The impact of climate change on subsistence strategies in northern Mesopotamia: the stable isotope analysis and dental microwear analysis of human remains from Bakr Awa (Iraqi Kurdistan)

by Rafał Andrzej Fetner

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Table of content

Preface.................................................................................................................................................4
Composition of the thesis......................................................................................................................6
Acknowledgements..................................................................................................................................7

Chapter One. Environment and subsistence in northern Mesopotamia..................................................8

1. Modern climate of northern Iraq....................................................................................................8
1.1 Drought in the Middle East (case study of 2007-2009 event).........................................................11
2. Some remarks on the modern day debate on the relation between climate and human
societies.............................................................................................................................................13
3. Adaptation as a response to climate changes..................................................................................15
4. Palaeoclimate of northern Mesopotamia..........................................................................................16
4.1. Climate between 6.5 ka and 3.2 ka BP............................................................................................17
4.2. The 3.2 ka BP event........................................................................................................................18
4.3. Palaeoclimate after 3.0 ka BP............................................................................................................20
5. Diet and subsistence in northern Mesopotamia.................................................................................20
5.1. Stable isotope evidence of human diet............................................................................................23
5.2. Dental microwear and diet..............................................................................................................23
5.3. Subsistence at Bakr Awa.................................................................................................................24

Chapter Two. The Shahrizor from the Bronze Age to the Middle Ages..................................................26

1. Archaeological investigation in the Shahrizor...................................................................................26
2. The Zagros foothills in the Early Bronze Age....................................................................................27
3. The Shahrizor in the Early Bronze Age...............................................................................................28
4. The late Early Bronze Age crisis.......................................................................................................29
5. Simurrum in the Middle Bronze Age..................................................................................................30
6. The Shahrizor between Babylonia and Assyria................................................................................31
7. The Late Bronze Age crisis...............................................................................................................32
7.1 The role of the climate in the Late Bronze Age crisis......................................................................35
8. Province of the Empire......................................................................................................................37
9. Classical period...................................................................................................................................39
10. Islamic period....................................................................................................................................40
11. Bakr Awa: case study.......................................................................................................................41
11.1. Results of archaeological investigations......................................................................................42

Chapter Three. Theory and techniques of dietary reconstruction.....................................................46

1. Analysis of carbon and nitrogen stable isotopes.............................................................................47
1.1. The isotopic analysis.......................................................................................................................47
1.2. Collagen.........................................................................................................................................48
1.3. Carbon in the food chain................................................................................................................49
1.4. Nitrogen in a food chain..................................................................................................................53
1.5. Analysis of the fossil remains.......................................................................................................56
2. Dental microwear analysis................................................................................................................60
Preface

The ancient history of Mesopotamia, the cradle of agriculture and civilisation, was shaped by climatic conditions and their rapid changes. The environment of northern Mesopotamia is sensitive to fluctuations in the amount of annual rainfall (Trigo et al. 2010). Occurrence of drought can limit area available for dry-farming, leading to a shortage of food and competition over the essential resources (Neumann and Parpola 1987). Such a case was attested at the end of the second millennium BC. A drought episode between 1200 and 900 BC affected subsistence of both the semi-nomads and farmers (Brinkman 1968; Neumann and Parpola 1987). As a result of the drought, crop failure became more common, and the pastures were not able to maintain flocks. In order to feed their flocks Arameans migrated into an already settled area engaging in a conflict with the Assyrian state, leading to its decline (Postgate 1992).

The LBA crisis caused a socio-economic deterioration that shaped northern Mesopotamia in the Iron Age (IA; Fales 2011; Kirleis and Herles 2007; Postgate 1992), shifting settlement from centred at one big centre dominating the area, as observed in the Bronze Age (BA), to numerous but small settlements widespread on the fertile areas, as visible in the IA and later (Brown 2014; Wilkinson et al. 2005).

The political shape of Mesopotamia changed as well. In the BA, Mesopotamia was a place of competition between several small states, from time to time dominated by one of them (Chavalas 2005; Liverani 2005). After a period of decentralisation and ruralisation during the time of crisis, the Assyrian state was first to recover and later dominated the whole of Mesopotamia and the neighbouring areas (Parker 2012; Pedde 2012). For the next centuries, ancient Northern and Southern Mesopotamia remained united under one ruler of the Assyrian (Parker 2012), Babylonian (Baker 2012) and later Achaemenid Empire (Beaulieu 2005; Henkelman 2012). The unification could have resulted in a greater cooperation between areas previously remaining in competing political units.

Changes were also observed in agriculture. Intensive irrigation in the IA allowed for an introduction of the more water demanding vegetables and fruit. In the more arid areas, millet was introduced as a summer crop, probably in order to increase agricultural productivity (Riehl and Nesbitt 2003). Changes were also attested in animal economy – a decrease in the importance of pigs and an increase in the chicken remains in animal bone assemblages (Redding 2015).

The Late Bronze Age (LBA) crisis is well attested in the areas of lower precipitation. However, some traits of the crisis were also attested in the areas with a relatively high annual precipitation, such as the Shahrizor. At Tell Bakr Awa, located in the eastern Shahrizor, traits of the crisis manifested in the absence of artefacts dated between 1200-900 BC. Before, in the Middle Bronze Age (MBA) and in the LBA, Bakr Awa was a wealthy urban centre, as indicated by its architecture and spectacular funeral findings. Later, after the LBA
crisis, only some stone pavements and earth interments rarely equipped in grave goods were attested in the excavated areas. Occupation after the drought episode was not long lasting, and Bakr Awa seems to have been abandoned during the Hellenistic and Sasanian periods (330 BC–AD 636; Miglus et al. 2011, 2013). The drought episode could have also affected the subsistence of Bakr Awa inhabitants. If the population was no longer able to pursue their subsistence economy, it had to adapt to new conditions in order to survive (Forbes 1989), and a change in subsistence may be reflected by a change in the human diet (e.g. Lee-Thorp 2008; Mahoney 2006). A comparison between the periods before and after the climatic and environmental change allows only for tracking permanent changes in the subsistence, probably associated with a reorientation of the local economy. The presented work aims to study permanent changes in the human diet at Bakr Awa in the context of the climatic and environmental changes at the end of the second millennium BC.

In the Shahrizor and the adjacent regions, three sites providing palaeoenvironmental (Marsh and Altaweel 2015) and palaeoclimate data are located (Reuter et al. 2012; Stevens et al. 2001). Unlike other parts of northern Mesopotamia, it may be possible to estimate the impact of the drought episode on the Shahrizor environment more precisely. Response to global climate changes could be regionally specific (cf. Roberts et al. 2011), therefore the presence of three palaeoclimate and palaeoenvironment proxies in the vicinity of Bakr Awa advocates the selection of this site to study climate-induced changes.

In order to investigate changes in the diet associated with the LBA crisis, human remains were analysed for stable isotope composition of bone collagen and proportions of microwear features on dental enamel. Human remains from Bakr Awa (Fetner 2011, 2014, 2015; Miglus et al. 2013) represent populations occupying the site in the Early Bronze Age (EBA) and the MBA (2500-1600 BC), later in the late Iron Age (IA; 800-300 BC), and in the Islamic (IS) period (AD 700-1900). Unfortunately, no human remains from the Late Bronze Age (LBA; 1600-1200 BC) or from the early IA (1200-900 BC) have been found.

Because the changes between the BA and the IA seemed to be permanent, in the present study, human remains dated to the BA and IA periods will be compared. The BA population is represented by the EBA and the MBA inhabitants of Bakr Awa. This population should provide good representation of urban economy at Bakr Awa in the BA before the LBA crisis. The IA population should represent the effects of the processes that took place during the LBA crisis. If possible, the IS population will be used as the population with a known subsistence – transhumance (cf. Le Strange 1905; Speiser 1927).

Stable isotope analysis of bone collagen, first method of choice, is one of the most broadly adapted methods of investigating the composition of human diet. For the area of northern Mesopotamia, this analysis can provide information about the share of animal proteins (meat, dairy products) and plants with a specific photosynthesis pathway (e.g. millet) in human diet (e.g. Ambrose and Katzenberg 2002; Lee-Thorp 2008).
Unfortunately, preservation of collagen in the warm and arid climate of the Middle East is rather poor. First attempts to analyse the stable isotope ratio of human collagen failed to provide numerous reliable data (e.g. Schutkowski 2012). The poor preservation of collagen discouraged researches to conduct the analysis. However, recent studies have showed that the poor preservation rate is typical for shallow graves, while the graves covered by a thick layer of soil provide good conditions for collagen preservation (cf. Sołtysiak and Schutkowski 2015a).

In the area of northern Mesopotamia, the stable isotope analysis of bone collagen was successfully conducted for Tell Sheikh Hamad – human and animal remains from the Achaemenid Parthian/Roman period (Höring and Jungklaus 2010), Tell Sabi Abyad - animal remains from the Late Neolithic (van der Plicht et al. 2012), Umm el-Marra – human remains from 2600-2200 BC (Batey 2011), and Tell Barri – human remains from the EBA to the modern period (Sołtysiak and Schutkowski 2015b). Recently, preliminary results of stable isotope analyses have been presented as conference announcements for the sites Tell Majnuna, the Late Chalcolithic (Styring et al. 2014), Tell Masaikh and Tell Ashara, the EBA – modern period (Sołtysiak and Schutkowski 2015a). Dental microwear analysis is the second method of choice. The analysis of proportion and size of traits left on the enamel surface can provide information about specific mastication of food items (Teaford and Walker 1984) and plant processing technology (cf. Sołtysiak 2011). In northern Mesopotamia, the microwear analysis was conducted for Abu Hureyra (Molleson et al. 1993), Tell Ashara and Tell Masaikh (Sołtysiak 2011). Both methods provide complementary data regarding human diet.

Results of both analyses will be compared with published data regarding human diet in northern Mesopotamia, including laboratory analyses and textual and archaeological sources.

**Composition of the thesis**

The thesis begins with a short description of the modern and ancient environment of northern Mesopotamia. In the first chapter, the impact of drought episodes on the Middle East environment and the adaptation to the frequently occurring shortages are discussed. The subsistence strategies attested in northern Mesopotamia (including Bakr Awa) are discussed in the context of adaptation to the frequently occurring droughts.

Next chapter describes the history of the Shahrizor between the mid-EB and the Middle Ages. In this chapter, political and economic history of the Shahrizor is discussed in the context of the Mesopotamian history. Special emphasis is put on the events of the LBA crisis and their impact on the Shahrizor. The chapter ends with a detailed description of the results of archaeological investigations at Bakr Awa.
Historical chapter is followed by a chapter discussing the theory and techniques of dietary reconstruction. In the chapter, biological mechanisms of carbon and nitrogen fractionation in terrestrial ecosystems and mammalian organisms are discussed, as well as the techniques of human diet reconstruction. The section about the stable isotope analysis is followed by a discussion about the aetiology of enamel microwear, concluded with a discussion about the reconstruction techniques.

Next, the material and methods of the present study are presented, followed by the results of both the stable isotope and dental microwear analyses. In the next chapter, the results are discussed in the context of climate and environmental changes as well as historical and socio-political changes observed in the Shahrizor. The thesis ends with a short conclusion.

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Chapter One. Environment and subsistence in northern Mesopotamia

Natural environment and agriculture of northern Mesopotamia were shaped by climatic conditions. As a result of a long tradition of agriculture and pastoralism, natural environment of Mesopotamia was greatly degraded. In historical times, northern Mesopotamia faced deforestation, slope erosion, stream incision and soil salinisation (Cordova 2005). Despite its serious impact on the local environment, anthropogenic influence can sometimes be difficult to distinguish from natural forces changing environment and landscape (Roberts et al. 2011).

The landscape of northern Mesopotamia is dominated by open oak woodlands, grasslands and riverine gallery forests in the river valleys. The main factor determining the type of environment is water availability. Steppe vegetation dominates in drier regions in the southern areas of northern Mesopotamia. Woodland is characteristic for the northern areas of northern Mesopotamia, including the Zagros and Taurus foothills, which receive great amounts of moisture. Water demanding vegetation dominates in the river valleys (Cordova 2005; Deckers and Pessin 2010; Roberts et al. 2011).

The ancient environment of the Shahrizor seems to have been rather stable – open woodland dominated by oaks and C3 vegetation, with a stable share of dry-steppe taxa (Atermisia and Chenopodicae). Great changes have been observed in the share of Gramineae, which coincide with climatic fluctuations as observed in the phytolith and pollen records. Despite the increasing aridity of the local environment, remains of wetland plants stayed visible through the whole record (Marsh and Altaweel 2015; Stevens et al. 2001).

Human induced impact on the local natural vegetation is difficult to assess (Roberts et al. 2011), and depends on the subsistence economy and resource management. The need for wood and area for cultivation resulted in deforestation, and later in slope erosion. Agricultural activity promoted expansion of cereals and agricultural weeds associated with them. Pastoralism also left an imprint on the natural environment. The dietary preferences of ovicaprids and bovids promoted plants avoided by those animals (Cordova 2005).

1. Modern climate of northern Iraq

Most of northern Iraq (cf. Fig. 1.1 and 1.2) lies in the hot-summer Mediterranean climate zone (Cs - according to Köppen's climate classification) and is characterised by hot, dry summers and mild winters (cf. Roberts et al. 2001). The region is characterised by high variability in the amount of annual rainfall (Fig. 1.3). In the North, in the area of the Zagros foothills, the annual precipitation is relatively high (more than 700 mm per year), but in the Euphrates valley it is lower than 200 mm. The average annual temperature varies between 17.9 and 21.6ºC.
Figure 1.1. Map of northern Mesopotamia with localisation of sites discussed in the text (map based on 'Near East topographic map' by Semhur/Wikimedia Commons/CC-BY-SA-3.0). The Shahrizor Plain in detail on Fig. 1.2.

Figure 1.2. Map of the Shahrizor Plain with localisation of sites discussed in the text (map based on the southern Sulaimaniyah, Iraq and Iran map published by National Imaginary and Mapping Agency © 1998 USA Government).
Figure 1.3. Average temperature and annual precipitation (hydrological year) for modern cities in northern Iraq and Syria (source: http://en.climate-data.org).
Seasonal and inter-annual variations in precipitation of northern Iraq are a result of the regional storm tracks and topography. In the eastern Mediterranean, lows form at the Polar Front and follow storm tracks eastward. The main storm track goes over Cyprus through Syria, Lebanon, northern Iraq to Iran. The second important storm track goes over Northern Africa through Israel to Iraq and Iran. Along those storm tracks, two-three lows can penetrate the continent in one winter/spring month. These lows are responsible for most of the moisture in winter and spring. Additionally, rapid heating of the ground surface in late spring promotes evaporation and could lead to thunderstorms (Stevens et al. 2001).

In summer, a lower atmosphere temperature anomaly develops over the Iranian Plateau. The anomaly produces an atmospheric circulation above the western plateau, which blocks the up-slope flow. The up-slope flow dominates during winter, providing moisture to the Zagros area. The Zagros Mountains and the Iranian plateau are largely responsible for both the orographically triggered winter precipitation and the complete lack of precipitation in summer. However, the topographic effects combined with the North Atlantic Oscillation provide the best explanation for the inter-annual variability (Evans et al. 2004). All major droughts in this region are caused by the lack of rainfall during several months of the winter half of the year (cf. below and Trigo et al. 2010: 1245–1246).

1.1 Drought in the Middle East (case study of 2007-2009 event)

The Middle East experiences regular droughts. Local droughts are more frequent, while prolonged droughts affecting the whole area of the Middle East are less common. Droughts affecting the whole Middle East area have different magnitude. A drought occurring once in a few decades usually lasts for two years (cf. Trigo et al. 2010). A drought episode occurring on a millennial scale lasts for centuries (e.g. 4.2 ka BP event, 3.2 ka BP event; Roberts et al. 2011). Millennia-scale drought episodes have not been observed in modern times. However, in the last 80 years, prolonged, two-year droughts have been observed at least three times (cf. Trigo et al. 2010). The effects of a prolonged drought could serve as an approximation of a much longer drought episode.

The last prolonged drought was observed between 2007 and 2009, when a synoptic anomaly over the Middle East blocked moisture from the Mediterranean and opened this area to the dry air from Iran and south-western Russia. As a result, the precipitation in central Iraq was reduced by 80% in the first hydrological year (October 2007 – September 2008) and by 70% in the second hydrological year (October 2008 – September 2009) of the event. During the two-year drought, most of the area of Iraq received less than 40% of the average annual precipitation (Trigo et al. 2010).

The accumulated average precipitation in Iraq at the end of the second hydrological year of the drought was more than two times lower than the long term average – c. 230 mm in comparison to 470 mm. As a result of the two year drought, the average soil moisture had
been continuously decreasing, and reached extremely low values in the beginning of the third hydrological year (October 2009; Trigo et al. 2010: 1249). The drop in the soil moisture could have been further caused by the use of ground water for field irrigation.

Prolonged droughts had affected Iraq's hydrology, as visible in river discharges. The impact of a prolonged drought on the Zagros foothill hydrology can be illustrated by the stream flow of the Little Zab and the Diyala rivers (Fig. 1.4). Presented data show the lowest values for years 1960 and 1999-2001, which coincide with the drought episodes observed in the Middle East between 1958-1960 and 1998-2000 (cf. Trigo et al. 2010).

**Figure 1.4.** Total river stream flow (in cubic meters per second) of the Little Zab (IRQ_T10) and the Diyala (IRQ_T16) for hydrological years 1931 to 2005. Data after Saleh (2010).
The drop in the annual precipitation significantly affected vegetation in northern Iraq. The local flora of northern Iraq had been under stress for five out of six analysed months (between January and June) in both successive years. In the growing period, the drought caused crop failure due to the lack of water during the germination of seeds. The decline in the cereal production was associated with both the extension and persistence of the drought (Trigo et al. 2010: 1253–1254).

Water stress in regions most relevant for Iraqi agricultural production results in a decrease of production quantity. As shown in Fig. 1.5, the prolonged droughts of 1999-2001 and 2007-2009 (cf. Trigo et al. 2010), led to a significant decrease in barley (a drought-tolerant cereal) production.

![Production of barley in Iraq](image)

Figure 1.5. Barley production (in Mt) in Iraq between 1961 and 2013 (FAOSTAT 2015).

As observed, the precipitation in the Middle East area can significantly decrease as a result of synoptic anomalies. The decrease observed had the greatest impact on environments which usually receive high amounts of rainfall, like the Zagros foothills. Moreover, the water stress in those regions led to a significant drop in agricultural production.

2. Some remarks on the modern day debate on the relation between climate and human societies

Better understanding of climate change dynamics and an ongoing discussion about climate's impact on modern and past economies have encouraged some scholars to 'resurrect' (Leroy 2006: 7) climate determinism (or environmentalism) in various forms (cf. Middleton 2012: 268–269). In this approach, climate or environment is considered to be the main (or exclusive) factor leading to a rise or collapse of human society or even civilisation (Butzer and Endfield 2012: cf.; Middleton 2012). According to Butzer (2012), the recent
return to environmentalism is not about fresh interest in the environment and society interference, but a continued failure to appreciate the complexity of such an interrelationship. The issue is not whether climatic change is relevant for socio-historical change, but how we can deal more objectively with coupled systems that include a great number of variables, among which climatically triggered environmental change is undeniably important (Butzer 2012: 3633).

The climate deterministic approach treats human cultures and societies as a product of environment (Isaar and Zohar 2007: xxvi). Optimal environmental conditions will lead to an increase in societal complexity, while abrupt changes (like drought episodes) will lead to a decline of this complexity (Middleton 2012: 268–269; cf. Neumann and Parpola 1987). A change in the climatic conditions, such as annual precipitation, can lead to an increase (or decrease) in environmental carrying capacity, visible in agricultural production. An increase in the carrying capacity could lead to a surplus production, decrease in grain prices, increase in population size, increase in social complexity etc. Analogically, a decrease will lead to a lower agricultural production, increase in grain prices, malnutrition, decrease in population size and social stress (e.g. Butzer 2012: 3638; Neumann and Parpola 1987; Weiss 1982).

In the climate deterministic approach, little attention is given to the political and economical markers of state devolution, or a strategic solution that may have been attempted but failed. Rarely considered are the attributes of cultural identity that might have been rejected or transformed (Butzer 2012: 3635).

In opposition to climatic determinism are models considering human agency (political, social and ideological drivers) as a main factor leading to a rise or collapse of human societies (cultural determinism). In cultural determinism, climate and environment are seen as a 'stage' of events, not an 'actor'. Climate deterioration can, but does not have to, lead to visible changes in human society. For example, decrease in precipitation can lead to a decline of cultural complexity, but does not have to. In times of climate deterioration, like a drought event, a decline of human society is seen as a result of a series of adaptation attempts that eventually failed, rather than a simple decrease in carrying capacity leading to a collapse (cf. Butzer 2012; Middleton 2012).

The main issue of any studies focusing on climate induced changes of past societies is the chronological correlation of events. The lack of high-resolution palaeoclimatological and archaeological data does not allow for precise indication of coincidence between climatic change and change observed in archaeological record. Moreover, changes in global oscillation can be regionally specific, and neighbouring regions can differ in their response to changing climate conditions. Current evidence, like radiocarbon dating – correlation of palaeoclimatic proxies with archaeological record – does not support simple cause and effect relationship between rapid climate-change events and cultural changes (Maher et al. 2011). But correlation is not causation. It must be demonstrated that climatic change does
3. Adaptation as a response to climate changes

Cultural adaptation to environmental changes includes subsistence decision-making based on variable and complex relationship of environment, economic interest, political goals and cultural preferences (Riehl 2009: 97). Strategies of coping with environmental stress include diversification and/or intensification of subsistence strategies, adoption of new resources, adoption of new mobility patterns, exchange and formation of new social networks (McIntosh et al. 2000; Tainter 2006).

Cultural adaptation to regularly occurring, short term variations in resource availability is characterised by continuous or frequent operations (e.g. annual collection and surplus storage). These operations involve the entire society in some cultural practices, such as diversification of crops or passing knowledge about so called famine food. This type of adaptation may lower the nutritional and social effects of environmental stress through continuous or regular investment in a buffering mechanism against resource shortage. Extreme or prolonged resources shortage does not necessarily lead to an adoption of entirely new responses, but to an acceptance of already known responses that would otherwise be neglected in favour of less costly alternatives; for example, a change from settled farming to nomadic pastoralism (Forbes 1989; Minnis 1996; Wossink 2009).

Another strategy of coping with environmental stress is to purchase essential resources from other societies. In order to do that, society experiencing environmental stress can establish or invest in social relations with societies living in an area not affected by environmental stress or with societies that pursue a different subsistence economy (Kelly 1995). Economic specialisation within limited region leads to stronger exchange relations between specialised groups than between groups practising more generalised strategies (Cashdan 1987). In the case when societies rely on different resources, or when periods of resources availability are exclusive, there are more reasons to engage in an exchange, because the resources are available and they could be repaid. Exchange as a mechanism of buffering the environmental stress on society is expected between groups experiencing exclusive fluctuation in resource availability (Wossink 2009: 39).

Society searching for an access to a particular resource can relocate to areas where the resource is available. Another possible strategy to gain access to the resource of interest is to submit to society controlling the resource. If these alternative solutions are not possible to perform, conflict remains the only way to gain access to resources. Conflict, territoriality and spatial defence are expected adaptive strategies in case of a resource shortage among groups experiencing similar fluctuation in resource availability, as a result...
of similar subsistence strategies. Engaging in an exchange network is less likely between those societies, because of a high risk that goods will not be repaid (cf. Wossink 2009: 39).

4. Palaeoclimate of northern Mesopotamia

Present knowledge about the past climate and environment of northern Mesopotamia is scarce. Most of the palaeoclimatological proxies come from the surrounding areas. One exception is the new spaleothem proxy from Kuna Bar Cave (Fig. 1.2) located in the Shahrizor (Reuter et al. 2012). In several cases, the lack of palaeoclimatological data was overcome by an incorporation of plant remains into environmental reconstruction, like pollen (e.g. Kaniewski et al. 2010), cereal seeds (e.g. Riehl et al. 2014) and phytoliths (e.g. Marsh and Altaweel 2015).

As mentioned above, climate’s impact on environment could be regionally specific and can depend on many factors, including distance from the main water reservoir and topography. Regionalism in environmental response to climatic changes could be observed through a comparison of several palaeoclimatological proxies (Kirleis and Herles 2007; Riehl et al. 2014; Roberts et al. 2011). Therefore, further reconstruction of palaeoclimate and palaeoenvironment will be focused on local changes in the Zagros foothills, with emphasis on the Shahrizor. For the reconstruction, published results of the lake sediments (Stevens et al. 2001; Wasylikowa et al. 2006; Wasylikowa and Walanus 2004), phytolith deposits (Marsh and Altaweel 2015) and spaleothem (Reuter et al. 2012) analyses will be used.

Lakes respond to climate change by their water balance, which is reflected in water level, salinity and stable isotope composition (Jones and Neil Roberts 2008). Several lakes located in the north and east of northern Iraq provide data for the climate reconstruction of northern Mesopotamia (cf. Roberts et al. 2011), among them Lake Zeribar, which is located nearest to the Shahrizor (cf. Fig. 1.2).

Lake Zeribar (35°32’ N, 46°07’ E) lays in the Zagros Mountains c.40 km from Bakr Awa. The lake is situated c. 1300 m.a.s.l. in a valley surrounded by parallel ridges that rise on elevation of 2100 m. Rainfall in the area occurs from October to May. Winters are dominated by dry, cold air from Siberian high, but at the same time wet depressions penetrate the region from the Atlantic Ocean and the Mediterranean Sea. Annual average precipitation at Zeribar is c. 800 mm. The radiocarbon dated cores of lake sediments from Zeribar provide climatological data for the last 40 000 years (Stevens et al. 2001; Wasylikowa et al. 2006; Zeist and Wright 1963).

Zeribar is separated from the Shahrizor by mountain ranges (up to 2100 m.a.s.l.), and the lake level is c. 550 m above the altitude of Bakr Awa. In consequence, orographic rainfall in the region of Bakr Awa does not fully correspond with water balance of Zeribar. Similar effect could be observed for pollens (cf. Altaweel et al. 2012). Despite those
limitation, proxy obtained from Zeribar should provide information about general climatic and environmental conditions of the Shahrizor.

Second source of the palaeoenvironmental and palaeoclimatological data is phytolith analysis. Sediments were sampled from geological trenches in the Shahrizor and archaeological contexts at Bakr Awa. Phytoliths were described according to shape, size and, if possible, identified (Marsh and Altaweel 2015). In order to collect sediments for phytolith analysis two trenches were opened, one near Bakr Awa and the second nearby, at Yasin Tepe. In the trench located in the area of Bakr Awa, a layer of Pleistocene gravel was reached at c. 6 m of depth. The sequence of sediments is dated only by a diagnostic fragment of pottery from the Achaemenid-Hellenistic period found 1.8 – 1.95 m below the modern surface (Altaweel et al. 2012). In the region of Yasin Tepe, a riverbank section was photographed, drawn and sampled for phytolith analysis. Later, three trenches were excavated to obtain geomorphological information and sediment samples. The deepest trench had 4.5 m, but no Pleistocene layers were reached. Artefacts, including pottery shards, were found in the canal cutting the topsoil. The sequence is not dated (Marsh and Altaweel 2015).

Third source for the palaeoclimate reconstruction is spaleothem data obtained from the Kuna Bar Cave (35°05’37.7”N, 45°38’47.1”E) located west of Darband-i Khan Lake, c. 25 km from Bakr Awa. The obtained data, a decadly-resolved oxygen isotope record, was dated using the U-Th method. The reconstructed climate profile covers last 2000 years (Reuter et al. 2012).

Fortunately, three sites providing information about the past climate are located not farther than 50 km from Bakr Awa. Unfortunately, the difference in the resolution and type of archive allows only for general observations and does not allow for comparison between global climate trends and the region specific response.

4.1. Climate between 6.5 ka and 3.2 ka BP

The mid-Holocene (6.5-4.5 ka BP) record of Zeribar indicates higher spring/summer precipitation than in the dry early Holocene. According to the record from Zeribar, modern climate was established c. 4.5 ka BP (Stevens et al. 2001: 753). After 4.5 ka BP, in the late Holocene, the level of Zeribar remained high, indicating great moisture in the region. The isotopic composition indicates continuing importance of spring precipitation. Return to more dry conditions, similar to those in the early-Holocene, occurred between 4.0 and 3.5 ka BP. Because of the large errors associated with radiocarbon dates, Stevens et al. (2001) stress the fact that further correlation with archaeological events should be robust. In the study by Wasylikowa et al. (2006), the pronounced shallowing was dated between 4500-3800 cal. BP. The oxygen record suggests a decrease in the spring precipitation. Drop in the lake water level indicates lower available moisture in the region (Stevens et al. 2001: 753).
753) and coincides with an increase in aridity in the Middle East around 4.5 – 4.0 ka BP (Riehl et al. 2014; Roberts et al. 2011) and the Bond Event 3 (Bond et al. 2001). The phytolith analysis of sediments collected in the geological trench at Bakr Awa shows some variation in the C\textsubscript{3} and C\textsubscript{4} flora ratio (climate index; cf. Burrough et al. 2012), but generally indicates stable conditions of a temperate regime with at least moderate annual rainfall for the period between c. 12.0 and 2.3 ka BP. The water stress index values (percent of cuneiform bulliform cells to the sum of grass phytoliths minus the elongate phytolith type; cf. Barboni et al. 2007) indicate high water availability with a trend of increasing aridity toward the modern times (Marsh and Altaweel 2015).

### 4.2 The 3.2 ka BP event

Another drought episode visible in the record of Zeribar started c. 3.2 ka BP and was probably associated with the Bond 2 event of the North Atlantic Oscillation (Bond et al. 2001). The North Atlantic Oscillation is affected by the energy output of the Sun. The General Climatic Model indicates that the reduction of solar activity will lead to the cooling of the high northern latitude atmosphere. Low temperatures of the high northern latitudes will lead to a southward shift in the northern subtropical jet, and reduced air circulation from tropical into subtropical zones (the Northern Hadley circulation). In response to those conditions the surface temperature of the Northern Atlantic will decrease and lead to an increase in the ice drift area. Lower evaporation rate at the Atlantic Ocean will result in a decrease in precipitation at lower latitudes (Bond et al. 2001: 2134).

The effects of the moisture decrease resulting from the Bond 2 event of the North Atlantic Oscillation can be seen in the record of sites located along the Middle East storm track which provides moisture to the Middle East (cf. above). Among those sites are, for example, Larnaca Salt Lake on Cyprus (Kaniewski et al. 2013), Tell Tweini in Syria (Kaniewski et al. 2010) and Zeribar in the Zagros Mountains (Stevens et al. 2001; Wasylikowa et al. 2006).

Larnaca Salt Lake (Kaniewski et al. 2013) is located on the eastern coast of Cyprus (34°52'51"N, 33°36'43"E; cf. Fig. 1.1). Palaeoclimatological data were obtained by an analysis of pollen from the sediment core B22'. The pollen record is radiocarbon dated for the last 3 500 years. Modern average annual precipitation at Larnaca is 351.5 mm, and the average year temp. is 19.6°C (Kaniewski et al. 2013).

In the study, Kaniewski at al. (2013) presented a pollen record divided into three groups: woodland, dry steppe and cultivated species. The pollen groups should reflect the changes in water availability. The proportion of the woodland pollen should be positively correlated with available moisture. On the other hand, the proportion of the dry steppe pollen should be positively correlated with an increase in local aridity. The proportion of
The cultivated species should allow for an estimation of human impact on the local environment.

The pollen record from the LBA indicates a decrease in the woodland in the region of Larnaca since 1450 BC. The decrease could have been caused by changes to the coastline and/or fire activity for agricultural purposes. Similar decrease in the woodland pollen record was observed c. 1200 BC. In this case the fire activity can be rejected, because the agricultural activity in the region decreased at that time, likewise, no significant changes in the coastline were observed. Between c. 1200 BC to 850 BC, the surroundings of the lake turn into a dry steppe, and the percentage of the cultivated species in the pollen record drops from c. 8% in c. 1300 BC to c. 1% in c. 1200 BC. The level of the cultivated species from the period before the climatic turbulence was reached once again c. 650 BC. Earlier, in the 8th c. BC, the percentage of the woodland pollen reaches the level from before the event. An increase in the dry steppe pollen in relation to the woodland pollen and a drop in the cultivated species was explained by a drop in the amount of rainfall in the last quarter of the second millennium BC (Kaniewski et al. 2013).

The second site, Tell Tweini (ancient Gibala) is located on the Mediterranean coast (35°22′17″N, 35°56′12″E; cf. Fig. 1.1). The palaeoclimatological study was based on the pollen analysis of two sediment cores (TW-1 from the Rumailiah River, and TW-2 from the spring of the Ain Fawar River). The oldest sample from the sediment core is radiocarbon dated to 4000 cal. BP (Kaniewski et al. 2010).

The pollen-based climate record shows more moist conditions from c. 3450 to 3150 cal. BP. A drought episode was observed between c. 3150 - 2750 cal. BP. During the episode, a temporary return to more moist conditions was observed around 2950 cal. BP, and was followed by the driest conditions in 2860 cal. BP. The pollen record also shows a decrease in agricultural production coinciding with the drought episode (Kaniewski et al. 2010: 210). The observation of the wetter period between two phases of the drought period is similar to the events of the North Atlantic Oscillation observed by Bond at al. (2001). It could support the thesis that the drought in the Near East was a result of solar influence on the North Atlantic Oscillation (cf. Kaniewski et al. 2010, fig.3).

At the third site, Lake Zeribar, the impact of the 3.2 ka event is visible in the increase of diatoms characteristic for brackish water. The increase in water salinity can be associated with a drop in the water level. High water levels were once again noted c. 2 500 BP (Wasylkowa et al. 2006). Also around the 3 200 BP, the increase in the δ18O values was observed. More positive values of the δ18O are associated with a lower annual precipitation (especially winter precipitation, when rain/snow is enriched in 16O) and a high evaporation rate during summer (Jones and Neil Roberts 2008; Roberts et al. 2011; Stevens et al. 2001). Moreover, between c. 3200-2900 BP, an increase in the Artemisia and Chenopodiaceae percentage is visible in the pollen record from the sediment cores 63J and 70B. Both plants are typical for arid and semiarid zones (Wasylkowa and Walanus 2004).
In summary, all three sites, located in the main Middle East storm track, show a shift to more dry conditions at the end of the second millennium BC. This shift coincides with the second Bond event of the North Atlantic Oscillation (Bond et al. 2001). The presence of drier conditions in all presented sites and other sites from the region of the Middle East (e.g. Bar-Matthews et al. 1998; cf. Roberts et al. 2011) shows that the 3.2 ka BP event was a widespread drought episode in the history of the Middle East. However, the same climate proxies show fluctuations in the occurrence of the event. It can be a result of differences in the resolution and dating of climate proxies or an effect of region specific responses to changes in the global climate (cf. Roberts et al. 2011).

4.3. Palaeoclimatic after 3.0 ka BP

Record from Zeribar shows more humid conditions between 3.0 and 1.0 ka BP (Stevens et al. 2001: fig. 3; Roberts et al. 2011). Around 2 300 BP, local environment at Bakr Awa was characterised by a slightly greater aridity than in the earlier strata. The drier conditions continue toward the modern times. However, conditions were still favourable for wetland plants (Marsh and Altaweel 2015).

The spaleothem record shows a long-term increase in aridity between c. 2000-700 BP, followed by a steady increase in moisture till the modern times. Known climatic anomalies, like the Northern Hemisphere Medieval Climate Anomaly (AD 1000-1300) and the Little Ice Age (AD 1500-1700), were not observed in the record. It suggests that the millennial-scale temperature and rainfall variability in this region cannot be strictly attributed to the forces responsible for the Medieval Climate Anomaly and the Little Ice Age, such as the variability in solar activity (Reuter et al. 2012).

5. Diet and subsistence in northern Mesopotamia

Human diet in northern Mesopotamia was based on agricultural produce, mainly cereals but also pulses, vegetables, fruit and oil (Ellison 1978; Riehl 2009). Meat was regularly consumed only by a limited part of the society; more common but not very frequent was the consumption of dairy products (Ellison 1978; Koliński 2003; Redding 2015; Zeder 1994).

In most parts of northern Mesopotamia, annual precipitation allows for stable dry farming, but the regularly occurring droughts led to an adaptation and frequent cultivation of drought tolerant cereals (Nesbitt and Samuel 1996; Riehl 2009; Riehl and Nesbitt 2003). In the EBA, barley occurred in most of the archaeological sites in a higher proportion and ubiquity in comparison to other cereals. Barley has been found more ubiquitous in areas characterised by a low annual precipitation (e.g. Euphrates valley; Riehl 2009 and the older literature there). In the regions of a higher annual precipitation, emmer wheat could dominate, like in Tell Karrana in the Tigris valley (Costantini and Constantini Biasini 1993). Tell Karrana is located in the area of a relatively high annual precipitation (more than
400 mm in the modern times), where stable dry farming cultivation of emmer was possible (Costantini and Constantini Biasini 1993; Riehl 2009: 100). In the EBA, free-threshing wheat, like emmer, was more common in the Khabur valley than in the Euphrates valley (Riehl 2009).

A decrease in the ubiquity of emmer and free-threshing wheat was observed in the MBA, while emmer was still noted in Tell Brak and Tell Mozan in the Upper Khabur (Riehl 2009: 100). This disappearance has been explained by higher labour required to process wheat in comparison to barley (Nesbitt and Samuel 1996). Additionally, the MBA was drier than the EBA (Roberts et al. 2011). Climate conditions promoted more drought and salinity tolerant barley (Nesbitt and Samuel 1996). However, in the more humid conditions of the Shahrizor, emmer wheat has been found in great proportion (Helbaek 1960).

No significant change in the proportion and ubiquity of main cereals was observed between the MBA and the LBA (Riehl 2009: 100). Significant changes in agriculture were observed in the IA. Among cereals, an increase in the spread of free-threshing wheat is observed. Moreover, millet becomes more visible in the archaeological record (Riehl and Nesbitt 2003).

Millet has been known in the Middle East since the Neolithic (Hunt et al. 2008), but never played a major role in human subsistence. As a drought tolerant species, millet was preferred in the arid areas. In the BA, it was cultivated in Tell Sheikh Hamad but in small amounts (van Zeist 2001). In the IA, millet seems to have been introduced as a summer crop to increase agricultural productivity (e.g. Nimrud; Helbaek 1966), however, it never became a major crop (Riehl and Nesbitt 2003).

Among non-cereal plants in the archaeological record, lentil seems to have been the most widespread in northern Mesopotamia. Similar to the wheat, lentil was more common in the EBA. In the MBA and the LBA the importance of lentil decreased (Riehl 2009: 100). An abundant sample of lentil (c. 250 seeds) was found in the MBA Shahrizor (Helbaek 1960). In the IA, greater ubiquity of lentil was noted in Nimrud (Helbaek 1966).

Garden pea was another broadly distributed pulse. Like lentil, garden pea was more common in the EBA and its importance seems to have decreased in the MBA and the LBA. In the IA, a slight increase in proportion was observed (Riehl 2009: 102–103).

Remains of bitter vetch were found in the Shahrizor (Helbaek 1960). Bitter vetch occurs regularly at the archaeological sites, more commonly in the northern areas. No significant changes in the proportion between periods have been observed (Riehl 2009: 100).

Across northern Mesopotamia, farming was mixed with animal breeding. The main source of meat and secondary products were sheep and goats. They were usually fed on local or more distant pastures. Some animals were kept within households and fed on fodder. These animals were usually kept for meat (Arbuckle 2012). Meat was regularly consumed only by a certain part of the society (e.g. high officials, soldiers), while others
relied only on agricultural produce rarely supplemented with meat and/or dairy products (Koliński 2003; Zeder 1994).

Pigs, bovids and ovicaprids were the most important animals in the food economy of northern Mesopotamia. Pigs were bred only for meat, while bovids and ovicaprids also provided secondary products (Arbuckle 2012; Redding 2015; Zeder 1994). The distribution of animals was a result of their adaptation abilities. Ovicaprids best adapt to various conditions due to their low water and food needs. Therefore, ovicaprids were frequent in both arid and humid environments of northern Mesopotamia (Arbuckle 2012; Koliński 2003). Bovids have greater needs in terms of food and amount of water. Bovids were more frequent in the more humid regions. Percentage of bovids remains in animal bones assemblages at archaeological sites usually varies between 5 and 20% (Koliński 2003). Pigs are the least adaptable and the most water demanding (Koliński 2003; Redding 2015). Moreover, pigs are not very mobile. Pigs are more frequent in the humid areas (10-25%), and less frequent in the arid areas of the Euphrates valley, Balikh and middle Khabur (less than 5%). Pigs were popular in the mountainous regions with high precipitation (Koliński 2003). Textual sources do not list pigs as livestock managed by state, suggesting that pigs could have been bred for private needs (cf. Redding 2015).

Chickens have been known in the Middle East from c. 2500 BC. Bakr Awa provides one of the earliest (c. 2300-2100) osteological remains of chickens in the Middle East (Piątkowska-Małecka 2015). Due to the under-representation of bird remains at many archaeological sites in the Middle East, the distribution of the hen and its impact on human subsistence is difficult to establish. Redding (2015) expects chickens to have been numerous in the villages and poor urban areas within the whole of northern Mesopotamia since about second millennium BC. In some areas, chickens replace pigs as the source of easily available animal proteins. Following the modern ethnographic research, Redding (2015) concludes that chickens could be popular among mobile herders, because of the secondary products (eggs) and their small size.

In ancient Mesopotamia, wild animals were still an important source of animal protein as well as entertainment - hunting (Zeder 1994).

Fish, birds and eggs played a secondary role as food sources and textual references to them are rare (Ellison 1978: 177–181, 1984: 94). Birds were served at feasts or as meals for important personages. Ordinary people could catch birds for food when required (Ellison 1978: 179). Among birds consumed in ancient Mesopotamia were geese, ducks, doves, pigeons, hens and chickens (Blench and MacDonald 2000; Ellison 1978: 179). Eggs collected from wild animals could have supplemented human diet (Ellison 1978: 181).
5.1. Stable isotope evidence of human diet

Studies of stable isotope signatures of human diet confirm the general picture of the diet in northern Mesopotamia (Batey 2011; Höring and Jungklaus 2010; Sołtysiak and Schutkowski 2015b). Unfortunately, the studies were conducted for sites located in the western area of northern Mesopotamia and do not fully correspond to the Shahrizor. Moreover, the analysed collections are dispersed in time. Two collections allow for insight into single periods only: Tell Umm el-Marra is dated to the EBA (Batey 2011), and Tell Sheikh Hamad to the Roman/Parthian period (Höring and Jungklaus 2010). Only the sample from Tell Barri, dated between the EBA and the modern period, allows for tracking the temporal changes in the stable isotope composition of human diet (Sołtysiak and Schutkowski 2015b). The collections significantly differ in number of analysed individuals. In Tell Sheikh Hamad only 16 out of 134 individuals meet the collagen quality criteria (Höring and Jungklaus 2010), and in Tell Barri – 71 out of 84 individuals (Sołtysiak and Schutkowski 2015b). No data concerning quality criteria was reported for Tell Umm el-Marra and the analysis has been based on 14 individuals (Batey 2011).

In general, the results indicate that human diet was based on C\textsubscript{3} plants (Batey 2011; Höring and Jungklaus 2010; Sołtysiak and Schutkowski 2015b). This observation corresponds with the results of the palaeobotanical analysis, indicating that main crops cultivated in the area of northern Mesopotamia are barley and wheat – C\textsubscript{3} plants (cf. above). Shift toward higher δ\textsubscript{13}C values is usually associated with consumption of ovicaprids grazing on pastures rich in C\textsubscript{4} plants (e.g. Sołtysiak and Schutkowski 2015b; cf. van der Plicht et al. 2012). Variations in the nitrogen values indicate broad spectrum of omnivorous diets (Batey 2011; Höring and Jungklaus 2010; Sołtysiak and Schutkowski 2015b).

Some sex based differences in diet were observed only in Tell Barri. Significant difference was observed in the EBA and the MBA. Males’ diet was more abundant in C\textsubscript{4} plant proteins, which could be a result of a consumption of meat and dairy products from animals grazing on pastures rich in the C\textsubscript{4} flora. However, the difference in the δ\textsubscript{15}N was not significant. In the later periods, the difference is insignificant (Sołtysiak and Schutkowski 2015b).

5.2. Dental microwear and diet

The only study of dental microwear for ancient northern Mesopotamia was conducted for Tell Masaikh and Tell Ashara in the middle Euphrates valley (Sołtysiak 2011). Unfortunately, in this case, the results also cannot fully correspond with the Shahrizor. The sample, 10 individuals dated between the EBA and the modern times, allows for temporal but not for sex- or status-based observations. Temporal trend toward less abrasive diet was observed, with the greatest shift occurring between the MBA and the Late Roman Period. Due to the lack of changes in the cultivated cereals and the type of consumed food stuff (e.g.
unleavened flat bread), the change was ascribed to a shift in the flour processing technology (Sołtysiak 2011).

5.3. Subsistence at Bakr Awa

Subsistence of the Bakr Awa inhabitants can be highlighted by an osteological analysis of animal remains, coupled with a phytolith analysis of the BA sediments and epigraphical sources from the site. Animal remains from Bakr Awa have been found in all of the investigated layers. The osteological analysis of animal bones from seasons 2010-2013 was conducted by J. Piątkowska-Małecka (2015). The osteological examination of bird remains was conducted by T. Tomek (Institute of Systematics and Evolution of Animals, Polish Academy of Sciences, Krakow, Poland). The phytolith analysis of sediments collected from the floors of the BA houses was conducted by A. Marsh (Marsh and Altaweel 2015). Cuneiform tablets in Bakr Awa were found in the LBA house (Al-Husaini 1962) and in Islamic secondary context. Fragments of cuneiforms were studied and translated by W. Meinhold (unpub.)

In the BA, subsistence was based on cereal cultivation. Phytoliths of both wheat and barley were attested on the site. Positive correlation between barley phytoliths and phytoliths of agricultural weeds suggests that these plants were brought to the site together. It suggests that, to some extent, barley (possibly a wild type) and weeds were used as fodder (Marsh and Altaweel 2015). The use of barley as fodder can be supported by the textual evidence from Bakr Awa (Meinhold unpub.). The correlation between wheat phytoliths and phytoliths of weeds is weak, which may suggest earlier separation out of the site. The correlation between wheat and barley is also weak and suggests that both cereals were processed separately (Marsh and Altaweel 2015). Palaeobotanical findings from Tell Qurtass (the Shahrizor Plain), dated to 2100-1700 BC, indicate cultivation of lentil, bitter vetch and wheat, including emmer and bread wheat (Helbaek 1960: 78–81). It is possible that similar taxa were cultivated at that time at Bakr Awa.

In the BA, the main source of animal proteins were ovicaprids. Cattle and pigs seem to have played a minor role in human diet (Piątkowska-Małecka 2015). However, the percentage of pig remains increased between the EBA and the MBA, suggesting that pigs became a more important source of meat in the later period. Unfortunately, the number of identified animal remains (NSIP) from the LBA is less than 120, which makes the comparison less reliable (Piątkowska-Małecka 2015).

Textual sources dated to the MBA show dichotomic subsistence known from other parts of northern Mesopotamia (e.g. Sallaberger 2004). Urban society of Bakr Awa acquired agricultural products (barley and wheat) from local farmers (tablet BA2476/002 and BA2569/004), while animals (ovicaprids and cattle) were obtained from herders (tablet

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1 Results of the analysis were kindly shared by Prof. P.A. Miglus.
Textual data is supported by the phytolith analysis, which shows that the agriculture of Bakr Awa was based on barley and wheat. Furthermore, the osteological analysis of animal bones corresponds with the textual sources mentioning the acquisition of ovicaprids and bovids. Except for animals provided by herders, pigs played an important role in the animal economy (Piątkowska-Malecka 2015), probably as an alternative source of meat.

Reconstruction of the subsistence in the IA and the IS can be based only on the results of the archaeozoological analysis. The number of identified animal remains from the IA occupation level is low. The most numerous are ovicaprids, the number of pig and bovid remains is very low (less than 35 over 124 collected bone pieces; J. Piątkowska-Malecka pers. com.). In the IA, the role of ovicaprids in the local economy seemed to be greater than in the BA. The decrease in the percentage of other taxa can indicate specialisation in ovicaprid herding.

Similar to the IA, Islamic animal economy was concentrated on ovicaprid exploitation. Cattle played a minor role in the subsistence. Significant drop in the percentages of pig remains could be a result of the specifics of local economy combined with a taboo on pork consumption. Significant increase is observed in the number of chicken remains (Piątkowska-Malecka and Tomek pers. com.). Chickens could have become a source of easily available meat. In contrast to pigs, chickens could provide secondary products of various kind (Redding 2015).
Chapter Two. The Shahrizor from the Bronze Age to the Middle Ages

1. Archaeological investigation in the Shahrizor

In the 19th c. and in the first half of the 20th c., archaeological investigations in the Shahrizor were aimed at identifying archaeological sites known from historical sources, and collecting cuneiforms inscriptions (Jones 1857; Rich 1836; Speiser 1927). Regular archaeological investigations have been conducted with various intensity in the area of the Shahrizor since the 1940s. In the 1940s, the Iraqi Directorate of Antiquity and Heritage conducted a prospection to document and date archaeological sites in the Shahrizor. The results were included in the Archaeological Sites of Iraq (Directorate General of Antiquities 1970). Later, between 1956 and 1961, the construction of the Darband-i Khan Dam led to a salvage survey and rescue excavations in the south-east part of the Shahrizor (Directorate General of Antiquities 1960, 1961; Janabi 1961). In that time, an archaeological excavation was also carried at Tell Bakr Awa (Al-Husaini 1962). In the 1980s and 90s, political situation in the region did not allow for archaeological excavations. Without state protection, archaeological sites were looted and vandalised.

At the begging of the 21st c. the Directorate of Antiquities and Heritage in Sulaimaniyah initiated an international archaeological research in the province, including the Shahrizor. In the last decade, several archaeological surveys have been conducted in the area of the Shahrizor Plain, including the survey at the northern bank of the Tanjero (Miglus et al. 2011), Shahrizor Survey Project (Altaweel et al. 2012), Sirwan (Upper Diyala) Regional Project (directed by T. Serifaglu, Bitlis Eren University, Turkey), Sulaimaniyah Governorate Archaeological Survey (directed by J. Giraud, Ifpo-Irak, Iraq), and Upper Tanjero Archaeological Survey (Kepinski 2014; Kopanias et al. 2015). Archaeological surveys were aimed at identification and description of archaeological sites and the rate of destruction associated with looting activity and warfare (Altaweel et al. 2012; Kepinski 2014; Kopanias et al. 2015; Miglus et al. 2011). Current archaeological investigations in the Shahrizor are aimed at an analysis of settlement patterns, past environment, culture, economy and social conditions (Altaweel et al. 2012; Kopanias et al. 2015; Miglus et al. 2011, 2013). Archaeological investigations are being conducted at Bakr Awa (Miglus et al. 2011, 2013), Tell Begum (directed by O. Nieuwenhuyse, Leiden University, The Netherlands), Bestansur (Matthews and Matthews 2012), Gurga Chiya (directed by D. Wengrow, University College London), Kunara (directed by Ch. Kepinski, French National Centre for Scientific Research and University of Paris I), and Tepe Marani (directed by D. Wengrow, University College London; Kopanias et al. 2015).
2. The Zagros foothills in the Early Bronze Age

Settlement in the Zagros foothills was determined by resource distribution, including water and pastures. Early states were located in the dry-farming zone of the Zagros piedmont or on the plains between the mountain ranges (Ahmed 2012: 492). Settlement in the plains and valleys separated by the mountain ranges led to an isolation and independence of local communities of farmers and herders. In such a region it is difficult to build a powerful united kingdom based on a centralised administration. Political landscape of the area was characterised by small independent self-sufficient political units (Ahmed 2012).

In contrast to the neighbouring regions, the EBA settlement in the Shahrizor seems to be stable in number (Altaweel et al. 2012). For example, in the later EBA (2600-2000 BC), the Erbil Plain faced an increase in the number of cities, similar to other parts of northern Mesopotamia (Ur et al. 2013: 97; Ur 2010). However, the type of settlement changed, which is especially visible in the area of the archaeological sites (cf. Ur et al. 2013: 110). In the Shahrizor, the number of archaeological sites had been similar since the 6th/5th millennium BC, however, we have no data about the size of those settlements (Directorate General of Antiquities 1970).

Agriculture and husbandry of small animals, supplemented by natural wild products, were able to sustain small communities. In the regions with limited area for cultivation, transhumance could serve as an alternative (Ahmed 2012: 485–516; Grecco 2003). Agriculture was based on dry farming, which is reflected in the scattered settlement pattern. Furthermore, population density is lower than in southern Mesopotamia (cf. Ur et
al. 2013), where agriculture was based on irrigation, which requires more manpower than dry-farming (Ahmed 2012). As shown by the phytolith analysis from Bakr Awa, the agriculture of the early EBA societies was based on barley and wheat (Marsh and Altaweel 2015). In the text from Fara (early third millennium BC), typical crops and products of Subarians (in this case probably inhabitants of the area east of the Tigris River; discussion for localisation of the Subartu see: Michalowski 1986) were barley, figs, pomegranates, plums, wool, textile, and sheep (cf. Gelb 1944: 31).

3. The Shahrizor in the Early Bronze Age

The mountains around the Shahrizor were inhabited by herders named Lullubeans (Klengel 1966). According to the textual data from Arrapha (=modern Kirkuk), Lullubeans inhabited lands east of Arrapha in its closest neighbourhood (Speiser 1930: 88). According to Geography of Sargon, lands of Lullubeans were neighbouring with Arrapha (Grayson 1974: 59). The large territory occupied by Lullubeans could reflect mobile herding practices. However, it is not clear if, in the EBA, Lullubeans occupied or at least used some parts of the Shahrizor Plain as a pasture (cf. discussion in Ahmed 2012: 76–77, 297–302). The eastern part of the Shahrizor (region at the junction of the Tanjero and Sirwan) could have been occupied by Simurrum (Ahmed 2012: 297–302; Frayne 2011). Lullubeans are seen as mountain dwellers following a semi-nomadic subsistence. They seem to have lived in tribal communities that could unite in times of foreign attacks (Ahmed 2012: 76–78). Textual sources from Yorgan Tepe (ancient Gasur), show cooperation between the inhabitants of Gasur and Lullubeans. Lullubeans provided Gasur with livestock (ovicaprids and bovids) in exchange for grain (Klengel 1966). Described situation could have been an isolated event or an example of cooperation between urban settlers and herders in the region of the Zagros foothills, maybe even an indication of a dimorphic society (cf. Sallaberger 2004).

As mentioned above, the eastern part of the Shahrizor could have been occupied by the kingdom of Simurrum. The oldest known reference to Simurrum occurs in a proverb dated to c. 2700 BC (Gurney and Kramer 1976: 38). The first clear historical reference to Simurrum comes from a year name of Sargon of Akkad (2344-2279 BC; Frayne 1993: 8). In Geography of Sargon, Simurrum is mentioned alongside other Transtigrian states, such as Subartu, Arrapha, Lullubum (Weidner 1952: 4–5). The core area of Simurrum was located in the Upper Diyala (also called Sirwan) valley. The capital was probably located in the eastern Shahrizor, near the junction of the Diyala and Tanjero (Frayne 2011: 511). Simurrum was ruled by ensi (Frayne 1993: 8), a ruler whose power was based on the city being the centre of a regional state (Altaweel et al. 2012: 10).

In the early history of Simurrum, the kingdom was recognised as an enemy of Akkad. Naram-Sin (2254-2218 BC), the king of Akkad, gained control over the mountain

2 All historical dates according to the Middle Chronology.
states that rose against him. King of Simurrum was among the rebellious rulers (Studevant-Hickman and Morgan 2006: 32). Presence of the Akkadian influence in the Shahrizor is visible in the material culture of Marif Tepe, located in the northern area of the Plain (Delougaz 1952: 195). The southern part of the Shahrizor is characterised by material culture with analogies in the Diyala valley (Altaweel et al. 2012: 25).

In the second half of the 3rd millennium BC, the kingdom of Hamazi with its eponymous capital city was located in the vicinity of the Shahrizor. Hamazi seems to have been a city in the mountains rather than in the plain. However, the exact localisation is uncertain, Frayne suggests it should be located c. 10 km southeast of Halabja (Frayne 2008: 47), while others suggest it should be located deep in the mountains of northwest Iran (Pettinato 1991: 62). A location near Sulaimaniyeh was also proposed (Jacobsen 1939).

Mountains east of the Shahrizor and the Diyala valley were inhabited by Guteans, who seem to have been semi-nomadic tribes moving their herds from the Zagros Mountains to the plains south of Simurrum and Arrapha (Ahmed 2012: 69–71; Hallo 1957: 719). The exact location of Guteans is difficult to pinpoint, because the term Guteans seems to also have a more general meaning, describing mountain dwellers in general, similar to Lullubeans (Ahmed 2012: 68–80).

Cities Gasur (Starr 1939) and Arrapha (Grayson 1974: 59; Speiser 1930: 88) were located south-east of the Shahrizor in the northern part of the central Transtigris plains. Both cities engaged in trade exchange with Lullubeans (Fincke 1993: 192; Klengel 1966).

Sometime after collapse of Akkad, Simurrum and the surrounding areas were subdued by Guteans. During the reign of the Gutean king Erridupizir, the king of Simurrum together with the Lullubean tribes rose in a revolt against Guteans. Rebels were defeated, but it is unknown for how long Simurrum was under the Gutean control (Ahmed 2012: 126; Altaweel et al. 2012: 10).

4. The late Early Bronze Age crisis

Around 2200 BC, some regions of northern Mesopotamia experienced a rapid change in the settlement pattern, including size decrease in many urban centres (e.g. Ur 2010; Weiss et al. 1993; Wossink 2009). As an explanation, Weiss et al. (1993) proposed a drought episode – a significant decrease in the average precipitation and probably in temperature (Staubwasser and Weiss 2006; Weiss et al. 1993). The proposed drought episode (‘4.2 ka event’) coincides with the Bond Event 3 of the North Atlantic Oscillation (Bond et al. 2001).

While the presence of a drought episode at the end of the EBA is well attested (cf. Chapter One), the question is the social response to the changing environmental conditions. In the opinion of Wilkinson (1997), the economy of the largest urban centres of those times operated close to the limits of sustainability. The largest urban centres could collapse as a result of a drought episode, while smaller settlements could survive through
a combination of exchange and extension of agricultural production (Wilkinson et al. 2007). According to Wossink (2009), natural population growth and the effects of the mid-third millennium urbanisation were found to be much more important factors in determining human-environment interactions than the increasing aridity during the late third-early second millennium BC. Inter-site competition, driven by the resource stress, was primarily the effect of the population growth, and the increasing aridity only reinforced the mechanism (Wossink 2009).

The evidence of crisis at the end of the EBA differs between regions. The areas of low annual precipitation were more affected. The most spectacular, but still isolated, case was the abandonment of Tell Leilan (Weiss et al. 1993). Other sites of northern Mesopotamia continued, with smaller size (e.g. Tell Brak; Bieliński 2002; and Chagar Bazar; Tunca et al. 2007); some seem to have been unaffected by the crisis (e.g. Pir-Hussein; Peasnell and Algaze 2010), others even flourished (e.g. Tell Bi’a; Miglus and Strommenger 2007).

Similarly, the response to the climatic change was regionally different (Wossink 2009). Reduction in the size of large settlements could be a result of a shift of local population towards pastoralism, relocation of the smaller sites in the areas of still arable lands, and decreased hierarchical power (McMahon 2012: 666). Pastoralism played an important role in the adaptation to the new environmental conditions. Nomadic tribes of Amorites spread into non-arable areas (Wossink 2009). Pastoral subsistence could be attractive to the inhabitants of the former urban areas of northern Mesopotamia, who adopted a new lifestyle (Sallaberger 2007: 450). As a result, herders and farmers engaged in stable exchange relations, providing both groups with mutual access to diverse resources, thereby stabilising the groups' respective economies (Wossink 2009).

Climate related changes in the settlement pattern are visible in the central Transtigris, where the number of sites decreased between the EBA and MBA by 40% (no information about changes in the settlement size was reported; Mühl 2012: 88). Similar trend was not observed in the Shahrizor (Altaweel et al. 2012; Directorate General of Antiquities 1970), suggesting that the crisis had no impact on local communities. In contrast to the central Transtigris, in the Erbil Plain an increase in the number of settlements and settled area was observed (Ur et al. 2013).

5. Simurrum in the Middle Bronze Age

In the first half of the 21st c. BC, Simurrum faced successive attacks of the kingdom of Ur. In order to reach the territories of Lullubum and Urbilum (=modern Erbil), the kings of Ur first had to clear away Simurrum, which was controlling the main routes along the Diyala (Hallo 1978: 72). Shulgi (2096-2048 BC) eventually battled the coalition of Urbilum, Simurrum, Lullubum and Karakina (Sallaberger 1999: 142–143). Position of the Simurrum king is not mentioned (Altaweel et al. 2012: 11). The ten year long war between Simurrum
and Ur resulted in the annexation of Simurrum (Owen 2000). In the 40th year of Shulgi’s reign, offerings from Simurrum were recorded. A governor of Simurrum was appointed two years later (Hallo 1978: 77).

The dependence lasted to the reign of Ibbi-Sin (2028-2004 BC), who once again held a campaign against Simurrum (Sallaberger 1999: 158). Under Ibbi-Sin, the states of the Zagros foothills emerged and expanded, which eventually led to a competition between them, similar to the one between Simurrum and Lullubum. After the collapse of the Ur Empire, in the early 20th c. Lullubum extended their territory as far as the region of Sharpul (cf. Fig. 2.1; cf. Ahmed 2012).

Later, between c. 2025 and 1950 BC, during the reign of the Simurrean king Iddin-Sin and his son, Simurrum extended their territory from the Diyala River valley in the East to the Little Zab in the West, however, their area of influence seems to have reached from the Rania Plain to the region of Sharpul (Ahmed 2012: 255–273; Frayne 1990).

Letters from Shemshara, dated to the 18th c. BC, present a detailed picture of the Transtigris (Eidem and Læssøe 2001). In the 18th c. BC, the Transtigris area was covered by many small kingdoms and tribal federations. The area was dominated by Hurrians, Amorites, Guteans and Lullubeans. Simurrum is not mentioned in the Shemshara letters, however, according to Eidem and Læssøe (2001), one letter (SH 827) addressed to an unknown king may in fact be addressed to the king of Simurrum. The letter gives an impression that the recipient is a king of a regional power (Eidem and Læssøe 2001: 137–138). Likewise, territories of the Shahrizor are not mentioned, but according to one letter (SH 812), Lullubeans, who should be occupying the mountain region in the vicinity of the Shahrizor, were peasants producing grain and livestock for export (Eidem and Læssøe 2001: 134–135).

According to the letters from Shemshara, the kingdom of Simurrum did not take part in the conflict between the coalition of Shamshi-Addu and Dadusha, and states between the Great and Little Zab (Charpin 2004: 166–167; Eidem and Læssøe 2001). In that time, Simurrum could have been a vassal of Guteans. About fifteen years later, the king of Simurrum played a marginal role in the struggle between Turrukku (region of Lake Urmia) and Guteans. Simurrum is mentioned for the last time as a place of birth of a slave woman sold in Babylonia in 1723 BC (Altaweel et al. 2012: 11).

6. The Shahrizor between Babylonia and Assyria

In his 37th year of reign, Hammurabi, king of Babylonia (1792-1750 BC), defeated the army of Guteans, Kakmum and the land of Subartum (Charpin 2004: 332). Probably at that time, Shahrizor, known under the name of Lullubum, became a part of the Babylonian state (Altaweel et al. 2012: 11–12). Later, in the early 16th c. BC, Kassites took control over Babylonia, and the Shahrizor became a part of the Kassite Empire (Heinz 2012: 716–720). As
a border province, between the 13th and 12th c. BC, the Shahrizor became a subject of conflict between Kassites and Assyrians. In the LBA, the city-state of Assur was transformed into a territorial state (Wilkinson et al. 2005: 25). By the 13th c. BC, kingdom of Assyria had sought to increase their control over the Little Zab. In the early 12th c. BC, a border between Assyria and Babylonia was established by a treaty. The agreement placed the Shahrizor in the Kassite domain. However, by the late 11th c. BC, the border agreement was no longer valid, and Assyrians extended their control, at least temporally, over the Shahrizor (Altaweel et al. 2012: 12).

The end of the LBA is characterised by a widespread decline of urban centres (Matney 2012: 571). Both Assyrians and Kassites withdrew from the region of the Shahrizor in the late 11th c. BC (Altaweel et al. 2012: 12).

7. The Late Bronze Age crisis

In the 13th c. BC, the Assyrian kingdom extended from the Balikh valley in the West to the Zagros foothills in the East, from the Upper Tigris in the North to Rapiqum/Hit (and for some time Babylonian cities) in the South (Brown 2013: 101). In Syria, Assyrian control was mainly limited to the river valleys and arable territories. Open steppe areas remained outside of the Assyrian control (Fales 2010: 68). The area of the Balikh and Euphrates valley became a zone of contacts with the semi-nomadic groups. The nature of contacts was complicated. As an example can serve the case of Suteans, a semi-nomadic tribe, inhabiting the steppe zone between the Balikh and the Euphrates (Szuchman 2007). Suteans appeared, at the beginning of the Assyrian independence and expansion, both as a helpful and an antagonistic group. They are often treated as a part of the Assyrian state system, or at least a client state. Suteans' importance is visible in the diplomacy of the Assyrian state. High state officials were sent to meet Sutean tribal leaders. Moreover, Assyrian administration treated Suteans differently from other non-Assyrian inhabitants of the kingdom of Assyria (Jakob 2009: 52–53).

The relatively rapid expansion of the Assyrian state in the reign of Shalmaneser (1274-1245 BC) and Tukulti-Ninurta I (1244-1208 BC) required an analogous rapid means of ensuring Assyrian control over new territories. New territories were handed to high officials, usually members and relatives of the royal family, standing at the top of the hierarchical administration of a district (cf. Jakob 2003). Despite their efforts, intensive administrative control was limited to the areas of the Assyrian core, eastern Jazira and river valleys. The former areas of the Kingdom of Mitanni were not tightly incorporated into the Assyrian state, and during the reign of Tukulti-Ninurta I, the incorporation was 'a work in progress' (Fales 2011: 23). Moreover, the region of Tur Abdin, an important passage between Upper Mesopotamia and the Upper Tigris, was never really brought under effective Assyrian state control and the region was a place of constants revolts. The revolts
blocked state communication between regions (Radner 2006: 283–284). One reason was chronic labour shortage, including soldiers who could have controlled territories outside the core area (Cancik-Kirschbaum 1996: letter 3). The lack of a fully reliable communication between the central authority and the outer regions could have promoted isolation and diminished the sense of unity (Brown 2013: 104).

After the period of rapid expansion, the Assyrian Kingdom entered a period of decline. First phase may be dated to the period following the reign of Tukulti-Ninurta I. The king's later years were marked by a strong internal opposition to his building and religious policies, and eventually culminated in the assassination (Fales 2011: 10). Civil wars and struggle for power, in combination with a larger regional breakdown in central authority, had an impact on the state. By the mid-12th century or a little later, the presence of Assyria in some areas appears to have waned or disappeared entirely, as indicated by the destruction and abandonment of several sites like Tell Chuera, Tell Sabi Abyad, Tell Sheikh Hamad (Brown 2014). By the end of the 12th and the beginning of the 11th c. BC, Assyria had lost control over the Balikh and lower Khabur River valleys and large parts of western Jazira (Brown 2013: 101).

The first phase of the Assyrian decline seems to have been a slow erosion of the Assyrian 'hold' on the Jazira, due to the dynastic troubles at Assur and the increasing separation in the diverse 'lands' that formed the western territories of the reign. No less important was the military conflict with Babylonia and the activity of the West Semitic semi-nomad groups in the Euphrates and Jazira (Fales 2011).

After the period of weakness, Assyria experienced a brief revival and a period of expansion under Tiglath-pileser (1114-1076 BC) and Ashur-bel-kala (1073-1056 BC; Grayson 1991: 102; Postgate 1992: 252–254). However, the reign of both kings was marked by an ongoing military conflict with the semi-nomadic Arameans. One reason for the military conflict could have been a climatic change. The increasing aridity between the 12th-9th c. BC probably led to a reduction of the vegetation cover in the Syrian desert, meaning the grazing and herding opportunities must have deteriorated. The semi-nomadic Arameans had to migrate elsewhere in search of pastures (Kirleis and Herles 2007: 31). Semi-nomadic groups could have used the weakness of the Assyrian state and tried to take control over pastures located in the areas occupied by farmers. Aramean pressure on the Assyrian settlement in Jazira could be one of the reasons of the military conflict (Postgate 1992).

Assyrians seemed to be unprepared for the military conflict with the Arameans, who, since the reign of Tiglath-pileser I, became the main enemy of Assyria. Tiglath-pileser I claimed to have plundered their lands and destroyed several settlements (Grayson 1991). In times of Ashur-bel-kala, Arameans occupied widespread areas. At that time, the Assyrian king conducted 15 military campaigns in the area of the Assyrian state. The reason for the campaigns seems to be a reconquest of territories earlier lost to the nomads (Kirleis and Herles 2007: 10; Neumann and Parpola 1987: 179).
A long delayed crisis finally hit Assyria during the 11th c. BC. The magnitude of the crisis was so intense that it effaced all of the military and political achievements of Tiglath-pileser. Assyrians retreated to their homeland. The core of the Assyrian Empire, unlike the regions west of the Tigris, were unaffected by the territory loss to the newly forming Aramean states (Radner 2011: 321–322). However, even in those times, in some enclaves of the Lower Khabur, political connections with the Assyrian state were never entirely severed (Fales 2011: 31). Starting from the late 10th c. Assyrian kings managed to reconquer former territories and later expand Assyrian borders, creating the Assyrian Empire (cf. Brown 2013: 99).

The period of the 11th and 10th c. BC, seems to have been an ongoing military conflict between Assyrians and Arameans, featuring plundering on both sides. This conflict could put economy of both societies at the limits of sustainability in a period of drought. Bad crops caused by a drought in an economically important area could lead to a crisis and severe famine (cf. Neumann and Parpola 1987 Appendix A).

Archaeological findings from the period of crisis are scarce. Some information can be obtained by comparing settlement patterns between the LBA and the IA. During the 15th-14th c. BC, the previously inhabited nucleated centres were abandoned in favour of smaller, often newly founded, rural settlements, pointing to a renewed agricultural exploitation of marginal areas (Brown 2013). A decline, in numbers and density, of these mid-LBA sites was followed by a second phase of settlement in the river valley from the 13th c. BC onward. Most of the new settlements seem to have been located toward the southern limits of the dry farming area (e.g. Ur 2002). The LBA Assyrian settlement pattern was characterised by an overall decrease in settlement density in the areas conquered and administrated by Assyrians. New settlements were located on older Mitanni sites and only little infrastructural improvements (e.g. roads and irrigation canals) were observed in the new Assyrian territories (Brown 2013: 101). The overall decrease in the LBA settlement in the area of the Tigris and Balikh River is followed by a marked increase in the IA settlement density. The increase may be an effect of the settlement of the previously mobile Aramean peoples (Wilkinson et al. 2005: 39).

Findings from the Middle Euphrates, dated to the 13th-10th c. BC, show adaptation to the new, drier conditions, as well as changes in the settlement pattern and subsistence. Location of Mashtabe suggests that the town was erected when water high levels were rare, and the place was abandoned when the average water level increased. The town itself was linked to a subsistence based on agricultural production connected with herding in the neighbouring steppe. Abandonment of other sites in the region suggests an adaptation of a semi-nomadic and non-urban pastoral economy. Presence of pottery with analogies in the Diyala valley suggests some kind of population movements into areas where conditions were still favourable for farming (Rouault 2009).
Decrease in the settlement density and site abandonment seem to have been an adaptation to the new conditions. In times of great aridity, and decrease in arable land, a shift to mobile pastoralism seems to be an adaptation acceptable for sedentary people (cf. Forbes 1989; and discussion in Chapter One). Sedentary populations shifting to pastoralism could reinforce the number of Arameans. The greater number of semi-nomads could increase pressure on other regions, leading to the exacerbation of the conflict. Moreover, mobile pastorals are more difficult to incorporate into state policy (cf. Salzman 2002), and the land of the nomads was possibly lost for the Assyrian state. The increase in the number of settlements in the later IA seems to be a reverse trend, more humid climate promoting sedentary way of life (Wilkinson et al. 2005: 39).

The period between 1200-900 BC was a long recession of varying intensity; it can possibly be subdivided into a period of gentle recession, down to the reign of Tiglath-pileser I, and a much more intense loss of power which saw Assyrian control wither to the minimal core of Assur heartland, for which external political agents – the Aramean tribes – are seen as responsible. The climate may have been a contributory factor – poor rainfall both weakened Assyria's agriculture base and forced Arameans north in search of pastures (Postgate 1992).

7.1 The role of the climate in the Late Bronze Age crisis

The LBA crisis was a period of socio-political upheaval, military conflicts and mass migrations in the eastern basin of the Mediterranean Sea. The role of the climate change in those events is the subject of the debate initiated by Carpenter (1966). According to Carpenter (1966), a drought episode was responsible for mass migration in the area of the eastern Mediterranean. Peoples moved from the areas affected by the drought into zones still suitable for farming. The migration caused conflict between the LBA states and led to the collapse of the LBA civilisation in the Aegean Sea.

In the area of the Middle East, the presence of drought and possible consequences for the local societies were investigated by Kay and Johanson (1981) and Weiss (1982), however, the results were not satisfying. In contrast to the previous papers, Neumann and Parpola (1987) used both the climate data and textual sources to highlight the impact of the drought on Mesopotamian societies (cf. below). Different approach was presented by Brentjes (1999), who compared the European 'Little Ice Age' and the LBA/IA transition in the Near East. In conclusion, he suggested a decrease in the monsoonal rainfall and increased aridity in Eurasia between 1350 and 950 BC. Later, Kirleis and Herles (2007) were first to incorporate pollen data into the discussion about environmental changes at the end of the second millennium. However, the discussed data were not univocal. Recently, Kaniewski et al. (2008, 2010, 2013) have made a great effort to investigate the presence and impact of the climate change at the end of the second millennium on the environment of the eastern
Middle East. Their studies were based on pollen records with high resolution radiocarbon dates (for a summary see Kaniewski et al. 2015).

Studies from the last 30 years support the thesis of a drought episode at the end of the second millennium BC (cf. Chapter One), and a drop in the agricultural production (Kaniewski et al. 2008, 2010, 2013). However, recent studies (Kaniewski et al. 2008, 2010, 2013; Kirleis and Herles 2007), focus on the Mediterranean coast, and the Levant, providing little support for Jazira and the Transtigris region. One exception is the pollen record from Bouara salt lake, at the Syria-Iraqi border (Gremmen and Bottema 1991). Obtained pollen record does not show traits of an increased aridity at the end of the second millennium BC. The lake is located in the Syrian dry steppe, and changes towards greater aridity would not greatly affect composition of the local flora (Kirleis and Herles 2007).

In addition to the environmental data, textual sources frequently present famines occurring in Assyria and Babylonia (Neumann and Parpola 1987). The textual sources from the 12th–10th c. BC contain numerous references to negative developments likely to result from unusual arid conditions (crop failure, famine), while references to good conditions (good crops, low prices) are almost totally lacking. Crop failures and grain shortages are naturally attested in other periods, too, but they are generally restricted to exceptional situations, like times of civil war (Neumann and Parpola 1987: 172–174).

Food shortage at that time was probably caused by insufficient rainfall in the vegetation period, however, other factors, including warfare, could possibly contribute to the occurrence of local famines. For example, a passage from the Assyrian Chronicle (Grayson 1975; Neumann and Parpola 1987: 178) dated to 1082 BC describes a famine among Assyrians (with possible cannibalism). The text does not mention the reason of the starvation, but mentions Arameans controlling roads and plundering the whole area. According to Brinkman (1968: 387), the famine among Assyrians could have been caused by Arameans that were blocking roads to the city and preventing any transport of supplies.

The textual references to the socio-political upheaval and nomad unrest led Brinkman (1968) to form a thesis that the collapse of Babylon was caused by disastrous nomadic raids. In that time, both farmers and nomads were simultaneously affected by food shortages. To obtain food nomads attacked settlers. Nomads were more likely to attack settled areas in a time of famine, when they were not able to produce food and when inhabitants of the settled areas were weaker than usual (Brinkman 1968: 280).

A model associating nomad activity with resource shortages was developed by Neumann and Parpola (1987), who showed correlation between occurring droughts, social stress and nomadic unrest in northern Mesopotamia. In their opinion, humid conditions before 1200 BC led to the population growth reaching its ecological limits. Under these conditions, even a slight decrease in the annual precipitation could disturb the equilibrium and lead to a famine. Severe shortage in essential resources seems to lead to a competition between groups of settled farmers and semi-nomadic herders, and eventually, to a dramatic
political, military and socio-economic crisis (Neumann and Parpola 1987: 161–162). However, not every nomad activity could be attributed to searching for food and/or pastures. In a passage from Babylonian Chronicle (Neumann and Parpola 1987: 179; Walker 1982), Arameans and 'an usurper' initiate a rebellion against the Babylonian state. The effect of the rebellion was plundering and destruction of sanctuaries, lands and cities.

The textual sources fit well with the proposed occurrence of a drought episode and a drop in agricultural production. However, a simple coincidence is not sufficient to prove causality between the drought episode and the socio-political upheaval. The most important issue is to assess if human populations before 1200 BC operated on the brink of the limits of ecological carrying capacity. Neumann and Parpola assumed that climate optimum before 1200 BC led to a growth of human population to its ecological limits, but did not prove the hypothesis (Neumann and Parpola 1987: 162). The chronological correlation between events is another issue. Radiocarbon dates are not precise enough to allow, for example, a comparison between changes in the pollen record and historical events (see radiocarbon dates in Kaniewski et al. 2010, for example). Moreover, the environmental response to the drought episode could be delayed in time as a result of local settings (cf. Roberts et al. 2011).

Without proving that before 1200 BC human population of northern Mesopotamia operated on the brink of the limits of ecological carrying capacity, it will be impossible to indicate the drought episode as a main factor responsible for the decline of the Assyrian Kingdom. Still, if not the main reason, the drought episode remains an important factor shaping historical events during the last quarter of the second millennium BC.

The period of the Assyrian decline lasted until c. 935 BC. Little is known about the period of crisis, but it seems clear that an almost complete restructuring of the society must have taken place due to the large-scale nomadisation, migration, internal population movement and technological and trade network changes, while there is also evidence for continuity (Fales 2008).

8. Province of the Empire

The Shahrizor seems to have been less severely affected by the drought. High precipitation in the region seems to have been able to sustain cultivation of main cereals (cf. Chapter One). Assyrian control over the Shahrizor remained till the last quarter of the 11\textsuperscript{th} c. and the withdrawal coincided with an increased involvement in the military conflict with Arameans in the southern part of the Assyrian state, and a retreat to the Assyrian homeland borders. Assyrians left the Shahrizor for more or less a century and when they tried to reconquer the region, the area was divided into many independent kingdoms (Altaweel et al. 2012: 12–13). Mazamua (=Zamua), as Assyrians called the region, was conquered by Ashurnasirpal II in 881-880 BC. A detailed description of the conquest provides some information about politics, geography and, to some extent, subsistence of the region.
(Annals of Ashurnasirpal II.24-86). The chronicle mentions sheep and oxen taken by Assyrians as spoils; cattle and horses are less common. The king also received a tribute from the kings of Mazamua. The tribute included oxen, sheep, horses and cattle. Moreover, after establishing the province Mazamua, Ashurnasirpal II also established a tribute for the province: wheat, barley and horses. Royal granaries were established in Dur-Assur (Annals of Ashurnasirpal II.24-86). Mazamua did not differ from the other lands described in the chronicle. Sheep and oxen were common spoils throughout the whole chronicle, goats and horses are less commonly mentioned. Sheep, goats and oxen are also commonly mentioned as a part of a tribute offered to Ashurnasirpal in many other regions mentioned in the annals. Barley, wheat and horses are also commonly enumerated as a part of the tribute paid by the province. In the context of Annals of Ashurnasirpal, subsistence of Mazamua was based on both agriculture and pastoralism, and does not significantly differ from subsistence observed in other regions. High number of towns and villages enumerated in the chronicle may indicate the importance of agriculture in the local subsistence.

After incorporation into Assyrian Empire, Mazamua was a subject of the Assyrian policy of deportation (Oded 1979; Tadmor and Yamada 2011) and intensification of agricultural production (cf. Wilkinson 2005). Assyrian strategy in land management was to put unused or underused land under cultivation, together with the introduction of new agricultural techniques, including bee-keeping. In many cases, putting unused land under cultivation required improvement and expansion of the irrigation canals network, especially in the steppe regions (Radner 2014: 106). The Assyrian Empire seems to have adapted multiple strategies of agricultural production: dry-farming areas within the marginal steppe lands were opened up for what must have been relatively low-yield rain-fed cultivation; and areas nearer the capital were irrigated presumably in order to increase yields above and beyond those obtainable under rain-fed cropping in the region (Wilkinson et al. 2005: 50).

The only obvious change in the agricultural techniques seems to be the introduction of summer crops (millet and sesame) on a wide scale. However, the scale of the summer crops introduction remains unclear. Millet and sesame are known from a single IA site (Riehl and Nesbitt 2003: 306).

An indirect premise about agricultural productivity of Mazamua could be the fact that this region was routinely used as an assembly point for Assyrian troops when Assyria was at war with Urartu (e.g. Sargon army in 714 BC). The main reason was the military significance of Mazamua, but any province where the army was stationed had to provide troops with foodstuff and fodder. For example, the Lahiru province provided 70 500 litres of grain per day for 30 000 soldiers of Sargon II (Marriott and Radner 2015: 128–129). The number of soldiers stationed in Mazamua during successive raids into the Zagros is unknown. Only one report provides a number (1430 men) of an incomplete gathering of Sargon's troops (Postgate 2000). Routine use of Mazamua as an army assembly point
suggests that the agricultural production and local supplies were high enough to spend them on local needs, tribute (Annals of Ashurnasirpal II.24-86), as well as supply the state army (Postgate 2000).

The impact of the Assyrian policy on the Shahrizor can be seen in the settlement pattern. The number of archaeological sites increased from three in the LBA to 93 in the IA (Directorate General of Antiquities 1970), or from eight in the LBA to 13 in the IA (Altaweel et al. 2012: 19). No information about settlement size was reported. Similar trend can be observed in the Erbil Plain (17 sites in the LBA and 37 sites in the IA) where an increase in the settled area is also observed (Ur et al. 2013) In the central Transtigris area, similar to the two previously mentioned regions, the number of sites increased from 241 sites in the LBA to 341 in the IA, but no information about settlement size was reported (Mühl 2012). Here, the steady increase in the settlement number is observed from the LBA and seems to be associated with the expansion of the irrigation network under the Assyrian reign (Mühl 2012: 88).

Moreover, in the Erbil Plain a tendency toward smaller settlements is visible. Only two out of 37 recorded IA sites had an area larger than 5 ha. According to Ur et al. (2013), this pattern appears to be an early evidence of a planned and imposed agricultural colonisation under the Assyrian reign (Ur et al. 2013: 102). Furthermore, the occupation area of the main tells was limited to few hectares, for example, Tell Baqtra, with c. 80 ha of settled area, was a first rank city during the BA. In the IA, the settlement was restricted to the high mound with c. 5 ha of occupied area (Ur et al. 2013: 97). Similar decrease in the occupation area could be observed at Bakr Awa ( Miglus et al. 2011, 2013).

9. Classical period

Between 630 and 609 BC, the Assyrian Empire went through a phase of terminal decline, which eventually resulted in its collapse. In the 7th c. BC, Babylonia gained independence from the Assyrian Empire, and together with Media they conquered Assyria in 612 BC. As a result, Babylonia gained control over the Assyrian heartland and a part of their territories (Baker 2012: 914). Mazama remained an Assyrian province until the collapse of the Empire in the 7th c. BC (Altaweel et al. 2012: 14).

Later, the Shahrizor became part of the Babylonian Empire, or, at least, it was one during the reign of Nebuchadnezzar II (604–562 BC; Vanderhooft 1999: 92). The IA Babylonian, as well as Assyrian, pottery types are known from several sites in the Shahrizor. However, influences from the neighbouring regions dominate in the material culture (Altaweel et al. 2012: 26). Later, during the Achaemenid period (550-330 BC), the Shahrizor was a part of the Satrapy of Media, however, presence of the Achaemenid archaeological material is not numerous (Altaweel et al. 2012: 14–15). The Shahrizor
remained an important point on the route between Mesopotamia and Iran through the Zagros Mountains throughout the later regimes of Achaemenids.

During the Babylonian and, later, Achaemenid reign, a decline of urban life was observed in the central Tigris area. No substantial post-Assyrian occupation levels have been detected at any of the former major urban sites. Babylonian activity is known from layers of destructions. No univocal infrastructural evidence of Babylonian presence in northern Mesopotamia during times of the Babylonian Empire has been found. The Transtigris was administrated by the local elite (Baker 2012: 927–928).

Since the IA, the Shahrizor was an important region of successive empires. Archaeological record of the Shahrizor reflects cultural changes in the current central region, but local traditions dominate in material culture (Altaweel et al. 2012).

Little is known about the Shahrizor during the Hellenistic (330-148 BC) and Arsacids rule (148 BC–AD 224). In that time, a route from Sardis to Susa led through the Shahrizor, as described by Herodotus (The History of Herodotus V, 52). Part of the route from Erbil to Ectabana was mentioned by Diodorus Siculus (The Library of History XVII 64.1-2). Avroman parchments, found in the cave at Kuh-e Salan in the Hawrman range (Minns 1915), provide some information about the Zagros foothills in that time. Two parchments were written in Greek and are dated to 88/7 and 22/1 BC. Third parchment was written in Parthian and is dated to AD 33 (Minns 1915). Use of the Greek language and Greek legal terminology suggests a long lasting impact of Greek culture and administration on the region. The impact may have been great because of a Greek diaspora presence in the Satrapy of Media (Shayegan 2011: 196)

In times of the Sasanian rule (AD 224-651), the Shahrizor was a part of the satrapy of Media. An abundance of findings from the Sasanian period indicates dense settlement in that time in the Shahrizor (Altaweel et al. 2012: 15). Under the Sasanian reign, the agriculture area in the Diyala valley was expanded to the maximal possible area the existing irrigation technique would allow (Kennedy 2011: 178). However, no Sasanian occupation was attested at Bakr Awa (Miglus et al. 2011, 2013).

10. Islamic period

After the Arabic conquest, the Shahrizor was a part of the Mosul province and later, as a separate administrative unit, was a part of Al-Jebel ('Mountains'; Christensen 1993: 151; Robinson 2000: 24–25). In the 7thc. Mosul was inhabited by Arabs. City was surrounded by fields; further from the city were the grasslands inhabited by Arab tribesmen who led a nomadic or semi-nomadic existence. Many of those groups were closely involved with the politics of the city. Beyond the steppe were the mountain provinces linked to Mosul (Kennedy 1981: 27) Despite the Arab settlement and the emergence of new urban
communities after the Islamic conquest in the 7th c. there is no evidence of a subsequent expansion of agriculture and settlement in the Diyala basin (Kennedy 2011: 178).

Following centuries have provided few descriptions of the Shahrizor. According to Ibn Hawkal, in the 10th c. the city of Shahrazur was a walled and fortified town inhabited by Kurds. Kurdish tribes occupied the surrounding, mostly fruitful, region (Le Strange 1905: 190). From the same century comes the testimony of another traveller, Ibn Muhalhal, who described the Shahrizor as a district with many towns and villages. He also mentions, that the chief city of the region was known among Persians as Nim-Rah (‘the Half-way House’), because it stood in the middle between Madain (Ctesiphon) and Shiz (Le Strange 1905: 190). This comment may suggest that the Shahrizor was still an important point on the interregional route. Four centuries later, when Shahrizor was a part of the Mongol Ilkhanate, Hamdallah al-Mustawfi described this region as flourishing and inhabited by Kurds (Le Strange 1905: 191).

At the end of the Ilkhanate rule, Kurdish tribes, led by Baba Ardalan, gained independence. The Shahrizor became a part of the independent Kurdish kingdom. By the end of the 16th c. the Kurdish kingdom was conquered and the Shahrizor became a part of the Ottoman Empire (Oberling 1988).

Kurds practiced vertical transhumance – during summer herds grazed in the mountains, while in winter lowland pastures were used. Islamic material culture is visible in the whole area of the Shahrizor. The latest occupation on tells is characterised by Kurdish Ware and dated to the Ottoman period (Altaweel et al. 2012: 27).

11. Bakr Awa: case study

Tell Bakr Awa (35°13’14”N, 45°56’26”E) is located in the south-eastern part of the Shahrizor Plain in the modern province of Sulaimaniyah (Iraqi Kurdistan). The tell consists of a c. 30m high citadel surrounded by a lower city (600x800 m; cf. Fig. 2.2; Miglus et al. 2011, 2013). First modern description of the tell was written by James Felix Jones in 1844. In 1927, the tell became of interest to Ephraim Speiser, who conducted first archaeological excavations. According to Speiser, Bakr Awa could be identified as the ancient city Atilia conquered by Ashurnasirpal II c. 880 BC, and renamed, after restoration, to Dur-Assur (Speiser 1927). To date, there is no evidence confirming proposed identification.

In 1960 and 1961 excavations at Bakr Awa were conducted by Iraqi archaeologists from the Directorate General of Antiquities of Iraq. The excavations were carried in two areas, one located on the south-western slope of the citadel (=current area BA 6), and in the eastern part of the lower town (=current area BA 2). Recorded stratigraphic sequence covered several layers from the Late Chalcolithic to the Islamic Period (IS). During the works, several graves were unearthed, but no information about human remains was reported (Al-Husaini 1962).
Present research was initiated by the Directorate of Antiquities of Sulaimaniyah. In September and October 2009, an archaeological survey was conducted in the area on the north-eastern bank of the Tanjero River. Based on the collected material, results of earlier archaeological excavation, threats of looting activity and the development of a modern settlement, tell Bakr Awa was chosen for further investigation (Miglus et al. 2011, 2013). From the beginning, the archaeological excavations have been directed by Prof. P.A. Miglus (Institute of Pre- and Protohistory, Heidelberg). During four archaeological campaigns between 2010 and 2014, the research effort was concentrated in five excavated areas; three of them are located in the lower town (areas BA 1, 2 and 5), and two are located on the citadel (areas BA 3 and 4; cf. Fig. 2.2). Excavated structures are dated between the early EBA and modern period (cf. Tab 1.1; Miglus et al. 2011, 2013).

11.1. Results of archaeological investigations

The oldest known occupation of the citadel at Bakr Awa is dated to the end of the 4th millennium BC (Al-Husaini 1962; Miglus et al. 2011, 2013). Occupation in the lower town seems to be a little bit younger. The oldest known occupation phase of the lower town is dated to the early 3rd millennium BC (Miglus et al. 2013: 65).

Little is known about the earlier phase of the EBA occupation in the lower town. The earliest strata were unearthed only in two deep soundings in area BA 2. In one, a deep homogeneous horizon was observed beneath a pebble floor. In the second, four occupation phases indicated by the remains of pebble floors were observed. However, no architectural remains were found. Unearthed artefacts have local character. The oldest excavated horizon was radiocarbon dated to the 29th c. cal. BC (Miglus 2013: 65).

Later phase of the EBA (second half of the 3rd millennium) consists of stone foundations of architectural constructions. Only one building was fully uncovered, a small single-room shrine (BA 2306) with parallels in the eastern Tigris region. The shrine was radiocarbon dated to the 23rd-21st c. cal BC (Miglus et al. 2013: 62-65). The function of other, partly unearthed, buildings remains uncertain (Miglus et al. 2013: 62). The EBA occupation gives evidence for strong integration with the Mesopotamian cultural sphere (Miglus et al. 2013: 68).
The MBA occupation phase consists of the remains of private and official architecture with spectacular funerary findings. Remains of private houses were uncovered in both area BA 1 and area BA 2 (Al-Husaini 1962; Miglus et al. 2011, 2013). The construction of the house from area BA 2 has parallels in the MBA southern and central Mesopotamia.
One room of the house contained an altar. Similar “domestic chapels” are known from southern Mesopotamia (Miglus et al. 2013: 53-54)

Chamber tombs (BA1108 and BA2500) made of burnt bricks were discovered beneath both houses (Miglus et al. 2011, 2013). Similar constructions are known from the MBA southern and central Mesopotamia (Miglus et al. 2013: 57). The tombs contained human remains, usually in secondary position, and many precious objects, including bronze weapons and jewellery. Artefacts find their parallels in both southern and northern Mesopotamia (including Assur) and Luristan (Miglus et al. 2013: 57–61). Remains of, probably sacrificed, animals were found in front of the entrances to both chamber tombs (Miglus et al. 2013: 61).

The burial rite indicates presence of a social stratification among the inhabitants of Bakr Awa. Except for the chamber tombs, precious metal objects and pottery vessels were found only in four earth graves (BA2084; cf. Miglus et al. 2011, 2013; BA2386, BA2688; BA2728). Other graves contained pottery vessels or a single metal object. Many graves did not contain grave goods (cf. Miglus et al. 2011, 2013).

The first half of the second millennium BC seems to have been a time of prosperity and far reaching contacts at Bakr Awa. Its material culture is influenced by both northern and southern Mesopotamia (Miglus et al. 2013: 68). The time of prosperity coincides with the ‘golden age’ of Simurrum and later, possibly, the Gutean rule over the state.

The LBA phase provides remains of architectural structures in area BA 2. In area BA 1, architectural remains are missing and only single findings can be dated to the LBA (Miglus et al. 2011, 2013). Cylinder seals and fragments of pottery with parallels in the Lower Diyala were found in the filling of a private house in area BA 2 (Miglus et al. 2013: 51). Earlier, during the Iraqi excavation (Al-Husaini 1962), cuneiform tablets (IM 63985-92, IM63994-5, IM 63998) dated to second half of the second millennium BC had been found (Miglus et al. 2013: 51). The material culture of the LBA shows similarities to northern Mesopotamia, however, the pottery indicates strong ties to Kassite Babylonia and proves cultural continuity from the late MBA to the LBA (Miglus et al. 2013: 68). The decrease in the occupation size (in BA 1) is dated to the Kassite reign and incorporation of Bakr Awa into a large territorial state.

The type of occupation changes between the LBA and late IA. During the BA, this part of the lower town was covered by stately architecture, including shrines and other official building. From the IA, single findings and some architectural remains (rubble pavements) and funeral findings are known. No artefacts or constructions dated between 1200-800 BC were found (cf. Miglus et al. 2011 and 2013).

The older IA occupation phase (8th-6th c. BC) consists of the remains of rubble pavements attested in both areas. Material culture has parallels in the southern Urartian and Median sites, as well as in the central Tigris region. No traces of the Assyrian occupation were attested in the lower town. Some fragments of Assyrian pottery shards
were found in the secondary context. A thick wall surrounding the citadel was probably built in the IA, but the precise dating is impossible. The younger of the IA strata unearthed in the lower town consists mostly of funeral findings. Following their burial inventory, at least two graves can be dated to the Achaemenid period (6th-4th c. BC) (Miglus et al. 2013: 49).

In the IA, the occupation in the area of the lower city seems to have decreased. The material culture reflects the traditions of Iran and only some artefacts bear reminiscence to the Assyrian heartland. During the Sasanian period no occupation was attested (Miglus et al. 2011, 2013).

Islamic settlement in the lower town was initiated in the Abbasid period (8th-13th c.) and continued to the Ottoman period (Miglus et al. 2013). Remains of architectural structures suggest that both the citadel and the lower town were inhabited. Distribution of artefacts, including glazed pottery, indicates that the citadel was occupied by wealthier citizens. The difference is also visible in the architecture. Reused burnt brick were found on the citadel, indicating presence of the medieval burnt brick architecture on the citadel (Miglus et al. 2013: 77–78). Fragments of cuneiform inscriptions dated to the MBA were retrieved from an Islamic trash pit.

In the lower city, below the modern surface, c. 30 graves (BA 2 and BA 5) were found. Upper parts of the graves were destroyed as a result of modern day looting activity. Burial rites and the stratigraphic context of the graves allow for ascribing the burials to the Islamic tradition, however, lack of burial objects does not allow for a more precise dating (Miglus et al. 2013).
Biochemical analysis of human remains is commonly used in dietary reconstruction. The base assumption of dietary reconstruction is the strict relation between the food consumed and the consumer, in other words 'you are what you eat'. Further studies have confirmed this assumption (DeNiro and Epstein 1978, 1981), but have also showed that the relation between the food ingested and the consumer tissues is more complicated (e.g. Fuller et al. 2004). Biochemical analysis of human tissues can provide some information about consumption of animals proteins, among others (cf. Ambrose and Katzenberg 2002; Lee-Thorp 2008).

Dental microwear analysis is less commonly used in dietary reconstruction. The base assumption of dental microwear analysis is the relation between mastication and the properties of food items visible in traits left by abrasive particles on the enamel surface. This assumption has been proved to be correct (e.g. Teaford and Walker 1984), although a comparative analysis requires a strict protocol (Gordon 1982). In contrast to biochemical studies, dental microwear analysis is sensitive to technological factors such as the type of food processing, therefore it can be used to track changes in the technology of plant processing (cf. Soltysik 2011).

Another method traditionally used in dietary reconstruction is the analysis of caries lesions (Hillson 1979). The base assumption is the relation between the sugars consumed and the presence of caries lesions (Hillson 2005: 294–295). Presence and frequency of dental caries may reflect the differences in the amount of sugars consumed in diet (Hillson 2005: 290–295, 1979). However, dental caries is the most strongly correlated with age-at-death, and the structure of the analysed skeletal collection can affect the results of the analysis. Moreover, early stages of the forming of caries lesions can be mistaken for diagenetic processes (e.g. colour change; Hillson 2005: 295–303).

Described methods are complementary to each other, giving insight into many aspects of everyday life, but the number of studies combining at least two of them is low, not to mention studies incorporating all of them.

For this study, I have chosen the carbon and nitrogen stable isotope analysis and the dental microwear analysis. Methods of choice provide different insights into the dietary patterns. The carbon and nitrogen stable isotope analysis allows for an assessment of food quality (e.g. the amount of animal proteins consumed), and can show the difference in the access to different types of foodstuff (cf. Lee-Thorp 2008). In contrast, the dental microwear analysis can provide some information about the quality of food items (e.g. the purity of cereal products), and the technology of food processing (cf. Soltysik 2011). Both methods can provide statistically significant results, even when the subsets analysed are not numerous (Pearson and Grove 2013; Soltysik 2011). This is especially important because of the low number of individuals from Bakr Awa dated to the IA (cf. Chapter Four).
Unfortunately, the low number of individuals does not allow for an incorporation of the dental caries analysis, in order to investigate the differences in the diet and subsistence between the BA and the IA. Another advantage of both methods is their relative resistance to bias associated with contamination. Both the unaltered collagen and the dental surface should provide reliable information about the diet of an individual (Ambrose 1990; King et al. 1999). Unfortunately, in many cases early stages of caries can be mistaken for enamel alternation.

In the present chapter, I will discuss biological basis, possibilities and limitations of both methods.

1. Analysis of carbon and nitrogen stable isotopes

The subject of this analysis is the stable isotope ratio of carbon and nitrogen in bone collagen. Collagen is a protein composed of several amino acids, among which some are synthesized in human organism from nutrient (non-essential amino acid); others, which cannot be fixed (essential amino acids), come directly from the digested foodstuff. Depending on the foodstuff’s characteristics, the ratios of carbon and nitrogen stable isotopes in consumer's tissue can change.

1.1. The isotopic analysis

An isotope is a variant of an element that varies in the number of neutrons. The variation in the number of neutrons, with the constant number of protons, leads to differences in the mass of isotopes. Different atomic mass leads to differences in both the reaction rate and bond strength. The physical properties of two isotopes are quantitatively different, with the largest difference occurring between lighter elements, where the percentile change in the mass is the greatest (e.g. deuterium has twice the mass of a hydrogen atom, while $^{13}$C isotope is c. 8% heavier than $^{12}$C isotope). Mass affects the potential velocity of a particle. In fixed environmental settings and imbued with constant kinetic energy, the particle with the greater mass will travel at a slower velocity. Isotopes also differ in the vibrational energy of the molecule. Heavier isotopes vibrate more slowly than the lighter ones, so the energy of a molecule with a heavy isotope is lower; they also form stronger and more stable bonds. The difference in velocity and bond strength between isotopes leads to a fractionation. As a result, the source and its compounds differ in isotopic composition (Sulzman 2007: 1–7).

Fractionation could be a result of three mechanisms: equilibrium, and the kinetic and nuclear spin. Equilibrium fractionation reactions are observed between chemical substances (reactant and product) or phases (e.g. vapour and liquid), where the distribution of isotopes differs and the reaction is in equilibrium. In these reactions, the reactants and products remain in close contact in a closed system and a back reaction can occur,
therefore a chemical equilibrium can be attained. The extent of difference in the final and initial masses in equilibrium fractionation reactions depends on temperature, with the greatest differences at the lowest temperatures. Moreover, heavier isotopes tend to accumulate where the bonds are the strongest (Bigeleisen 1965; Sulzman 2007: 7–8). Kinetic fractionation is observed in irreversible or unidirectional reactions (e.g. evaporation in open systems). In kinetic reactions, both the bond strength and isotope velocity are important. Kinetic reactions are associated with processes like evaporation, diffusion, dissociation reactions and enzymatic effects. Kinetic fractionation is often quite large (usually much larger than equilibrium fractionation) and result in an accumulation of lighter isotopes in their products, like in evaporation, where the gas (the product) is enriched in lighter isotopes. The magnitude of the isotopic kinetic fraction is usually constant. Nuclear spin fractionation is not mass dependent, and arises as a result of the differences in the nuclear structure of isotopes and leads to differences in the nuclear spin. The importance of this type of fractionation is unclear in most circumstances, and is omitted in most cases (Sulzman 2007).

The isotopic ratio of a given element is calculated in relation to standard material. The isotopic ratio is expressed as δR, and calculated following **For. 1.** Values of δR are expressed per mill (‰).

\[
\delta R = \left( \frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 1000
\]

**Formula 1.** Formula for the isotopic ratio calculation: \( R \) - heavy-to-light isotope ratio, \( R_{\text{sample}} \) ratio of the sample: \( R_{\text{standard}} \) - ratio of standard material.

The discrimination factor (Δ) refers to the degree to which the process fractionates against a heavy isotope and it can be expressed by **For. 2.**

\[
\Delta R_{A-B} = \delta R_A - \delta R_B
\]

**Formula 2.** Simplified equation of the discrimination, \( \Delta R_{A-B} \) is the discrimination rate, the \( \delta R_A \) is the stable isotope ratio of product and \( \delta R_B \) is the stable isotopic ratio of reactant.

### 1.2 Collagen

The organic component of bone matrix is in c. 90% composed of type I collagen. The next most abundant is osteocalcin, which constitutes c. 7-8% of the organic component of the bone (Niedźwiedzki and Kuryszko 2007: 40–46).

Type I collagen contains three chains of amino acids and can be described as -Gly-X-Y-, where Gly is glycine (C\(_2\)H\(_5\)NO\(_2\)) and X and Y are following positions that can be taken by other amino acids, like proline (C\(_5\)H\(_9\)NO\(_2\)), hydroxyproline (C\(_5\)H\(_9\)NO\(_3\)) and alanine (C\(_3\)H\(_7\)NO\(_3\)). Other amino acids are less common. Glycine, proline, hydroxyproline and alanine are non-essential amino acids and can be synthesised by human organism (cf. Howland et al. 2003).
1.3. Carbon in the food chain

In the case of terrestrial flora, the source of carbon is atmospheric CO$_2$, with a spatially and temporally variable stable isotopic ratio. An analysis of the ice cores and oceanic sediments has shown that the value of $\delta^{13}$C has changed over time (Leuenberger et al. 1992). The exploitation of fossil fuels has led to an accelerated decrease in the atmospheric $\delta^{13}$C value from the pre-industrial period (c.-6.5‰) to the modern times – c.-8‰ (cf. Keeling et al. 2005; Marino et al. 1992).

Spatial variation in $\delta^{13}$C in atmospheric CO$_2$ is related to the type of biosphere – terrestrial or marine (cf. Keeling et al. 2005), latitude and season. The most extreme example of a spatial variation of $\delta^{13}$C is the so called canopy effect (van der Merwe and Medina 1991). In a dense canopy where the gas exchange is limited, the respired CO$_2$ is depleted in $^{13}$C. As a result, local flora, which re-uses CO$_2$, will be depleted in $^{13}$C in comparison to the flora of open environments (van Klinken et al. 2002: 42).

Carbon becomes bioavailable as a result of the photosynthetic processes in the cells of a plant. The path of carbon through a leaf contains many steps where fractionation can occur. Therefore, the product of photosynthesis has a different value of the carbon isotopic ratio ($\delta^{13}$C) from the carbon source. The degree of fractionation depends on the type of photosynthesis and environmental conditions, including water availability, etc. A model of carbon fractionation in plants was proposed by Farquhar et al. (1982) and is summarised in For. 3.

\[
\delta^{13}C_{leaf} = \delta^{13}C_{atm} - a - (b - a)\frac{c_i}{c_a}
\]

**Formula 3.** Simplified formula of carbon fractionation in leaf proposed by Farquhar et al. (1982): $\delta^{13}C_{atm}$ - atmospheric carbon isotope ratio; $a$: fractionation value during diffusion of CO$_2$ into leaf; $b$: fractionation value of CO$_2$ fixation; $c_i/c_a$: ratio of intercellular and ambient concentration of CO$_2$.

A more detailed model also considers the discrimination during transportation of CO$_2$ across leaf’s boundary layer. In the case of thin boundary layers in some plants and types of leaves, this factor is negligible. Another factor, the fractionation that occurs as the gas-phase CO$_2$ dissolves in the cell wall and then diffuses through liquid water to the chloroplast is small (less than 1‰) and relatively constant, therefore it is also negligible. The last factor is the discrimination during respiration (including photorespiration). The in vivo studies of plant tissue do not show fractionation during respiration (Lin and Ehleringer 1997), however, wild plants almost always fractionate and their products are enriched in relation to the substrate by 2-3‰ (Ocheltree and Marshall 2004). The value of fractionation resulting from photorespiration lays between 0 and 9‰. The exact fractionation is difficult to estimate, because photorespiration takes place in chloroplasts and the products are immediately recycled in photosynthesis. In the case of complete recycling, no fraction would be observed (Ghashghale et al. 2003).
Carbon metabolism in leaf consist of several steps (cf. Fig. 3.1) which affect the final product of photosynthesis. Carbon is discriminated against $^{13}$C from the beginning during the diffusion of CO$_2$ into a leaf. Atmospheric CO$_2$ enters the leaf via stomata, where the first discrimination against $^{13}$C is observed. Kinetic properties promote lighter molecules that enter stomata more easily (Marshall et al. 2007: 23) First step, the diffusion of CO$_2$ into the leaf, is analogous in all plants. Next step depends on plant physiology and type of photosynthesis. Several different pathways of photosynthesis are observed among primary producers. The most common are the Calvin cycle, the Hatch-Slack cycle and the Crassulacean acid metabolism, called C$_3$, C$_4$ and CAM photosynthetic pathway respectively (O’Leary 1981).

In the Calvin cycle, the CO$_2$ dissolved in water is transported to chloroplasts where the ribulose-1,5-biphosphate carboxylase/oxygenase (RuBisCO) fixes carbon into primary product. Because fixing of heavier atoms requires more energy, the RuBisCO discriminates against $^{13}$C. Variations observed in the discrimination rate are highly dependable on water availability (O’Leary 1981; Smith and Epstein 1971).

In the Hatch-Slack cycle, the second step of the photosynthetic pathway is the fixation of CO$_2$ by phosphoenolpyruvic acid (PEP) into a carboxylase. In this step, the discrimination against $^{13}$C is negative. Next, the carboxylase is transported to the bundle sheath cells, where CO$_2$ is released and fixed by the RuBisCO, analogous to the Calvin cycle. Concentration of CO$_2$ resulting from the fixation into the carboxylase and then the transportation to the bundle sheath of the plant can help avoid photorespiration which is common in C$_3$ plants in warm climate (O’Leary 1981; Smith and Epstein 1971).

Plants using the Crassulacean acid metabolism divide steps of the Hatch-Slack cycle. The fixation of CO$_2$ by PEP and the transportation occur during the night, and the RuBisCO fixing during the day. Some plants can use the CAM facilitatively, for example, they use the C$_3$ pathway in favourable conditions and change to the C$_4$ during drought. Because the CAM plants discriminate against $^{13}$C as much as the C$_4$ plants, it is impossible to distinguish them using $\delta^{13}$C alone. The global mean of the $\delta^{13}$C values of the CAM plants is c. -11‰, and the facultative CAM plants range between -27‰ (light period) and -11‰ (dark period) (O’Leary 1981).

---

3 Combination of $\delta^{13}$C and $\delta$D can allow for distinguishing between the C$_4$ and CAM plants (Luo and Sternberg 1991).
Figure 3.1 Simplified carbon fractionation in a terrestrial ecosystem (based on Marshall et al. 2007 and Howland et al. 2003).
As mentioned above, several factors can affect the discrimination rate, the most important among them being temperature and humidity, including water stress. Both factors are associated with and can influence both the stoma activity and biochemical fixation of carbon (Marshall et al. 2007; O’Leary 1981: 555–558).

During periods of high temperature and low humidity, stomata are closed in order to conserve water (low stomata conductance). As a result, the CO$_2$ concentration in the leaf decreases, and proportionately more $^{13}$CO$_2$ is fixed, resulting in less negative plant $\delta^{13}$C values (van Klinken et al. 2002: 42). In time of water shortage, the intercellular concentration of CO$_2$ will be lower and more $^{13}$CO$_2$ will be fixed in the photosynthetic processes. In drier periods, the $\delta^{13}$C values of plant tissue should be elevated compared to wetter periods (Araus et al. 1997; Farquhar et al. 1982; Flohr et al. 2011). In most cases, discrimination factors remain constant, and since water availability influences changes in the discrimination rate of $^{13}$C the most, the $\delta^{13}$C values are used to track changes in the water in the plant’s environment and, indirectly, in the climate (cf. Riehl et al. 2008). In the Mediterranean conditions, the amount of annual rainfall explains 73% of the variations in the carbon discrimination rate (Araus et al. 1997: 114).

The bioavailable carbon is fixed into animal tissues from digested food (input). The input must equal the integrates isotope composition of the carbon which is incorporated into the body, and the carbon which is lost due to respiration and excretion (output). Therefore, enrichment in $^{13}$C of the whole animal relative to its diet must be balanced by $^{13}$C depletion in the respired and excreted carbon (DeNiro and Epstein 1978: 499–500).

As mentioned above, amino acids could be synthesised in organism (non-essential), or have to be taken from the foodstuff (essential). The most common amino acids that form collagen are fixed in animal organisms, therefore collagen is enriched in $^{13}$C in comparison to the bulk of food. Controlled study showed enrichment between the bulk of food and the consumer at a level of 1-2‰ (DeNiro and Epstein 1978: 499), however, an isotopic spacing between collagen and the whole diet can range from 0.5 to 6.1‰. The variation in isotopic spacing can be explained by the different proportion of essential amino acids and synthesised non-essential amino acids incorporated into collagen protein (Howland et al. 2003).

Essential amino acids and non-essential amino acids, whose sole precursors are essential, comprise 21.5% of carbon atoms in collagen, defining the minimum amount of routing from a diet protein to bone collagen (Howland et al. 2003: 55). The share of essential carbon atoms in collagen also depends on the quality of the diet. In diets relatively rich in proteins, the $\delta^{13}$C value of collagen is controlled by that of proteins, while in low protein diets, contribution from dietary carbohydrates and lipid is evident (Howland et al. 2003).

The enrichment between the whole diet and the bone collagen $\delta^{13}$C values could be explained by the enrichment observed in some of collagen's constituent amino acids. Glycine and glutamate constitute c. 17 and c. 10% of carbon atoms in collagen respectively,
and have been shown to be enriched in \( ^{13}\text{C} \) in comparison to the whole diet by 8 and 6\% respectively. Essential amino acids, like threonine and valine, display similar \( \delta ^{13}\text{C} \) values in both the diet and bone collagen (Howland et al. 2003: 55).

The isotopic composition of animal diet can be estimated following the \( \delta ^{13}\text{C} \) values of animal tissues. The estimation has to be corrected by the fractionation occurring during the incorporation of carbon into animal tissues. The fractionation that occurs during tissue formation varies between types of tissues. Therefore, the results of an analysis of single tissue are less reliable than the results of a whole body analysis (DeNiro and Epstein 1978: 504). Experimental studies have shown that collagen reflects the protein intake (e.g. Howland et al. 2003; Robbins et al. 2005). Carbohydrates and lipids have a limited impact on collagen composition (Howland et al. 2003).

### 1.4 Nitrogen in a food chain

Despite its abundance, atmospheric nitrogen (\( \text{N}_2 \)) is unavailable for most organisms because of the strength of the triple bond between the two nitrogen atoms in a molecule, and only some species of Bacteria and Archaea have evolved an ability to convert \( \text{N}_2 \) to reactive nitrogen (Galloway et al. 2004: 158).

Reactive nitrogen is produced in both the natural and anthropogenic way. Natural way of producing reactive nitrogen includes lightnings and biological nitrogen fixation. When they strike, lightnings generate high temperatures, producing NO from molecular oxygen and nitrogen in the atmosphere. Next NO is oxidized to \( \text{NO}_2 \) and then to \( \text{HNO}_3 \). In this form, reactive nitrogen is introduced into terrestrial ecosystems, primarily over tropical terrestrial areas (Galloway et al. 2004: 158). Much more effective in producing reactive nitrogen is the biological nitrogen fixation process – the conservation of atmospheric nitrogen into ammonia (\( \text{NH}_4^+ \)), nitrites (\( \text{NO}_2^- \)) and nitrates (\( \text{NO}_3^- \)) by nitrogenese enzymes (Evans 2001).

Atmospheric \( \text{N}_2 \) has a very stable \( \delta ^{15}\text{N} \) value of about 0\% (Mariotti 1983), however, the \( \delta ^{15}\text{N} \) values vary in ecosystems as a result of biological nitrogen fixation, recycling within the biosphere and re-releasing of \( \text{N}_2 \) (Robinson 2001). Nitrogen cycles vary depending on local ecosystems, and any prediction of \( \delta ^{15}\text{N} \) in local environment is usually inaccurate (Handley and Raven 1992).

In general, \( \delta ^{15}\text{N} \) value in soil and plants is slightly higher than in the atmosphere, and is usually about +1-4\%, however, variability ranges between -10\% and 10\% have been observed (Handley and Raven 1992). Among the factors that can affect the value of \( \delta ^{15}\text{N} \) in local environment are: aridity, leaching (with high precipitation), anoxia and salinity (cf. Heaton 1986; Shearer et al. 1983). The values of \( \delta ^{15}\text{N} \) are inversely related to the volume of rainfall. The strongest relation is observed in the areas with mean annual
precipitation lower than 400 mm, but also in these cases, the values of $\delta^{15}$N are variable (Handley et al. 1999; Heaton 1986).

Plants uptake nitrogen from the soil solution in a form of ammonia ($\text{NH}_4^+$) and nitrate ($\text{NO}_3^-$; Bloom 1988). Assimilation of ammonia occurs through glutamine synthetase in plant roots (Yoneyama et al. 1991). Nitrate is converted to ammonia as a result of nitrate reductase, and subsequently enters the glutamine synthetase (Mariotti et al. 1982). Many plants show distinct preference for the form of compounds and can change preferences in accordance with changing environmental conditions (cf. Evans 2001).

**Figure 3.2** Simplified nitrogen fractionation in a terrestrial food chain (based on Evans 2001 and Koch 2007).
Nitrogen up-taken by a plant enters a pool which will be synthesised into organic components (Handley and Raven 1992; Yoneyama et al. 1993). Because the cycle is usually closed, the up-taken nitrogen is not realised back into the soil and $\delta^{15}N$ of the plant tissue is similar to the values of the soil, despite the discrimination during nitrate reductase and glutamine synthetase (cf. Fig. 3.2). Open cycles are observed in environments where nitrogen availability exceeds the needs of plants. However, in most ecosystems, the needs of plants exceed nitrogen supplies, so the discrimination would not be observed (Evans 2001: 123).

Some plants acquire nitrogen through a fungal symbiont situated in the plant’s roots. The difference in the $\delta^{15}N$ values between the fungal symbiont and the host could reach 8‰ (Högberg 1997). The difference reflects the physiology of the fungus, as it is usually enriched in $^{15}N$ in comparison to the nitrogen available in the soil, and the $^{15}N$ depleted amino acids are transferred to the plant. However, the amount of the depleted nitrogen transferred to the plant is small in weight, and does not significantly differentiate plants of the same genera but with a different mycorrhizal status (Högberg et al. 1999).

Some plants, including legumes, are able to fix atmospheric nitrogen thanks to the symbiosis with the rhizobia bacterium located in root or stem nodules. Despite the great variability in the $\delta^{15}N$ value of specific compounds in root nodules (between -8.9 to +10.2‰), the fractionation observed for the whole plant is small (between -0.2 and 2.0‰) and relatively stable (Yoneyama et al. 1998).

In a food chain, the $\delta^{15}N$ values vary with trophic levels with stepwise enrichment in $^{15}N$ of about 2-6‰ (DeNiro and Epstein 1981; Hedges and Reynard 2007; Minagawa and Wada 1984). The cause for the nitrogen shift in animal tissues is not fully understood. For an organism on a diet rich in proteins, daily nitrogen intake exceeds requirements for nitrogen balance. The organism will catabolise the carbon skeletons of amino acids as fuel, and shed the striped amine group as urea, leading to a high proportional loss of body nitrogen as urea and a high diet to tissue fractionation. An organism on a low protein diet uses most of its dietary nitrogen to create body proteins and, consequently, has a lower urea nitrogen flux, which reduces the diet-to-tissue fractionation. However, there is an observed gap between the enriched tissues and the depleted products (Ambrose 1991; Pearson et al. 2003).

The fractionation of nitrogen isotopes between diet and tissue may vary among animals in different states of nitrogen balance (Hedges and Klinken 2002; Koch et al. 2007). Animals in a positive nitrogen balance (e.g. growing) fix more nitrogen than organisms in a homoeostasis, and, consequently, have a lesser nitrogen flux and less diet-to-tissue fractionation (e.g. Fuller et al. 2004, 2005). On the other hand, animals in a negative nitrogen balance (e.g. starvation) can re-use their own tissues enriched in $^{15}N$ to acquire nitrogen. This re-use will lead to an even greater enrichment of synthesised tissues (cf. Oelbermann and Scheu 2002).
The enrichment in $^{15}\text{N}$ in mammals is broadly similar, with the value of about 3‰ (but the value of 2-6‰ is also possible), however, there are no data on the exact enrichment in $^{15}\text{N}$ in human bone collagen. Enrichment factor in humans can depend on the type of diet and nitrogen balance (Fuller et al. 2004, 2005; Hedges and Reynard 2007). However, there are no laboratory studies showing the relation between a controlled diet and human collagen. Many of the laboratory studies show the relation between a more or less controlled diet and the easily available tissues such as plasma and blood cells (O’Connell et al. 2012), and keratin (Fuller et al. 2005). Sometimes, the enrichment of these tissues is extrapolated to collagen (O’Connell et al. 2012), however, the relation of those tissues to collagen is not fully understood, therefore these estimations have to be treated with caution (cf. O’Connell et al. 2001; Williams et al. 2011).

To estimate the diet composition of a human individual, the $\delta^{15}\text{N}$ value of the human individual has to be compared with the animals with a known diet, and the potential foodstuff. It is assumed that human individuals on a diet based exclusively on plants will have $\delta^{15}\text{N}$ values similar to herbivores, those on a mixed plant-animal diet to omnivores, and finally, those on animal protein only products – to carnivores (Fig. 3.3; Hedges and Reynard 2007 also for discussion).

1.5. Analysis of the fossil remains

Information about isotopic composition of an animal’s diet may be obtained from its fossil remains if two conditions are met: 1) the isotopic composition of the component synthesised by the animal must have remained unaltered by diagenetic processes, 2) the relationship between the diet and the $\delta R$ value of such a component, and the $\delta R$ value of the diet of the animal in which it was synthesised must be known (DeNiro and Epstein 1978: 503). As described above, the relationship between diet and animal collagen, despite some uncertainties, is known. Collagen protein sheltered in bone matrix is relatively resistant to external factors and can survive for even 100 000 years (Koch et al. 2007: 102).
The most crucial for bone diagenesis is the period between death and burial. In that time, human body may be a subject of different funerary practices, that might include draining blood, stripping flesh from the bones, or baking. These practices modify and accelerate collagen deterioration (Bell et al. 1996). Degradation of collagen is the transition from an insoluble protein to a more soluble gelatine (Zioupos et al. 1999). Collagen denatures when hydrogen bonds are broken, then fibrils dissolve relatively quickly (cf. Collins et al. 2002). This process begins during lifetime, with increasing the number of crosslinks leading to an increase in brittleness and fragility of collagen molecule (Collins et al. 2002: 387; Zioupos et al. 1999). The process is retarded by the presence of minerals (Kronick and Cooke 1996) and the close packing of fibrils (Miles and Ghelashvili 1999), and is accelerated by elevated temperature, moisture, alkali pH, bacterial activity, and damage to organic structure (Collins et al. 2002; Hedges 2002; Smith et al. 2007). Moreover, collagen preservation and its isotopic composition can vary within one archaeological site due to the localisation of fire places, cooking practices, variations in sediment matrix chemistry, time since interment, bone and tooth density (cf. Ambrose 1990: 449).

As mentioned above, high temperature can accelerate collagen degradation. Collagen begins to become unstable in the temperature of 37ºC (Leikina et al. 2002). In higher temperatures, boiling of the organic fraction of bone could be observed. The effect of
a prolonged exposure to high temperatures could be similar to chemical deproteination (cf. Roberts et al. 2002).

An extreme pH of the burial environment may have similar effect on collagen. The alkali can accelerate hydrolysis (cf. Rudakova and Zaikov 1987), while acids can dissolve bioapatite and expose collagen to microbes (Collins et al. 2002). However, the mineral fraction of bone can locally neutralise soil pH, and consequently mitigate collagen deterioration. On the other hand, an extensive mineral alteration could alkalise the soil, and lead to collagen hydrolysis. This process could be potentially accelerated by the presence of limestone in the grave (Collins et al. 2002; Hedges 2002; Smith et al. 2007). Products of corpse decomposition, like organic acids and carbonates, may affect the pH of the burial environment and lead to hydrolysis and swelling, without the extensive dissolution of bioapatite (Collins et al. 2002; Manning 2000).

Bone mineral is in profound disequilibrium with water, therefore hydrology of the site will play an important role in degradation of bone tissue (Hedges 2002). Mineral transformation will expose collagen to an accelerated chemical and biological degradation (Collins et al. 2002: 386). Conditions in which microbial chemical deterioration will be retarded are the same as those used to preserve proteins. Water will also cause dissolution of bone minerals, and then, in dry environment, the re-precipitation will take place. Ambient water will penetrate bone tissue in wetter periods, and leave it with dissolved collagen gelatine in drier periods. The process will be repeated in the following wetter period. Therefore, collagen will be flushed from the bone (Collins et al. 2002; Hedges 2002; Smith et al. 2007).

The most common mechanism of bone deterioration that can occur just after death is the microbial activity. Microbial activity is optimised at the near neutral pH conditions which would otherwise protect the bone. Microbes and fungi produce acidic pH environment, where the mineral fraction of bone could be dissolved. Removal of apatite permits access to organic fraction by the extracellular microbial enzymes, which causes effects similar to chemical deterioration. Microbial attack is concentrated on discrete zones of destruction, known collectively as microscopic focal destruction zone. Bone tissue depleted of organic matter as a result of microbial deterioration is located next to hypermineralised zones containing large disorganised crystallites (Collins et al. 2002; Pitre et al. 2013; Smith et al. 2007).

Burial customs and burial environment can seriously alert bone collagen, and in extreme situations all the collagen from the bone could be lost. However, the isotopic composition of collagen can remain unaltered even when large amount of protein is missing (cf. Ambrose 1990; DeNiro 1985; van Klinken 1999).

The procedure of collagen extraction does not distinguish between collagen and non-collagenous proteins of a bone, therefore the analysed substance can contain not only collagen but other compounds of the organic matrix of the bone. In practice, other
compounds of bone's organic matrix are less resistant to taphonomic factors and can dissolve quicker than collagen. As a result, collagen should constitute nearly all of the weight of a sample. The second source of sample contamination are the external compounds of dry bones, like microbes or fungi that can alert the composition of the extracted sample. In order to avoid contamination of that type, any visible changes on the bone surface are mechanically removed. Therefore, the product of extraction should nearly consist of collagen protein only (Ambrose 1990; Brown et al. 1988; DeNiro 1985; van Klinken 1999). To distinguish collagen protein from other organic substances extracted from the bone, some authors use quotation marks or other forms of emphasising the fact that both substances are not one and the same. In the present paper, I will use word 'collagen' for both protein and substance extracted from the bone. However, I am aware of the fact that, to some extent, the extracted substance could contain remains of other organic substances.

The quality of extracted collagen can be controlled with the use of the molar C/N ratio which in modern collagen ranges between 2.9-3.6 (DeNiro 1985), the percentage of carbon and nitrogen in extracted collagen (Ambrose 1990), and the percentage of collagen in dry bone (van Klinken 1999). The C/N ratio and collagen concentration in bone are less reliable indicators of the quality of extracted collagen than the carbon and nitrogen concentration. When these measures fail, carbon and nitrogen concentration in extracted collagen provides the most unambiguous quality indicator (Ambrose 1990: 447). In vivo, about 95% of bone nitrogen is in collagen (Collins et al. 2002: 387), therefore the amount of nitrogen in extracted collagen should be less susceptible to contamination by the presence of other, non-collagenous, compounds (e.g. lipids).

The collagen extracted using different methods proposed by DeNiro and Epstein (1981), Brown et al. (1988), and later modified by Richards and Hedges (1999) slightly varies in the δ\(^{13}\)C composition (±0.32‰), while the variance in δ\(^{15}\)N was not observed (Jørkov et al. 2007).

Stable isotope ratio is measured via the isotope ratio mass spectrometry (IRMS). Mass spectrometer separates charged atoms or molecules on the basis of their mass-to-charge-ratio. Basic components of the isotope ratio mass spectrometer are an inlet system (here, a dual-inlet system and a continuous flow system can be distinguished\(^4\)), an ion source, a mass analyser and an ion detector. Samples are introduced to the mass spectrometer as a gas via the inlet system. In the continuous flow system, combusted samples are carried in a helium stream through a chromatographic column. Using the valve, the eluant of interest is sent into the mass analyser while other gases are sent to waste. In the ion source, released and accelerated electrons enter the ion box where they impact on a sample gas, forming positively charged particles. The resulting ion beam is

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\(^4\) In present study an isotope ratio mass spectrometer with continuous flow was used, therefore it will be described in detail.
repelled by an electromagnetic field towards a flight tube and focused with two parallel
plasters to form a thin beam. Then, the ion beam enters the mass analyser, where
a magnetic field, perpendicular to the flight path, bends the beam; with the lighter isotope
beam bending more than the square root of the mass-to-charge ratio. Ions of identical mass
are then focused once more, by passing through a machine referred to as the α-split. The
beams produced are broad peaks, thereby making the system insensitive to drift. Broad
peaks also ensure optimal capture in the Faraday cups of the ion detector. The cups are
connected to the ground via a high ohmic resistor and the ion current flowing through the
resistor creates voltage that is used as an output from the mass spectrometer. The voltage is
fed to a computer system, which converts relative signal strength to a ratio and then to a δR
(cf. Sulzman 2007).

2. Dental microwear analysis

Dental enamel is a hard substance made of bioapatite that creates the crown of the tooth.
Enamel is formed once during lifetime, therefore any changes to enamel surface will
remain or will be effaced by other changes. During mastication, abrasive particles in or on
food items affect the surface of the tooth, leaving characteristic traits – subject of dental
microwear analysis. The source of abrasive particles in human diet are abrasive bodies
included in plant tissues, and extraneous grit added to foodstuff during processing and
originating from the surroundings. Studies conducted on wild animals with a known diet
showed differences between taxa with different dietary behaviour, such as grazers and

The scope of dental microwear analysis is very narrow and can highlight only the
last few days of life of an individual. However, bigger and deeper traits can remain on
dental surface for weeks. The turnover of dental microwear depends on food abrasivity. For
animals with a relatively soft diet, the turnover can take weeks. For animals with an
abrasive diet, old traits can be obliterated after a few days, causing the 'Last Supper' effect,
meaning that the microwear pattern can highlight only the last meal consumed. However,
in the case of human individuals, the expected diet is not as abrasive, and the dental
microwear pattern should reflect consumption during the last few days (Teaford 2007;
Ungar et al. 2008).

Dental microwear analysis was successfully applied in the bioarchaeological studies
of the Middle East populations concerning changes in subsistence between hunter-
gathering and farming (Mahoney 2006), in the Neolithic population (Molleson et al. 1993) as
well as changes in the plant processing technology (Jaworski et al. 2015; Soltysiak 2011).
Most of all dental microwear analysis of human individuals provides information about
plant processing techniques and the hardness of food (Soltysiak 2011; Teaford and Lytle
1996).
2.1. Mastication

Mastication as a process can be divided into two phases of tooth movement in relation to centric occlusion: phase I preceding centric occlusion, and phase II following it (Butler 1952; Krueger et al. 2008). During phase I, wear faces are produced along the surface leading away from the crest as the teeth move upwards and lingually into centric occlusion. During phase II, the wear facet is produced in the tooth basin as the teeth come into full centric occlusion and then move parallel to the occluding surfaces (Krueger et al. 2008: 485). Facets produced during phase I and phase II have different patterns of microwear, even on a single tooth. The difference is the result of the jaw movement and power strokes during mastication. Because of a minimal muscle activity and jaw bone strain that occur following centric occlusion in some primates, the importance of phase II of mastication to chewing has been questioned (cf. Wall et al. 2006). However, features covering phase II facets distinguish species with different diets in a more predictable way (cf. Teaford and Walker 1984), which was supported by experimental studies (Krueger et al. 2008).

The difference between facets of phase I and phase II may result from the food volume with its associated abrasivity interposed between surfaces as they contact each other. In this case the most sharply delineated facets of phase I are most likely formed at a stage in the mastication process when few food particles are interposed between the teeth. The prevalence of the tooth-tooth contact occurring later in the mastication cycle might obliterate or obscure wear features produced more specifically by food or the grit adhering into it. Phase II facets in the trigonid and talonid basins are partly produced at the end of the phase I movement as food is compressed between the relatively flat opposing surfaces. In the later stages of the masticatory cycle, some food particles and abrasives entrapped in the trigonid and talonid basin may still produce microwear features. Differences may relate to the angle of mastication surfaces, relative to the planes of the wear faces themselves. Phase I facets are produced largely at the time when the anatomy of teeth dictates when the most perceived occlusion should occur. Because of tooth anatomy, the masticatory forces of phase I are concentrated on the leading edges of the surfaces and likely orientated to the surfaces at an acute angle. Phase II movement and accompanying facets it produces are less rigidly constrained by the anatomy of teeth (Krueger et al. 2008: 490). The different phases facets reflect differences in the tooth-food interactions during mastication and should not be mixed in an analysis (Gordon 1982; Teaford and Walker 1984).

Tooth-on-tooth contact also has an influence on dental microwear texture, and can produce a pattern of small pits. However, the power stroke during the non-masticatory movements of jaw is low. If it occurs, tooth-to-tooth contact can snatch away micro-fractures in the area of contact (Walker 1984). Mastication of relatively soft food can also cause tooth-on-tooth wear – small pits caused by the tooth-tooth strokes (Teaford 2007).
Microwear patterns reflect occlusal movements, which are related directly to the fracture properties of the food being chewed. Abrasive particles, either in or on food items, cause microwear, with the microwear's features such as size, shape and orientation depending, in large measure, on whether the abrasives are scraped along the surface or pressed into the enamel by the force normally directed to that surface (Gügel et al. 2001; Scott et al. 2012; Ungar 2007).

Crushing is usually observed when hard or brittle food items are masticated. Crushing is accomplished by generating greater compressive forces as occlusal surfaces contact each other at a higher angle of approach. Mastication of hard food items likely causes pits, because pieces of hard food or their associated abrasives are pressed into enamel as teeth approach one another with force applied to the occlusal plane. Animals that crush hard, brittle foods typically have complex pitted occlusal surfaces. This could also be applied to carnivores which specialise in meat and sinews as well as to those that chew bone. The microwear that results from crushing is composed of multiple overlapping pits as abrasives in or on food item cause microflaking of the occlusal facet (Gügel et al. 2001; Scott et al. 2012; Ungar 2007).

Grinding is usually observed when tough and fibrous food items (graze, leaves and though flesh) are masticated. During grazing, opposing surfaces slide past one another, at an angle of approach more parallel to the facets themselves. The pattern resulting from this process is composed primarily of parallel and subparallel scratches and, in the case of grinding, without a regular pattern. Mastication of tough food will cause scratches, because the abrasives are dragged along the occlusal surface as opposing teeth shear past one another. Animals that shear trough items exhibit surfaces with long parallel striations. Similarly, the microwear of tough-grass grazers tends to be characterised by greater homogeneity (parallelism) in the scratch orientation than that of the more generalist browsers. Scratches are formed as wear particles are dragged across the occlusal surface (Gügel et al. 2001; Scott et al. 2012; Ungar 2007).

Microwear features such as density, relation of pits to scratches, linearity, or feature size can be related to the dietary behaviour or other types of tooth use (Ungar and Spencer 1999). Differences in the intensity of such a wear should be the consequence of the type and quality of abrasive material in the diet. The size and variability of wear-inducing particles can be reflected by heterogeneity (Scott et al. 2006). Potentially, more heterogeneous microwear could result from larger wear-inducing particles as large features (especially pits) are added in a more random fashion (Scott et al. 2012: 571).

2.2 Abrasive particles

In each case the actual wear causing particles are the same: phytoliths or other silica-based structures in the plant itself (cf. Gordon 1984; Teaford et al. 2006), or the exogenous grit
(Nystrom et al. 2004; Teaford and Lytle 1996). Silica (biogenic and pedogenic) is among the abrasives that most often have been implicated in the formation of microwear. The role of phytoliths in producing microwear, although questioned by Sanson et al. (2007), has been amply documented in numerous experimental and naturalistic studies (e.g. Gügel et al. 2001; Hummel et al. 2010).

Because only a few types of food can scratch enamel, the dental microwear pattern can be highly influenced by extraneous abrasives (Peters 1982). Microwear patterns can be caused by 'indirect effect' of food on dental microwear. Certain food preparation techniques can introduce abrasives into food, causing high incidence of microscopic scratches on teeth – not caused by food itself but by the methods with which they were prepared (cf. Teaford and Lytle 1996). Experimental study showed that the differences in food processing techniques may well lead to differences in the rates of tooth wear. The study of Teaford and Lytle (1996) has shown that sandstone-grounded cornmeal can produce more than twice the number of new microwear features than hard-grounded cornmeal. The reason for this is the greater abrasive potential of sand, which is c. 10 times higher than that of opal phytolithes (Newesely 1993). Dietary grit can significantly affect the dental microwear pattern, making the differences between sexes and age groups insignificant (Nystrom et al. 2004). Another source of abrasive particles can be the wind-blown dust or sand (cf. Ungar et al. 1995).

On the other hand, some food processing techniques, such as boiling, may lead to a significant decrease in abrasivity and the amount of microwear produced (Gügel et al. 2001; Molleson et al. 1993).

2.3 Taphonomic factors

After death, number of taphonomic factors can potentially damage enamel and obliterate the ingestion related traits. Taphonomic factors can seriously affect dental surface and exclude as much as 75% of samples from an analysis. However, taphonomic factors would destroy the dental surface rather than change the pattern of microwear. Therefore, it is easy to distinguish between surface changes resulting from mastication from those associated with taphonomic processes (King et al. 1999; Puech et al. 1985).

Microwear features can be removed by acids. As shown by King et al. (1999), after 2h immersion in a 2.5% water solution of hydrochloric acid, almost all of the microwear features were removed. Citric acid (lemon juice) was less destructive – after 46h of immersion only the finer microwear features were removed, and the remaining defects became deeper with sharper margins.

Microwear can also be altered by sediment. As shown by King et al. (1999), sediment has the potential to alter dental microwear patterns, but the modification is in the form of
an obliteration of features rather than an alteration of existing patterns or a formation of new features (King et al. 1999).

The surface of enamel can be destroyed by abrasive particles and acids in the soil, making the excavation and cleaning techniques ever more important to its survival. Of no less importance is the time of the exposition of dental enamel to those agents. The damaged surface is characterised by a chaotic pattern of defects differing in size and shape (King et al. 1999; Puech et al. 1985). Some substances can adhere to enamel surface making analysis impossible.

2.4 Analysis

Analysis of dental microwear can be conducted using two and three dimensional images of the analysed surface (cf. Scott et al. 2006; Ungar et al. 2008).

In the traditional method, an image of the magnified surface is taken, followed by the description of traits. The image can be taken using a light microscope or a scanning electron microscope (SEM). Typical magnification is x100 and x300. Dental microwear analysis consists of measuring and counting linear and non-linear features located on the enamel surface. Linear traits can be defined as traits with one axis at least four times longer than the other; non-linear traits are defined as traits with the longer axis less than four times longer than the shorter axis. Furthermore, those traits can be divided into finer and coarse traits (cf. Sołtysiak 2011). Counting of traits might be semi-automatised, thanks to computer software (Ungar 2002).

The most important issue faced by the low magnification light microscope and the SEM techniques is the measurement error. In his study, Gringe et al. (2002) estimated an average intraobserver error rate in the analysis of dental microwear using the SEM technique at 7%, and an average interobserver error rate at 9%. On one hand, one source of error is the subjectivity in ascribing features to the given categories; on the other hand, there is the problem with data lost due to the employment of a two dimensional photography to characterise three dimensional surface (Ungar et al. 2008: 397). Fully automated computer programs for description of microwear texture had been considered as a solution for the subjectivity in the description, but this technique did not separate taxa as well as the more conventional approaches did (Grine and Kay 1987). Another important issue is characterising the three dimensional surface based on a two dimensional photography. The analysed features are suggested by a shadow and light or electron beam intensity decreasing with depth, so the final image will depend on the relation between the surface and the source of light or electrons, and optics or electron collector. Any changes in this relation will result in a change to the final image. N. Solounias and G. Semprebon (2002: 7) have noted that, ‘adjusting the manner in which light strikes the cast (i.e. angle of
incident light beam and intensity), the visualization of microwear features can vary from none visible to a few or many'.

The SEM technique was criticised for being time-consuming and expensive. Instead, low-magnification optical microscopy combined with a personal computer was proposed as a fast and inexpensive method. But that approach did not resolve limitations of light microscopy that had moved researchers to the SEM. To resolve that problem, some researchers adopted the use of microscopes that allow to measure three dimensional surfaces, such as a confocal microscope (Scott et al. 2006).

The confocal microscope can produce a three dimensional model of the studied surface. Next, the model is analysed using a scale-sensitive fractal analysis (SSFA). The analysis is automated and no observer is involved. This approach eliminates inter- and intraobserver errors (Scott et al. 2006: 344). In the SSFA analysis following features are taken under consideration: complexity, anisotropy (Scott et al. 2005), heterogenity, scale of maximal complexity and textural fill volume (Scott et al. 2006).

According to Scott et al. (2006: 344), 'the white-light confocal microscope is a dramatic improvement over the SEM for microwear analysis'. Main advantages of the confocal microscope over the SEM are a very high resolution and an ability to produce three dimensional models of the surface; it is also less expensive, because it uses white light instead of electron beams. It also requires no vacuum or special mounting or coating of specimens. Moreover, the SSFA provides accurate and repeatable characterisation of dental microwear texture. The main disadvantage of the SSFA is that it is still uncertain how to interpret data obtained (e.g. anisotropy). Moreover, an automated analysis cannot omit dirt on the analysed surface. Due to limitations in programs for the description of dental microwear texture, and the inherent limitations of the newly proposed techniques, these methods have not been broadly adopted.
1. Human remains from Bakr Awa

Human remains unearthed at Bakr Awa come exclusively from the lower town. Human remains have been found in various types of funeral context: tombs, vessels and simple earth graves. Some human remains were also retrieved from trash and looting pits. During four excavation seasons at Bakr Awa (2010-2014), 90 individuals with completeness higher than 5% were unearthed: 45 individuals from the BA, 13 individuals from the IA, and 32 individuals from the IS (Fetner 2011, 2014, 2015; Miglus et al. 2013).

Individuals from the BA were buried in vessels within an architectural context (neonates and infants), simple earth graves, and spectacular chamber tombs (BA1108 and BA 2500). Six graves (BA1108, BA2084, BA2386, BA2500, BA2688, BA2728) contained pottery vessels and metal objects (jewellery, weaponry and vessels). The other graves, if they contained any grave goods, usually contained a single pottery vessel or metal object (cf. Miglus et al. 2011, 2013).

Individuals from the IA were buried in the graveyard. Individuals were buried in vessels (children and one adult individual BA2222), and in simple earth graves. If equipped, human individuals had a single object (a pottery vessel, a tool or a piece of jewellery; Miglus et al. 2011, 2013).

Individuals from the IS come from graveyards located in two different parts of the tell (areas BA 2 and BA 5). Graves from area BA 2 were partly destroyed and the upper part of graves was missing. Individuals were buried in extended position on a side and facing south-west. In area BA 5, graves were intact. Grave pits were covered with flat stones, which, in some cases, prevented filling the pit with soil. Similar to area BA 2, human individuals were lying in extended position facing south-west. Graves from the IS did not contain any grave goods (Miglus et al. 2011, 2013).

Human remains were examined by the present author during three excavation seasons between 2011-2014 in the excavation base in Halabja and Bakr Awa (Fetner 2011, 2014, 2015; Miglus et al. 2013).

2. Material for the stable isotope analysis

Sixty samples of human and animal bones from Bakr Awa were selected for the stable isotope analysis (Tab. 4.1). Human and animal remains were unearthed during three seasons between 2010 and 2013. Forty five samples belong to human individuals representing the BA (20 individuals), the IA (13 individuals) and the IS (12 individuals) populations of Bakr Awa.
The BA subset represents the early occupation phase at Bakr Awa. Four individuals (two neonates and two adults) come from the late EBA (23rd-21st c. BC). One adult individual (BA2265/2) was found in a secondary context (Fetner 2011; Miglus et al. 2013).

The MBA occupation phase is represented by 16 individuals. Graves' inventory suggests that three individuals (BA2084/9, BA2084/11 and BA2386/1) had a high social position. Lower social position seems to characterise the other 10 individuals. Three graves (BA2189, BA2357 and BA 2358) were partly destroyed and the information about burial inventory is incomplete (Fetner 2014; Miglus et al. 2013).

The IA subset (13 individuals) represents the population occupying Bakr Awa in the 8th-4th c. BC. Twelve individuals come from the funeral context and one individual (BA2087/7) from a secondary context. Grave goods, single objects, were found in three graves only (BA1156, BA2200 and BA 2222) (Miglus et al. 2011, 2013).

The IS subset (12 individuals) represents the youngest occupation at Bakr Awa, between about the 7th and 19th c. As mentioned above, human remains were unearthed in the graveyard. Graves did not contain any grave goods, therefore more precise dating is impossible (Miglus et al. 2011, 2013).

Animal remains of fifteen specimens of known dietary preferences were selected to obtain an approximation of the local ecological settings. Among the specimens are herbivores (bovids, ovicaprids, equids) and opportunistic omnivores (pig and canids). Animal remains were identified by J. Piątkowska-Małecka, Department of Bioarchaeology, University of Warsaw, Poland.

3. Method of the stable isotope analysis

The osteological and odontological study of human remains was performed by the present author (Fetner 2012, 2014; Miglus et al. 2013). Sex was assessed for adult individuals following the morphology of pelvis (Acsádi and Nemeskéri 1970; Phenice 1969) and skull (Acsádi and Nemeskéri 1970), as well as dimensions of long bones (Oliver 1960). Age was assessed for subadults following measurements of bones (many methods after Schaefer et al. 2009), tooth development and eruption (Gustafson and Koch 1974; Smith 1991; Ubelaker 1989) and fusion of epiphyses (many methods after Schaefer et al. 2009). Age-at-death of adult individuals was assessed following the morphology of pubic symphysis (Suchey Brooks system after Buikstra and Ubelaker 1994), auricular surface (Lovejoy et al. 1985), tooth attrition (Lovejoy 1985), and suture closure (Meindl and Lovejoy 1985).

Bone samples were prepared according to the modified Longin (1971) method as described in Richards and Hedges (1999). First, a bone sample (c. 1g of dry bone) was cleaned in an air blaster with particles of aluminium oxide and then powdered in a hand mortar. Next, the sample was put in a weak (0.5 M) water solution of hydrochloric acid (HCl) for demineralisation. The process of demineralisation proceeded for a few days in the
temperature of c. 4ºC. After the demineralisation, the sample was washed three times with MilliQ water. Next, the solution of the sample and the pH 3 MilliQ water was heated to 65-70ºC for 48 hours in order to gelatinise the organic fraction of the bone. After two days, the gelatinised sample was filtered with an Ezee Filter® separator. Then, the sample was frozen in liquid nitrogen and freeze-dried.

Dry samples were analysed in the SerCon Callisto CF_IRMS 20-22 Stable Isotope Mass Spectrometer with Europa EA-GSL Sample Preparation System in the Research Laboratory for Archaeology and History of Arts, University of Oxford (United Kingdom). For the mass spectrometry analysis reference samples were used: alanine, L-glutamic acid (USGS40; δ¹³CVPDB= -26.39‰; δ¹⁵NAM= -4.52‰), ammonium sulphate (IAE-N₂; δ¹³CVPDB= -20.34‰; δ¹⁵NAM=0.47‰), sucrose (IAE-CH6; δ¹³CVPDB= -10.45‰) and collagen extracted from a bone of a modern day seal. Alanine was used as a homogeneous material for automatic correction of the mass spectrometer's drift. Other standards were used to determine the level of δ¹³C and δ¹⁵N in relation to the international standards (PeeDee Balamite (VPDB) for carbon and Atmospheric Nitrogen (AIR) for nitrogen).

The drift-corrected data provided by the mass spectrometer were normalised using the Kragten method for uncertain calculation (IAEA 2012). The script in R Statistical Language (R Core Team 2014) was kindly shared by Erika Nitsch. The quality of collagen was assessed following the collagen yield in the dry bone (>0.5%) (van Klinken 1999), percentage of carbon (>8%) and nitrogen (>2.5%) mass in collagen (Ambrose 1990), and C/N ratio of modern bones (2.9–3.6; DeNiro 1985).

The preparation and analysis of the sample were performed by the present author under the supervision of dr Erika Nitsch, School of Archaeology, University of Oxford, United Kingdom.

The obtained data were tested for the between-group differences in distribution of the δ¹³C and δ¹⁵N values using non-parametric tests: the Kruskal-Wallis test for three or more subsets, and the Mann-Whitney U test for two subsets. Statistics were calculated in R Statistical Software (R Core Team 2014).

### 4. Material for the dental microwear analysis

For the dental microwear analysis, single permanent lower second molars were selected. The occlusal tooth-surface of 31 individuals was unaltered, and the enamel of the protoconid was not worn completely (2nd to 5th stage by Scott 1979). The BA is represented by 15 individuals, the IA – 7 individuals, and the IS – 11 individuals (Tab. 4.1).

The BA subset includes one individual (BA2265/6) from the EBA and 14 individuals from the MBA. Seven individuals from the MBA (four individuals from the chamber tomb BA1108, one from BA2500, and two individuals from BA2084) had burial inventory indicating high social status (Miglus et al. 2011, 2013). Among the individuals of the lower
social position, one (BA1311/1) had a single piece of jewellery. The grave of the second individual of the lower social position was not equipped. Six individuals from this subset were also studied for carbon and nitrogen isotopic composition of collagen (cf. above).

The IA subset (7 individuals) represents population occupying Bakr Awa between the 8th and 4th c. BC. All individuals come from the funeral context, and all of them were studied for carbon and nitrogen isotopic composition of collagen (cf. above).

The IS subset (12 individuals) represents the youngest occupation phase. Nine individuals come from the funeral context and two individuals were retrieved from the secondary context (BA2196). Five individuals from this subset were studied for carbon and nitrogen isotopic composition of collagen (cf. above).

5. Method of the dental microwear analysis

The occlusal surface of selected teeth was cleaned with a soft brush and acetone. Then, a negative mould of each tooth was made in the ZA 22 Mould silicone, which is characterised by its low viscosity (4 000 mPas) and high accuracy in the reproduction of details (better than 2 µm). According to the study of Galbany and colleagues (2006), a low-viscosity silicone provides high quality casts for the SEM analysis. After 90 minutes of immersion in the silicone, the tooth was replaced by the polyurethane resin (Rencast FC52). After 2h, a positive cast was obtained.

In the Laboratory of Electron and Confocal Microscopy, Faculty of Biology, University of Warsaw, the occlusal surface of casts was covered by a thin layer of gold and examined with the electron scanning microscope (LEO 1430 VP). Phase II of mastication (Krueger et al. 2008), or more specifically facet x of the protoconid (Kay 1977) as a good predictor of individual diet (cf. discussion in Chapter Four), has been chosen for examination. At least three overlapping images (magnification of 300 times) were taken for every specimen. The micrographs were taken with the assistance of Julita Nowakowska, Laboratory of Electron and Confocal Microscopy, University of Warsaw, Poland.

The obtained micrographs were analysed using a semi-automatic software – Microwear 4.02 (Ungar 2002). All linear and non-linear microwear features were distinguished, measured and counted. Linear features were defined as those having length at least 4 times greater than their width. Then, linear features were divided manually using GNU Image Manipulation Program (GIMP) v. 2.8 into striae (width ≤ 4 µm) and scratches (width > 4 µm). Non-linear features were divided into punctures (longer axis ≤ 20 µm) and pits (longer axis > 20 µm).

To avoid bias resulting from the low number of observations, only images with more than 50 marked traits were selected for further statistical analysis. Differences in proportion of traits between micrographs of a single tooth were tested using the Pearson chi-square test. Differences between subsets were tested with the non-parametric tests: the
Kruskal-Wallis test for three or more subsets and the Mann-Whitney U test for two subsets. Distribution of features was also analysed using the Correspondence Analysis (CA). Statistical testing was performed using R Statistical Software (R Core Team 2014).

Table 4.1. Summary description of analysed human individuals.

<table>
<thead>
<tr>
<th>Number</th>
<th>Period</th>
<th>Sex</th>
<th>Age</th>
<th>Context</th>
<th>Analysis</th>
</tr>
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<td>20-30</td>
<td>Earth grave</td>
<td>Isotope and microwear</td>
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<td>Microwear</td>
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<td>IS</td>
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<td>30-40</td>
<td>Earth grave</td>
<td>Isotope</td>
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</table>
Chapter Five. Results

1. Results of the stable isotope analysis

Fifty seven out of 60 bone samples contained preserved collagen (Tab. 5.1 and 5.2). The preservation of collagen varies between the periods (Fig. 5.1), but the difference is statistically insignificant (Kruskal-Wallis statistic value: H=1.14, df=2, p=0.487). However, the difference in the preservation of nitrogen between the periods is significant (Kruskal-Wallis statistic value: H=6.13, df=2, p-value=0.047). A statistically significant difference was observed between the BA and the IS (Mann-Whitney statistic value: U=364, p-value=0.035). The difference between the BA and the IA approached significance (Mann-Whitney statistic value: U=251, p-value=0.054). No significant difference was observed between the IA and the IS (Mann-Whitney statistic value: U=122, p-value=0.969).

Figure. 5.1 Preservation of collagen and nitrogen in all samples according to the period of origin (here and in the following box-and-whiskers plots presented in this chapter: band indicates the median, box indicates the 1st and 3rd interquartile distance, whiskers indicate the largest and smallest observations within the distance of 1.5 times the box size from the nearest quartile, points indicate observations outside of the whiskers range).

Fifty samples had collagen yield higher than 0.5%, 42 samples had concentration of both carbon and nitrogen higher than 8% and 2.5% respectively. Also 42 samples had the C/N ratio between 2.9-3.6. In total, 36 samples met all quality criteria (Fig. 5.2).
Figure 5.2. Preservation and quality of collagen in all samples.
Twenty seven human samples met all the quality criteria. Among them (Tab. 5.2) are the remains of, possibly breastfed, infants. Unfortunately, the number of children between one and four years of age is low (five individuals from three periods), and does not allow for a reliable estimation of the period of breastfeeding. The comparison between the children 3 years old and younger (n=10), and the older individuals (n=17) shows significant difference in the $\delta^{13}C$ values (Mann-Whitney statistic value: $U=31$, $p=0.035$) and in the $\delta^{15}N$ values (Mann-Whitney statistic value: $U=42$, $p=0.015$), therefore these children will be omitted from further analysis and discussion.

Seventeen samples of human individuals more than 3 years old met the quality criteria, among them 10 individuals from the BA, 5 from the IA, and 2 from the IS (Tab. 5.2). Nine animal samples met the quality criteria (Tab. 5.1).

Because of the small number of samples in the IS subset, only a general observation about the human diet in the IS period can be made, and the results will be omitted in further discussion about the temporal changes in diet. Despite the low number of individuals in both the IA and the IS subsets, the subsets will remain separate. One reason is the chronological distance of at least 1000 years between the subsets; second reason is the possible hiatus in the occupation of Bakr Awa after the Achaemenid period. In order to avoid mixing two possibly different subsistence strategies, the subsets will remain separate.

Table 5.1. Results of the stable isotopic analysis of animal remains. Samples meeting quality criteria are given in bold.

<table>
<thead>
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<th>Taxon</th>
<th>Period</th>
<th>Coll [%]</th>
<th>C [%]</th>
<th>N [%]</th>
<th>C/N</th>
<th>$\delta^{13}C$</th>
<th>$\delta^{15}C$ sd.</th>
<th>$\delta^{15}N$</th>
<th>$\delta^{15}N$ sd.</th>
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</table>
To compare human individuals with animals of known dietary preferences, the animals were grouped according to their dietary preferences (Tab 5.3): opportunistic omnivores (pigs and dogs) and herbivores (ovicaprid, bovids, equid). The differences in the $\delta^{13}$C and $\delta^{15}$N values between omnivores and herbivores (Fig. 5.3) are insignificant (Mann-Whitney statistic values for the $\delta^{13}$C: U=27, $p=0.149$; and for the $\delta^{15}$N: U=16, $p=0.876$). Results indicate that the diet of omnivores was based mainly on C$_3$ plants, with a small amount of animal proteins. However, the lack of significance can be affected by the low number of samples under investigation. Therefore, this result should be treated with caution.

**Figure 5.3.** Comparison between the $\delta^{13}$C and $\delta^{15}$N values of omnivores and herbivores.
Table 5.2. Results of the stable isotopic analysis of human remains. Samples meeting quality criteria are given in bold.

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<th>% C</th>
<th>% N</th>
<th>C/N</th>
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<th>$\delta^{15}$N</th>
<th>$\delta^{15}$N sd.</th>
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<td>Age</td>
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<td>% C</td>
<td>% N</td>
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<td>δ¹⁵N</td>
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Human individuals (including children) exhibit a narrow range in the δ¹³C values (c. 2.2‰), with the mean at -19.34‰; greater range is observed for the δ¹⁵N values (c. 5.7‰) with the mean at 7.51‰ (Fig. 5.4).
Figure 5.4. The distribution of the $\delta^{13}C$ and $\delta^{15}N$ values for human individuals (children included) and animals of known dietary behaviours.

The difference in the $\delta^{13}C$ values between human individuals (older than 3 years) and animals (Fig. 5.5) is insignificant (Mann-Whitney statistic value: $U=98$, $p$-value=0.879), as opposed to the difference in the $\delta^{15}N$ values (Mann-Whitney statistic values: $U=140$, $p$-value=0.005). On average, human individuals were enriched in $^{15}N$ in comparison to animals by 2.1‰. The results suggest that human diet was mainly based on $C_3$ plants and supplemented with a variable amount of animal proteins.
Figure 5.5. Comparison between human (children excluded) and animal individuals.

The sample size (3 males and 5 females from three periods) does not allow for a sex-based comparison of the diet.

The comparison between periods (Fig. 6.7) shows a significant difference in the δ^{13}C values (Kruskal-Wallis statistic value: $H=10.95$, df=2, p-value=0.004), while the differences in the δ^{15}N values are insignificant (Kruskal-Wallis statistic value: $H=2.85$, df=2, p-value=0.240). The diet of the IA individuals was enriched in ^{13}C in comparison to the BA individuals, however, it was still based mainly on C_3 plants. Even more enriched was the diet of the IS individuals (Fig. 5.6).

The BA individuals exhibit a narrow range of the δ^{13}C values (c. 0.7‰), and a great range of the δ^{15}N values (c. 3.9‰). The BA subset splits into two groups. First group (cluster A) of individuals (BA2084/11, BA2358/1 and BA2386/1) has high values of δ^{15}N (mean: 8.69‰). The second group (cluster B), consisting of the other BA individuals, has low values of δ^{15}N (mean: 5.93‰). The δ^{13}C values are similar between groups.
Figure 5.6. Stable isotope values (with 95% ellipses for the BA and the IA) for individuals according to the period of origin and animals with known dietary preferences.

Among individuals from cluster A, two individuals were of high social status. The grave of the third individual was partly explored in the 1960s and the information about the grave inventory is missing. Among individuals from cluster B, only individuals of lower social position were noted. The graves of two individuals were partly destroyed and the information about the burial inventory is missing.

The difference observed in the $\delta^{15}$N values between individuals from these two clusters is high. The difference between the mean values of both groups is 2.8‰ – c. 70% of the range of the BA nitrogen values. Moreover, the ranges of both clusters do not overlap. Therefore, the difference between these two clusters will be treated as significant.
Table 5.3. Descriptive statistic for the $\delta^{13}C$ and $\delta^{15}N$ values for human individuals and animals of known dietary preferences from three periods.

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Figure 5.7. The comparison of the $\delta^{13}C$ and $\delta^{15}N$ values between periods.

The IA individuals also exhibit a narrow range of the $\delta^{13}C$ values (c. 0.8‰) and the $\delta^{15}N$ values (c. 1.6‰). In comparison to the BA subset, the IA individuals have higher values of $\delta^{13}C$, the difference between the mean values of the IA and the BA subsets is c. 0.6‰. The difference is statistically significant (*post hoc* Mann-Whitney statistic value: $U=2$, $p$-value=0.003). The difference in the $\delta^{15}N$ values is small. The difference in the mean values between the IA and the BA subsets is c. 0.1‰ and statistically insignificant (*post hoc* Mann-Whitney statistic values: $U=18$, $p$-values=0.437).

One individual from the IS has the $\delta^{13}C$ and $\delta^{15}N$ values similar to the individuals from the IA subset, second individual is enriched in both $\delta^{13}C$ and $\delta^{15}N$. 
2. Results of the dental microwear analysis

Out of 31 second lower molars selected for the analysis, 20 teeth had an unaltered facet x of protoconid, with 10 of them belonging to the BA (Tab. 5.5), 5 to the IA (Tab. 5.6) and 5 to the IS (Tab 5.7).

The characteristics of the enamel microwear of the studied individuals are presented in Tab. 5.5–5.7, together with the results of the Pearson chi-square test for differences in proportions of traits between micrographs of the same facet. In four cases (BA1089/1, BA2084/11, BA2500/36, BA2196/4); the difference is significant.

Table 5.5. Results of the microwear analysis of the BA individuals with Pearson’s chi-square test for independence. Str – striae, Scr- scratches, Pun – punctures, Pit – pits (for description see Chapter Four).

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<th>Scr</th>
<th>Pun</th>
<th>Pit</th>
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Table 5.6. Results of the microwear analysis of the IA individuals with Pearson’s chi-square test for independence. Str – striae, Scr- scratches, Pun – punctures, Pit – pits.

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<tr>
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<td>72-014</td>
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<tr>
<td>75-032</td>
<td>BA1089/1</td>
<td>?</td>
<td>40-50</td>
<td>194</td>
<td>32</td>
<td>35</td>
<td>4</td>
<td>265</td>
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<td>4</td>
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<td>66</td>
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<td>209</td>
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<tr>
<td>75-034</td>
<td></td>
<td></td>
<td></td>
<td>153</td>
<td>43</td>
<td>67</td>
<td>4</td>
<td>267</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80-051</td>
<td>BA1156/1</td>
<td>M</td>
<td>40-50</td>
<td>148</td>
<td>23</td>
<td>49</td>
<td>12</td>
<td>232</td>
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</tr>
<tr>
<td>80-053</td>
<td></td>
<td></td>
<td></td>
<td>93</td>
<td>38</td>
<td>16</td>
<td>9</td>
<td>156</td>
<td></td>
<td></td>
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<td>80-054</td>
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<td>10</td>
<td>213</td>
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</tr>
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</table>

Table 5.7. Results of the microwear analysis of the IS individuals with Pearson’s chi-square test for independence. Str – striae, Scr- scratches, Pun – punctures, Pit – pits.

<table>
<thead>
<tr>
<th>ID</th>
<th>Individual</th>
<th>Sex</th>
<th>Age</th>
<th>Str</th>
<th>Scr</th>
<th>Pun</th>
<th>Pit</th>
<th>N</th>
<th>$\chi^2$</th>
<th>df</th>
<th>p-value</th>
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<tbody>
<tr>
<td>57-001</td>
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<td>?</td>
<td>adult</td>
<td>153</td>
<td>78</td>
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<td>268</td>
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<tr>
<td>57-002</td>
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<td>9</td>
<td>259</td>
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<td>57-003</td>
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<td></td>
<td></td>
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<td>57-004</td>
<td></td>
<td></td>
<td></td>
<td>96</td>
<td>138</td>
<td>18</td>
<td>15</td>
<td>267</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>62-017</td>
<td>BA2056/1</td>
<td>F</td>
<td>20-35</td>
<td>38</td>
<td>24</td>
<td>6</td>
<td>14</td>
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<td>62-019</td>
<td></td>
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<td>49</td>
<td>20</td>
<td>18</td>
<td>13</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>69-023</td>
<td>BA2037/1</td>
<td>?</td>
<td>13-16</td>
<td>168</td>
<td>47</td>
<td>30</td>
<td>10</td>
<td>255</td>
<td>6.09</td>
<td>4</td>
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<tr>
<td>69-024</td>
<td></td>
<td></td>
<td></td>
<td>134</td>
<td>52</td>
<td>31</td>
<td>10</td>
<td>227</td>
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<tr>
<td>69-025</td>
<td></td>
<td></td>
<td></td>
<td>104</td>
<td>62</td>
<td>19</td>
<td>6</td>
<td>191</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70-026</td>
<td>BA2045/1</td>
<td>F</td>
<td>30-40</td>
<td>67</td>
<td>28</td>
<td>13</td>
<td>5</td>
<td>113</td>
<td>2.35</td>
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<td>0.671</td>
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<td>10</td>
<td>4</td>
<td>119</td>
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<td>30</td>
<td>7</td>
<td>4</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>78-055</td>
<td>BA2196/30</td>
<td>?</td>
<td>adult</td>
<td>40</td>
<td>15</td>
<td>53</td>
<td>15</td>
<td>123</td>
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<td></td>
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<td>51</td>
<td>26</td>
<td>111</td>
<td>8</td>
<td>196</td>
<td></td>
<td></td>
<td></td>
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<td>20</td>
<td>90</td>
<td>9</td>
<td>191</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In three cases (BA1089/1, BA2084/11, BA2500/36) the difference between micrographs is the result of different proportions of non-linear traits, which can occur when higher and lower areas of the same facet are photographed. Moreover, in the case of BA2084/11 and BA2500/36, a relatively low number of traits observed could contribute to the bias in the final result. In the case of 2196/4, the difference cannot be explained by the variation in the proportion of non-linear traits between micrographs. The remains of BA2196/4 were retrieved from the secondary context and unspecified taphonomic factors could have affected the microwear pattern. Due to the small size of the IS subset, the individual will be included in further analysis.

In general, the microwear patterns are dominated by fine and linear traits (Fig. 5.9). The differences between analysed periods are visible in the proportion of the linear traits (Tab 5.8). In the IA subset, there are more fine features than in the other subsets. It can indicate a less abrasive diet than in the other periods. Conversely, in the BA subset there are more coarse traits than in the other subsets, indicating a more abrasive diet. No difference in the traits orientation was observed, indicating similar mastication pattern.

Table 5.8. Descriptive statistic and results of the Kruskal-Wallis test for three periods.

<table>
<thead>
<tr>
<th></th>
<th>Bronze Age</th>
<th>Iron Age</th>
<th>Islam</th>
<th>Kruskal-Wallis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>sd.</td>
<td>mean</td>
<td>sd.</td>
</tr>
<tr>
<td>Striae [%]</td>
<td>46.4</td>
<td>17.9</td>
<td>58.3</td>
<td>8.7</td>
</tr>
<tr>
<td>Scratches [%]</td>
<td>29.7</td>
<td>11.3</td>
<td>20.5</td>
<td>7.0</td>
</tr>
<tr>
<td>Punctures [%]</td>
<td>15.9</td>
<td>9.6</td>
<td>16.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Pits [%]</td>
<td>7.9</td>
<td>5.8</td>
<td>4.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Orientation [°]</td>
<td>35.2</td>
<td>37.0</td>
<td>38.3</td>
<td>2.73</td>
</tr>
</tbody>
</table>

Table 5.9. Results of the post hoc Mann-Whitney test for microwear features for three periods.

<table>
<thead>
<tr>
<th></th>
<th>Mann-Whitney statistic values</th>
<th>Bronze Age - Iron Age</th>
<th>Iron Age - Islam</th>
<th>Bronze-Islam</th>
</tr>
</thead>
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<tr>
<td></td>
<td>U</td>
<td>p-value</td>
<td>U</td>
<td>p-value</td>
</tr>
<tr>
<td>Striae [%]</td>
<td>108</td>
<td>0.010</td>
<td>182</td>
<td>0.043</td>
</tr>
<tr>
<td>Scratches [%]</td>
<td>305</td>
<td>0.011</td>
<td>85</td>
<td>0.110</td>
</tr>
<tr>
<td>Punctures [%]</td>
<td>169</td>
<td>0.312</td>
<td>180</td>
<td>0.051</td>
</tr>
<tr>
<td>Pits [%]</td>
<td>286</td>
<td>0.044</td>
<td>105</td>
<td>0.402</td>
</tr>
<tr>
<td>Orientation [°]</td>
<td>162</td>
<td>0.233</td>
<td>150</td>
<td>0.133</td>
</tr>
</tbody>
</table>
Figure 5.8. Proportion of microwear traits for three periods (all micrographs included).

The main difference in the diet’s abrasivity is observed between the BA and the IA. Minor differences are observed between the IA and IS periods. No difference was observed between the BA and the IS.

Unfortunately, the low number of males and females in the periods analysed (cf. Tab. 5.6-5.8) does not allow for a reliable comparison of the sex-based differences in the diet.

The analysis of the BA individuals of different social status (7 individuals of high and 3 individuals of low social position) shows no significant differences in the proportions of microwear traits, indicating a diet of similar abrasivity (Tab. 5.11). However, the proportions of microwear traits are more variable among the individuals of higher social
position. The difference in the variability is probably the effect of the sample size (Fig. 5.9).

Table 5.10. Comparison between the high and low status individuals.

<table>
<thead>
<tr>
<th></th>
<th>High status (n=7)</th>
<th>Low status (n=3)</th>
<th>Mann-Whitney statistic value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>sd.</td>
<td>mean</td>
</tr>
<tr>
<td>Striae [%]</td>
<td>48.6</td>
<td>21.4</td>
<td>42.4</td>
</tr>
<tr>
<td>Scratches [%]</td>
<td>27.9</td>
<td>12.8</td>
<td>33.3</td>
</tr>
<tr>
<td>Punctures [%]</td>
<td>15.8</td>
<td>11.3</td>
<td>16.2</td>
</tr>
<tr>
<td>Pits [%]</td>
<td>7.8</td>
<td>6.7</td>
<td>8.2</td>
</tr>
</tbody>
</table>

Figure 5.9 Comparison between proportions of microwear traits for the BA individuals of different social position (all micrographs included).
In order to make the correspondence analysis more clear, the mean of microwear features was calculated for each individual. The difference in proportions of microwear traits is visible in the correspondence plot (Fig. 5.10). The BA individuals are broadly distributed between linear traits and punctures, while the IA individuals, with an exception of one individual (BA1088/7), cluster around striae. The IS individuals cluster between striae and scratches, with an exception of one individual (BA2196/30) clustering at punctures. The CA confirms that the diet in the IA was less abrasive, while the diets of the BA and the IS individuals were more variable in abrasivity. The BA individuals of high social position are broadly distributed between the traits of the microwear analysis (Fig. 5.10).

Correspondance Plot

Figure 5.10. The CA biplot for individuals analysed according to the period of origin.
Chapter Six. Discussion

1. Collagen preservation

Despite the lack of a significant difference in the percentages of preserved collagen, the preservation of nitrogen in collagen differs significantly between periods. The highest amount of nitrogen has been observed among the BA samples and the lowest among IS samples. The difference is also visible in the number of samples which meet the quality criteria – 90% of the BA and 33% of the IS samples. The negative correlation between collagen quality and time since interment suggests that factors other than the sample’s age played a major role in the collagen preservation (cf. Collins et al. 2002). Among factors affecting collagen quality are the method of extraction, burial customs, type of soil, extreme pH, organic acids, temperature and water penetration (Collins et al. 2002; Nielsen-Marsh et al. 2007; Smith et al. 2007).

Collagen from all samples was extracted following the same protocol (cf. Chapter Four), therefore this factor can be excluded as the reason for the difference in the proportions of the nitrogen.

Among other factors, the thermal history of bone seems to be the most important in collagen preservation (Collins et al. 1995). In the area of Bakr Awa, air temperature can reach 40°C, and the temperature of ground exposed to the sun should be even higher (cf. Chapter One and Bollongino and Vigne 2008). The temperature of soil beneath the surface will depend on the soil’s thermal diffusivity. As shown for archaeological sites in Syria (for climate settings of the region cf. Fig. 1.3), at the 1st m of depth, estimated temperature varies between 5°C in winter and 33°C in summer. At the 4th m depth, summer maximum was c. 26-29°C and winter minimum c. 8-11°C. Thermal stability at c. 20°C was approximated between the 6th and 12th m of depth. The difference depends on soil composition and its thermal diffusivity (Bollongino and Vigne 2008). Therefore burials located deeper should have been less affected by the annual changes in temperature. However, the level of ground and the depth of graves can change with the accumulation of the successive layers of tell. It means that even burials discovered deep beneath the modern ground were for some time relatively shallow and exposed to high temperatures and annual temperature variations. Later, burials were covered by successive layers and the pace of covering could also affect the thermal history of bone. Burials can be once again exposed to high temperatures as a result of an archaeological excavation (or looting activity), when the layers providing stable conditions are removed.

Another important factor affecting the preservation of collagen is moisture. Water can contribute to the process of recharging, in which the degraded collagen in a form of a soluble gelatine is rinsed from the bone (Hedges 2002; Hedges et al. 1995). The process most likely takes place in relatively shallow graves characterised by high annual amplitude
of soil moisture, like the IA and IS graves from Bakr Awa. As the surrounding soil was drying out, water was sucked from bone and replaced only when the soil was re-wetted (Hedges et al. 1995). High temperatures during dry months could contribute to gelatination of collagen and promote rinsing in wetter periods. In contrast to the IA and IS burials are the BA burials located in the architectural context. Location of burials beneath the households and later under successive layers of architectural construction made of mud brick and clay, could, in some cases, prevent water penetration and provide more stable conditions, where gelatination and rinsing were limited. Moreover, clay is known to inhibit the process of decay by preventing water penetration (Carter and Tibbett 2008; Forbes 2008).

Other factors can also contribute to the collagen preservation. Grave BA2084 contained two individuals, one of them (BA2084/9) was relocated to the side of the grave before the second interment (cf. Miglus et al. 2011). The individual in the secondary position had greater amount of collagen in the bone tissue (3.5%) in comparison to individual BA2084/11 (0.9%), unearthed in the primary position. However, the quality of collagen was better in the remains of BA2084/11 (42.6% of carbon and 15.2% of nitrogen in the collagen sample) than in the remains of BA2084/9 (5% of carbon and 1.7% of nitrogen in the collagen sample). In the discussed case, burial customs (placing a second interment in a grave) most likely affected the nitrogen preservation rate in human remains of the older burial. Relocation of burial could put human remains out of equilibrium between bone tissue and soil accelerating changes in the biochemical composition, due to the differences in soil pH. Acids originating from decaying soft tissues can affect acidity of grave environment (Forbes 2008), and affect collagen preservation. Conversely, alkali bioapatite can neutralise the acidic solution by dissolution (Carter and Tibbett 2008; Forbes 2008).

In neutral pH, collagen deterioration can be accelerated by a microbial attack in the areas of mineral dissolution. However, the microbial attack affects bone only in zones of alteration, while the remaining part of the bone is undergoing chemical deterioration (Collins et al. 2002).

In the case of Bakr Awa, the difference in the collagen preservation could be explained by the location of burials. Earth burials from the IA and IS periods located in the graveyard were much more exposed to annual variation in temperature and soil moisture. While the BA burials located within the households seem to have been protected to some extent from atmospheric factors.

2. Animal diet

Animal diet was based mainly on the C₃ plants. δ¹³C of analysed animals did not reach a cut-off point for the diet with a significant portion of C₄ plants (δ¹³C= -18‰) proposed by Pearson et al. (2007). The highest values of δ¹³C was attested in herbivores that could have
grazed on pastures with C\textsubscript{4} plants. The lowest values were noted for pigs, indicating diet based on agricultural products. The $\delta^{13}$C value of an ovicaprid individual from the IS is similar to the values of pigs and suggests that this animal was fed on agricultural products. Between those values fall the $\delta^{13}$C values of canids. The similarity in the $\delta^{15}$N values between herbivores and omnivores indicates that the diet of omnivores was in great proportion based on plants. This trend is especially visible in pigs, which also exhibit low values of $\delta^{13}$C.

Similar observations were reported for animal remains from Tell Barri (Soltysiak and Schutkowski 2015b) Tell Sabi Abyad (van der Plicht et al. 2012) and Tell Sheikh Hamad (Höring and Jungklaus 2010). Low values of $\delta^{13}$C were observed for pigs in Tell Barri (Soltysiak and Schutkowski 2015b) and Tell Sabi Abyad (van der Plicht et al. 2012). In Tell Barri the $\delta^{15}$N values of pigs are usually lower than those of ovicaprids, indicating plant based diet (Soltysiak and Schutkowski 2015b) similar to Bakr Awa. A pig from Tell Sabi Abyad had the $\delta^{15}$N value higher that ovicaprids and other herbivores indicating consumption of animal proteins (van der Plicht et al. 2012). Canids usually have the $\delta^{13}$C values higher than pigs, but their $\delta^{15}$N falls in the range of the $\delta^{15}$N values of pigs, indicating similar, mostly plant based, diet (cf. Höring and Jungklaus 2010; Soltysiak and Schutkowski 2015b). The $\delta^{13}$C values of ovicaprids vary between c. -20‰ and even -15‰ (Soltysiak and Schutkowski 2015b; van der Plicht et al. 2012), indicating diet based on C\textsubscript{3} plants (either agricultural products or wild plants) with a varied share of wild C\textsubscript{4} grasses.

3. Human diet

Similar to other studies from northern Mesopotamia (Batey 2011; Höring and Jungklaus 2010; Soltysiak and Schutkowski 2015b), the diet of Bakr Awa individuals was based on C\textsubscript{3} plants and supplemented with animal proteins. Differences in the mean values of $\delta^{13}$C and $\delta^{15}$N between archaeological sites (Tab. 6.1) can be explained by the characteristics of local settings, including precipitation and share of C\textsubscript{4} grasses in local pastures. Among presented sites, Bakr Awa receives the highest amount of annual rainfall (more than 700 mm per year), while at Tell Sheikh Hamad it amounts to less than 200 mm per year. The difference in the $\delta^{13}$C values between regions of the Middle East can be observed in the stable carbon analysis of barley (Riehl et al. 2014). In the case of $\delta^{13}$C, the water stress effect could be disrupted by direct or indirect consumption of C\textsubscript{4} plants. Both Tell Sheikh Hamad and Umm el-Marra are located in a steppe zone where animals could have had greater access to C\textsubscript{4} plants. The stable carbon isotope composition of animal proteins could have had greater impact on the bone collagen stable isotope signature than plant proteins, even enriched due to lower water availability.
Table 6.1. Descriptive statistic of the $\delta^{13}$C and $\delta^{15}$N values for Bakr Awa, Tell Barri (Sołtysiak and Schutkowski 2015b), Tell Sheikh Hamad (Höring and Jungklaus 2010) and Umm el-Marra (Batey 2011) individuals. The publication of Umm el-Marra lacks collagen quality control data, therefore results obtained should be treated with caution (n.d.= no data).

<table>
<thead>
<tr>
<th>Chronology</th>
<th>$\delta^{13}$C</th>
<th>$\delta^{15}$N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>med</td>
</tr>
<tr>
<td>Bakr Awa EBA- Middle Ages</td>
<td>27</td>
<td>-19.5</td>
</tr>
<tr>
<td>Barri EBA- modern period</td>
<td>71</td>
<td>-19.2</td>
</tr>
<tr>
<td>Sheikh Hamad Achaemenid-Parthian/Roman</td>
<td>14</td>
<td>-18.4</td>
</tr>
<tr>
<td>Umm el-Marra EBA</td>
<td>11</td>
<td>n.d.</td>
</tr>
</tbody>
</table>

In comparison to Tell Ashara and Tell Masaikh (Sołtysiak 2011), the diet of Bakr Awa inhabitants was more abrasive in all periods. In contrast to the study of Sołtysiak (2011), no clear temporal change toward finer traits was observed at Bakr Awa. Similar to the BA and the Roman Period in Tell Ashara and Tell Masaikh (Sołtysiak 2011), significantly more finer traits were observed in the IA than in the BA. A reverse trend was observed between the IA and the IS; in the IS, there is significantly less striae than in the IA. This reverse trend was not observed in the Euphrates valley, where the increase in the fine traits share continues to the IS (Sołtysiak 2011). Moreover, the difference between the BA and the IS is insignificant, which is interesting because different devices for grinding were attested at Bakr Awa in both periods: in the BA a saddle quern, and in the IS a rotary quern (Peter Miglus, pers. com.). No grinding devices were attested in the IA. Unfortunately, to date, grinding devices from Bakr Awa were not a subject of petrological analysis, therefore it is impossible to discuss the relation between the material of the grinding device and the size of microwear traits.

Little is known about the correlation between ancient grinding technology and microwear pattern. During grain processing, abrasive particles originating from grinding tools (cf. Gügel et al. 2001) or surroundings (cf. Ungar et al. 1995) can be added to the flour. On the other hand, flour can be purified (cf. Gügel et al. 2001). The amount and size of abrasive particles introduced to the flour can depend on the type or material of grinding tools used (cf. Smith 1972). Grinding tools made from large-grained and relatively soft rocks can produce greater abrasions than the fine-grained igneous grinding tools (Teaford and Lytle 1996). At Bakr Awa, both the saddle quern and the rotary quern were made from large-grained and fine-grained rocks (cf. Fig 6.1). Use of a grinding tool, made from a similar material, can possibly introduce similar abrasive particles to the flour, regardless of the technique of grain processing. Similar abrasive particles can produce undistinguishable microwear pattern, as observed on the teeth of the individuals from the BA and the IS.
On the other hand, the process of flour purification can remove abrasive particles regardless of grinding technology (Gügel et al. 2001). In ancient Mesopotamia, purification was done with sieves (Curtis 2005). The linguistic data indicate use of reed sieves, but other materials were also used (Ellison 1978: 118). At Bakr Awa, sieves made from local reeds could have been in use. The use of reeds in the BA has been confirmed by the phytolith analysis (Marsh and Altaweel 2015). An unchanged technique of reed sieves preparation could result in a similar purification of flour in the early and late periods. Unfortunately, organic material is less likely to survive in archaeological record and the role of the sieve type in the flour quality at Bakr Awa has to remain speculative.

Figure 6.1. Surface of a quern from Bakr Awa: A and B (both from BA2746) dated to the BA; C (BA3116/10) and D (5001/10) dated to the IS (photo by author).

3.1. The Middle Bronze Age

The BA subsets discussed in both the isotopic and microwear analyses contain only one individual from the EBA each, therefore the discussion below will be limited to the MBA. Diet of the MBA individuals was based on C3 plants supplemented with animal proteins. The results of the stable isotope analysis are supported by the phytolith analysis, which indicates that wheat and barley were main cereals cultivated at Bakr Awa in the BA
Among animals consumed were ovicaprids, bovids, pigs. Single bone pieces of deer and birds were also attested at the site (Piątkowska-Małecka 2015).

The MBA individuals differed in access to animal proteins. The access seems to have depended on the individual's social position. Two individuals exhibiting high $\delta^{15}\text{N}$ values (BA2084/11 and BA2386/1) were buried together with grave goods, indicating high social position (cf. Miglus et al. 2011, 2013). The grave of the third individual (BA2358/1) was partly explored in the 1960s, but no data regarding burial goods are available. The remaining part of the grave was explored in 2013 by the present author (Fetner 2014). The explored part of the grave did not contain any burial goods. The type of the grave did not differ from other earth graves from that period (both with and without valuable burial goods). The group of individuals with lower $\delta^{15}\text{N}$ values includes only individuals of low social position. Their graves usually contained a single object. Many graves did not contain any objects. One grave (BA2189) was partly destroyed and the information about its burial inventory is incomplete (cf. Miglus et al. 2011, 2013).

The difference in the mean values between both groups is c. 2.8‰ for $\delta^{15}\text{N}$ and c. 0.1‰ for $\delta^{13}\text{C}$. Both nitrogen and carbon stable isotopes reflect the proportion of animal proteins in diet. The enrichment factor is rather stable (cf. DeNiro and Epstein 1978, 1981). In this case, trophic enrichment in $^{13}\text{C}$ does not reflect trophic enrichment in $^{15}\text{N}$. It can be explained through a consumption of animal proteins with different $\delta^{13}\text{C}$ signatures. The carbon isotopic signatures of individuals consuming great amount of meat depleted in $^{13}\text{C}$ can be similar to the carbon isotopic signature of individuals consuming low amount of meat enriched in $^{13}\text{C}$. As a result, the trophic enrichment in $^{13}\text{C}$ can be missed, while the trophic enrichment in $^{15}\text{N}$ will be noted.

An analogous case was reported for an Anglo-Saxon cemetery at Wally Corner (UK), dated from the mid-5th to the late 6th/early 7th c. AD (Privat et al. 2002). The dietary pattern shows significant difference in $\delta^{15}\text{N}$ but no enrichment associated with higher consumption of animal proteins was observed for the $\delta^{13}\text{C}$ values. It was a result of an access to animal proteins of different isotopic signature. The isotopic evidence suggests that members of the upper class consumed more animal proteins of herbivores (the $\delta^{13}\text{C}$ values ranged between -21.8‰ and -21.2‰, the $\delta^{15}\text{N}$ values ranged between 5.8 and 6.4‰), while the lower class consumed more omnivores (one pig: $\delta^{13}\text{C}=-20.9\%_o$, $\delta^{15}\text{N} =6.0$) and/or fresh water fish (isotopic values not reported; cf. Privat et al. 2002).

As discussed above, at Bakr Awa, animal $\delta^{12}\text{C}$ values vary between -20.4‰ and -18.4‰. The lowest values were observed for animals bred within the household (including pigs). The highest values were observed among animals that could have grazed in pastures (e.g. equid). The expected enrichment in $^{13}\text{C}$ (at a level c. 60%) was observed between pigs and individuals of high social status. Because the analysed pig remains were retrieved from the IS context, the observation cannot be strictly associated with pork consumption among individuals of high social position. Moreover, in Mesopotamia, pig household breeding was
the subsistence of non-elite families (Zeder 1998). This observation can be supported by the results from Tell Barri, where consumption of pork is negatively correlated with the $\delta^{13}C$ values (Sołtysiak and Schutkowski 2015b).

The high status individuals could have consumed meat and dairy products of animals bred on agricultural products within the household. High correlation between barley and agricultural weeds observed in the phytolith analysis supports the thesis that animals could be bred on a biomass, including barley (Marsh and Altaweel 2015). The importance of the household breeding could be noted in the share of pig remains. The highest share of pig remains in the history of Bakr Awa was observed in the MBA (Piątkowska-Małecka 2015). Among household bred animals could also be ovicaprids (cf. Arbuckle 2012).

Low status individuals could consume meat and dairy products acquired mainly from animals grazing on pastures rich in $C_4$ grasses. Presence of $C_4$ flora in the Shahrizor was confirmed by the phytolith analysis (Marsh and Altaweel 2015). At the MBA Bakr Awa, animals could be obtained from local herders, as suggested by textual sources from Bakr Awa (Meinhold unpub.).

The isotopic difference between social groups could therefore be the result of a varying access to different types of meat. Individuals of high social status commonly consumed meat and dairy products acquired from animals bred within the household (cf. Arbuckle 2012). Diet of the low status individuals was based on agricultural products less frequently supplemented with animal proteins from animals obtained from local herders.

This status-based division in the access to certain types of food items is not visible in the microwear analysis. Meat and dairy products are too soft to leave distinctive traits on enamel (Peters 1982). Some traits could be left by exogenous abrasive particles in meat/dairy products in food items (cf. Ungar et al. 1995). Cereal products processed on a quern were probably more abrasive. In contrast to the Euphrates valley (Sołtysiak 2011), inhabitants of Bakr Awa seem to have consumed food items of lower quality and more abrasive.

3.2. The Iron Age

Similar to the BA, diet of the IA individuals was based on $C_3$ plants supplemented by animal proteins, probably of ovicaprids, bovids and pigs (J. Piątkowska-Małecka, pers. com.). In comparison to the BA individuals, the IA individuals had diet more enriched in $^{13}C$ (0.6‰). Moreover, the IA individuals consumed more animal proteins than the low social status individuals from the BA, but less than the individuals of high status.

The diet of the IA individuals differs also in the proportion of enamel microwear traits. In contrast to the BA individuals, the IA individuals had greater proportion of fine traits dominated by striae. The results suggest that food items consumed by the IA
individuals were relatively less abrasive. It could be the result of a change in cereal processing/preparing technology.

These observation can be supported by the study on the individuals from Tell Ashara and Tell Masaikh (Soltysiak 2011), where a shift toward finer traits between the BA and the Roman Period was observed. The change was attributed to a non-specified change in grinding technology, possibly the introduction of an animal-powered rotary mill (Lewis 1997). In the case of Bakr Awa, the technological shift could be the result of the introduction of the Olynthus mill (cf. below).

Unfortunately, the IA occupation phase at Bakr Awa is characterised by a low number of findings that could be associated with settlement. No devices for food processing were recorded (Miglus et al. 2013).

3.2.1 Change in subsistence between the Middle Bronze Age and the Iron Age

As mentioned above, in comparison to individuals from the MBA, individuals from the IA had less abrasive diet enriched in $^{13}$C isotopes. The enrichment could be explained by greater direct and/or indirect consumption of C$_4$ plants. Direct consumption of C$_4$ plants could be the result of millet or sorghum cultivation. Indirect consumption of C$_4$ plants could be the result of consumption of meat and dairy products of animals consuming C$_4$ plants in form of fodder or during grazing on pastures.

Another explanation is an overall increase in the $\delta^{13}$C values in the environment as a result of lower water availability in the late IA. The lower water availability should lead to an increase in the $\delta^{13}$C values of plants and their consumers. In periods of lower water availability the proportion of C$_4$ plants in pastures should also increase (cf. Collatz et al. 1998).

3.2.1.1 Water availability

The isotopic composition of Zeribar sediments shows temporary depletion in $^{18}$O between c. 2000 - 1300 BC in relation to the average value, which indicates a relatively wetter period. Later, the proportion of $^{18}$O increases and c. 1000 BC the $\delta^{18}$O value crosses the mean. The highest values of $\delta^{18}$O are observed in the first half of the first millennium BC, indicating a relatively drier period (Roberts et al. 2011: 150). The rapid increase in the $\delta^{18}$O values in the 13$^{th}$ c. BC coincides with the Bond Event 2 (Bond et al. 2001; Roberts et al. 2011). The period following the drought episode seems to have been drier than the MBA, as shown by the stable isotope composition of Zeribar sediments (Roberts et al. 2011). The phytolith analysis supports observation from Zeribar. Drier conditions were attested in the upper part of the section dated from around the Achaemenid/Hellenistic period to modern times (cf. Marsh and Altaweel 2015).
In drier periods, plants incorporate more $^{13}$C isotopes due to water conservation (Araus et al. 1997; Riehl et al. 2014). Cereals growing in the Mediterranean conditions show high correlation between annual rainfall and carbon discrimination rate (Araus et al. 1997: 114). Differences observed in the $\delta^{13}$C values depend on the precipitation rate. In the study of Wallace et al. (2013), the greatest differences were observed for environments with medium (250-499 mm) and low (less than 250 mm) precipitation. The discrimination rate between those regimes varies from 1 to 2.5‰. The difference between environments of high (500-700 mm) and medium precipitation was lower, between 0.4 and 1.2‰ (Wallace et al. 2013). Considering the fact that the modern climate (c. 700 mm) of the Shahrizor is drier than the MBA climate (Marsh and Altaweel 2015; Roberts et al. 2011), any differences in the carbon discrimination rate between the MBA and the periods after the drought episode (3.2 ka event) should be lower than 1‰ or even 0.5‰ (Wallace et al. 2013). The difference is similar to the difference observed between human individuals from the MBA and the IA. Water stress and the resulting increase in the $\delta^{13}$C values in the local environment may have contributed to the enrichment observed in human diet in the IA.

Increased aridity also favours dry-tolerant plants with the $C_4$/CAM photosynthetic pathway (Collatz et al. 1998) which can lead to an increase in the average $\delta^{13}$C values in a bulk of animal food and animal tissues. Conversely, the area of marshlands with $C_4$ reeds, which could be used as pastures, can decrease in a drier period (cf. Hall 1928: 30 and 32; cf. de Wet 1978: 483). The presence of marshland reeds in the region of Bakr Awa was attested by the phytolith analysis. The share of marshland phytoliths in the sediment samples does not significantly differ between periods, despite changes observed in local aridity (Marsh and Altaweel 2015).

Greater aridity in the IA, in comparison to the MBA, could have led to an overall increase of $\delta^{13}$C in the environment, through conservation of water in plant tissues and/or an increase in $C_4$/CAM plants in the local flora. This increase could be reflected in human diet and may lead to a collagen enrichment in heavier carbon isotopes. However, without more precise palaeoclimatological data, it is impossible to assess the overall enrichment in $^{13}$C and its impact on human diet.

### 3.2.1.2 Change of local economy

The MBA seems to have been a period of Bakr Awa's prosperity. According to the textual sources from Bakr Awa, the town was provided with agricultural products (mainly barley and wheat) by farmers living in the surrounding villages. Animals, mostly ovinoparids, were provided by the local herders. Some animals, like pigs, could be bred in households as an easily available source of meat. Foodstuff obtained from the surrounding producers was redistributed by the local administration among the inhabitants of Bakr Awa (Meinhold unpub.). Access to food depended on the social position of an individual – the diet of
individuals of ‘low’ social position was mainly based on plant foodstuff, while the high status individuals seem to have consumed great amounts of animal proteins. Less is known about Bakr Awa economy in the later periods. In the LBA, agriculture was based on wheat (Marsh and Altaweel 2015) and the number of collected animal remains is low. Later in the late IA (800-300 BC), animal economy was based on ovicaprids, and the share of pig remains decreased to 13% (J. Piątkowska-Małecka, pers. com.).

The change is also visible in the material culture. In the MBA, houses of wealthy citizens and spectacular funeral findings were attested in area BA 1 and BA 2. In the LBA, occupation continued in area BA 2, but in area BA 1 only single artefacts were found. No artefacts or architectural remains from the early IA were found. Some kind of occupation reappeared in the late IA. In both area BA 1 and BA 2 single stone pavements and graves were noted. In the BA, the material culture of Bakr Awa was strongly tied to the Mesopotamian sphere as seen in the artefacts and architecture. That seems to have changed sometime between the LBA and the IA. In the late IA, the material culture of Bakr Awa was strongly tied to the Zagros tradition (e.g. Urartu). Individual artefacts (including Assyrian palace ware) have analogies in the Mesopotamian cultural sphere. Strong influence of the Zagros societies could be associated with an increase in pastoral economy in the Shahrizor.

In this context, a change in diet was observed. The IA individuals consumed more proteins with heavier carbon isotope, as a result of direct or indirect consumption of C\textsubscript{4} plants. Direct consumption of C\textsubscript{4} plants (millet and sorghum) in the IA was less likely. Sorghum was not attested in the palaeobotanical assemblages from northern Mesopotamia and the relief from Nineveh is a doubtful evidence (cf. Hall 1928: plate 30 and 32; de Wet 1978) for sorghum cultivation in northern Mesopotamia in the IA.

Introduction of millet was a part of the Assyrian land management policy. Drought tolerant millet seems to have been introduced in the drier regions of the Assyrian Empire probably as a summer crop due to an increase in the agricultural productivity of those regions. Palaeobotanical findings of millet are known from Nimrud, where millet seems to have been an important crop, even if not a major one (Helbaek 1966). In the Shahrizor, the introduction of millet was not necessary. High annual precipitation (cf. Chapter One) was able to sustain stable cultivation of the most common crops – barley and wheat.

The high amount of annual precipitation did not force a change in the spectrum of plants under cultivation. However, between the MBA and the IA, a change in the animal exploitation becomes visible. The IA animal economy seems to have been more focused on ovicaprid herding than in the MBA. At the same time, the pooled proportion of bovid and pig remains was relatively low – c. 20%. In comparison to the MBA, the proportion of pig remains decreased by c. 13%. The increasing role of ovicaprids could be associated with a greater exploitation of the local or more distant pastures. However, none of the animals analysed reached the cut-off point for consumption of C\textsubscript{4} plants (Pearson et al. 2007). It could have been an effect of the relatively humid climate of the Shahrizor where climate
conditions do not favour C\(_4\) plants over C\(_3\) plants, therefore the C\(_4\) flora does not dominate in the grassland environment (cf. Collatz et al. 1998).

The change in animal exploitation could have been caused by socio-political changes attested in the region of the Shahrizor. In the MBA, Bakr Awa seems to have been an important city of the local state (Simurrum), later incorporated into the Gutean kingdom, and finally conquered by Babylonia. Shortly before the LBA crisis, the Shahrizor and maybe Bakr Awa were under Assyrian control (Ahmed 2012; Altaweel et al. 2012). In that time, inhabitants of Bakr Awa seemed to profit from cooperation with the herders, while the areas around Bakr Awa were under cultivation (Meinhold unpub.).

In the 11\(^{th}\) c. Assyrians withdrew from the Shahrizor due to the weakness of their own state (Altaweel et al. 2012: 12). During the reconquest in the 9\(^{th}\) c. Assyrians met many independent states in the Shahrizor and the surroundings areas (Annals of Ashurnasirpal II.24-86). The decentralisation and, probably, ruralisation had an impact on local subsistence, which could have become less specialised and more self-sufficient.

The IA economy of the Shahrizor seems to have also been shaped by the Assyrian land management and the increase in the area under cultivation (Altaweel et al. 2012; Wilkinson et al. 2005). In the Erbil Plain, this policy was realized by increasing the number of small settlements (Ur et al. 2013). Rapid increase in the number of settlements in the IA in comparison to the earlier periods was observed in the Shahrizor (Directorate General of Antiquities 1970). However, no data regarding settlement size was reported.

Later, in the Achaemenid period (600-300 BC), a decrease in urban life in the Transtirgis area was observed. In the Shahrizor, the number of settlements decreased significantly, but was still higher than in the LBA. Similar trend was observed in the Erbil Plain (Ur et al. 2013) and the central Transtigris region (Mühl 2012). The decrease in the number of urban centres could have strengthened the rural character of the region.

Ruralisation and the decrease in the average settlement size (cf. Ur et al. 2013) promoted self-sufficiency. Moreover, more people were engaged in agricultural production (Wilkinson et al. 2005). In contrast to the MBA Bakr Awa, in the IA, every single household was probably engaged in agricultural production and animal breeding. The proximity of animals gave Bakr Awa inhabitants greater access to animal proteins than the one had by the 'low status' individuals in the MBA. Greater access to ovicaprids and their secondary products led to a decrease in the importance of pork. The consumption of the ovicaprids' secondary products enriched in \(^{13}\)C and the parallel decrease in pork's (enriched in \(^{12}\)C) share in the human diet could have led to the increase in the \(\delta^{13}\)C values of the IA individuals.

Ovicaprids could have also been acquired from herders operating in the Zagros Mountains. However, in contrast to the MBA, the cooperation between herders and farmers could have been more direct. The thesis about more direct contacts between the Bakr Awa inhabitants and the herders operating in the Zagros Mountains could be supported by the
presence of a significant amount of artefacts with analogies in the Zagros cultural tradition (Miglus et al. 2011, 2013).

Greater access to animal products as a result of ruralisation and the increased cooperation between herders operating in the Zagros Mountains could have led to the shift in δ\(^{13}\)C from the MBA to the IA.

An analogous shift in δ\(^{13}\)C (c. 0.5‰) was observed in Barri between the MBA and the LBA (Soltysiak and Schutkowski 2015b). Like at Bakr Awa, the shift seemed to be the result of lower consumption of pork (meat depleted in \(^{13}\)C) and increased consumption of ovicaprids and cattle (and their secondary products) enriched in \(^{13}\)C isotopes. Second factor taken into consideration was higher variability in subsistence together with a possible introduction of dry-tolerant C\(_4\) cereals, unlikely in Bakr Awa.

Change in the subsistence strategy in Barri could be associated with changes in the cooperation between herders and cultivators. In the LBA, in the region of Barri, herders became more independent, which resulted in an increased isolation between plant cultivators and herders operating in the dry steppes that forced the settled population to introduce a higher direct exploitation of ovicaprids and a wider use of more arid areas for agriculture. The observed change occurred during rather stable climate conditions, and it is likely that it was the effect of the social and economic, not environmental, factors (Soltysiak and Schutkowski 2015b).

### 3.2.1.3 Change in the cereal processing technology

In the MBA Mesopotamia, grain was processed within the household or in a 'house of the mill' controlled by the state or a temple (Forbes 1965). Presence of the 'house of the mill' in the states of the Zagros foothills during the MBA is suggested in the Shemshara Letters, in which transports of grain and flour to Turrukkeans during their war with Guteans were requested (SH 822). The presence of flour as goods for transportation suggests that the state was able to process great quantity of flour. Moreover, flour could have been transported across large distances, e.g. from the Rania Plain to the region of Lake Urmia (Eidem and Læssøe 2001). Professional millers could have worked in the 'house of the mill' (Forbes 1965: 145).

In the BA, cereals were processed on a saddle quern and this technique did not change over the time. In the IA, an Olynthus mill was introduced to the Middle East. The oldest representation is known from Tyre and dated to the 7\(^{th}\) c. BC (Frankel 2003). Further east, the Olynthus mill was found in the IA strata in Tell Halaf (northern Syria; Oppenheim and Hrouda 1962: 39). Other forms of milling stones, including the rotary quern, are younger (Alonso Martinez 1996), and were introduced to the Middle East not earlier than the Hellenistic period. The Roman army played an important role in the distribution of the
rotary quern (cf. Netzer 1991: 290–291), but even then the rotary quern was not broadly adopted and was used alongside the Olynthus mill (Frankel 2003).

During the BA, in the Bakr Awa lower town, cereals were grained on a saddle quern within the household. Later in the IA, some aspects of grain processing could have changed. First of all, Assyrian royal granaries were established in Dur-Assur (=Bakr Awa according to Speiser (1927); Annals of Ashurnasirpal II.24-86). The presence of Assyrian royal granaries at Bakr Awa could have possibly accelerated the technological shift in grain processing, such as an early introduction of the Olynthus mill. The presence of Olynthus mills in the IA capital of the Assyrian province was confirmed by archaeological findings (Oppenheim and Hrouda 1962). Olynthus mills could have been introduced to Bakr Awa not earlier than the 7th c. BC and could have been used later, during the Achaemenid reign. According to Forbes (1965: 148), Olynthus mills seem to be associated with the production of flour on a larger scale than needed for a single household. However, the introduction of new grinding techniques (e.g. new types of grinding stones) does not necessarily impact on the microwear pattern, as shown by the comparison of the BA and IS subsets.

Use of grinding stones, both the quern and/or Olynthus mill, of better quality could serve as another possible explanation. In this case, the presence of royal granaries and an interregional route could have also had a positive impact on the local processing technology, and grinding stones of good quality could have become more common in the area. As observed in the Middle East, grinding stones trade operated at great distances (Williams-Thorpe and Thorpe 1993).

Change in the grain processing technology, either through an introduction of new techniques or devices of a better quality, could contribute to better quality of the final product. Consumption of good quality flour could result in a softer and less abrasive diet. But without archaeological findings of grinding devices from the IA, the present discussion has to remain more or less tentative.

3.2.1.4 The role of climate in the subsistence change

The drought episode between 1200-900 BC could have affected the subsistence at Bakr Awa in two ways – directly, through a decrease in available moisture leading to a regular crop failure, and indirectly, by affecting the socio-political landscape of northern Mesopotamia and consequently of the Shahrizor.

Archaeological, palaeobotanical and palaeoclimatological data available do not allow for an assessment of the direct impact of the drought episode on Bakr Awa subsistence (Marsh and Altaweel 2015; Reuter et al. 2012; Roberts et al. 2011). However, as discussed above, it is unlikely that the drop in annual precipitation led to a crop failure that forced people to change their subsistence strategy.
There are more data regarding the impact of the drought episode on northern Mesopotamia in general. However, many various factors contributed to the shaping of the society and politics of the IA (cf. Chapter One and Two). In the early IA, Mesopotamia faced movement of peoples, introduction of new groups, widespread nomadisation and the decline of former states (Fales 2011; Kirleis and Herles 2007; Neumann and Parpola 1987; Postgate 1992). The impact of climate on those events was discussed in Chapter Two.

The crisis led to the ruralisation in Mesopotamia and, at times, to the adaptation of a new subsistence (Brown 2013; Kirleis and Herles 2007; Neumann and Parpola 1987). After the crisis, the Assyrian policy strengthened the rural character of most areas, by promoting smaller and more widespread settlements, irrigation, cultivation of previously uncultivated lands (Wilkinson et al. 2005) and deportations (Oded 1979). However, this policy was not new. Similar pattern and the tendency toward numerous but small settlement was observed in the LBA in the areas incorporated into the Assyrian Kingdom (Brown 2014; Mühl 2012; Ur et al. 2013). It is possible that the drought episode negatively affected the Assyrian policy, which was continued in the IA with renewed energy. Moreover, the settlement of the mobile Aramean population could have given an opportunity for a more widespread adoption of the new settlement pattern. In the Achaemenid period, the rural character was strengthened, when the political centre was transferred to southern Mesopotamia and the importance of northern Mesopotamia decreased (Khatchadourian 2012). The adaptation of a more mobile subsistence strategy could have also impacted on the animal exploitation (e.g. the decrease in pigs) observed at a different time in northern Mesopotamia (Redding 2015).

### 3.3. The Islamic Period

The diet of the two individuals from the IS was rich in $^{13}$C and $^{15}$N in comparison to the individuals from the older periods and indicates high consumption of animal proteins. High proportion of ovicaprids suggests that a great amount of animal proteins could have come from milk and its products. The high values of δ$^{13}$C seem to support this observation. The increase in the bird (chicken) importance to the local subsistence (T. Tomek, pers. comm.) could have also contributed to the elevation of the δ$^{15}$N values.

The proportion of microwear traits places abrasiveness of the IS individuals’ diet between the diets of the BA and the IA individuals. As discussed above, the change in the grinding technology between the BA and the IS seems not to have contributed to the change in the dental microwear pattern. Similar microwear pattern could be the result of the household flour processing. Flour quality could vary, and some products could be abrasive and produce more coarse microwear traits.

In the Islamic period, the discussed region was of minor importance and grinding tools made of better material may not have been introduced here, as opposed to the
regions more crucial for the state economy. Such a case was observed in Kültepe in Anatolia, where dental microwear showed no shift between the MBA and Hellenistic/Roman periods, most likely due to the decrease in the region's importance (Jaworski et al. 2015).
Chapter Seven. Conclusion

In the MBA, the diet of the Bakr Awa inhabitants depended on the social position of an individual. Individuals of higher social position regularly consumed more animal proteins (meat and dairy products), while the diet of individuals of lower social strata was based on plants (probably barley and wheat), with small content of animal proteins. No difference in food abrasivity was observed between individuals of different social position.

In the IA, the inhabitants of Bakr Awa consumed more animals proteins than the BA individuals of lower social position, but less than the individuals of high social status. Moreover, the diet was more abundant in heavier carbon isotopes. This was probably the result of the lower consumption of animals bred within the household, especially pigs, and the greater share of animal proteins of ovicaprids grazing on pastures. Also the lower availability of moisture in the IA and the following periods could have increased the overall level of the carbon isotope ratio in the environment and promoted the C₄ flora.

In comparison to the BA, the diet of the IA inhabitants of Bakr Awa was less abrasive, probably as a result of the shift in the technology of grain processing. This shift could have been a result of the introduction of the Olynthus mill and/or grinding devices of better quality to the region. But many processes of the grinding technology that could potentially contribute to the flour purity cannot be reconstructed with archaeological methods, therefore the discussion on factors that could have possibly resulted in the less abrasive diet of the IA individuals has to remain more or less tentative.

Many factors could have contributed to the change in subsistence at Bakr Awa between the MBA and the IA. The drought episode between 1200-900 BC seems to have had a limited impact on subsistence strategies of peoples inhabiting the Shahrizor Plain. Modern data show that a serious decrease (e.g. by 200 mm) in annual precipitation should not lead to crop failure of the typically cultivated cereals, such as barley. Moreover, the pastorals and farmers occupying the Shahrizor and its vicinities in the BA could have stabilised their respective subsistences through a regular exchange, limiting the danger of food shortage. The change observed in the subsistence was probably the effect of socio-political changes during the LBA crisis, including ruralisation and the decline of nuclear urban centres. In the late IA, the rural character of most areas of northern Mesopotamia was strengthened by the Assyrian land management and promotion of small but numerous settlements. As a result, many more people were engaged in agricultural production; what is more, small rural communities were probably more self-sufficient. Later, the decline of urban centres during the Achaemenid period strengthened this tendency even more. It is possible that in the lower town at Bakr Awa an urban economy during the BA and a rural economy during the IA and later can be observed, and the difference in diet is the result of the difference between the specialised economy of the BA urban centre and the self-sufficient village economy of the IA.
Low preservation rate of collagen makes diet reconstruction of the transhumant communities occupying the Shahrizor in the Middle Ages unreliable. It is interesting that, despite the obvious change in the grinding tools assortment and the introduction of the rotary quern, diet abrasivity does not differ from the MBA and the IA diet. It indicates that a difference in grinding devices does not necessarily lead to a difference in abrasivity of food items, and therefore in microwear pattern.

The changes observed do not seem to be the direct effect of the drought episode, but the climate could have enforced some socio-economical processes in the early IA, which can be observed at Bakr Awa. One of these processes could be the decentralisation and the increase in exploitation of local and/or more distant pastures. The integration of the Zagros foothills and the mountain areas could have also led to the increased cooperation between lowlanders and highlanders.
References


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