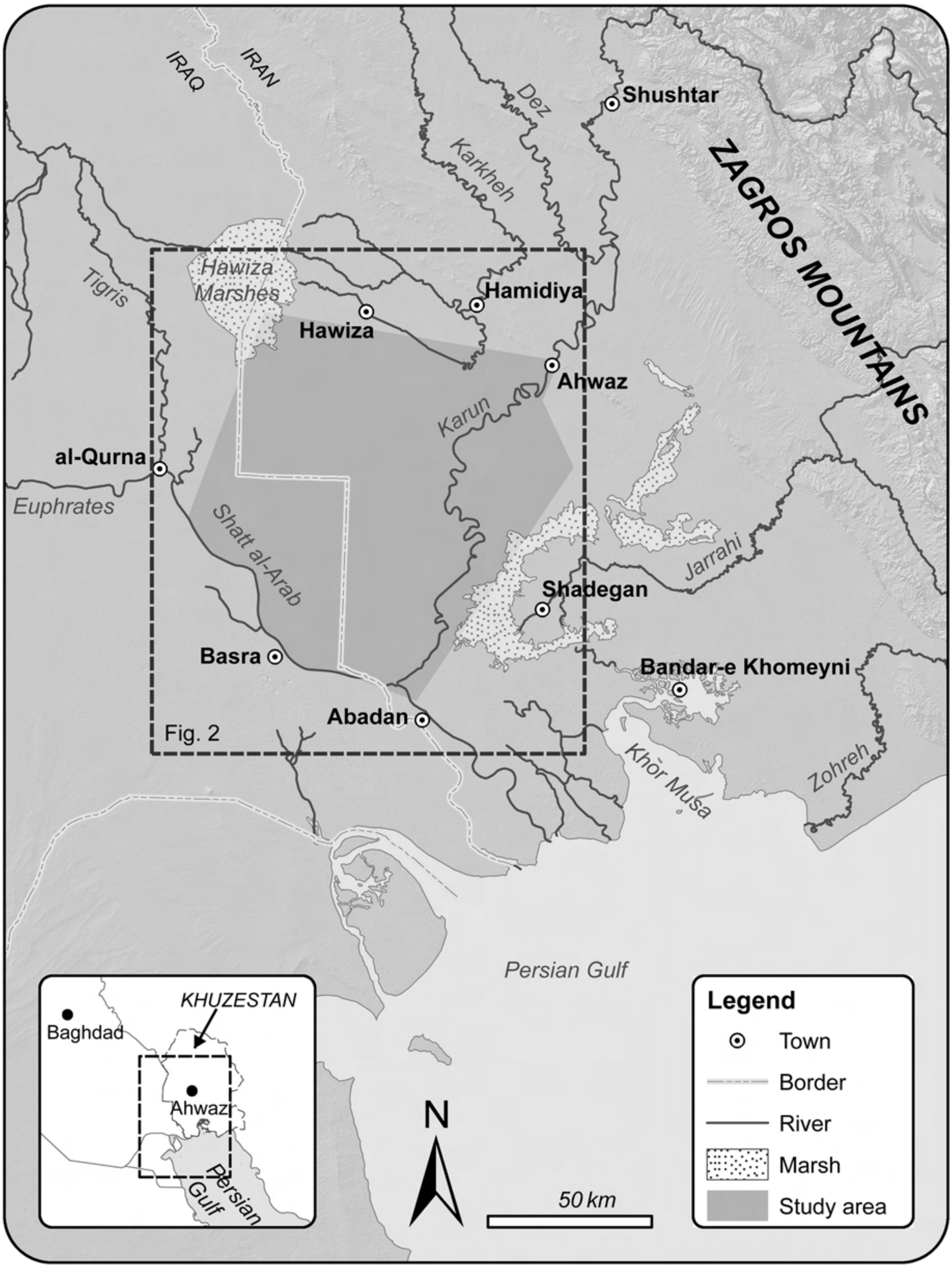

Figure 11.1: Location of the study area in Lower Khuzestan.

the Zagros Mountains, causing extensive seasonal flooding of the marshes. The present case-study is restricted to the western part of the plain, including the Karun and its palaeochannel belts. The area is bounded by the modern channel belts of the Karun (inclusive), Karkheh and Shatt al-Arab, and the Hawiza Marshes (Figure 11.1).

Previous research

Geology

Since the 19th century researchers have debated the Holocene evolution of the Mesopotamian plain, based on historical sources and archaeological data. Early theories claimed that, as a result of post-glacial sea level rise, the head of the Gulf shifted far inland, followed by gradual retreat caused by delta progradation (*e.g.* Beke 1835; Ainsworth 1838; de Morgan 1900).

Lees and Falcon (1952) challenged these 19th century concepts and instead suggested a delicately balanced system between tectonic subsidence and sedimentation. This scenario was strongly criticised in the 1970s by authors who emphasized the influence of sea-level changes on the evolution of the Shatt al-Arab delta, rather than tectonics (Purser 1973; Larsen 1975; Larsen and Evans 1978). Later research in the region supported this view (*e.g.* Sanlaville 1989; Baltzer and Purser 1990; Lambeck 1996; Sanlaville and Dalongeville 2005). The latter authors provided evidence for a maximum post-glacial transgression to a sea level of +1–2m at around 4300 BC in Lower Mesopotamia, with the presumed shoreline extending as far as present-day Nasirya, Amara and Ahwaz. They suggested that this maximum was followed by a period of rapid progradation of the Tigris-Euphrates-Karun delta.

However, recent work by Heyvaert and Baeteman (2007) has proved that this proposed Holocene high water above present-day levels never occurred, and the lateral extension of the sea did not reach as far as Ahwaz. This study showed that during the early and middle Holocene the Lower Khuzestan plain was a low-energy tidal embayment. The sedimentary infill of this embayment was controlled by the interplay between fluvial sediment input and decelerating sea-level rise.

Relatively little attention has been paid to the evolution of the alluvial systems of Lower Khuzestan. Meander patterns of an abandoned river across the plain between Ahwaz and the Shatt al-Arab were briefly mentioned by Hansman (1967) and Kirkby (1977), both using aerial photographs. Later, the same palaeochannel was also mapped from satellite imagery (Baeterman *et al*. 2007). Hansman attributed the meanders to a former course of the Karkheh and used it to identify the ruins of the ancient city of Spasinou Charax. Kirkby, on the other hand, attributed the meanders to the Karun, or a combined Karun-Karkheh flow, based on a relationship between meander wavelength and bankful discharge, though Hansman's identification of Spasinou Charax remained undisputed. Baltzer and Purser (1990) recognized the present Karun channel as the main channel belt of a large alluvial fan with a radius of about 100km. Heyveart and Weerts (2007) demonstrated that the evolution of this Karun 'megafan' is the product of repeated avulsions.

Archaeology

Only very limited archaeological information is available. The most extensive survey was carried out by McCown in 1948, who recorded 44 sites in the vicinity of Ahwaz and Hawiza. But, these were only the ones visible from roads he could drive along and the material was left unpublished for almost four decades (ultimately published by Alizadeh 1985). Based on surface finds of pottery most sites were attributed to Sasanian (*c*.221–640 AD) or Islamic (after *c*.640 AD) times, and a few to the Seleucid (*c*.312–140 BC) and Parthian periods. This view was confirmed by a recent survey (Gasche and Paymani 2005) which noted another 15 sites, all occupied between Seleucid and Islamic periods. Further significant information is provided by Hansman (1967), who identified the ruins of Naisan with the ancient city of Spasinou Charax. Kirkby (1977) mentioned extensive canal systems of Sasanian or Early Islamic age extending from an old course of the Karun. The sum total of these investigations provides a rather limited and geographically biased distribution of archaeological sites (Figure 11.2).

Historical texts

Documentary information on the alluvial landscapes of Lower Khuzestan is very sparse before Islamic times. No textual data exist prior to 1200 BC, and after that most of the information is from two short periods of external military expeditions. The earlier (744–694 BC) records regular military campaigns by the Neo-Assyrian Empire against Chaldean and Aramean tribes in Southern Iraq and Khuzestan, while the later (331–316 BC) records the activities of Alexander the Great and the war between his successors, Eumenes and Antigonus. These pre-Islamic sources have been studied numerous times, most recently by Cole and Gasche (2007). From the earliest period, the only information is a number of river names, of which Uqnû has been identified with the Karun River. They conclude that at least from Hellenistic times onward, the Karkheh (called both Eulaeus and Choaspes), Dez (Koprates) and Karun (Pasitigris/Tigris) rivers joined in a single river, which was variously named Eulaeus, Choaspes and Pasitigris. This river finally flowed into the Tigris some 50km south of present-day al-Qurna in Iraq, near the ruins of Spasinou Charax.

From the 9th century AD onwards, a large corpus of Arabic texts studied by Le Strange (1905) and Schwartz (1896–1929) offer more information. According to both authors, the Karun (called Dujail in the Early Islamic period) broadened out soon after leaving the city Ahwaz to become a tidal estuary, called Nahr as-Sidra (the Lotus River). The estuary finally reached the sea at Sulaimanan, the location of which is unknown. The information for the study area lists a number of towns, which are depicted along the river in sketch maps that accompany the manuscripts, but none of them can be located exactly. Finally, the Buyid ruler Adud ad-Dawla (*c*.980 AD) is known to have dug a canal between the Karun and the Shatt al-Arab, but further details are lacking. Both Lestrange and Schwartz assumed that the Karun flowed in its present-day bed during the Early Islamic period.

The present study: sources and methods

The multidisciplinary study of landscape evolution presented here draws on data and expertise from four research fields, namely remote sensing, geology, archaeology, and historical

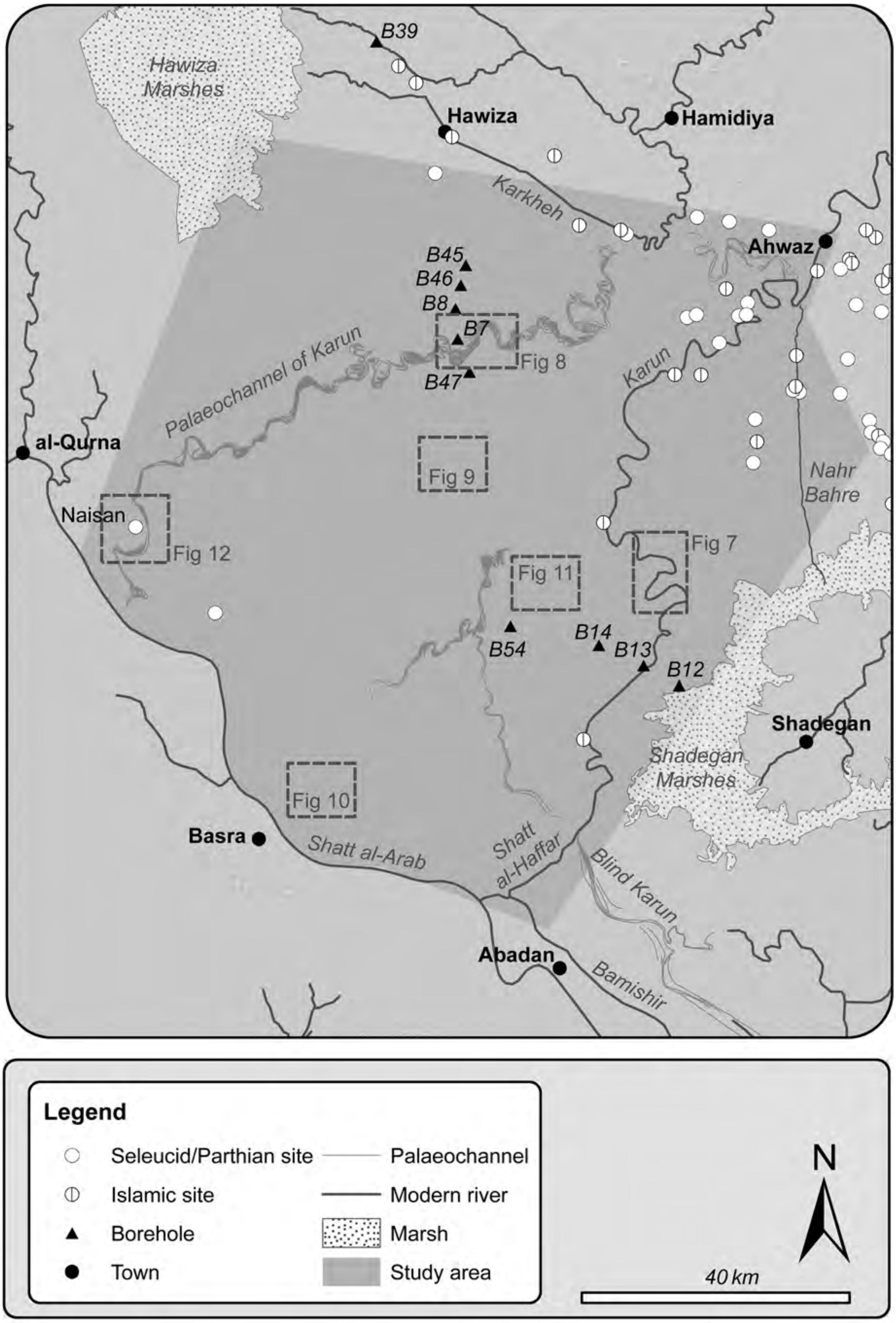

Figure 11.2: Location of archaeological sites (after Hansman 1967; Alizadeh 1985; Gasche and Paymani 2005), geological boreholes and main watercourses of the study area. The frames indicate the position of the images displayed in Figures 11.7–12.

	Natural environment:	**Traces of human activity:**
Remote sensing (image analysis)	geomorphology, present & past river courses	present & past settlements, irrigation canals
Geology (coring)	sedimentary stratigraphy	
Archaeology (surveying)		past settlements & chronology
Historical texts & maps (analysis)	past river courses	past settlements, chronology & toponyms

model of landscape evolution

Table 11.1: Schematic framework of the multidisciplinary approach in this study, leading to an integrative model of landscape evolution.

Landsat ETM+	20 & 27 Jan 2002	Paths 165 & 166; rows 38 & 39	8	15/30/60 m	Wet season
Landsat ETM+	28 July & 4 Aug 2001	Paths 165 & 166; rows 38 & 39	8	15/30/60 m	Dry season
Landsat MSS	3 June 1973	Path 178; rows 38 & 39	4	80 m	
CORONA KH-4A: mission 1035-1	23 Sep 1966	Revolution 040D; frames 12-20	1	*c.* 3 m	Acquired from USGS
CORONA KH-4A: mission 1045-2	5 Feb 1968	Revolution 182D; frames 75-81	1	*c.* 3 m	Acquired from CAMEL

Table 11.2: Characteristics of the satellite imagery used in this study.

geography (Table 11.1). Remote sensing data provided a firm framework for the other data sources. Satellite images were used to map past and present landscape features, including traces of human activity. Geological fieldwork involved the analysis of sedimentary sequences from boreholes and therefore mainly concerned the long-term evolution of the natural environment. Archaeological fieldwork included the survey of ancient settlements and resolving their age based on datable ceramics. So far, the archaeological component has been limited to the results described in the previous section. Historical texts and maps provided scattered information on the position of rivers and settlements through historical times, which could sometimes be related to features still visible in the landscape.

The use of a GIS was essential for rigorous integration of project data, allowing the management and interpretation of different information.

Remote sensing

The principal goal of using remote sensing data was to create a geomorphological map of the study area. A working procedure was developed for the consistent mapping of the semi-arid, alluvial landscapes of Mesopotamia, taking into account the typical interaction between natural and human processes (Walstra *et al.* submitted).

The working procedure can be summarised in three stages:

- Acquisition and pre-processing of remote sensing imagery, including the scanning of hardcopy images and geo-referencing of digital files.
- Recording of past and present landscape elements, including traces of human settlement and land use.
- Presentation of the results in a geomorphological map, depicting landforms and their underlying processes.

The geomorphological map focussed principally on the origins and chronology of landforms, clearly identified in the mapping attributes. Colours (of areas and lines) were assigned to the principal geomorphological processes and their relative age. Because of the focus on alluvial processes, further distinctions were made between the various alluvial landforms and processes, and their associated hydrological features (natural and artificial, active and abandoned).

The main data sources for the geomorphological mapping comprised Landsat and CORONA imagery (Table 11.2) acquired through the USGS EarthExplorer portal (see Fowler this volume; USGS 2009b). Since the end of 2008, the entire Landsat archive held by the USGS is available free of charge, while scanned CORONA negatives are available on-demand at a reasonably low charge (US$30 per image). A considerable collection of CORONA imagery is also held by the Center for Ancient Middle Eastern Landscapes (CAMEL) in Chicago (Oriental Institute 2008).

Landsat imagery

The Landsat program was designed to provide repetitive global coverage of the earth's landmasses, in particular for geological and land cover mapping. Its multispectral capabilities are suited to distinguish between aspects of lithology and vegetation and can therefore be used to map broad geomorphological units (USGS 2003). The large swathe of a single scene (185km) provides a broad view of the landscape that cannot be perceived from the ground or from aerial photographs. The data provided by the USGS are processed to a geometric accuracy of better than 30m (Gutman *et al.* 2008; USGS 2008) and also has good radiometric consistency. Thus Landsat imagery formed the ideal base for our geomorphological mapping and also provided ground control for geo-referencing of the CORONA images (below).

The study area is covered by four Landsat scenes (paths 165–166, rows 38–39). A set of images from summer 2001 was selected as a base for the mapping and additional images from early 2002 indicated the seasonal variations in moisture conditions and vegetation cover. The images were supplied by the USGS as individual bands in ready-to-use GeoTIFF format and subsequently stacked for display of multi-colour band combinations. A pan-sharpened image was produced using the false-colour infrared band combination 432 and panchromatic band 8. These image processing tasks were performed using ERDAS IMAGINE software.

CORONA imagery

CORONA images from 1966 and 1968 were acquired for the study area (missions 1035–1 and 1045–2). Both missions provided frames with a format of 5.54 × 75.7cm, corresponding to a ground cover of about 16.6 × 226km at a maximum resolution of 3m (USGS, 2009a). While they provide a unique record of the landscape before destruction wrought by modern, large-scale cultivation, the images do suffer from distortions due to the oblique and panoramic viewing angle.

Using ArcGIS software, image patches of about 5.5 × 10.5cm were individually geo-referenced. Using about 20 control points from the Landsat data, a second-order polynomial transformation was applied to rectify the large panoramic distortions. Independent checkpoints revealed a satisfactory accuracy of about 30m, comparable to the quality of reference data.

Image interpretation and mapping

Firstly, the broad geomorphological units were mapped, based on the interpretation of the Landsat imagery for land use patterns, vegetation cover and drainage characteristics. Interpretation of modern infrastructure and hydrological features was supported by modern topographical maps, as ground checks were not readily possible. The combination of images from different seasons aided the distinction of seasonal streams and marshes.

The high-resolution CORONA images allowed a more precise mapping of small landscape features, such as meander cut-offs (oxbow lakes), scroll-bars and crevasse splays. More importantly, palaeo-hydrological features no longer visible in the present-day landscape could be recorded. A distinction was made between natural watercourses, including river channels and crevasse channels, and man-made features, such as irrigation and drainage canals. Superimposition of, and connections between, traces of palaeochannels and canals helped to establish a relative chronology of different hydrological systems and their associated alluvial landforms. Comparison of the positions of river meanders between Landsat and CORONA images revealed varying dynamic and stable river sections.

Geological survey

During two fieldwork campaigns in 2004 hand-operated cores were collected to a depth of 5–10m below the surface. Preliminary interpretation of lithology, sedimentary structure and macrofossils was undertaken in the field and a limited number of subsamples were taken for laboratory analyses, *i.e.* palaeoecological analyses (foraminifera and diatoms) and radiocarbon dating. The spatial distribution and succession of stratigraphical units was reconstructed using cross-section profiles along transects of boreholes. The positions of transects were selected based on the location of palaeochannels mapped from satellite imagery and the locations of individual boreholes were recorded with a handheld GPS device. Elevations were derived from topographical maps.

Historical documents

Texts

A corpus of historical texts that deal with Khuzestan in the last 2500 years was collected. The first useful texts are the Greek descriptions of Alexander the Great's conquests and a number of other Greek and Latin texts were also valuable, notably Strabo's *Geography*, Pliny's *Natural History*, Ptolemy's *Geography* and Marcian's *Periplus* (for a survey of sources see appendix in Cole and Gasche 2007).

The Sasanian period is poorly represented, and it is only from after the Muslim conquest in the 640s that a large number of texts dealing with Khuzestan can be assembled. This corpus of Arabic texts contains more than 100 works in different genres, including geography, historiography, social history and legal and literary works. These are not distributed evenly over time, so while the earliest works date from the 9th century, the bulk of our knowledge comes from 10th-century works. After the 13th century, very few important sources were found.

A number of European travellers and explorers visited the wider region from the 16th century onwards, but it is only in the 19th century that these provide useful information about Khuzestan, with the rise of interest in Persia of European imperialist powers, especially Great Britain. The 19th century also saw the first archaeological missions in Khuzestan.

Maps

A variety of maps were used in this study. The oldest are the 10th-century regional maps of the so-called Islam Atlas

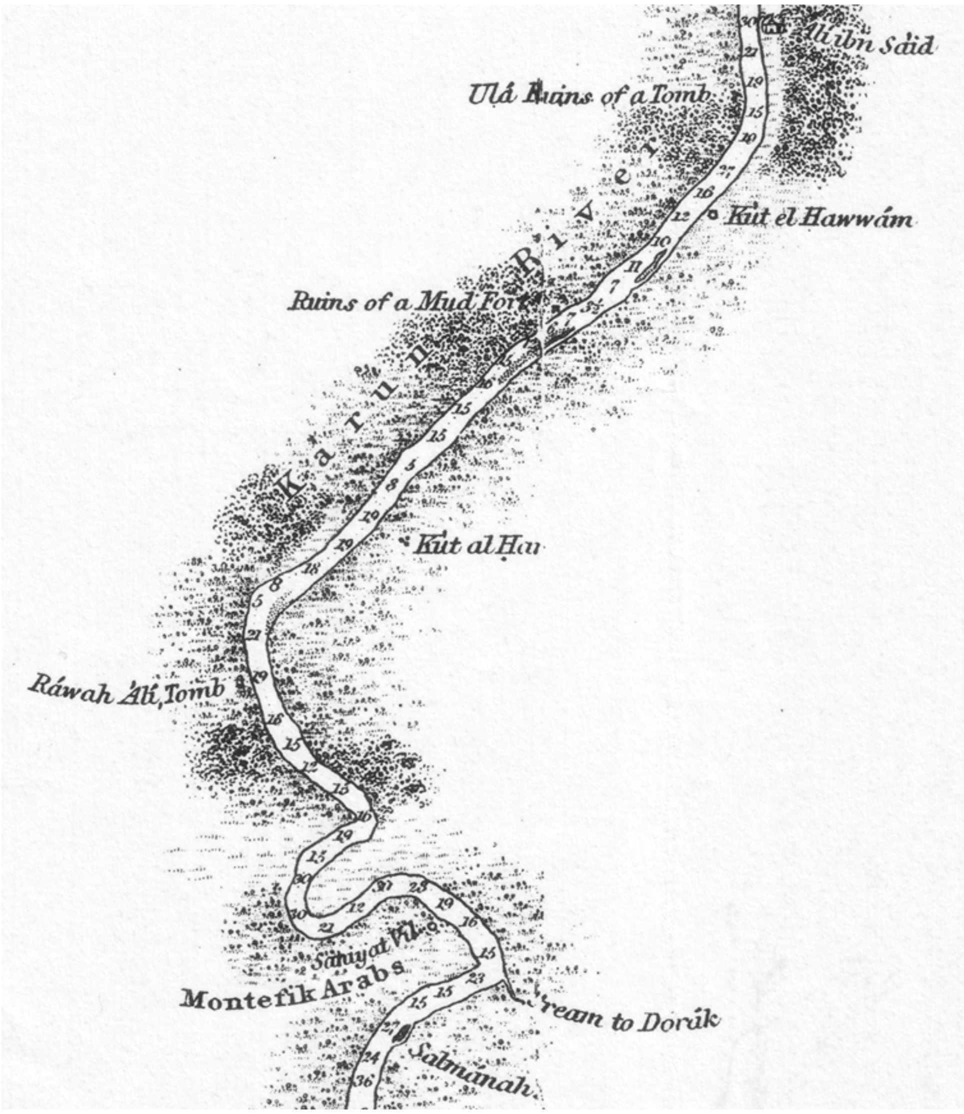

Figure 11.3: Detail of Chesney's map of the Karun, with indication of depth soundings, villages, ruins, and tribal camps. Original scale 1:253,440 (from Chesney 1850).

(al-Istakhri 950; al-Muqaddasi *c.*990; Ibn Hawqal *c.*990), which are extremely schematic, and cannot be interpreted without reference to an accompanying text. A second set of maps was made by the 12th-century geographer al-Idrisi (*c.*1165) for the Norman kings of Sicily and these are equally schematic.

More detailed are the maps used by European ships on the way to India, although depiction of the study area did not become very realistic until the early 17th century, even if these maps only show the coastal strip. The first reliable European maps of mainland Khuzestan appear in the 19th century, when British explorers penetrated the region for imperialistic purposes. A British expedition surveyed the Euphrates, Tigris and Karun rivers between 1835 and 1837 in order to assess their suitability as trade routes (Figure 11.3; Chesney 1850; Ainsworth 1888). The border area between Iraq and Iran (then the Ottoman and Persian empires) was the subject of two major international survey campaigns (in 1848–52 and 1913–14) in an attempt to solve border conflicts (Ryder 1925).

The study area is covered by a number of modern topographical map series, valuable both for their wealth of toponyms and as an aid in the interpretation of satellite imagery:

- 1:50,000 map sheets published by the Iranian National Cartographic Centre (1999)
- 1:50,000 sheets published in the 1960s by the British War Office (Great Britain War Office, 1962–1963)
- 1:100,000 geological map sheets (Iranian Oil Operating Companies, 1966–1972)
- 1:200,000 maps published by the former Soviet Union (SSSR Glavnoe Upravlenie Geodezii i Kartografii, 1963–1992) – see Figure 11.4
- 1:200,000 map sheets published by the German Army (Generalstab des Heeres, 1942)

The maps were scanned, imported into ArcGIS and geo-referenced using the coordinates displayed on the map sheets.

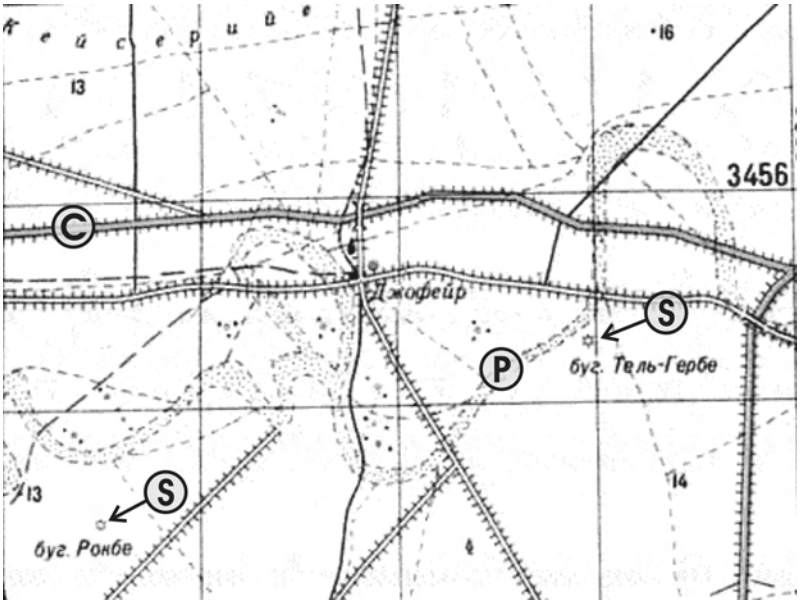

Figure 11.4: Soviet map displaying modern canals (C), a palaeochannel (P) and possible archaeological sites (S). Original scale 1:200,000 (from SSSR Glavnoe Upravlenie Geodezii i Kartografii, 1963–1992).

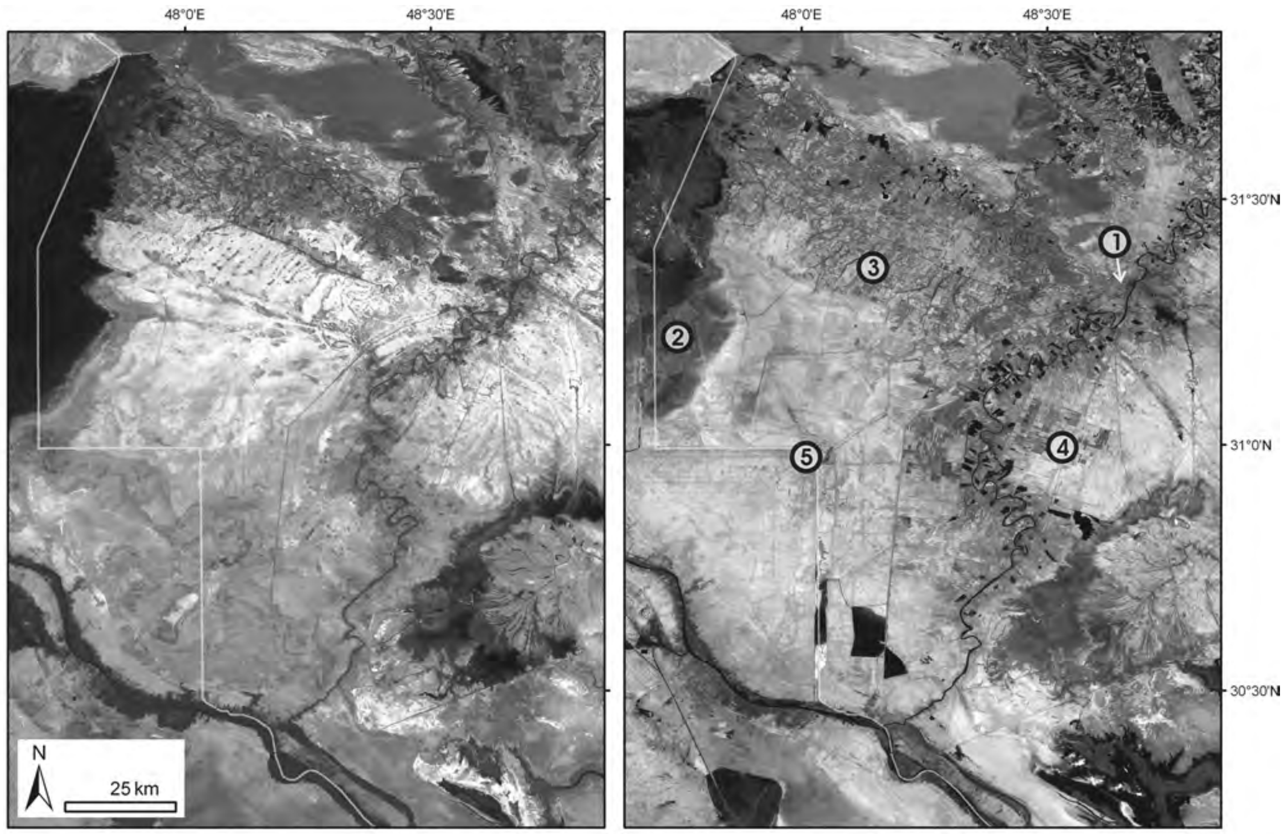

Figure 11.5: Landsat image mosaics from 1973 (left) and 2001 (right) illustrating the massive landscape changes that have taken place over the last decades: (1) urbanization of Ahwaz, (2) decline of Hawiza Marshes, (3) reactivation of old irrigation systems, (4) construction of new, large-scale irrigation systems, (5) war trenches and bunkers.

Results

Remote sensing

Modern landscape change

Comparative satellite views from 1973 and 2001 created from Landsat image mosaics clearly illustrate the massive landscape changes in the region during the second half of the 20th century (Figure 11.5). The urban area of the city of Ahwaz has increased enormously, from about 15km^2 in 1966 to more than 112km^2 in 2001, a growth mirrored in population statistics, which document the growth from a small village of 700 inhabitants in the late-19th century (Curzon 1890) to a city of more than 1.3 million people in 2006 (Statistical Centre of Iran 2006). The extent of the Hawiza marshlands has declined dramatically as flood control works and increased demands for irrigation gradually reduced water supply throughout the 20th century. Moreover, during the 1980s and 1990s large parts of the marshes were drained for military purposes. Based on analysis of the satellite imagery, it is estimated that between 1973 and 2000 the area of the marshes had shrunk by two-thirds (Partow 2001).

Agricultural land use has increased, for example taking in an area currently irrigated by the southern Karkheh branch, which was wasteland until the 1970s. It is documented that flow through this branch abruptly stagnated in 1837 after an avulsion near Hawiza, whereby the river left its bed for an irrigation canal (Loftus 1857). Recently, discharge through this branch has resumed and the abandoned irrigation canals are back in use. Also a recent development is the construction of large-scale irrigation systems, which cover huge areas and are made up of large, rectangular blocks.

The area was in the middle of the conflict zone during the Iran-Iraq war in the 1980s and the entire border zone is covered by a dense pattern of causeways, trenches and bunkers.

These developments have removed many traces of past landscapes over large areas and demonstrate the importance of archival sources, such as CORONA imagery, which predate the most destructive changes.

The geomorphological map

Three successive channel belts associated with the Karun River were identified and mapped (Figure 11.6). The alluvial ridge of the present-day Karun (K3) marks the eastern limits of the study area. The upper and middle sections of the river display a highly dynamic morphology, characterised by winding meanders with abundant scroll-bars, some meander cut-offs and large crevasse splays. A sequence of satellite images clearly shows that some meanders migrated significantly over the last decades (Figure 11.7). The lower section contains some rather straight river segments which appear stable. The palaeochannel of the Blind Karun (K3a) branches off in south-eastern direction, away from the study area.

A very distinct palaeochannel belt (K2) crosses the plain in west-south-western direction from the city of Ahwaz to near the ancient site of Spasinou Charax, a distance of more than 100km. The channel must have entered the alluvial plain through the same breach in the anticline as the river does nowadays, in the city of Ahwaz, but its upper section is obscured by later deposits and the urban area. Approximately 10km west of its entrance, its first meanders appear on the surface. For a short distance the palaeochannel is covered again, this time by deposits from the nearby Karkheh, but after its reappearance it can be traced all the way to its confluence with a Tigris/Shatt al-Arab palaeochannel. Scroll-bars, abandoned meanders and crevasse splays are clearly visible (Figure 11.8), suggesting the river was subject to dynamics similar to the present-day Karun. A pattern of meanders located directly north of the K2 indicates that the Karkheh, through palaeochannel Kh1, once was a tributary of the Karun.

In the southern, central part of the plain another palaeochannel belt (K1) was detected. It appears sharply west of the modern highway and railway link between Ahwaz and Khorramshahr. Distinct meanders can be traced for about 14km southwards after which the channel belt splits into two branches. The eastern branch can be followed to its intersection with the present-day Karun; there it lines up remarkably well with the K3a palaeochannel on the other side of the K3. Also noteworthy is a pattern of channels leaving from the same eastern branch, bifurcating in north-western direction. Their orientation, more or less opposite to the supposed direction of river flow in the main branch, seems to rule out crevasse channels. Rather the system appears to have a tidal origin, comparable to the network of tidal channels in the present-day Khor Musa embayment. The contours of the western branch gradually fade out and eventually disappear underneath irrigation structures. It is unclear whether both branches were active simultaneously or sequentially. The meanders of the K1 branches are less pronounced on the satellite imagery than the K2 meanders, a logical indication of older age. On the other hand, Landsat images from the 1970s show this part of the plain was still regularly flooded during wet seasons – the impact of water and salt precipitation surely contributed to degradation of the soil and surface features.

Faint traces of a palaeochannel were detected between channel belts K1 and K3. As the channel lines up perfectly with east to west orientated meanders on the other side of the Karun, in the Shadegan Marshes, it is assumed to be a former Jarrahi course (J1). Some scattered traces parallel to the Shatt al-Arab were found as an indication of a former course of this river (or Tigris, as the Euphrates probably had a separate outlet in the past). Parts of this channel are obscured by irrigation structures.

Ancient irrigation patterns were mapped throughout the study area. No doubt the most impressive network consists of the diverging canals intersecting the K2. This system can be traced back to a huge feeder canal from the present-day Karun at Ahwaz. Outside the city traces of the canal become vague, but further to the west it can be seen extending from a K2 meander, suggesting that the canal re-used part of the old river bed. The canal is very distinct, measuring more than 120m across and extending in a straight line for about 18km. At that point, the canal branches to the south, southwest and northwest. Some branch canals extend for more than 40km and they all eventually end in distinct 'herringbone' field patterns (Figure 11.9). Some of the canals clearly cut the K2 meanders and crevasse splays, indicating they date from a later period. A similar fan of huge canals, some terminating at herringbone field patterns, was detected east of the K3 river bed. These canals fan out from a feeder canal that flowed parallel to the present-day Karun bed south of Ahwaz, and which can be tracked nearly to the dam of Ahwaz on CORONA images. The westernmost of these canals is cut by the K3 channel, indicating that the irrigation system predates K3.

A broad zone some distance away but parallel to the Shatt al-Arab is covered with regular patterns of ridges at 100–120m intervals, clearly representing ancient fields (Figure 11.10). Also further inland from the river large

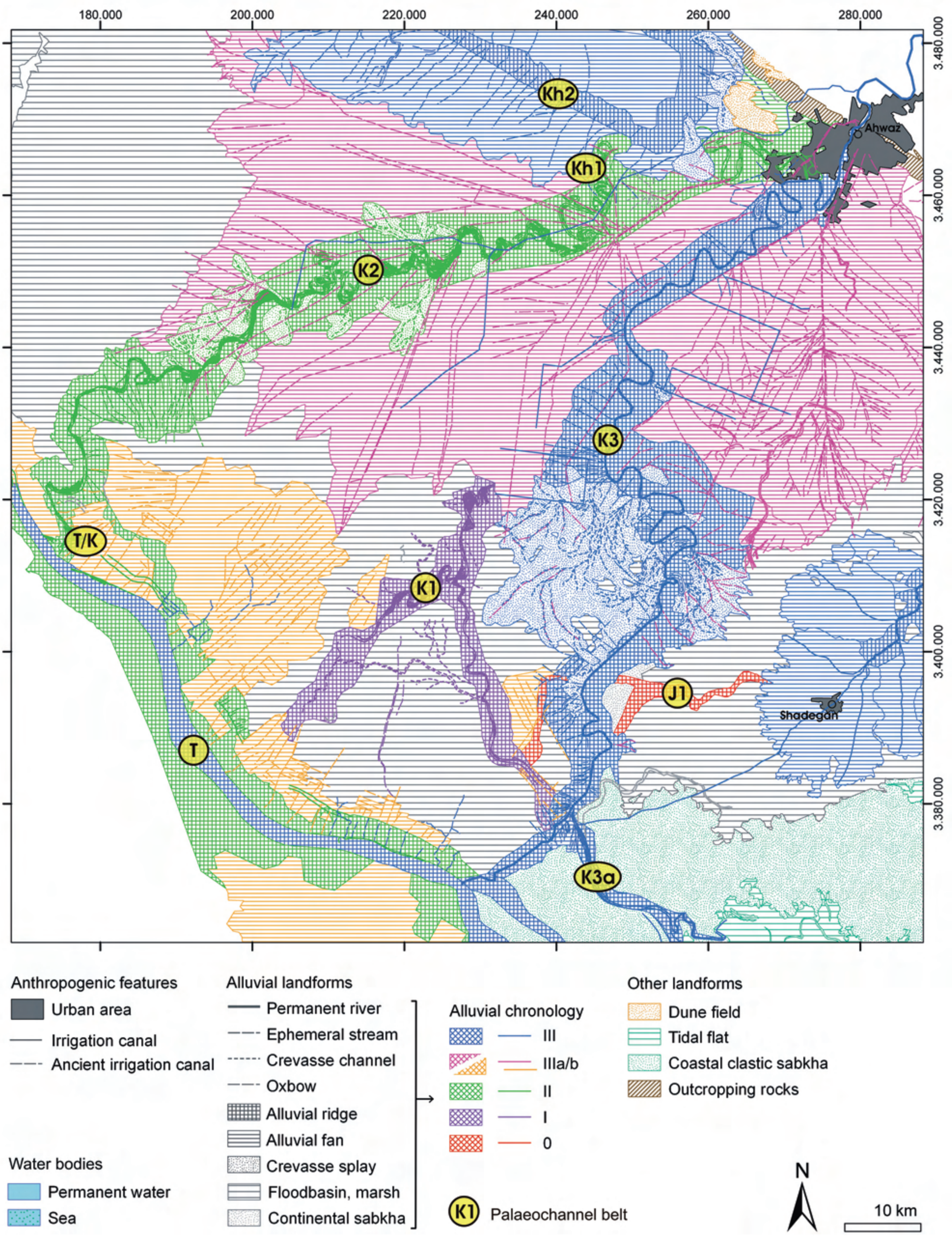

Figure 11.6: Geomorphological map of the study area.

Figure 11.7: CORONA (left) and SPOT (right) image showing a Karun section with typical scroll-bars, an oxbow lake and lateral migrating meanders (CORONA: DS1045-2182DF078, SPOT: 5 146-287/8-06/06/22, © CNES 2006, Distribution Spot Image S.A., France, all rights reserved)

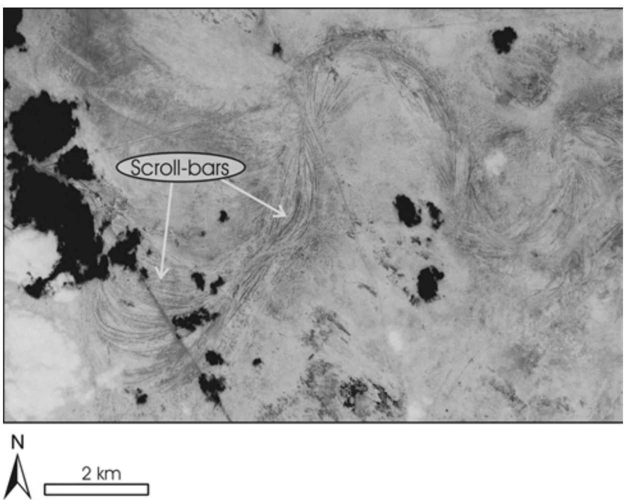

Figure 11.8: CORONA image (DS1045-2182DF076) showing meanders and scroll-bars of palaeochannel K2.

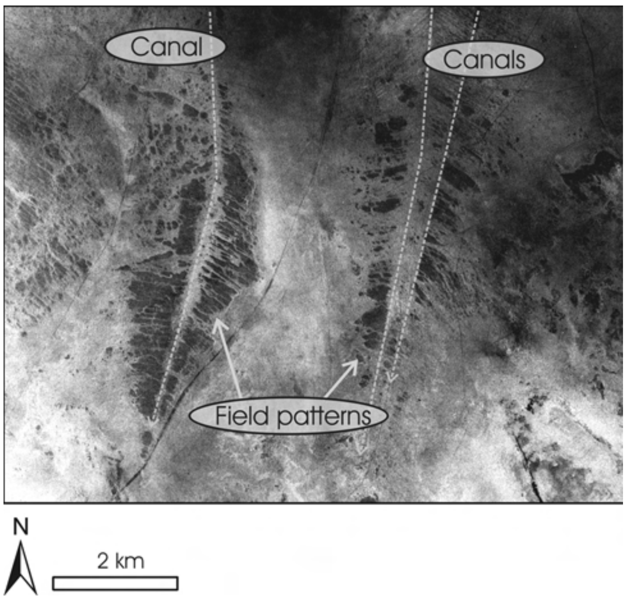

Figure 11.9: CORONA image (DS1035-1040DF016) displaying 'herringbone' field patterns in the central plain.

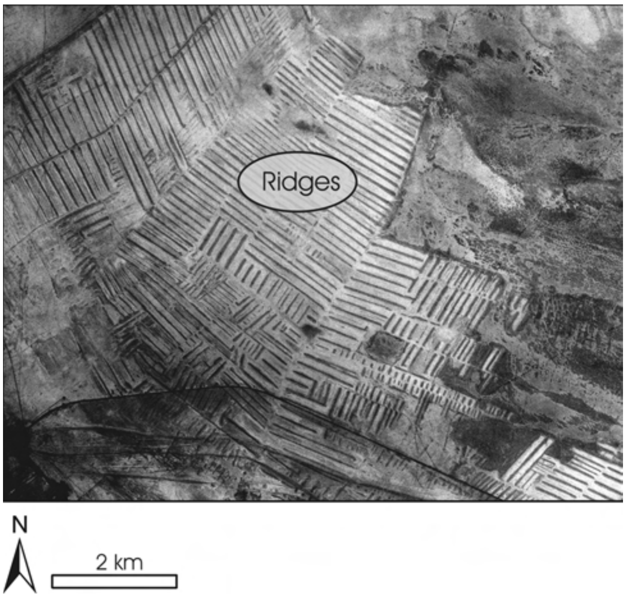

Figure 11.10: CORONA image (DS1035-1040DF018) showing regular patterns of ridges, close to the Shatt al-Arab.

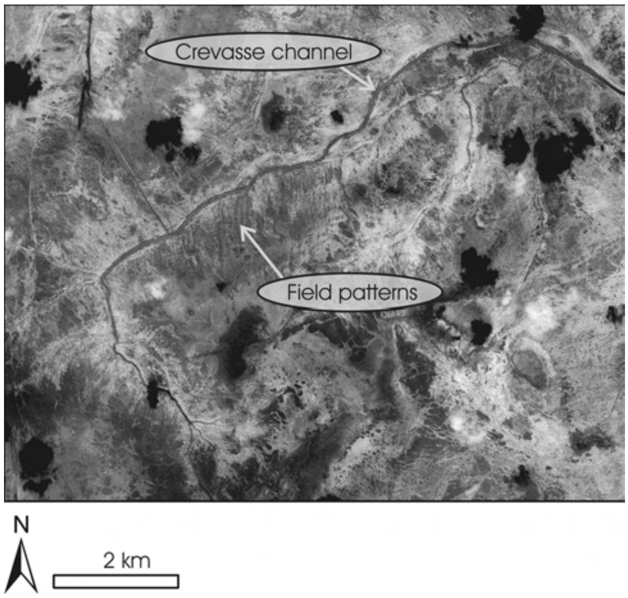

Figure 11.11: CORONA image (DS1045-2182DF078) showing field patterns along a large crevasse channel.

swathes of field patterns were identified. Based on their orientation they may be linked to the ridges, although much less pronounced due to the effects of seasonal flooding in later times. Scattered fragments of field patterns were detected within the crevasse splay complexes of the K3, usually located along the main crevasse channels (Figure 11.11). At first sight they have a strong resemblance to the 'herringbone' patterns, suggesting that the crevasse channels re-occupied former irrigation canals. However, their general orientation cannot be related directly to this large-scale irrigation system and they may rather be local systems attached to the natural crevasse channels. Relatively recent structures are represented by local, small-scale irrigation systems taking water directly from the main channels of the Karun and Shatt al-Arab. Remarkably similar patterns were found along the lower section of the K2 (Figure 11.12), possibly fed from the abandoned lower river bed by water pushed up by the tide from the Shatt al-Arab.

To the north, the study area is delimited by irrigation patterns connected to the lower Karkheh branch (Kh2). Its irrigation canals branch off at right angles from the main channel and extend over a distance of about 10km. It is worth noting that the straight, lower sections of both Karkheh branches fit perfectly in the diverging pattern of the 'herringbone' system. This suggests that they originate from the same period, although only the Karkheh branches remained intact up to modern times. To the west, the study area is bordered by the Hawiza Marshes, extending westwards to the Tigris. In the southern half of the plain large areas were seasonally inundated well into the 1970s. Nowadays, as a result of increased water demands and flood control, these areas are dry year-round and have changed into desolate wastelands. Soil marks of palaeochannels and irrigation canals, if ever present, have vanished due to the effects of repeated flooding.

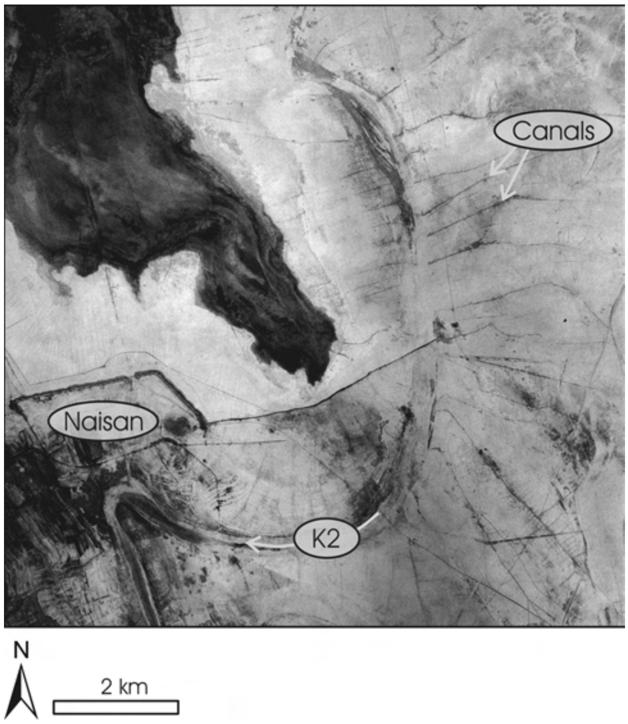

Figure 11.12: Small-scale irrigation systems along the lower section of K2, near the ruins of Naisan/Spasinou Charax (CORONA image: DS1035-1040DF016).

Geological data

During two field campaigns a total of 52 boreholes were sampled, of which only 10 are relevant to the current analysis, divided between three transects across the floodplain (for locations see Figure 11.2). The detailed facies analysis of the Holocene sequence enabled identification of three sedimentary units corresponding to fluvial, coastal and brackish-freshwater environments (Heyvaert and Baeteman 2007):

- Unit 1 (fluvial deposits): compact, reddish brown, silty clay to clayey silt, sometimes with sandy layers. Abundance of rootlets, salt crystals, scattered oxidation spots and mollusc shells. Because it proved difficult to distinguish between levee, crevasse-splay and channel deposits, a distinction was only made between clayey to silty flood basin deposits and sandy to silty channel belt/crevasse-splay deposits. Position in sequence: mostly the upper 4–6m.
- Unit 2a (clastic coastal sabkha deposits): alternation of mud with compact, laminated, red-brown, silty clay layers. Towards the upper part of the unit concentrations of salt and gypsum crystals occur. Position: mostly covering Unit 2b and overlain by Unit 1.
- Unit 2b (intertidal mudflat deposits): soft, water-saturated, blue to greyish mud or silty clay, sometimes with laminations of brown-grey mud. Position: mostly overlaying brown, compact clay identified as the pre-trangressive surface.
- Unit 3 (brackish-freshwater marsh deposits): blue to greenish blue, silty clay with vegetation remnants and numerous molluscs. Towards the upper part occasionally thin layers of black, peaty mud or gyttja occur. Position: intercalated with Unit 1 or directly overlaying Unit 2b.

The pre-transgressive surface below these units gradually slopes from a level of +3.5 to +5.5m in the northern part of the plain to below -5.5m towards the south.

A first transect (B45, B46, B8, B7, B47) crosses the Karun palaeochannel K2 in the central part of the floodplain. The fluvial deposits cover coastal deposits at a level of about -0.5 to 0m. The lower part of two cores (B7 and B45) consisted of a layer of sand and silt more than 2m thick, interpreted as channel belt/crevasse splay deposits. The other boreholes are characterised by up to 6m thick flood basin deposits (for a stratigraphic profile, see Figure 2.8 in Heyvaert 2010). No datable organic material was recovered.

Another transect (B54, B14, B13, B12) crosses the present-day channel belt of the Karun (K3). Two cores (B13, B12), located in the direct vicinity of the river, are characterised by channel belt/crevasse splay deposits overlain by clayey overbank deposits. In the easternmost of these boreholes, organic layers were found intercalated with flood basin deposits. These organic deposits can be attributed to a former extension of the Shadegan Marshes, covered by recent overbank deposits of the Karun. West of the Karun almost the entire sequence consists of coastal deposits. Only the upper 1m consists of flood basin deposits. Judging from the base of the fluvial deposits, the channel belt K3 is incised into the underlying coastal deposits (see Figure 2.9 in Heyvaert 2007). No datable organic material was recovered.

A third transect is located in the northern part of the plain, across Karkheh palaeochannel belt Kh2. Although outside the present study area, one of the cores (B39) is relevant for its radiocarbon dated (1240–1310 cal BP) sample of organic material (see Figure 2.10 in Heyvaert 2010). The sample was collected from a layer of brackish-freshwater deposits, below a 2m thick layer of channel belt/crevasse splay deposits and 4m flood basin deposits, both attributed to the Karkheh palaeochannel.

Archaeological data

Since 2004, no field survey has been conducted in the Lower Khuzestan plain. Archaeological sites proved very difficult to detect from CORONA images, because of their apparently limited optical contrast. In a preliminary analysis, Hritz (2007) was able to identify only 11 of the known sites on CORONA imagery; an additional 21 'new' sites were noted, but these have not yet been verified in the field.

This does not necessarily mean that no sites are present in the 'empty quarters' of Khuzestan. The German and Soviet topographical maps have specific symbols to depict mounds, and some are labelled as archaeological sites. A number of mounds even have toponyms which indicate they must be quite significant features (see Figure 11.4). A quick inspection indicated hundreds of these mounds throughout Khuzestan, some lie close to palaeochannels and irrigation systems, and it is very likely that at least some of these mounds represent archaeological sites. However, the reliability of this information needs verification in the field.

Documentary evidence

The embouchure of the Karun

The Roman historian Pliny (VI 138, *c.* 79 AD) records that the Karun (Eulaeus) joined the Tigris near Spasinou Charax, the city founded by a local ruler called Hyspaosines/Spasines (*c.*140–120 BC) on a man-made mound between the two rivers and identified by Hansman (1967) with the site of Naisan. This indicates that the Karun flowed in its K2 bed at least in the 2nd century BC. Pliny (VI 139, *c.*79 AD) also notes that Spasinou Charax was a refoundation of a city built by Alexander the Great and later destroyed by the rivers, and while this suggests that the K2 bed was already active in the 4th century BC, this is less certain.

The time when the Karun left its K2 bed is harder to determine. Schuol (2000) established from the bilingual inscriptions from Palmyra that Spasinou Charax is the Karkh Maisan mentioned in Arabic sources. Karkh Maisan does not figure in the Arabic accounts of the Muslim conquests (in the 640s) as a city, only as a *kura* (district), suggesting the city itself had gone to ruin by the early 7th century. The causes of this are not known and may or may not be connected to a shift of the Karun course.

In the extensive corpus of Early Islamic and later sources, shifts in the lower course of the Karun are hard to pinpoint. Certainly, its present-day course discharging via the Shatt al-Haffar and Shatt Bamishir is recent. Until the 18th century, the Karun discharged into the sea through

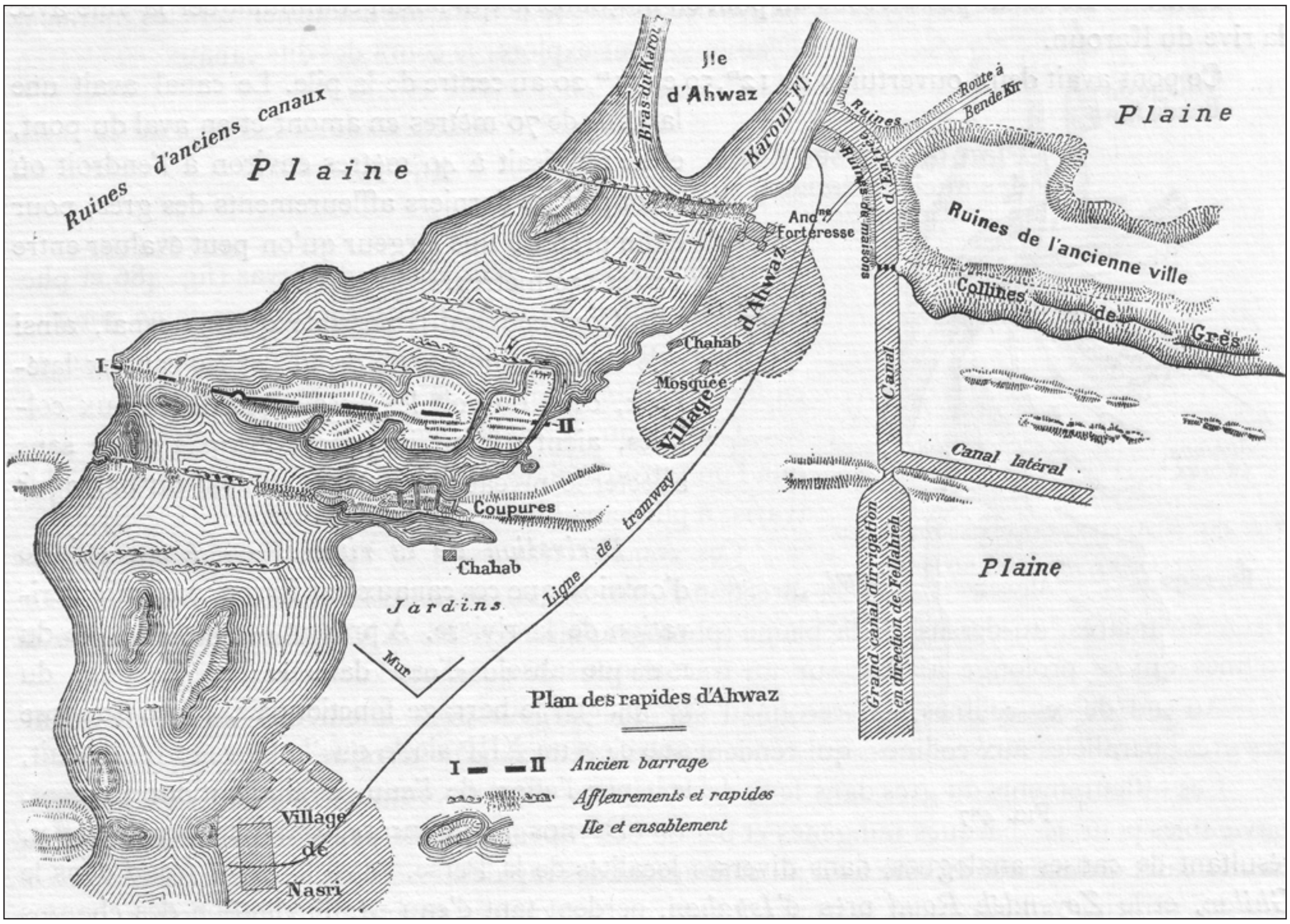

Figure 11.13: Sketch map of the ruins of the dam and canal systems in Ahwaz (from Graadt van Roggen 1905).

a third channel called the Qubban, running more or less parallel to the Shatt al-Arab and Shatt Bamishir but about 10km to the east. Further changes in its course are indicated by 19th-century European travellers who described how in 1763 the Persian ruler Karim Khan destroyed a dam constructed at the entrance of the Haffar channel, with the result that it became the main branch of the Karun. The other outlet was abandoned and has since been called Karun al-Aʻma or "Blind Karun" (Kinneir 1813; Layard 1846; Wilson 1925).

A century earlier, in the year 1665, the French traveller Jean de Thévenot ascended the Karun via the Qubban channel (de Thévenot 1727). He describes a canal named Haffar connecting to the "Schat-el-Aarab", which interestingly was only 3–4m wide near its entrance at the time. While continuing on the Shatt al-Arab, de Thévenot describes arriving at the tip of an island called "Chader", separated from the land of Basra by a channel that was used by boats sailing to "Bahrem" (Bahrein). This clearly corresponds to the island on which the city of Abadan is located. Today, the island lies between the Shatt al-Arab and Shatt Bamishir, but in de Thévenot's days both branches must have belonged to the Shatt al-Arab.

This was also the situation a century before, when the Italian Gasparo Balbi descended the Shatt al-Arab from Basra in 1580, arriving at a large island in the middle of the Shatt (Balbi 1590). According to his description, the western branch was used by boats sailing to "Barren" (Bahrein) and the eastern branch by boats heading for "Ormuz" (Hormuz, *i.e.* the Persian shore). This is exactly the same description as in the 13th-century Arabic geographical dictionary of Yaqut (1179–1229), which describes two branches of the Shatt al-Arab, one used by boats sailing to Bahrein, the other by those heading for India, separated by the island of Abadan.

The earliest Arabic written sources for the lower Karun (Ibn al-Faqih al-Hamadhani 9th century; al-Yaʻqubi *c.*905) state that the river discharged into the sea independently from the Tigris/Shatt al-Arab near a fortress called Hisn Mahdi. The 10th-century geographer al-Muqaddasi (*c.*990) adds that it entered the sea near Abadan, located along the Shatt al-Arab outlet, and that the area between the two estuaries was a salt flat (*sabkha*). It seems likely that this river bed was the Blind Karun. A number of canals that connected this outlet of the Karun with the Tigris/Shatt al-Arab are mentioned in the 9th and 10th-century sources (at-Tabari 9th–10th century; Ibn Sarabiyyun *c.*945; al-Muqaddasi *c.*990), but there is no solid evidence that any of these can be identified with the Shatt al-Haffar canal.

The Karun/Dujail between Ahwaz and its embouchure

Early Islamic sources for the course of the Karun between Ahwaz and its embouchure are limited. None of the places connected to this part of the river (Jubbā, Sūq al-Arbaʻā', ad-Dūlāb) have been identified. Possibly, these localities were not even situated on the main branch, because the distances mentioned by Arabic geographers suggest they lay along a straight canal rather than a meandering river.

The author Ibn Sarabiyyun (*c.*945) mentions two blocked former watercourses that once connected the Tigris to the Karun, perhaps pointing to a shift in the Karun shortly before the 10th century. However, it is more likely that damage to both waterways was caused by the Zanj revolt, which devastated the entire region between 869 and 883 AD. The Zanj were black slaves who had been employed in land reclamation works around Basra, removing salinated topsoil. This salty soil was apparently scraped up from the surrounding basins and heaped up in large ridges up 2m in height and about 75m wide at their base (Nelson 1962), which are still clearly visible on aerial imagery across a huge area on both sides of the Shatt al-Arab (see Figure 11.10).

Only with the records of British explorers in the 19th century is there certainty that the river flowed in its present (K3) bed. However, it seems likely that the river followed this course for some time before, since two ruined Shiite shrines on the banks of the river were mentioned by the 19th-century travellers (Layard 1846; Loftus 1857; Curzon 1890). Based on a drawing by Curzon, Gasche and Paymani (2005) dated the form of the dome on these shrines to the 12th–14th centuries, although this is only a *terminus post quem*, since similar 'pine-cone' domes were still regularly being constructed in Khuzestan at the beginning of the 20th century (Unvala 1929).

The irrigation systems of the lower Karun plain

In his description of Ahwaz the geographer al-Muqaddasi (*c.* 990) mentions a dam built across the Karun in order to raise the water level and so feed irrigation canals. The dam divided the river into three streams – the main branch and two canals. One canal branched off from the east bank of the river and ran through the city driving waterwheels and crossed by a baked-brick bridge attached to a mosque. A contemporary of al-Muqaddasi, the poet-traveller Abu Dulaf Ibn al-Muhalhil (10th century), mentions the same canal (including the bridge-with-mosque and water wheels), and adds that it flowed southwards to al-Basiyan, a town in the vicinity of present-day Shadegan.

Ruins of the dam were investigated in about 1900 by Dutch engineer Graadt van Roggen, who was commissioned by the Persian Shah to devise a plan in order to revive the old waterworks of Khuzestan (Graadt van Roggen 1905). His sketch map (Figure 11.13) of the area depicts a huge canal branching off from the left bank of the Karun upstream of the dam, and the ruins of a baked-brick bridge along it. The canal is labelled "irrigation canal leading to Fellahiye" (the former name of present-day Shadegan), and is surely the one described in the Arabic texts and called Nahr Bahre on modern maps (see Figure 11.2). His map also depicts a large canal inlet on the west bank of the river, above the dam. This canal can be identified with the feeder canal of the 'herringbone' irrigation system west of the K3, and might be the second irrigation canal al-Muqaddasi referred to.

The Arabic sources do not explicitly describe this second irrigation canal nor the irrigation systems attached to both feeders that branched off from the dam, probably because the sources were more concerned with urban than rural affairs. On the other hand, the 9th-century historian at-Tabari does mention heavy investments in the plain of Ahwaz during the Early Islamic period.

	Undated sites (from topographical maps)	Seleucid/Parthian sites	Classical sources	Sasanian/Early Islamic sites	Sasanian/Early Islamic irrigation works	Early Islamic Zanj ridges	Islamic shrines	Arabic sources	19th-century explorers
K1	O	·	·	·	X	·	·	·	·
K1/K3	·	O	·	O	·	·	·	·	·
K2	O	O	O	·	X	·	·	·	·
K3	·	·	·	·	·	·	O	·	O
K1/K3a (Blind Karun)	·	·	·	·	·	·	·	O	X
K3b (Haffar)	·	·	·	·	·	·	·	O	O
Kh1	·	O	·	·	X	·	·	·	·
T1/K2	O	O	O	·	·	X	·	·	·

O = indicator for activity, X = indicator for end of activity

Table 11.3: Indicators for establishing the chronology of mapped palaeochannel belts in Lower Khuzestan.

Integration: landscape evolution (Table 11.3)

No direct indicators have been found for the age of palaeochannel K1, nor for possible associations of its upper course with the Seleucid/Parthian sites south of Ahwaz. Certainly, K1 predates the large Sasanian/Early Islamic irrigation systems, since its upper section is covered by 'herringbone' field patterns. The channel is probably also older than palaeochannel K2, judging from the lower visibility of its meanders on satellite imagery. Topographical maps suggest the presence of a few archaeological sites which may be associated with K1, but they have not been verified or dated in the field. In a later phase, the eastern branch of K1 seems to have served as a tidal channel; this would fit in a scenario whereby the Karun shifted to channel K2 and the tide was able to penetrate further inland.

The founding and abandonment of Spasinou Charax provides strong evidence for dating palaeochannel K2 – the course was active from at least the 2nd century BC (perhaps even since the 4th century BC) and had probably been abandoned by the early 7th century AD. Moreover, the channel belt is intersected by canals of the large Sasanian/Early Islamic irrigation system, thereby providing a *terminus ante quem* for K2. Topographical maps suggest the presence of more archaeological sites along the K2 channel, but these have not been verified and dated in the field either.

The earliest evidence for channel K3a is in 10th-century textual sources which have the Karun entering the sea near Abadan, and can be identified with the Blind Karun outlet. The discharge shifted temporarily to the Haffar Canal around the 14th century, and once again, definitively in 1763. There is little evidence about the upper course of K3.

The Karkheh was once a tributary of the Karun as is clearly indicated by the palaeochannels Kh1 and K2 joining together. This is confirmed by Kirkby's analysis of meander wavelengths, which suggests the K2 carried the combined flows of both rivers. Just like K2, the Kh1 meanders are intersected by canals of the Sasanian/Early Islamic irrigation system, thereby providing an end-date. Indirect, but consistent, evidence is provided by a radiocarbon date associated with an organic layer below alluvial deposits of Karkheh channel Kh2 (B39), indicating that abandonment of its predecessor, Kh1, most likely did not occur before 640–710 AD.

A combined Tigris/Karun flow must have been active during the time when Spasinou Charax was inhabited. Only small segments of this T1/K2 channel are still visible on the surface, while other parts are covered by Zanj ridges indicating that the channel was already abandoned in the late 9th century AD. The large, radially diverging canals with typical 'herringbone' field patterns extend on both sides of the K3 channel and clearly postdate the K2 and Kh1 palaeochannels. The system is associated with the ruins of a dam across the Karun in Ahwaz. Remnants of similar dams have been attested along the Karkheh, Dez, Jarrahi, and Karun (Graadt van Roggen 1905). Due to their sheer size, these irrigation works are traditionally attributed to a major colonization program of the Khuzestan plain in Sasanian times, which included the building of weirs across the rivers to raise water to the level of intake canals (Christensen 1993). However, there is no material proof for this date. In fact, archaeological sites associated with the canals east of the K3 were dated to Seleucid/Parthian times (Gasche and Paymani 2005). This suggests at least a precursor of the irrigation system and the dams existed at that time. Also the chronological inconsistency of the K3 channel intersecting one of the main canals can be explained if part of the irrigation system was already in place while K2 (or even K1) was still active, and the canals to the west were built out further after the river shifted to the K3 channel. At the end of the 10th century, Arabic sources still refer to the dam in Ahwaz and important irrigation canals feeding from it, perhaps on both banks of the river. It is unknown when the system fell in disuse.

Conclusion

During the late Holocene, an avulsion-controlled Karun megafan developed in the Lower Khuzestan plain. Based on the interpretation of satellite data, at least three different Karun channels were detected. A chronological framework is provided by archaeological sites and textual sources. The Karun occupied its present-day position (K3) from the 10th century onwards (possibly earlier). Its lower reach initially discharged via the Blind Karun into the sea until 1763 AD, when the artificial Shatt al-Haffar became the main outlet. A very distinct palaeochannel belt (K2) crosses the plain in west-south-western direction from the city of Ahwaz. This channel was active at least since the 2nd century BC (possibly in the 4th century BC) and probably abandoned by the early 7th century AD. A Karkheh palaeochannel (Kh1) was identified as a tributary of this channel. Traces of a third palaeochannel (K1), located in the central plain, probably represent the oldest Karun channel present at the surface, although no direct indicators for its age were found.

The presence of extensive irrigation systems highlights the important role of human activity in the development of the Lower Khuzestan plain. The most impressive system is associated with the dam across the Karun in Ahwaz which was active during Sasanian and Early Islamic times, possibly even earlier. In addition, there is clear evidence of human actions (construction and destruction of dams) which caused repeated avulsions in the lower reaches of the present-day Karun. Similar impacts may have contributed to the other channel shifts in historical times.

This study clearly demonstrates the advantage of an interdisciplinary approach in reconstructing the alluvial history of the Lower Khuzestan plain. The use of archival satellite imagery and textual sources proved invaluable, especially because of the region's limited accessibility for field surveying.

Acknowledgements

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