The Holocene palaeoenvironments of the Rift Margin in Southern Jordan (Wadi Faynan)

Hwedi Abdulsalam Mohamed BSc., M.A.

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Declaration

I declare that no material in this thesis has previously been submitted for a degree at this or any other university.

ABSTRACT

This thesis addresses the sequence and causes of Holocene environmental change in the rift margins of Southern Jordan, with special reference to vegetation history, climate change and human impacts on the landscape. The study area is the Wadi Faynan and it's tributaries, which drain into Wadi Araba from the rift-marginal mountain front. This area is undergoing geo-archaeological investigation by a multidisciplinary team coordinated by the British Institute for Archaeology, Amman, the Department of Antiquities, Amman and some British Universities. The climate and vegetation of the Wadi Araba is desertic. The summit of the mountain front is in the Mediterranean climate and vegetational zone. The vegetation of the Wadi Faynan and it's tributaries is an extremely degraded steppe. The Wadi Faynan is an area of copper mineralisation and was in Bronze Age to Roman times one of the World's most important copper mining areas. The Wadi Faynan was also once a major agricultural area, with extensive flood water farming systems, but these are now abandoned.

Comparatively little is known about the Holocene climate, the vegetational sequence and the history of human impact in the southern Levant. The Wadi Faynan research project was set up to investigate these issues, with especial references to the issue of desertification. This Thesis explores these issues using stratigraphic and palynological, molluscs, plant macrofossils and sedimentological data from the sequence of Holocene deposits in the research area, together with a radiocarbon dating programme where suitable materials were available.

The samples on which this Thesis is based were obtained by members of the Wadi Faynan expedition in 1996 and by the author in early 1998. Samples from eighteen sites have been analysed, fourteen sites contained pollen, and twelve of these contained sufficient pollen for detailed analysis.

The Holocene sequence is described and attributed to one formation, the Faynan Formation, which is divided into five members. These are the Faynan Member - early Holocene fluvial deposits; the Dana Member - late Holocene fluvial deposits; the Khirbet Member - late Holocene lacustrine deposits and cistern fills; the Atlal Member - late Holocene anthropogenic deposits and the Tell Loam Member - late Holocene aeolian deposits.

A pollen biostratigraphy consisting of eight assemblage-biozones is erected. This, together with the lithostratigraphy described above and the results of the radiocarbon dating programme, enable correlation of the Holocene deposits of the Wadi Faynan, and the identification of a sequence of environmental change.

The Faynan Member consists mostly of epsilon cross-bedded fluvial deposits, with some palaeosols, though at one locality there is a transitional to multichannel deposition. This member contains pollen and plant macrofossil assemblages suggestive of a steppe environment close to the transition to a Mediterranean woodland and attributed to the PCP, PPA, PAP biozones. Molluscs which require perennial waters are present. Deposition of the Faynan Member ceased about 5740 $\pm$ 35 BP (uncal.) (HD-12337).

There is a long hiatus in the fluvial sedimentary record, which recommences with the Dana Member in the Late Holocene, dated to 390 $\pm$ 50 BP (uncal.) (Beta- 115214). The Dana Member was laid down by multichannel streams, which rapidly aggraded substantial terrace gravel bodies and alluvial fans. The deposits contain pollen assemblages dominated by Chenopodiaceae and desertic species, comparable with the present vegetation in the Wadi Araba and attributed to the C biozone. Incision terraces following the deposition of alluvial fans of the Dana Member contain pollen very similar to that now accumulating in the research area, attributed to the CL Biozone, and dated to 100 ± 50 BP (uncal.) (Beta-119602).

The hiatus between the fluvial units was addressed by the analysis of lacustrine fill deposits attributed to the Khirbet Member, of anthropogenic deposits of the Atlal Member and aeolian deposits of the Tell Loam Member. The later two units did not contain sufficient pollen for reliable analysis, but the Khirbet Member contained abundant pollen. Deposits from a Chalcolithic cistern-fill contained assemblages consistent with a well vegetated steppe environment and attributed to the PCPJ Biozone. The deposits of the lacustrine fill behind the Barrage at Khirbet Faynan show a sequence of pollen assemblages commencing around 2630 ± 50 BP (uncal.) (Beta-110840). At the base of the sequence, pollen attributed to the CLP Biozone are consistent with a degraded steppe environment, with indications of probable arable agriculture. These assemblages are followed by assemblages consistent with a slightly more degraded steppe, without regular agriculture, attributed to the CPE Biozone. The following C Biozone is characterised by extremely high counts for Chenopodiaceae and thus enables correlation of this part of the sequence with the Dana Member. The top of the sequence contains pollen consistent with a degraded steppe and similar to that accumulating today. This is attributed to the CL Biozone.

The environmental sequence thus shows a slow change from the 'good steppe' environments of the early Holocene, with progressive degradation up to the Late Holocene, around 350 radiocarbon years before present. At this time there was a major desiccation episode which came to an end around 100 radiocarbon years ago. Resolution of the calendar age of this event is made difficult by the nature of the radiocarbon calibration curve in the late Holocene.

With regard to the vegetation sequences, as it has been demonstrated that there is a clear division between the Southern Levant sites in Saudi Arabia, Jordan, Sedom, the Hula Basin and Syria, and Northern Levant sites in Turkey and Iran. In the Southern Levant sites, as in North Africa, there was a major deterioration in the environment, with most of the area becoming drier around 6,000-5,000 BP, whereas in Turkey and Iran, at this time, the environment become wetter and forest spread and become more dense. Sites from Saudi Arabia, through Jordan, Palestine and Syria shows higher rainfall than occurs at present, in the period between 10,000 and 6,000-5,000 BP. The Wadi Faynan results show the same pattern of a wet early Holocene. The critical evidence from the Wadi Faynan is the presence of *Corylus,* which requires summer rain. This implies a different pattern of climate at that time, with summer rains resulting from a monsoonal pattern of circulation.

The causes of the Early Holocene alluviation are likely to be the result of a partial response to the soil erosion brought about by the introduction of herding and arable agriculture. There is no sign of alluviation in response to early mining activity. In the Late Holocene, also, there is no signs of aggradation as a response to mining activity or agricultural development. Alluviation in the late Holocene appears to have taken place as a response to extreme aridity. Importantly, in recent times, desertic conditions appear to have retreated from the Wadi Faynan.

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Dedication

I would like to dedicate this thesis to my father who took pride and gave support throughout all my studies, but who sadly passed away before their completion.

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CHAPTER ONE: INTRODUCTION

1.0 Introduction

1.1 Introduction

This thesis will address the sequence and causes of Holocene environmental change in the rift-margin mountains of southern Jordan using palynology as the main research tool. Particular attention will be paid to vegetation history, climate change, the history of human use of the landscape and the impact of human activity and other factors on vegetation and geomorphology.

The history of Late Quaternary climate change in the western part of the Middle East is poorly resolved. There is considerable information for the northern Levant, particularly Turkey (e.g. van Zeist and Bottema 1982; Bottema and van Zeist 1981; Bottema and Woldring, 1984; van Zeist *et al.,* 1975), Western Iran (van Zeist and Bottema, 1977; Bottema, 1986) and parts of Palestine (summarised in Horowitz, 1979, 1992) and much is known about North Africa and Sahara, to the south (e.g. Gilbertson and Hunt 1996a,b; Kutzbach and Street-Perrott, 1985; Ritchie and Haynes, 1987; Pachur and Kropelin, 1987; McCauley *et al.*, 1982; Wendorf and Schild, 1980). There is very little known, however about the southern Levant apart from research in the Azraq Basin in central Jordan (Garrard *et al.* 1985a, b, 1987, 1988; Gilbertson *et al.* 1985), and in Southern Jordan (Henry, 1995), and in the Negev (Goldberg, 1986) there are indications that the Pleistocene climatic phases in the Southern Levant are out of phase with those in the Northern Levant and a survey of the regional literature (Chapter 2) shows major inconsistencies between authors, even within small areas. This thesis aims to produce a detailed sequence of climate change for the southern Levant to test whether this area is out of phase with the northern Levant.

The history of the human use of the landscape in the Levant is known mostly from archaeological work, and particularly studies of the lithic technology, though there are an increasing number of palaeoeconomic studies (Henry, 1995; Harris, 1996). Little direct evidence of land use from palynology and other environmental evidence has been gained in the southern Levant, though there is more information for the northern Levant (e.g. Bottema and van Zeist, 1981; van Zeist and Bottema, 1982). In particular, the age and nature of early agriculture in the southern Levant are very poorly known except in the Azraq Basin (Garrard *et al.* 1985a, b, 1987, 1988).

Recent research in the Mediterranean countries (authors in Lewin *et al.*, 1995; Hunt and Gilbertson 1995) suggests that human activity has had a significant impact on geomorphic systems, in particular on valley aggradation patterns. Clearance and farming have been demonstrated to lead to ground instability and erosion (Hunt, 1995; Morgan, 1986) and consequently sedimentation in water courses and the accumulation of substantial fluvial terrace deposits characterised by trough cross-bedded coarse gravels (authors in Lewin *et al.*, 1995). This pattern does not seem to occur in more arid environments, for instance, the Tripolitanian predesert (Gilbertson and Hunt 1996a,b) and is at variance with that proposed for the Jordan rift margins north of the Dead Sea (Vita-Finzi and Dimbleby 1971). The reasons for the complex sedimentation pattern in the Tripolitanian predesert are still unclear. This thesis will examine alluviation patterns in another very arid area, to throw light on the processes involved.

The activities of humans can impact on the landscape in other ways. Mining is widely recognised to have significant impacts on alluviation patterns in temperate and semi-arid environments (Macklin and Lewin, 1986; authors in Lewin *et al.*, 1995). The impact of mining in a very arid environment is less well known. This thesis will test the relationship between mining episodes and alluviation patterns in the very arid environment of southern Jordan.

1.2 The Wadi Faynan Project

This Thesis is part the Wadi Faynan Project (Barker *et al.*, 1997). The area was selected because of the following reasons:

- Ecotonal position on the margin between desertic and Mediterranean climate zones: therefore it is sensitive to climatic change.
- Availability of a rich Holocene archaeological sequence with evidence of mining and floodwater farming and "... ideal for an inter-disciplinary investigation of a desert landscape and of the long term exploitation of its plant, animal and mineral resources." (Barker *et al.*, 1997).
- Modern threats to this remarkable landscape from development suggest that the resource studied are unlikely to be available for future generations.

Further details of the research area can be found in Ch. 3.

The Wadi Faynan Project is coordinated by the British Institute for Archaeology and History in Amman, the Department of Antiquities of Jordan, the Universities of Leicester, Huddersfield and Nene University College, Northampton. This multidisciplinary study has involved a total of twenty-two British and Jordanian academics, and the author.

1.3 Aims and objectives

The principal aim of this thesis is to construct a vegetation history of the study area (see Ch. 3 for description), and from this to deduce the palaeoclimatic history and the history of human impact on the vegetation, for comparison with existing models. Subsidiary aims are to examine the impact of farming and mining on a very arid landscape. To do this, the following objectives were formulated:

1. To establish a Holocene stratigraphic sequence for the study area in the Wadi Faynan and its tributaries in southern Jordan as a framework for the research.
2. To erect a pollen biostratigraphy and thus identify the sequence of vegetational events in the research area.
3. To identify local depositional environments using a combination of palynological, palaeontological, sedimentological and geochemical methods.
4. To build a geochronological sequence for the study area, to enable identification of the timing of events by dating the framework established by lithostratigraphy and pollen biostratigraphy, using suitable dating techniques such as radiocarbon.

1.4 Conclusion

The results of this work, when integrated, will enable these aims to be met. The detailed theoretical context of the study is set out in Chapter 2. The research area is described in Chapter 3. The research methods are described in Chapter 4. The results of the field and laboratory investigations are set out in Chapter 5 and synthesised, interpreted and discussed on in relation to the regional literature in chapters 6 and 7. The conclusions form Chapter 8.

CHAPTER TWO: BACKGROUND TO THE RESEARCH

2.0 Background To The Research

2.1 Introduction

In this chapter, the background to the research is described. This lies in three main areas: climate change, land use and valley alluviation and the impact of human activity, especially mining.

A considerable amount of information related to climate change in the northern Levant exists, in particular for Turkey (van Zeist and Bottema 1982; Bottema and van Zeist 1981; Bottema and Woldring, 1984; van Zeist *et al.*, 1975), Western Iran (van Zeist and Bottema, 1977) and parts of Palestine (Horowitz 1979, 1992). Little is known about the southern Levant, except the research which took place in the Azraq Basin in central Jordan (Garrard *et al.* 1985a, b, 1987, Gilbertson *et al.* 1985) and in south Jordan (Henry, 1979, 1982, 1986, 1995; Henry *et al.* 1981, 1983). The work of Vita-Finzi (1969) suggests that climatic factors may have led to alluviation in the Mediterranean countries although this has been contested (authors in Lewin *et al.*, 1995). However, the interaction of climate and alluviation in more arid areas, such as Southern Jordan, is not yet clear. Little direct evidence of land use has emerged from palynology, most having come from archaeological studies (Levy, 1983; Henry, 1995).

Recent research in the Mediterranean countries suggests that human activity has had a significant impact on geomorphic systems, in particular on valley aggradation patterns. Clearance and farming have been demonstrated to lead to ground instability and erosion (Hunt, 1995; Morgan, 1986) and consequently sedimentation in water courses and the accumulation of substantial fluvial terrace deposits characterised by trough cross-bedded coarse gravels (authors in Lewin *et al.*, 1995).

Human activity has impacted on the landscape in many ways. Mining is widely recognised to have had significant impacts on alluviation patterns in temperate and semi-arid environments (Macklin and Lewin, 1986; authors in Lewin *et al.*, 1995). The impact of mining in very arid environments (e.g. Jordan) is less well known. It has not been established whether there is a relationship between mining activity and alluviation patterns in this region. The aim of this thesis is to shed light on all these issues.

2.2 Palaeoclimates of the Levant

Introduction

Given the local variation and difficulties of radiocarbon dating deposits over 20,000 years old in arid lands, it is not surprising to see discrepancies between or even within some areas from the point of view of palaeoclimate (Table 2.1). Palaeoclimate and palaeovegetation reconstructions rely on data from different sources. Wright (1992), Goldberg and Rosen (1987) and Horowitz (1979, 1992) reported problems which create deficiencies in reconstructions of palaeoclimates and palaeovegetation as follows:

1- Distinguishing regional events from local events.

2- Distinguishing climatic events from events with other causes.

3- Dating resolution and reliability.

4- Distinguishing effects of particular climatic variables from each other (e.g. temperature vs. precipitation).

5- Distinguishing natural from cultural effects (especially with respect to fauna, macrobotanical and pollen samples).

6- The necessity of assuming certain constants in interpreting data (e.g. assuming constant rates of sedimentation in pollen accumulation on lake beds).

7- The ancient climates or environments may have no modern analogues and consequently may have left "signatures" which cannot be interpreted correctly

8- Vegetation may lag significantly behind climatic change and may thus "blur" the record.

9- The use of relative terms like "humidity" and "aridity" is open to mis-interpretation.

10- Arid land pollen can produce misleading results due to local contributions, such as by vegetation around springs, salt-pans or human settlement.

11- In arid lands, the combination of poor pollen production due to the scarce, usually insect pollinated vegetation, accompanied by relatively high rates of sedimentation (due to strong erosional processes and the predominantly clastic nature of the deposits), leads to the dilution of pollen in sediments.

12- Weathering processes are harsh and destructive in arid lands, chiefly caused by strong insolation, rapid wetting and drying, and salt growth which results in rather rapid disintegration and break up of most biological remains.

Generally, the Near East is considered to be hardly suitable for palynological research because of a presumed scarcity of pollen-bearing sediments. It has however, been found to be better than expected, although pollen-bearing sediments are very unevenly distributed (van Zeist and Bottema, 1991).

Shaw and Thomas (1993) reported almost the same sort of problem relating to discrepancy in palaeoclimate signature between some sites in the Kalahari, in which this context has been referred to poor resolution of some of the data, particularly before 20,000 BP.

In spite of these discrepancies and problems, there are rough trends of climatic events across the region. There is limited evidence from the Last interglacial and earlier times from various locations in the southern Levant including Jordan, Northern Palestine and the Hula Basin, Syria, Saudi Arabia, Levant, and the Negev. The following is a general description of the climatic events in the Levant from the last interglacial (see table 2.1).

Interval I (*ca.* 80,000-55,000 BP)

This interval of time appears to have been characterised by a generally moist climate (Henry 1979,1982; Copeland and Vita-Finzi 1978; Zeuner *et al.*, 1957; Schwartz *et al.*, 1979, Bar Yosef and Vandermeersch, 1981; Jelinek 1981; Farrand 1979; Sakaguchi 1978; Vogel 1979), though short dry phases occur in some areas of the Negev, Levant, Northern and southern Palestine and Hula Basin (Goldberg 1981, 1976; Jelinek 1981; Horowitz 1979; Tchernov, 1981). It is a possibility that these short phases of aridity were mislocated in the time scale because of the lack of precision of dating, as mentioned above.

Interval II (*ca.* 55,000-35,000 BP)

This interval of time is characterised by dry conditions across the whole Levant (Henry 1995, 1986; Marks 1977; Goldberg 1981; Horowitz 1979). Spells of moisture were recorded by Goldberg (1981) in the southern Levant1.

Interval III (*ca.* 35,000-25,000 BP)

This interval of time is characterised by a generally moist climate (Goldberg 1981; Horowitz 1979; Henry 1986; Marks 1977). Some areas of the Levant such as Levant 1 and Jordan were experienced a dry climate (Marks 1977, Henry 1986, Goldberg 1981; Horowitz, 1979). This may again reflect the uncertainties of dating arid-zone sediments (Williams *et al.*, 1998).

Interval IV (*ca.* 25,000-15,000 BP)

This interval reflects dominantly dry conditions (Goldberg 1981, 1986; Jado and Zotl, 1984; Schulz and Whitney, 1986; Horowitz, 1979; Henry, 1986, 1995; Marks, 1977), with spells of wet phases in some localities such as south Jordan (Henry 1986, 1995). Wet phases in Negev have been recorded by Goldberg (1981) starting as early as 16,000 BP. Furthermore, in the Azraq Basin, humid and steppic conditions were predominant in the early part of this interval (Garrard *et al.*, 1987, 1988; Garrard and Byrd, 1992). In connection to the Azraq Basin, this dry phase is not shown in the palaeoclimate table (2.1) because, the results from the Azraq Basin most probably reflect high groundwater levels because of low evaporation in the cold climate.

Interval V (*ca.* 15,000-11,000 BP)

Parts of this interval are characterised by a general trend of moist conditions across the whole Levant (Henry, 1982, 1986; Marks 1977; Henry and Leroi-Gourhan 1981; Henry *et al.*, 1981; van Zeist and Bottema, 1982; Hunt *pers. comm.*, 1998). Dry conditions are known about 10,000 BP in the Negev (Henry 1986; Bar-Yosef and Valla, 1991), also in the Negev dry conditions are known from about 12,000 (Goldberg, 1981). In south Jordan dry conditions has been recognised by Henry, (1986) and in the Azraq Basin by Garrard *et al.*, (1985a, 1985b, 1987, 1988) Garrard and Byrd, (1992). General reviews of the Levant also suggset short periods of dry conditions (Henry, 1981; Bar-Yosef and Tchernov, 1966).

Interval VI (*ca.* 11,000-9,000 BP)

This interval is characterised by generally dry conditions (Henry, 1986, 1995; Goldberg, 1981; Bar-Yosef and Valla, 1991; Henry *et al.*, 1981; Bar-Yosef and Tchernov, 1966). Some wet spells had been recorded in Saudi (Schulz and Whitney, 1986; Jado and Zotl, 1984), North Palestine and the Hula Basin (van Zeist and Bottema, 1982).

Interval VII (*ca.* 9,000-Middle Holocene)

In general reviews of the Levant, some areas experinced moist conditions around 9,000 BP (Henry, 1986; Noy *et al.*, 1980). Some areas in Saudi Arabia experienced wet conditions during this period (van Zeist and Bottema, 1991; Schulz and Whitney, 1986; Jado and Zotl, 1984). This interval appears to have been dominated by arid conditions in southern Jordan (Henry, 1995) except a moist phase from c. 9,000 to 8,500 BP which was described by Henry (1986) as an exception to the prevalent pattern. Garrard *et al.*, (1986) record more moist conditions around 8,250 to 8,500 BP in the eastern desert of Jordan. Syria experienced moist conditions around 9,000 BP (Leroi-Gourhan, 1981). The Hula Basin in North Palestine experienced moist conditions between 7,700 and 10,000 BP and the Negev as well between 9,000 and 8,000 BP (Henry, 1986). The Negev also experienced wet spells during the Chalcolithic (Goldberg, 1981). Dry conditions had been recorded in Syria (Bottema, 1989) and Saudi (Jado and Zotl, 1984; Schulz and Whitney, 1986) during most of this period.

Interval VIII (*ca.* Middle Holocene-Recent)

Very few authors have published information for this interval. Vita-Finzi and Dimbleby (1971) recorded a ? Medieval steppe-desert flora of very arid aspect from the Wadi Kofrein (Jordan). Further details (palynology) relating to this period can be found in (Tables 2.4 and 7.2) and are discussed in Chapters 6 and 7).

Table 2.1 Palaeoclimate of Jordan and neighbouring areas based on literature review of author's assessments of climate change (for sources see following page)

Date (BP)	Jordan 1	Jordan 2	Negev 1	Negev 2	Negev 3	N. P+Hula B.	N and S P.	LEV. 1	LEV.2	Syria	Saudi
0-5000											
5-6000											
6-7000											
7-8000											
8-9000				? ?							
9-10000											
10-11000											
11-12000											
12-13000											
13-14000											
14-15000											
15-16000											
16-17000											
17-18000											
18-19000											
19-20000											
20-21000											
21-22000											
22-23000				? ?							
23-24000											
24-25000											
25-30000											
30-35000											
35-40000											
40-45000											
45-50000											
50-55000											
55-60000											
60-65000											
70-80000											

Key

Dry phase

Wet phase

No information

Data in the above table is based on reviewing the work of the following authors: **Jordan** 1,2 and 3 Henry (1979, 1982, 1986, 1995); McNicoll *et al.* (1985); Copeland and Vita-Finzi (1978); Zeuner *et al.* (1957); Marks (1981a); Goldberg (1981); Garrard *et al.* (1986, 1987, 1988); Garrard and Byrd (1992). **North and south Palestine and North Palestine Hula Basin** Bar-Yosef and Vandermeersch (1981); Farrand (1979); Jelinek (1981); Goldberg (1981); Marks (1977); Bottema and van Zeist (1981); van Zeist and Bottema, (1982); Horowitz, (1979); Rosen, (1995).

Syria Sakaguchi (1978); Leroi-Gourhan (1981); Bottema, (1989).

Levant 1 and 2 Goldberg (1981, 1986); Horowitz, (1979); Tchernov, (1981); Noy *et al.* (1980); Henry (1986); Bar-Yosef and Tchernov (1966). **Negev** 1, 2 and 3 Schwartz *et al.*, (1979); Marks (1977); Goldberg (1981), 1986; Henry and Lerio-Gourhan (1976); Henry *et al.* (1981); Henry (1981, 1982, 1983); Tchernov (1981); Bottema and van Zeist (1981).

2.3 The Vegetation sequence in the Levant

Pollen studies attempt to reconstruct local and regional images of the past vegetation from fossilised pollen recorded in from ancient deposits. As pollen grains accumulate in a stratified sequence of sediments, they also provide a record of vegetational change through time (Faegri and Iversen, 1989; Moore *et al.*, 1991). From the evidence of past vegetation the nature of the past climate pattern can be estimated.

van Zeist and Bottema (1982) showed that there is a general scarcity of pollen-bearing sediments in the Near East. Palynological investigations of late Quaternary and early Holocene environments in the Near East have concentrated upon Turkey, Palestine, Syria and Iran (van Zeist and Bottema 1982). Much useful palynological information has been produced from the Ghab in the north-west Syria and Hulah Basin in north Palestine (van Zeist and Bottema, 1982).

Similarly, plant macrofossil analyses may also provide a record of vegetational change, though this is not usually the main purpose of such work. Furthermore, the most important aspect of modern archaeobotanical research (plant macrofossil analyses) is that it deals not only with environmental reconstruction but also seeks to examine on the interrelationships between people and plants. People, from the earliest times, have relied on plants for subsistence (Butzer, 1982). The earliest people relied upon plants not only for their foods, but for wood for construction and fuel, fibres for clothing, tools and other crafts, and other components for medicine, and for socio-religious symbols (Ford, 1979).

The following is a review of palynological and plant macrofossil investigations which have been carried out in different areas of the Levant (see figure 2.1), including Jordan.

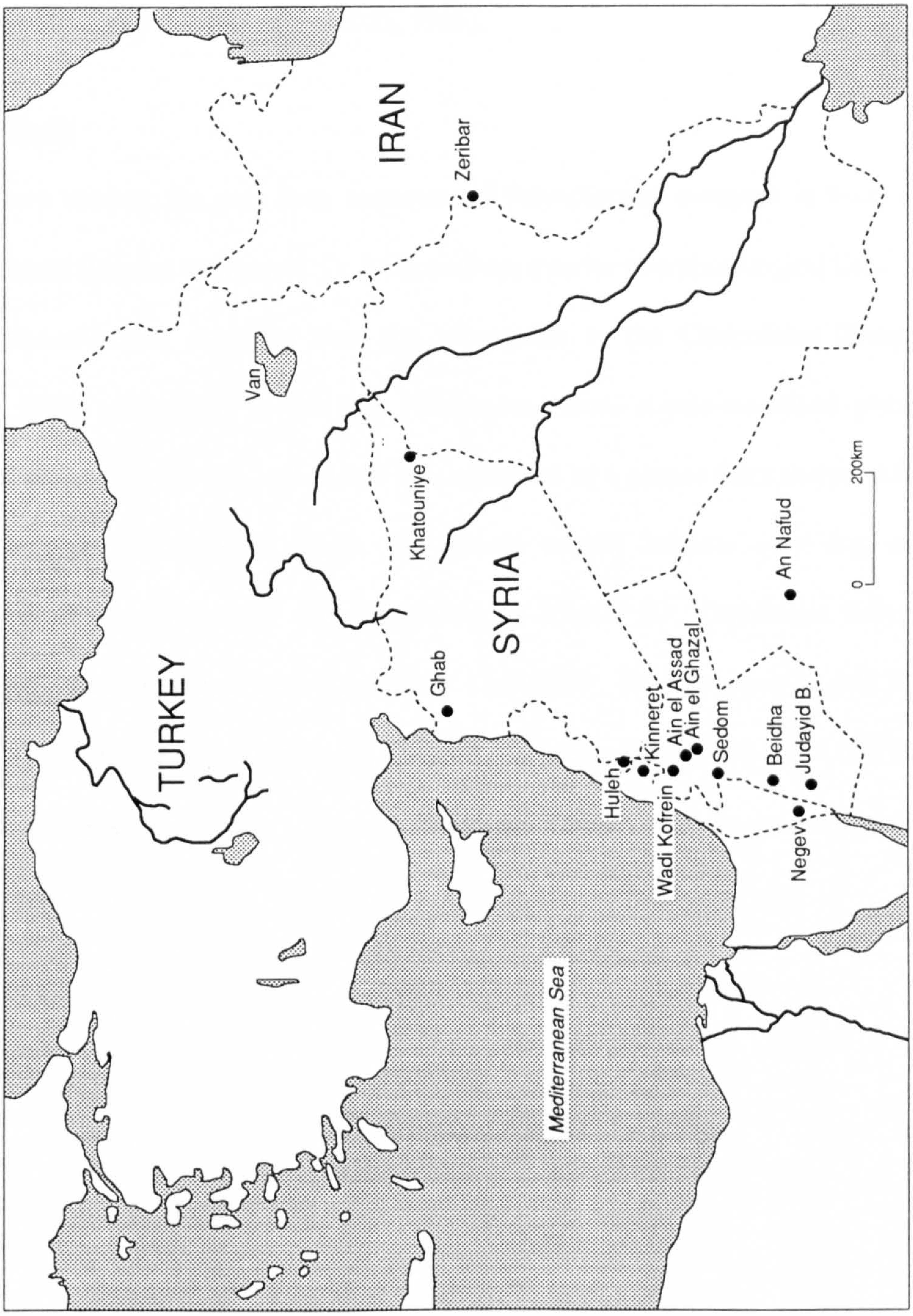


Fig. 2.1 Map of Eastern Mediterranean and the Near East with the location mentioned in the text (modified after van Zeist, Bottema, 1991)

2.3.1 Jordan

Previous Palynological investigations in southern Jordan are reviewed below. For most of the Holocene the environment was desertic, though steppe environments were recorded at Beidha by Fish (1989) and forest in the Early Holocene at Ain Ghazal by Rollefson and Simmons (1985, 1988).

Judayid Basin

In southern Jordan, the only long sequence of Palynological evidence is from the Judayid basin (located in Figure 2.1). Analysis from a series of archaeological sites give a discontinuous sequence from the Mousterian to the Chalcolithic (Emery-Barbier 1995: table 2.2). In the late Pleistocene, short steppe-woodland phases occurred around 18,000 BP, and 13,000 BP, separated by a phase of dry steppe. After the second steppe-woodland phase, the climate rapidly became very dry, and Chenopod- dominated steppe was established by 12,800 BP. Conditions became increasingly desiccated and were desertic by 11,000 BP. Sites between 11,000 BP, and 6,000 BP were not sampled. In the Chalcolithic, between 6,000 BP and 4,000 BP, conditions were very dry, and a Chenopod dominated desert vegetation predominated.

Table 2.2 Summary of Palynological investigations and Climatic reconstruction (after Emery-Barbier, 1995)

Archaeological period	Date BP.	Site	Climate	Biotype
Chalcolithic	4,000-6,000	J 14/J 24	Very dry	Chenopod dominated desert
Hiatus				
	11,000 12,000		Very dry	Chenopod-dominated desert
	12,700	J 2 J202	Dry	Steppe desert
	13,000	J 202	Moist	Woody grassy steppe
		J 31	Slightly humid	*Artemisia* steppe, becoming wooded
	15,000	J 26	Dry	Dry steppe desert
Epipalaeolithic	18,000	J504	Moist	Wooded steppe
Upper Palaeolithic	38,000	J403 J412	Dry Slightly humid	Alternating grassy steppe and chenopod-dominated steppe-desert

Ain el Assad, Azraq

Ain el Assad is located on the western edge of the dry bed of Pleistocene Lake Azraq (figure 2.1) at elevations of approximately 505 m above Sea level. Pollen analysis from Ain el Assad was conducted by Kelso and Rollefson (1989). The results which they obtained are given below in table (2.3). The samples of Holocene age suggest an extremely arid, desertic environment.

Table 2.3 Palynological investigation results of Ain el Assad.(after Kelso and Rollefson, 1989)

Depositional environment	**Layer no.**	**Age**	**Climate**
Aeolian beds	1, 2b	Neolithic	very dry - lots of Chenopodiaceae
Soil profile	2b	Long period of weathering, probably early Holocene	Lots of Chenopodiaceae (Liguliflorae)
Marsh deposits	3	Uncertain, could be late glacial	Gramineae, Steppic
Marsh deposits	3	Uncertain	Lots of Chenopods, i.e. dry

Ain Ghazal

An excavations at Ain Ghazal, near Amman, showed that the Pre-Pottery Neolithic (PPCB, PPNC) habitation of the site dated to 9,200-7,700 BP. The natural vegetation in the 9th millennium BP was oak-dominated woodland. The inhabitants of the site levied a heavy toll on the arboreal resources. Timber was used heavily for more than one purpose including construction, domestic fuel and the manufacture of plaster. The Ain Ghazal evidence points to the almost complete deforestation of a considerable area affected by early-Neolithic man (Rollefson and Simmons 1985, 1988), though given the regional patterns, climate change might also have contributed to the deforestation.

Beidha

Preliminary palynological results consisting of nine samples, spanning a period preceding the first Natufian occupation to the Nabatean, shows that the environment was open and steppe-like over much of late Quaternary time, like other pollen investigations from archaeological sites in southern Jordan (Leroi-Gourhan 1984; Darmon 1984; Emery-Barbier 1995). In The lower Natufian horizon (?Late Glacial) the environment was dry steppe followed by a good steppe in the (?early Holocene - Neolithic/Chalcolithic) and the environment seems to have deteriorated again to be a degraded steppe in Nabatean times (?2,500 BP) (Fish, 1989).

Wadi Kofrein

A snapshot of later, probably medieval conditions is given by the work of Vita-Finzi and Dimbleby (1971) from the Wadi Kofrein. A single pollen analysis from peaty deposits in a young terrace in the Wadi Kofrein was heavily dominated by Chenopodiaceae, suggesting a very dry, desertic environment.

2.3.2 Syria

The Ghab sequence described by Niklewski and van Zeist, (1970) covers the late Pleistocene to early Holocene. This sequence show high arboreal pollen (50%) between 25, 000 and 20,000 BP. A fluctuation in arboreal pollen (20-45%) with a considerable amount of *Artemisia* and Chenpodiaceae took place from c. 20,000 to about 14,000 BP. Between 14,000 and 11,000 BP a sharp decline in arboreal pollen (10%) took place, after which arboreal pollen rises again with *Quercus, Pistacia, Olea* and *Ostrya / Carpinus Orientalis* dominant. Baruch and Bottema (1991) interpreted the diagram (Niklewski and van Zeist diagram) as showing steppe-desert vegetation dominant in the Pleniglacial, reflecting cold and dry conditions, with significant tree growth. Between 14,000-11,000 BP, Baruch and Bottema suggested that the forest contracted, perhaps because of high evaporation and temperature depression. After 11,000 BP trees grew again due to increases in temperature and precipitation. The forest expanded in the early Holocene from 10,000-8,000 BP (Baruch and Bottema 1991).

Rosner and Schabitz (1991) analysed the upper Holocene development of vegetation in the Khatouniye area, eastern Syria. The pollen analyses indicate the dominance of steppe vegetation in the whole profile and thus arid to semi arid conditions. The general climatic character was changed in the Roman epoch. There was a period of about 300 years in which the humidity was probably higher. Evidence for this seen in an increase of tree pollen and soil development.

2.3.3 Palestine

Several pollen diagrams have been prepared for sediments in the Hulah basin, in northern Palestine. This basin is located at the northern end of the Jordan Rift Valley. Two of these pollen diagrams will be described below.

1- At first Hulah Basin sequence was described by van Zeist and Bottema (1982, based on Tsukuda's pollen diagram) as follows:

- Before 24,000 BP open forest was dominant in north Palestine.
- From 24,000 BP to 14,000 BP steppe-forest was dominant, which reflected dry cold conditions. This interval of time matches that noted in the Ghab sequence.
- At 14,000-10,000 BP an expansion of the oak forest took place and reached a peak at c. 10,000 BP.
- 10,000-7,400 BP arboreal pollen values decrease again, suggesting that more open vegetation had expanded at the expense of the oak-dominated forest.

4,500- ?present: after 4,500 BP the interference of man led to decline in tree-pollen values.

2- Baruch and Bottema (1991) described another pollen diagram from the Hulah Basin. This new description conflicted in places with the earlier Hulah core described previously by van Zeist and Bottema (1982, 1991). The new pollen diagram was suggested to be more reliable since it was based on a single well - dated core, rather than the shorter joined cores studied previously. This new core showed an expansion of forest at c. 15,000 BP, with further increase at c. 13,000 BP to reach a maximum expansion at c. 11,500 BP. This expansion of forest was interpreted as a result of increasing humidity, presumably because global temperatures are assumed to rise through the Late Glacial period. This conflicted with the interpretation of the earlier diagram, in which the forest contracted between 11,500 and 10,000 BP, which had been interpreted as a climatic deterioration with decreased temperature (Baruch and Bottema 1991). Differently from previous pollen diagrams, the new Hulah diagram shows severe conditions immediately preceding the Holocene. Baruch and Bottema (1991) describe early Holocene (10,000-9,000) re-expansion of forests, implying an increase in precipitation, assuming a higher global temperature.

Palynological studies of radiocarbon dated cores collected from the Hulah basin and some archaeological sites in Palestine seem to indicate that there were two periods of time in which the climate was apparently more humid than at present. It was concluded that at these times vegetation belts moved southwards and the share of olives in the natural maquis increased until about 2400 BC and from 2100 until 1100 BC (Horowitz, 1974). Dry phases were recorded at around 2250 and 950 BC (Horowitz, 1974).

Lake Kinneret

A palynological investigation of a 5 m long core from Lake Kinneret, northern Palestine, shows evidence of vegetational changes during the last 5,300 years, as a result of human activities. The apparently still intact forest which surrounded the Lake until the end of the third millennium BC was heavily decimated in the second and first millennium BC, following which large scale olive cultivation was practised in the area. After 550 AD, with the abandonment of the olive groves, the natural forest regenerated. As a result of renewed forest clearing activity during the last 250 years, the forest contracted again (Baruch, 1986).

Lower Jordan Valley

Pollen analysis of Fazael VIII and Salibiya IX which are located in the lower Jordan Valley, suggest humid conditions at about 12,000 BP. These moist conditions were followed by a progressive drying out which peaked at around 10,000 BP (Darmon, 1984, 1987).

Charcoal in cave deposits from the Mount Sedom on the shore of the Dead Sea (Palestine) suggests an open forest dominated by oak, in the period 4,580-4,250 BP and steppe or desertic environments after that time (Frumkin *et al.*, 1991).

Negev

In spite of the destructive activity of man for several thousands of years, a considerable number of *Pistacia atlantica* trees are still found in the Central Negev highlands. For that reason it is assumed here that in the early Holocene, under more humid climatic conditions, a sort of forest-steppe was present in the Central Negev (van Zeist and Bottema, 1991). Furthermore, pollen spectra obtained from a few Natufian and pre-pottery Neolithic B (PPNB) sites in the Central Negev suggest more humid conditions in the Pleistocene /Holocene transitional period and in the early Holocene (Horowitz, 1979). In addition, to the previous sites, Horowitz (1979) investigated sites of Chalcolithic Age in the Central Negev and he concluded that during Chalcolithic times climatic conditions were once more some what better than at present, enabling habitation.

2.3.4 Saudi Arabia

The evidence of former Lakes in the An Nafud area consists of deposits of cemented sand, calcareous crust and diatomites (Schulz and Whitney, 1986). The An Nafud lake beds were formed in two periods, between 34,000 - 24,000 BP and between 8,400-5,400 BP. The Holocene lake beds suggest very shallow lakes or marshes with alternating wet and dry phases. The pollen spectra derived from the lake beds suggests that the flora of the area was essentially the same as that of today. For the early Holocene, a denser Herb cover may be assumed (van Zeist and Bottema, 1991). Furthermore, Sanlaville (1992) reported two humid phases in the Arabian peninsula, dated 30,000 to 20,000 BP and 10,000 to 6,000 BP.

2.3.5 Western Iran

In Western Iran, pollen diagrams were prepared from sediment cores taken from Lake Zeribar (van Zeist and Bottema, 1977). Only the record from 14,000 BP will be reviewed here because the older periods are beyond the scope of this thesis.

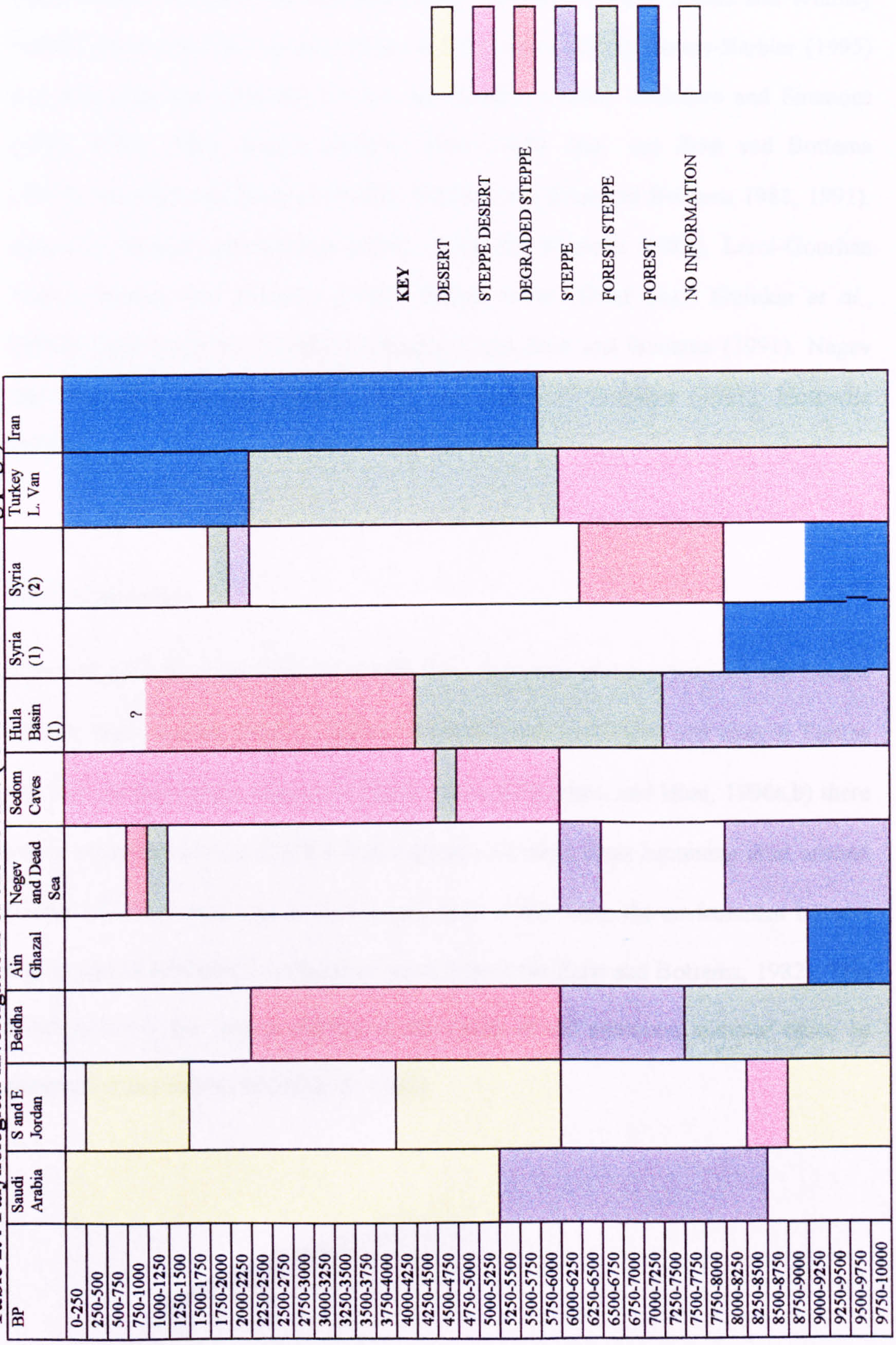
At the period between 14,000 and 10,500 BP, the conditions for tree growth seem to have been slightly better than in previous periods, as it is shown by the small increase in the tree pollen values. Nevertheless the overall aridity must have prevented more luxuriant tree growth. During this period, which coincides with the greater part of the Late Glacial, temperatures must have risen considerably, but the general climate remained dry. The period between 10,500 and 6,000 BP. was characterised by a slow increase in tree pollen values, such as *Quercus* and *Pistacia*. On the other hand, herbaceous pollen values remained high suggesting oak-pistachio forest-steppe which in time became somewhat denser. It is probable that in the early Holocene the temperature can not have been the limiting factor for tree growth, but one must assume that the dry climate prevented the trees from rapid expansion. In general, the climate in western Iran in the early Holocene was relatively warm and dry (van Zeist and Bottema 1982). The following period (6,200 to 5,400 BP) reflected the replacement of the forest-steppe by the Zagros forest. The marked increase in tree pollen percentages is entirely accounted for by *Quercus*. The upper zone of the Zeribar diagram reflects predominantly forest vegetation. It was suggested that during the last 5,500 years, the Zagros Oak forest vegetation must have been present in the Zeribar area and that the humidity in this period reached modern levels (van Zeist and Bottema, 1982).

2.3.6 Southeast Turkey

Information on the Holocene has been obtained from Lake Van which is situated in the Taurus Mountains of south-eastern Turkey, 1650 m above sea level. The Lake Van diagram covers nearly the whole Holocene (the base of the diagram is varve-dated to 9,800 BP (van Zeist and Bottema, 1982). Zones 1-3 (9,800-6,300 BP) of the diagram reflected predominantly desert-steppe vegetation, in which Chenopodiaceae, *Ephedra* and *Artemisia* alternately played important parts. During the early Holocene, low temperature was a limiting factor for tree growth as well as the dryness which also prevented the expansion of trees. Zones 4 and 5 (6,300-3,600 BP) show a gradual increase in the tree pollen values, suggesting that during the period concerned to the south and southwest of the Lake the desert-steppe was gradually replaced by forest. The spread of the trees points to an increase in humidity, most probably caused by higher precipitation (van Zeist and Bottema 1982). In the period covered by zone 6 (3,600-2,500 BP) the forest vegetation with predominant oak reached its maximum expansion in south and southwest of the Lake were covered with forest. Predominantly steppe vegetation is assumed for the region on the north and east of the Lake. The decline in oak-pollen values and the increase in Herb-pollen percentages in zones 7 and 8 (?800 BP-?present) should most likely attributed to the interference of human activities (van Zeist and Bottema 1982).

The previous review of palynological investigations in the Levant has been summarised in table (2.4).

Table 2.4 Palynological investigations of the Levant (for sources see following page)



The palynological information which the above mentioned table was based on are derived from reviewing the work of the following authors:
Saudi Arabia: van Zeist and Bottema (1991), Sanlaville (1992), Schulz and Whitney (1986), South and East Jordan: Kelso and Rollefson (1989), Emery-Barbier (1995) and Vita-Finzi and Dimbleby (1971). Ain Ghazal (Jordan): Rollefson and Simmons (1985, 1986, 1988). Beidha (Jordan): Fish (1989). Iran: van Zeist and Bottema (1977), van Zeist and Bottema (1982). Turkey: (van Zeist and Bottema 1982, 1991). Syria (1): Baruch and Bottema (1991). Syria (2): Bottema (1989), Leroi-Gourhan (1981), Rosner and Schabitz (1991). Sedom caves (Dead Sea): Frumkin *et al.*, (1991). Hula Basin (1) (Northern Palestine): van Zeist and Bottema (1991). Negev and Dead Sea: Darmon (1984, 1987), van Zeist and Bottema (1991), Horowitz (1979).

2.3.7 Conclusion

It can be seen from the table (2.4) that there is a clear division between the Levant sites in Saudi Arabia, Jordan, Sedom, the Hula Basin and Syria, and sites in Turkey and Iran. In the Levant sites, as in North Africa (Gilbertson and Hunt, 1996a,b) there was a major deterioration in the environment with most areas becoming drier around 6,000-5,000 BP, where as in Turkey and Iran, at this time, the environment became wetter and forest spread and become more dense (van Zeist and Bottema, 1982). This trend probably fits with a shifting to the north of the monsoon summer rains, as observed in the Sahara (COHMAP, 1988).

2.4 Archaeobotany

Introduction

Perhaps the most important aspect of modern archaeobotanical research is that it relies not only upon on environmental reconstruction but also seeks to examine the interrelationships between people and plants. People, from the earliest times, have relied on plants for subsistence (Butzer, 1982). The earliest people relied upon plants not only for their foods, but for wood for construction and fuel, fibres for clothing, tools and other crafts, and other components for medicine, and for socio-religious symbols (Ford, 1979).

Many researchers have attempted to use archaeobotanical remains such charred seeds and fruits as an indicator of vegetational and environmental change (see Moore and Hillman, 1992). The following section will dicuss the importance of plant macrofossils and palaeobotanical remains in relation to palaeoenvironment reconstruction. The three following sites were selected from the literature, based on their good records and relevance to the research topic.

Mount Sedom: Palestine

Charcoal in cave deposits from the Mount Sedom on the shore of the Dead Sea (Palestine) suggests an open forest dominated by oak, in the period 4,580-4,250 BP and steppe or desertic environments after that time (Frumkin *et al.*, 1991).

Beidha: Jordan

An a brief moist episode suggested by palaeobotanical and geomorpholoical evidence obtained for the PPNB site of Beidha is dated between *ca.* 9,000 and 8,500 BP (Henry, 1986)

Tell Abu Hureyra: Northern Syria

Plant macrofossil remains including Charred seeds and fruits were used as an indicator of vegetational and environmental change over the period 11,500 to 10,000 BP. These Botanical samples show exploitation of flora from steppic and forest-steppe environments (Moore and Hillman, 1992).

2.5 The impact of metal mining and smelting on forest vegetation

Introduction

Extensive research in the Wadi Faynan by Hauptmann and Weisgerber (1987, 1992), Hauptmann (1989, 1990), Al-Najjar *et al.*, (1995) suggests that this area was the scene of large-scale metal mining and smelting in the late prehistoric to Mamluk periods. The following section therefore reviews literature dealing with the impacts of ancient metal smelting on forest vegetation.

Previous discussions concerning the exploitation of woodlands for fuel during prehistoric times have been generalised and characterised by a lack of solid evidence. Attention has been paid to determining the amount of wood fuel required to support prehistoric mining and metalworking operations. This has been achieved in many ways, among them the quantification of industrial debris by using experimental data from firesetting experiments, also supported by reasoning and speculation. The results from such studies have indicated that the amount of fuel consumed and the potential level of woodland clearance were influenced by the scale of mining or metalworking (Mighall and Chambers, 1993).

Experimental evidence

In order to determine how much wood was used for fuel, for firesetting rocks during mining and during burning in furnaces for metalworking, various experiments have been carried out. Firesetting experiments enabled archaeologists to estimate how much branchwood or charcoal was needed to extract a specific amount of ore (Mighall and Chambers, 1993). An experiment performed in England and Wales suggested ratios of timber to spalling of 1: 0.8 and 1:3; a timber to charcoal ratio is

7:1, and the timber to rock waste ratio has been estimated to be 1:1 (Pickin and Timberlake 1988). Mighall and Chambers (1993) suggested that a enormous amount of timber was used at Bronze Age copper mines at Mount Gabriel, south-west Ireland. The rock extracted from 31 mineworkings totalled 3923 tonnes. Wood consumption, based on a 1:2 wood to rock ratio and experiments (1:0.27 wood to rock ratio), is estimated to have been between 1962 tonnes and 14533 tonnes. Furthermore, Stos Gale *et al.*, (1988) suggested that metal production in the Cycladic Island ceased during the Bronze Age because of local deforestation, though there is no evidence to support this suggestion.

The quantification of ironwork debris or copper slag heaps enables archaeologists to estimate the amount of wood necessary to processes the ore. In the Weald of Kent the six main centres for ironworking produced 66,000 tonnes of iron using 792,000 tonnes of charcoal between AD 120-140. This led to clearance up to 15 km^2 of woodland (Cleere, 1974). Recent investigation at Bryn Castell, in north Wales, suggests nearly 116 tonnes of wood were used to process 1776 kg of raw ore to yield 156 kg of iron during two stages of ironwork which took place around 100 BC and AD 150-250 (Crew, 1990). Based on the types of wood which was used, Crew (1990) estimated that between 2.5 ha (for mature oak) and 5 ha (for alder) were needed. These are useful general estimates for the quantity of woodland which would have been cleared for the sake of ironwork.

For iron production the ratio between the ore and fuel (charcoal) is 1:3. The production of about one tonne of charcoal would required around six tonnes of wood (Scott, 1990).

Wood and charcoal finds

In some earlier studies little attention has been paid to establish whether individual tree species were preferred for a specific function or not (Mighall and Chambers, 1993). According to a review of charcoal identifications from mining and metalworking sites in Yugoslavia, Ireland, Wales, England, and Scotland, Mighall and Chambers (1993), suggested that a variety of tree types were used for early mining and metalworking. *Quercus* and *Corylus* appear to be the most frequently used. Similar tree types may have been used for different functions, for example *Quercus* and *Corylus* were used in both firesetting and in smelting furnaces. In the research area, in Jordan, information on wood and charcoal finds had been reviewed from earlier archaeobotanical work in the research area (chapter 3).

2.6 Mediterranean Alluviation

2.6.1 Introduction

The Wadi Faynan is a fluvial landscape (Ch. 3), and a sequence of Holocene and Pleistocene terrace deposits can be found (Barker *et al.*, 1997). In other Mediterranean countries, such deposits have been used as evidence for climatic change and human activity (Lewin *et al.*, 1995). There is, however, considerable debate about the origins of the terrace deposits of Mediterranean countries: this is summarised below.

2.6.2 Early studies

The first key study of valley alluviation in the Mediterranean region was by Judson (1963a) in the Gornalunga Valley in Sicily. Geological and archaeological studies established that there were two historic age deposits (Judson, 1963a,b; 1968). These deposits were a terrace deposit which was laid down between the 8th century BC and 325 BC, with a depth about 8-10 m, (figure 2.2, no. 19) and after a period of erosion, a second, but less extensive deposit, the result of alluviation of probably medieval age. This second deposit has a thickness of 4-5 m (figure 2.2, no. 20). It was thought to be the equivalent of one north of Rome, in Southern Etruria. In Southern Etruria, 3-8 m of stream deposits buried Roman structures and date from either the late Roman or the Medieval periods (figure 2.2 no. 18). Judson (1963 a,b) did not reach a conclusion on the causes of these alluviation events.

Man's influence on the formation of fluvial deposits is clear in Greece as well. The Alpheus river started to bury the classical places of Olympia not earlier than AD 500 (figure 2.2, no. 27). The 10 m terrace mainly accumulated during Medieval times.

Budel (1965, 1977) states that the most important reason for several changes in fluvial activity was the strong impact of man on nature. On the other hand, Dufaure (1976), supported the concept of anthropogenic initiation of sedimentation in Roman times, but credits its build-up between the 8th and 15th Centuries as mainly due to climatic reasons (figure 2.2, no. 28).

2.6.3 Modern Research

Study of the alluviation patterns in the countries around the Mediterranean really started with the work of Vita-Finzi (1969), whose work summarised the history of late Quaternary valley deposition. Vita-Finzi defined two major phases of alluviation in all Mediterranean countries, termed the Older Fill and Younger Fill. Each fill resulted from the silting up of stream channels, valley floors and coastal plains that had been incised during a preceding erosional phase. The colour of these two fills was different, with the Older Fill tending toward red tones and the Younger Fill toward browns and greys.

Vita-Finzi dates the Older Fill to the late Pleistocene (*ca.* 50,000-10,000 BP), but indicated that the Younger Fill was deposited between late Roman (*ca.* 400 AD) and early Medieval times (figure 2.2, no. 1-9). The age of both Fills was based on archaeological finds. Vita-Finzi (1969), concluded that climatic change was the primary factor responsible for the major phase of Holocene alluviation and valley sedimentation which he identified throughout the Mediterranean. Periods of valley infilling, alternating with those of erosion in the valleys and simultaneous Delta growth, have been documented by Vita-Finzi (1969, 1972). The Older Fill (I) was deposited between 50,000-10,000 BP. Then, until 2,000 BP, there was erosion and down cutting, with deposition of deltaic material between 5,000 and 2,000 BP. The Younger fill (Fill II) was laid down between 1600-300 BP and from 300 BP until the present there was erosion and increased deltaic building (Figure 2.2, no. 10 and figure 2.3).

Since Vita Finzi's work (1969) two schools of thought have developed. One school follows Vita-Finzi and they suggest that climatic factors caused Late Holocene alluviation. Among those who prefer the climatic explanation are Leopold (1976), Bintliff (1977), Vita-Finzi (1969, 1972, 1975, 1976), Devereux (1982) and Hemple (1982, 1984a,b). The other school supports anthropogenic factors. Among early workers who preferred the anthropogenic explanation are Bell (1982), Douglas (1967), Butzer (1972, 1974), and Dimbleby (1972). Since then valley alluviation in the Mediterranean coastlands has been a very important subject with much debate.

2.6.4 The "Climatic School"

Bintliff (1976a, 1976b, 1977) found that the model of Vita-Finzi (1969), was applicable in Greek archaeological sites. He suggested that aggradation of the Older Fill needed much higher rainfall than occurs at present, and he correlated it with the presumed pluvial phase which took place in the early-middle part of the last Glaciation. On the other hand, he conformed with Vita-Finzi when he related and attributed the Younger Fill to climate change, which took place between the middle of the first millennium A.D. and late Medieval times.

Hemple (1982;1984 a,b) is considered to be among those who suggest that the climatic factor is causal in alluviation and he reports that the debris/alluvial fills and terraces of the basins, valleys and coastal plains in Greece and Crete were deposited before significant human activity took place. On the other hand, Hemple (1982;1984a,b) suggested that ancient gravels built up before the Wurm high glacial, and younger deposits were deposited at the end of Wurm, in the Holocene during the "Atlantic phase of the Holocene". He refered only to the most recent phase of sedimentation to anthropogenic causes (figure 2.2, no. 29 and 30). He also mentioned that deforestation has not had a big effect because the forests existed in the plains and therefore deforestation did not cause soil erosion (since he observed the Greeks and Phoenicians mainly settled in the coastal plains). Most recent sedimentation, however, is initiated by human activity. Moreover, he contended that the woods mentioned as existing from Antiquity (Mediterranean oaks and conifer) offer little protection against soil erosion. Thus, he suggested that many historical fills were caused by climate, not by man. Hemple (1982, 1984 a, b) gives examples from south Greece and Crete, where the valley bottoms filled mainly before the cultivation of the land commenced.

Gilbertson in Tripolitania, Libya, (in Barker and Jones, 1981), recognised that in Wadi Merdum and Wadi N'f'd there were two episodes of sediment aggradation. these Gilbertson termed as "Older Fill" and "Younger Fill" and said they were deposited by fluvial processes. The Older Fill often contained Palaeolithic artifacts. On the other hand, the Younger Fill is composed of fine aeolian and fluvial sands and loams which are lying in channels and basins cut in to the Older Fill. The age of the Younger Fill was proposed as late Holocene. These two units (Older and Younger Fills) were considered as equivalent to the upper and lower terrace deposits as defined by Vita-Finzi in Wasdi Lebda and the Jefara Region.

Radiocarbon ages and pottery date the building-up of valley fills in the Algrave (S. Portugal), starting from 2,000 years ago and finishing some time after AD 1400, (figure 2.2, no. 11). Devereux (1982), presumed that an increase in rainfall rather than agricultural practices was the reason.

Northern Sinai experienced an alternating periods of deposition and erosion since the early Middle Palaeolithic with extensive gravel deposition to a height of about 19 m above the present wadi floor till the final period of silt deposition which is documented over much of the area; although barren of artifacts; it yielded radiocarbon dates of 1755 and 655 BP which Goldberg (1984) suggest as pointing to deposition during wetter intervals and erosion during drier intervals (figure 2.2, no. 26).

2.6.5 The "Anthropogenic School"

Environmental change in the Mediterranean Basin induced by human activity can be traced back to the Neolithic agricultural revolution in the Near East around 8000 BC (Macklin *et al.*, 1995). Furthermore, an agro-ecosystem was established in the entire coast of the Mediterranean in areas which were suitable for farming around 5000-4000 BC, and since that time these areas were subjected to human interference (Ammerman and Cavalli-Sforza, 1971).

The Mediterranean basin is very large and has diversity in its human history, bedrock, tectonic activity, climate and vegetation. Because of all these, Butzer (1969) raised a criticism of the Vita-Finzi model (1969). Furthermore, the interactions of vegetation cover, soil properties, and denudational forces have been neglected at the specific level (Butzer, 1974).

Further review of the later Holocene valley alluviation in the Mediterranean, by Bell (1982), showed that the valley fills were deposited diachronously. Accordingly, the climate factor was argued to be unlikely or at least is not as important as anthropogenic factors. Bell (1982) stressed that the causal agent for alluviation was human disturbance of the landscape. Alluviation occurred at different times at different localities, so climatic change was unlikely to be the main reason behind the pattern of Mediterranean valley alluviation. Several studies have supported Bell (1982). Among these studies are Davidson (1971), Davidson *et al.* (1976), Wagstaff (1981), Gilbertson *et al.* (1983), Davidson (1980), Gomez (1987), Pope and van Andel (1984), van Andel *et al.*, (1986), Chester and James (1991). Furthermore, even Vita-Finzi (1976) has acknowledged that Mediterranean valley sedimentation was to an extent diachronous. It has also been pointed that dating of these sequences is often problematical (Hunt and Gilbertson, 1995)

In the Platani Valley, Salso Valley and Dottaino Valley in eastern Sicily, terraces were studied and classified by Neboit (1983, 1984a). A terrace was recognised up to 10 m above the river bed, which contained pottery from the 3rd century BC. (Greek Epoch), (figure 2.2, no. 21) and an Older terrace at 15-20 m above the river bed. This higher terrace contained no archaeological material, but had some on its surface, probably from the 18th century BC. (figure 2.2, no. 22). A younger terrace of 5 m, was of unknown age. It contained reworked artifacts. The main reason behind the formation of these terraces was suspected to be human activity.

In Tripolitania, Libya, The "Younger Fill" at Beni Ulid was subjected to a study by Gilbertson and Jones (Barker and Jones, 1982), and from this study they concluded that the climate in the Romano-Libyan period was almost similar to that of today and that intensive farming caused alluviation rather than a response to climate change. They suggested that soil erosion which may have resulted from overgrazing. On the other hand, near Beni Ulid, in the Wadi N'f'd and on the plateau near Wadi Gobeen, the sedimentological changes in the Wadi deposits were thought to be related to the irrigation practices in the Romano-Libyan times as well as to natural environmental fluctuation (Barker *et al.*, 1983). The very high salinity in the Wadi floor sediments was detected by electrical conductivity studies and interpreted in terms of water table elevation which was induced by irrigation and greater flood frequency, of obvious significance in influencing agriculture. Gilbertson *et al.*, (1984) redefined the Older Fill and Younger Fill as Cobbly Fill and Wadi Alluvium respectively, and they found that their first correlation of Older/Younger fill to the Older and Younger terrace deposits of Vita-Finzi (1969) was not easy and precise.

Alluvial deposits in the lower Vasilikos Valley (Cyprus) were investigated by Gomez (1987), and four alluvial terraces have been identified at heights of approximately 10 m, 25 m, 55 m, and 80 m, above the bed rock floor of the Valley. The younger fill in the lower Vasilikos Valley differs in two ways from the deposits which were described by Vita-Finzi (1969). First, it is composed of two (not one) distinct units, a coarse (channel zone) and finer (flood plain) deposits. Secondly, radio-carbon dating suggests that the overbank sedimentation in the lower Vasilikos Valley was under way by Aceramic Neolithic time (*ca.* 5800-5250 BC.).

In Spain, in the Ebro Valley, three valley fills have been recognised by van Zuidam (1975). The two older ones, according to van Zuidam, were caused by natural processes and the younger fill, which was deposited between 700 BC and AD 117, was caused by anthropogenic activity (figure 2.2, no. 12).

In Basilicata, Southern Italy, Bruckner (1986, 1990), identified four periods of accumulation. The first one was climatically/eustatically caused, whereas the other three were dated to the Greek-Roman Epoch (figure 2.2, no. 23), Medieval times (figure 2.2, no. 24) and the last two centuries (figure 2.2, no. 25), owing their origin to human activities such deforestation and farming. The vulnerability of the environment (Mediterranean subtropics, easily erodable marls and clays, steep relief), was the main reason why human influence on nature had significant effects, including badlands formation in the hinterland and on the Valley slopes, and the creation of enormous sediment accumulations in the valleys and on the coastal plains (Bruckner, 1986).

Holocene coarse and fine grained alluvial deposits from the Feccia Valley, Tuscany Italy, have been described by Gilbertson *et al.*, (1983), and Hunt and Gilbertson (1995). They show that there are two sets of palaeochannel fills, and three sets of coarse alluvium. The palaeochannel fills contained pollen, molluscs and plant macrofossils reflecting a relatively well-vegetated landscape. On the other hand, some of the coarse alluvium was laid down after clearance phases. The phases of gravel sedimentation may be related to historical and archaeological evidence for periods of intensification of human activity and expansion of farming in the area. The depositional regime changed very rapidly. Two sets of palaeochannel fill deposits and two sets of coarse sediments accumulated since the fifteenth century AD.

The early history of the Bifero Valley, Molise, Italy predominantly reflects tectonic activity in the lower Pleistocene and a mixture of tectonics and climate change in the middle and late Pleistocene. In the Holocene, human activity played a very important role in shaping sedimentation patterns. The archaeological and geomorphological investigation which was carried out by Barker and Hunt (1995), defined the major phases of land use expansion and/ or agricultural intensification. These human activity phases coincide with aggradation phases. The phase of late Samnite/ early Roman aggradation does not compare well with the Vita-Finzi model (1969), of a climatically controlled late Roman/early Medieval Younger fill. Instead, where palaeoecological evidence is present, signs of cleared landscape and soil erosion are evident during aggradation phases. Generally the human activity appears to have been the dominant influence on fluvial activity in the Holocene.

It can be noted that many of these studies are extremely simplistic conceptually. For instance, assumptions are made that river systems behave similarly from their headwaters to the sea (Graf, 1983 b. c, d). In practice, few rivers behave in this way, though very few palaeo-fluvial studied have docummented this, one notable exception being Rose (1995). Very rarely are concepts such as threshold behaviour considered (Hunt *et al.*, 1992).

2.6.6 Delta expansion in Historic time

Deltas throughout the Mediterranean underwent rapid expansion in the late Holocene. Examples are the deltas of the rivers Ebro, Rhone, Aigues-Mortes, (which was a coastal port at the time of the Crusaders), Tiber (the former port of Rome, Ostia antica, is now silted completely), Arno (Pisa was isolated from the sea in the Medieval periods), and Po (a rapid delta growth since the 12th century) (Bruckner, 1986). Rathjens (1979) discussed the causes behind the formation of deltas, and he refers them to the deforestation, production of charcoal for fuel, the cultivation of grain and olive trees, and widespread goat keeping.

In Tunisia, due to extensive deforestation (in 146 BC) in the Majerda Valley, sedimentation took place in the valley bottom and also to seaward in the river's delta. A fragmentary barrier spit began to develop by the 5th century AD (figure 2.2, no. 16), by the 13th century AD, this barrier spit consisted of distinct islands, then littoral drift began to close the passes between the islands during the 13th and 14th century (figure 2.2, no. 17). By the 16th century the barrier spit was more or less continuous (figure 2.2, no. 17) (Thornton *et al.*, 1980).

In west Turkey, phases of delta growth can be precisely dated by archaeological findings. Furthermore, there are many coastal archaeological sites which were partly covered by alluvial deposits, with their harbours silted up. Among these sites are the cities of Ephesus and Miletus (Bruckner, 1986). According to Eisma (1978), the delta of Kucuk Menderes river progressed slowly between 750 and 300 BC (figure 2.2 no. 32), then in the period 300-100 BC (figure 2.2 no. 31) it moved forward rapidly for a distance about 5 km and then with decreasing speed in Roman times 100 BC- AD 200 (figure 2.2 no. 34), and finally more slowly in Early Middle Ages AD 200-700 (figure 2.2 no. 33). On the other hand, the data which relate to Buyuk Menderes delta (Maiandros) are less complete, but the delta formation seems to have had a similar history up to the Early Middle Ages (Bruckner, 1986).

2.6.7 Anomalous arid-zone alluviation patterns

A number of arid-zone areas show patterns which are not easily related to either the climatic explanation put forward by Vita-Finzi (1969) or to human influence as suggested by Bell (1982).

In the Musandam Peninsula of northern Oman, the wadis are floored by the calcrete-capped alluvial and colluvial Fills of the Makhus Formation. The relationship of this formation to the coastal aeolinites gave indications that this formation was deposited during the last major marine regression (15-20,000 BP). About 10,000 BP incision supervened and outside those areas that are affected by the subsidence has persisted until the present day, barring a brief depositional episode (represented by the Khasab terrace) (figure 2.2, no. 15) which was dated by means of archaeological finds to between the fifteenth and nineteenth centuries A. D. (Vita-Finzi, 1978).

In Tunisia, two very low post-Islamic Holocene terraces have been reported (Ballais, 1995). One of these terraces is at Henchir Rayada which contains Islamic pottery from 10th-11th century (figure 2.2, no. 14) and the other one at Wadi Akarit which radiocarbon dated to 610 $\pm$ 110 BP (figure 2.2, no. 13). These terraces were thought to be similar to the several aggradations recorded from around the Mediterranean by Vita-Finzi (1969) but clearly do not conform closely to his model. The sedimentological characteristics indicate stratification which is comparable to that forming under the present day conditions.

In Tripolitania, re-study of the evidence put forward by Barker and Jones (1981, 1982) and Barker *et al.*, (1983) showed that the pattern of alluviation was not simple and did not conform to the Vita-Finzi model (1969) (Gilbertson *et al.*, 1984, 1987;

Hunt *et al.*, 1986; Anketell *et al.*, 1995). A major early Holocene alluviation phase seems to have accompanied the Neolithic colonisation and agricultural development of the Tripolitanian wadis. The Roman-Libyan flood water farming systems were built on stable wadi floors, and appears to have functioned without sedimentation and erosion problems until the 16th Century AD. During the 16th Century AD, a major sedimentation episode deposited up to 8 m of alluvium in the wadi floors (Gilbertson and Hunt in Barker *et al.*, 1996). Alluviation after the Early Holocene was thus clearly not linked with the 1st-4th Centuries AD, or with its decline in the 5th and 6th Centuries AD. Neither does it conform to the Vita-Finzi (1969) model.

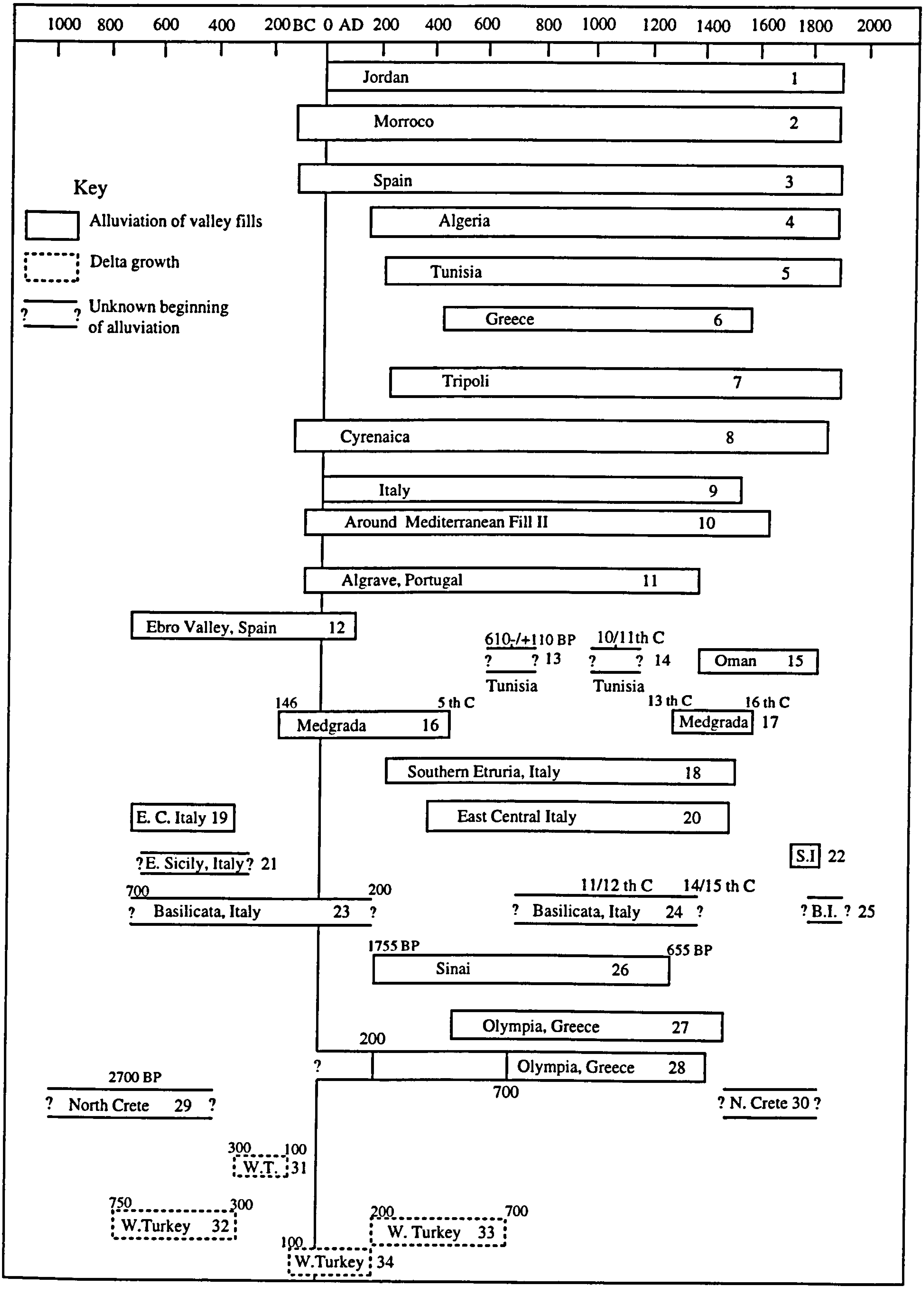


Figure (2.2) Selected historical alluviation in the Mediterranean region.

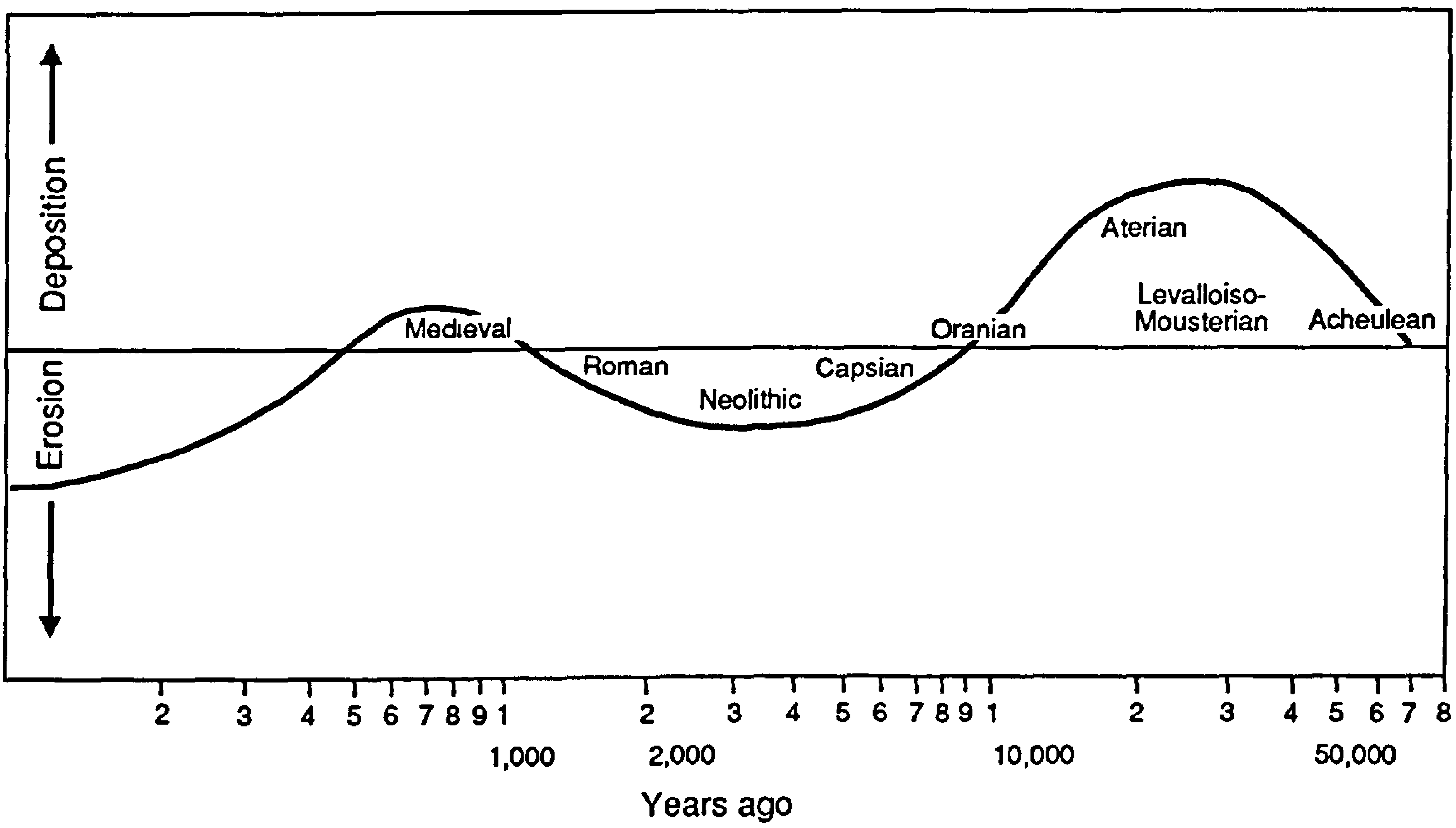


Fig. 2.3 Chronology of erosion and deposition in Mediterranean area. A logarithmic scale is used for time (after Vita-Finzi, 1972)

2.6.8 Alluviation in Jordan

Wadi Hasa

Near Qal'at el Hasa, the Wadi Hasa is bordered by remains of alluvial fills. The history of accumulation and erosion of these fills must be considered in any account of the regional environmental record. Table 2.5 describes the fills (Copeland and Vita Finzi, 1978).

Table 2.5 Alluvial Fills in the Wadi Hasa.

Fill number	Description	Thickness (m)	Age based on attribution of artifacts	Age based on radiocarbon dating
Fill IV	A well-bedded deposit of fine gravel, sand and silt	2	Contains Roman and later shreds (one dating from AD 1250-1400 : Historical Age)	Less than 2000 years old.
Fill III	Well-bedded silty sands with basal limestone gravel	5	Contains Kebaran (Epipaleolithic) artifacts	3950+/- 150 BP
Fill II	Largely water laid angular to subangular fine gravel and silt. This unit cuts in to fill I	1	Contains Pre-Kabaran (Upper Palaeolithic) artifacts	9200-8640 to 6000 BC
Fill I	Highly calcareous silt and clay containing bands of gravel, much of angular flint.	30	Contains Middle Palaeolithic artifacts	Middle Pleistocene to 14000 BC

The following alluvial chronology was proposed by Copeland and Vita Finzi (1978):

- Fill I was deposited and accumulated during or after the Middle Palaeolithic occupation and continued up to early Upper Palaeolithic.
- Fill I was incised and the Fill II was deposited during the Late Pre-Kebaran (Upper Palaeolithic).
- Incision was renewed and accumulation of Fill III took place during or after the Kebaran.
- Fill III was incised before the Roman period and deposition of Fill IV took place during or after Roman times and continued into Medieval times.
- Fill IV was incised after the Medieval period.

Wadi Kofrein

In the lower Wadi Kofrein, fills which are represented by terraces have been described by Vita Finzi and Dimbleby (1971) as follows in table 2.6.

Table 2.6 Alluvial Fills in the Wadi Kofrein.

Fill	Description	Thickness (m)	Age
Younger deposit	Predominantly well bedded clayey silt, usually buff in colour, with horizons iron stained.	4	Medieval
Lower terrace	Bands of peaty material in the upper part, one of these bands is 0.3 m thick, yielded pollen. This Fill contains Roman potsherds.	30	Medieval

The Wadi Kofrein has an ephemeral regime at the present day. Aggradation by streams with different seasonal or even perennial regimes are indicated by the well stratified character of the Wadi Kofrein deposits, and the peaty material (Vita Finzi and Dimbleby 1971).

2.6.9 Discussion

From the previous review, it can be recognised that, in the Holocene a multicasulity is more likely, in many instances, than a simple climatic causality of valley alluviation. The influence of human activity and climate will vary from area to area, depending on local agricultural and climatic history, rock type, vegetation, hydrology and so on (This point was made previously by Butzer, 1969; Hunt *et al.*, 1992). The pattern of Mediterranean alluviation is demonstrably complex (see figure 2.2). Simple explanations are therefore unlikely: a view cogently expressed by Cooke and Reeves (1976). Those workers studied the cutting and filling of arroyos and canyons in California and Arizona. They reached no firm conclusions, but they favoured climatic factors in Arizona and human factors in California. These workers point to the possibility of multi-causality and the difficulties of linking cause and effect in simple fashion. In the Pleistocene, however, anthropogenic causes are unlikely to be significant: climatic and tectonic causes are likely, but the pattern of alluviation events is not uniform around the Mediterranean.

2.7 The impact of early mining and smelting on ecology and river behaviour

Mining activity and stream activity may interact in the fluvial environment in a number of ways. The mining wastes, in the form of solutes and sediments, may enter streams where they are dispersed, and then redeposited. The input materials and the modification of discharge characteristics may lead to repercussions in term of channel morphology and dynamics (Lewin *et al.* 1977). Large scale sedimentation may occur because metal pollution may eliminate bankside and channel vegetation, thus promoting sediment mobility (Lewin *et al.* 1995). Furthermore, mining often liberates very large quantities of sediment, which may themselves impact significantly on channel morphology and river behaviour (Macklin and Lewin, 1986; Graf, 1988). In addition, historical mining and smelting has an effect on the landscape in other ways, amongst these ways, are the following: changes in woodland composition caused by pollution and by extraction of fuelwood, promoting river valley alluviation and sedimentation (Mighall and Chambers 1993).

2.8 Rainwater Harvesting and Flood Water Farming

2.8.1 Introduction

The Wadi Faynan is known to be an area where floodwater farming and rain water harvesting has been used over the last 5000 years (Barker *et al.*, 1996; Ch. 3).

Water harvesting is a term which was introduced first by Geddes in 1963 (Myers, 1974) to define the collecting and the storage of water, whether it is from runoff or from creek flow, for the purpose of irrigation. The term water harvesting was used to describe methods of collecting the various types of runoff from a variety of sources using different harvesting techniques (Reij *et al.* 1986). Bruins *et al.* (1985) recommended that the terms 'runoff farming' and 'rainwater-harvesting agriculture' can be used interchangeably and defined it in the following manner: Rainwater-harvesting agriculture is farming in dry regions by means of runoff rainwater from whatever type of catchment or ephemeral stream. The term 'rainwater harvesting' was also used by Boers and Ben-Asher (1982) to describe the taking of slope runoff or ephemeral channel flows for human use. In many arid lands, the surface water used is often derived largely from a few storms: consequently the term floodwater farming is appropriate when the centres of cultivation are in valleys or basins on upland plateaus (Gilbertson, 1986). Bryan (1929) used the term, 'floodwater farming' to describe the surface water harvesting and farming techniques of native Americans in Arizona and the neighbouring states and Mexico. These people used walls and brushwood fences to divert and concentrate occasional runoff onto small plots which could be cultivated. Reviews by, amongst others, Gilbertson (1986), Bruins *et al.*, (1986) and Gilbertson and Hunt (1996b) show that similar ancient wall-based technology has been widely used in drylands world-wide. Evenari *et al.*, (1982) and Bruins *et al.*, (1985) tried to reconstruct a flood water farming system in the Negev desert of Palestine. Few functioning ancient irrigation systems have been investigated, whatsmore archaeological studies of ancient systems have been fairly cursory. Because few ancient floodwater farming systems still function, there is a tendency, exemplified by the work of Burns and Denness (1985) to equate their non-functional status with past environmental collapse or climate changes (Hunt and Gilbertson, 1998).

As has been indicated by Gilbertson *et al.* (1984) and Gilbertson and Hunt (1996b), the technology of floodwater farming systems can be complex. The hydrology of floodwater farming system is, however, divisible into the simple categories which are shown in table 2.7.

Table 2.7 Hydrological functioning of rainwater-harvesting and floodwater-farming system (after Hunt and Gilbertson, 1998).

Type of system	Function
Slope catchment systems	Concentrate and divert ephemeral runoff on hillslopes into farmed areas or cisterns
Diversion system	Divert often ephemeral channel flows from valley floors into farmed areas or cisterns
Impoundment (liman) systems	Check dams impound ephemeral floodwaters on valley floors, or other low-lying areas, leading to infiltration and storage of the water in the valley fill.
Combination systems	These are systems which used combinations of the above techniques.

Generally, ancient floodwater farming systems had environmental effects on the landscape in the past, since the farmers needed to direct the runoff water to their farms. This affected the general pattern of alluviation and sedimentation. Beside this, the diversion and impoundment of the water may have had an effect on the natural vegetation cover. Hunt *et al.* (1987) and Gilbertson and Hunt (1996a) suggest that flood-water farming systems have a positive effect on biodiversity. On the other hand, irrigation water often brings with it dissolved material which may accumulate in the soil to increase the salt content. Moreover, water tables produced by irrigation, combined with strong evaporation lead to salt precipitation in the upper layer of the soil (Williams *et al.*, 1998; Roberts, 1998); thus, effects which are caused by flood-water farming methods may have been negative, as with mining activity or pastoral grazing.

What follows is a brief review of floodwater farming in some areas of the Middle East and North Africa, which places the water harvesting systems of the Wadi Faynan in context.

2.8.2 Jordan

Rainwater harvesting and flood water farming are will be discussed in detail in Chapter 3.

2.8.3 Syria

The first primitive Neolithic dry-land farming communities developed and herding on the steppe began to spread about 8,000-6,500 BP (Bottema, 1989).

2.8.4 Palestine

During the Chalcolithic period, more than 5000 years ago, runoff and flood water farming was practised along the Wadi Beersheva in the north Negev (Levy, 1983). Many flood water farming systems in the Negev desert are believed to date back to around 2500 years BC (Evenari *et al.*, 1971). During the Middle Bronze I period (*c.* 2200- 2000 BC), the central Negev highlands were settled extensively and runoff farming was probably practised in suitable wadis (Evenari *et al.*, 1958; Cohen and Dever 1980). According to Cohen (1976) and (Cohen and Dever,1980) runoff farming settlements in the central Negev dated back to the 10th century BC, in King Solomon's region. The fortresses and agricultural settlements were destroyed during Shishak's Campaign in Palestine. Extensive remains of ancient desert agriculture appear in the central Negev and adjacent region of northeastern Sinai. Thousands of check-dams and countless little stone mounds were built in numerous wadis over thousands of hectares of hilly uplands. These ancient constructions were built to enable rain-fed farming based on run-off water. These systems date back to several periods, the Iron Age, and particularly to Nabatean, Roman, Byzantine and early Arab times (Bruins, 1990).

During the Nabatean-Byzantine period (*c.* AD 100-700), rainwater harvesting agriculture reached a peak of development in the Negev (Evenari *et al.*, 1971, 1982).

2.8.5 Yemen

Near the town of Mari'b, a large dam, called 'the Great Dam' was built around 750 BC across Wadi Dhana to collect the runoff water, for the irrigation of two great agricultural fields, located along the northern and southern flanks of the wadi. The Dam worked for at least 1300 years and was repaired many times, until it was finally destroyed and abandoned about AD 575 (Le Baron Bowen 1958; Brunner and Haefner, 1986). Other remains of runoff farming systems have been discovered in different areas of the Yemen. Some of these remain in use to day (Evenari *et al.*, 1982).

2.8.6 South Arabia

Irrigation was carried out by the ancient states of South Arabia in the period ranging from 700 B.C. to the early Centuries A.D. In the Beihan, there are a numbers of abandoned irrigation works. These show that the Qataban was no exception to the general high development of irrigation in ancient South Arabia (Le Baron Bowen, 1958).

2.8.7 Libya

Ancient flood water farming systems based on sophisticated technology were reported in the Tripolitanian pre-desert (Gilbertson *et al.*, 1984; 1993; Hunt *et al.*, 1986; Barker *et* al., 1996). The precipitation in this area was the limiting factor for both ancient and modern farming (Gilbertson and Hunt, 1990). In the middle Holocene, this area, like the rest of north Africa, suffered from waves of climatic change and became more arid. Aeolian processes dominated, interrupted occasionally by winter floods, in a landscape characterised by grass steppe, which is essentially the same as today (Gilbertson *et al.*, 1993).

Floodwater farming was practised in pre- Roman times in Tripolitania, and still used today near Jebel Nefousa (Le Houerou and Lundholm, 1976). According to Le Houerou and Lundholm (1976), a large catchment basin which concentrates runoff has remained in use for almost 2000 years. Furthermore, large scale ancient flood water farming systems in the pre-desert of Tripolitania have been mapped and studied by the UNESCO Libyan valley survey (Barker *et al.*, 1996). During the first century AD, open farms and floodwater farming systems were built in large numbers by the local people (Barker *et al.*, 1996). Permanent settlement and sedentary farming most probably reached its peak during the second and third centuries AD and continued into the 5th century AD (Barker *et al.* 1996). Floodwater farming continued in some areas into the Islamic period. Gasr Abzam and its systems were still active 400 years ago (Barker *et al.*, 1996).

2.8.8 <u>Egypt</u>

Many remains of ancient rainwater-harvesting agricultural systems have been reported in Egypt (Mariout region), in particular along the coastline from the west of Alexandria to the Libyan border (Kassas, 1972).

2.8.9 Conclusion

Although in some areas it would appear that flood water farming and rain water harvesting can have benefits for the environment, this is not the case at all places. In many places the relationship is unproven. Questions therefore, emerge as to the role and importance of flood water farming (FWF) and rain water harvesting (RWH) in the Wadi Faynan, and especially their sustainability and environmental relationships.

2.9 Conclusion

In this chapter, the theoretical background to the study has been set out. Problems exist with our understanding of a number of issues, especially climate, environmental change and vegetational history in southern Levant, and the history and impact of human activity, especially agriculture and mining on river behaviour and alluviation in the arid zone. Numerous differences of view can be seen to exist. The remainder of this thesis addresses these issues.

CHAPTER THREE: THE STUDY AREA

3.0 The Study Area

3.1 Introduction

This chapter will describe the research area in the context of Jordan. Particular attention will be paid to the geology, climate, vegetation, and record of prehistoric settlement and human activity, especially mining and metalworking in the research area.

3.2 Location

The Wadi Faynan study area lies at the edge of a mountain front in south-western Jordan, immediately east of the trough of the Wadi Araba, which runs south from the Dead Sea to the Gulf of Aqaba (figure 3.1). The principal area of research is located at the confluence of three wadis, the Wadi Ghuwayr, Wadi Shayqar and Wadi Dana, which emerge from the mountain front and join to form the Wadi Faynan. The Wadi Faynan (plate 3.1), is typically, but not always, a broad low basin 100-200 metres above sea level, which eventually opens into the low plain of Wadi Araba (Barker *et al.*, 1997).

Plate 3.1 The Wadi Faynan braidplain from the Khirbet Faynan archaeological site.

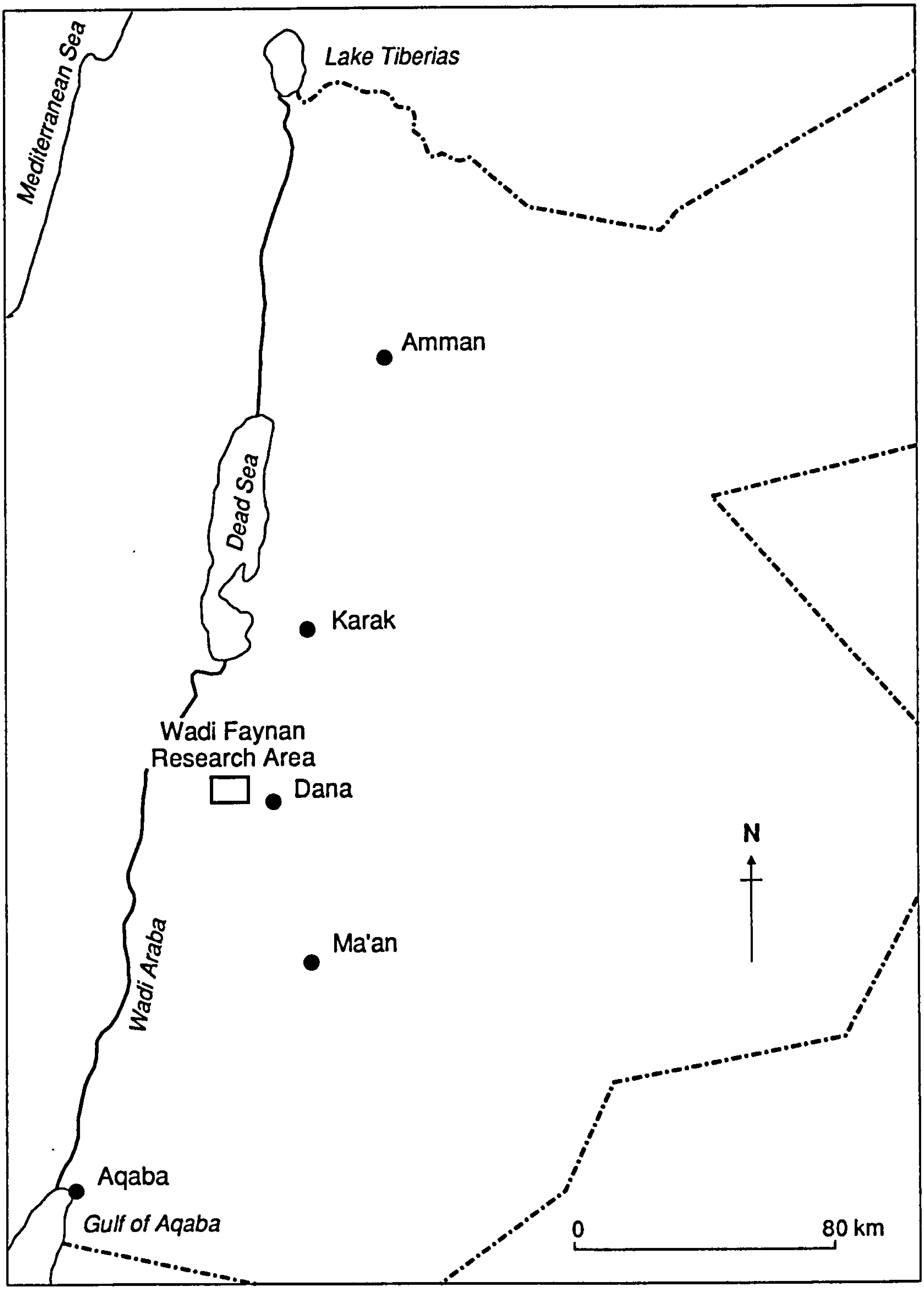


Fig. 3.1 Location map of the research area

3.3. Geological setting

Sedimentary rocks cover almost the whole of Jordan. Basement is exposed in the South West and characterised by Precambrian plutonic and metamorphic rocks and a minor occurrence of Upper Proterozoic sedimentary rocks. The thickness of thesedimentary rock cover increases in a Northeast direction, where progressively younger rocks are exposed (Bender, 1974a,b). Unmetamorphosed Cambrian, Ordovician and Silurian sandstone and shale of continental and marine origin, reach a maximum thickness of 1,800 m and overlie unconformably the pre-Cambrian rocks. These Palaeozoic rocks consist mainly of clastics, with some thin carbonates. They dip gently north and north-east beneath the Cenozoic sequences (Bender, 1975).

Following peneplanation, Triassic rocks were deposited. A pattern of north west to south east transgressions took place several times during the Mesozoic. From the Jurassic to the Lower Cretaceous, the sequence is predominantly clastics and marine carbonates. These together with the Palaeozoic sediments, form an important lower aquifer complex in Jordan. Widespread deposition of carbonates occurred during the Upper Cretaceous, comprising a variety of marls, limestone and dolomitic limestones. Carbonate deposition continued into the Tertiary and the sequence forms a major upper aquifer complex (Bender, 1975).

Major volcanic activity occurred during the Late Proterozoic and Early Cambrian (quartz porphyries, in the Wadi Arabah), during the ?Late Jurassic and Neocomian (mafic and intermediate eruptive rocks, in the Wadi al Arabah and west of the Jordan River), and during the Miocene, Pliocene and Pleistocene (extensive basalt volcanism). Quaternary basaltic rocks are found in the north east of Jordan. They cover about one seventh of the country. Minor basaltic intrusions are also found along the east escarpment of the Jordan Rift Valley, and are usually associated with faults (Bender, 1975).

3.4 Surface Geology of the Study Area

Introduction

Geological mapping in southern Jordan (where the research area is located) was done by Bender (1974a), Powell (1989a,b) and McCourt and Ibrahim (1990). Early mapping work was compiled by Bender (1968). Geological maps for Umm el Amad and Khirbet an Nahas were produced by the French National Public Institute (1974). Furthermore, detailed geological investigation was undertaken by Rabb'a and Ibrahim (1988), Rabb'a (1994), Barjous (1992), Gold (1964) who produced a geological map at 1: 100,000 scale covering the Faynan area and Van Den Boom and Ibrahim (1965) who produced a geological map at 1: 25,000 scale for the Wadi Dana area and reported the occurrence of copper and manganese. The lithological section (figures 3.2 and 3.3) shows the outcrops of the research area. The following Formations and rock units are exposed in the research area (see the geological map of the research area, figures 3.4 and 3.5).

Aqaba Complex

The Aqaba Complex with the Araba Complex represents the basement rocks in southern Jordan and both are almost exclusively Late Proterozoic (less than 800 M*a*). Both Complexes consist of meta-volcanosedimentary sequences, plutonic calc-alkaline granitoids, and andesitic and rhyolitic volcanics. These rocks are overlain in the north and east by the Ram sandstone of Lower Palaeozoic (Cambrian-Ordovician) age (Barjous, 1992).

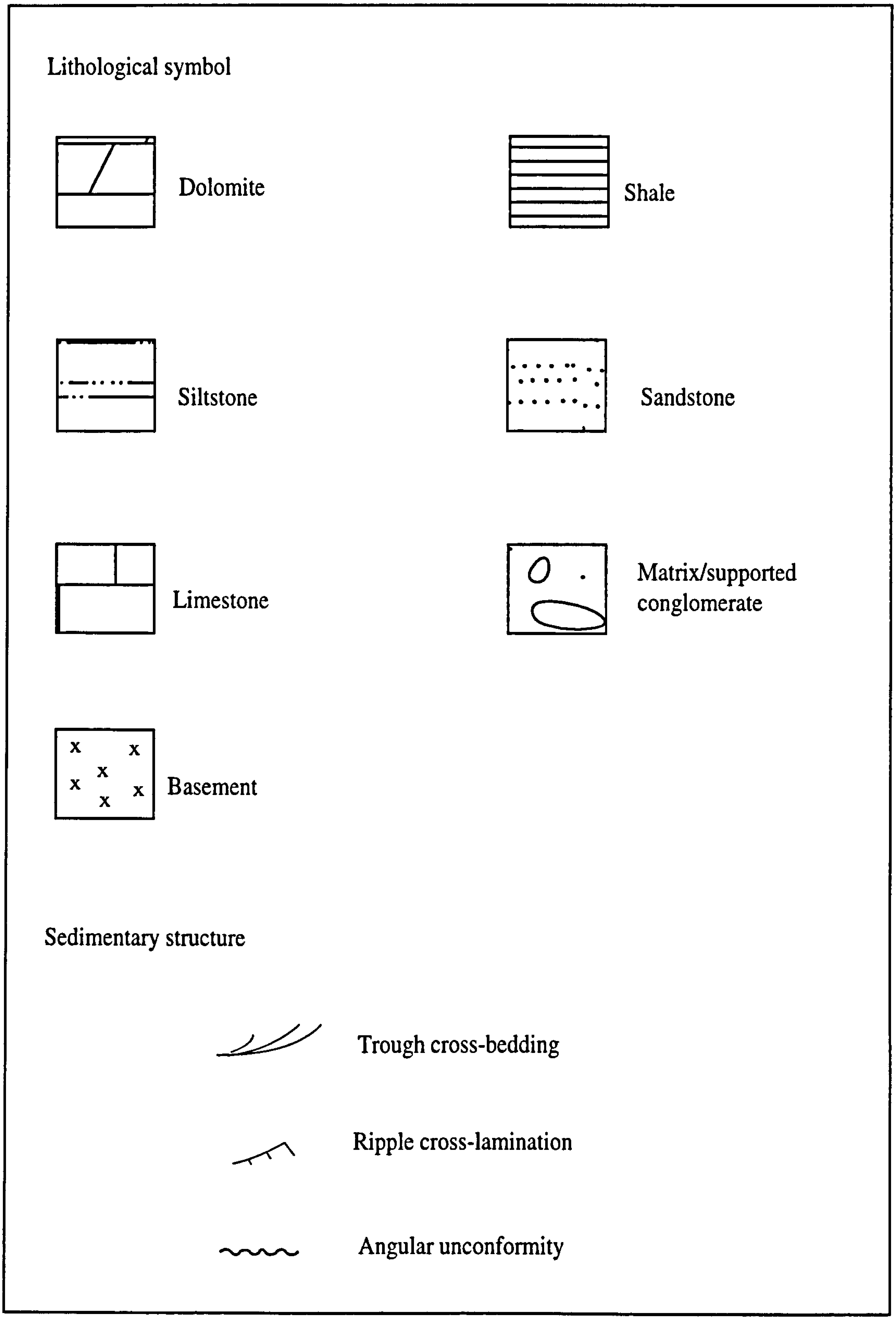


Fig. 3.2 Legend for lithological section (Fig. 3.3).

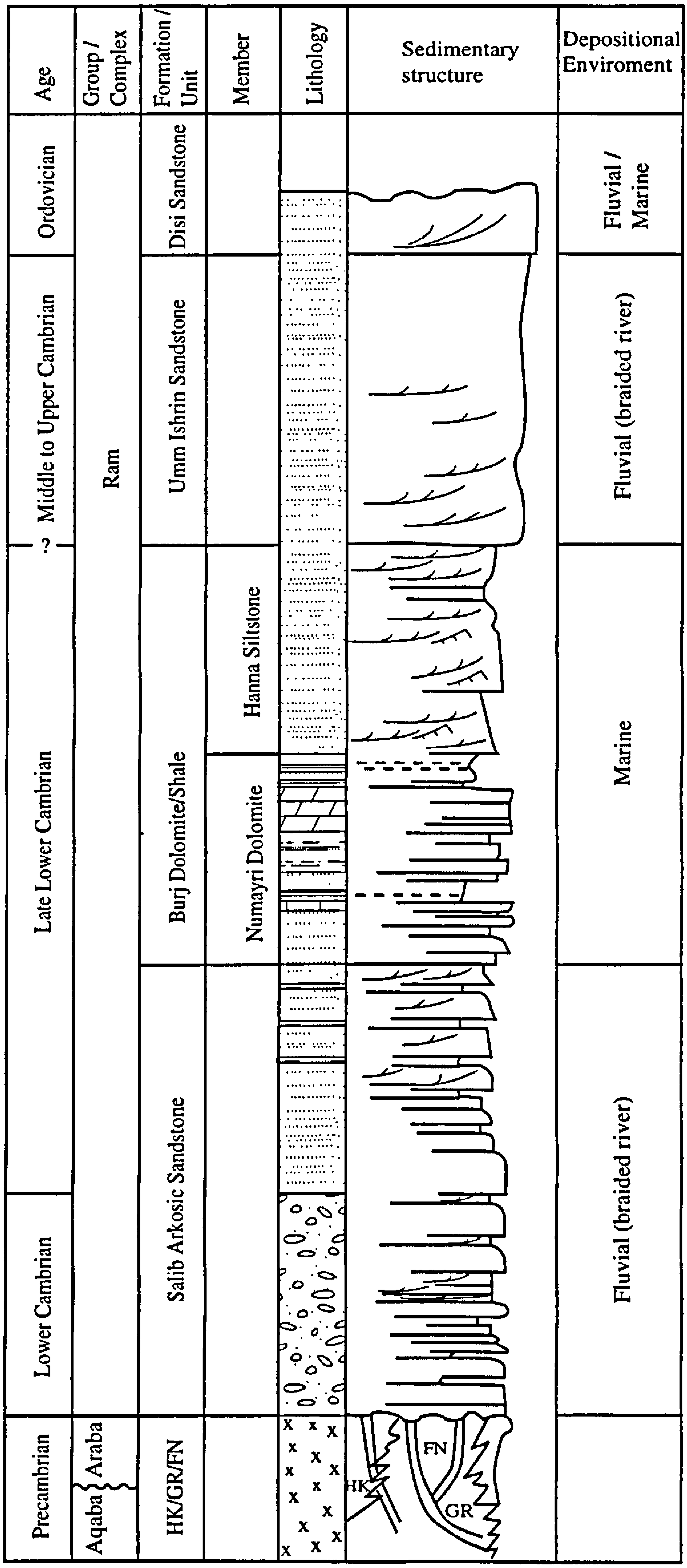


Fig. 3.3 Geological succession in the study area
(Modified from Rabb'a, 1994).

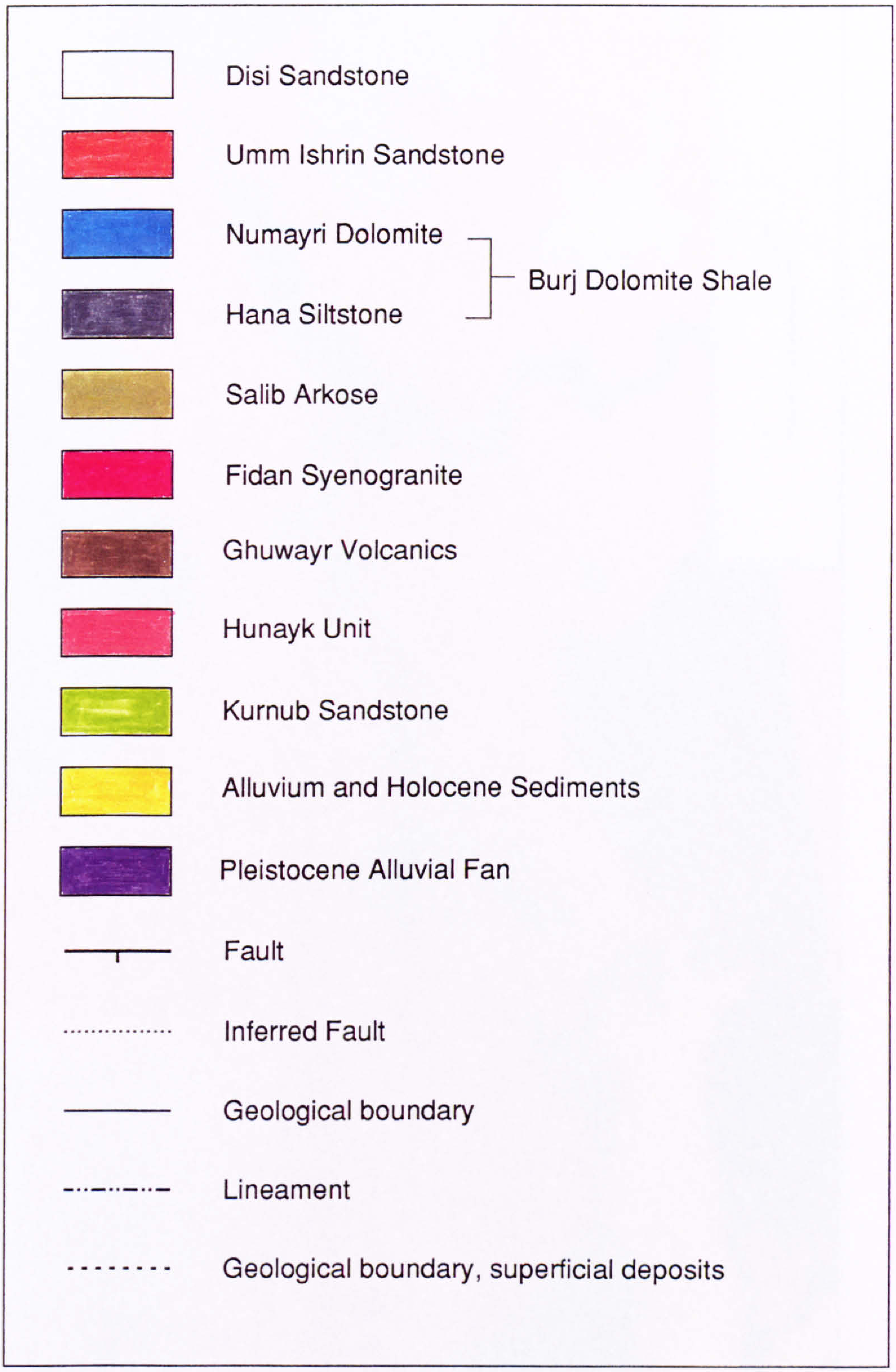


Fig 3.4 Key for Geological Map of the study area

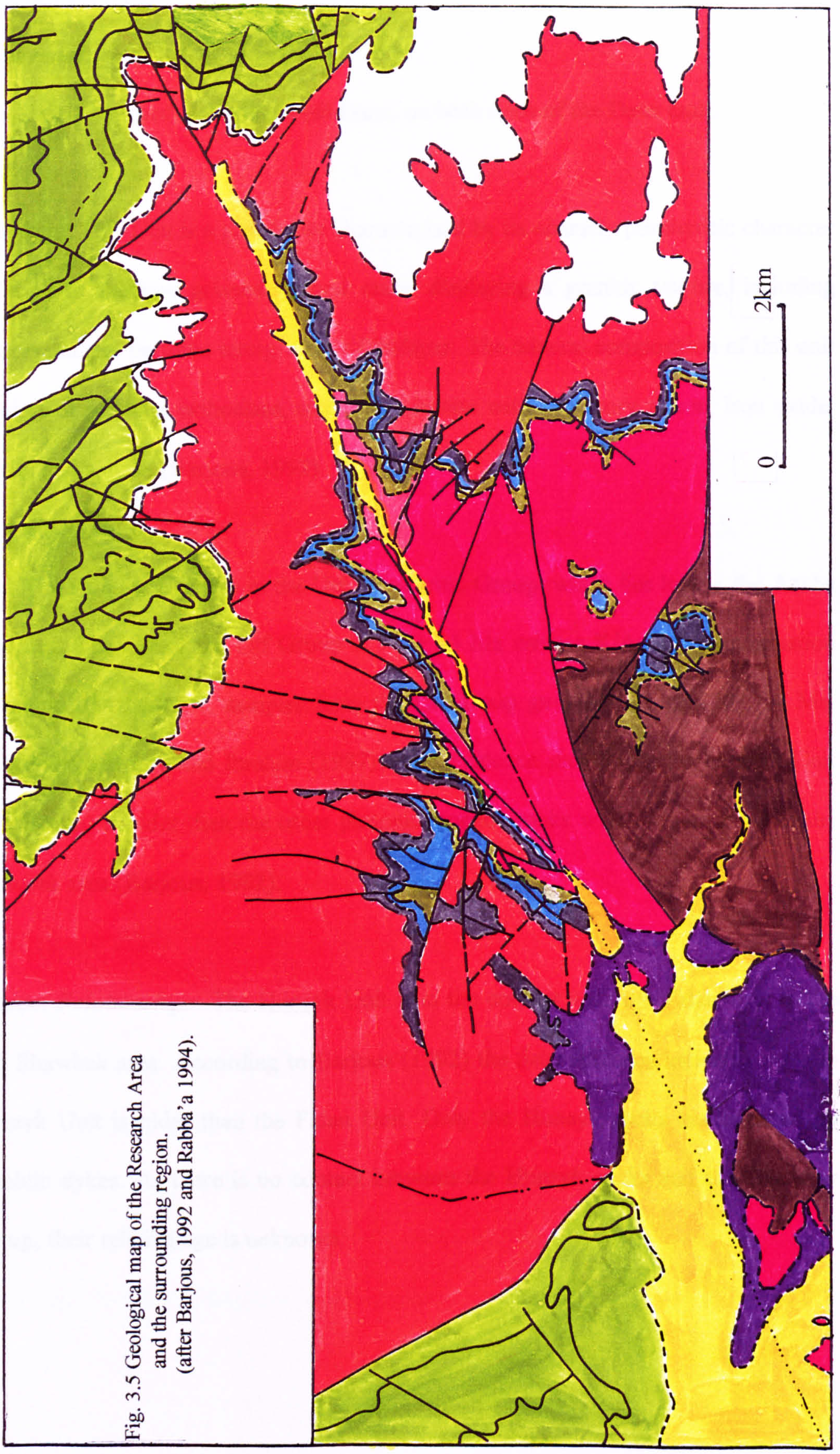


Fig. 3.5 Geological map of the Research Area and the surrounding region. (after Barjous, 1992 and Rabba'a 1994).

Hunayk Unit (HK)

Occurrence:

This Unit is exposed along the Wadi Dana, on both sides of the Dana fault.

Lithology: This Unit is a porphyrite characterised by its coarsely porphyritic character and fine to medium grained ground mass, displaying a granitic texture, including holocrystalline, perthitic intergrowth of feldspar. The mineral composition of this unit consists of perthite, orthoclase, quartz and biotite with accessory zircon, iron oxide, apatite and sphene (Barjous, 1992).

Age: The Hunayk Unit lies in the Urf Porphyritic Group, which lies low in the Aqaba Complex. The age of the Urf Group is 587$\pm$ 14 Ma using a K/Ar age determination technique. Furthermore, samples from the Urf group gave an age of 620$\pm$ 14 Ma, according to Brook and Ibrahim (1987). Field evidence shows that the Hunayk Unit (Urf Group) is older than the other plutonic igneous rocks which are exposed in the Shawbak area (Barjous, 1992).

Contact Relationships: The Hunayk Unit is in the contact with the Fidan Unit in the Ash Shawbak area. According to Barjous (1992) the field evidence indicates that the Hunayk Unit is older than the Fidan Unit. Only the Hunayk rocks are intruded by rhyolitic dykes. As there is no contact between the Hunayk rocks and the Ghuwayr Group, their relative age is unknown.

Ghuwayr Volcanic Group (GR)

Occurrence: The Ghuwayr Group has a rectangular outcrop which is located in the western part of the Dana Horst. The Ghuwayr rocks are highly jointed and a smooth erosional plane separates them from the overlying the Cambrian Sandstone.

Lithology: The Ghuwayr Volcanics comprise green basic lava, with pillow lava, tuffisite with pyroclastic fragments and silty volcaniclastic sediments which contain ripple marks on bedding surfaces (Barjous, 1992).

Deposition environment: There is evidence of burrows and desiccation cracks indicating shallow water deposition for the sedimentary parts of the sequence.

Contact relationships : There is a sharp contact between the Ghuwayr volcanics and the Fidan Syenogranite.

Age: The Ghuwayr volcanics lie in the Aqaba Complex, which is Late Proterozoic in age (Barjous, 1992).

Araba Complex

Fidan Syenogranite (FN)

Occurrence: In general this is the plutonic phase of the Araba Complex. The Fidan unit is exposed in the western part of the Dana horst and along the northern side of Wadi Dana. It is highly fractured and weathered.

Lithology: The Fidan rock is characteristically a holocrystalline, fine to medium grained, equigranular, weathered red granite. The mineralogical composition of the rock consists of pink alkali feldspar, smoky quartz and black flaky biotite (Barjous. 1992).

Contact relationships: This unit is in contact with the Ghuwayr group and Hunayk unit.

Age: Rb-Sr study of the Fidan rocks suggested an age of 538 $\pm$ 30 Ma. (Barjous, 1992). The Faynan group is the plutonic equivalent of the Ahaymir volcanics, which range in age between 560 $\pm$ 10 and 510 $\pm$ 6 Ma, according to Brook and Ibrahim (1987).

Ram Group

Salib Arkosic Sandstone Formation

Occurrences: This Formation overlies unconformably the irregular erosional surface developed on the Aqaba and Araba complexes. It outcrops in the slopes below the escarpment in the west of the Shawbak area. The complete sequence is exposed in the western part of the Wadi Dana (Barjous 1992).

Lithology: Generally, the Formation consists of yellow-brown, red brown, purple and violet, medium to very coarse grained arkosic and sub-arkosic bedded sandstone. Along Wadi Dana, a basal conglomerate comprises pink and red-brown matrix-supported conglomerate with pebbles of quartz and rock fragments derived from the surrounding igneous rocks. Toward the top the conglomerate is interbedded with red-brown silty mudstone. This part of the Formation is characterised by yellow-brown colours, massive beds of conglomerate, and a very distinctive tabular bedding leading to step-like weathering morphology (Barjous 1992).

Thickness: This Formation ranges from 0 to 70 m in thickness.

Contact relationships The base of the Formation is clearly defined at the erosional unconformity above the Aqaba or Araba complex Barjous, (1992), and the top is defined at the boundary between the thick to thin beds of brown, locally pebbly, Sandstone of the Salib Formation and the overlying yellow-brown to reddish brown thin-bedded, ferroginous siltstone with Cu and Mn minerals of the Burj Formation (Rabba, 1994).

Age: the upper age limit of the Salib Formation has been determined from the presence of late Cambrian trilobites, brachiopods and hyolithids in the overlying Burj Formation (Brook and Ibrahim, 1987). No age indicative macrofossils have yet been found in the Salib Formation (Barjous, 1992). In the research area the Formation overlies the Faynan Granitic group unconformably. These igneous rocks have an age of 538 $\pm$ 30 ma. (Brook and Ibrahim, 1987).

Depositional Environment: The lithofacies and sedimentary features of the Salib Formation indicate fluvial deposition, predominantly in braided rivers (Barjous 1992).

Burj Dolomite-Shale Formation

Occurrence: This Formation has been divided into three members north of the Shawbak sheet (Powell, 1989a), but in the research area only two of these members can be identified:

I- Numayri Dolomite Member

The name of this member has been used by Powell (1989a) for the well exposed carbonate unit in Wadi Numayri. It consists of rose to white, medium to fine grained sandstone passing upwards to buff-brown, silty sandstone, intercalated with black shale. The upper most part of this member commonly consists of black shale with irregular concentrations of copper and magnesium minerals.

Thickness: The thickness of this member ranges between 25-30 m.

Depositional environment: The marine origin is indicated by the presence of Brachiopods, trilobites and hyolithids in the carbonates of the Numayri Dolomite.

II- Hanneh Siltstone Member

This member has been introduced by Powell (1989a), for the lithologies overlying the massive carbonate beds. In the research area, this member consists of a lower shale unit and upper sandstone. The shale is green to dark brown and intercalated with a thin bed of sandstone rich in copper and manganese mineralization. The mineralization occurs in the uppermost part of the unit as cavity and fracture infillings, pores and varies in places along the bedding planes (Rabb'a, 1994).

Thickness: the thickness of this Member ranges from 30-50 m (Rabb'a 1994).

Boundaries: The base is taken at the contact between the yellow-brown to orange cross-bedded pebbly sandstone and the level-bedded, dark brown cross-laminated sand stone or dark brown sandy dolomite of the Numayri Dolomite. The top is taken at the base of red-brown massive Umm Isrin formation (Rabb'a 1994).

Depositional Environment: Powell (1989a), from a study of the different lithofacies and fossil content, provided evidence for both local marine transgression and regression within the Burj Formation. The Hanneh Siltstone was probably laid down in a shallow subtidal to intertidal environment.

Umm Ishrin Sandstone Formation

Occurrence: This formation, crops out mainly along the eastern part of the study area, (Rabb'a, 1994). This formation forms distinct steep, rugged, massive, red-brown weathering cliffs. The lithological homogeneity and strong jointing are the characteristic elements of this formation (Rabb'a 1994).

Lithology: This Formation consists of yellow-brown, red-brown grey and mauve-red, medium to coarse grained, massive weathered sandstone, subarkosic in part, intercalated with thin beds of mauve-red, very finely laminated micaceous siltstone.

Thickness: the thickness of this Formation ranges between 220 and 300 m.

Boundaries: The base of the formation is taken at the base of the massive, red-brown, medium to coarse grained trough cross bedded sandstone (Rabb'a 1994). The formation is overlain in the study area by the Disi Sanstone formation (Rabb'a 1994).

Age: The age of this Formation is set by that of the underlying Burj Formation (Late lower Cambrian).

Depositional Environment: The evidence indicates that the depositional environment was a fluvial braided river system, similar to those prevailing during the deposition of the Salib Formation.

Disi Sandstone Formatiom

Occurrence: The Disi Sandstone Formation cropsout as a belt between the Umm Ishrin Sandstone and the Kurnub Sandstone in the Shawbak area, and in general it is restricted to the escarpment which is faces Wadi Arabah. The maximum thickness of the Formation occurs in the Dana Horst. It is distinguished by massive pale grey to white massive rounded, weathered morphology (Barjous 1992).

Lithology: The lithology of this Formation consists of pale grey medium to coarse grained, well lithified, massive bedded quartz arenite sandstone, with large scale trough cross bedding.

Thickness: The thickness ranges between 300 and 350 m.

Boundaries: The base is defined at the boundary between the well jointed, harder, red brown, medium grained sandstone of Umm Ishrin Formation and the over lying white to grey medium to coarse grained sandstone of the Disi Formation (Rabb'a, 1994). The top is regionally defined by the unconformity between the friable Kurnub Sandstone and the massive Disi Sandstone (Rabb'a, 1994).

Age: The age of the Disi Sandstone Formation is late Cambrian to early Ordovician.

Depositional environment: Fluviatile conditions interrupted by two short periods of marine transgression is considered to be the deposition environment for the Disi Sandstone Formation. The river systems are believed to be of meandering type with intermediate sinuosity (Barjous 1992).

Later Units

The following formations do not exist in the research area, but are exposed in nearby areas which are more or less neighbouring or adjacent to the research area. These formations are mentioned here and listed in table 3.1, despite them not existing in the research area, because they have contributed materials to the Quaternary deposits of the research area. These formations are:

Kurnub Sandstone Group (KS)

Occurrence: The Kurnub Group crops out along faulted scarps zone (eastern escarpment facing the Wadi Araba floor) in the west of Shawbak area along some Wadis in the northwest part of Shawbak (Barjous, 1992).

Lithology: This group consists of multi coloured sandstone, massive white sandstone and brown coarse sandstone (Bender, 1974). In a detailed section of the Kurnub Sandstone Group taken from the area of the Salawan fault at Wadi Al Hamra, the lithology consisted of white, pale yellow and pink, medium to coarse grained quartzose sandstone, planar cross bedding and fining upwards cycles (Barjous 1992).

Age: The age of this group ranges from Albian-Aptian (Cretaceous) (Barjous, 1992).

Ajlun Group

Occurrence: Throughout most of Jordan, the Ajlun Group overlies unconformably the Kurnub sandstone.

Lithology: This group consists of a thick sequence of predominantly carbonate rocks (limestone, dolomite and marl) of Late Cretaceous (Cenomanian to Turonian, and locally Coniacian) age (Rabb'a, 1994). Six Formations are recognised (Powell, 1989a): in upward sequence, the Naur Limestone (lithology: green clay, red/brown siltstone intercalated with thin beds of sandstone and veins of gypsum); Fuheis; Hummar; Shuayb (lithology: greenish-clay marl, with intercalations of limestone, gypsum and calcareous mudstone and/or siltstone); Wadi As Sir Limestone (lithology: well bedded, massive limestone and dolomite with subsidiary calcareous sandstones, sandy limestone and intercalations of gypsum and chert); and Khureij Formation (Rabb'a, 1994). The Khureij Formation is not present even in the neighbouring areas (Rabb'a, 1994).

Age: The age of this Group ranges between the Cenomanian and Turonian (Late Cretaceous).

Belqa Group

Occurrence: The Ajlun Group is uncomformably overlain by the Belqa Group throughout Jordan.

Lithology: Chalk, marl, chert and phosphorite are the most common constituents of the Belqa Group, but in the south dolomite and quartz sandstone are also present.

Age: The Group ranges in age between Late Coniacian and Eocene. This Group is divided in to six formations, which are as follows: Wadi Umm Ghudran, Amman Silicified Limestone, Al Hisa Phosphorite, Muwaqqar Chalk Marl, Umm Rijam Chert Limestone and Wadi Shallala (Powell,1989b). Five Formations are present in the area adjacent to the research area.

Dana Conglomerate Formation (DC)

Lithology: This Formation consists of thick and massive beds, of poorly sorted, clast-supported conglomerate, comprising rounded to subrounded pebbles, cobbles and boulders of chert, chalk and chalky limestone, derived from Umm Rijam Formation, in a fine grained sand to granule grade matrix (Rabb'a, 1994).

Age: the age of this Formation Late Oligocene to Miocene (Rabb'a, 1994).

Table (3.1): The chronological sequence of the groups and formations not outcropping in the research area (after Rabb'a, 1994).

Age	Formation	Group
Tertiary		
Late Oligocene to Miocene	Dana Conglomerate	
Middle Eocene	Umm Rijam Chert-Limestone	
Cretaceous		
Santonian-Campanian	Amman silicified Limestone & Al Hasa	Belqa group
Santonian- Campanian	Phosphorite (undifferentiated)	
Coniacian	Wadi Umm Ghudran	
Turonian	Wadi As Sir Limestone	Ajlun group
Cenomanian-Turonian	Shueib/Hummar/Fuheis	
Cenomanian	Naur Limestone	
Albian-Aptian	Sandstone (undivided)	Kurnub group

3.5 Quaternary Geology

The Quaternary deposits of Jordan are predominantly of fluvial and aeolian origin,with lacustrine marls and clays in internal basins. The Quaternary geology of Jordan was studied early by Picard (1965: summarized by Bender, 1974a), and Bender (1974b, 1975). Barjous (1992), and Rabb'a (1994) made general studies of the Quaternary of the research area, and recently Barker *et al.*, (1997) reviewed and expanded on the Quaternary studies of Barjous and Rabb'a for the research area. The following table (3.2) summerises Quaternary deposits of the research area, following Barker *et al.*, (1997).

Table (3.2). Quaternary deposits in the research area.

Rabb'a (1994) Barjous (1992)	**Barker *et al.*, (1997)**	**Description**	**Age (after Barker *et al.*, 1997)**
Al	Dana Beds	Trough cross-bedded sands and gravels containing abundant mine spoil debris	Late Holocene
Al	Faynan Beds	Trough cross bedded gravels passing into clay plugs and overbank loams containing a Neolithic site	Early/Middle Holocene
Plf	Shayqar Beds	Trough cross-bedded gravels, sands and loams, fragmently carbonate, indurated, with Middle Palaeolithic artifacts resting on their surface.	Middle/Late Pleistocene
Plg 2	Ghuwayr	Trough cross-bedded gravels, loams and muddy diamicton and containing occasional Middle Palaeolithic artifacts, and with middle and upper artifacts resting on their surface	Middle Pleistocene.

3.6 Geomorphology

Geomorphology of Jordan

According to Bender (1975) Jordan can be divided in to several physiographic provinces (figure 3.6) which are as follows:

- Southern Mountain Desert;
- Mountain Ridge and Northern Highlands East of the Rift;
- Central Plateau (including Al Jafr and Al Azraq and Wadi as Sirhan Basin);
- Northern Plateau Basalt;
- North-eastern plateau;
- Wadi al Arabah- Jordan Rift.

Geomorphology of the Research Area

The research area lies within two distinct geomorphological provinces corresponding to the Rift valley floor and the Highlands east of the Rift. The most distinctive geomorphological feature of these two provinces is that it forms part of the Wadi Araba which extends for some 175 km from Aqaba north to the southern shoreline of the Dead Sea, forming the valley floor which extends to the Gulf of Aqaba-Dead Sea Rift. The Wadi Araba is a large alluviated depression, infilled by Quaternary and earlier clastic sediments deposited by alluvial and aeolian processes. The graben has, until recent geological times, continuously lowered the base level of the wadis and perennial braided rivers draining to the west (Bender 1974). The Rift Valley escarpment is a major, developed topographic feature due to deep active incision and headwall erosion of the Wadi Dana and Wadi Ghuwayr/ Al Bustan drainage system. It is bounded by areas of relatively low relief at the top of the scarp to the east and by

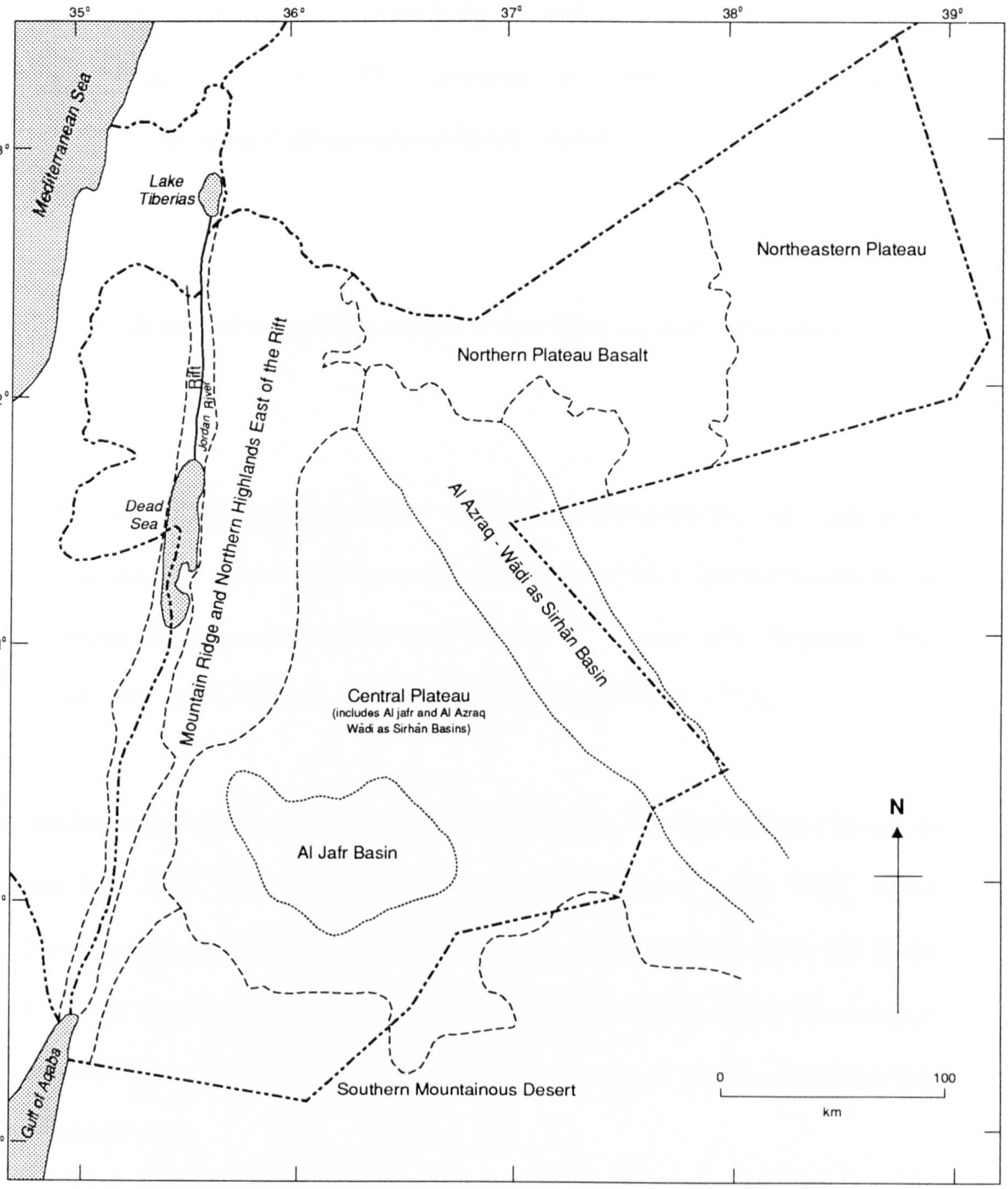


Fig. 3.6 Physiographic-geologic provinces, Jordan (after Bender, 1968)

the topographically subdued Wadi Araba floor to the west (Rift Valley floor) (Barjous 1992). The wadis are usually narrow in the base and wider at the top (V-shaped), and the topography is characterised by steep subvertical cliffs, with a step-like morphology and flat-topped summits (Rabb'a 1994). The major wadis, include Wadi Fidan, Wadi Faynan and Wadi Ghuwayr, are oriented northwest-southeast, presumably reflecting a tectonic control (Rabb'a 1994).

3.7 The Modern Fluvial Environment in the Wadi Faynan: an analogue for the past.

The modern fluvial environment in the Wadi Faynan is a braidplain, with highly active and unstable anastomosing flow patterns (see plates 3.2-3.11). Such environments and processes are typical of arid land rivers (Bell, 1998; Church, 1996; Ferguson, 1993; Schick *et al.*, 1987; Frostick and Reid, 1987; Bristow and Best, 1993).

Braided river channels on alluvial ground frequently migrate during flow events, so that they flow along different courses during successive events (Bell, 1998). Furthermore, Graf (1983 b, c, d) notes that the main-flow channel in the Salt River, Utah, can migrate laterally up to 1.6 km in response to floods. Graf (1983 b) argues that the high-magnitude, low frequency floods appear to control channel development in dryland rivers.

Braided rivers vary over time. Historical records and field data collection conducted by Graf (1983 c) for arroyo systems in south-central Utah show that total stream power decreased in the downstream direction during a deposition period before 1896 and increased downstream during an erosion period thereafter. Similarly, a major period of arroyo incision between periods with no great incision were noted in Arizona and California between 1850 and 1920 by Cooke and Reeves (1976).

The regime of arid zone rivers is characteristically unsteady and the uncertainities of hydrologic input coupled with the highly variable effects of transmission loss make their behavior more difficult to predict than that of their humid zone counterparts (Knighton and Nanson, 1997). In arid and semi-arid streams, the discontinuous operation of the fluvial system precludes the mutual adjustments between form and process normal in rivers in some more humid environments. According to Graf (1983 c) two situations prevail: one when processes control forms during catastrophic flow events, and the other when forms control processes during smaller flow events.

Plate 3.2 Shows the modern Wadi Faynan braidplain, looking upstream from site 5021. The great width (about 325 m) of the braidplain is evident. A large channel runs down the right hand side of the Photograph and across the foreground centre, where it divides into a number of smaller channels between fluvial dune forms. In the centre of the photograph, a large, complex medial bar is crossed by smaller channel. There are some very large imbricated boulders visible on the bar top, and areas of fine sediment drape left by falling flows. Some of the medial bars bear vegetation, evidence that part of the braidplain are stable over a period of 10 years or more.

Plate 3.3 Shows the braidplain of the Wadi Asheir, deeply incised into Pleistocene alluvial fan sediments, and in the foreground the confluence with Faynan. A number of prominent braid bars are seen in the centre of the photograph.

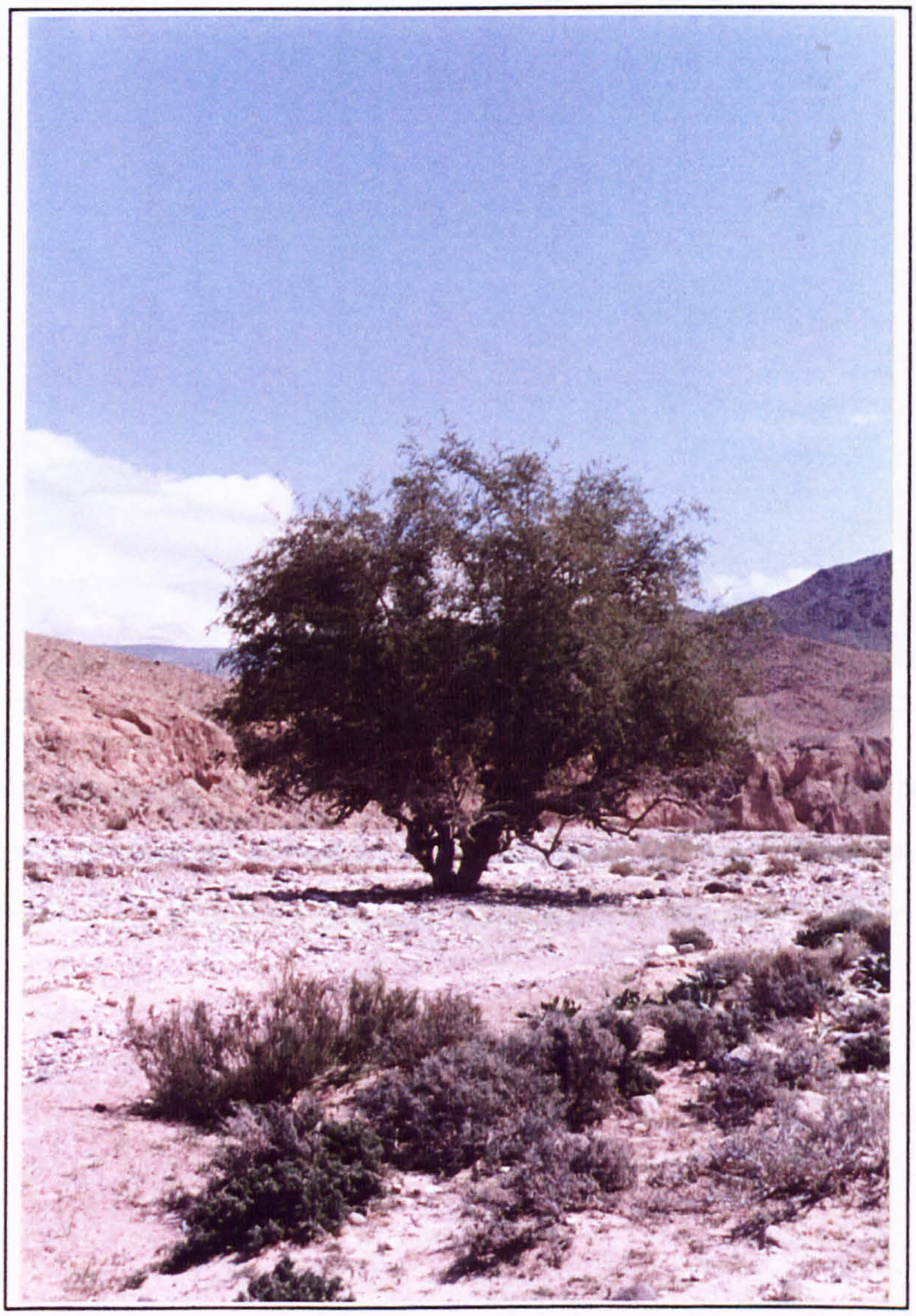


Plate 3.4 Shows an Acacia tree in the main channel of the Wadi Ghuweir. This illustrates the rarity of truly catastrophic flows in the Wadi Faynan tributaries.

Plate 3.5 Shows a drying ephemeral flow in the Wadi Ghuweir. Low-stage sand and silt sedimentation is evident close to the remaining water, and in the lee of some rocks. Most of the boulders are imbricated, with their long axes normal to the direction of flow.

Plate 3.6 Shows an ephemeral flow in the Wadi Ghuweir gorge. Large lateral bars flank the flow. In the middle ground, a chute channel separates the lateral bar from a small medial bar.

Plate 3.7 Shows a reach of the Wadi Dana between the Bedouin village and RSCN camp . A large medial bar is evident near the centre of the photograph. This is composed of very large boulders. The channel between the bars is floored with gritty sand.

RSCN: Royal Society for the Conservation of Nature (Jordan).

Plate 3.8 Shows non-wadi fluvial forms near site 5518. This is a Pleistocene terrace surface, overlain by Nabatean/Roman industrial waste. A network of shallow channels separated by areas of vegetation, covers most of the terrace surface. The channel sediments are mostly fine gravels and coarse sands, though occasional small boulders are present.

Plate 3.9 Shows sediment supply to the Wadi Asheir near its confluence with the Wadi Faynan, in this case from talus cones of Nabatean/Roman spoil heaps.

Plate 3.10 Shows sediment supply to the Wadi Faynan, near site 5021. Here, the indurated late Pleistocene and Holocene sediments are failing as a result of undercutting by the wadi. Large masses of sediment collapse into the wadi channel and are washed away. The wadi floor in this area shows flat-topped bars covered with imbricated small boulders. Between the bar forms are shallow silt-filled channels.

Plate 3.11 Sediment supply to the Wadi Ghuweir from a gully network near site 5510. This dissects Holocene terrace deposits but also drains rocky slopes above the terrace. Extremely coarse boulders floor the gully. All finer sediment was removed during flood events.

3.8 Soils

Introduction

Investigations on Jordanian soils carried out by many workers have been summarised by Bender (1974a) and Aresvik (1976). The following, Table 3.3 is a description of soil types as summarised by Bender (1974a) and Aresvik (1976).

Soils in the Research Area

Generally, soils in the study area are now very degraded. Most of the mountain slopes are bare rock, and skeletal soils have formed in alluvial deposits. Alluvial soils are derived from material which was deposited by running water. This soil type has a wide distribution in Jordan. They vary in texture from coarse soils in some wadis to fine silty clay in the flood plains of the wadis (Aresvik, 1976). Alluvial soils are extremely common in the research area, especially in the Wadi Faynan (field observation by the author, 1998).

The Yellow soils are typical of the arid climate and of a steppe vegetation. They are extremely calcareous and vary in origin from weathered limestone and chalk to colluvial loess (loess is present in Quaternary deposits of the research area (see Ch. 5) (field observation by C. O. Hunt, 1997). These soils suffered badly from degradation: uprooting of the shrubs for fuel, excessive ploughing, overgrazing, and the erosion of wind and water (Aresvik, 1976).

Table 3.3 Description of soils in Jordan (Bender, 1974a; Aresvik, 1976)

Type of Soil	Properties and Location
Red Mediterranean Soils	This type of soil cover is usually derived from carbonate rocks, but it also occurs on sandstone and basaltic rocks. It covers an area in the Irbid- Ramtha depression, along the high lands east of the Rift from Ajlun via Madaba-Kerak-Tafileh as far as Shawbak.
Yellow Mediterranean Soils	This type of soil is considered as a transitional type between the Red Mediterranean soils and Yellow steppe soils and is related to the cooler zone of semiarid climate with precipitation between 250 and 350 mm.
Yellow Steppe Soils	This type of soil is described as having yellowish brown A or weakly developed A horizons which do not show any distinguishing features from underlying horizons. B horizons are not developed due to the lack of illuvial processes. This type of soil covers a more or less wide belt east of the Yellow Mediterranean soils, and extends from Syria in the north to Ras en Naqab. It is also found in the Zerqa valley and south of the Ghor Faria, associated with undeveloped skeletal soils on wadi gravels and on exposed rock.
Grey Desert Soils	This type of soil is developed in areas with precipitation of < 150 mm per year. This soil is hardly developed due to the restriction of chemical weathering under desert conditions and because of severe wind erosion. The concentration of the organic matter is seldom reaches more than 0.5% in the A horizon. These are equated with grey Desert soils with dense flint pavement (Hamada), which is widespread in Eastern Jordan. Rendzinas occur as local soil formations, at the outlet of theYarmuk Valley and in the montains of Ajlun. This soil is characterised by a thick dark grey-brown to almost black A- horizon of friable structure.
Grumosols	A-C soils with high clay contents and salt, and are associated with red soils, located in Amman were identified as Grumosols.
Marl soils	This type of soil consists of yellow-brown to grey-brown loam materials. They occur in the area of Nablus.
Chernozems	This soil is found on basalts in the Irbid area and south of Rashadiya. They are described as a dark-grey-brown chernozem-like soils of heavy texture.
Solonchaks	Humus-rich solonchaks can be found in areas with high ground water levels south-west of Deir Alla, south of Ghor faria and on the north and south shores of the Dead Sea. They correspond to meadow solonchaks and show high sodium salt contents. In the highlands, the most important soil-forming material is limestone which is usually weathered in to calcareous or silty clay, in the wetter areas it assumes a typically reddish brown.

3.9 Climate

Introduction

Jordan is climatically divided as a result of the influence of the Mediterranean Sea, which is reflected by the precipitation. The level of precipitation differentiates the inhabited zone from the desert. The desert flora is developed where rainfall is less than 200 mm. The Mediterranean climate of Jordan is greatly modified by continental air masses and altitude, which ranges from 150 m below Sea level to 1140 m above sea level (Rabb'a 1994). The altitudinal differences cause a great deal of variation in the local climate which ranges from almost tropical to nearly cool temperate. On the other hand, climatic differences are also apparent between the north and the south. In the north, winds are moister than in the south. Southern Jordan (where the research area is located) is not far from the Sahara Arabia desert belt. On the windward slopes of the highlands, rainfall is much higher than on the leeward slopes. The high lands east of the rift have altitudes from 600 m to 1500 m above sea level.

Precipitation

A significant feature of the rainfall of Jordan is the coincidence between the rainfall and the relief, as we can see from the rainfall map (figure 3.7) (Aresvik, 1976). However, relief is not the only factor which determines the rainfall distribution in the region.

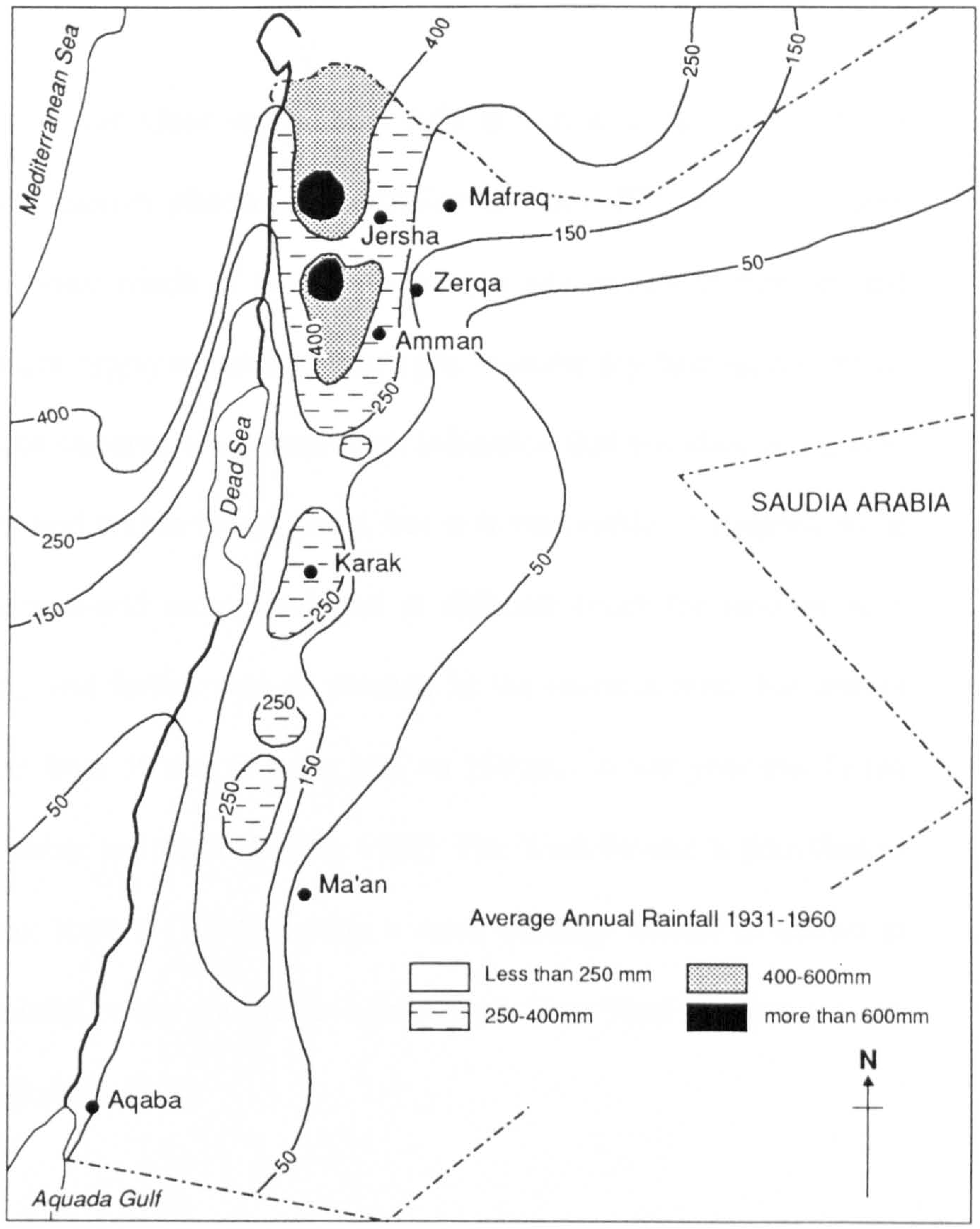


Fig. 3.7 Rainfall distribution of Jordan (after Aresvik, 1976)

As the distance increases from the sea, the rainfall decreases. The rainfall also decreases from north to south. Average rainfall is 400 mm, but this varies with relief from 200 to 600 and even 700 mm in the higher parts. All desert regions receive less than 50 mm (figure 3.7). Snow is not uncommon, but restricted to the high lands (Aresvik, 1976).

The relative humidity in the Ghor varies from 70% in winter to less than 50% in summer, while in the eastern plateau the variation is from 75% to 35 %. Dew originates from the cooler winds of the Mediterranean and occurs in summer and gives beneficial moisture supply to summer crops grown under dry farming conditions (Aresvik, 1976). In the research area, there is no indication that the climate has ever been other than semi-arid within recent times, but it is reasonable to suppose some variation within the semi-arid range, and that at different times the streams have flowed more strongly, and further than at present. In the research area, the present rainfall is estimated at from 50 mm in a dry year to 150 mm in wet year and falling mainly between November and April (Raikes, 1980). The Wadi Faynan is described as a dry desertic climate: Rabb'a (1994) reports a mean monthly rainfall as shown in Table 3.4, whereas rainfall on the plateau (3-4 hours walk from Wadi Faynan) is more than 200 mm a year (Rabb'a 1994).

Table 3.4. Mean monthly rainfall in the research area (after Rabb'a, 1994)

Month	Mean Rainfall (mm)
January	8.0
February	17.1
march	13.1
April	7.6
May	1.4
June	0.0
July	0.0
August	0.0
September	0.1
October	1.7
November	5.0
December	17.2
Total	62.2

Seasonality

The rainy season starts in October and continues through March and April, with the heaviest rain falling in December (17.2 mm) and the first three months of the year (8.0, 17.1 and 13.1 mm for January, February and March respectively) The summer months have little rain (0.0, 0.0, 0.0 and 0.1 mm for June, July, August and September respectively). Variations in the rainfall intensity and duration take place from year to year, which affect the forage and crop productivity (Jordan Climatological Data Handbook, 1988).

Temperature

Temperature variation is not so great as the rainfall, and tends to be in inverse proportion to altitude. In Jordan the temperature increases toward the interior, decreases with the altitude, and increases from north to south, and from west to east. The mean summer temperature in mountanous regions is around 17^{0}C, the maximum temperature in August lying between 31° C and 33° C. In winter, the mean temperature is about 15° C (Jordan Climatological Data Handbook, 1988).

The southern Ghor area, which is a narrow 660 km strip, and 400 m below sea level stretching from the lake of Tarabia in the north, displays an entirely different temperature pattern with a high average summer temperature rising to more than 40° C. In January, when it is coldest, the temperature seldom falls below 14 °C.

Toward the eastern desert regions, the mean summer temperature in the steppe area rises to 20°-21° C, and maximum temperature in August rises to 36 °C. January is also warmer than in the neighbouring highlands. Further inland, temperatures are more extreme. The Badia area which extends to the east of the country, is known for its vastness and dry climate. Climatically, the Badia is widely recognised as a transition zone between the Mediterranean environment of the Jordan Valley and the fully arid environment which characterizes the interior desert areas of the far eastern slopes of the highland areas Jordan (Al-Homoud, 1995). Rabb'a (1994) reported (for Shawbak area in which the research area is located) that the mean monthly temperature in summer is high, reaching 26.8 °C in August. The absolute maximum temperature recorded between 1966-1980 was in July and reaches 38.2 °C and the absolute minimum was in February 12 °C (Jordan Climatological Data Handbook, 1988).

Winds

The dominant wind throughout Jordan is westerly to southwesterly. Easterly winds are cold and dry in winter, and hot and dusty in spring and summer. Moisture-laden winds from the Mediterranean contribute to the ability of windward slopes to support the vegetation which is found there. The wind predominating throughout much of the year is westerly to south westerly. A hot dry wind, the Khamasin, is common in the spring. Some times in the autumn, this wind blows from the east, bringing with it a fine desert dust and frequently raising the temperature to a high level. This has a destructive effect on the vegetation (Aresvik, 1976). In the research area the main wind regimes affecting the area are North-West flow during summer and the South-east flow during the rest of the year (Al-Qudah *et al.*, 1993).

3.10 Palaeoclimate

Introduction

This section describes the environmental changes which took place in Jordan from 80,000 BP to the present day. There are discrepancies between different workers, and sometimes within the studies of one worker. These may be due to regional factors. Moreover, shortage of radiocarbon dating in many sites may be related to the lack of good preservation of the materials which can be dated. There are also difficulties of dating material older than the effective termination of radiocarbon dating around 30,000 - 40,000 BP (Butzer, 1982). Figure 3.8 showing locations mentioned in palaeoclimate context.

From *ca.* 80,000 to 60,000 BP

A humid period was deduced from alluvial fills in the Judayid Basin (Henry,1979, 1982, 1995) and (Henry *et al.*,1983), alluvial fills in Wadi Hama (McNicoll *et al.*,1984), and alluvial fills in Wadi Hasa (Copeland and Vita- Finzi, 1978). Furthermore, the alluvial fill found in the Khirbet Samara Formation in the Azraq area corresponds to this interval of time (Henry, 1986). Lacustrine sediment has been found in the Jafr depression (Zeuner *et al.*, 1957). The lake deposit which is found in the upper reaches of Wadi Hasa belongs to this time (Henry,1986). In some areas, desiccation started around 60,000 but in other areas, humid conditions remained, furthermore, radiometric determinations, indicate that the humid interval persisted from as early as 100,000 to 80,000 BP, and to as late as 55,000 years ago (Henry, 1986).

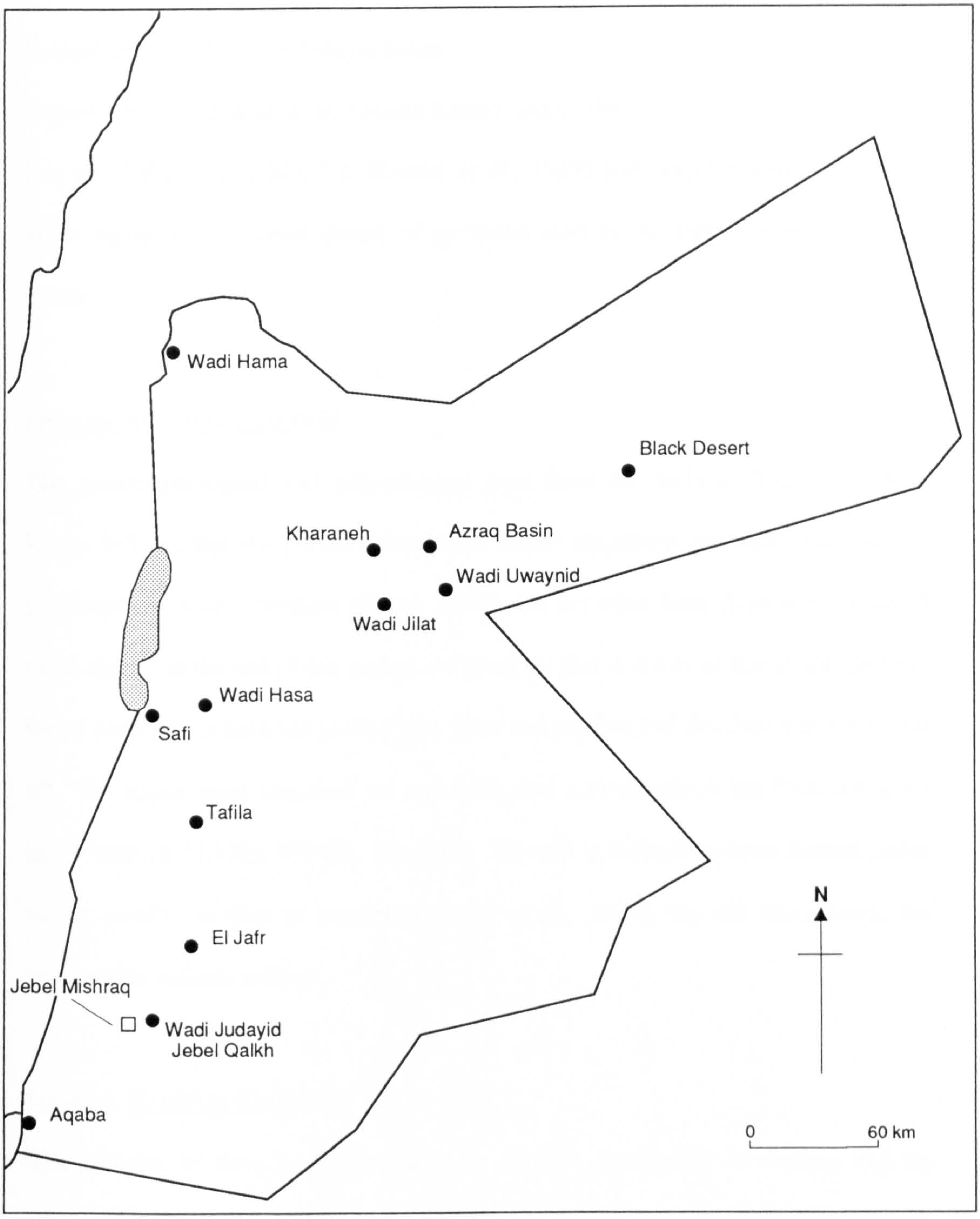


Fig. 3.8 Map showing locations mentioned in the text

From *ca.* 60,000 to 55,000 BP

This time interval is characterised by dry conditions with:

Erosion of the early fill in Judayid basin;

Deposition of drift sand in the Judayid Basin (Henry, 1986);

Dry-up of the ancient lake Jafr (Zenner *et al.*, 1957) and brackish water which was accompanied by the development of gypseous marl in the Jafr depression (Henry, 1986).

From *ca.* 55,000 to 20,000BP

The geomorphological and palynological data from the Judayid Basin and Wadi Hisma indicate that the period started with humid conditions and soon gave way to progressively drier conditions (Henry, 1986). On the other hand there is evidence of rapid change at the end of this period. At Wadi el- Jilat 9, 0.6 m of fluvial silt has been found overlying compacted aeolian silts. Two soil profiles had developed in the fluvial silt. The upper most contained an archaeological horizon which has been dated on burnt bone to 21,150± 400 BP, (Ox-A19). The soil is thought to have formed under wetter conditions than at present (Garrard *et al.*, 1986). On the other hand, the aeolian silts indicate aridity.

From *ca.* 20,000 to 11,000 BP

This interval of time is characterised by climatic complexity in Jordan, and an alternation of moist and dry cycles of 2000- 3000 years duration took place (Henry, 1986), with:

- moist conditions before 19,000 BP,
- dry conditions between 19,000 and 15,000 BP,
- moist conditions at 15,000 BP,
- dry conditions between 15,000 and 13,000 BP and
- a major moist episode between 13,000 and 11,000 BP.

The evidence related to the early moist episode is principally derived from the Kebaran site at Wadi Hama 26 (McNicoll *et al.*,1984) resting on the edge of the Jordan Valley and Kharaneh 4 (Muheisen, 1983) which is located in the Azraq Basin. Wadi Hama 26, dated to 19,000 BP, is contained within a moist -ground palaeosol and associated with carbonized plant remains. In addition to that, at Kharaneh 4, the earliest occupation of the site is represented by a Kebaran horizon (phase D) contained within alluvial clays reflective of moist conditions (Henry, 1986).

The second moist interval is defined by the sites of Wadi el-Jilat 10 (Garrard *et al.*,1986), Kharaneh 4, phase C, (Henry,1986) and J504 (Henry,1982). Wadi el-Jilat 10 is dated to 14,790 (OXA 520), phase C at Kharaneh 4 is found within alluvial sediments indicative of moist conditions. The occupation of J 504 was found in a rock shelter overlooking a dry lake bed. It contained pollen spectra with high frequencies of oak, elm, walnut, and conifers in an area that presently receives less than 100 mm of rainfall.

A dry episode is defined at Kharaneh 4 by phases C and D which are contained within aeolian sand. The artifactual assemblages of these phases suggest affinities with the Geometric Kebaran complex and an age of 13,000 and 14,500 BP (Henry,1986).

The final moist episode of the interval is principally identified at early Natufian sites of Wadi Hama 27 and Wadi Judayid (J2), where Wadi Hama 27 is found within clay resting on travertine, the occupation of Wadi Judayid (J2,C), dates to ca. 12,500 BP Furthermore the occupation of Wadi Judayid is associated with faunal (*Ovis* sp., *Bos* sp.) and pollen (high Graminae including Cereal and arboreal frequencies) evidence of quite moist conditions. This moist episode is likely to have began earlier than 12,500 BP as indicated by the high frequencies of grasses and arboreal pollen in the sediments of the late Hamran site of Jebel Hamra J202 (Henry,1986).

<u>From *ca.* 11,000 to 5,000 BP</u>

Generally, a dry environment occured after 10,000 BP. In early Natufian horizons at Wadi Judayid and Beidha, drift sand was deposited. The pollen spectra of the drift sand unit at Wadi Judayid confirms a return to drier conditions as desert vegetation. Generally dry conditions appear to have continued after 10,000 BP, as indicated by the presence of early A ceramic Neolithic horizon (site J 24, layer C) with drift sand within the Judayid Basin. The dry conditions appears to have been replaced by a brief moist episode, from ca. 9,000 to 8,500 BP. This has been indicated by palaeobotanical and geomorphic evidence from the well dated pre-pottery Neolithic B site of Beidha. The eastern desert of Jordan also experienced moist conditions at this time, which led to the PPNB occupation of Wadi el-Jilat 7 dated between ca., 8,800 and 8,250 BP. A return to drier conditions apparently took place after 8,500 BP. In the Judayid Basin, many Chalcolithic sites were discovered stratified within slightly weathered sands. These sands yielded pollen spectra which reflected desert conditions. These dry conditions are dated by radiocarbon to 5,800 BP (Henry,1986).

3.11 The Biogeographical Regions in Jordan

Introduction

Long (1957) divided Jordan into nine bioclimatic regions, based on the analysis of climatic data of twenty four stations in Eastern Jordan. Al-Eisawi (1985) followed the same method which was used by Long (1957). The climatic data (rainfall and temperature) of thirty one stations between 1966-1980 was analysed and the distribution of the resulting bioclimatic zones Table 3.5 are shown in figure 3.9. Among the studied stations are Shawbak (close to the study area). This is considered to lie in a semi-arid Mediterranean bioclimatic zone of cool variety.

Table (3.5). Bioclimatic zones (after Al-Eisawi, 1985).

Bioclimatic zones	Variety	Typical Station
Sub-humid Mediterranean.	warm and cool	Ras Muneef, Ajloun
Semi-arid Mediterranean.	warm	Irbid, Amman, Madaba, Taybeh and Baka'a
Semi-arid Mediterranean.	cool	Shawbak
Arid Mediterranean	cool	Mafraq, Al-Jiza, Al-Qurein and Wadi-Dhuleil
Arid Mediterranean	warm	Zerka
Arid Mediterranean	very warm	Deir Alla, Al-Baquara, Shouneh North.
Saharan Mediterranean	cool	Al-Jafr, H-4, Ma'an, H-5 and Al-Azraq
Saharan Mediterranean	warm	Belt of land with an average width of 20 km. along the Eastern Hills to the east of Jordan
Saharn Mediterranean.	very warm	Ghor Safi, Wadi-Araba and Aqaba area

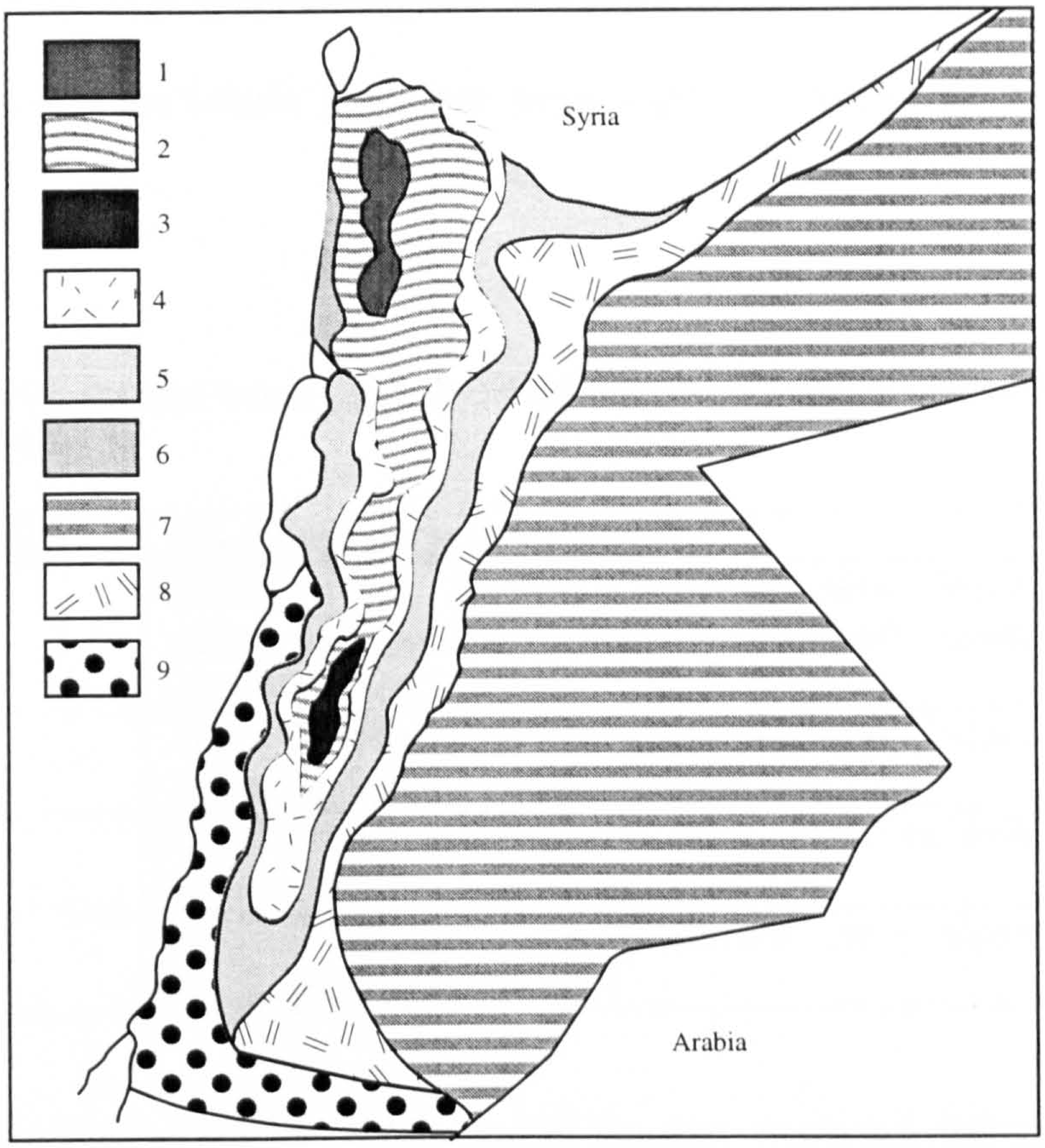


Fig. 3.9 Bioclimatical map of Jordan (after Al-Eisawi, 1986)

Key:
1: Sub-humid Mediterranean bioclimatic warm and cool varieties
2: Semi-arid Mediterranean bioclimate, warm variety
3: Semi-arid Mediterranean bioclimate, cool variety
4: Arid Mediterranean bioclimate, cool variety
5: Arid Mediterranean bioclimate, warm variety
6: Arid Mediterranean bioclimate, very warm variety
7: Sahara Mediterranean bioclimate, cool variety
8: Sahara Mediterranean bioclimatic, warm variety
9: Sahara Mediterranean bioclimate, very warm variety

3.12 The vegetation regions of Jordan

Bioclimatic regions

According to different workers, among them Zohary (1962, 1973), Beskok (1971), Poore and Robertson (1964), Boulos and Lahham (1977), Jordan can be subdivided into different bioclimatic or biogeographical regions. In Zohary's (1973) delimitations of the vegetation regions in the Middle East, four major regions of vegetation are found (Table 3.6).

Table (3.6) Zohary's vegetation zones and their relationships with bioclimate zones of Al- Eisawi (1985).

Zohary's vegetation regions	Bioclimate zones (Al-Eisawi)
Mediterraneam	Mediterranean, Semi-Arid Mediterranean- warm variety and Semi-Arid Mediterranean-cool variety (zones 1, 2 and 3 in figure 3.9).
Irano-Turanian	Arid-Mediterranean-cool, warm and very warm varieties (zones 4, 5 and 6 in figure 3.9).
Saharo-Arabian	Saharan-Mediterranean, cool and warm varieties (zones 7 and 8 in figure 3.9)
The Sudanian region.	Saharan- Mediterranean bioclimate- very warm variety (zone 9 in figure 3.).

The main characteristics determining the distribution of the four vegetional regions which were suggested by Zohary (1973), and shown in figure 3.10, are as follows.

1. The Mediterranean region

This region includes almost all the mountain ranges which extend from the north in Irbid down to the south in Ras En-Naqab. They have a mean annual rainfall over 300 mm. The soils are types of Terra Rosa and Rendzina, which are the richest in the

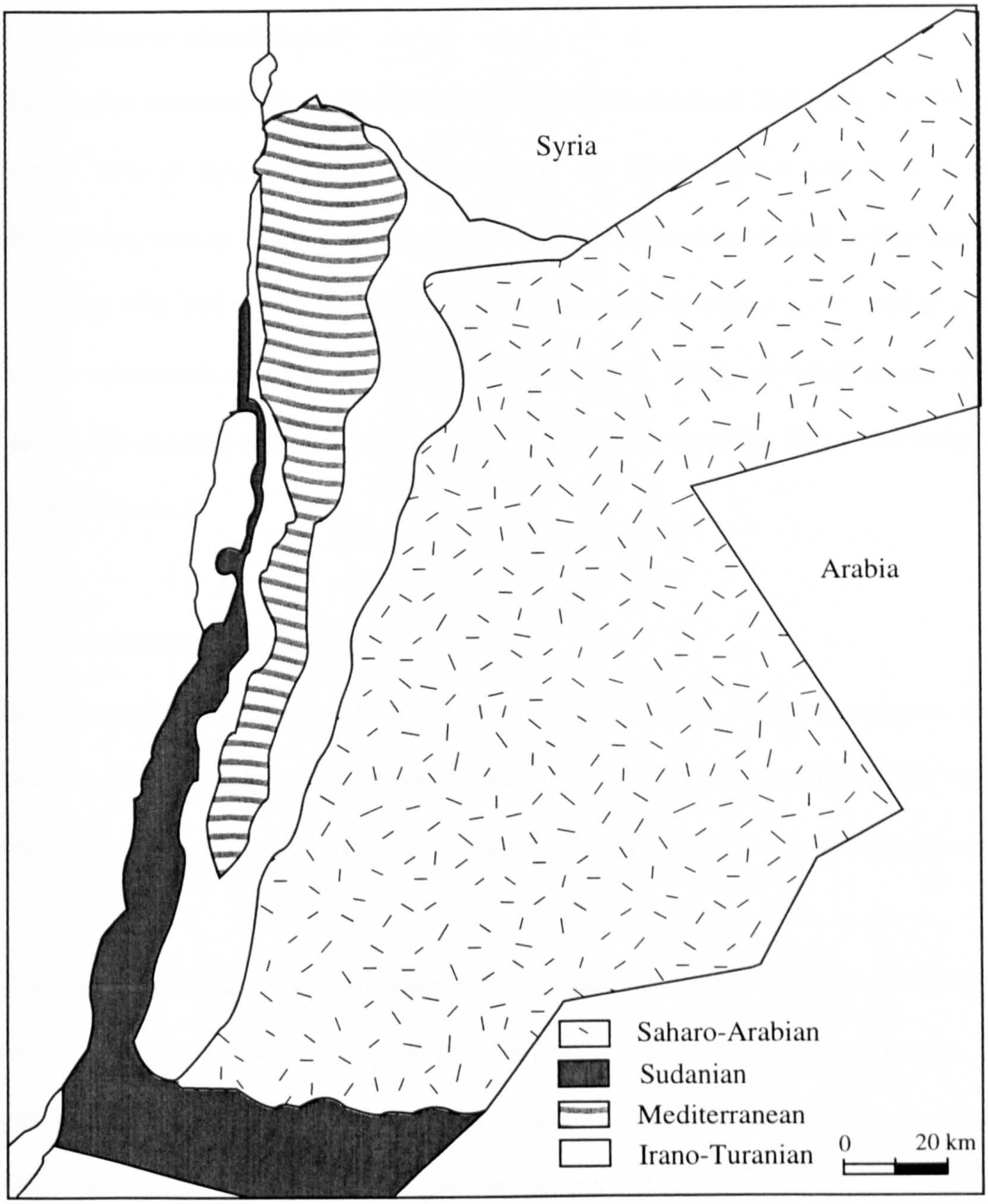


Fig. 3.10 The four vegetation zones in Jordon (after Zohary, 1973).

country and support the best vegetation, especially the forest climax of *Pinus halepensis, Quercus calliprinus, Q. ithaburensis, Ceratonia siliqua,* and *Pistacia.*

2. The Irano-Turanian region

This region surrounds all of the Mediterranean region except in the north, forming a narrow strip in some places. It may interrupt the Mediterranean region in some depressions, such as Wadi Mujeb and Wadi Al-Hasa. The mean rainfall in this region is usually over 150 mm but less than 300 mm. The soil is mostly poor, eroded and mostly calcareous or of loess type. The vegetation is mainly of small shrubs and bushes like *Retama ratum, Ziziphus lotus, Artemisia herba-alba, Noea mucronata, Anabasis syriaca.*

3. The Saharo-Arabian region

This comprises the majority of Jordan and borders the Irano-Turanian region to the east. The mean annual rainfall is over 50 mm but less than 150 mm. The soil is very poor and mostly of hamada type with some sandy hamadas, saline soils and mud flats.

The vegetation is very poor and sometimes does not exist, especially in the mud flats and on watersheds. Most of the plant cover is restricted to the wadis where there is enough soil moisture to sustain some vegetation. The most common species are *Artemisia herba-alba, Achillea fragrantissima, Phlomis, Astragalus, Stipa, Trigonella* spp. The research area falls within this bioclimate region at present.

4. The Sudanian region

This region comprises the Rift Valley south of Deir Alla including the area of the Dead Sea, Wadi Araba, Aqaba and the Granite Mountains in the south including part of Wadi Rum. The mean annual rainfall is usually less than 50 mm. The soil is mostly sandy or sandy hamada, some granite fragments and saline soils. The vegetation here is desertic; where water is present the vegetation is related to tropical types and includes *Acacia* spp. *Balanites aegyptiaca, Calotropis procera, Maerua crassifolia, Salvadora persica, Haloxylon persicum, Ocradenus baccatus, Panicum turgidum* and others (Al-Eisawi, 1985).

3.13 Vegetation in Jordan

The distribution of vegetation in Jordan roughly follows the variations in the amount of precipitation. Where there is enough precipitation forest exist. Where there is little rain, there is steppe and where there is no rain there is desert. The rain is not the only factor controlling the distribution of the vegetation cover, but also the soil, geology, underground water, and differences in temperature play an important role in the vegetation distribution in the country. In the higher parts of the upland regions, where the rainfall is more than 300 mm, the vegetation is of distinctly Mediterranean type, with forests of pines and different varieties, for instance oak and bushes. Due to overgrazing , agriculture and firewood cutting the forest areas have shrunk to a narrow discontinous strip along the eastern escarpment of the Rift Valley and to occasional patches on top of the highlands. This forest has been destroyed over the centuries, for fuel, for agriculture and for grazing (Zohary, 1973).

In the steppe region, the climate is more continental than Mediterranean. Rainfall varies between 150 mm and 300 mm and generally the plant cover is grass and *Artemisia*, especially where soils are relatively stable.

In the desert region, rainfall is generally below 100 mm. The vegetation is extremely poor in both variety and density, except in wadi bottoms, channels, and depressions. In the typical flint-strewn desert, there are large surfaces bare of any vegetation. In the sandy desert, such extensive bare surfaces are not common, but in between the individual shrubs, the ground is quite bare of vegetation, occasionally few short annual grasses are found. Between the steppe and desert regions there is a broad transitional zone, linked to steadily decreasing precipitation levels (Aresvik, 1976).

3.14 Vegetation of southern Jordan

Introduction

This section describes the vegetation of the area immediatly adjacent to the research area, and thus most likely to be encountered in this research. Southern Jordan is considered as one of the most important regions in the Middle East from the geobotanical point of view. It is of great interest in vegetation ecology because it is the meeting place of the Mediterranean, Irano-Turanian and Saharo-Arabian regions (Kurschner, 1986).

Kurschner (1986) studied the vegetation of Southern Jordan (where the study area is located) and noticed that there are conspicuous changes in the vegetation and in the composition of the flora over relatively short distances. Kurschner's study has divided southern Jordan into vegetational units in which the criterion used was the change in the dominance of taxa from one floristic region to the next. Figure 3.11 represents the vegetational units which Kurschner (1986) recognised in the research area, and these units are as follows:

Desert and Xeromorphic dwarf shrublands.

The following subdivisions lies under the Desert unit:

Sand with shrubs characterised by a *Haloxylon persicum* community type. This type is distributed in the SE. desert (surrounding al-Mudawwara) and Wadi Araba.

Hammada salicornica community type which is distributed in the southern desert (surrounding Wadi Rum).

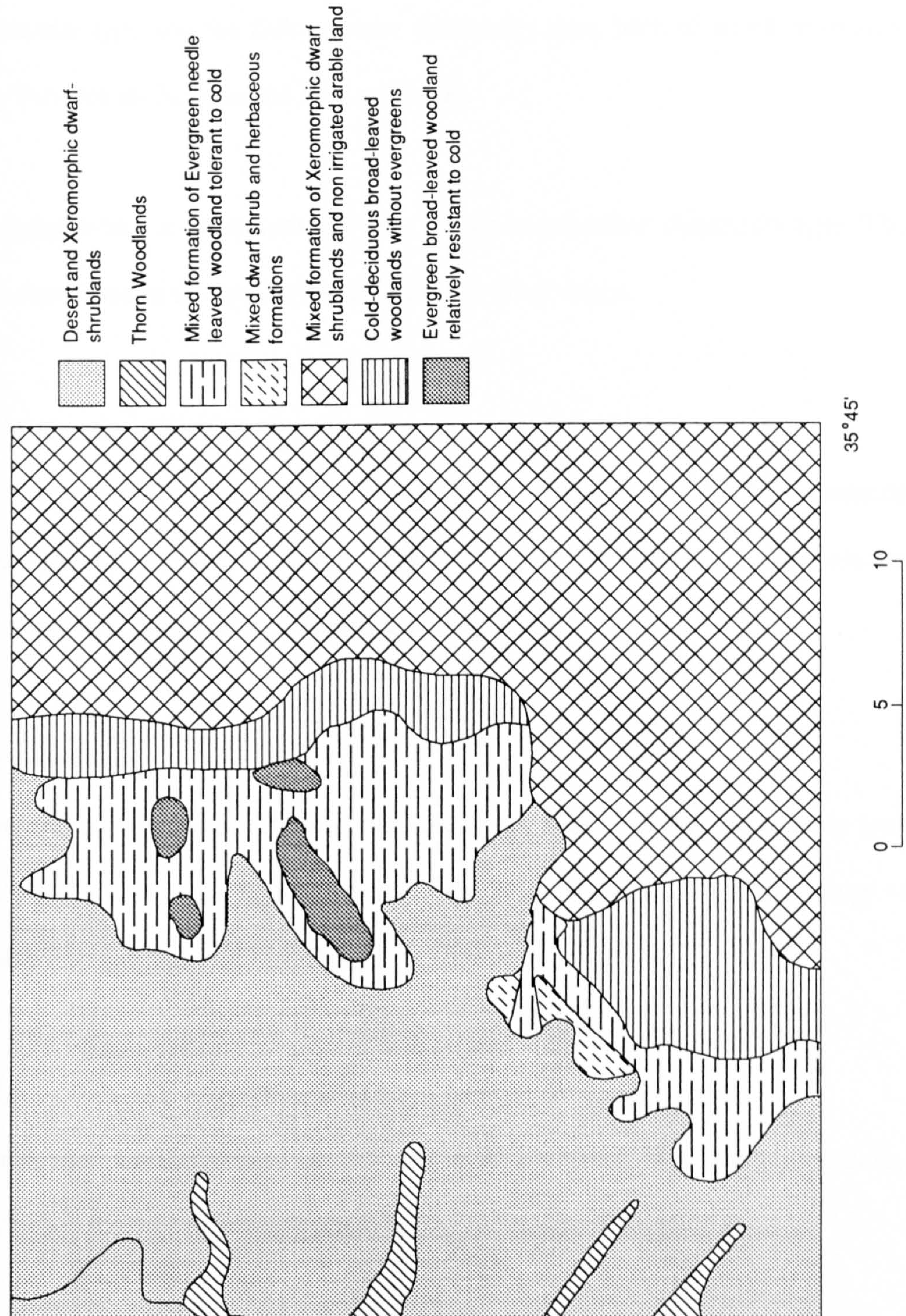


Fig. 3.11 Vegetation units in research area(Modified after Harald Kurschner,1986)

Sand desert with dwarf-shrubs which is characterised by the *Echioilon fruticosum* commmunity type and the *Zilla spinosa* community type, both of which distributed mainly between al-Quwaira and Ra's an-Naqab.

Rock desert which is characterised by the *Anabasis articulata* community type. This type is distributed in the eastern desert, locally in Wadi Araba.

Xeromorphic dwarf shrublands

The vegetation which characterises this unit is the *Artemisia herba-alba* community type and the *Haloxylon articulatum* community type. These types are distributed in the Western hills and plateaus (Edom), at 800-1,500 m.

Thorn Woodlands.

The vegetation which characterises this unit is the *Acacia tortilis* community type which is distributed in the Southern parts of the Wadi Araba and the surroundings of al-Aqaba.

Mixed formation of Evergreen needle leaved woodland tolerant to cold

The vegetation which characterises this unit is the *Juniperus phoeniceae* community type which is distributed in the Western border mountains, 600-1,500 m.

Mixed dwarf-scrub and herbaceous formations (steppic)

The vegetation which characterises this unit is the *Sarcopoterium spinosum* community type. This vegetation type is distributed in the Western hills and plateaus (Moab, N. Edom). The *Salvia dominica-Ballota undulata* community type is also characteristic.

Mixed formation of Xeromorphic dwarf shrublands and non irrigated arable land

A wide variety of vegetation lies under this unit. The following are some samples. *Artemisia herba-alba, Astragalus spinosus, Noaea mucronata, Onionis natrix* ssp. *natrix, Alkanna strigosa, Alyssum iranicum, Astragalus platyraphis, Carex pachystylis, Poa sinaica, Ranunculus damascenus, Scorzonera jurdaica, Tragopogon collinus. Rumex dentatus, Lactuca undulata, Ziziphora tenuior.* These are distributed near Shawbak (close to the study area), at elevations of 850 m.

Cold- deciduous broad-leaved woodlands without evergreens

The vegetation which characterises this unit is the *Pistacia atlantica* community. This type is distributed in the Western border mountains and plateaus, around 1,400 m.

Evergreen broad-leaved woodland relatively tolerant to cold

The vegetation which characterises this unit is the *Quercus calliprinos* community type. This is distributed in the Western border mountains, at 1,200-1,600 m.

3.15 Vegetation in the Research Area

A detailed zonation of the vegetation has been carried out in the Edom mountains, Wadi Faynan and Wadi Dana by Baierle *et al.* (1989). Table 3.7 and figure 3.12 summarise this zonation.

Table (3.7).The vegetation (zones) in the Edom Montains and Wadis Faynan and Dana (modified after Baierle *et al.*, 1989)

	Desert bush vegetation	Extreme steppe- desert	Steppe-desert	Wooded steppe	Med.evergreen wood land	Steppe woodlan d
Dominant vegetation	*Haloxylon- persicum*	*Acacia* *A. radiana* *Anabasi* *articulatas* *Traganum nudatum*	*Anabasis* *Gymnocarpos* *Halogeton* *Salsola* *Zygophyllum*	*Juniperus* *Artemisisa* *Helianthemum* *Salsola*	*Quercus* *Phoenix* *dactylifera*	*Pistacia*
Woody spp.	*Retamaraetam, calligenum comosum*	*Ochradenus* *Retama raetam* *Ziziphus*	*Acacia* *Moringa* *Juniperus* *Retama* *Phoenix*	*Amygdalus* *A.* *Korschinskii* *Atriplex* *halimus* *Pistacia* *Retama*	*Colutea* *Crataegus* *Daphane* *Pistacia*	*Crataegu s*
Wadi vegetation	*Acacia* *Haloxylon persicum* *(Tamarix)* *(Retama)*	*Retama raetam* *Tamarix* *Ziziphus* *Acacia* *(Haloxylon)*	*Populus* *Salix* *(S. pseudosafsaf)*	*Salix* *(S.pseudo-safsaf* *Nerinm* *Retama* *(Tamarix)*	*(S. pseudo-safsaf)* *(Nerium)* *(Retama)* *(Tamarix)*	-

A very detailed plant list for the Wadi Dana was produced as part of the Royal Society for the Conservation of Nature (RSCN) Rangeland Management Plan for the Dana Nature Reserve (Swenne, 1995). This divides the Survey Area into three plant zones. Low-level Acacia Sub-Tropical Vegetation, with 282 species present in the Wadi Faynan and lower part of the Wadi Dana. All the survey sites lie within this vegetation type. At higher altitudes on the slopes of the Wadi Dana, Indo-Turanian Mid-Altitude Steppe, with 310 species, is present. At high altitude, on the plateau, Mediterranean Semi-Arid Vegetation, with 379 species, is present. Unfortunately, the report does not list which species are present in the three vegetation types, or the percentage cover.

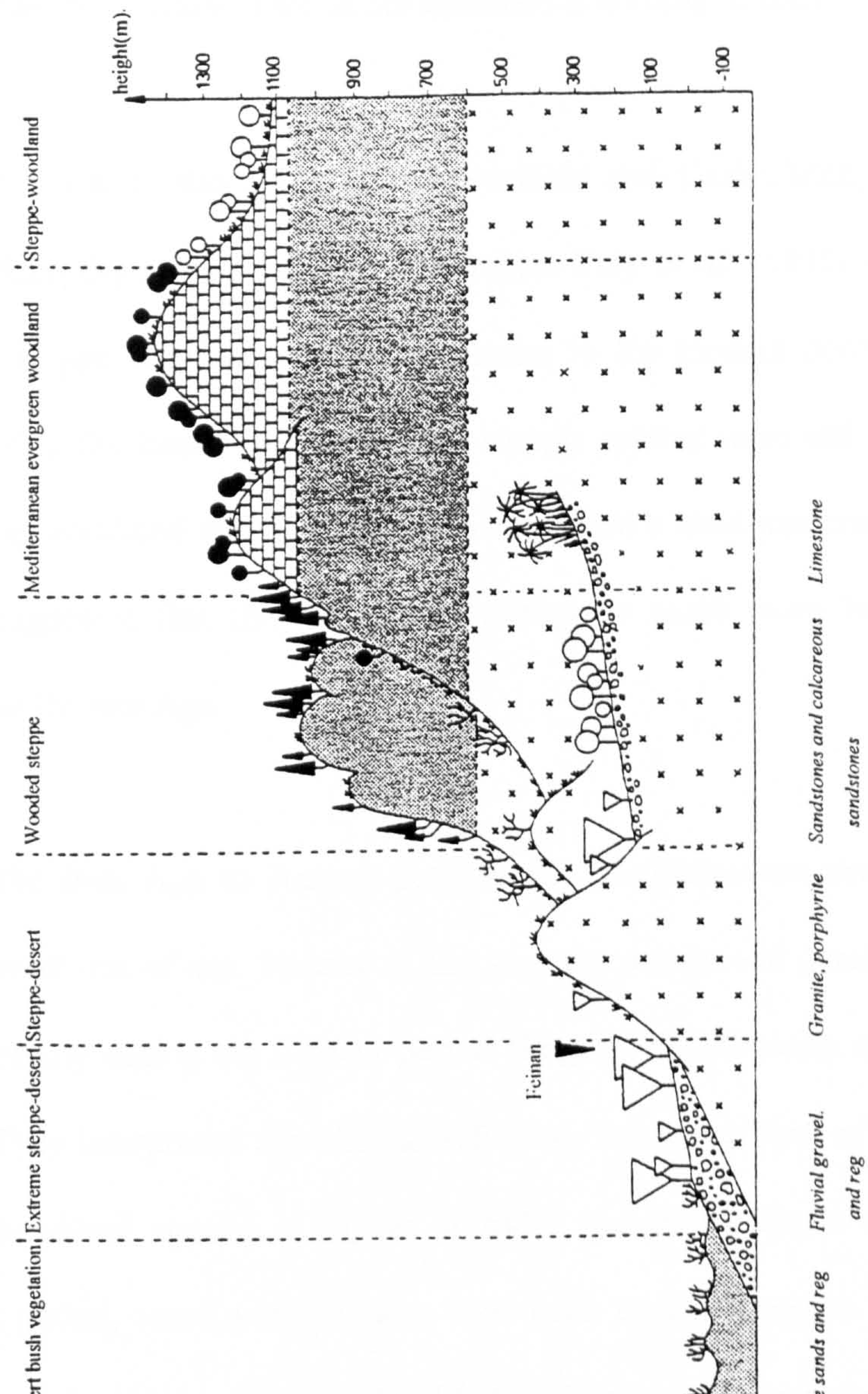


Fig. 3.12 Vegetation (Zones) in the Edom Mountains and Wadis Faynan and Dana (after Baierle *et al.*, 1989).

3.16 Archaeobotanical work in the study area

A series of papers (Baierle *et al.* 1989, Frey *et al.* 1991; Engel, 1993) have documented archaeobotanical research on the charcoal inclusions in metal-processing slags from archaeological sites in the study area. These are summarised in Table 3.8. In this table, the species of wood are classified according to their dominant habitat.

As can be seen in this table, in the Neolithic and Chalcolithic, the charcoal was derived from dry steppe and very dry steppe. Frey *et al.* (1991) suggested that this reflected steppe vegetation type very similar to the modern community during this time. During the Bronze Age, although steppic species were still used, species from the steppe-woodland and Mediterranean zones were used predominantly. Frey *et al.* (1991) suggested that this indicated a change to much more humid environments during the Bronze Age.

During the Iron Age to Roman periods, the Mediterranean and steppe-woodland species went out of use. Species of the very dry steppe and desert zones were used predominantly during the Roman period (Engel 1993; Barierle *et al.* 1989; Baierle 1993). They interpreted this shift as reflecting the withdrawal of the Mediterranean steppe-woodland species to higher altitudes, possibly because of drought. In the Mamluk period, wood use seems to have been mostly from the Mediterranean and steppe-woodland zone (Frey *et al.*, 1991). This was again interpreted as evidence for more humid conditions and the advance of woodland down the mountain slopes.

Table 3.8. Results of archaeobotanical work in the research area (Modified after Baierle *et al.*, 1989, Frey *et al.*, 1991, Engel, 1993). The figures are represent percentages.

Environment	Characteristics (ssp)	Neolithic			Chalcolithic Fidan 4	Early Bronze Age (Barqua el Hetiye)	Early Bronze Age Faynan 9	Late Bronze Age Faynan 9	Late Bronze Age Faynan 16	Iron Age	Persian Age	Roman Age	Mameluke Age
		5345 to 5240 BC	5210 to 4910 BC	4330 to 4165 BC				2900-2500 BC	2570-2330 BC	900-700 BC	550-400 BC	100-400 AD	1260-1516 AD
Mediterranean	*Quercus calliprinos*						7.3	3.7-5	12.2-15				62.3-84.7
	Pistacia atlantica					1.0	30.8						
	Olea europea						15.1	11.2-15.6	7.2	0-7.1			5.9-13.6
Steppe-woodland	*Juniperus phoeneca*						14.1	63-67	59.7	0-5.4			15.3-28.6
	Raetama raetam						10.0						
Dry Steppe	*Tamarix* sp.				40	95	1.6	3.5-5.2	3.9-4.7	55.2-91.6	41.5-52.4		2.5-3.4
	Zygophyllum-dumosum						0.05						
	Moringa per-peregrina						2.9						
	Phoenix dactylifera									0-30.8	0.8-3.2		
Very dry Steppe	*Acacia* spp.					0.1	1.2				7.2-11.1	12.1-13.8	
	Retama raetam		85.2	100	60			1.0-2.2	2.3-4.7	2.0-10.2	22-32	14.3-19.0	
	Zizyphus spina-christi	91.2	14.8				1.0						
	Lycium shawi	8.8					0.2						
Desert	*Haloxylon persicum*					4.0			3.4-4.7	1.6-13.3	4.5-4.7	58.6-68.9	
	Ephedra						0.1					1.1-2.6	

3.17 Settlement in Jordan

Introduction

Settlement in Jordan has extended over long period of time, from the lower Palaeolithic to the present day. A complete review of the settlement history for Jordan is outside the scope of this study. For the region, the settlement history can be divided into a number of episodes (Table 3.9).

Table (3.9). A chronology of archaeological periods in the Middle East (after Goldberg and Bar-Yosef, 1990

Period	Start date	Equivalent to BP
Arab/ Mameluke	640 AD.	1,310
Roman	37 AD.	1,913
Persian	586 BC.	2,536
Iron Age	1,200 BC.	3,150
Bronze Age	3,300 BC.	5,250
Chalcolithic	*ca.* 6,500 BP.	
Neolithic	*ca.* 9,000 BP.	
Epipalaeolithic	*ca.* 18,000 BP.	
Upper Palaeolithic	*ca.* 40,000 BP.	
Middle Palaeolithic	*ca.*150,000 BP.	
Lower Palaeolithic	*ca.* 1000,000 BP.	

Settlement in the study area

The lithic artifacts collected within the study area indicate that the locality was visited by prehistoric people, certainly from the Middle Palaeolithic (Late Middle and Early Late Pleistocene) and then the Epipalaeolithic period (18,000 years ago) through to the later prehistoric periods (Barker *et al.* 1997).

The foci of settlement for Epipalaeolithic groups at the threshold of agriculture were the springs in the upper sections of Wadis Ghuwayr and Dana (Finlayson and Mithen, 1997).

By the eighth millennium BC (10 k BP), the Wadi Ghuwayr springs were the base for a fully-fledged agricultural community (Wadi Ghuwayr 1: Simmons and Najjar 1996). The location is typical of many early farming sites in the Near East- presumbly because the spring provided naturally irrigated land for cereal fields and animal pasture (Bar-Yosef, 1995).

In the sixth and fifth millennia BC, however, there were later Neolithic and Chalcolithic settlements about 1 km from the Dana-Ghuwayr confluence at Tell Wadi Faynan (Al-Najjar *et al.*, 1990). Geomorphological investigations indicate that this settlement was located in a relatively rich and diverse aquatic landscape, very different from today. A more or less perennial stream flowed by the site and most probably the farmers grew their crops beside it, much like the first farmers had been doing at the Wadi Ghuwayr springs described above (Barker *et al.*, 1997, 1998). The concentrations of material around Tell Wadi Faynan and along the main tributary wadi to the south suggest that the Neolithic and Chacolithic farmers practised off-site activities such as pastoralism and hunting around their settlements on the Wadi floor as well as growing their crops by the watercourses (Barker *et al.*, 1997,1998).

Barker *et al.*, (1997, 1998) and Hunt and Gilbertson (1998) reported that a group of circular depressions on the edge of the Wadi Faynan field system (WF4), are probably water catchment structures of Chalcolithic /Early Bronze age. There are also complex patterns of cairns and simple terrace walls associated with pottery and lithics. The terrace walls have been found in the upper slopes outside the later main field system in the Wadi Faynan. These also are water control structures similar to the microcatchment water control systems and simple terrace walls which were found by Levy at Shiqmim in the Negev, dated to the Chalcolithic period (Levy, 1987). The development of Chalcolithic floodwater farming was probably a response to the aridity which developed by 3050-1350 BP (Barker *et al.*, in press). The Chalcolithic period was associated with the exploitation of copper ores and with new systems of land use which are characterised by deliberate management and storage of surface flood water (Barker *et al.*, in press).

The begining of the major phase of wall building in the Wadi Faynan is probably more or less contemporary with the begining of major settlement at Khirbet Faynan (probably Iron Age II). This reflects the development of a large scale copper exploitation system in the area (Hauptmann 1990; 1992). Settlement at Khirbet Faynan and settlement of the farming in the field system continued through Iron Age, Nabatean and Roman periods and came to the end in the Arabic period (Hauptmann, 1990). The Barrage at Khirbet Faynan (5017) is associated with dates of Iron Age II (Hauptmann 1990).

3.18 The history of mining in the Faynan area

Introduction

Mining in the Faynan area (Research Area) is based on copper. This can be summarised as follows (following Khouri, 1988). In the Research Area, the copper mining and smelting figure 3.13, has been studied by a research project of the German Mining Museum at Bochum, West Germany (Hauptmann, 1989, 1990), Hauptmann and Weisgerber (1992).

There are many habitation and metal-working sites in the Wadi Fidan. According to the preliminary analysis of extensive pottery and flint tool scatters, these sites were inhabited over a long period spanning the Neolithic to the Byzantine eras (Khouri, 1988). The pottery from Wadi Fidan sites dates predominantly from the late Neolithic/Chalcolithic period, with some shreds from the late Bronze, Iron, late Roman and Byzantine periods (Khouri, 1988).

Copper types in the Faynan area

The copper deposits in the Faynan area cover an area about 30 km^2, and these copper deposits classify as follows:

1. A very high-grade copper ore intergrown with Manganese minerals, concentrated in a two metre thick horizon. Some of it is partly exposed as a layer near the surface, but more dips into the mountains (Kouri, 1988).

2. Lower-grade copper ore is found abundantly throughout the area in the White Nubian Sandstone Formation (Khouri, 1988).

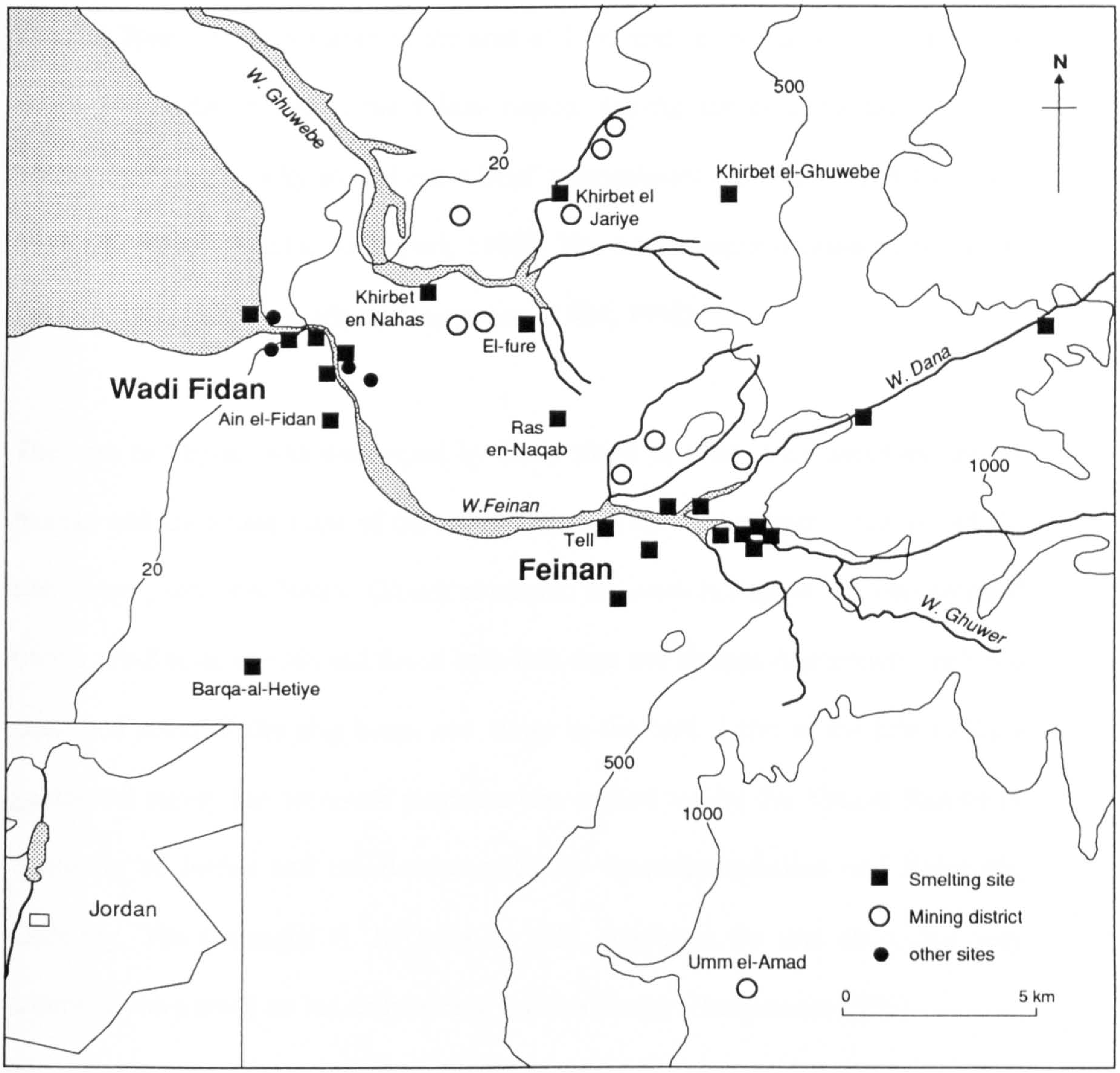


Fig.3.13 Mining areas, smelting sites in the Wadi Faynan and surrounding areas (after Hauptmann and Weisgerber, 1992)

History of research

Khirbet Feinan is one of the most important and best preserved ancient copper mining and smelting centres in the Middle East (Khouri, 1988). Musil first examined the area in 1898, followed by Frank in 1934 and Glueck in 1935 (Khouri, 1988). Hans-Dietel Kind of West Germany surveyed the area in 1966 and he estimated that there were about 200 ancient mines in the Feinan region. Jobling surveyed the area in 1979, MacDonald and Koucky carried out a brief reconnaissance survey around Faynan in 1985 (all references cited in Khouri, 1988). The most extensive research at Faynan has been undertaken recently by Hauptmann (1989, 1992).

The area of Faynan was discovered by Alois Musil in 1904, who noted mainly the Roman and Byzantine ruins of the ancient town. Thirty years later, Fritz visited the site. Some years later Nelson Glueck continued the work in Faynan. He concentrated on the pre-Roman periods and found both Iron Age and Bronze Age pottery, and also described some of the slag heaps and mines in the area. Later in the late 1950s a geological survey for economic purposes was carried out by the Natural Resources Authority of Jordan and the Bundesanstalt fur Geowissenschaften und Rohstoffe, Germany. The Geologist H. D. Kind in 1965, published the first short, but very comprehensive study on the early mining and metallurgy (Hauptmann, 1990).

It is clear that Faynan was the major copper mining and smelting centre on the East side of the Wadi Araba, as can still be seen from the extensive remains on the large (over 500 × 300 meters) Khirbet Faynan site. Khirbet Faynan is flanked to the North by Wadi Dana, and to the South by the junction of Wadi Ghuweir and Wadi esh-Sheger. The main site comprises the large central mound of Khirbet Faynan, surrounding by a sprawling array of ancient walls, building and floor remains, reservoirs and aqueducts, agricultural fields, churches, slag heaps, terraces, mills, wells, roads and other structures. All these remains and structures reflect the frequent use of this site through time. The pottery which was collected at Faynan dates from the Chalcolithic, Early Bronze, Iron, Nabataean, Roman and Mamluke periods. (Khouri, 1988).

History of mining and metallurgy in the Faynan area

The area of Faynan is located some 60 km south of the Dead Sea at the foothills of the Rift Valley. This area has been investigated recently for the ancient mining and metallurgical activity (Hauptmann, 1989; 1990). The results of these investigations can be seen in Table 3.10.

Table 3.10 History of mining and metallurgy in the Faynan area:

Pre- Pottery Neolithic (8th-7th Millennium BC)	The first use of copper ores in the Feinan area is dated to the 8th/7th Millennium. 'Greenstone' beads and green powder for cosmetic purposes from Feinan became popular all over Jordan and Palestine (Hauptmann, 1990).
Pottery Neolithic (6th- 5th Millennium BC)	A number of copper pieces and some 'greenstone' beads were discovered at Tell Wadi Feinan. This reflected the use of copper, but so far no metallurgical treatment has been found (Hauptmann, 1990).
Chalcolithic (4th Millennium BC)	As in other Chalcolithic settement in Jordan and Palestine, the first evidence of metallurgical activities in the area appears in the second half of the 4th millennium (Hauptmann *et al.*, 1992). Only little pieces of Chalcolithic slag and copper prills were found at Faynan. They indicate small scale metallurgical operations (Hauptmann, 1990).
Bronze Age (3d Millennium BC)	The first extensive mining and metallurgical activities are dated to the Early Bronze Age. From this period until the Late Iron Age, very rich copper-manganese ores from Dolomite Limestone-Shale unit were exploited. This led to the opening of numerous mines in Wadi Khalid and Wadi Dana. The volume of the slag heaps suggests a production of metal on a scale of 100-300 tons. (Hauptmann, 1990). Relative to the Chalcolithic, the mining and pyrotechnology now reveal improvment which was reflected during the excavation of 31 smelting furnaces at Faynan 9 and 11 (Hauptmann, 1990).
Iron Age (1st Millennium BC)	The second main period of copper production dated to the Iron Age II. Two smelting sites show metallurgical activites on an industrial scale. It should be stressed that in this period the largest copper production of the entire Near East beside Cyprus is concentrated in the Faynan area (Hauptmann, 1990). At Fayanan, mining and smelting were carried out on a large very well organised and sophisticated scale with improved geological understanding. This is reflected in the exploitation of deep mineralization by shafts 60 m deep (Hauptmann, 1990, 1992).
Roman Period	The exploitation of the rich copper mineralization in the dolomite-limestone -shale unit in earlier periods left the Romans only the low-grade copper in the Cambrian Sandstone. (Hauptmann, 1990, 1992). Large scale mining and smelting resumed in the Roman era, at Umm el - Amad, 7 km south of Feinan. The Romans also re-opened mines that had been first worked 2,500-3,000 years earlier during the Chalcolithic/ Early Bronze ages and they used these mines as entrances for the new underground mines through shafts and deep connected underground passages (Khouri, 1988). The German team discovered 1.5 m high galleries, suggesting that the Romans used animals to transport the ore inside the mines as well from the mines to the central smelting works at Faynan (Hauptmann, 1989).
Early Arab period	Mining and smelting activity around Faynan declined rapidly after the Roman period. After 500 AD the role of Feinan as a major copper supplier in the Levant ended (Hauptmann, 1990; Hauptmann *et al.*, 1992). Evidence has been found for small-scale smelting during the early medieval Islamic periods at el-Furn, Faynan, Ain Fidan and probably in the Wadi Dana (Khouri, 1988).

3.19 Flood water Farming (FWF)/ Rain Water Harvesting (RWH) in Jordan

There is evidence of ancient floodwater farming systems at Beidha, in the Edom mountains of southern Jordan. These are thought to have been in use during the Neolithic age, nearly 9,000 years ago. Today, the area receives a low annual precipitation of around 170 mm (Kirkbirde, 1966).

In other parts of the Jordanian desert, in particular north of the Azraq Oasis, ancient barrages, cross wadi walls and wadi walls controlled and directed flood water, to irrigate cereal and barley fields (Gilbertson and Kennedy, 1984).

In the Black Desert of Syria and Jordan, access to ground water and springs is difficult because of the geomorphology, climate and environmental aspects of this desert. Cultivation reliant on water harvesting was only possible after the winter rain. Thus, water harvesting was responsible for converting this barren land in to a life-supporting environment. The development of the city of Jawa over 5000 years ago in the Black Desert required complex social organisation and technology, including a large dam, and other water harvesting constructions (Helms, 1981). The Wadi Rajil, in the Jebel Druze provided the catchment for this water harvesting system. Storms in the Wadi Rajil are characterised by high intensity and short duration with an average annual rainfall over 500 mm, which is high in comparision to Jawa which has an average annual rainfall of 150 mm (Helms, 1981). Jawa was reliant on the drainage that flowed from the Jebel Druze. Snow melt water in the Jebel Druze also supplied a small amount of runoff to the Wadi Rajil (Helms, 1981).

3.20 Flood Water Farming/ Rain Water Harvesting in the Research Area

Study of floodwater farming systems in Wadi Faynan was conducted by Barker *et al.*, (1996, 1997, 1998, in press) (see plate 3.12) and Hunt and Gilbertson (1998). The Wadi Faynan lies on the edge of extremely rugged terrain on the margins of the Rift Valley south of the Dead Sea. Rainfall is around 50-150 mm per year, depending on altitude and the natural vegetation is degraded steppe-desert, as the result of overgrazing. According to Hauptmann *et al.* (1992) the Wadi Faynan area was a major copper mining and smelting centre throughout later prehistory and early historic time. There were three peak periods associated with mining and smelting activities in the Middle Bronze Age, Iron Age II and Roman period.

Neolithic farming in the region was associated with signs of permanent water bodies and a scrub-rich steppe environment which did not require irrigation. By the Chalcolithic, the steppe vegetation started to degrade and the water harvesting catchment systems started to appear. Site 5015 is typical, a small slope catchment system and cistern are associated with buildings containing bronze age potsherds. This system is slighted by walls associated with a larger-scale system of water harvesting probably dating to the Nabatean to Byzantine (classical) period (Hunt and Gilbertson, 1998). Plate (3.12) represents the herring-bone field system of the Wadi Faynan (WF4.3) Barker *et al.* (1997).

The Classical-period irrigation system provided irrigation water which allowed the growth of foodstuffs to support miners and smelters living at the nearby site of Khirbet Faynan. It is a large scale combination system incorporating both diversion systems and slope catchment systems lying on late Quaternary terraces of the Wadi

Plate 3.12 Shows a kind of water distribution system which is found in the Wadi Faynan field system (WF4.3, at the south-eastern margins of the field system) where walls run obliquely in a herring-bone pattern down the mountain sides to trap both overland flow and gully flow and led this harvested water into the fields below (Barker *et al.*, 1997). (Photograph: Courtesy of C. O. Hunt).

Faynan. Water was diverted using a dam from the spring-fed Wadi Ghuweir conveyed along a 1.5 km conduit which crossed the Wadi esh-Shegar on an aqueduct and supplied a reservoir (cistern) and mill of Roman age, before passing into the exteme eastern end of the floodwater farming system. (This water supplemented the ephemeral runoff diverted from minor wadis and from the steep slopes behind the terraces. This runoff water was distributed downslope across the terraces by a system of small channels). The palynological studies of Mohamed and Hunt (1998) and Barker *et al.* (in press) indicate that olive and cereals were grown in these fields (See Ch. 5 for details). Biodiversity declined in these fields, and aridification intensified some time after the abandonment of the system, probably in the early Arab period.

3.21 Conclusion

This chapter has described the study area in the context of Jordan. Geologically, the area is complex, with copper mineralization in Cambro-Ordovician rocks which have proved a magnet for prehistoric and historic settlement. Soils are presently extremely damaged, but in the past a range of soil types were present. The Wadi Faynan is a very arid area, with seasonal rainfall more intense with altitude. This has shaped the pattern of vegetation, which ranges from desert in the Wadi Araba to relict Mediterranean dry woodland on the Jordan plateau, though this pattern has been modified by human activity (e.g. mining) and climate change during the Holocene. Numerous settlements have been occurred in the area. These were often reliant on the rain water harvesting for their food.

CHAPTER FOUR: METHODS

4.0 Methods

4.1 Introduction

The problems identified in chapter 1 and 2 were addressed by a programme of field work and laboratory work, which is described in this chapter.

4.2 Field work

4.2.1 Introduction

An initial field season in the Wadi Faynan was carried out by an Anglo-Jordanian team of archaeologists and geomorphologists in April 1996 and a second season in 1997 (Barker *et al.* 1997; Barker *et al.*, 1998). The final field season was in March-April 1998. Geomorphological fieldwork in the 1996 and 1998 field seasons on which this thesis is based was carried out by C. O. Hunt, D. D. Gilbertson, J. Grattan, S. McLaren and the author. It comprised the following.

4.2.2 Mapping.

Initially, the Quaternary deposits of the study area were virtually unknown (the geological survey of study area was not available to the 1996 party). The first priority was therefore to map and describe the major Quaternary sediment units in the field area. This was done on foot, using air photographs as base maps. The use of air photographs enabled large scale Quaternary features to be mapped rapidly, using breaks of slope. The results of this mapping were published in Barker *et al.* (1997).

4.2.3 Detailed field investigation

Sections and other features were located on air photographs, measured using 30 m tapes and drawn to scale in the field following the conventions in Gardiner and

Dackombe (1983). Samples were taken from each sedimentary unit and horizons thought to be significant, were more intensively sampled for dating, palynology, geochemistry and sedimentology, after cutting the section face back a minimum of 0.1 m, to avoid problems of contamination or oxidation of organic matter, which is known to be a severe problem in hot arid lands (K. J. Dorning, *pers comm.* to C. O. Hunt, 1984). Furthermore, the selection of the field sites within the Wadi Faynan system was constrained by availability of only a few exposures. Augering, using 100 mm and 60 mm diameter Eijkelkamp augers, was used to extract samples from reservoir lacustrine deposits and cistern fills.

All samples were bagged in clearly labelled polythene self-seal bags and then double bagged, for transport to the laboratory. Samples for radiocarbon dating were wrapped in tin foil and then double bagged in polythene self-seal bags. Sampling was constrained by the need to be able to air-freight samples to the UK, so sample sizes were by necessity small (averaging 250.0 g).

4.3 Palynological and Palynofacies Analyses

4.3.1 Introduction

Pollen analysis is considered as the most important method for the reconstruction of the past flora, vegetation and environment (Faegri and Iversen, 1989). Dimbleby (1976) states that, the most significant information which can emerge from pollen analysis of archaeological sites is ecological, and it may be possible to tell what the contemporary environment was like and how it has been changed, perhaps under human influence. In this study, pollen analysis was undertaken to reconstruct the local and regional vegetation of the past, and to deduce the sequence of climatic and environmental change which has taken place in the region. Evidence can be extracted from pollen analysis concerning human activity in the past: activities such as cultivation and pastoral agriculture (Lowe and Walker, 1997; Horowitz, 1992).

In addition to the pollen analysis, palynofacies analysis (Combaz, 1964: the study of the whole organic assemblage found in non-acetolysed palynological preparations) was undertaken by the author. This has the potential to play an important role as a palaeoenvironmental tool, since characteristic assemblages of organic materials are generated by different types of human activity (Hunt and Coles, 1988) and in different depositional environments (Combaz, 1964). In general, it was considered that the use of palynofacies was likely to provide valuable information about past human activity in the research area (Hunt and Coles, 1988).

Samples for palynological analysis were collected, from different sites which were suitable for palynological investigation, during the field work, (see section 4.2.3.) It was noted that for palynological preparation, there are several different techniques available. For instance Brown (1960), Moore *et al.* (1991) and Faegri and Iversen (1989) described palynological techniques based on acetolysis and Hydrofluoric acid maceration.

4.3.2 Palynological preparation techniques

The technique selected in this study is a standard palynological technique known as "sieving and swirling" (Hunt 1985). This method has been chosen instead of the other methods because of

- its simplicity;

- its inexpensive nature;
- its lack of dangerous chemicals such as Hydrofluoric acid. Hydrofluoric acid treatment, acetolysis and especially their combination, may prove hazardous and importantly, cause partial or even total destruction of the pollen grain (Hafsten, 1959). The use of standard acetolysis and Hydrofluoric acid maceration is known to give poor results when used in arid zone sediments (Fish, 1985);
- it is stated to be appropriate for pollen expected to be fragile, from sediments such as calcium rich tufas, cave sediments and river terrace sediments (Hunt 1985) because the minimum chemical treatment has little effect on damaged exines. For all the above reasons, the technique of Hunt (1985) was adopted. This is described in Appendix 2.

The whole residue was examined and all pollen, spores and all other organic walled microfossils were identified and recorded. Pollen was identified using Moore *et al.* (1991), and Hunt (*pers. comms.*, 1996-1998), collection of arid land pollen and some other publications related to arid land pollen (Breilie, von der, 1961; Haddad,1961; Rossignol and Pastouret, 1970; El-Oqlah, 1983; Al-Eissawi, 1986; Al-Eissawi and Dajani, 1987, 1988; Karim and El-Oqlah, 1989).

4.3.3 Palynofacies analysis

A palynofacies (Combaz, 1964) count was made for each sample. One or more randomly chosen transects were made, near the centre of the slide, and all organic particulates encountered were identified and counted, using terminology adapted from Batten (1982); Branigan *et al.*, (1988); Tyson (1995) and Hunt and Coles (1988).

4.3.4 Fluorescence microscopy

A Fluorescence Microscope was used in this study. This is because it is useful for recognising reworked grains, for studying of very thinwalled material, and for discriminating between particles of different botanical origin (Traverse, 1988). Fluorescence microscopy can sometimes demonstrate a difference in fluorescence level between *in situ* and reworked palynomorphs (Traverse, 1988). Reworked palynomorphs are usually (but not always) more poorly preserved than the palynomorphs that came into the basin of deposition from contemporaneous vegetation. This can be recognised from their corroded, ragged or thin walls, or their different natural colour (Traverse, 1988). They also fluoresce further to the red end of the spectrum than *in situ* grains. When a fluorescence microscope is used the specimens are illuminated with intense ultraviolet light (Traverse, 1988). In this study, an Olympus BH2-RFCA fluorescence microscope was used to check for recycling and contamination. Most palynomorphs examined under fluorescence microscopy in this study fluoresced a dark red colour or did not fluoresce at all. Assemblages showed relatively uniform fluorescence characteristics, suggesting an absence of contamination and little detectable recycling.

4.3.5. Pollen nomenclature

Pollen nomenclature is constantly changing as taxonomists reclassify the parent plants. Pollen nomenclature in this thesis follows Moore *et al.* (1991), except in a few cases. Pollen of the Family Compositae is identified into the sub-families Lactuceae, for fenestrate pollen, and Asteraceae for non-fenestrate, echinate pollen which is not attributable to individual genera. Older terminology is retained for brevity where the new terminology is extermely long-winded. The term 'Filicales' is retained rather than

'Pteropsida (monolete) indeterminate' as suggested by Bennett *et al.* (1994) and the term (*Corylus*) is retained rather than their 'Corylus avellana type', since in this region there is little possibility of confusion with the pollen of *Myricagale*.

4.3.6 Pollen diagram construction

The vertical axes of the relative pollen percentage diagram represent depth usually in metres, and the horizontal axes show the proportional abundance of the pollen types, and are indicated by the use of a bar histogram (Moore *et al.*, 1991). Conventionally, the pollen diagram is arranged in groups. For most of the studied sites the pollen types were divided into ecologically significant groups which include far-travelled, plateau, cultivated, waterside, steppeland, dryland, indeterminate, algae and fungal. This division helps to distinguish groups of pollen types that may have some form of association with ecology or human activity.

4.3.7 Pollen diagram zonation

It is conventional and convenient to divide pollen diagrams into zones or units on the basis of their pollen content (Moore *et al.*, 1991). The conventional method of subdividing pollen diagram is the pollen assemblage zone. The use of zones, which are artificial, is for conciseness to aid in the interpretation of the pollen diagram (Moore *et al.*, 1991). Within a pollen zone, a local pollen assemblage which describes local vegetation change and also regional pollen which is used to describe regional vegetation change can be detected. For each site, pollen assemblages were distinguished by eye, and are labelled from the base to the top as local pollen assemblage biozones in Chapter 5.

4.3.8 Macrofossil analysis

All coarse fractions of samples subjected to sediment analysis were examined for macrofossils, and these were separated and retained for examination where they were found. The molluscs and plant macrofossils were identified by Dr. C. O. Hunt.

4.4 Sediment analysis

4.4.1 Particle Size Analysis

Introduction

The measurement of particle size analysis is one of the most important techniques of sediment analysis. It helps in the understanding of the processes of transportation and deposition of sediments, both at present and in the past, and it is therefore important in studies both of contemporary processes and of palaeoenvironments. On the other hand it is also a very good tool for the description and classification of deposits (Briggs, 1977).

Furthermore, grain size analysis of fluvial sediments enable checking of taphonomic patterns [in some areas very high *Pinus* and Fern spores figures are associated with coarse sandy alluvium as in the Feccia Valley: Hunt and Gilbertson (1995)]. Moreover, Clay-sized particles correlate significantly with *Pinus*, *Quercus* and *Populus* pollen. These pollen types settle, as clay does, in slack water. Chenopodiaceae, *Artemisia*, other Tubuliflorae, and undeterminate pollen types correlate with sand-sized particles, and are deposited by more turbulent water (Fall, 1987).

Method

The method used to measure the particle size in this study was the method of Hunt (in Press.). This is a simple wet sieving method for determining the percentage of sand, silt and clay. This method was used rather than the more common pipette or hygrometer methods (Gale and Hoare, 1991) because of its rapidity. This method is described in Appendix 2.

4.4. 2 Estimation of organic matter content by loss on ignition

Introduction

This method was used to give an approximation of the percentage of organic matter in the sample. In general, high carbon contents may indicate more productive biological conditions or an occupation horizon (Gale and Hoare, 1991). A wide variety of procedures exist for estimation of organic matter content of materials. These procedures fall into three categories: organic carbon may be determined by measuring the amount of carbon dioxide evolved during dry or wet decomposition, plant organic matter may be determined from loss in mass resulting from either ignition in a furnace or oxidation with hydrogen peroxide, and oxidable organic matter may be determined by oxidation with chromic and other acids (Hesse, 1971; Metson, *et al.*, 1979; Nelson and Sommers, 1982). All the methods mentioned above suffer from deficiencies and because organic matter is of variable chemical composition, these methods tends to give inconsistent results when applied to different materials (Gale and Hoare, 1991).

Method

In this study a standard method was used: 'loss on ignition' as advocated by Gale and Hoare (1991). This is described in Appendix 2.

4. 4. 3 Estimation of Calcium Carbonate-equivalent content

Tests for Carbonates provide evidence for the presence of limestone, chalk, or calcite in a soil (Goodyear, 1971). Furthermore, enrichment of calcium carbonate is common in many old arid-zone soils in the research region (Dan, 1977), and since it will increase with time, so it may give a qualified indication of age. A number of authors (summarised in Moore and Webb 1978) suggest that strongly calcareous sediments do not contain pollen. This was refuted by Hunt (1987). In this study calcium carbonate content was monitored to establish whether there was any relationship with pollen preservation.

There are several procedures for measurement of the carbonate content of geological material. It may be determined gasometrically, by measuring the volume of carbon dioxide evolved during the reaction of the material with HCL or other acids. Alternatively, the carbonate may be determined by reaction with excess acid and back titration with alkali (Gale and Hoare, 1991). There is also another method, which is to dissolve a material in excess hydrochloric or other acid and measure its resultant loss in mass. Gale and Hoare (1991) recommended the gasometric method because the titration method may give highly anomalous results compared with those obtained by using the other methods.

Method

In this study, the carbonate was measured by the use of the gasometric method, because the error in this method is reported to be less than 1% whilst the results of the other analysis methods have greater errors (Gale and Hoare 1991). There are several types of calcimeters for gasometeric determination of carbonate concentrations, including the Van Slyke, Chittick, Collins and Bascomb (Gale and Hoare, 1991). From the above mentioned calcimeters, the Bascomb (1961) calcimeter has been chosen for this study because it possesses the largest sample capacity and is therefore likely to introduce the smallest sampling errors. Indeed, the weight of the sample which can be analysed in the Bascomb calcimeter is ten times as greater as that suitable for the Collins calcimeter: this enables a substantial sample to be analysed.

The calcimeter will deal with samples containing up to 1.0 gram, instead of < 0.1 gram, as demanded by the Collins calcimeter (Bascomb, 1961). This method can be outlined in the numerous steps (following Bascomb, 1961; Gale and Hoare, 1991), which can be found in Appendix 2.

4.4.4 Magnetic Susceptibility

Introduction

Magnetic susceptibility presents valuable information about the mineralogy and geochemistry of the samples (Dearing, 1994). The magnetic susceptibility of sediments can be affected by a number of natural and anthropogenic processes (Ellwood *et al.* 1996). Highly magnetic mineral phases, primarily the iron oxide minerals magnetite and maghemite, which increase the susceptibility in sediments, are readily produced by a number of processes. These processes incorporate chemical oxidation during weathering (Ellwood *et al.* 1986), chemical reduction by bacterial organisms (Frankel *et al.*, 1979) and chemical oxidation from natural or man made fire (Ellwood *et al.* 1996).

The magnetic susceptibility figures which were obtained from analysis of sediment in the research area were assumed to be mostly the result of human activity, because the sediments were sampled from archaeological sites or near mining and smelting sites. In a few cases, signs of pedogenic activity could be seen in sections and this correlates with raised magnetic susceptibility values. Bacterial activity in these sediments appears to be low once horizons are buried, since organic matter survives well once it is buried. This is unsurprising, given the reported heavy metal concentrations, for instance in the Khirbet Barrage sediments (5017).

Method

The samples were crushed using a pestle and mortar to less than 2 mm in diameter (Gale and Hoare, 1991). The material must not be ground, because this can alter the state of the minerals in the samples, Then the crushed samples were potted in 10 cm^3 pots and placed in the Bartington MS2 system to record the susceptibility. This method is described in Appendix 2.

4.4. 5 Colour Determination

Colour determination often gives an indication of age, since iron minerals 'age', with minerals passing progressively from brown, through yellow to red (Macklin, 1986). Colour may also give an indication of whether a sample is oxidised (yellow or red colours) or reduced (blue, green or grey colours) and thus whether it is likely contain organic matter.

The colour of each air dry sample was determined using a Munsell soil colour chart (Rock Colour Chart Committee, 1991).

4.5 Radiometric Methods

4.5.1 Radiocarbon dates

Introduction

Dating techniques are fundamental to an understanding of the natural and cultural changes which took place during the Holocene, without these dating an important events such as the Neolithic (agricultural) revolution would float in time (Roberts, 1998).

Method

Radiometric dating techniques were used to provide an indication of the age of the samples, so that could be placed in a chronological sequence. Radiocarbon dating for selected samples only was carried out in a designated laboratory external to Huddersfield University (Beta Analytic Incorporation: Radiocarbon Dating Service, Miami, Florida, USA). Accelerator mass spectrometry (A M S) was carried out on small samples. If sample size was large enough (over 40 g of charcoal), then the cheaper scintillation counting method was used.

Very few samples were suitable for radiocarbon dating, because of the very low organic matter contents in virtually all of the deposits studied. Where available, samples of sediment containing charcoal, or wood or plant macrofossils were collected. A total of four samples of wood, charcoal or plant macrofossils were located in the study area and all were subjected to radiocarbon dating. Two samples relatively rich in comminuted charcoal were also radiocarbon dated from the base of the Khirbet Barrage sequence (site 5017).

4.5. 2 Heavy Liquid Separation of Organic Matter

Introduction

This method was carried out to separate organic matter from the detritus, calcium carbonate and other minerals in samples studied. This purified organic matter was then sent for radiocarbon dating in a designated laboratory external to Huddersfield University (Beta Analytic Incorporation: Radiocarbon Dating Service, Miami, Florida, USA).

Method

This method (Guillet and Planchais, 1969) used a solution of Zinc Chloride (at density of 1.8) as an alternative to bromoform, which is an intensely toxic compound. Zinc chloride is not highly toxic, although it is a dangerous by ingestion. Furthermore, Bromoform is carbon-based and might therefore contaminate radiocarbon samples. The steps of this method can be found in Appendix 2.

4.5. 3 Optical Stimulated Luminescence

The purpose of this technique is to measure the luminescence emitted from the most light sensitive electron traps in particular minerals, especially quartz and feldspar following exposure to light (Huntley *et al.* 1985). The optical stimulation has been provided by using a green light source or infrared light source (Wintle *et al.* 1994). This technique is applicable to minerals of a wide range of ages (Smith *et al.* 1990), and the lower practical limit appears to be around 1000 years (Aitken 1990).

Optical dating for selected samples were carried out at the University of Wales, Aberystwyth Laboratory by Dr. G. Duller. In the research area, only samples of Pleistocene age were suitable for OSL dating, so OSL results are not used in this thesis.

4.6 Data handling

Pollen diagrams have been drawn using the Tilia package. Cluster analysis using Ward's Method has been done on some sediment samples, using the SSPS package.

4.7 Conclusion

The methods described above were applied in the study area and in the laboratory.

The results of this work can be seen in chapter 5.

CHAPTER FIVE: THE HOLOCENE SEQUENCE

5.0 The Holocene Sequence

5.1 Introduction

This chapter describes the results of field work and laboratory analyses of selected sites (figure 5.1). The sites were selected to provide a chronological coverage of the early to late Holocene. The Holocene deposits of the Wadis Faynan, Dana, Ghuweir and Esh-Shegar are here designated as the Faynan Formation. The type sections for the Faynan Member lie within the Wadis Faynan, Dana, Esh-Shegar and Ghuweir. Within this formation, a number of units of member status are recognised here (Table 5.1). These are described in the following sections. For each member, an overview is given, followed by the detailed descriptions of the sites attributed to this member.

Table 5.1 Units of Member status and sites at which they were found

1- <u>Faynan Member: Early Holocene Fluvial sites:</u>

This member includes:

Site 5510 (Base)

Site 5500/5015

Site 5021

Site 5021 will be considered as the type section of the Faynan Member

2- <u>Dana Member: Late Holocene Braided Alluvium</u>

This member includes:

Site 5025

Site 5509

Site 5520

Site 5510 (Top)

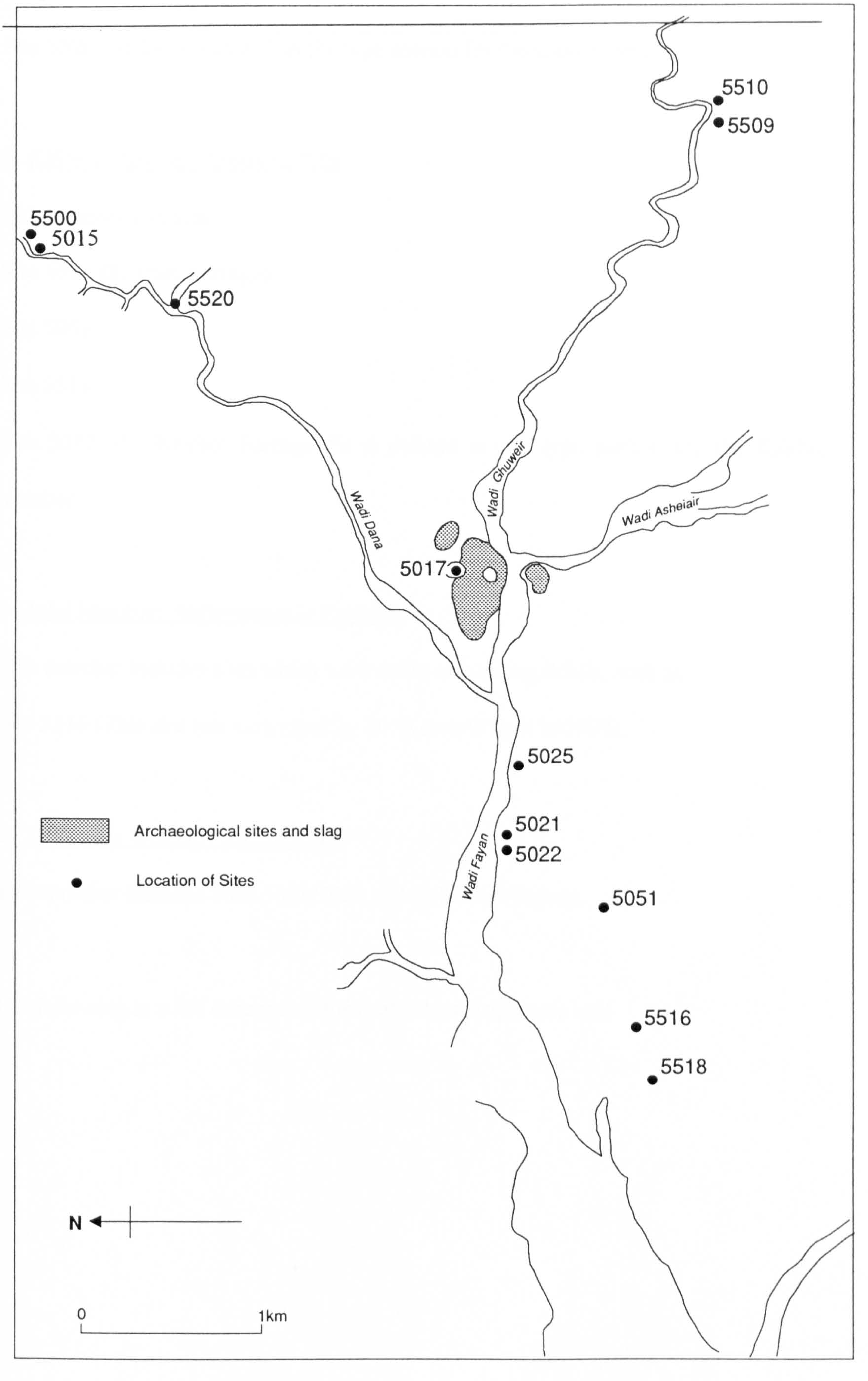


Fig. 5.1 Location map of the studied sites

Site 5520 will be considered as the type section for the Dana Member

3- <u>Khirbet Member: Reservoir Fills</u>

This member includes:

Site 5017 (Khirbet Barrage)

Site 5051

Site 5518

Site 5017: the Khirbet Barrage fill is defined as the type section for the Khirbet member.

4- <u>Atlal Member: Anthropogenic Deposits</u>

This member includes sites which were made of building debris, such as:

Site 5516 (This site was excavated by Dr. Karen Wright in 1997).

5- <u>Tell Loam Member: Aeolian unit</u>

This member includes Sites 5021/5022 and Tell Wadi Faynan.

The following is a full description for each lithostratigraphic unit

5.2 Faynan Member: Early Holocene gravel Unit

5.2.1 Description

The Faynan Member is composed of bodies of silt, sand and gravel, and overlies older gravels of Pleistocene age. The Faynan Member often shows epsilon cross-bedding evidence of deposition in meandering streams. It is richly fossilferous.

The deposits are 0-1.5 metres thick. They are associated with and crop out 4-8 metres above the present wadi floor at Tell Wadi Faynan which is an excavated later Neolithic and Chalcolithic settlement with calibrated radiocarbon dates from the sixth to the later fifth millennia BC (Al-Najjar *et al.* 1990). The Faynan Member at this location consists of a complex set of fine grained silts, biological remains, discarded ash and Neolithic midden materials including fragments of animal bone and charcoal (Barker *et al.* 1997). The midden materials accumulated in the quiet waters of a pond or stream measuring perhaps 5-10 m across, whose longevity must probably be measured in years rather than months. These deposits are particularly important because they point to environmental conditions on the floodplain at the time of the Neolithic settlement being substantially different from those which prevail today (Barker *et al.*, 1997): there was relative stability, quiet and perennial water, and notable biological production, in unmistakable contrast with the mixture of drought and flooding in the Wadi today (Barker *et al.* 1997).

5.2.2 Age:

The Faynan Member was deposited in the early Holocene: a conclusion based on radiocarbon and archaeological evidence (see below: sites 5021 and 5015).

5.2.3 Relationships

The geomorphological and archaeological relationships for the Faynan Member remain uncertain, though they were probably complex. The Dana Member rests unconformably aganist an erosion surface cut in the Faynan Beds and older units. The Faynan Member rests unconformably on older gravels of Pleistocene age.

5.2.4 Distribution

The Faynan Member is found in the Wadi Faynan, Wadi Dana and Wadi Ashayqar and was recorded at sites 5021, 5015, 5500, and 5510 (see figure 5.2).

Type site

The type section for the Faynan Member is site 5021 which is located in the Wadi Faynan.

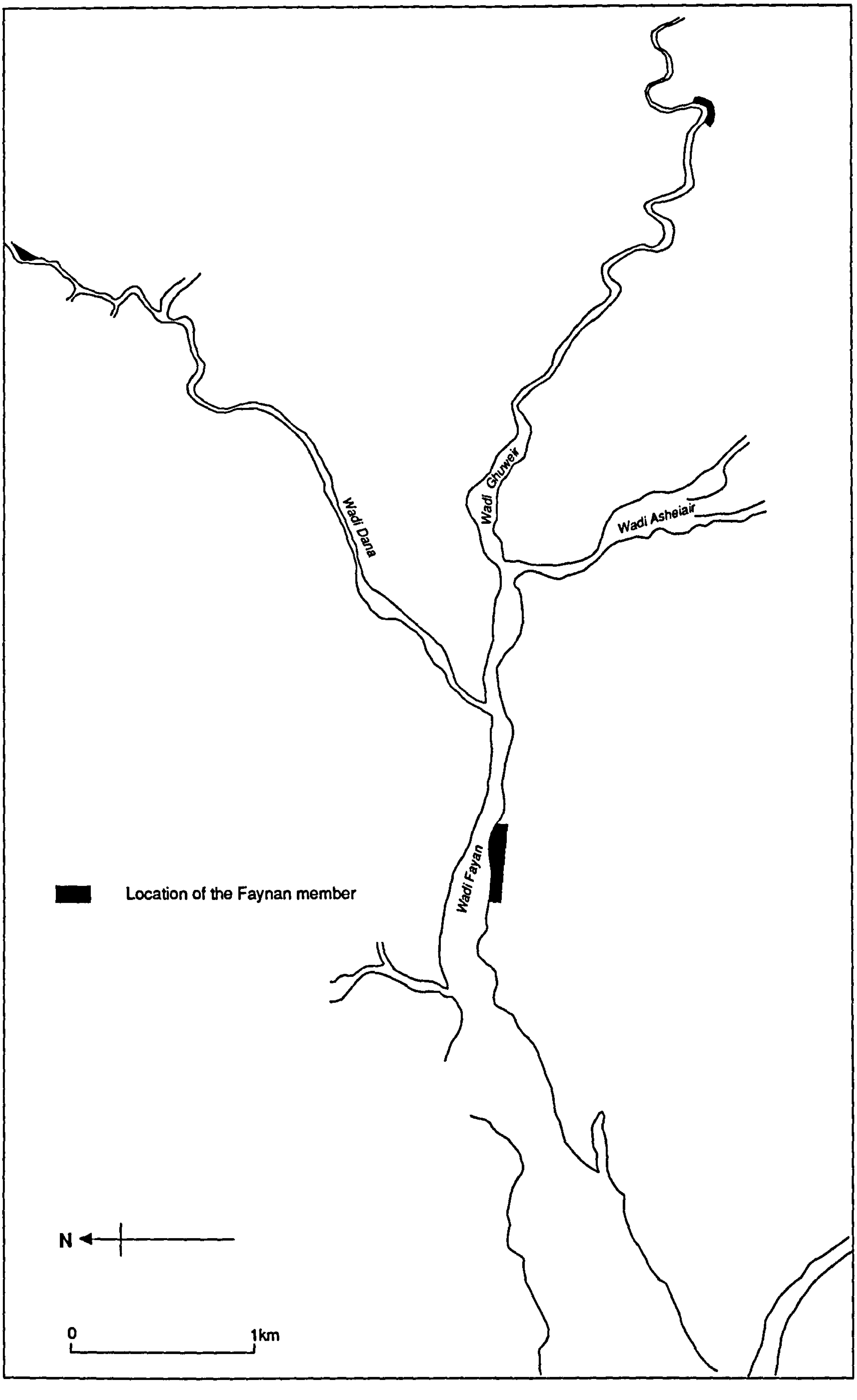


Fig. 5.2 Map showing location of the Faynan member in the research area

5.2.5 Site 5510

5.2.5.1 Introduction

This site consists mostly of alluvial fan sediments 14 metre thick in the Wadi Ghuweir. These deposits were divided into seven units based on sedimentary structure and lithology (figure 5.3, plate 5.1). These units are described in table (5.2). Thirteen samples were collected from this site.

Table 5.2 Units descriptions of site 5510

Unit no.	Thickness (in meters)	Descriptions
Unit 1	0.0-1.2	Coarse imbicated gravel
Unit 2	0.0-1.0	Fossiliferous marls/clays-meandering stream, in-channel deposits. Conformable base.
Unit 3	0.0-1.5	Small-scale trough cross bedding, very coarse gravels through to fine sands. Erosive base in places.
Unit 4	4-4.5	Large scale trough cross bedding, fine gravels and sands, conformable base.
Unit 5	0.0-2.5	Fine gravels and slackwater sandy marls incised into unit 4. Position suggests alluvial fan sediments. Erosive base.
Unit 6	0.0-1.5	Sands and gravels, small-scale trough cross-bedding. Wadi sediments. Conformable base.
Unit 7	4-6.0	Alluvial fan sediments, inclined-bedded, coarse angular gravels in large-scale cross-sets. Some slackwater sands

5.2.5.2 Sediment analysis

Sediment analysis of the site 5510 can be seen in (figure 5.4), and can be divided into two units, described below.

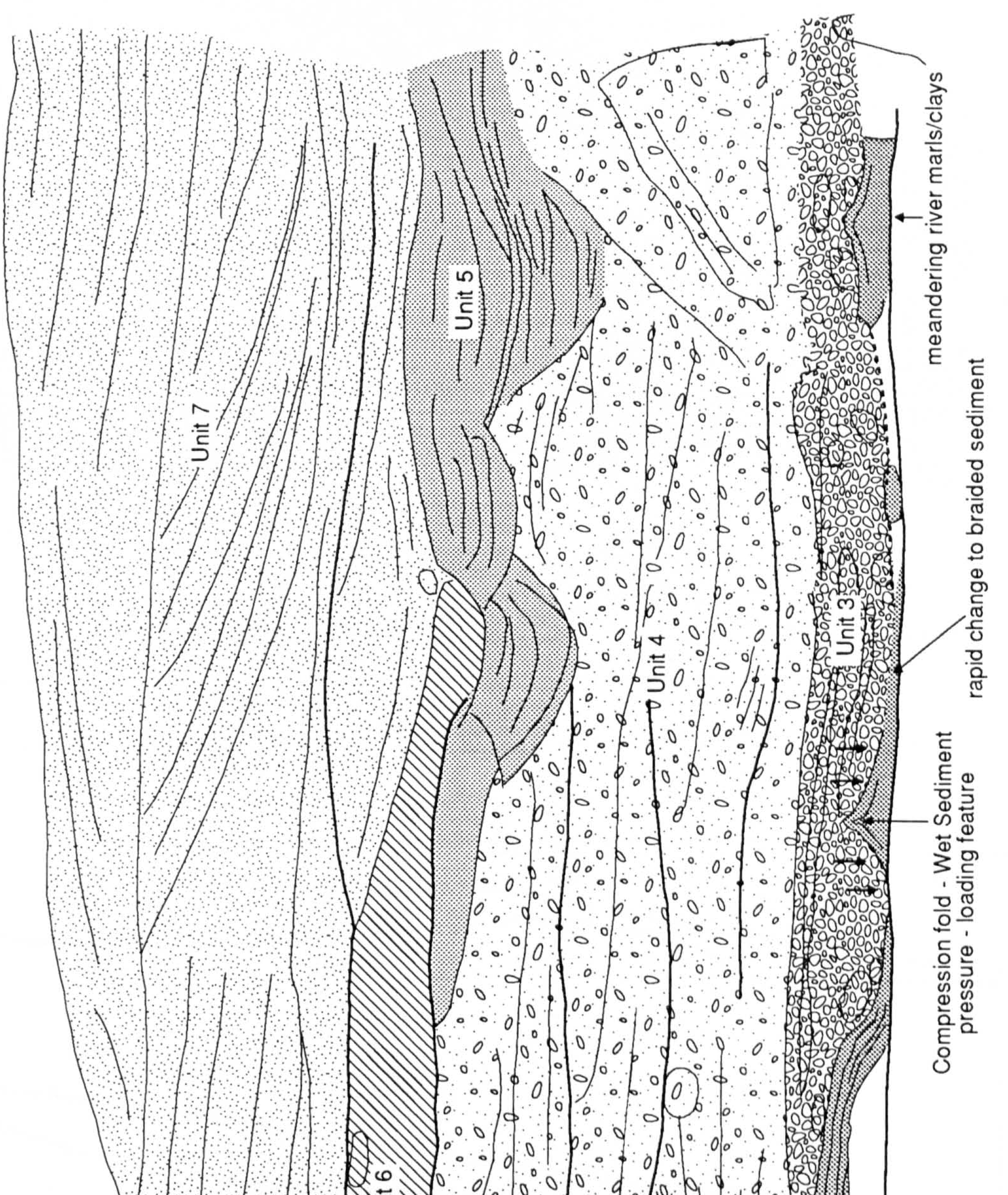
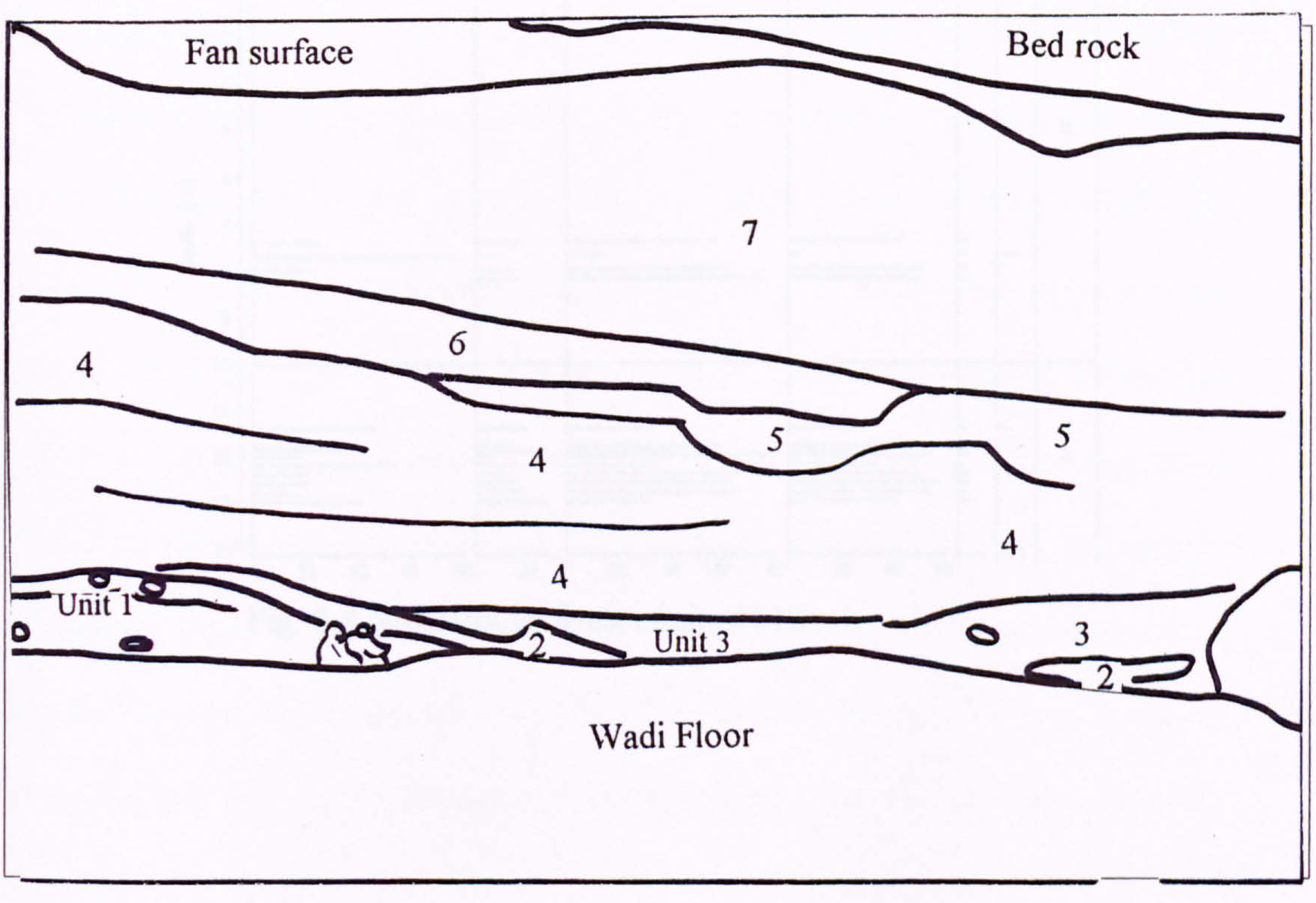


Fig. 5.3 Sketch section of site 5510

Plate 5.1 Site 5510 Wadi Ghuwayier, showing Holocene sequence, unit numbers conform to those in the text.



Explanation for plate 5.1

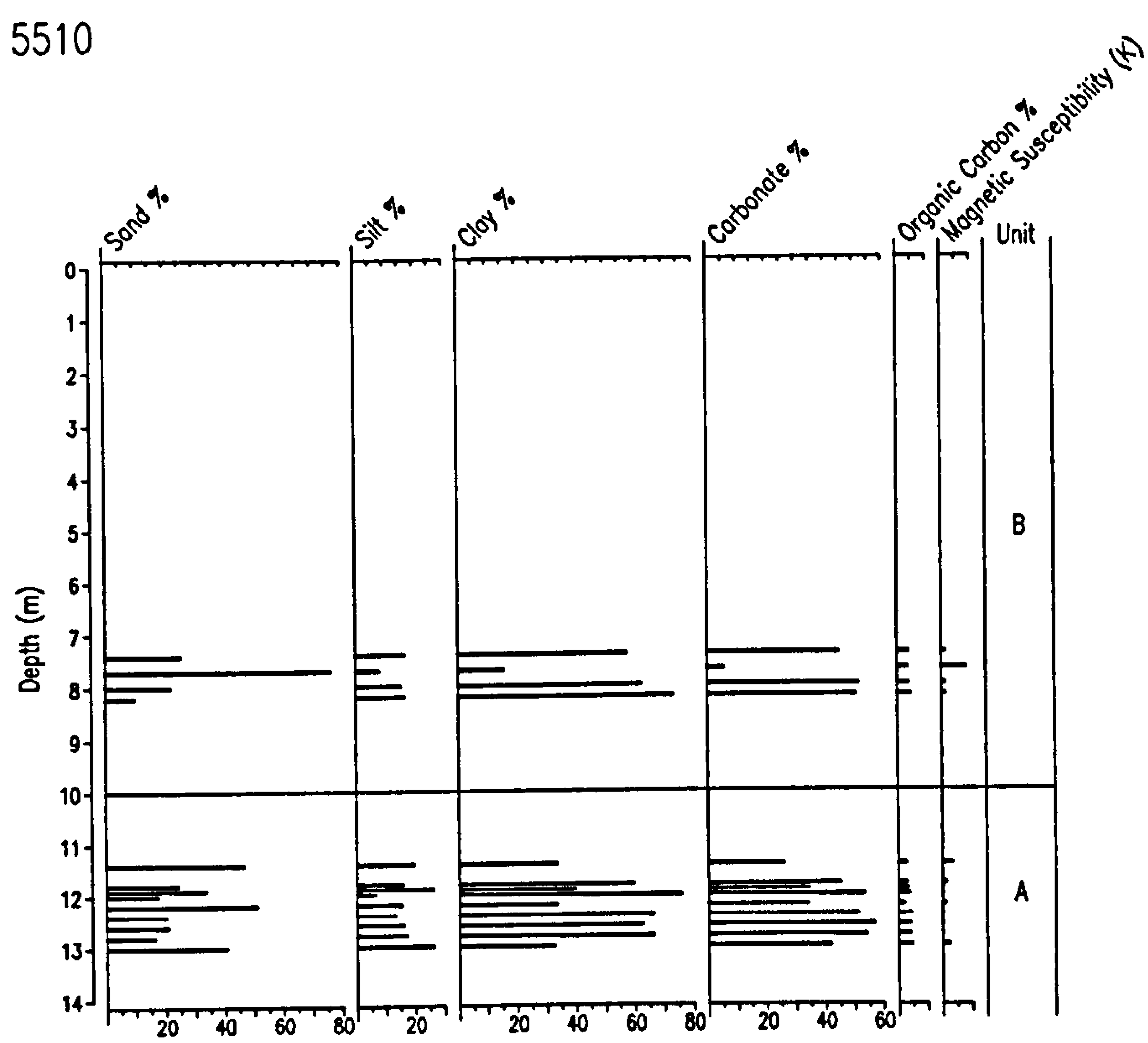


Fig. 5.4 Sediment analysis of site 5510

Unit A

This unit is equivalent to stratigraphic units 2 and 3 and represents the lower part of the diagram (figure 5.4). It is characterised by a high percentage of clay (32.7-76%), moderate percentage of sand (17-51%) and relatively low percentages of silt (6.6-26.5%). A relatively high percentages of carbonate (25.7-54.4%) has been recorded in this zone. A very slightly decreasing (4.7-2.19%) trend toward the top of this zone in organic carbon has been detected. Magnetic susceptibility varies in this zone (0.38-3.26 k) and does not show any pattern.

Unit B

This unit is equivalent to stratigraphic unit 4 and represents the upper part of the diagram (figure 5.4). This horizon is characterised by very high clay (15.6-73.4%), relatively low silt (7.9-16.8%) as might be expected and moderate to low sand (if the peak at depth 7.7 m is excepted) (9.9-25.5%). Carbonate is generally high (45-50.9%) and it does not show any trend. Organic carbon ranges between 3.4 and 4.4% and almost seems consistent in this zone. Magnetic susceptibility values mostly range between 1.2 and 1.4 k, with peak (8.44 k) at depth 7.7 m. In this horizon the carbonate recorded was relatively low and generally it seems that the magnetic susceptibility is opposed to the carbonate reading. Generally, because during the sampling we tried to concentrate on sampling from fine sediment for the purpose of palynology, the largest component of the sediments was clay. The high magnetic susceptibility value at sample R is a consequence of the sample being taken from an ash layer. Charcoal which is represented by ash reflected burning by people, but some fires may have begun during droughts or may have been caused by lightning (Tolonen, 1986). Moreover, such burning episodes create magnetically enhanced mineral particles which increases the magnetic susceptibility measurement.

5.2.5.3 Palynology

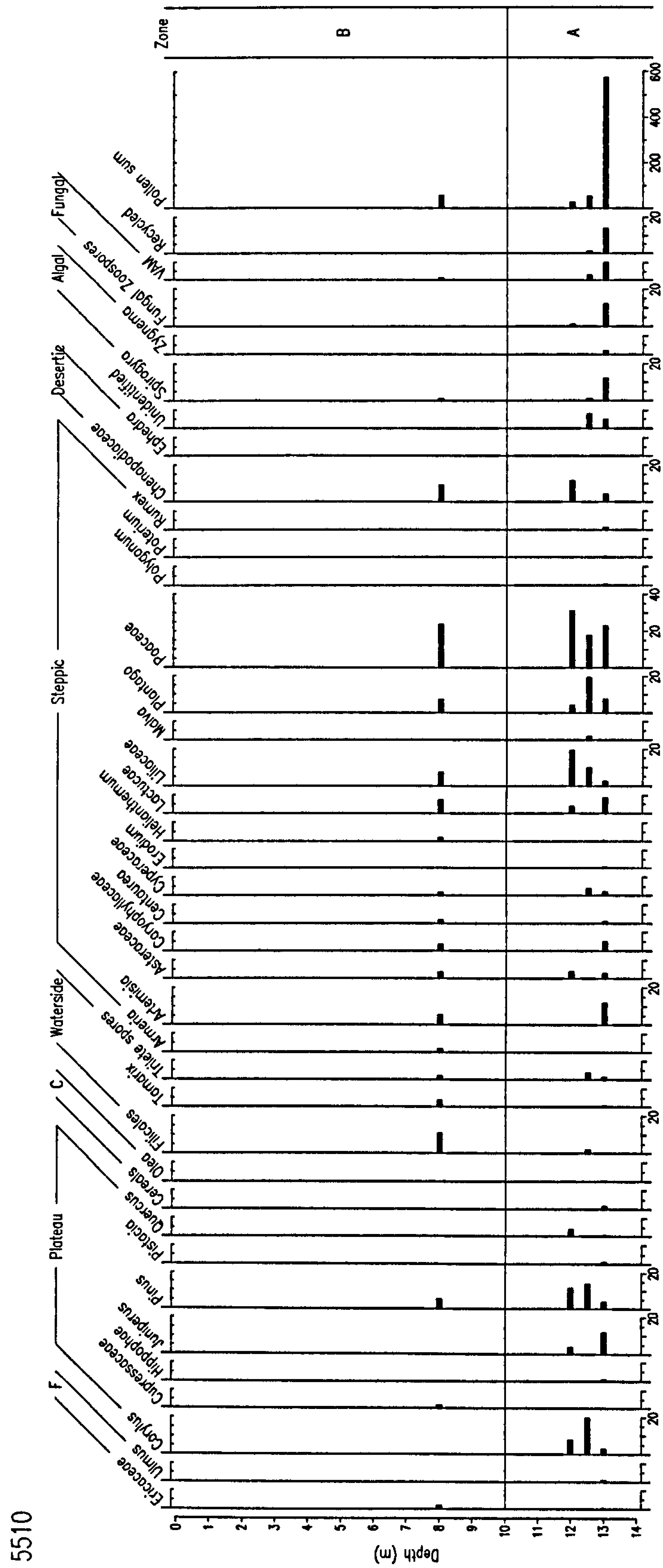
Some samples contained very low pollen and others contained no pollen, so samples are grouped together whenever they were from the same stratigraphic horizon (following Horowitz, 1992). Thus the pollen counts of the samples M1, M2, M3 and M4 were grouped together at depth 12.5 m, the pollen counts of F, G, H, and K were also combined together at depth 12 m and the pollen counts of samples O, P, R, and Q were lumped together at depth 8 m. Sample N at depth 13 m was rich in pollen and not grouped. The pollen diagram (figure 5.5) is divided into two assemblage biozones. A description of each assemblage biozone is presented below.

Assemblage biozone A

This assemblage biozone is characterised by significant counts of tree and shrub pollen including *Corylus* (3-19%), *Pinus* (3.5-15%), *Juniperus* (3-12.5%), *Quercus* (0.5-4%) and the occasional presence of *Ulmus*, *Pistacia*, *Hippophae*, Ericaceae and Cupressaceae (0-1%). The pollen of steppeland taxa is dominant in this zone, including Poaceae (18-30%), *Plantago* (4-19%), Liliaceae (2-18%), *Artemisia* (12.5%), Caryophyllaceae (5%), Cyperaceae (2-3.5%), Asteraceae (3-4%), Lactuceae (4-8%) and the occasional presence of *Rumex*, *Poterium*, *Malva*, *Helianthemum* and *Centaurea* (0.5-1%). Waterside species are also present including Trilete spores (1-3.5%), Filicales (undifferentiated) (2%) and rarely *Tamarix* (1%).

Cereal type (2%) and occasional *Olea* (<1%) which may or may not reflect cultivation. Desertic species, represented by Chenopodiaceae (3-11%) and rarely

Fig. 5.5 Palynology of site 5510. All pollen, spores and other microfossils are calculated as % total pollen and spores



Ephedra (<1%) are also present. Unidentified taxa are also present (4-7%). Algal microfossils are present including the benthonic *Spirogyra* (1.5-2.5%) and *Zygnemataceae* (3%). Also fungal microfossils are present including fungal zoospores (1.5-13%) and VAM (3-10%). Recycled pre-Quaternary pollen are also present (1-14%).

Assemblage biozone B

This Assemblage biozone is characterised by a decline in tree pollen compared to the previous zone. *Pinus* is present (6%). Other tree pollen were present, but in low concenrations including Cupressaceae and Ericaceae (1.5-2%). Steppeland taxa are present, including Poaceae (22%), *Plantago* (7.5%), Liliaceae (6%), *Artemisia* (5%), Asteraceae (3%), Lactuceae (6%). *Helianthemum* (2%), Caryophyllaceae (3.5%), Cyperaceae (2%) and *Centaurea* (2%). Desertic species are present including Chenopodiaceae (8%). Unidentified taxa are also present (4-8%). Algal microfossils are present including the benthonic *Spirogyra* (1%) and Fungal microfossils are present including VAM (1.5%).

5.2.5.4 Palynofacies

The palynofacies of this site was divided into two units which can be seen in (figure 5.6). A description of each unit is presented below.

Unit A

This unit lies between 10 and 14 metres and represents the lower part of the diagram. It is characterised by very high counts of Amorphous matter (90-99%). Fungal spores

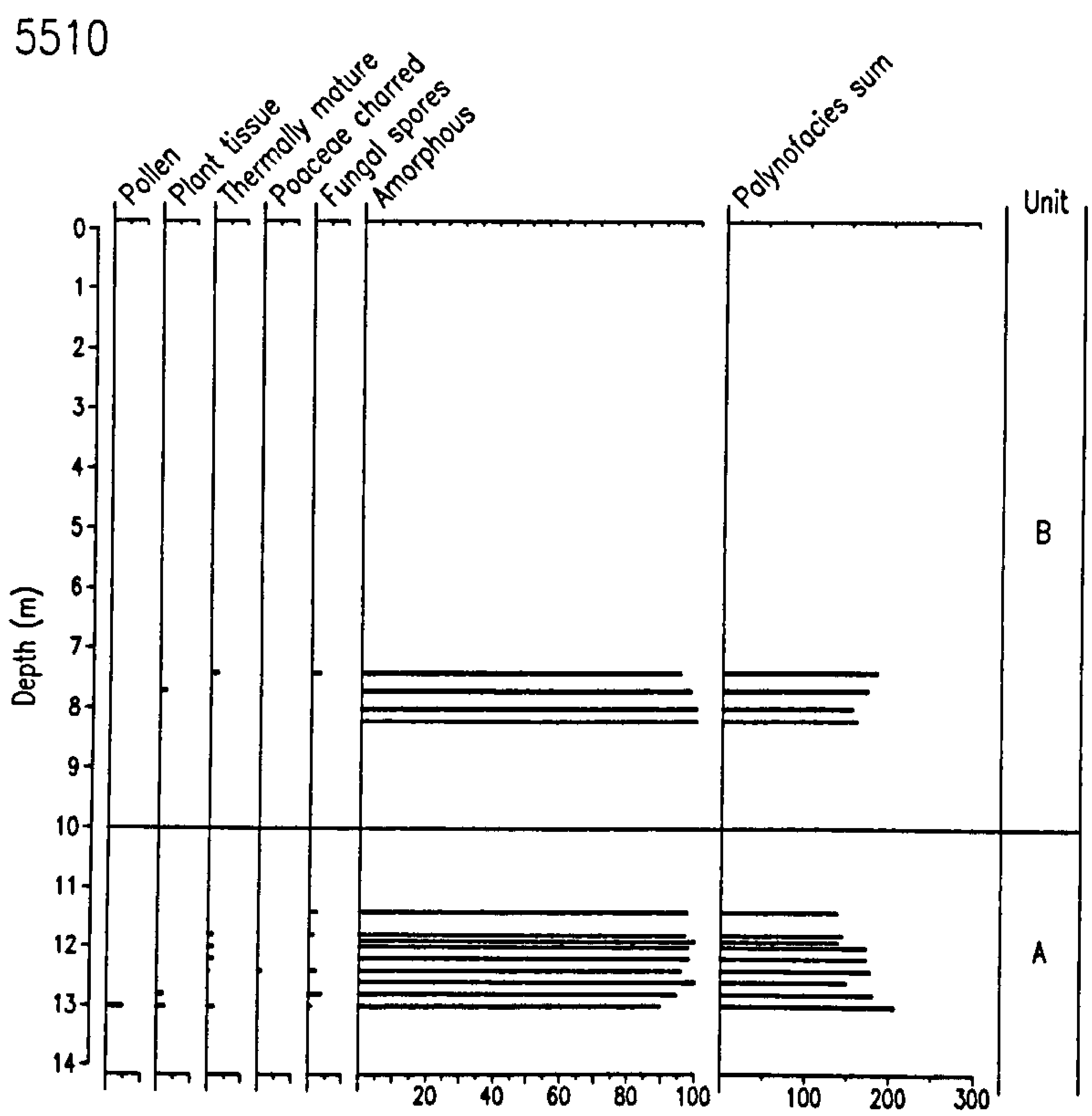


Fig. 5.6 Palynofacies of site 5510. All particulate organic matter is calculated as % total particulate organic matter

(2-4%), thermally mature (1-3%), plant tissue (2-3%) and occasionally pollen and Poaceae charred are present.

Unit B

This zone lies between 7 and 10 metres and represents the upper part of the diagram. This zone is characterised by very high counts of Amorphous matter (95%-99%) and occasional presence of fungal spores (3%), thermally mature (3.5%) and plant tissue (2%). Thermally mature and poaceae charred decline sharply in this zone and also fungal spores and plant tissue have dramatically declined.

5.2.5.5 Plant Macrofossils

Plant macrofossils (Macrobotanical remains) are usually considered as auxilliary evidence in a palynological interpretation (Butzer, 1972) but have the advantage of indicating unequivocally the former presence of a plant. Plant macrofossils were recovered from 5510 N. The identification are listed below in Table (5.3).

Table 5.3 Plant macrofossils from site 5510 N

Macrofossils	Number
Quercus ilex (leaf)	6
Olea sp. (wild) (stone)	2
Cupressus sp. (leaf)	1
Caryophyllaceae (achene)	1
Chenopodiaceae (achene)	1
Poaceae (seed)	3
Cyperaceae (nutlet)	3
Hippuris sp. (stone)	1

These plant macrofossils provide direct evidence of the presence of oak, wild olive and cupressus trees adjacent to the wadi floor during the Early Holocene (plates 5.2, 5.3, 5.4, 5.5), together with an assortment of herbaceous plants (Caryophyllaceae, Chenopodiaceae, Poaceae, Cyperaceae) and the aquatic *Hippuris*.

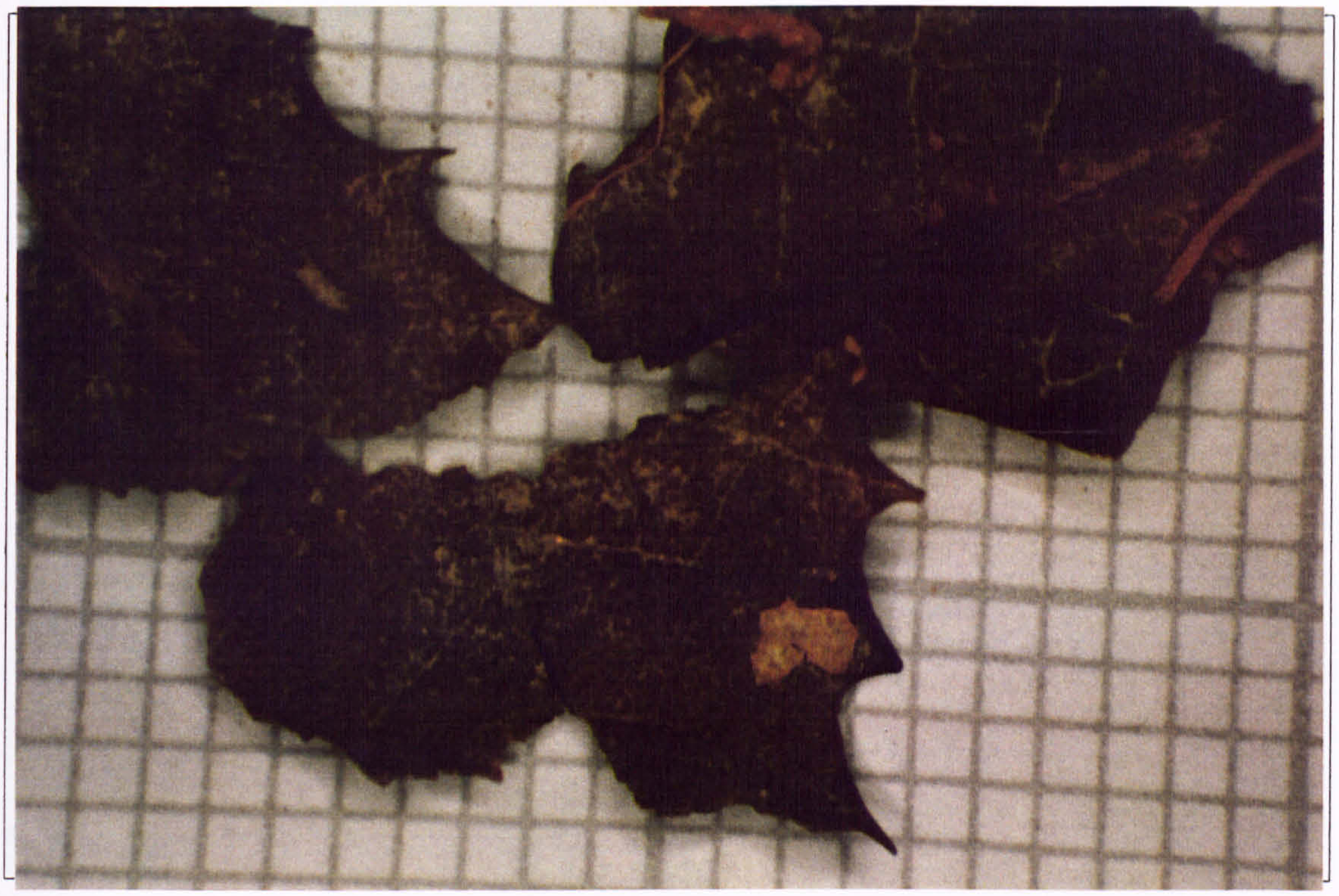


Plate 5.2 Oak leaf from site 5510 (N)

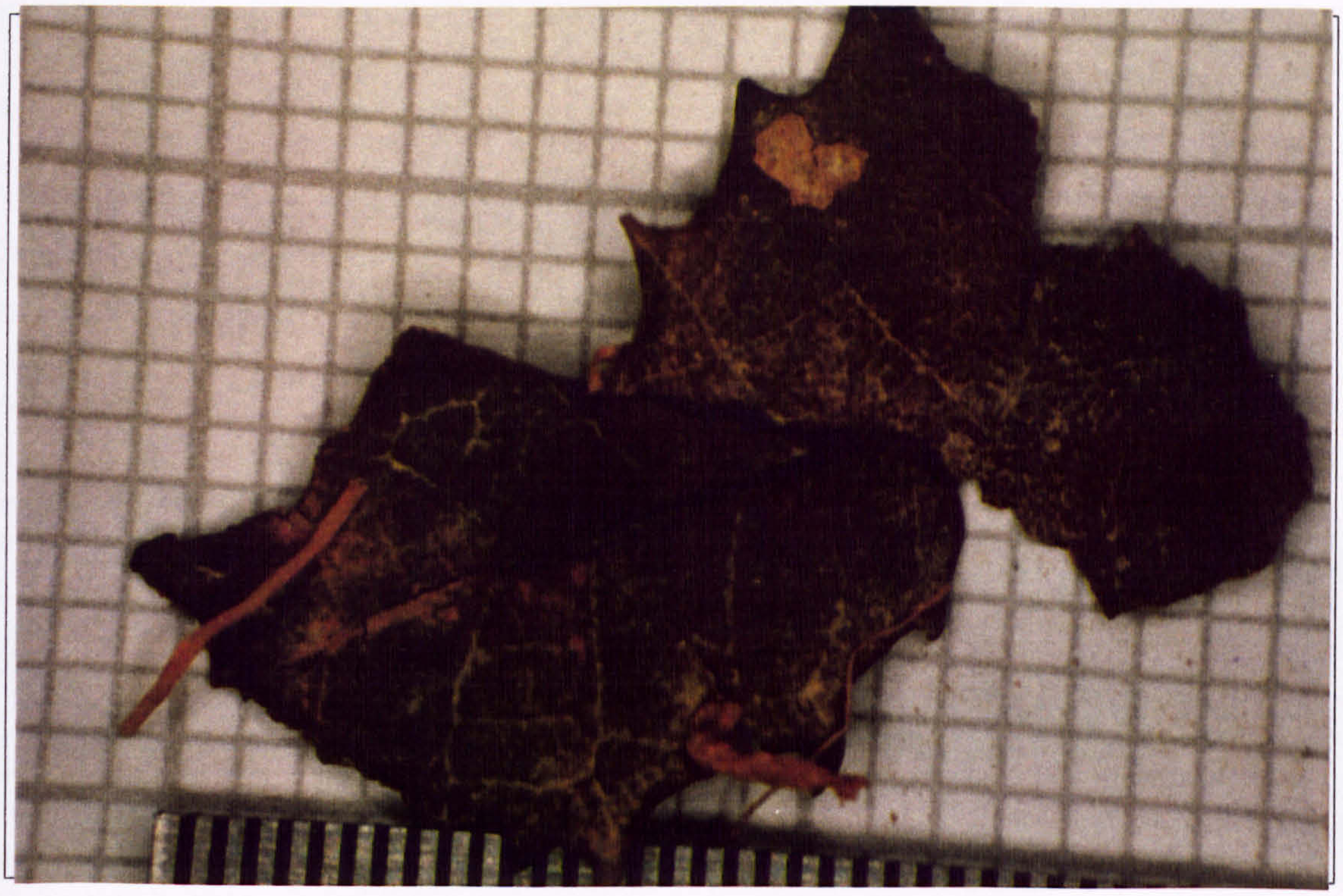


Plate 5.3 Oak leaf from site 5510 (N)

Plate 5.4 Olive stones discovered from site 5510 (N)

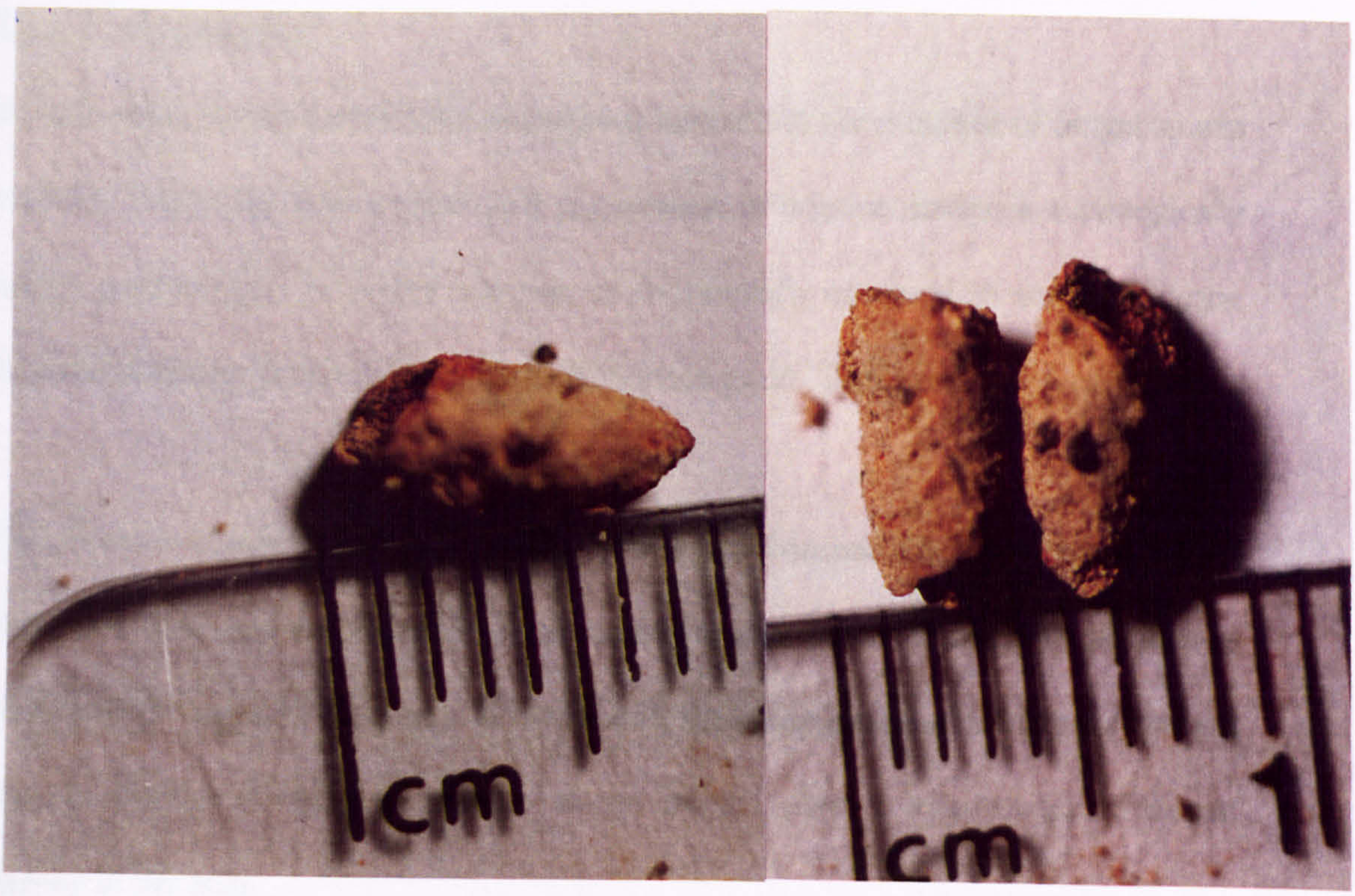


Plate 5.5 Olive stones discovered from site 5510 (N)

5.2.5.6 Dating

A sample of oak leaves was submitted for accelerator radiocarbon dating from sample 5510 N. The sample was heavily contaminated with modern carbon (probably through micro-infestation) and was undateable (Beta-119601). Local pollen biozone A equates biostratigraphically with biozone A from site 5500/5015, both being characterised by high *Corylus*, *Pinus*, Poaceae, *Plantago* and Liliaceae, and is thus likely to be more than 7,500 years old. Biozone B is similar to biozone B at site 5021; both are typified by *Pinus*, Poaceae, *Plantago* and diverse steppe assemblages. It is therefore about 6,000 years old.

It is suggested that unit 7, which are clearly alluvial fan sediments, may be equivalent to the alluvial fan sediments at site 5509. They were, however, inaccessible and could not be sampled.

5.2.5.7 Interpretation

In both units, the high counts for amorphous matter and the presence of fungal spores probably reflect the post-depositional degradation of organic matter in a biologically active environment. A similar process of degradation occurred in early Holocene deposits at Grerat D'nar Salem, Libya (Gilbertson *et al.*, 1994).

The presence of low counts of thermally mature and Poaceae charred probably reflect some sort of human activity such as processing cereals or the burning of the grass to clear land for agricultural crops. In biozone B, the disappearance of Poaceae charred and the decline of thermally mature matter might reflect a contraction of human activity in the area.

Event sequence inferred

1. Energetic sedimentation, deposition of imbicated coarse gravel ? Late Pleistocene (Unit 1).

2. Low energy ? perennial flows; chemical solution and biogenic precipitation of carbonates in a meandering river. Early Holocene (Unit 2).

3. Breakdown of meandering system. Small-channel braided alluviations. ? Deforestation by people or by climate change ? (Unit 3).

4. Large-scale cross-bedding, developing in mostly sandy sediments. Trough-cross bedding Unit 4. ? sheet wash or aeolian activity removing soil mantles in the wadi sides around this site.

5. Alluvial fan activity starts and wadi incises. Erosion surface develops on Unit 4

6. The developing alluvial fan is overtopped by wadi sedimentation (Unit 6).

7. Alluvial fan dominant. Wadi sedimentation negligible, ?

8. Incision and cessation of alluvial fan development.

5.2.6 Site 5021 (Type section)

5.2.6.1 Introduction

This site, (figure 5.7, plate 5.6) consists of 1.5 m of epsilon cross-bedded of pale-grey silts, stony silty diamicts and ash beds all with much ash, charcoal, bone and potsherds. Traces of reed-rhizomes and dessication-cracks occur in a few levels. The deposits infill a small channel incised into the Pleistocene gravels, dated to approximately 45,900 BP (G. Duller *pers. comm.*, 1998), the channel fills dated at the top to *c.* 6110 ± 75 BP uncal. (HD 12338) (Al-Najjar *et al.*, 1990) and are overlain by *c.* 1.2-1.6 m of aeolian silt. Eleven samples were collected from the epsilon cross-bedded silty channel fill.

This site is the Till Wadi Faynan site of Al-Najjar *et al.* (1990). This Neolithic site partially overlays the channel and is dated to 5,000-6,410 years BP. It is therefore *c.* 1,000 years later than the site 5015, but earlier than site 5051. The samples considered below are taken from the epsilon cross-bedded silty channel fill below the archaeological site.

5.2.6.2 Sediment analysis

The sediment diagram, (figure 5.8) can be tentatively divided into two units. Below is a general description of each unit.

Unit one (lower unit: samples a-d)

This Unit is generally characterised by high levels of clay (72-88%), [if the low level in sample a is excepted] and low levels of silt (11-18%). Generally, the proportion of clay rises when that of silt falls and vice versa. There are low percentages of sand (2-

Fig. 5.7 Sketch section of site 5021

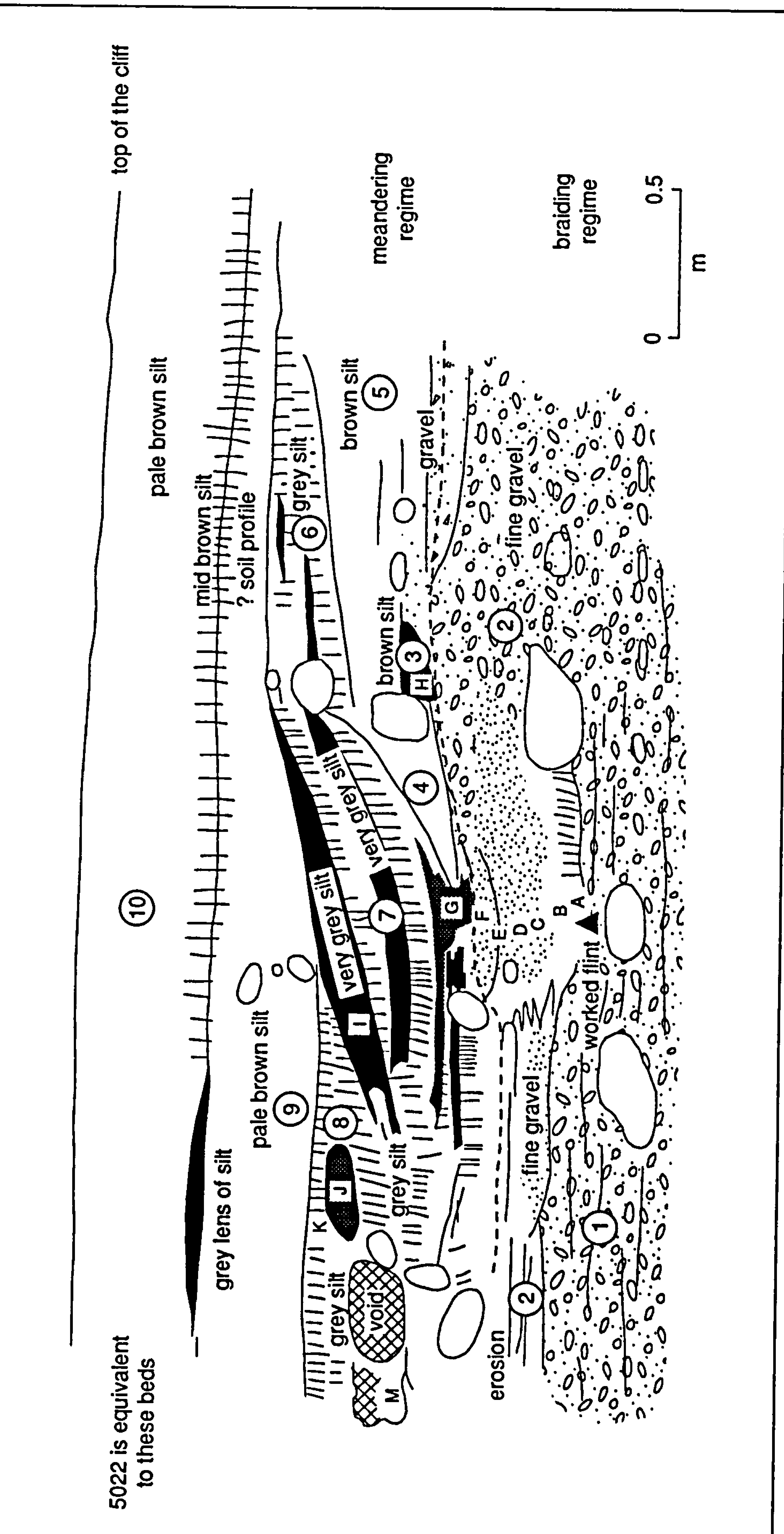
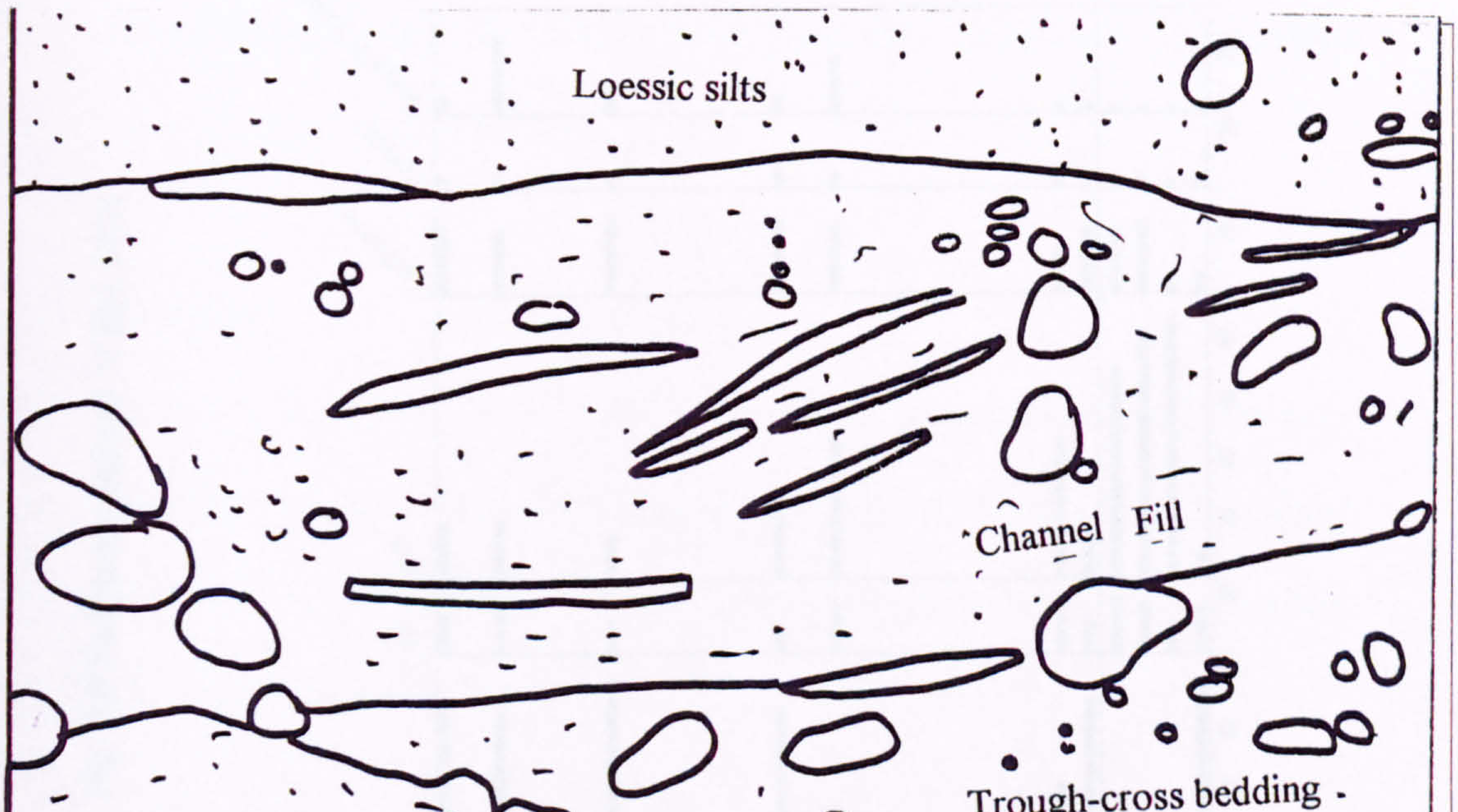


Plate 5.6 Site 5021 showing the stratigraphic relations of the channel fill



Explanation for plate 5.6

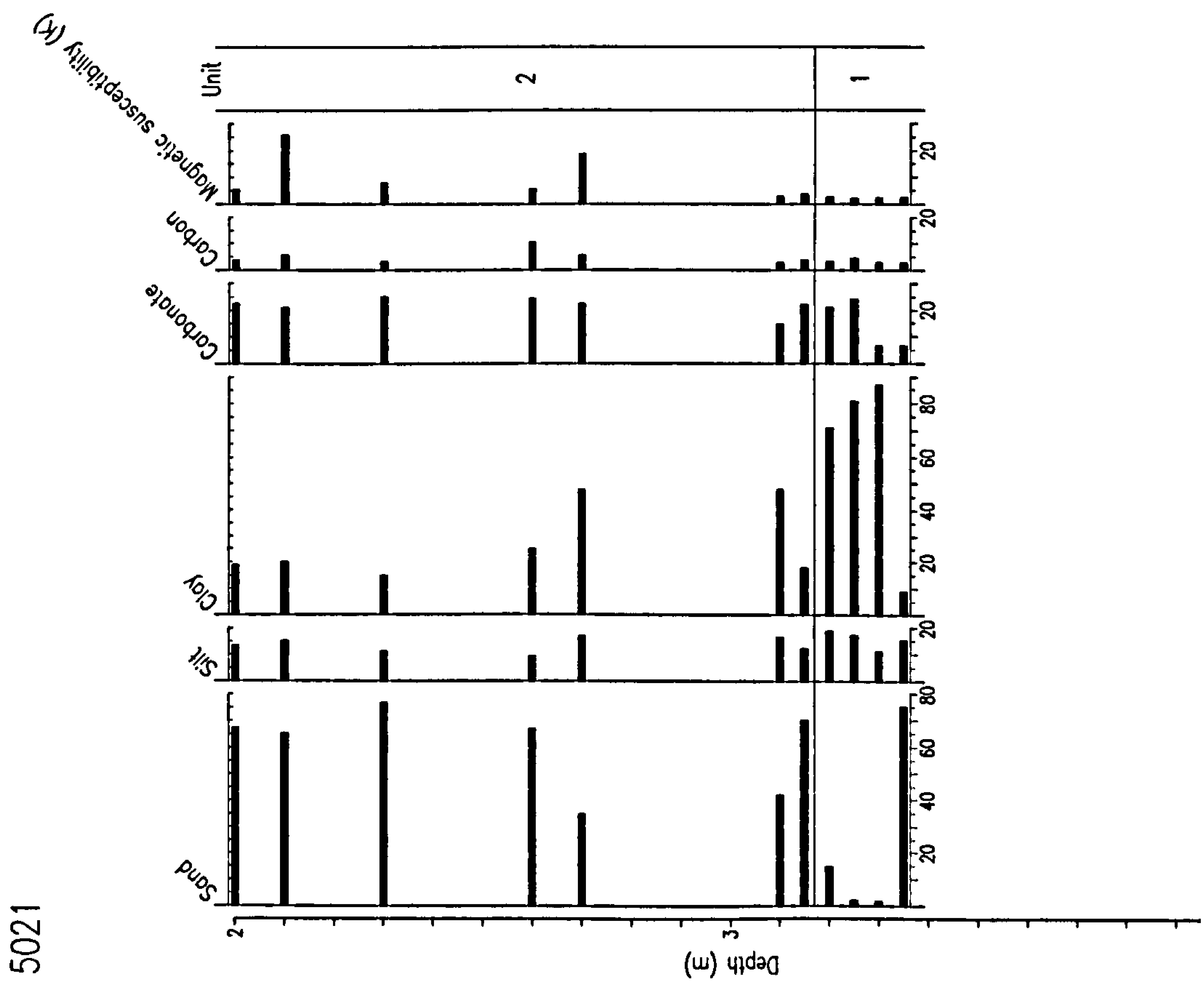


Fig. 5.8 Sediment analysis of site 5021

14%), again if the peak at a level is excepted. In this Unit, the value of Magnetic Susceptibility is low and ranges between 2 and 4 k. Carbon values shows a slightly increasing trend towards the top of this Unit (4-6%), and carbonate (which is derived from nearby rocks and sediment, mostly shell fragments) shows an increasing trend from the lower part of this Unit towards the top (7-22%).

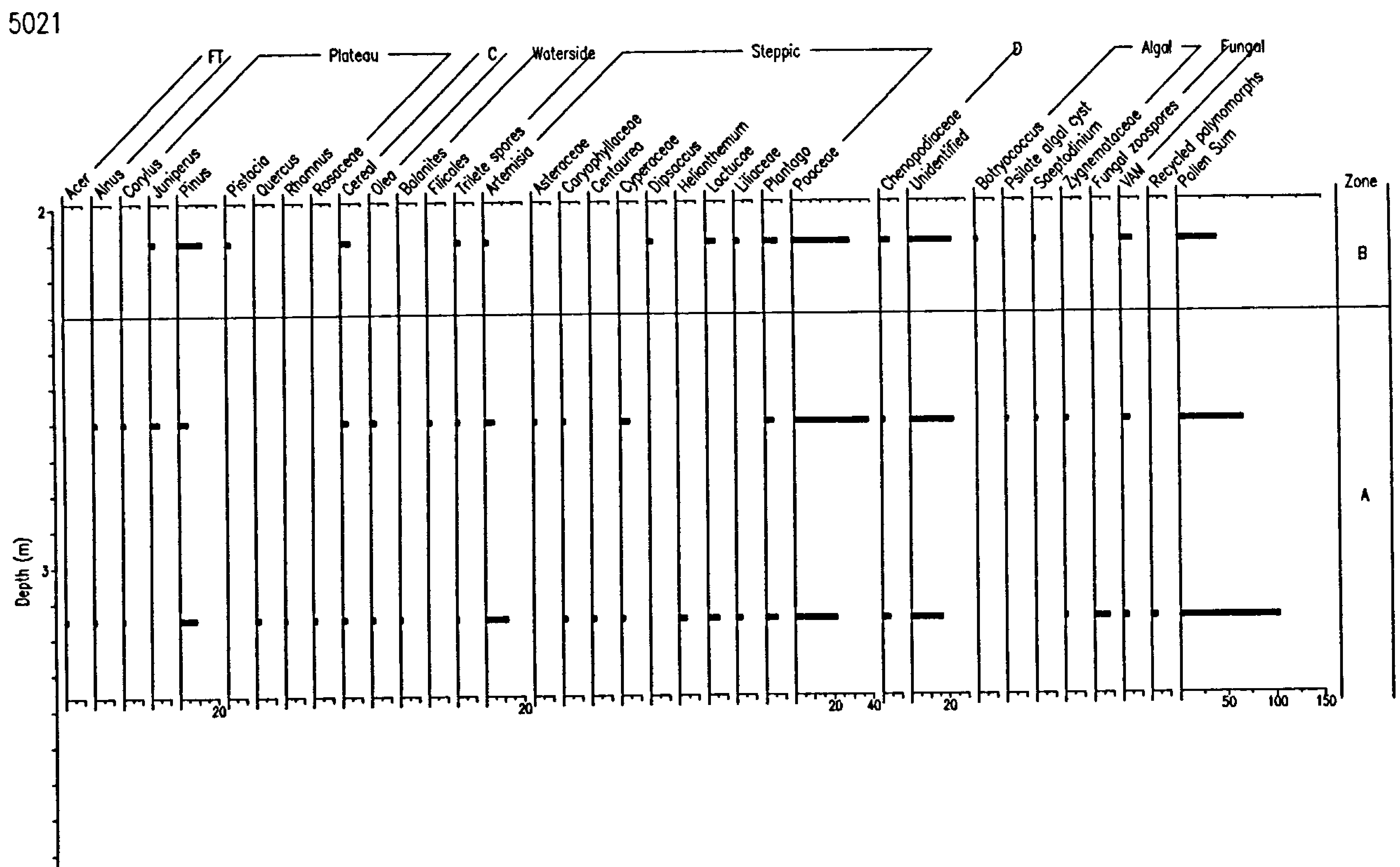
Unit two (Upper unit: samples e-k)

Generally, the depositional energy in this unit was greater than in the lower Unit. High proportions of sand can be seen (43-75%), and sand deposition shows a general increase towards the top of this Unit. Clay in this Unit starts with a low level at sample e and then increases (46-48%) at samples f and g and decreases towards the top (27-20%). Silt generally shows a reverse trend to clay and in this unit the values of silt are less than the percentages of clay (10-18%). Magnetic susceptibility values generally increases towards the top (4-19 k); carbon increases towards the top (5-12%), probably because this unit contains cultural deposits. Carbonate also increases towards the top of this Unit (12-22%).

5.2.6.3 Palynology

Pollen recovery was poor in many horizons, so counts from adjacent samples were aggregated following Horowitz (1992). The pollen diagram of the site 5021, (figure 5.9) can be considered as two biozones. Below is a description of their contained palynology, described by each biozone.

Fig. 5.9 Palynology of site 5021. All pollen, spores and microfossils are calculated as % total pollen and spores



Assemblage biozone A (samples: a,b,c,e and h)

This assemblage biozone is characterised by a relatively high percentages of Poaceae (21-38%) a relatively high proportion of *Artemisia* (5-12%), with *Plantago* (4-6%), *Centaurea* (1.5%), Liliaceae (4%), *Helianthemum* (4.5%), Cyperaceae (2%), Caryophyllaceae (1-1.5%), Chenopodiaceae (1-4%), Asteraceae (1.5%), Balanites (1%) and Lactuceae (5%). Potential cultivated taxa are present such as *Olea* (1.5-2.5%) and Cereal type (1.5-2.5%). Fairly sparse tree pollen is recorded, such as *Pinus* (4-9%), *Juniperus* (5%) and occasionally *Rosaceae* (2%), *Rhamnus* (1%), *Quercus* (2%). Other tree taxa are present rarely: including *Corylus* (1-2%), *Almus* (1%) and *Acer* (1-1.5%). Waterside species- identified by trilete spores are also present rarely (1-1.5%). Unidentified taxa are present (17-21%). Also present are fungal zoospores (8%) and VAM (3.5-4%). Algae were also detected, including *Saeptodinium* (1%), Psilate algal cyst (1.5%) and Zygnemataceae (1.5-2%).

Assemblage biozone B (samples i and j)

This assemblage biozone is characterised by a relatively high percentages of Poaceae (30%), *Plantago* (8%), Liliaceae (3%), *Dipsaccus* (3%), *Artemisia* (2%), Chenopodiaceae (5%) and Lactuceae (5.5%). A relatively high proportion of potential cultivated taxa were present, especially Cereal-type (5.5%). Plateau species were detected, including *Pistacia* (2.5%), *Juniperus* (2.5%) and relatively high levels of *Pinus* (12%). Water side species are rare (Trilete spores: 2.5%). Unidentified taxa are present (20%). Algae were also detected occasionally, including *Botrycoccus* (1%) and *Saeptodinium* (1%). Fungi are also present- VAM (6%) and Fungal zoospore (1%).

5.2.6.4 Palynofacies

The results of palynofacies analysis can be seen in figure 5.10. It can be seen that there are considerable differences between the palynofacies assemblages in the two units in the diagram. Set out below is a description of these units.

Unit one

This unit lies between 3.5 and 2.65 m and is dominated by high counts of amorphous matter (45-86%) and relatively low counts of thermally-mature wood (8-43%). Pollen grains are virtually absent. Also, VAM are present in low percentages (4%), fungal zoospores (3-4%) and Poaceae (charred) are present (4-20%).

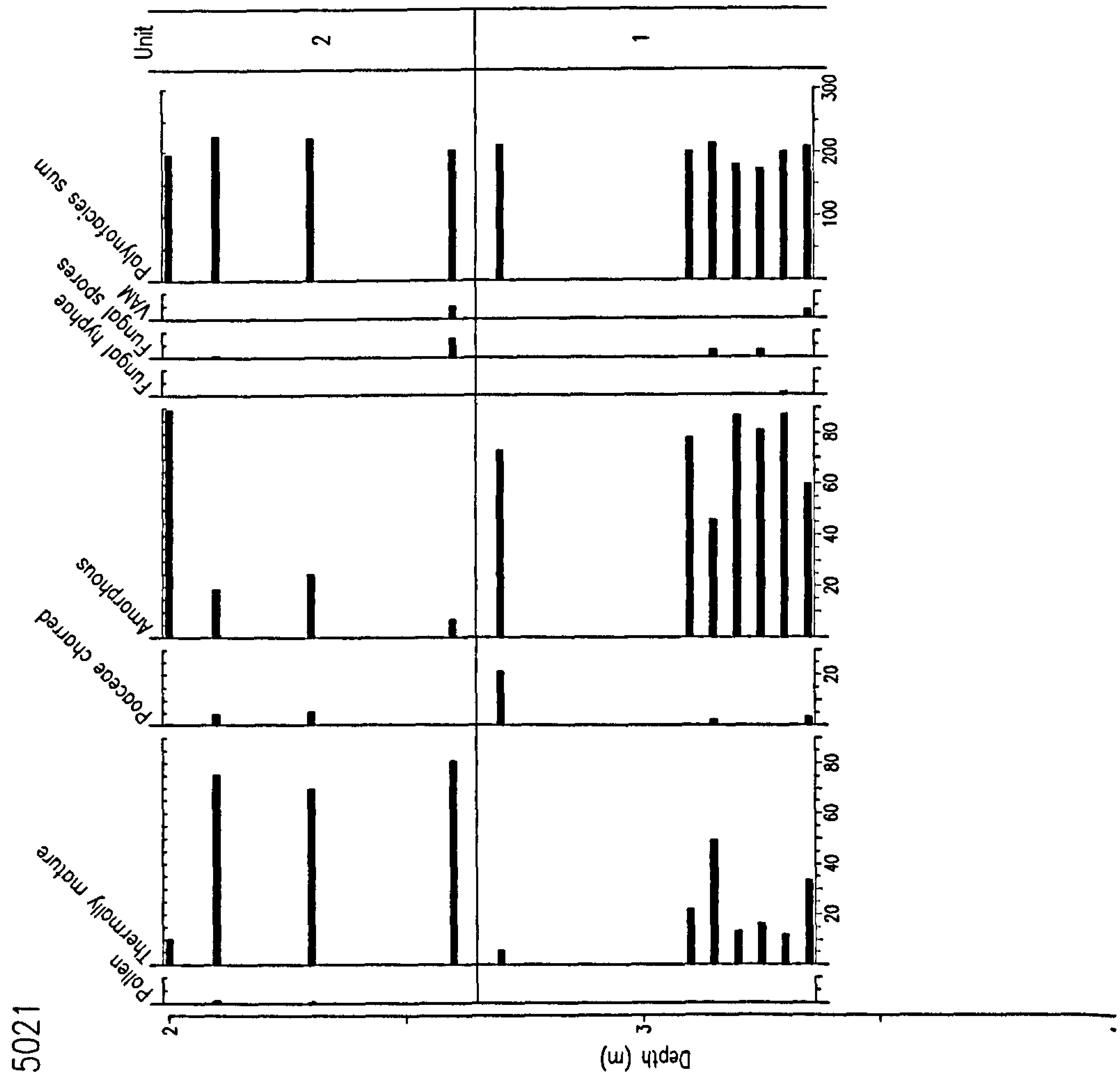
Unit two

This unit lies between 2.65 and 2.0m and is characterised by a high level of thermally mature wood (69-85%). Relatively low levels of amorphous matter (if the peak at 2.70 is excepted) are present (6-25%).

5.2.6.5 Molluscs

Three specimens of mollusc *Melanopsis praemorsa* (Linnaeus) were recovered from this site. This is a freshwater species which requires permanent water (Pfleger and Chatfield, 1983).

Fig. 5.10 Palynofacies of site 5021. All particulate organic matter are calculated as % total particulate organic matter



5.2.6.6 Diatoms

Analysis of some samples revealed the presence of frustules of the diatom *Navicula* which in this context must be considered to be an aquatic organism (The analysis carried out by F. B. Pyatt at the Nottingham Trent University, *pers. comm.* 1998).

5.2.6.7 Dating

Al-Najjar *et al.*, (1990) secured radiocarbon dates of 6410 ± 115 BP uncal. (BC 5520-5270) (HD 10567) and 6,360 ± 45 BP uncal. (BC 5345-5240) (HD 12335), from the base of the archaeological site, which interdigitates with the channel fill deposits described above. A date, higher in the archaeological site of 5740 ± 35 BP uncal. (BC 4675-4575) (HD 12337), overlies the end of fluvial depsition in aeolian sediments. A date of 5,375 ± 30 BP uncal. (BC 4330-4165) (HD 12336) was obtained within, from 1.05 m from the surface of the aeolian sediments (Al-Najjar,1990).

5.2.6.8 Interpretation

From the results shown above, it seems probable that the environment was a dense (rich) steppe with relatively high biodiversity. The incidence of relatively high levels of Poaceae probably reflects grasses on the steppe and reeds by the river. Reed rhizomes have been found in the sediments at this site. In zone one of the palynofacies, the high incidence of amorphous matter may be derived from decay products of aquatic flora or dumped rubbish from the site into the water body. The high clay content of these deposits suggests insufficient current movement to wash away fine-grained organic matter. A considerable quantity of Poaceae (charred) may reflect the processing of cereal grains in or around the site, or any sort of burning of grass; maybe accidently or on-purpose. Furthermore, the high levels of thermally mature material in zone two of the palynofacies diagram could be interpreted as a result of some form of human activity which involved a great deal of burning.

The meandering channel suggested by the epsilon cross-bedding could be attributed to climatic conditions very different from the seasonal rainfall and considerable aridity of the present, with a less seasonal climate, perennial water in the Wadi and less flashy discharge (cf. Briggs and Gilbertson, 1980). A similar conclusion can be deduced from the presence of the shells of *Melanopsis praemorsa* which requires permanent water.

5.2.7 Site 5015/5500

5.2.7.1 Introduction

Site 5500 is located beneath site 5015 in the Wadi Dana. Consequently the pollen and palynofacies counts of both sites were dealt with together as one sequence. The following is an analysis and interpretations of the sediments, geochemistry, palynology, palynofacies and geochronology of this sequence.

5.2.7.2 Geomorphological relationships

Site 5015/5500 (figure 5.11) lies about 10 m above the current floor of the Wadi Dana, on a fluvially-cut surface on a bedrock-spur itself eroded across Fidan Syenogranite (FN) of Pre-Cambrian age. The site lies about 3 m lower than site 5016, which is about 50 m downstream. This loessic site has been provisionally OSL dated to approximately 15,000 $\pm$ 1100 BP (G. A. T. Duller, *pers. comm.* 1998).

5.2.7.3 Stratigraphy

The stratigraphy of the site is complex. At 5500 (figure 5.12, plate 5.7), 1.6 m of fine shelly gravels with a lens of ashy sand (sample K) pass conformably upward into 0.4 m of sand with shelly horizons at the base (sample G). The sands are overlain by 0.5 m of ashy silt (sample F), which in turn is overlain by 0.7 m of silt (sample D). These are overlain by colluvium about 0.3 m thick.

5015 appears to be stratigraphically higher (Figure 5.13, plate 5.8) than the 5500. 1.5 m of coarse epsilon cross-bedded gravel are overlain by up to 0.5 m of sand (sample C), on which is developed a palaeosoil (sample B) 0.2 m deep. The palaeosol contains

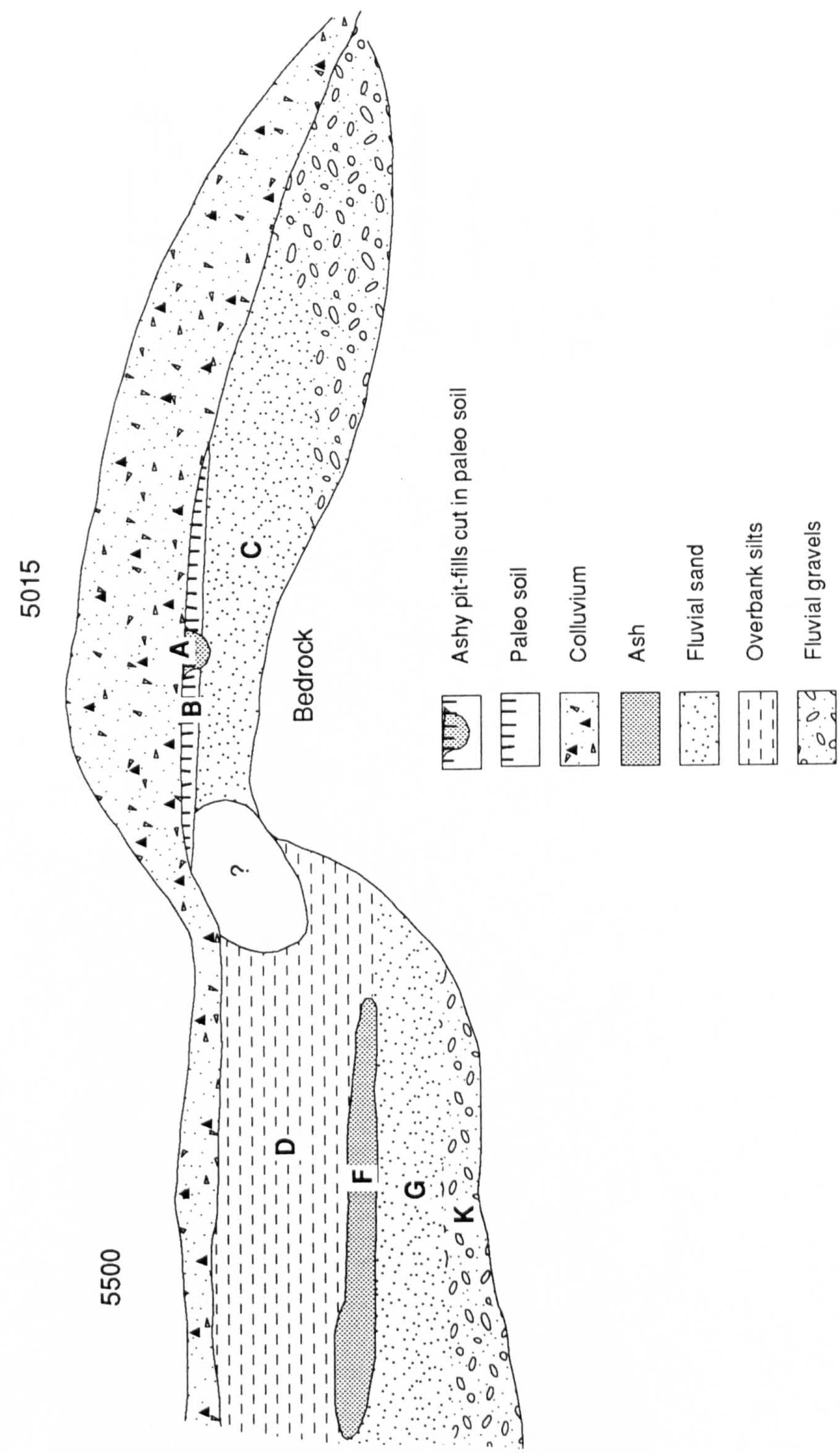


Fig. 5.11 sketch section showing stratigraphical relationships at site 5015/5500

Fig. 5. 12 Sketch section of site 5500

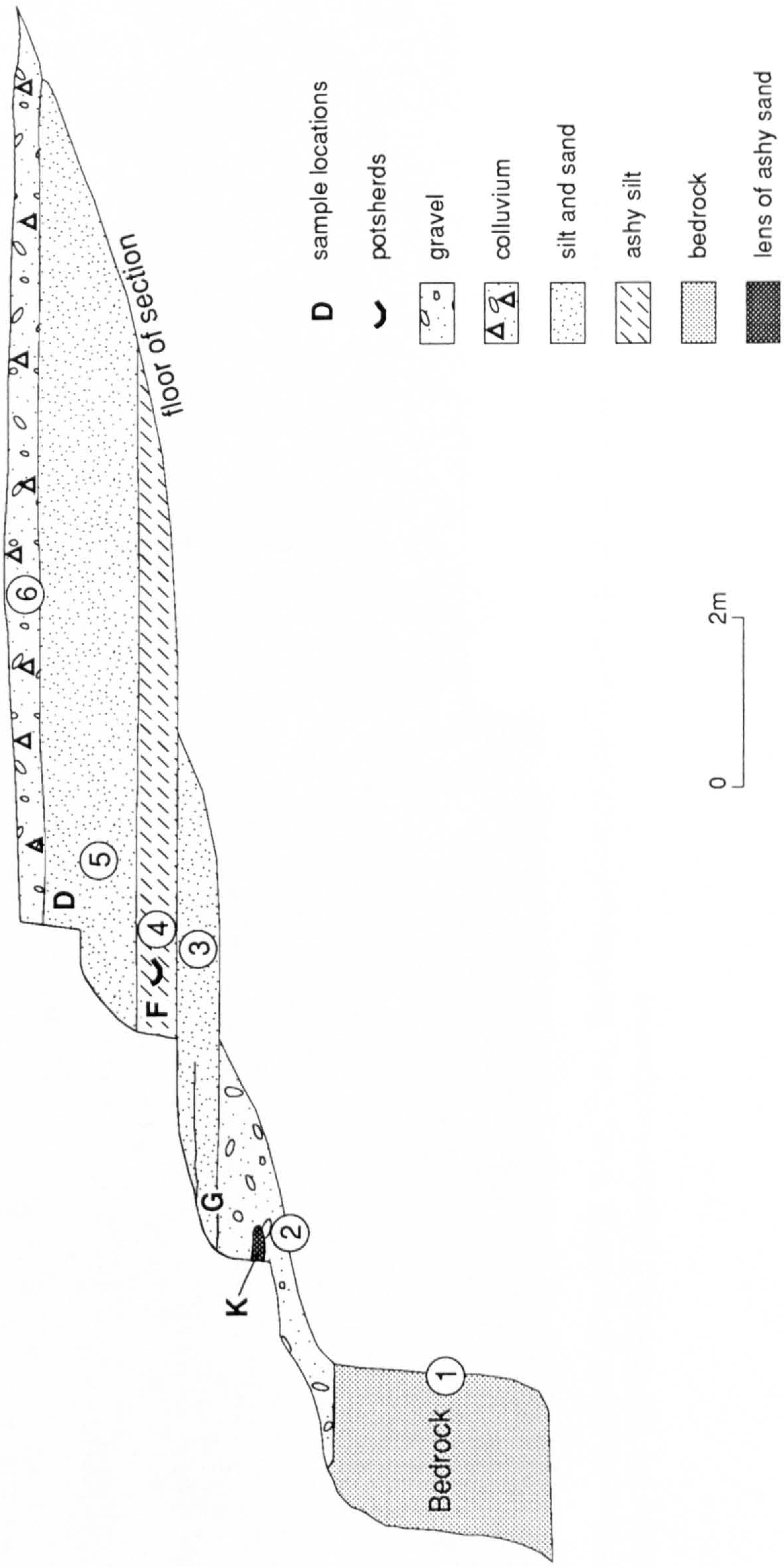


Plate 5.7 Composite photo of site 5500, Wadi Dana, showing gravels (2) passing up into silts and sands (3,5) with ashy horizon (4) and capped with colluvial gravels (6). See following page for explanation.

Explanation for plate 5.7

Fig. 5.13 Sample location of the site 5015

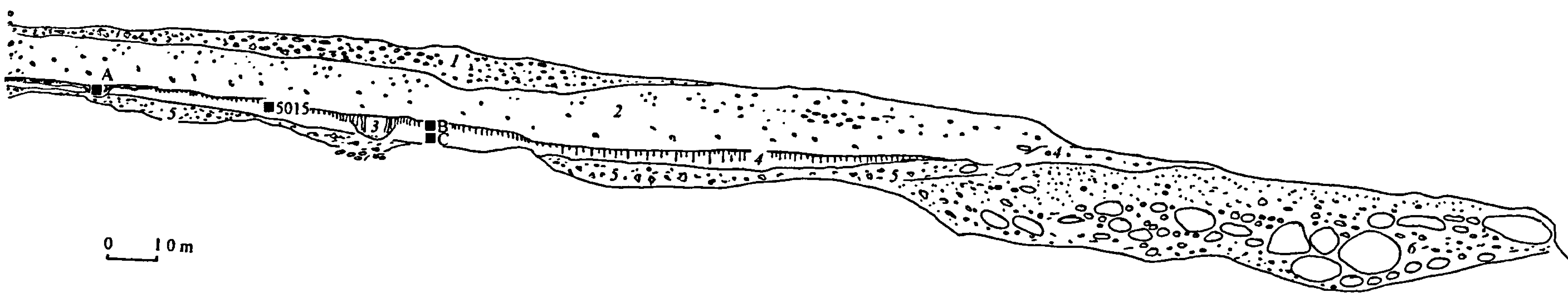
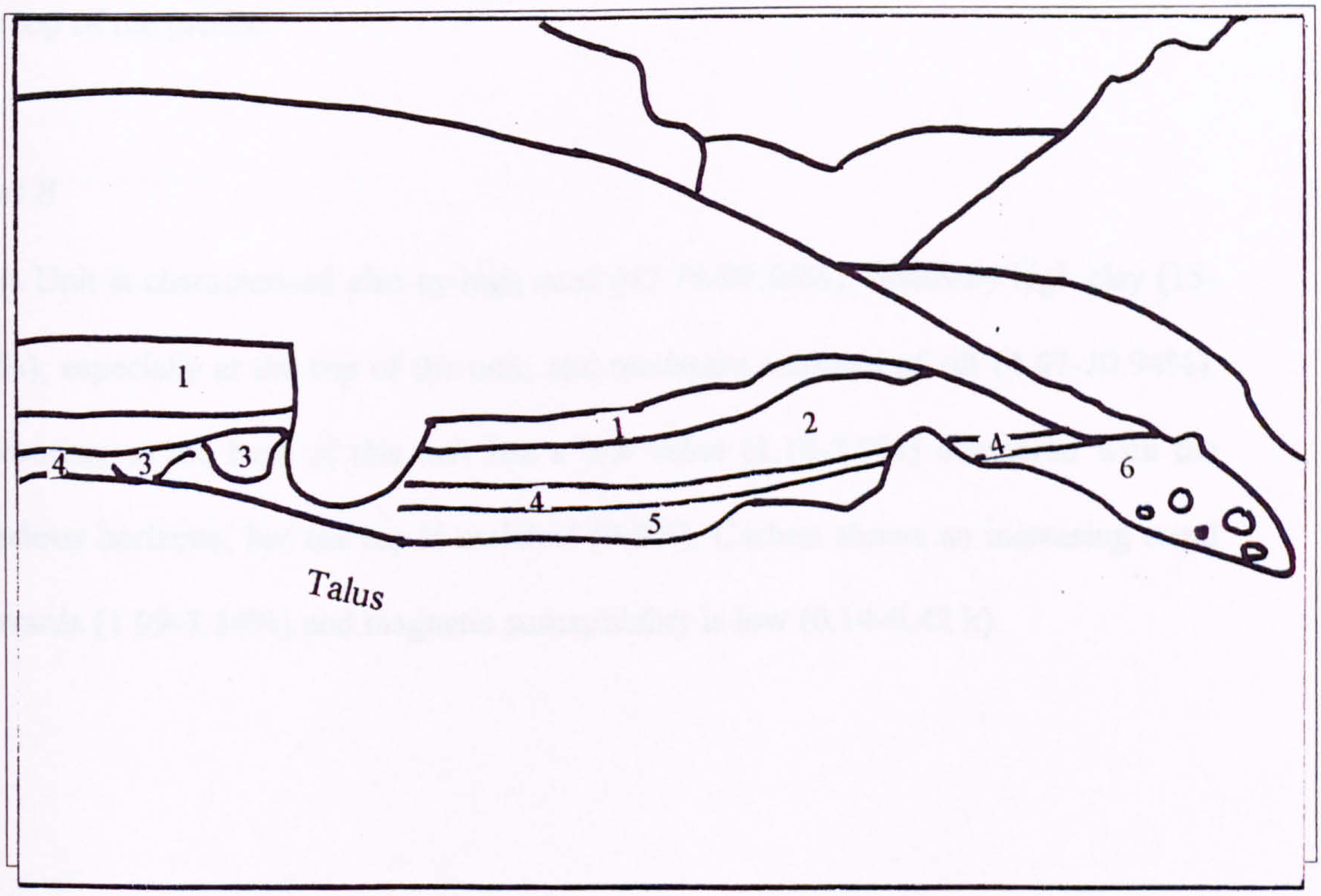


Plate 5.8 Site 5015 Wadi Dana, showing basal gravels (6) overlain by overbank sediments (5), ashy archaeological deposits (4) and colluvium (1,2)



Explanation for plate 5.8

calcified root tubules and is enriched with clay. It also contains a significant amount of ash and occasional neolithic artifacts. A number of ashy-pit fills were cut in the paleosoil (sample A). The palaeosoil radiocarbon dated to 7,240 ± 90 BP uncal. (Beta-111121). The palaeosoil and pit fills are overlain by stony and silty colluvium up to 1.6 m thick.

5.2.7.4 Sediment analysis

Sediment analysis can be seen in (figure 5.14). The sediment diagram can be divided into three layers: below is a description of each unit.

Unit A

This Unit is characterised by high sand (60.26-68.33%), relatively high clay (18.88-27.19%) and moderate amounts of silt (12.55-14.59%). Carbonate (5.83-15.99%), Carbon (1.83-2.43%) and magnetic susceptibility (0.91-2.56 k) all increase towards the top of the profile

Unit B

This Unit is characterised also by high sand (47.78-80.66%), relatively high clay (15-34%), especially at the top of the unit, and moderate amounts of silt (4.67-20.94%). Carbonate at the base of this unit has a low value (1.16-2.9%) compared with the previous horizone, but the top is enriched (9.8%). Carbon shows an increasing trend upwards (1.99-3.34%) and magnetic susceptibility is low (0.14-0.42 k).

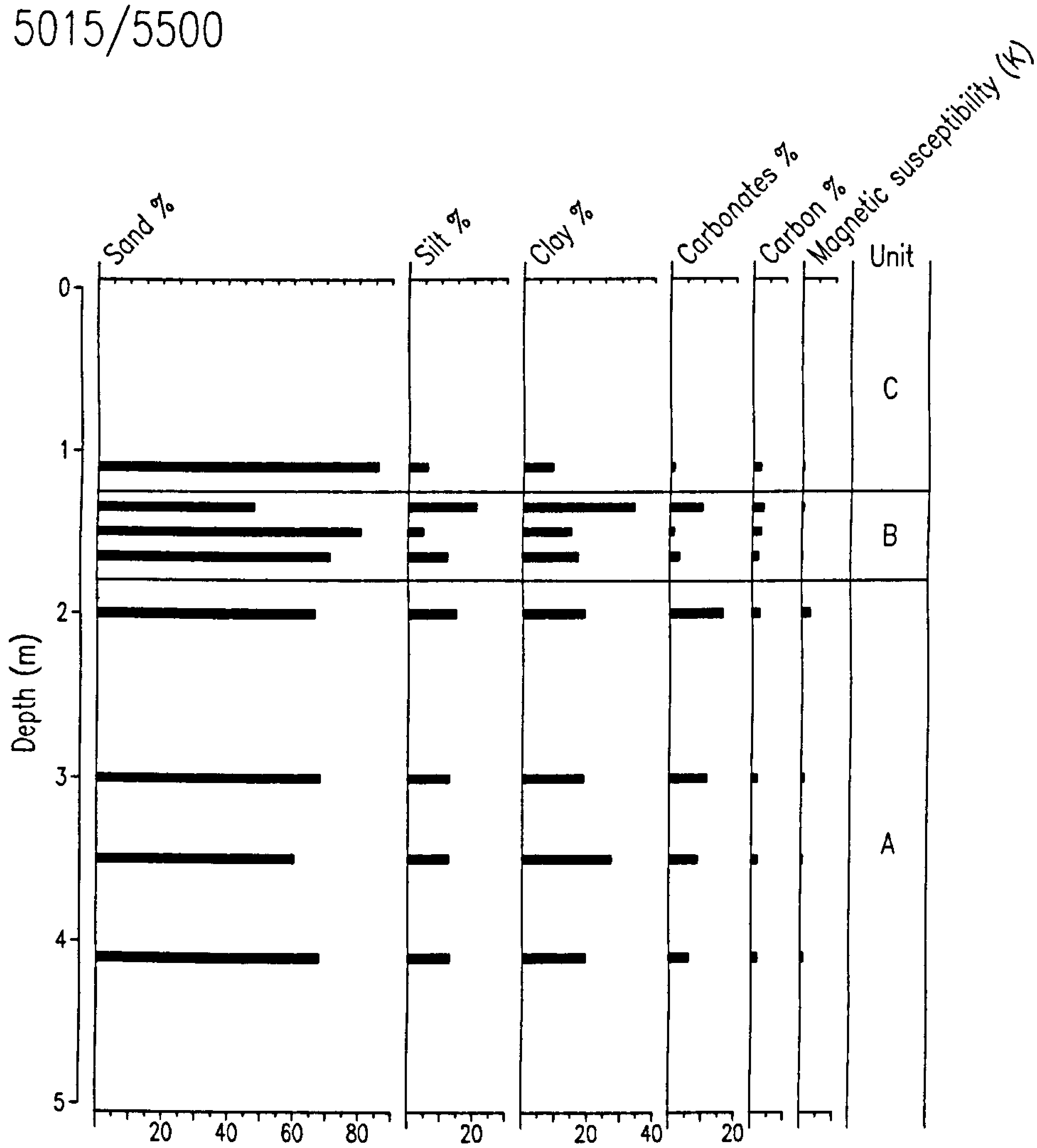


Fig. 5.14 Sediment analysis of site 5015/5500

Unit C

This unit (the pit fills) are characterised by the highest percentage of sand (85.72%), moderate clay (9%) and low silt (5.78%). Carbonate is very low (1%), Carbon is lower than the previous unit (2.35%) and magnetic susceptibility has the lowest value througout the whole samples (0.24 k).

5.2.7.5 Palynology

The pollen diagram (figure 5.15) is divided into three assemblage biozones: A, B and C. Set out below is a descriptions of each zone.

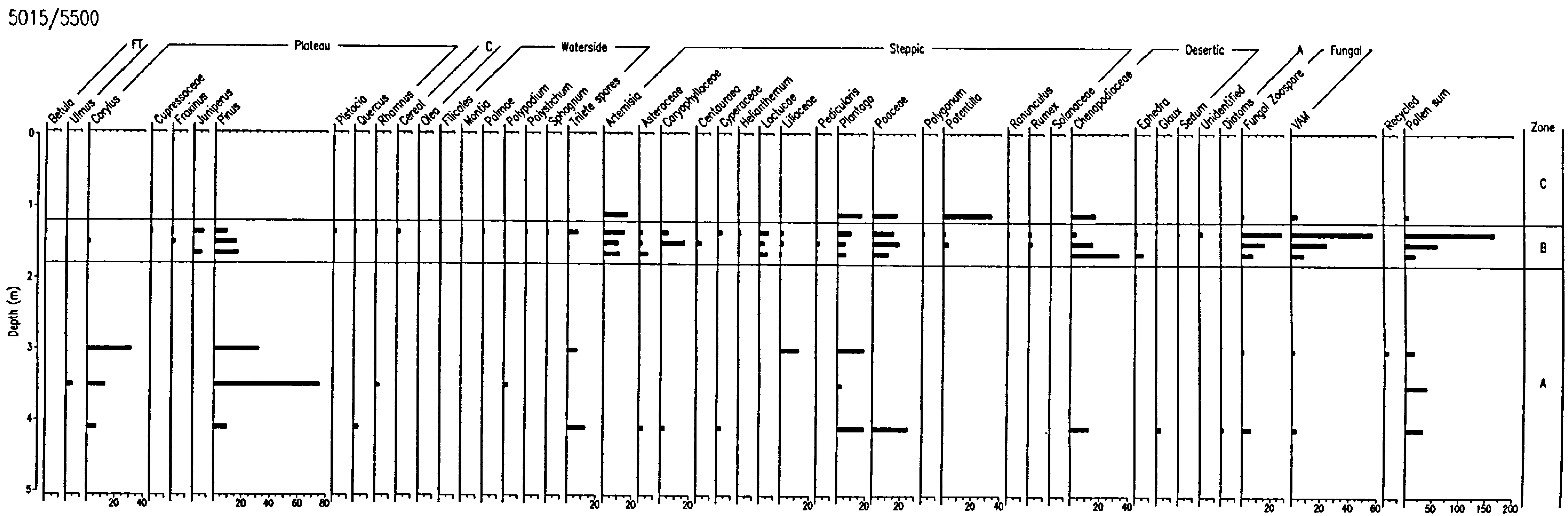
Assemblage biozone A

This assemblage biozone is characterised by relatively high counts of tree pollen including *Corylus* (6-32%), *Pinus* (5-75%), *Ulmus* (5%), *Quercus* (3%) and *Rhamnus* (2.5%). Also important are Poaceae (25%), *Plantago* (2-19%), Liliaceae (12%), Cyperaceae (2%), Asteraceae (2.5%) and Caryophyllaceae (2%). Waterside species are present including Trilete spores (7-13%) and Palmae (2%). Potential cereal types (4%) may reflect cultivated plants. Desertic species include Chenopodiaceae (12.5%) and *Glaux* (3%). Algal microfossils are recorded occasionally, including Diatoms (1%). Fungal microfossils include fungal zoospores (1-6%) and VAM (1.5-2.5%). A low proportion of recycled pre-Quaternary pollen is also present (2%).

Assemblage biozone B

This assemblage biozone is characterised by the presence of plateau taxa (but less than the previous zone) including *Pinus* (8.5-17.5%), *Juniperus* (5.5-7%), *Fraxinus*

Fig. 5.15 Palynology of site 5015/5500. All pollen, spores and other microfossils are calculated as % total pollen and spores



(1.5%), *Corylus* (1.5%), *Pistacia* (1.2%), Cupressaceae (0.5%), *Rhamnus* (0.5%), *Quercus* (0.5%) and *Betula* (0.5%). Steppeland taxa recorded include Poaceae (6-18.5%), *Plantago* (5-9.5%), Caryophyllaceae (5-17%), *Artemisia* (10-15%), *Centauraea* (0.5-3.5%), Liliaceae (1.5-2%), Cyperaceae (3%), *Rumex* (1-2%), *Potentilla* (0.5-3.5%), *Polygonum* (1.5%), *Pedicularis* (1.5%), *Helianthemum* (2%) and occasionally Solanaceae and *Ranunculus* (<1%). Desertic taxa include Chenopodiaceae (15-35%), *Ephedra* (0.5-6%) and occasionally *Sedum* (<1%). Waterside taxa are present including Trilete spores (7%) and occasional Filicales, *Sphagnum*, *Montia*, *Polystichum* and Palmae (1%). Cereal type (1.5%) and occasional presence of *Olea* (0.5%) may or may not reflect cultivation.

Assemblage biozone C

This assemblage biozone is characterised by an absence of tree pollen and generally very sparse steppeland taxa include Poaceae (17%), *Plantago* (17%), *Artemisia* (16%) and *Potentilla* (33%). Desertic taxa include Chenopodiaceae (17%). Fungal microfossils are present and include fungal zoospores (1.5%) and VAM (4%).

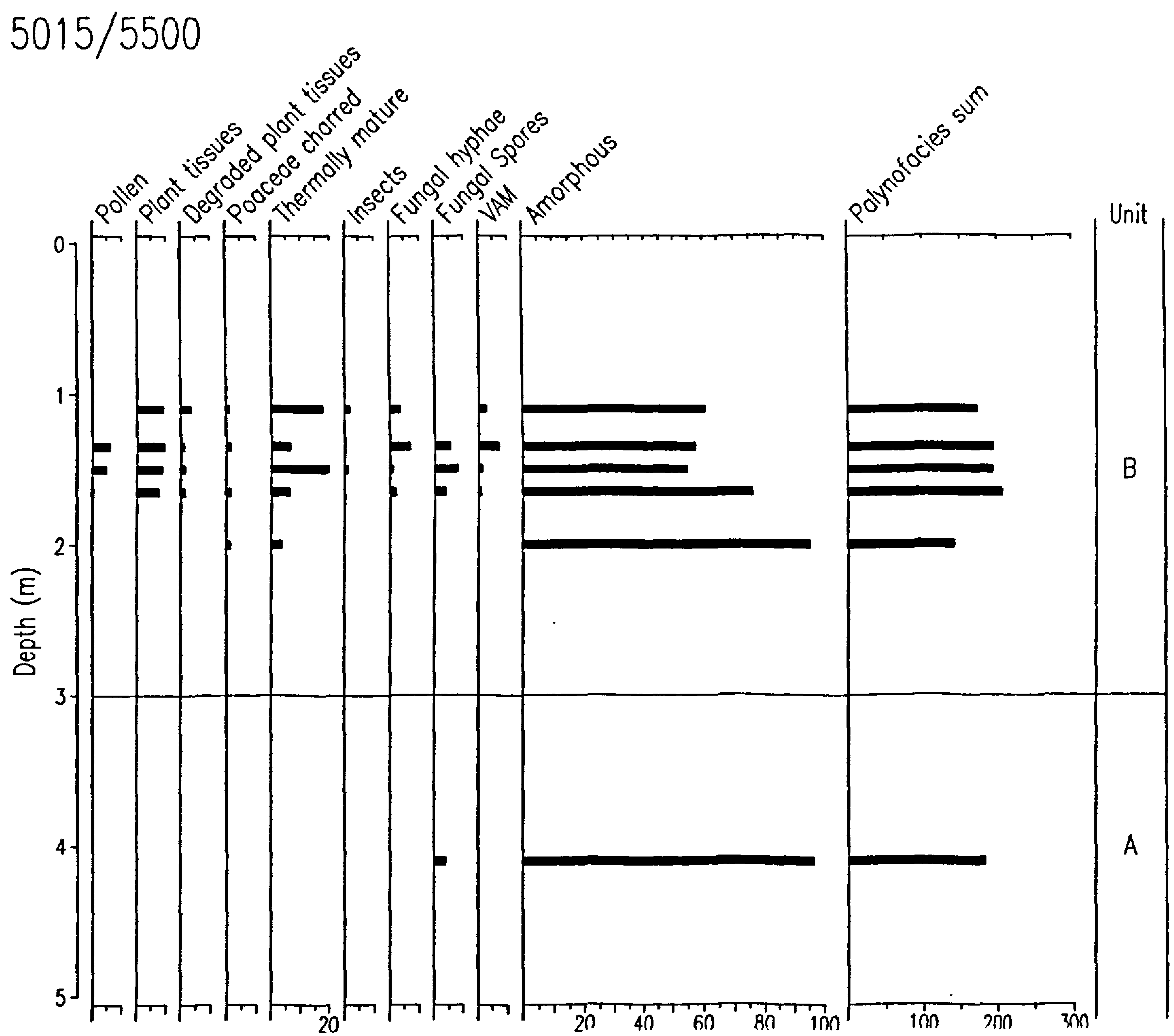
<u>5.2.7.6 Palynofacies</u>

The palynofacies Units can be seen in figure 5.16, which can be divided into two further Units. The following is a description of each unit.

Unit A

This unit is characterised by high counts of Amorphous matter (97%) and very low counts of fungal spores (5%).

Fig. 5.16 Palynofacies of site 5015/5500. All particulate organic matter are calculated as % total particulate organic matter



Unit B

This Unit is characterised by high counts of Amorphous matter (65-98%), thermally mature (5-20%); Poaceae (charred) were also present (2-2.2%), and plant tissue (6-9%). Degraded plant tissue was recorded (1.5-5%). Fungal remains detected included fungal hyphae (1.5-7%), fungal spores (3-7%) and VAM (2-8%). Pollen grains were also present (1-5%).

5.2.7.7 Molluscs

A number of specimens of *Melanopsis praemorsa* (plates 5.9 and 5.10) were recovered from #5500 k and #5500 G. One specimen of *Lymnaea* sp. (plate 5.11) was found in #5015 C, together with two specimens of ? *Theba* sp. (plate 5.12). *Melanopsis praemorsa* is indicative of clear perennial running water and *Lymnaea* is also aquatic, but less demanding in its requirements. Together, they point to perennial running water at this site. The genus *Theba* is today associated with relatively dense steppic vegetation in the research area (field observation by the author, 1998).

5.2.7.8 Interpretation

Results from site 5015/5500, a site of Neolithic age on a terrace of the Wadi Dana, suggests that deposition in a meandering fluvial environment was responsible for the lowest Units. The presence of *Melanopsis praemorsa* similarly suggests perennial running water. The high counts for *Corylus* and other tree taxa suggest nearby steppe-forest in local biozone A, with a loss of trees through local biozone B and C. Perhaps people were cultivating cereals in a relatively stable steppic landscape. Tree pollen presumed to derive from the plateau is relatively common. At some time,

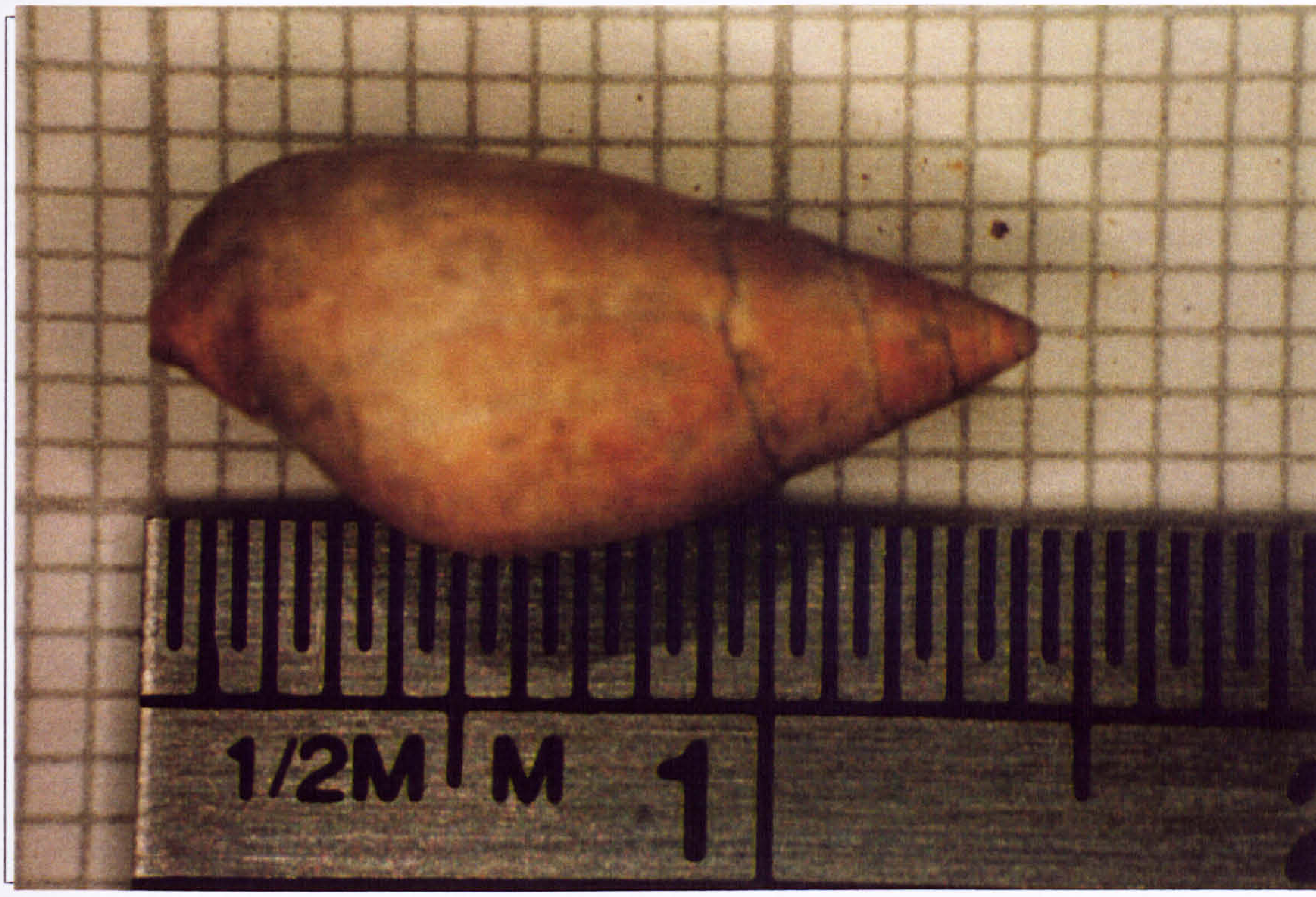


Plate 5.9 *Melanopsis praemorsa* recovered from layer K at site 5500

Plate 5.10 *Melanopsis praemorsa* recovered from layer G at site 5500

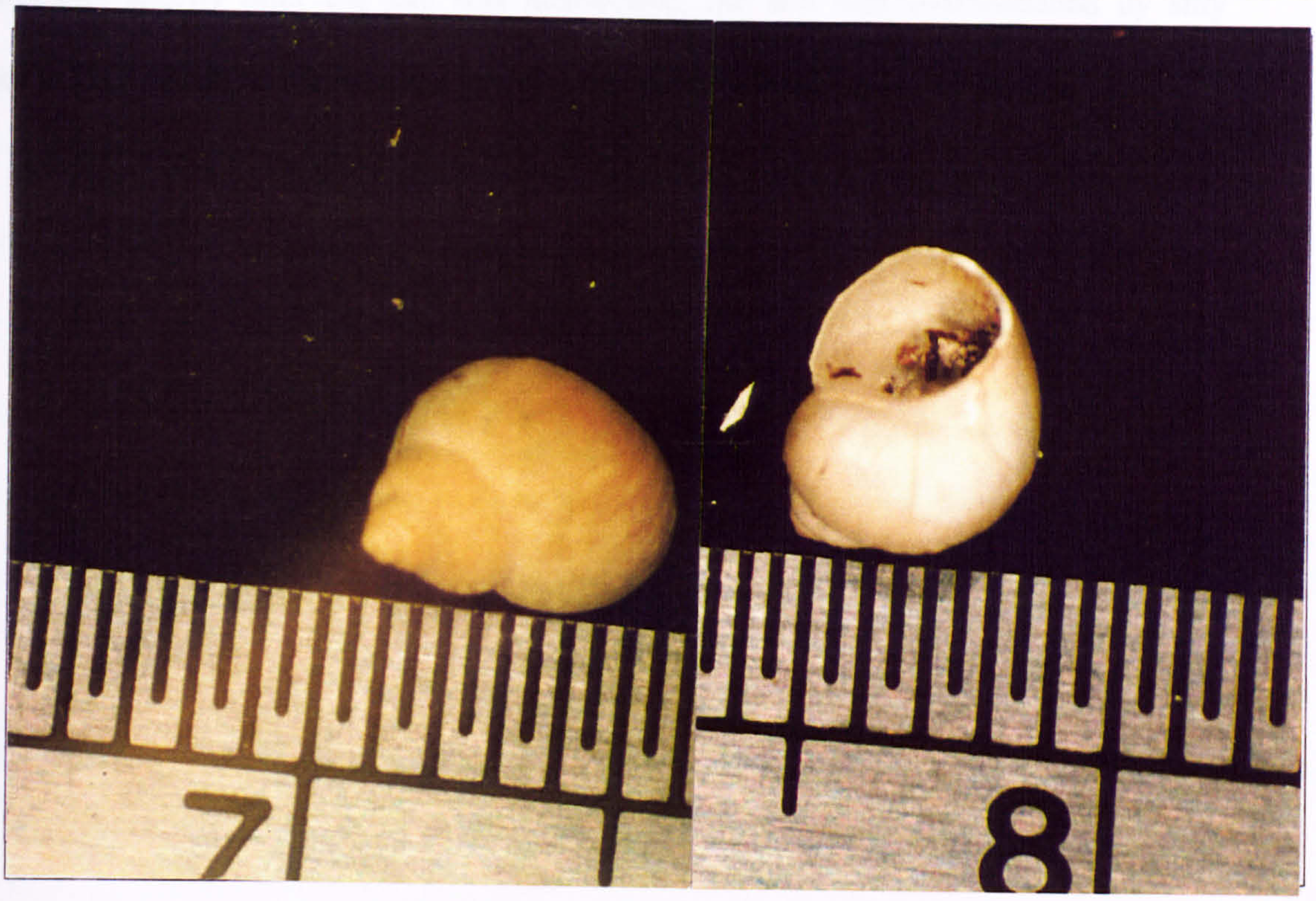


Plate 5.11 *Lymnaea* sp. (aquatic snail) recovered from site 5015 (C).

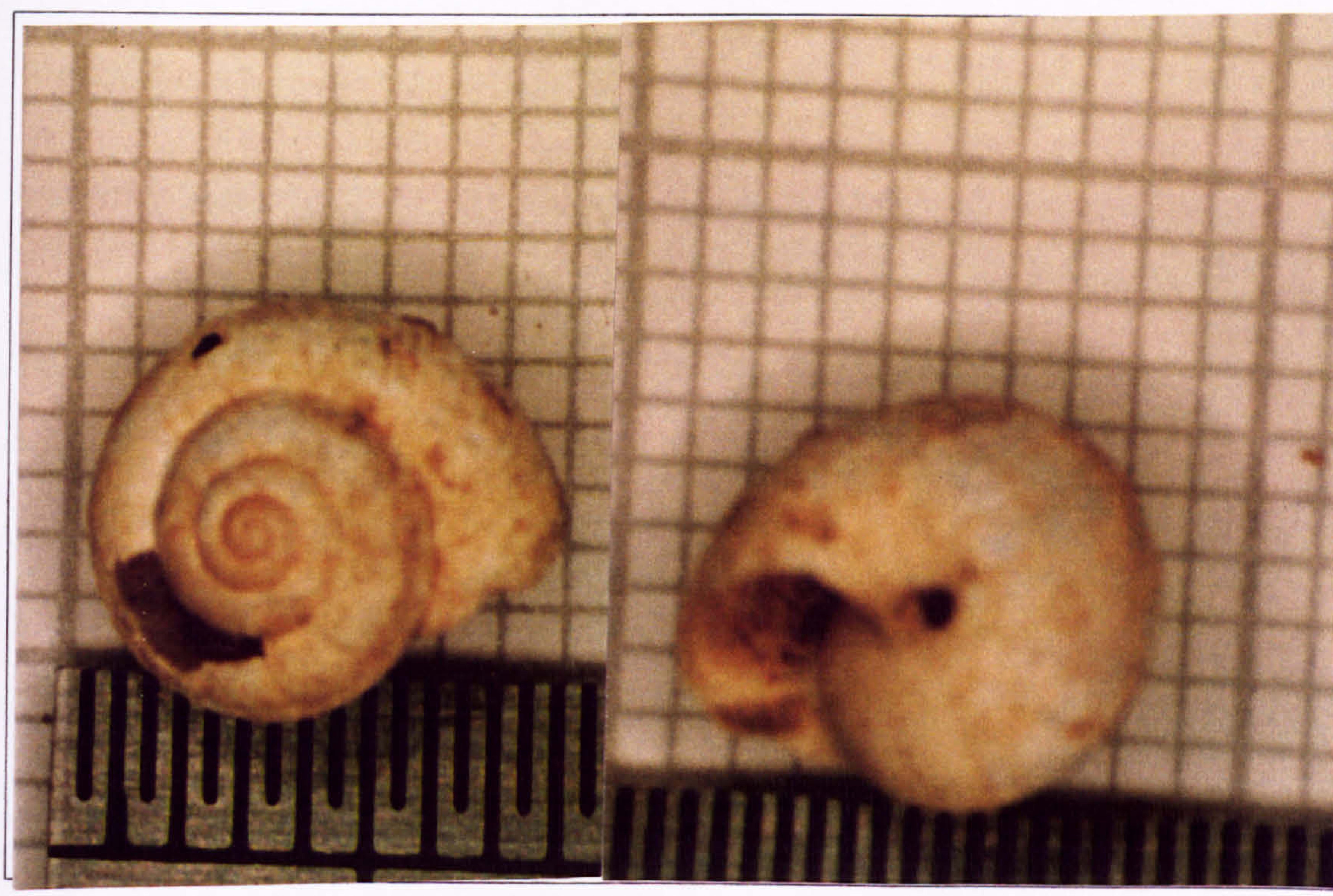


Plate 5.12 ? *Theba* sp. (land snail) recovered from site 5015 (C).

probably shortly after the site was abandoned, the site was overwhelmed by silty colluvium, which is evidence for environmental degradation and soil erosion.

5.3 Dana Member: Late Holocene Braided unit

5.3.1 Introduction

The Dana Member is composed of bodies of trough cross-bedded sandy gravel, sands and gravel. It is found underlying low terrace surfaces and alluvial fans in the Wadis Faynan, Ghuweir and Dana. The deposits are up to 7 m thick, but normally between 1 and 2 m thick. They rest with non-sequence on the Faynan Member at 5510 in the Wadi Ghuweir, but elsewhere they occupy a trench cut through the earlier Holocene and Pleistocene deposits, adjacent to the modern wadi.

At site 5025, gravels assigned to the Dana Member overlie sandy fluvial deposits radiocarbon dated to 390 $\pm$ 50 BP uncal. (Beta- 115214). Charcoal within the Dana Member is dated to 110 $\pm$ 50 BP uncal. (Beta- 119600) at site 5509. In an incision terrace cut into an alluvial fan of the Dana Member site (5520), wood yielded a date of 100 $\pm$ 50 BP uncal. (Beta-119620) The Dana Member can thus be relatively securely dated to the very late Holocene.

5.3.2 Relationships

The Dana Member rests unconformably on an erosion surface cut in the Faynan Member and older beds. It was subsequently incised by the channels of the modern braided plain.

5.3.3 Distribution

The Dana Member is extensive in the Wadis Faynan, Dana and Ghuweir (see figure 5.17) and sampled at sites 5510, 5509, 5520.

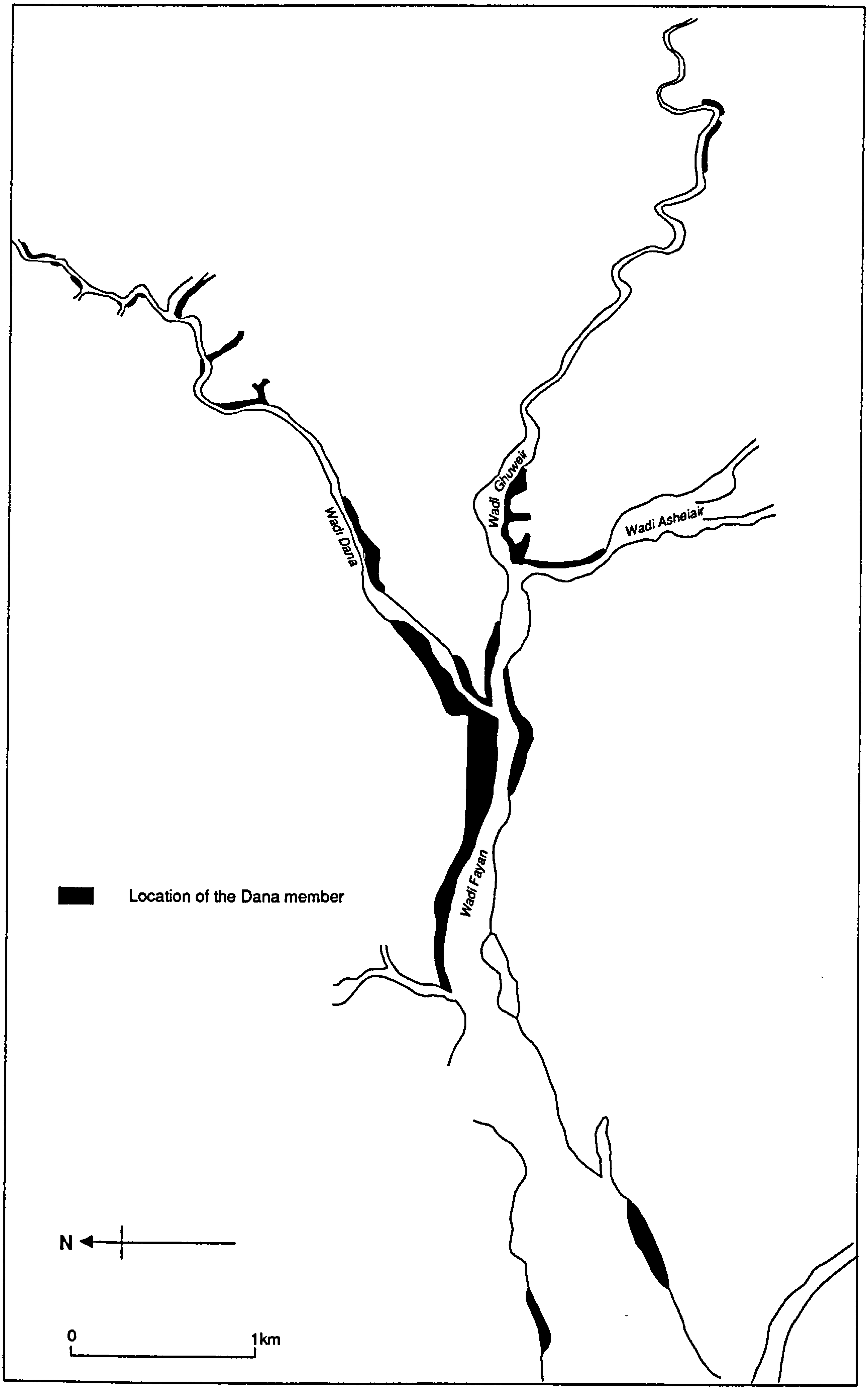


Fig. 5.17 Map showing location of the Dana member in the research area

5.3.4 Type section

The type site of the Dana Member is site 5025, in the Wadi Faynan

Site 5025: Type section

5.3.4.1 Stratigraphy

Site 5025 (figure 5.18, plate 5.13) is of Late Holocene age. The site is a low terrace mapped as the Dana Beds by Barker *et al.* (1997), postdating site 5021, i.e. post-Neolithic. The site consists of 1.0 m of trough cross-bedded gravels (samples A, B and N). A thin fine sand horizon 0.02 m thick rests upon this gravel (sample C). A weathered and contorted sand body 0-0.9 m thick overlies the silt, (sample D) which is overlain by 0.3-1.5 m of shocked gravels and then a further 0.8 m of aeolian silts. Resting upon the terrace surface eroded across all the deposits are a number of wadi cross-walls.

5.3.4.2 Sediment analysis

The sediment diagram (figure 5.19) can be "roughly" divided into two units. The two units show similarities in their depositional pattern. Below are a description of these two units.

Unit one

This Unit is trough cross-bedded gravel. The samples (A, B and N) are from sandy channel fills. This unit shows a high level of sand (94.38%) at the lower horizon. Silt has a very low percentage (<1%) and clay is 5%. Carbonate has a level of 8.5% and carbon level is very low (1%). The magnetic susceptibility is not shown in the diagram

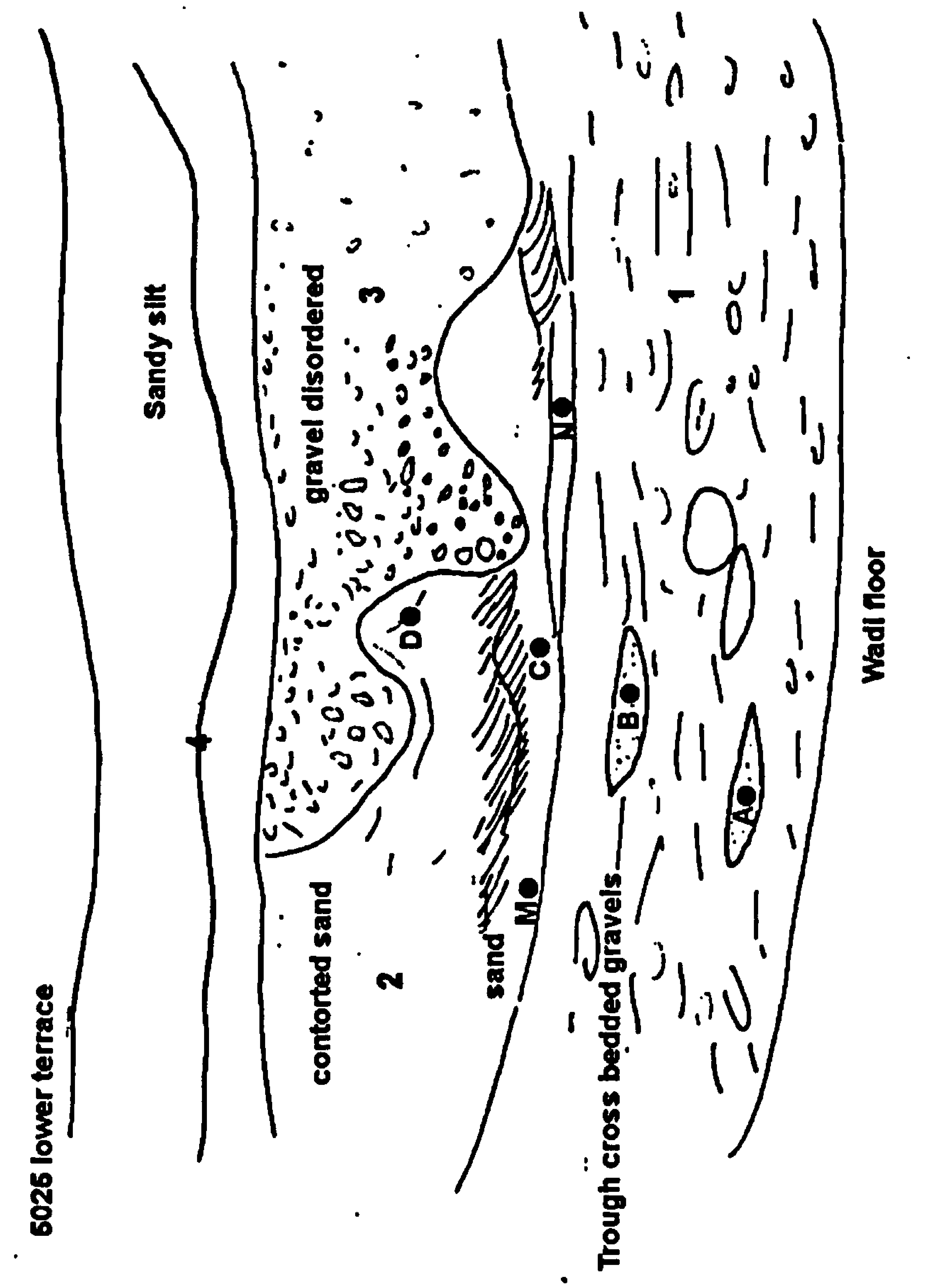
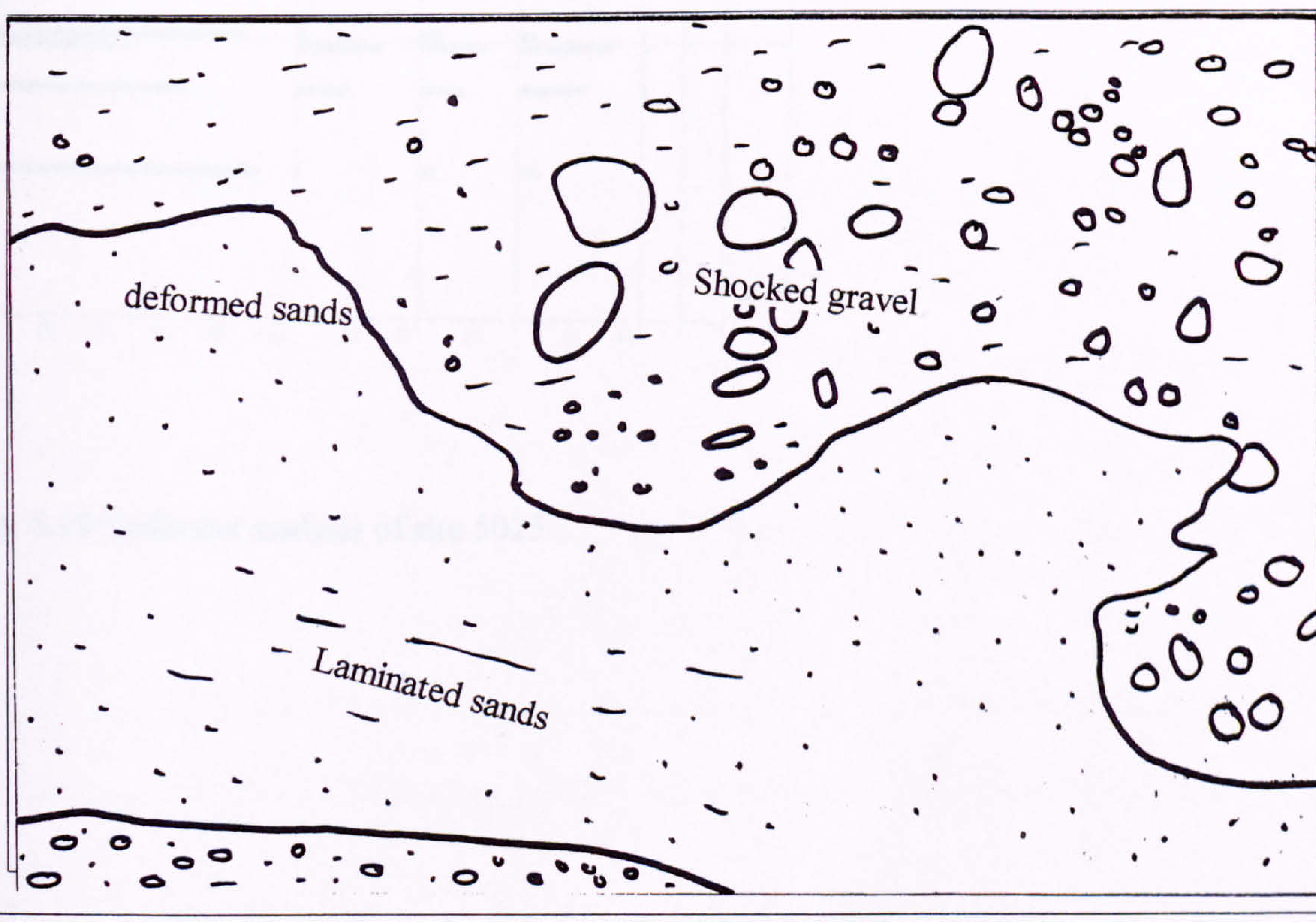


Fig. 5.18 Sketch section of site 5025

Plate 5.13 Site 5025 showing earthquake shocked sediments



Explanation of Plate 5.13

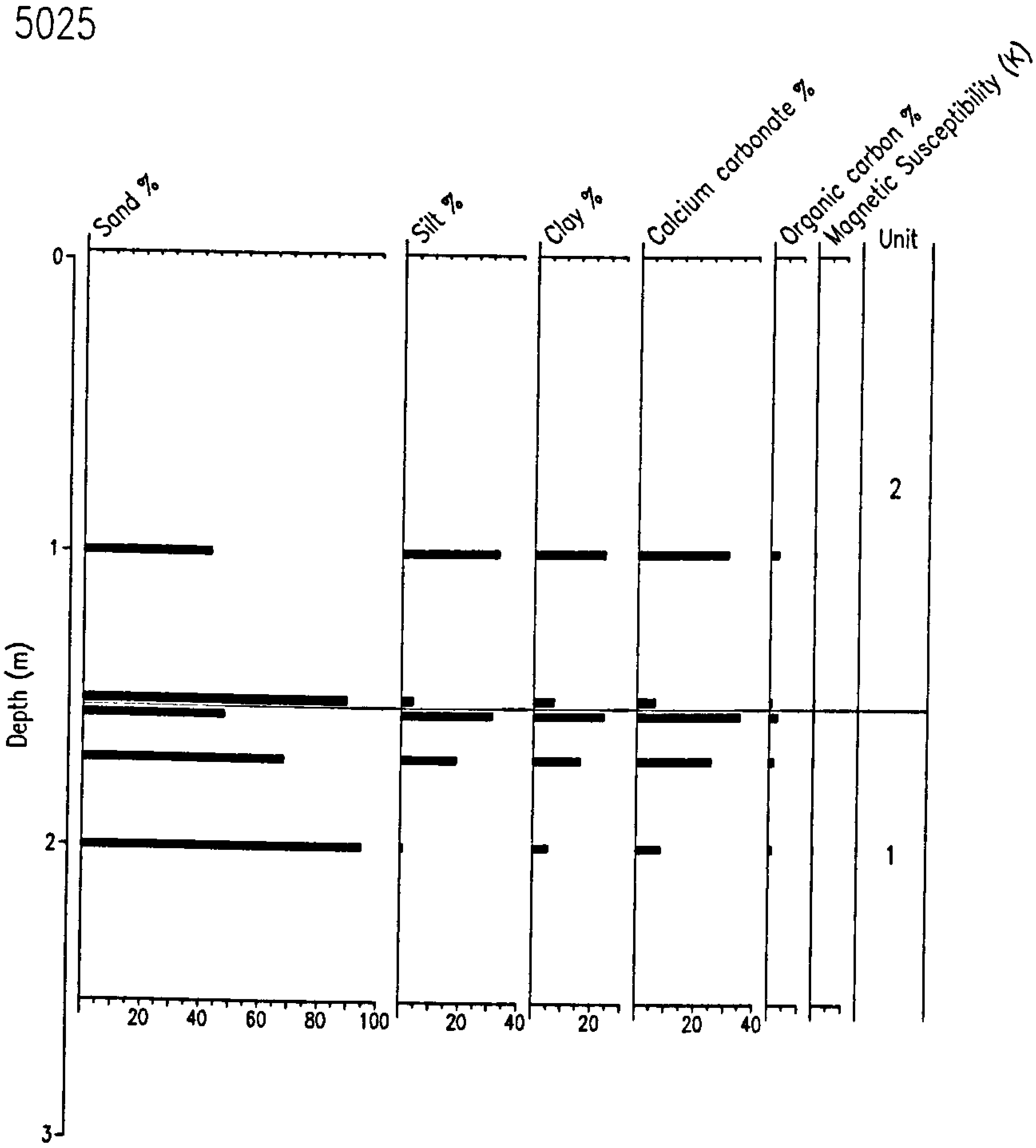


Fig. 5.19 Sediment analysis of site 5025

because it has a very low value (0.018-0.027 k). At the middle horizon of this unit the proportion of sand droped to 67.85%, silt (18.67%), clay (16%) and calcium carbonate (25.42%) increased. At the upper horizon of this unit the proportion of sand relatively decreases (44.7%), and the percentages of silt (31.03%), clay (24%), carbonate (32.5%), and carbon (2.69%) all increased.

Unit two

A very high proportion of sand occurs in the lower horizon (c) of this unit. Silt (3.85%), clay (7%) and carbonate (6.16%) show very modest percentages. Carbon is extremely low in this horizon (0.67%) and magnetic susceptibility has an extremely low value (0.013 k). At the upper horizon of this unit (d) the proportion of sand decreases (43%), and the percentage of silt (32.94%), clay (24%), carbonate (30.57%), and carbon (2.67%) all relatively increase. The magnetic susceptibility has a very low value (0.036 k).

5.3.4.3 Palynology

The pollen diagram of this site (figure 5.20) can be considered as one assemblage biozone. The description of this biozone is given below.

This assemblage biozone is characterised by Poaceae (5-8%), *Potentilla* (1-2.5%), *Rumex* (1.5%), *Solanaceae* (5%), *Spergula* (1%), *Trifolium* (2-13%), *Vicia* (2%), *Allium* (1%), *Lotus* (1%), Leguminosae (3%), *Helianthemum* (2 - 6%), Cyperaceae (5%), *Centaurea* (1-4%) Caryophyllaceae (2-18%), *Artemisia* is (4-9%) and percentages of *Plantago* ranging between 20-4%. Taxa typical of open, eroding ground and deserts are also present, mostly Chenopodiaceae which shows an increase

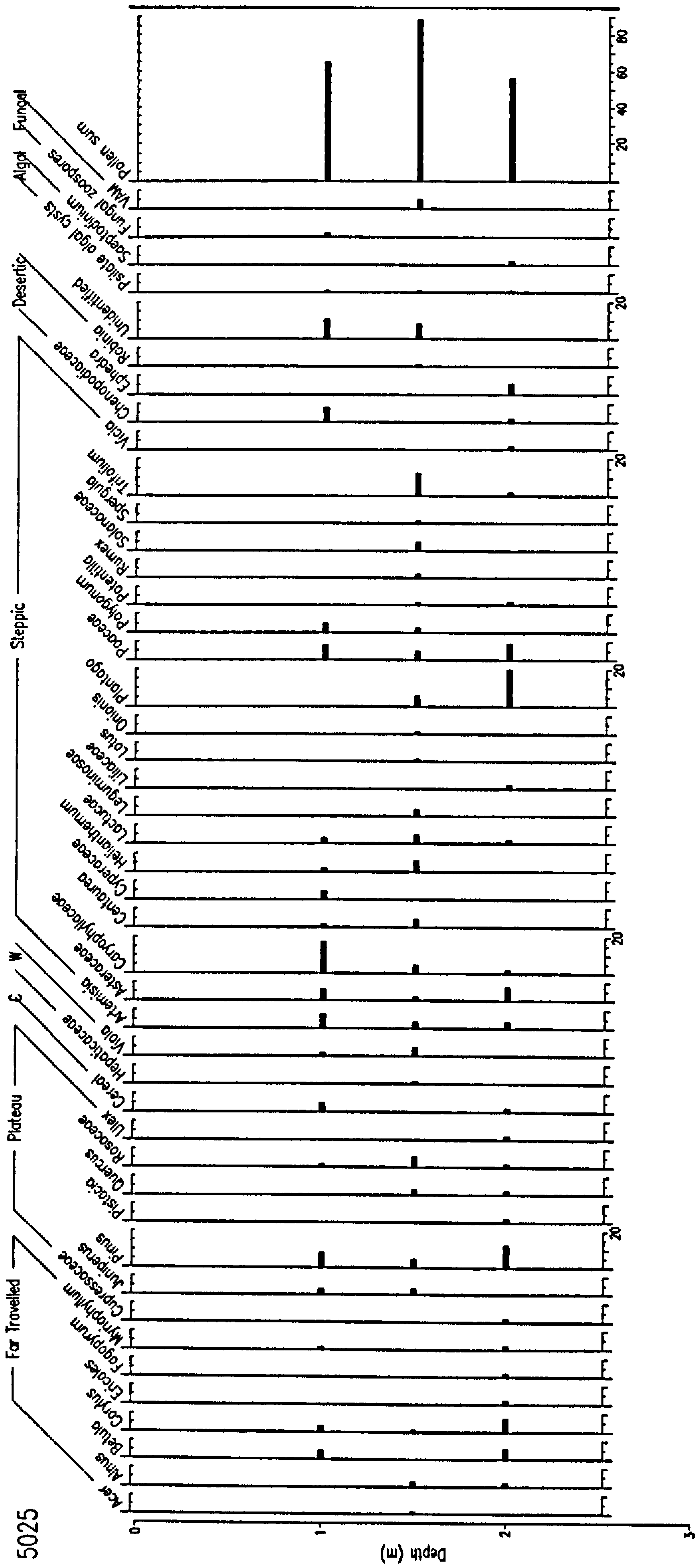


Fig. 5.20 Palynology of site 5025. All pollen, spores and other microfossils are calculated as % total pollen and spores

towards the top of the profile (2-9%). *Ephedra* (6%) and *Robinia* (1.5%) also occur. Asteraceae (5-7%) and Lactuceae (2-5%) which reflect a steppic environment (Janssen and Woldring, 1981) shows a slight increase towards the top of this biozone. Water-side species were present occasionally, such as Hepaticeae (1%) and *Viola* (1-4%). Cereal-type is present (2-5%). Fairly sparse woody 'tree' pollen occur, such as *Ulex* (2%), Rosaceae (2-6%), *Quercus* (1.5-2.5%), *Pistacia* (2%) *Juniperus* (3-4%) and Cupressaceae (2.5%). *Pinus* decreases towards the top of the profile (13-5%). Far-travelled taxa are also present, occasionally, such as *Acer* (1%), *Fagopyrum* (1.5%), *Ericales* (1.5%), *Alnus* (1.5-2.5%), *Corylus* (8-2%) and *Betula* (4-5.5%). Generally, far-travelled species decrease upward in this biozone, which could be interpreted as a consequence of an increase in the apparently 'sparse' local flora. Algae are present, including Psilate algal cysts (1-1.5%) and *Saeptodinium* (2%). Fungi are occur occasionally, including fungal zoospores (2%) and VAM (3%).

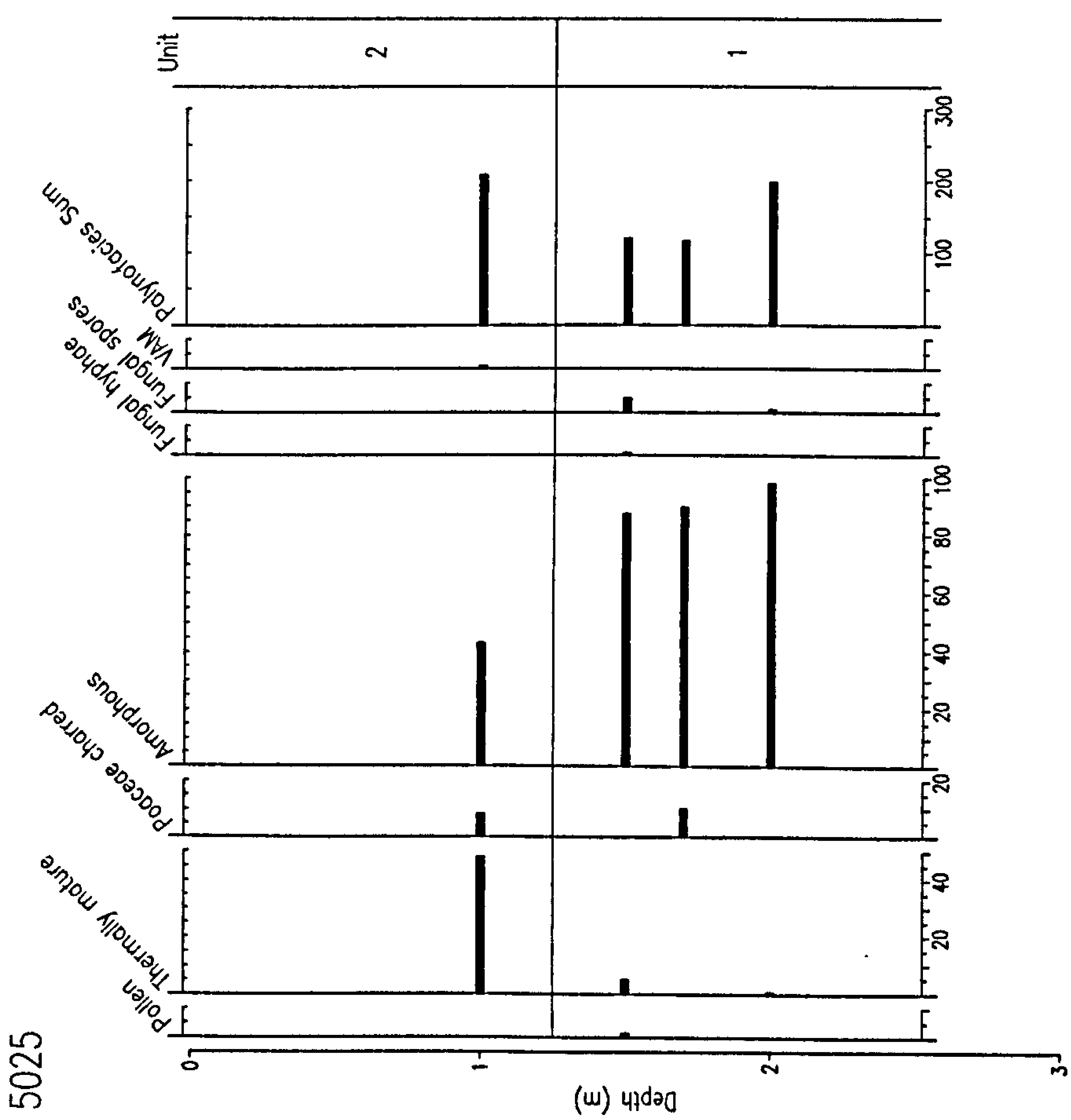
5.3.4.4 Palynofacies

The palynofacies diagram figure 5.21 can be divided into two units.

Unit one

This unit (samples a, b and c) is characterised by high levels of amorphous matter (88-98%) and low counts of thermally mature (1-5%). Also Poaceae (charred) are present (11%). Pollen occur occasionally (2%), as do fungal spores (1-6%).

Fig. 5.21 Palynofacies of site 5025. All particulate organic matter are calculated as % total particulate organic matter



Unit two

This unit (sample D) shows a relatively high level of thermally-mature matter (48%) and a relatively low proportion of amorphous matter (41%). Also, Poaceae (charred) (9%) and a very low level of VAM (1%) occur.

5.3.4.5 Dating

A radiocarbon date of 390 ± 50 BP (Beta- 115214) was obtained on wood from the middle silt/sand unit (sample M).

5.3.4.6 Interpretation

From the pollen diagram figure 5.20, a sparse, degraded steppe environment is indicated by the preponderance steppic taxa much as *Plantago*, Caryophyllaceae, Poaceae, *Trifolium* and *Helianthemum*. Desertic taxa such as Chenopodiaceae are comparatively rare, but overall increase upwards. Human activity may be indicated by the Cereal type pollen and by the high counts for thermally mature material. The lower unit can be interpreted as braided alluvium. The energy of deposition of this unit appears to decrease upward. It is overlain by silts and sands reflecting quiet water sedimentation, perhaps away from the main channel, and then by coarse gravels which seem to have been disrupted by earthquake shock, presumably while wet. These deposits are overlain by aeolian sands which presumably reflect the eventual abandonment of the channel.

5.3.5 Site 5509

5.3.5.1 Stratigraphy

Site 5509 (plate 5.14) is a low terrace/ alluvial fan deposit in the Wadi Ghuweir and its surface lies about 4 m above the modern wadi floor. Three units can be distinguished (table 5.4 and figure 5.22).

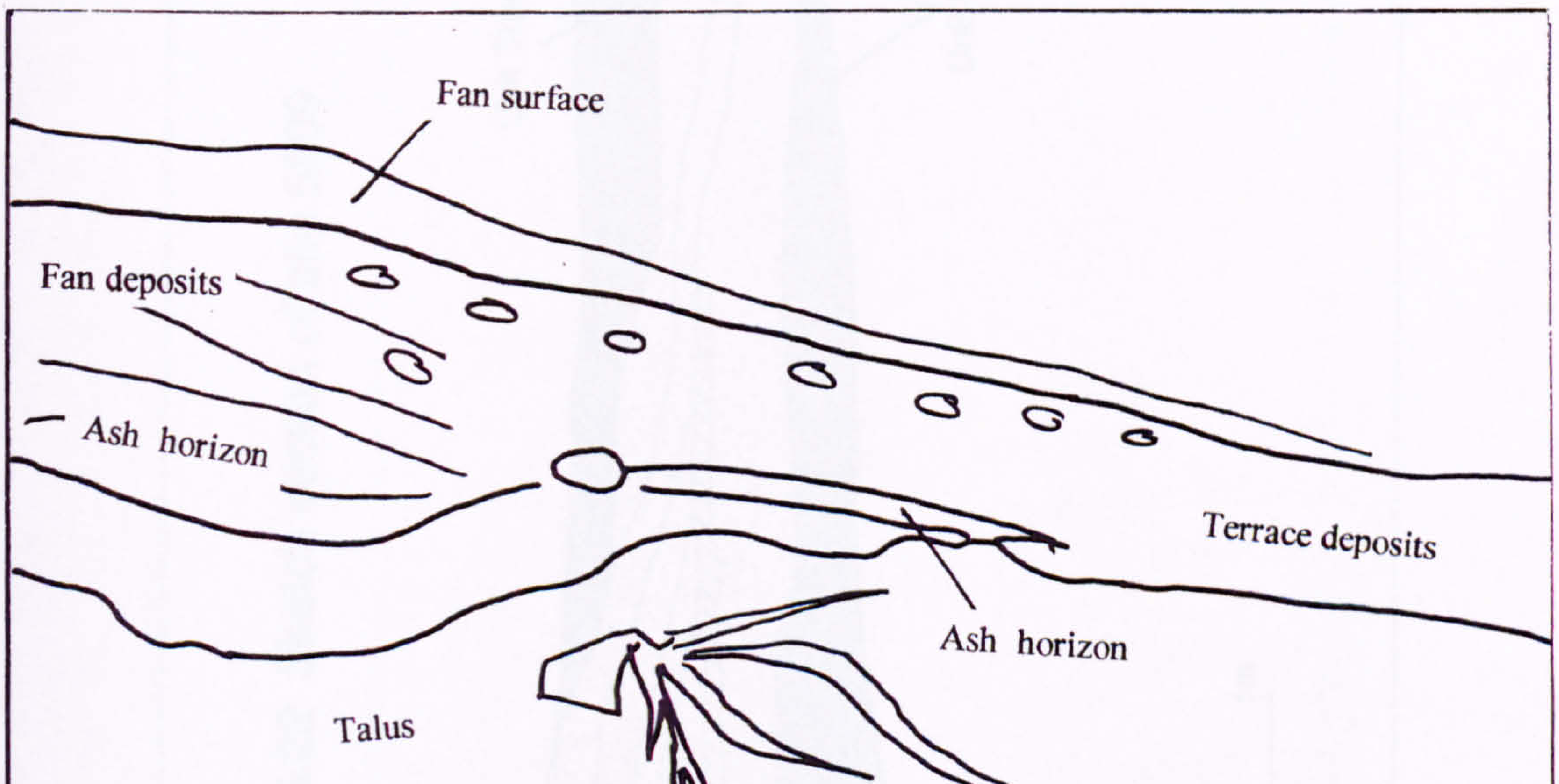
Table (5.4). Unit descriptions of site 5509

Unit no.	Thickness (in meters)	Description
Unit 1	1.0-1.5	Sand and gravel infilling, large scale trough cross-beds, of main wadi
Unit 2	0.0-1.2	Obliquely-bedded sand, fine gravel and ash of coalescing alluvial fans from side wadi.
Unit 3	0.0-0.7	Coarse cobbly gravel infilling a hallow in the existing topography. Channel deposit of main wadi

5.3.5.2 Sediment analysis

Three samples were analysed for their grain size analysis and geochemistry (figure 5.23). Generally, the sand shows a decreasing trend from the lower part to the upper part of the diagram (88.05-77.49%). Silt shows a slight increasing trend upwards from 2.39% to 6%. Clays display a similar but more rapidly increasing trend from 9.56% to 16.43%. Calcium carbonate rises from 12.88% at the base to 37.9% and then drops to 10.68%. Organic carbon shows a slight increasing trend upwards 1.3 to 1.7%. Magnetic Susceptibility shows a similar pattern to carbonate with a relatively low value at the base (3.3 k), increasing to (13.1 k) in the middle part of the diagram, where a lot of charcoal is present, before it drops to 5.1 k at the top of the sequence.

Plate 5.14 Site 5509 showing the interfingering of fan and fluvial terrace sediments



Explanation of Plate 5.14

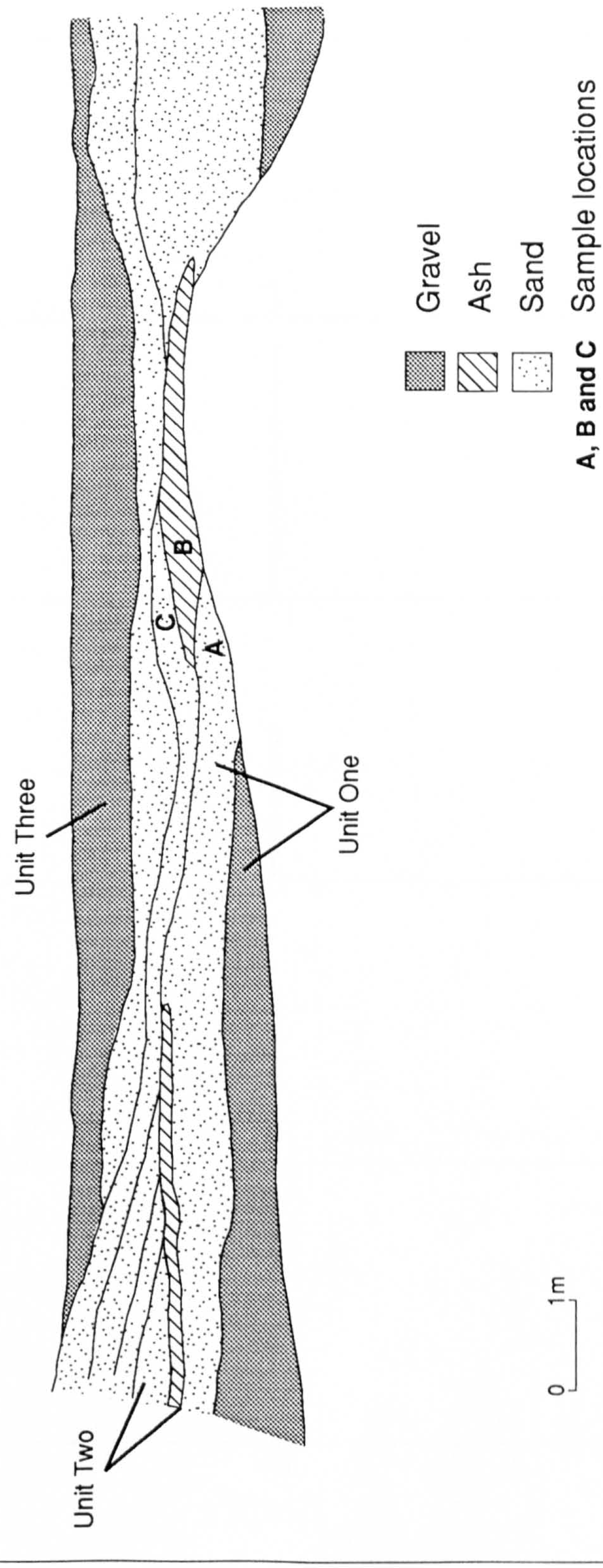
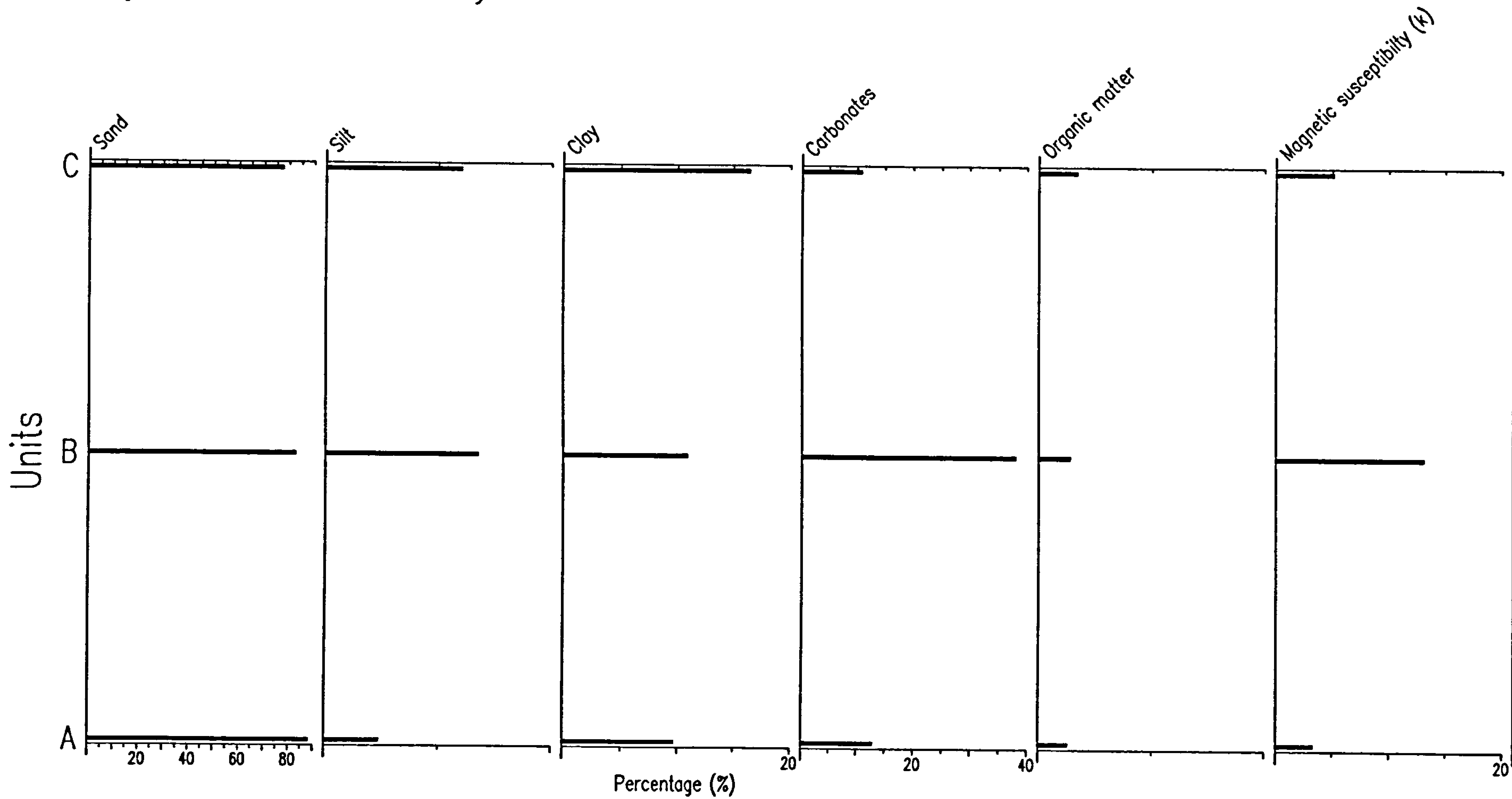


Fig. 5.22 Sketch section of site 5509

Fig. 5.23 Sediment analysis of site 5509



5.3.5.3 Palynology

Samples from site 5509 produced a very modest number of pollen grains, so the pollen data were not represented graphically. Table (5.5) show the pollen counts for this site.

Table (5.5) Pollen analysis of Site 5509

Species	**5509a**	**5509b**	**5509c**	**Total nos (a, b and c)**	**% of total numbers**
Ephedra	1		3	4	7.1
Liliaceae	2			2	3.5
unidentified	2		3	5	8.9
Cereal					
Poaceae	1			1	1.7
Chenopodiaceae	13	6	13	32	57.1
Armeria			1	1	1.7
Plantago	1			1	1.7
Caryophyllaceae	1			1	1.7
Asteraceae		2	4	6	10.7
Cyperaceae	1		1	2	3.5
Filicales			1	1	1.7
Total Pollen	**22**	**8**	**26**	**56**	**99.3**
Fungal zoospores	3	1	7	11	
VAM	0.0	0.0	10	10	

5.3.5.4 Palynofacies

The palynofacies analysis of site 5509 (table 5.6) shows that the upper and lowermost samples (a and c) are dominated by fungal hyphae, with some amorphous matter and a little charcoal. These counts may reflect material eroding from soil and entering the fluvial system. The middle sample (b) contains high counts for charcoal, which reflects the high macroscopic charcoal content of this unit.

Table (5.6) Palynofacies of site 5509

Sample no.	5509 a	5509 b	5509 c
Percentage	%	%	%
Charcoal	12.2	35.5	4.7
Poaceae charred	0	4	0
Amorphous	36.3	53	32.3
Fungal hyphae	51.5	7	58.8
Fungal spores	0	0	4

5.3.5.5 Interpretation

Three events, not much separated in time and probably coinciding with intensive human activity can be recognised. These events are as follows:

1- Aggradation of unit 1, with large-scale trough cross-bedding in the main wadi in large floods. Some alluvial fan activity interfingers with these fluvial deposits.

2- Unit 2, no large floods evident in the Wadi. Alluvial fans build out into the channel area. Aggradation ceases- ? incision.

3- Aggradation of unit 3. Large-scale floods in the Wadi. No signs of alluvial fan activity.

4- Channels in alluvial fans and wadi both incise.

The high sediment flux evidenced and required for aggradation, together with the abundant Charcoal in Unit 1 and unit 2, may suggest that people were affecting soils and sediments around this site.

The pollen content (table 5.5) of site 5509 is sparse, and moderate to poorly preserved. The high counts of Chenopodiaceae and relatively high Asteraceae and the presence of *Ephedra* probably reflect a very degraded environment. The other pollen include low counts of Poaceae, *Plantago*, Caryophyllaceae, *Armeria* and Liliaceaeare suggesting herbs tolerant of a degraded environment. The high incidence of fungal zoospores and fungal hyphae in samples a and c and the relatively high counts for VAM in sample c may reflect soil erosion.

5.3.6 Site 5520

5.3.6.1 Stratigraphy

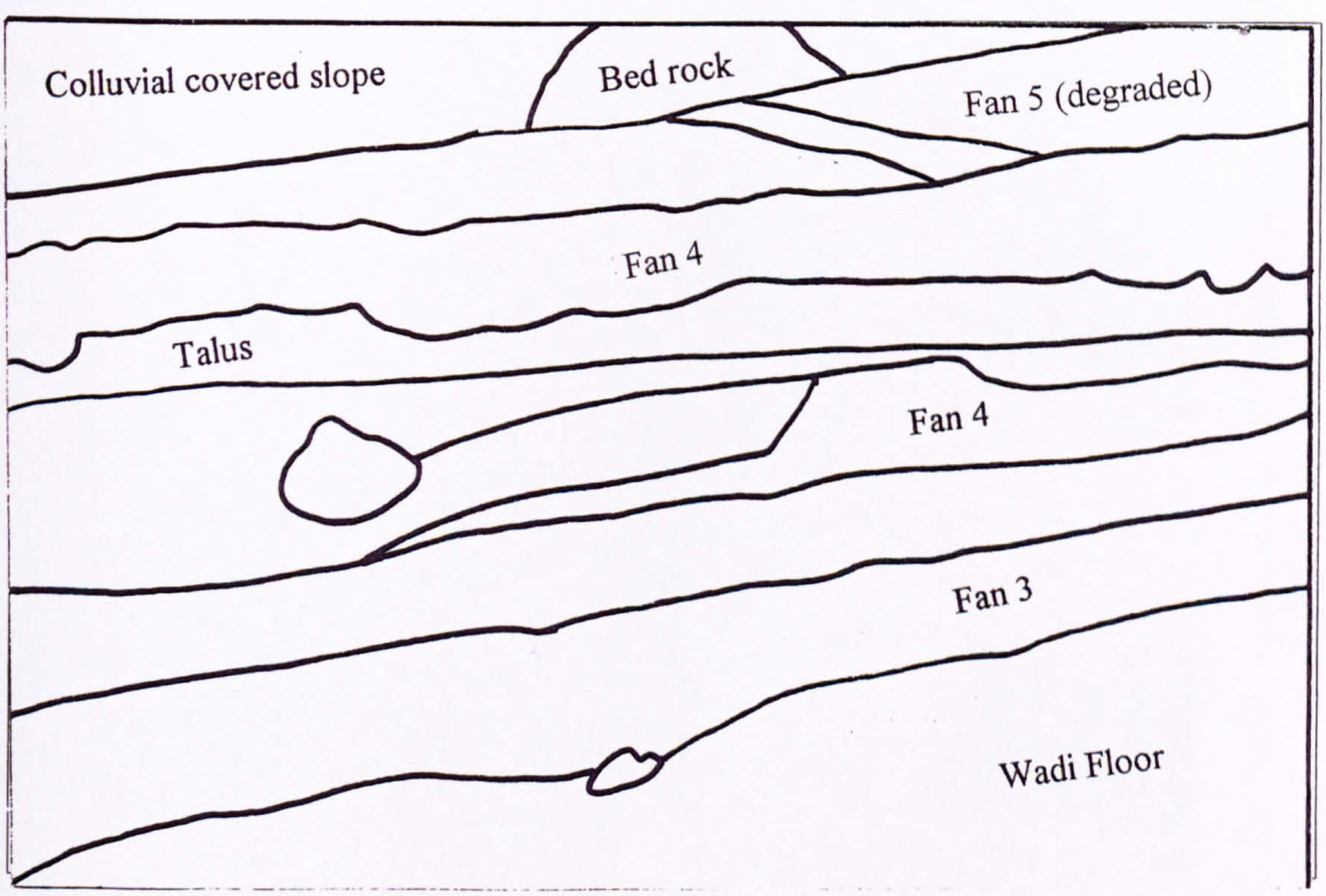
Site 5520 is typical of a number of low terrace fragments and alluvial fan deposits in Wadi Dana. This site consists of a thick gravel terrace, which passes laterally into an alluvial fan almost 4 metres thick, together with a number of incision terraces which cut through these deposits (plate 5.15). The following is a description of the section (figure 5.24) numbered as on the diagram.

Unit 1. Interdigitating alluvial fan (1), slackwater sands (2) and terrace trough cross-bedded sand gravels (1), with ash lenses (3) (fan 5) separated from the younger deposits on the site by an angular unconformity caused by incision.

Unit 2. An incision terrace into the alluvial fan, with trough cross-bedded sandy gravels (4) interdigitating with fluvial slackwater sands (5) and silts (6) (fan 4) and resting against older deposits. Wood was recovered from the slackwater sands for radiocarbon dating. This unit is separated from the younger deposits by an angular unconformity caused by incision.

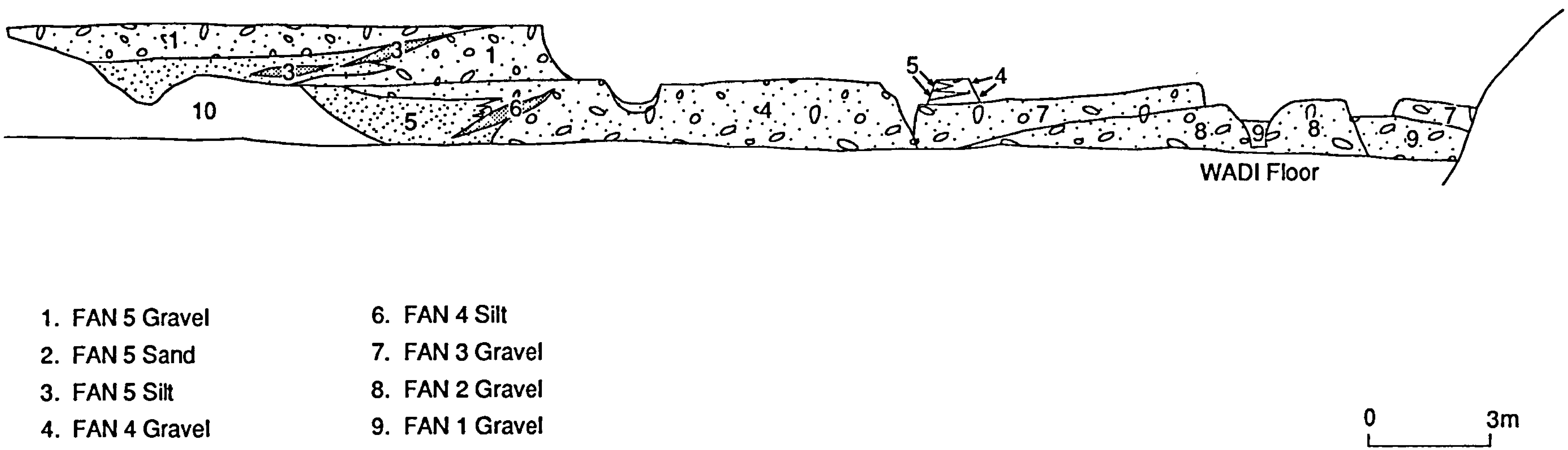
Unit 3. An incision terrace of the alluvial fan, with trough cross-bedded gravels (7) resting against older units (fan 3); this unit is separated from the younger deposits by an angular unconformity caused by incision.

Plate 5.15 Site 5520 showing sequence of incision terraces into alluvial fan of late holocene age, Wadi Dana



Explanation for Plate 5.15

Fig. 5.24 Sketch section of site 5520



1. FAN 5 Gravel
2. FAN 5 Sand
3. FAN 5 Silt
4. FAN 4 Gravel
5. FAN 4 Sand
6. FAN 4 Silt
7. FAN 3 Gravel
8. FAN 2 Gravel
9. FAN 1 Gravel
10. TALUS

Unit 4. An incision terrace of the alluvial fan, with trough cross-bedded gravels (8) containing leaves of *Nerium* (fan 2) and resting against older deposits. This unit is separated from the youngest deposits on the site by an angular unconformity caused by gullying and incision.

Unit 5. The currently active fluvial and gully-fill deposits of the alluvial fan, which show in places evidence of braided bedforms (fan 1).

5.3.6.2 Sediment analysis

Sediment analysis of the site 5520 is presented in figure 5.25. The sediment percentage diagram is divided into three units, described below.

Unit 5 (Fan 5)

Fan 5 is 2 m thick. The samples are characterised by high percentages of sand (85-89%), and low percentages of silt (5.1-7.2%) and clay (5.8-7.6%). Carbonate ranges between 3.8 and 6 %, organic carbon ranges between 1.2 and 1.9% and the magnetic susceptibility recorded a relatively high reading (7.6-19.1 k), probably due to the inclusion of soil ferromagnetic minerals or mining wastes.

Unit 4 (Fan 4)

This unit totals 3 m in thickness and is characterised by high percentages of sand (76.6-93.6%), and low proportions of silt (2.1-11.2%) and clay (4.2-12.1%). Carbonate ranges between 6.3 and 8.2%, organic carbon varies from 1.8 and 2.8% and the magnetic susceptibility shows a relatively high reading (3.6-20.8 k).

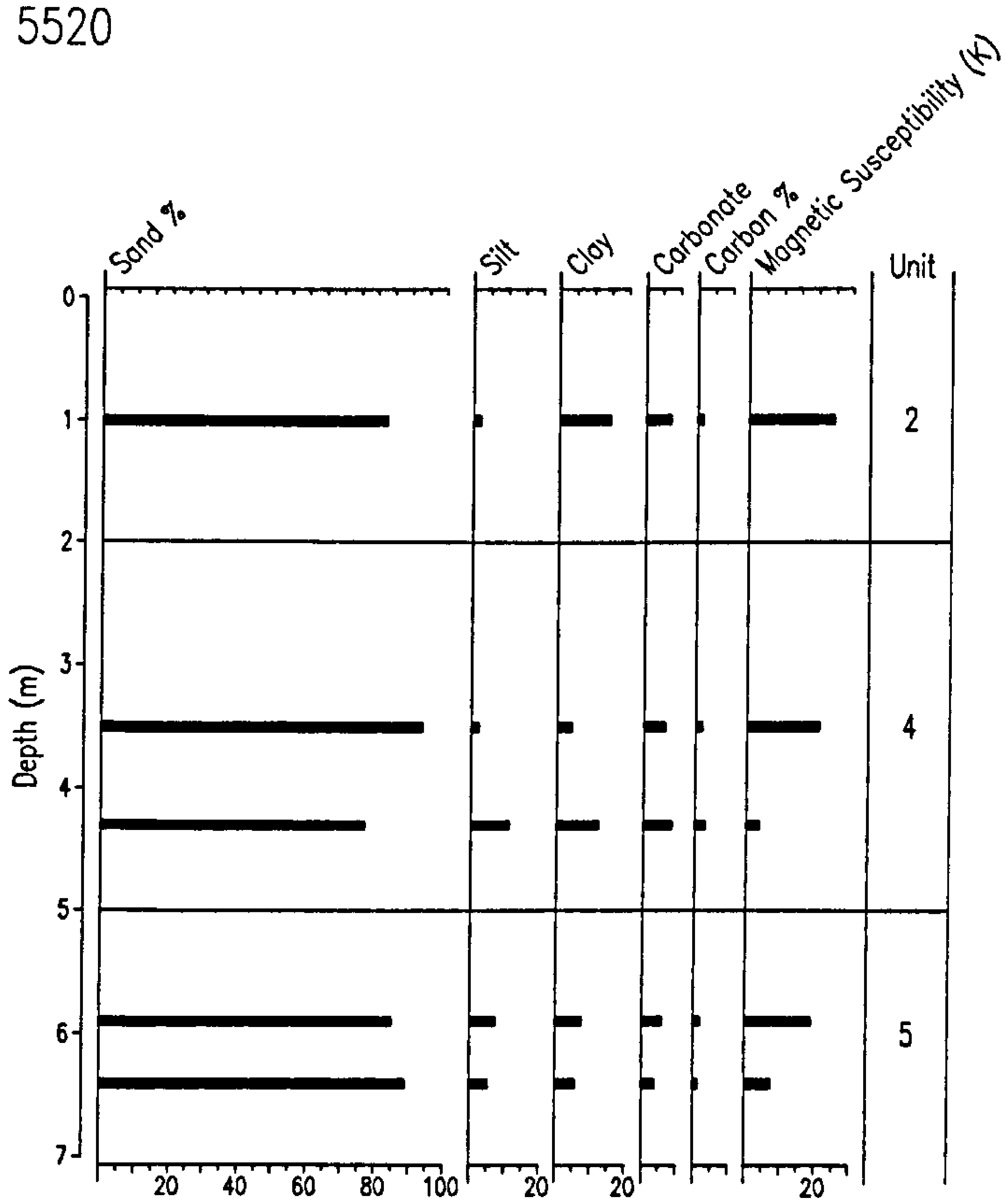


Fig. 5.25 Sediment analysis of site 5520

Unit 2 (Fan 2)

This fan is about 2 m in total thickness and characterised by high percentages of sand (82.9%) and a low proportion of silt (2.1%) and a moderate amount of clay (14.9%). The Carbonate content is 7.4%, organic carbon 1.6% and magnetic susceptibility shows a very high value (24.6 k).

5.3.6.3 Palynology

The pollen diagram of site 5520 can be seen in figure 5.26. This diagram can be divided into three assemblage biozones. These assemblage bizones are discussed here by stratigraphic unit.

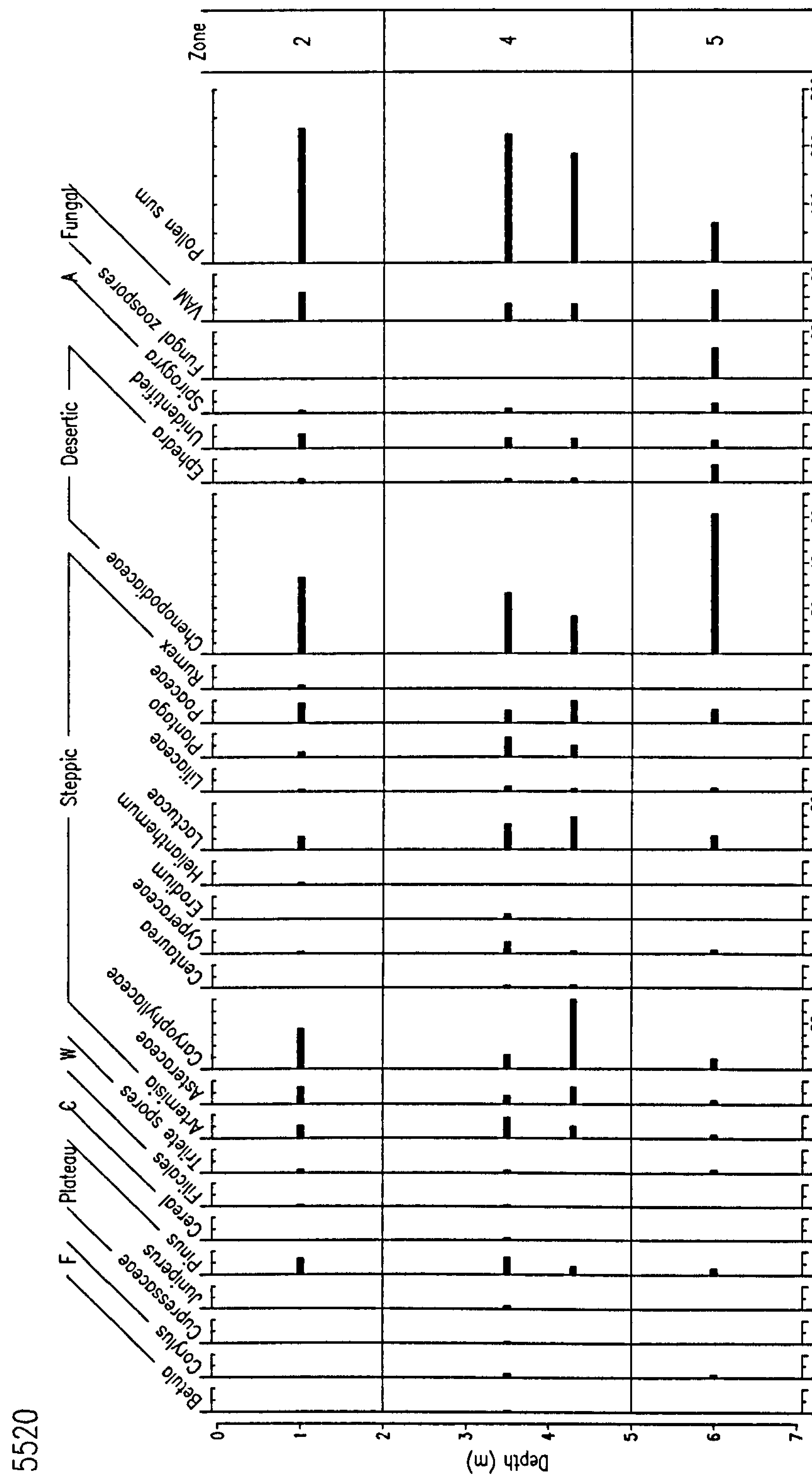
Assemblage biozone (Fan five)

This assemblage biozone is characterised by a dominance of Chenopodiaceae (61%) and a moderate count of *Ephedra* (7.5%). The very sparse tree pollen present includes *Pinus* (3%) and far-travelled taxa such as *Corylus* (2%). Trilete spores are present rarely (1.5%). Steppeland taxa include Poaceae (5.5%), Caryophyllaceae (4%), Cyperaceae (1.5%), Liliaceae (1.5%), Asteraceae (1%) and Lactuceae (5%). Unidentified taxa were present (2.5%). The Algae are represented by the benthonic *Spirogyra* (3%). Fungal microfossils occur, including fungal zoospores (13%) and VAM (13.5%).

Assemblage biozone (Fan 4)

This assemblage biozone is characterised by a relative increases in Poaceae (6-8%), *Plantago* (5-8%) and Caryophyllaceae (6-19%). Other taxa e.g. Liliaceae (1-1.5%),

Fig. 5.26 Palynology of site 5520. All pollen, spores and other microfossils are calculated as % total pollen and spores



Helianthemum (2%), Cyperaceae (0.5-4%), Asteraceae (2.5-5%), Lactuceae (10-13%) and *Centaurea* (0.5-1%) were detected. A relative decline in Chenopodiaceae (17-25%) and *Ephedra* (1-1.5%) has been recorded. Unidentified taxa (2-3.5%) are also present. Cereal type (1%) is occasionally present. Waterside species are rare but include Trilete spores (1%) and Filicales (undifferentiated) (1%). Far-travelled taxa are very rare, including *Betula* (<1%). Sparse plateau-tree pollen were found including Cupressaceae (<1%), *Juniperus* (1.5%) and *Pinus* (3-7%). Fungal microfossils are present including VAM (6-7%) and Fungal zoospores 0-2. *Spirogyra* (2%) is sometimes found.

Assemblage biozone (Fan 2)

This assemblage biozone is characterised by relatively high Chenopodiaceae (34%) and Caryophyllaceae (16%) and low *Ephedra* (2%). Steppeland taxa occur including Poaceae (7.5%), *Plantago* (2.5%), *Artemisia* (5%), *Rumex* (1.5%) and occasional Liliaceae, *Helianthemum* and Cyperaceae (<1%). In general steppeland taxa are less common in this unit, compared with the other two units. The only plateau taxon present is *Pinus* (6%).

<u>5.3.6.4 Palynofacies</u>

The results of palynofacies analysis can be seen in figure 5.27. Although it seems there are no considerable differences between palynofacies units at various levels in the diagram, for the purpose of detecting of minor differences the palynofacies diagram can divided into three units. The following is a description of each unit.

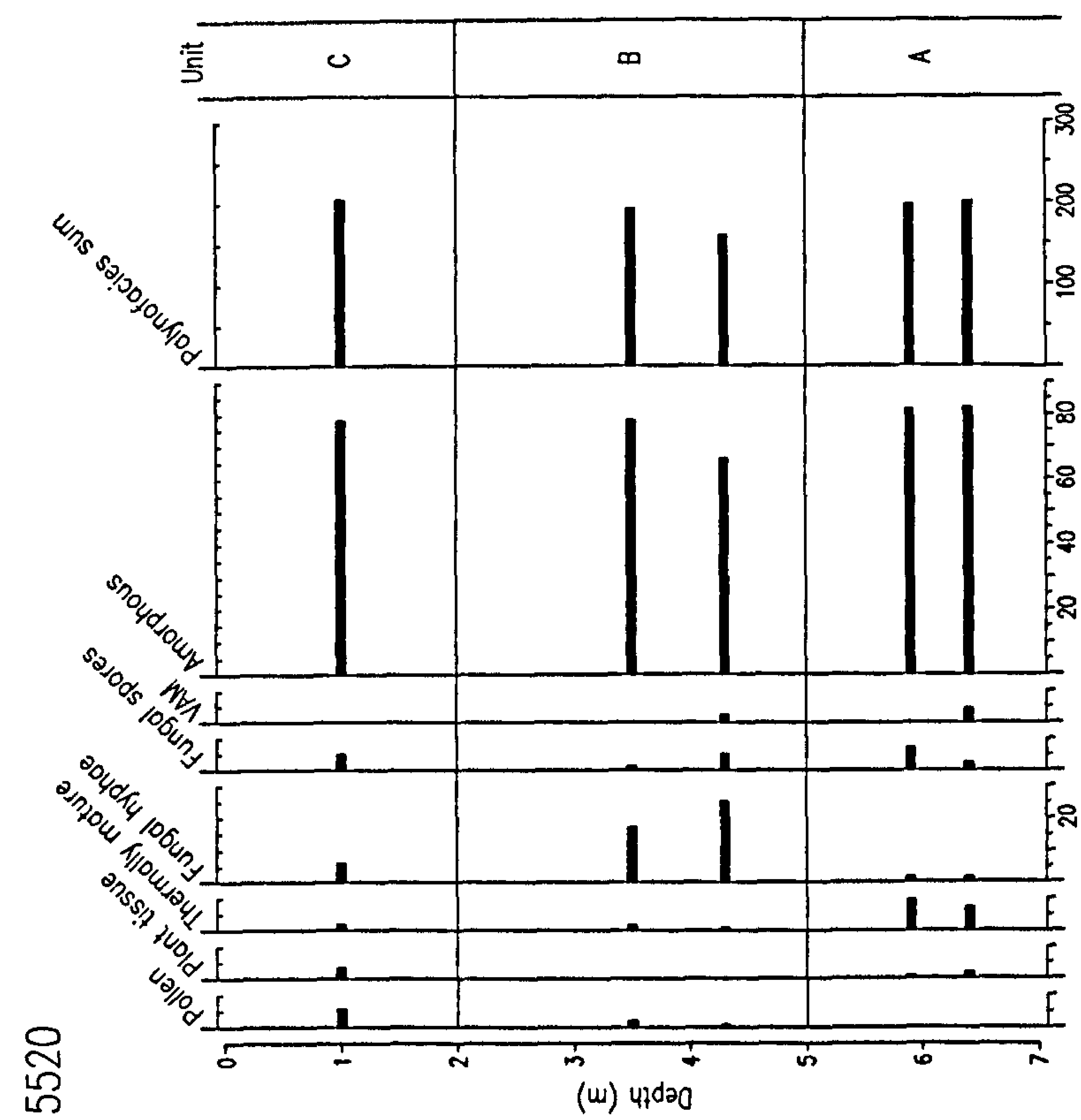


Fig. 5.27 Palynofacies of site 5520. All particulate organic matter is calculated as % total particulate organic matter

Unit A (Fan 5)

This Unit is dominated by amorphous matter (82-83%) with low VAM (5%), fungal hyphae (1.5-2%), plant tissue (1-2.5%) and fungal spores (2-6.5%). A moderate amount of thermally mature (7-9%) was present.

Unit B (Fan 4)

This Unit is characterised by a high incidence of amorphous matter (64-79%) and low percentages of VAM (2.5%), fungal spores (0.5-5%), thermally mature (0.5-1.5%) and pollen (0.5-2%). A moderate quantity of fungal hyphae (18-25%) were recorded in this unit.

Unit C (Fan 2)

This Unit is characterised by high amorphous matter (78%) and low counts for fungal spores (5%), fungal hyphae (6%), thermally mature (2%), plant tissue (3.5%) and pollen (6%).

5.3.6.5 Dating

The sediments of Fan 5 contain pollen assemblages comparable (because of their high Chenopodiaceae counts) with those from zone KH-3 at the Khirbet barrage site, (and to the rather sparse assemblages from 5509). These are dated at 5509 at 110 ± 50 BP uncal. (Beta-119600). Fan 4 is younger than Fan 5. It contains wood dated to 100 ± 50 BP (Beta-119602). Pollen from this and younger fans compares well with pollen of zone KH-4 at Khirbet Barrage. Fan 2, the youngest unit distinguished here, is thus shown to be modern. The deposits at site 5520 are therefore of very late Holocene age.

5.3.6.6 Event sequence

1- The oldest unit is an alluvial fan (fan 5), composed of sandy gravels (1), overlain by slackwater fluvial sand and silt (2) with a lens of ashy silt (3). This is overlain by terrace gravels (1)

2- After erosional activity and incision, alluvial fan number 4 was deposited, which consisted of gravel (4), interbedded with lenses of sand (5) and silt (6).

3- Erosion took place again, then sedimentation by an alluvial fan (fan 3). This consisted mainly of gravel (7).

4- Incision took place again, then alluvial fan (fan 2) was deposited, which consisted mainly of gravel (8).

5- An incision interval occurred, then alluvial fan (fan 1) was deposited. This consists mainly of gravel (9).

6- Much of the older deposits became mantled with talus (10).

5.3.6.7 Interpretation

Site 5520 is of very late Holocene age. Its floodplain and alluvial fan sediments accumulated in a very arid environment, as suggested by the high Chenopodiaceae and *Ephedra* in the Fan 5 sediments. Some time before *c.* 100 ± 50 BP uncal. (Beta-119602), but after *c.* 110 ±50 BP uncal. (Beta-119600), aggradation ceased and a set of incision terraces accumulated in conditions of relatively greater precipitation as shown by pollen evidence for the return of steppic vegetation.

Generally, the palynofacies diagram is dominated by high counts of amorphous matter and the presence of the fungal hyphae and spores, these probably reflects *in-situ* decay processes. The higher counts for thermally mature matter in the samples from Fan 5 may reflect human activity nearby.

5.4 Khirbet Member: Reservoir Fills

5.4.1 Introduction

The Khirbet Member consists of silty sands and silts of lacustrine origin, deposited in reservoirs and cisterns of mid to late Holocene age. The dating of the fills is dependent largely on the association of the impoundment structures with other archaeological features and artifacts.

5.4.2 Distribution

The Khirbet Member is found within impoudment structures such as dams and cisterns (see figure 5.28).

5.4.3 Age

Mid to Late Holocene, based on archaeological and radiometric evidence.

5.4.4 Khirbet Barrage site (5017): Type section

5.4.4.1 Introduction

Khirbet Barrage site is an ancient reservoir fill near Khirbet Faynan Tell. It is shown in figure 5.29 and plate 5.16. Figure 5.30 represents a cross-section of this site. This site is of Late Iron age 2630 $\pm$ 50 BP uncal. (Beta-110841) to Modern in antiquity. The type section is a borehole in the fill of the reservoir. The following are the sedimentological and palynological investigations, as well as palynofacies analyses.

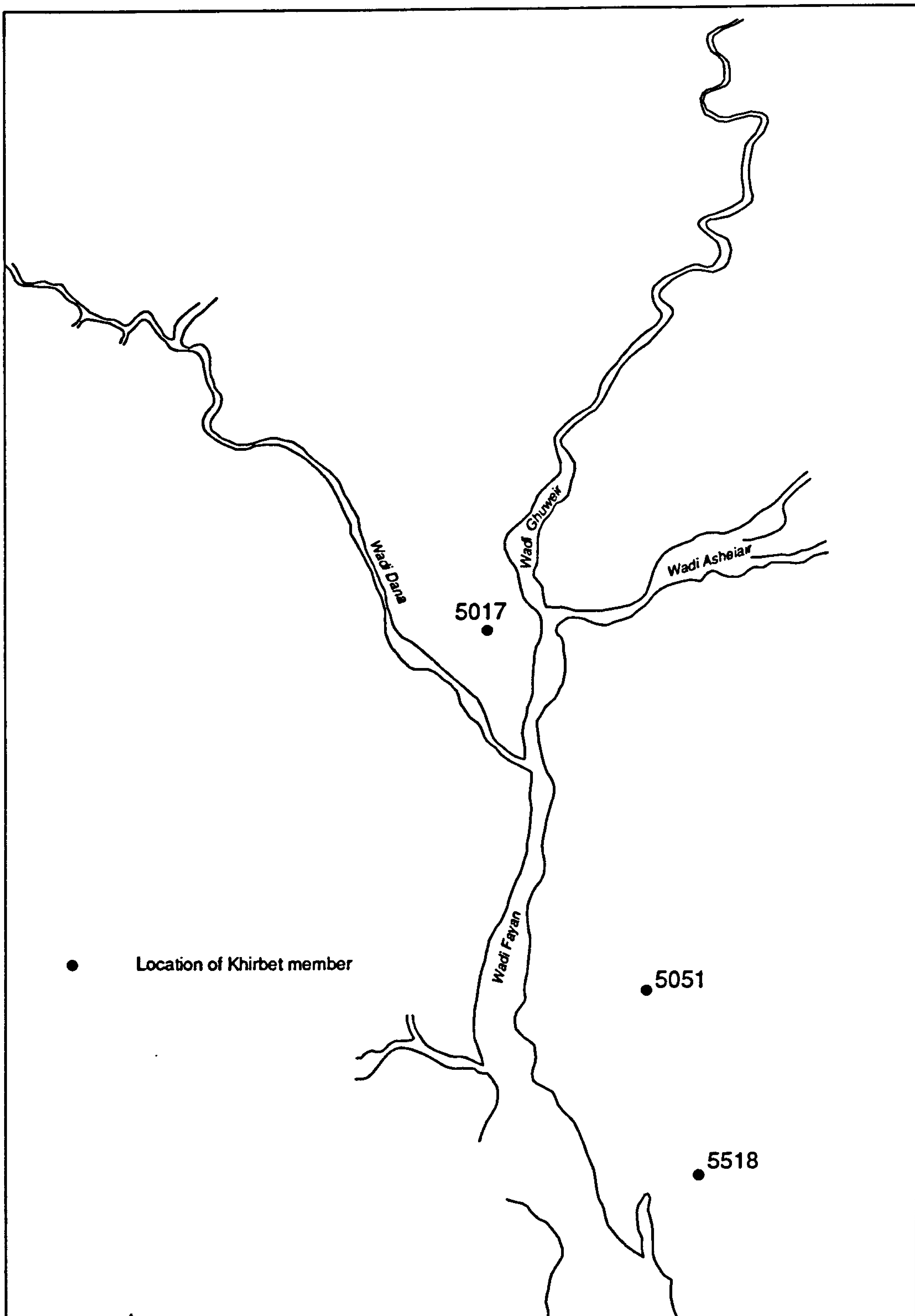


Fig. 5.28 Map showing location of the Khirbet member in the research area

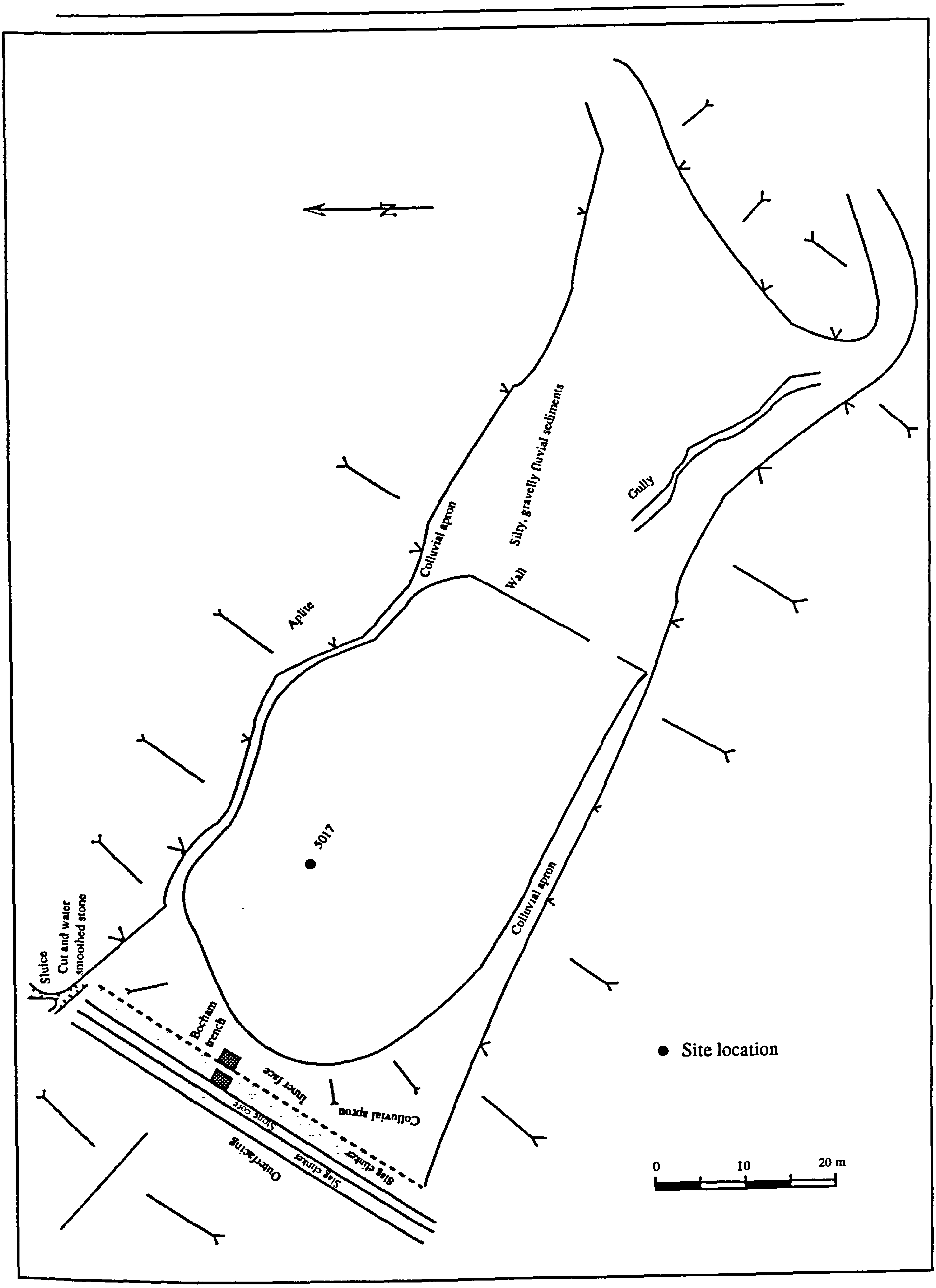
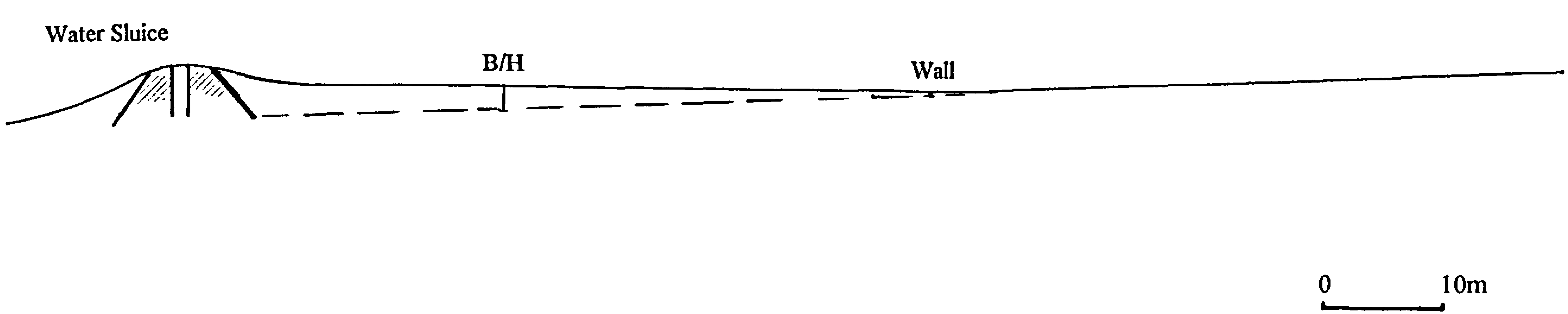


Fig. 5.29 Khirbet Barrage site.

Plate 5.16 Khirbet Barrage site (5017)

Fig. 5.30 Cross section of the Khirbet Barrage site



5.4.4.2 Sediment analysis

The results of the analysis of the Khirbet Barrage sediments can be seen in figure 5.31. These can be tentatively divided into three units. A description for each unit is given below

Unit 1

This oldest unit lies at depth between 2.35 and 1.75 m (the bottom part of the core). The sediments consist of clayey silty sands. Sand percentages are relatively high, ranging between 25- 65%. The clay in this unit is also high, usually ranging between 40-50%. but with a peak value of 75% between 2.20 and 2.25 m. The lower part of this unit is characterised by high percentages of silt, ranging between 20-33%. In the upper part of this unit, the silt decreases to 20%. The carbonate percentages in this unit are the lowest values in the whole core, ranging between 7-12 %. In this unit, as in the whole core, organic carbon shows no evident pattern in its abundance. The values ranged between 4 and 6%. The magnetic susceptibility in this unit shows relatively high values, the highest in the whole core, ranging between 13 and 22 k.

Unit 2

The sediments of this unit, which lies between 1.75 and 1.05 m, are clayey sandy silts and silty clayey sands. Sand ranges between 21 and 47%, peaking at the bottom and at the top of this unit. Clay ranges between 37 and 48% and peaks in the middle of this unit. The highest proportion of silt coincides with those of clay, and range between 25 and 31%. The carbonate in this unit gradually increases upwards to 1.35 m, after which it drops gently from 22 to 19%.

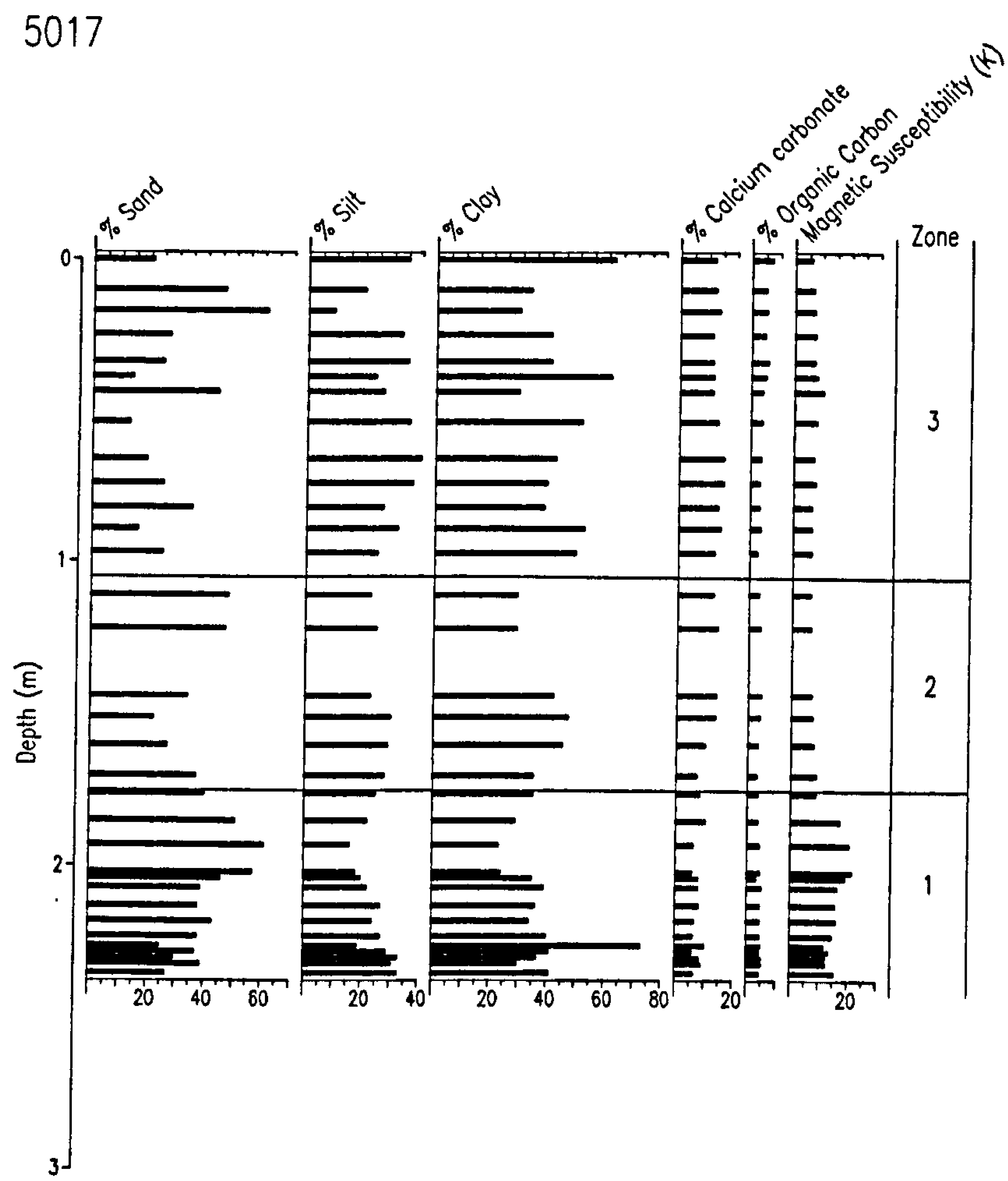


Fig. 5.31 Sediment analysis of site 5017

The organic carbon in this unit, as in the lower unit, shows no evident pattern, and ranges between 2 and 5%. The magnetic susceptibility drops abrubtly at the base of this unit, from 18 k at the end of unit one, and then declines gently towards the top ranging between 6 and 10 k.

Unit 3

The sediments of this unit, which lies between 0 and 1.05 m, are rather variable. Most are silty clays with some sand, but some are clayey sand with some silt. The sand percentages fluctuate and there is no systematic increase or decrease of the proportion of sand in this unit. In the uppermost parts of the unit, the peak value for sand is 45%, but in general, sand ranges between 17 and 30%. Clay values are high in this unit, varying between 62 and 30%, with peaks at depths of 1.00, 0.9 and 0.35 m. Silt is common, and peaks in the middle of this unit with percentages of 35 and 38%. The carbonate figures in this unit are generally higher than in the lower horizons. They range in the lower part of the unit between 13 and 17% and at the upper part of the unit between 10 and 13%. The organic carbon in this unit very slightly increases from bottom to top, the values range between 2 and 5%. In this unit magnetic susceptibility remains low, ranging between 6 and 10 k.

5.4.4.3 Cluster analysis

Cluster analysis was carried out on the sand, silt and clay percentage data (see figure 5.31) for the Khirbet Faynan sediments. The information which was gained from the cluster analysis tentatively suggested the core sediments be allocated into four groups. Figure 5.32 shows graphically these groups. The descriptions and characterisations of each group are given below:

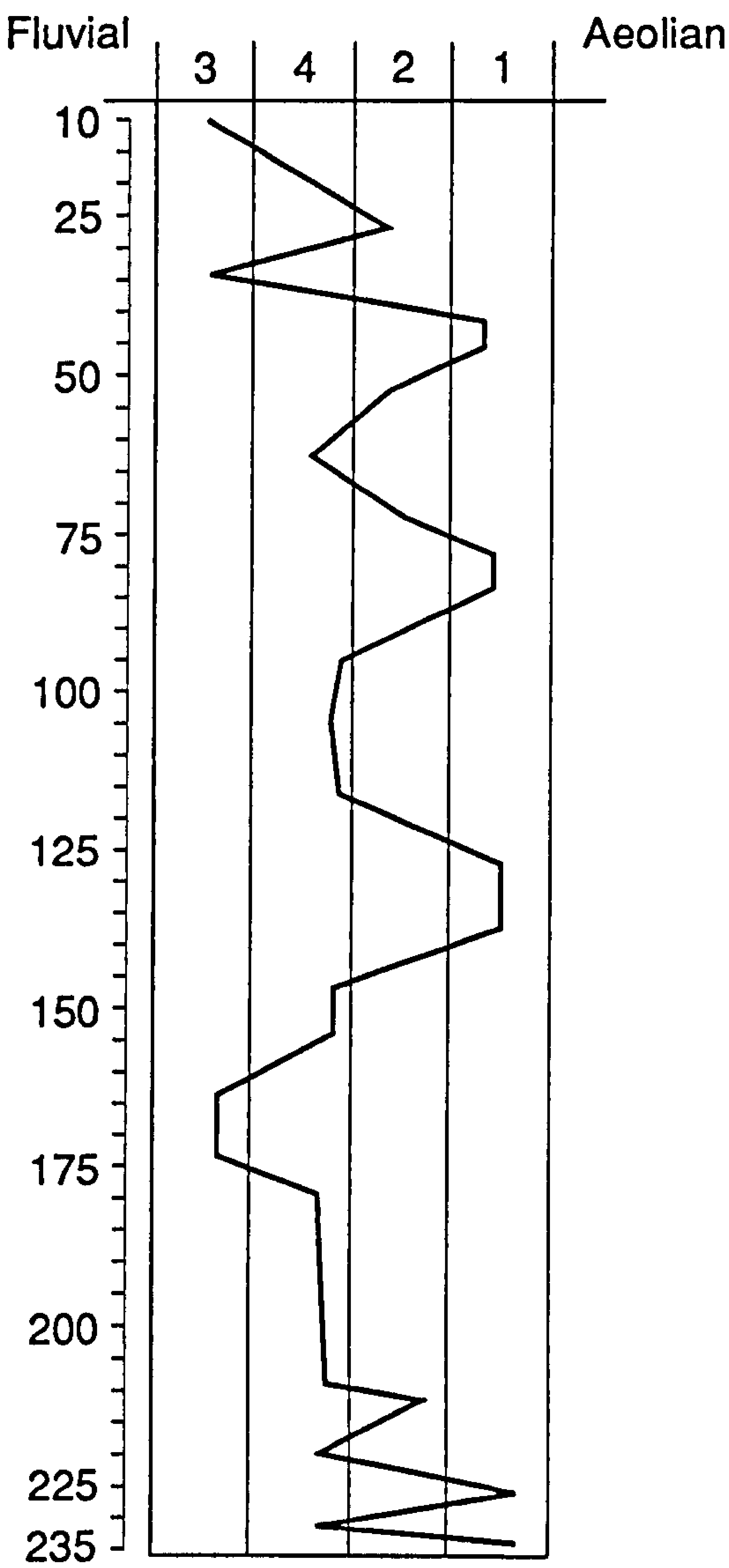


Fig. 5.32 Cluster analysis results of Khirbet Barrage site.

Group 1

Characterised by low sand, moderately high clay, silt is quite high. This group probably reflects significant aeolian input.

Group 2

This group is characterised by low sand, moderate silt and very high clay. This group is also characterised by high carbonate levels. This group probably reflects slow settling out in quiet water and some aeolian input (due to the presence of moderate silt).

Group 3

This group is characterised by very high proportion of sand, very low silt and low clay, and probably reflects high energy fluvial input.

Group 4

This group is characterised by moderately high sand, moderate silt and fairly low clay. These probably reflect fluvial input, but is not as high energy as group 3.

With regard to the above cluster analyses, it can be demonstrated that this sort of analyses does not supply meaningful results in this case. Cluster analysis was therefore not carried out on the other sites.

- The other parameters such as carbon, carbonate, magnetic susceptibility are not dependent on grain size (sand, silt and clay). These parameters did not show any covariation with the sand, silt and clay, which might have been related to past human activity in the catchment or related to the hydrology of the catchment. In addition, there is no straight forward relationship evident between the palynological analysis and the sedimentological data obtained. The pollen assemblages can, therefore, be regarded as independent of sedimentary facies.

5.4.4.4 Palynology

The pollen diagram figure 5.33 can be tentatively divided into four assemblage biozones. The descriptions of each zone are given below.

Assemblage biozone KH1

This oldest assemblage biozone lies at depths between 2.36 and 1.90 m. It is characterised by high counts for Chenopodiaceae (20-50%). Also important are Poaceae (4-9%), Lactucae (16-45%), *Artemisia* (0-9%), *Plantago* (1-4%), Caryophyllaceae (0-10%), *Rumex* (0-3.5%), Cereal-type pollen (0-4%), *Olea* (0.5-1%) and *Ephedra* (1-17%). *Ephedra* is especially common between 1.95 and 2.10 m. Fairly sparse tree pollen grains are present, such as *Pinus* (1-7%), *Juniperus* (1.5-8%) and *Quercus* (1-4%). Water side taxa present in this zone include *Tamarix* (1-2%), *Pistacia* (0-1.5%) and *Nerium* (2%). Trilete spores also occur (1-5%). Fungi were found, and were represented by Fungal zoospores (2-14%). Algae were detected, including *Saeptodinium* (7-19%) and Zygnemataceae (1-5%).

Assemblage biozone KH2

This assemblage biozone lies at depth between 1.90 and 1.05 m and is characterised by high counts of Chenopodiaceae (22-45%) which are almost evenly distributed through this zone. Latuceae are present in relatively high percentages (17-36%). Also

Fig. 5.33 Palynology of site 5017. All pollen, spores and other microfossils are calculated as % total pollen and spores

5017

important are Poaceae (0-7%), *Plantago* (1.5-4%), Caryophyllaceae (2-12%), *Artemesia* (0-9%), *Rumex* (0-0.5%) and *Ephedra* (1.5-9%). Water-side taxa are present in this zone including *Pistacia* (0-10%) though *Tamarix* is rare, hardly reaching 1%. Trilete spores are common (4-15%). Plateau taxa are present in this zone. There are relatively high counts for *Pinus* (2-18%), *Juniperus* (0-10%), *Quercus* also occur (0-4%). Cerealia-type are occasionally detected in this zone, but the Cerealia are low pollen producers. *Olea* is present in this assemblage biozone occasionally (*Olea* is also a low pollen producer). *Tilia*, a far travelled species was found (0-3%). Fungi are present, mainly fungal zoospores (1-10%). Algal microfossils also occur in this zone, mostly Zygnematacae (1-8%), *Saeptodinium* (1-2%) and Diatoms (2-4%).

Assemblage biozone KH3

This assemblage biozone lies at depth between 1.05 and 0.6 m. In this biozone, the assemblages contain very high counts for Chenopodiaceae, ranging between 57 and 87% and Caryophyllaceae (0.5-3%). Very little grass pollen is present; Poaceae hardly reached 1%. Very few steppic indicators were present such as Lactuceae (5-25%) and Asteraceae (1.5-8%). Furthermore *Artemesia* and *Plantago* were present, with percentages not greater than 1%; *Ephedra* was also occurs (0-4%). "Cultivated" taxa can be found occasionally, including *Olea* (0-0.5%). *Pistacia* is present rarely (0-0.5%) and *Tamarix* occurs with less than 1%. Plateau taxa occur in this assemblage biozone, including *Pinus* (0-5%) and *Quercus* (0-3%). Fungi are represented by Fungal zoospores (18%). Diatoms were found in low percentages (1-2%).

Assemblages biozone KH4

This youngest assemblage biozone lies between 0.6 and 0.0 m (surface) and includes the surface sample. Steppic taxa are common, including Poaceae (1-19%), *Plantago* (0-6.5%), *Poterium* (0-1%), *Rumex* (0-1.5%), Caryophyllaceae (0-7%), *Artemesia* (1-9%), *Armeria* (1-2%), Lactuceae are common (6-47%) and Asteraceae (5-18%). Chenopodiaceae occur in this assemblage biozone (15-40%), and *Ephedra* (1-4%) are also present. The water-side taxa in this biozone include *Pistacia* (0-7%), *Tamarix* (2%) and *Nerium* (3%). *Olea* is present in this assemblage biozone (0-4%). Cerealia-type pollen (0-2.5%) occur occasionally. Plateau taxa include *Pinus* (1- 3%) and *Quercus* (0-3.5%). Fungi were found, mostly fungal zoospores (2-11%). Algae, included *Saeptodinium* (1-3%) and *Botrycoccus* (1%) were occured.

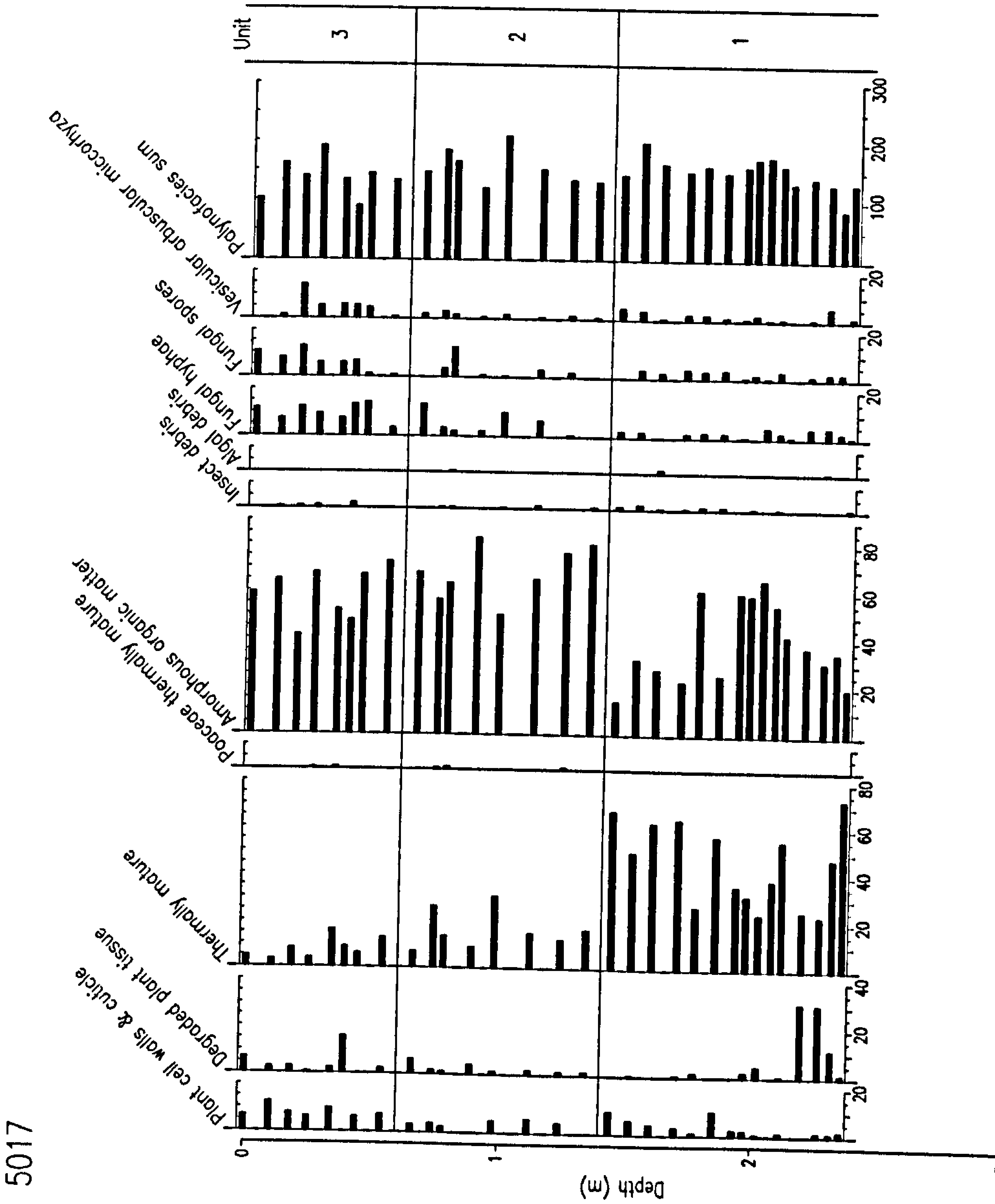
5.4.4.5 Palynofacies analysis

The results of the counts of organic fragments were presented in percentage terms, and the results of palynofacies diagram can be seen in figure 5.34. The palynofacies diagram tentatively is divided into three units.

Unit 1

This Unit lies at depths between 2.36 m and 1.40 m. It is characterised by very high levels of thermally mature matter (24-74 %) and also relatively high amorphous matter (13-65%). Degraded plant tissue was present and mainly concentrated at the lower part of this unit (12-32 %) and declined toward the top of this unit (2-3%). Plant cell walls and cuticles were found and increased toward the top of this unit from 2 to 3% in the lower part, to 8-11% at the upper part. Fungal spores occured with an increasing trend toward the top of the profile (2-3% to 5-6%). VAM were noted with

Fig. 5.34 Palynofacies of site 5017. All particulate organic matter is calculated as % total particulate organic matter



an increasing trend toward the upper part of this unit, increasing from 1 to 4-5%, (excepting a relatively high level value of VAM at depth 2.25 m). Fungal hyphae were found, at the lower part of this unit, ranging between 1 and 6%, but decreasing upward (1-4%). Insects and Algal debris were present occasionally, but with no evident regular pattern.

Unit 2

This Unit lies at depths between 1.40 m to 0.60 m and it was characterised by a high proportion of amorphous matter (52-81%), and relatively low levels of thermally mature (10-15%) with two peaks at depth 0.98 m (32%) and 0.76 m (29%). VAM are present with low concentrations. Fungal hyphae and Fungal spores were found and both showed a general increasing trend toward the top of this unit. Plant cell walls and cuticles were detected but showed no evident trends.

Unit 3

This is the uppermost zone and it occurs at depths between 0.60 m and the surface (0.0 m). This unit is characterised by small percentages of thermally mature matter (15-5%), decreasing toward the top of this unit (3-5%). Amorphous matter is also present with high levels (40-60%), but less than the lower unit. VAM (6-14%), fungal hyphae (8-11%) and fungal spores (7-12%) were all found and all showed a general increasing trend toward the top of this unit.

5.4.4.6 Dating

The base of this reservoir fill has been radiocarbon dated to 2630 ± 50 BP (Beta-110841). The peak in Chenopodiaceae in pollen assemblage biozone KH-3 invites comparison with the similar peak in site 5520, which ended before 100 ± 50 BP (Beta-119602). A high proportion of Chenopodiaceae is associated with a date of 110 ± 50 BP (Beta-119600) at site 5509. A date of 390 ± 50 BP (Beta-115214) predates the Chenopodiaceae peak at site 5025. It is likely, therefore, that assemblage biozone KH-3 started just after 390 BP and ended between 110 and 100 BP.

5.4.4.7 Interpretation

The Khirbet Barrage fill is a lacustrine unit, which accumulated upstream of the Khirbet Barrage. The sedimentary information points to an approximately cyclic alternation between sandy clayey silts and clayey silty sands, which may reflect changes in the energy of runoff and quantity of aeolian input through approximately the last two and a half thousand years of its accumulation. Sedimentation rates appear to have been very low for much of this time, but accelerated about 350 years ago.

In general, the following suggestions, which are related to palynology and palynofacies can be made. In the assemblage biozones KH-1 and KH-2 (lowest section of the core) evidence of both steppic (Poaceae, *Artemesia*, *Plantago*, *Acacia*, *Pistacia*) and desertic taxa (Chenopodiaceae, *Ephedra*) have been detected. The steppe vegetation was rather degraded, but low counts for *Acacia* and *Pistacia* (both low pollen producers) in the basal sample suggest that the demand for wood-trees-had at that stage not completely eliminated the local woody flora. The low counts for trees such as pine, juniper, oak and olive are probably from trees that were growing on the plateau, though olives could have been cultivated in the local flood water farming systems. At the end of assemblage biozone KH-3, Chenopodiaceae and the drought indicator *Ephedra* became common. These changes might point to aridification. In the assemblage biozone KH-3, the cereal-type pollen has disappeared, which probably suggests the end of arable farming near the Khirbet. Also in this assemblage biozone, the desert taxa such Chenopodiaceae, reach a peak, and a very sharp drop of Poaceae takes place. Furthermore, even most of the tree pollen from the plateau had disappeared. This evidence suggests that this biozone represents a very dry phase around the Khirbet Barrage.

Assemblage biozone KH-4 represents the uppermost part of the core and it is characterised by a relatively sharp drop in the Chenopodiaceae, and an increase in the abundance of the steppe vegetation (Poaceae, *Artemisia, Plantago*). Also in this assemblage biozone, the tree pollen *Pinus, Juniperus* and *Olea* are relatively more common, as well as an introduced Australian genus *Eucalyptus.* This could be interpreted in two ways. One may be the climate has ameliorated and human activity had stopped. Alternatively, this might reflect a steppic flora that may have only recently established itself in the old reservoir basin, especially since it is now virtually full of sediment and the seasonal inundation (flood) is very short. The modern regional vegetation is very sparse and still dominated by Chenopodiaceae.

The palynofacies units at the base of the Khirbet Barrage sequence show very high counts for thermally mature material (which results from burning), and high counts for amorphous matter, typical of terrestial environments where decay processes have occured *in situ*. With passage towards the top of the core, the proportions of thermally mature material decrease, whereas the amorphous organic matter, fungal spores, VAM and fungal hyphae increase slightly towards the top of the core. One explanation is that at the lower part of the core, intensive human activity took place.

The plant cell walls and cuticle, and degraded plant tissues were probably mostly produced by the local flora in the catchment.

In the upper part of the core the proportions of thermally mature material decreases. This may be due to termination of human activity near the Khirbet Barrage. The high counts for VAM and fungal material may reflect *in situ* pedogenic activity in the top part of the reservoir fill in recent times.

5.4.5 Site 5051

5.4.5.1 Introduction

This site is of Chalcolithic age (Hunt and Gilbertson, 1998). Samples from this site were collected from an old cistern which is a part of small catchment system (figure 5.35, plate 5.17). The following are the sedimentological, palynological and palynofacies analyses carried out at this site.

5.4.5.2 Stratigraphy and sedimentology

From this site, 7 samples were collected using an Eijkelkamp auger. The stratigraphy is described in table (5.7) below.

Table 5.7. Stratigraphy of site 5051

Depth (in meters)	Descriptions
0.0	surface
0-0.17	Greyish orange (10YR 7/4), coherent sandy silt.
0.17-0.24	Dark yellowish orange (10YR 6/6), slightly damp, sandy silt with bits of shells
0.24-0.28	Dark yellowish orange (10YR 6/6), gritty sandy silt
0.28-0.44	Dark yellowish orange (10 YR 6/6), very loose gravelly sandy silt
0.44-0.50	Dark yellowish orange (10YR 6/6), very gravelly sandy silt
0.50-0.53	Dark yellowish orange (10YR 6/6), extremely gravelly sandy silt, hit solid at 0.53 m.

The results of sediment analysis are described below. Figure 5.36 shows the results graphically. The diagram can be divided in to two sections (units).

Unit 1

This Unit lies between depths of 0.15 m and 0.53 m. Sand in this unit generally increases from 45% by weight at 0.15 m to 71% at the bottom of the core. Silt and

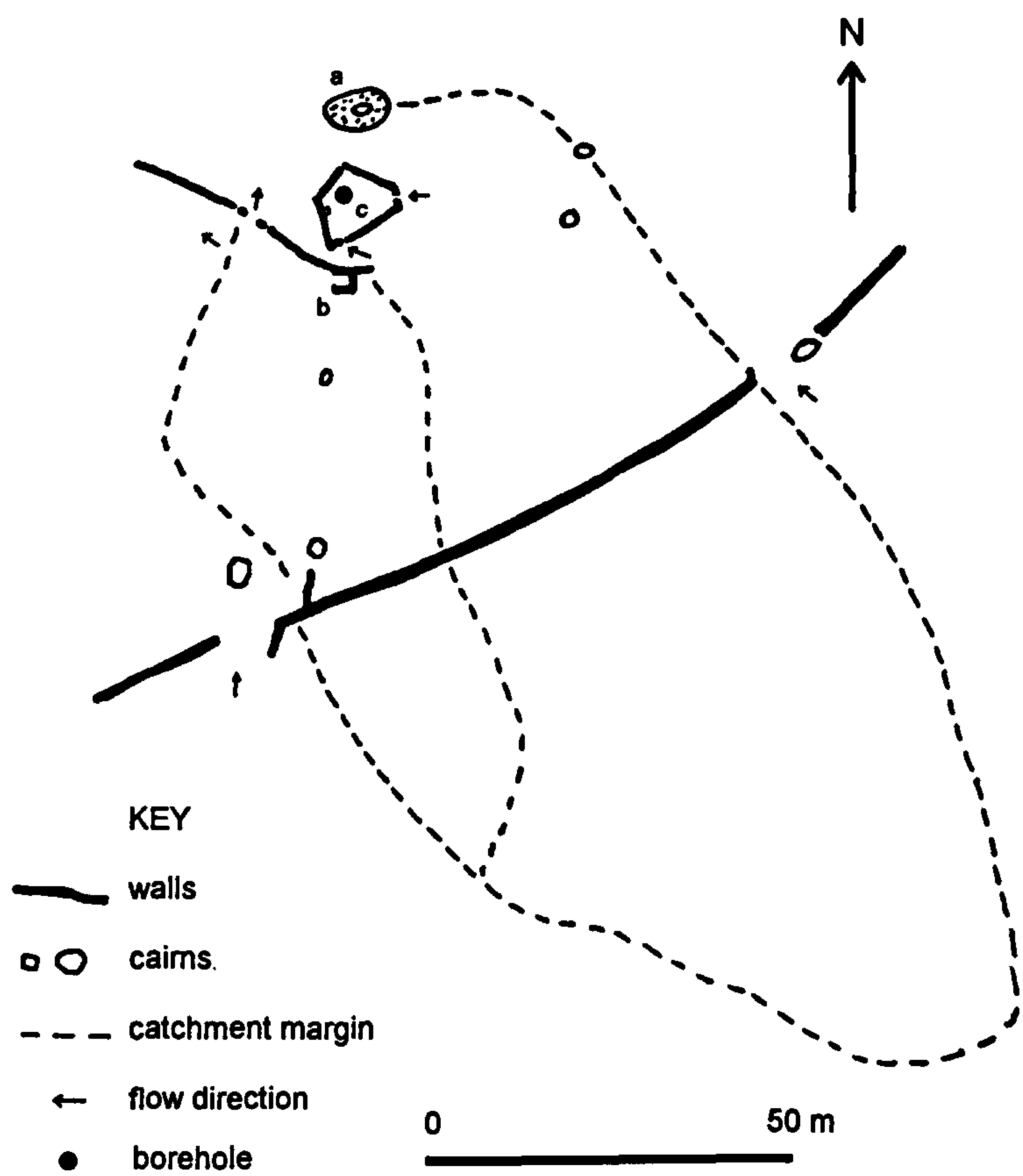


Fig. 5.35 A chalcolithic catchment system and cistern in the Wadi Faynan. This figure is produced from Hunt and Gilbertson (1998)

Plate 5.17 Site 5051

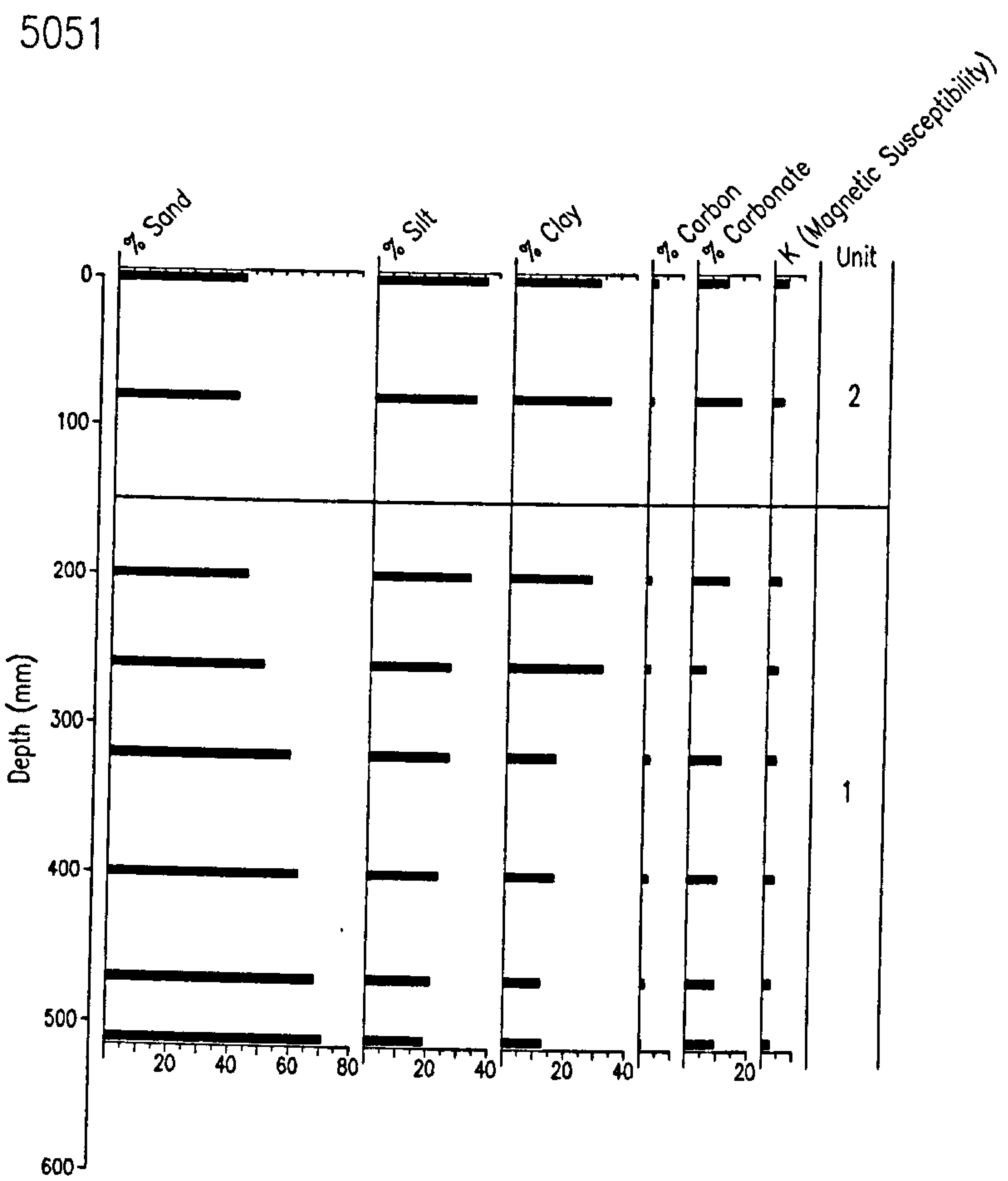


Fig. 5.36 Sediment analysis of site 5051

clay generally display an apposite trend. Silt decreases from 30% at depth of 0.15m to 19% at the bottom of the core. The same thing happened to the clay which decreases from 30% at depth of 0.15 m to 12% at the bottom of the core.

Organic carbon does not display a regular pattern through the column, but generally decreases toward the bottom of the core from 2-3% at 0.15 m to 1% at the bottom. Carbonate generally shows no trend and its values fluctuate randomly between 5% and 11%. Magnetic Susceptibility slightly increases from the bottom (2.5 k) toward the top of the profile (4 k at 0.15 m).

Unit 2

This Unit lies between the surface and a depth of 0.15 m. Sand has a value of 41% by weight at the surface, and decreases to 38% at the base of the unit. Silt is 36% at the surface and decreases to 33% at the base of this unit. Clay increases from the top of this unit (28%) toward the base (32%). Organic carbon decreases from the top (4%) to the base of this unit (2.5%). Carbonate increases from top to bottom, from 10% to 16%. Magnetic Susceptibility decreases from top (5 k) to bottom (3.5 k).

5.4.5.3 Palynology

Palynological investigations were also carried out. The pollen results diagram is shown in figure 5.37. The results are discussed below. The information from the pollen diagram (figure 5.37) can be considered as one biozone. This biozone lies between the surface and 0.53 m and is characterised by high counts of Caryophyllaceae (15-25%) and Asteraceae (6-22%). Also important are Poaceae (6-19%), Lactuceae (1-6%), *Artemisia* (5-12%), *Plantago* (11-19%),

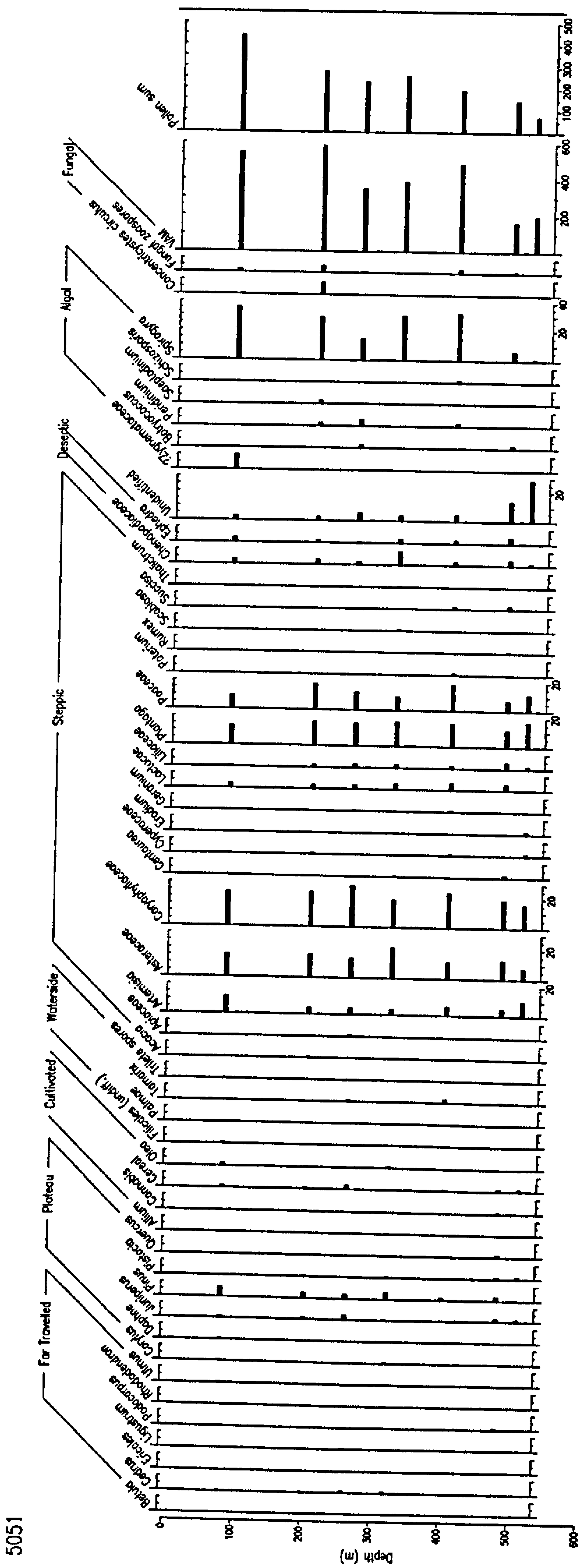


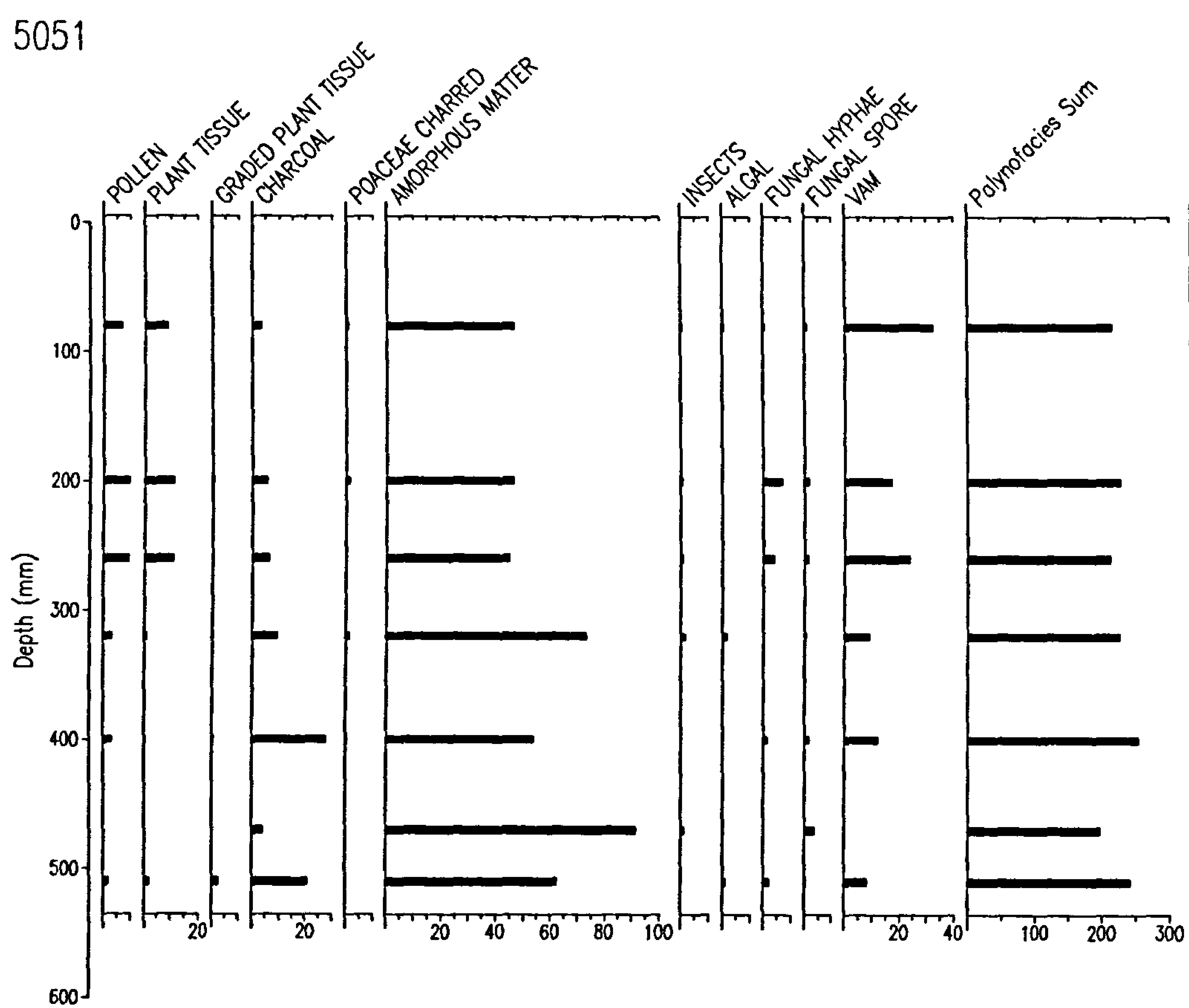
Fig. 5.37 Palynology of site 5051. All pollen, spores and other microfossils are calculated as % total pollen and spores

Ephedra (1-4%), Chenopodiaceae (2-8%), *Liliaceae* (1-4%) and some other taxa which occur occasionally, and include *Centaurea*, *Geranium*, *Poterium*, *Succisa* and *Rumex*. All the above taxa are characteristic of steppe-land. Fairly sparse tree pollen are present, such as *Pinus* (0-6%), *Juniperus* (1-3%) and *Quercus* (0.5-1%). In addition, cultivated species may also be present in this biozone, such as Cereal-type (1-3.5%) and *Olea* (1-2%). Occasionally grains of palm are present, reaching 1%. Water-side species also occur occasionally, including *Tamarix* (1-4%), and *Pistacia* (1-3%). Fungi are present, and are represented by Fungal zoospores (1-8%) and huge amounts of VAM (190-600%). Algae were found, including Zygnemataceae (0-10%), *Concentricystes circulus* (0-9%), *Peridinium* (1-4%), *Botrycoccus* (2-3%). *Spirogyra* frequently occurs in considerable quantity in this biozone (7-38%).

5.4.5.4 Palynofacies

The results of palynofacies analyses can be seen in figure 5.38. In this diagram, one zone which covers the whole core (from surface to 0.53 m) can be recognised. It is characterised by high proportions of amorphous matter, especially in the lower part of the core, but these concentrations decrease upward. The percentage of amorphous matter varies between 62-93% in the lower part of the core and 45-47% in the upper part of the core, with peaks at depths of 0.48 m and 0.41 m; with percentages of 92% and 72% respectively. A high proportion of thermally mature material was concentrated mainly at the lower part of the core (21-30%), and this proportion decreases upward to 6-4%. Pollen is present in low percentages 2-4% in the lower part of the core from 0.53 m to 0.36 m, and then increases progressively toward the upper part of the core (8-9%). Plant tissue was present in low percentages in the

Fig. 5.38 Palynofacies of site 5051. All particulate organic matter are calculated as % total particulate organic matter



lower part of the core (1-2%) and then progressively increases in abundance toward the top of the core (10-12% at 0.08 m), but again starts to decrease near the surface. Degraded plant tissue occurred in very low percentages (1-3%) but generally decreased toward the top of the core. VAM also increases from the base of the core (9%) toward the top of the core (33%). Fungal hyphae and insects and fungal spores were occasionally present.

5.4.5.5 Interpretation

In general, from the results and the depositional context, the site can be interpreted as a location of a former body of water. Moreover, from the division of the sediment diagram, a cyclicity may be detected. Two cycles of deposition appear to have taken place. The first one started with high energy which diminished and the second cycle is characterised by moderate to low energy of deposition.

The general trend of Magnetic Susceptibility which decreases from top to the bottom of the core could be interpreted as the result of the input of increasing quantities of ash transported from other areas, in which burning or industrial activity took place, especially later than the Chalcolithic. Alternatively, this patten may reflect increasing quantities of soil eroding in the catchment. Such an explanation is suggested also by the figures for VAMs (see below).

From the pollen diagram, the palynological investigation suggested a relatively diverse steppic landscape, but tree pollen is rare, suggesting, that perhaps, the area became less humid than in the Neolithic (eg. site 5015/5500), or that people removed trees.

This site is, however, further from the plateau where the trees lived than site 5015, so such conclusion must be viewed with some caution.

The palynofacies shows a high count for amorphous organic matter, which is typical of terrestrial environments where decay processes have been occurred *in situ* and especially of sites with intense human activity (Hunt and Coles 1988). The high counts of thermally mature material are likely to be the product of charring. Some of the charred material is most probably of monocotyledonous origin and may be charred grass or cereal straw. In most natural environments, thermally mature material is very rare (less than 2%, C. O. Hunt *pers. comm.*, 1997), so the high count in the lower half of this borehole may reflect past human activity. The high count of amorphous matter supports this interpretation. On the other hand, in the upper part of the borehole, the pollen percentage increases and the thermally mature and amorphous matter decreases, probably due to the termination of local human activity after the abandonment of the cistern. The high rates of VAM in the upper part of the core probably suggest soil erosion.

5.4.6 Site 5518 (W.F. 148)

5.4.6.1 Introduction

This site was suggested by Prof. Barker (G. W. W. Barker, *pers. comm.* 1998)to be a water-catchment structure of Late Chalcolithic/ Bronze age date (figure 5.39 and plate 5.18). A section was cut near the centre of the structure, which had interior dimensions of ≅ 22 × 12 m. The stratigraphy of this site consists of silty alluvial fill which contains few stones. The stratigraphy is described in table (5.8).

Table (5.8) stratigraphy of site 5518

Depth (in metre)	Descriptions
0.0-0.10	Compacted mid-brown (10 YR 5/4) sandy silts with roots
0.10-0.52	Compacted mid-brown (10 YR 5/4) stony sandy silts

One sample was taken from the basal 0.10 m. (see figure 5.40).

5.4.6.2 Palynology

The pollen results can be seen in table (5.9) in which the pollen percentages were not taken because the pollen counts were very small.

Table (5.9) Pollen counts from site 5518

Species	No. of grains
Corylus	1
Rosaceae	1
Caryophyllaceae	1
Poaceae	1
Plantago	2
Chenopodiaceae	1
Asteraceae	8
Saeptodinium	1

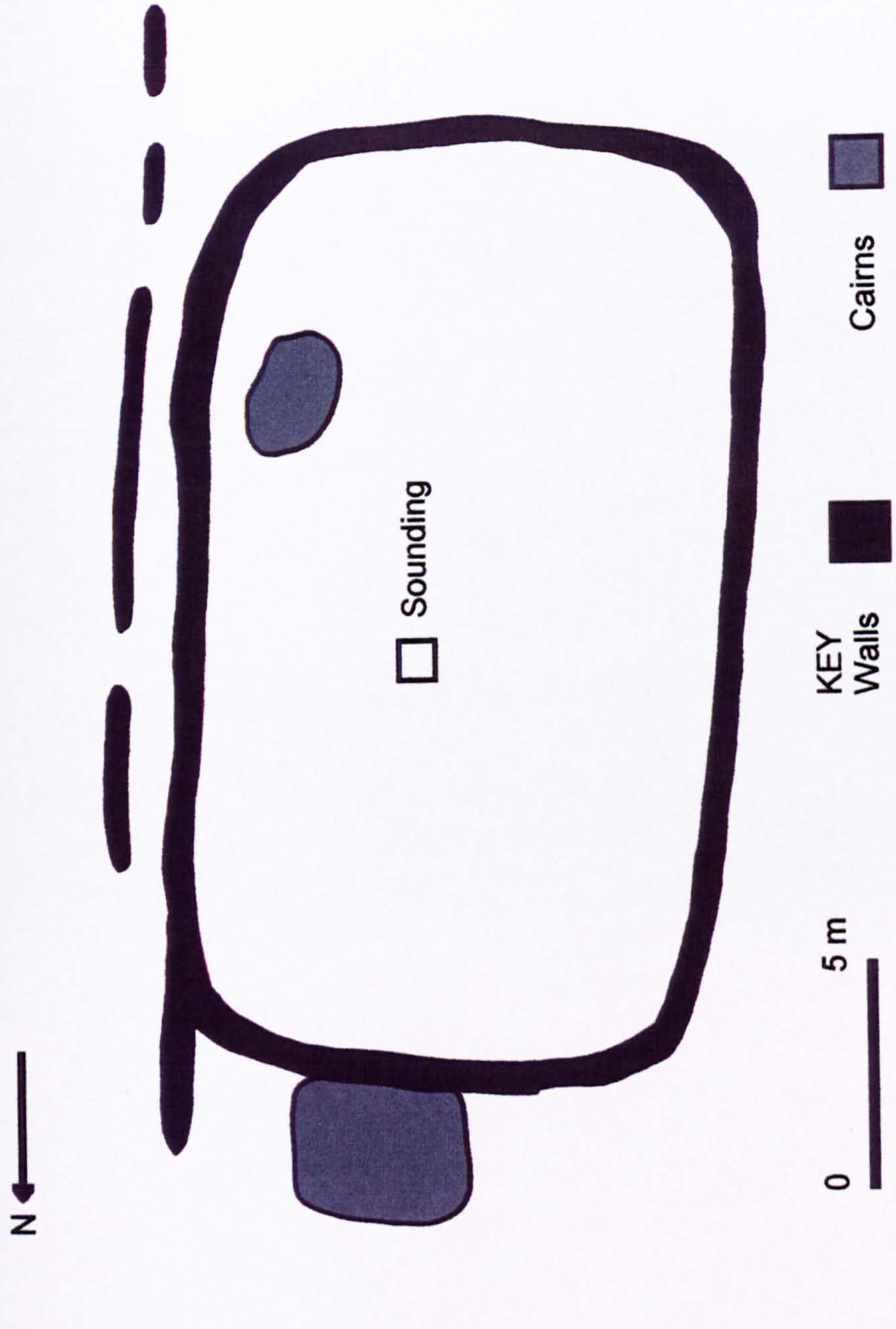
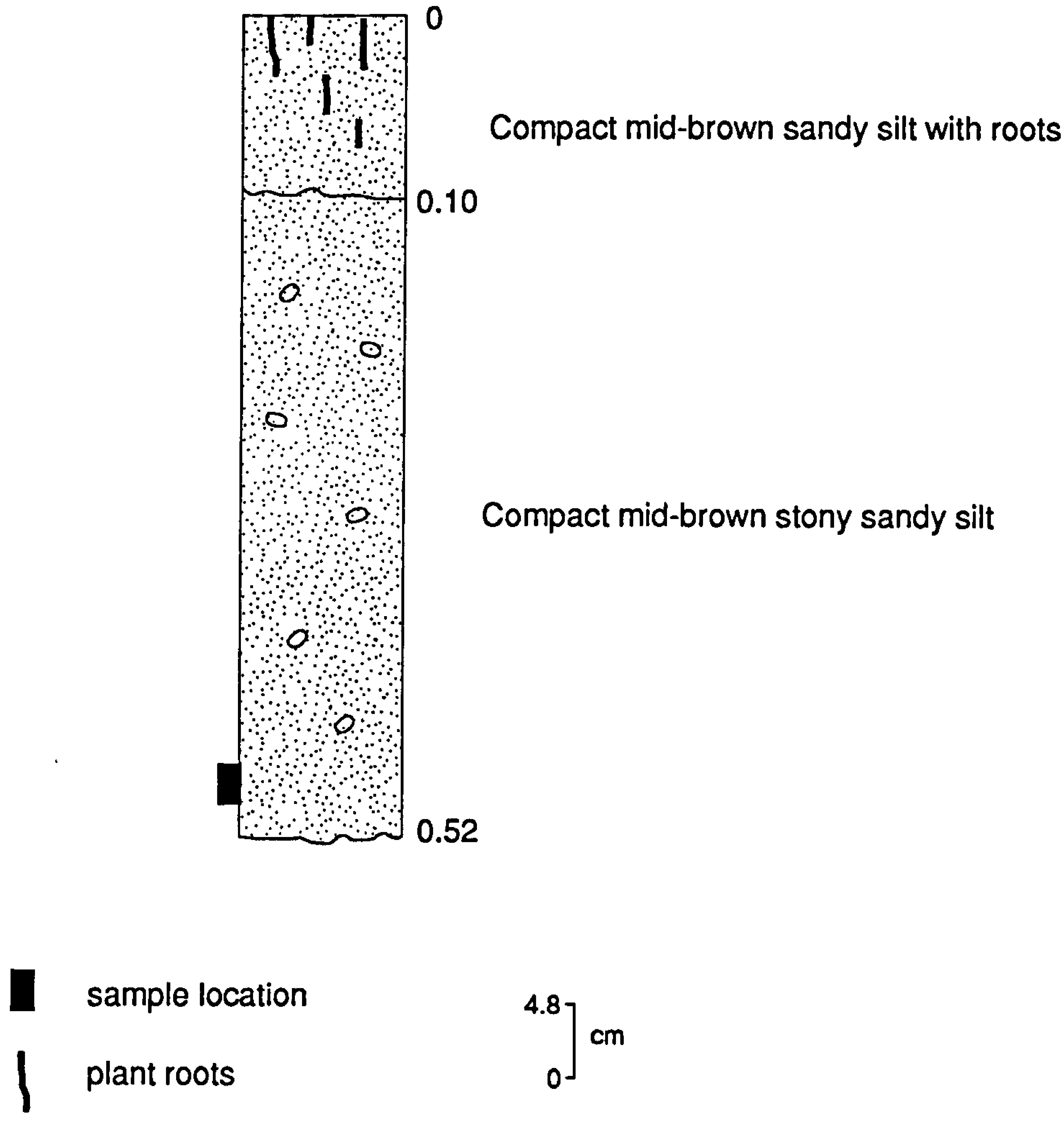


Fig. 5.39 site 5518 showing water catchment structure of Late Chalcolithic/Bronze age (Modified from Barker *et al.*, in press).

Plate 5.18 Site 5518

Fig. 5.40 Sketch section of site 5518



The count for this site (5518) was only 16 grains, among these 8 grains of Asteraceae, 2 grains of *Plantago*, and one grain each of *Corylus*, Rosaceae, Caryophyllaceae, Poaceae, Chenopodiaceae and one *Saeptodinium* cyst.

5.4.6.3 Interpretation

The pollen grains which derived from this site probably reflect the degraded remnants of the steppe environment. The *Saeptodinium* cyst is also consistent with a waterlain environment. One grain of *Corylus* which is probably far-travelled is present at the site.

5.5 Atlal Member: Anthropogenic deposits

5.5.1 Introduction

The Atlal Member is composed of building rubbles and anthropogenic debris, and has been mapped by archaeologists (Barker *et al.* 1997, 1998).

5.5.2 Description

The Atlal Member consists of a heterogenous mixture of shaped and unshaped building stones, slag, quarry waste, mudbricks, ash and potsherds and other debris. Superficial examination of the anthropogenic deposits of the area suggests that the composition of the units varies within and between sites.

5.5.3 Age

The Atlal Member encompasses remains broadly of Neolithic to Byzantine age on archaeological evidence (Barker *et al.*, 1997, 1998).

5.5.4 Relationships

The Atlal Member is in places interbedded with fluvial, colluvial and aeolian Holocene sediments.

5.5.5 Distribution

The Atlal Member is found predominantly at the Khirbet Faynan, near the confluence of the Wadis Dana, Esh-Sheqar and Ghuweir figure 5.41, but small occurrences are widely distributed and not shown on the map (see plates 5.19 and 5.20). These areas are being mapped by the archaeologists of the Wadi Faynan Project.

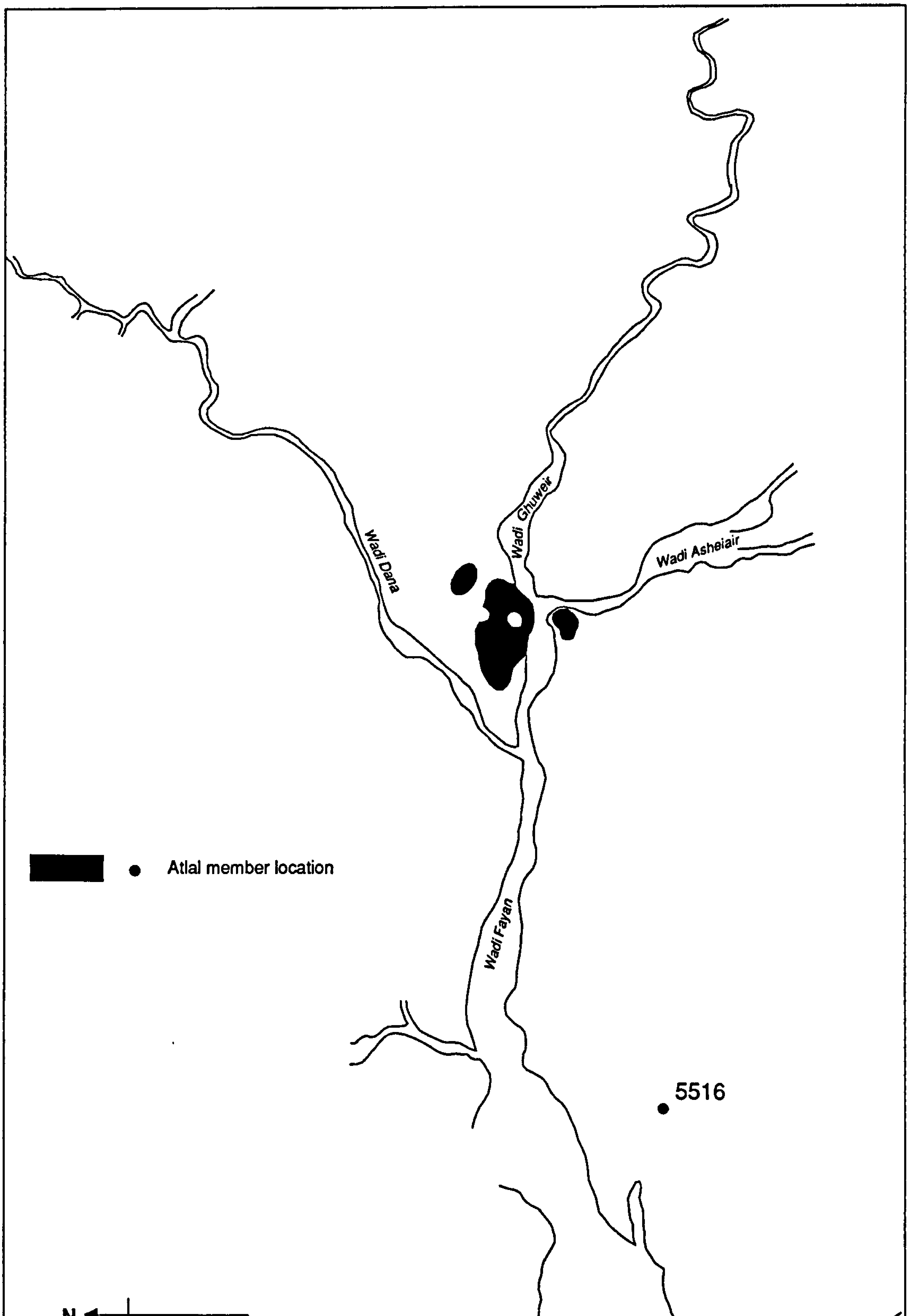


Fig.5.41 Map showing location of the Atlal member in the research area

Plate 5.19 show patchy, small occurrence (not mapped) of the Atlal Member, in the research area.

Plates 5.20 show patchy, small occurrence (not mapped) of the Atlal Member, in the research area.

5.5.6 Type section

5.5.6.1 Introduction

Site 5516 was investigated as an example of a Bronze age site, since sites of this age are difficult to find in the research area. This site has been excavated by a UCL archaeological team led by Dr. K. Wright (1996-1998).

5.5.6.2 Stratigraphy

The stratigraphy of this site is shown in plate (5.21), and figure 5.42. The following is a description of the different layers which were identified in the field (see table 5.10).

Table (5.10) Stratigraphy of site 5516

Layer	Thicness (in m.)	Stratigraphic description
Layer 1239	0.20	Sandy silty material deposited by wind, and containing gravels
Layer 1241	0.18	An ashy layer; cultural layer.
Layer 1240	0.10	Clayey material most probably derived from mud bricks.
Layer 1239	0.45	Coarse sand/silt and gravel of aeolian and colluvial origin.
Layer 1235	0.36	Dumped unsorted angular to very angular gravels with no imbrication. Some sherds have been found in this layer.
Upper Layer (uncoded)	0.50	Brown, yellow silty sand with scattered gravels of colluvial origin. A land snail (*Helix* sp.) found in this layer.

5.5.6.3 Sediment analysis

Three samples were collected from the site. The sediment description can be found in appendix (3). These sediments consist mainly of sandy silt.

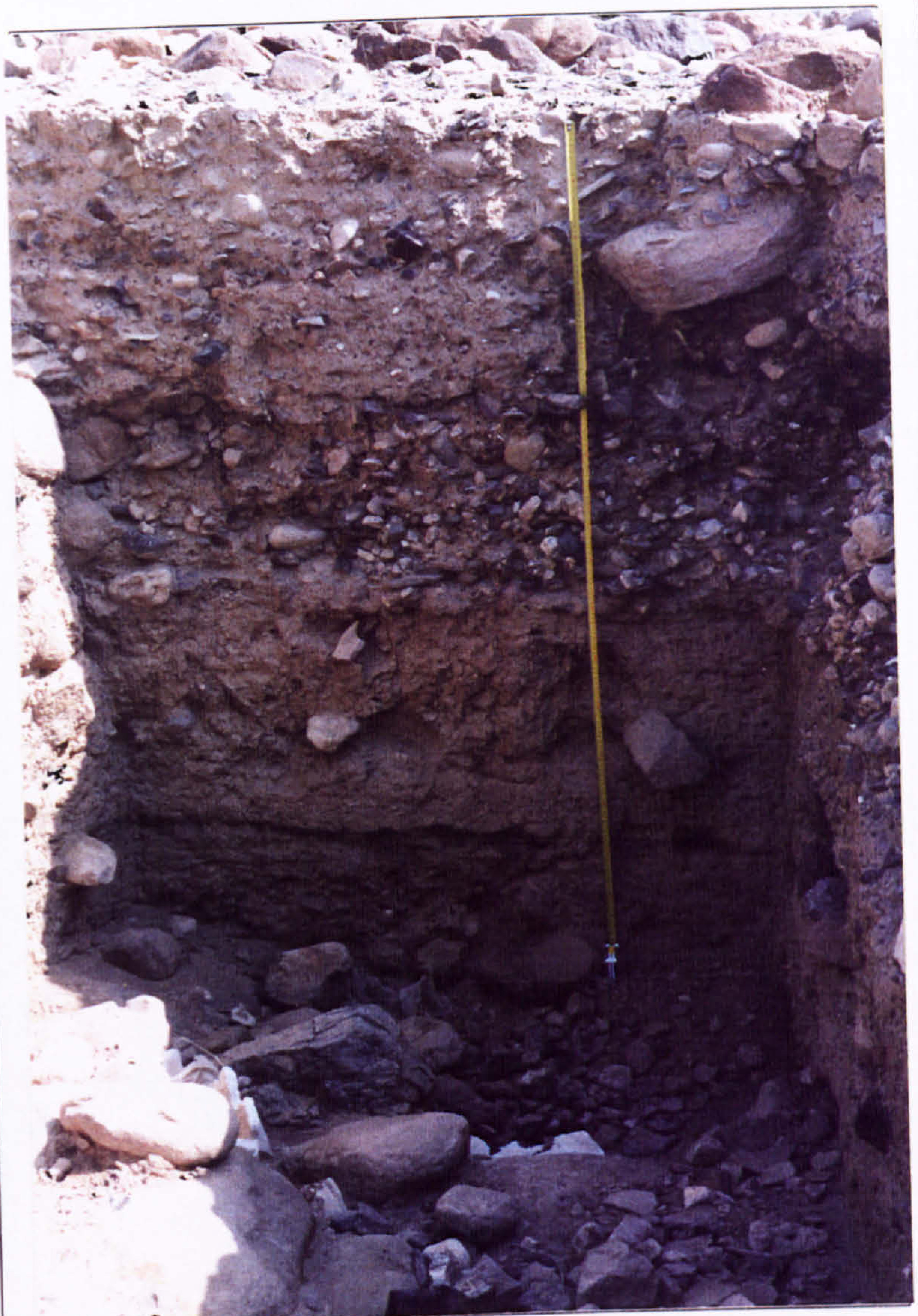


Plate 5.21 Showing site 5516

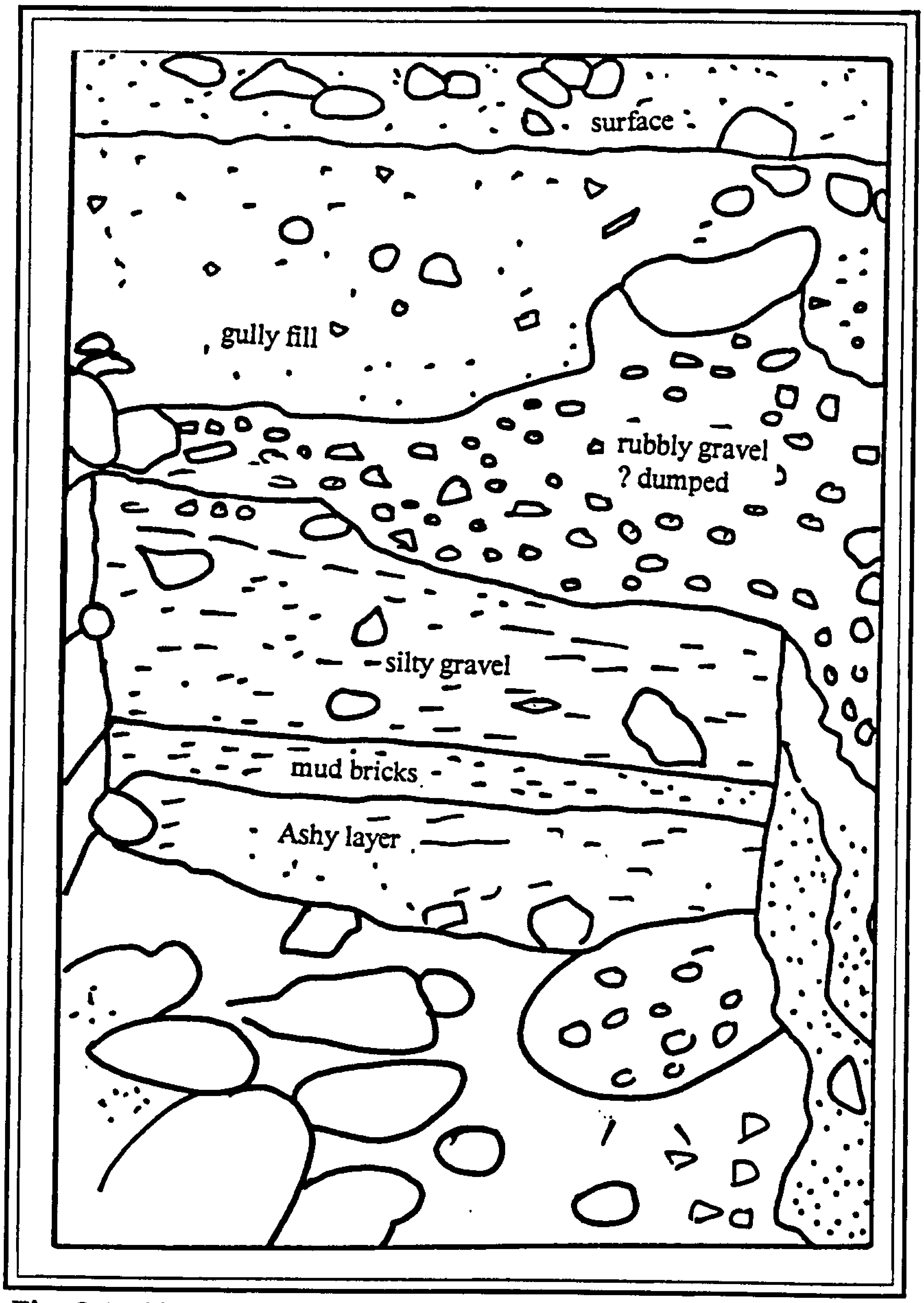


Fig. 5.42 Sketch section of site 5516

5.5.6.4 Palynology

The three samples collected from this site were subjected to palynological investigation. Two of these samples were barren and only one sample contained pollen grains which were very poorly preserved as well as sparse. The count totalled only 25 grains; among these were 6 grains of Poaceae, 4 *Juniperus*, 3 Chenopodiaceae, two grains of each Caryophyllaceae, *Poterium*, Cereal type and one grain of each *Pinus*, *Olea*, Cyperaceae, *Plantago*, Asteraceae and Lactuceae (table 5.11).

Table (5.11) Pollen counts from site 5516

Species	5516.1	5516.2	5516.3
Pinus	0	0	1
Juniperus	0	0	4
Olea	0	0	1
Caryophyllaceae	0	0	2
Cyperaceae	0	0	1
Poterium	0	0	2
Poaceae	0	0	6
Cereal type	0	0	2
Plantago	0	0	1
Chenopodiaceae	0	0	3
Asteraceae	0	0	1
Lactuceae	0	0	1

5.5.6.5 Age

Early Bronze age based on archaeological finds (shreds) (Dr. A. Wright, *pers. comm.*, 1998).

5.5.6.6 Interpretation

The assemblage from layer 5516.3 is dominated by plants such as Poaceae, *Poterium*, Caryophyllaceae and is consistent with a degraded steppeland. Some pollen seems to have been derived from the plateau, such as *Pinus* and *Juniperus*

Environmental interpretations based on pollen from archaeological sites are often criticised (Bottema and Woldring, 1984) but some workers believe it is possible to obtain good results from archaeological sites, among them Horowitz (1992), Davis (1990) and Dimbleby (1985). Dimbleby said " the presence of pollen is a positive feature in a site and to ignore it is to miss a potential source of evidence about the past." (written communication to J. Carrion and M. Dupre [1992] Carrion and Dupre, 1994).

5.6 Tell Loam Member

5.6.1 Introduction

The Tell Loam Member consists of sandy silt (loess) of aeolian origin and contains, in places, skeletal soil profiles.

5.6.2 Age

At the type section (5022), the Tell Loams overlie the Neolithic site radiocarbon to 5375 $\pm$ 30 BP uncal. (BC 4330-4165) (HD 12336) (Al-Najjar *et al.*, 1990) and are overlain by Nabatean and Roman artifacts (G. W. W Barker and D. J. Mattingley, *pers. comm.*, 1998).

5.6.3 Relationships

At 5022, the Tell Loam Member overlies the Faynan Member, apparently conformably.

5.6.4 Distribution

The Tell Loam is thickest at its type section, but a thin veneer of aeolian sediment is generally distributed in the research area which was too thin to map, except in active water courses and on steep slopes (figure 5.43).

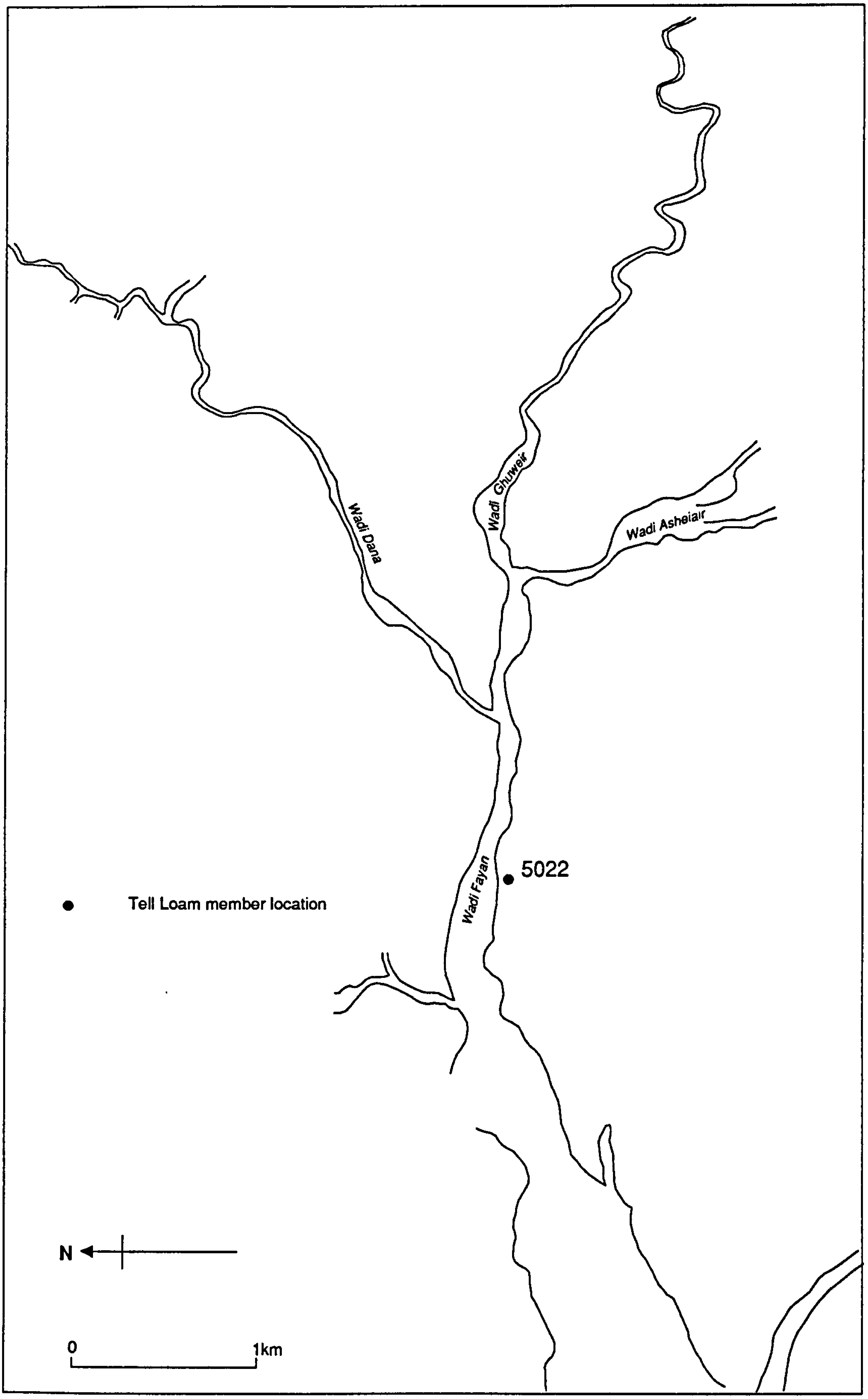


Fig. 5.43 Map showing location of the Tell Loam member in the research area

5.6.5 Type section

The type section is site 5022

5.6.5.1 Intoduction

The thickest aeolian sediments are at Tell Wadi Faynan (plate 5.22) in the Wadi Faynan. These were sampled in an attempt to find pollen in the interval between the Neolithic and Nabatean (see figure 5.44).

5.6.5.2 Stratigraphy

The Tell Loam Member is almost a 2 metre thickness of buff slightly clayey silts, with desiccation horizons, occasional small gravel filled scours, horizons of calcite induration and small soft calcite nodules (see table 5.12). The Tell Loam Member overlies the Late Neolithic site at 5021 and underlies Nabatean-Roman sherds and debris (Barker, *pers. comm.*, 1998). The presence of Nabatean and Roman debris on the top of this site probably preserved it from wind erosion and deflation.

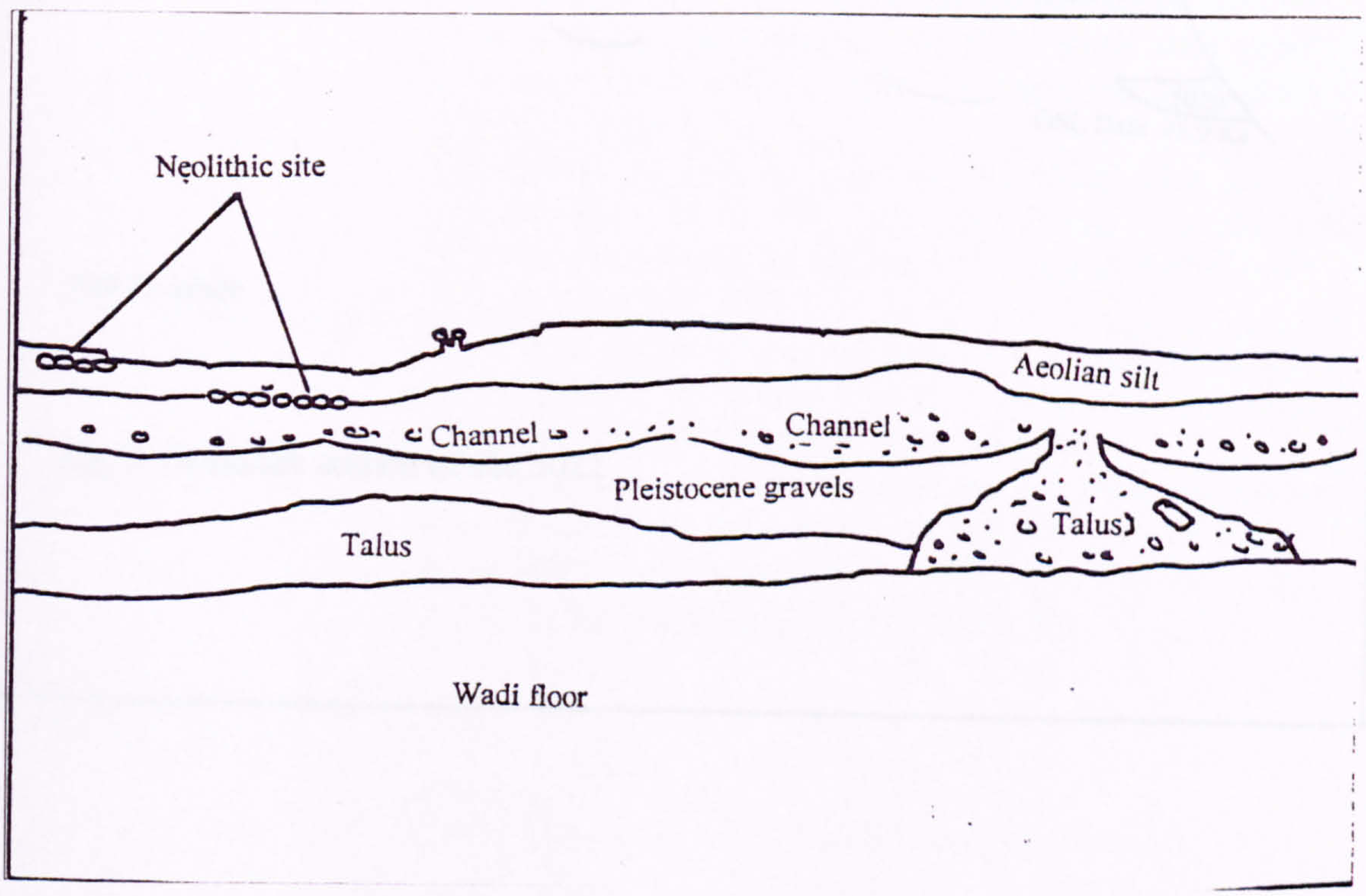
5.6.5.3 Palynology

Samples were collected from this site and have been investigated palynologically and all were found barren of pollen and spores.

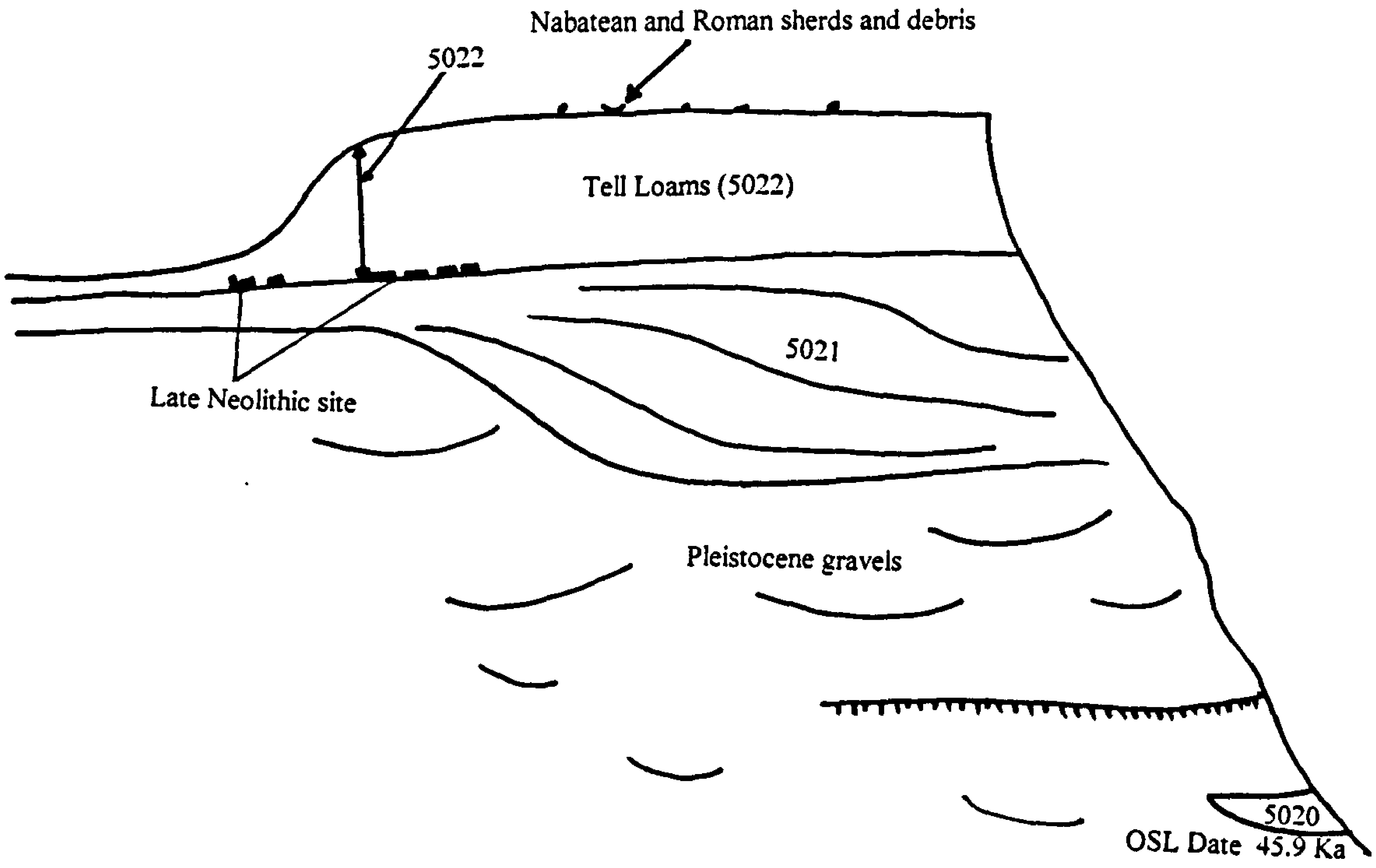
5.6.5.4 Dating:

The Tell Loam Member overlies a Late Neolithic site and under lies Nabatean- Roman debris.

Plate 5.22 Showing sites 5021 and 5022 in Wadi Faynan



Explanation for plate 5.22



Not to scale

Fig. 5.44 Sketch section of site 5022

Table (5.12) Stratigraphic description of the type section of the Tell Loam Member (5022)

Layer	Thickness (in m.)	description
1	0.02	Compact laminated silty clay, pale brown, with odd stones and potsherds of Nabatean and Roman age. Sharp lower boundary.
2	0.04	Ashy, friable silt with root pores; small, weakly developed, irregular blocky structure, light grey/brown, with Nabatean and Roman potsherds and flints. Transitional lower boundary
3	0.31	Compact clayey silt with root pores; fine, strong blocky structure, occasional root holes, pale grey with brown; some charcoal and occasional stones. Sharp lower boundary.
4	0.11	Compact clayey silt with root pores; fine blocky structure, some root pores, very pale grey/ brown, paler at base; with odd snails and stones. Sharp lower boundary.
5	0.22	Compact slightly clayey silt, fine blocky structure; with occasional gritty lenses and stones and a clear stone line at the base, abundant root pores; occasional snails and charcoal Erosive base.
6	0.12	Compact clayey silts with soft calcareous nodules, stony, coarse blocky structure, few root holes, pale grey brown; occasional flints and potsherds. Sharp lower boundary.
7	0.24	Compact clayey silts with irregular calcareous nodules, fine columnar or prismatic structure, some root pores, occasional potsherds and charcoal fragments. Transitional lower boundary.
8	0.07	Compact clayey silt, calcium indurated, fine strong columnar structure, few small root holes, pale yellow-brown, corresponds to highest 14-C date in Najjar's site. Sharp lower junction.
9	0.40	Compact slightly clayey silt with odd pebbles moderately strong blocky structure, large root casts, rare calcareous nodules, sharp but irregular lower boundary.
10	> 0.02	Compact ashy, slightly clayey silt, structureless, containing much potsherds, lithic fragments and charcoal. This is the horizon on which the Neolithic inhabitants of Tell Wadi Faynan built their buildings. Base not seen.

5.6.5.5 Interpretation:

At Tell Wadi Faynan (site 5022) the Tell Loams suggest mainly aeolian deposition of Late Neolithic to Nabatean age, separated by short periods of soil formation.

CHAPTER SIX: SYNTHESIS

6.0 Synthesis

6.1 Introduction

In this Chapter, information presented in Ch. 5 is synthesised, in a number of ways. First, a pollen biostratigraphy is established and interpreted in terms of vegetational and climate change through the Holocene. Second, the alluvial history is established and the causes of alluvial events are identified.

6.2 Pollen Biostratigraphy

Introduction

The synthesis of the local pollen records shown in Chapter five are set out below (Table 6.1) as a formal pollen assemblage-biostratigraphy. Radiocarbon dates are stated at 2 sigma, 95% probability and are shown in figures (6.1a and 6.1b).

<u>Poaceae- Corylus- Pinus Assemblage Biozone (PCP)</u>

Definition

The assemblage biozone is defined on the usually high occurrence of Poaceae (16-32%), *Pinus* (5-70%), *Corylus* (4-32%), *Plantago* (4-20%) and the some times high occurrence of Liliaceae (4-18%), *Juniperus* (0-15%), *Artemisia* (0-15%). Other characteristic species often present include *Quercus* (0-4%), *Ulmus* (0.5-2.5%), Caryophyllaceae (0-2%). Other species, e.g. *Rumex* (0-1%), *Hippophae*, *Potentilla* (0-0.5%), *Pistacia* (0-0.5%), *Malva* (0-1.5%), Cyperaceae (0-2%), *Centaurea* (0-1.0%), *Helianthemum* (0-0.5%) are occasionally present. The end of this biozone is defined on the decline of *Corylus*, a slight decline of *Pinus* and Poaceae and the disappearance of *Ulmus*.

Table (6.1). A formal pollen assemblage-biostratigraphy.

Assemblage-biozone	**PCP**	**PPA**	**PAP**	**PCPJ**	**CLP**	**CPE**	**C**	**CL**
Approximate date BP uncal.	pre-*ca.*7200	*ca.*7200-6400	*ca.*6400-5700	*ca.*5700-3000	*ca.*3000-2000	*ca.*2000-350	*ca.*350-100	*ca.*100-0.00
Plateau								
Ulmus	0.5-2.5							
Corylus	4-32	0-2		0-1			0-2	0-7
Quercus	0-4	0-2		0-1.5	1-4	0-4	0-3	0-3.5
Rhamnus	0-2	0-1			0-0.5			
Pinus	5-70	7-19	5-14	0-6	1-7	2-18	0-5	1-13
Junipers	0-15	0-8	0-2	1-3	1.5-8	0-10		0-3.5
Pistachia	0-0.5	0-1	0-2		0-1.5	0-10	0-0.5	0-7
Olea	0-0.5	0-3		1-2	1-2	0-1.5	0-0.5	0-4
Acer		0-1						0-1
Cupressaceae			0-2					0-2
Steppic								
Poterium	0-0.5			0-0.5	0-0.5			0-1
Artemisia	0-13	12-18	3-5	5-12	0-9	0-9	0-2	1-8
Poaceae	16-32	10-38	22-28	6-19	4-9	0-7	0-6	1-19
Plantago	4-20	3-11	5-7	11-19	1-4	1.5-4	0-0.5	0-19
Rumex	0-1	1-2.5		0-1	0-3.5	0-0.5		0-2
Caryophyllaceae	0-2	1-16	0-4	15-25	0-10	2-12	0-5	1-30
Liliaceae	4-18	1.5-4	3-6	1-4	0-0.5		0-2	0-3.5
Acacia				0-1	0-1			0-0.5
Cereals	0-2	0-2.5	0-5	1-3	0-4	1-2		0-5
Asteraceae	0-4	1-5	0-3	6-22	4-13	4-15	1.5-8	2-16
Lactucae	0-8	3-6	5-7	1-5	16-45	17-36	6-21	1.5-47
Desertic								
Chenopodiaceae	0-13	2-35	5-9	1-8	4-47	22-45	57-87	0-40
Ephedra	0-0.5	0-6		1-4	1-17	1.5-9	0-7	0-6

Key

Major characteristic species

Minor characteristic species

2-2 Less significant species

Approximate date BP uncal.: The dates are shown in this table are radiocarbon dates from material selected from different sites (this study) and four radiocarbon dates from Al-Najjar *et al.* (1990).

PCP: Poaceae-*Corylus-Pinus* Assemblage Biozone.

PPA: Poaceae-*Pinus-Artemisia* Assemblage Biozone.

PCPJ: *Plantago*-Caryophyllaceae-Poaceae-*Juniperus* Assemblage Biozone.
CLP: Chenopodiaceae-Lactuceae-Poaceae Assemblage Biozone.
CPE: Chenopodiaceae-*Pinus-Ephedra* Assemblage Biozone.
C: Chenopodiaceae Assemblage Biozone.
CL: Chenopodiaceae-Lactuceae Assemblage Biozone.

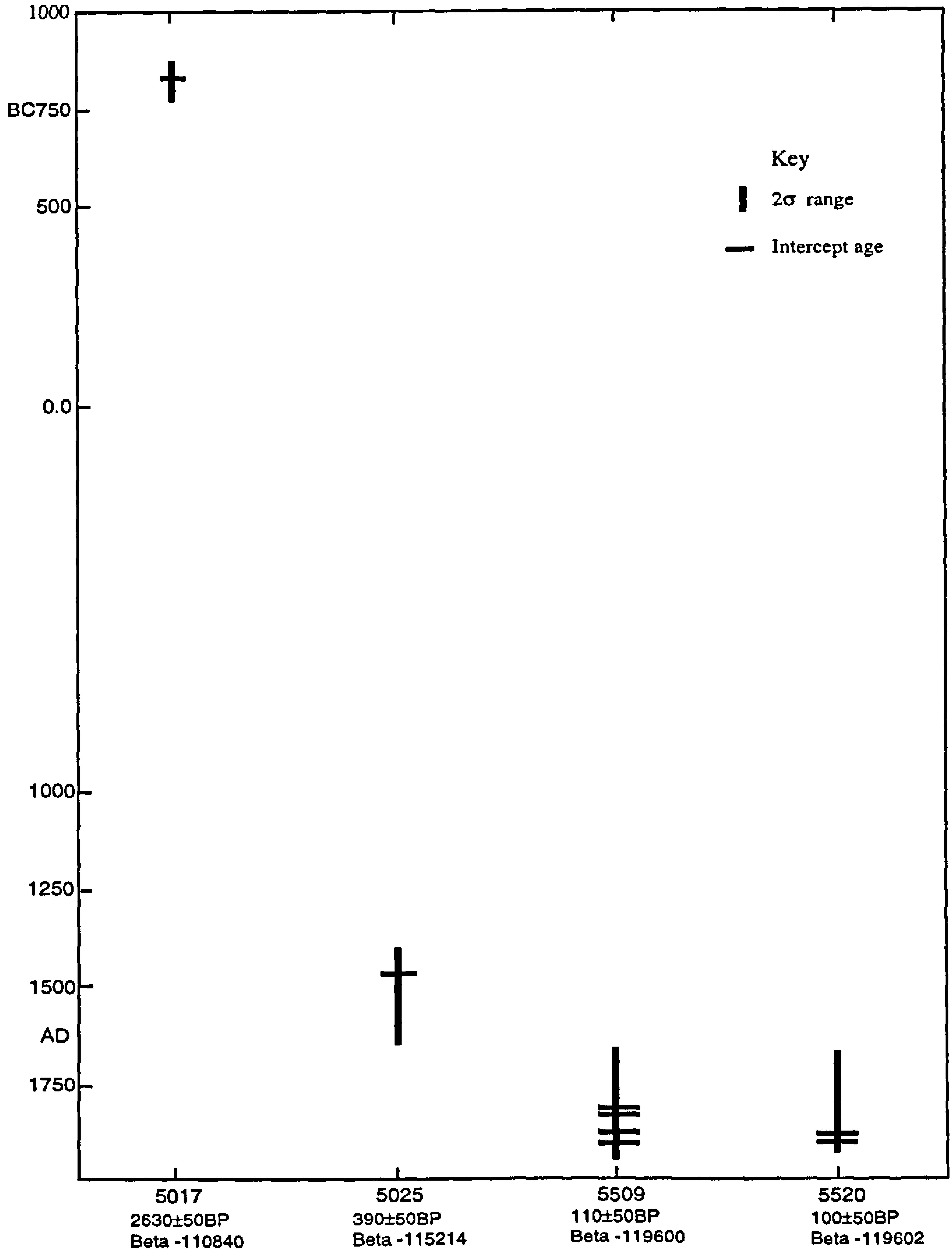


Fig. 6.1a Radiocarbon dates of the studied sites

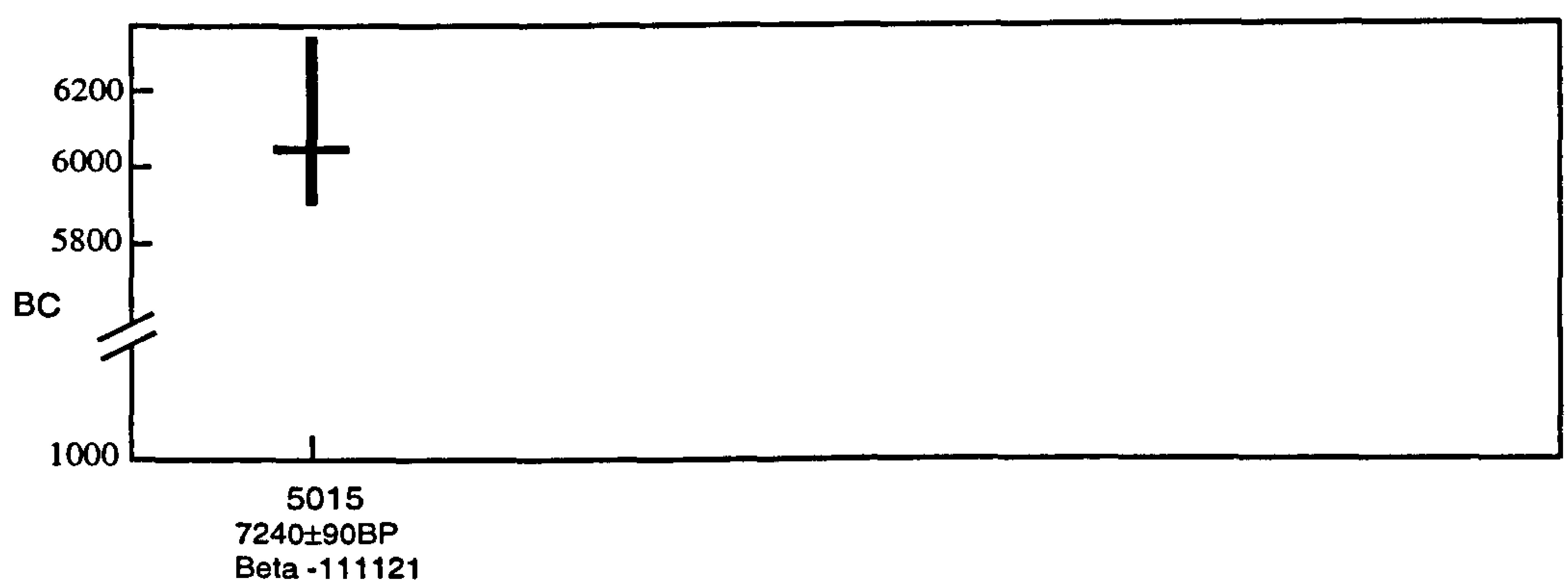


Fig. 6.1b Radiocarbon dates of the studied sites

Type locality

The type locality for this biozone is site 5510 in the Wadi Ghuweir. Assemblages of this biozone have been recovered from the basal 1.5 m of this section. It can also be recognised at site 5015/5500 in the Wadi Dana.

Dating

Predates date of 7240 $\pm$ 90 BP uncal. (BC 6205-5940) (Beta-111121) at site 5015.

Notes

Assemblages earlier than this biozone have not yet been found in the study region.

Interpretation

The high counts for Poaceae, *Plantago* and other herbaceous species such as *Artemisia*, *Malva*, *Rumex*, Cyperaceae, *Centaurea*, *Helianthemum* are characteristic of steppic landscapes (see Modern taphonomy diagram, Appendix 1 also Bottema and Barkoudah, 1979). The relatively high counts for tree pollen are dissimilar to all modern vegetation types now present in the Levant. The modern plateau flora still has relict stands of *Juniperus* and *Pinus* and assemblages from these are shown in figure A1.2 (taphonomy diagram, Appendix 1). *Corylus* and *Ulmus* are, however, completely absent from the region and in the absence of macrofossil- evidence, their position in the landscape is uncertain. It is possible that these species were part of a richer former plateau flora; alternatively they may have been living in sheltered valley floor sites adjacent to springs and standing water, alongside other waterside species such as the ferns and *Tamarix*. Macrofossils of *Quercus* and *Olea* (plates 5.2, 5.3, 5.4, 5.5 in Ch. 5) from site 5510 suggest, perhaps that these species were living in the wadis, close to the watercourses. It is perhaps likely that the *Corylus* and *Ulmus* were growing in similar locations. The presence of occasional Cereal-type pollen may be consistent with the activities of early farmers or may simply reflect the wild cereals that grow naturally in the area.

Poaceae- Pinus- Artemisia Assemblage-Biozone (PPA)

Definition

The assemblage biozone is defined on high Poaceae (10-38%), *Pinus* (7-19%) and *Artemisia* (12-18%), a moderate presence of *Plantago* (3-11%) and variable Chenopodiaceae (4-35%). Often present are *Corylus* (0-2%), *Quercus* (0-2%), *Rhamnus* (0-3%), *Juniperus* (0-7%), *Olea* (0-3%), Carophyllaceae (1-16%), Liliaceae (0-4%) and Cereal pollen (0-2%). Other species which are sometimes present include *Acer* (0-2%), *Balanites* (0-1%) and *Ephedra* (0-4%).

The base of this assemblage biozone is defined on the top of the preceding PCP biozone. The top of this biozone is defined on the disappearance of *Corylus*, *Pistacia*, *Quercus*, and *Rhamnus*.

Type locality

The type locality for this assemblage biozone is the fossil soil horizon (1.2-1.7 m) at site 5015 in the Wadi Dana. It can also be recognised at 5021 (zone A) in the Wadi Faynan.

Dating

This biozone has been dated to 7240 ± 90 BP uncal. (BC 6205-5940) (Beta-111121) at site 5015. This is consistent with the Neolithic artifacts at this site (G. W. W. Barker, *pers. comm.* 1996). At site 5021, the top of the biozone lies with 14-C dates of *c.* 6410 ± 115 uncal BP (HD 10567) (BC 5520-5270) (Al-Najjar, 1990).

Interpretation

The high incidences of Poaceae and *Artemisia*, together with moderate *Plantago* and the frequent occurrence of Caryophyllaceae, Liliaceae, and other typically steppic species is consistent with a predominantly steppeland landscape (e.g. Bottema and Barkoudah, 1979). The high counts for *Pinus* and frequent occurrence of *Juniperus, Corylus, Olea* and *Quercus* suggest the presence of a Mediterranean woodland biotype. Waterside plants such as the ferns, Palms and *Balanites* suggest occasionally rich waterside vegetation.

The rise of Chenopodiaceae and *Ephedra* suggests areas of very dry, possibly disturbed ground. The occurrence of cereal pollen in this biozone is perhaps consistent with the activities of early farmers, though it may also indicate wild cereals.

<u>Poaceae-Artemisia-Plantago Assemblage-Biozone (PAP)</u>

Definition

The base of this assemblage biozone is defined on the top of the preceding (PPA) assemblage biozone. The assemblage biozone is defined on high Poaceae (22-28%), *Pinus* (5-14%) and moderate *Artemisia* (3-5%), *Plantago* (5-7%), Liliaceae (3-6%), Chenopodiaceae (5-9%) and Lactuceae (5-7%). Other species which are some times present include *Juniperus* (0-2%), Cupressaceae (0-2%) *Pistacia* (0-2%) and Ericaceae (0-1.5%). Cultivated species are also present occasionally including Cereal pollen (0-5%).

Type locality

The type locality for this assemblage biozone is site 5510 in Wadi Ghuwier (zone B) and the biozone has also been recognised at site 5021 in Wadi Faynan (zone B).

Dating

The base of this biozone has been dated to 6410 $\pm$ 115 BP uncal.(BC 5520-5270) (HD 10567) (Al-Najjar, 1990). At the top of the 5021 are dates of 5740 $\pm$ 35 BP uncal. (BC 4675-4575) (HD 12337) (Al-Najjar, 1990). The next biozone is associated with Chalcolithic site 5051 and therefore started by c. 5000 BP.

Interpretation

High Poaceae, moderate *Plantago*, and *Artemisia* are an indication of a steppic environment, but one with fewer signs of disturbance and drought than the preceding biozone. Some waterside vegetation including *Pistacia* and some plateau flora including *Pinus* and *Juniperus* existed, so this flora was much like the modern one in aspect, although apparently less degraded.

Plantago-Caryophyllaceae-Poaceae-Juniperus Assemblage-Biozone (PCPJ)

Definition

The base of this assemblage biozone is defined on the top of the preceding (PAP) assemblage biozone. This assemblage biozone is defined on high *Plantago* (11-19%), Caryophyllaceae (15-25%), Poaceae (6-19%) and moderate *Pinus* (0-6%) and *Juniperus* (1-3%). A decline of *Corylus* (0-1%) and *Quercus* (0-1.5%) has been recorded in this biozone. At the base of the biozone a slight decrease in Poaceae and a slight increase in *Artemesia* has been recorded. A very slight appearance of Palmae has been recorded in the top of this biozone.

Type locality

The type locality for this assemblage biozone is site 5051, an old cistern which is a part of small catchment system near Wadi Faynan of probable Chalcolithic age (Hunt and Gilbertson, 1998).

Dating

This biozone has been dated by association with archaeology (G. W. W Barker *pers. comm.* 1996) to the Chalcolithic age at site 5051.

Interpretation

The presence of *Plantago*, Caryophyllaceae, Poaceae, *Artemisia* are all suggestive of a steppic environment (cf. Bottema and Barkoudah, 1979), but one which was slightly degraded. Caryophyllaceae can tolerate disturbance and the presence of Chenopodiaceae and *Ephedra* could be a signs of drought (El-Moslimany, 1990). The slight reappearance of the Early Holocene waterside flora, including *Corylus* and *Quercus*, is suggested. Cultivated species include Cereal pollen and *Olea*. These are probably consistent with the farming activity. The presence of high Lactuceae and Asteraceae, which are resistant to degradation (Havinga, 1984) suggests that the grains of these taxa are probably recycling from old soils. This could be consistent with soil erosion from farming practice.

Chenopodiaceae-Lactuceae-Poaceae Assemblage Biozone (CLP)

Definition

The base of this assemblage biozone is not seen but can be defined at the top of preceding (PCPJ) assemblage biozone. The assemblage biozone is defined on high Chenopodiaceae (4-47%), Lactuceae (16-45%), Asteraceae, (4-13%), Poaceae (4-9%) and *Ephedra* (1-17%). The biozone is also defined on presence of moderate counts for *Plantago* (1-4%), Caryophyllaceae (0-10%), *Pinus* (1-7), *Juniperus* (1.5-8%) and *Olea* (1-2%). A general decrease of *Plantago*, Poaceae and Caryophyllaceae is recognisable if compared with the previous biozone (PCPJ). An increases of *Pinus* and *Quercus* and a general disappearance of *Pistacia* mark the top of this biozone. This assemblage biozone is characterised by a dominance of Chenopodiaceae. There is a slight increase of Poaceae towards the top of this biozone. There is a steady increase in the percentage of Lactuceae, especially at the top of this biozone.

Type locality

The type locality for this assemblage biozone is the Khirbet barrage, site 5017 which is an ancient reservoir fill near Khirbet Faynan Tell. Assemblages of this biozone have been recovered from the depth of 1.90 to 2.36 m (local biozone KH-1) of the reservoir fill.

Dating

This biozone has been radiocarbon dated to 2630 ± 50 BP uncal. (BC 845-775) (Beta-110840) at the base.

Interpretation

According to the different types of flora identified above, which include Poaceae, Caryophyllaceae, *Plantago*, and the presence of desertic flora such as Chenopodiaceae and *Ephedra*, there was probably a degraded, desiccated steppe environment (cf. Appendix 1). The presence of soil erosion is indicated by the high counts for Lactuceae and Asteraceae. There was a small plateau flora including *Quercus*, *Pinus* and *Juniperus*.

<u>Chenopodiaceae- Pinus- Ephedra Assemblage Biozone (CPE)</u>

Definition

The base of this assemblage biozone is defined on the top of the preceding (CLP) assemblage biozone. The assemblage biozone is defined on high Chenopodiaceae (22-45%), *Pinus* (2-18%) and *Ephedra* (1.5-9%), and the presence of moderate amounts of *Plantago* (1.5-4%), *Artemisia* (0-9%), Poaceae (0-7%), Cereal pollen (1-2%) and Caryophyllaceae (2-12%). Other taxa were not always present but include *Trifolium* (2-13%), *Juniperus* (0-10%), which declines at the top of this biozone, *Pistacia* (0-

10%), *Quercus* (0-4%), which relatively increases at the top of this biozone and *Olea* (0-1.5%).

Type locality

The type locality for this assemblage biozone is site 5017, the Khirbet Barrage site, which is an ancient reservoir fill near Khirbet Faynan Tell. Pollen Assemblage of this biozone have been recovered from the depth of 1.05 to 1.90 m (KH2) of the reservoir fill. The biozone is also seen at site 5025.

Dating

There is no firm dating for the base of this biozone but its base may be estimated to lie around 2,000 BP. Its top is defined by a date of 390± 50 uncal. (AD 1430-1645) (Beta-115214) at site 5025, which lies close to the top of the biozone.

Interpretation

The incidence of high Chenopodiaceae, Lactuceae and Asteraceae and some *Ephedra*, *Plantago*, Caryophyllaceae, Liliaceae, *Glaux* and *Rumex* might reflect a very degraded steppe environment (cf. Appendix 1). The relatively high presence of plateau flora such as *Pinus*, *Juniperus*, *Quercus* and *Pistacia* may be the result of exaggeration by the low local pollen production caused by aridity. Cultivated taxa, including *Olea* and Cereals, are probably consistent with the human activity and farming practice evident from archaeological records (Barker *et al.*, 1997, 1998).

Chenopodiaceae Assemblage Biozone (C)

Definition

The base of this assemblage biozone is defined on the top of the preceding (CPE) assemblage biozone. The assemblage biozone is defined on high Chenopodiaceae (57-87%) and relatively high Lactuceae (6-21%). Other species including Poaceae (0-6%), Caryophyllaceae (0-5%), *Ephedra* (0-7%), *Artemisia* (0-2%) and Liliaceae (0-2%) were present. The top of this assemblage is defined on decline of *Pinus* (0-5%) and *Quercus* (0-3%) and disappearance of *Juniperus* and *Pistachia*. Cultivated taxa became rare: *Olea* declined to 0-0.5% and Cereals disappeared.

Type locality

The type locality for this assemblage biozone is site 5017, the Khirbet Barrage site which is an ancient reservoir fill near Khirbet Faynan Tell. Assemblages of this biozone have been recovered from the depth of 0.60 to 1.05 m (KH-3) in the reservoir fill and also from the basal unit (unit 5) of site 5520 which is a sub-recent alluvial fan deposit in the Wadi Dana, and from site 5509 in the Wadi Ghuweir.

Dating

There are no firm dates for the base of this biozone but it may be estimated to be later than 14-C date of 390 ±50 BP uncal. (AD 1430-1645) (Beta 115214) at site 5025 so the C assemblage biozone probably started in the latest Medieval or early post-Medieval. A radiocarbon date of 110 ±50 BP uncal. (AD 1670-1950) (Beta-119600) at 5509 is associated with a pollen assemblage assigned to this biozone, but at 5520 a radiocarbon date of 100 ± 50 BP uncal. (AD 1670-1780 or AD 1795-1945) (Beta-

119602) is associated with an assemblage of the next biozone. It is therefore probably that the assemblage zone-top lies between 110 and 100 BP radiocarbon years, and most likely in the nineteenth century AD.

Interpretation

The incidence of very high Chenopodiaceae and relatively high Lactuceae and the presence of *Ephedra* and Caryophyllaceae all suggest either a very degraded steppe environment and/or a steppe-desert environment (cf. El-Moslimany, 1990). The presence of relatively high *Pinus* and other plateau taxa, is probably not a sign of these increasing, but probably proportions were exaggerated by low local pollen production.

Chenopodiaceae- Lactuceae Assemblage-Biozone (CL)

Definition

The base of this assemblage biozone is defined on the top of the preceding (C) assemblage biozone. The assemblage biozone is defined on high Chenopodiaceae (0-40%), Lactuceae (1.5-47%), Caryophyllaceae (1-30%) and moderate Poaceae (1-19%) Asteraceae (2-16%), *Plantago* (0-19%), *Artemisia* (1-8%) *Pinus* (1-8%), *Corylus* (0-7%), *Pistacia* (0-7%). Other taxa present include *Juniperus* (0-3.5%), *Olea* (0-4%), *Acer* (0-1%), *Rumex* (0-2%), Liliaceae (0-3.5%), *Poterium* (0-1%) and cultivated taxa such as cereals (0-5%). The appearance of *Casuarina* and *Eucalyptus* at the top of the biozone has been recorded at site 5017.

Type locality

The type locality for this assemblage biozone is site 5017, the Khirbet Barrage site, which is an ancient reservoir fill near Khirbet Faynan Tell. Assemblages of this biozone have been recovered from the depth of 0.60 m to 0.0 m (surface) (local biozone KH-4) of the reservoir fill. They have also been recovered from the units 2 and 4 in a recent alluvial fan deposit of site 5520 in Wadi Dana.

Dating

An assemblage assigned to this assemblage biozone has been dated to 100 $\pm$ 50 BP uncal. (AD 1670-1780 or AD 1795-1945) (Beta 119602) at site 5520 and an assemblage assigned to the preceding C biozone has been dated to 110 $\pm$ 50 BP uncal. (AD 1670-1950) (Beta-119600) at site 5509. The base of the biozone is estimated to be between 110 and 100 BP radiocarbon years, probably in the nineteenth century AD The biozone extends to the present day.

Interpretation

The presence of flora include more Poaceae, *Artemisia*, *Plantago*, Liliaceae, Caryophyllaceae and a decline of Chenopodiaceae compared with the previous biozone (C). These all suggest a degraded steppe but less so than in biozone C. More tree taxa are present. These were probably mostly from the plateau e.g. *Pinus*, Cupressaceae, *Olea*, *Quercus*, *Juniperus*, but probably also far-travelled species from Europe such as *Corylus* and *Acer*. This may reflect changes in ambient winds, with more winds coming from the NW during the flowering season. The appearance of the exotic Australian ssp. is noteworthy. *Eucalyptus* was planted in the area at the old mining camp in the Wadi Dana, in the 1930s and on the plateau and *Casuarina* also planted as an ornamental and shade tree on the plateau (G. W. Barker, *pers. comm.*, 1998).

6.3 Alluvial History

Introduction

The alluvial history in the Wadi Faynan catchment can be inferred from the information set out in table 6.2 and figure 6.2. Assessment of the channel plan form was deduced from bedforms, grain size and by reference to modern analogues in the Wadi Faynan and elsewhere (see Ch. 3). A model of Late Glacial and Holocene landscape development has been developed from this information and this model is set out in figure 6.3. The following is a brief synthesis and description of the events inferred for the Wadi Faynan catchment.

For simplicity and better comparability with other radiocarbon data (Heim *et al.*, 1997), the chronology is discussed in uncalibrated radiocarbon years.

Late Glacial

Braided sedimentation (trough cross-bedded gravels) and loess deposition (site 5016 and unit 1 at site 5510).

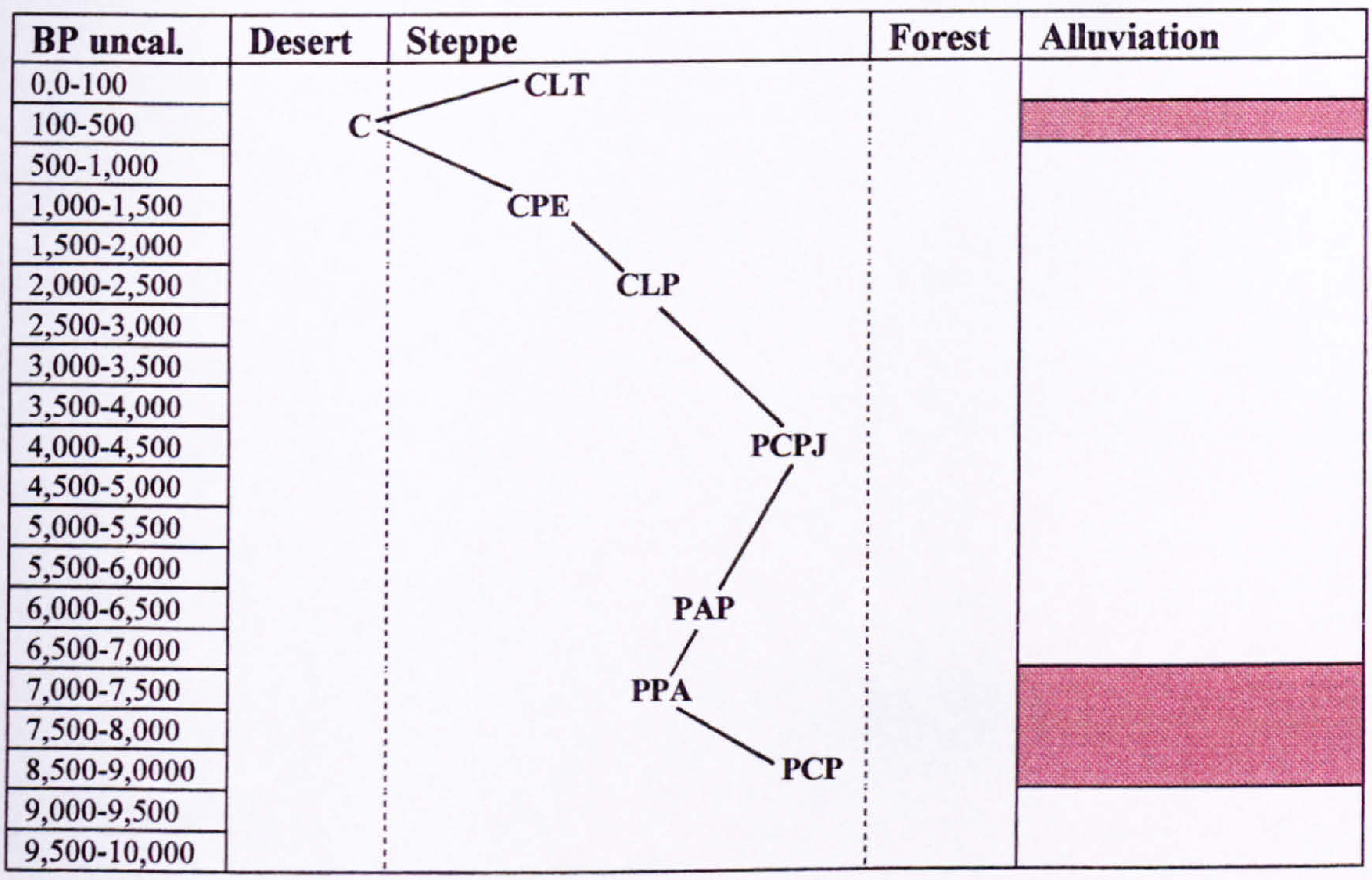
Very dry, arid (Figure 6.3 [A]).

Early Holocene to Neolithic

Pollen Biozones PCP, PPA, PAP

The silt-filled meander plug shows sedimentation by a meandering stream occurred at 5510 (unit 2). Epsilon cross-bedded fine gravels and sands show significant aggradation by meandering streams tooks place at 5500/5015, around 7240 BP uncal. (Beta-111121). The epsilon cross-bedded silty gravels and meander plugs show similar sedimentation by meandering streams occurred at 5021 until *ca.* 5740 ± 35 BP uncal (HD- 12337) (Al-Najjar, 1990). On pollen, plant macrofossil and mollusc evidence there was a humid climate with perennial water (figure 6.3 [B]). But At 5510, braided aggradation units 3, 4, 5, composed of trough cross-bedded gravels accumulated until *ca.* 5700 ± 35 BP uncal. (based on pollen correlation with 5021).

Table (6.2) A chronology of wadis alluviation and vegetation type in the research area.



There was a pattern of localised aggradation in the tributary wadis in the earlier Holocene, but not extending into the Wadi Faynan to any significant extent that can now be detected. In the Wadi Dana, aggradation seems to have been in a meandering river, a distinctly unusual phenomon in the Quaternary where most meandering rivers have incised or been stable (authors in Lewin *et al.*, 1995; Hunt, 1995), while in the Wadi Ghuwueir aggradation was braided after an intial meandering stage. Possibly sediment supply in the Ghuwueir was sufficiently high to force a localised transition

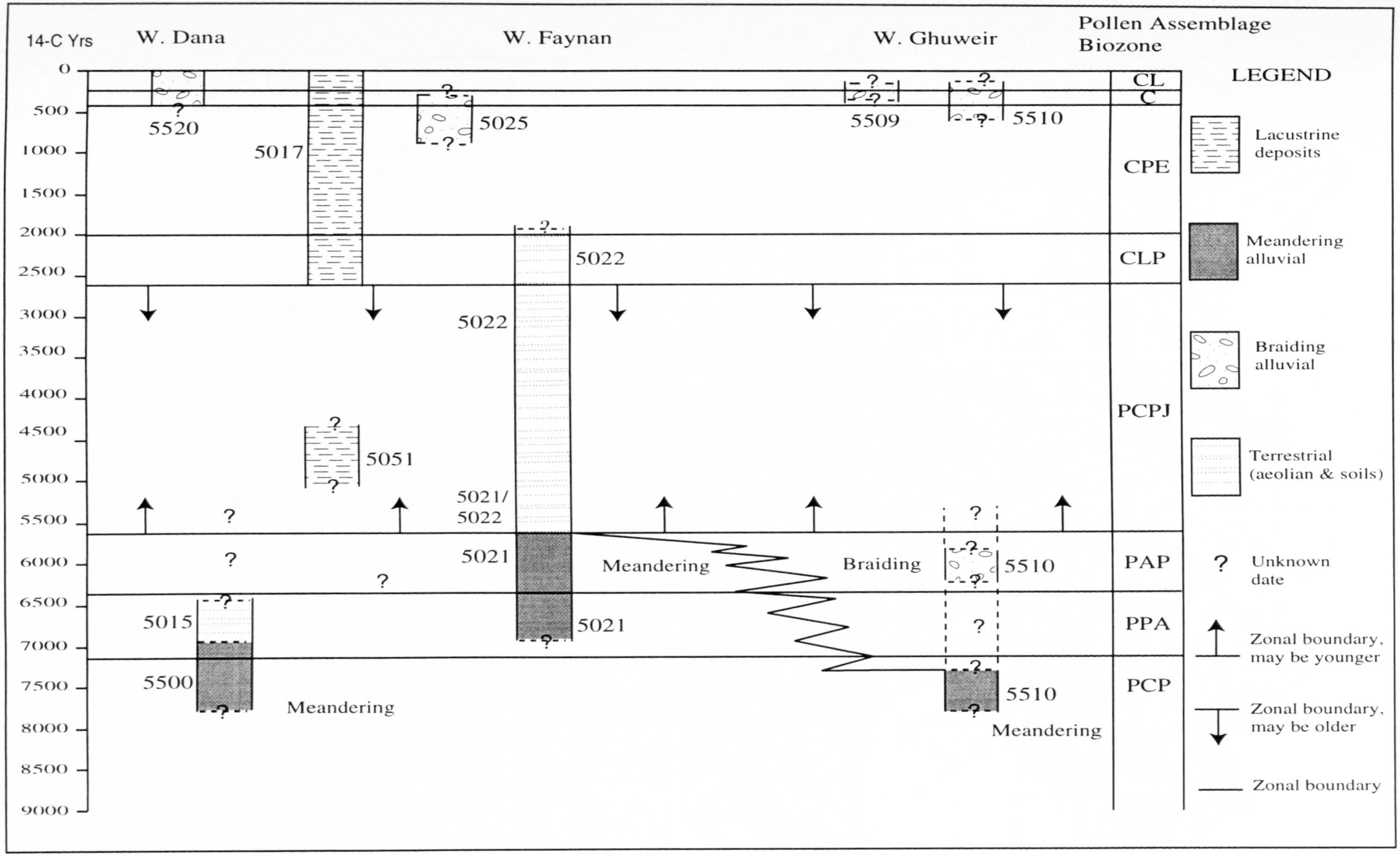


Fig. 6.2 Diagram showing facies relationships in the study area.

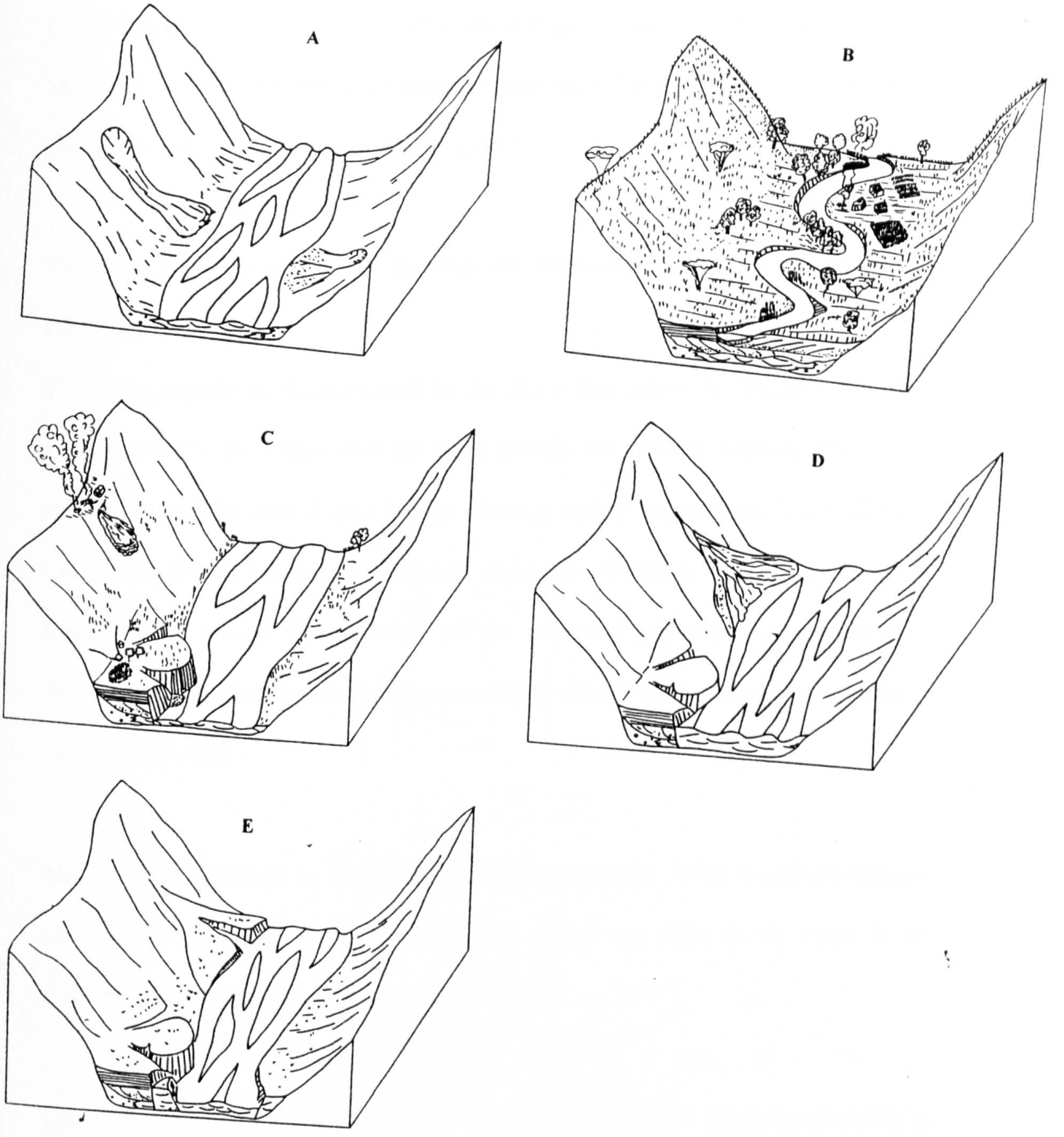


Fig. 6.3 Late Glacial and Holocene landscape models, developed in this study.

(A) Late Glacial (B) Early Holocene to Neolithic.
(C) Chalcolithic to post-Medieval (D) Little Ice Age (350-100 BP).
(E) Modern (100-0.0 BP).

to braiding (Schumm, 1979), especially where large tributaries entered the Wadi, as at site 5510. Similar braided to meandering transitions have been found in Holocene alluvial fan environments in Italy by Ori (1982).

The causes of this change to braiding are uncertain, and might be one of the following:

Tectonics impacts as demonstrated in the Dead Sea region by Frostick and Reid (1989) and for an Italian river by Hunt (1995) are unlikely because the alluvial geometry, with the depositional wedge thinning rapidly downstream, is not likely to have resulted from tectonic displacement along the rift-margin faults. The major rift-margin faults are all down stream of the sediment aggradation discussed here. Sediment supply changes are thus the most likely reason for the change to braiding in the Wadi Ghuweir.

Mining, which can lead to alluviation (Macklin and Lewin, 1986) is unlikely because there are low metal levels in site 5015/5500 and at site 5021 (F. B. Pyatt, D. D. Gilbertson and J. Grattan *pers. comm.*, 1998).

Landsliding might be a possible cause. A slow landslide would supply much debris to the wadi and perhaps induce braiding downstream, but the bedrock is of the wrong type. There are no clay layers or shale to work as a lubricant surface and there is no morphological evidence for large scale landsliding on the aerial photography. It is also unlikely for there to have been landslides in both wadis at the same time.

The most likely hypothesis is that human activity caused this episode of alluviation. The most likely human activity is of some form of agriculture. Cereal pollen has not been recovered from the aggraded sediments in any quantity, so the impact of grazing by sheep and goats on the steep hillsides of the Ghuwayer and Dana is perhaps the most likely. At site 5016, a thick loess deposit of Late-Glacial age was found beneath stony colluvium (Hunt, C. O. *pers. comm.* 1997). Loess is very erodible (Mucher and de Ploey, 1977) and would have been extremely vulnerable to erosion once livestock had removed the vegetation cover (figure 6.3 [C]). This would have given a rapid initial pulse of sedimentation with the first intensive grazing of the area. Sheep and goats are reported at the nearby Neolithic site at Beidha from 8,500 BP (Harris, 1996) and have been found in early Neolithic sites in the Wadi Fidan (Richardson, 1997). Furthermore, by the beginning of the seventh millennium, goat herding was widely practiced throught the southern Levant (Kohler-Rollefson in press, Kohler-Rollefson and Rollefson, 1990).

Chacolithic-(post-Medieval) (350 BP)

There is no sedimentary evidence of fluvial environments for this period. Indirect evidence from pollen analyses points to aridification and normal models (e.g. Briggs and Gilbertson 1980; Lewin *et al.*, 1995) would suggest that this would lead to a transition to braided sedimentation and aggradation as soils and sediments previously bound by vegetation would become mobilised by ephemeral runoff and moved into the wadi. During this period, however, the wadi incised, suggesting that sediment supply was minimal.

The incision might point to the operation of some other factor. It is possible that an increase of wadi slope through the relative down-throwing of the Wadi Araba and uplift of the Faynan area would be sufficient to cause incision. Similar tectonically-controlled incision has been reported by Hunt (1995) and Vita-Finzi (1969).

Aggradation is recorded from 5025, dated to approximately 390 BP, so this episode of incision had ended by this time (figure 6.3 [C]).

350-100 BP (Pollen biozone C)

Braided fluvial sedimentation (trough cross-bedded gravels) occurred at 5025, 5520 and 5509, plus fan sedimentation at 5520, 5510 and 5509. The pollen evidence suggests a very degraded, desert-steppe landscape. The alluviation was perhaps the result of soils and sediments liberated from a vegetation cover by aridity and moved into the wadis by episodic flash floods (figure 6.3 [D]).

At site 5025 the date of ca. 390 BP and sand deposition, predate the aridity peak seen at the Khirbet Barrage (Chapter 5 and 6). This was followed by a major gravel unit (at site 5025), which could reflect the onset of aridity. Aggradation by braided river at site 5025 was thus initiated *ca.* 350 BP. Aggradation by braided rivers at sites 5509 and 5520 occurred before *ca.* 100 BP. Subsequently, incision took place after *ca.* 100 BP.

Aggradation in the late Holocene, e.g. at sites 5509 and 5520, was probably a response to aridity, i.e. the river behavior corresponds to the climatic model of Briggs and Gilbertson (1980), but at vastly lower aridity regimes than envisaged by Vita-Finzi (1969).

100 BP- Recent (Pollen biozone CL)

There was incision to modern wadi floor level as vegetation recovered, as shown by the pollen evidence. The key site is 5520, where incision terraces are found (figure 6.3, [E]).

Aeolian activity

There is no evidence for aeolian activity in the early Holocene, and there is little evidence for it in the late Holocene. Between late Neolithic and Nabatean, aeolian activity occured and is represented by the Tell Loam Member (site 5022). The thickness of the Tell Loam Member at site 5022 is probably due to the geographic location of this site. First, 5022 was not protected by the mountain front and this site could accumulate sediment blowning in from the Wadi Araba. Second, this site was close to the agricultural fields of the Neolithic, Chalcolithic and Bronze Age settlements of Wadi Faynan (Barker *et al.* 1996, 1997, 1998). Sediments blown from the fields probably accumulated in the low ground beside the wadi.

6.4 Conclusion

The discussion above suggests that some aspects of aggradation in the Early Holocene may be related to human activity. Generally, with regard to the causes of the Early Holocene alluviation, there are signs of alluviation as a partial response to agricultural development (e.g. herding and arable agriculture). There is no sign of alluviation in response to early mining activity. In the late Holocene, there are also no signs of aggradation as a response to mining activity or agricultural development. Alluviation in the Late Holocene appears have taken place only as a response to extreme dryness.

CHAPTER SEVEN: DISCUSSION

7.0 Discussion

7.1 Introduction

In this Chapter, the issues raised in Ch. 1 and Ch. 2 will be addressed. These are the vegetation sequence, palaeoclimates, alluviation (which includes discussion of the evidence for human activity such as early agriculture, animal herding and mining activity), and the significance of the impact of flood water farming/ rain water harvesting in the surface hydrology and more general environmental change.

7.2 Palaeoclimate reconstruction

Introduction

As a pollen assemblage from a particular time and place is a function of the regional flora and vegetation, which are significantly influenced by regional climates, there has to be a relationship between palaeopollen assemblages and past climates. This relationship is complex and the business of extracting information about past climates from the pollen is not simple (Birks, 1981) especially in times of significant human impact on the landscape. It is apparent that short-term climatic fluctuations do not always registered in the pollen record, for instance (Lamb *et al.*, 1995). Nevertheless, this palynological approach has proved to be one of the major tools which changes in vegetation may be traced and the past climatic conditions reconstructed (Grove, 1988).

In Chapter 2 the pollen records and palaeoclimate of the Levant have been discussed. There was a lack of agreement between workers (as summarised in Ch.2). In the southern Levant the early Holocene was characterised by steppe and forest floras and thus, probably a humid climate. The later Holocene was characterised by desertic and steppe flora and thus probably an arid climate. In the Northern Levant, however, the

Early Holocene was characterised by desert steppe and forest steppe and the later Holocene by the spread of dense forest. Based on palynological evidence in Ch. 5, the synthesis of the local pollen records in the Wadi Faynan area were set out as a formal pollen assemblage-biostratigraphy in Ch. 6. This pollen biostratigraphy was used to create a palaeoclimatic history of the research area (figures 7.1 and 7.2) based on estimates of the vegetation of the various phases and comparison with possible modern analogues (Table 7.1). The palaeoclimate history of the Wadi Faynan research area is summarised below.

Table (7.1) Some present day vegetation analogues*

Area	Amount of rainfall/year	Vegetation
Shobak	315 mm	Broadleaved woodland (Oak).
Tafila	250 mm	Broadleaved woodland (Oak).
Wadi Faynan	c. 100 mm	Very poor steppe.
Safi	70 mm	Salt desert.
W. Araba/Aqaba	30 mm	Acacia scrub/ desert.

* Sources: Jordan Climatological Data Handbook (1988), Kurschner (1986), Tariq (*pers. comm.*, 1998).

Early Neolithic

This interval of time is now known in the study area from the following sites: site 5510 (base) and site 5500, which are attributed to biozone PCP in the pollen assemblage-biostratigraphy, and also sites 5021 (base) and site 5015 which are attributed to biozone PPA in the pollen assemblage-biostratigraphy. These assemblage-biozones are characterised by high tree pollen and high Poaceae, *Artemisia*, *Plantago* and pollen of other steppic herbs. The study area thus probably lay just outside the margin of the forest, with good steppe plus some trees. The precipitation therefore was probably a little less than at Tafila which lies just inside the forest margin (Table 7.1), so maybe around 200 mm.p.a. (see figures 7.1 and 7.2).

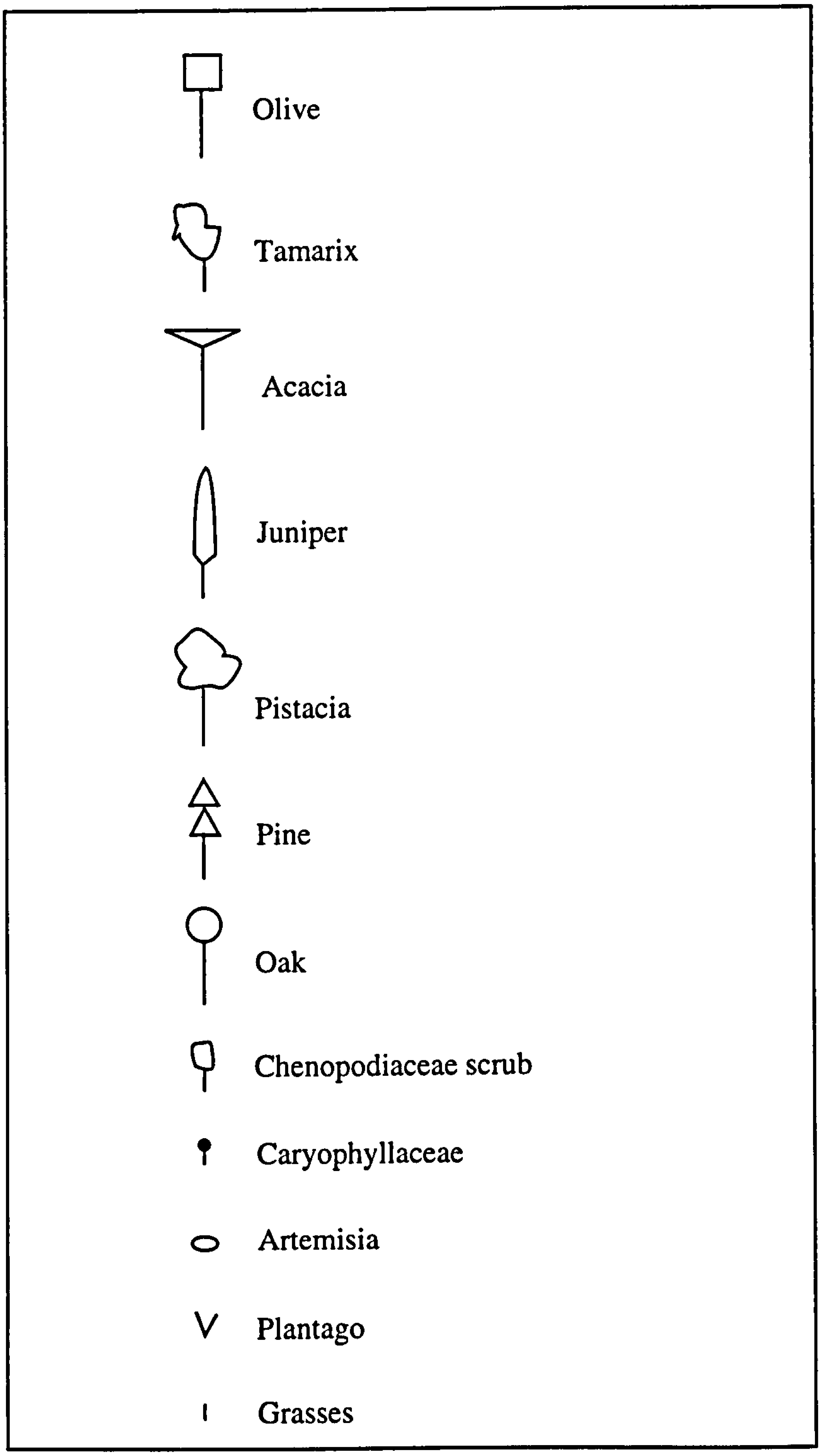


Fig. 7.1 Key to species (see Fig. 7.2).

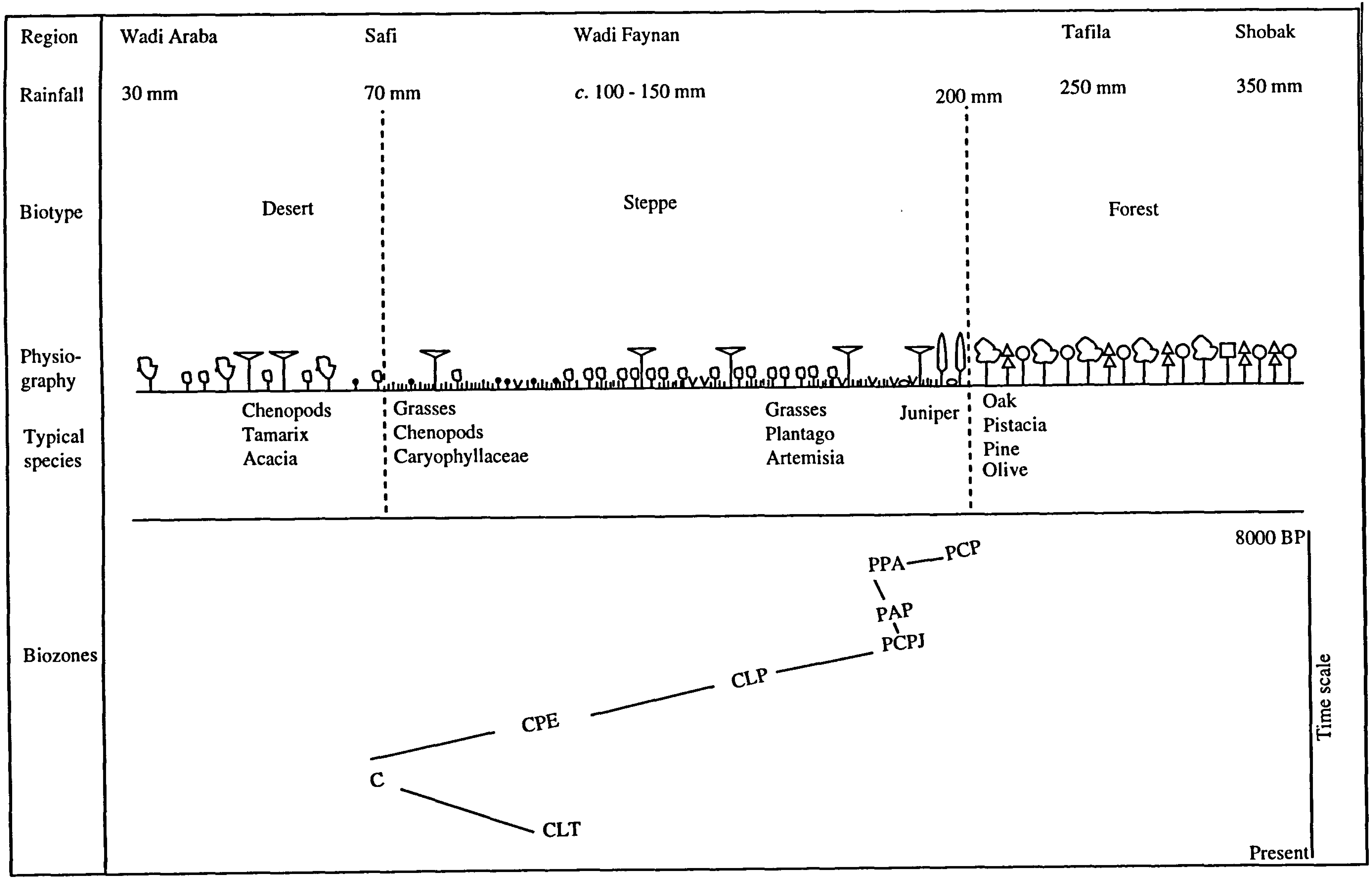


Fig. 7.2 Vegetational history of the Wadi Faynan, with Plant and Biotype distribution related to Rainfall.

Late Neolithic-Chalcolithic

This interval of time contains the following sites in the study area: site 5021 (top of the section), site 5510 (B), which are zoned as the PAP biozone, and also site 5051 which is attributed to the PCPJ biozone. These assemblage biozones are characterised by declining tree pollen and high counts for steppic species, especially Caryophyllaceae, *Artemisia*, *Plantago* and Poaceae. There is no good modern analogue for the pollen record, but this period was one characterised by a good steppe vegetation. Through reference to table 7.1 it appears that the precipitation was certainly less than modern rainfall at Tafila but more than that at Wadi Faynan today, so a rough estimation could be made at 150 mm p.a.(figures 7.1 and 7.2).

Bronze Age

The data from sites 5516 and 5518 are so poor that no estimate can be made with any confidence.

Nabatean (around 2,500 BP)

This period is represented only at the base of Khirbet Barrage site (5017), which is the CLP biozone in the pollen assemblage-biostratigaphy. The pollen assemblages are characterised by high Chenopodiaceae, some *Ephedra* and some other steppic taxa, basically similar to the flora of the present day from taphonomic studies (appendix 1). The precipitation is infered to be in the order of *ca.* 100 mm p.a. which is the present rainfall in the Wadi Faynan (see figures 7.1 and 7.2).

Roman -Medieval (around *ca.* 2,000-400 BP)

This period is known from the Khirbet Barrage site (local zone KH-2) and at site 5025, which are attributed to the CPE biozone. The pollen assemblages are characterised by slightly higher Chenopodiaceae than in the CLP biozone, but the steppic flora was still relatively healthy and probably like that of today or a little more degraded. The ancient rainfall can be estimated roughly between 70 and 100 mm p. a. (see figures 7.1 and 7.2).

Post-Medieval (*ca.* 400-100 BP unical.)

This period contains the penultimate local assemblage-zone at the Khirbet Barrage site (local zone KH-3) and is also known from site 5520 and site 5509. It is attributed to the C biozone. This interval contains a strong Chenopodiaceae peak, which most probably represents a desert environment dominated by these plants. As a rough estimate, the palaeovegetation is equivalent to the environment today at Safi and Aqaba, suggesting a rainfall of 30-70 mm p. a. (see figures 7.1, 7.2 and figure 3.8 in Ch. 3 which locate Safi and Aqaba).

Recent (around *ca.* 100-0 BP unical.)

This period contains the uppermost zone of Khirbet Barrage site (local zone KH-4), site 5520 (units 4 and 2), and those other sites which are attributed to the CL biozone. Pollen assemblages from this biozone are comparable with those from the taphonomic study (Appendix 1). This period therefore, shows a relatively healthier steppic flora than in the C biozone and most probably an environmental amelioration in the study area. From the rainfall point of view, it was probably similar to that which prevails today. Estimates of modern precipitation in the Wadi Faynan are between 100-125 mm. p. a. (Tariq *pers. comm.*, 1998).

Problems

The following points should be borne in mind as limitations affecting the above deduction of palaeoclimate:

1- Significant human influence on vegetation has probably meant that the both modern and past vegetation zones do not only reflect rainfall and temperature.

2- None of the flora is truly temperature-limited, therefore, it is not possible to estimate temperature change with any precision; yet undoubtedly temperature change would affect moisture availability and thus these estimates of past rainfall.

3- There are no good modern analogues in the area for early Holocene (or even as late as Chalcolithic) vegetation. In this context it must be borne in mind that largely "natural" vegetation is almost non-existent in the Middle East (van Zeist and Bottema, 1991).

Regional palaeoclimate

In North Africa, several lines of solid evidence, based on scattered data, show that areas currently occupied by hot desert were relatively cool and moist during the earlier Holocene (10,000 to approx. 4,000 yr BP). This conclusion was reached from evidence including former lake levels (Kutzbach and Street-Perrott 1985; Street-Perrott *et al.* 1991); buried lake sediment (Haynes *et al.* 1979, 1989); faunal remains (Pachur and Kropelin, 1987); pollen (Ritchie and Haynes 1987, Gilbertson and Hunt 1996 a,b) and archaeology (Wendorf and Schild, 1980). This cool moist climate was caused primarily by the influence of the southwest monsoon (Ritchie, 1991; COHMAP, 1988).

A stronger monsoonal circulation and a northward shift of tropical convectional rain brought much more moisture to the Sahara than it does now, as well as to Arabia and north-west India. The present thesis shows that this climatic pattern also occurred in Jordan.

The more intense heating of continental interiors in summer created stronger monsoon circulation over Asia and Africa which brought rain farther north (Whyte, 1995). From about 10,000 to *c.* 5,000 Cal. yr BP was a truly massive extension in the zone of high-level lakes and water surplus, not only into the semi-arid Sahel but into the Sahara desert itself (Fontes and Gasse, 1991). As a result, much of the Sahara was savannah grassland rather than desert (Whyte, 1995).

However, shifts in atmospheric circulation during the early-mid Holocene did not bring increased rainfall to all mid-latitude regions. Those areas out of reach of sub-tropical moisture sources instead became drier than they are at present. Areas like the Mediterranean, beyond the reach of the monsoon, may have been drier (Whyte, 1995).

In Iran and Turkey, for example, the advance of woodland vegetation commenced around 12,500 Cal yr BP, but was not complete until 6,300 Cal yr BP and this time lag may have been linked to early Holocene climatic aridity (Roberts and Wright, 1993).

Within the second half of the Holocene there was sustained aridity and suggestions of small-scale fluctuations in wetness. In Libya Pachur and Braun (1980) reported that the dry phase of the second half of the Holocene was interrupted by moister conditions in *c.* 3,000-2,000 BP. Throughout North Africa in the period between 2,400-1,400 BP Mawson and Williams (1984) reported humid conditions. Marked changes in precipitation are reported in Morocco (Lamb *et al.*, 1995) and in the Nile head waters (Hassan, 1981).

Circulation patterns approximately similar to the present were established by c. 5,000 BP. The monsoonal circulation was insignificant in this regime, which is dominated by coastward-moving weather systems. The fluctuations noted by Pachur and Braun (1980) and Mawson and Williams (1984) may have been similar in nature to the fluctuation seen in research area and possible across much of the Middle East and North Africa in the Late-Medieval to Nineteenth Century recorded above as the C pollen biozone (Ch. 5 and 6). P. A. Smithson (*pers. comm.* 1998; Hunt *et al.*, in prep.) suggests that this pattern is linked to the Mediterranean Oscillation. Investigations of the current climate in Palestine suggested negative rainfall anomalies associated with positive pressure anomalies in the eastern Mediterranean and/or an easterly or southerly circulation over the area (Kutiel, *et al.*, 1996). This circulation would be associated with low zonal circulation index. In many cases, dry conditions in Palestine are associated with below normal pressure conditions and rainfall over central and western Europe. Weakening of the Siberian winter anticyclone can mean that fewer depressions are blocked in the Eastern Mediterranean Basin reducing winter rains (P. A. Smithson, *pers. comm.* 1998; Hunt *et al.*, in prep.)

The meridional atmospheric circulation intensity increased in the North Atlantic after about 1400 AD, based on work on ice cores (Kreutz *et al.*, 1997). The Little Ice Age was characterised by substantial meridional circulation strength variability. A high frequency of blocking and meridional flow has been demonstrated over California in this period (Haston and Michaelson, 1997). In southern Spain, documentary evidence indicates relatively wet years during the Little Ice Age (Vallve and Martin-Vide, 1998; Barriends, 1997, Rodrigo *et al.*, 1995) and flooding as would be expected from the Mediterranean Oscillation relationship (Hunt *et al.*, in prep.). Such a circulation would favour southerly winds over Wadi Faynan and hence drought. It is clear, therefore, that the palaeoclimate patterns deduced from the record in the Wadi Faynan are consistent with our emerging understanding of global Holocene palaeoclimate and circulation patterns (Hunt *et al.*, in prep.).

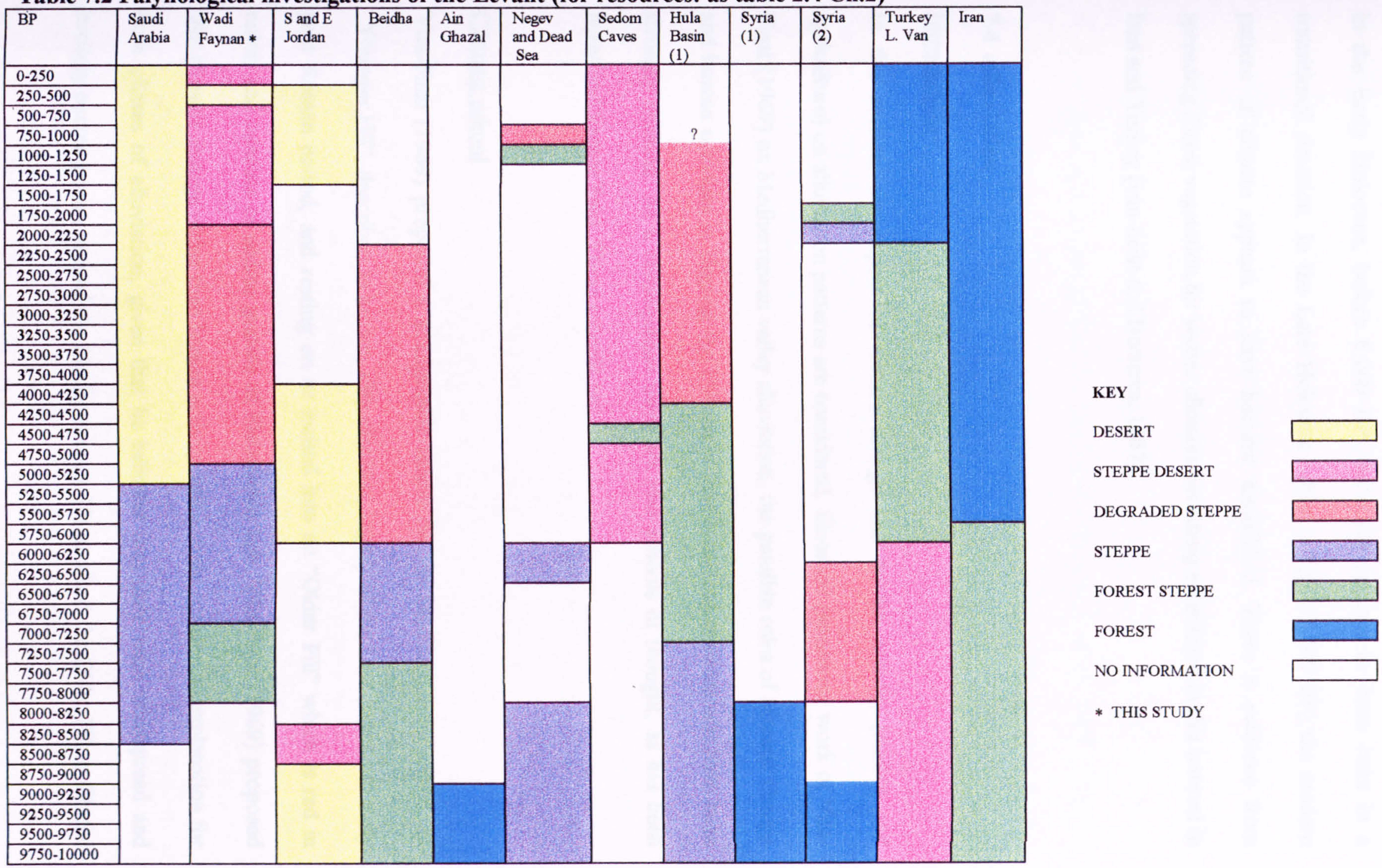
7.3 Comparison of regional vegetation sequences

It can be seen from the table (7.2), that there is a clear division between the southern Levant sites in Saudi Arabia, Jordan, Sedom, the Hula Basin and Syria, and northern Levant sites in Turkey and Iran. In the southern Levant sites, as also occurs in North Africa (Gilbertson and Hunt, 1996), there was a major deterioration in the environment with most areas becoming drier around 6,000-5,000 BP, whereas in Turkey and Iran, at this time, the environment become wetter and forest spread and became more dense (van Zeist and Bottema, 1982).

For the northern tropics, particularly in Africa and Asia, palaeoclimatic data and global circulation models (GCMs) show that the orbitally induced increase in solar radiation in summer 12,000 to 6,000 BP enhanced the thermal contrast between land and sea and thus produced strong summer monsoons, which served to raise lake levels in regions that are arid today (COHMAP members, 1988).

Sites from Saudi Arabia, through Jordan, Palestine and Syria shows higher rainfall than occurs at present, in the period between 10,000 and 6,000-5,000 BP (table 7.2). There are however some discrepancies in the pattern which may be due to threshold effect or poor dating. The Wadi Faynan results show the same pattern of a wet early Holocene. The critical evidence from Wadi Faynan is the presence of *Corylus,* which requires summer rain. This implies a different pattern of climate at that time (since today we have winter rainfall in the southern Levant and summer drought). The pattern was perhaps more like that of the monsoonal regime in India today; a situation which was previously suggested by Horowitz and Gat (1984) for Northern Palestine and which is in agreement with the COHMAP (1988) model.

Table 7.2 Palynological investigations of the Levant (for resources: as table 2.4 Ch.2)



There is a contrasting pattern in the early Holocene in Iran and Turkey, which was dry in the Early Holocene, before 6,000 BP. Syria (2) appears to have been in a transitional situation. In the Late Holocene, after *c.* 6,000/5,000 BP, the modern pattern of climate appears to have become established. There is evidence from spreading forest vegetation for wetter climates becoming established in this interval in Iran and Turkey (van Zeist and Bottema, 1982).

7.4 Alluviation

Introduction

In this section, the impact of climate change and human activity (mining and agriculture) on alluviation patterns are considered. Since the pioneering work of Vita-Finzi (1969) on Mediterranean valley alluviation, the possible roles of climatic change and human activities in shaping the Holocene Mediterranean environment have been strongly debated. As a consequence there are two schools of thought, as has been noted in Chapter Two. These schools are:

Climatic school

Vita-Finzi (1969) proposed a stratigraphic model for the Mediterranean valleys, of "Younger Fill", described as brown, silty alluvium, largely of the Late-Roman to early post Roman period, and resting on or incised into an "Older Fill" which is red in color, and consists of coarse gravels of Pleistocene age. Vita-Finzi (1969) proposed that climatic change rather than human activity was a more convincing explanation for both phases of alluviation, given that he believed that they were widespread and broadly contemporary around the Mediterranean. He ascribed the Older Fill to Glacial conditions, and the Younger Fill to a more recent time of cold wet conditions. Since then a variety of earlier and later episodes of alluviation in the Mediterranean Basin have been studied. The Vita-Vinzi model of climatic causes was supported by further reseach (Vita-Finzi 1975; Bintliff 1977, 1982).

Anthropogenic School

A good deal of literature (Davidson 1971, 1980; Davidson *et al.* 1976; Wagstaff 1981; Bell 1982; Gilbertson *et al.* 1983; Pope and van Andel 1984; van Andel *et al.* 1986, 1990; Chester and James 1991) suggested that alluviation occurred at many different times at many different localities, and thus in most cases climatic change was unlikely to be as important as human disturbance of the landscapes. Furthermore, recent work, summarised by the authors in Lewin *et al.*, (1995), suggests that the position of the fills is regionally varied. The Pleistocene gravels formed mostly during ephemeral flood events in generally 'arid-stage' environments, while the 'Younger Fill' is a polyphase deposit, ranging from the Neolithic to modern times and largely resulting from river aggradation as a response to hydrological and sediment flux variation caused by deforestation and agricultural soil erosion.

Other pattern of alluviation

Some desert areas show a different pattern related to the causes of alluviation. Among these areas, is the Tripolitanian pre desert (Barker *et al.*, 1996), Tunisia (Ballais 1995) and the Arabo-Persian Gulf (Vita-Finzi 1978), in which the timing of alluviation does not fit the Vita-Finzi model. In Tripolitania and Tunisia, the alluviation took place as late as Medieval to post-Medieval times, probably 700-400 BP and again after 400 BP. This also does not fit the known pattern of human activity in the region because alluviation occurs as the population in this area appears to decline (Barker *et al.*, 1996).

The Wadi Faynan catchment (study area)

From the studies of the vegetational and alluviation history presented in Chapter Six, there is reasonable evidence for a climatic event in the period *ca* 350-100 BP uncal. This interval correlates with the C biozone (Chenopodiaceae peak) which indicates drought (quote in Chapter 6). The climatic association of the deposition biozone C is not the same as proposed by Vita-Finzi (1969) in which the alluviation described by Vita-Finzi took place in wet conditions. In contrast in the Wadi Faynan, alluviation is ascribed here to dry conditions.

The Early Holocene, alluviation in the Wadi Faynan (Ch. 6) may coincide with early herding (discussed by Harris, 1996; Kohler-Rollefson, in press). It has no visible association with climatic causes in this area. The early Holocene episode of aggradation thus fits the ideas of "anthropogenic school", but the putative high human impact of the period 2,500-1,500 BP (Nabatean-Roman) was not accompanied by an alluvial event in the Wadi Faynan (Ch. 6). This is hard to reconcile with the ideas of the "anthropogenic school". It is possible that this anomaly occurs because most of the available sediment had already been flushed out of the Faynan catchment in the Early Holocene.

Conclusion

Evidence from the Wadi Faynan does not fit with the Vita-Finzi model (1969), and after the Early Holocene; neither it does not fit well with anthropogenic model (among others Davidson 1980; Pope and van Andel 1984; van Andel *et al.*, 1986; Chester and James 1991), In many ways, it might be compared with the broadly similar record which was found in the Tripolitanian predesert (Barker *et al.*, 1996), in Tunisia (Ballais, 1995) and in the Arabo-Persian Gulf (Vita-Finzi, 1978). It is therefore very likely that the geomorphological controls affecting alluviation in such very arid areas are very different from those operating in the more Mediterranean countries. In the very dry countries, it would appear that drought may lead to alluviation.

7.5 The impact of mining on alluviation

Introduction

The mining and smelting of copper has taken place in the Faynan area since Neolithic times (Hauptmann 1989; Hauptmann and Weisgerber 1987). The main archaeological site is Khirbet Faynan, which is assumed to have been a principal focus of mineral extraction and processing in the Middle East in the Nabatean, Roman and Byzantine periods (Hauptmann, 1989, 1992; Hauptmann *et al.*, 1992).

In principle mining and smelting could have lead to increased sediment supply to the channel: the consequence of the direct input of fine mining waste, and the indirect destabilisation of coarser alluvial fills, probably through vegetation destruction by toxicity and consequently the removal of cohesive fine material from the flood plain surface (Lewin *et al.*, 1977). Layers of Nabatean age in the Khirbit Barrage fill have very high concentrations of heavy metals (Grattan, *pers. comm.*, 1998), so it is clear that mining and smelting in the Faynan area produced a very toxic effluent.

Many authors (among them Lewin *et al.*, 1977, 1995; Macklin and Lewin, 1986; Graf 1988; Mighall and Chambers 1993) have demonstrated that mining and smelting activities tend to cause channel alluviation by increasing the sediment supply; from spoil heaps which may liberate large quantities of sediment, and from pollution of the bankside and channel vegetation, thus promoting sediment mobility. Inevitably "Miners" also cut down or otherwise harvested a lot of timber for smelting, which would have caused soil destabilisation and consequent erosion and alluviation.

Wadi Faynan

In the study area, the preliminary results of geochemical analysis at the Faynan Member sites 5015/5500 aged 7240 ± 90 BP uncal. (Beta-111121) and site 5021 aged 6410 ± 115 BP (HD-10567) show extremely low levels of heavy metals (F. B. Pyatt and D. D Gilbertson *pers. comm.* 1998) at these sites it is clear that mining and smelting activities did not play any role in promoting changes in alluviation.

These sites pre-date the main mining and smelting episodes in the Faynan area. Similarly, very low heavy metal contents have been established for the Dana Member site 5520 (F. B. Pyatt, *pers. comm.* 1998). Therefore, some other explanation must be sought for this notable aggradation (see section 7.4).

Possibly past mining activities did cause some sort of alluviation in the area, but it may be that it was very small and its consequences have had subsequently been eroded away. Alternatively, some other explanations are possible, amongst which are the following:

1- The toxicity of mine spoil was not sufficient to destabilise vegetation over large enough areas, and hence to mobilise sediment and cause alluviation. This may be because some vegetation in the Wadi Faynan was already adapted ecotypes to high heavy metal concentrations and grows today even on spoil heaps, which are highly toxic (F. B. Pyatt, *pers. comm.*, 1998).

2- The amount of mine spoil generated was not sufficient to promote to alluviation.

It is clear from a comparison of the inferred timing of known alluvial phases and metallurgical activities in the research area (table 7.3) that these are out of phase and unlikely to be related in any simple direct manner.

Table (7.3) A chronology of history of mining and metallurgy and wadis alluviations in the research area (This study).

Time BP uncal.	Era	Mining phases	Metallurgical Activity	Alluviation
0.0-100				
100-500				Dana Mbr
500-1,000				
1,000-1,500	Byzantine			
1,500-2,000	Roman			
2,000-2,500	Nabatean			
2,500-3,000	Iron			
3,000-3,500				
3,500-4,000				
4,0000-4,500				
4,500-5,000				
5,000-5,500	Early Bronze			
5,500-6,000				
6,000-6,500	Chalcolithic			
6,500-7,000				
7,000-7,500				
7,500-8,000	Neolithic			Faynan Mbr
8,500-9,0000				
9,000-9,500				
9,500-10,000				

Key

Metallurgical activity

Intense mining

Mining (small amounts)

Wadi alluviation

7.6 Flood Water Farming (FWF) /Rain Water Harvesting

Introduction

In Chapter Two, questions were raised about the role, importance and sustainability of Flood Water Farming (FWF)/ Rain Water Harvesting (RWH) in the Wadi Faynan. In this section the role and environmental context of FWF/ RWH in the research area are reassessed in the light of the informations gained in this study.

Early FWF/RWH systems

In the Neolithic there is evidence for rainfed agriculture, but not FWF. In the Chalcolithic, small catchment systems started to appear (see figure 5.35. in Chapter 5). Site 5051 is typical. This is a small slope catchment system and cistern associated with a building containing Chalcolithic potsherds, *ca.* 5,000-4,000 BP (Hunt and Gilbertson, 1998). These systems were built possibly because at this time overall rainfall was diminishing (see Chapter 6). Alternatively, there may have been more people needing water, or needing water supplies away from rivers, or the temporal patten of its availability was altering.

No further catchment systems are recorded until those of Nabatean age (*ca.* 2,500 BP) (Hunt and Gilbertson, 1998). Archaeologists have found very few sites of later Bronze Age or Iron Age date in the Wadi Faynan (G. W. Barker, 1998 *pers. comm.* to C. O. Hunt) perhaps because population declined or the subsistence-base changed. The reasons for their absence are beyond the scope of this thesis, but there is no particular sign of any environmental cause in spite of the soil erosion apparent at site 5051 and WF 148 and WF 3. Thus, causes might be social, political or economic.

The Nabatean-Roman catchment system

The Nabatean-Roman people used slope catchments, and a long-distance conduit (Hunt and Gilbertson, 1998; D. Crook *pers. comm.* 1998; Barker *et al.* 1997, 1998) to irrigate farms to feed the large-scale mining and metal-working population at the nearby site of Khirbet Faynan. They built the Khirbet Barrage for water supply purposes. The large-scale compound diversion/slope catchment system, lying on the late Quaternary terraces of the Wadi Faynan, utilised water which had been diverted via a 1.5 km long conduit and aqueduct from a diversion dam in the spring fed Wadi Ghuwayr. This water was eventually fed into a cistern and mill of Roman age, before passing into the floodwater farming system (Hunt and Gilbertson, 1998). Investigation of soils in this system shows no evidence of contemporaneous salinisation (Hunt, *pers. comm.* 1998). The lack of salinisation has been previously reported for other FWF/RWH systems (Barker *et al.*, 1996; Gilbertson, 1986, Evenari *et al.* 1971).

From the evidence at Khirbet Barrage site (Chapters 5 and 6), it is clear that FWF/RWH was happening in a rather degraded steppe landscape. Cultivation of Cereal and perhaps Olive took place and there have also been sheep-and goat- herding on the surrounding hills.

The causes and timing of the ending of the Nabatean-Roman FWF are unclear. In Khirbet Barrage sequence (Chapter 5), cereal and olive pollen are found only rarely above 2.0 m. Heavy metal concentrations fall above 2.02 m (Barker *et al.*, in press). Other indicators of industrial activity persist until higher levels in the core. Magnetic susceptibility values do not fall until 1.75 m and the peak of thermally mature material persists until 1.5 m (see Chapter 5). It is possible that the peaks in magnetic susceptibility and thermally mature material persist because these relatively stable products recycled for a considerable period.

Evidence of environmental degradation can be seen from the ending of the continuous curve for Poaceae at 1.90 m, which is taken as the end of the CLP biozone (local assemblage KH-1). If the ending of intensive FWF is taken as decrease in a cereal and olive pollen and the fall in heavy metal concentrations at 2.02 m, then the end of the continuous curve for Poaceae falls later. The environmental deterioration that this suggests thus post-dates the end of intensive FWF (If, however, the decreases in the other indicators of industrial activity more accurately reflect the end of FWF, then the end of FWF post-dates the environmental decline indicated by the end of the continuous Poaceae curve).

It is likely, therefore, that political, social or economic factors, possibly the collapse of Roman trading networks (Randsborg, 1991), caused the end of industrial activity and this in time led to the ending of large-scale FWF.

It seems, however, that small-scale FWF persisted until the early 20th century in the Wadi Faynan (Abu Fouaz, *pers. comm.* 1998) this small-scale FWF seems to have survived the very significant environmental event of the C biozone in the period *c.* 350-100 uncal. BP, during which rainfall in the Wadi Faynan seems to have declined significantly.

Conclusion

Since the Chalcolithic, agriculture in the Wadi Faynan has relied to an extent on rain water harvesting RWH, flood water farming FWF and diversion systems. Other authors found that such flood water farming and irrigation will lead -in some situations-to soil degradation and soil salinity (Bruins *et al.*, 1986; Pacey and Cullis, 1986; Barker *et al.*, 1996). There is no evidence from the vegetation sequence or alluviation patterns found in this study to suggest that either these practices proved harmful to the environment. This conforms to the results reached by other authors who worked in the arid and semi-arid lands (Evenari *et al.*, 1971).

CHAPTER EIGHT: CONCLUSION AND RECOMMENDATIONS

8.0 Conclusion and recommendations

8.1 Introduction

This thesis has addressed issues of vegetation sequence, palaeoclimate, alluviation, rain water harvesting/ flood water farming and the impact of mining on the arid environment, with special reference to the Faynan area of the Jordanian Desert. These issues are of more than local concern. In one form or other they recur in many other arid lands. The thesis has also explored through application the use of palynology and palynofacies analyses in deserts, a practice which is relatively unusual in old world palynology.

8.2 Vegetation sequence

A complete Holocene vegetation sequence for southern Jordan has not previously been available. This thesis has therefore addressed the establishment of a pollen biostratigraphy for the research area, from which a vegetation sequence could be deduced and interpreted.

Detailed pollen analyses were carried out, which can be seen in Chapter Five, synthesised in Chapter Six and discussed in Chapter Seven. From these analyses and discussions and a review of the regional literature it can be seen that sites from Saudi Arabia, through Jordan, Palestine and Syria (see table 7.2) had more abundant vegetation (and so had more rainfall than present) between 10,000 and 6,000-5,000 BP. In the late Holocene, after *ca.* 6,000/5,000 BP, the modern pattern of vegetation and climate appears to have become established.

The Wadi Faynan results show the same pattern of an early Holocene in which trees and shrubs thrived suggesting wetter conditions than present. Critical evidence from Wadi Faynan is the presence of *Corylus* which requires summer rain together with macrofossils of *Quercus*, Cupressaceae, *Hippuris* sp. and *Olea*, together with aquatic molluscs which required perennial river flow. Wadi Faynan experienced dry phases in the late Holocene, in which most of the dominant species in that interval points to steppe (for instance *Rumex*, Asteraceae, Lactucae: species identified by Janssen and Woldring, 1981 as typically steppic). In the period *ca.* 350-100 BP, the vegetation was dominated by Chenopodiaceae, with *Ephedra*. Carrion and Munuera (1997) point to this type of vegetation as typical of very degraded, arid steppe. The results from the Wadi Faynan area, combined with the results of the literature review of the vegetation sequence of the Levant demonstrate that there is a contrasting pattern in the early Holocene with Iran and Turkey, which were drier in the Early Holocene before ca. 6,000/5,000 BP. After this time there is evidence from spreading forest vegetation for wetter climates becoming established in this interval in Iran and Turkey (Ch. 7).

8.3 Palaeoclimate reconstruction

Although the broad patterns of Holocene palaeoclimate change have been established firmly for the Northern Levant and Turkey, a review of the literature (Ch. 2) appears to show that there are discrepancies with this pattern in the southern Levant. A lack of high-quality data in the southern Levant has made resolution of this problem more difficult. This thesis has used the pollen biostratigraphy (Ch. 6) as a basis for palaeoclimate reconstruction (Ch. 7).

A palaeoclimate reconstruction has been made, based on the pollen biostratigraphy which is discussed in detail in Chapter Six. This has been done by comparing this pollen based recored with some present day possible vegetation analogues (Ch. 7). Given the problems discussed in Chapter Seven, such as the human influence on the vegetation, unavailability of exact analogues, and also given that the flora is not truly temperature-limited, we can not estimate temperature change with any degree of quantitative/ precision or reliability. For example, temperature change would affect the moisture availability and as a consequence the rainfall figures suggested can only be an approximation. Taking all the above mentioned problems in consideration, the following palaeoclimate sequence (table 8.1) can be proposed.

Table 8.1 Environmental conditions and palaeoclimate in the research area

Assemblage biozone	**Approximate date BP uncal.**	**Environmental conditions**	**Palaeoclimate (precipitation) estimate**	**Nearest modern analogue Ω**
PCP	Pre-7200	Steppic landscape	200 mm	Dana-Tafila
PPA	*c.* 7200-*c.* 6400	Predominant steppe landscape	150 mm	Dana
PAP	6400-*c.*5700	Steppic landscape, less signs of disturbance	150 mm	Dana
PCPJ	5700-*c.*3000	Steppic landscape	No estimation exist; not enough pollen recovered to rely on.	?
CLP	3000-*c.*2000	? probably degraded landscape	100 mm	Wadi Faynan
CPE	2000-*c.*350	probably very very degraded landscape	70-100 mm.	Wadi Faynan
C	350-*c.*100	Extremely degraded steppe ? Steppe-desert	30-70 mm.	Safi
CL	*c.* 100-0.0	Degraded steppe landscape	100-125 mm.	Wadi Faynan

Ω Vegetation at Dana, in the hills to the east of the research area, is regarded as a reasonably close analogue of early Holocene vegetation. There is, however, no nearby meteorological station.

The above palaeoclimate sequence from the Wadi Faynan is comparable with other palaeoclimate sequences from the Southern Levant (Ch. 7) but contrasts strongly with the palaeoclimate sequences in the Northern Levant (Ch. 7). Clearly, a major climatic discontinuity separates the Northern Levant countries (Turkey and Iran) from the Southern Levant countries (Jordan, Palestine, parts of Saudi Arabia). Palaeoclimate patterns seen in the Wadi Faynan can also be recognised in the Gulf states and North Africa (Ch. 7). The evidence of a summer-wet Early Holocene in the Wadi Faynan corroborates the calculations of the COHMAP members (1988) for a strong summer monsoon in the North Africa and Middle East arid zone during the Early Holocene. In the Late Holocene, the evidence for an extremely dry phase 350-100 uncal. BP in the Wadi Faynan seems to be supported by similar (though less definitive) indications in the Persian Gulf and North Africa. Comparison of this phase of aridification with the North European Little Ice Age (Ch. 7) seems justifiable.

8.4 Alluviation

In order to resolve uncertainties about the causes of Holocene alluviation in arid landscapes (Ch. 2), and to ascertain to what extent Mediterranean patterns are applicable in the desert of southern Jordan, this thesis has addressed the timing and environmental relationships of alluviation in the example of the Wadi Faynan system.

It has been claimed that a clear correlation between sediment units and climate does not exist and in reality the factors controlling wadi erosion and deposition are quite complex (Rosen, 1986). Furthermore, there is a disagreement about the climatic factors which cause erosion and which cause deposition. Some authors (among them Vita-Finzi, 1969) prefer to correlate alluviation with generally moist conditions due to increased runoff and sediment transportation, with wadi incision taking place with desiccation, devegetation and lower water tables (Goldberg, 1984). Other authors suggested that the alluviation takes place during dry phases due to increased colluviation and that wadi incision occurs during wet phases which increase the water in the drainage lines (Thomas, 1997; Bell, 1982). Finally, some authors suggest that these episodes of wadi incision and alluviation takes place in transitional stages from wet to dry or from dry to wet (see Cooke and Reeves, 1976). In this research, not only the sediment bodies were examined but also their content of fauna (snails) and flora (pollen, palynofacies and plant macrofossils). This integrated suite of studies established the "palaeoecology" of such bodies of sediment and consequently allowed the identification of these sediments as deposited during wet or in dry phases. This was a very broad-brush approach which, given present levels of uncertainty with dating and absence of data, at least enabled a start to be made in this subject. Obviously finer points, including issues concerning possible deposition in periods of general environmental change, or by extreme events, can not be easily addressed in this way. Nevertheless the stress in this research on the use of palaeoecological indicators (fauna and flora) has served to overcome partially the problems related to determining the climatic contexts of deposition and incision phases of wadis.

The pollen analyses and palynofacies analyses, supported by snails and plant macrofossils, provided a palaeoenvironmental reconstruction of the early Holocene to late Holocene alluviation, which can be categorised into two broad forms:

In the Early Holocene, the Wadi Faynan experienced relatively wet conditions, which took place from early Neolithic to as late as the early Chalcolithic. This interval of time was characterised by a high incidence of tree pollen including *Pinus*, *Corylus* and *Juniperus*. Furthermore, plant macrofossils - leaves of *Quercus*, Cupressaceae and stones of *Olea* - are present as well as water loving snails. Moreover, herbaceous plants were present in high numbers. During this time, up to 6 m of alluviation occurred.

In the Late Holocene, from the Chalcolithic time onwards, the Wadi Faynan experienced more or less dry climatic conditions. From the point of view of palynology, this interval of time is characterised by a sharp decline in arboreal pollen and increasing amount of desertic species such as Chenopodiaceae and *Ephedra* and presence of species such as *Rumex*, Asteraceae and Lactuceae which are strongly suggestive of dry steppe conditions (Janssen and Woldring, 1981). During this time up to 7 m of incision occurred.

The interval *ca*. 350-100 BP shows a very very degraded steppe environment or probably steppe-desert from the presence of very high Chenopodiaceae and *Ephedra*. Probably the climate during this interval was much drier than today's climate. During this time, 2-4 m of alluviation occurred.

The interval *ca.* 100-0.0 BP is probably similar to today's climate since the pollen assemblages are similar to modern ones. During this time, up to 4 m of incision has occurred.

It is likely in the early Holocene that the alluviation was caused partially by some sort of human activity such as herding and arable agriculture. Although separating human from climate-induced changes in the stream regime is complex (Rosen, 1986), it seems clear that climatic conditions were wetter and vegetation significantly denser than today. In contrast the alluviation in the late Holocene appears to have taken place in very dry climatic conditions. Furthermore, human activity such as smelting and metal working does not seem to play a role in the late Holocene alluviation episode (Ch. 7).

The Holocene alluvial history of the Faynan region still has large gaps because of the lack of alluvial bodies of mid to late Holocene age. These could be washed out (down Wadi Araba) from the Faynan system or could be blown away as a consequence of the aridity and dry climate which was predominant after Neolithic time. Alternatively, the deposits may have been possibly covered by later sediments. As a result, this research recommends more work on Holocene alluviation in and around the research area.

8.5 Flood Water Farming (FWF) and rain water harvesting (RWH)

To allow cropping in dry regions, people have used FWF and RWH over a long period of time. Modern irrigation schemes are often associated with environmental degradation (Williams *et al.*, 1998). It might be expected that similar problems were associated with ancient FWF/RWH in the Faynan. FWF/RWH in the research area seems to have started in the Chalcolithic. A cistern fill (site 5051) shows signs of soil erosion, but the pollen analysis suggests that a healthy steppe vegetation was still present. In the later Holocene, the great Nabatean/Roman FWF/RWH system in the Wadi Faynan seems to have finished operating (as seen by the fall in cereal pollen at the Khirbet Barrage site [5017]) long before intense environmental degradation and aridification set in, probably around 500 BP. The phases of FWF/RWH in the Wadi

Faynan are also clearly out of phase with alluviation episodes. An important point to make about FWF/ RWH in the research area is that it is not associated with any environmental problem and it does not seem to have initiated alluviation.

8.6 Impact of mining

In some parts of the world, metal extraction and smelting has caused severe environmental impacts, with widespread valley alluviation and vegetation damage (Ch. 2). This thesis has therefore investigated the impact of mining in the Wadi Faynan.

The mining of copper has taken place in the Faynan area since Neolithic times and smelting activity since the Bronze Age. The end of significant mining and smelting, as seen in the Khirbet Barrage sequence (5017) does not seem to have been accompanied or followed by any change in the vegetation. It has been found that mining and smelting activity does not play any role in wadi alluviation (see Chapter Seven). It can therefore be argued that in the case of the Wadi Faynan, mining and smelting had comparatively minor effects on vegetation.

8.7 Future work

Not all the evidence put forward in this thesis is very strong. Field work in rough terrain like Wadi Faynan is difficult in many ways. Many pollen counts are based on low numbers. There are few radiocarbon dates because many sedimentary units have not yielded suitable material for dating.

The hypotheses erected in this thesis therefore need testing, either in the Wadi Faynan, or in similar areas in Jordan or further afield. This would enable the results of this thesis to be evaluated.

- There are intriguing patterns found in the Wadi Faynan, and also apparent from literature. One of the most striking is the 350-100 BP arid phase which caused alluviation in the Wadi Faynan. Alluviation of approximately this date has been noted from Oman to Tunisia, but dating is unfortunately poor and no palaeoenvironmental work has been done on these sequences. A research programme could usefully address the chronology and role of aridification in the formation of these deposits.
- Further palynological and plant macrofossil studies are recommended, especially of early Holocene deposits which might help the evaluation of the research finds, particularly the unusual and unexpected presence of *Corylus* trees and in general the relatively dense Early Holocene vegetation. These further palynological and plant macrofossils studies and results in southern Jordan could be compared with the research results here to establish the vegetation history of the southern Levant more firmly.
- The alluvial deposits in the research area do not fit with the Vita-Finzi (1969) model. Furthermore, after the early Holocene these do not fit well with the anthropogenic model. In order to evaluate the effect of climate and people on alluviation, further work is needed to make fine resolution studies of this problem and probably to introduce a new model for arid land alluviation. Moreover, such work may shed light on the lack of alluvial bodies of Chalcolithic to early modern age in the Wadi Faynan.

- More generally, there is a need to continue to survey and collect information on the Quaternary geology, palaeoecology and archaeology in this area in a clearly directed and interdisciplinary manner. This will provide one really good case study with sufficient "hard" information which can be used to address the inter-and multi-disciplinary and multifaceted questions that are asked. Hopefully, other studies in broadly similar areas, will follow.

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APPENDIX ONE: TAPHONOMIC STUDIES

1.1 Introduction

No researcher has carried out modern pollen-rain or taphonomic studies in the research area. Similarly, virtually no work has been done examining patterns of palynofacies distribution at the present day. Uncertainties therefore exist in the interpretation of the Holocene pollen spectra and palynofacies assemblages documented in this thesis. In order to resolve these uncertainties, a small taphonomic study was carried out in and near the research area.

Modern pollen studies are providing increasingly valuable in the interpretation of fossil pollen assemblages, but relatively little work has been done in the arid and semi-arid regions of the world (Ayyad *et al.*, 1992). Various authors have investigated the modern pollen rain in the Middle East for taphonomic purposes. These include: Bottema and Barkoudah (1979) in Lebanon and Syria; Horowitz (1969, 1979) in Palestine; van Zeist *et al.* (1970) in southeastern Turkey; Weinstein (1976) in Palestine; Wright *et al.* (1967) in Western Iran; Rossignol (1969a) in the Dead Sea; El-Moslimany (1983) in Jordan, Iraq, Kuwait and Saudi Arabia; Schulz and Whitney (1986) in Saudi Arabia; Ayyad, *et al.* (1992) in Egypt.

Tarasov *et al.* (1998) attempted to distinguish between warm and cool steppes. In order to refine vegetation and climate reconstruction, they analysed a set of modern pollen spectra from the Mediterranean and Kazakhstan regions. This analysis was based on statistical assessment in order to relate pollen taxa abundances to warm and cool grass/shrub plant functional types (PFTs). The results of these analyses shows that it is possible to distinguish between cool and warm steppe biomes with a high degree of confidence. Table (A1.1) show these results.

Table A1.1: Plant functional types and assigned pollen taxa following (Tarasov *et al.*, 1998).

Code	Plant funtional types PFTs	Pollen taxa included
cgs	Cool grass/ shrub	*Hippophae*, Polygonaceae
wgs	Warm grass/ shrub	*Armeria*, Boraginaceae, Brassicaceae, Crassulaceae, *Echium*, Euphorbiaceae, Fabaceae, Lamiaceae, *Rosmarinus*, Scrophulariaceae, *Thymus*, *Zizyphus*.
sf	Steppe forb/ shurb	Apiaceae, Asteraceae subfam. Asteroideae (Asteraceae), Asteraceae subfam. Cichoriodeae (Lactuceae), Campanulaceae, Caryophyllaceae, *Centaurea*, Dipsacaceae, *Filipendula*, *Galium*, *Helianthemum*, *Plantago* sp., *Plantago lanceolata*, Plumbaginaceae, Ranunculaceae, Rosaceae, Rubiaceae.
wdf	Warm desert forb/ shrub	*Ephedra fragilis*, Tamaricaceae, Zygophyllaceae.
df	Desert forb/ shrub	*Ephedra* (including *Ephedra distachya*).
sf/df	Steppe/ desert forb/shurb	*Artemisia*, Chenopodiaceae
g	grass	Poaceae
ec	Eurythermic conifer	*Juniperus*, *Pinus* (*Diploxylon*)
ts	Temperate summergreen	*Acer*, *Euonymus*, *Fraxinus excelsior type Quercus (deciduous)*
ts1	Cool-temperate summergreen	*Carpinus*, *Corylus*, *Fagus*, *Frangula*, *Tilia*, *Ulmus*
ts2	Warm-temperate summergreen	*Castanea*, *Platanus*, *Juglans*, *Rhamnus*, *Vitis*, *Myrica*, *Ostrya*, *Fraxinus ornus type*
wte1	Cool-temperate broad-leaved evergreen	*Buxus*, *Hedera*, *Ilex*
wte2	Warm-temperate sclerophyll shrub/tree	*Cistus*, *Pistacia*, *Rhus*, *Olea*, *Myrtus*, *Acacia*, *Phillyrea*, *Ceratonia*, *Mercurialis*

All of the comprehensive surface studies have been done in semi arid to mesic regions, where annual precipitation is greater than 200 mm. Only El-Moslimany (1983) has reported from regions with rainfall of 150 mm or less, like the research area.

In Jordan, (excluding El-Moslimany, 1983) no work of this sort has been done. Some of the gaps in the knowledge of modern pollen deposition in desert marginal environments will be filled in the work which is presented here.

With the understanding of palynofacies assemblages, even greater problems exist. The first palynofacies studies, e.g. Combaz (1964) and Batten (1982) analysed the palynofacies assemblages found in ancient rocks assigned to a given environment on sedimentological criteria. The only published palynofacies study examining modern assemblages was by Hart (1986) who examined the marine to non-marine transition in the Mississippi Delta (USA) depositional environments. The taphonomic study presented in this thesis is thus a first attempt to analyse the deposition of particulate organic matter in an arid terrestrial environment.

1.2 Method

Samples for the study of modern pollen accumulation where collected from different places in the research area, (figure A1.1). Samples were taken from a variety of environments including fire places, furnaces, eroding sites (Hamada), soil profiles, alluvial basins, and wadi floors. Two samples were taken from wooded sites on the plateau near Petra, for comparison. These samples were processed using standard methods (chapter 4).

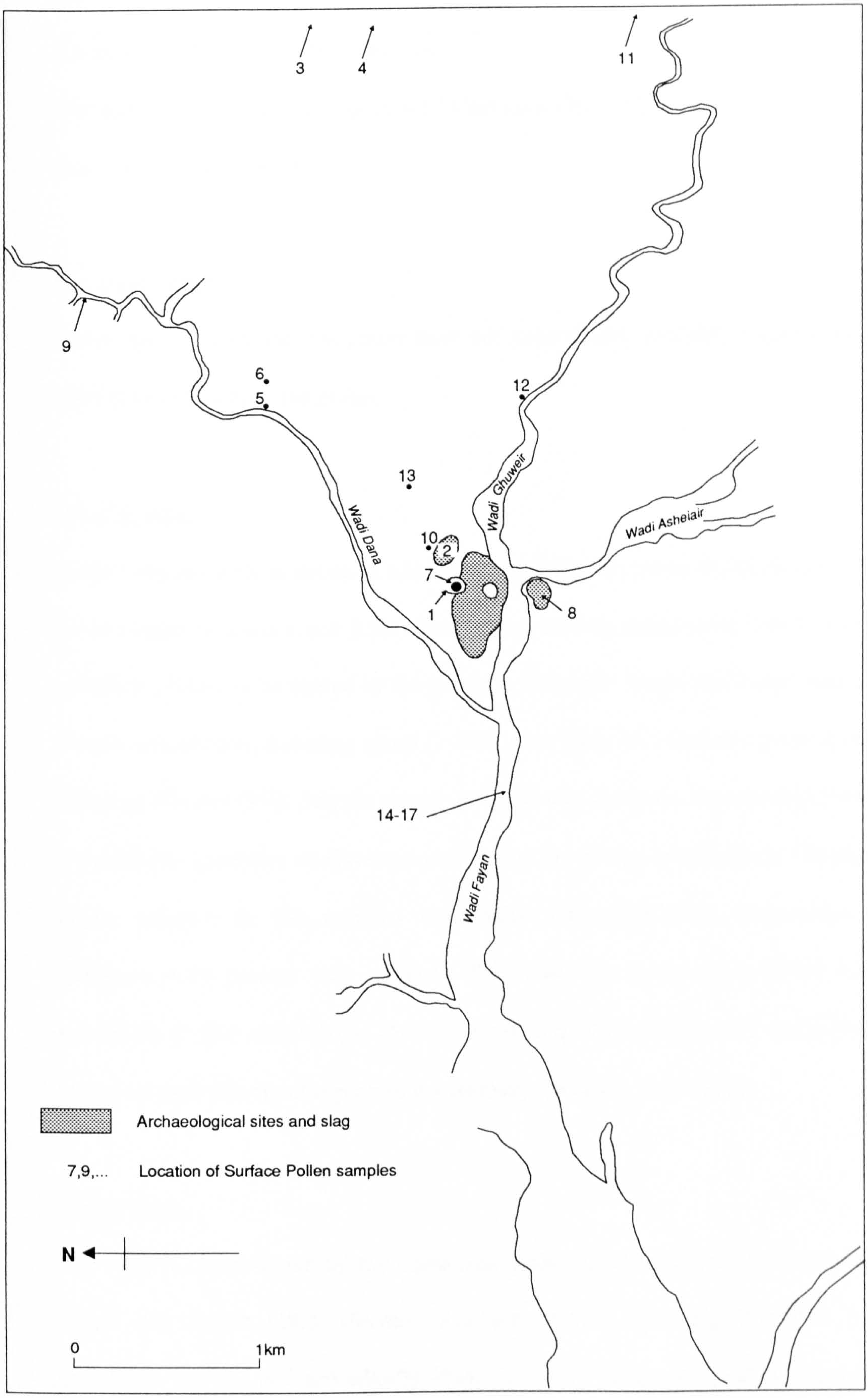


Fig. A1.1 Location map of surface pollen studies in the Wadi Faynan

1.3 Results of surface pollen analysis

The surface pollen diagram (figure A1.2) has been divided into four zones. Below is a description for each zone.

Fire places zone

Pollen spectra from the fire places have not been found, probably because burning activity would destroy the pollen.

Wooded zone

Plateau species were common in this zone, especially *Juniperus* which reached 91%; *Pinus* ranged between 5 and 8.5%. *Juniperus* is heavily represented here in a pollen spectrum which can be related to the presence of Juniper forest. Cultivated taxa were present occasionally, including cereal (1-4%). Also water side taxa was present rarely, including Filicales (1%). Steppic species are common, especially *Artemisia* (1.5-61%). Considerable quantities of *Artemisia* pollen may have been indigenous in the plateau steppe adjacent to the sampled woodlands. Caryophyllaceae, Cyperaceae and Labiateae were present very rarely (1-2%). *Plantago* is common (13%) as are Asteraceae (7.5%) and Poaceae (1-5%). Desertic taxa are present very rarely (<1%). Fungal microfossils are also present occasionally, including VAM (1%).

Steppic zone

This zone is characterised by the occasional presence of far travelled taxa including *Carya* and *Fagus* (1%). Plateau taxa are present including *Pistachia* (8%), *Eucalyptus* (3.5%), and sporadically *Pinus* (1-2.5%), *Juniperus* (1-2%), *Hippophae* (2%), and occasional presence of *Casuarina*, Cupressaceae, *Euonymus*, *Quercus*,

Fig. A1.2 Palynology of the surface samples. All pollen, spores and other microfossils are calculated as % total pollen and spores

Rhamnaceae, Rosaceae (<1%). Cultivated taxa present including cereal (0.5-1.5%) and *Olea* (0.5%). Water side taxa are present including *Nerium* (1.5%) and occasionally *Tamarix* (<1%). Steppic taxa including *Artemisia* (2-13%), Asteraceae (4-15%), Lactuceae (2-31%) and *Plantago* pollen values are conspicuously high (8-42%), which is probably due to rather intensive grazing. Poaceae (2-27%), Caryophyllaceae (2-6%), *Centaurea* (0.5-1.5%) and occasionally *Helianthemum*, *Polygonium* and Umbelliferaceae (<1%) are present. Desertic taxa are also present including Chenopodiaceae (5-38%), *Ephedra* (4%) and occasionally Cruciferae (<1%). Unidentified taxa are common (2-26%). In waterlain samples Algae are occasionally present such as *Spirogyra* (<1%), and fungal microfossils are also present including VAM (1-480%) and fungal zoospores (2.5-3.5%).

Degraded steppic zone

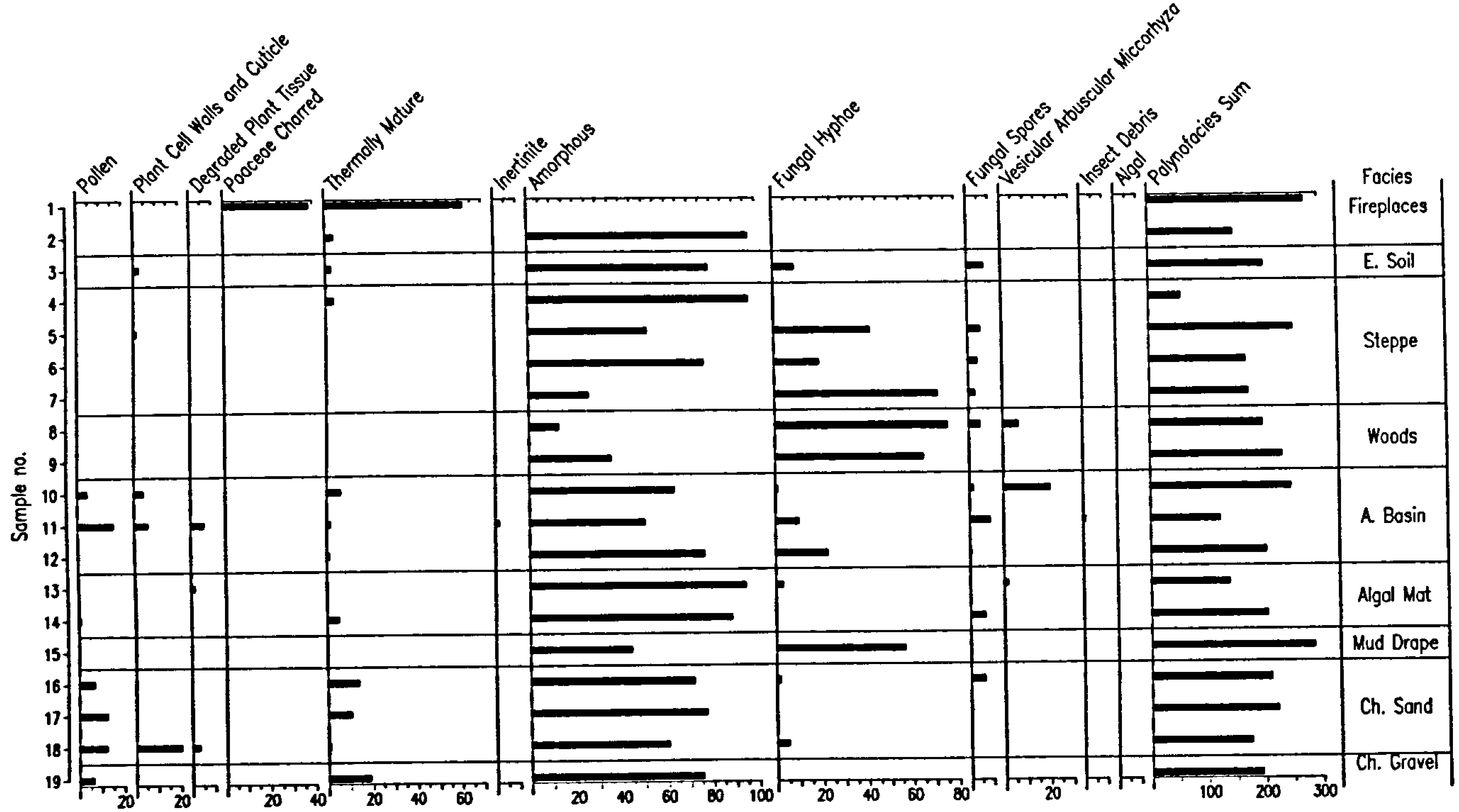
This zone is characterised by low counts of far travelled species including *Alnus* (0.5-2%), *Corylus* (2.5%), *Cedrus* (1%) and occasionally *Betula* and *Fagus* (<1%). Plateau taxa are also present including *Juniperus* (1-16%), Cupressaceae (1-7%), *Pinus* (1-6%), *Pistachia* (1-4%), *Rhamnus* (0.5-1.5%), *Quercus* (0.5-1.5%), *Casuarina* (0.5-2%) and occasionally *Ulex*, *Euphorbia*, *Eucalyptus*, *Daphne*, *Circaea* (<1%). Cultivated species are present including cereal (1-6%) and *Olea* (1-8.5%). Water side taxa are also present including Trilete spores (0.5-6%), *Tamarix* (1%), Palm (1%), Filicales (1-2%). Steppic species are present including *Artemisia* (9-28%), *Plantago* (2-24%), Poaceae (10-17%), Caryophyllaceae (4-15%), Asteraceae (2-18%), Lactuceae (3-8%), *Helianthemum* (4-6%), Cyperaceae (0.5-5%), *Centaurea* (0.5-1.5%), *Alchemilla* type (1%), Campanulaceae (1%), Labiateae (1%), Liliaceae (1-4%), *Lotus* (1.5%), *Polygonum* (1%), *Poterium* (1%), *Rumex* (0.5-5%), *Solanaceae* (2%) and occasionally *Vicia, Valeriana, Trifolium, Saxifraga, Sanguisorba, Medicago,* and *Lithospermum* (<1%). Desertic species are also present such as Chenopodiaceae (7-26%) and *Ephedra* (1-8%). Unidentified pollen is common (2-15%). Algal microfossils are present including Diatoms (2-8.5%), *Saeptodinium* (3-35%), *Spirogyra* (1-10%), Zygnemataceae (1.5%), *Mougeotia* (2.5%) in samples from river beds. Fungal spores are also present including VAM (0.5-3%) and fungal zoospores (1%). Recycled preQuaternary material is occasionally present (3%). In general, the surface pollen spectra from the degraded steppic zone is characterised by a relatively large amount of far travelled and plateau elements.

1.4 Results of surface palynofacies analysis

Results are shown in figure A1.3, with samples re-numbered for convenience to group them into depositional environments. Some interesting patterns can be distinguished The two hearth sites show very different patterns. The Bedouin hearth (sample 1) contains only thermally mature material, some attributable to the Poaceae. This reflects incomplete, low-temperature combustion, whereas in Hauptmann's high-temperature furnace (sample 2) relatively complete combustion was obtained and little thermally mature material has survived burning. The amorphous matter in this sample appears to be largely siliceous and probably reflects fused phytoliths from the wood burnt in Hauptmann's firing experiments.

The sample from degraded steppe (eroded soil) (sample 3) and steppe environments (samples 4-7) are dominated by amorphous matter and fungal hyphae, in varying proportions, and fungal spores are usually present. Thermally mature material in some samples probably reflects either natural fires or ash dispersed from a Bedouin camp

Fig. A1.3 Palynofacies of the surface samples. All particulate organic matter is calculated as % total particulate organic matter



fire at some time in the past. Since thermally mature material is virtually inert it has a very long residence time in the environment.

The samples from the wood land environments are both dominated by fungal hyphae, with some amorphous matter. Fungal spores and VAMs are present in one sample. The high incidence of fungal hyphae probably reflects energetic decay processes in the wood land environment.

The samples from two of the alluvial basin are rather distinctive. These are samples (samples 10 and 11) from the deeper basins at the Khirbet Barrage (site 5017) and site 5051, where water stands for a number of weeks each year. These samples are characterised by relatively high counts for pollen, high amorphous, some plant cell walls and cuticle and some fungal spores. One sample has a high counts for VAMs and the other contains some insect debris. The shallower alluvial basin, on the hamada above the Khirbet Barrage (sample 12) is comparable with the samples from the steppe land environments, with dominance by amorphous matter, some fungal hyphae, a few fungal spores. The relatively good preservation of a wide range of organic matter in two of the alluvial basin samples might be because organic matter in these locations is rapidly buried under accumulating sediments which therefore can not rapidly be broken down by some combination of oxidation, microbial or fungal decay processes, or wetting/dry cyclicity, as appears to be the case in the most of the other samples.

The two samples from the algal mats (samples 13 and 14) in wadi-floor backwaters are heavily dominated by amorphous matter, probably from the *in-situ* breakdown of the algae themselves. The algal mats seem to have trapped small quantities of other types of organic matter, such as pollen, degraded plant tissue, thermally mature matter, fungal hyphae, fungal spores and vesicular arbuscular miccorhyza (VAM).

The sample from the mud drape (sample 15) was taken only a few metres from one of the algal mat samples, but is rather different, containing very abundant fungal hyphae and amorphous matter. The mud drape was very recently deposited, from a flood within the past fortnight of collection (Abu Fouz, *pers. comm.* 1998) so it is very likely that the fungal hyphae are derived from eroding soil profiles.

The final set of samples (samples 16-18 from sandy in-channel sediments and sample 19 from in-channel gravels) were all taken a few metres from each other on the floor of the Wadi Faynan and are quite similar to each other. They all contain large quantities of amorphous matter, some pollen and some thermally mature matter. One sample also contains some plant cell walls and cuticle and some fungal hyphae. As with the alluvial basins, the preservation of pollen in this environment is probably the results of rapid burial. The heavy thermally mature material (Hunt, 1994) is preferentially deposited in these high energy environments.

1.5 Conclusion

To conclude, *Juniperus* is heavily represented here in a pollen spectrum which can be related to the presence of *Juniper* forest. The pine wood sample showed a suprisingly low percentage of *Pinus* pollen, perhaps due to low local pollen production (maybe *pinus* trees are streesed by recent drought). *Artemisia* and Chenopodiaceae percentages are relatively lower than might be expected for a typical steppic environment probably due to them being shaded out.

The steppic samples are very variable, but some have relatively high counts of taxa such as Poaceae, *Plantago*, Chenopodiaceae, Lactuceae, Asteraceae, and *Artemisia*. The reason for the variability are unclear, but some of the areas sampled had recently been fenced off and may not have reached a floral equilibrium.

The degraded steppic samples shown generally high Chenopodiaceae, *Artemisia*, Poaceae, Caryophyllaceae and Asteraceae. These plants are all locally represented, albeit very heavily grazed. These samples also show relatively high counts for plateau and far-travelled species, probably because the local pollen productivity is low.

On the whole, however, there are consistent changes between the groups of samples, which suggests that these biotypes should be reliably identified in ancient pollen spectra. The pollen spectra of the surface samples shown in fig. A1.2 are in many cases rather dissimilar to the Holocene pollen spectra found in the research area (Ch. 5). Where appropriate, however, the information from this diagram has been used in interpretation of the Holocene spectra.

Similarly, with the palynofacies sampling, consistent or near-consistent patterns of occurrence can be distinguished. The low-temperature Bedouin hearth is particularly distinctive, but characteristic patterns were obtained from most of the other environments sampled. These results can then be used to help interpret the Holocene palaeoenvironments of the research area (Chapter 5).

APPENDIX TWO: METHODOLOGICAL PROCEDURES

2.1 Pollen preparation technique,

The preparation procedures, based on (Hunt, 1985) were employed for all pollen samples. The following steps summarise the method:

1- The sample was placed in a beaker and boiled for 10 minutes in a 5% solution of potassium hydroxide (KOH). Lumps were broken up by occasional stirring with a glass rod.

2- The beaker was removed from the heat and allowed to cool for a few minutes. The suspension was sieved through 100 micron nylon mesh to remove coarse sand, and on nominal 10 micron nylon mesh to remove clay minerals and fine organic particles.

3- The resulting 100-10 micron fraction was "swirled" or panned gently on a clock glass to remove the fine silt and fine sand fraction, and the remaining organic concentrate was stained with fuchsin and mounted on microscope slides in Aquamount.

2.2 Particle Size Analysis

Method

Samples of approximately 1.0 g were oven dried, then weighed, disaggregated in a 5% sodium hexametaphosphate (calgon) solution, then wet sieved through 63 micron and 5 micron wet sieves. The material retained on each sieve was transferred to an evaporating dish, oven dried, and weighed. The percentage of sand is determined from the weight of material retained on the 63 micron sieve. The approximate percentage of silt is determined from the weight of the material retained on the 5 micron sieve, and the percentage of finest silt and clay is the weight of the material lost through the 5 micron sieve, which can be determined by subtraction.

2.3 Estimation of organic matter content by loss on ignition

Estimation of organic matter content by loss on ignition were determined using loss on ignition method. The steps of this method are outlined below:

1- Weigh the labelled crucible to .001 g (M1).

2- Weigh ~5 g of the sample into the crucible.

3- Dry the crucible and it's contents in the oven at 105 °C for 24 hours.

4- Remove the crucible from the oven: place it immediately in the dessicator to cool to room temperature.

5- Remove the crucible and its contents when cooled from the dessicator and weigh immediately (M2).

6- Put the sample in the furnace to reach a temperature of 430 °C for 24 hours.

7- Remove the crucible and its content from the furnace, and place them immediately in the dessicator to cool to room temperature. When the crucible and its contents have cooled to room temperature, weigh immediately (M3).

The percentage by mass lost-on-ignition in the sample may be determined from the following equation (Gale and Hoare, 1991).

$$100[(M2-M1)-(M3-M1)]/[(M2-M1)]$$

Where M1 is the mass of the crucible in grams (g), M2 is the mass of the crucible plus the sample dried at 105 °C for 24 hours, and M3 is the mass of the crucible plus the sample ignited at 430 °C for 24 hours.

2.4 Estimation of Calcium Carbonate-equivalent content

Estimation of Calcium Carbonate-equivalent content were determined used the method outlined below:

1. Weigh three samples of 0.9000-1.000 g of the sediment in to separate labelled 250 cubic cm Quickfit flasks.
2. Open tap1 (see figure A2.1), on the calcimeter, insert groundglass joint G in to the top of the flask and attach the joint clip to joint B/G.
3. Open tap 2 and raise water reservoir D until levels in both tubes of manometer C rise just above the zero graduation.
4. Close tap 2 and lower reservoir D to bench level, adjust the fluid level in manometer C to read zero by using tap 2.
5. Close tap 1.
6. Open acid inlet tap 3 and run enough acid to flask B to make the sample just fluid.
7. Before the reaction ceases, open tap 2 and allow the water in the left hand tube of the manometer to fall to 10-12 mm above that in the graduated, right-hand tube, this to prevent any unnecessary difference in pressure between that inside and that out side the calcimeter.
8. Close tap 2.
9. Add further acid sparingly to the flask B by opening tap 3, then close tap 3.
10. Repeat steps 7-9 until completion of the reaction, wait~2 minutes to allow heat to dissipate and then carefully open tap 2 and let the manometer water run out until the levels in the two tubes of manometer are equal.
11. Record the volume of gas evolved (V) by noting the amount of water displaced from the right-hand graduated, side of the manometer.

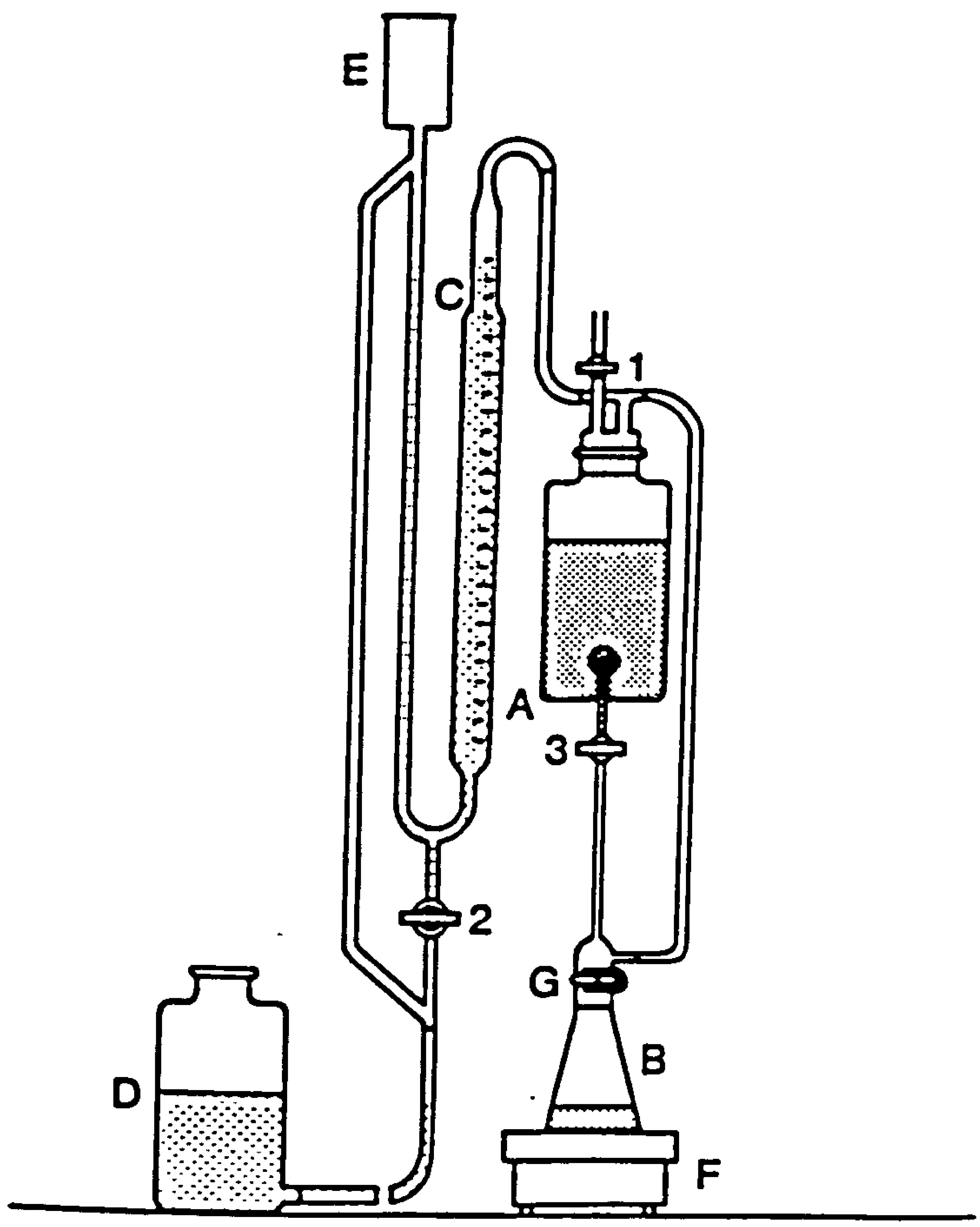


Fig. A2.1 Bascomb calcimeter (after Bascomb, 1961)

12. Record the air temperature in the immediate vicinity of the Basecomb calcimeter (T).

13. Record the barometric pressure (P).

Apply in the equation (Gale and Hoare,1991. P. 269) to calculate the percentage by mass of calcium carbonate-equivalent

$$(VPC)/(M1T)$$

Where, V is the volume of carbon dioxide evolved during the reaction (in cubic centimetres), P is the Barometric pressure (in mm Hg), C is a constant which equal 0.1605 and T is the temperature (in Kielvin, which is K= $^{O}C+273.15$).

2.5 Magnetic Susceptibility

The following steps summarise the method:

1- Weigh the plastic pot of the 10 cm^3.

2- Put the subsample of the <2 mm fraction in to pot and reweigh it.

3- Place the pot in to MS2 system and record the susceptibility.

4- Samples were at first recorded using the frequency measurement at the 1.0 range. This range has been noted by Dearing (1994) to be trustworthy with the samples that have volume susceptibility or κ (Greek k or kappa), reading of >30.

5- Samples which had a value less than 30 were then measured in the 0.1 range: air-readings were taken before and after sampling to eliminate any instrumental drift that may be taking place. The gained results were then converted to show magnetic susceptibility per gramme.

2.6 Heavy Liquid Separation of Organic Matter

<u>Method</u>

All procedures take place in a fume cupboard, using glassware that has been specially acid washed and then rinsed in distilled water and dried completely. The heavy liquid used - Zinc Chloride (ZnCl)- is immiscible with water. If water is introduced, the Zinc will be precipitated as Zn_2O and the preparation ruined. The following steps (following Guillet and Planchais, 1969) summarise this method:

1- Put sample in a very large beaker (1.0l or bigger). Add 10% HCl and wait for the reaction to cease. If lots of bubbles are evolved, they can be wetted down with a fine jet of distilled water. When the reaction ceases, add a little more HCl to check that the reaction is finished.

2- Let the sample settle, then pour off the supernatant.

3- stir the resultant slurry and pour it in to centrifuge tubes until they are a quarter full. Top up with strong HCl (50%), stir, balance the tubes carefully and spin at 1000 rpm for five minutes.

4- Pour off the supernatant and top up with conc. HCl, stir, balance the tubes carefully and spin at 1000 rpm for five minutes.

5- Repeat this step three times.

6- Pour off the supernatant and top up with ZnCl, stir, balance the tubes carefully and spin at 1000 rpm for ten minutes.

7- The organic matter should be floating on the ZnCl solution and should be carefully poured off into fresh centrifuge tubes. Top up the original tubes with ZnCl, stir, balance the tubes carefully and spin at 1000 rpm for ten minutes.

8- Pour off in to fresh centrifuge tubes any further organic matter; discard the mineral matter which has sunk.

9- To the tubes containing the HCl/ZnCl mix, add conc. HCl , stir, balance the tubes carefully and spin at 1000 rpm for five minutes.

10- Pour off the supernatant, add more conc. HCl, stir, balance the tubes carefully and spin at 1000 rpm for five minutes.

11-Repeat this step three times.

12- pour off the supernatant, add 50% HCl, balance the tubes carefully and spin at 1000 rpm for 5 minutes.

13- Pour off the supernatant, add distilled water, stir, balance the tubes carefully and spin at 1000 rpm for 5 minutes.

14- Repeat this step 3 times.

15- Pour off the supernatant. The organic matter can then be gently resuspended by stirring and poured in to a glass sealable container, and refrigerated until needed.

APPENDIX THREE: SAMPLES DESCRIPTIONS

Table A3.1 Sample descriptions, site 5510

Sample number/ Depth in m.	Description
5510 M1 (12.2)	Yellowish gray (5Y 7/2) silty sand.
5510 M2 (12.4)	Light olive gray (5Y 5/2) coarse silty sand
5510 M3 (12.6)	Dusky yellow (5Y 6/4) silty sand.
5510 M4 (12.8)	Dusky yellow (5Y 6/4) silty sand.
5510 P (8.0)	Very pale orange (10 YR 8/2) coarse sand
5510 O (8.2)	Moderate orange pink (5 YR 8/4) very coarse sand.
5510 F (12)	Pale yellowish brown (10 YR 6/2) coarse sand.
5510 Q (7.4)	Moderate orange pink (5 YR 8/4) gravelly coarse sand.
5510 R (7.7)	Dark yellowish brown (10 YR 4/2) coarse silty sand.
5510 K (11.4)	Grayish orange (10 YR 7/4) silty sand.
5510 H (11.8)	Moderate yellowish brown (10 YR 5/4) coarse silty sand.
5510 G (11.9)	Pale yellowish brown (10 YR 6/2) silty sand.
5510 N (13)	Grayish orange (10 YR 7/4) silty sand.

Table A3.2 Sample descriptions, site 5021

Sample number	Descriptions
1 (a)	Light olive gray (5 Y 6/1) finegravel
2 (b)	Greenish grey (5 GY 6/1) sandy silt
3 (c)	Greenish grey (5 G 6/1) silt
4 (d)	Greenish grey (5 G 6/1) sandy silt
5 (e)	Greenish grey (5 G 6/1) silt
6 (f)	Light olive grey (5 Y 6/1) Grey silt
7 (g)	Dark greenish grey (GY 4/1) silt
8 (h)	Grey green (5 G 5/2) silt
9 (i)	Olive grey (5 Y 4/1) silt
10(k)	Light olive grey (5 Y 6/1) silt
11(x)	Greyish orange (10 YR 7/4) silt

Table A3.3 Section description, site 5015

Number	Description
1	Pale to mid brown breccia with a silty matrix: stony hillslope deposit.
2	Pale brown silts containing some angular rock fragments: stony colluvium with aeolian input.
3	Dark grey sandy silt infilling pits containing occasional Neolithic artifacts. Pit fills of Neolithic age.
4	Silty sand with carbonate induration of root channels, occasional Neolithic artifacts, very dark to top: aeolian cover sand on which a soil profile has developed.
5	Gray-brown sandy silt occasional stones: colluvium and overbank sediment.
6	Imbricated fluvial gravels and boulders: deposits of wadi channel.

Table A3.4 Sample descriptions, site 5500

Sample/ Depth (in metre)	Descriptions
(D) 2.0	Dark yellowish brown (10YR 4/2) Sand
(F) 3.0	Pae brown (5YR 5/2) Sandy gravel
(g) 3.5	Dusky yellowish brown (10 YR 2/2) coarse sand
(K) 4.10	Dark yellowish brown (10 YR 4/2) Sand

Table A3.5 Sample descriptions, site 5025

Sample	Descriptions
A	Moderate yellowish brown (10 YR 5/4) coarse sand.
B	Pale yellowish brown (10 YR 6/2) sand.
C	Pale yellowish brown (10 YR 6/2) silty sand.
D	Pale yellowish brown (10 YR 6/2) silty sand.

Table A3.6 Sample descriptions, site 5509

Sample number	Descriptions
A	Moderate yellowish brown (10 YR 5/4) sandy silt.
B	Dark yellowish brown (10 YR 4/2) sand/silt
C	Pale yellowish brown (10 YR 6/2) coarse sand.

Table A3.7 Sample descriptions, site 5520

Sample/Depth	Descriptions
5520 (2) at 1m	Moderate brown (5 YR 3/4) coarse sand
5520 (4) at 3.5 m	Moderate brown (5 YR 4/4) coarse sand
5520 (5) at 4.3 m	Dark yellowish brown (10 YR 4/2) sand
5520 (6) at 5.9 m	Moderate brown (5 YR 4/4) coarse sand
5520 (7) at 6.4 m	Moderate yellowish brown (10YR 5/4) sand

Table A3.8 Sample descriptions of Khirbet Barrage, site 5017

Depth (in meters)	Description
0.0	Surface sample: Pale brown (5YR 5/2) silt.
0-0.2	Moderate yellowish brown (10 YR 5/4) silt.
0.15-0.20	Dark yellowish orange (10 YR 6/6), orange yellow buff silt.
0.2-0.3	Moderate yellowish brown (10YR 5/4), orange yellow buff silt.
0.3-0.38	Moderate yellowish brown (10YR 5/4), pebbly silt.
0.4-0.48	Moderate yellowish brown (10 YR 5/4) silt.
0.48-0.59	Moderate yellowish brown (10 YR 5/4)silt.
0.59-0.72	Dark yellowish orange (10 YR 6/6) silt.
0.72-0.77	Moderate yellowish brown (10 YR 5/4) silt
0.77-0.88	Moderate yellowish brown (10YR 5/4) silt.
0.88-0.9	Dark yellowish orange (10 YR 6/6) silt.
0.9-1.06	Moderate yellowish (10YR 5/4) silt.
1.06-1.17	Dark yellowish orange (10YR 6/6) silt.
1.17-1.28	Dark yellowish orange (10 YR 6/6) silt.
1.28-1.40	Moderate yellowish brown (10 YR 5/4) silt.
1.40-1.48	Dark yellowish orange (10 YR 6/6) silt with a stony layer.
1.48-1.55	Dark yellowish orange (10 YR 6/6) silt.
1.55-1.65	Moderate yellowish brown (10 YR 5/4) silt.
1.65-1.74	Moderate yellowish brown (10YR 5/4) silt.
1.74-1.80	Moderate yellowish brown (10 YR 5/4) silt.
1.80-1.90	Moderate yellowish brown (10YR 5/4) silt.
1.90-1.96	Pale brown (5 YR 5/2) silt, turning to grey buff towards the bottom
1.96-1.99	Pale yellowish brown (10YR 6/2) silt.
1.99-2.05	Pale yellowish brown (10YR 6/2) silt.
2.05-2.10	Pale yellowish brown (10 YR 6/2) silt.
2.10-2.15	Moderate yellowish brown (10 YR 5/4) silt.
2.15-2.21	Dark yellowish brown (10 YR 4/2) silt.
2.21-2.27	Dark yellowish orange (10YR 6/6) silt.
2.27-2.29	Grayish orange (10 YR 7/4) silt.
2.29-2.33	Grayish red (10YR 4/2) silt.
2.33-2.34	Dark yellowish orange (10 YR 6/6) silt.
2.34-2.36	Moderate yellowish brown (10 YR 5/4) silt.
2.36	bedrock.

Table A3.9.Stratigraphy of site 5051

Depth (in meters)	Descriptions
0.0	surface
0-0.17	Greyish orange (10YR 7/4), coherent sandy silt.
0.17-0.24	Dark yellowish orange (10YR 6/6), slightly damp, sandy silt with bits of shells
0.24-0.28	Dark yellowish orange (10YR 6/6), gritty sandy silt
0.28-0.44	Dark yellowish orange (10 YR 6/6), very loose gravelly sandy silt
0.44-0.50	Dark yellowish orange (10YR 6/6), very gravelly sandy silt
0.50-0.53	Dark yellowish orange (10YR 6/6), extremely gravelly sandy silt, hit solid at 0.53 m.

Table A3.10 Sample descriptions, site 5516

Sample	Descriptions
5516.1	Moderate yellowish brown (10 YR 5/4) silty sand
5516.2	Pale yellowish brown (10 YR 6/2) silty sand
5516.3	Pale yellowish brown (10 YR 6/2) silty sand

APPENDIX FOUR: POLLEN AND PALYNOFACIES ELEMENTS

4.1 Pollen

Plate 1: Trees and shrubs

Alnus (A) from site 5025, *Acacia* (B) from Khirbet Barrage site (5017), *Corylus* (C) from site 5500, *Casuarina* (D) from Khirbet Barrage site (5017), *Ligustrum* (E) from site 5051, *Tamarix* (F) from site 5510

Plate 1 : far travelled taxa

Myriophyllum (G) from site 5025

Fagopyrum (H) from site 5025 from site 5051

Plate 2: Trees and shrubs

Juniperus (A) from site 5015/5500, *Pinus* (B) from site 5520, *Quercus* (C) from site 5510, *Corylus* (D) from site 5510, Cupressaceae (E) from site 5025, *Olea* (F) from Khirbet Barrage site (5017), *Acer* (G) from site 5025, *Pistacia* (H) from site 5510.

Plate 3: Trees and shrubs

Daphne (A) from site 5051, *Robinia* (Australian sp.) (B) from Khirbet Barrage site (5017). ? *Ulmus* (C) from site 5510, *Quercus* (D) from Khirbet Barrage site (5017), *Tamarix* (E) from site 5510, *Euonymus* (F) from site 5021, *Palmae* (G) from site 5015/5500, *Casuarina* (H) from Khirbet Barrage site (5017).

Plate 4: Trees and shrubs

Betula (A) from site 5025, Rosaceae (B) from Khirbet Barrage site (5017), *Rhamnus* (C) from site 5021, *Alnus* (D) from site 5500, *Hippophae* (E) from site 5510, Cupressaceae (F) from site 5510, *Quercus* (G) from site 5025, *Eucalyptus* (H) from Khirbet Barrage site (5017).

Plate 5: Steppe taxa

Cyperaceae (A) from site5510, *Plantago* (B) from site 5051, *Elaeagnus* (C) from site 5051, Poaceae (D) from site 5021, Cereal type (E) from Khirbet Barrage site (5017), *Poterium* (F) from Khirbet Barrage site (5017), Caryophyllaceae (G) from Khirbet Barrage site (5017), Lactuceae (H) from site 5520.

Plate 6:

Malva (A) from site 5510, Asteraceae (B) from site 5509, *Poterium* (C) from Khirbet Barrage site (5017), *Artemisia* (D) from Khirbet Barrage site (5017), *Erodium* sp. (E) from site 5520, *Artemisia* (F) from site 5051, *Potentilla* (G) from site 5025, *Geranium* (H) from site 5051.

Plate 7:

Trifolium (A) from site 5520, *Helianthemum* (B) from site 5025, Solanaceae (C) from site 5025, *Trifolium* (D) from site 5021, *Ranunculus* (E) from Khirbet Barrage site (5017), *Helianthemum* (F) from site 5025, *Limonium* (G) from site 5051, Liliaceae (H) from site 5025.

Plate 8:

Centaurea (A) from site 5025, *Saxifraga* (B) from site 5021, Umbelliferae (C) from Khirbet Barrage site (5017), *Sanguisorba* (D) from site site 5051, *Scabiosa* (E) from site site 5051, Leguminosae (F) from site 5025, *Geranium* (G) from Khirbet Barrage site (5017), *Rumex* (H) from site 5051.

Plate 9: Desert taxa

Cruciferae (A), from Khirbet Barrage site (5017), *Ephedra* (B), from site 5051 and Chenopodiaceae (C), from Khirbet Barrage site (5017) and *Euphorbia* (D), from site 5051.

Plate 9: Wet land taxa

Filicales (E), from site 5021, *Viola* (F) from site 5025, Trilete spore (G) from site 5510, Trilete spore (H) from Khirbet Barrage site (5017).

4.2 Palynofacies elements

The classes of organic fragment commonly used in palynofacies analysis and used in this study are described briefly in Appendix 5 (Table A5.1), and the commonest are illustrated in the following plates.

Plate 10: palynofacies

Degraded plant debris (A) from Khirbet Barrage site (5017).

Plant fragment (B) from Khirbet Barrage site (5017).

Wood charcoal (C): thermally mature sieve plate from a woody plant, from site 5051.

Plant tissue (D) from site 5051.

Plant cuticle (E) from Khirbet Barrage site (5017).

Insect scale (F) from site 5051.

Insect egg (G) from site 5051.

Plate 11

Thermally mature wood fragment showing characteristic pores, probably *Juniper* or *Pinus* (A) from site 5021.

Insect debris (B) from Khirbet Barrage site (5017).

Plate 12

Amorphous organic matter (A) from Khirbet Barrage site (5017).

Poaceae, thermally mature (B) from Khirbet Barrage site (5017).

Plate 13: Fungal microfossils

Fungal spore (A) form Khirbet Barrage site (5017).

Vesicular arbuscular miccorhyza VAM (B) from site 5520.

Fungal spore (C) from Khirbet Barrage site (5017).

Fungal spore and hyphae (D) from Khirbet Barrage site (5017).

Fungal spore(E) from site 5051.

Fungal zoospore ((F) from site 5025.

Soil fungal spore(G) form Khirbet Barrage site (5017).

Fungal spore(H) form site 5051.

Plate 14:Algae

Saeptodinium cyst (A) from Khirbet Barrage site (5017).

Spirogyra (B) from site 5051.

Botryococcus (C) from site 5051.

Type 114 : algae of slow-moving water (D) from Khirbet Barrage site (5017).

Botryococcus (E) from site 5051.

Psilate algal cyst (F) from Khirbet Barrage site (5017).

Diatoms (G) from Khirbet Barrage site (5017).

Diatoms (H) from Khirbet Barrage site (5017).

Plate 15:

? Zygnemataceae (A) from site 5051.

? Zygnemataceae (B) from site 5051.

Plate 16: Recycled microfossils

Gymnodinium sp. (A) Cretaceous recycled dinocyst, from site 5510.

Achomosphaera sp. (B) Cretaceous recycled dinocyst, from site 5510.

Ctenidodinium sp. (C) Cretaceous recycled dinocyst, from site 5510.

Endoscrinium sp. (D) Cretaceous recycled dinocyst, from site 5500.

Ciratricosisporites sp. (E) Cretaceous/ Tertiary recycled spore, from site 5510.

Achomosphaera sp. (F) Cretaceous recycled dinocyst, from site 5510.

? *Cometodinium* sp.(G): Cretaceous recycled acritarch, from site 5510.

Gymnodinium sp. (H) Cretaceous recycled dyonscyst, from site 5510.

Plate 1

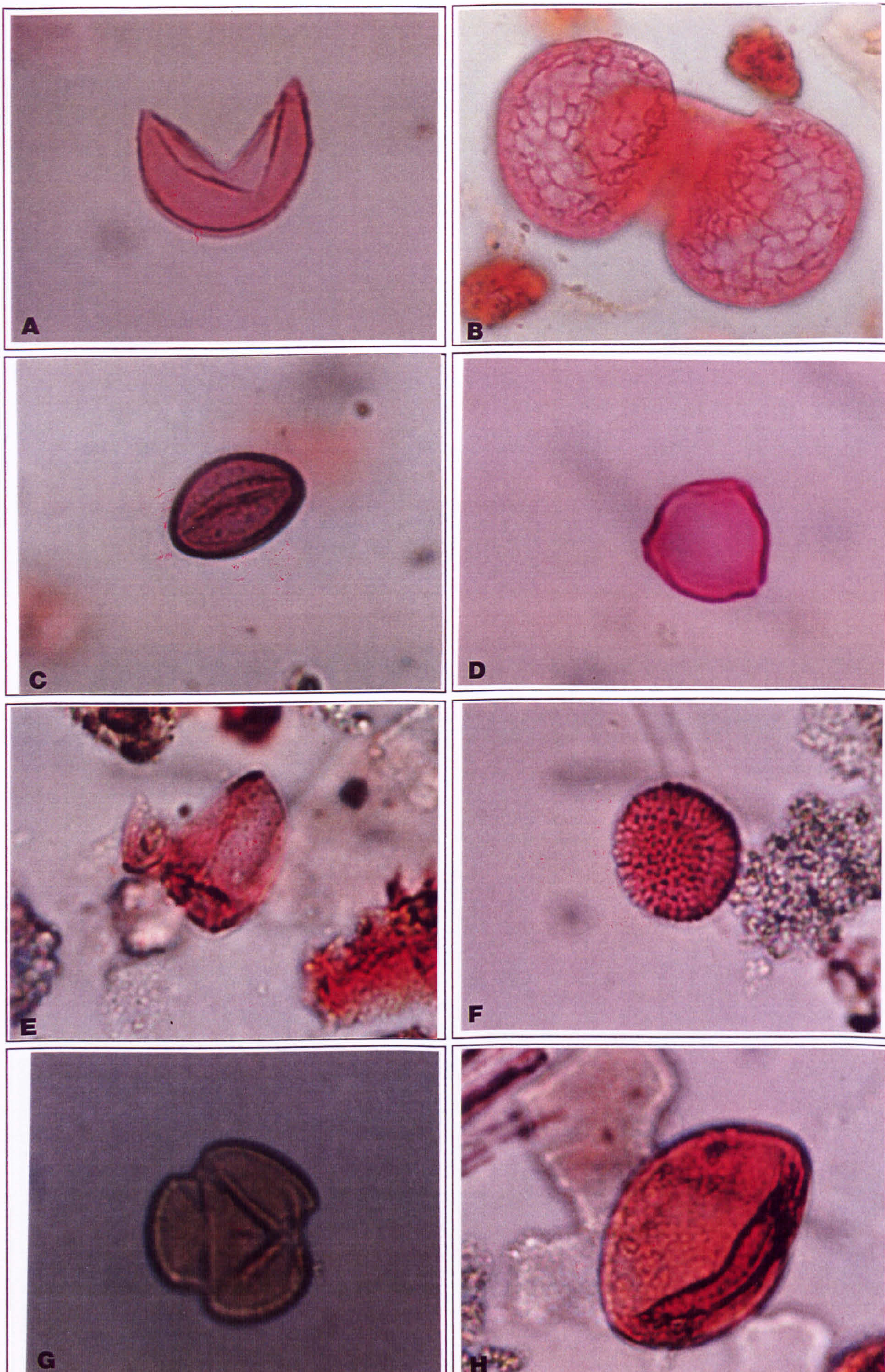


Plate 2

Plate 3

Plate 4

Plate 5

Plate 6

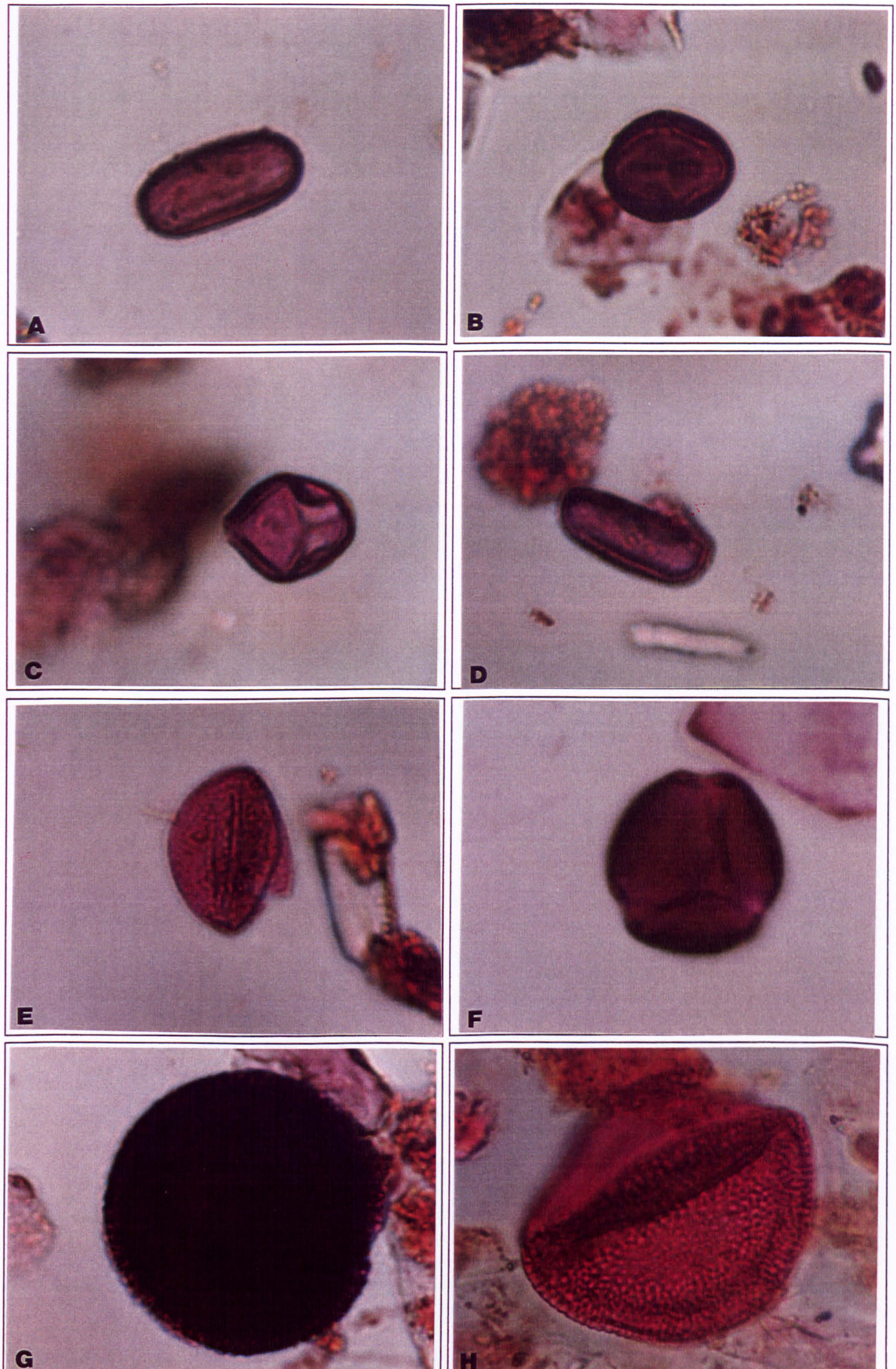


Plate 7

Plate 8

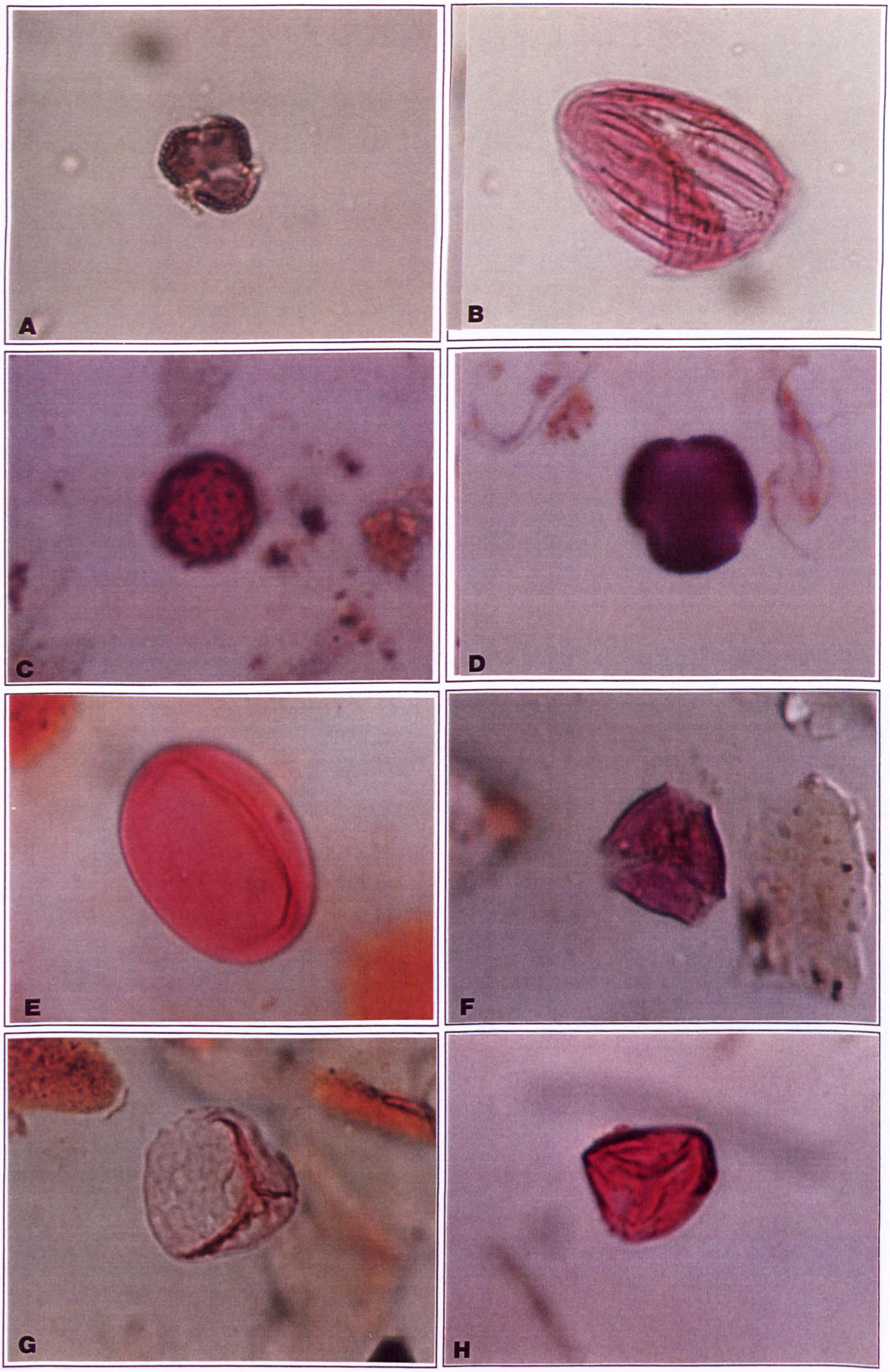


Plate 9

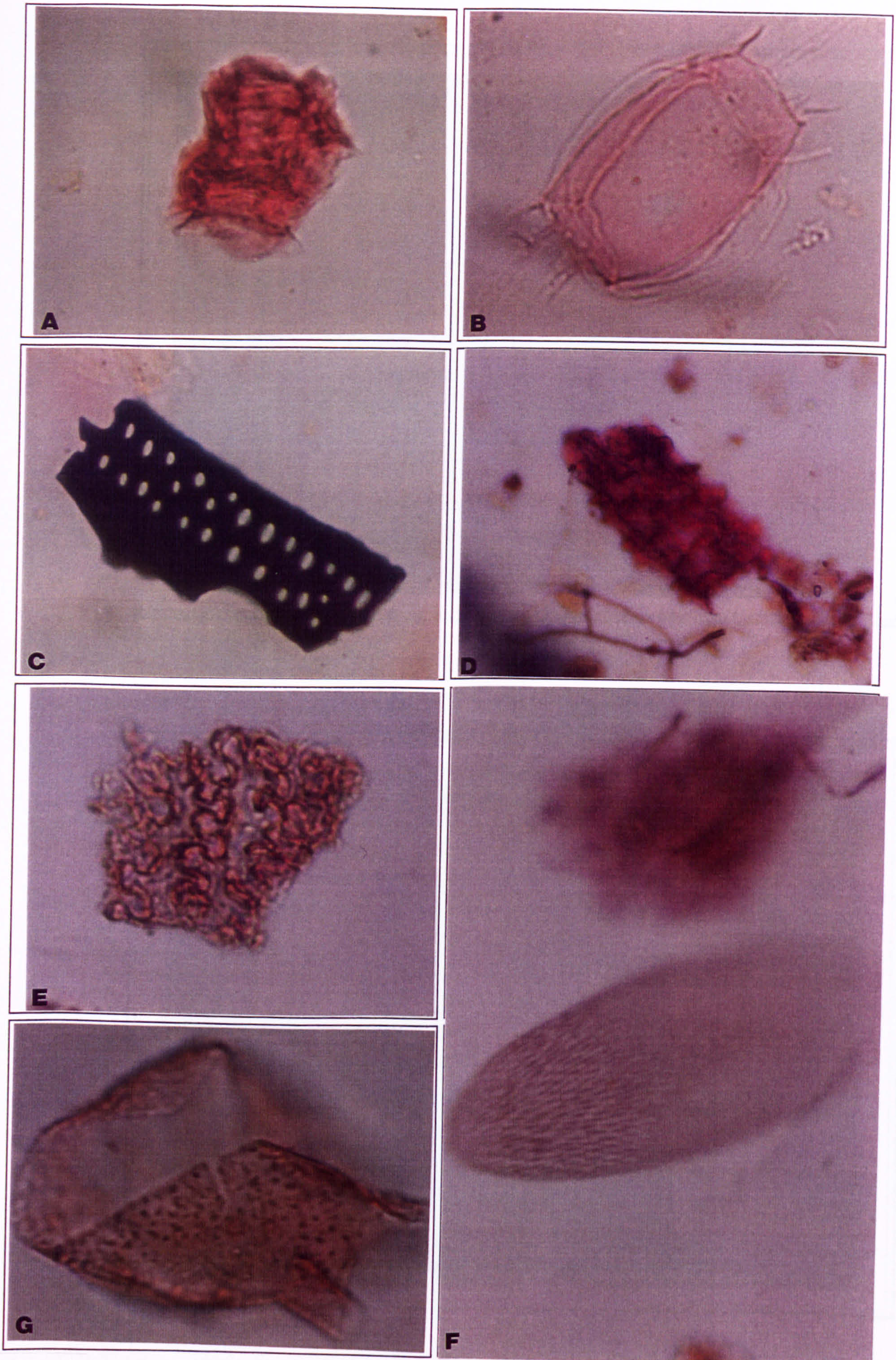
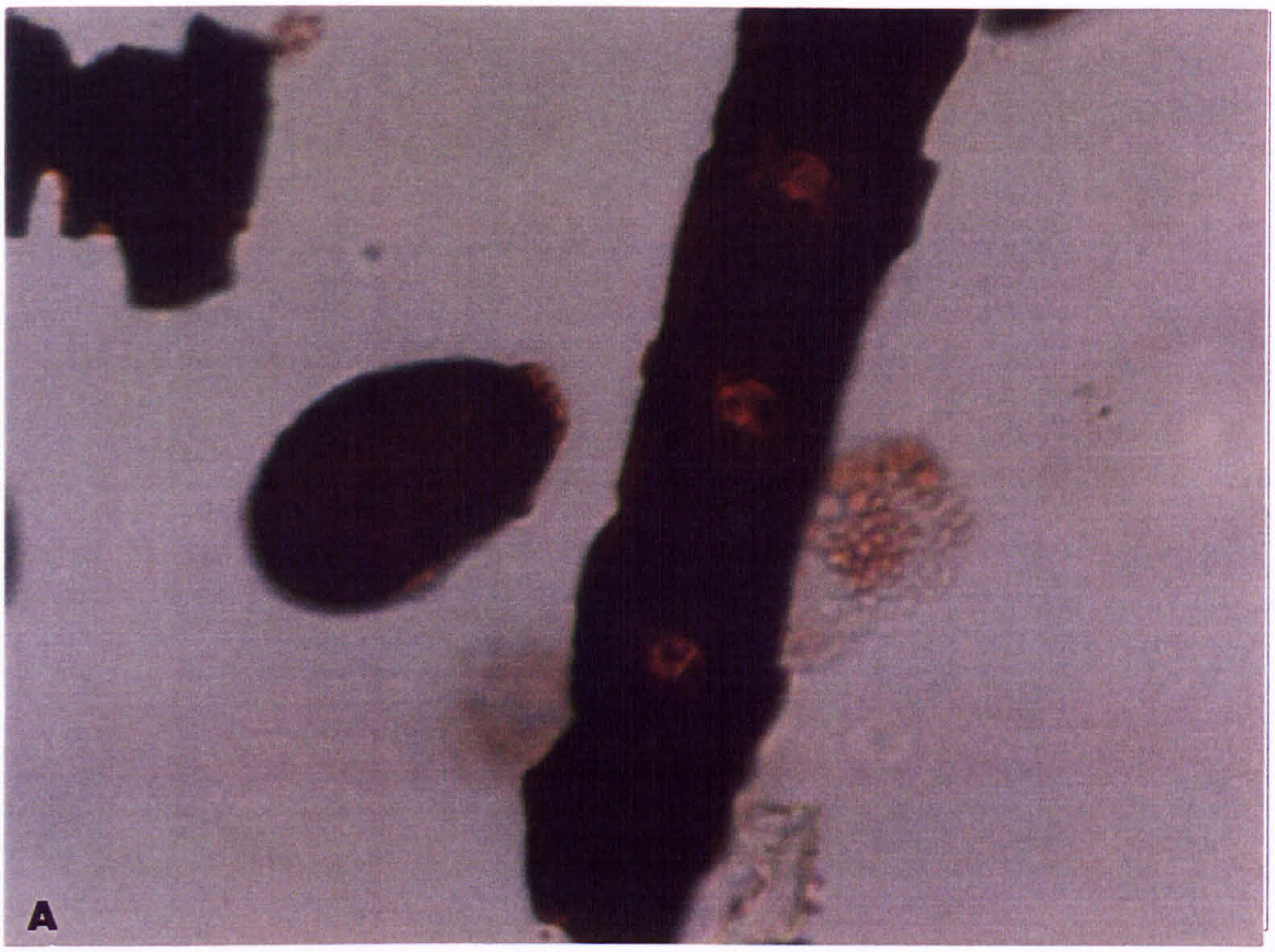


Plate 10



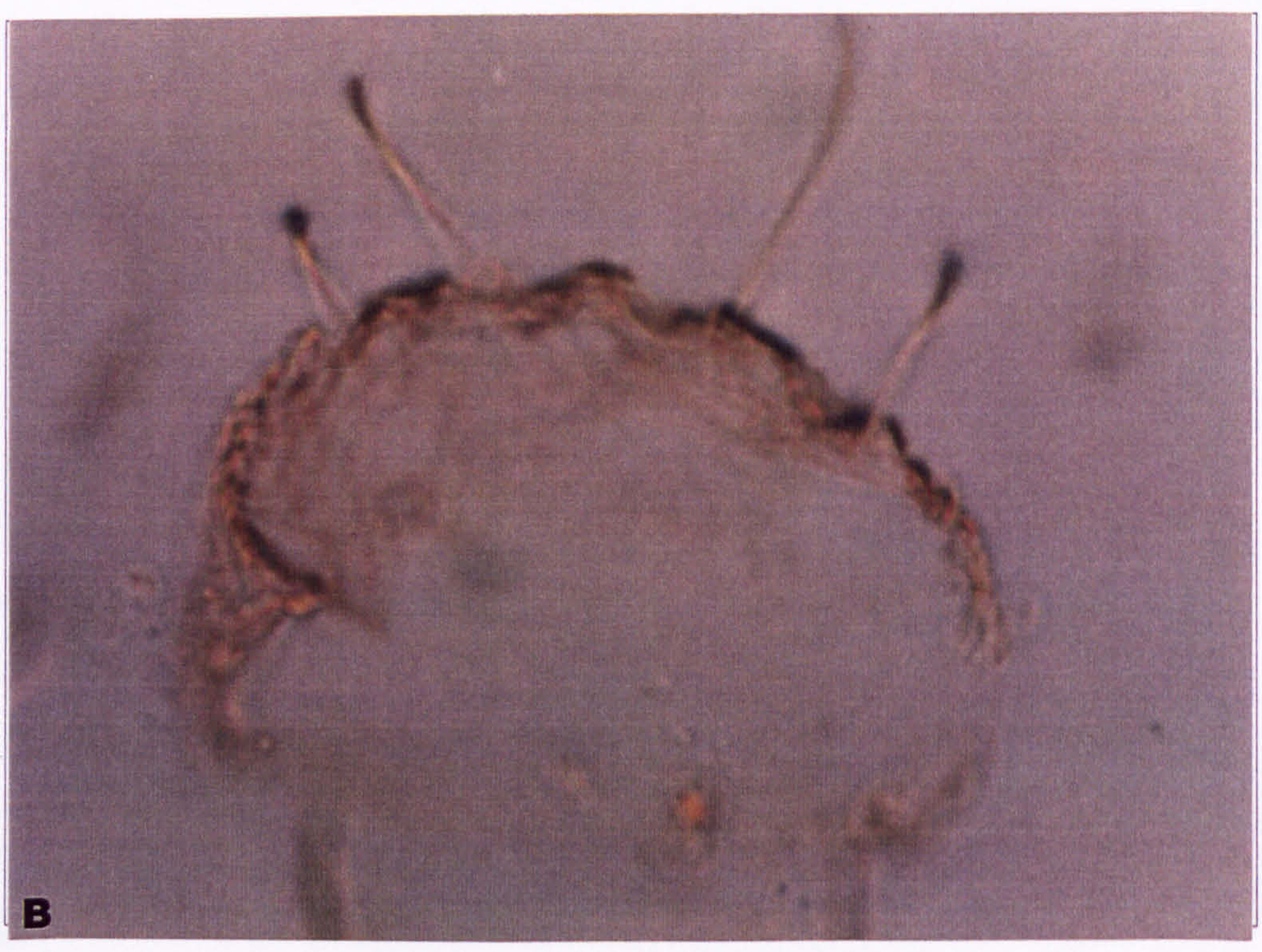
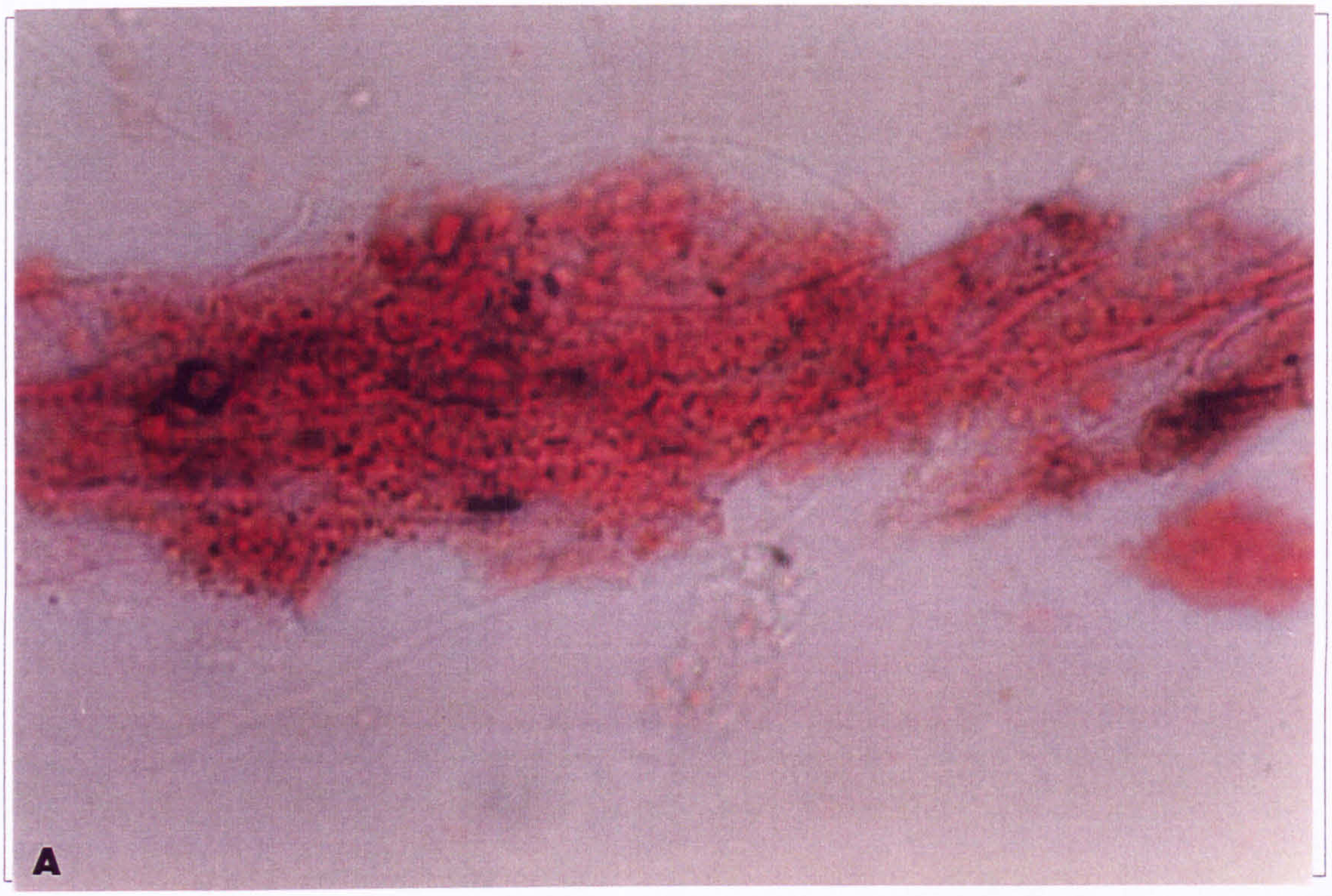


Plate 11



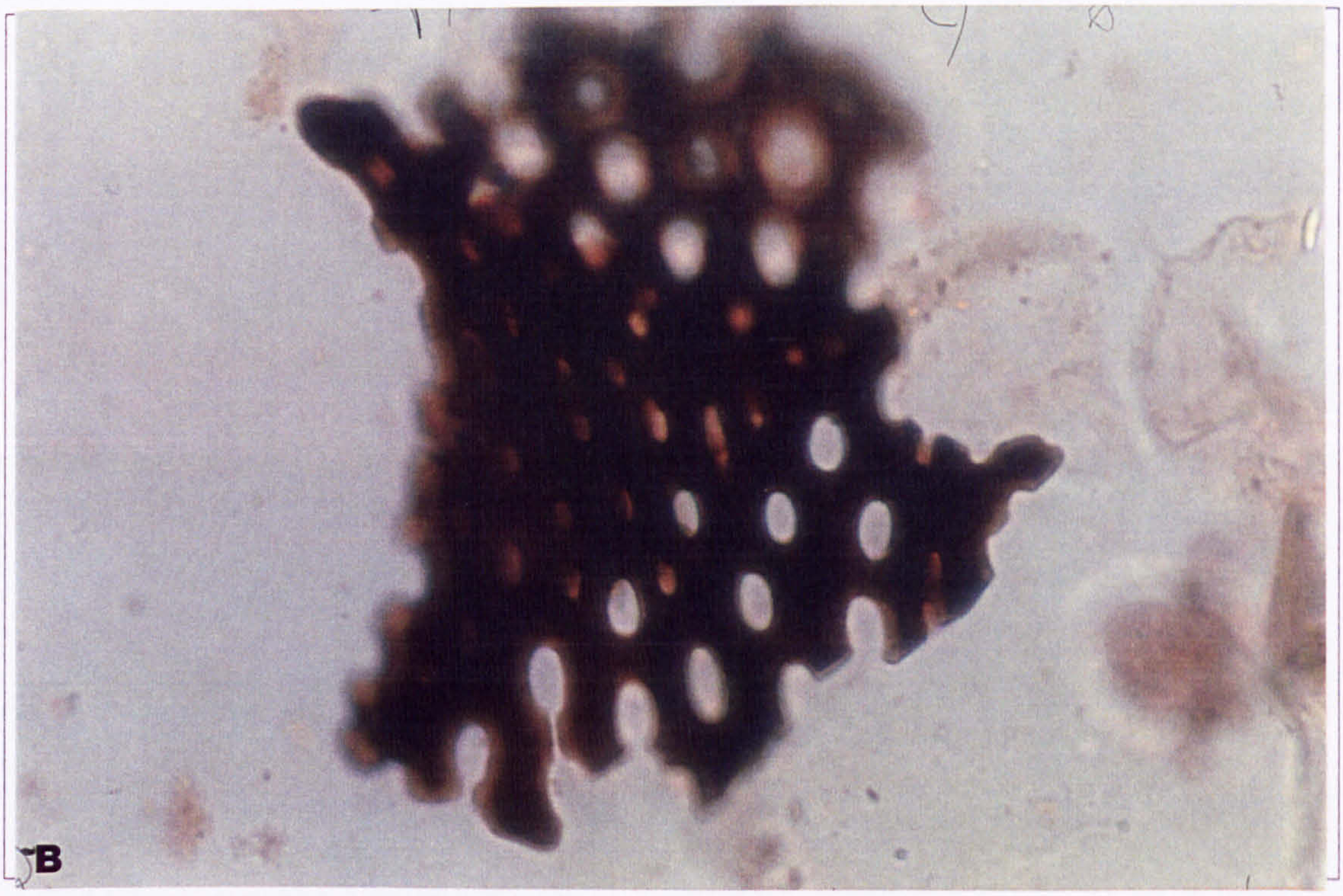


Plate 12

Plate 13

Plate 14

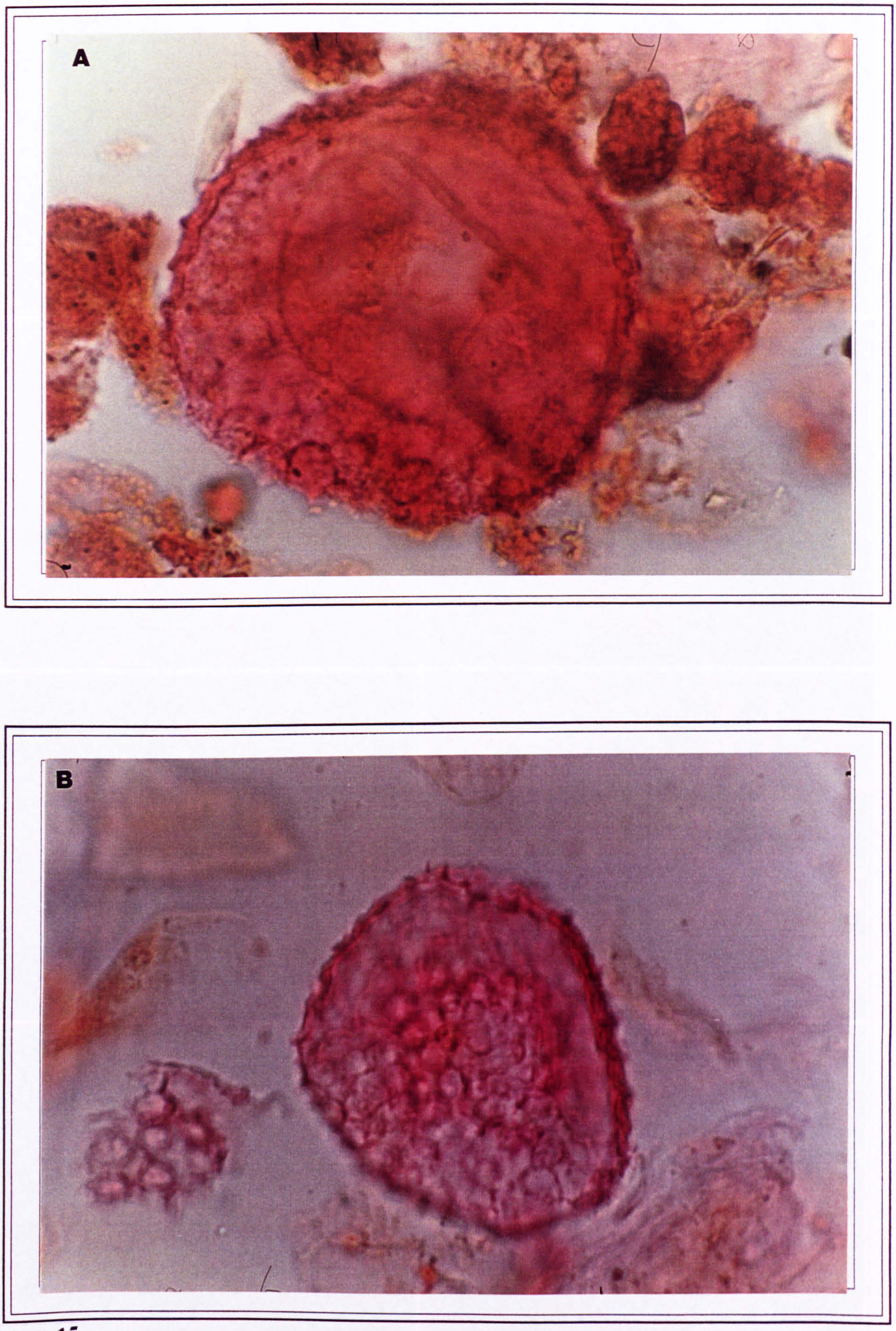


Plate 15

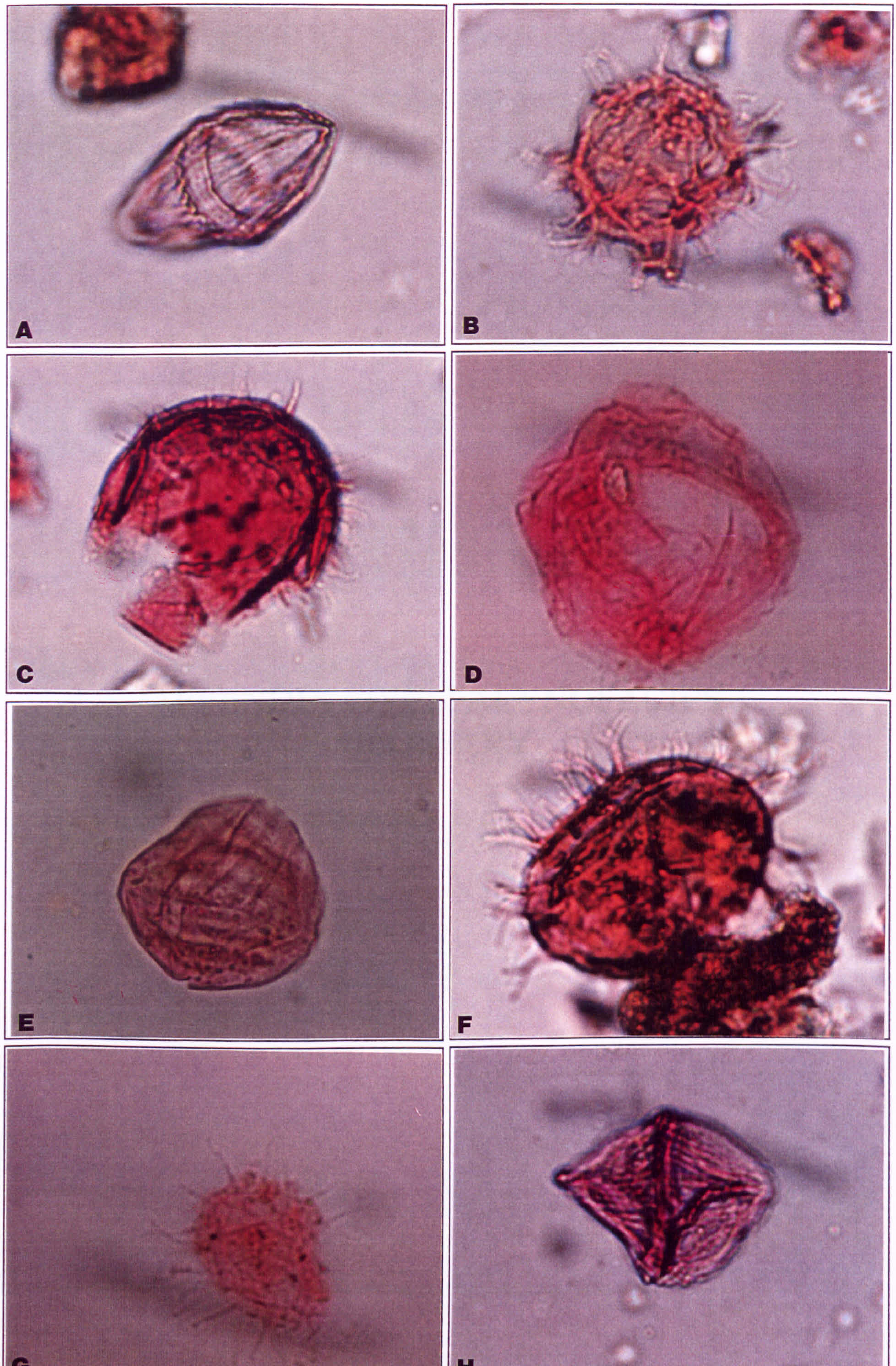


Plate 16

APPENDIX FIVE: PALYNOFACIES GLOSSARY

Table A5.1 Palynofacies: definitions of the particulate organic matter types (following Hunt and Coles, 1988; Tyson, 1995)

Palynofacies element	Definitions of the particulate organic matter type
Pollen	particles showing the morphological characteristics of pollen, even when too degraded to allocate to particular taxa
Plant cell walls and cuticle	particles showing the characteristics of fragments of leaf cuticle or plant cell walls, including structures such as stomata and sieve-plates. The particles must appear relatively 'fresh' to be allocated to this category.
Degraded plant tissue	particles showing some trace of the structures of plant cuticle or cell-walls, but badly degraded, 'fuzzy' in outline, or heavily perforated
Poaceae charred	particles showing some of the characteristics of Poaceae-elongate rectangular cells, characteristic perforation patterns-but thermally mature as the result of burning.
Thermally mature	particles showing the characteristic dark brown colour produced by charring of wood and vegetable matter, but not attributable to the Poaceae.
Inertinite	particles of black, inert carbon derived from the bed rock
Amorphous	particles showing no definite structure, usually 'woolly' in appearance, derived from other types of organic matter by decay processes.
Fungal hyphae	particles showing the elongate tubular shape and white, yellow or brown colouration of fungal hyphae.
Fungal spores	spherical, ovoidal, tubular, spinose or irregular spores, usually brown in colour except for some fungal zoospores, which are spinose and white to yellow in colour
Vesicular arbuscular miccorhyza	balloon-shaped white to pale yellow smooth or undulate sacs, produced by miccorhyzal symbionts on plant roots.
Insect debris	fragments showing the typical morphology of arthropod cuticle-spinose sheets, joined appendage fragments, moth scale, multi-faceted eyes, of white to yellow colour.
Algal	particles showing the typical morphology of algal spores or cysts.

APPENDIX SIX: RADIOCARBON DATES

6.1 The research area (Wadi Faynan).

Table A6.1 Radiocarbon dates from Wadi Faynan; this study*

Reference	Site/ Location	^{14}C-ages BP	^{14}C-ages cal.	Intercepts
Beta-119602	5520: Wadi Dana	100 ± 50	AD 1670-1780 AD 1795-1945	AD 1890 AD 1905
Beta-119600	5509: Wadi Ghuwayr	110 ± 50	AD 1670-1950	AD 1825 and AD 1835 and AD 1880 and AD 1915
Beta-115214	5025: Wadi Faynan	390 ± 50	AD 1430-1645	AD 1475
Beta-110840	5017: Khirbet Barrage	2630 ± 50	BC 845-775	BC 805
Beta-111121	5015: Wadi Dana	7240 ± 90	BC 6205-5940	BC 6030

*Radiocarbon dates are stated at 2 sigma, 95% probability
Cal.: Calibrated results.
BP: Before present (before 1950), which is Conventional radiocarbon age.
Intercept: Intercept of radiocarbon age with calibration curve.

5.2 Tell Wadi Faynan

Fig. A6.2 Radiocarbon dates from Tell Wadi Faynan, (after Al-Najjar *et al.* 1990).

Reference	Province	^{14}C-ages BP	^{14}C-ages cal. BC
HD 12336	Loess/ 5022	5375 ± 30	4330-4165
HD 12337	Top of channel /5021	5740 ± 35	4675-4575
HD 12338	" " "	6110 ± 75	5210-4910
HD 10567	Within channel/ deposits of 5021	6410 ± 115	5520-5270
HD 12335	" " "	6360 ± 45	5345-5240