ECONOMIC GEOLOGY RESEARCH INSTITUTE

HUGH ALLSOPP LABORATORY

University of the Witwatersrand
Johannesburg

THE UMM AL BINNI STRUCTURE, IN THE MESOPOTAMIAN MARSHLANDS OF SOUTHERN IRAQ, AS A POSTULATED LATE HOLOCENE METEORITE IMPACT CRATER: GEOLOGICAL SETTING AND NEW LANDSAT ETM+ AND ASTER SATELLITE IMAGERY

SHARAD MASTER and TSEHAIE WOLDAI

• **INFORMATION CIRCULAR No. 382**

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

THE UMM AL BINNI STRUCTURE, IN THE MESOPOTAMIAN MARSHLANDS OF SOUTHERN IRAQ, AS A POSTULATED LATE HOLOCENE METEORITE IMPACT CRATER: GEOLOGICAL SETTING AND NEW LANDSAT ETM+ AND ASTER SATELLITE IMAGERY

by

SHARAD MASTER[1] and TSEHAIE WOLDAI[2]

([1]Impact Cratering Research Group, EGRI-HAL, School of Geosciences, University of the Witwatersrand, Johannesburg, South Africa. e-mail: masters@geosciences.wits.ac.za.
[2]International Institute for Geoinformation Sciences & Earth Observation (ITC), Enschede, The Netherlands, e-mail: Woldai@itc.nl)

ECONOMIC GEOLOGY RESEARCH INSTITUTE
INFORMATION CIRCULAR No. 382

October, 2004

THE UMM AL BINNI STRUCTURE, IN THE MESOPOTAMIAN MARSHLANDS OF SOUTHERN IRAQ, AS A POSTULATED LATE HOLOCENE METEORITE IMPACT CRATER: GEOLOGICAL SETTING AND NEW LANDSAT ETM+ AND ASTER SATELLITE IMAGERY

ABSTRACT

A *c.* 3.4 km diameter circular structure, discovered in southern Iraq on published satellite imagery by Master (2001), was interpreted to be a possible meteorite impact crater, based on its morphology (its approximately polygonal outline, an apparent raised rim, and a surrounding annulus), which differed greatly from the highly irregular outlines of surrounding lakes. The structure, which is situated in the Al 'Amarah marshes, near the confluence of the Tigris and the Euphrates Rivers (at 47°4'44.4" E, 31°8'58.2" N), was identified by Master (2002) as the Umm al Binni lake, based on a detailed map of the marshes published by Thesiger (1964). After the almost complete draining of the marshes since 1993, the lake has disappeared, and in recent Landsat TM, SPOT and ASTER satellite imagery, it appears as a light coloured area, due to surface salt encrustations.

The alluvial plains of Iraq occupy a structural trough which is linked to active subduction-related orogenic processes in the Zagros mountains of Iran. The bedrock in the region close to the Tigris-Euphrates confluence consists of marine clastics of the Dibdibba Formation (Miocene-Pleistocene). The overlying Holocene marine sediments of the Hammar Formation contain a Recent fauna consisting of gastropods, lamellibranchs, scaphopods, bryozoa, crab and echinoid fragments. The Hammar Formation, in turn, is overlain by Recent delta-plain and delta-front deposits of the Mesopotamian Plains, in which there were numerous marshes and permanent lakes until the recent destruction of the marshlands. It is estimated that the Recent sediments of the Tigris-Euphrates plains were deposited in the last 5000 years, during which 130-150 km of seaward progradation has taken place.

Because of the extremely young nature of the sediments in the marshlands of the Tigris-Euphrates confluence area (<5000 years), it is difficult to find a geological explanation for the shape of the Umm al Binni structure. The postulate that the structure was formed by a Recent bolide impact can account for the simple bowl-shaped geometry with markedly polygonal outline, and the apparent rim and annulus around the structure in pre-1993 imagery. Master (2001, 2002) speculated on the possible consequences of this structure, if it was indeed of impact origin, for Bronze-Age Mesopotamia, and suggested that it might possibly be linked with an ~2350 BCE "ash" layer found at Tell Leilan (Syria) and in sea-sediment core off Oman, re-interpreted by Marie-Agnes Courty (1998) to be an impact fallout layer. Master (2001, 2002) also suggested that an impact-generated tsunami could have been responsible for the Babylonian and Sumerian "flood" legends of Atra-Hasis, Utnapishtim and Ziusudra, as recounted in the appendix to the Epic of Gilgamesh, and other accounts.

Recent Landsat TM and high-resolution ASTER satellite imagery over the Al 'Amarah marshes shows a marked reduction in the amount of marshland vegetation in imagery from 2000, compared with imagery over the same area in 1976. The Umm al Binni lake now consists of a dry lake bed encrusted with white salt deposits. The high resolution ASTER imagery clearly shows a strikingly polygonal outline of the lake, which is in strong contrast to the highly irregular outlines of most of the other former marshland lakes within the region. The new images of the dry lake show a highly asymmetrical aspect to the lake: the

southern half has smooth straight edges to the polygon sides, whereas in the northern half these edges are more irregular. The southeastern part of the crater is surrounded by a series of scalloped concentric zones, which are similar in appearance to ejecta blankets from young terrestrial and non-terrestrial impact structures. However, ejecta-type material is totally absent from the northern half of the Umm al Binni structure. If the feature is of impact origin, then it should have a symmetrial ejecta blanket surrounding it on all sides, unless it was the result of a very low-angle oblique impact, or if part of the ejecta blanket was eroded away. There is at least one example of a terrestrial impact structure (the Tsenkher structure in Mongolia) with only a partially preserved ejecta blanket, due to the removal by erosion of the rest of the ejecta around it. The high-resolution imagery shows the presence, in an area that was marshland just a decade ago, of a possible village or settlement about 4 km ENE of the Umm al Binni structure, from which paths radiate in all directions, possibly caused by domestic animal tracks. A road leads to this settlement from the northeast. This shows that the area is currently accessible overland. It is imperative that the structure now be studied on the ground in order to determine its origin, and that this be done before the proposed re-flooding of the marshes again makes the area inaccessible. However, all past and current attempts to study the structure on the ground have been frustrated by the extremely dangerous political and military situation that has prevailed in Iraq in the past 3 years.

_________________oOo_________________

THE UMM AL BINNI STRUCTURE, IN THE MESOPOTAMIAN MARSHLANDS OF SOUTHERN IRAQ, AS A POSTULATED LATE HOLOCENE METEORITE IMPACT CRATER: GEOLOGICAL SETTING AND NEW LANDSAT ETM+ AND ASTER SATELLITE IMAGERY

CONTENTS

__________________oOo__________________

Published by the Economic Geology Research Institute
(incorporating the Hugh Allsopp Laboratory)
School of Geosciences
University of the Witwatersrand
1 Jan Smuts Avenue
Johannesburg
South Africa

http://www.wits.ac.za/egru/research.htm

ISBN 1-86838-348-2

THE UMM AL BINNI STRUCTURE, IN THE MESOPOTAMIAN MARSHLANDS OF SOUTHERN IRAQ, AS A POSTULATED LATE HOLOCENE METEORITE IMPACT CRATER: GEOLOGICAL SETTING AND NEW LANDSAT ETM+ AND ASTER SATELLITE IMAGERY

INTRODUCTION

Master (2001) discovered a *c.* 3.4 km diameter circular structure in the marshes of southern Iraq, on satellite imagery published by North (1993) (Fig. 1), and interpreted it to be a possible meteorite impact crater based on its morphology (its approximately polygonal outline, an apparent raised rim, and a surrounding annulus), which differed greatly from the highly irregular outlines of surrounding lakes. The structure, which is situated in the Al ’Amarah marshes, near the confluence of the Tigris and the Euphrates Rivers (at 47°4’44.4” E, 31°8’58.2” N), was identified by Master (2002) as the Umm al Binni lake, based on a detailed map of the marshes published by Thesiger (1964). Following the Gulf War of 1991, Saddam Hussein’s regime embarked on a massive programme to drain the Al ’Amarah marshes, by building a huge canal named the “Glory River” parallel to the Tigris River (Fig. 2) (North, 1993a,b; Wood, 1993; Pearce, 1993, 2001; Hamid, 1994; Partow, 2001a; Naff and Hanna, 2002). After the almost complete draining of the marshes since 1993 (Munro and Touron, 1997; Partow, 2001a,b; Nicholson and Clark, 2002), the Umm al Binni lake has disappeared, and in recent Landsat TM and ASTER satellite imagery, it appears as a light-coloured area, due to surface salt encrustations (Fig. 3). Following the Iraq War of 2003, there are moves afoot to re-flood the marshes in an attempt to restore its devastated ecology (Brookings Institution, 2003; Jacobsen, 2003; Lubick, 2003; Martin, 2003; Sultan *et al*., 2003).

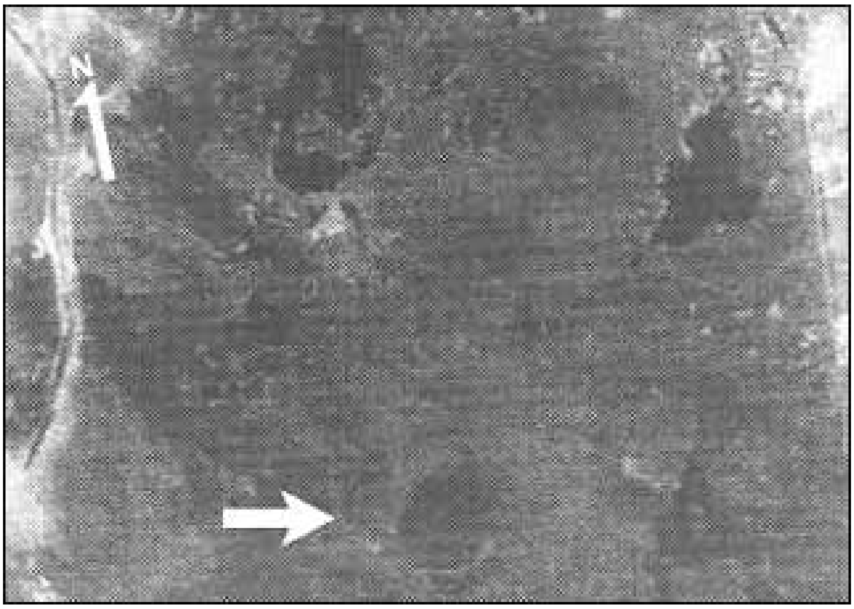
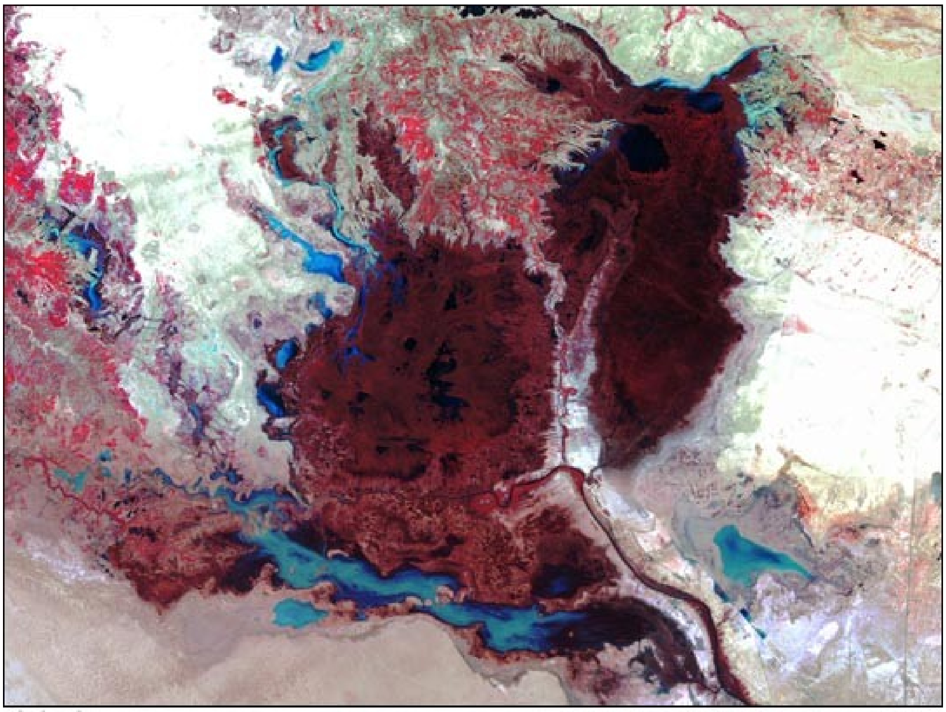


Figure 1: *Detail of published Landsat image (from Master, 2001; enlarged from an image published by North, 1993), showing the* c. *3.4 km diameter Umm al Binni lake (arrow), and other marsh lakes with highly irregular outlines, in the Al ’Amarah marshes of southern Iraq.*

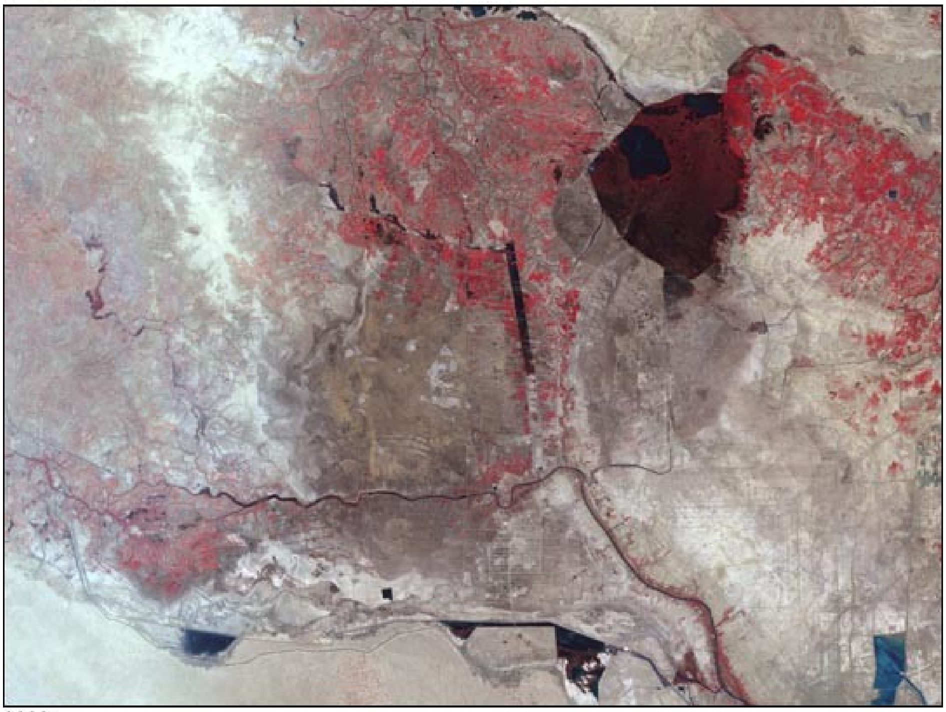
Figure 2: *Map of southeastern Iraq showing extent of former marshlands, and water diversion projects. Image from:* [*http://geography.about.com/library/maps/ Iraq_marshes_1994.jpg*](http://geography.about.com/library/maps/Iraq_marshes_1994.jpg)

GEOLOGICAL SETTING

The alluvial plains of Iraq occupy a structural trough, known as the Mesopotamian Basin (Fig. 2), which is linked to active subduction-related orogenic processes in the Zagros mountains of Iran and northeastern Iraq (Jassim and Buday, 2004). The Mesopotamian Basin is part of the larger Zagros foreland basin associated with the closure of the Neotethys ocean and the collision of the Arabian passive margin and Eurasian plate (Nowroozi, 1972; Beydoun *et al.*, 1992; Bahroudi and Talbot, 2003). Convergence in the Zagros collision zone still continues, and the region is currently tectonically active (Knetsch, 1955; Lees, 1955; Mitchell, 1957, 1958b; Nowroozi, 1972; Berberian, 1995). The Mesopotamian Basin is floored by Neoproterozoic crystalline basement rocks of the Arabian shield (Bahroudi and Talbot, 2003).



1973 -1976



2000

Figure 3: *Landsat MSS false-colour composite images showing the destruction of the marshlands of southern Iraq between 1976 and 2000. The red areas show vegetated marshland. The lakes that appear as black areas within the marshlands in the earlier images, appear as white areas in the 2000, because of desiccation and encrustation with white salt. Most of the destruction took place in the period from 1992 to 2000. Images from Partow (1991b).*

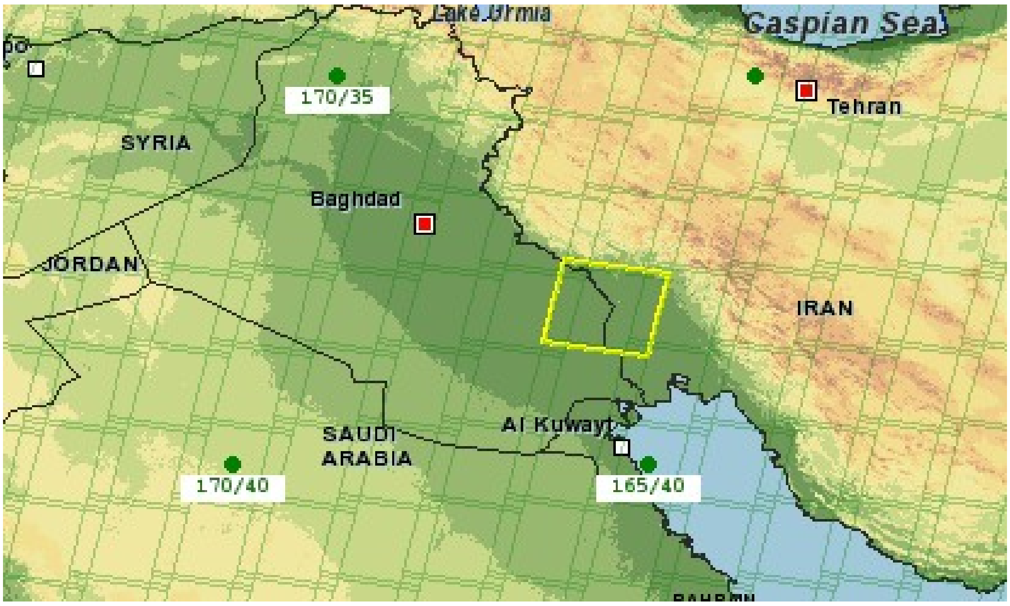


Figure 4 : *Study area location map. The green strips correspond to satellite flight paths in a N-S direction. The study area is shown in yellow. 170/40 indicates the path and row corresponding to the Landsat TM and ETM+ images. The Mesopotamian Basin, at a low elevation, is shown in dark green colour. Higher elevations of the Zagros Mountains in Iran and northeast Iraq are shown in brown and yellow colours.*

Overlying this basement is a thick pile of Phanerozoic sedimentary rocks consisting of:

(1) an attentuated Palaeozoic succession of Cambro-Ordovician, Devonian-Lower Carboniferous, and Upper Permian rocks; (2) a well-developed Mesozoic succession of Triassic, Jurassic and Cretaceous rocks; and (3) a Cenozoic succession of Eocene to Pliocene rocks, overlain by Pleistocene to Holocene alluvium (Beydoun *et al*., 1992; Alsharhan and Nairn, 1997; Sharland *et al*., 2001). The alluvium, consisting of clay, silt, sand and gravel, is related to the floodplain of the Euphrates and Tigris rivers and associated swamps, as well as to marine incursions (Loftus, 1855; Buringh and Edelman, 1955; Baghdadi, 1957; Buringh, 1969). The Tigris and Euphrates rivers and their tributaries arise in the mountains of Syria, Turkey, northern Iraq and Iran, and they join, after traversing through marshlands, at Al Qurna, north of Basra, to form the Shatt al Arab estuary, which extends for 140 km from Basra to The Gulf (Al Ghunaim *et al*., 1994). The Karun River, rising in the Iranian Zagros, joins the Shatt al Arab at Khorramshahr, about 40 km ESE of Basra. A mineralogical study of the sediments of the Tigris and Euphrates Rivers, the Shatt al Arab, and some older terraces, shows similar source areas with the main light mineral fraction made up of quartz, cryptocrystalline silica, carbonates, biotite, muscovite, chlorite and plagioclase feldspars, while 32 heavy mineral species were identified (Philip, 1968). The suspended loads of the Tigris and Euphrates show marked differences, with the Euphrates richer in both chlorite and expandable lattice clays (Berry *et al*., 1970).

The Mesopotamian region has the world's oldest examples of large-scale water engineering for irrigation purposes, and the Euphrates and Tigris river systems have been extensively canalized for more than four millennia (Ionides, 1937; Lloyd, 1943; Adams, 1958; Haigh, 1951; Lees and Falcon, 1952; Lees, 1955; Buringh, 1957; Harris and Adams, 1957; De Vaumas, 1955, 1958; Nelson, 1962; Adams and Nissen, 1972; Rzóska, 1980; Wagstaff, 1985; Naff and Hanna, 2002; Alsam and Krasny, 2004). A Sumerian clay cuneiform tablet from Nippur records regular field irrigation at about 1750 BCE [1] (Jacobsen, 1951)[2]. Smith (1872) mentioned waterworks on the Tigris River undertaken during the reign of Hammuragas in the mid-Second Millenium BCE. Herodotus, who flourished *c*. 490-425 BCE, refers to waterworks in Babylon, and the confluence of the Tigris and Euphrates rivers (Herodotus, 1972). Nearchus, in his voyage of 325 BCE, mentioned that the Euphrates and Tigris had separate entrances into the sea or an estuarine gulf (De Morgan, 1900; Hansman, 1978). Historical evidence from cuneiform tablets indicated that the Third Millenium BCE cities of Ur and Eridu were linked to the sea (Larsen, 1975). Jacobsen (1960) published inscriptions which tell of a ships registry on the shore of the sea near Ur. The Eridu hymn (Falkenstein, 1951) made reference to the shadow of Eridu, which spreads over the sea. However, as pointed out by Jacobsen (1960) and Hansman (1978), the reference to the sea near Ur may in fact refer to a western extension of the Hawr al Hammar lake. Le Strange (1905), citing the Islamic geographer Baladuri (1866, 1918), indicated that the large Hawr al Hammar lake south of the Euphrates and west of Basra was only formed during the reign of the Sassanian king Kubadh I in the fifth century CE [3] by breaching of levees on the Tigris. Following their repair in the following reign, the waters of both rivers rose again in flood in 636 CE, and inundated the surrounding country. From Chesney's (1850) description of the lower course of the Euphrates, it appears that the lake did not exist in 1835-1837. According to the Naval Intelligence Geographical Handbook (1944), quoted by Roux (1960), the Hawr al Hammar was formed soon after 1870, when the Euphrates burst its right bank between Suq-ash-Shayukh and Al Qurnah, after being burdened by an exceptionally high flood from the Shatt al Gharraf, and converted the Hammar marshes into a wide expanse of lake. The elders of Kubaish told Roux (1960) that in their fathers' time the area now occupied by the lake consisted of cultivated fields. Thus the Hawr al Hammar lake appears to have formed several times in the last four millenia in response to the breaching of levees during large floods. The siltation and saltiness of many Mesopotamian watercourses, formerly ascribed to poor agricultural practices (Jacobsen and Adams, 1955; Buringh, 1957), are now thought to have arisen partly as a result of climatic changes, such as increased aridity (Weiss *et al*., 1993; Issar, 1995).

Modern changes in the morphology of the delta region have been recorded on Admiralty charts dating from as early as 1826, with various updates (Chesney, 1850; Admiralty Naval Staff, 1918; Lees and Falcon, 1952). Recent changes in the course of the Lower Euphrates were noted by Cadoux (1906). In the last few decades the Shatt-al-Arab (on the Iraq/Iran border) and the Khawr as Sabiyah (a possible former mouth of the Euphrates north of Kuwait) have been extensively dredged to keep the channels open for large ships such as oil tankers (Al Ghunaim *et al*., 1994). Several new large canals built in the past decade have drained the Al Amarah marshes and the Hawr al Hammar, and devasted their ecology (Partow, 2001a,b). The marshlands of southern Mesopotamia have been the home of the Marsh Arabs or Ma'adan for millennia, and their way of life (described by Moritz, 1888; Thesiger, 1954, 1958, 1964; Salim, 1962; Westphal-Hellbusch and Westphal, 1962; and Young, 1976, 1977) has been severely disrupted by the draining of the marshes (Nicholson and Clark, 2002; Brookings Institution, 2003). The shifting watercourses of the Mesopotamian floodplain thus represents a dynamic system in which there is an interplay of natural processes, including neotectonic subsidence, fluvial (and aeolian) aggradation, eustatic marine incursions, and human-induced canalization, draining and dredging (Nicholson and Clark, 2002).

---

[1] Before Common Era ≡ BC

[2] Note that Mesopotamian chronologies are still under debate (Collon, 2000), and the dates for the Second Millenium BCE are only approximate.

[3] Common Era ≡ AD

The bedrock in the region close to the Tigris-Euphrates confluence consists of marine clastics of the Miocene-Pleistocene Dibdibba Formation (Macfayden, 1938; Rees Williams, 1952; Mitchell, 1956; Baghdadi, 1957; Larsen and Evans, 1978). These rocks consist mainly of sandstones, granulestones and conglomerates with rounded igneous clasts and white quartz pebbles, in places with calcareous cements (Baghdadi, 1957). In *c.* 1325 CE, the Medieval traveller Ibn Battuta described red pebbles paving the court of the mosque of Ali in Basra as having been derived from Wadi'l-Siba, about 10 km north of Zubair, near the present Shu'aiba Junction southwest of Basra (Gibb, 1962). These pebbles are likely to be igneous clasts from the Dibdibba Formation. The overlying Holocene marine sediments (fine silts and silty clays) of the Hammar Formation contain a Recent fauna consisting of gastropods, lamellibranchs, scaphopods, bryozoa, crab and echinoid fragments (Loftus, 1855; Hudson *et al.*, 1957; Eames and Wilkins, 1957; Mitchell, 1958a; Dance and Eames, 1966; Macfayden and Vita-Finzi, 1978). The Hammar Formation, in turn, is overlain by Recent delta-plain and delta-front deposits of the Mesopotamian Plains, in which there were numerous marshes and permanent lakes until the recent destruction of the marshlands (Lees and Falcon, 1952; Philby, 1959; Larsen and Evans, 1978; Partow, 2001).

The geological and geographical history of the Tigris-Euphrates-Karun delta region and the head of the Persian/Arabian Gulf has been debated since the 1830s. Beke (1834, 1835) argued from historical evidence that the former head of the Gulf was situated much farther inland in Mesopotamia, based on the voyage of Nearchus in 325 BCE, under instruction from Alexander the Great, as recounted by Arrian in his Indica (e.g., Arrian, 1983), and by the geographer Strabo (Larsen and Evans, 1978; Hansman, 1978). As a result of the Euphrates Expedition of 1835-1837 (Chesney, 1850), the first geological mapping of Mesopotamia was carried out by Ainsworth (1838), and was followed by the work of Loftus (1855) along the current Iraq/Iran frontier. Schläfli (1864) and Moritz (1888) described the geography of lower Mesopotamia. Tomaschek (1890) attempted a topographical reconstruction of Nearchus' coastal voyage from the Indus to the Euphrates. De Morgan (1900) published very influential diagrams showing the reconstructed palaeogeography of the Mesopotamian delta region, utilizing information from the Assyrian king Sennacherib's expedition against the Elamites in *c.* 696 BCE, and Nearchus' voyage (Larsen and Evans, 1978; Hansman, 1978). Lees and Evans (1952) questioned the model of a simple outbuilding of the Mesopotamian delta, as argued by De Morgan (1900), and presented evidence for a more complex interplay of tectonically-induced subsidence and fluvial (and aeolian) aggradation in the delta region. This was supported by the observations of Ionides (1954), Smith (1954), Hudson *et al.* (1957), Mitchell (1957, 1958a,b) and Hansman (1978). Roux (1960) discovered Neo-Babylonian and Kassite (last half of Second Millenium BCE) sites on the southern part of the Khawr al Hammar, an area that was reportedly submerged beneath the waters of The Gulf at this time (De Morgan, 1900). Many authors have presented evidence for the presence of Recent marine or estuarine fauna far inland from the current head of the Gulf, especially in the vicinity of Basra (Loftus, 1855; Eames and Wilkins, 1957; Hudson *et al.*, 1957; Mitchell, 1958a; Dance and Eames, 1966), but also at Qurmat Ali (Al Qurna) and Amara (Macfayden and Vita-Finzi, 1978), and as far inland as the Abu Dibbis depression southwest of Baghdad (Voûte, 1957). Ai-Adili (2004) studied clay minerals from the West Qurna Field, and found mainly mixed-layer illite-smectite clays and chlorite, suggesting a marine depositional environment. While such evidence was explained as the result of marine incursions due to tectonic subsidence (Lees and Falcon, 1952; Mitchell, 1957), Larsen (1975) and Larsen and Evans (1978) invoked eustatic sea-level changes, and attributed the marine sediments to transgressions during Holocene highstands. This is supported by radiocarbon dating of marine terraces in the Mudairah and Al Bahra areas of Kuwait, which are dated at between 4570 ± 70 years B.P. and 3250 ± 80 years B.P. (Al-Asfour, 1978). More recently, the discovery of the remains of a 9000 year-old boat far inland in the Kuwaiti desert points to a former rise in Holocene sea level (Lawler, 2002). Larsen and Evans (1978) estimated that the Recent sediments of the Tigris-Euphrates plains were deposited in the last 5000 years, during which about 130-150 km of seaward progradation has taken place.

ORIGIN OF THE UMM AL BINNI STRUCTURE

Because of the extremely young nature of the sediments in the marshlands of the Tigris-Euphrates confluence area (<5000 years), it is difficult to find a geological explanation for the shape of the Umm al Binni structure. Salt diapirs are common in the Makran coast of Iran and in the Persian Gulf, but are absent from the Mesopotamian Basin (Edgell, 1996). Sinkholes are present in Eocene and Miocene limestones (Damman Formation) of the Southern Desert in western Iraq (Baghdadi, 1957), but they are two orders of magnitude smaller, as seen on X-SAR Shuttle Radar imagery. The only possible large sinkhole (Al Naqib, 1967), is the 2.75 km diameter Al Umchaim structure in western Iraq which, from its circular crater-like morphology, has been postulated to be a meteorite impact crater (Merriam and Holwerda, 1957; Underwood, 1994). The sediments of the Mesopotamian plain are undeformed, while their substrate is only very gently folded (Lees and Falcon, 1952; Lees, 1955). There is no Recent igneous activity in the Mesopotamian basin (Buday *et al*., 1980; Weiss *et al.,* 1993). The presence of extensive young volcanic fields in adjacent areas of Jordan, Saudi Arabia and Syria prompted Mitchell (1958c) to propose that the Al Umchaimin structure in western Iraq was produced by surface collapse following magma withdrawal in a volcanic intrusion. However, there is a complete absence of igneous rocks at this structure, which is regarded as of meteorite impact origin (Underwood, 1994). Thus an origin of the Umm al Binni structure by salt doming, karst dissolution, interference folding or igneous intrusion can be effectively ruled out.

The postulate that the structure was formed by a Recent bolide impact can account for the simple bowl-shaped geometry with markedly polygonal outline, and the apparent rim and annulus around the structure in pre-1993 imagery. For a crater of 3.4 km diameter, scaling equations given by Shoemaker (1983) can be used to calculate the size of an impacting body. For an impactor made of iron with a density of 7860 kgm^{-3}, and using a range of densities of the target of 1500 to 2000 kgm^{-3}, one derives the diameter of a spherical impactor to be between 90 and 108 m, or roughly 100 m. An iron impactor of this diameter, travelling with a velocity of 20 kms^{-1}, would have an energy of 7.86×10^{17} J, or the energy equivalent of 9400 Hiroshima atomic bombs (20 kT TNT equivalent). A similar calculation done for an impactor made of typical asteroidal material with density of 2380 kgm^{-3} yields a diameter of about 355 m. If the postulated impact site was under water, the water column would have absorbed some of the energy, resulting in a smaller crater than if the impact had been on dry land (Ormö *et al*., 2001). Hence, estimates of the bolide diameter are only a minimum, and the bolide could have been larger and more energetic. A wet impact would also have generated huge tsunamis.

Master (2001, 2002) speculated on the possible consequences of this structure, if it was indeed of impact origin, for Bronze-Age Mesopotamia, and suggested that it might possibly be linked with an ~2350 BCE “ash” layer found at Tell Leilan, Syria (Weiss *et al*., 1993), and in sea-sediment core off Oman (Kerr, 1998), re-interpreted by Courty (1998) to be an impact fallout layer. Master (2001, 2002) also suggested that an impact-generated tsunami could have been responsible for the Babylonian and Sumerian “flood” legends of Atra-Hasis, Utnapishtim and Ziusudra, as recounted in the appendix to the Epic of Gilgamesh, and other accounts (Smith, 1876; Haupt, 1880, 1883; Suess, 1904; Speiser, 1958; Sandars, 1960; Civil, 1969; Lambert and Millard, 1969; Tigay, 1982; George, 2003a,b). Matthews (2001) and Britt (2001) suggested that meteorite or cometary impacts could have been responsible for the demise of the Akkadian culture at *c*. 2300 BCE, and they suggested that the possible impact structure in the Al ’Amarah marshes of Iraq could have been partly responsible for this. Following these speculations, a host of commentators in the popular press and on the internet rushed to print in sensational articles about meteorite impacts causing the end of Mesopotamian civilizations. It was pointed out by Lyons (2001), and by Master (2002), that the proposed impact structure has not yet been investigated on the ground, and has not been proven to be of impact origin. Until it has been properly studied, and dated, it is pointless speculating about its possible role in ancient history.

NEW SATELLITE IMAGERY

Recent Landsat TM and high-resolution ASTER satellite imagery over the Al ’Amarah marshes shows the paths and rows (Fig. 2) for the Landsat images obtained. The new Landsat TM and ETM+ images are shown in Figure 5a and 5b. A false-colour image showing the marshland (red) surrounding the Umm al Binni and other lakes (black), can be seen in an image (Fig. 5a) acquired in 1990. The same area seen in an image acquired 10 years later (Fig. 5b), shows the almost total destruction of the marshland vegetation through the draining of the marshes and the drying up of all the former lakes and wetlands. These features now appear light-coloured because of salt encrustation. Investigations of these former lake beds revealed that some of the salt crusts are up to 60 cm deep (Sultan *et al*., 2003). The salt crusts are probably formed from the evaporation of the brackish marsh waters, which are known to be quite saline (Russel, 1956), and from evapotranspiration of subsurface waters, which are also saline (e.g., in the Dibdibba Formation aquifers, Hassan and Al-Kubaisi, 2002).

A high resolution ASTER image (acquired in April 2001) of the Tigris-Euphrates confluence area has been studied in the Visible-Near-Infra-Red (VNIR) bands (Figure 6). In this image it

(a) **(b)**

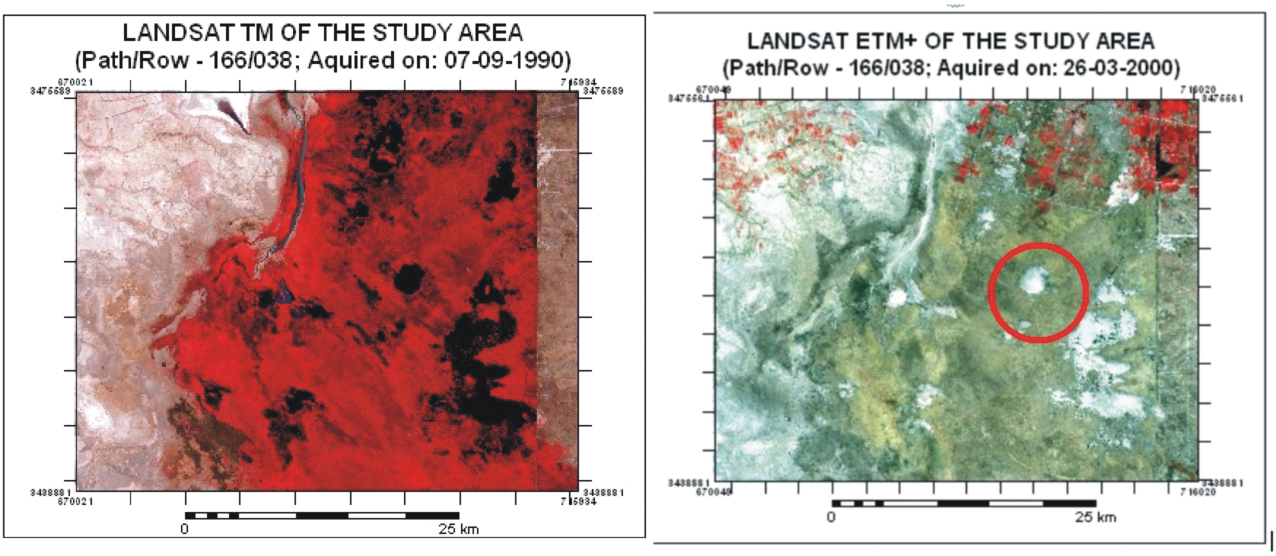


Figure 5: *Landsat TM (a) and Landsat ETM + (b) bands 4,3,2 in RGB order of the study area acquired on the 7th September 1990 and 26th March 2000. Images (a) and (b) are sub-windows of larger Landsat scenes. Note the changes in marshland as denoted by reddish colour (marshy area covered by vegetation designating high chlorophyll content) and dark colour (designated as water bodies) in (a) as compared to light yellowish grey (no vegetation) and light tones (due to surface salt encrustations) in (b). Most of the water bodies in the area have disappeared and have become encrusted with salt (shown by their high reflectance signatures in all bands). As a result, the Umm al Binni structure (shown by red circle), which was filled by fresh water (dark in a) is seen with light tones in (b).*

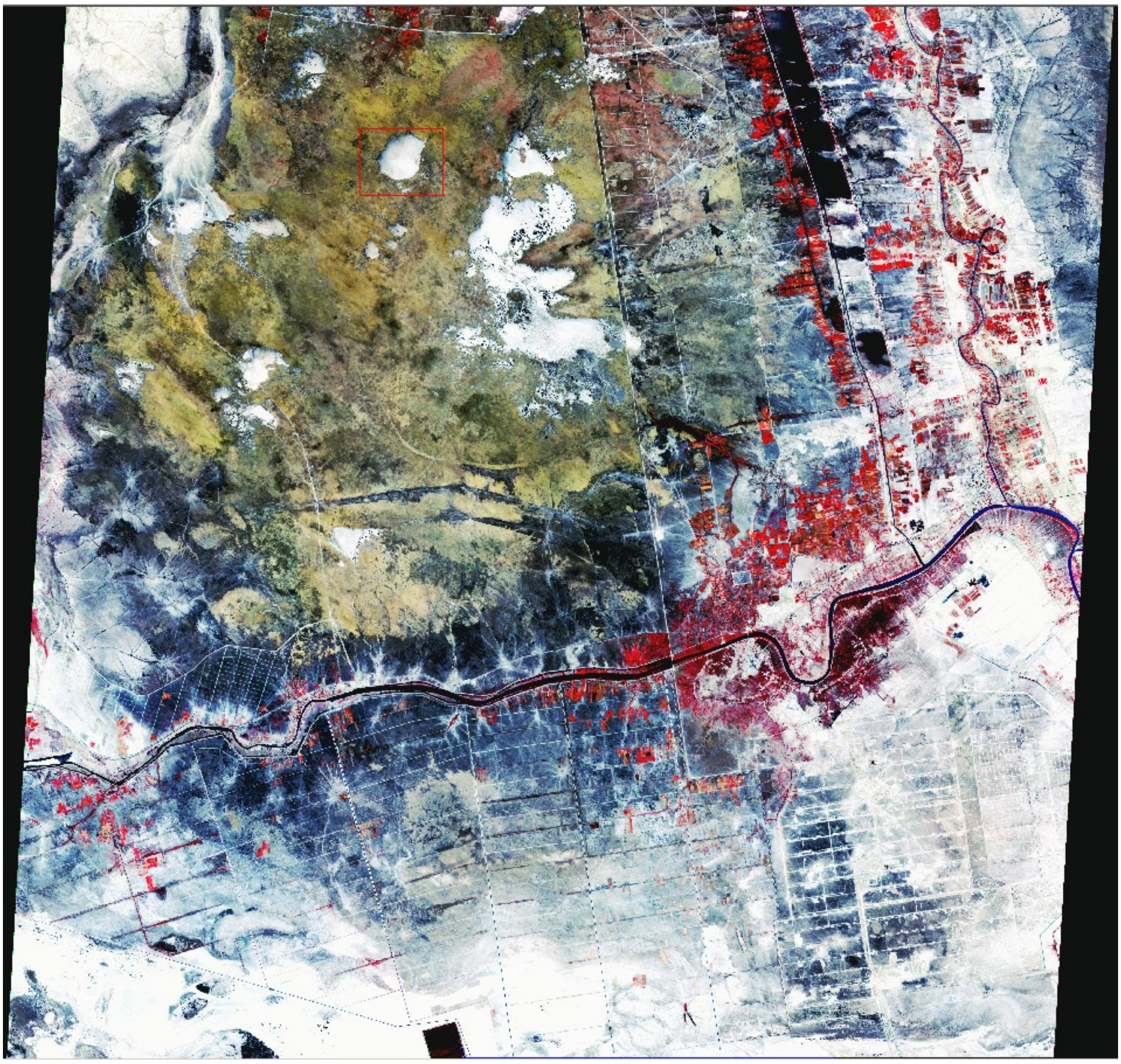


Figure 6: *ASTER VNIR (Visible Near Infrared) image of the confluence between the Euphrates (flowing from left to right) and the Tigris (top to bottom) rivers – showing also the canal parallel to the Tigris which was used to drain the marshes, Former marsh lakes appear white. The Umm al Binni structure is shown outlined by the red rectangle. AST_L1B_00304142001074934_01232004124911) bands 1,2,3 in RGB order of the study area (Coordinates: ULX=679992.550102, LRX=725003.687500, ULY=3471760.447664, LRY=3434939.750000) acquired on the 14th April 2001.*

can be seen that the marshlands have been completely destroyed, and the only vegetation is present in irrigated fields along the Euphrates and along the new canal parallel to the Tigris. The Umm al Binni lake is now a dry lake whose bed is encrusted with white salt deposits (Figs. 7, 8). The high resolution ASTER imagery clearly shows a strikingly polygonal outline of the lake, which is in total contrast to the highly irregular outlines of most of the former marshland lakes within the region. The new images of the dry lake show a highly asymmetrical aspect to the lake: the southern half has smooth straight edges to the polygon sides, whereas in the northern half these edges are quite irregular and are neither smooth nor polygonal. The

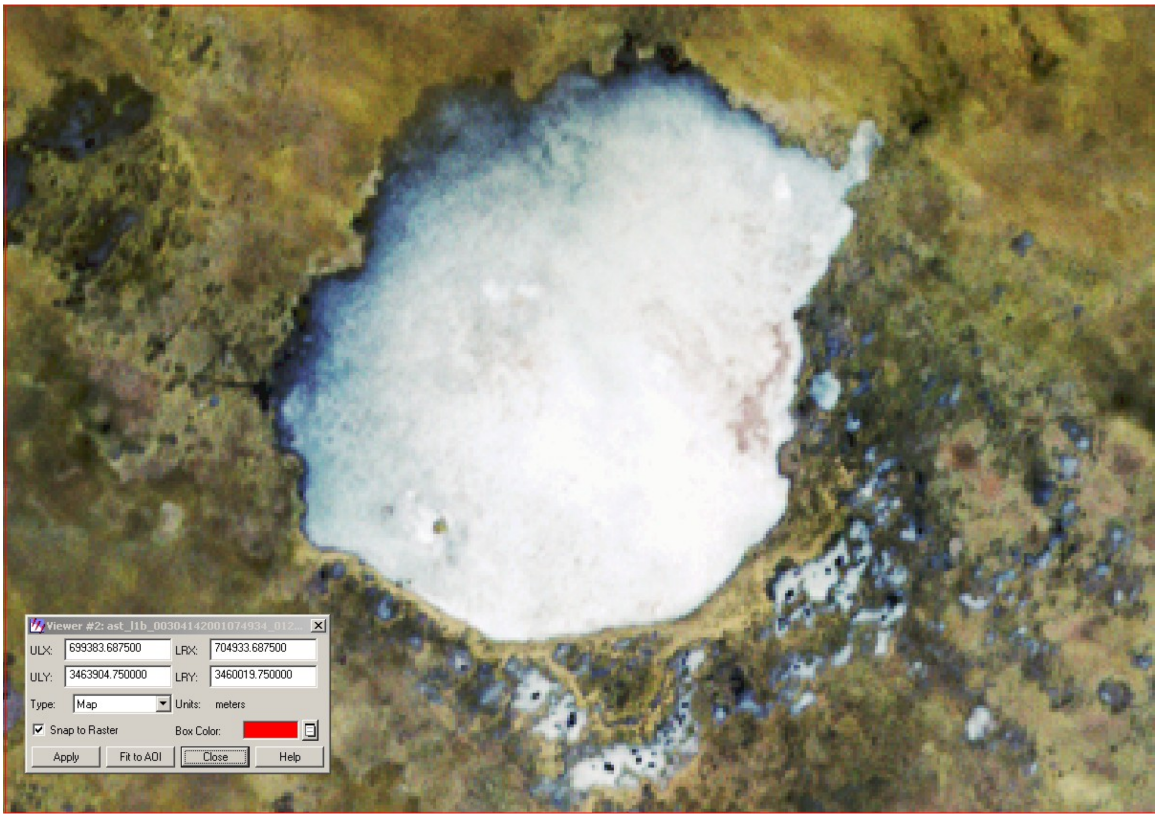


Figure 7: *ASTER VNIR (Visible Near Infrared) bands 3,2,1 (in RGB order) of the Umm al Binni structure (enlarged from Figure 6). The morphology of the crater (roughly polygonal outline and raised rim) is clearly different from the surrounding lakes viewed in all images shown above. The southern part of the crater is surrounded by a series of scalloped concentric zones, which in appearance are similar to ejecta blankets from young terrestrial and non-terrestrial impact structures. The structure is quite asymmetrical - only the southern half has straight, polygonal outline, a scalloped "ejecta-blanket" type zone, and a pure white salt crust. The northern part of the structure is characterized by irregular outline, absence of "ejecta-type" scalloped material, and the presence of dark-reflecting material lining the crater rim. These "ejecta-type" material are totally absent from the northern half of the structure.*

southern part of the "crater" is surrounded by a series of convex-outward scalloped concentric zones, which in appearance are similar to fluidized ejecta blankets from young terrestrial and non-terrestrial impact structures (Moore *et al*., 1974; Melosh, 1989). However, this "ejecta-type" material is totally absent from the northern half of the structure. If the structure is of impact origin, then it should have a symmetrial ejecta blanket surrounding it on all sides, unless it was the result of a very low angle oblique impact, or if part of the ejecta blanket was eroded away (Melosh, 1989).

In Figure 8, long streaks trending southwards (diagonally to the bottom right in the image) from the edge of the structure are interpreted as flow lines showing the former position of channels in the marshlands. These lines show up as blue streaks in the false colour composite of Figure 9, which shows the Thermal Infra-Red (TIR) bands 12,13,10 in RGB order. In these images, higher thermal reflectance shows up as red (warm) colours and lower thermal reflectance shows up as blue (cool) colours. In the inset (Fig. 9), which shows a close up of the

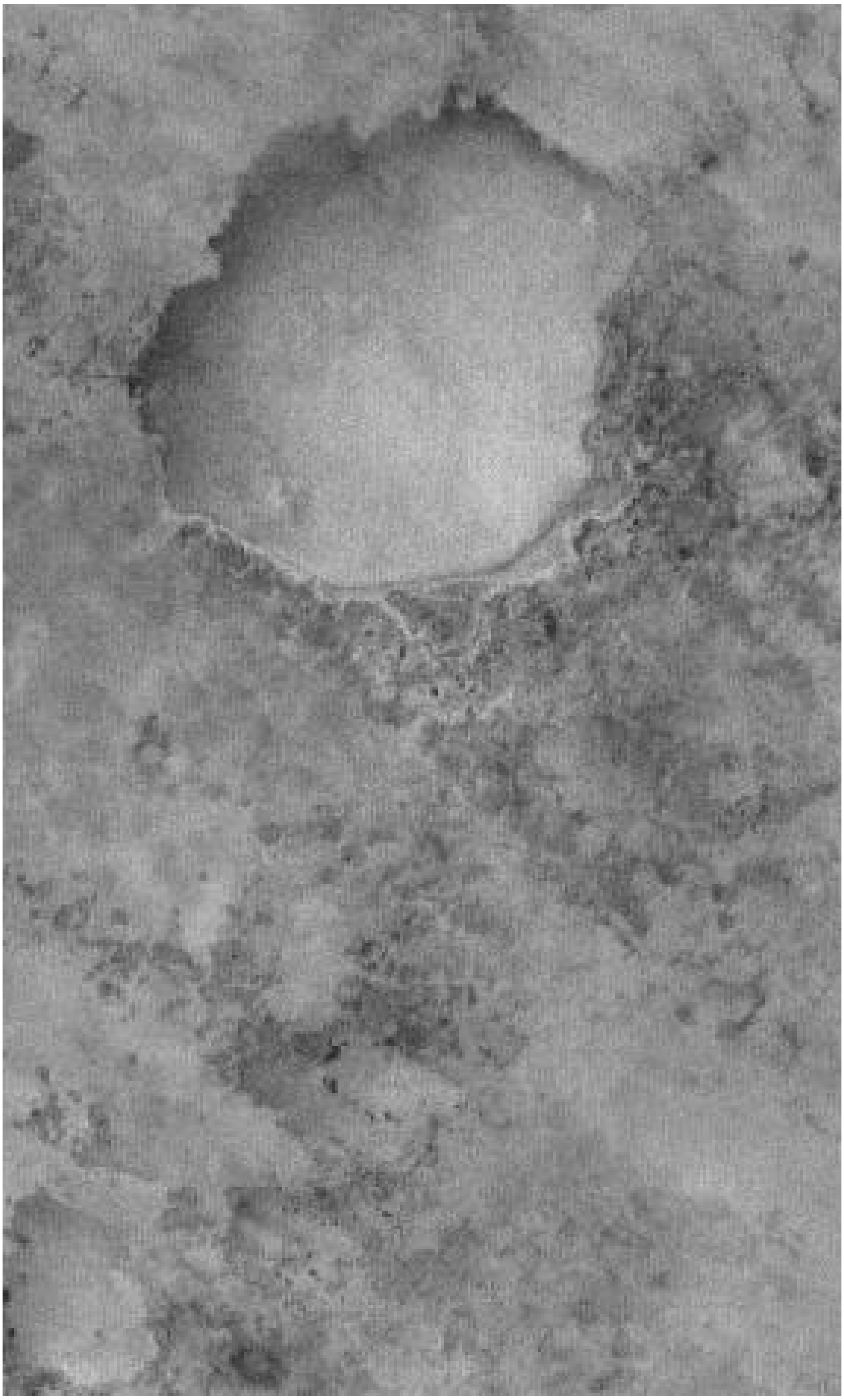


Figure 8: *ASTER image (monochrome) of the Umm al Binni structure, and the surrounding country to the south. Long streaks trending southwards (diagonally to the bottom right in the image) from the edge of the structure are interpreted as flow lines showing the former position of channels in the marshlands.*

Umm al Binni structure, a north to south gradation can be observed, corresponding to a decrease in thermal reflectance, from areas that were pure white (i.e., salt encrusted - seen in the images of Figs. 7 and 8), to the northern part of the structure, where there is a dark band adjacent to the rim (probably corresponding to an increase in the clay content, and a decrease in the amount of salt). In the area surrounding the Umm al Binni structure, there is an opposite effect: the "ejecta-like" scalloped material to the south has a lower reflectance than the smooth "ejecta-free" area to the north of the structure. The blue streaks going past the edge of the Umm al Binni structure are interpreted as representing former channels where increased clay fractions were deposited, in contrast to the areas to the north of the structure, where erosion took place. It is also inferred that some deposition of clay minerals took place in the northern rim of the structure and the marked north-south asymmetry of the Umm al Binni structure (in terms of smoothness and polygonality of outline; presence or absence of "ejecta-like" material, and the differing TIR and VNIR spectra is explained by invoking a north to south water flow within the marshes. This flow eroded an originally continuous "ejecta" blanket, and was obstructed by the presence of the crater with an uplifted rim, in the northern part of which there was more deposition of clays. There is at least one additional example of a terrestrial impact structure (the Tsenkher structure in Mongolia, Fig.10) with only a partially preserved ejecta blanket (Fig. 10), due to the removal by erosion of the rest of the ejecta around it (Komatsu *et al*., 1998, 1999).

The high-resolution imagery also shows the presence, in an area that was marshland just a decade ago, of a village or settlement about 4 km ENE of the Umm al Binni structure, from which paths radiate in all directions, possibly caused by domestic animal tracks (Fig.11). This village corresponds to the position of the former island village of Ishan abu Shajar, which was visited by Wilfred Thesiger in 1951. The following is Thesiger's description of this village in his 1964 book:

"…we reached Abu Shajar, an island of dark, bare earth, three hundred yards across and perhaps ten feet high at its highest point. The shore was surrounded by reedbeds. Thirty or fourty houses had been erected close together in a haphazard manner along the water's edge. Buffaloes stood wherever there was a space, a series of small pits round each house preventing them from actually rubbing against the walls. The people here were Shaganba."

A road leads from Abu Shajar northeast towards the larger settlement of Qubur. This shows that the area is currently accessible overland. It is imperative that the structure be studied on the ground in order to determine its origin, and that this work be done before the proposed re-flooding of the marshes again makes the area inaccessible. All previous attempts at studying the structure on the ground have been frustrated by the dangerous political and military situation that has prevailed in Iraq in the past 3 years.

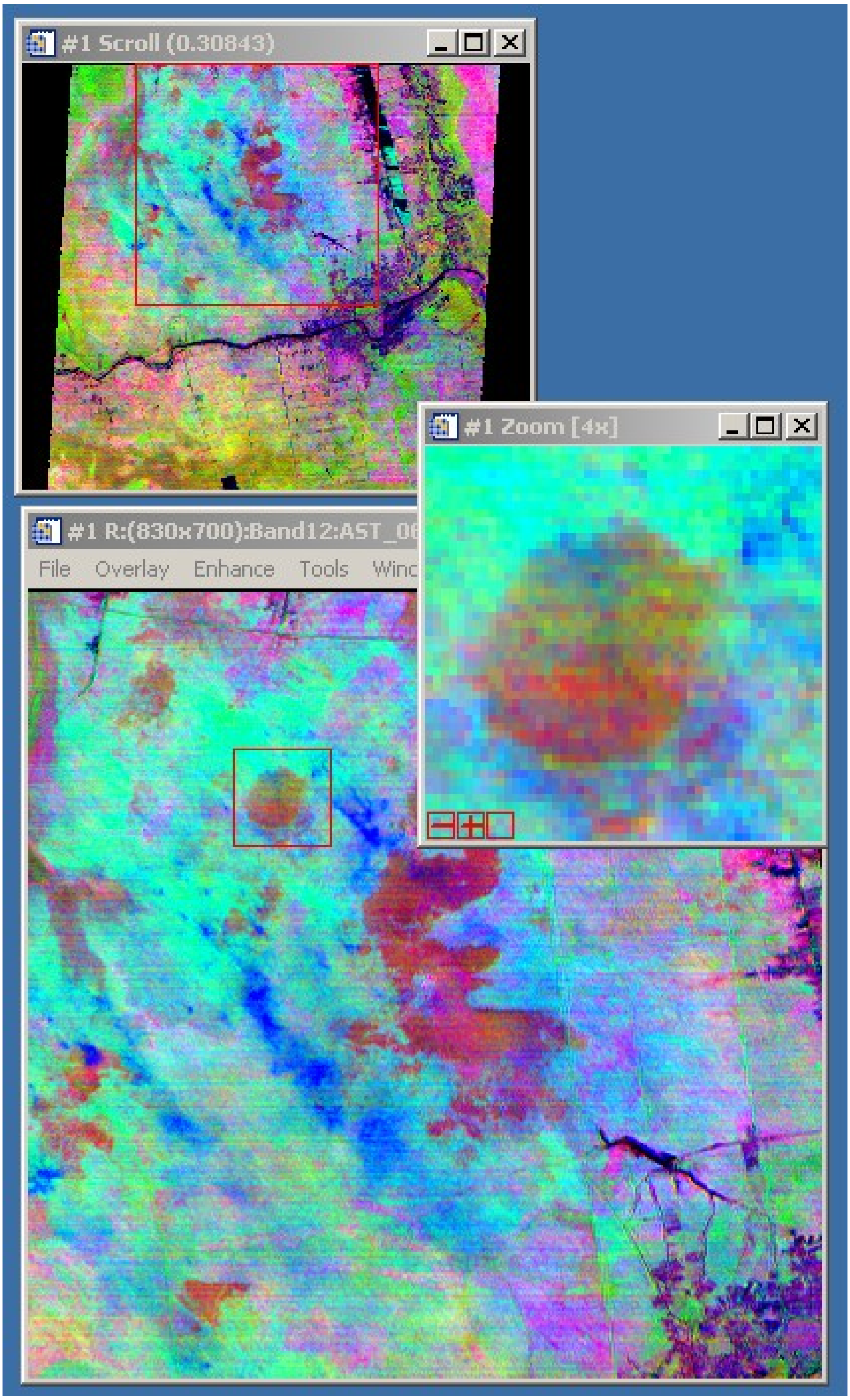


Figure 9: *ASTER image with Thermal Infrared (TIR) false colour composite bands 12,13,10 in RGB order. The upper image covers the whole ASTER scene of Figure 6. An enlargement of the inset above is shown below with the Umm al Binni structure enlarged 4 times in the middle right part.*

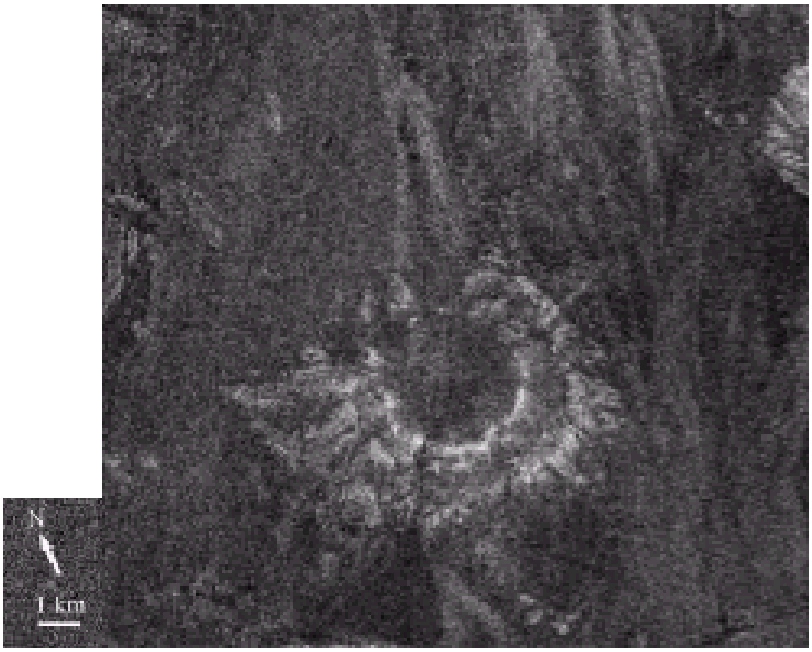


Figure 10: *Radar image of the Tsenkher impact crater, Mongolia, showing a bright semi-circular rim surrounded on the south by an ejecta blanket, while the northern part has been eroded away by fluvial fans (after Komatsu* et al.*, 1998, 1999).*

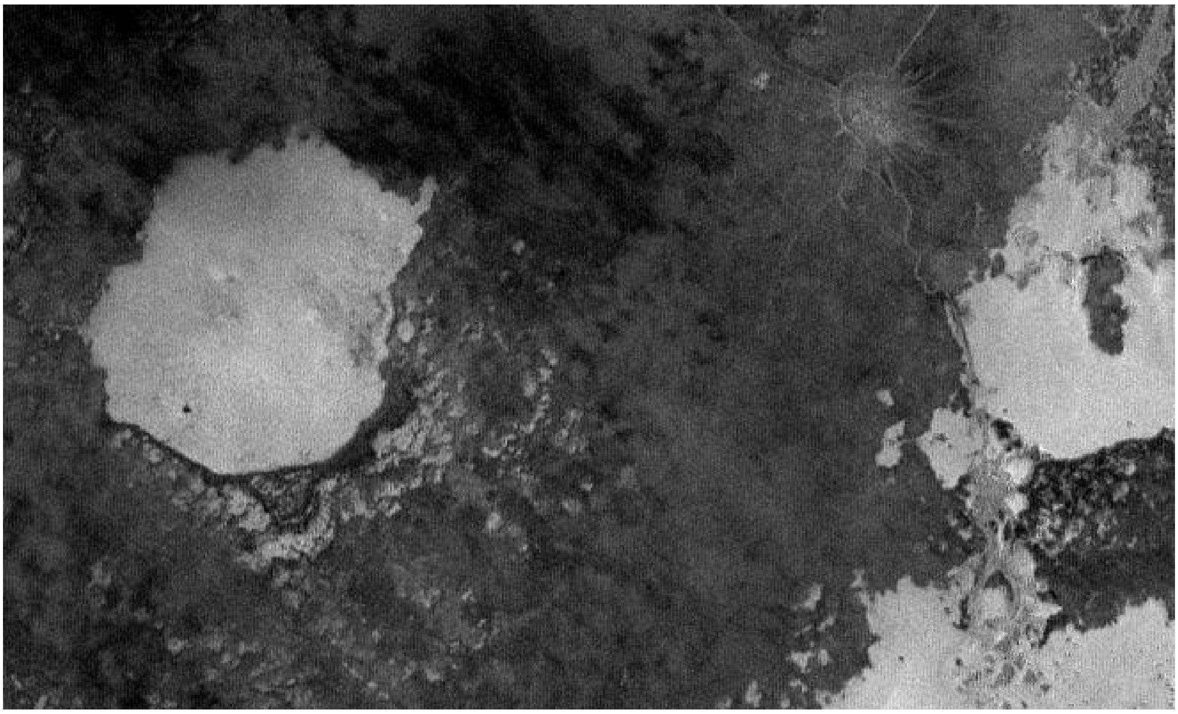


Figure 11: *ASTER satellite image showing Umm al Binni (left) and the northern end of Haur az Zikri (right). Near the northeast edge of the image, is the former island village of Ishan abu Shajar, from which domestic animal paths radiate in all directions, and a road leads to the northeast, towards the larger settlement of Qubur.*

PROPOSALS FOR FUTURE RESEARCH

If the security situation improves it is proposed that the following lines of research be undertaken on the Umm al Binni structure: (1) the structure needs to be examined along its entire rim, where a search should be made for deformation features such as overturned sediments, and breccias. The scalloped terrain to the south of the structure must be given special attention; (2) gravity and magnetic profiles should be made in a north-south direction. A gravity survey will be especially useful in delineating the shape of the crater bottom, and in deciphering the nature of its fill (e.g., Wong *et al*., 2001). A magnetic survey will help identify any igneous rocks, or subsurface magnetic rocks that may have been brought up in a central uplift (Pilkington and Grieve, 1992); (3) it is also proposed that a series of augur holes be drilled in a north-south profile, extending from well beyond the structure (in order get some kind of "background" reading), through the "ejecta" layer in the south, through the crater, and out onto the northern flanks. The augur cores from outside the structure should be examined petrographically and geochemically in order to detect any "fallout" layers related to a possible impact event (e.g., Franzen, 2002). The cores from inside the structure must be examined petrographically in order to detect macroscopic and microscopic evidence for shock deformation (planar deformation lamellae, diaplectic glasses, impact melts, microbreccias, pseudotachylites, shatter cones) (French, 1998); and (4) if the structure shows evidence for an impact origin, then it needs to be dated. This can most likely be done using radiocarbon dating, because of the young age of the country rocks.

Only once all of the above has been accomplished, will it be feasible to evaluate the possible role this structure may have played in the history of Mesopotamia.

REFERENCES

Adams, R.M. (1958). Survey of ancient water courses and settlements in central Iraq. *Sumer*, **14(1-2)**, 101-103.

Adams, R. McG. And Nissen, H.J. (1972). *The Uruk Countryside: The Natural Setting of Urban Societies.* The University of Chicago Press, Chicago, 241 pp.

Admiralty Naval Staff (1918). *Geology of Mesopotamia and its borderlands*. British Admiralty, International Department, London, 116 pp.

Ai-Adili, A.S. (2004). The study of clay minerals and their applications in petroleum projects-West Qurna Field, Iraq. In: *Geology of the Arab World. Agenda and Abstract of the Seventh International Conference on the Geology of the Arab World*, Cairo University, Giza, Egypt, February 2004, p. 20.

Ainsworth, W. (1838). *Researches in Assyria, Babylonia, and Chaldea; Forming Part of the Labours of the Euphrates Expedition*. John W. Parker, London, 343 pp.

Al-Asfour, T. (1978). The marine terraces of the Bay of Kuwait. *In:* Brice, W.C. (Ed.), *The Environmental History of the Near and Middle East Since the Last Ice Age*. Academic Press, London, 245-254.

Al-Baladuri (1866). *Kitab Futuh al-Buldan.* De Goeje, Leiden.

Al-Baladuri (1918). *Kitab Futuh al-Buldan, I.* New York, 453-456.

Al Ghunaim, A.Y., Ghunemi, Z.E.D.A., Abd al Razzaq, F.H.A., Al Mayyal, A.Y., Al Aryan, J.Y. and Moati, Y.A. (1994). *Iraq Navigational Outlets*. Centre for Research and Studies on Kuwait, Almansoria, Kuwait, 78 pp.

Al Naqib, K.M. (1967). Geology of the Arabian Peninsula: southwestern Iraq. *U.S. Geological Survey Professional Paper*, **560-G**, p. G7.

Alsharhan, A.S. and Nairn, A.E.M. (1997). *Sedimentary Geology and Petroleum Geology of the Middle East.* Elsevier Science, 843 pp.

Arrian (Flavius Arrianus) (1983). *Anabasis Alexandri Books V-VII.* With an English translation by P.A. Brunt. Loeb Classical Library, Harvard University Press, Cambridge, Massachusetts, USA, 589 pp.

Baghdadi, A.I. (1957). Ground-water in Iraq, its domestic use, supply and planned utilization of under-ground reservoirs. In: *Seccion IV: Geohidrologia de Regiones Aridas y Sub-aridas*, Congreso Geologico Internacional, XX[a] Sesión, Ciudad de México, 231-246.

Bahroudi, A. and Talbot, C.J. (2003). The configuration of the basement beneath the Zagros Basin. *Journal of Petroleum Geology*, **26(3)**, 257-282.

Beke, C.T. (1834). On the former extent of the Persian Gulf and on the comparatively recent Union of the Tigris and Euphrates. *London and Edinburgh Phil. Mag. and J. Sci.*, Ser. 3, **IV**, 107-112.

Beke, C.T. (1835). On the historical evidence of the advance of the land upon the sea at the head of the Persian Gulf. *London and Edinburgh Phil. Mag. and J. Sci.*, Ser. 3, **VI**, 401-408.

Berberian, M. (1995). Master "blind" thrust faults hidden under the Zagros folds: active tectonics and surface morphotectonics. *Tectonophysics*, **241**, 193-224.

Berry, R.W., Brophy, G.P. and Naqash, A. (1970). Mineralogy of the suspended sediment in the Tigris, Euphrates, and Shatt-al-Arab rivers of Iraq and the Recent history of the Mesopotamian plain. *Journal of Sedimentary Petrolology*, **40**, 131-139.

Beydoun, Z.R., Hughes-Clarke, M.W. and Stoneley, R. (1992). Petroleum in the Zagros Basin: A Late Tertiary foreland basin overprinted onto the outer edge of a vast hydrocarbon-rich Paleozoic-Mesozoic passive-margin shelf. *In*: Macqueen, R.W. and Leckie, D.A. (Eds.), *Foreland Basins and Fold Belts.* AAPG Memoir 55, Tulsa, Oklahoma, USA, 309-339.

Britt, R.R. (2001). Comets, Meteors and Myth: new evidence for Toppled Civilizations and Biblical Tales. Posted 13 November 2001. http://www.space.com/ science-astronomy/planetearth/comet_bronzeage_011113-1.html

Brookings Institution (2003). The Iraqi Marshlands: can they be saved? Assessing the human and ecological damage. A Brookings Forum sponsored by the British Embassy and the Brookings-SAIS Project on Internal Displacement, Brookings Institution, Washington, D.C., USA, http://www.brook.edu/dybdocroot/comm/ events/20030507.pdf

Buday, T., Kassab, I.I.M. and Jassim, S.Z. (1980). *The Regional Geology of Iraq. Volume 1: Stratigraphy and Paleogeography.* State Organisation for Minerals, Baghdad, 445 pp.

Buringh, P. (1957). Living conditions in the lower Mesopotamian plain in ancient times. *Sumer*, **13(1-2)**, 30-46.

Buringh, P. (1969). *Soils and Soil Conditions in Iraq*. Ministry of Agriculture, Baghdad, Iraq, 322 pp.

Buringh, P. and Edelman, C.H. (1955). Some remarks about the soils of the alluvial plain of Iraq, south of Baghdad. *Netherlands Journal of Agricultural Science*, **3**, 40-49.

Cadoux, H.W. (1906). Recent changes in the course of the Lower Euphrates. *Geographical Journal*, **38**, 272-273.

Chesney, F.R. (1850). *The Expedition for the Survey of the Rivers Euphrates and Tigris, carried on by order of the British Government in the years 1835, 1836 and 1837, preceded by geographical and historical notices of the regions*. 2 Volumes. Longmans & Green, London, 799, 778 pp.

Civil, M. (1969). The Sumerian flood story. *In:* Lambert, W.G. and Millard, A.R. *Atra-Hasīs: The Babylonian Story of the Flood*. Clarendon Press, Oxford, 198 pp.

Collon, D. (2000). Implications of introducing a Low Mesopotamian Chronology. *BANEA Newsletter, British Association for Near Eastern Archaeology*, **13**, July 2000, 6-9.

Courty, M.-A. (1998) Causes and effects of the 2350 BC Middle East anomaly evidenced by micro-debris fallout, surface combustion and soil explosion. *In:* Peiser, B.J., Palmer, T. and Bailey, M.E. (Eds.), *Natural Catastrophes During Bronze Age Civilisations:*

Archaeological, Geological, Astronomical and Cultural Perspectives. British Archaeological Reports -S728, Archaeopress, Oxford, 252 pp.

Dance, S.P. and Eames, F.E. (1966). New molluscs from the Recent Hammar Formation of south-east Iraq. *Proceedings of the Malacological Society, London,* **37**, 35-43.

De Morgan, J. (1900). *La Délégation en Perse, Mémoires*. Tome I, Leroux, Paris, 4-48.

De Vaumas, E. (1955). Etudes Irakiennes, première Série. *Bulletin de la Société Géographique d'Egypte*, **28**, 125-194.

De Vaumas, E. (1958). Le Contrôle et l'Utilisation des Eaux du Tigre et de l'Euphrate. *Revue Géographique Alpine*, **1958**, 235-331.

Eames, F.E. and Wilkins, G.L. (1957). Six new molluscan species from the alluvium of Lake Hamar, near Basrah, Iraq. *Proceedings of the Malacological Society, London,* **32(5)**, 198-203.

Edgell, H.S. (1996). Salt tectonics in the Persian Gulf basin. *In:* Alsop, G.L., Blundell, D.L. and Davison, I. (Eds.), *Salt Tectonics*. Spec. Publ. Geol. Soc. London, **100**, 129-151.

Falkenstein, A. (1951). Die Eridu Hymne. *Sumer*, **7**, 119-125.

Franzen, L. (2002). Cosmic activity as detected from raised bog stratigraphies in Northern Europe and Siberia. Cause, or non-cause, to climate deterioration and Dark Ages in Middle and Late Holocene? *In:* Leroy, S. and Stewart, I.S. (Eds.), *Environmental Catastrophes and Recovery in the Holocene*, Abstracts Volume, Department of Geography, Brunel University, Uxbridge, West London, U.K., 29 August - 2 September 2002, 32-33.

French, B.M. (1998). *Traces of Catastrophe: A Handbook of Shock-Metamorphic Effects in Terrestrial Meteorite Impact Structures*. LPI Contribution No. **954**, Lunar & Planetary Institute, Houston, Texas, USA, 120 pp.

George, A.R. (2003a). *The Babylonian Gilgamesh Epic: Introduction, Critical Edition and Cuneiform Text.* 2 Volumes, Oxford University Press, 1176 pp.

George, A.R. (2003b). *The Epic of Gilgamesh: The Babylonian Epic Poem and Other Texts in Akkadian and Sumerian*. Penguin Classics, Harmondsworth.

Gibb, H.A.R. (1962). *The Travels of Ibn Battuta, A.D. 1325-1354*, *Vol. II.* Hakluyt Society, Cambridge Univ. Press, London, p. 277.

Haigh, F.F. (1951). *The control of the Rivers of Iraq and the utilization of their waters.* Baghdad.

Hamid, H. (1994). Saddam 'nettoie' les marais Irakiens. *Courier International*, **33**, No. 168, 20-26 January 1994.

Hansman, J.F. (1978). The Mesopotamian delta in the first millenium B.C. *Geographical Journal*, **14**, 49-61.

Harris, S.A. and Adams, R.M. (1957). A note on canal and marsh stratigraphy near Zubediyah. *Sumer*, **13(102)**, 157-162.

Hassan, H.A. and Al-Kubaisi, Q.Y. (2002). Pliocene groundwater evolution of the Dibdiba aquifers, Iraq. *In:* Youssef, E-S.A.A. (Ed.), *Geology of the Arab World. Agenda and Abstrcts of the Sixth International Conference on Geology of the Arab World*, Cairo University, Giza, Egypt, February 2002, p. 67.

Haupt, P. (1880). *Der keilinschriftliche Sintfluthbericht, eine Episode des babylonischen Nimrod-Epos*. Habilit.-Vorl. Geh. a. d. Univ. Göttingen; 8°, Leipzig 1881.

Haupt, P. (1883). Excursus: Der keilinschriftliche Sintfluthbericht. *In:* Schrader (Ed.), *Keilinschriften und Altes Testament*, 2 Aufl., Giessen.

Herodotus (1972). *The Histories*. Translated by Aubrey de Sélincourt. Revised, with an Introduction by A. R. Burn. Penguin Books, Harmondsworth, 653 pp.

Hudson, R.G.S., Eames, F.E. and Wilkins, G.L. (1957). The fauna of some Recent marine deposits near Basra, Iraq. *Geological Magazine*, **94 (5)**, 393-401.

Ionides, M.G. (1937). *The regime of the rivers Euphrates and Tigris*. London, 278 pp.

Ionides, M.G. (1954). The geographical history of the Mesopotamian Plains. *Geographical Journal*, **120(3)**, 394-395.
Issar, A.S. (1995). Climate change and the history of the Middle East. *American Scientist*, **83**, 350-355.
Jacobsen, L. (2003). Scientists hope to restore historic Iraqi marshlands. *Milwaukee Journal Sentinel*, Milwaukee, Wisconsin, USA, 4 May, 2003.
Jacobsen, T. (1951). An agricultural document from Nippur. *Sumer*, **7(1)**, 77-78.
Jacobsen, T. (1960). The waters of Ur. *Iraq*, **22**, 174-185.
Jacobsen, T. and Adams, R. (1958). Salt and silt in ancient Mesopotamian agriculture. *Science*, **126**, 1251-1257.
Jassim, S.Z. and Buday, T. (2004, in press). The tectonic framework of Iraq. *In:* Jassim, S.Z. (Ed.), *Geology of Iraq*. Geologyiraq.cz
Kerr, R.A. (1998). Sea-floor dust shows drought felled Akkadian Empire. *Science*, **279**, 16 January 1998, 325-326.
Knetsch, G. (1955). Lebendige Tektonik im Irak. *Geologische Rundschau*, **43(1)**, 227-232.
Komatsu, G., Olsen, J.W. and Baker, V.R. (1998). A possible impact structure in southern Mongolia. *Lunar and Planetary Science*, **XXIX**, Abstract No. 1226, Lunar and Planetary Institute, Houston, Texas, USA (CD-ROM).
Komatsu, G., Olsen, J.W. and Baker, V.R. (1999). Field observation of a possible impact structure (Tsenkher structure) in southern Mongolia. *Lunar and Planetary Science*, **XXX**, Abstract No. 1041, Lunar and Planetary Institute, Houston, Texas, USA (CD-ROM).
Lambert, W.G. and Millard, A.R. (1969). *Atra-Hasīs: The Babylonian Story of the Flood.* Clarendon Press, Oxford, 198 pp.
Larsen, C.E. (1975). The Mesopotamian delta region: a reconsideration of Lees and Falcon. *Journal of the American Oriental Society*, **95**, 43-57.
Larsen, C. E. and Evans, G. (1978). The Holocene geological history of the Tigris-Euphrates-Karun delta. *In:* Brice, W.C. (Ed.), *The Environmental History of the Near and Middle East Since the Last Ice Age*. Academic Press, London, 227-244.
Lawler, A. (2002). Archeology: Report of oldest boat hints at early trade routes. *Science*, **296**, 1791-1792.
Lees, G.M. (1955). Recent earth movements in the Middle East. *Geologische Rundschau*, **43**, 221-226.
Lees, G. M. and Falcon, N. L. (1952). The geographical history of the Mesopotamian Plains. *Geographical Journal*, **118**, 24-39.
Le Strange, G. (1905). *The Lands of the Eastern Caliphate. Mesopotamia, Persia and Central Asia, from the Moslem Conquest to the Time of Timur*. Oxford University Press, Cambridge, 26-27.
Lloyd, S.H. (1943). *Twin Rivers*. Oxford University Press, Oxford.
Loftus, W.K. (1855). On the geology of portions of the Turko-Persian Frontier, and of the districts adjoining. *Quarterly Journal of the Geological Society*, *London,* **XI**, 247-344.
Lubick, N. (2003). Iraq's marshes renewed. *Geotimes*, October 2003, 25-27.
Lyon, I. (2001). The importance of peer review. *Meteoritics and Planetary Science*, **36(12)**, p. 1569.
Macfayden, W.A. (1938). Water supplies in Iraq. *Iraq Geol. Dept., Publ.* ***No. 1***, Baghdad, 206 pp.
Macfayden, W. A. and Vita-Finzi, C. (1978). Mesopotamia: the Tigris-Euphrates delta and its Holocene Hammar fauna. *Geological Magazine*, **115**, 287-300.
Martin, G. (2003). A dream of restoring Iraq's great marshes. Wetlands destroyed by Hussein could thrive again. *San Francisco Chronicle*, 7 April 2003.

Master, S. (2001). A possible Holocene impact structure in the Al 'Amarah Marshes, near the Tigris-Euphrates confluence, southern Iraq. Abstract, 64th Annual Meeting of the Meteoritical Society, Vatican City, 10th-14th September, 2001, *Meteoritics and Planetary Science*, Vol. **36(9)**, **Supplement**, p. A 124.

Master, S. (2002). Umm al Binni lake, a possible Holocene impact structure in the marshes of southern Iraq: geological evidence for its age, and implications for Bronze-age Mesopotamia. *In:* Leroy, S. and Stewart, I.S. (Eds.), *Environmental Catastrophes and Recovery in the Holocene*, Abstracts Volume, Department of Geography, Brunel University, Uxbridge, West London, U.K., 29 August - 2 September 2002, 56-57. http://atlas-conferences.com/cgi-bin/abstract/caiq-15.

Matthews, R. (2001). Meteor clue to end of Middle East civilisations. http://www.portal.telegraph.co.uk/news/main.jhtml?xml=/news/2001/11/04/wmet04.xml&sSheet=/news/2001/11/04/ixhomef.html

Melosh, H.J. (1989). *Impact Cratering: a Geologic Process*. Oxford Monographs on Geology and Geophysics, No. **11**, Oxford University Press, New York, 245 pp.

Merriam, R. and Holwerda, J.G. (1957). Al Umchaimin, a crater of possible meteoritic origin in western Iraq. *Geographical Journal*, **123**, 231-233.

Mitchell, R.C. (1956). Aspects géologiques du désert occidental de l'Iraq. *Bulletin de la Société Géologique de France*, **6(6)**, 391-406.

Mitchell, R.C. (1957). Recent tectonic movements in the Mesopotamian Plains. *Geographical Journal*, **123(4)**, 569-571.

Mitchell, R.C. (1958a). Recent marine deposits near Basrah. *Geological Magazine*, **95(1)**, 84-85.

Mitchell, R.C. (1958b). Instability of the Mesopotamian Plains. *Bulletin de la Société Géographique d'Egypte*, **31**, 127-139.

Mitchell, R.C. (1958c). The Al Umchaimin crater, western Iraq. *Geographical Journal*, **124**, 578-580.

Moore, H.J., Hodges, C.A. and Scott, D.H. (1974). Multi-ringed basins- illustrated by Orientale and associated features. *Proceedings of the Fifth Lunar and Planetary Science Conference*, LPI, Houston, 71-100.

Moritz, B. (1888). Zur Geographie und Ethnographie von Süd-Mesopotamien. *Verhandlungen der Gesellschaft für Erdkünde zu Berlin*, **15**, 195, 199.

Munro, D.C. and Touron, H. (1997). The estimation of marshland degradation in southern Iraq using multitemporal Landsat TM images. *International Journal of Remote Sensing*, **18(7)**, 1597-1606.

Naff, T. and Hanna, G. (2002). The marshes of southern Iraq: a hydro-engineering and political profile. *In:* Nicholson, E. and Clark, P. (Eds.), *The Iraqi Marshlands: a Human and Environmental Study*. The Amar International Charitable Foundation, AMAR Publications, London.

Nelson, H.S. (1962). An abandoned irrigation system in southern Iraq. *Sumer*, **18**, 67-72.

Nicholson, E. and Clark, P. (2002). *The Iraqi Marshlands: A Human and Environmental Study*. The Amar International Charitable Foundation, AMAR Publications, London.

North, A. (1993a). New evidence shows marshlands draining away. *The Middle East*, London, No**. 227**, Oct. 1993, 22-23.

North, A. (1993b). Saddam's water war. *Geographical Magazine*, July 1993, 10-14.

Nowroozi, A.A. (1972). Focal mechanism of earthquakes in Persia, Turkey, West Pakistan, and Afghanistan and plate tectonics of the Middle East. *Bulletin of the Seismological Society of America*, **62(3)**, 823-850.

Örmo, J., Shuvalov, V. and Lindström, M. (2001). A model for target water depth estimation at marine impact craters. *Meteoritics and Planetary Science*, **36(9)**, Suppl., p. A154.

Partow, H. (2001a). The Mesopotamian Marshlands: demise of an ecosystem. Early Warning and Assessment Technical Report, UNEP/DEWA/TR.01.2.Rev.1. Division of Early Warning and Assessment, United Nations Environment Programme (UEP), Nairobi, Kenya. www.grid.unep.ch/activities/sustainable/ tigris/marshland. Also: http://gridz.cr.usgs.gov/publications/meso.pdf

Partow, H. (2001b). Landsat witnesses the destruction of Mesopotamian ecosystem. NASA Goddard Spaceflight Center, Scientific Visualization Studio, http://svs.gsfc.nasa.gov/vis/a000000/a002200/a002210/Mesopotamia_v2.html

Pearce, F. (1993). Draining life from Iraq's marshes. *New Scientist*, **1869**, 17 April 1993, 11-12.

Pearce, F. (2001). Iraqi wetlands face total destruction. *New Scientist*, **2291**, 4-5.

Philby, H.St.J. (1959). The eastern marshes of Mesopotamia. *Geographical Journal*, **125**, 65-69.

Philip, G. (1968). Mineralogy of Recent sediments of Tigris and Euphrates rivers and some of the older detrital deposits. *Journal of Sedimentary Petrology*, **38**, 35-44.

Pilkington, M. and Grieve, R.A. (1992). The geophysical signature of terrestrial craters. *Reviews in Geophysics*, **30**, 161-181.

Rees Williams, W. (1952). The origin of the Al Batin in the Al Dibdibba. *Sumer*, **8(2)**, 217-219.

Roux, G. (1960). Recently discovered sites in the Hammar Lake District. *Sumer*, **16**, 20-31.

Russel, J.C. (1956). Historical aspects of soil salinity in Iraq. *Majallatu-'Zzira'ati'l-Iraqiyan, Ministry of Agriculture Iraq*, XI(2-3), 204-215.

Rzóska, J. (1980). *Euphrates and Tigris, Mesopotamian Ecology and Destiny*. Dr. W. Junk bv. Publishers, The Hague.

Salim, S. M. (1962). *Marsh dwellers of the Euphrates Delta*. Athlone Press, London, 157 pp.

Sandars, N. K. (1960). *The Epic of Gilgamesh.* Penguin Books, Harmondsworth, 128 pp.

Schläfli, A. (1864). Zur physikalishen Geographie von Unter-Mesopotamien. *Schweiz. Denkschr*., 1864, p. 4 .

Sharland, P.R., Archer, R., Casey, D.M., Casey, R.B., Hall, S.H., Heward, A.P., Horbury, A.D. and Simmons, M.D. (2001). *Arabian Plate Sequence Stratigraphy*. GeoArabia Special Publication **2**, 371 pp.

Shoemaker, E.M. (1983). Asteroid and comet bombardment of the Earth. *Annual Reviews of Earth and Planetary Science*, **11**, 461-494.

Suess, E. (1904). *The Face of the Earth (Das Antlitz der Erde)*,. Volume 1. Clarendon Press, Oxford, 604 pp.

Smith, G. (1872). Early history of Babylonia. *Transactions of the Biblical Archaeological Society*, **1**, 55-62.

Smith, G. (1876). *The Chaldean Account of Genesis*. Sampson Low, Marston, Searle and Rivington, London, 319 pp.

Smith, S. (1954). The geographical history of the Mesopotamian plains. *Geographical Journal*, **120(3),** 395-396.

Speiser, E.A. (1958). The epic of Gilgamesh. *In:* Pritchard, J. B. (Ed*.), The Ancient Near East, Volume I, An Anthology of Text and Pictures*. Princeton University Press, Princeton, 40-75.

Sultan, M., Becker, R., Al-Dousari, A., Al-Ghadban, A.N. and Bufano, E. (2003). Water, agriculture and land cover: lessons for the post-war era. *Geotimes*, October 2003, 22-24.

Thesiger, W. (1954). The marshmen of southern Iraq. *Geographical Journal*, **120(3)**, 272-281.

Thesiger, W. (1958). Marsh dwellers of southern Iraq. *National Geographic*, **113(2)**, February 1958, 204-239.

Thesiger, W. (1964). *The Marsh Arabs*. Longmans, Green, London. Reprinted 1967, Penguin Books, Harmondsworth, 233 pp.

Tigay, J.H. (1982). *The Evolution of the Gilgamesh Epic*. University of Pennsylvania Press, Philadelphia, 384 pp.

Tomaschek, W. (1890). Topographische Erlaüterung der Küstenfahrt Nearchs vom Indus bis zum Euphrat. *Sitzungsberichte der Königliche und Kaiserliche Akademie der Wissenschaften, Wien*, **121**.

Underwood, J.R. (1994). Al Umchaimin depression, western Iraq: an impact structure? *In:* Dressler, B.O., Grieve, R.A.F. and Sharpton, V.L. (Eds.), *Large Meteorite Impacts and Planetary Evolution.* Geological Society of America Special Paper 293, Boulder, Colorado, 259-263.

Voûte, C. (1957). A prehistoric find near Razzaza (Karbala Liwa). Its significance for the morphological and geological history of the Abu Dibbis depression and surrounding area. *Sumer*, **13**, 135-148.

Wagstaff, J.M. (1985). *The Evolution of Middle Eastern Landscapes: An Outline to A.D. 1840.* Croom Helm, London, 304 pp.

Weiss, H., Courty, M.- A., Wetterstrom, W., Guichard, F., Senior, L., Meadow, R. and Curnow, A. (1993). The genesis and collapse of Third Millenium North Mesopotamian civilization. *Science*, **261**, 995-1004.

Westphal-Hellbusch, S. and Westphal, H. (1962). Die Ma'dan: Kultur und Geschichte der Marschenwohner im Süd-Iraq. *Forschungen zur Ethnologie und Sozialpsychologie*, *Berlin*, **4**, 11.

Wong, A.M., Reid, A.M., Hall, S.A. and Sharpton, V.L. (2001). Reconstruction of the subsurface structure of the Marquez impact crater in Leon County, Texas, USA, based on well-log and gravity data. *Meteoritics and Planetary Science*, **36**, 1443-1455.

Wood, M. (1993). Saddam drains the life of the Marsh Arabs. *The Independent*, Saturday 28 August 1993.

Young, G. (1976). Water dwellers in a desert world. *National Geographic*, **149(4)**, April 1976, 502-523.

Young, G. (1977). *Return to the Marshes: Life with the Marsh Arabs of Iraq*. Collins, London. Reprinted (1987), Penguin, Harmondsworth, 184 pp.

oOo