Environmental change and human history in the Jabal Harûn area, Jordan

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1. Introduction

1.1 Background: the Finnish Jabal Harûn Project

Jabal Harûn, “the Mountain of Aaron”, is located ca. 5 km southwest of Petra, the ancient capital of the Nabataeans and the most famous tourist attraction in Jordan (Map 1.1). According to Jewish, Christian and Muslim tradition, the mountain is the burial place of Aaron.

Map 1.1 Map of Jordan. The location of Petra is marked with a star.
of Moses’ brother Aaron. The Finnish Jabal Harûn Project (hence the FJHP) is a multi-disciplinary project directed by professor Jaakko Frösén, University of Helsinki, which conducts archaeological research centred on Jabal Harûn and its surroundings. The project consists of two interrelated parts: the excavation of a Byzantine monastery/pilgrimage centre on the top plateau of Jabal Harûn, directed by Ph.D. Zbigniew Fiema, and a survey in the surroundings of the mountain, directed by Mika Lavento, professor of archaeology at the University of Helsinki. The FJHP is a part of “Ancient and Medieval Greek Documents, Archives and Libraries” research unit, which was nominated as a Centre of Excellence in Research by the Academy of Finland in 2000-2005. After a reconnaissance season in 1997 (Frösén et al. 1998) the full-scale excavation and survey started in 1998. The fieldwork has taken place over a period of five to eight weeks between July and September every year between 1998-2003 (Frösén et al. 1999; 2000; 2001; 2002; 2003; 2004). In 2001 the survey team was not on the field and in 2004 there was no field season. The final survey season, which extended the survey area beyond the immediate vicinity of Jabal Harûn, took place in August 2005. The material from the final season was still in the process of being analysed while this work was written.

The aims of the intensive, multi-period survey are to study all evidence of past human activity in the environs of the mountain, and to understand the role of the Jabal Harûn area in the regional context and to shed light on the history of the extensive runoff cultivation system surrounding Jabal Harûn. The area surveyed so far covers ca. 6 km² including Jabal Harûn and its immediate vicinity. To the south and west the area is geomorphologically restricted by the local watershed formed by limestone hills called Naqb Abu Khushayba and the fault line of Naqb ar-Ruba’i, while to the east and north it is limited by the Al-Farasha ridge and the channel of Wadi an-Naqb (Maps 1.2 and 1.3). The FJHP survey methodology and results will not be touched here as they are discussed in detail below in Chapter 2.3.2.
Map 1.2 Petra and the Jabal Harûn area.

Map 1.3 The FJHP survey area. Contour interval 10 m. (FJHP/H. Junnilainen.)
1.2 Objectives of the dissertation

It is generally held that erosion is one of the main forces changing the landscape in the Near East, and that human-induced environmental change and erosion is of very old origin in the Levantine countries (Goudie 1987: 20; Thirgood 1981). Although climatic or environmental change have been suggested by several archaeologists as possible reasons for the changes in settlement in southern Jordan (e.g. Hart & Falkner 1985: 268; MacDonald 2001), there is still relatively little actual work on the subject, particularly concerning the historical times. However, it seemed that past climatic changes and human activities could be expected to have significantly changed the landscape of the Jabal Harûn area. Therefore it was considered that a study of erosion in the Jabal Harûn area could shed light also on the human history of the area, and the reconstruction of past environmental conditions could give additional information to help to understand the phenomena observed in the archaeological record in the FJHP survey area.

The questions this work set out to answer were: Is it possible to recognise and date periods of erosion and deposition in the Jabal Harûn area? If such periods could be recognised and dated, is it possible to connect them to climatic changes known from the palaeoclimatic record to have taken place in the Near East, or to periods of human activity in the Jabal Harûn area? In addition to the detection of major climatic changes it was hoped that sedimentary studies could shed light on the land use of the area, particularly the construction and abandonment of the runoff farming system. It was expected that the periods of its use and abandonment should be reflected in the sedimentary record, and if these periods could be dated, a chronology could be obtained for the system. In the course of the survey work it also became apparent that evidence of some archaeological periods were completely missing from the Jabal Harûn area. This led to the emergence of new questions, namely whether catastrophic erosion could have wiped out traces of human activity from certain periods, and whether unfavourable environmental change, caused either by natural factors or by human agency, could have rendered the environment unsuitable for humans to live which could explain the gaps in the archaeological record.
It was expected that changes in climate and/or land-use should be reflected in the sedimentary record as phases of erosion and aggradation. Therefore, in order to answer the abovementioned questions, a number of geomorphological and sedimentological studies were carried out as part of the FJHP survey fieldwork. The studies included the mapping of wadi terraces along Wadi al-Mahattah and Wadi al-Farasha to record the number of terrace levels, presumably representative of the erosional and depositional history of the area. Certain terraces along Wadi al-Farasha were then selected for closer examination by cleaning sediment profiles that were recorded and sampled for later laboratory analysis of sediment facies and observations about the lithological composition of the layers. To obtain a chronology for the sedimentation and erosion phases detected in the sediment profiles samples were also taken for OSL dating. The results of the geomorphological and geological studies were then to be compared with the record of the Near Eastern palaeoclimate obtained from published studies on the subject, and with the geoarchaeological data available from elsewhere in central and southern Jordan, to test the validity of the results, and also to complement them. Finally the results of the environmental studies were combined with the picture of human history in the area, as reconstructed from the archaeological evidence from the FJHP survey and published archaeological research in the wider Petra region, to see if changes in the human activity and in the environment appear to be related.

1.3 Theoretical considerations

The proliferation of the use of scientific methods in archaeological research in the 1960s and 70s was related to the introduction of New Archaeology, which challenged the then prevalent culture-historical approach. The birth of New Archaeology was related to contemporary developments in geography and social sciences. It adopted many ideas and methods from these and was heavily influenced by e.g. systems theory. The central archaeologists involved in the development of the New Archaeology were Lewis Binford in the United States and David Clarke and Colin Renfrew in Britain. New Archaeology has later become known as processual archaeology, as it tended to view past cultures and their different aspects as
interlinked processes. The objectives of processual archaeology were oriented towards defining universal “laws” concerning human cultures rather than studying the particulars of a specific culture. Technology and environment were considered to have a predominant role in human adaptation to nature, and culture was seen as humankind’s extrasmatic means of adaptation. (Trigger 1989: 294-303.) Cultures were thought to be basically static and cultural change was attributed to external factors, such as environmental or economic stress (Shanks & Tilley 1987: 54; Trigger 1989: 305). The aim of the New Archaeology was for scientific and objective archaeology, which led to the proliferation of statistical, mathematical and other scientific methods in archaeological research starting in the 1960s (Shanks & Tilley 1987: 56). The quest for objective, value-free data, together with the emphasis on the environmental adaptation of cultures, partially explains also the increased interest in research methods borrowed from geology, geography and biological sciences.

Doubts towards the New Archaeology were expressed already in the 1970s, and not just by the defenders of the formerly predominant culture-historical approach, but the processual archaeological theory started to be increasingly seriously challenged in the 1980s (Trigger 1989: 328; Shanks & Tilley 1987: 1-3). The main points of this criticism, presented by Michael Shanks and Christopher Tilley in their Re-Constructing Archaeology: Theory and Practice (1987) were the New Archaeology’s positivist approach, the separation of objective facts from theories and concepts, the predominant position of ecology and economy in archaeological explanation, the reduction of the symbolic and social world to a mere extension of the natural one, and reification and the belief in empirical regularity of cultures (Shanks & Tilley 1987: 29-32; 46-56).

The movement that began in the 1980s to call for more theoretically informed archaeology is nowadays usually broadly termed post-processualism. The origins of post-processualism are within the critique of the processual theory among archaeologists, but it has been also significantly influenced by the post-modern critique in fields such as sociology and anthropology (Trigger 1989: 338-354; Hodder & Hutson 2003: 206-207). Due to its diverse origins post-processualism is not a uniform school of thought, but rather a collection of theoretical and
philosophical viewpoints like contextual archaeology (Hodder & Hutson 2003: 156-205), post-colonial archaeology (Gosden 2001) and feminist archaeology (Hodder & Hutson 2003: 228-231), to mention but a few. There is not just one predominant paradigm in contemporary archaeological theory, but multiple perspectives. The overarching element in these various viewpoints is that they emphasize the role of the researcher and the present society in interpreting the past, maintaining that the past is a construct of the present. As a result they share a more or less relativist view of explanation in archaeology. Some post-processual archaeologists have even adopted an extreme relativist position, claiming that it is not possible to gain any objective evidence of the past, and therefore all interpretations are considered equal. Common to many of these approaches is also an emphasis on the importance of the social world in defining human actions, and the role of individual agents in the formation of the archaeological record. (Shanks & Tilley 1987: 122-126; Trigger 1989: 328-339, 381.)

The approach in the work at hand is largely empirical as a result of the emphasis on geological methods and data. It could probably be considered to bear a processualist theoretical legacy, as the development of both survey methodology and geoarchaeology are related to the New Archaeology. Some of the more radical post-processualists have rejected the use of environmental data considering that it leads to inevitable empiricism and environmental determinism in the archaeological interpretation (Roskams & Saunders 2001: 61-62). However, being empirical is not the same as being an empiricist (Shanks & Tilley 1987: 115).

In Reconstructing Archaeology: Theory and Practice Shanks and Tilley (1987: 108) maintain that

*understanding the past is a dialectical process occasioned by continual adjustment of ideas, concepts and representations and is not something that could be fixed by a single method?.*

Although this work concentrates on “the environmental explanation”, this should be considered rather as the starting point of a hermeneutic circle leading to the dialectical process of archaeological interpretation (Shanks & Tilley 1987: 104-105), than as an attempt to offer an all-encompassing, environmentally driven explanation for the changes in human activity
observed in the Jabal Harûn area. This dialectical process has been on-going through the period of work on this dissertation. From the originally strongly empiricist and processually oriented point of departure the interpretative circle has already grown wider, through frustration at - and finally acceptance of - the limits of the archaeological interpretations available through the use of scientific data, and into looking for other, more human-centred explanations and interpretations, which do not necessarily exclude but complement the earlier ones.

1.4 Arrangement of the work

This introductory chapter has dealt with the background of this work and the research questions, as well as the theoretical orientation of this work. Chapter 2 moves to another subject, starting with a short discussion of what geoarchaeology is, and proceeding to a brief review of geoarchaeological research done in archaeological surveys particularly in Greece, as many of the methods of modern archaeological survey in the eastern Mediterranean, and consequently also the geoarchaeological questions asked and techniques used by the surveyors, have been developed there. Far from attempting to be all-inclusive, this review is meant to give an impression of the general development of the field of geoarchaeology in survey archaeology in the eastern Mediterranean, and to illustrate with some examples the changing research trends from the early days of geoarchaeological research to the present. Following this review there is a short introduction to geoarchaeological research carried out in archaeological surveys in Jordan. Also far from providing an exhaustive list of every project using geoarchaeology in Jordan - those are far too numerous to be presented here - it attempts to illustrate the interests and objectives lying behind the application of geoarchaeological techniques in different projects working in Jordan. Chapter 2 also contains a review of the history of archaeological research of the Petra region, concentrating on surveys. A summary of the FJHP survey methodology is included. Finally, questions concerning the reliability and problems of using and interpreting survey data are acknowledged and discussed in some depth.
Chapter 3 deals with the environmental setting of the research area. It begins with a short review of the palaeoclimatic data available in an attempt to give an idea of the general climatic development in the Levant, to lay down the foundation for later comparisons of the results of sedimentological studies and the palaeoclimatic record. A description of the past climate of southern Jordan and vegetation history of the Petra area is included, based on available data. Chapter 3 also includes the description of the environmental setting of the Jabal Harûn area, including bedrock, geomorphology, present day climate and vegetation.

Chapter 4 turns from the natural setting to the human agency. It contains a review of the settlement history in the Petra region based on published archaeological work, mainly surveys, by various researchers. The aim of Chapter 4 is to sketch the outline of the known human activities and settlement in the Petra region. The objective is not to give a detailed account of the sites and settlement in the Petra region through the ages, as such an undertaking seems far beyond the scope of this work, and the published information available is too restricted in many respects to attempt this, as the archaeological data from the Petra region is still very patchy. No doubt this is partially due to a bias in archaeological research in the Petra area that has preferred the Iron Age and the Classical periods as opposed to the prehistoric or the Late Classical and Islamic periods. After the presentation of the human history in the Petra region in general, a summary of the FJHP survey results up to the 2003 season is presented.

Chapter 5 returns to environmental questions, first discussing erosional processes and dryland hydrology in semi-arid regions in general, and then taking a look at the hydrology of the Jabal Harûn area and how both natural and human-induced erosional processes operate there, or can be expected to have operated in the past. It also lays out the foundation for the following Chapter 6, which finally concentrates on the geoarchaeological studies carried out in the Jabal Harûn area. The methods and results of the environmental studies, namely the mapping of wadi terraces, lithofacies studies and OSL dating, are presented and discussed in Chapter 6 to form a picture of what it is possible to know of the environmental development of the Jabal Harûn area based on results of the geoarchaeological studies.
In the final chapter, Chapter 7, the results of the geoarchaeological studies in the Jabal Harûn area are compared to, and combined with, the palaeoclimatic data presented in Chapter 3, and geoarchaeological studies from other areas in central and southern Jordan. This is done in order to both compare and complement the results of geomorphological and sedimentological studies in the Jabal Harûn area with data from other sources. After this the picture of human history in the Jabal Harûn area is compared to that of the environmental development to see whether the phenomena seen in the archaeological record could be connected to the environmental history of the area. Finally, the role of environmental change in determining human activity is discussed critically and some other potential factors are suggested for further study.
2. Research history

2.1 The definition of geoarchaeology

"Every archaeological problem starts as a problem in geoarchaeology"

Renfrew 1976:2

Geology and geography have had an important role in archaeology since the birth of the discipline in the 19th century - after all, one of the first researchers of the Palaeolithic was a geologist, Sir Charles Lyell, and the principle of stratigraphic succession, which forms the basis for all archaeological excavation, was introduced into archaeology from geology (Renfrew 1976: 2-3; Rapp & Hill 1998: 5-6). Geographical surveys in the British colonies made a significant contribution to the accumulation of knowledge about their archaeological research by recording also archaeological sites in the late 19th century (Goudie 1987: 13). Many early archaeological excavations were also carried out by earth scientists (Butzer 1982: 35-36). However, for several decades the main application of earth-science methods within archaeology was the use of geological deposits or formations to date archaeological materials.

Starting from the 1950s and 60s a wide scope of earth-science methods began to be adapted for the benefit of archaeological research and work done in the field increased considerably (Renfrew 1976: 2; Butzer 1982: 35-36; Rapp & Hill 1998: 12-15). This phenomenon was related to the increased interest in scientific methods in the 1950s brought on by the development of dating methods and the rise of the New Archaeology in the 1960s, which in itself was partially stimulated by the contemporary theoretical discussion in geography (Wagstaff 1987: 26-29). One of the main focuses of the New Archaeology was the human adaptation to nature, which necessitated the reconstruction of past environments (Wagstaff 1987: 29). The call for more rigorous data collection and focus on behavioural patterns based on the analysis of material cultural remains led to an increased interest in site formation.

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1 A thorough overview of the history of geoarchaeology is presented in Rapp & Hill 1998:4-17.
processes and artifact taphonomy. Answering these questions called for the application of methods adopted from natural sciences, which led to the emergence of the subfields generally termed together as environmental archaeology, including palaeoethnobotany, zooarchaeology - and geoarchaeology. (Rapp & Hill 1998: 13-15; Wagstaff 1987: 29-30.)

The terms “geoarchaeology” and “archaeological geology” have been used since the emergence of the subdiscipline in the 1970s (Rapp & Hill 1998: 3). However, Butzer pointed out already in 1982 (1982: 36) that there were varying views of what the term “geoarchaeology” actually encompassed, and the goals and techniques used were not identical. In a recent article Canti notes (2001: 104) that the difficulty and disagreement in defining the term “geoarchaeology” seems to be related to the variable scales at which geoarchaeological research is carried out. Butzer (1982: 37) listed “at least five” major interests in geoarchaeological field studies, namely survey techniques using varying procedures to locate sites or features, documentation of site forming processes and the spatial context of a site in a larger setting, techniques for differentiating cultural and natural features, development of temporal contexts by relative or absolute dating and integration of data for environmental reconstruction. Clearly these varying objectives also need different methods and approaches.

In the introduction to an early book on the subject, *Geoarchaeology* by Davidson and Shackley (1976), Renfrew (1976: 2) stated that

“geoarchaeology is primarily concerned with the context in which archaeological remains are found”.

Similarly, in an article discussing the role of geoarchaeology, Gladfelter (1977: 519) defines it as

“an approach to man’s past that focuses upon the geomorphological context of artifacts.”

These definitions describe geoarchaeology as being something related only to the immediate context in which archaeological remains are found. On the other hand, some archaeologists have tried to approach the definition of geoarchaeology by listing various methods of study. In his review of the foundations of geoarchaeology Butzer argues that rather than a repertoire
of techniques or “a processual counterpart to geochronology” geoarchaeology is primarily a conceptual approach, whose objectives should be discussed “in terms of the study components, the procedures and the ultimate collaborative goals” (Butzer 1982: 36).

In recent books dealing with the subject of geoarchaeology, the definitions are still variable. Rapp & Hill (1998: 1-2) favour a broad definition, saying that

“...geoarchaeology refers to the application of any earth-science concept, technique or knowledge base to the study of artifacts and the processes involved in the creation of the archaeological record.”

They maintain that in geoarchaeology “the framework and questions posed are strictly archaeological” as opposed to “archaeological geology” which is “geological research that has direct relevance to one or more archaeological contexts”. In their view, also dating, provenance and site location are included in the description of geoarchaeology insofar as they use methods derived from the earth-sciences to answer archaeological questions (Rapp & Hill 1998: 3-4).

French (2003: 3), on the other hand, takes a less all-encompassing view in his recent book Geoarchaeology in Action, emphasizing the view already expressed by Renfrew and Gladfelter that geoarchaeology is primarily focussed on soils and sediments. According to him,

“Geoarchaeology is the combined study of archaeological and geomorphological records and the recognition of how natural and human-induced processes alter landscapes. The main aim of geoarchaeology is to construct integrated models of human-environmental systems and to interrogate the nature, sequence and causes of human versus natural impacts on the landscape.”

Despite three decades of discussion and geoarchaeological research, the definition of geoarchaeology is still far from clear. There has even been discussion about whether geoarchaeology can be an acceptable term as it linguistically gives the impression of meaning “the archaeology of geology”, but so far no better candidate has emerged to describe the use
of earth-science methods in archaeology (Canti 2001: 105). While the discussion of its exact definition continues, geoarchaeology has established itself in the archaeological terminology. It is being practised widely and for various research goals, and despite the lack of a comprehensive description of the term “geoarchaeology”, most archaeologists have at least some idea of the kind of approach and methods indicated by it. To conclude, although single practitioners in the field of geoarchaeology may include a somewhat different set of methods under the definition “geoarchaeology”, all of them would probably agree with French that geoarchaeology is “part of archaeology, inextricably linked, not just geological research” (French 2003: 3).

2.2. History of geoarchaeological research in eastern Mediterranean surveys

2.2.1 Geoarchaeological research in archaeological surveys in eastern Mediterranean

Pioneering work in geoarchaeology in eastern Mediterranean was carried out in the Messenia survey in Greece already in the 1960s, when earth-scientists were included in the survey team (McDonald & Rapp 1972; Rapp & Hill 1998: 14), but the origins of the boom for geoarchaeological research in Mediterranean survey archaeology can be seen to be related to the increased interest in the application of scientific methods in archaeology generated by the spreading of processual archaeological theory with its requirements for objective, quantifiable data and reconstructions of past environments. Later on the methodological and theoretical development of archaeological survey as a research field in its own right has also been an important incentive for applying a wide array of geoarchaeological research methods in archaeological surveys, varying from soil micromorphology and geophysics to sedimentological studies.
An important work in the geoarchaeology of the Mediterranean was Claudio Vita-Finzi’s *The Mediterranean Valleys* (1969). Vita-Finzi studied phases of erosion and alluviation over the whole of the Mediterranean, and came to the conclusion that there were two major river aggradation phases that could be detected in all the areas surveyed. The resulting deposits appeared to be of similar age, and therefore Vita-Finzi termed them as the Older Fill, dating to the Pleistocene, and the Younger Fill, dating to the Middle Ages (Vita-Finzi 1969: 92-102). Vita-Finzi maintained that such a widespread increase in erosion and aggradation could only be caused by climatic changes, namely increased rainfall during the early part of the last Glaciation and again following the Medieval Climatic Optimum, during the Little Ice Age (Vita-Finzi 1969: 114-115). With his theory Vita-Finzi challenged the then prevalent Uniformitarian model of erosion in the Mediterranean region and pointed out that erosion and the resulting environmental change had not been a steady and continuous process over the millennia, but had occurred as relatively short-term events in a punctuated equilibrium.

A geoarchaeological component became commonplace in surveys in the Mediterranean, especially in Greece, over the 1970s. Much of the early geoarchaeological research was inspired by Vita-Finzi’s theory. Archaeologists doing regional surveys would find alluvial valley fills and relate these to Vita-Finzi’s Older and Younger fills (Bintliff 1992: 125). Especially John Bintliff promoted Vita-Finzi’s model among archaeologists (Jameson *et al.* 1994: 183-184). However, as more work was carried out it became apparent that the history of erosion in the Mediterranean lands was much more complicated than suggested by Vita-Finzi (see *e.g.* Pope & van Andel 1984: 285-287; Zangger 1992: 133-135). Changes in environment were not contemporaneous even over one region, nor could they be accommodated within a simple model of two phases of wide-scale climatic change (Wagstaff 1981: 249-258). This realisation led to the search of new explanations for the environmental change, and human activity, especially deforestation due to land clearance for cultivation, was pinpointed as the main cause of erosion (Bintliff 1992: 125-127; Zangger 1992: 135). It could even be said that the explanations of environmental change swung from climatic determinism to anthropogenic determinism. The research by van Andel and Jameson (*e.g.* Pope and van Andel 1984;
Jameson et al. 1994) in the southern Argolid had a particularly important role in this change of attitude.

Van Andel studied the evolution of the landscape in the southern Argolid in connection with an archaeological survey by the Argolid Exploration Project, Stanford University, directed by Jameson and van Andel between 1979 and 1983. He recorded seven stages of alluviation separated by periods of landscape stability (Jameson et al. 1994: 182). Three of these dated to the Pleistocene while four had taken place during the Holocene (Pope & van Andel 1984: 292-293). Notably there were no alluvial deposits related to the Last Glacial Maximum or the deglaciation and the beginning of the Holocene, which made the climatological explanation questionable. On the other hand he noted that a major phase of soil erosion has followed the spread of agriculture in Greece by 500 - 1000 years (Jameson et al. 1994: 189-192). This caused van Andel to conclude that the dominant control of the Holocene stages of erosion was more likely to be related to human activities, particularly agriculture and the use or neglect of soil conservation methods (Pope & van Andel 1984: 297). Therefore he compared the river degradation-aggradation cycles with the archaeological evidence of population fluctuations and land-use, related to economic and political factors. Although not all erosion phases could be satisfactorily related to population and settlement pattern changes, and more importantly, not all population fluctuations were reflected in the erosional history, van Andel explained this with changes in soil conservation methods - mainly the use or neglect of terracing - and concluded that the Holocene erosion and aggradation phases in the Argolid were related to human activities (Pope & van Andel 1984: 302-303).

With his model van Andel set the example for other contemporary archaeologists for studying and explaining environmental change in the eastern Mediterranean (Acheson 1997: 169; Bintliff 2002: 419-420). Human, rather than climatic explanation for environmental change was now preferred (e.g. Zangger 1992). It could even be said that the explanations turned from climatic to anthropogenic determinism. This development should probably be seen in the context of the contemporary growing ecological awareness and disillusionment with
technological development, which also influenced the conceptual orientation of archaeology (Trigger 1989: 319-326).

The model first presented by Pope and van Andel (1984) and later elaborated by van Andel and Runnels (1987: 101-117) and Jameson and van Andel (1994: 348-414) has been questioned by Endfield (1995) and Acheson (1997). The core in Endfield’s (1995: 242-245) criticism was that in the “van Andel model” data was fitted to the prevalent theory of anthropologically induced erosion and climatic factors were largely ignored as an explanation for the Holocene period, although they were accepted for the Pleistocene. Acheson criticized particularly the way how settlement patterns, formal economic trends and environmental change were tied together into an all-inclusive explanation in the final publication of the Argolid survey, *A Greek Countryside. The Southern Argolid from Prehistory to the Present Day* (Jameson et al. 1994). Both Endfield (1995: 244-246) and Acheson (1997: 183-185) questioned the interpretation that the use or neglect of soil conservation methods (i.e. terracing) was the main factor controlling erosion since people first started cultivation in the Argolid. Foxhall (1996) has also criticized the use of terracing as an explanation for stages of erosion and landscape stability, as there was no early archaeological or textual evidence for terracing in mainland Greece (see also Rackham & Moody 1992; French & Whitelaw 1999). Lately for example Endfield (1995: 246-247) and Bintliff (2002: 420-422) have been calling for explanations which would take into consideration both human and natural factors. A lasting virtue of van Andel’s study was that it managed to raise the awareness among archaeologists that erosion is probably often induced by complicated interplay of both human and natural factors rather than one or the other exclusively, and that erosion histories of different areas and their responses to the same climatic changes may vary considerably.

The shift in the emphasis of archaeological surveys in the eastern Mediterranean from wide regional surveys to smaller geographically defined areas since the 1980s, initialised by the developments of survey methodology (e.g. Cherry 1983) and the adoption of the landscape archaeological point of view, which emphasize a multi-period, siteless survey carried out by intensive fieldwalking as opposed to the earlier, often areally very extensive site- and/or
period-oriented surveys, has also influenced the goals of geoarchaeological research (Cherry 1994: 91-92). The scope of geoarchaeological methods used and questions asked has widened considerably (Cherry 1994: 96-97). Instead of trying to establish the environmental development of a wide area, geoarchaeology in survey projects is now more concerned with understanding the mechanisms and complicated relationships between human actions and environmental change operating in a specific landscape and affecting the preservation of sites and artefact taphonomy, as these are considered necessary in understanding the dynamic interaction between people and their environment over time.

2.2.2 Geoarchaeological research in archaeological surveys in Jordan

Geoarchaeological research has been a part of several survey projects in Jordan. The main objective has usually been reconstructing the environment or understanding site formation processes. A particular interest in many projects has been reconstructing the Pleistocene and Early Holocene environments to understand and explain prehistoric subsistence strategies (e.g. Henry et al. 1981; Garrard et al. 1994; Maher & Banning 2001; Coinman 2004). However, geoarchaeological questions and environmental change appear to have been of less interest for archaeologists working with the historical periods, probably due to the different research traditions of prehistoric and classical archaeology.

Early geoarchaeological work in Jordan was carried out by Vita-Finzi in Wadi al-Hasa (Vita-Finzi 1969: 83-88) and the geoarchaeology of the area has been studied also later on several occasions, for example by Copeland & Vita-Finzi (1978), Schuklenrein and Clark (1994, 2001), Hill (2000) and Coinman (2004). The Hesban Expedition in central Jordan which begun in 1968 came to include the survey of bedrock, surficial geology and soils, as well as climatological, hydrological, and phytological conditions at Tell Hisban and its vicinity (LaBianca & Lacelle, eds. 1986; Harrison 1997: 6). In southern Jordan Henry, Hassan and others (1981) investigated the alluvial fans and wadi terraces in Wadi Judayid in conjunction with a survey in the Ras an-Naqb area in 1979, and Henry continued the work later in Wadi
Hisma. The aim of their research, as well as most geoarchaeological investigations carried out in Wadi al-Hasa, was to reconstruct the Pleistocene - Early Holocene environment mainly in order to understand human subsistence and settlement patterns. (See Map 4.1 for the locations.)

In the 1980s archaeological surveys with a geoarchaeological component or having even primarily geoarchaeological goals began to proliferate also in Jordan like elsewhere in the Mediterranean area. Among these are the long-running Wadi Ziqlab geoarchaeological survey in north-western Jordan directed by Edward Banning, started already in 1981 (Banning 1983; Field & Banning 1998; Maher & Banning 2001), the multi-disciplinary Madaba Plains Project which started in 1984 with the objective to expand from the work carried out by the Hesban Expedition (Harrison 1997: 6-7), and the survey of the Azraq basin in northeastern Jordan by Andrew Garrard and others, mainly between 1982-1989 (Garrard et al. 1988; Garrard et al. 1994), to mention but a few.

The geoarchaeological study in Wadi Ziqlab has been conducted in connection with the archaeological survey of the area. Particular attention has been paid to site formation processes, especially to understanding the influence of geomorphological processes to settlement patterns between the Epipalaeolithic and Late Neolithic (Maher & Banning 2001: 65). During the survey several buried sites were found in a systematic subsurface testing of colluvial slopes and the wadi bottom, which confirmed that hillslope processes had distorted the results of the surface survey performed first. The project has also studied modern landslides in order to identify different slope processes and to discern the impact they have on site burial, artifact transport and prehistoric land use. (Field & Banning 1998: 596-614.) The investigations have included geomorphologic study of the deposits as well as sedimentological and pedological analyses (Maher & Banning 2001: 65-66).

The main objective of the geoarchaeological research in the Azraq basin was to understand the different environments and human subsistence and settlement strategies during the Late Pleistocene and Early Holocene. Geomorphological and sedimentological studies were carried
out in the centre of the Azraq basin and its inflow wadis to reconstruct hydrological and climatic history. The research also included the study of faunal and botanical remains from the archaeological sites chosen for detailed study. (Byrd & Garrard 1990: 81; Garrard et al. 1994:177-183.)

In the 1990s geoarchaeological surveys extended to southern Jordan. The Southeast Araba Archaeological Survey, carried out during three field seasons in conjunction with the Roman Aqaba Project in the 1990s (Niemi & Smith 1999, Smith et al. 1997), and the Wadi Faynan Landscape Survey by the Centre for the British Research in the Levant (CBRL) between 1996-2000 (Barker 2002: 208; Barker et al. 1997, 1998, 1999, 2000) both included a geoarchaeological component.

In the Southeast Araba Archaeological survey geoarchaeological research was conducted along 75 km in the southeastern Wadi ‘Arabah, stretching as far north as to Wadi Abu Barqa (Niemi & Smith 1999: 792). The geoarchaeological study included geomorphologic interpretation of fluvial systems based on aerial photos and descriptions of sediments and soils at selected sites to interpret changes in the palaeoenvironment and palaeoclimate of the area (Niemi & Smith 1999: 791-792). Later in the 1990s the inter-disciplinary Wadi Faynan Landscape Survey was aimed at the reconstruction of the environment in Wadi Faynan and also at understanding the processes of desertification and environmental degradation in dryland areas in general (Barker et al. 2000: 27-29). The research included geomorphological, sedimentological and palynological studies. A particularly large body of data was collected about the environmental impacts of the Roman-Byzantine mining and smelting industry in the area (Pyatt et al. 2000).

However, in the Petra area the interest in geoarchaeological or environmental studies has been limited so far. Geoarchaeological research has been carried out at the Natufian and PPNB site of Bayda (Byrd 1989b). Palaeoenvironmental data was also collected for the Tübingen Atlas of the Middle East in the 1980s mainly in the Sabra area (Schyle & Uerpmann 1988: 39) and by the Early Holocene research project directed by Gebel (Gebel 1988). Both of these studies
have been aimed at understanding the Early Holocene environments. Much less interest has been paid to the later prehistory and historical periods. Fall (1990) has studied the vegetation of the Roman, Byzantine and Early Islamic periods using pollen recovered from fossil Hyrax middens in the surroundings of Petra. The palaeobotanical studies carried out at excavations in Petra and its vicinity have so far concentrated mainly on cultivated plants (Karg 1996; Jacquat & Martinoli 1998; Frösén et al. 2001b: 386-387). The recent multi-period archaeological surveys by the Department of Antiquities (‘Amr et al. 1998; ‘Amr & al-Momani 2001) and by IFAPO (Tholbecq 2001) have not included geoarchaeological research.

2.3 Archaeological surveys in the Petra region

2.3.1 Sources of archaeological survey data for the Petra region

Archaeological research in the Petra region has mainly concentrated on excavations in the town itself, which is reflected in the lack of systematic survey data from the surroundings. For a long time the knowledge of archaeological sites in the area surrounding Petra was largely based on the early research by Brümnow and Domaszewski in the late 19th century, Musil in the early 20th century (Tholbecq 2001: 399-400) and Nelson Glueck in the 1930s (Glueck 1945). Later on, research by Manfred Lindner and Naturhistorische Gesellschaft Nürnberg on various locations over three decades has filled in the picture especially regarding to the Bronze and Iron Ages and the Nabataean period (e.g. Lindner 1987; Lindner et al. 1996a-b; Lindner et al. 2000).

However, it was only in the 1980s that archaeological surveys began to be carried out in southern Jordan. In the survey of Edom, Hart and Falkner (1985) surveyed the area between Tafila and Ras an-Naqb (Map 4.1), but their survey was rather sporadic and concentrated on ceramic material only, meaning effectively the periods from the Iron Age forwards as no Bronze Age material was found in the survey (Hart & Falkner 1985: 256). Part of the same
area has recently been surveyed by the Tafila-Busayra Archaeological Survey (TBAS), which has included also the prehistoric periods (MacDonald 2004). Killick (1986; 1987) made a survey in the surroundings of ‘Udhruh concentrating on the Roman to Byzantine periods. Around 200 sites, most of them not previously known, were reportedly recorded in the survey (Killick 1986: 432), but unfortunately there is very little information about them available, as the results of the survey have not been published. Graf (1992, 1995) has surveyed mainly Nabataean to Byzantine sites in the eastern plateau in connection with his survey of the Via Nova Traiana. While the periods between the Iron Age and the Byzantine period have thus received quite a lot of attention, a palaeoenvironmental investigation led by Gebel in the early 1980s is the only example of the survey of Epipalaeolithic and Neolithic settlement in the Petra area (Gebel 1988).

Nevertheless, most of these surveys have been site-oriented and concentrated on certain questions or periods only. In addition to the work by the FJHP, only two surveys in the late 1990s, namely the Wadi Musa Water Supply and Wastewater Project survey by the Department of Antiquities of Jordan in 1996 and 1998-2000 (‘Amr et al. 1998; ‘Amr & Al-Momani 2001) and the Jabal ash-Sharah Survey (JSS) carried out by the French Institute of Archaeology in the Near East (IFAPO) in 1996-1997 (Tholbecq 2001) can be considered systematic multi-period surveys, although the Jabal ash-Sharah survey excluded the prehistoric periods (Tholbecq 2001: 399).

Although the Wadi Musa Water Supply survey was carried out as a part of an engineering work and therefore it only covers a narrow area along the new water pipeline, it probably provides the most complete cross-section available of the settlement in the Petra region. The survey recorded archaeological sites from the edge of the Wadi ‘Arabah in the west via Wadi Musa to at-Tayyiba in the south and to Jiththa on the eastern desert margin (‘Amr & al-Momani 2001: 253-254). Relatively detailed results of the survey have been published in the Annual of the Department of Antiquities of Jordan (‘Amr et al. 1998; ‘Amr & al-Momani 2001). The total number of sites recorded in the survey is 132, most of which were newly discovered during the course of the project (‘Amr & al-Momani 2001: 283).
The Jabal Shara Survey (JSS) comprised the Wadi Musa drainage basin, concentrating on the time period from Iron Age to late Islamic (Tholbecq 2001: 399). Unfortunately only the preliminary results are available so far, and no detailed information of the sites is available. The work was based on a preliminary investigation of aerial photographs, on which sites were identified prior to visiting them. The total number of sites visited by the JSS is 160, including both previously known and newly identified sites (Tholbecq 2001: 400).

2.3.2 The FJHP survey

The FJHP survey is an intensive, total survey which means that in principle the whole area is fieldwalked. In practice the steepest slopes are not surveyed as walking there would be very difficult and potentially unsafe. However, it is considered likely that any archaeological material on those slopes would have been washed down. The surveyed area (Map 2.1) is divided into tracts typically measuring ca. 50-60 x 100 m (Appendix B), which are walked usually by 4-6 people walking at 10 m distance of each other. A description form is filled for every tract, including its location, the archaeological finds and other remains detected, tract geomorphology, degree of erosion and vegetation. All the surface finds detected are collected and subsequently washed, sorted and counted. All the lithics and the diagnostic pieces of pottery (rims, handles and painted sherds) are saved for identification and study. (Lavento et al. in press.)

The FJHP survey is a siteless survey, which means that the whole area is surveyed regardless of the number of finds. Sites are defined on the field or sometimes afterwards on the basis of find concentrations and/or structural remains. The number and nature of surface finds, geomorphological factors, interrelationships between installations, and the boundaries of the site, including a sketch, are recorded on a form to ensure uniform documentation of sites. Sites are also photographed and the structures are sometimes drawn in detail. Small soundings have been made at several sites to get more information about the site or structures. The dating
of the sites is based on the analysis of lithics and/or pottery found from the site, as well as architectural details in the case of building remains. (Lavento et al. in press.)

On the field the survey staff works with the personnel from the Department of Photogrammetry at the Helsinki University of Technology. A total station is used to measure all archaeological structures and locations defined as sites. Tract corners are likewise measured with total station or portable GPS. By using a network of known control points in the survey area, measured with GPS and total station, the measurements can be transformed to a global coordinate system (UTM) (Frösén et al. 1999: 370-371). This enables the accurate positioning of the structures and tracts on maps. Photogrammetric measurements are used to record extensive terrace wall systems and major structural remains.

Map 2.1 The area surveyed by the FJHP team on a digital elevation model. (Map: FJHP/H. Junnilainen & A. Erving).

The total number of sites recorded in the FJHP survey between 1998-2003 is 182 (Appendix B). The most common site category is formed by hydraulic installations, namely barrage and terrace wall systems. Most of these sites were previously not recorded. Other common site
types are lithic scatters and remains of building structures, which often yield also pottery. Building remains include possible farmhouses, cultic installations and small buildings often related to an ancient caravan route which crosses through the survey area (Frösén et al. 2000: 418; 2001a: 389-391; Zayadine 1985: 164). Most of these buildings have been dated to the Nabataean-Early Roman period on the basis of the pottery found in relation to the structures, but there are also a few structures which have no associated pottery. Other sites include rock-cut Nabataean graves, water channels and cultic installations. There are also numerous rock drawings especially on the slopes of Jabal Harūn, many of them related to pilgrimage to the mountain.

2.3.3 The nature and problems of survey data

As can be seen from the material presented above, it is not straightforward to infer periods of human occupation in the Petra area from the available survey data. The attention of the archaeologists has been largely focussed on a few sites, such as Bayda, Umm al-Biyara and Petra itself, and at certain periods, particularly the Iron Age and the Classical periods. As a result also the surveys have been mostly period- and site-oriented. The lack of systematic, multi-period surveys means that our understanding of many archaeological periods in the Petra region is still patchy at best. Particularly the Prehistoric and Islamic periods are clearly under-represented in archaeological research, and therefore also archaeological data and information concerning these periods can be expected to be lacking.

The whole concept of site is problematic. The definition of a site is always subjective, and different archaeologists and research traditions use different criteria on what is called a site (Mattingly 1999: 6; Fentress 1999: 48-49; Banning 2002: 81-82). In survey reports it is seldom explicitly stated how the sites have been defined, which adds an element of uncertainty and potential error into the use of the results. Survey results are most often presented as numbers of sites dated to each archaeological period. The number of sites alone can give a very misleading picture of the settlement and activity in an area, unless information on the types
and sizes of the sites is also available. It should also be borne in mind that human activity does not just concentrate on certain isolated points (sites) but there is a wide variety of activities that take place outside these specific locations, and archaeological materials cover the landscape in a more or less continuous manner (Zvelebil & Beneš 1997). Non-site or off-site survey (Foley 1981; Rhoads 1992; Dunnell 1992; Alcock et al. 1994: 137-138; Banning 2002: 7-8, 19-20) attempts to take into consideration the whole of this evidence to form a comprehensive picture of the past human activities that have taken place in the landscape.

A central problem with survey data is its representativeness. It is seldom that archaeologists have the possibility to exhaustively survey every part of their research area. Rather more common are various techniques of sampling to choose parts of the research area that can be considered to be representative of the area as a whole (Cherry 1983; Mattingly 1999; Banning 2002: 113-132), or prospecting for the archaeology in the landscape by using e.g. aerial photographs before actually going into the field (e.g. Tholbecq 2001; MacDonald 2004). The choice of survey methods result in a variable resolutions of data produced, which constitutes a problem when comparing the results from different surveys.

Also taphonomic or post-depositional factors, i.e. various processes influencing site preservation, can influence surface survey results (Banning 2002: 72-74). The Petra region considered, erosion is probably one of the most important taphonomic factors affecting the preservation of archaeological sites. Erosion can destroy or obscure archaeological sites by transporting materials or through the burial of the site (Waters & Kuehn 1996: 484-485; Field & Banning 1998). Even if the site is not completely destroyed, erosional processes may transport some or all of the material downslope and obliterate any intra-site variability (see e.g. Wainwright 1992).

Aside from problems of survey methodology or site taphonomy, there are problems concerning the archaeological material that forms the source of the interpretation and dating of a surveyed site. Most often sites are dated by surface collection of pottery only, which is subject to many sources of error (Millett 1999; Malone & Stoddart 1999). The dating of
pottery is usually based on excavated pottery stratigraphies, and where a detailed stratigraphy is not available, it is difficult to date finds more accurately than to a certain period (Cherry 1983: 379), as for example is the case with the Ayyubid-Mamluk pottery, which is commonly grouped together although it represents a period of 250 years (Walmsley 2002: 523). The resolution of the dating is also variable: Nabataean fineware styles can be dated with an accuracy of decades (Schmidt 1996), but usually the accuracy of a dating based on surface pottery is within the range of a century at best (Schick 1994:137). The dating of pottery is usually based on diagnostic elements which are often less frequent in surface collections (Rutter 1983:137-138; Malone & Stoddart 2000:95). Particularly the transitional forms from the late Byzantine to the early Islamic period are poorly known and therefore difficult to date (Fiema 2002a:203). The pottery of the Islamic periods has also received little attention so far, and the lack of excavated stratigraphies is a problem (Schick 1997: 81; Walmsley 2002: 523). Moreover, the hand made pottery of the Ayyubid and early Mamluk period (11th-13th centuries) is typologically very variable which complicates the accurate identification and dating of the survey finds (Walmsley 2002: 549-550).

Different archaeological periods may also vary highly in the distinctiveness of their pottery. A combination of processes may increase the proportion of coarse wares in surface collection, as fragile pottery is unlikely to survive for long periods on the surface. (Malone & Stoddart 2000: 96.) The common ware types are more difficult to identify and date due to small stylistic differences. The styles also tended to change less quickly in the common wares and may have overlapped considerably (Millett 1999: 54-57; Schick 1994:137; Gerber & Fellman Brogli 1995).

Another problem is the variable preservation of pottery and other materials from different periods. Prehistoric ceramics are usually less resistant to degradation as their firing temperature has been low. If exposed on the surface, they will therefore be rapidly destroyed by trampling and erosional processes. (Malone & Stoddart 2000:96.) The problem of degradation is not limited to the prehistoric pottery. It has been noted for example that Byzantine ware is less durable than Nabataean ware, which is likely to cause its under-representation in a surface
collection. Likewise the rather robust flint material from the Middle Palaeolithic is less vulnerable to trampling by people and animals and less subject to the transporting effects of erosion than the microlithic flint material from the later periods.

In interpreting the results of surface survey there is also the problem of how representative the material on the surface is of the material beneath the surface (Cherry 1983: 398-399; Gaffney 1999; Malone & Stoddart 2000: 101; Field & Banning 1998). Evidence of earlier periods may be buried under later settlement or a later intensively settled period may obscure earlier periods of less intense settlement, which can therefore go unrecognised in surface survey (Schick 1994: 136-137). There are examples where older material has been found on the surface of a site, where it has been spread during the renovation of a structure, and only excavation has revealed the later phases of occupation at the site (Schick 1994: 136). The common practice of re-use of building materials and ancient structures, which is well-documented in the Petra region and appears to have taken place throughout the archaeological time (e.g. 'Amr et al. 1998: 521, 526; ‘Amr & al-Momani 2001: 267), is also likely to lead to the disappearance of archaeological remains even at places where the original site is not covered by later occupation.

The land-use practices during a certain period also affect the visibility of that period in the archaeological record. Sedentary communities tend to leave more material remains than those with subsistence based on nomadic animal husbandry (Finkelstein 1995: 24-26). Moreover, many extensive forms of land-use, such as hunting, gathering and herding, leave few archaeologically detectable traces. It can be suggested that the population in the Petra region has fluctuated between sedentary and mobile ways of living (Finkelstein 1995: 26-27), and during many periods which are archaeologically very poorly represented the more mobile alternative was the dominant one, although it seems plausible that the mobile element was always present at least in the outskirts of the sedentary settlement. Later land-use and heavy erosion can also easily wipe out ephemeral archaeological remains such as short-lived campsites.
Also the availability and use of pottery and other materials influence the archaeological visibility of a cultural period (Malone & Stoddart 1999: 101). When the use of “formal” flint artifacts ends, the tool side of archaeological cultures becomes almost invisible in a surface survey. Metal objects have often been too precious to be discarded, and their material may have been re-used. It is also unlikely that very old metal objects would be found in a surface survey, as they will quickly get corroded and broken. On the other hand, there is evidence that the use of flint as a material for tools such as threshing sledges may continue into late historic times (Avner 1998: 167-169), and also the Bedouin in the Petra area have used flint during the historical period (Kujit & Russell 1993).

The amount of pottery in use and the rate of its deposition in the landscape may vary during different archaeological periods depending on such factors as the economic situation, how valuable pottery has been regarded and for what purposes it has been used (Alcock et al. 1994: 141; Malone & Stoddart 1999: 101). One example of the varying use of pottery from a period to another is the Nabataean to Byzantine period. During the Nabataean period the Nabataean fine ware pottery found its way into the landscape in several ways. It seems to have been relatively abundant at the settlement sites, but it is even more abundant at the numerous cultic sites dotting the surroundings of Petra. In the FJHP survey a dense background scatter of Nabataean-Early Roman pottery has also been found in parts of the ancient field system (Lavento & Huotari 2002: 103-105), possibly indicating intensive cultivation and the practice of manuring (Lavento et al. forth.b). Pottery distributed in the surroundings of archaeological sites is commonly attributed to the practice of manuring the fields with a mixture of animal dung and household refuse (Bintliff & Snodgrass 1988; Alcock et al. 1994: 142). The small farmsteads or hamlets which are found located near the fields seem to support this model for cultivation (see Alcock et al. 1994: 148). The lack of later pottery after the Nabataean-Early Roman period does not, however, necessarily mean that the area was not used at all. In a more extensive mode of cultivation the fertilization of fields may be taken care of in different ways which leave no material evidence, for example by rotating crops and fallow or by keeping animals in the fields after the harvest (Alcock et al. 1994: 147-148).
Last but not least it should be borne in mind that longer archaeological periods are also likely to be represented by more sites and materials than short periods - for example the Middle Palaeolithic covers tens of thousands of years while the whole of the Epipalaeolithic only lasts a few thousand years. Thus the numerous Middle Palaeolithic sites in the Jabal Harûn area do not necessarily mean very intense human activity, as they may be the result of thousands of years of human visits to the area. On the other hand the abundance of Nabataean material from a period of only a hundred years means very intensive use of the area during that time.
3. The environmental setting of the research area

3.1 Past climate of the Near East

3.1.1 The nature of the palaeoclimatic data

Although there is an increasing body of data on the past climate of the Near East, the results from different studies are far from unambiguous. It appears that the climate has varied considerably within a relatively small geographical area and the changes in climate have not been simultaneous or even similar over the Near East. Different research methods also produce data of variable resolution. It is attempted here to use climatological reconstructions preferably based on data that is independent of archaeological evidence, as it is felt that climatic reconstruction based on the availability of archaeological evidence has a strong likelihood to lead to a circular argument.

It should be borne in mind that due to the temporal resolution of different sources for palaeoclimatic data only the long-term climatic changes are likely to be visible in the record. However, it is short-term events such as floods or drought years not represented in the palaeoclimatic records, that are noticed by people and have an immediate impact on their lives. What the palaeoclimatic record does tell us, however, is whether the likelihood of e.g. drought years has increased during a certain period of time.

Relatively little climatic data is available from Jordan, and even less for the southern part of the country, including the Petra region. The palaeoclimatic data from Jordan is mainly based on sedimentological and geochemical evidence from Lake Lisan sediments (Abed 1985; Abed & Yaghan 2000; Landmann et al. 2002) and wadi fan sediments in the Jordan Valley - Wadi ‘Arabah (Vita-Finzi 1969: 83-88; Henry 1986). Additional palaeoclimatic data relevant for southern Jordan is available from the studies of the isotopic composition of corals in the Red Sea (Moustafa et al. 2000). Geoarchaeological studies, which have been carried out
particularly in Wadi al-Hasa (Vita-Finzi 1969: 83-88; Copeland & Vita-Finzi 1978; Schuldenrein & Clark 1994, 2001; Hill 2000; Coinman 2004) and in the northern and north-eastern parts of the country, like Wadi az-Zarqa (Palumbo et al. 1996), Wadi Ziqlab (Field & Banning 1998; Maher & Banning 2002) and the Azraq basin (Byrd & Garrard 1990; Garrard et al. 1994), also yield palaeoenvironmental information. For southern Jordan geoarchaeological and palaeoenvironmental information is available from the studies in the Ras an-Naqb area (Henry et al. 1981), Wadi Faynan (Barker et al. 2000) and southeastern Wadi ‘Arabah (Niemi & Smith 1999, Smith et al. 1997). However, there are more variable sources of palaeoclimatic information available from studies on the western side of the Wadi ‘Arabah - Jordan Rift, and although applying this data for the eastern side of the Rift may admittedly be risky, as the climatic history of the two areas is not necessarily altogether similar, it is nevertheless considered that the data from the western side of the Rift can be used as a proxy to understand the generic climatic development in the area.

Palynological studies have been carried out at various locations in the northern parts of the Levant. The pollen cores closest to southern Jordan have been studied from the Hula Basin by Horowitz (1979: 217-230), van Zeist and Bottema (Bottema & van Zeist 1981; van Zeist & Bottema 1982; 1991) and Baruch and Bottema (1991), from Lake Gennesaret by Horowitz (1979: 231-233) and Baruch (1990), and from the Dead Sea Basin also by Horowitz (1979: 234-236) and Baruch (1990). Palynological studies have also been carried out from sediments at many archaeological sites (e.g. Horowitz 1979: 245-254, Leroi-Gourhan 1982), but according to van Zeist and Bottema (1991: 115) these results are problematic for inferring the overall picture of vegetation in the surroundings of the site because of the selective formation of the pollen record at archaeological sites.

Bar-Matthews and others (Bar-Matthews et al. 1997, 1999; Vaks et al. 2003; Bar-Matthews & Ayalon 2004) have studied the climatic indications of the carbon and oxygen isotopic composition of speleothems in the Soreq and Ma’ale Efrayim caves. Fluctuations of Dead Sea levels have been studied by many researchers (Frumkin et al. 1994; Geyh 1994; Frumkin & Elitzur 2002; Enzel et al. 2003). Various palaeoclimatological studies have also
been carried out in the Negev desert: palaeosoil formation (Goldberg 1981, 1994; Goodfriend and Magaritz 1988), palaeohydrology (Frumkin et al. 1998), early Pleistocene lake deposits (Ginat et al. 2003) and Late Pleistocene arboreal vegetation (Baruch & Goring-Morris 1997).

However, as the main interest of the research has often been the climatic changes during and soon after the termination of the last Glacial, a lot of the available palaeoclimatic data concentrates on the Late Glacial - Early Holocene period. Another relatively well-known period of climatic change is between ca. 6000-5000 BP. During the later Holocene the climatic changes in the Near East have been of a smaller magnitude, which makes them more difficult to discern from different records of palaeoclimate. Much less climatic data is therefore available for the later Holocene. The palynological data available for the later Holocene cannot be reliably connected to the climate, as the changes in the vegetation are more likely to be the result of human activity such as cultivation and clearing of forests. In this work the late Holocene climate has been mainly inferred from the Dead Sea levels (e.g. Bruins 1994; Geyh 1994) For the historical period, there is a dendrochronological sequence from southernJordan which covers roughly the last four centuries, studied by Touchan and Hughes (1999).

3.1.2 Climate of the Near East from the Pleistocene to the present

Based on the study of sediments in the northern Jordan Valley it seems that the climate of the Near East was very arid during the Neogene (Late Pliocene), but became more humid towards the end of the Neogene and Early Pleistocene. In this period the central and northern Jordan Valley was occupied by freshwater lakes. During the Pleistocene (beginning at 1.8 Ma) arid and humid periods have alternated. (Abed 1985: 88-89.) Studies of lake deposits from Lake Zihor in the southern Negev have revealed at least three periods of humid climate separated by dry periods and lake desiccation during the Early Pleistocene (Ginat et al. 2003: 453-457). In Wadi al-Hasa several cycles of soil development and the formation of travertine in springs has taken place before 200 000 BP (Schuldenrein & Clark 1994: 46).
Information about climatic changes in the Mediterranean scale after 200,000 BP is available from studies of sapropel formation in the basins of the Mediterranean Sea (Kallel et al. 2004). Sapropels were usually formed in conditions of increased rainfall, which caused desalinization and stratification of the water in the Mediterranean Sea, resulting in bottom water anoxia which led to the deposition of organic rich horizons (sapropels). The periodic sapropel formation indicates humid climatic periods around 195,000 BP, 170,000 BP, 122,000 BP, 96,000 BP and 80,000 BP. Most of these periods appear to have been warm, with the exception of the period between 180-170,000 BP, which is related to the cooling of climate. Another period of cooling, reflected by the desalinization of sea water but not with sapropel formation, is associated with the first Heinrich event ca. 140,000 BP. (Kallel et al. 2004: 317-319.)

Isotopic studies of speleothems in Soreq Cave, Israel, also indicate warm and wet periods between 107-101,000 BP and 85,000-79,000 BP, and a period of very high rainfall and increased erosion between 124,000-119,000 BP (Bar-Matthews & Ayalon 2004: 372-385).

These humid periods indicated by the formation of sapropels cover most of the Middle Palaeolithic1. A humid period corresponding to the Middle Palaeolithic is also evidenced by the existence of a high lake stand in Wadi al-Hasa (Schuldenrein & Clark 1994: 46) and by the sediments of Lake Lisan, the predecessor of the Dead Sea, which indicate a high lake stand between ca. 70,000 - 45,000 BP (Landmann et al. 2002: 54, see also Bartov et al. 2002: 17-18). Towards the end of the Middle Palaeolithic - beginning of the Upper Palaeolithic (ca. 40,000 BP) the climate appears to have become drier (Henry 1986: 9-10). There is evidence of periods of cooler and drier climate in the isotopic composition of the Soreq Cave speleothems around 45,000 BP and 35,000 BP (Bar-Matthews & Ayalon 2004: 372-385). Also by the sedimentary evidence it seems that during the Late Pleistocene the climatic trend was similar to that of the present, and the southern parts of the Jordan Rift have been more arid than the northern parts (Abed 1985: 90).

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1 Please refer to Appendix A for the dating of the archaeological periods.
Several climatological studies have now shown that the notion that glacial and interglacial periods in Europe corresponded to cool and rainy pluvial periods and warm and arid interpluvials in the Near East is oversimplified. It appears that at least during the last (Würm) glacial there have been both cool and warm humid periods and cold and very arid periods in the Near East. Both the sedimentary evidence and the oxygen isotope data from speleothem studies point towards a wetter period ca. 30 000-22 000 years ago, followed by cool and arid climate during the Last Glacial Maximum ca. 22 000 - 17 000 BP (Henry 1986: 10; Goodfriend & Magaritz 1988; Byrd & Garrard 1990: 92; Abed & Yaghan 2000: 30; Bar Matthews et al. 1997: 161-164). The level of Lake Lisan was at its maximum between 27 000 - 23 000 BP (Bartov et al. 2002: 19). There were lakes and marshes also in southern Sinai (Gladfelter 1997:382-383), Wadi al-Hasa (Schuldenrein & Clark 1994: 46; Coinman 2004: 79-80) and the Jafr basin in southern Jordan (Abed & Yaghan 2000: 30). There is evidence of high lake stand in Wadi al-Hasa between ca. 26 000 - 20 000 BP, followed by recession and replacement of the lake by marshy environments (Schuldenrein & Clark 1994: 46; Coinman 1994:93). Dry climatic conditions during the Last Glacial Maximum are also supported by the terminal deposits of Lake Lisan (Abed & Yaghan 2000: 30; Bartov et al. 2002: 19).

Speleothem data and pollen analysis indicate that as glaciers in Europe melted, temperatures gradually began to rise and precipitation increased also in the Near East after ca. 17 000 BP (Bar Matthews et al. 1997: 164; Baruch & Bottema 1991: 16; Landmann et al. 2002: 55; Goodfriend & Magaritz 1988; Byrd & Garrard 1990: 92). It has been suggested that precipitation was less seasonal than at present, with drier winters and wetter summers (Roberts & Wright 1993: 198-199). However, the development towards warmer climate was not continuous, as there were large-scale fluctuations. Both speleothem and palynological studies give evidence that a warm and humid phase, which corresponds to the Bølling/Allerød interstadial in Europe, ended abruptly at ca. 11 500 BP, followed by arid, cool climate, probably due to the global reversal to the glacial conditions during the Younger Dryas (Bar Matthews et al. 1997: 164-166; Baruch & Bottema 1991: 6-17). On the other hand, Wright (1993: 464-465) has suggested that the drying trend was the result of the southward shift of
monsoonal rains and the strengthening influence of the Mediterranean climatic regime in the Near East. The isotopic composition of the Soreq cave speleothems does not indicate monsoonal rains as a source of rainfall during the Late Pleistocene (Bar-Matthews et al. 1999: 86). However, monsoonal rains might have reached the more southern parts of the Levant (Abed & Yaghan 2000: 30-31) as apparently happened during the later Holocene (Moustafa et al. 2000: 749).

There is plenty of evidence from various sources that the climate of the Early Holocene, corresponding to the beginning of the Neolithic period in the Near East, was considerably wetter than at present (Hoelzmann et al. 2004: 228-230; Bar-Matthews et al. 1997: 165, 1999: 91; Bar-Matthews & Ayalon 2004: 377-385; Baruch & Bottema 1991: 17; Fontugne et al. 1994: 83; El-Moslimany 1994: 121). Bar-Matthews and Ayalon have calculated that there was at least 20% more rainfall than at present (Bar-Matthews & Ayalon 2004: 381). Sedimentological studies from Bayda have revealed that the onset of massive erosion happened around the beginning of the Early Neolithic period (Field 1989: 86). Bar-Matthews and others (Bar-Matthews et al. 1997: 165) have suggested that during this period heavy rainstorms occurred throughout the year. However, the palynological evidence is not in complete agreement with the speleothem data. Although the forests expanded again, the earlier deciduous oak forests seem to have been replaced by evergreen oak and other Mediterranean type vegetation (Baruch & Bottema 1991: 17). This change might be explained by the climate beginning to resemble that of the present day, i.e. rainy winters and dry summers, which on the other hand does not fit with Bar-Matthews’ suggestion of year-round storms (see also El-Moslimany 1994: 122, 129).

It is generally considered that after ca. 7000 BP the climate of the Near East has resembled that of today (e.g. Bar-Matthews et al. 1997: 161-166), i.e. semi-arid with dry, hot summers and periodical winter rains, which often come as heavy rainstorms. The data from the Sahara-Sahel regions and the Arabian Peninsula suggests that changes in climate became more temporally and spatially variable after the Early Holocene wet period (Hoelzmann et al. 2004: 230-231). It has been suggested that in the Late Chalcolithic period - beginning of the Early
Bronze Age the climate was more humid than at present, although, it should be emphasized, still within the climatic semi-arid range (Bruins 1994: 304; Frumkin et al. 1994: 321-329). This period is marked by the highest level of the Dead Sea during the mid-Holocene (Frumkin & Elitzur 2002: 337). Summer temperatures appear to have been higher whereas winter temperatures were lower than at present (Moustafa et al. 2000: 748). This led to effectively higher winter precipitation than at present, but it seems possible that rainfall occasionally occurred also during the summer months. This may be related to changes of monsoonal activity recorded e.g. in the Arabian Sea and on the coast of Oman (Lückge et al. 2001; Lézine et al. 2002), related to changes of solar radiation. The monsoonal rains from the Indian Ocean may have reached the Gulf of ‘Aqaba (Moustafa et al. 2000: 742-749), which could have brought summer rains as far as to southeastern Jordan. However, it is not known whether these rains could have reached the Petra area.

Towards the end of the Early Bronze Age the climate again took a drier turn, possibly becoming even more arid than at the present during the Middle Bronze Age, as indicated by the drop of the level of the Dead Sea, which began around 2300-2100 BC depending on the sources (Enzel et al. 2003: 268; Frumkin & Elitzur 2002: 337). An arid climatic phase is also reflected in the isotopic record of the Soreq cave speleothems between 4600-4000 BP (Bar-Matthews et al. 1999: 91; Bar-Matthews & Ayalon 2004: 381) and severe aridification in northern Africa and the Arabian peninsula is indicated at several sites between 4000-3600 BP (Hoelzmann et al. 2004: 230-231). A high stand of the Dead Sea between ca. 1440 - 1260 BC indicates a return to more humid conditions, correlating with the Late Bronze Age (Frumkin & Elitzur 2002: 337). From around 1200 BC there was a falling trend of the Dead Sea level, which continued until 500 BC and even a few hundred years later (Frumkin & Elitzur 2002: 337-338). This indicates that a more arid climate prevailed through the Iron Age and the Persian and Hellenistic periods (see also Bruins 1994: 304-307), which broadly agrees with the evidence of larger scale climatic changes influencing northern Africa and the Arabian Peninsula (Hoelzmann et al. 2004: 231).
There was a relatively short more humid period from the early 2nd century BC until the 3rd century AD (Bruins 1994: 307-308; Frumkin et al. 1998: 108-109), but after that the climate gradually became increasingly arid, which is indicated by the fall of the Dead Sea level between the 5th and middle to late 8th centuries AD (Bruins 1994: 308; Enzel et al. 2003: 268). After the mid-9th century somewhat more humid conditions once again prevailed until the end of the Early Islamic period around the end of the 11th century AD (Bruins 1990: 96; Bruins 1994:308-309). The palaeohydrological data from the Negev desert indicates a period of increased flood frequency around AD 1000 (Frumkin et al. 1998: 108). Based on the studies of Dead Sea levels and wadi alluviation in the Negev, the latest phases of increased rainfall occurred *ca.* AD 1200-1300 and *ca.* AD 1550-1650 (Geyh 1994: 133-135; Bruins 1990: 96).

Touchan and Hughes (1999) have made a reconstruction of precipitation between AD 1600-1995 in southern Jordan based on dendrochronological sequences of *Juniperus phoenicea* from the Dana Reserve and Tor al-Iraq. They noted that the average interval between drought years in southern Jordan is roughly four years, while the maximum interval was sixteen years (between 1664-1680). Most drought events had a duration of one year, but there were a few events that lasted for two years or longer. However, based on the dendrochronological data, periods of drought longer than five years are unlikely in southern Jordan. The long period without drought at the end of the 17th century AD perhaps indicates that the more humid climatic phase dated by Geyh (1994: 135) to *ca.* AD 1550-1650 may have continued until the beginning of the 18th century. On the other hand, a period of greater aridity has been inferred from environmental data in Wadi Faynan between *ca.* AD 1600-1850 (Barker 2000: 80), and in the Negev desert wadi incision has taken place from the beginning of the 18th century to the present (Bruins 1990: 96).
**Table 3.1** An outline of the main climatic trends in the Near East since 200 000 BP, based on the sources cited in the text.

<table>
<thead>
<tr>
<th>Period / kyr</th>
<th>Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pleistocene</strong></td>
<td></td>
</tr>
<tr>
<td>195 000</td>
<td>warm and wet</td>
</tr>
<tr>
<td>180 000-170 000</td>
<td>cool and wet</td>
</tr>
<tr>
<td>around 140 000</td>
<td>cooling event</td>
</tr>
<tr>
<td>124 000-119 000</td>
<td>warm and very wet</td>
</tr>
<tr>
<td>107 000-101 000</td>
<td>warm and wet</td>
</tr>
<tr>
<td>101 000-</td>
<td>drier conditions</td>
</tr>
<tr>
<td>around 96 000</td>
<td>warm and wet</td>
</tr>
<tr>
<td>- 85 000</td>
<td>drier conditions</td>
</tr>
<tr>
<td>85 000-79 000</td>
<td>warm and wet</td>
</tr>
<tr>
<td>79 000-45 000</td>
<td>warm and humid</td>
</tr>
<tr>
<td>45 000-30 000</td>
<td>cool and arid</td>
</tr>
<tr>
<td>30 000-25 000/22 000</td>
<td>more humid</td>
</tr>
<tr>
<td>25 000/22 000-19 000/17 000</td>
<td>cool and arid</td>
</tr>
<tr>
<td>17 000-11 500</td>
<td>gradually rising temperature and precipitation</td>
</tr>
<tr>
<td>11 500-10 000</td>
<td>cool and arid (Younger Dryas)</td>
</tr>
<tr>
<td><strong>Holocene</strong></td>
<td></td>
</tr>
<tr>
<td>10 000-8 500</td>
<td>rising temperature and precipitation</td>
</tr>
<tr>
<td>8500-7000</td>
<td>warm and very wet</td>
</tr>
<tr>
<td>7000-</td>
<td>warm, fluctuations between more arid and more humid conditions but general trend towards increasing aridity</td>
</tr>
<tr>
<td>4600-4000</td>
<td>warm and very arid</td>
</tr>
<tr>
<td>4000-</td>
<td>warm and aridic, centennial scale fluctuations between more arid and more humid conditions</td>
</tr>
</tbody>
</table>
3.1.3 Present day climate of Jordan

The semi-arid climate of Jordan reflects the country’s location in the transitional zone between the Mediterranean climate in the west and the arid climates in the east and south. Summer is generally hot and dry and rainfall is limited to the winter months. The climate of Jordan is controlled by the general circulation over the Mediterranean. In winter there is mainly an interrupted westerly circulation over Jordan, while in summer there is desert climate controlled by the subtropical high pressure cells. During the winter the westerlies are strengthened over the Mediterranean. Cold polar air masses from Europe frequently invade the Mediterranean basin, causing cyclones to be generated. The cyclones affect Jordan between October-November and April. In summer, the Azorian high pressure belt is strengthened and expanded, blocking the cyclones from the eastern Mediterranean. (Shehadeh 1985: 25.)

Rainfall in Jordan is controlled by physiogeography and latitude. Areas of high elevation receive more rainfall. This results in the situation that rainfall is the most abundant in the northwestern part of Jordan, and decreases towards the desert areas in the eastern and southern parts of the country. The decrease of rainfall from north to south is related to the increased distance from the main tracks of the Mediterranean depressions. Due to the physiogeography of the country - the highest elevations are at the mountain range stretching along the eastern side of the Wadi ‘Arabah - Jordan Rift - rainfall also decreases from the Jordanian plateau to the bottom of the Jordan - Wadi ‘Arabah Rift and towards the badia in the east. As the mean annual rainfall decreases, the rains also become more spatially and temporally variable. (Shehadeh 1985: 30-31.)

In the Petra region rainfall is most abundant on the slopes of the ash-Sharah mountains, where the mean annual precipitation is ca. 200 mm. Due to the orographic nature of rainfall the mean annual precipitation drops sharply both towards the west and to the east, being ca. 150 mm in Petra and only c. 50 mm at the bottom of Wadi ‘Arabah and in Ma’ an in the eastern plateau. Most of the rainfall in the Petra region comes in the winter months between December and March. (Meteorological Dept., http://www.jmd.gov.jo/.) The annual variation in the
amount of rainfall is also high. The rains become more temporally and spatially variable with
distance from the ash-Sharah range (Shehadeh 1985: 30-31). Together with the fact that the
Jabal Harûn area is totally reliant on the local rains as its source of water this implies that
periods of aridity may have a more pronounced impact on the area.

The variation of temperature is also considerable in the Petra area. The warmest month is
August with the mean maximum temperature of 29.6°C (Wadi Musa, period 1984-1998). Respectively the coldest month is January with the mean minimum temperature of 4.3°C. (Meteorological Dept., http://www.jmd.gov.jo/.) In high elevations temperatures may drop below zero and there can be snow. Not only the seasonal but also the diurnal variation of temperature and humidity is great.

3.2 The geology and geography of the Jabal Harûn area

3.2.1 Tectonics in the Petra region

Jabal Harûn lies on the westernmost edge of the escarpment which forms the eastern margin
of Wadi ‘Arabah, between the floor of Wadi ‘Arabah and the highlands of the Jordanian
Plateau. The Rift valley escarpment is characterised by deep incision and headwall erosion of
large wadis such as Wadi Musa. The general drainage of the area is towards Wadi ‘Arabah.
The escarpment is also dissected by several major faults. The faults and joints partly control
the drainage of the wadis, and in deep canyons have formed in the zones of weakness. (National Resources Authority 1995.)

Wadi ‘Arabah is part of the Jordan Rift, which forms the northernmost part of the East African - Red Sea - Levantine Rift, a long fault system stretching about 6000 km from East Africa to North Syria. According to the present view, the formation of the Rift was caused by the Arabian plate moving to the NNE relative to the Sinai microplate. (Abed 1985: 81-82.) The tectonic evolution of the area began with an epeirogenic phase during the Late Eocene-
Oligocene with the regional regression of the Tethys. The first phase of faulting began during the Middle Miocene at the latest. The tectonic movements related to the formation of the Rift had a complex influence on the entire region, controlling its drainage development and the erosional and depositional processes. (Barjous & Mikbel 1990: 52; National Resources Authority 1995.)

The major fault systems in the Petra region are the Wadi ‘Arabah fault and the Al-Quwayra and Wadi Musa fault systems (Fig. 3.1). The Wadi ‘Arabah fault, which stretches from the northern part of the Gulf of ‘Aqaba to the Dead Sea, striking 15-20° diagonally across the Wadi ‘Arabah floor, is the principal structural feature of the area and controls the geomorphology of the immediate Wadi ‘Arabah region and beyond. The fault affects both Pleistocene to recent sediments and older rocks. Geophysical studies have suggested two active periods of faulting during the Neogene, from 27 Ma to 15 Ma BP and from 5 Ma to the present, with a passive interval between these phases. The fault is defined by straight low scarps in Pleistocene and recent sediments, which are up to 60 m higher in elevation than the surrounding Wadi ‘Arabah floor. The sinistral strike-slip movement along the Wadi ‘Arabah fault is 107 km. (Barjous & Mikbel 1990:50-51, 55.) The fault is still active and its movement is ca. 5 mm per a year at present (Barjous 14.8.2005). There is evidence of earthquakes in the Petra area during the classical period (Russell 1985), probably related to the movement of the Wadi ‘Arabah fault, but no major earthquakes have occurred along the fault during the last 800-1000 years (Barjous 14.8.2005; Amit et al. 1999: 90).

The Al Quwayra fault zone, located ca. 4 km west of Petra, stretches from Saudi Arabia in the south to the Finan area in Jordan in the north. The fault zone consists of three subparallel faults which run in a generally NE-SW direction and intersect with each other (Fig 3.1). The central fault is the main one, with sinistral strike-slip movement of 40 km. Several small drag folds affect the Upper Cretaceous rocks exposed along the fault zone. The earliest phase of the Al-Quwayra fault zone precedes the period of the formation of the Jordan Rift, as its formation started already during the Pre-Cambrian period, when there is evidence of the existence of a structural weakness zone in the area. Rejuvenated movement along this fault and
its branches has taken place several times. The last discernible phase of movement has been dated to the Pliocene-Pleistocene. (Barjous & Mikbel 1990: 55-57.)

East of the Al-Quwayra fault zone there is the Wadi Musa fault zone (Fig 3.1), which consists of a parallel set of faults exhibiting sinistral horizontal movement, intersected by the Al-Quwayra fault. The fault zone forms an arc, concave to the west, which could be the result of the horizontal rotation of blocks around and along the major strike-slip faults. The faults of the Wadi Musa fault zone diverge into subparallel faults and affect the Cretaceous and Cambrian bedrock strata in the escarpment area. (National Resources Authority 1995.)

Between the major faults there are SE-NW trending faults which show dip-slip and reverse movement. The downthrow of these faults is small. Some of them were generated before the Neogene formation phase of the Wadi ‘Arabah fault and were rejuvenated during the formation of the Gulf of ‘Aqaba - Dead Sea Rift. (Barjous & Mikbel 1990: 57.)

Tectonic movement has caused extensive jointing along weakness zones in the sandstone area of the Wadi ‘Arabah escarpment. The joint system forms a network in the sandstone area between Wadi ‘Arabah and Jabal ash-Sharah. In the Petra area individual joints can be traced for distances up to 500 m. The joint planes are mainly vertical and the surfaces are slightly polished and a few centimetres apart. The intensity of jointing varies between different bedrock units and beds, being higher in the mudstone-siltstone beds than in the sandstones. The trends of the fault system are controlled by three different episodes of tectonic movement. The post-Ordovician - pre-Lower Cretaceous stresses affected only the Palaeozoic rocks. The tectonics mainly responsible for the jointing of the Cambrian to Ordovician sandstones are the stresses related to the formation of the Dead Sea transform fault starting from the Miocene and continuing up to the present day, and the tectonism within the Miocene Ash Shawkab fold belt. (Jaser & Barjous 1992: 9-10.)
Fig. 3.1 Faults in the Petra region marked on a satellite photograph. Note the network of jointing in the sandstones (courtesy of M. Barjous).
3.2.2 Bedrock

Tectonic movement has led to the formation of the complicated lithology in the Jabal Harûn area. The survey area lies immediately to the east of the main Al-Quwayra fault and the branches of this fault system reach also the Jabal Harûn area (Fig 3.1). A branch fault of the Al-Quwayra system runs in approximately N-S direction through the survey area west of Jabal Harûn, dividing the bedrock sharply into limestones to the west of the fault and sandstones to the east of it (Map 3.1). (Natural Resources Authority 1995.) To the west of the limestone area there is the main Al-Quwayra fault, which intersects with the fault running across the study area both further to the north and immediately to the south of it. As a result of drag from the movement of the Al-Quwayra fault, the limestone area forms an anticline, which folds towards the south. There is no evidence of active faults existing in the Jabal Harûn area itself. The faults have not affected the existing sediment deposits in the research area, and at places the fault line is covered with later colluvial and alluvial material, which indicates that the deposition of these sediments has taken place after the period of faulting. (Barjous 14.8.2005.)

Limestones form the bedrock of the southern and southwestern part of the FJHP survey area (Map 3.1, Fig. 3.2). The main limestone units in the Jabal Harûn area are the Cambrian Wadi as-Sir Limestone (WSL), Wadi Umm Ghudran Limestone (WG) and ‘Amman Silicified Limestone (ASL) units. The limestones have mainly been formed in marine shallow subtidal shelf environments, and contain fossils of marine macrofauna. The lower part of WSL, which forms the oldest unit in the study area, is massive dolomitic limestone interbedded with marly limestone, silty mudstone and chert nodules, while the upper part of the WSL is formed of massive-bedded, sandy dolomitic limestone. There is an unconformity with Wadi Umm Ghudran limestone. The lower part of WG is massive chalk, which changes upward to thin-bedded cherts interbedded with massive sandstone and dolomitic micrite, changing to marly limestone, silty marl and quartzite in the upmost part of the unit. The lower part of ASL is massive autobrecciated dark grey chert interbedded with dolomitic limestone, which is succeeded by thin to medium bedded pale grey chert and dolomite, while the middle part is formed of thin layers of chert and the upmost part are subconcretionary chert. (Natural Resources Authority 1995.)
The major occurrences of chert suitable for raw material for stone tools in the Jabal Harûn area are to be found within the ASL.

The sandstones, which form the northern and eastern parts of the survey area, including Jabal Harûn itself (Map 3.1), belong to the Cambrian to Ordovician Ram Sandstone Group, but only the lower part of the sequence is preserved in the area due to the high palaeorelief. The upper plateau of Jabal Harûn, as well as most of the surroundings of the mountain to the east and southeast, are formed of Umm 'Ishrin Sandstone (IN), which is a medium to coarse-grained, partly subarkosic massive sandstone with beds of finely laminated micaceous siltstone, formed in a . IN forms the very distinct, steep cliffs, which form the upper slopes and mountaintops of Jabal Harûn (Fig. 3.3). Underlying IN are the micaceous sandstones and siltstones of Abu Khushayba Sandstone (AK), which forms the lower slopes of Jabal Harûn and Jabal Farasha. The sandstones are heavily jointed following the trends of the master joint system in the area. (Jaser & Barjous 1992: 7, 9-10; National Resources Authority 1995.)

On the northern side of Jabal Harûn the bedrock is the Al Bayda Quartz-Feldspar Porphyry (BA), which represents the earliest lithostratigraphic unit in the area. The formation of the unit is related to Late Proterozoic-Early Cambrian volcanic activity. The unit is formed of massive homogenous lava with a distinct palaeotopography beneath the sandstones. (Jaser & Barjous 1992: 5; Natural Resources Authority 1995.) Small exposures of volcanic porphyry can also be found at places on the foothills and southeastern slopes of Jabal Harûn (Map 3.1), sometimes overlain by conglomerates of Salib Arkosic Sandstone formation, which is the lowest member of the Ram Group, formed of porphyry fragments in a sandstone and silt matrix (Jaser & Barjous 1992: 6-7).
Fig. 3.2 The limestone hills to the southwest of Jabal Harûn.

Fig. 3.3 Jabal Harûn seen from the south. The N-S trending fault can clearly be seen as a sharp change of the bedrock close to the foot of the mountain.
### 3.2.3 Topography and soils

The average elevation of the Jabal Harûn area is between 1000-1100 m asl, while the top of the mountain reaches 1320 m, being the highest point in the landscape between the Jabal ash-
Sharah and Wadi ‘Arabah. Beyond the limestone hills the terrain falls rapidly down towards
the floor of Wadi ‘Arabah (ca. 90 m asl).

The landscape is characterized by deep wadis and rugged sandstone mountains like Jabal
Harûn itself (Fig. 3.3). The top of Jabal Harûn is capped by massive sandstone, which forms
a wide plateau below the summit of the mountain. The top plateau is separated from the lower
slopes by a scarp with a height varying between some tens of metres. Below the scarp the
more easily erodible middle and lower slopes of the mountain are covered in colluvial mantle.
Similar structure, although with less pronounced cap and scarp, can be seen on Jabal Farasha.
The limestone hills have a more rounded relief defined by the erosion of the tilted beds, with
harder beds forming protruding escarpments (Fig. 3.2). In most parts of the limestone area
only a thin, stony layer of erosional debris covers the partially exposed bedrock on the slopes.

The Jabal Harûn area is dissected by a dense network of ephemeral channels (wadis) and their
tributaries. The limestone hills to the west of the mountain form a part of a small watershed.
The channels in the research area, which start from the limestone hills and on the slopes of
Jabal Harûn and Jabal Farasha, run to a predominantly eastern-northeastern direction. The
largest of these channels, Wadi as-Saddat and Wadi al-Farasha, join at the foot of the
mountain to Wadi an-Naqb, which runs to the east towards Petra, joining Wadi al-Waqt,
which runs to the north between Jabal Harûn and Jabal al-Barra. Finally the wadi joins into
Wadi as-Siyyagh (Wadi Musa), which collects the rain waters from the whole Petra area and
discharges them to the Wadi ‘Arabah (see Maps 1.2 and 1.3). The main channels follow the
zones of structural weakness such as the joints of the sandstone. As a result of the relatively
high channel gradients and bedrock channels defined by pre-existing weakness zones, the
channels tend to be narrow and relatively straight.

As a result of the predominance of narrow bedrock channels in the area, and the very small
area of relatively flat ground which could act as a sedimentation basin, there are only a few
remaining alluvial sediments in the area of study. The most extensive areas of alluvial
sedimentation are at the foot of Jabal Harûn, close to the juncture point of Wadi as-Saddat,
Fig.3.4 The area of alluvium to the southwest of Jabal Harûn (photo: FJHP/M. Mustonen).

Fig.3.5 A thick sediment deposit in Wadi an-Naqb, eastern side of Jabal Harûn (photo: FJHP/M. Mustonen).
Wadi al-Farasha and Wadi an-Naqb (Fig. 3.4). There the sediments appear to have accumulated at least partially as the result of the building of hydraulic structures and terracing for agricultural use, and parts of the area are still being tilled for cultivation. A few accumulations of thick alluvial deposits can also be found along Wadi an-Naqb on the north-east side of Jabal Harûn (Fig 3.5).

The sediments in the Wadi as-Saddat basin are mainly fine sand. Rather few archaeological finds have been collected from the tracts in the fields on the alluvium of Wadi as-Saddat or from the test pits dug there. In one test pit excavated behind a barrage at Site 70 (Appendix B), several thin sand laminae were recorded. This agrees with sediment deposition by slow current or overbank flooding. Macrofossil analysis of the preserved plant remains from the test pit showed no changes in the vegetational composition (Tenhunen 26.1.2005). A radiocarbon date from charcoal found in the same test pit yielded a late historic date. It appears that due to heavy erosion, the sediments in the alluvium of Wadi as-Saddat are mostly relatively young and they have been deposited during the last few centuries.

There are also a few fragmentary wadi terraces and other accumulations of sediment, especially along Wadi al-Mahattah, Wadi al-Farasha and Wadi an-Naqb, some of them several metres thick and showing several different layers or periods of sedimentation. The highest and best preserved terrace level is probably Pleistocene or older, as indicated by the remains of a Middle Palaeolithic site on top of the remnant terrace below Jabal al-Farasha. The younger levels are even more fragmentary and therefore difficult to separate, but at least five different terrace levels can be suggested (see chapter 6.1.2). The lowest terraces along Wadi al-Farasha probably indicate lateral wadi channel migration and sedimentation during historical times. Coarse, handmade pottery, which is probably of Ottoman date (Lavento et al. 2004: 233) has been found on these terraces, and they are still used for camping by the Bedouin.

In the 1:250 000 soil map by the Ministry of Agriculture (1994), the soils of the research area are described as stony, sandy or silty clay loams. They are usually shallow and moderately to
highly calcareous, non-saline or moderately saline (Ministry of Agriculture 1994). The soils can be classified into yellow soils which are formed in areas of 100-200 mm of annual rainfall. Yellow soils are calcareous and contain very little organic matter. They are shallow, and soil development is weak. The A horizon is absent or nearly absent. The depth of the soil profile seldom exceeds 45 cm and the soil horizons are weakly differentiated. (Moorman 1959: 19-20 and the map on p. 66.) Carbonate and clay eluviation-illuviation are the dominant pedogenic processes (Khresat 2001: 150). The calcium carbonate content and soil friability typically increase with depth in the soil profile (Moorman 1959: 19). In the research area the absence of recent soil profiles indicates that the current rate of erosion and/or accumulation is higher than that of pedogenesis. (Frösén et al. 1999: 394-396.)

At places there are carbonate horizons in buried soils. A carbonate horizon is a product of illuvial processes (Khresat 2001: 145), which suggests soil formation has taken place during a period of more stable environment and different climatic conditions than those of the present day. There are also occurrences of colluvial sediments which contain angular slabs of sandstone in massive, cemented calcareous matrix (calcrete). The eroded remnants of these sediments can be found in different parts of the sandstone area. These sediments are often deeply dissected by wadis or retain traces of earlier wadi positions as erosional terraces high above the present channels, and therefore it can be suggested that their age is very high and their formation may be related to the earlier phases of the tectonic movements which created the present topography of the area. A particularly thick sediment of this type has been preserved below Site 128 at the foot of Jabal Farasha (Fig. 3.6, for map reference see Appendix B). Small remnants of cemented calcareous sediments have also been preserved at places in the limestone area (Fig. 3.7).
Fig. 3.6 A cemented palaeosoil below Site 128 on al-Farasha ridge.

Fig. 3.7 Calcrete in the limestone area (survey area H, see map 2.1).
3.3 Vegetation

3.3.1 Past vegetation in southern Jordan

The scarcity of pollen-bearing sediments is a common problem in reconstructing the vegetation in the Levant. The pollen record for the Levant comes mostly from the basins in northern parts of the Jordan Rift and Syria, but due to the dry climate there are no water bodies where pollen would be preserved in the southernmost parts of the area. The other source of information on past vegetation, namely the palaeobotanic studies at archaeological sites, have mostly concentrated on the remains of cultivated plants. Therefore there is very little direct evidence of the past vegetation of the area. Another problem is the fact that much of the palynological and palaeobotanical work in the area until recently has been concerned with the vegetation during the Pleistocene-Holocene transition, the recognition of early agriculture and the introduction of new crops (Bottema 1999: 10; Miller 1991: 135-137), and much less attention has been given to the rest of the Holocene.

The amount of precipitation is the main limiting factor on the vegetation in Jordan, as well as in the Near East in general (Touchan & Hughes 1999: 291). As the pollen cores from the Levant are from the more humid northern parts of the Jordan Rift, it is problematic to try to infer the past vegetation of southern Jordan from them. It can be supposed that during the more humid and forested periods arboreal vegetation has probably been more extensive also in the south, as indicated in the study by Baruch and Goring Morris (1997) who analysed wood charcoal from hearths at Upper Palaeolithic - Epipalaeolithic sites in the Central Negev Highlands, spanning the period between ca. 18 000 - 10 000 BP. Baruch and Goring-Morris found out that during the more humid Late Pleistocene both juniper (Juniperus phoenicea) and Paliurus spina-christi were present in the Central Negev Highlands, although they do not grow in the area today.

The vegetation of the Near East is generally seen as depleted and degraded by millennia of human intervention (Zohary 1973: 653; Thirgood 1981: 85-87). It has been suggested that
people had a considerable impact on the vegetation through agricultural and building activities and herding as early as during the Pre-Pottery Neolithic Period (Köhler-Rollefson & Rollefson 1990; Yasuda et al. 2000). However, although it can be demonstrated that long term human occupation of large sites changed their vegetational surroundings, it seems probable that this impact was rather localized. Both Behre (1990: 224-227) and Bottema (1999: 13-14) have pointed out that agriculture first began in an open landscape where the composition of vegetation was not fundamentally changed by early farming, and the impact only becomes visible in pollen records when cultivation moved to a forested environment. Behre (1990: 224) also notes that the natural pattern of forest, forest-steppe and steppe has been changed also by climatic factors. Pollen analysis from sediments at the site of Bayda indicated that the immediate environment of the site has been mainly steppe-like with sparse trees for most of the Quaternary period, but it was considered possible that the slopes of the ash-Sharah mountains were more forested (Fish 1989: 91; Byrd 1989b: 14-15).

The latter half of the Holocene in the Near East has often been seen as a period of progressive replacement of natural landscapes and vegetation by cultural activity. However, while this may be true on a broad scale, at smaller temporal and spatial scales the picture may be different, with periods of more human influence on the landscape alternating with ones when human impact has been negligible (Roberts 1990: 55-56). A good example of the varying human impact are the pollen cores from the Lake Kinneret (Gennesaret) (Baruch 1990). During the Late Holocene the area appears to have been considerably more densely forested than at present. Although there is a marked decrease of oak (*Quercus*) and increase of olive (*Olea*) which can be related to Early Bronze human activity, this period seems to have been limited to the 2nd millennium BC and the forest recovered afterwards. Another period of decline of arboreal vegetation seems to have begun in 1600 BC, corresponding to a marked increase in settlement activity. After 350 BC there is a sharp rise in the percentage of *Olea* pollen, related to intensive olive cultivation that continued until the second half of the 3rd century AD. The drop of *Olea* pollen in the 3rd century can be connected to the economic policy of the Roman Empire that was unfavourable to the olive cultivation in the Judean Mountains. Forest regeneration followed the regression of olive cultivation, but the composition of the forest
differed from earlier deciduous oak forest, being dominated by evergreen oak and pistachio. Continuous human interference of varying intensity can be seen in the pollen core since the middle of the 1st millennium AD. However, it is only after AD 1800 that a large scale removal of forest cover has taken place in the Lake Kinneret area, related to renewed land clearing and the development of charcoal industry (Baruch 1990: 283-287).

Palaeobotanic studies carried out at excavations in Petra and its surroundings have so far mainly concentrated on cultivated plants. However, Fall (1990) has analysed the pollen from Hyrax middens collected from the Petra area. The samples were radiocarbon dated from 1750 BP to 1120 BP, covering the Late Nabataean - Early Roman, Byzantine and Early Islamic periods. The results indicate a severe decline of arboreal vegetation in the surroundings of Petra after the Byzantine period. Also the pollen from shrubs and herbs such as *Artemisia* and *Ephedra* decline after the Byzantine period, while pollen from taxa indicating disturbance increases, which Fall considers to be the result of foraging by livestock. The pollen composition of the midden dated to the Early Islamic period strongly resembles that of the present day, probably indicating that by the 10th century the composition of the vegetational landscape in the surroundings Petra was already very similar to what can be seen today. However, due to the source of the pollen data, Fall’s results cannot be taken as an indicator of the situation in the wider Petra region, but are more likely to represent the state of vegetation in the immediate surroundings of the city itself.

Several millennia of human influence has undeniably changed the vegetation composition in the Near East, although it can be disputed to which extent people have just speeded up a change brought upon by climatic oscillations (Fall et al. 2002: 464-472; Bottema 1999). Although the degradation of the Near Eastern landscape has been often attributed to a deforestation caused by the Romans (Thirgood 1981: 86), it appears that in many areas severe deforestation has actually started as late in the 19th century (Baruch 1990: 287). The First World War in particular was damaging to the Near Eastern forests regionwide, as large supplies of wood were needed for fuelling Ottoman military trains on the Hijaz railway (Baruch 1990: 287; Beals 1965: 679).
3.3.2 Present day vegetation in the Petra region and Jabal Harûn area

The Petra region is located at the meeting point of four phytogeographic regions, namely the Irano-Turanian, Mediterranean, Saharo-Arabian and Sudanian (Künne & Wanke 1997: 243; Al-Eisawi 1985: 50-51). The vegetation is dominated by Irano-Turanian type shrub steppe. The main steppic taxa include *Artemisia herba-alba*, *Hammada salicornia* and *Anabasis articulata*. *Noea mucronata* and *Peganum harmala* invade the artemisia steppe degraded by the grazing by goats. *Thymelea hirsuta*, *Ephedra campylopoda* and *Ononis natrix* are also common semi-steppe elements. (Fall 1990: 274.) Degraded Mediterranean type Juniperus (*Juniperus phoenicea*) forest is found especially at the higher elevations (Al-Eisawi 1985: 54, Künne & Wanke 1997: 250-251). Occasionally there are also pistachios (*Pistacia atlantica*) and *Cretaegus aronia* trees (Fall 1990: 274). The Sudanian and Saharo-Arabian components concentrate on elevations below 900 m asl, like *Retama raetam* which grows mainly on the sandy soils in wadis (Fall 1990: 274; Künne & Wanke 1997: 246). The wadis with a high water table also support hydrophytic vegetation including tamarisk (*Tamarix nilotica*) and oleander (*Nerium oleander*) (Künne & Wanke 1997: 248-250).

In the Jabal Harûn area there is mainly a mixture of degraded *Juniperus* forest and Irano-Turanian steppe vegetation (see Al-Eisawi 1985: 54-55). *Artemisia herba-alba* is rather rare probably due to browsing by goats (Tenhunen 26.1.2005). *Squill* (*Urginea maritima*), which is indicative of poor soils (Tenhunen 26.1.2005), is common on sandy loams. Sparse stands of trees, mainly juniper (*Juniperus phoenicea*) can be found on the slopes of the sandstone outcrops, which concentrate runoff and create favourable moisture conditions for tree growth (Baruch & Goring Morris 1997: 253). On the slopes of Jabal Harûn there are also some dwarfed specimens of pistachio (*Pistacia atlantica*), which can probably be considered a relict species in the area. Oleander (*Nerium oleander*) grows in the Jabal Harûn area only on the bottom of the largest wadi, Wadi an-Naqb, indicating that elsewhere there is not enough water available for its growth.
4. The human history of the Petra region and Jabal Harûn area

4.1 Settlement history of the Petra region

4.1.1 Transitory campsites - From the Middle Palaeolithic to the Epipalaeolithic period

Extensive research of early prehistoric sites in central and southern Jordan has been carried out in the eastern tributaries of Wadi ‘Arabah north of Petra, for example in Wadi al-Hasa (Coinman et al. 1988; Clark et al. 1987, 1992) and the Dana - Wadi Ghuwayr - Wadi Faynan area (Finlayson et al. 2000), as well as to the south in the Ras an-Naqb area (Henry et al. 1981; Henry 1982) (see Map 4.1 for the locations). In the Southeast Araba Archaeological Survey, however, evidence of Lower/Middle Palaeolithic occupation was found only in the northern part of the surveyed area near Gharandal, and there was no conclusive evidence of Upper Palaeolithic (Smith et al. 1997:48-49).

Only a few limited surveys concentrating on the Palaeolithic-Epipalaeolithic periods have been carried out in the Petra region (Gebel 1988, Schyle & Gebel 1997). In many surveys lithic sites or find material have not been included at all. Therefore we can expect that our picture of these periods in the Petra region is very incomplete. In general wherever in the region these periods have been included in the survey, numerous lithic scatters have been found (e.g. ‘Amr et al. 1998: 504) and many more can be expected to exist in the areas not surveyed.

Lower Palaeolithic (Acheulean)\(^1\) sites are mainly known from northern Jordan (e.g. Macumber & Edwards 1997), but there are a few sites also from southern Jordan, such as Fjaje, near Shawbak (Rollefson 1985), and Wadi Qalkha in the Ras an-Naqb area (Henry 1986: 12-14)

\(^1\) Please refer to Appendix A for the dating of the archaeological periods.
Stray finds of bifaces testify of the earliest human presence also in the Petra region during the Lower Palaeolithic period, although the nature of this presence cannot be determined (e.g. ‘Amr & al-Momani 2001: 281).

The Middle Palaeolithic (Levantine Mousterian) is much better attested in Jordan than the Lower Palaeolithic. Evidence of Middle Palaeolithic occupation has been found in a wide area, including the Azraq basin (Garrard et al. 1988), Wadi al-Hasa (Coinman et al. 1988) and on the central Jordanian Plateau (MacDonald 2004: 281) as well as in the uplands and piedmont area of Wadi Hisma (Henry 1988: 11-15) and in the Ras an-Naqb area (Henry 1986: 14-15). Middle Palaeolithic rockshelters have been studied in Wadi al-Hasa, but they appear to be less common in southern Jordan, where open-air sites seem to be dominant. As a consequence most of the sites are eroded and deflated. (Henry 1982: 422.) Middle Palaeolithic sites are also found in the Petra area, where they seem to concentrate on the western part of the Petra plateau. Like in the Ras an-Naqb area, the sites found in the Petra region are mainly eroded surface scatters. There are large such sites at Adh-Dhaman (Adh-Dhaman 3) and Ra’s an-Nyazi. A rare example of Middle Palaeolithic artefacts in situ is at Sunakh 2, near Jabal al-Barra (Map 1.2). (Schyle & Uerpmann 1988: 39-41.)

There are two at least partially co-existing Upper Palaeolithic (40 000 - 25 000 BP) technological traditions in the Levant: the Ahmarian and the Levantine Aurignacian. Although the geographical distribution of the traditions overlaps, the distribution of Ahmarian sites is mainly southern while the Levantine Aurignacian has a predominantly northern distribution. (Henry 1982: 428.) Ahmarian sites are found in rockshelters and caves in Northern Israel and Lebanon, but in southern Levant Ahmarian assemblages are usually found in open-air sites in highlands (Gladfelter 1997: 363-366). In general the Upper Palaeolithic sites are smaller in size, less numerous and more ephemeral than Middle Palaeolithic or Epipalaeolithic sites, which has led to the interpretation that the population was formed of small, highly mobile hunter-gatherer groups (Lieberman 1993: 604).
Upper Palaeolithic is well attested in Wadi al-Hasa (Coinman et al. 1988; Coinman 2004). A number of sites are known also in Wadi Hisma, including four rock-shelters (Henry 1988: 15-18) and in the Ras an-Naqb area (Henry 1982: 427-430). A few sites are known from the Petra area, although they have not been systematically surveyed except in Wadi Sabra. Probably the best known site is the one in Siq Umm al-Alda ca. 11 km north of Petra, on an old playa remnant which forms the northern bank of Wadi Siq Umm al-Alda. (Schyle & Gebel 1997: 149-150.) In addition there are at least three close-lying localities with Upper Palaeolithic finds, which probably form a single site, in Wadi Sabra, and one above ‘Ain al-Ansab in upper Wadi Sabra. At all of these sites Upper Palaeolithic material is eroded from fine-grained sediments of a high terrace. The material of the Upper Palaeolithic sites shows considerable variability, which may indicate that both technological traditions existed also in the Petra region. (Schyle & Uerpmann 1988: 41-47.)

The Epipalaeolithic period marks the transition from the Palaeolithic to the Neolithic, and it is characterized by increasing diversity of tool complexes and subsistence modes in the Levant, and particularly so in Jordan (Henry 1986: 17). The Early Epipalaeolithic is divided chronologically into two cultural complexes: the Kebaran (20 000-14 500 BP) and the Geometric Kebaran (14 500-12 800 BP). The Kebaran sites are mainly restricted to the Mediterranean zone, while the Geometric Kebaran has a wider distribution, ranging from northeast Syria to the deserts of Negev, Sinai and Jordan (Lieberman 1993: 604; Bar-Yosef & Belfer-Cohen 1992: 25). Both Kebaran and Geometric Kebaran sites are small and dispersed, which indicates the continuation of the mobile hunting and gathering strategy of the Upper Palaeolithic. Contemporary with the Kebaran complexes is the Mushabian complex (14 500-11 000) which is known from the semi-arid steppe and desert areas from northern Sinai, the Negev and southern Jordan up to the Judean hills in the north. (Bar-Yosef & Belfer-Cohen 1992: 25-26.) In addition there are other contemporary assemblages known from the Azraq basin and southern Jordan (Bar-Yosef & Belfer-Cohen 1992: 26), such as the Hamran industry defined in the Ras an-Naqb area (Henry 1985: 73).
The Epipalaeolithic period is generally well-attested in Jordan (Henry 1986: 17). Epipalaeolithic is represented by numerous sites in the Wadi Hisma (Henry 1988: 18-32) and Ras an-Naqb area (Henry 1985: 73) and likewise in Wadi al-Hasa (Coinman et al. 1988). They have been also reported on the plateau to the east of Wadi al-Hasa (MacDonald 2004: 281) (Map 4.1), but no Epipalaeolithic sites were detected in the area of the Southeast Araba
Archaeological Survey (Smith et al. 1997: 49). In the Petra area the best known Early Epipalaeolithic site is the Mdamagh rockshelter to the north of Petra, which was sounded by Kirkbride, who described the assemblage as “Micro-Kebaran”. Later Schyle and Uerpmann have made a sounding at the site, but actual excavations have not been carried out. According to Schyle and Uerpmann the artefacts from the upper part of the sounding correspond to the Kebaran technology, while the lowest layers resemble Late Upper Palaeolithic assemblages from Central Jordan Valley. (Schyle & Uerpmann 1988: 48-49.) Early Epipalaeolithic material has also been found in Wadi Sabra (Sabra 1 and Sabra 3) and Adh-Dhaman (Adh-Dhaman 2) (Schyle & Uerpmann 1988: 52-63). Unspecified Epipalaeolithic material was also detected on nine sites in the Jiththa sector in the Wadi Musa Water Supply and Wastewater Project survey (‘Amr & Al-Momani 2001: 278-281).

Settlement and subsistence models for the Middle and Upper Palaeolithic and Epipalaeolithic periods have been developed for the west-central and southern Jordan (Henry 1987; 1995) and the Negev area (Marks & Freidel 1977). The models are mainly based on alternating either radiating or circulating mobility strategies, depending on the prevailing climatic and environmental conditions. Henry has suggested a particular model for southern Jordan, based on his work in Wadi Hisma, operating on vertical rather than radiating or circulating transhumance (Henry 1985, 1987; 1995). Lately the suitability of Henry’s model for west-central Jordan has been disputed by Neeley (2004), who has demonstrated with data from Wadi al-Hasa and the Tafila-Busayrah Archaeological Survey that the mobility strategies over the Palaeolithic and Epipalaeolithic in these areas were more varied than Henry’s model suggests, combining elements of radiating and circulating mobility strategies, and largely tied to the lakes which existed in the areas during the Pleistocene.

The Late Epipalaeolithic corresponds to the Natufian culture (12 800-10 300), which has been the focus of much archaeological research as it is considered the period of the first permanent settlements and the earliest agriculture (Bar-Yosef & Belfer-Cohen 1992: 32). Sites classified as Natufian are found throughout the Levant, but the core-area of the culture is in central Levant (Bar-Yosef & Belfer-Cohen 1992: 29). The Late Natufian extended over
a larger geographic region than the Early Natufian, as far south as the western Negev lowlands and northern Sinai, and there are considerable changes in the character and distribution of archaeological material over the Natufian period (Bar-Yosef & Belfer-Cohen 1992: 29-31). It has been suggested that during the Natufian period there was a shift from the earlier circulating mode of mobility to a radiating pattern with a sedentary base camp and locales for specialised activities (Byrd 1991: 260). However, the nature of the Natufian settlement, subsistence strategies, reasons for sedentarization and the accompanying beginning of agriculture are a much discussed subject (e.g. Byrd 1989a; Bar-Yosef & Belfer-Cohen 1992; Lieberman 1993) which is far beyond the scope of this work.

In southern Jordan the character of the Natufian settlement seems to have been different from the Mediterranean core-area. The Natufian occupation in Bayda appears to have been a short-term or seasonal encampment with repeated stays for a portion of the year over a long period of time, rather than a sedentary village (Byrd 1991: 259-260). There is little evidence of plant-processing, and hunting appears to have been the main form of subsistence (Byrd 1991: 258-259). The case is the same with most of the Natufian sites in the southern and eastern Levant (Byrd 1991: 260; Lieberman 1993: 606). Contemporary with the Natufian there were also several more mobile hunter-gatherer cultures in the arid parts of the southern Levant, such as the Mushabian complex and the Harifian which followed the Late Natufian in the Negev and Sinai (Lieberman 1993: 604; Bar-Yosef & Belfer-Cohen 1992: 28, 31).

Besides Bayda Natufian sites in the Petra area are known in Wadi Sabra (Sabra 1), Wadi al-Mataha and at the foot of the al-Barra massif (Gebel 1988: 73-74). Gebel (1988: 74) describes the site Sunakh 1 by the al-Barra massif as a probable large camp site which may represent several Natufian occupations. Byrd (1991: 261) has commented that the research of the Natufian period in southern Jordan has been concentrating on the sandstone shelf, and the eastern desert margins as well as Wadi ‘Arabah have received little attention, which is likely to lead to an incomplete picture of this period. In addition other Late Epipalaeolithic sites with material that has not been defined as Natufian have been located by the al-Barra massif and in Wadi as-Slaysil (Gebel 1988: 76).
4.1.2 Early villages - From the Pre-Pottery Neolithic period to the Early Bronze Age

The Early Pre-Pottery Neolithic (PPNA) is poorly known in southern Jordan. There are only a few known PPNA settlements so far (e.g. Barker 2000: 72). Most of the sites are either ephemeral or seasonal campsites. In the Petra area there is one such site (Sabra 1) in Wadi Sabra, where the PPNA Khimian industry has been identified (Gebel 1988: 78). The reason for the end of sedentary life in after the Natufian period in many parts of Levant has been thought to be the increasing aridity and cooling of climate related to the climatic change towards more glacial conditions at the end of the Pleistocene (Bar Matthews et al. 1997: 164-165). It has been postulated that while the worsening climate led to the beginning of agriculture in the Mediterranean core-area of the Natufian culture, in the environmentally more marginal areas it resulted in people reverting back to a more mobile hunter-gatherer way of life, which made it possible to utilize the diminishing resources more effectively (Moore & Hillman 1992).

However, during the Middle PPNB period several villages came into existence also in southern Jordan, including the wider Petra region (Map 4.2). The first of these to be studied archaeologically was Bayda, which was excavated by Kirkbride between 1957-68 (Kirkbride 1966) and in 1983 (Kirkbride in Byrd 1989b: 7). For a long time Bayda was also the only PPNB site known from the eastern side of Wadi ‘Arabah, but research in the 1980s and 1990s has located several other sites, spanning the Middle and Late Pre-Pottery Neolithic. Large scale excavations have been carried out by the Carsten Niebuhr Institute in the Middle PPNB Shaqarat Mazyad (Kaliszan et al. 2002), in the Late PPNB Basta by the Department of Antiquities of Jordan, Yarmouk University and the Free University of Berlin, directed by Muheisen and Nissen (Gebel et al. 1988; Nissen et al. 1991: 13), and in the Late PPNB Ba’ja by Gebel and his team from the Free University of Berlin (Bienert & Gebel 1998). Also the Late PPNB Al-Basit in modern Wadi Musa has been excavated (Fino 1998), but later it has become apparent that the site is larger and more long-lived than originally thought (‘Amr & al-Momani 2001: 262-264). In the Wadi ‘Arabah PPNB occupation has been found concentrated near ‘Ain Tayyiba (Smith et al. 1997: 50).
In addition to the PPNB villages there are scatters of lithic material probably indicating various activities in the landscape by the inhabitants of the villages such as gathering, hunting and obtaining raw materials for tools and decoration, firewood and building material. These sites have been located for example near Bayda, in the Wadi Musa area (‘Amr et al. 1998: 504, 510, 519) and in Wadi Sabra (Gebel 1988: 83).

Map 4.2 PPN villages in the Petra region.

After the well-represented Pre-Pottery Neolithic period, Pottery Neolithic is poorly known in southern Jordan (Smith et al. 1997: 51), although in northern Jordan occupation continues to the pottery Neolithic at sites such as ‘Ain Ghazal (Rollefson & Simmons 1988). A few Pottery Neolithic sites were detected in the Wadial-Hasa survey and in Wadi Fidan and Wadi Feifa in the Southern Ghors and Northeast Arabah Survey (MacDonald 1992: 157-158). A Late Neolithic/Chakolithic settlement has been revealed by excavations at Tell Wadi Faynan.
No Pottery Neolithic sites were found in the Southeast Araba Survey, but they have been reported in the Eilat area (Smith et al. 1997: 51). Evidence of Pottery Neolithic occupation in the Petra area has so far been found only in Al-Basit (‘Amr & al-Momani 2001: 262-264). It has been suggested that the large villages of the preceding period were abandoned in southern Jordan as the result of the exhaustion of the natural resources which led to the collapse of the Pre-Pottery Neolithic society (Köhler-Rollefson & Rollefson 1990; Gebel 1998).

Likewise there are still very few sites in the Petra area that date to the Chalcolithic period, which forms the transition from the Neolithic to the Bronze Age. Possible Chalcolithic material has been reported from a couple of sites in the Wadi Musa Water Supply and Wastewater Project survey (‘Amr et al. 1998: 510; ‘Amr & al-Momani 2001: 280). Chalcolithic settlement has been attested in Wadi Faynan (Barker 2000: 70) and in Wadi ‘Arabah, where a clear continuity from the Chalcolithic period to the Early Bronze Age can be seen (Smith et al. 1997: 51-56; Niemi & Smith 1999: 799-803). Also in Wadi Hisma (Henry 1988: 33-35) and the Ras an-Naqb area there is ample evidence of Chalcolithic occupation, apparently with herding as the subsistence base. Large sites with architectural remains are found in the highlands within the Judayid Basin, while the lowland sites are smaller, consisting of thin lithic scatters with no architecture. The Chalcolithic of the Ras an-Naqb area seems to considerably differ from that in Wadi ‘Arabah in material culture and subsistence patterns, and bears strong affinities with the Chalcolithic of the Sinai. (Henry 1982: 439-443.)

During the Early Bronze Age the number of sites increased in many regions in the Levant, for example in the northern Jordan, the Negev and Sinai (Beit Arieh 1983: 40-47; Avner 1998: 152-157). The Bronze Age in southern Jordan is very different in character from the northern and central parts of Jordan, and resembles more that of the Negev and Sinai (Bienkowski 1992b: 7). The evolution of cities did not take place in southern Jordan, but extensive Early Bronze Age settlement is known from Wadi ‘Arabah, where the settlement apparently continues from the Chalcolithic period and seems to be connected with the mining and smelting of copper ore (Niemi & Smith 1999: 799-803; Rothenberg & Glass 1992: 141-142). Also
in Wadi Faynan the first phase of intensive exploitation of copper ore takes place during the Early Bronze Age and there is abundant evidence of Early Bronze Age activity, including evidence of early runoff farming (Barker et al. 2000: 28-37; Barker 2000: 72). The increase in copper production sites in the Wadi ‘Arabah from the Chalcolithic to the Early Bronze Age is considered to be related to the trade between the Near East and Egypt and the main routes of the trade passed along the Wadi ‘Arabah and through the Negev and Sinai (Lindner et al. 1990: 199-204). Also in the Negev Highlands in Biq’at ‘Uvda and southern Negev a proliferation of sites takes place during the late Early Bronze - early Middle Bronze Age (Finkelstein 1989: 130-131).

There are a few Early Bronze Age settlements in the Petra area (Map 4.3). They are often not closely dated, but by the few dates available it seems probable that not all of them were inhabited at the same time (Lindner et al. 1990: 193-199; Schaub 1992: 163-164). There is a small settlement in Sabra, 6.5 km from Petra (Lindner 1992b: 199-200; Lindner & Zeitler 1998: 539-542) and a settlement of ca. 25 houses in Wadi as-Sadah, 13 km south of Jabal Harûn (Lindner 1990: 77-79), which has been dated by pottery to EB I-II (Lindner et al. 1990:193-199). Remains of buildings, likewise dated to EB II, have been found also on Umm Saysaban, located north of ad-Deir above Wadi Mirwan (Lindner & Zeitler 1998: 542.). Early Bronze Age pottery has also been reported from Jabal al-Khubtha in Petra (Lindner et al. 1997: 178; Lindner & Zeitler 1998: 542). Moreover, Early Bronze Age sites lacking a closer description have been reported also in Jabal Fidre, Jabal Shudayfah (Lindner 1998; Lindner et al. 2001: 307-308) and Umm Babayn (Lindner et al. 1997: 178). In addition to these settlements, scatters of lithic artifacts and pottery sherds have been recorded for example in Sabra and on Jabal al-Khubtha in Petra (Lindner & Zeitler 1998: 542) and at Ba’ja IV (Bienert et al. 2000: 122), and some pottery dated to late EB IV-MBI has been reported near Petra (Schaub 1992: 163-164).
None of the EBA sites in the Petra area are as large as their contemporaries in the Negev. The settlements are usually located near a permanent source of water, but it has been suggested that the sites may also be only semi-permanent, seasonal dwellings (Lindner et al. 2001: 308). The character of these settlements is agricultural and domestic. No metal objects have been found, and the find material consists mainly of lithics, some pottery and stone tools. It seems that animal husbandry (mainly goat) and small scale agriculture were the basis of the economy at the settlements. There is no definite evidence of copper mining in the Petra area during the Early Bronze Age although ancient mining has been reported from Wadi as-Sabra (Lindner 1992b: 193-201). It seems that during the Early Bronze Age the Petra area was not in any significant way involved in the regional exchange of goods. (Lindner & Zeitler 1998: 542.)
4.1.3 The formation of tribal entities - Middle to Late Bronze and the Iron Age

Towards the transition from the Early Bronze to the Middle Bronze Age, some or more likely several factors contributed to the abandonment of many of the urban centres in the northern Jordan and Palestine. This abandonment seems to have at least partially led to the relocation of population. There is an enormous increase in the number of small settlements and camp sites during this period, especially in the Negev Highlands (Finkelstein 1989: 130-131), but also in the Jordan Valley and northern Jordan (Prag 1992: 155).

During the early Middle Bronze Age urban settlement was renewed in Palestine and new, large fortified sites appeared (McGovern 2004: 288). There are newly settled urban sites also in the northern Jordan Valley and northern Jordan (Najjar 1992: 149-153; McGovern 2004: 287). However, towards the south settlement seems to thin out: in central Jordan there is very little evidence of Middle Bronze settlement and in southern Jordan it seems to disappear altogether (McGovern 2004: 288). During the same period the number of settlements seems to diminish also in the Negev Highlands (Finkelstein 1989: 137). McGovern (2004: 288-289) relates the Middle Bronze settlement pattern of Jordan to the urbanization process and economic situation in Palestine. Southern Palestine appears to have been the centre area of the Middle Bronze economic network. The emerging city-states of northern Jordan were involved in this socio-economic network, and during the Middle Bronze Age the urbanization phenomenon spread southwards.

The small sites of the Early Bronze Age in the Petra area were probably not long-lived, and during the Middle and Late Bronze Age very little evidence of sedentary occupation or indeed human presence is known from southern Jordan (Bienkowski 1992b: 6; Smith et al. 1997: 56; MacDonald 2004: 281; McGovern 2004: 288). MacDonald (1992: 157-158) reports no Middle Bronze sites either from the Wadi al-Hasa or the Southern Ghors and Northeast Arabah Survey. According to Bienkowski (1992b: 6) there are two sites with reportedly Middle Bronze Age pottery south of Wadi al-Hasa: Tell el-Kharaza and Sela, but the material has not been published. To these can be added the only site in the Petra region reported to
include a Middle Bronze age element, in the area of the modern town of Wadi Musa (‘Amr & Al-Momani 2001: 264-265). In addition Schaub (1992: 163-164) reports late Early Bronze or early Middle Bronze sherds in an undefined location near Petra.

During the Late Bronze Age the abandonment of the several of urban settlements occurred again in Palestine. However, the situation was different in northern Jordan, where several of the larger urban centres continued from the preceding period (Najjar 1992: 152-153; McGovern 2004: 292) and the number of settlements even increased. However, fewer sites show continuation of occupation in central Jordan (McGovern 2004: 292), which seems to have been sparsely populated. MacDonald reports no Late Bronze sites in the Southern Ghors and north-eastern ‘Arabah survey and only six sites probably dating to Late Bronze Age in Wadi al-Hasa, all of them small and located in the extreme western part of the survey area (MacDonald 1992: 113, 199). Hart and Falkner report no sites at all predating Iron Age in the Edom survey (Hart & Falkner 1985:256), nor have they been found later by MacDonald (2004: 281) in the Tawilan-Busayrah survey. Conclusive evidence of copper production in Wadi Faynan during the Middle and Late Bronze Age is also lacking (Bienkowski 1992b:6; Barker 2000: 75; but see also Hauptmann & Weisberger 1987).

However, there is no reason to suggest complete depopulation of southern Jordan during the Middle Bronze Age, but rather a reversal to a more mobile way of living seems to have taken place (Bienkowski 1995: 53). Egyptian written sources dating to c. 1800 BC mention tent-dwelling, probably pastoral or semi-nomadic people, who were organized in “clans” led by “chiefs” in the area of southern Jordan (Bienkowski 1992b: 3). Bienkowski has postulated that the nomadic people of southern Jordan had a close economic connection with the more urban parts of the area and were dependent on the trade and surplus produced by the cities. Therefore the economic florescence of the cities of Palestine and the central and northern parts of Jordan during the Middle Bronze Age and the subsequent political instability and economic decline in the Late Bronze Age influenced also the people in southern Jordan. Bienkowski sees the sedentary settlements of the Late Bronze Age in southern Jordan as a sign that lacking the
surplus from the cities the indigenous people were forced to settle and practice agriculture to produce food. (Bienkowski 1992b: 7-8.)

The existence of Early Iron Age (Iron I, ca. 1200-1000 BC) sites in southern Jordan is a much disputed question. Glueck dated the Iron Age sites between the 13th-8th centuries but later excavations by Bennett in Tawilan, Busayrah and Umm al-Biyara have yielded no material datable prior to the end of the 8th century (Bienkowski 1992b: 6-7). Finkelstein has argued that some material from the sites excavated by Bennett could be dated to Iron I but Bienkowski disagrees strongly (see Bienkowski 1992a; 1992c: 104-110; Finkelstein 1992a, 1992b). He dates most Iron Age sites in southern Jordan to Iron II with the exception of some sites in the western part of Wadi al-Hasa, which he considers to be possibly earlier (Bienkowski 1992b: 6-7). Lately Iron Age settlements dated to the 9th century BC have been discovered also in Wadi Faynan (Bienkowski & van der Steen 2001: 23).

Around 700 BC there is a great expansion of settlement in southern Jordan in the area which is known from the 8th century BC in the Biblical and Assyrian sources as Edom (Bienkowski 1992b: 1-3). Therefore the cultural phase corresponding to Iron II is usually called Edomite in southern Jordan. The area of Edomite culture comprises the region south of Wadi al-Hasa as far as Wadi Hisma, including the Petra area (Bienkowski 1992b: 1). Later the territory of Edom may have extended also across the Wadi ‘Arabah, although the actual nature of the Edomite involvement in the Negev is unclear (Bienkowski 2001: 270-271; Bienkowski & van der Steen 2001).

The emergence of a more complex Edomite state has been attributed to the development of the Arabian trade. The control of copper production for trade has also been brought up as a reason for the formation of the Edomite kingdom (Levy 2004: 256-258). Bienkowski considers that the Assyrian state had a significant role as a catalyst in the development of Iron Age Edom. In the Assyrian textual sources Edom appears as a tributary of Assyria. Bienkowski does not believe, however, that this meant there were actually Assyrian troops in Edom before 668-631 when they entered Edom under Ashurbanibal (Bienkowski 1992b: 71)
Otherwise there is little evidence of direct contact between Edom and Assyria, but the Assyrian cultural influence as well as the economic opportunities and political stability Assyria created were important for the development of its tributaries (Bienkowski 1992b: 5). Bienkowski has also pointed out that Edom was not really urban, the only real city in the area being Busayrah which acted as an administrative centre. Other settlements are usually unfortified villages or farms and it seems probable that part of the population remained semi-nomadic (Bienkowski 1992c:99-104.) Lately both Bienkowski and van der Steen (2001; van der Steen 2004) and Levy (2004) have suggested that the Edomite society was based on heterarchic tribal organization composed of kin groups, comparable to that of the 18th century Bedouin, rather than on a hierarchic power structure.

There are several Iron Age II settlements in the greater Petra area (Map 4.4). The character of the settlements is predominantly rural and agricultural. Notably most of them lack the painted pottery found in Busayrah. Instead there is heavy, thick-walled plain pottery which seems to be typical of the Petra region. (Bienkowski 1995:56.) Another specialty of the Petra region are the sites located on almost inaccessible mountaintops, like Umm al-Biyara (Bienkowski 1990: 91), Jabal as-Suffaha (Lindner et al. 1998), Umm al-Ala and Baja III (Lindner et al. 1996b: 137). Other sites are open villages and farms like elsewhere in the territory of Edom (Bienkowski 1995: 56). The nature and purpose of the mountaintop sites is unclear. Lindner refers to them as “strongholds”, but it is unclear whether the name is an appropriate definition of their use. Certainly the mountaintop sites seem poorly suited for permanent settlement as they usually have no source of water other than rainfall stored in cisterns and there is no cultivable land. They may have served as administrative or cultic centres for tribes or clans, maybe for periodical gatherings, or as defensive strongholds in times of unrest (Lindner et al. 1996b: 162-163; Lindner & Knauf 1997). The lack of stratigraphy at excavated sites does not help to solve the question. In addition to the village sites and “strongholds”, there are also several smaller sites with evidence of Edomite occupation in the Petra region (‘Amr et al. 1998; Tholbecq 2001: 402).
4.1.4 From a kingdom to a part of an empire - From the Nabataean to the Byzantine period

After the end of the Edomite settlement in the 5th century BC at the latest there is again little evidence of permanent settlement in the Petra region, and the evidence of settlement is scarce in the whole of the southern Jordan during the Persian period or the Ptolemaic and Seleucid rule of the Early Hellenistic period (Bienkowski 1990: 196-197; Bienkowski 1995: 60; Smith et al. 1997: 56; Tholbecq 2001: 402). Although a continuity of human occupation by pastoral nomads has been suggested (Hart & Falkner 1985: 268; Bienkowski 1995: 62; 2001: 270-271), the conclusive archaeological evidence is lacking. The more striking therefore is the Late Hellenistic or, more accurately, Nabataean period when the landscape suddenly seems to fill with settlements, watchtowers, cultic sites and various other remains of human activity.
The Nabataean rule expanded to a large geographical area, extending to the Negev and Sinai in the west and stretching in the north to south direction from Hawran in southern Syria to the Hisma area in the south, and further south along the Red Sea to Medain Saleh in the Hijaz (Map 4.5) (Kennedy 2000: 34; Hammond 1973: 30-40). From this period onwards the Petra region, probably for the first time in its history in an actual sense, became an integrated part of a much wider realm - first the Nabataean kingdom and then the Roman and Byzantine Empire. To discuss all the evidence related to the Nabataean and Roman periods would obviously be too large an undertaking for the purposes of the present work. The following presentation will therefore concentrate on giving an outline of the settlement trends in the Petra area.

The writings of Diodorus Siculus describe the Nabataeans as nomadic people in the Petra area as early as in the late 4th century BC (Graf 1992: 254). However, Graf (1992: 254-255) has dated the earliest archaeological remains of Nabataean occupation to the 3rd century BC in Wadi Hisma, while the remains in the Petra area seem to be mainly from the 2nd century BC onwards (see e.g. ‘Amr et al. 1998). It is not clear when the city of Petra was founded, but by architectural and textual evidence it has been considered to have taken place in the 1st century BC. At the same time Nabataean settlement seems to have rapidly proliferated in the surrounding area. Surveys have recorded numerous sites described as small farmsteads and evidence of agricultural installations such as terracing and wadi barrages all over the Petra region (‘Amr et al. 1998; Tholbecq 2001: 403-404). In the modern Wadi Musa area also luxurious Nabataean “villas” have been excavated (‘Amr & al-Momani 2001: 266-267; ‘Amr et al. 2002). Several roads guarded by watchposts and towers criss-crossed the area from east to west and north to south (Tholbecq 2001: 403; Graf 1995; Zayadine 1985; Lindner 1992a). Larger settlements were established along the caravan routes in Bayda and Wadi Sabra (Hammond 1973: 44; Lindner 1992b: 193, 201; Lindner & Zeitler 1998).
The period of the most intensive human activity and settlement seems to have been relatively brief, however. Although the annexation of Nabataea by Rome in 106 AD does not appear to have influenced Petra itself, which became the capital of the province of Arabia and continued to be a centre of trade also under the Roman rule (Graf 1992: 256-259), many
small settlement sites, particularly in the western part of the Petra region, apparently fell out of use between the 2nd and 3rd centuries AD (see ‘Amr *et al.* 1998; Graf 1992: 256). It seems that most of the Nabataean-Roman settlements in the fringes of Wadi ‘Arabah were abandoned by the early 4th century AD at the latest. The mining of copper in Abu Khushayba and the settlement in Sabra also ceased after the 3rd century AD (Lindner 1987: 292; Lindner 1992a: 265; Lindner *et al.* 2000: 554, 549-550; Lindner & Gunsam 2002: 237-238). On the other hand, the continuation of settlement from the Nabataean to the Roman period seems to be strong in the Jabal ash-Sharah region (Tholbecq 2001: 402-404). It is generally considered that in the late the 3rd century the long-distance caravan trade declined as a result of the contemporary political and economic crisis of the Roman Empire. Although trade revived in the 4th century, the trade routes shifted to the north and south of Petra, which consequently lost its position as a centre of commerce. (Fiema 2002a: 238.)

In northern and central Jordan and in Palestine the Byzantine period (4th-mid 7th century AD) witnessed the expansion of both urban and rural settlement and intensification of agriculture (Graf 2001: 470-472; Walmsley 1996: 148-151). The number of sites increased dramatically in the area north of Wadi al-Hasa (Graf 2001: 470-472), and the period from the mid-5th to the late 6th/early 7th century appears to have been the peak of sedentary settlement in Jordan (Piccirillo 1985: 257-258; Graf 2001).

It seems though, that while the other Byzantine provinces of *Palaestina* were flourishing, the Petra region took a different turn. Even with the new evidence from the Petra papyri and excavations in the city itself it is undeniable that the urban settlement in Petra was constricting during the Byzantine period (Fiema 2002a: 220-225). Also in the hinterland of Petra the Late Roman and Byzantine periods are represented by diminishing number of sites. The number of settlements fell not just at the fringes of Wadi ‘Arabah, but also on the western slopes of Jabal ash-Sharah (Tholbecq 2001: 402-405; ‘Amr *et al.* 1998: 516-529). At the same time, however, it is reported that new settlements were established east of the *Via Nova Traiana* and in the surroundings of ‘Udhruh after the 4th century (Killick 1986: 438; Graf 1992: 259). The reason for the apparent move of the focus of settlement towards the desert margin in the
east can hardly have been related to environmental conditions. The increasing importance of the eastern caravan routes and the economic opportunities they offered have been suggested as an explanation (Fiema 2002a: 232-234). Notably, however, the existence of the largest settlements seems to have continued also in the western part of the region, and some of these settlements even expanded during the late Byzantine period (‘Amr et al. 1998; 2000: 241; Tholbecq 2001: 405).

The character of the settlements and the society on the whole appears to be more rural in the late Byzantine period which is also reflected in Petra itself (Fiema 2002a: 241-242). During the Nabataean-Early Roman period Petra was the only town within its region. In the Byzantine period there were also other towns, namely Augustopolis (Udhruh), Kastron Zadakathon (Sadaqa) and Kastron Ammatha (Hamam) (Map 4.6) which apparently evolved into towns from military fortresses established during the 4th century (Fiema 2002b: 131). Instead of one strong centre there seem to have been several smaller nuclei in the region. This development is probably related to the lessened grip of the central power of the southern Jordan (Fiema 2002a: 231-232).

The Negev in the Byzantine period forms a stark contrast to the Petra area. Several towns were founded and there was also vast expansion of rural settlement and run-off agriculture (Rubin 1989: 71; Haiman 1995: 29-30). It has been argued that Byzantine expansion of sedentary settlement and agriculture in the Negev was the result of imperial attention (Broshi 1980: 1; Haiman 1995: 32, 44-45; Rosen 2000: 47). All types of settlements from cities or towns to hamlets and single farmsteads can be found in the Negev during this period (Broshi 1980: 1; Rosen 2000: 45-46). The lack of settlement hierarchy in Petra region is one of the intriguing differences compared to the Negev, as the majority of the known sites from the Petra region seem to be villages or small towns. In this respect the Petra area differs also from the southernmost parts of central Jordan. In Wadi al-Hasa the Byzantine settlements are mainly small, although there are also some villages (MacDonald 1988: 248).
The archaeological data currently available is inadequate to answer the question of whether the phenomenon taking place in the Petra region during the Late Roman and Byzantine period is rather that of nucleation and relocation of settlement, or whether depopulation actually took place in southern Jordan. Nor can it reveal whether and to what extent the reportedly new settlements in the eastern part of the region were the result of relocation of already settled population or the settling of the previously semi-nomadic or pastoral element of the population, which is almost completely invisible in the historical sources for the whole period but in all likelihood present at least at the desert margin (Piccirillo 1985: 259-260; Schick 1994: 147).

4.1.5 Changing focus of power - from the Early Islamic period to the Ottoman rule

There is no immediate impact of the Islamic conquest (634-635 AD) visible in the archaeological record. Most of the villages existing in the Petra area during the late Byzantine period seem to continue to the Early Islamic period (‘Amr et al. 2000: 241-243; ‘Amr & al-Momani 2001: 267). The same is not true for Petra itself. The last mentions of Petra in the Byzantine written sources are in the 6th century (Fiema 2002a: 192-195). Likewise the city is missing from later writings by Abbasid geographers (Schick 1997: 76). Although the date of the abandonment of Petra is not clear, on the basis of the textual and archaeological evidence it seems likely that Petra as a city ceased to exist sometime during the later 7th century (Fiema 2002a: 241).

The Early Islamic settlement in the Petra region seems to have been mainly rural in character, with some quite substantial villages continuing from the late Byzantine period (‘Amr et al. 2000: 241-243; ‘Amr & Al-Momani 2001: 267). Some earlier sites were apparently also resettled during the Early Islamic period (‘Amr et al. 1998). Christianity seems to have continued among the local population (‘Amr et al. 2000: 241). Agriculture, including olive cultivation, was practised in the Jabal ash-Sharah area as can be judged from the olive press remains found for example in Khirbat Nawafila (‘Amr et al. 2000: 244).
It should be noted that settlement in the Negev did not end with the Islamic conquest either, but settlement and agriculture continued and even expanded during the Umayyad period (Rosen 2000: 53; Haiman 1995: 34). It was only in the beginning of the Abbasid rule at the turn of the 8th and 9th centuries that the settlements in the Negev were abandoned (Haiman 1995: 41, 45). It has been suggested that this was caused by the changing focus of power following the transfer of the capital from Damascus to Baghdad, which resulted in the lessened significance of the Negev area (Haiman 1995: 45).

A considerable decline of settlement seems to take place around the late Umayyad - early Abbasid period also in the Petra region. In the Jabal ash-Sharah a gap of settlement starting from the 8th century AD is reported by Tholbecq (Tholbecq 2001: 405) and Hart and Falkner (1985: 258, 268). However, both Schick (1997: 81) and Walmsley (2002: 525) have pointed out that the apparent decline of permanent settlement for Abbasid, Fatimid and Seljuq periods may partly be due to a bias of earlier archaeological research and the fact that the material culture of these periods is poorly known due to the lack of excavations. Recent archaeological research has brought forth first evidence of settlement continuing through the Abbasid and Fatimid periods at the site of Khirbat an-Nawafa (‘Amr et al. 2000: 243-244) and possibly also at Khirbat al-Mu’allaq (‘Amr et al. 2002: 244; cf. Lindner et al. 1996a). Nevertheless, in the light of the present archaeological knowledge settlement appears to cease after the Umayyad period at most known sites (‘Amr et al. 1998; ‘Amr & Al-Momani 2001: 267-268), possibly indicating an increase of semi-nomadic population (Schick 1997: 82).

The 10th and 11th centuries were a period of prolonged warfare between the central Fatimid government in Cairo and their opponents in Palestine. However, it is unclear to which extent this unrest affected southern Jordan. (Schick 1997: 76-77.) Nevertheless, the written sources of the period give proof that the picture of depopulation got from the archaeological finds is exaggerated. In the listings of early 10th century Arab geographers ‘Adhruh (Udhruh) is mentioned alternately as the capital of the district of ash-Sharah or al-Jibal (Schick 1997: 75). In the late 10th century ‘Adhruh and Mu’an (Ma’an) are mentioned as townships in the ash-

In 1071 the Seljuq forces invaded southern Jordan. The historical sources record the presence of Seljuq military force in Wadi Musa in 1107. (Schick 1997: 77-78.) Walmsley (2002: 518) has postulated that Wadi Musa became an important centre for the ash-Sharah district during the Seljuq period, and also Schick (1997: 79) considers Wadi Musa the major settlement in the area by the beginning of the 12th century. However, it seems that there was not a permanent Seljuq military presence in the area, as Baldwin I with his crusaders was able to make his first expedition to Wadi Musa without resistance (Schick 1997: 78-79).

That the Petra area was strategically important during the Crusades in the 12th century, is testified both by the written sources and the Crusader castles and keeps of the area, namely al-Wu’ayra (Li Vaux Moise), al-Habis, and the structures on top of Jabal ‘Atuf (Vannini & Vanni-Desideri 1995). Baldwin I’s campaigns to Wadi Musa took place in 1100 and 1106-1107. It is mentioned in the Crusader chronicles that during the second campaign the crusaders smoked the local people out of their caves and stole their flocks (Schick 1997: 79), which may indicate that people lived in the Nabataean tombs of Petra (McKenzie 1991: 144). The main settlement in the valley was probably at Khirbat an-Nawafla (‘Amr et al. 2000: 244-246), but evidence of occupation during this period has been found also in the modern Wadi Musa area (‘Amr & al-Momani 2001: 268). Walmsley has suggested that the castle of al-Wu’ayra may have been built around the same time as the ash-Shawbak castle (built in 1115) (Walmsley 2002: 518-519) but Schick (1997: 80) considers that the date of the construction of the al-Wu’ayra castle may be later, perhaps after the first revolt which Baldwin II suppressed in Wadi Musa in 1127. In 1144 the town again rebelled against the Crusader domination and the castle of al-Wu’ayra was captured and held for a while, although eventually the fortress was besieged and recaptured by Baldwin III (Schick 1997: 80-81 Walmsley 2002: 519). Walmsley (2002: 519) has suggested that the al-Habis castle was probably built after this second rebellion to observe the local population and to monitor the routes from Wadi ‘Arabah (see also Schmid & Studer 2003: 482). There are quite a few
small, short-lived Middle Islamic settlements in the Petra region. Many of these appear to date to the earlier part of the Ayyubid-Mamluk period and are in inaccessible locations, which indicates a heightened need for protection. These sites may date to the Crusader period. (Lindner 1999.)

The Crusader sources also give some testimony of the socio-economic conditions of the early 12th century, mentioning villages along the route from Zughar to Wadi Musa. The valley of Wadi Musa is described as “rich in the fruits of earth” and having olive groves and water mills (Walmsley 2002: 520). The account by William of Tyre of the suppressing of the rebellion in 1444 mentions that “the entire region was covered in luxuriant olive groves”, which the crusaders decided to cut down to break down the resistance of the locals (Schick 1997: 81).

The period of Crusader dominion was not long-lasting in southern Jordan. After Salah ad-Din (Saladin) defeated the Crusader army in the battle of Hattin in 1187, the castles of al-Karak and ash-Shawbak capitulated in 1188 and most of Jordan was joined under the administration of one of Salah ad-Din’s sons, who governed from Cairo (Walmsley 2002: 520). In this Ayyubid-Mamluk period (late 12th - beginning of the 16th century), expansion of sedentary settlement seems to have taken place. The village at the site of Khirbat an-Nawafla, identified by ‘Amr with the village of al-‘Udmal mentioned in the account of the travel of Sultan Baybars from Cairo to Baghdad (Zayadine 1985), grew to its largest extent (‘Amr et al. 2000: 244; ‘Amr & Al-Momani 2001: 268) and several other village sites were re-occupied during this period (‘Amr et al. 1998; ‘Amr & Al-Momani 2001). Domestic houses and courtyards have been excavated at Khirbat an-Nawafla. There are also well-preserved remains of an olive press and agricultural tools dated to this period, testifying to agricultural activities. (‘Amr et al. 2002: 244.)

After the Mamluks were defeated in 1516, the rule of Transjordan passed to the Ottoman sultans for almost 400 years. Southern Jordan was part of the province of Syria. In practice, however, the hold of the Ottoman central authority of southern Jordan was weak after the 16th century until the administrative reforms of the mid-19th century (van der Steen 2004: 451).
Although the Early Ottoman period is yet poorly known archaeologically many villages in the ash-Sharah region appear to have continuously existed at the more or less same location from the Ayyubid-Mamluk period to the 19th century (‘Amr et al. 1998; ‘Amr & al-Momani 2001; ‘Amr et al. 2001).

There is little mention of nomads in the literary sources of the Islamic period although Arab tribes probably formed a substantial part of the population, as during the preceding periods (Schick 1994: 147). The accounts of the Crusader historians, however, give some indications that a mixed settled and nomadic population existed (Walmsley 2002: 520). Nine multi-period camp sites have been recorded in the Jiththa sector by the Wadi Musa Water Supply and Wastewater Project survey, testifying to the existence of nomadic population in the eastern parts of the Petra region (‘Amr & Al-Momani 2001: 278).

Starting in the early 19th century western travellers began to visit Petra in the wake of John Burckhardt. From their records over the 19th and early 20th century we know that there was a Bedouin tribe called the Liathneth living in and around the small town of Elji (Wadi Musa), and that Bedouin - most probably of the B’dul tribe - were living in the caves of Petra for the winter season, although it seems that the control of the site was disputed and may have changed hands over time. (McKenzie 1991: 140-141.) More detailed descriptions from the early 20th century confirm that the B’dul were living in the caves of Petra for the rainy and cold season, while during spring they camped with their flocks of goats and spent the summer in the high mountains around Petra, nevertheless not moving far from their district (McKenzie 1991: 142-143).

4.2 Human history of the Jabal Harûn area

The earliest finds in the Jabal Harûn area are bifaces (handaxes) which belong to the Lower Palaeolithic Acheulean tradition. However, all except one have been found outside find
concentrations. The bifaces seem to be connected to large, abraded flakes, but the diachronic relationship of these is uncertain (Lavento et al. 2004: 230).

The largest group of the lithic finds in the Jabal Harûn area belongs to the Middle Palaeolithic Levallois technology (Lavento et al. 2004: 230). The material clearly concentrates on the limestone hills in the western part of the survey area, where surface sites have been determined on the basis of find concentrations (Map 4.7) (Frösén et al. 2001b: 382-384). Middle Palaeolithic material has also been found as stray finds all over the limestone area. Over 30 Levallois points have been found, but most of these come from outside the find concentrations (Jansson 2002: 192). Otherwise tools are rare, but numerous flake and point cores have been found in the find concentrations. On the basis of the finds it can be suggested that the Jabal Harûn area has been utilised for obtaining raw material. Clearly recognisable Upper Palaeolithic finds are lacking in the Jabal Harûn area. (Lavento et al. 2004: 230.)

There are three Epipalaeolithic sites, Sites 59, 92 and 138 (see Map 4.7 and Appendix B). Site 59 consists of a small shelter-like structure built close to the hilltop in Area T. Epipalaeolithic lithic material was found associated with the structure. Site 92 which is located in the sandstone area to the west of Jabal Farasha, is areally more extensive and has an Epipalaeolithic/Neolithic character (Frösén et al. 2001b: 383-384). Site 138 is located in Area P on top of the Al-Farasha Ridge on the south side of Wadi an-Naqb. The sites 92 and 138 yielded a considerable number of artifacts. The assemblages include cores and core fragments, microburins, blades and backed bladelets (Frösén et al. 2001b: 383-384; Frösén et al. 2003: 309).

There are also a number of lithic scatters which could not be dated to any period. These sites yield clearly man-made chipped stones but no identifiable artifacts or other datable material (Lavento et al. forth.a). One possibility is that these sites represent flint use during the historical periods (see Kujit & Russell 1993).
After the Epipalaeolithic period there seems to be an almost total gap of several millennia in the archaeological record for human activity in the Jabal Harûn area. There are only a few stray finds dated to the Pre-Pottery Neolithic period and no material datable to the Pottery Neolithic, Bronze or Iron Age. As evidence for the Middle and Late Bronze periods is very
scarce in southern Jordan in general, it is hardly surprising that these periods are not present in the Jabal Harûn area. The situation with the other periods is more puzzling considering that there are several sites dated to the Early Bronze and Iron II (Edomite) periods in the greater Petra area. The reason for this apparent lack of human activity is far from clear. Changing territorial behaviour and land use of the developing societies during the Neolithic and later periods have been cited as one possible explanation (Lavento et al. forth. a). Another possibility is “the environmental explanation”, which is discussed in Chapter 7.

Against the complete lack of evidence from the preceding periods the boom of activity which takes place in the Jabal Harûn area during the Nabataean period is striking. Most of the datable finds and structures appear to originate from this period (Frösén et al. 2003: 307; Lavento et al. 2004: 232). In addition to a pronounced background scatter of pottery sherds there are remains of several buildings. A number of these are probably related to the ancient caravan route that crosses the Jabal Harûn area en-route from Petra to Wadi ‘Arabah (Frösén et al. 2000: 418; 2001b: 389-391; 2003: 312; Zayadine 1985: 164). Many of these structures can be described as watch towers or guard posts. However, there is also a large multi-room building with a central courtyard in area T (Site 49), which may have served as a caravan station (Frösén et al. 2001: 372). Alternatively it could be interpreted as a single farmstead. Buildings of this type are common elsewhere in the Petra region during the Nabataean period (e.g. ‘Amr et al. 1998: 538, 540). Another possible farmstead or a cluster of a few small houses (Site 128) is located on the ridge of Al-Farasha in Area P (see Appendix B).

Although it is very difficult to reliably date the agricultural installations, it is considered that at least the earliest phase of the extensive system of barrages, terrace walls and combinations of these dates to the Nabataean period (Fig. 4.1). This conclusion is based on the large quantities of Nabataean pottery sherds found on the slopes particularly in area C (Appendix C). (Lavento & Huotari 2002: 103-104.) The distribution of the Nabataean-Roman pottery agrees with the idea that it has been spread as a result of manuring the fields (see Chapter 2.3.3). Intensive farming is also supported by the presence of small farmsteads or hamlets in
the area. (Lavento et al. forth.b.) Surprisingly enough, there is little Nabataean pottery from the fields in the alluvial area between Wadi al-Farasha and Wadi as-Saddat. However, this is probably explained by the apparently relatively young age of these sediments resulting from heavy erosion in this area (see Chapter 3.2.3).

**Fig. 4.1** Part of the runoff farming system to the west of Jabal Harûn. Terraces and barrages in Wadi as-Saddat.

In addition to the agricultural activities and the caravan route and related structures there are also Nabataean cultic sites. Several of these are to be found in the eastern part of the survey area, in close proximity to Wādī an-Naqb. Remains of a cultic building as indicated by a capital and a small rock-cut water basin can be found in close connection to two rock-cut graves that are located on the southeastern lower slope of Jabal Harûn (Site 164). Nabataean betyls, including one anthropomorphic carving (Sites 166 and 184; see also Lindner 1997: 287-288), are located in the gorge of Wādī an-Naqb in the easternmost corner of the survey
area (Frösén et al. 2004: 112). There are remains of wall lines as well as carved stones and column drums in front of the anthropomorphic carving, which Lindner (1997: 287-288) has identified as a representation of Isis. There has also been a rather substantial Nabataean building on top of Jabal Harûn as indicated by the tower-like structure incorporated in the later Byzantine pilgrimage centre and re-used architectural stones found in the excavation (Fiema 2004: 133). A cultic purpose for this structure has been suggested (Lindner et al. 1988: 95-97) but as very little of the original Nabataean building has been preserved its function is indeterminate (Fiema 2004: 133). However, there are several rock-cut water channels (Sites 10, 182, 183) and two cisterns (Sites 5 and 10) on the top plateau of Jabal Harûn, as well as a rock-cut grave (Site 183) and two niches (Site 4) (Frösén et al. 1998: 492-494; Frösén et al. 2004: 111-112). (Appendix B.)

Despite the numerous remains dated to the Nabataean period, the intensive Nabataean activity in the Jabal Harûn area seems to have been relatively short lived. Based on the dating of fine ware ceramics from the survey area, the activity began in the 1st century AD and ended already by the early 2nd century (Lavento et al. forth.b). It seems that permanent settlement in the Jabal Harûn area ceased for a period after the Nabataean times except for the top of the mountain. The monastery/pilgrimage centre on top of Jabal Harûn was most probably founded during the late 5th century (Fiema 2004: 133), but pottery from the 1st to the 4th century AD has also been found in the survey of the top plateau of the mountain. The phases of the construction and use of the monastic/pilgrimage centre have been dealt with by e.g. Fiema (2004), and they will not be discussed in detail here.

There are very few signs of late Roman or Byzantine activity (3rd - 6th centuries AD) in the area surrounding Jabal Harûn. Only the watchtower (Site 54) at the edge of Area T overlooking to Wadi ʻArabah has yielded a considerable amount of Byzantine pottery (Frösén et al. 2000: 418). The lack of a background scatter of Byzantine pottery is particularly puzzling, as it could be expected that the runoff farming system in the surroundings of the mountain was used for producing food for the monastery.
The ecclesiastical use and occupation of the monastery continued on the basis of present ceramic evidence at least until the 7th/8th century (Frösén et al. 2003; Fiema 2004: 137-138). Al-Mas’udi mentions around the mid-10th century that Jabal Harûn was in the possession of Christian Melkites (Schick 1994: 146). According to the Crusader sources, a monastery on top of the mountain was visited by the crusaders during the expedition of Baldwin I to Transjordan in 1100 (Schick 1997: 79) and other records mention the presence of a church there (Fiema 2004: 129). The last reference to a church on Jabal Harûn dates to early 13th century when there were two Greek monks living there (Fiema 2004: 129).

However, in the surroundings of the mountain pottery from the Early Islamic period is absent. There are only a couple of structures which could be indicative of human activity during the Early Islamic period. On the Al-Farasha Ridge there is a structure (Site 136) which closely resembles the open mosques known from the Negev, dated to the 7th-8th centuries (Frösén et al. 2003: 310-312). The pottery associated with the structure was Nabataean - Early Roman, probably indicating that it was originally built during the Nabataean period and later re-used as an open mosque. Another possible indication of Early Islamic activity is Site 118, remains of a structure which today is not much more than a pile of stones on the lower slope of Jabal Harûn, facing to the southeast. This structure yielded no pottery, although a couple of Nabataean sherds were found close by, but these could easily originate from the slopes above. However, the structure resembles the description of the watchposts in the Negev dated to the Early Islamic period, interpreted as used for watching over the fields during the harvest period (Haiman 1995: 35). This idea is supported by the fact that Site 118 offers a view to the alluvium where the most extensive fields of the area are located. There are also numerous undatable terrace walls and barrages on the slopes of both Jabal Harûn and Jabal Farasha. In his study of the Byzantine and Early Islamic agriculture in the Negev Haiman (1995: 34) has pointed out that runoff agriculture actually reached even further into the desert during the Umayyad period than during the Byzantine period, which has been generally held as the period of most extensive agriculture in the Negev.
A large number of thick handmade pottery sherds with coarse fabric and organic temper have been found on the ledges of the northeast summit of Jabal Harûn and at the foot of the cliffs. The sherds are sometimes painted with black or red geometric decoration or have a reddish slip. The painted sherds can be identified as Ayyubid-Mamluk pottery, or early hand-made painted pottery, which dates to the 11th - 13th centuries (Hendrix et al. 1997: 289-306; Khadija 1992: 345-356). By the stylistic characteristics of the decoration it can be tentatively suggested that the pottery found on Jabal Harûn may date rather to the earlier part of the period (see ‘Amr et al. 2000: 244; Brown 1988: 230-240). There are also rather undefined wall lines on the northeast summit of the mountain and some of the pottery seems to be related to these structures. As this type of pottery has not been found in the area of the monastery it seems that what settlement there was on the mountain had moved to the heights of the northeast summit. Similar pottery has also been found immediately below the summit by the cliff face, where it probably originates from the settlement above. The painted pottery closely resembles that found in Petra itself for example in Wadi Farasha (Schmid & Studer 2003: 481-482) and in the Crusader castle of Al-Wu’ayra to the northeast of Petra (Tonghini & Vanni Desideri 2001). The Islamic well on top of the mountain has been built in the mid-14th century, dated by the dedicatory inscription. Much of it has been constructed reusing the stones from the ruins of a Byzantine church which had earlier stood on the summit (Fiema 2004: 129).

During the Middle Islamic period settlement reappeared also in the surroundings of the mountain. A farmstead or small hamlet consisting of a few buildings is located on the northeastern slope of Jabal Harûn (Site 109, Appendix B). A considerable amount of painted Ayyubid-Mamluk pottery has been found on the surface and in the soundings made inside the structures (Frösén et al. 2004: 112-113). The northeastern slopes of Jabal Harûn are terraced and some Ayyubid-Mamluk pottery has been found in parts of the area, indicating that the terraces may have been in use during the period.

After the Middle Islamic period permanent settlement seems to disappear from Jabal Harûn and its surroundings. The archaeological finds that can be related to the period between the
13th and 20th centuries include camp sites, threshing floors and a lime kiln (Site 24), which has been stacked, but not fired (Frösén et al. 1999: 399). There is some handmade pottery with coarse mineral temper, which has been tentatively labelled Ottoman (Tonghini & Vanni Desideri 2001: 715), and a few pieces of what may be 17th to 19th century “Ottoman pipes” (Tonghini & Vanni Desideri 2001: 717). There are also some small buildings in the traditional style, which have been built by the Bedouin to use for storage of e.g. agricultural implements. In addition there are remains of temporary campsites with no datable materials. Particularly on the slopes of Jabal Harûn there are also numerous rock carvings. Many of these, the “footsteps” in particular, are related to the pilgrimage to the mountain.

The accounts of 19th century travellers indicate that the B’dul lived in the Jabal Harûn area (McKenzie 1991: 142), probably during the summertime, and it is known that some of the fields by the foot of Jabal Harûn were still cultivated by them in the early 20th century (Russell 1995: 695). The general picture it gives of the use of the Jabal Harûn area since the Middle Islamic period is that of an area seasonally or periodically used for camping in connection to herding and agricultural activities and pilgrimage to the shrine of Aaron.
5. Erosion and hydrology in semi-arid areas

5.1 Mechanisms of erosion in semi-arid areas

5.1.1 Weathering

Erosional processes start with the weathering of bedrock. In arid and semi-arid areas the most important forms of weathering are mechanical, due to the limited availability of water for chemical weathering. However, moisture is a significant agent in the mechanical weathering of rocks. Moisture in arid and semi-arid environments is available not only from rainfall, but also as fog and dew which concentrates on the rocks. Often moisture in desert environments is highly alkaline or saline, which increases silica mobility in rocks. The solution of silica may result in weathering forms such as tafoni. The continual wetting and drying of rock surface as a result of large diurnal moisture changes can also cause rock disintegration as a result of isothermal expansion and contraction as a reaction to changes in moisture content. (Goudie 2000: 29-32.)

Moisture also has a role in salt weathering, which is an important form of mechanical weathering in arid environments. Various salts within the rocks become soluble and crystallize or hydrate and dehydrate as a result of temperature and humidity changes. These processes cause rock disintegration, generate silt-sized debris and prepare the rock for further weathering by wind and water. In addition micro-organisms, lichens and fungi can cause biological weathering on rock surfaces. (Goudie 2000: 32-35.)

It should also be borne in mind that arid environments have not necessarily always been arid, but during earlier climatic phases there have been other weathering mechanisms at work, and their weathering products are inherited. Although chemical weathering is relatively unimportant under arid climatic conditions, during more humid climatic periods its role has been more significant. (Goudie 2000: 32.)
5.1.2 Erosion by water and wind

The role of climate as an erosion control is dominant at the macro-scale. At a local scale, however, several other factors become significant. These include geology and geomorphology, hydrology, soils, vegetation and the influence of human actions and animal life. (Morgan 1986: 5-6.)

In semi-arid areas rainfall and runoff are important controls of erosion. The role of vegetation cover in erosion is also significant, as it influences the generation of runoff (Thornes 1987: 41-44; Beven 2001: 67). Maximum erosion is caused by high intensity rainfall on a sparsely vegetated surface. Runoff and erosion are at their highest in semiarid, Mediterranean-type shrublands when the mean annual rainfall is 200-300 mm (Bull & Kirkby 2001: 7; Beven 2001: 67). More rainfall means more vegetation which intercepts rainfall and protects the soil surface from erosion (Morgan 1986: 3). On the other hand, although less rainfall means less vegetation, it also means less potential for runoff generation (Beven 2001: 67).

Runoff threshold, which means the amount of effective rainfall needed for runoff generation, tends to be low in semi-arid areas. Factors encouraging low runoff threshold are related to local geology, lack of vegetation, soil chemistry, high slopes and thin soils (Bull & Kirkby 2001: 9). In addition to vegetation cover, the infiltration capacity of the soil is an important control of runoff generation (Morgan 1986: 14). Studies in two different watersheds in the Negev Highlands and Beersheva region have revealed that even 2 mm of rainfall was enough to generate runoff in a rocky arid area in the Negev Highlands. However, since most rainfall in the area comes as brief showers, the runoff generated in the rocky upper slopes usually infiltrated when it reached the stony colluvial slope. (Yair & Kossovsky 2002: 50.)

Erosion by water starts with rainsplash on fine-grained soil. During intense rainstorms the impact velocity of raindrops can move the grains on the surface (Bull & Kirkby 2001: 10). Rainsplash can also cause the formation of a surface crust by re-arranging the grains on the soil surface to form a compacted layer which reduces soil erosion. On the other hand the
formation of surface crust creates an impermeable layer, which reduces infiltration and results in increased runoff. (Baird 2000: 166, 169.) Soils most vulnerable to crusting are loams and sandy loams (Morgan 1986: 18-19). Stones on the soil surface can also increase infiltration rate, protect the soil surface and increase runoff, depending on the amount of stones and their location in the soil profile (Baird 2000: 166; Beven 2001: 68).

Unconcentrated runoff causes so-called sheet-wash or overland flow on the soil surface. Generally overland flow does not take place as a continuous sheet of water but rather as small braided flows without pronounced channels. (Morgan 1986: 21; Baird 2000.) Concentration of overland flow can result in rill or gully erosion. Rill erosion takes place when overland flow becomes channelled when travelling downslope. Rills are generally ephemeral features and may be wiped out by e.g. ploughing. However, they may transport considerable amounts of sediment. (Morgan 1986: 27-28.) Gullies are relatively permanent ephemeral channels, which can carry very large sediment loads. The initiation of gullying is a complex process. Erosion occurs at the gully head, causing the retreat of the scarp. Additional erosion takes place along the gully banks as scouring, slumping and bank collapse. (Morgan 1986: 29-30.) Gully erosion may take place along natural drainage lines or man-made elements such as roads (Poesen et al. 2001: 229-230). The threshold for gullying decreases if the vegetation cover is removed as the result of e.g. ploughing (Poesen et al. 2001: 248; Morgan 1986: 29). Gullies are associated with accelerated erosion, and they are considered to be a sign of landscape instability (Morgan 1986: 29).

In the Mediterranean region erodibility is the highest in the beginning of the rainy season, as the regeneration of vegetation cover lags about a month behind the starting of the rains (Bull & Kirkby 2001: 4; Morgan 1986: 10). In sparsely vegetated areas a large storm can deplete the sediment supply (Mannaerts & Gabriels 2000: 411), or exhaustion of the sediment supply may take place as the rainy season progresses (Reid 2001: 119). Subsequent rainfall events can remobilise the sediment and transport it further down the drainage system (Mannaerts & Gabriels 2000: 411).
Wind erosion selectively removes the smallest particle sizes. Particles may move by surface creep, by saltation or in suspension. Wind can remove the fine grain sizes with a particle size of less than 0.5 mm, which causes enrichment of soil surface in larger particles (Morgan 1986: 35-39). Vegetation is also an important control of wind erosion because it reduces wind speed near the surface. The formation of surface crust also protects fine soils against wind erosion. However, ploughing or other disturbance to the soil surface can break the surface crust and increase the effectiveness of wind erosion. (Bull & Kirkby 2001: 10.) In disturbed areas on fine soils, wind erosion causes deflation of the soil surface, resulting in the formation of a deepening hollow from which the soil is removed (Breed et al. 2000: 442).

Erosion can also happen as mass movements such as rock falls or debris flows on slopes when the shear strength of the sediment is exceeded, for example as the result of wetting. Vegetation, particularly tree cover, may protect against mass movements as the roots bind the soil (Morgan 1986: 61). Although mass movements resulting from the wetting of the sediment are probably not very common at present day in the Jabal Harûn area, they may be caused by rare extreme rainfall events. Mass movements such as rockslides may also be caused by tectonics, and considering that the Jabal Harûn area belongs to the Wadi ‘Arabah - Jordan Rift, which is a tectonically active area, this type of mass movements are likely to occur. The areas likely to experience mass movements in the Jabal Harûn area are particularly the steep slopes of the sandstone massifs where abundant colluvial material is present.

5.2 Dryland hydrology

5.2.1 Dynamics of ephemeral dryland channels

Rivers in arid and semi-arid areas differ from those in more humid regions. A typical feature of most dryland channels is that the flow is ephemeral, occurring only for short periods during and immediately after rainstorms. The strong seasonality of rainfall means that for the most part of the year the channels are dry. The amount of rainfall and its spatial distribution also varies.
from year to year in arid and semi-arid areas. As a result there may be only a few flow events annually, or, in extreme cases, several years between flows. (Reid 2001: 121.) Due to the characteristics of rainfall, runoff and flow in semi-arid areas, the relative importance of many fluvial processes is different in dryland channels compared to those of more humid regions, where the flow is generally perennial and the importance of storms in generating runoff is much smaller (Bull & Kirkby 2001: 4-6). Typically dryland rivers have high width/depth ratio and low sinuosity and are often braided. The channels tend to have sand or gravel beds, and the channel bed topography tends to be subdued; in single thread streams the beds are often near horizontal and planar. The large channel width and bed flatness are likely to be related, as the flow depth is shallow in a wide channel. (Reid & Frostick 2000: 215.) Because of the high variability of rainfall both temporally and spatially only parts of a fluvial system may be active during a storm and therefore the catchment area is not necessarily a reliable indicator of the amount of runoff (Bull & Kirkby 2001: 6, see also Pilgrim et al. 1988 on rainfall-runoff modelling in semi-arid regions).

The combination of brief but intense rainfall and sparse vegetation in semi-arid areas leads to high surface runoff rates, which causes hillslope erosion. As the permeability of the soil is often low, rapid concentration of runoff water into channels may cause flash floods (Hassan 1985: 55-56). The high erosion rate together with limited amount of water available for runoff leads to high sediment concentration in the flow (Bull & Kirkby 2001: 6). On the other hand, as rainfall often lasts only a short time, much of the runoff may infiltrate already before reaching the channel, or into the loose alluvium in the channel bed, and the flood discharge of rivers may increase only slowly or even decrease downstream (Bull & Kirkby 2001: 6; Beven 2001: 63). Surface properties also play an important role in the generation and continuity of runoff in semi-arid areas both at the hillslope and watershed scale (Yair & Kossovsky 2002: 54-55).

In ephemeral channels, which are dry for most of the year a flood event occurs whenever there is streamflow, regardless of the amount of water in the channel (Graf 1988: 83). The flood hydrographs of semi-arid channels have three typical characteristics. Firstly, they exhibit a steep rising limb that incorporates a bore. Secondly, the flood recession is also steep, related
to the importance of overland flow in generating runoff. Thirdly, the whole process of flooding and recession tends to be very short-lived, often lasting no longer than few hours. (Reid & Frostick 2000: 208-210.) Graf (1988: 89-93) has classified floods in dryland channels into four types according to their duration and character: flash floods, single peak events, multiple peak events and seasonal floods. Flash floods, which have short duration ranging from a few minutes to a few hours and are often associated with an advancing bore, are typical for small channels with relatively small drainage areas, and they are usually associated with convectional precipitation and thunderstorms. Single peak flood events may last from few hours to many days, and they are related to tropical storms or frontal precipitation. Likewise multiple peak floods usually result from this type of precipitation, either due to multiple rainfall events or because of tributary contributions to the main stream, and may be either brief or last for several days or even weeks. Seasonal floods are typical in large, perennial streams which originate outside dryland areas.

The discharge and, consequently, sediment transport capacity of dryland rivers depends on several properties, namely the magnitude of the flood, channel width, the velocity of the flow, the depth of the flow and interaction with roughness elements, which include changes in channel bed grain size and bedforms, channel bed vegetation and the shear effect from the banks. The estimation of these discharge parameters in dryland channels is, however, problematic due to the characteristics of the flow. (Graf 1988: 84-87.)

The ready availability of sediment for transport and often very high sediment concentration of the flow are important factors when hydraulic processes in ephemeral rivers are considered. Sediment is available from overland flow, bank erosion and channel bed scour (Bull & Kirkby 2001: 7). The sediment is transported in suspension and as bedload by saltation and tractation. As a result of the high sediment concentrations, the shear strength of the flows in dryland channels is generally higher than in perennial rivers. Studies of ephemeral channels in the Negev desert, Israel, have revealed that the suspended sediment concentration of dryland rivers can be very high, up to 68% by weight in flash flood flows (Reid 2001: 118, 120), which means hyperconcentrated flows (Costa 1988: 114). When the sediment concentration
threshold is exceeded in a hyperconcentrated flow, its shear strength increases exponentially, thereby enhancing the erosive effectiveness of the flow. If the sediment concentration in the flow increases to over 70% by weight, the flood turns into a debris flow, where solid particles and water move together as a single body. (Costa 1988: 114-118.)

Bedload transportation plays a more important role in ephemeral than in perennial rivers, being at least an order of magnitude higher in dryland channels. The bedload flux is a function of excess shear stress, being the largest in the channel centre, but near the banks the sidewall drag reduces boundary shear and thereby bedload flux. The size-selective entrainment of sediment is counteracted by the weak armouring of the channel beds (Laronne et al. 1994), related to the abundant availability of material of all grain sizes. Although bedload does not always make a contribution to the sediment transport in dryland channels, the amount of bedload can be very high during a flow event, and the grain size of the largest particles may also be larger than is usual in perennial rivers. (Reid 2001: 109-110, 115-116.) Particles of pebble to cobble size have been reported to be transported as bedload by flood flows over predominantly sandy stream beds in the Negev (Reid & Frostick 2000: 220), while in the US cobbles and even small boulders have been reported to be transported in suspension during extreme floods in very narrow and confined bedrock channels (Baker & Kochel 1988: 124).

The amount of sediment in transport also influences the properties of the flow. Water flows are Newtonian flows, which can be laminar or turbulent. In laminar flows all the molecules in the fluid move parallel to each other in the direction of transport. In fluvial conditions laminar flows occur when flow velocities are low or the depth is shallow. However, turbulent flows are much more common in fluvial transport and deposition. In turbulent flows molecules move in all directions but the net movement is in the transport direction. Turbulent flows are initiated in high flow velocities. (Nichols 1999: 38-39). Sediment is transported in water flows by turbulence, shear, lift, drag and dispersive stresses. Water and sediment are two separate, distinct phases, and sediment is transported in suspension or by saltation and rolling along the channel bed. The capacity of water flows to transport sediment is relatively small, resulting in very small shear strength. (Costa 1988: 113-118.)
In hyperconcentrated flow, the decrease of fall velocity of the sediment particles enables fine sediments to remain in suspension for longer periods of time, increasing the rate of sediment transport which results in a larger shear strength than in water flows. Solids and water form separate components of the flow. The primary sediment support mechanisms in hyperconcentrated flow are buoyancy, dispersive stress and turbulence. Particle collisions extract energy from the flow and when the flow slows, coarser particles are deposited. Hyperconcentrated flows differ from water floods, but they are also considered to behave like Newtonian flows, although they may have characteristics of both water and debris flows (Svendsen et al. 2003: 8-9). (Costa 1988: 113-118.)

The hydraulic properties of debris flows are significantly different from water and hyperconcentrated flows. In contrast to water and hyperconcentrated flows, in debris flows solid particles and water form a single, viscoplastic body, which is a non-Newtonian flow. As the sediment concentration increases, the shear strength of the flow increases exponentially. (Costa 1988: 116-118.) Debris flows move by gravity, which means that the initiation of debris flows requires slope. However, once a flow has started moving, the slope needed to overcome the friction which stops the flow is only 1 degree. Debris flows are typically laminar flows. (Nichols 1999: 54; see also Dasgupta 2003: 270-271) Also the sediment transport mechanisms are different, namely cohesive strength, buoyancy, grain interactions and structural support. When sediment is deposited from a debris flow, no separation into solid and liquid components takes place. (Costa 1988: 116-118.)

5.2.2 Fluvial forms and deposits in drylands

Wide, gravel- or sand-bedded braided channels are considered typical of dryland environments. However, relatively low sinuosity single channel streams are common for mountainous regions such as the Petra area. Other common fluvial forms in drylands include flood plains and alluvial fans. (Graf 1988: 118-119.) Fans are also common between tributaries and the main channel because different parts of the area often produce runoff during
different rainfall events (Bull & Kirkby 2001: 7). The bedforms and fluvial deposits associated with these channel types basically resemble those found in perennial systems, but there are also differences as a result of the discontinuity of flow in ephemeral rivers and the large sediment load in transportation, which may cause hyperconcentrated flows or debris flows in wadis.

The channel bed is subject to frequent scouring and filling during the flow events, when material taken from the channel bed is transported only for a short distances and replaced. As a result, the channel bed is highly mobile but there are little or no detectable channel changes from one flood event to another. It has been noticed that only the relatively rarely occurring high magnitude flood events cause significant change in dryland channels. (Bull & Kirkby 2001: 7-8.) On the other hand, it may take fifty years for the channel to recover from an extreme event (Knighton & Nanson 2000: 188). Climate change and human land use can also trigger major changes in flood magnitude and frequency (Bull & Kirkby 2001: 7).

When the capacity of the stream decreases as a result of infiltration to the stream bed or gradient change, the transported sediment is deposited (Hassan 1985: 55-56). Reid and Frostick (2000: 224-225) characterise ephemeral stream deposits as typically thin (between 10-30 cm) beds with horizontal primary structures, usually comprising a set of alternating coarser and finer laminae. The sequences are often punctuated by thin drapes on clay which has settled from the waning flow. However, different sedimentary environments and variable types of flows create different types of deposits.

Svendsen et al. (2003) have studied hyperconcentrated flow deposits in the Skeleton Coast Erg, Namibia. They noted that the deposits were typically massive or have crude horizontal stratification with no scour and fill structures. The deposits were moderately to well-sorted, with grain size ranging from fine sand to cobbles. The grains exhibited normal grading and the clasts were horizontally oriented and frequently imbricated. Basal contacts varied from sharp to gradual. Absence of sedimentary structures was common in hyperconcentrated flow deposits, which was explained by the high sediment content of the flow, which disables the development of sedimentary structures. (Svendsen et al. 2003: 8-9,18.) Other studies have
also shown that sediments deposited by hyperconcentrated flows tend to be massive or have poorly developed stratification, with clast-supported non-cohesive open-work structure and possibly reverse-graded subunits. As compared to sedimentation from water flows, there is a decrease in the relative amount of fine-grained sediments. (Costa 1988: 119.)

Debris flow deposits may also occur in dryland settings. The deposits are characterised by the uniform distribution of all grain sizes and have very or extremely poor sorting. There are no sedimentary structures and the sediment is usually matrix-supported. Reverse grading is typical, and large clasts have a random or poorly preferred orientation depending on the amount of water in the debris flow. Also positive skewness and bimodal grain-size distribution can be indicative of debris flows. (Costa 1988: 119.)

Sneh (1983) has divided the depositional environments in Wadi el-Arish, Sinai, into three different types of floodplain. Confined floodplains are found in the upper parts of the drainage with deep, vigorous currents. The width of the floodplain is up to a few hundred of metres and it is bounded by relatively steep banks. Open floodplains have shallow currents and a width ranging from hundreds to thousands of metres. Terminal floodplains are flats in the distal end of the drainage system, where the energy of the flood dissipates. Sneh noticed that all of these environments have their characteristic sedimentary sequences which reflect the behaviour of the flood in each environment. (Sneh 1983: 1273-1274.)

In confined floodplains along Wadi el-Arish the major bedforms were channel bars, which are constantly breached by floods due to changes in the stream path. Typical deposits are pebble-bearing horizontal or cross-stratified sands and sandy plane beds around 40 cm thick, created by the high energy flows during the first stage of the flood. The waning of the flood results in the formation of sets of climbing ripples and mud drapes covering the units. These units form an upward-fining succession of longitudinal channel bar sediments. The sedimentary units are laterally discontinuous, with geometric continuity of a few metres only, and texturally coarse. (Sneh 1983: 1273-1275, 1276.)
Open floodplains are characterised by thin units between 20-40 cm. Climbing ripples and mud layers a few centimetres thick are typical, reflecting more shallow currents. Characteristic structures include mega ripples and medium to small scale trough cross strata. Upper flow regime plane beds also occur, but they are less common than in confined floodplain sequences. In terminal floodplains micro-cross laminated fine sands and occasional thin layers of muds result from the low-intensity, lower flow regime floods and the short-time ponding of water. Finely bedded or massive mud beds are common. (Sneh 1983: 1275-1277.)

Alluvial fans are formed in areas where streams emerge from confined mountain drainages. They exhibit both horizontal and vertical variation in materials. Ephemeral streams create fans with complex facies with crosscut beds, filled channels and inclined bedding. Transmission losses create upward fining sequences on fan surfaces. Likewise horizontal fining of material can occur, as the flow capacities decrease towards the distal part of the fan. As the fan grows larger, also upward-coarsening sequences develop because as the fan grows the distal and central locations change. Also rejuvenated erosion in the headwaters areas, the creation of subsidiary fans and the trenching of the upper portion of the fan contribute to the complexity of the alluvial fan sequences. (Graf 1988: 120.)

5.2.3 Hydrology of the Jabal Harûn area

The system of ephemeral channels and tributaries in the Jabal Harûn area is very dense, which is typical of semi-arid areas with hilly or mountainous topography. The area itself forms but a small part of the whole catchment area of Wadi as-Siyyagh (Wadi Musa). The main channels in the Jabal Harûn area are Wadi al-Mahattah - Wadi al-Farasha channel, which collects the runoff from the limestone area and the western and northern slopes of Jabal Farasha, and Wadi as-Saddat which collects the runoff from the southern slopes of Jabal Harûn. These two wadis join into Wadi an-Naqb at the foot of the mountain (see Map 1.3). Dozens of small tributaries join these main channels from the slopes. Wadi an-Naqb runs to the northeast and joins Wadi al-Waqt, which runs to the northwest between Jabal Harûn and Jabal al-Barra in
a rocky gorge, finally joining into Wadi as-Siyyagh (Wadi Musa) to the north of Jabal Harûn, which discharges into Wadi ‘Arabah in a large alluvial fan area. However, in the study area there are no large wadis running east to west that would be capable of collecting and transporting large volumes of water and sediment, such as Wadi Sabra to the south of the Jabal Harûn area, or Wadi as-Siyyagh itself.

The channels of the main wadis in the Jabal Harûn area tend to follow the fault and joint lines in the bedrock, which indicates that the development of the channel network is controlled by the tectonic evolution of the area as a part of the Rift valley escarpment, particularly the movement and rejuvenation phases of the Al-Quwayra fault system and its branches, the last active phase of which has been dated to the Pleistocene at the latest (Barjous & Mikbel 1990: 56-57). There is no evidence of later tectonic movements which might have affected the drainage of the channels in the research area (Barjous 14.8.2005).

As a result of the high stream gradients\(^1\) and main channels being defined by the weakness zones in the bedrock, the wadis in the Jabal Harûn area tend to be narrow and relatively straight. Due to the channels being often deeply incised into the bedrock, they are unlikely to significantly change their course, although lateral migration of channels apparently occurs in the small, relatively flat alluvial area at the foot of Jabal Harûn and Jabal Farasha, as evident from cut bank and point bar development. The present-day channels are mainly bedrock or sand and gravel-bedded, but material of all grain sizes is introduced into the channels all along from the steep slopes by colluvial processes and slumping, wasting and gullyng of the wadi banks. The channel beds are relatively flat, and exhibit changes in grain size over short distances as well as across the channel. No downstream fining of the channel bed can be noticed, probably as the result of the constant addition of material into the channel. The channels are not extensively vegetated, but some shrubs and occasional trees can be found on the channel beds. Transmission losses are likely to be negligible in the upper parts of the wadis, but

\(^1\) The gradient of the Wadi al-Mahattah-Wadi al-Farasha channel is 65 m/km, while the gradient of Wadi as-Saddat is 199 m/km, both to the junction of Wadi an-Naqb.
increase in the alluvial area and particularly in the channel of Wadi an-Naqb. On the other hand, the dense network of tributaries counteracts transmission losses in the scale of the study area, as the area is small enough to receive precipitation simultaneously. However, runoff is likely to be created differentially even within this small area, with the bare and steep sandstone areas creating more runoff than the limestone hills.

Alluvial sediments and terrace formations are relatively rare in the Jabal Harûn area as a result of the steep relief and narrow, mostly rocky channels, resulting in the lack of sedimentary basins. Tributary deltas are quite common in the junction of a tributary and a main channel. These formations are typical for arid and semi-arid areas, and they are the result of the uneven generation of runoff in areas of different topography and bedrock, which leads to different flow intensities in the tributary and the main channel. When a flood in a tributary reaches the main channel, the sudden drop in the flow velocity and the resulting drop of its transport capacity cause deposition of the sediment. (Bull & Kirkby 2001: 7.) Thick, sandy deposits of this type can be seen especially on the southern and southeastern side of Jabal Harûn where high velocity flows from the steep slopes of the mountain enter the channel of Wadi an-Naqb.

Rainfall in the Jabal Harûn area is rare even during the winter. There may be only a few rainy days in a season. Low intensity rainfall can last for a day or two at a time, but there are also occasional thunderstorms (according to a local informant, Harûn Dakhlallah). That winter rainfall at present day can create enough runoff to transport large amounts of sediment can be seen from an example in Wadi as-Saddat. In connection to the building of the dirt road to the foot of Jabal Harûn, a high ridge of loose sediment and boulders was bulldozed to form a dam across the wadi in 1999 and the sediment was still there in 2000. However, two years later, in 2002, water had almost completely washed away a considerable portion of this mass (see Figs. 5.1 and 5.2). Likewise one flood was enough to fill a modern stone-built masonry dam with water in Wadi an-Naqb during the winter 2002-2003 (information from Harûn Dakhlallah). Despite high evaporation rates during the summer months and the fact that flocks of goats and sheep were regularly brought to drink from the pool, there was still a lot of water in the dam as late as in August 2003.
Fig. 5.1 The bulldozed dam in Wadi as-Saddat in 2000.

Fig. 5.2 The middle part of the dam had been washed away in 2002.

With decreasing mean annual rainfall in semi-arid areas also the spatial and temporal variation of rainfall increases, which means greater annual variation in the amount of rainfall the area receives. In the Petra region the amount of annual rainfall drops sharply towards the Wadi
‘Arabah, which means that the spatial variation of rainfall also increases from the Jabal ash-Sharah to the bottom of the Wadi ‘Arabah. As the Jabal Harûn area lies in the margins of the Wadi ‘Arabah, the variability of rainfall can be considered to be high. Therefore it is likely that periods of drought and longer-term climatic changes towards more aridity would have affected the Jabal Harûn area even more acutely than the areas on or near to the slopes of the ash-Sharah mountains. Decrease in the number of rainfall events in the case of a drought period can be postulated. Another factor which makes the Jabal Harûn area particularly vulnerable to drought is its dependency on local rainfall. These conditions imply that periods of relative aridity and even shorter droughts are likely to have had a more pronounced impact in the Jabal Harûn area than in many parts of the surrounding landscape. As droughts would have affected such activities as agriculture and herding in the area, these considerations are potentially important in interpreting how people have used the Jabal Harûn area.

5.3 Erosion in the Jabal Harûn area

5.3.1 Natural factors causing erosion

It can be supposed that the mechanisms of weathering and erosion in the Jabal Harûn area have been the same as long as the climate has been relatively similar to that of the present day, that is roughly the last 7000 years. Because of the low mean annual precipitation, chemical weathering is probably not very significant at present, although it is likely to have been more important during the more humid climate phases in the past. The sandstones contain tafoni which are the result of water permeating the stone. The limestones show also signs of chemical weathering. Salt weathering is probably an important factor in the mechanical breakage of rocks considering the large diurnal and seasonal changes in temperature and the availability of moisture. The limestones, sandstones and volcanic rhyolite that form the bedrock of the area are all relatively easily weathered under the prevailing climatic conditions. In addition to easily weathering bedrock, the steep relief, seasonality of precipitation and sparse vegetation are all factors which contribute towards enhancing the effectiveness of erosion.
The most important erosive force is rainwater. All the factors encouraging a low runoff threshold are present in the Jabal Harûn area. Surface runoff causes overland flow, washing away sand and fines and exposing bedrock to further weathering. Concentration of runoff on the slopes causes rill and gully erosion (Fig. 5.4). Under conditions of no disturbance the sandy loams of the area soon develop a hard surface crust that diminishes the effectiveness of erosion by surface wash but also slows down the infiltration rate of water into soil, thus increasing runoff. However, breaking of the surface crust as a result of ploughing or the use of motor vehicles renders these soils vulnerable to erosion by running water and can start wind-erosion during the dry season. Many sand and silt layers in the Jabal Harûn area are also very consolidated as a result of the concentration of carbonate from soil water, and they are not easily eroded under normal conditions. Nevertheless, gullying or slumping can start on a consolidated wadi bank if runoff water from above is concentrated at one point (Fig. 5.5).

Wind erosion has a less important role in the Jabal Harûn area, as there is little loose soil elsewhere except in parts of the top plateau of the mountain. Elsewhere wind erosion may cause selective removal of fines from the soil surface. Together with the work of overland flow of water this leaves a surface enriched in coarse materials, resulting in so-called armouring of the soil, which may reduce infiltration. Strong evening winds carry sand from Wadi ‘Arabah and abrasion by the blowing sand erodes rock faces. Wind can also cause deflation at places where the surface crust on fine soils has been broken by ploughing, animals’ hooves or car wheels.

5.3.2 Human-induced erosion

5.3.2.1 Runoff farming

The impact of human activity in the past has likely both prevented and promoted erosion in the Jabal Harûn area. Particularly the construction, use and abandonment of the extensive runoff farming system can be expected to have had a significant effect on the erosion history of the
Fig. 5.4 Gully erosion on the limestone slopes in survey area H.

Fig. 5.5 Gullying and slumping in a wadi bank, Wadi as-Saddat.
area. Barrages slow down the flow of water and degradation of channels, accumulating alluvial sediments in basins. The building of terrace walls prevents erosion on slopes by slowing down soil creep and overland flow. Fine-grained soil accumulating on the terraces absorbs water, reducing the amount of overland flow and the effects of slope wash. Cultivated plants bind water into the soil as well as protect the soil from the erosive effects of rainfall and runoff. Thus the building of barrages and terrace walls should lead to a period of decreased erosion and sedimentation in the wadis as long as the area is under cultivation and the structures are maintained.

On the other hand, there is evidence from Negev that the ancient farmers actually caused increased erosion of fine-grained sediment from the slopes by collecting stones and exposing the ground surface to runoff (Bruins 1990: 92-93). Their intention may have been to increase runoff generated by rainfall but as a result also fine soil was washed from the slopes to the cultivated areas on valley floors (Bruins 1990: 93). Studies have revealed also that terracing does not necessarily prevent erosion (Rackham & Moody 1992: 124), and the prevention of erosion may not even be a reason for building terraces. In the UNESCO survey of the floodfarming systems in Libya it was noticed that the building of cross-wadi barrages on valley floors concentrated flow on certain areas which became heavily gullied (Gilbertson et al. 2000: 150).

Studies of the runoff cultivation systems in the Negev have revealed that the installations are confined to steep rocky areas with the average annual rainfall of 70-100 mm (Yair & Kossovsky 2002: 55). Yair and Kossovsky explain this with the runoff generation properties of different surfaces. Bare, rocky surfaces are likely to cause runoff even during brief, not very intensive rainfall events and water harvesting is therefore more effective in those areas than in areas which receive a higher mean annual rainfall, resulting in more extensive vegetation and soil cover and less runoff. (Yair & Kossovsky 2002: 55.)

In areas under cultivation different crops have different influence on soil erodibility (Morgan 1986: 61; Bull et al. 1999: 205). Studies of runoff generation on different modern cultivations
have shown that the least runoff is generated on fields where olives are grown with semi-natural understorey. Correspondingly the highest runoff is produced on fields with perennial crops using mechanical tillage and weed control (Beven 2001: 67). Therefore also changes in the agricultural practices may have caused such consequences as intensifying runoff and erosion which probably were not anticipated by the ancient farmers. Soils with low organic matter content, like those in the Jabal Harûn area, are also vulnerable to soil exhaustion as a result of cultivation, which in turn can lead to the depletion of plant cover and erosion (Morgan 1986: 4, 51).

After the maintenance of the hydraulic structures ceases, they slowly become buried and/or collapse. In areas where vegetation quickly reclaims the abandoned terraces the structures appear to be quite stable and resistant to collapse (Rackham & Moody 1992: 129) but it is suggested that in cases when the renewal of natural vegetation is prevented by grazing, aridity or a lack of nutrients in the soil, the abandonment of cultivation is likely to increase runoff and erosion on the slopes (Pope & van Andel 1984: 297; Zangger 1992: 136; Bull et al. 1999: 205). In the Jabal Harûn area many terrace walls and barrages are at present day very fragmentary. On the other hand, research in the Negev indicates that many terraced wadis have not suffered erosion even after abandonment (Bruins 1990: 97). In the light of this contradictory evidence it seems probable that the consequences of terrace abandonment are not always similar, but are dependent on various factors like the amount of rainfall, natural vegetation, steepness of slope and channel gradient.

If the terrace walls and barrages collapse, like in the Jabal Harûn area, soil accumulated behind them becomes available for transport. With less soil to absorb water, the surface runoff created by rainfall increases. Concentration of runoff along standing parts of terraces and barrages causes gullying, which effectively transports sediment into channels. As a result there is more water and sediment available in the wadis which can result in increased stream velocity and enhanced wadi bank and channel bed erosion. The increased velocity of flow and transported bedload is likely to cause further break-down of barrages. On the other hand channels may become choked with sediment, if the amount of sediment available for transport
is higher than the transportation capability of the flows. Therefore, provided that the amount or characteristics of rainfall do not change significantly, the period soon after the abandonment of cultivation should be one of increasing volumes of erosion and alluvial deposition.

The construction of the hydraulic structures in the Jabal Harûn area seems to have begun during the Nabataean period, but parts of the system have been in use as late as in the 20th century (Lavento & Huotari 2002: 103, 105). Several periods of construction and use are indicated by repairs and differences in the structure of the barrage walls. Judging from their present state of preservation, parts of the system have clearly been abandoned earlier, while other parts were farmed and maintained. It can be suggested that there have been several periods of construction, use and abandonment of the runoff farming system, which were not necessarily synchronous over the whole area. (Lavento & Huotari 2002: 104-105.)

5.3.2.2 Removal of vegetation

A human activity which has quite probably had marked environmental consequences in the Jabal Harûn area is the logging of trees for fuel and building material. This activity is likely to have continued for a very long time, but its extent or effect in antiquity is difficult if not impossible to prove with the data available. Nevertheless, some hypotheses on the subject of human influence on vegetation can be posed.

In the light of the settlement history of the Petra region (see Chapter 4.1) the intensification of human activity in the area seems to have taken place relatively late. There were several Pre-Pottery Neolithic villages in the Petra area, but their impact on vegetation is likely to have been localized (Fall et al. 2002: 447). Likewise, considering the apparently small size and number of Early Bronze Age sites in the Petra area, and the almost complete lack of later Bronze Age sites, it seems unlikely that any large-scale environmental deterioration as a result of human activity would have taken place during the Bronze Age. There is no evidence in the Petra area of large-scale goat herding as in the Negev during the Early-Middle Bronze Age transition (Finkelstein 1989). Therefore the human impact on vegetation would have probably been
restricted to the immediate vicinity of the sites. The settlement activity intensified during the Iron Age (Edomite period), but did not last very long. However, a more pronounced human impact on the environment as a result of logging, agriculture and herding can be suggested for the Edomite period considering the extent of settlement and potential increase in population.

The end of the Edomite Iron Age marks a gap in the settled occupation, but rather than actual depopulation a reversal back to a more mobile way of life can be suggested (Bienkowski 1995: 63; Hart & Falkner 1985: 268).

Considering the lack of archaeological finds from the Jabal Harûn area between the Neolithic period and Iron Age it seems unlikely that any human activity of significant scale took place in the area for several millennia. The area could have been used for hunting, gathering and herding, all of them activities which leave little archaeologically recognisable traces. Hypothetically it can be suggested that herding in the area may have intensified during the Iron Age. That would have had an impact on the vegetation as it favoured those plant species which are resistant to browsing by goats, a situation that can be seen in the present day vegetation of the area. It has been also suggested that the building of barrages and terraces may have been already practised by the Iron Age population (Lindner et al. 1996b: 150).

However, the beginning of considerable, intensive human impact on the environment in the Jabal Harûn area, and in the whole of the Petra area in a wider perspective, is likely to date to the Nabataean period, when also the building of the hydraulic installations seems to have begun at a large scale (Lindner et al. 1996a: 111-113; Lindner et al. 2000: 553; ‘Amr et al. 1998: 504, 516, 532, 539; Tholbecq 2001: 403-404).

In her study of pollen in fossilised Hyrax middens in the Petra area Fall noticed a drop of arboreal pollen through antiquity and especially after the Byzantine period (Fall 1990: 277-278). It seems likely that the city of Petra would have required large amounts of wood for fuel and building material especially during its heyday in Nabataean times. The woodland reserves around the town would have been soon used up and longer trips to obtain firewood and timber were needed. Wood for the needs of Petra could have been easily obtained from the Jabal Harûn area which was located along a caravan route. Burned wine pressing waste dating
to the Nabataean-Roman period has been found in an oven in Ez-Zantur, as well as charcoal from fruit-bearing trees (Jacquat & Martinoli 1998: 29), which probably indicates that firewood was already scarce in the surroundings of the town.

Fall (1990: 277-278) noticed also the decline of pollen from shrubs and herbs such as Artemisia and Ephedra in the sample dated to the Early Islamic period, while pollen from taxa indicating disturbance increased. She translates this phenomenon as the result of increased foraging by goats in the surroundings of Petra after the city was more or less abandoned. A similar situation can be seen with the present day vegetation in the Jabal Harûn area, and it can be suggested that this has been the case already in the Nabataean period, maybe even during the Iron Age.

Sheep and goat herding also has a negative effect on the renewal of arboreal vegetation in the area as the animals eat shoots. Over-grazing by goats changes the vegetation, leading to an increase of plants not edible or palatable for goats (Zohary 1973: 652). Goats are generally considered to be the worst animal culprits in enhancing erosion, as they eat plants and shoots, leaving the soil surface bare and compacted and vulnerable to erosion by water and wind (Khresat et al. 1998: 626). Goat herds also wear paths on the slopes, which can concentrate runoff and lead to rill and gully erosion (Brown & Quine 1999: 5).

Deforestation was heavy in the Near East during the First World War when trees were felled to be used as fuel for locomotives on the Hijaz railway (Baruch 1990: 287; Beals 1965: 679). However, in the air photos of the Jabal Harûn area taken in the 1960s there are still considerably more trees growing in the area than at present. The area was probably too remote and difficult to reach to provide fuel for the locomotives. It can be supposed that mainly the gathering of firewood has caused the marked reduction of trees during the 20th century.

Transportation with motor vehicles is an increasing cause of erosion in the Jabal Harûn area at present day. Vehicles moving outside tracks displace surface stone cover and expose the
surface for erosion by runoff. Wheels can also disturb vegetation and break the surface crust of fine sediments, enabling erosion by wind and enhancing the effect of running water. Dirt roads effectively concentrate runoff, acting as channels during rainfall (Brown & Quine 1999: 5). Tourism in Petra is the most important source of income for both the inhabitants of Wadi Musa and the B’dul Bedouin. If in the future larger-scale tourism is to reach Jabal Harûn, it will also increase the need for transportation to the mountain. To prevent worsening erosion and denudation of the ground surface as well as to prevent more damage to the ancient structures on the mountain and in its immediate vicinity, a system for monitoring the use of the area for tourism and for example restricting visitors to use only certain pathways would be seriously needed.
6. Geoarchaeological research in the Jabal Harûn area

6.1 Relative chronology of wadi terraces

6.1.1 The basis of forming a chronology for terrace formations

River terraces are landforms which represent former channel levels, elevated above the active channel as a result of channel incision. Terraces can be either depositional or erosional features, and their formation results from fluvial adjustment over a variety of timescales to internal and external controls such as basin uplift, base-level fall and climatically induced decrease of sediment supply, which cause the river to alter its gradient. Episodes of channel degradation and aggradation can result in a series of valley fills and terraces of different height. (Lewis & Maddy 1999: 112; Bridge 2003: 340, 342-343.) However, terrace surfaces are not always underlain by fluvial deposits, and therefore a distinction should be made between terraces as a landform and the underlying sediments (Lewis & Maddy 112).

Terraces can be used to reconstruct the degradation and aggradation periods of channels. For the purpose of reconstruction, the relative ages of the terrace surfaces and the deposits beneath them need to be established. (Bridge 2003: 342-343.) Terraces are commonly defined with respect to height above the present channel. However, the degree of altitudinal separation between terraces does not necessarily indicate the timescale of terrace development, although terraces which extend over the whole basin probably represent formation over long periods of time and are usually the result of stream adjustment to uplift or tectonic movement. (Lewis & Maddy 1999: 112.) Relating terraces to each other is done by studying the development of palaeosoils and the degree of degradation of terrace scarps and by matching the heights of paired terraces on either sides of the valley, if these do occur. Stratigraphic correlation of distinctive lithologies or erosion surfaces can also be used, but it is not considered very reliable. (Bridge 2003: 342-343.)
Due to recurring aggradation and degradation periods, the picture of erosion and deposition obtained through the investigation of terrace levels may be incomplete. A further complication is that a particular terrace does not necessarily have a constant age and elevation, and it may not be distinguishable from others. (Bridge 2003: 341-342) Terraces are also often fragmentary, and as the responses of the channel to an event may be different in upstream and downstream reaches of the basin, correlation of terraces may be difficult. The temporal resolution of the investigation of terrace levels is usually relatively low. (Lewis & Maddy 1999: 112.)

Wadi terrace formations along Wadi al-Mahattah and Wadi al-Farasha in the Jabal Harûn area were mapped during the field season in 2002 (Maps 6.1 & 6.2). The aim of the investigation was to form a relative chronology for the terraces and to identify sedimentary sequences suitable for OSL-dating. Relating different terraces to each other was done by measuring their relative height from the ancient or, in most cases, modern wadi bed, and by comparing their sedimentary composition and structures. The task was complicated by the heavy erosion of the terrace formations, their small lateral extent - usually only a few square metres - and highly variable sedimentary sequences, which made it very difficult to relate separate remnant terraces to each other by anything else than their height from the modern wadi bed. This can clearly can be misleading as the different terraces, although of the same height, may be the result of different processes and are not necessarily synchronous. Considering the connectivity of the hillslopes and channels in the Jabal Harûn area, it is likely that many deposits classified as wadi terraces include both colluvial and fluvially transported material. However, sixteen terrace formations were mapped, and it is suggested that at least five different terrace levels can be separated (Table 6.1, Fig. 6.1).

6.1.2 Relative chronology of wadi terraces in the Jabal Harûn area

For the sake of clarity it is necessary to separate here the use of the term terrace from the sedimentary processes. The term terrace is used here to refer to a landform rather than to infer
that the deposits underneath the surface of the terrace are of fluvial origin (Lewis & Maddy 1999: 112). The terraces in the Jabal Harûn area are often the result of both depositional and erosional processes. On the slopes of Jabal al-Farasha and Jabal Harûn there are traces of erosional terraces cut into the bedrock high above the modern channel of Wadi an-Naqb. These terraces formed before the breaching of a bedrock threshold in the Wadi an-Naqb to the southeast of Jabal Harûn (Barjous 26.8.2002). Also the occurrence of flint pebbles on the southern lower slopes of Jabal Harûn testify to the earlier stages of the Wadi an-Naqb. Because there is no flint present in the sandstones, the pebbles are thought to have been transported there by fluvial processes. The breaching of the threshold, probably related to the tectonic developments that took place during the Pleistocene at the latest (Barjous & Mikbel 1990: 57), would have caused a period of rapid degradation of the wadi beds.

The mapped terraces were observed along the Wadi al-Mahattah - Wadi al-Farasha channel, in an area covering ca. 0.2 km² (Map 6.1 & Map 6.2). This is the only part of the Jabal Harûn area with sedimentary deposits which are potentially fluvial. There are a few deposits several metres thick located further along the channel of Wadi an-Naqb to the southeast of Jabal Harûn, but otherwise the wadi channels are narrow and rocky and no sedimentary deposits have been preserved in them.

Fig. 6.1 A schematic presentation of the terrace levels along the Wadi al-Mahattah - Wadi al-Farasha.
Table 6.1. Terrace levels along Wadi al-Mahattah - Wadi al-Farasha.

<table>
<thead>
<tr>
<th>Terrace no</th>
<th>Terrace base/top height from modern wadi bed, metres</th>
<th>Terrace group</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>(base eroded) / 6 m</td>
<td>II</td>
</tr>
<tr>
<td>T2</td>
<td>0.4-0.5 m / 2 m</td>
<td>III</td>
</tr>
<tr>
<td>T3</td>
<td>0.4-0.5 m / 2 m</td>
<td>III</td>
</tr>
<tr>
<td>T4</td>
<td>0.4-0.5 m / 2 m</td>
<td>III</td>
</tr>
<tr>
<td>T5</td>
<td>(base eroded) / 8 m</td>
<td>I</td>
</tr>
<tr>
<td>T6</td>
<td>- / 1,5 m</td>
<td>IV</td>
</tr>
<tr>
<td>T7</td>
<td>- / 1,8 m</td>
<td>IV</td>
</tr>
<tr>
<td>T8</td>
<td>5 m / 13 m</td>
<td>I</td>
</tr>
<tr>
<td>T9</td>
<td>- / 1,8 m</td>
<td>IV</td>
</tr>
<tr>
<td>T10</td>
<td>1,5 m / 6 m</td>
<td>II</td>
</tr>
<tr>
<td>T11</td>
<td>- / 1,8 m</td>
<td>IV</td>
</tr>
<tr>
<td>T12</td>
<td>- / 2 m</td>
<td>IV</td>
</tr>
<tr>
<td>T13</td>
<td>- / 1 m</td>
<td>V</td>
</tr>
<tr>
<td>T14</td>
<td>- / 1 m</td>
<td>V</td>
</tr>
<tr>
<td>T15</td>
<td>- / 2 m</td>
<td>IV?</td>
</tr>
<tr>
<td>T16</td>
<td>? / 5 m*</td>
<td>IV?</td>
</tr>
<tr>
<td>T17</td>
<td>- / 0.5 m</td>
<td>V</td>
</tr>
</tbody>
</table>

* T16 is located within T17. There are remains of a small building atop the terrace remains, which is likely to increase its top height too much.

The channel of Wadi al-Mahattah - Wadi al-Farasha is altogether ca. 1.7 km long, and together with Wadi as-Saddat, it joins the channel called Wadi an-Naqb, southeast of Jabal Harûn (Map 6.1). The gradient of the modern wadi, calculated from its starting point to the junction with Wadi as-Saddat, is 65m/km. In its upper part Wadi al-Mahattah runs mainly in a narrow bedrock channel between the limestone hills, and only a few of the remnant terraces mapped are located along this stretch of the channel. There is a bedrock threshold in the Wadi al-Mahattah channel with a height of drop of ca. 5 m after the wadi enters the area of
sandstone bedrock, which complicates relating the terraces above and below the threshold (see Map 6.2). As the channel network of the area is very dense, there are also several tributaries joining the studied channel from the surrounding slopes, adding to the difficulty of understanding the depositional processes.

The oldest and highest terrace level recognised in Wadi al-Mahattah and Wadi al-Farasha could be observed at two points, T5 and T8 (Map 6.2, Fig. 6.2). The top levels of these heavily eroded terraces are at the same height and both of them consist of flint-rich sandy gravel with a few larger clasts of flint and autobrecciated chert. This indicates that the beds of ‘Amman Silicified Limestone (Map 6.2) are a major source area of the sediment. No sedimentary structures could be observed in these terraces due to their heavily eroded state. T5 is located just above the threshold in Wadi al-Mahattah, and its top is currently 8 m above the modern wadi bed. T8, on the other hand, is located below the threshold, and its current height from the modern wadi bed is 13 m. However, T8 is located on top of a sandstone shelf, and its base level is 5 m above the modern wadi. The location of T8 strongly suggests that this earliest terrace level was formed before the breaching of the threshold in Wadi al-Mahattah.

Unfortunately not much material is available to date this first terrace level. A scatter of Middle Palaeolithic Levallois-type flint flakes and artifacts (Site 127, Appendix B) was detected in the archaeological survey on top of T8. There was flint material also on the surface of the lower terraces (T7 and T9) as a result of erosion. As the artifacts did not appear to originate from the slope above T8 and no man-made flint material occurred within the terrace sediments as observed in a gully profile, it is suggested that the archaeological site is more or less in-situ and the terrace pre-dates the site. The dating of the archaeological material suggests that T8 and the clearly contemporaneous T5 on the opposite side of the wadi have a minimum age of more than 40 000 years.

T1 and T10 are tentatively grouped together as level II, but they form a more problematic case. T1 is located along Wadi al-Mahattah (Map 6.2, Fig. 6.3), slightly upstream of the
Map 6.1 The area where the mapped terraces are located (see also Map 6.2).

Map 6.2 Map of terraces along Wadi al-Mahattah and Wadi al-Farasha. The locations of excavated vertical profiles are marked with arrows.
Fig. 6.2 Terraces T5 and T8.

Fig. 6.3 T1 along Wadi al-Mahattah.
junction of a smaller tributary. The base of the terrace appears to be only 0,2-0,3 m above the modern wadi bottom and the height of the terrace surface is ca. 6 m above it, but this may be the result of erosion, as the formation is heavily eroded. The sediment is also heavily cemented. There seem to be alternating sandy and gravelly layers, but without the possibility to excavate a profile the sedimentary sequence remains uncertain. T10 on the other hand is located along Wadi al-Farasha. The top of T10 is also 6 m above the modern wadi bed, but the terrace is currently completely above the channel, because the modern wadi has incised ca. 1,5 m into the sandstone under the terrace. Also this terrace is heavily eroded and gullied.

The third terrace level is formed of a group of three relatively poorly preserved terraces T2, T3 and T4. These terraces are all located above the threshold, along Wadi al-Mahattah (Map 6.2). All of them consist of an eroded layer of flint-rich gravel and calcareous material on top of sandstone bedrock, and their surfaces are partially covered with erosional debris derived from the sandstone slopes above. Their base is ca. 0,4-0,5 m above the modern channel bed, but their top height is only ca. 2 m above the modern wadi bottom, which suggests that they are either very heavily truncated or younger than the previous two terrace groups. However, the base height from the modern wadi bed suggests they are older than the terraces of similar top height but with base at the level of the modern wadi bed below the threshold.

The terrace level IV is represented by the largest group of terrace remains, which are considered to result from a number of processes and to be actually somewhat diachronous, although probably within a relatively short time span. The terraces are located along the Wadi al-Farasha with their tops rising ca. 2-1,8 m above the modern wadi bottom (Map 6.2). Several layers of deposition indicating variable conditions of flow can be detected in all these terraces. Some layers observed are also likely to represent colluvial processes from the slopes and/or erosion and redeposition of material from older terrace levels above. There are remains of a probably Nabataean barrage, with only the lowest row of stones left, partially covered by slightly slumped sediment from T7 (Fig. 6.4), and a curved stone structure, likewise interpreted as a probably Nabataean, partially covered by material from T7 (Site 129, Appendix B). Middle Palaeolithic material, apparently derived from the top of T5 above, was
found on the surface of T7 and T9, but it was not detected within the deposits. It is suggested
that these terraces are roughly contemporaneous with the Nabataean period (Appendix A).

T6, despite being at about the same level as the terraces in the fourth group, completely differs
from those in character. It is located at the junction of Wadi al-Mahattah and Wadi al-
Farasha. The nearly two-metre deposit consists entirely of fine sand with a few fine pebble-
sized limestone clasts, and there are no detectable sedimentary structures, indicating that T6
might be the result of just one chaotic erosion and deposition event. T6 also appears to
partially cover the same curved stone structure as T7 (Fig. 6.5).

T15 and T16 were also tentatively included into the fourth terrace level, but they should
probably be considered as a separate level of their own. T15 is located on the Wadi al-
Farasha side of a narrow stretch of land separating the channels of Wadi as-Saddat and Wadi
al-Farasha (Map 6.2). The present height of the terrace from the wadi bed is ca. 2 m, and
there are remains of a Nabataean-Roman road (Site 82, Appendix B) on top of the terrace.
Whether T16 is originally part of the same formation as T15 is unclear. The top of T16 is ca.
5 m above the wadi bed, but there are the ruins of a Nabataean-Roman building (Site 88,
Appendix B) on top of the terrace, which may give it a misleading height. The pottery
associated with the archaeological structures indicates a terminus ante quem of ca. 2000 BP
for both T15 and T16. Therefore the relationship of the structures and the formations suggests
that T15 and T16 are probably somewhat older than the other terraces in group IV, and
should actually be considered as a different terrace level.

The lowest and presumably the youngest group of terraces includes T13, T14 and T17 (Map
6.2, Fig. 6.1). These formations are difficult to define as they join the alluvium which has
apparently been deposited mainly due to the construction of barrage structures and lateral
channel migration, which seems to be partially caused by the building and later abandonment
of the hydraulic installations. The barrages are suggested to originally date from the Nabataean
**Fig. 6.4** The Nabataean barrage partially covered by T7.

**Fig. 6.5** T6 partially covers a probable Nabataean structure. Modern wadi bottom to the right.
period, although their usage has continued until recently and they probably represent several different periods of construction and use (Lavento & Huotari 2002: 104-105). Pottery of possibly Ottoman date (up to the early 20th century) has been found on the surface of these alluvial sediments, but notably the Nabataean ware found appears to be derived from the slopes above. Together with the height of the deposits ranging ca. 0.5-1 m above the modern wadi bed this suggests a later historical date for these sediments. The area of the alluvium has been under cultivation as indicated by clearance stone heaps, and the fields have been tilled even recently.

Clearly a considerable incision of the wadi bed has taken place after the formation of terrace level I. It is suggested that this earliest mapped terrace level could be related to the Pliocene-Pleistocene tectonic activity along the Al-Quwayra fault and its branches, which has influenced the Jabal Harûn area, and it may represent at least partially a colluvial valley fill. The finds of apparently in situ Middle Palaeolithic flint material on top of T8 suggest that the fill was formed more than 40 000 years ago. Terrace level I was also formed before the breaching of the sandstone threshold in the Wadi al-Mahattah channel. It seems that after this threshold was breached, the channel downstream of the threshold has deepened by as much as five metres, leaving T8 on top of a sandstone shelf while the bases of the terraces above the threshold appear to be not much above the modern wadi bed. Whether the degradation of the Wadi al-Farasha channel took place before or after the Middle Palaeolithic activity cannot be ascertained.

Around 1.5 m channel incision into the sandstone bedrock has taken place in Wadi al-Farasha after the formation of T10, which is classified into terrace level II. Above the threshold the incision of the channel into the bedrock below terrace level III is only ca. 0.5 m. However, it seems that the wadi bed in Wadi al-Mahattah - Wadi al-Farasha is not at a significantly different level at present than it was ca. 2000 years ago. This is indicated by the remains of barrages built on the wadi bed, thought to be of Nabataean origin, as well as by the level of a most likely Nabataean step-like structure cut into the sandstone in the channel of Wadi al-Farasha opposite T8 and T9. This observation suggests that there have been periods of
channel aggradation and/or lateral channel migration during the last 2000 years which have resulted in the deposition of at least the lowermost terrace level, level V, and possibly also the deposition of at least some of the level IV terraces, which appear to partially cover presumably Nabataean structures.

6.2 Lithofacies analysis

6.2.1 Sedimentary facies and the principle of lithofacies analysis

Sedimentary *facies* forms the basis of the interpretation of sedimentary strata. It is the sum of the characteristics of a sedimentary unit, including its dimensions, texture and structure, and biogenic content. (Nichols 1999: 62-63.) Sediment texture includes the grain size, grain morphology, micromorphology, fabric and sorting of the sediment, as well as sediment colour and clast lithology. Sedimentary structures are produced by physical, chemical and/or biogenic processes and include sediment sequences and cycles, type of bedding, erosional structures, bounding surfaces and deformation structures. (Jones 1999.)

The term *lithofacies* means that the description of the sediment is confined to such textural and structural characteristics which are the product of physical and chemical processes. These characteristics relate to the processes active at the time of deposition of the sediment. (Nichols 1999: 62-63.) Of the textural characteristics of a sediment, grain size, grain morphology and lithology are the main indicators for the source and transportation conditions of the sediment. Sedimentary structures may be formed before, during and after the deposition of the sediment, and give information about the processes involved in the transport and deposition, as well as post-depositional changes. Certain combinations of sediment texture and structure are considered typical for particular modes of sediment transport. (Jones 1999.)

*Facies analysis* means the interpretation of sedimentary strata in terms of its depositional environments. However, many different environmental conditions may produce similar
deposits, which means that isolated lithofacies do not permit the interpretation of the environmental conditions during the deposition of the sediment. Therefore the recognition of *lithofacies associations* is important for the deduction of the depositional environment. (Nichols 1999: 63.) Lithofacies associations are formed of lithofacies which occur together and are formed under similar conditions, regardless of their position in a sedimentary sequence. The procedure of facies analysis involves two stages: firstly the recognition of facies which can be interpreted in terms of processes, and secondly the establishment of facies associations, which reflect combinations of processes, which in turn are related to the environments of deposition. (Nichols 1999: 64.)

*Facies sequence* means a facies association with the facies occurring in a particular order. (Nichols 1999: 64.) Facies sequences (also termed facies successions) are formed of a series of facies which pass gradually from one into another, usually bounded by a sharp or erosive junction or a hiatus in the deposition of sediment (Reading & Levell 1996: 20). However, lithofacies models are essentially autocyclic while sedimentary sequences may reflect both autocyclic and allocyclic processes (Reading & Levell 1996: 21, 35). Therefore the value of vertical lithofacies sections for interpreting the environmental conditions during the deposition is often limited (Collinson 1996: 61, 69).

### 6.2.2 Excavation of sediment profiles

Altogether four vertical sediment profiles (Fig 6.6, WF1-4) were excavated during the field seasons 2002 and 2003 in three different locations along Wadi al-Farasha (Map 6.2). The main reason for the excavation of sediment profiles was to take OSL samples, as it was hoped that it would be possible to date periods of erosion and deposition potentially related to climatic change or human activity. The younger deposits were considered to be of particular interest, as it was expected that changes in human activities, particularly in the agricultural use of the area, might be reflected in the sedimentary record as periods of increased erosion and deposition. The locations for the excavated profiles were chosen on the basis of the
observations made during the mapping of the terraces, choosing terraces judged to be of different age by their level above the modern wadi bed. Exposures ca. 0.8-1.0 m wide and with up to 0.4 m lateral depth were excavated into each terrace. When possible, the section was excavated down to the modern wadi bed level, but in the case of WF3 in T10, which was the deepest deposit (up to 4.5 m) and located on a bedrock base ca. 1.5 m above the modern channel, only the top 2.65 m were excavated. Three of these sections were further extended in 2005 to obtain more information of the sedimentary sequences, joining profiles WF1 and WF2, and widening profile WF4. WF3 was not further excavated due to its difficult location. Unfortunately it was not possible to carry out more extensive excavation of vertical profiles to the wadi terraces as a result of both the limited number and size of the formations, and the restrictions imposed upon the work by the very basic technology (consisting of a workman with a pickaxe) available and the tight time schedule for the fieldwork.

The sediment profiles were measured and photographed and a field sketch was drawn of each profile, to be used later for the logs and section drawings. A description was written of each sedimentary unit, including an estimation of grain size, description of clast lithology and roundness, fabric and sorting, observed sedimentary structures, type of contact with other units, the presence of pedogenesis, biological processes and any observed archaeological remains. Most units were also sampled for later laboratory analyses of particle size and clast lithology. However, in the case of very coarse units it was not possible to take a sample large enough to be representative. For these units, maximum and typical grain size and clast lithology were determined by measurements in the field.

All the samples taken from the sediment profiles were sieved in the laboratory using the normal dry sieving method (Gale & Hoare 1991:80-81). Particle-size was determined on the Udden-Wentworth scale refined by Friedman and Sanders (e.g. Jones et al. 1999: 43). The enrichment of calcium carbonate caused problems with sieving the samples from the cemented sandy layers, as it causes the individual grains to attach and form “nodules” of variable size, and it proved impossible to try to mechanically break all of these down to get accurate sieving results. In practice this means that in the heavily cemented sand layers the larger sand grain
sizes are over-represented in the sieving results. It would be possible to disaggregate cemented materials by chemical pretreatment, but as the procedure is likely to affect the mineralogy and particle size of the sediment, it is not recommended for sands (Gale & Hoare 1991: 94).

The samples from gravelly units were also analysed for clast lithology which can shed light on sediment provenance and transport and help to correlate or differentiate the units (Gale & Hoare 1991: 165). The division was made simply into limestones, silicified limestone, sandstones and porphyry. The lithological analysis of sieved samples was based on macro- and microscopic study of the clasts, namely grain morphology, colour and grain surface properties. There may be a risk of erroneous classification as the method relied on the visual characteristics of the clasts only, but the dominant bedrock types of the area are mostly easy to distinguish in this manner. The analysis was carried out after the sieving from pebble grain size (4-16 mm or 2-4 mm depending on the sample) by classifying a minimum of 300 clasts (Gale & Hoare 1991: 173). Particle roundness was visually determined for each lithology following the classification adapted from Krumbein (1941) and Powers (1953) (Jones 1999: 13-14; Jones et al. 1999: 44).

In addition to the samples from the vertical sediment sequences, two samples were taken from the modern wadi bed for comparison material in 2005. The modern channel bed is generally rather poorly sorted. Most commonly the channel bed contains all grain sizes from sand to pebbles or cobbles, but there are also better sorted deposits which consist mainly of sand or gravel. The bed grain size varies over short distances and also across the channel, reflecting the variable velocity of the flow and the introduction of material into the channel from the surrounding slopes and by erosion of the channel banks. No consistent downstream sorting of bed material can be observed, but better sorted material of sand to gravel size generally occurs at places where the wadi bed is relatively even and coarser and more poorly sorted.

---

1 Porphyry clasts in the sediments studied are likely to originate from the conglomerates of the Salīb formation exposed in small areas on the lower slopes of Jabal Farasha, rather than from the bedrock unit of Al-Bayda quartz-feldspar porphyry, see also Chapter 3.2.2 and Map 3.1.
deposits where larger clasts are introduced into the channel from the adjacent slopes. Also obstacles such as vegetation or boulders cause changes in the bed grain size as they increase bed roughness. The samples taken (see Map 6.2 for the sampling location) represented moderately well sorted gravel with the median particle size of fine pebbles, and sand with a bimodal size distribution (medium and very coarse sand). The portion of silt and clay in the wadi bed deposits is small, being 2% of total weight in the studied samples. This is likely to be the result of the transport of the <0.063 mm fraction in suspension during the flow events. Thin drapes of deposited mud can be noticed at such places where standing pools formed on the channel bed after a flood, but these deposits tend to be swept away by the next flood.

6.2.3 Typical lithofacies units in the Jabal Harûn area

Seven different lithofacies can be separated in the four vertical profiles from the Jabal Harûn area (Table 6.2, Fig. 6.6). Some of them occur in all of the profiles, while others are limited to one profile only. The lateral continuity of the units is difficult to determine due to the limited extent of the exposures and the small size and fragmentary preservation of the terrace formations themselves. Furthermore, the deposits were revealed to be very discontinuous and complicated with lateral lithofacies changes over distances of only a few metres. In addition to the sedimentary logs (Fig 6.6) also the full vertical sections are presented below (Figs. 6.9-6.11) to illustrate the considerable lateral changes in the deposits over very short distances.

The lithofacies codes used in the following descriptions are after or adapted from Miall (1996: 79). The interpretations of depositional processes involved are mainly based on the fluvial lithofacies models by Miall (1977; 1985; 1996: 79, 99-123) and on a number of studies on ephemeral stream deposits such as Sneh (1983), Stear (1985), Martin & Turner (1998) and Svendsen et al. (2003).
Table 6.2 Typical lithofacies in the Jabal Harûn area. For more detailed lithofacies descriptions and interpretations, see the text.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Description</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sm</td>
<td>fine to medium red sand with occasional pebble-sized clasts</td>
<td>hyperconcentrated flows or post-depositional alteration</td>
</tr>
<tr>
<td>Sh</td>
<td>horizontally bedded fine to medium red sand with occasional pebble-sized clasts, contains thin beds or lenses of coarser sand and/or laminae</td>
<td>lower flow stage flood deposits</td>
</tr>
<tr>
<td>Gh</td>
<td>horizontally stratified, clast-supported, imbricated pebbles</td>
<td>longitudinal bedforms and lag deposits</td>
</tr>
<tr>
<td>Gcg</td>
<td>moderately sorted, crudely bedded, weakly imbricated and clast-supported pebbles with a weak normal grading</td>
<td>hyperconcentrated flows</td>
</tr>
<tr>
<td>Gci</td>
<td>inverse-graded, weakly imbricated and clast-supported pebbles</td>
<td>high-strength debris flows or a low-strength flows with inertial bed load</td>
</tr>
<tr>
<td>Gcm</td>
<td>massive, moderately to poorly sorted, clast-supported pebbles with no grading</td>
<td>pseudoplastic debris flows, low-strength debris flows or bedload deposition</td>
</tr>
<tr>
<td>Gmm / Gmg</td>
<td>poorly sorted pebbles in a sandy matrix, usually no grading, sometimes a weak normal grading (Gmg)</td>
<td>high-strength debris flows / slope processes</td>
</tr>
</tbody>
</table>

Massive, consolidated red sand (Sm)

Lithofacies Sm (Fig. 6.6, WF1-3) consists of moderately to well sorted fine to medium red sand with a few pebble-sized clasts, mainly smaller than 4 mm. The beds of Sm appear massive, and they are moderately to heavily cemented by accumulation of calcium carbonate. Sand grain sizes form nearly 90% of the sediment, while the percentage of clay and silt is ca. 10%. The beds are 15-60 cm thick and have planar, non-erosional bases.

Considering the heavy cementation of the sand and the presence of many plant roots in these units, the lack of detectable sedimentary structures may be the result of post-depositional processes such as bioturbation and pedogenesis (Miall 1996: 123; Martin & Turner 1998: 16), which can destroy structures such as laminae or thin bedding. Very rapidly deposited, well-sorted sediments may also appear massive (Costa 1988: 118). It is also possible that the
Fig. 6.6 Schematic sediment logs from the Jabal Harûn area.
massive sands are true massive deposits, which were deposited from hyperconcentrated or debris flows (Miall 1996: 123; Collinson 1996: 81; Svendsen et al. 2003: 18). In semi-arid areas, these types of flow may result from high sediment concentrations in a flow, related to limited vegetation and high erosion rates, or from mass-flows related to processes such as bank collapse (Martin & Turner 1998: 27-29). High sediment concentration increases flow viscosity, resulting in reduced settling velocity and laminar flow which disables the development of sedimentary structures (Svendsen et al. 2003: 18; Martin & Turner 1998: 27). Deposition of massive sands may take place within the channel or in the adjacent overbank area (Martin & Turner 1998: 18).

**Horizontally bedded red sand (Sh)**

Lithofacies Sh (Fig. 6.6, WF4) consists of moderately to moderately well-sorted, fine or medium red sand with occasional pebble-sized clasts smaller than 4 mm. The beds contain thin (3-5 cm) beds or lenses of medium to coarse sand and occasional laminae, while parts of them may appear massive. Around 75% of the sediment consists of sand grain sizes, while the proportion of clay and silt is ca. 10%. The beds are 25-70 cm thick, laterally discontinuous and weakly to moderately consolidated as a result of enrichment of calcium carbonate. Their bases are non-erosional and often somewhat mixed with the top of the underlying unit.

Planar beds form under two flow regimes: beds of coarse sands and gravels form under lower stage flow when the critical flow velocity is reached and the particles start to move along the bed surface. Under these conditions, bed roughness prevents flow separation and the formation of ripples. The conditions result in horizontal planar lamination which tends to be poorly defined. (Nichols 1999: 50.) At high flow velocities, upper stage plane beds are formed in all sand grain sizes. The upper stage flows produce well-defined planar lamination typical of flash flood deposits. (Miall 1996: 1996: 120; Nichols 1999: 50; Stear 1985: 218, Tunbridge 1981.) Both flow regimes may occur during the first stage of a flood in ephemeral rivers (Sneh 1983: 1274; Stear 1985: 218). Considering that the stratification in lithofacies Sh is mostly poorly defined, it could be considered to represent mostly the lower flow stage deposits (Nichols 1999: 50). The beds or lenses of coarser sand probably represent changes
in flow velocity during different stages of a flood or in different parts of the channel, while the laminae may indicate deposition either under a transition to the upper flow regime or during a waning phase of a flood (Stear 1985: 218).

**Clast-supported, horizontally stratified gravel (Gh)**

Lithofacies Gh occurs in all four vertical profiles (Fig. 6.6). It consists of clast-supported, imbricated pebbles, often with alternating thin (1.5-10 cm) beds of fine to medium pebbles and very fine pebbles or coarse sand, although in some cases the grain size is homogenous through the unit. The matrix is filled with fine to medium sand, which comprises from 33% up to 48% of the facies, resulting in bimodal size distribution. The clay and silt content of the facies is only 1-2%. The clasts are very angular to sub-rounded depending on their lithology. The thickness of the beds is 20-40 cm and their bases are typically sharp and in some cases erosional.

Coarse-grained units are typical of high-energy ephemeral river deposits (Candy *et al.* 2004: 2516). According to Miall (1996: 79) horizontally bedded, clast-supported gravelly units are typical of longitudinal fluvial bedforms and lag deposits. Finer clasts and sand can infiltrate the clast framework under lower flow velocities (Miall 1996: 101). Deposition from bedload within the channel during floods can therefore be suggested. The alternating bedding of coarser and finer materials may represent subsequent floods of different magnitude or stages of the same flood.

**Clast-supported, crudely bedded, normally graded gravel (Gcg)**

Lithofacies Gcg (Fig. 6.6, WF1-3) consists of moderately to moderately poorly sorted, crudely bedded, weakly imbricated clast-supported pebbles. The poorly defined beds are horizontal or dip 10-18 degrees to the presumed direction of flow. The units of Gcg exhibit a weak normal grading. The median grain size is fine to medium pebbles, but the beds may contain also finer grained subunits. The matrix is filled with sand which constitutes 22-26% of the facies, while the amount of clay and silt is only 1-3%. The clasts are very angular to sub-rounded depending on their lithology. The beds are from 20 cm up to at least 90 cm thick and their bases are relatively sharp but non-erosional.
These units are probably deposited by hyperconcentrated flows as suggested by the clast-supported fabric, weakly developed bedding and clast imbrication (Costa 1988: 120). The dipping beds could be related to avalanche-type processes, while the horizontal beds probably represent sediment transported as bedload during high-energy floods. The normal grading in the horizontally bedded units is probably related to decreasing stream velocity during the deposition. (Svendsen 2003: 18.)

**Clast-supported, inverse graded gravel (Gci)**

Facies Gci consists of moderately sorted, inverse-graded, weakly imbricated and clast-supported pebbles. The grain size ranges from fine pebbles to small cobbles. The matrix is filled with fine to medium sand, which comprises 27% of the sediment. The clay and silt content of the sediment is only 2%. The clasts are very angular to sub-rounded depending on their lithology. There is only one occurrence of this facies (Fig. 6.6, WF3). The bed is 20-30 cm thick and shows a sharp, possibly erosional base.

The inverse grading can be indicative of varying modes of deposition, either from a clast-rich, high-strength debris flow, where inverse grading may be locally produced by bed shear (Nichols 1999: 54-55) or as a low-strength flood flow with inertial bed load (Miall 1996: 106). Inverse grading also develops in grain flow deposits as a result of the differentiation of particles during the flow. Grain flows are sediment gravity flows, but unlike debris flows, the grains are supported by grain-to-grain interactions rather than a matrix formed of sediment and fluid, and the flow characteristics differ from those of laminar debris flows. (Dasgupta 2001: 266, 268-269.)

**Clast-supported, massive gravel (Gcm)**

Lithofacies Gcm consists of massive, clast-supported pebbles with no grading (Fig. 6.6, WF1-2, WF4). The matrix is filled with sand which constitutes ca. 25% of the facies. The amount of silt and clay in the deposits is only 1%. Two different types of this lithofacies can be defined. Gcm₁ is moderately sorted and the clasts are oriented and often weakly imbricated, while Gcm₂ is poorly sorted and the clasts have no imbrication or preferred orientation. The two
types of this lithofacies often occur together and without clear boundaries. The median grain size in Gcm1 ranges from fine to medium pebbles. In Gcm2 the typical clast size is coarse pebbles to small cobbles, but also small boulders occur in some units, typically as floating on the top of the unit. The clast roundedness varies widely depending on the lithology of the clasts. The beds of Gcm are 5-40 cm thick and laterally discontinuous with usually sharp and often erosional bases.

Both types of Gcm could be the result of low-strength, low viscosity debris flows (Miall 1996: 108). Deposition of Gcm2 from laminar debris flows is supported by the boulder-sized clasts occasionally floating on top of the unit (Nichols 1999: 55), and the often erosional lower boundaries (Costa 1988: 118). A higher water content giving rise to some turbulence (hyperconcentrated flow) could explain the imbrication and orientation of clasts in Gcm1 (Costa 1988: 120). It is also possible that the units of Gcm1 represent bedload deposition (Collinson 1996: 62). This could be indicated by the small amount of fines, which would be transported in suspension. Data from the Negev proves that clasts up to cobble size (>128 mm in diameter) can be transported by flash floods as bedload (Reid & Frostick 2000: 220). However, fines may also be washed from debris-flow deposits during or after deposition by dewatering processes (Svendsen et al. 2003: 20).

Massive, matrix supported conglomerate (Gmm/Gmg)

Lithofacies Gmm (Fig. 6.6, WF1-2, WF4) consists of poorly sorted, matrix supported gravel. The matrix is fine to medium sand and constitutes ca. 50% of the lithofacies. The amount of silt and clay in the sieved samples was only 3%. Typical clast size is usually coarse pebbles to small cobbles, but in some beds the typical clast size ranges between fine to coarse pebbles and there may be occasional boulders. The clasts are angular to sub-rounded depending on their lithology, and have no imbrication or preferred orientation. Usually there is no grading, but in some units a weak normal grading is present (Gmg). The beds are 20-30 cm thick and laterally discontinuous with relatively sharp but non-erosional bases.
Facies Gmm is likely to be the result of debris flows, as suggested by matrix support, the poor sorting of the deposits and the lack of sediment fabric (Nichols 1999: 55). Some of these flows probably originated from the surrounding steep slopes. The somewhat better sorted beds of Gmm, such as the top units of WF1-2 and WF4, may have been deposited in a different manner, by the combination of colluvial processes and sheet wash.

6.2.4 Results of clast lithological analysis

There were no remarkable differences in the lithology of the sampled gravelly sediments from the vertical profiles and the modern wadi bed. As the deposits are located in a headwater area, all the lithologies can be expected to be locally derived. The lithological composition of the gravelly units is mainly limestones and silicified limestone, which form 36-70 and 12-55% of the sediment respectively. Although the wadis run through the sandstone area, sandstone clasts constitute only 5-25% of the samples. The enrichment of silicified limestone and limestone in pebble-sized material is considered to result from their higher durability in transport. Although the transportation distances in the Jabal Harûn area are short, the material on the wadi bed and channel banks is subjected to frequent scouring and re-working, which rapidly erodes the less-durable sandstones. Sandstone clasts in the samples are usually rounded to well-rounded, while limestone clasts are subangular to subrounded and silicified limestone clasts are subangular to angular. The differences of roundedness are considered to be related to the differential erodibility of the parent materials rather than difference in time in transportation. However, it is suggested that the proportion of silicified limestone indicates the maturity of the sediment, as it is the most durable rock in the area. Therefore, the larger the proportion of silicified limestone in the sediment, the longer the time it has been in transportation and/or the more it has been re-worked. (Nichols 1999: 23; Gale & Hoare 1991: 166.) The highest proportion of silicified limestone (42-55%) occurred in the Gh and Gcm units of WF3 and WF4, while the similar lithofacies units in WF1-2 appeared less mature with only 12% of silicified limestone.
On the other hand, the size of the primary erosional products is also likely to affect the lithological composition of the sediments. The sandstones of the research area readily yield sand-sized material as the primary weathering product. In the units containing large pebbles, cobbles or boulders both sandstone and limestone clasts were present. These were generally more rounded than the silicified limestone clasts of similar size in the same layer, while the latter tended to be very fractured. Sandstone clasts were most abundant in the units containing large pebbles or cobbles which probably represent debris flows from the adjacent slopes, and in the topmost units, thought to be the result of slope processes and sheetwash, i.e. in the units with short transportation distances and short time spent in transport.

6.2.5 Description of the vertical profiles

WF1-2
WF1 and WF2 were excavated in T15, a terrace with a height of 2 m along Wadi al-Farasha (Map 6.2). Above T15 there is a higher terrace along Wadi as-Saddat, which separates the two wadis. The whole lateral extent of T15 is ca. 12 m along the wadi. There are remains of a collapsed barrage which has caused disturbance in the deposits approximately 5 m upstream of the excavated profile, and the formation ends ca. 4 m downstream of the profile. The section WF1-2 is ca. 2 m high and 3.1 m wide after the two vertical profiles WF1 and WF2 were joined in 2005. The profile (Figs. 6.7. and 6.9) can be divided into two sequences separated by the erosional surface bounding the upper limit of the massive fine sand unit (Sm). The sand unit is very heavily cemented with carbonate, and enrichment of carbonate has taken place also in the gravelly units below it, resulting in the formation of a carbonate horizon at the depth of 100-130 cm (Fig. 6.6, WF1). The horizon is characterised by carbonate coatings on the gravel clasts, corresponding to Gile’s stage I (Gile et al. 1966: 349). The horizon is considered to be pedogenic and indicative of a stable period with relatively slow erosion and sedimentation rates (Alonzo-Zara 2003: 288-289) sometime after the deposition of the massive sand unit but before the deposition of the upper sequence.
**Fig. 6.7** The section WF1-WF2 in T15, extended in 2005. The white line indicates the erosional boundary.

**Fig. 6.8** The section WF4 in T7, extended in 2005. The white lines indicate erosional contacts.
Fig 6.9 Section drawing of WF1-2. The numbers indicate the approximate order of deposition. However, some units are overlapping or may be synchronous.
Two flint flakes were found in the lower sequence of WF1-2 at the depth of 100-130 cm (Fig. 6.6). These had clearly been transported with the sediment as there were no other archaeological finds. One of the flakes represented Levallois technology, and was very worn, while the other was probably of post-Middle Palaeolithic date and in good condition (Hertell 19.8.2002). The dating of the flakes suggests that the deposition of the lower part of the excavated terrace has probably taken place after the Middle Palaeolithic, that is, less than 40,000 years ago. The Nabataean-Roman archaeological structures on top of T15 indicate that the deposition of the top sequence took place more than 2000 years ago.

WF3
Profile WF3 was excavated in T10 located along Wadi al-Farasha (Map 6.2). T10 is currently completely above the wadi bed, on a bedrock base with a height of 1.5 m that is being undercut by the wadi. The deposit is 4.5 m thick but stretches only a few metres laterally. Only the top 2.65 m of the deposit were excavated for the section, which is 0.6-1.0 m wide. There appear to be four deposition events in WF3, each consisting of gravelly lithofacies with massive sand (Sm) on top, separated by sharp boundaries representative of erosion and/or hiatus in sedimentation (Figs. 6.6, 6.10). There are no coarse debris flow deposits in WF3 like in the other two profiles. The sand units are moderately cemented with carbonate, which may indicate stable periods and pedogenic activity between the depositional events. No carbonate enrichment was detected in the gravelly units. Archaeological materials were not found during the excavation of the cleaning.

WF4
WF4 was excavated in terrace T7, which is located below T8, downstream of the junction of Wadi al-Farasha and Wadi al-Mahattah (Map 6.2). There are partially buried remains of a Nabataean barrage just 1.5 m downstream of the excavated profile. Upstream of the profile the terrace bank has been slumped and gullied. The excavated section of the terrace is ca. 1.8 m high and 1.8 m wide after the extension in 2005. The sedimentary units in WF4 are laterally very discontinuous and there are several erosional contacts between the units (Figs. 6.8, 6.11). The terrace is located in a rather narrow stretch of the Wadi al-Farasha channel.
Fig. 6.10 Section drawing of WF3. The numbers indicate the order of deposition.
Fig. 6.11 Section drawing of WF4. The numbers indicate the approximate order of deposition. However, some units are overlapping or may be synchronous.
and connected with steep slopes, which may explain the extreme lateral discontinuity of the units. The fine to medium sand units are weakly to moderately consolidated and show enrichment of carbonate, which may indicate stable periods with pedogenic processes after their formation. Although Middle Palaeolithic flint material from the site (Site 127) on top of the higher terrace T8 was found on the surface T7, no flint flakes were found within the deposits during the excavation of WF4. One very worn piece of Nabataean pottery was found in the Gcm unit 6/WF4 (Fig. 6.6, WF4, Fig. 6.11), which indicates that the unit in question was deposited not earlier than ca. 2000 BP.

6.2.6 Discussion of the results of lithofacies analysis

It proved impossible to relate lithofacies from different profiles on the basis of textural or structural characteristics. Each of the excavated sections shows a number of depositional processes, with considerable lateral lithofacies changes over distances of a few metres only. The lithofacies sequences observed in the vertical profiles may be the result of a few high-magnitude events of short duration only. Between these events there may have been long periods of deposition and/or erosion which are not reflected in the sedimentary record.

The models presented in the interpretation of the lithofacies units are essentially autocyclic. Therefore it is not possible to draw straightforward conclusions of the climate or environment during the deposition of the studied lithofacies. However, many of the studied lithofacies appear to be the product of debris flows or hyperconcentrated flows. These types of deposits are typical of semi-arid areas and ephemeral channels (Nichols 1999: 55). Likewise the horizontally bedded, often texturally coarse sediments represented by lithofacies Sh, and to some extent also Gh, indicate high sediment concentrations during fluvial transport (Sneh 1983: 1277), which is characteristic of ephemeral dryland channels where the flow events are short-lived and the flow is often supercritical due to the low water to sediment ratio (Reid 2001: 121).
The considerable lateral changes in the studied profiles can be related to several geomorphological factors present in the Jabal Harûn area. The input of water and sediment from the dense network of tributaries causes frequent changes in the flow conditions along the main channels, which results in laterally discontinuous deposits (Stear 1985: 220). The deposited sediments are also subject to the scouring of the channel bed and bank collapse. The high relief of the area encourages the initiation of debris flows. Furthermore, the channels are immediately connected to the steep slopes, which results in sediment transported by slope processes being deposited in the overbank area and even within the channel perimeter.

The periods of soil formation indicated by the enrichment of carbonate, which was mostly detected in the sandy deposits, suggest relatively long periods of low sedimentation and/or erosion rates during or after the deposition of these units (Alonzo-Zara 2003: 288-289, 291). The formation of calcrete horizon in terrestrial settings is related to pedogenic processes or the presence of groundwater. For groundwater carbonate horizons to form, the water table needs to be stable for long periods, which makes it seem unlikely that groundwater calcretes would have been formed in the Jabal Harûn area. Pedogenic calcrete horizons are mainly formed under arid and semi-arid climatic conditions, and they are usually considered indicative of more arid conditions. However, there is evidence that in some semi-arid and arid environments carbonate horizons are formed under more humid climatic spells. (Alonzo-Zara 2003: 286-287; Goodfriend & Magaritz 1988.) At present day the rate of erosion is too high for pedogenesis to take place in the Jabal Harûn area. Therefore it is suggested that the enrichment of carbonate in the soil profiles is indicative of periods with more rainfall and stabilizing vegetation than at present (Alonzo-Zara 2003: 291).

As a summary, the lithofacies in the vertical profiles studied from the Jabal Harûn area could be considered to represent a sedimentary environment typical of a semi-arid headwater area with rugged relief, dense channel network and high channel gradients. The climatic conditions that can be implicated from the studied lithofacies sequences are broadly similar to those prevailing in the area at present day. On the basis of the evidence of periodic pedogenic activity, it can be suggested that stable periods with relatively little erosion or deposition have
alternated with periods of heavy erosion and/or rapid deposition of sediments. It is further postulated that the periods of soil formation are related to more humid climatic phases than that of the present.

6.3 OSL dating

6.3.1 The principle of OSL dating

Two practical considerations influenced the choice of dating method. Firstly, the soils in the Jabal Harûn area contain very little organic material other than roots of recent vegetation. Secondly, the nature of the erosional and depositional events in the area gave a reason to believe that the context of organic material within the sediment may be mixed. Therefore C14-dating was deemed unusable, and optically stimulated luminescence dating (OSL) was chosen as the method for dating the sediment samples.

OSL is a trapped charge dating method which is based on the time-dependent accumulation of electrons and holes in the crystal lattice of certain common minerals. When a mineral is formed, all its electrons are in a ground state. Naturally occurring radioactive minerals emit rays which ionize atoms, causing negatively charged electrons to be transferred from the atoms in a valence band to a conduction band. After a short time most electrons recombine with the positively charged holes which remain near the valence band. However, all natural minerals contain defect sites such as lattice defects, at which electrons and holes can be trapped. Some of the traps are light sensitive. In OSL dating, trapped electrons are activated by light exposure, which causes most of them to recombine with the holes. When the electrons combine with holes which are luminescence centres, light emission is observed. (Grün 2001:47, 50.)

The exposure of the mineral to sunlight resets previously stored trapped electrons. This resetting is called the zeroing event. When the mineral is subsequently buried after the zeroing,
new electrons and holes are trapped (Grün 2001:47-48). This trapped charge can be measured. When light in a narrow frequency range is focused on the sample, it activates the electrons in the light sensitive traps. The electrons combine with luminescence centres and the sample emits light (Fig. 6.12) (Grün 2001:50). The intensity of the light is dependent on the amount of the electrons which is in proportion to the “build-up” i.e. the time that has passed since the last zeroing event and the deposition of the sediment (Eskola 8.10.2004). By plotting the light emission against the time elapsed, a shine-down curve is acquired (Grün 2001:50).

**Fig. 6.12** The principle of OSL dating (http://www.ees.lanl.gov/Resources/osl/BriefOSL.shtml).

6.3.2 OSL sampling locations and procedure

Samples for OSL analysis were taken during two field seasons, in 2002 and 2003. In 2002 two locations were chosen for sampling: T15 (WF1-2) along Wadi al-Farasha below the “Nabataean Road” (Site 82), and T10 (WF3), a terrace of Wadi al-Farasha with the height of *ca.* 6.5 m (Map 6.2). These locations were chosen because there appeared to be several
easily recognisable layers of sedimentation and it was hoped that these layers would show clear differences in age. In 2003 one more location was sampled in T7, a low terrace that was deemed to be relatively young, near the junction of Wadi al-Mahattah and Wadi al-Farasha (Map 6.2). The units sampled in each location with the corresponding OSL sample numbers are presented below in Chapter 6.3.3, Table 6.3 (see also Figs. 6.9-6.11).

Sampling was carried out by hammering a sharpened iron pipe horizontally into the cleaned sediment. The method for retrieving the samples was suggested by the professor of Quaternary geology at the University of Oulu, Juha-Pekka Lunkka. Originally the plan was to use PVC plastic pipes, but these were discarded as they broke when hammered into the very hard, consolidated sediments. The outer end of the pipe was sealed originally with a plastic stopper and later with aluminium foil and duct tape as it proved that the plastic stoppers also broke when hammered. The pipes used were of 47 mm in diameter and they were 300 mm long. Slightly smaller pipes, 250 mm long, with a diameter of 30 mm, were used in 2003 to prevent the mixing of thin sediment layers. After all the pipes had been hammered into the sediment they were dug out, as pulling the pipes out resulted in the sediment being poured out of them and getting mixed. After the pipe was taken out, the other end was immediately sealed with aluminium foil and duct tape. By this procedure the end of the sample might be very briefly exposed to light but the middle part of the sample, which was used for dating, remained unexposed. The pipes were then stored in a black plastic bag out of direct sunlight and transported to Finland as personal luggage to avoid exposure to radiation.

6.3.3 Results of OSL dating

The OSL analyses were carried out in the Dating Laboratory of the Finnish Museum of Natural History by Lic. Phil. Kari Eskola. The analyses were done on quartz-grains separated from the sample using the improved single-aliquot regenerative dose (SAR) protocol described by Murray & Wintle (2000). In this protocol, hundreds or thousands of grains are measured and the age obtained for the sample is based on the OSL signal of all these grains.
weighted by their brightness. Originally the single-grain (SG) protocol was tried, but due to the relatively weak OSL signal of the quartz present in the samples, it did not provide results and the SAR protocol had to be used instead. The advantage of the SG protocol would have been the ability to observe single grains in heterogeneous material, enabling the elimination of the ageing effect of incompletely zeroed grains from the final results. (Eskola 8.10.2004.) The annual $\beta$ radiation dose was determined from separate samples for dose rate determination (Bøtter-Jensen & Mejdahl 1988), and the ratio of $\beta$ and $\gamma$ radiation was used to calculate the amount of $\gamma$ radiation. The combined annual $\beta$ and $\gamma$ radiation dose was determined to be relatively low, ca. 1.0-1.2 mGy/a. However, the uncertainty of the result is ca. 10% as the ratio of $\beta$ and $\gamma$ radiation is not known in the sampling location. (Eskola 4.4.2005.) However, considering the uncertainties in determining both the dose rate and the equivalent dose, the inaccuracy of the results is more likely to be closer to 20% (Eskola 9.12.2005).

The first six samples were analysed from units 4 and 7 in profile WF3 during the winter 2002-2003. The results of the analyses are presented in Table 6.3 below. As can be seen from the results, the age determined for the samples varied between 61 000-91 000 years for WF3 unit 4 and between 59 000-75 000 years for WF3 unit 7 (Fig. 6.10). The facts that the age determined for samples from the same layer was greatly variable and younger dates were obtained from unit 4 than from the stratigraphically younger unit 7, strongly suggested that zeroing of the quartz in the sediment was incomplete. Therefore it was decided to take more samples in 2003. These were collected from WF4 in T7 (Map 6.2, Table 6.3), together with $\beta$ samples for determining the annual radiation dose.

The ages of the new samples from WF4 were determined during winter 2003-2004 (Table 6.3, Fig. 6.11). Samples 1-3/03 from WF4 unit 5 were dated between 2 400-2 000 years and samples 4-5/03 from WF4 unit 3 yielded ages of ca. 4 300 and 3 100 years respectively (Fig. 6.11), although ca. 3000 years would probably be a more correct age also for sample 5/03 (Eskola 19.2.2004). The sample number 6/03 was unsuitable for OSL dating, probably due to the mixing of the sediment. However, as these results were encouraging, the rest of the samples from 2002 were analysed in the hope of getting more useful results. These results
were again a disappointment, though, as zeroing was proved to be incomplete for all of the samples from WF2 and WF3 (Eskola 29.4.2004).

Table 6.3 The results of the OSL analyses. For information on the sediment profiles see Figs. 6.6. and 6.9-6.11. Note: samples 1/02 and 3/02 were discarded as the pipes were imperfectly filled resulting in the mixing of the sample in the pipe.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Sampling location</th>
<th>Unit</th>
<th>OSL date (ka)</th>
<th>Dose rate (mGy/a)</th>
<th>Equivalent dose D_e, Gy</th>
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<td>T15/ WF1-2</td>
<td>8</td>
<td>67 ± 15</td>
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<td>101.1 ± 20.01</td>
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<td>108.0 ± 19.13</td>
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<td>1.09</td>
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<td>1.65</td>
<td>101.2 ± 19.62</td>
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<tr>
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<td>132.7 ± 12.82</td>
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<td>1.64</td>
<td>147.9 ± 28.43</td>
</tr>
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<td>1.47</td>
<td>98.39 ± 29.67</td>
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<td>136.1 ± 48.48</td>
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<td>2.1</td>
<td>1.1</td>
<td>2.26</td>
</tr>
<tr>
<td>2/03</td>
<td>T7 / WF4</td>
<td>5</td>
<td>2.0</td>
<td>1.2</td>
<td>2.39</td>
</tr>
<tr>
<td>3/03</td>
<td>T7 / WF4</td>
<td>5</td>
<td>2.4</td>
<td>1.1</td>
<td>2.58</td>
</tr>
<tr>
<td>4/03</td>
<td>T7 / WF4</td>
<td>3</td>
<td>3.1</td>
<td>1.2</td>
<td>3.77</td>
</tr>
<tr>
<td>5/03</td>
<td>T7 / WF4</td>
<td>3</td>
<td>4.3</td>
<td>1.2</td>
<td>4.98</td>
</tr>
</tbody>
</table>
6.3.4 Discussion of the OSL dates

The OSL results from the samples from profiles WF1-2 and WF3 clearly indicate that zeroing of the sediment has been imperfect. Munro and others (1997) have dated Pleistocene and later aeolian sediments in the ad-Disa area, south of Ras an-Naqb (see Map 4.1 for the location). Also in their results the uncertainties of the OSL dates were large, but Munro and others interpreted this to be the result of high scatter in OSL signals as the result of dominating individual bright grains, thought to be due to the different quartz host rocks around ad-Disa, rather than incomplete zeroing (Munro et al. 1997: 99).

The poor zeroing of quartz grains in most of the dated deposits is comparable to the results of Porat et al. (1997) who dated feldspar from wadi fan sediments from the western Wadi ‘Arabah using IRSL (infra red stimulated luminescence). They found a large scatter in the equivalent dose regardless of the measurement protocol used, and concluded that the zeroing of the sediment was imperfect due to the rapid transportation and sedimentation in the wadis (Porat et al. 1997; 2001). In a further study of modern colluvial and fluvial sediments in the area close to Elat, Porat et al. (2001) found out that also modern slackwater deposits had high, scattered equivalent doses, resulting into residual ages as high as 15 ka. They concluded that this was the result of flash floods, which carry very high coarse sediment loads over short distances. Due to the mode of transportation the sand grains are rapidly buried and not all the grains are exposed to sunlight. Furthermore they noted that repeated transport appeared to improves the luminescence sensitivity of the samples. However, the lowest equivalent doses for modern samples were close to being fully bleached. Therefore Porat et al. recommended the use of single-aliquot or single-grain protocols for a large number of grains to get the lowest equivalent dose values which would give the most accurate age estimates. (Porat et al. 2001.)

Considering the character of the Jabal Harûn area, with very short transportation distances and close connectivity of hillslopes and channels, it seems, in the light of the studies by Porat et al. (1997, 2001), that the short-lived nature of the flood events, the potentially very high sediment load in transport, and short transportation distances are a likely explanation for the poor
zeroing of the sand in many of the OSL samples. Furthermore, some of the sandy deposits sampled may represent the rapid re-deposition of sediment from older deposits, perhaps transported as a mass or hyperconcentrated flow rather than in fluvial transport, as indicated by the lack of detected sedimentary structures.

Possibly the use of the single-grain protocol, as was originally intended, would also have given different results. Unfortunately this was not possible due to the poor quality of the quartz grains in the samples, which resulted in a weak OSL signal. The poor quality of the quartz grains might be due to the reason that they are derived from the sandstones as the result of weathering processes and have re-entered transportation.

The OSL results from WF4 (T7) differ from those from WF1-2 and WF3. They appear to indicate a longer time between the erosion and deposition of the sediment, with enough time for the eroded material to be on surface or in transport for the zeroing of quartz grains to take place. The results from WF4 also suggest that T15 is actually somewhat older than T7, as the younger dated deposit in WF4 is ca. 2000 years old, but the road built partially on T15 is approximately of the same age, which means that the top of T15 must have been stable by that time.

It was hoped that the OSL dates would help to connect the periods of sedimentation to climatic phases and periods of human activity in the Jabal Harûn area, but due to the incomplete zeroing of the sediments, the OSL dates obtained are mostly of no use in dating the periods of sedimentation and erosion, with the exception of the dates from two units in WF4. Originally it was also hoped that the OSL results would help to date the periods of the construction, use and abandonment of the runoff farming system. However, although the age of the younger dated unit (no 5) in WF4 corresponds roughly to the period that has been suggested for the construction of the hydraulic structures on the basis of archaeological evidence, there is not enough data to confirm the connection. Due to the weak OSL signal and the problems of determining the ratio of $\beta$ and $\gamma$ radiation and the equivalent dose, the
uncertainties of the dates obtained are too high to reliably connect the deposition of the sediment to archaeologically datable human activity.
7. Discussion: Environmental change and human history

7.1 Comparison of the data from the Jabal Harûn area with other palaeoclimatic and geoarchaeological information

The deposition of the lithofacies sequences in the vertical profiles studied in the Jabal Harûn area appears to have occurred under more or less similar climatic and environmental conditions as the present ones. It is postulated that more humid phases within the overall semi-arid climatic range have taken place during the development of the calcic horizon in WF1 and the enrichment of carbonate detected in the other profiles. However, due to the poor zeroing of the samples, the OSL dates obtained from the Jabal Harûn area give little information about the age of the deposits, and there are only a few archaeological finds to aid in their dating either. Comparisons of the observations from Jabal Harûn area with other areas in southern Jordan are therefore needed to form at least a broad picture of the probable course of the environmental development of the Jabal Harûn area. The closest points for comparison for the results from the Jabal Harûn area are from the palaeoenvironmental and sedimentological studies carried out in Bayda (Field 1989), Wadi Faynan (Barker et al. 1997; Barker 2000; McLaren et al. 2004), Wadi al-Hasa (Schuldenrein & Clark 1994), Wadi Judayid in the Ras-an-Naqb area (Henry et al. 1981), Wadi ʿArabah (Niemi & Smith 1999) and the Negev Desert (Goodfriend & Magaritz 1988; Frumkin et al. 1998) (see Map 4.1 for the approximate research locations).

The following comparison is based on the reconstructions of climatic conditions, but it should be noted that the margins of the Wadi ʿArabah Rift are tectonically active areas, and all the studied locations immediately to the east of the Rift have been influenced by a variety of tectonic events. The Wadi al-Hasa area is affected by the tectonic subsidence in the Dead Sea area, while the Wadi Faynan area and the Petra region have been subjected to different phases of tectonic activity related to the formation of the Wadi ʿArabah fault and other
approximately north-south oriented fault systems such as the Al-Quwayra fault zone. Some of these tectonic processes have ended while others continue during the present day, that the Unfortunately the neotectonics of the eastern side of Wadi ‘Arabah have not been studied (Barjous 14.8.2005). Therefore the tectonic controls of erosion and deposition at the different locations are poorly understood and generally overlooked in the interpretation of the sedimentary sequences from the comparison areas, a situation which adds an uncertainty to the comparisons between different locations. In the Jabal Harûn area there is no evidence of significant tectonic movement occurring after the Pleistocene (Barjous 14.8.2005), and therefore the lower terrace levels from II to VI are considered to be related to climatic rather than tectonic controls.

The highest terrace level along the Wadi al-Mahattah - Wadi al-Farasha channel, represented by terraces T5 and T8, indicates that large-scale erosion and sedimentation took place in the Jabal Harûn area probably during the Pleistocene, before the Middle Palaeolithic period\(^1\). A major alluviation period is deemed to predate the Middle Palaeolithic Mousterian period in Wadi Judayid, Ras an-Naqb area. Climate with seasonal aridity but considerably higher rainfall than at present, around 300 mm, is suggested, indicated by the precipitation of carbonate nodules during this period. (Henry 1981: 121.) Also in Wadi Faynan the Late Pleistocene is associated with powerful, aggrading rivers. Middle Palaeolithic materials have been found both within and on the surface of the deposits, suggested therefore to be \(\text{ca.} 150 000-50 000\) years old. (Barker et al. 1997: 24-26; McLaren et al. 2004: 151.) In Wadi al-Hasa discrete cycles of sedimentation associated with soil formation and the existence of springs have been reported for the period between \(\text{ca.} 200 000-90 000\) BP (Schuldenrein & Clark 1994: 46). However, without any dating for the deposits it is not possible to judge whether the phase of erosion and sedimentation represented by terrace level I in the Jabal Harûn area was related to climatic conditions or to the last active phase of the formation of the Al-Quwayra fault system, which took place during the Pliocene-Pleistocene (Barjous & Mikbel 1990: 57).

\(^1\) Please refer to Appendix A for the dating of the archaeological periods.
The formation of the highest terrace level was followed by considerable wadi downcutting in the Jabal Harûn area. This period of channel degradation might be comparable to Wadi Judayid, where the early moist period was followed by cooler and drier conditions when wadi downcutting and accumulation of dunes took place (Henry et al. 1981: 121). This drier period is thought to possibly correspond to the aridification during the Upper Palaeolithic. It is, however, possible that the period of wadi degradation in the Jabal Harûn area after the deposition of the terrace level I was related to the tectonic movements of the last active phase of the Al-Quwayra fault rather than to climatic controls, and it may have taken place already before the Middle Palaeolithic.

A second period of deposition is evidenced by the terraces T1 and T10. On the basis of the vertical profile from T10 at least four deposition events appear to have taken place. Each of these events has resulted in the deposition of gravelly lithofacies topped by a fine sand lithofacies. The poor zeroing of the sediments noticed in the OSL dating seems to indicate rapid deposition of the sediments, possibly from hyperconcentrated or debris flows. The deposition events are separated by a hiatus in sedimentation, and possibly also erosion, as indicated by the sharp boundaries between the sequences. The sand units exhibit enrichment of carbonate, considered to be evidence of pedogenesis and more humid climatic conditions than at present.

At the site of Bayda, the closest location to the Jabal Harûn area, the aggradation by ephemeral streams started during the Late Pleistocene and continued throughout the period of the Natufian occupation in Bayda, with evidence of decreasing flow strength and weak soil development during the periods when there was no sediment deposition. Field has argued that the formation of the valley fill which today exists as remnant terraces indicates less intense rainfall than at present, because runoff from torrential rains would have washed the sediment away. (Field 1989: 86-88.) In Wadi Judayid alluviation resumed after the Glacial and continued possibly until the Epipalaeolithic with torrential storms indicated by frequent cut-and-fill structures and rapid lateral and vertical facies changes as well as the frequent occurrence of large stones. Somewhat drier conditions than during the earlier moist phase,
with rainfall perhaps around 250 mm, have been postulated, meaning still considerably higher rainfall than at present (Henry et al. 1981: 121). In Wadi al-Hasa accumulation of alluvium and formation of minor alluvial fans took place after the Late Glacial Maximum until around 15 000 BP (Schuldenrein & Clark 1994: 46-47). From the Negev there is evidence of extensive erosion after the formation of a palaeosol dated to ca. 28 000 BP, suggested to have occurred during the Last Glacial Maximum, and evidence of the formation of a relatively weak palaeosol around 13 000 BP (Goodfriend & Magaritz 1988). In Wadi Faynan dry conditions prevailed during and immediately after the LGM, as indicated by windblown sediments. The youngest fluvial deposits in the area range from 15 800 BP to 100 years old, having been formed under similar or slightly wetter conditions than at present. (McLaren et al. 2004: 151.) Comparison with these other locations leads to the suggestion that the formation of the second terrace level in the Jabal Harûn area may have taken place during the terminal Pleistocene.

After the formation of terrace level II erosion and considerable wadi incision have taken place in the Jabal Harûn area, leaving T10 on top of a 1.5-metre bedrock shelf, undercut by the wadi. A comparable period of massive erosion and wadi degradation has been dated to the Early Neolithic in Bayda, where it has washed away a considerable portion of the Natufian site. The erosion has been attributed to an increased intensity of rainfall and sudden rainfall events. (Field 1989: 88-90.) This agrees well with the palaeoclimatic data indicating increased rainfall and intense rainstorms during the early part of the Holocene corresponding to the Early Neolithic (e.g. Bar-Matthews et al. 1997:165). Erosion and degradation have been reported as the main processes after ca. 9000 BP also both in Wadi al-Hasa (Schuldenrein & Clark 1994: 46) and Wadi Judayid (Henry et al. 1981: 123). In the southeastern Wadi ‘Arabah the early to mid-Holocene is represented by a phase of widespread alluvial fan aggradation, probably related to increased sediment supply, and greater stream discharges are inferred particularly for the Chalcolithic (Niemi & Smith 1999: 808-809). Likewise the data from Wadi Faynan point towards a wet period during the Early Holocene, particularly during the later Neolithic and the Chalcolithic period, when there appears to have been a perennial stream in Wadi Ghuwayr (Barker 2000: 70).
Gradual aridification of climate followed the wet Early Holocene as a result of rising temperatures and decreasing amount of rainfall. Since ca. 7000 BP the climate of the Near East has gradually began to resemble that of the present day, although there have been oscillations towards both more humid and more arid conditions within the semi-arid climatic regime (e.g. Bar-Matthews et al. 1997). In the Jabal Harûn area erosion and wadi incision seem to have been the dominant processes for most of the Holocene, and it seems that sediment entering transport has mainly been removed from the area. However, periodical alluviation has also taken place. It seems probable that there have been also earlier small-scale alluviation phases during the later Holocene, but the two units that have been OSL dated in WF4 (T7) date to 4300-3100 BP (unit 2) and 2400-2000 BP (unit 5) (Fig. 6.11). Weak soil development has taken place during or after the deposition of each unit, indicating that rainfall was probably higher and the area more vegetated than at present. The deposits are separated by a period of erosion and deposition of gravel and pebbles from debris flows. There are also other terraces (T6, T9, T11, T12) along the Wadi Farasha whose age judging by their height from the modern wadi bed roughly corresponds to the deposits dated in WF4.

The palaeoclimatic information for the period of formation of unit 2 in WF4 is somewhat contradicting. Halite was formed in the Dead Sea basin around 4000 BP, indicating aridity. Around 3200-3000 BP there was a high stand of the Dead Sea, corresponding to the Late Bronze Age - beginning of the Iron Age (Geyh 1994: 134; Bruins 1994: 305). This period was followed by desiccation, which continued at least until 2300 BP (Geyh 1994: 135). However, as it is likely that the older OSL date should also be closer to 3000 BP (Eskola 19.2.2004), the period of the deposition of fine sand and subsequent soil formation corresponds well to the humid period recorded in the Dead Sea levels.

A short humid climatic phase has been dated between 2000-1700 BP by the Dead Sea levels (Geyh 1994:135). Bruins (1994: 307-308) considers that humidity started to increase already during the second half of the Early Nabataean period, in the 2nd century BC, reaching a peak around the end of the 1st century AD and continuing into the 3rd century AD. An increase either in the amount or seasonality of rainfall in the Aqaba coastal zone during the Nabataean-
Roman period is suggested by Niemi and Smith on the basis of their studies in Wadi ‘Arabah (1999: 812). Also palaeohydrological studies from the Negev indicate a higher runoff around 2000 BP (Frumkin et al. 1998: 108-109). The OSL age of layer 5 in WF4 seems to fit fairly well into this palaeoclimatic framework. There is evidence of one more undated period of erosion and subsequent deposition on top of unit 5, apparently followed by gradual incision of Wadi al-Farasha to its present level.

The lowest terrace levels appear to be at least partially accumulated as the result of the construction of the hydraulic structures. The location of the supposedly Nabataean barrages and other structures in relation to the modern wadi bed indicates that the Wadi al-Farasha channel is not at a significantly lower level today than around 2000 BP. The most recent wadi terraces are just ca. 0.5 m above the modern wadi bed. It seems that they have been deposited as the result of the lateral migration of the channel, partially related to the existence of the hydraulic structures, and their age is probably just a few hundred years.

The evidence from Wadi as-Saddat appears to be contrary to that from Wadi al-Farasha, as it seems possible that most of the sediment in the alluvial basin at the foot of Jabal Harûn has deposited during the last two or three centuries, preceded by a period of heavy erosion. On the other hand, the largest and most well-preserved barrages can be found in Wadi as-Saddat, indicating that it has been until recently under cultivation and the barrages in the wadi have been maintained. Unfortunately soundings excavated by several barrages have not yielded any information about their age, although several occasions of reparations and changes to the structures can be detected (Lavento & Huotari 2002: 104-105). The gradient of Wadi as-Saddat is very high (199 m/km), which is likely to explain why erosion appears to have been more effective in the Wadi as-Saddat channel than in the Wadi al-Mahattah - Wadi al-Farasha channel, which has a considerably lower gradient (65 m/km).
7.2 Connecting the environmental data with the archaeological evidence

How then does the environmental evidence and palaeoclimatic data presented above correspond to the archaeological traces of human presence in the Jabal Harûn area? Can any relationship be seen between the periods of human activity and the presumably more favourable climatic periods with high rainfall, and vice versa, do the periods of human presence correspond to the cool or arid climatic phases?

The climate was considerably more humid than at present during the period corresponding to most of the Middle Palaeolithic, as the existence of lakes in southern Jordan proves. The Jabal Harûn area seems to have been frequently visited during this period. Activities taking place included raw material procurement and probably also hunting, as indicated by the finds of Levallois points outside the find scatters (Jansson 2002: 193-195). Following Henry’s vertical transhumance theory it could be suggested that the Jabal Harûn area also formed a route between Wadi ‘Arabah and the Jordanian plateau in the east for both grazing animals and people hunting them (Jansson 2002: 195). Considering the higher rainfall, water might have been available in the area year round stored in the wadi beds which were not as deeply incised between the hills as at present. The area would probably also have been more forested and it is likely that it offered plant and animal resources quite different from those available there today.

It seems that after the Middle Palaeolithic human activity in the Jabal Harûn area diminished considerably. This change is contemporary with the shift towards more arid climate in the Near East. Although some of the undated flint material may be Upper Palaeolithic, there is no definite evidence of human activity in the Jabal Harûn area before the Epipalaeolithic. There are not many Upper Palaeolithic sites in the Petra region either. Generally the decreased number of sites during the Upper Palaeolithic is attributed to the worsened climatic conditions during the late Glacial. As suggested before, a change towards more arid climate would
severely affect the availability of water in the Jabal Harûn area, which reduced its attractiveness for animals and people. It can also be suggested that in the Jabal Harûn area, which is mainly ca. 1000 m or more above the sea level, the aridity and low winter temperatures may have restricted tree growth particularly during the last Glacial Maximum.

After the last Glacial the climate became warmer and wetter. Based on the comparison with other locations in southern Jordan it is suggested that the second terrace level with its recurrent erosion and deposition events is related to the climatic amelioration during the Late Pleistocene. The Early Holocene, corresponding with the beginning of the Neolithic period, witnessed a climatic phase with increased rainfall and intense rainstorms. Heavy erosion has been correlated with this period in Bayda and Wadi Judayid. It is suggested that significant erosion and wadi incision took place also in the Jabal Harûn area during the wet Early Holocene. The corresponding Early Neolithic period is represented in the Jabal Harûn area by few stray finds only, indicating that the use of the area has been only occasional, such as gathering and hunting.

As it was briefly mentioned earlier in Chapter 2.3.3, erosion and burial of sites may affect the picture we can get of the archaeology of a certain region. It seems possible that the heavy erosion postulated for the Late Pleistocene and Early Holocene may have obliterated evidence of Upper Palaeolithic, Epipalaeolithic and perhaps also the Neolithic period in the Jabal Harûn area. In areas such as Wadi Ziqlab in northern Jordan, hillslope erosion has also buried sites on the valley floor (Field & Banning 1998: 596). However, the Jabal Harûn area is hilly and there are not many basins where sediment would accumulate. No evidence of in situ archaeological remains within the deposits was detected during the mapping of wadi terraces or excavation of sediment profiles, and altogether very few finds were recovered from the wadi terrace deposits. Considering the fragmentary preservation of the wadi terraces on one hand, and the apparently young age of many alluvial deposits on the other, it seems unlikely that buried sites would be found in the Jabal Harûn area.
Gradual aridification of the climate followed the wet early Neolithic, and since around 7000 BP the climate of the Near East has resembled that of the present, that is semi-arid with fluctuations both towards more humidity and more aridity than today. After the Pre-Pottery Neolithic period datable archaeological finds completely cease in the Jabal Harûn area for a period of several millennia, lasting to the Iron Age. It seems that the geological processes at work have been relatively similar to those of today. Eroded materials entering transport have mostly been washed away from the area, a situation similar to that of the present day, although periodical alluviation during the more humid climatic periods has probably taken place.

It is not until the Nabataean period that people seem to return to the Jabal Harûn area. Following the beginning of the Christian era there is evidence of intensive Nabataean agricultural activity in the Jabal Harûn area during the 1st century AD. The reconstructions of the climate of the Near East point towards a humid period, with more rainfall than at present, contemporary with the Nabataean activity. However, the period of intensive land-use in the Jabal Harûn area seems to have been brief, not much more than a century in duration. In the light of the archaeological evidence activity in the Jabal Harûn area seems to considerably diminish in the 2nd century AD. The climate of the Byzantine and Early Islamic periods has been considered even more arid than at present (Bruins 1994: 308-309). There is conspicuously little evidence of human activity in the surroundings of Jabal Harûn during these periods, although the monastery/pilgrimage centre was established on the mountain and continued to be occupied at least until the 8th century AD.

The Middle Islamic period is again represented by more archaeological finds in the Jabal Harûn area, although the human activity appears nowhere near as intensive as during the Nabataean period. This period also corresponds to a more humid climatic phase (Geyh 1994: 135; Bruins 1994: 308-310). An increase of settlement is apparent also elsewhere in the Petra region. In most parts of the area settlement seems to continue on to the Ottoman times at more or less at the same locations, but in the Jabal Harûn area settlement ends after a relatively brief spell of activity. After the Middle Islamic period permanent settlement is no longer resumed,
and archaeological traces of human activity are few and far apart in time. The Jabal Harûn area apparently continued to be used by semi-nomadic herders. In the 19th century travellers report the B’dul Bedouin cultivating small fields and herding their goats in the surroundings of Jabal Harûn (McKenzie 1991: 142-143).

7.3 Interpreting the human history in the Jabal Harûn area

One of the early hypotheses in this work was that the climatically more favourable periods should be represented by more archaeological material. However, as can be seen from the summary of the climatic and human history of the Jabal Harûn area presented above, there is a gap in the archaeological record from the Neolithic period to the Iron Age. It seems that the Jabal Harûn area did not manage to attract humans even during the presumably environmentally more favourable periods corresponding to the Neolithic and the Early Bronze Age. Some archaeological periods corresponding to phases of wetter climate, like the Late Bronze – Early Iron Age, are poorly known from southern Jordan in general, so their absence from the Jabal Harûn area is hardly a wonder. However, during the Early Bronze Age and later Iron Age there were settlements and other sites within a few kilometres from Jabal Harûn which raises the question of why are there no remains from these periods in the area. Erosion and intensive land-use during the Nabataean period may have wiped out remains of less intensive earlier human activity, but considering that some evidence of Epipalaeolithic and Neolithic periods remains it seems unlikely that all the evidence of later periods would have been somehow selectively completely destroyed. Although it is not necessary to suppose that people never visited the area, the total lack of any datable material from a period spanning several millennia strongly indicates that the area was used only occasionally and then for such activities that leave little archaeologically recognisable traces, such as hunting or herding.

The hydrology of the area may well explain why the area has not been attractive for habitation or farming during most of the Holocene. During the period from the Early Neolithic to the Bronze Age people seem to have favoured locations close to perennial sources of water for
settlement. Perhaps even during the more humid climatic periods of the Holocene there were no such locations in the Jabal Harûn area, which is completely dependent on local rainfall. As noted earlier in Chapter 5.2.3, under climatic conditions like those of the present day, rainfall at the fringes of Wadi ‘Arabah is both spatially and temporally variable, which makes it an unreliable source of water. Moreover, there are no perennial sources of water available in the Jabal Harûn area unless methods for storing water are used. The hilly topography of the area also makes it mostly difficult to cultivate, and the thin and nutrient deficient soils of the limestone hills make poor agricultural land.

Methods for storing rainwater were used in the Petra region during the Iron Age at the latest as evidenced by cisterns on Umm al-Biyara, and it has been suggested that some field walls could be dated already to the Edomite Iron Age (Lindner et al. 1996b: 150). However, it seems that the focus of settlement during the Iron Age was on Jabal ash-Sharah and the Jordanian plateau. As the later Iron Age was part of an aridic climatic phase, it could be argued that the apparent concentration of settlement in the Jabal ash-Sharah region was the result of that area receiving the highest rainfall in the Petra region. In the light of the above considerations concerning the availability of water in the Jabal Harûn area, a plausible explanation for the gap in the human activity in the area is that the environment was too marginal for settlement and agriculture without large-scale endeavours to store water and build terraces and barrages. However, if we accept this explanation for the lack of human activity for most of the Holocene, we must ask what brought the Nabataeans to the area in the first place?

With its topography, thin soils and large areas of bare rock surface the Jabal Harûn area is very well suited for run-off cultivation (Yair & Kossovsky 2002: 55). There is evidence from the agricultural experiments in the Negev that the mean annual rainfall of ca. 100 mm can be transformed to ca. 400 mm of effective precipitation by collecting runoff (Rosen 2000: 50-51). The rainfall in the Jabal Harûn area in the Nabataean times was probably higher than that, as the period corresponds to a favourable climatic phase with more rainfall than at present. Ethnoarchaeological data from the Petra region proves that considerably high yields of barley
and wheat can be obtained also at present day by the use of runoff farming (Russell 1995: 696-697). During the Nabataean period runoff farming methods would probably have enabled the cultivation of not only cereals, but also olive and vine. However, disadvantages such as the lack of permanent water sources still existed. Nabataean cisterns and water channels have been found on the top of Jabal Harûn, but notably, none have been discovered in the immediate surroundings of the mountain.

The vast amount of 1st – early 2nd century pottery found in the area has been considered as possible evidence of manuring (Lavento et al. forth.b). Together with the existence of building remains which could be interpreted as small farmsteads the spread of pottery is suggestive of intensive farming, possibly mixed farming such as olive cultivation with the growing of cereals or pulses as understorey. However, the climatic explanation does not offer any reason why the cultivation and settlement started. The climatic change towards more humidity could hardly have been the only inducement for people to settle in the Jabal Harûn area, as there were other areas much better suited for agriculture in the Petra region. Although the Jabal Harûn area is very well suited for run-off cultivation, the construction of hydraulic installations would have been labour intensive and considering the topography of the area the fields were by necessity small. The “traditional” explanation would probably be that the Nabataeans were suffering from a shortage of agricultural land as a result of expanding trade and increasing settled population in Petra, and had to resort to the cultivation of even marginal areas. However, in the light of the present archaeological data it is not possible to evaluate this explanation. An alternative explanation is that the reasons behind the agricultural utilization of the Jabal Harûn area were not dictated by simple economic necessity and environmental conditions more favourable than before. It is suggested that the development of agriculture and settlement in the Jabal Harûn area during the Nabataean period is strongly related to the routes of communication crossing the area, and had also other than purely economic incentives.

The period of intensive land-use seems to have been brief, not much more than a century in duration. In the light of the archaeological evidence the activity in the area seems to considerably diminish in the 2nd century AD. Buildings and farms and even cultic places were
abandoned. Only at some locations, most notably on the top plateau of Jabal Harûn, some type of activity was continued, but its nature is still unclear. Particularly striking is the complete lack of background pottery scatter from the later periods. Clearly this change in the distribution of find material reflects an actual change in the use of the Jabal Harûn landscape, but what kind of change, and why did it take place?

Let us now consider the hypothesis that the lack of background pottery scatter from the Late Roman, Byzantine and Early Islamic periods indicates abandonment of cultivation in the 2nd century AD, and that this change was related to climatic change or human-induced environmental deterioration.

The reconstructions of the climate of the Near East point towards a humid period corresponding to the Nabataean period, and gradually increasing aridity after the 1st century AD (Bruins 1994: 307-308). The climate of the 5th to 8th centuries AD, corresponding to the Byzantine and Early Islamic period, has been considered more arid than at present (Bruins 1994: 308-309; Frumkin et al. 1994: 323). It was postulated earlier in Chapter 5.2.3 that changes towards more aridity would have been more pronounced in the Jabal Harûn area than in the Jabal ash-Sharah or in Petra itself. It can be deduced that an arid climatic trend would have caused the rains in Jabal Harûn area to become more unreliable, with increasing likelihood of drought, resulting in crop failure. If several drought years had followed each other, this would probably have been enough reason to cease cultivating the area.

Another possible explanation is that the intensity of cultivation exceeded the capacity of the soil. The soils of the Jabal Harûn area are poor in the nutrients phosphorus and nitrogen (Khresat et al. 1998: 625, 628), which makes them vulnerable to the exhaustion of nutrients while under cultivation. The exhaustion of the soil in turn leads to poor crop yields and an increased risk of erosion (Morgan 1986: 4, 51). In Wadi Faynan, where considerable environmental pollution from copper mines probably caused crop failures, the very dense off-site pottery scatter has been interpreted as the farmers’ attempt to enhance the productivity of the fields by intensive manuring (Barker 2002: 210). Did the Nabataean farmers try to
combat nutrient exhaustion in the Jabal Harûn area by manuring? Did they finally fail and abandon cultivation in the area because of soil exhaustion, leaving it bare of vegetation and susceptible for catastrophic erosion which made the area unsuitable for cultivation for centuries? Unfortunately the sedimentary evidence does not help to answer these questions, as there are no dated deposits relating to this period.

There are also some lines of evidence which argue against a wholesale abandonment of the hydraulic farming system in the Late Roman, Byzantine and Islamic periods. The climatic development towards more aridity was gradual, but the abandonment of the sites in the area seems to have been rapid, even abrupt. By the dating of the pottery, it also happened while the climate was still relatively favourable. On the other hand, as has been noted previously, the absence of archaeological evidence cannot be simply translated into the absence of human presence. Because human activity continued on the top of the mountain through these periods, people cannot have been completely absent from its surroundings either. There is evidence that not all of the hydraulic structures were abandoned at the same time, but repairs and reconstructions have been made apparently at several times and during different periods (Lavento & Huotari 2002: 104-105).

The outlying Nabataean settlements in the southern parts of the Jabal ash-Sharah escarpment and on the eastern plateau seem to have been abandoned during the 2nd century (Graf 1992: 256). Many settlements in the fringes of Wadi ‘Arabah were also abandoned between the 2nd and 4th centuries (‘Amr et al. 1998; Lindner 1992a:265; Lindner et al. 2000: 549-550, 554). The decline of settlement noticed in the Jabal Harûn area is therefore not an exceptional phenomenon, as similar development was taking place elsewhere in the Petra area. The start of the decrease in the numbers of settlement sites is also roughly contemporaneous with the Roman annexation of Nabataea, which hints that reasons for the abandonment might be related to political, economic and social changes probably introduced by the new rule, rather than climatic conditions.
It would seem unlikely that the monastery/pilgrimage centre on Jabal Harûn did not utilise the runoff farming system at all. As Alcock et al. (1994: 147-148) have argued, not all forms of cultivation include manuring of the fields with household waste. Therefore the disappearance of background pottery may as well indicate a change in agricultural practices, related to such factors as changes in rural settlement and land ownership. The area is only ca. 5 km from Petra, which means that the fields could have been easily cultivated by farmers living in the town of Petra itself. In a more extensive mode of cultivation the fertilization of the fields could have been taken care of in ways that do not leave material evidence, such as rotating crops and fallow or by keeping animals in the fields after the harvest (Alcock et al. 1994: 147-148). It is also possible that the farmland surrounding the mountain was owned by the monastery. It seems unlikely that the monks taking care of the pilgrimage centre would have toiled on the fields themselves. More likely the fields were leased out to farmers, apparently a common practice by large landowners in Petra during the period covered by the Petra papyri (Koenen 1996: 184; Gagos & Frösén 1998: 480). Moreover, pottery does not end up in the landscape just through agricultural activity, but through various cultural practices (Alcock et al. 1994: 144). The lack of systematic off-site data from elsewhere in the Petra region makes it impossible to conclude which explanation is the most likely one in Jabal Harûn area.

The preceding argumentation does not mean to suggest that periods of abandonment of the runoff farming system did not occur at all. Quite on the contrary, judging from the differential preservation of the structures parts of the system have been abandoned for a long period while others have been repeatedly taken into use and repaired. One possible period of abandonment could be suggested to have taken place during the Late Roman period, before the establishment of the monastery/pilgrimage centre on Jabal Harûn. Perhaps only parts of the system were utilized during the Byzantine period, and a similar situation seems a likely scenario also for the Islamic period, although separate parts of the system may have been utilised during different times. In the light of the lack of later archaeological finds it can be suggested that a period of abandonment occurred again after the Middle Islamic period. The latest period of cultivation began during the 19th century at the latest, as known from historical sources, and
continued until the early 20th century. Shorter breaks in the agricultural activity have probably also taken place for example during prolonged periods of drought.

From an environmental point of view the Jabal Harûn area appears marginal for human settlement and seems to have few resources that could attract people to the area. However, during the Middle Palaeolithic and the Nabataean period, and on a smaller scale also in the Middle Islamic period, there has been even intense human activity in the area. If we accept that the reasons behind the human activity were probably not solely related to environmental conditions, we must also accept that the marginal environment of the Jabal Harûn area is not enough of an explanation for the lack of activity during the periods which are not represented by finds.

The concept of affordances (Ingold 2000: 166-168) might offer a useful alternative way of regarding the variable activity in the Jabal Harûn area throughout the archaeological time. The difference between resources and affordances is that while resources are seen as always present in the landscape, affordances are only realised through human actions (Llobera 2000: 124). Affordances can be the traditional availability of water, food and raw materials, but also such things as places of worship or ritual, routes of communication or locations that offer good visibility. Central to the concept of affordances is that their existence is relative to the subject, that is, an individual or a group of people (Ingold 2000: 268). Therefore different characteristics of the Jabal Harûn area would have been considered important by the people inhabiting the Petra region during different times, and indeed characteristics found to be undesirable by some could be considered affordances by others. For example the hilly topography, large expanses of bare rock and thin soils, which appear to constitute poor agricultural land, are actually ideal for runoff farming, but this affordance was not realised before the Nabataeans started cultivating the area. Naturally, environmental change can also introduce changes in the affordances offered by an area, but also human modification of the landscape can introduce new affordances and so influence later human activity. The runoff farming system in the Jabal Harûn area is an example of such an affordance. After the labour-intensive initial construction of the system, the repair and maintenance of the structures
required considerably less effort (Rackham & Moody 1992: 130). Even after periods of abandonment it would therefore be relatively easy to take parts of the system back into cultivation, which apparently has also happened several times during its existence. The collapsed buildings that can be found in the area would have also offered an easily exploitable source of ready-made building stone for the repairs.
8. Conclusion

Together with the results from geoarchaeological studies and palaeoclimatic data from Jordan and Israel it is possible to form a general picture of the environmental development in the Jabal Harûn area. Although human activity can be expected to have caused localized changes in the vegetation and environment of the Petra region as early as during the Pre-Pottery Neolithic period, in the light of the archaeological evidence it seems that there is no reason to suggest a significant human impact on environment in the Jabal Harûn area before the Nabataean period. It appears that the erosion events and alluviation detected in the sedimentological record are mainly related to climatic factors. Although human impact on the environment could not be conclusively proved by the sedimentological studies, mainly due to the lack of datable deposits, there is also no doubt that human activity has changed the Jabal Harûn environment – the best proof of this is the still existing runoff farming system, which has left a human imprint over the whole landscape.

An early phase of erosion and accumulation of sediment probably took place during the Pleistocene, before or during the Middle Palaeolithic period. This period may have been related to tectonic movements during the last active phase of the Al-Quwayra fault system. It was followed by erosion, which removed most of the valley fills in the Jabal Harûn area, leaving only a few remnant terraces which are represented by the highest terrace level detected in Wadi al-Mahattah and Wadi al-Farasha. A period of aggradation, with deposition events separated by a hiatus in sedimentation and pedogenesis, took place in the Jabal Harûn area most probably during the climatic amelioration of the Late Glacial and afterwards, possibly continuing to the end of the Pleistocene which would correspond to the Epipalaeolithic, as based on the comparison with other locations in southern Jordan. This period of erosion and accumulation was followed by significant channel incision, possibly attributable to the increased rainfall and intense storms during the Early Holocene.
It seems that after the Early Holocene channel incision and transport of sediment from the Jabal Harûn area have been the dominant processes, interrupted by small-scale alluviation phases. Only one of these alluviation phases has been dated. It started around 4000-3000 years ago and continued until somewhat after the beginning of the Christian era. Since then accumulation of sediment has taken place mainly as the result of lateral channel migration, and in the areas where terraces and barrages constructed for runoff farming have directed and slowed down the flow of water. There are also some chaotic deposits, probably indicating relatively rare extreme rainfall and erosion events. Erosion and channel incision have been more intense in wadis with a very high gradient like Wadi as-Saddat, while in Wadi al-Farasha the level of the wadi bed has apparently not changed significantly since the Nabataean period.

The construction and use of the runoff farming system, which appears to have begun in the Nabataean period, signifies a considerable intentional human modification of the Jabal Harûn landscape. It can be expected to have influenced the processes of erosion and deposition in the area by influencing the generation of runoff on the slopes and changing the hydrodynamic conditions in the wadis. Originally it was hoped that these changes would be reflected in the sediment deposits and that OSL dating would have enabled the dating of the periods of construction, use and abandonment of the runoff farming system. However, most of the sediment deposits studied in the area appear to be older than the hydraulic structures. Only terrace levels IV and V seem to date to roughly contemporary or later than the hydraulic structures. Due to the weak OSL signal the dates obtained from WF4 were unfortunately too inaccurate to correlate the deposits with human activity, although it can be suggested that the period of deposition dated around 2000 BP may have been related to the construction of the runoff farming system. However, many more dates from different deposits would be needed to confirm this hypothesis. Considering the poor zeroing of the sediment in most of the OSL samples, which resulted in only five out of twenty samples giving a date for the period of deposition, it is questionable whether carrying out more OSL analyses would be justified. Apparently the sediment transportation processes represented by the deposits in the Jabal Harûn area were mostly of a short duration and involved high sediment concentrations, which
prevented the zeroing of the quartz grains in the sediment, and renders the OSL method unsuitable for the dating of the resultant deposits.

At a brief glance it seems that many of the changes in the settlement and land use in the Jabal Harûn area, and even in the wider Petra region, could be neatly explained by climatic conditions and related environmental change, although there are some notable exceptions like the sudden increase of settled occupation in the Petra region during the Edomite Iron Age which was not a particularly favourable period climatically. With a closer look there seem to be more of these inconsistencies, and therefore it seems like it would be intellectual laziness to attempt to explain all or even most of the variation of settlement and human activity by environmental changes alone. Some of the changes may have been climatically induced, but nevertheless it is always human societies that respond to environmental change, and that response is not mechanistic or always similar throughout the archaeological time, but strongly governed by various cultural factors such as available technology and subsistence strategies, social structure and internal and external politics.

It should also be noted that the simplistic division of climatic phases into favourable and unfavourable on the basis of the amount of rainfall only does not give a realistic picture of the complexity of the relationship between people and environment. The absolute amount of rainfall is not the only climatic variable influencing the environmental conditions. Important variables are also temperature, which affects the amount of evaporation, and the seasonality and character of rainfall. The same amount of rainfall has a different impact depending on the other variables. Low intensity rainfall which lasts for days at a time is more favourable for vegetation - and therefore also agriculture - than rare high intensity storms of short duration, which generate large amount of runoff resulting in less infiltration and more erosion than the low-intensity events. For accurate and reliable reconstruction of the environmental setting all these variables would need to be accounted for, which is impossible with the currently available data.
That changes in the human use and significance of the Jabal Harûn area have taken place is indisputable. However, to evaluate the significance of environmental, cultural, socio-economic and political factors in the changing use of the Jabal Harûn area, a careful comparison with the archaeological evidence from the other areas surrounding Petra is needed to form a comprehensive picture of the human history in the region. Only then will it be possible to decide whether certain phenomena are only characteristic of the Jabal Harûn area, when a localized reason such as the exhaustion of soils or localized drought could be suggested, or whether the phenomena observed in the Jabal Harûn area can be connected to social, political and economic developments over a wider area, and what - if any - role the climatic and environmental changes have played in the choices of the human communities living in the Petra region.
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Abbreviations

ADAJ: Annual of the Department of Antiquities in Jordan
BAR IS: British Archaeological Reports, International Series
BASOR: Bulletin of the American Schools of Oriental Research
Earth-Sci. Rev.: Earth-Science Reviews
JRA: Journal of Roman Archaeology
PEQ: Palestine Exploration Quarterly
SHAJ: Studies in the History and Archaeology of Jordan

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# General Chronology for the archaeology of Jordan

<table>
<thead>
<tr>
<th>Period</th>
<th>Date Range</th>
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</thead>
<tbody>
<tr>
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<td>&gt;200 000-120 000 BP</td>
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<td>Middle Palaeolithic</td>
<td>120 000-40 000 BP</td>
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<tr>
<td>Upper Palaeolithic</td>
<td>40 000-20 000 BP</td>
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<td>Epipalaeolithic</td>
<td>20 000-10 500 BP</td>
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<tr>
<td>Early (Pre-Pottery) Neolithic</td>
<td>8 500-5 500 BC</td>
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<tr>
<td>Late (Pottery) Neolithic</td>
<td>5 500-4 500 BC</td>
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<tr>
<td>Chalcolithic</td>
<td>4 500-3 500 BC</td>
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<tr>
<td>Early Bronze Age</td>
<td>3 500-2 200 BC</td>
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<tr>
<td>Middle Bronze Age</td>
<td>2 200-1 550 BC</td>
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<tr>
<td>Late Bronze Age</td>
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<td>Iron Age</td>
<td>1 200-332 BC</td>
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<td>509-336 BC</td>
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<td>Hellenistic period</td>
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<td>Nabataean period</td>
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<td>Roman period</td>
<td>64 BC - 300 AD</td>
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