

**DESERT ENVIRONMENT AND AGRICULTURE
IN THE CENTRAL NEGEV AND KADESH-BARNEA
DURING HISTORICAL TIMES**

CENTRALE LANDBOUWCATALOGUS



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PROMOTOREN: dr. ir. L. J. Pons

hoogleraar in de regionale bodemkunde

dr. A.M. van der Woude

hoogleraar in de agrarische geschiedenis

N 108201, 1083

Hendrik J. Bruins

**DESERT ENVIRONMENT AND AGRICULTURE
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DURING HISTORICAL TIMES**

Proefschrift

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MIDBAR FOUNDATION
P.O. Box 78
3860 AB Nijkerk
The Netherlands

or

H.J. Bruins
Jacob Blaustein Institute for Desert Research
Ben-Gurion University of the Negev
Sede Boqer Campus, 84990
Israel

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Cover: The valley oasis of Ein el Qudeirat (Kadesh-Barnea) in the north-eastern Sinai desert; note the northern wall on Gebel el Qudeirat and the central Negev mountains at the horizon.

**BIBLIOTHEEK
DER
LANDBOUWHOGESCHOOL
WAGENINGEN**

1. About one third of the world's terrestrial surface is occupied by dry lands, usually divided into hyper-arid, arid and semi-arid zones. Runoff farming is the only form of agriculture based upon local rainfall which is possible in the arid zone *senso stricto*, besides extensive livestock rearing.
2. Runoff farming or rainwater-harvesting agriculture is farming in dry regions by means of runoff rainwater from whatever type of catchment or ephemeral stream.
H.J. Bruins, M. Evenari, U. Nessler (1986) Rainwater-harvesting agriculture for food production in arid zones: the challenge of the African famine. Applied Geography 6:13-32.
3. The following runoff farming systems are distinguished, arranged in order of increasing hydro-geomorphic scale:
 - 1) Micro-catchment system
 - 2) Terraced wadi system
 - 3) Hillside conduit system
 - 4) Liman system
 - 5) Diversion systemA thorough understanding of the landscape is required, in terms of geology, geomorphology, soils, climate and hydrology, to evaluate the suitability of an area for runoff farming and to design the proper system in each particular situation, taking socio-economic factors into account.
H.J. Bruins, M. Evenari, U. Nessler (1986) Rainwater-harvesting agriculture for food production in arid zones: the challenge of the African famine. Applied Geography 6:13-32.
4. Pastoral nomadism is doomed to stagnation, because increased production in nomadic society as a whole is, to any significant extent, impossible.
Khazanov, A.M. (1985:71,76) Nomads and the outside world. Cambridge University Press.
5. Combinations of semi-extensive livestock rearing and runoff farming ought to be considered in the arid zone of developing countries to increase local food production and to enhance system viability.
6. The promotion of agrarian self-sufficiency in developing countries suffering from malnutrition and famine should be the main policy guideline in agricultural development cooperation.
7. Internal food reserves must form an integral part of self-sufficient agricultural systems in arid regions, as a buffer for the inevitable years of drought.

8. Instrumental records of weather observations indicate that from about 1950 extreme variations in climatic patterns began to occur in many parts of the world. Agricultural planners ought to take this into account. Buffer stockpiles of food should be formed in vulnerable agro-climatic regions. Diversification of agro-ecosystems should be stimulated to lessen the impact of climatic shocks, as the one-crop economy was at the root of many of the greatest famines in the past.
Partly based on Lamb, H.H. (1982) Climate, history and the modern world. London: Methuen.
9. There appears to be a relationship between the major historic period of sediment accumulation in the Kadesh-Barnea valley, from A.D. 1200-1700, and climatic conditions associated with the so-called Little Ice Age.
10. Experimental archaeology can make an important contribution to the understanding of the past.
11. Geologists and archaeologists should beware of the "reinforcement syndrome" by which new data are forced into an existing stratigraphic framework without evaluating the validity of the framework in the light of the new data.
Modified after Watkins, N.D. (1972) Reviews of the development of the geomagnetic polarity time scale and discussion of prospect for its finer definition. Geological Society of America Bulletin 83:551-574.
12. "The steady onward flow of time, which is the essence of the cause-effect relation, is something which we superimpose on to the ascertained laws of nature out of our own experience; whether or not it is inherent in the nature of time, we simply do not know".
Jeans, Sir James (1930:32) The Mysterious Universe. New York: Macmillan.
13. To understand a phenomenon we have not only to know what it is, but also how it came into being.
Boas, F. (1940:305) Race, Language and Culture. New York: Macmillan.
14. Without the unique food provisioning of manna, the ancient Israelites would have perished during their sojournment in the hyper-arid to arid Sinai desert, after the Exodus from Egypt.

H.J. Bruins.

Desert Environment and Agriculture in the central Negev and Kadesh-Barnea during historical times.

Auditorium, Agricultural University of Wageningen; 23 May 1986.

ABSTRACT

Bruins, H.J. (1986) Desert Environment and Agriculture in the central Negev and Kadesh-Barnea during Historical Times.

Doctoral dissertation, Agricultural University of Wageningen, The Netherlands. XI + 219 p., 27 tables, 29 figures, 48 photos, 228 refs, 2 app. Dutch summary.

Land use based on local rainfall in the arid zone *sensu stricto* is often limited to pastoralism, sometimes combined with very marginal rainfed farming, unsuccessful in most years. A more sophisticated form of rainfed agriculture - runoff farming - has been practised in the central Negev and adjacent north-eastern Sinai by a sedentary population in certain historical periods, particularly during Byzantine times from the 5th to 7th century A.D. The environment of the Runoff Farming District in the Negev is described, as well as the mechanics of rainwater-harvesting agriculture or runoff farming. Five systems of runoff farming are distinguished on hydro-geomorphic criteria. Excavations have been carried out in ancient runoff farming wadi terraces at Horvat Haluqim, apparently dating back some three millennia, and in Nahal Mitnan, attributed to the Late Byzantine - Early Arab period. The practising of runoff farming at Horvat Haluqim in antiquity has been substantiated by specific soil development in an ancient wadi-terrace layer, indicative of periodically flooded conditions. Calculations have been made about food production, based upon wheat yields, in relation to estimated population levels in the past. Besides runoff farming, oasis-irrigation agriculture in the region could only be practised at a very few spots. The valley oasis of Kadesh-Barnea or Ein el Qudeirat, situated in northeastern Sinai, is one of the most outstanding places in this respect in the entire Sinai-Negev desert, endowed with a copious spring and cultivable soils. The systems of irrigation agriculture are described, whilst the remnants of ancient aqueducts have been dated by radiocarbon. The valley stratigraphy and soil development have been investigated in detail, in relation to the tell (mainly composed of ancient Israelite fortresses, although the Early Fortress might date back to the Late Bronze age, as suggested by C-14 dates), and in relation to ancient remnants of irrigation agriculture, dated by radiocarbon to the Bronze age and the 7th century A.D. Dramatic cut-and-fill processes have occurred in the Kadesh-Barnea valley during historical times. These remarkable changes have been substantiated, in addition to the stratigraphic evidence, through the detection of specific soil development, particularly the microscopic discovery of authigenic pyrite. A detailed chrono-stratigraphy has been established based upon radiocarbon dates, determined by the Isotope Physics Laboratory of Prof. Mook (University of Groningen). All the radiocarbon dates have been calibrated from conventional C-14 years into historical years. The carrying capacities of the Runoff Farming District and the Kadesh-Barnea - Quseima region have been calculated and the outcomes are compared with former population levels. The relationships between the landscape, climatic and agricultural history are evaluated. A clear time-correlation exists between valley aggradation and a relatively wet climate, as well as between valley incision and a relatively dry climate. There is a bit of irony in the conclusion that runoff farming was not practised by a sedentary population in the central Negev desert in those periods during the last three millennia when the climate was relatively wet. Internal and/or external food reserves must have been an integral part of a sedentary runoff farming society, as a buffer for the inevitable years of drought.

Key words: historic land-use in an arid desert, desert environment, arid zone farming, ancient agriculture, runoff farming, environmental archaeology, paleo-climate/landscape/land-use relationships, soil development, geology.

Aan Willie,

Esther, Naomi, en Irit

לְמוֹלִיךְ שְׂמוּ בַּמִּדְבָּר

To him which led his people through the desert

(Psalm 136:16)

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Without the many radiocarbon dates determined at the Isotope Physics Laboratory of professor Dr. W.G. Mook, University of Groningen, the absolute basis of stratigraphy - time - would have been lacking in the investigation of the fascinating environmental history of the Kadesh-Barnea valley. The C-14 dates proved to be very important in the framework of this dissertation. Hence I am indebted to professor Mook for his willingness to cooperate in this research, and for his comments on parts of the text.

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1 Introduction

FOOD PRODUCTION AND DROUGHTS

About one third of the world's terrestrial surface is occupied by dry lands, situated in nearly 70 countries. People living in dry regions face special problems to produce enough food in a high-risk environment from an agricultural point of view. This is exemplified by the conditions of drought and famine that have struck parts of the African continent during the seventies and eighties, causing suffering for many people. There appears to be growing evidence that weather fluctuations have increased in frequency and amplitude during the last two decades, resulting in greater instability in local and world food supplies (Abel et al., 1981; Lamb, 1982).

The study of the impact of climatic variations and change upon landscape and agriculture in dry regions deserves attention in view of these problems. It is necessary to include the past in this field of research, apart from intrinsic archaeological and historical objectives. Those involved in agricultural planning and food production need to be aware of the possible frequency and amplitude of fluctuations in the weather and climate in a certain region. The experience of the present generation in terms of climatic change and its effect upon landscape and agriculture only covers a relatively short span of time. Climatic patterns in the past may well have been more radical and extreme than those within present human memory, and, by implication, may be so in the future as well. A reasonable assessment of this amplitude, the frequency of variation, and its likely impact on environment and agriculture can only be established when the factor time is greatly extended beyond the present to include the past.

Whereas interactions between climate and landscape are to a significant extent not in the realm of human control and influence, the issue of food production and food provision is more than just the passive result of physical environmental factors upon human activity. It is, therefore, important also to study the question of human adaptation or lack of adaptation to climatic variations or change. The value of this field of endeavour is of major relevance to the problems of modern world planning, as described in an excellent article by Ingram, Farmer and Wigley (1981): "It is plain that in order to advance the study of human adaptations to climatic variations to the point where the findings may be of real use to modern planners, it will be necessary to try to specify more clearly what degrees and types of climatic stress impose the greatest problems of successful response, and to seek to identify more rigorously the key features of more or less adaptive societies".

An interesting investigation in this direction was made by Bowden et al. (1981) in arid and semi-arid regions. They examined material on agriculture in the US Great Plains in the period A.D. 1880-1979, on droughts in the Sahel region of Africa during 1910-1915 and 1968-1974, and on the societies of the Tigris-Euphrates Valley from 6000 BP to the present. The complementary hypotheses are discussed that, over time, societies adapt to cope with 'minor' climatic stresses, but that, thereby, they do little to decrease, and may actually increase, their vulnerability to 'major' stresses of rare frequency.

Both in the Sahel and the American Great Plains the key factor in reducing vulnerability appeared to be the integration of each area into a wider economic system. However, Bowden et al. warn that there may prove to be a limit to the effectiveness of such integrative mechanisms in the future. More climatic stress in the Sahel, coupled with other factors, could precipitate system collapse in this region with an already fragile resource base.

Mooley and Pant (1981) collected data on the 32 principal droughts which affected India during the period 1771 - 1977. These droughts resulted in famines, causing hardship to a large number of people. Statistic tests showed the droughts to occur randomly in time, following a Poisson probability model of occurrence in a 5- or 10-year period. These droughts caused food shortages, whereby prices of available food rose beyond the purchasing power of the rural population, pushing the farmer deeper in debt and leading to both exploitation and riots. The authors advocate the building up of food grain reserves in rural areas and special funds to afford more protection against drought events.

The question of human adaptation to climatic variation is a complex one,

whose systematic study has only just begun. Although it is unrealistic to draw simple parallels with former situations and societies, it is reasonable to suppose that some useful lessons might be learned from past events. Accordingly, politicians and planners have begun to show a lively interest in identifying and measuring the effect of climatic fluctuations and changes on past societies (Ingram et al., 1981).

CLASSIFICATION OF DRY LANDS AND LAND-USE

Dry lands are generally classified into three major groups or zones: hyper-arid, arid, and semi-arid regions. Although ranked together, the large differences in environment and land-use between each of these dry zones cannot be emphasized strongly enough. Unesco (1979) has developed a useful system to delimitate hyper-arid, arid, and semi-arid regions on the basis of measurable data expressed as aridity indices. The degree of bioclimatic dryness or aridity depends on the relative amounts of water gained from rainfall and lost by evaporation and transpiration. Bioclimatic aridity can thus be expressed in terms of the ratio P/ETP , in which P is the mean value of annual precipitation and ETP the mean annual evapotranspiration. The marked differences between the dry zones are shown in Table 1.

This threefold division of the dry lands largely coincides with historic land-use development in these regions. It should be emphasized that only the semi-arid zone is suited for normal rainfed agriculture and sedentary livestock rearing. The hyper-arid zone corresponds to the true or inner desert, a deserted no-man's land without any agricultural or pastoral land-use, except in oases or along exotic rivers. The term arid zone needs some clarification to avoid semantic entanglement, because this term is also used in the literature to denote the three defined dry regions together. In this dissertation the term is generally used in its narrow, defined sense. The arid zone, *sensu stricto*, is traditionally a nomad's land, practicable for nomadic livestock rearing, but too dry for common rainfed farming.

There exists, however, a specialized form of farming based upon the use of runoff water generated by local rainfall, which is suitable for the arid zone: rainwater-harvesting agriculture or runoff farming. These synonymous terms are used interchangeably and defined as farming in dry regions by means of runoff rainwater from whatever type of catchment or ephemeral stream (Bruins et al., 1986). Runoff collection may also be used in the semi-arid zone to improve the

TABLE 1. Classification, characteristics and land-use of the dry zones
(largely based upon information from Unesco, 1979)

HYPER-ARID zone:	<ul style="list-style-type: none">- P/ETP ratio is smaller than 0.03- annual rainfall is very low- interannual rainfall variability up to 100 %- very sparse vegetation- no rainfed agriculture or grazing
ARID zone:	<ul style="list-style-type: none">- P/ETP ratio ranges from 0.03 - 0.20- annual rainfall 80 - 150 mm in winter rainfall areas 200 - 350 mm in summer rainfall areas- interannual rainfall variability 50-100 %- scattered vegetation- nomadic livestock rearing is possible- agriculture based upon local rainfall only feasible through rainwater-harvesting techniques: runoff farming
SEMI-ARID zone:	<ul style="list-style-type: none">- P/ETP ratio ranges from 0.20 - 0.50- annual rainfall 200 - 500 mm in winter rainfall areas 300 - 800 mm in summer rainfall areas- interannual rainfall variability 25-50 %- discontinuous vegetation with perennial grasses- rainfed agriculture and sedentary livestock rearing are common

viability of rainfed farming (Huibers, 1985). There is a fundamental difference, however, between the use of runoff in arid and semi-arid zones. In the former zone the amount of direct rainfall is not sufficient in most years to sustain a crop. By collecting and storing the runoff rainwater of a certain landscape catchment into the soil of a smaller cultivable area, the actual amount of concentrated water in this latter area (rain + runoff) may be adequate to practise agriculture. In the semi-arid zone direct rainfall is sufficient in most years to raise a crop. Runoff generated in the agricultural fields themselves, not necessarily from adjacent non-arable catchments, may be stored in shallow ponds as a source of additional irrigation water in times of

moisture stress (Huibers, 1985). Thus the use of runoff in semi-arid zones increases the viability of rainfed farming. In arid zones runoff water is absolutely essential to practise agriculture based upon local rainfall, the amount of runoff conducted unto the agricultural fields being much larger than the amount of direct rainfall itself.

As local food production within the arid zone ought to increase, especially in rural or remote areas, rainwater-harvesting agriculture seems to have a largely untapped potential in this respect (Le Houerou and Lundholm, 1976). Moreover, there is a limit to the use of extraterritorial river water or good-quality groundwater in the arid zone for irrigation purposes. Regions irrigated with water from exotic rivers like the Nile, Tigris, Euphrates, and Indus are the exception rather than the rule.

Rainfall is often the only available water source for many arid regions. However, rainfall amounts and its intra-annual and inter-annual variability (Berkofsky, 1984) must be studied carefully to assess the suitability of a certain arid region for rainwater-harvesting agriculture. In areas of similar mean annual precipitation, regions of greater rainfall variability are less viable from an agronomic point of view. Suitability of a region for runoff farming not only depends upon climate, but also very much upon landscape and soil properties. A sandy or flat landscape is usually a disadvantage in this respect.

THE CENTRAL NEGEV DESERT AND THE VALLEY OASIS OF KADESH-BARNEA

This dissertation deals with the interactions of climate, landscape and agriculture, during historical times, in the arid region of the central Negev hills and the valley oasis of Ein el Qudeirat or Kadesh-Barnea, situated in an adjacent part of north-eastern Sinai. The ancient meaning in Hebrew of the word "negev" is dryness, which is very appropriate indeed. The Negev and Sinai form part of the largest planetary desert belt on earth, extending from the Atlantic coast of Saharan west Africa unto India. Within the division of dry zones, as presented in Table 1, the hills of the central Negev and north-eastern Sinai belong to the arid zone *sensu stricto*.

The present mean P/ETP aridity index for this region is about 0.07. This is quite a low figure, which shows that the central Negev hills are situated at the dry edge of the arid zone, close to the hyper-arid zone of the inner desert. One might expect that marginal nomadic livestock rearing would be the

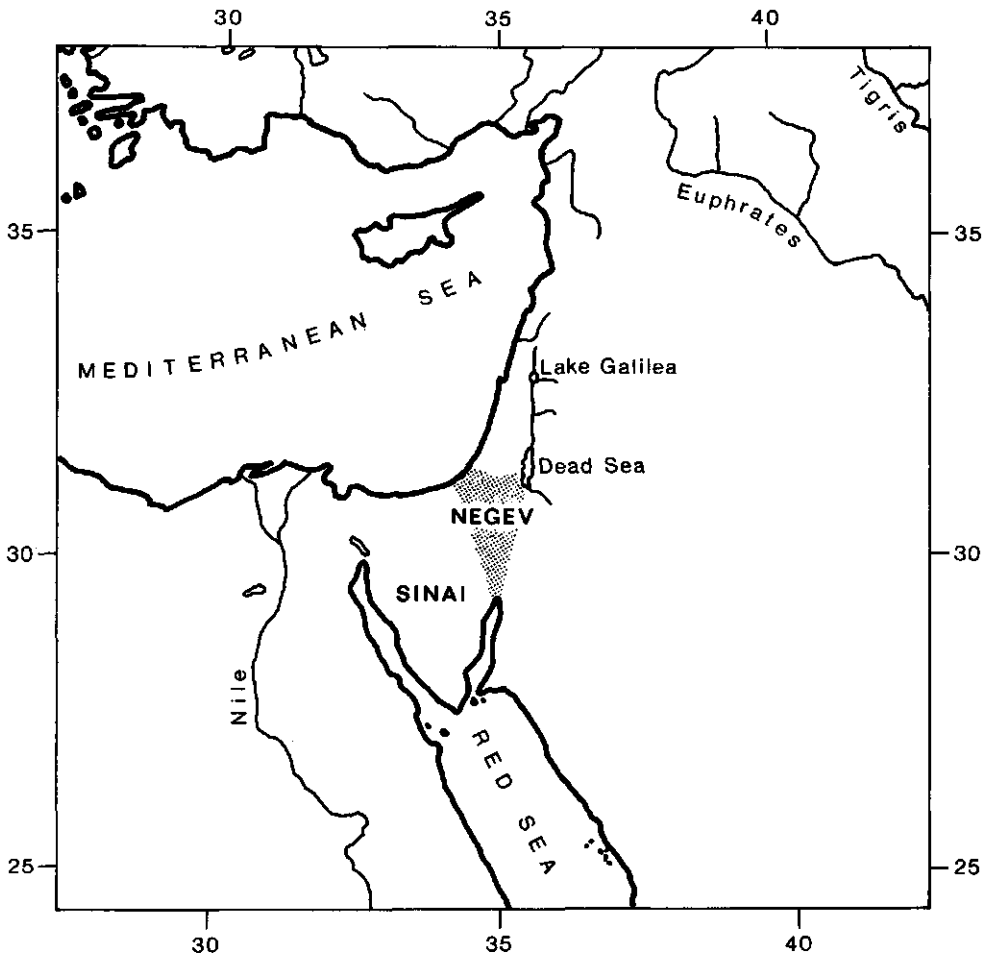


FIGURE 1. The location of the Negev and Sinai as a land-bridge between Africa and Asia.

sole type of land-use possible in such a dry region. The fact of the matter is, that runoff farming based upon local rainfall was carried out here extensively in time and space (Kedar, 1967; Evenari et al., 1971, 1982).

Orthodox irrigation agriculture from a permanent water source, on the other hand, could only be practised at a very few places in this entire region during former times. The Kadesh-Barnea valley in north-eastern Sinai constitutes the main centre in this respect, due to the rare existence of a spring with copious, good-quality water, and adjacent cultivable land.

In conclusion of this introduction a brief sketch of the following chapters

is hereby presented. The desert environment and geography of the runoff farming district are described in considerable detail in the second chapter of this dissertation. The mechanics of runoff farming, its main regional history, as well as hydrological and geomorphic aspects, are presented in chapter 3, which includes a description of the different runoff farming systems in relation to landscape properties (Bruins et al., 1986a).

Pastoralism or extensive livestock rearing has, in various forms, often played an important role in the arid zone. Its different systems have been discussed in chapter 4 in a somewhat wider regional and historical perspective, because remains of this type of land-use cannot always be traced in archaeological and historic terms with the same kind of detail as sedentary runoff farming or oasis agriculture.

Ancient man-land relationships concerning runoff farming were studied at the site of Horvat Haluqim (chapter 5), apparently dating back some three millennia (Cohen, 1976), and in Nahal^{*} Mitnan (chapter 7) of apparent Late Byzantine origin (Haiman, 1982). The sedimentary and archaeological stratigraphy of ancient runoff farming wadi terraces were investigated, as well as the related Late Holocene soil development. The potential food production of runoff farming in antiquity, calculated on the basis of wheat yields, is discussed in chapter 6 and related to the site of Horvat Haluqim and its estimated former population.

A detailed study of the Kadesh-Barnea area in chapters 8-11 revealed quite astonishing valley changes with unusual soil development during historical times. Archaeological remains and radiocarbon dates from charcoal provided valuable stratigraphic time markers. There seems a possibility, as indicated by some of these carbon-14 dates, that irrigation agriculture with water from the local spring was already practised in the Kadesh-Barnea valley during the Middle or Late Bronze age, whilst the Early Fortress might perhaps be older than hitherto assumed (Cohen, 1980, 1981, 1983). Potential food production levels in the Kadesh-Barnea valley are calculated and compared with estimated population levels in antiquity, whereby the post-Exodus sojournment of the ancient Israelites in the desert is also touched upon.

The relationships between the landscape, climatic and agricultural history of the central Negev desert and Kadesh-Barnea are discussed in the final chapter of this dissertation. The viability of runoff farming in such a dry region is evaluated. Possible food production levels of the runoff farming district in antiquity are calculated and compared with estimated former population numbers.

**Nahal = wadi = ephemeral stream*

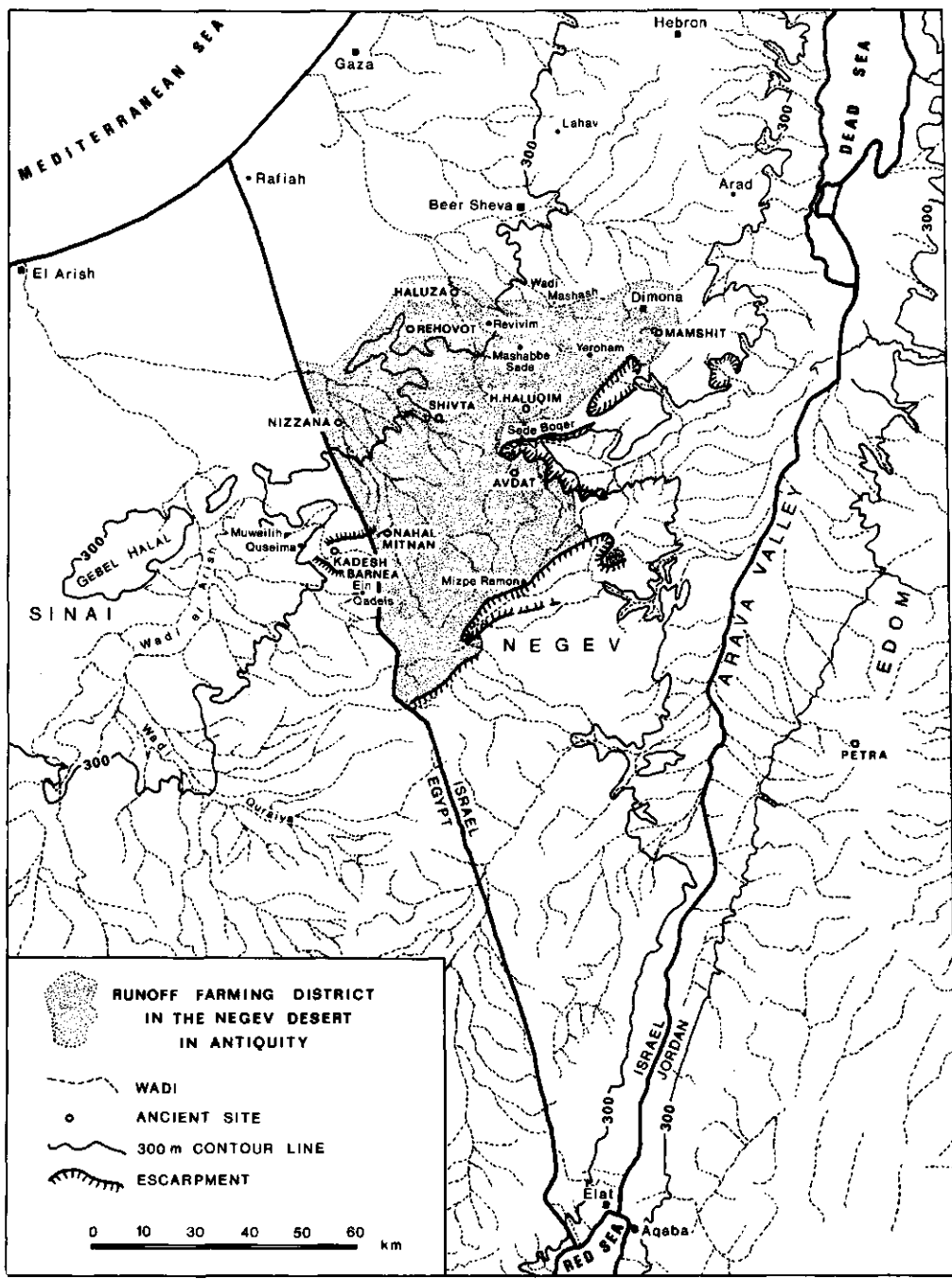


FIGURE 2. The Negev and the location of the runoff farming district.

2 Environment of the runoff farming district in the Negev desert

GENERAL SETTING

Although the Negev constitutes only a tiny part of the huge Saharo-Arabian desert belt, it can be regarded as one of the most famous deserts in the world. Its fame is, however not so much based upon unique geographical attributes, but due to its connection with the Book of books. The first times the Negev is mentioned in the Scriptures (Genesis 12 and 13, quoted below) suggest its environmental qualities as a region suited for pastoral livestock rearing in the Middle Bronze Age (around 1900 B.C.), for Abraham used to stay in the area with his flocks. However, when a famine struck the land, Abraham went to Egypt.

It seems likely that the famine was caused by a drought, typical for marginal dry areas. Egypt often proved to be a regional place of refuge in such a situation. Its agriculture and livestock production are dependent upon the Nile water, fed by rains in tropical Africa and, therefore, unaffected by droughts over the Levant. Another important geographic aspect of the Negev is its role, together with Sinai, as a natural land-bridge between Africa and Asia.

"And Abram journeyed, going on still toward the Negev. And there was a famine in the land; and Abram went down into Egypt to sojourn there; for the famine was grievous in the land... and he had sheep, and oxen, and he asses,.. and she asses, and camels" (Genesis 12:9,10,16). "And Abram went up out of Egypt, he, and his wife, and all that he had, and Lot with him, into the Negev. And Abram was very rich in cattle..." (Genesis 13:1,2).

The precise limits of the Negev are disputable in geographical terms.

Especially in a southwesterly direction, there is no clear natural boundary separating the Negev from the Sinai, except perhaps Wadi el Arish and its tributary Wadi Quraiya. The political boundary between the Negev and Sinai was drawn in 1906 as the result of an agreement between Britain and Turkey. Thus the Negev and Sinai were demarcated along a more or less straight line running from the Mediterranean coast near Rafah unto the Red Sea just south of Elat. Today this line constitutes the border between Israel and Egypt.

The eastern boundary of the Negev is made up by the Arava rift valley, running from the southern part of the Dead Sea to the northern tip of the Red Sea near Elat. The Arava valley separates the Negev from the mountainous regions of Moab and Edom, both of which are part today of the Hashemite Kingdom of Jordan. The border between the latter kingdom and the Negev was demarcated by the British government in 1922, and follows the lowest course through the Arava rift valley.

The northern boundary of the Negev is not well defined. In the coastal plain and southern Judean foothills, it is situated in a semi-arid transition zone of dry farming. Here the boundary coincides more or less with the present 350 mm rainfall isohyet, roughly marking the lower limit of wheat growing without the need of auxiliary irrigation in most years. In this area the boundary may be depicted as running from the Mediterranean Sea near Gaza to Lahav (ancient Ziqlag) at the south-western corner of the Judean Hills (Orni and Efrat, 1971). While the boundary continues further eastward along the southern extremity of the Judean anticline, the rainfall isohyets sweep to the north as the Negev merges with the Judean Desert. The area between Arad and Sedom at the southern tip of the Dead Sea forms the diffuse boundary between the two deserts.

The total area of the Negev, within its present political and administrative boundaries, encompasses about 12,000 square kilometers. Rainwater-harvesting agriculture or runoff farming was practised in antiquity by a sedentary population in the central Negev hills (roughly 3000 years ago and in the period from about A.D. 100-700) in a region of some 2,000 square kilometers, of which only 2 % was actually farming land (Kedar, 1967), made suitable for runoff agriculture in the course of time by man-made engineering works. This region, henceforth referred to as the runoff farming district, is the prime geographical object of this dissertation, together with the Kadesh Barnea oasis in Sinai, just across the border with Egypt. As has already been noted, there is no clear geographical boundary between the Negev and Sinai. Thus, Kadesh-Barnea can be regarded as lying in an area which forms the natural

extension of the central Negev hills into Egypt. In this perspective, it is no surprise that the area of ancient runoff farming found in the Negev continues across the Egyptian border into Sinai. The areal extent and boundaries of the runoff farming regions in the Sinai have not been established yet.

GEOGRAPHY OF THE RUNOFF FARMING DISTRICT

The principal work to determine the extent and distribution of ancient runoff farming in the Negev was carried out by Kedar (1967). The runoff farming district in the central Negev hills encompasses an area of about 2,000 square kilometers (200,000 hectares or 2,000,000 dunams), which is nearly 17 % of the entire Negev. The combined total area of all the agricultural fields within the runoff farming district has been some 4004 hectares. Thus only 2 % of the entire district was made up by cultivable fields. These ancient fields are situated in the valleys, where the runoff waters tend to concentrate naturally, after having been generated by a rain storm. Only in the valleys are the soils deep enough to function as a water storage medium and buffer for agricultural purposes.

Runoff agriculture requires two principal landscape units: (1) a runoff producing territory, and (2) a related, lower lying, runoff receiving area, consisting of cultivable land. The ratio between runoff receiving area and runoff producing area depends upon the climate, but is also dictated by the composition of the landscape. The larger the amount of rainfall, the smaller the required size of the runoff contributing area. The relation between runoff producing hills and runoff receiving valleys determines the potential area suited for runoff farming. A good understanding of the landscape is crucial in the planning of runoff farms. The runoff receiving soils, usually situated in the valleys, must be suited for this type of agriculture. Sufficient depth and a good water-holding capacity are important attributes in this respect.

The average ratio in the runoff farming district between runoff receiving fields and related runoff producing areas is 1:18. The range of variation of this ratio within the district runs from 1:9 to 1:33 (Kedar, 1967). This is a nearly four-fold difference, which cannot be explained in terms of climate as average climatic differences within the district are small. It demonstrates the effect of local landscape properties upon the ratio. The main varying factors are natural drainage density, the natural size of the valleys and the surface quality of the runoff contributing area in terms of runoff production.

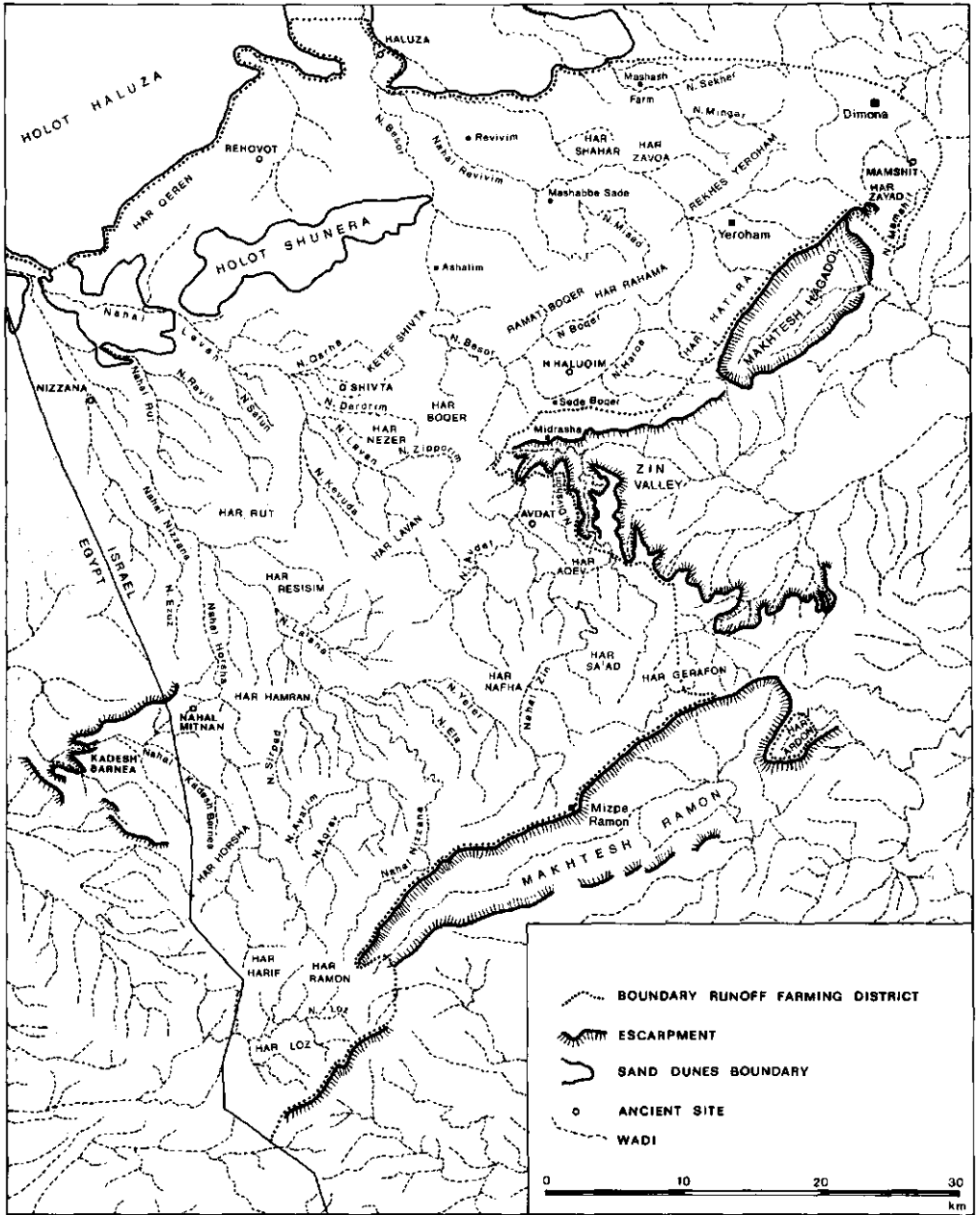


FIGURE 3. Geography of the runoff farming district

The runoff farming district is a hilly region, ranging in altitude from about 200 meters in its north-western part to 1000 m in the south.

- The NORTHERN boundary of the district runs from Wadi Azariq at the Egyptian border, near the confluence of Nahal Nizzana and Nahal Lavan, in a north-eastern direction along the first anticlinal range of Har Qeren. The boundary follows the southern edge of the Halutza sand dunes towards the remains of Halutza (Elusa, Hallasa), one of six ancient Nabatean-Byzantine towns in the runoff farming district. The other towns are Nizzana (Nessana, Auja Hafir), Rehovot (Rehovot Banegav, Ruheiba), Shivta (Sobata, Subeita), Avdat (Oboda, Abdeh), and Mamshit (Mampsis, Kurnub). The first name for each site is the one used on modern Israeli maps, whereas alternative spellings or names used in the literature or on older maps, according to Negev (1982), are put behind brackets. These towns were abandoned in the wake of the Muslim-Arab conquest in the 7th century A.D.

From Halutza, the northern district boundary continues eastward, along the southern edge of another field of sand dunes, to Nahal Sekher (Wadi Mashash). Here the actual boundary differs somewhat from the one drawn by Kedar (1967), as remains of runoff farming are also present along the valley of Nahal Sekher and Nahal Mingar. The area around the modern town of Dimona and the ancient town of Mamshit constitutes the north-eastern corner of the runoff farming district.

- The EASTERN district boundary runs from here in a south-western direction along Nahal Mamshit to the Makhtesh Hagadol, an impressive erosion cirque in the Hatira anticline. From the north-western cliff of the Makhtesh Hagadol, the boundary sweeps westward through Sede Boqer, circumventing the large Zin Valley with its canyons, while moving back eastward to the Avdat area. The boundary continues southward along the Nahal Aqev cliff to Har* Aqev, subsequently bending east to the edge of the Zin Valley and again due south along Har Gerafon towards the grandiose northern cliff of the very large Makhtesh Ramon erosion cirque. Isolated remains of ancient runoff farming fields are found on Har Ardon, which forms the northeastern rim of the Makhtesh Ramon.

- The SOUTHERN boundary of the runoff farming district coincides with the impressive Makhtesh Ramon cliff, which constitutes a veritable environmental border-line. On Har Ramon, the district reaches with 1025 m its highest altitude. From here the boundary moves slightly east around the westernmost extension of the Makhtesh Ramon, before continuing south-westward along the cliff of Mézoqe Loz to the Egyptian border.

Kedar divided the runoff farming district into 10 zones (Figure 4), and

*Har = hill or mountain

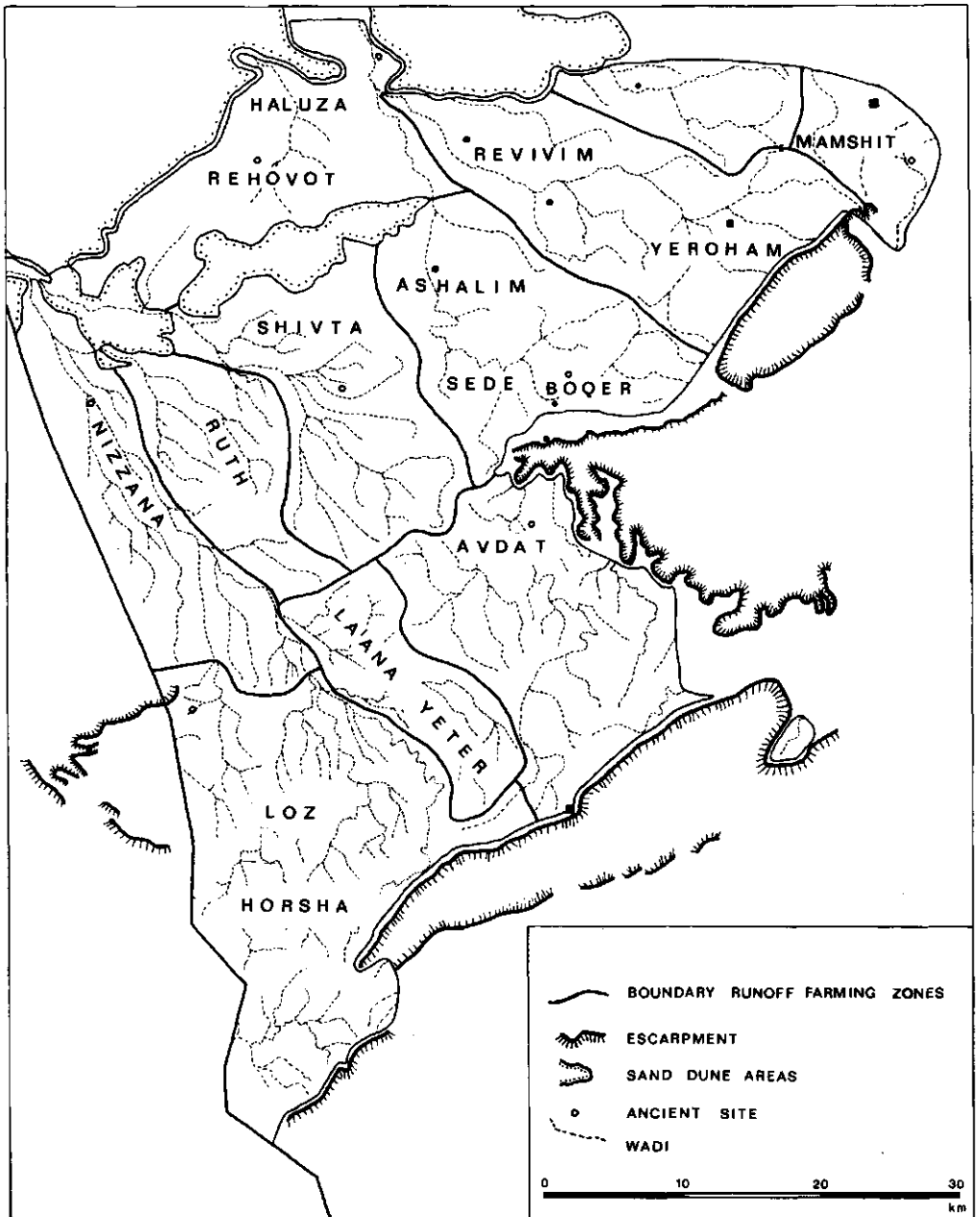


FIGURE 4. Zonal division of the runoff farming district (based on Kedar, 1967)

determined for each zone a number of relevant data, which are quoted here, albeit in a somewhat different order than in the original Hebrew version (Kedar, 1967, chapter 8). The ten zones are arranged from west to east, and from north to south. The first zone is the Halutza - Rehovot area, situated in the north-western corner of the runoff farming district. This zone is bound by sand dunes in the north, west and south, and by Nahal Besor in the east. The next six zones are lying between the former zone and a line, made up by the Eocene Avdat Plateau, the Zin Valley and the Makhtesh Hagadol erosion cirque. These zones are listed in a sequence going from west to east: Nizzana zone, Ruth zone, Shivta zone, Sede Boqer - Ashalim zone, Yeroham - Revivim zone, and Mamshit zone. The three remaining southern zones of the district are likewise listed from west to east: Loz - Horsha zone, La'ana - Yeter zone, and Avdat zone.

TABLE 2. Zonal division of the runoff farming district (based on Kedar, 1967)

NAME OF ZONE	TOTAL AREA (hectares)	AGRICULT. FIELDS (ha)	FIELDS % OF ZONAL AREA	FIELDS % OF ALL FIELDS
1. Haluza-Rehovot	15,800	239	1.5 %	6.0 %
2. Nizzana	17,000	1489	8.7 %	37.2 %
3. Ruth	9,200	237	2.5 %	5.9 %
4. Shivta	18,800	495	2.7 %	12.4 %
5. Sede Boqer-Ashalim	25,500	303	1.3 %	7.6 %
6. Yeroham-Revivim	27,900	227	0.9 %	5.7 %
7. Mamshit	6,200	42	0.7 %	1.0 %
8. Loz-Horsha	42,300	200	0.5 %	5.0 %
9. La'ana-Yeter	22,400	95	0.4 %	2.4 %
10. Avdat	12,500	678	4.5 %	16.9 %

Kedar (1967) also determined within each zone the areal distribution of the runoff farming fields in relation to wadis, drainage basins, or other geographic points of reference. These relevant data, first published in Hebrew, are worthwhile to be quoted as well (Table 3), as they give more insight into the respective importance of certain catchment areas and ephemeral streams in ancient runoff agriculture.

TABLE 3. Areal distribution of runoff farming fields within each zone of the runoff farming district (after Kedar, 1967).

RUNOFF FARMING DISTRICT ZONE	EPHEMERAL STREAM VALLEY OR OTHER REFERENCE	RUNOFF FARMING FIELDS (hectare)
1. HALUZA - REHOVOT Zone:	Nahal Besor	101
	Nahal Rehovot	128
	Internal valleys	10
2. NIZZANA Zone:	Nahal Ezuz	455
	Nahal Nizzana (within this zone)	1034
3. RUTH Zone:	Nahal Ruth and its tributaries	124
	Nahal Raviv	112
	Nahal Safun and Nahal Perach	1
4. SHIVTA Zone:	Nahal Shezaf and its tributaries	66
	Nahal Qarha drainage basin	118
	Nahal Zetan drainage basin	51
	Nahal Derorim drainage basin	44
	Nahal Lavan	126
	Southern tributaries Nahal Lavan	155
5. SEDE BOQER - ASHALIM Zone:	Nahal Haroa	119
	Nahal Boqer	19
	Nahal Baqara	52
	Wadi el-Umzira	25
	Wadi um-Terafa	9
	Nahal Besor (within this zone)	78
6. YEROHAM - REVIVIM Zone:	Surroundings of Revivim	60
	Surroundings of Mashabbe Sade	58
	Surroundings of Yeroham	109
7. MAMSHIT Zone:	North-western part	30
	South-eastern part (diversion system)	12
8. LOZ - HORSHA Zone:	Northward drainage area	
	Nahal Nizzana (within this area)	83
	Nahal Agrav, Sirpad, and Ayarim	31
	Nahal Horsha	49
	Southward and eastward drainage areas	13
	Westward drainage area (Nahal Loz)	25
9. LA'ANA - YETER Zone:	Nahal La'ana (northern part)	45
	Nahal La'ana (southern part)	11
	Nahal Yeter and its tributaries	40
10. AVDAT Zone:	Nahal Zin drainage basin	167
	Nahal Avdat drainage basin	449
	Nahal Divshon drainage basin	48
	Plateau between N.Zin and N.Divshon	13

The amount of runoff farming fields related to the lower part of Nahal Nizzana (1034 ha) is absolutely outstanding. The second largest areal extent of ancient agricultural fields is in Nahal Ezuz (455 ha), also in the Nizzana zone, followed by the drainage basin of Nahal Avdat (449 ha). These latter figures are well above the average of the remaining catchments and the three mentioned areas combined represent nearly 50 % of all the ancient agricultural fields in the runoff farming district.

GEOLOGY AND GEOMORPHOLOGY

The Negev is located at the edge of the Arabo-African craton, whose Precambrian rocks are only exposed in the south near Elat. During the Cratonic Stage, lasting for most of the Phanerozoic until the Oligocene, transgressions issued from the former Tethys Ocean (Mediterranean Area) in the NNW, controlled by mild vertical tectonic oscillations. Several sedimentation cycles produced a typical platform sedimentary cover of mature clastics and carbonates that were deposited over flat continents or in shallow epeiric seas (Garfunkel, 1978).

Rather accentuated earth movements occurred in the Late Triassic and during the Late Jurassic - Earliest Cretaceous. A new phase of tectonic activity, the results of which are significant even today for the runoff farming district, began in the Senonian Period of the Late Cretaceous and continued into the Tertiary. It produced a series of faults and broad asymmetric folds, all having a northeast-southwest to east-west alignment. These structures, extending from the Euphrates River in Syria, through northern Jordan, Israel, and Sinai into Egypt, comprise the Syrian arc of Krenkel (1924). The associated folded anticlines in the central Negev rise gently on the north-western side and dip often sharply on the south-eastern side, markedly influencing the present day geomorphology of the region.

The last major transgression occurred during the Eocene, by which carbonates were deposited over large portions of the platform (Benjamini, 1979). The sea extended probably 1000 km inland from the present coastline, but its retreat and the onset of terrestrial conditions in the area began in the Late Eocene, followed by a period of extensive erosion that produced a rather flat landscape (Garfunkel and Horowitz, 1966). Relics of the middle Tertiary topography in the Negev are still preserved today (Garfunkel, 1978). Eocene rocks are predominant in the runoff farming district (Figure 5).

The originally continuous Arabo-African craton was rifted apart in the Late Cenozoic, a process that perhaps began in the Oligocene. These earth movements produced the present plate boundaries in Israel and nearby countries. The Dead Sea rift forms part of the boundary of the new Arabian plate (Bentor et al., 1965; Freund, 1965; Garfunkel, 1978). Strong vertical movements considerably changed the pre-rifting topography of the region. The land surface surrounding the Dead Sea became the lowest continental spot on earth, situated about 400 meter below the level of the Mediterranean Sea. A variety of sediments and evaporites (salts), several kilometers thick, accumulated in the subsiding rift valleys.

The areas adjacent to the rift valleys were often strongly uplifted and appear today as veritable mountainous walls. Especially the regions of Moab and Edom east of the Arava Valley, look impressive when viewed from the eastern Negev. The Mediterranean coastal plain and offshore region to the west subsided a few kilometers since the Neogene. The northwestern Negev is, therefore, rather flat and covered with Quaternary loessial (Yaalon and Dan, 1974; Bruins, 1976; Bruins and Yaalon, 1979) and sandy deposits.

The boundaries of the runoff farming district clearly relate to the southwest-northeast trending fold belt. The first anticline of Har Qeren, bounding the coastal plain, marks the northwestern limit of the district. The eastern and southern district boundary follows the Hatira and Ramon anticlines, and the intervenient steep margins of the Zin Valley which makes a major westward dent into the central Negev highlands (Figures 2,3,4,5).

The agricultural fields within the runoff farming district are situated in valleys of ephemeral streams of first or higher order. Quaternary loessial deposits have accumulated in these valleys and form an ideal parent material for cultivable soils well suited for rainwater-harvesting agriculture. The hills and mountains of the district are largely composed of carbonate rocks formed under marine conditions during the Upper Cretaceous and Lower Tertiary. The geological formations making up these hills, whose lithological properties are important factors in runoff production, can be divided into three main groups: (1) The Judea Group, (2) the Mount Scopus Group, and (3) the Avdat Group.

Runoff farming can only be successful if enough runoff water is generated in a certain catchment area under the prevailing rainfall regime. Geomorphology and surface lithology of the catchment are important factors in this respect. An outline is, therefore, given about the lithological characteristics and areal distribution of the three geological groups within the runoff far-

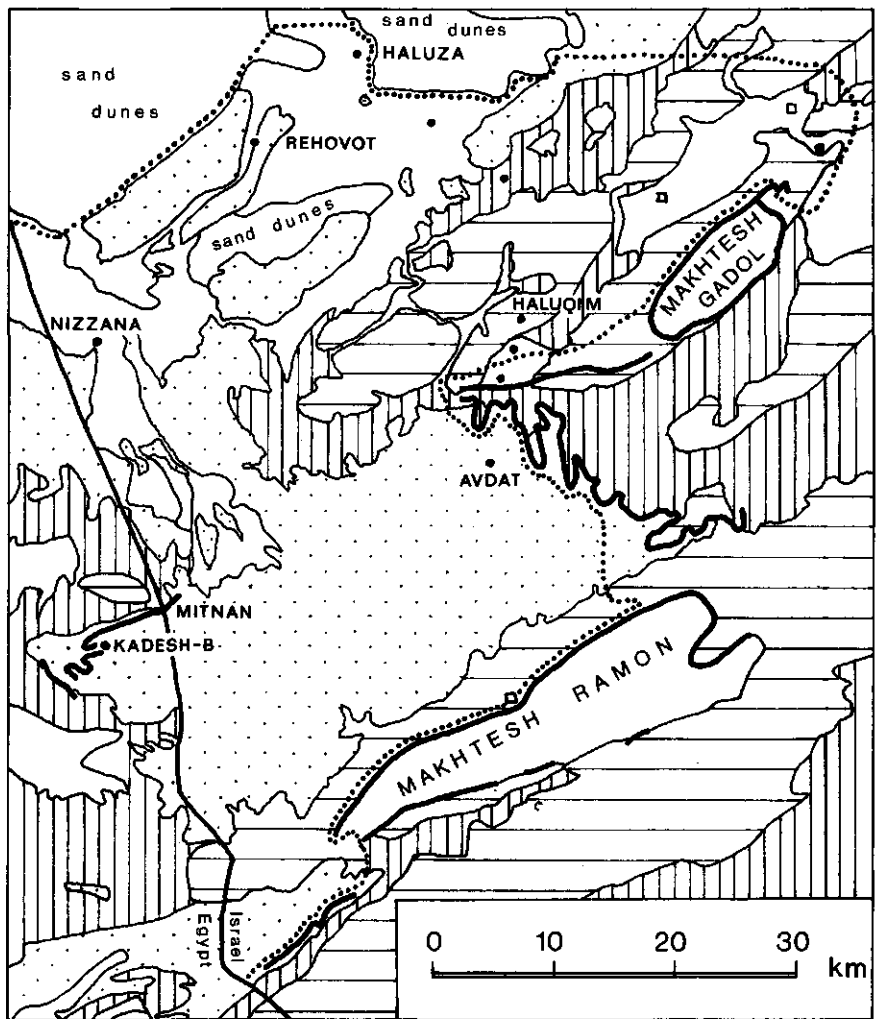
ming district.

1) The JUDEA GROUP is characterized by HARD LIMESTONE and DOLOMITE rocks of Cenomanian and Turonian age (Arkin and Braun, 1965; Bartov and Steinitz, 1974). Its rocks cover approximately 20 % of the runoff farming district and dominate the anticlinal hills in the northeastern part, bound to the west and south by Nahal Kevuda, Nahal Zipporim and the Zin Valley. Extensive outcrops of the Judea Group are found in the Shivta, Sede Boqer-Ashalim, Yeroham-Revivim, and Mamshit zones on the following anticlinal ranges: Givot Kevuda, Ketef Shivta, Har Nezer, Har Boqer, Ramat Boqer, Har Haluqim, Har Rahama, Rekhes Yeroham, Har Shahar, Har Zavoa, and the Hatira anticline with Har Zayyad (Figures 3,4,5). In the southern part of the district the Judea Group crops out in the Avdat and Loz - Horsha zones along the entire northern cliff of the Makhtesh Ramon, as well as further west on Har Ramon, Har Horsha, and Har Harif. Two small, isolated outcrops are found on Har Sa'ad and Har Nafha in the Avdat Zone.

2) The MOUNT SCOPUS GROUP usually consists of SOFT CHALK and MARL of Senonian, Maastrichtian, and Paleocene age (Flexer, 1968; Bartov et al., 1972). Its rocks cover about 5 % of the runoff farming district and generally appear on the outskirts of the areas occupied by the Judea Group. Relatively extensive outcrops occur in the central part of the district, in the Ruth and Shivta zones, west of Shivta and Nahal Kevuda, and north of Har Lavan. Another major area is situated in the northern part of the Yeroham - Revivim zone, northeast of Mashabbe Sade, in between Nahal Misad and Nahal Sekher (Wadi Mashash). Smaller outcrops are found in the syncline of Yeroham and Sede Boqer, as well as north of Sheluhat Kadesh Barnea and Har Hamran in the Nizzana zone.

3) The AVDAT GROUP is composed of Eocene LIMESTONE and CHALK with variable amounts of chert (Bentor and Vroman, 1963; Braun, 1967; Benjamini, 1979, 1980; Benjamini and Zilberman, 1979; Zilberman, 1981). Its rocks cover about 65 % of the runoff farming district, appearing almost everywhere except in the north-eastern part of the district.

Neogene and Quaternary terrestrial deposits, composed of coarse clastics, sand and loess, make up the remaining 10-15 % of the district. Neogene deposits are found particularly in the Dimona-Yeroham-Sede Boqer syncline. Quaternary sediments are widespread in the northwestern part of the district and



Legend:

- | | | | |
|-------|--------------------------------------|-------|--------------------|
| ——— | Judea Group (Limestone and dolomite) | ----- | District boundary |
| | Mount Scopus Group (Chalk and marl) | ————— | Prominent cliffs |
| | Avdat Group (Limestone and chalk) | ~~~~~ | Geolog. boundaries |

FIGURE 5. Geology of the runoff farming district

occur also in all the ephemeral stream valleys.

As already mentioned, Kedar (1976) divided the runoff farming district into 10 zones and determined for each zone the total area of ancient agricultural

fields (Tables 2, 3; Figure 4). A comparison between the landscape factors and the percentage of ancient agricultural fields does show a clear relationship in certain zones, as discussed below. The influence of socio-economic and political factors, superimposed upon the geo-environmental zonal potential, is indicated by the density of runoff farms around urban centres. The three zones with the highest percentages of ancient fields (8.7 %, 4.5 %, and 2.7 %) are those related to the Nabatean-Byzantine cities of Nizzana, Avdat, and Shivta, respectively.

However, the distinct influence of geomorphology and lithology upon the area that could be reclaimed in each zone by runoff farming in antiquity seems, nevertheless, apparent in a number of cases. When the Nizzana zone is compared with the Halutza - Rehovot zone, it is clear that both zones had urban centres and large areas of potentially cultivable land with loessial soils. The Halutza - Rehovot zone, which contained larger towns in antiquity than the former area, has, nonetheless, only 1.5 % of runoff farming fields, compared to 8.7 % for the Nizzana zone.

The respective landscape characteristics of the two zones seem to be the principal causes for this difference. The geomorphic division between runoff producing hills and runoff receiving cultivable lands, as well as the large catchment and suitable terrace plains of Nahal Nizzana, are clearly advantageous for runoff farming in the Nizzana zone. There is a clear lack of runoff producing hills and too much flat land in the Halutza - Rehovot zone, as well as in the Yeroham - Revivim zone, due to the extensive valley plains of Nahal Besor and Nahal Revivim. Moreover, the widespread occurrence in and around the latter regions of sand dunes, which absorb all the rainwater without generating any runoff, is an additional lithological disadvantage that also limits the runoff farming potential.

The other zones are situated in more mountainous and rocky terrain. The ratio and division between runoff producing hills and runoff receiving valleys seem to be the main geomorphic factors that determine the potential area suited for runoff farming. However, the properties of the individual hill-slopes and valleys, in terms of runoff production and storage, respectively, are also very important. The local effect of lithology, surface covering, and slope angle in runoff production was investigated in detail in two different case studies.

Shanan and his colleagues (Evenari et al., 1971; Shanan, 1975; Shanan and Schick, 1980) stress the runoff producing qualities of gentle, loess covered slopes, free of stones, which they investigated in the Eocene Avdat area. Yair

(1981, 1983) arrived at quite a different conclusion in his studies of an instrumented hillslope section on hard (Turonian) limestone rocks of the Judea Group in the Sede Boqer-Ashalim zone. Yair considers bedrock outcrops and steep stony slopes as advantageous for the production and transmission of runoff. Gentle loess covered slopes play a negative role in his opinion. These seemingly contradictory view-points appear both to be correct within their own context.

More comparative research is needed to evaluate the ramifications of these different results in terms of various runoff farming systems (Chapter 3), e.g. micro-catchments on very gentle sloping loess versus other systems that receive their runoff water particularly from rocky slopes. The hillslope runoff model of Yair yet requires, as he acknowledges (Yair, 1983), an appropriate explanation for the function, in his model, of the already much debated stone mounds on the hillslopes (Tadmor et al., 1958; Shanan, 1975).

CLIMATE

The Negev is situated in the northern, subtropical part, of the large planetary desert belt that extends from North Africa to India. Aridity in the Negev is, therefore, mainly the result of descending dry and stable air masses of global high-pressure cells, situated beyond the tropical convection zone. Climatic conditions are typical of a winter rainfall desert. The planetary pressure system shifts southward in winter, bringing Israel under the influence of a westerly circulation system with rain bearing depressions from the Mediterranean. The Negev is situated on the southern edge of this circulation system in winter, as most depressions follow a more northward trajectory over Cyprus. Mean annual precipitation decreases, as a result, from about 300 mm in the northwestern Negev to some 25 mm in the extreme south near Elat. Depressions sometimes arrive from the south along a narrow belt over the Red Sea and cause sudden cloudbursts accompanied by torrential floods in the Negev and Sinai deserts (Ashbel, 1973).

The average temperature in Januari, the coldest month, is about 12 degrees Celsius in the north-western Negev and nearly 16 degrees in Elat. The hottest month is August, having average temperatures of about 27 in the north-west and 33 degrees Celsius in the extreme south. Daily maximum temperatures in summer are regularly above 40 degrees Celsius in the Arava rift valley (Rosenan, 1970). P/ETP indices range from 0.390 near Gaza in the north-western Negev to

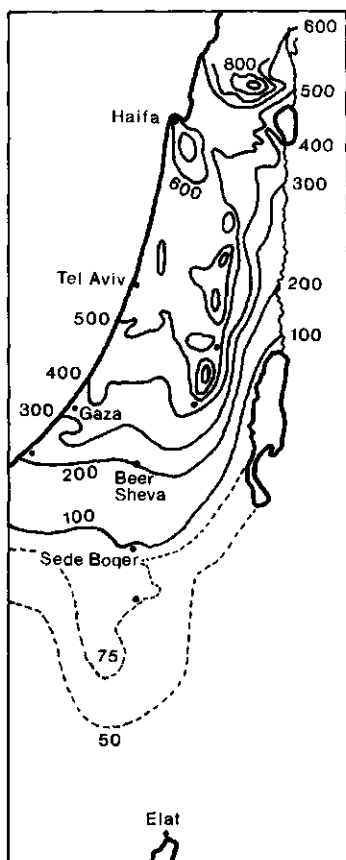


FIG. 6. Rainfall isohyets

0.009 near Elat in the extreme south. Aridity, therefore, ranges from semi-arid in the north-west to hyper-arid in the south and east, as defined by Unesco (1979).

The climate of the runoff farming district in the central Negev hills is typically arid, situated between the semi-arid northern Negev and the hyper-arid regions to the south and east. The arid region actually protrudes southward into the hyper-arid surroundings, due to the elevation of the central Negev. However, only the rising northern and western parts of the central Negev highlands, directed towards the trajectory of rain bringing depressions in winter, receive relatively more rain. The eastern and southern parts of the highlands receive less rain, as soon as the general topography begins a downward trend, because of the rainshadow effect and increasing structural aridity southward. It is quite striking how the eastern and southern boundary of the runoff farming district coincide with topographic features, which mark a more or less sharp decline in elevation. This surely is a major climatic and environmental border.

Average annual rainfall amounts in the runoff farming district range from about 120 mm in the north to some 75 mm in the south-east. These data are based on various measurements in the area in the course of the 20th century, as shown in Table 4. Most of the precipitation occurs erratically between November and April. Interannual rainfall variability is high, being on the average above 50 %.

The rainfall regime in the central Negev is usually very gentle with low rainfall intensities (Katznelson, 1959; Shanan et al., 1967). The average amount of rainy days at Sede Boqer, situated in the central-eastern part of the runoff farming district, is 26, based upon a 28 year record from 1951/52 - 1979/80. The mean annual rainfall over this period is 93.5 mm. About half of these rainy days register less than 1 mm per day. More than 10 mm rain/day can be expected on only three days per year, on the average.

TABLE 4. Average annual precipitation in the runoff farming district.

Recording Period	Location	Elevation (m)	Runoff Farming Zone	Mean Annual Rainfall (mm)
1943-1963	Revivim	290	Yeroham-Revivim	101
1934-1962	Mashabbe Sade	350	Yeroham-Revivim	103
1970-1984	Wadi Mashash	370	Yeroham-Revivim	117
1942-1948	Mamshit	450	Mamshit	135
1901-1930	Nizzana	250	Nizzana	86
1960-1976	Shivta	350	Shivta	88
1951-1980	Sede Boqer	470	Sede Boqer-Ashalim	94
1960-1984	Avdat	565	Avdat	87
1958-1978	Mizpe Ramon	890	Loz-Horsha / Avdat	78

A rainfall of 25 mm/day is expected no more than once every two years and a rainfall of 50 mm/day is highly improbable (Shanan et al., 1967). An analysis of rainfall intensities at Avdat, during the period 1959/60 - 1971/72, showed that main rain-storms, important for runoff farming, can be divided into three principal types (Shanan, 1975):

- Type A consists of a principal rainfall lasting for about 6-8 hours, during which period some 10 mm of rain falls. The maximum intensities will be relatively low: 6-7 mm/hour for a period of a quarter of an hour, and 3-4 mm/hour for a one hour duration. After two hours the average storm intensity drops to below 2.5 mm/hour and levels off at about 1.5 mm/hour. This type of rain-storm occurs virtually every year.

- Type B consists of a principal rainfall lasting for about 6 hours, during which period some 12 mm falls. Maximum intensities for short durations are 60-100 % greater than for the former type A. Intensities of 12.4 mm/hour may occur during a period of a quarter of an hour, and 5.3 mm/hour for a one hour duration. After 2 hours the average rainfall intensity is 3.2 mm/hour, dropping to 2.4 mm/hour only after some 4 hours of rain. The average intensity for the six hour rain-storm period will be 2 mm/hour. This type of rain-storm can be expected to occur once every two years.

- Type C consists of a single rainfall of extremely high intensity, which occurred on only one occasion (5-10-1965) in the period from 1959/60 - 1971/72. The entire rain-storm produced 35 mm of rain in six hours. Thus, the average rainfall intensity was almost 6 mm/hour. Maximum intensities for short periods: 28 mm/hour for a period of a quarter of an hour or half an hour, 19 mm/hour for a one hour duration, and 13 mm/hour for a 2 hour duration. This type of rain-storm with a duration of 4 hours seems to have a frequency of once in five years, and with a duration of 6 hours once in about 20 years (Shanan, 1975).

Temperatures in the runoff farming district are of course influenced by altitude. Mean annual temperatures range from about 20 degrees Celsius in the northwest of the district (200-350 m) to 17.8 C at Mizpeh Ramon (890 m) in the south. Mean temperatures of the coldest month (January) and hottest month (August) are about 12 C and 27 C, respectively, in the northwest and about 9 C and 25 C in the south. Differences between day and night temperatures are typically large for an arid desert region, being about 14 degrees Celsius on a yearly average (Rosenan, 1970). Frost may occur in the valleys of the runoff farming district during 20 to 30 nights in winter, especially in the more elevated parts of the district (Evenari et al., 1971). During Hamsin 'or Sharav weather conditions in spring and autumn, hot and dry winds from the Arabian desert may raise the temperature to 40 degrees Celsius or more.

Dew is an important phenomena in the central Negev hills, occurring on approximately 150-200 nights each year. The average annual surface dewfall at Avdat is about 33 mm (Evenari et al., 1971). Although the effect of dew on cultivated crops has not been definitely ascertained, Duvdevani (1953) concluded from his experiments that it has a growth promoting effect.

SOILS AND VEGETATION

Soils occupy the uppermost part of the earth's crust, being in direct contact with the atmosphere. Their properties differ from the underlying rock material, as a result of interactions between this rock material and the environment over periods of time. Apart from weathering of the parent rock, soils in the Negev are usually influenced by the influx of aeolian dust and salt (Yaalon, 1964; Yaalon and Ganor, 1973). In the case of loess deposits the exotic dust from the air has become a parent material of its own. Climate,

living organisms, and landscape position are major soil forming factors.

In Israel the landscape approach was adopted in the study of soils, emphasizing the effect of geomorphic position and parent material on soil development. An impression of the areal coverage of parent materials in the Negev has been summarized by Yaalon (1981). About 60 to 65 % of the area is composed of rocky deserts with bare rocks and desert lithosols. Some 15 % are regs of the sedimentary plains or plateaus covered by desert pavements. Another 5 to 10 % are loessial plains with soils characterized by secondary carbonate formation at various depths. Some 10 % are sand fields with mostly shifting sand dunes, and about 4 % is taken up by ephemeral stream channels and alluvial fans.

Since the vegetation of a region is also influenced by the environment, there usually exists a strong relationship between the soils of an area and its plant geography. Four phytogeographical regions of characteristic floral composition and obvious environmental significance have been recognized in the Negev:

- 1) The MEDITERRANEAN phytogeographical region is limited to the northern Negev fringe, bounded by the 300 mm rainfall isohyet.
- 2) The IRANO-TURANIAN region is situated between the 300 and 80 mm isohyets and its floral composition, therefore, dominates the runoff farming district.
- 3) The SAHARO-ARABIAN region generally coincides with the hyper-arid zone, limited to areas receiving less than 80 mm of mean annual rainfall.
- 4) TROPICAL SUDANIAN flora has infiltrated into the hot Arava rift valley, bounded by the isotherm of 23 degrees Celsius (Zohary, 1966; Danin, 1983).

Vegetation in the hyper-arid Saharo-Arabian region is restricted to favourable habitats like ephemeral stream channels and rock crevices, where the runoff water concentrates naturally. Both fluvial and wind erosion is severe, due to the absence of a vegetational cover. The surface deposits are, therefore, depleted of fine soil material, which is partly redeposited as loess in the semi-arid desert fringe (Yaalon and Dan, 1974). As weathering is slow in the very dry climate and erosion severe, soils are not well developed. Desert Lithosols (Lithic Torriorthents) and Coarse Desert Alluvium (Typic Torrifluvents) are characteristic soils of the hyper-arid region. Stable landscape surfaces like sedimentary terraces and plateaus, covered and protected by desert pavement (Reg or Hammada), exhibit the best developed authigenic desert

soils (Dan et al., 1982), called Reg soils in Israel (Gypsiorthids and Camborthids in the American soil taxonomy system; USDA, 1975).

North of the runoff farming district, in the semi-arid part of the Irano-Turanian and Mediterranean floral regions, the amount of rainfall is usually sufficient to enable the formation of a rather continuous vegetational carpet. Soil erosion is restricted. Aerosolic dust from the Sinai and Sahara deserts could, therefore, accumulate to form rather thick and continuous loess deposits in the north-western Negev (Yaalon and Dan, 1974; Ganor, 1975; Bruins, 1976; Bruins and Yaalon, 1979). Soils are mature with well developed soil profiles, exhibiting calcic horizons (Light Brown soils; Haploxeralfs, Paleixeralfs, and Xerochrepts).

The arid runoff farming district is characterized by a diffuse vegetational cover, dominated by an Irano-Turanian floral composition. The scattered vegetation cannot prevent severe erosion. However, in favourable habitats like valleys, where the runoff concentrates, vegetation is often sufficiently dense to enable deposition of loessial fines eroded from the hillslopes. Soil development is usually slow, but somewhat more marked than in the hyper-arid zone (Dan, 1981). The eastern and southern boundary of the runoff farming district is of major environmental significance: This line coincides with the southeastern boundary of both the soil association of Brown Lithosols - Loessial Serozems (Figure 7) and the Irano-Turanian floral region.

The soil associations found in the runoff farming district are shown in Figure 7 and listed in Table 5. An estimation is given in Table 5 of their respective areal coverage in the district, as deduced from the soil map of Israel (Dan et al., 1975).

BROWN LITHOSOLS ON HILLSLOPES OF HARD CALCAREOUS ROCKS

Rocky hills and mountains dominate the runoff farming district, constituting about 70 % of the region. Weathering of the hard limestone and dolomite rocks is very slow, due to the dry climate. The soils on these hard calcareous hills are, as a result, mainly formed from aeolian loessial dust mixed with parent rock fragments. These shallow soils, designated as Brown Lithosols (Lithic Torriorthents), are largely confined to pockets and crevices among the hillslope bedrock, where they are protected from accelerated erosion.

Most of these soils are saline, but the upper soil layer has a low salt content due to the leaching effect of the rainfall. Salinity in the subsoil is less in places where runoff from surrounding bedrock outcrops can accumulate. The additional moisture from runoff water also enables the development of a

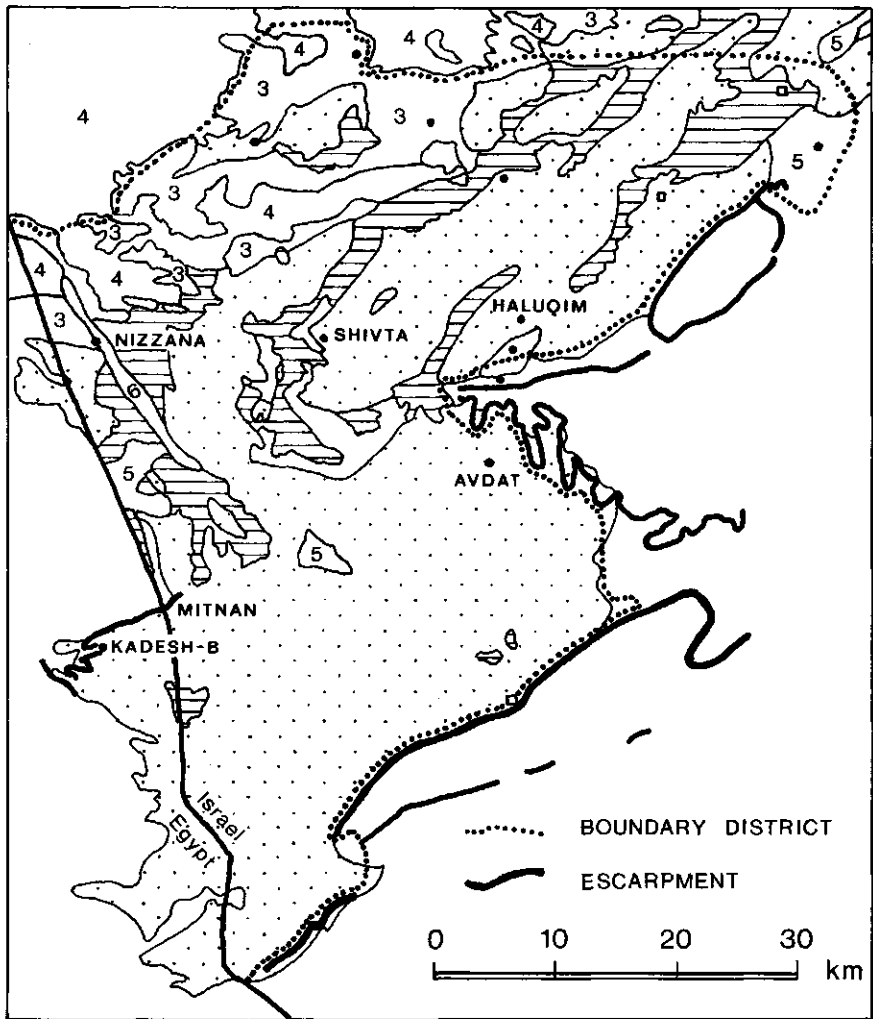


FIGURE 7 & TABLE 5. Soil associations of the Runoff Farming District

SOIL ASSOCIATION	GEOMORPHIC POSITION	AREA
1) Brown Lithosols and Loessial Serozems	Hillslopes and valleys	65 %
2) Loessial Serozems	Plains, plateaus, valleys	15 %
3) Sandy Regosols and Loessial Serozems	NW plains and valleys	10 %
4) Sand Dunes	NW plains and valleys	5 %
5) Calcareous Desert Lithosols	Hillslopes	3 %
6) Reg soils and Coarse Desert Alluvium	Nahal Nizzana valley	1 %

relatively rich vegetation, mainly composed of small desert shrubs (Danin et al., 1975; Yair and Danin, 1980; Dan, 1981). The *Artemisia herba alba* - *Reaumuria Negevensis* plant association covers most of the limestone hillslopes on the Avdat Plateau.

This association is replaced by the *Artemisia herba alba* - *Gymnocarpus decander*, *Artemisia herba alba* - *Salvia lanigera*, and the *Artemisia herba alba* - *Thymelaea hirsuta* plant associations on the (Judea Group) limestone and dolomite hillslopes of the northern part of the runoff farming district. The various *Artemisia* associations are replaced in the drier parts of the district and on south facing slopes by the *Zygophyllum dumosum* - *Reaumuria negevensis* plant association (Danin, 1983).

CALCAREOUS DESERT LITHOSOLS ON HILLSLOPES OF SOFT CALCAREOUS ROCKS

Weathering of soft calcareous rocks in the runoff farming district, like chalk and marl, is somewhat faster. Soils developed on hills composed of these parent materials are not only formed from exotic airborne loess. They contain a proportionally larger share of weathered rock fragments than soils developed on hard rocks. Soils on chalk and marl, therefore, reflect to a larger extent the composition of the underlying parent material. These soils are included among the Calcareous Desert Lithosols (Lithic Torriorthents) and cover certain parts of the Shivta, Ruth, Nizzana, and La'ana-Yeter zones.

Calcareous Desert Lithosols are more saline than Brown Lithosols on hard rocks. Outcrops of bedrock are less common and vegetation is scarce (Dan, 1981). *Reaumurietum negevensis*, *Reaumurietum hirtellae*, and many other plant associations, often related to certain geological formations, are found on these soft calcareous rocks (Danin, 1983).

YOUNG ALLUVIAL SOILS IN THE ACTIVE STREAM CHANNELS

The valleys of the runoff farming district are largely covered by loessial sediments. Coarse gravel deposits are generally confined to the major wadis, like the broad Nizzana Valley. The younger sediments associated with active ephemeral stream channels do not show soil profile differentiation. Any textural variations are essentially due to fluvial sedimentation. These young soils are called Alluvial Loess (Typic Xerofluvents) and Coarse Desert Alluvium (Typic Torrifluvents), both of which are largely non-saline. Carbonate content in the Alluvial Loess soils varies according to rock characteristics in the surrounding area. These soils are highly calcareous in catchments dominated by chalk and marl, when their vegetation is often character-

rized by the *Atriplex halimus* - *Achillea fragrantissima* plant association (Danin, 1983). Carbonate content in Alluvial Loess soils is much lower in areas of hard limestone and dolomite rocks (Yaalon and Dan, 1974).



PHOTO 1. Spring vegetation in the Western wadi of Horvat Haluqim, just upstream from the cistern and terraced fields.

The NON-SALINE ALLUVIAL LOESS SOILS situated in active ephemeral stream channels, represent the BEST WATERED HABITAT in the runoff farming district. This habitat benefits from runoff floods every year. The vegetation is often a dense steppe of shrubs, such as *Thymelaea hirsuta* and *Retama raetam*, plants like *Achillea fragrantissima*, and various annual and perennial grasses, as well as herbs belonging to the more humid Mediterranean floral community. The latter include *Avena sterilis*, *Oryzopsis miliacea*, *Hordeum spontaneum*, *Lolium rigidum*, *Cynodon dactylon*, *Trigonella arabica*, *Medicago* spp, and others (Hillel and Tadmor, 1962; Danin, 1983).

A most remarkable feature of the runoff farming district is the occurrence of large *Pistacia atlantica* trees at higher elevations. The highest density of trees is found above 700 meter. Altitude is, however, not the most important factor in the distribution of the atlantic pistachio, as most of these trees appear in the Loz-Horsha zone in association with large outcrops of smooth-faced limestone, ideal in runoff production (Danin, 1983).

LOESSIAL SEROZEMS

Older Loessial deposits on natural wadi terraces and in synclinal plains exhibit a distinct profile differentiation. A shallow calcic horizon and

saline layers at depth characterize these soils, defined as SEROZEMS. Gypsum is usually present and some clay illuviation may also occur. Salinity in the subsoil reaches 2 % of soluble salts or even more. The upper 30 cm are almost free of salts, marking the average depth of effective rainfall penetration.

There is often a good correlation between salt content of the soils and the stability and age of the pedomorphous surfaces. This indicates that most of the salts are airborne, slowly accumulating with time in a dry non-leaching environment (Dan and Yaalon, 1982). The B horizon of the somewhat less developed Loessial Serozems is of a cambic nature and has a loamy texture (Camborthids or Calciorthids). More mature Serozems, usually on the higher terraces, may display an argillic B horizon of clay loam texture (Haplargids). Petrocalcic stony Serozems on Neogene or Early Pleistocene geomorphic surfaces exhibit strongly developed calcic horizons and even calcrete (Dan, 1981).

Serozems are found in all the zones of the runoff farming district, especially in the synclinal plains of the southwest-northeast trending fold belt and in the valleys of Nahal Nizzana, Nahal Kevuda and Nahal Lavan. They also occur, however, in Pleistocene aeolian loess on high plateaus in the Avdat and Loz-Horsha zones of the central Negev mountains. The vegetation on the Serozems is at lower altitude characterized by scattered low shrubs of *Hammadetum scopariae* and *Zygophyllum dumosum*, and above 700 meter by *Anabasetum syriacae* (Danin, 1983). The present moisture regime is generally poor, as most loessial plains, plateaus and natural wadi terraces do not receive runoff water. It seems that most Serozems are paleosols formed in a somewhat wetter arid to semi-arid climate during the Late Pleistocene (Dan et al., 1973; Issar and Bruins, 1983).

SANDY SOILS

Sand occurs extensively in the northwestern part of the runoff farming district. Most of the young aeolian sand dune deposits do not reveal any soil development (Torripsamments and Quartzipsamments). The beginning of pedogenesis may be detected in the young sandy Regosols (Typic Xerorthents) developed on stable sand covers. Some darkening of the upper soil layer has taken place, as well as incipient lime segregation in the subsoil. The soils underneath the sand on the foot-slopes of hilly areas mainly originate from chinks and conglomerates. These Brown Lithosols and Rendzinic Desert Lithosols (Torriorthents) are mixed with sand in their upper soil layer. Soils underneath the sand in the valleys and plains include various Serozems, as well as young alluvial loess deposits (Dan, 1981).

The vegetation of the sandy areas is quite lush, in spite of the dry climate. This is due to a favourable moisture regime as a result of deep rainfall penetration into the sand. The dominant plant of the mobile sand dunes, and sometimes the only species present, is the perennial grass *Stipagrostis scoparia*. It grows only in sites that are continuously being covered by new sand. Vegetation of the stable sand fields consists of a mixed community of shrubs and grasses, dominated by the *Artemisia monosperma* - *Retama raetam* plant association, accompanied by *Thymalea hirsuta*, *Convolvuletum lanati*, *Echiochilon fruticosum*, *Neurada procumbens*, *Iris mariae* geophytes, and grasses like *Stipagrostis ciliata*, *Stipagrostis obtusa*, *Panicum turgidum*, *Pennisetum divisum*, and *Aristida* species (Hillel and Tadmor, 1962; Waisel et al., 1978; Danin, 1983).

In more humid regions of the world sand constitutes the driest of habitats, due to rapid drainage and failure to retain sufficient moisture and nutrients. However, the opposite situation generally prevails in arid regions, where sandy soils offer more favourable moisture conditions for plant growth than do finer-textured soils. This is because of the sands higher permeability to rain and, hence, greatly reduced runoff losses. Rainfall is usually so scant in the desert, that no appreciable percolation takes place beyond the reach of plant roots. Moreover, since sand retains less moisture per unit of depth than finer-textured loessial soils, less moisture remains near the soil surface, where it might be subject to subsequent evaporation (Hillel, 1982, p.103).

Notwithstanding these assets, the virtual absence of runoff in sandy areas renders them unsuitable for runoff farming. Any form of agriculture, including rainwater-harvesting agriculture, requires much more water (250-500 mm) than the average annual precipitation (100 mm) in the area. For the requirements of runoff farming, therefore, by which relatively large quantities of runoff water must be stored in the root zone, the disadvantages of sand felt in more humid regions become apparent. Loessial soils, on the other hand, virtually omnipresent in the wadis of the runoff farming district, are well suited for this ingenious and yet ancient form of desert agriculture.

3 Runoff farming in the region

INTRODUCTION

The crucial factor in the settlement of an arid desert is the assured supply of water for man, his animals and crops. Since the Negev is not endowed with a river that brings in water from more humid regions, local rainfall and runoff has been the only water source for most of the past. Only in the 20th century it became possible, after the establishment of the State of Israel, to build a pipeline that carries water from the more humid northern part of the country to the Negev. The transportation of this water is becoming increasingly more expensive, whereas the amount that can be allocated to the Negev is limited. In 1975 about 125 million cubic meters of water was piped into the Negev for irrigation agriculture, which is 11.5 % of the total amount of water used for agriculture in Israel (Hillel, 1982).

Springs and wells in shallow groundwater reservoirs, naturally fed by runoff waters, were the only available, more permanent, water sources in antiquity. The number of these shallow groundwater sources are few and the amount of water that can be tapped from these springs and wells is very scanty. Their water is sometimes slightly brackish and their potential for irrigation agriculture has always been negligible, except for the site of Kadesh-Barnea. Deep 'fossil' groundwater is known to exist in the Negev at several hundreds to more than thousand meter below the surface. Use of this generally brackish water in antiquity would have been unthinkable, as its possible utilization is even problematic today.

Since springs and wells in the runoff farming district are few in number, alternative solutions had to be made in the past to ensure a satisfactory

infrastructure of potable water. Hundreds of cisterns were constructed in antiquity to collect and store some of the runoff rainwaters as essential drinking water for man and his animals. Open-pit cisterns, known from the Israelite Period, are usually considered to be older than roofed cisterns excavated into bedrock. Most cisterns of the latter type were probably constructed in the Nabatean and Byzantine Periods (Evenari et al., 1971; Hillel, 1982).

Without cisterns the establishment of trade routes, towns and agricultural settlements would have been impossible in the past. The extensive form of livestock grazing in this arid region is equally impossible without a regular occurrence of watering points, which only cisterns could provide for. Runoff farming and livestock grazing, based upon local rainfall and runoff waters, have been the dominant types of land-use in the district during historical times.

TERMINOLOGY OF RAINWATER-HARVESTING AGRICULTURE OR RUNOFF FARMING

Before dwelling upon the essence of runoff farming, it seems impossible to bypass semantics, as ideas and logic are conveyed through words. In view of the variant usage of words in the literature related to the topic under consideration, as well as the various meanings adhered to these words, it seems clarifying to state at least the author's position, already published elsewhere (Bruins et al., 1986a).

The term "water harvesting" seems well established in the literature since it was probably first used by Geddes (1963), who defined it as "the collection and storage of any farm waters, either runoff or creek flow, for irrigation use". Myers (1975) modified this definition to "the practice of collecting water from an area treated to increase runoff from rainfall and snowmelt" (cf. Hollick, 1982).

Whatever definition is preferred, water harvesting clearly has a hydrological meaning and cannot be regarded as an agronomic term. Moreover, on the face of it, water harvesting does not specify what kind of water is harvested, i.e. rainwater, river-water, groundwater, etc., neither for what purpose it will be used. Water harvesting is of course a term in its own right, but it cannot be an alternative for runoff farming, since the latter term is intrinsically agronomic in character.

"Rainwater harvesting" (Boers and Ben-Asher, 1982) is already more specific

as far as the source of the water is concerned. Yet, also this term is purely hydrological in its wording. "Waterspreading" (Newman, 1963; Cunningham, 1975) and "waterponding" (Newman, 1966; Cunningham, 1970) are hydrologic terms used in Australia to describe the control of runoff water from rain-storms.

"Floodwater farming" (Bryan, 1929) is a fundamentally different term, as it clearly states the purpose for which the floodwater is used: farming. The question is whether this hydro-agronomic term can be regarded as fully synonymous with runoff farming. From a geomorphic point of view, floodwater is derived from a stream channel, either occupied by an ephemeral stream or by a perennial river. Examples of floodwater farming from ephemeral streams are the Ak-Chin (arroyo mouth) fields of the Hopi Indians of Arizona (Hack, 1942) and the Limans at the Wadi Mashash experimental runoff farm in the Negev desert (Evenari et al., 1982). The early agricultural systems on the floodplain of the Nile (Butzer, 1976) are a form of floodwater farming related to a perennial river.

Although nearly all the water used for agricultural purposes is somehow derived from rainwater, it seems better to make a distinction between ephemeral streams and perennial rivers, as far as irrigation farming is concerned. The relaxation time between actual rainfall and the eventual use of this water for agriculture is usually short in the case of floodwater farming from ephemeral streams, but very long for perennial rivers. Since "floodwater farming" may seem to include both of these quite different situations, the term is not specific enough to characterize the type of agriculture under discussion. Moreover, the term excludes rainwater-harvesting agricultural systems that utilize runoff water collected as overland or sheet-flow, which cannot be classified as floodwater. Various micro-catchment systems (Evenari et al., 1971; Shanan and Tadmor, 1976; Boers and Ben-Asher, 1982), therefore, would not fit the term floodwater farming.

There is, however, a need for a concise unifying term that is general enough to include all types of agricultural systems based upon rainwater harvesting methods. In order to harvest rainwater from whatever type of catchment, the rain has to flow as RUNOFF over a surface or in a channel before it can be stored into the soil, a cistern, a pond, a tank, etc. From the storage medium, the water can then be made available, passively or actively, for agricultural purposes. Hence the term RUNOFF FARMING or RUNOFF AGRICULTURE seems precise, short and yet general enough to function as a comprehensive hydro-agronomic tag to label the agricultural systems under discussion. As such, the term has been used by Evenari and his collaborators during the last

25 years (Evenari et al., 1982).

As already mentioned previously, Huibers (1985) has correctly drawn attention to the fundamental difference in the use of runoff rainwater for farming in semi-arid or arid regions. In the semi-arid zone direct rainfall is normally sufficient to sustain a crop. Runoff water is here merely collected as a by-product from the local rainfall, useful to irrigate the crops in times of moisture stress. However, in the arid zone runoff water is absolutely essential to practise agriculture based upon local rain, since direct rainfall alone is hardly ever sufficient. Rainfed farming in the semi-arid zone with additional runoff collection (Huibers, 1985) is, therefore, not reckoned to be runoff farming as defined below.

The hydrological term runoff is not always properly understood by the average individual, since runoff is not a common word occurring in everybody's vocabulary. For that reason RAINWATER-HARVESTING AGRICULTURE may be an alternative general term instead of runoff agriculture, being less concise but more descriptive and perhaps easier understood. In this dissertation the terms runoff farming and rainwater-harvesting agriculture are used interchangeably and defined as follows: - RAINWATER HARVESTING AGRICULTURE IS FARMING IN ARID REGIONS BY MEANS OF RUNOFF RAINWATER FROM WHATEVER TYPE OF CATCHMENT OR EPHEMERAL STREAM - (Bruins et al., 1986a,b).

HISTORY OF RUNOFF FARMING IN THE NEGEV.

CHALCOLITHIC

There are indications that already during the Chalcolithic Age, more than 5000 years ago, runoff farming was practised along the ephemeral stream of Nahal (wadi) Beersheva in the Northern Negev (Levy, 1983). There seems as yet no evidence that check-dams were used at that time. For a successful functioning of the system, the geomorphic position of the loessial floodplain during Chalcolithic times must have been only slightly higher than the ephemeral stream channel, so that seasonal floodwaters could inundate the floodplain readily and wet the soil to sufficient depth.

The present geomorphic situation is rather different, as the stream channel of Nahal Beersheva and many other wadis in the area are in a downcut position, well below the former floodplain level. Today, this particular type of runoff farming would not be possible at the same sites due to a change in valley morphology.

BRONZE AGE

The Central Negev Highlands were settled quite extensively during the Middle Bronze I period (ca. 2200 - 2000 B.C.), and there is circumstantial evidence that some kind of runoff farming was probably practised in suitable wadis (Evenari et al., 1958; Cohen and Dever, 1980).

ISRAELITE PERIOD

Archaeological structures and terraced wadis, possibly contemporaneous with the former, might indicate that rainwater-harvesting agriculture was practised in the Negev during the Israelite II period or Middle Iron Age (Aharoni et al., 1960; Cohen, 1976). These runoff farming settlements date, in the opinion of Aharoni et al (1960) and Cohen (1976, 1980), to the 10th century B.C., and are presumed to have been established during the reign of King Solomon. There is, however, a clear lack in chrono-stratigraphic data in the Negev concerning the end of the Late Bronze Age and the first centuries of the Iron Age. Remnants of runoff farming sites that belong to the Iron age have also been found in the Judean desert (Stager, 1976).

LATE NABATEAN-ROMAN-BYZANTINE-EARLY ARAB PERIOD

After a gap of perhaps a millennium, runoff farming in the central Negev was again practised in the 1st century A.D. by the Nabateans. In the opinion of Negev (1982a) it was probably with the accession to the throne of Rabel II in A.D. 70, that the bulk of the Nabatean population abandoned its tents, exchanging them for excellently-built houses. From the late 80s to the late 90s of the 1st century A.D. the completion of runoff farms was inaugurated in the region of Avdat (Negev, 1982a).

During the Byzantine period, from the 4th-7th century A.D., rainwater-harvesting agriculture came to the peak of its development in the Negev desert (Mayerson, 1955, 1960a; Kedar, 1957, 1967; Evenari et al., 1971; Kloner, 1975; Negev, 1982b). The unique Nizzana documents from the 6th and 7th centuries A.D., discovered in 1937 by the Colt expedition in two ancient Byzantine churches during excavations in Nizzana, mention the growing of wheat, barley, aracus (a legume), grapes, olives and dates. There is also evidence that figs and pomegranates were cultivated (Kraemer, 1958; Mayerson, 1960a).

The Muslim-Arab conquest in 636 A.D. brought about large political, economic and religious changes in the region, and inaugurated the beginning of the end of the runoff farming hey-days in the Negev. The eastern part of the runoff farming district, where the churches of Avdat were set on fire, may

have been abandoned more rapidly than the western area. It seems that runoff farming continued to function here for some time during the Early Arab period (Kraemer, 1958; Mayerson, 1960a; Negev, 1981, Haiman, 1982).

BEDOUIN FARMING

Bedouins, as semi-nomads, have sometimes engaged in runoff farming, or very marginal farming with direct rainfall only, using the remaining fields of former periods, which they rarely repair. Yet new terrace walls have also been built by Bedouin, especially in small wadis (Mayerson, 1960b). As this kind of farming is carried out by individual families and not planned by a central authority, it may well have occurred throughout certain historic periods, about which we can only guess. In this context Mayerson (1960b:33) made an appropriate remark on runoff farming remains in the Negev in general: "For the most part we are dealing with humble field remains which have a uniformity and anonymity resistant to identification".

MODERN ISRAELI RUNOFF FARMING

Shortly before the State of Israel came into being in 1948, the newly established kibbutz of Revivim, in the Yeroham - Revivim zone, attempted to use runoff techniques in agriculture. These efforts in runoff farming were also taken up by the settlers of kibbutz Mashabbe Sade and kibbutz Sede Boqer in the early fifties. However, a pipeline with imported water from the north made pipeline-irrigation possible, which completely changed the course of agricultural development in these settlements (Hillel, 1982). Since 1958 three experimental runoff farms, near Shivta, Avdat and Wadi Mashash, were established in the Negev by Evenari, Shanan, and Tadmor (1971, 1982).

HYDROLOGY OF RUNOFF FARMING

The major source of water in the Negev hills is the surface runoff from winter rains. The gentle nature of the rainfall regime in the area has already been described. Most rainfalls are in the range of 0-6 mm per day. Even exceptional rain-storms with more than 20 mm of precipitation are usually composed of several individual showers, separated by sunny or windy periods (Yair et al., 1978). Rainfall intensities equal to or greater than 20 mm/hour have an average cumulative duration of only 15 minutes per year (Kutiel, 1978; Yair, 1983). Wide variations occur also in the areal distribution of

rainfall on small watersheds, due to the influence of topographic differences (Sharon, 1972). Hillside slopes receive twice the amount of rainfall recorded on peaks of hills and knolls in the Avdat area. These ridge and valley differences are probably due to raindrops being blown away from peaks (Shanan, 1975).

As soon as rain starts falling, it will hit both the vegetation of a certain area as well as the ground. Since vegetation is sparse in the region, interception storage is small and amounts to no more than 0.2 mm for a 12 mm rainfall (Evenari et al., 1975). What will happen to the rain that hits the ground, depends essentially on two factors:

1. The quantity of rain falling with time, i.e. the rainfall rate;
2. The amount of rainwater that can be absorbed by the ground with time, i.e. the infiltration rate.

The latter factor is obviously dependent upon the nature of the ground, which may be solid bedrock, bare soil, or a mixture of bedrock outcrops, stones and soil. The initial infiltration rate of ploughed loess soils in the Avdat area, consisting of some 25 % fine sand, 55 % silt and 20 % clay, is some 18 mm/hour. This initial rate decreases fast and sharply to a final constant infiltration rate of about 2-3 mm/hour (Evenari et al., 1975), because a wet surface crust is formed. The puddling effect of the raindrops causes the wet upper loess layer to slake, as very fine particles and swelling clays clog the surface, thereby greatly reducing infiltration (Hillel, 1959, 1964).

The hillslopes in the Avdat area are covered with a mixture of loess and stones. These colluvial soils or lithosols have a permanent loessial crust with an average thickness of 4.6 mm on a 1 % slope, 3.8 mm on a 10 % slope, and 2.6 mm on a 20 % slope. The initial infiltration rate of these hillslope lithosols is much lower than the 18 mm/hour measured in cultivated loess soils in the valley. Although of rare occurrence, it is noteworthy that rainfall with an intensity of more than 15 mm/hour breaks the soil crust, thereby causing an increase in infiltration (Shanan, 1975). Seasonal temperature also effects infiltration rates, as higher temperatures in autumn and spring cause a 1.8 and 1.4 fold increase, respectively.

The threshold amount of rainfall needed to generate slope runoff in arid regions is rather low. Varying with soil moisture conditions and rain properties, it amounts to 1-2 mm for massive bedrock and 3-5 mm for a stony soil cover (Yair and Klein, 1973; Shanan, 1975; Yair and Lavee, 1976). In the latter case, most of this water is used to wet and saturate the loessial crust and to seal its cracks (Shanan, 1975).



Photo 2. Glistening runoff generated on hillslopes in the Avdat area during a rain-storm, causing stream-flow in Nahal Zin below.

As soon as the rainfall rate is larger than the infiltration rate, the excess water first accumulates in little depressions, which are due to irregularities of the ground surface. This initial loss of runoff water is called depression storage, and amounts to about 1 mm in the Avdat area (Evenari et al., 1975). If the rainfall continues at a higher intensity than the infiltration rate, a thin, shining sheet of water is formed on the ground surface (Photo 2).

This accumulated rainwater will now begin to run off on a sloping surface with a certain velocity as overland flow. In case of sufficient rainfall duration and intensity, the overland flow of runoff water will reach the first natural drainage channels. The velocity of channel flow is larger than of overland flow, an important difference to keep in mind! If the rainfall continues, the first order wadis are filled with runoff water and a real desert flood may develop, by which the runoff waters also reach the large wadis (Photo 2).

In case of intermittent rain showers, water will evaporate from moist soil

surfaces. With resumed rainfall the soil surface needs to be saturated again before runoff will appear. Evaporation is thus a hydrological loss from the system in runoff production. Measured with a USWB Class A Pan, evaporation on the Avdat farm-stead hill varied from 2.5 to 3.6 mm/day in the winter season (Evenari et al., 1971). Evaporation during day time was about 2 to 3 times higher than at night. As described by Shanan (1975), evaporation from moist to saturated soils is approximately 0.7 times that of an open water surface in a USWB Class A Pan. Hence evaporation from a saturated soil surface crust in the Avdat area in winter is between 1.8 to 2.5 mm/day.

Shanan also studied the hydrological effect of the removal of stone cover from hillslopes upon runoff production. The ancient farmers in the runoff farming district used to change the natural stone cover on many hillslopes by concentrating them into mounds and gravel strips (Evenari et al., 1971, 1982). Shanan reached the conclusion that the removal of stones from the soil surface results in the forming of a continuous loessial crust, which is advantageous for runoff production in the gentle rainfall regime of the Negev.

The rainfall infiltration is initially larger on loess soils with a natural stone cover, because air is able to escape through vesicular layers beneath the stones. As the soil surface becomes more and more saturated with rain-water, the air escape routes around the periphery of the stones are sealed. When this threshold is reached, the overall effect of the stone cover on rainfall infiltration is reversed. Infiltration on a stone covered slope is now less than on a loess slope cleared of stones, because the stones are impermeable whilst the loess isn't. Since most rains in the Negev are gentle and of rather short duration, this threshold is usually not attained, however, according to Shanan.

It has been measured by Shanan that stone clearance brings about an increase in average annual runoff production of 24 % on 10 % slopes and of nearly 50 % on steeper 20 % slopes (Shanan et al., 1969; Shanan, 1975). Apart from decreased infiltration under gentle showers, another positive effect of stone clearance might be considered. The reduced resistance to runoff overland flow perhaps leads to an overall increase in its velocity. This might result in lower transmission losses and higher runoff yields, which could help to explain the dramatic increase in runoff yield from the steeper 20 % slopes.

Average seasonal runoff yields in the area of the Avdat experimental runoff farm were investigated by Shanan during the years 1964/65 - 1968/69. Data from very small plots (natural stone cover), the southern man-made conduit catchments, and the large natural eastern catchment are presented in Table 6.

TABLE 6. Average annual runoff yields in the catchment area of the Avdat experimental runoff farm, during the period 1964-65 to 1968-69 (average annual rainfall during those years: 94.7 mm * ; based on data from Shanan, 1975).

CATCHMENT SIZE	CHARACTERISTICS (natural stone cover)	AVERAGE RUNOFF YIELD		
		Per unit of area (mm)	Percentage * of rainfall (%)	Absolute quantity (cubic m)
OVERLAND FLOW				
80 m square	1 % Slope	26.3 mm	27.8 %	2.1 m ³
80 m square	10 % Slope	21.8 mm	23.0 %	1.7 m ³
80 m square	20 % Slope	11.4 mm	12.0 %	0.9 m ³
OVERLAND AND CONDUIT FLOW				
1.0 ha	Conduit catchment 5	10.6 mm	11.2 %	106.0 m ³
3.1 ha	Conduit catchment 4	5.4 mm	5.7 %	167.4 m ³
3.7 ha	Conduit catchment 6	5.7 mm	6.0 %	210.9 m ³
4.3 ha	Conduit catchment 7	5.8 mm	6.1 %	249.4 m ³
5.4 ha	Conduit catchment 2	11.7 mm	12.4 %	631.8 m ³
5.5 ha	Conduit catchment 3	4.3 mm	4.5 %	236.5 m ³
7.0 ha	Conduit catchment 1	8.1 mm	8.6 %	567.0 m ³
OVERLAND AND WADI FLOW				
345 ha	Natural Eastern catchment	0.5 mm	0.5 %	1725.0 m ³

Small catchments generally yield more runoff per unit of area than large catchments. The reaction time between the onset of rainfall and the beginning of runoff production is also shorter in the case of small catchments, as compared to large ones. The sizable eastern catchment of the Avdat farm (345 ha) will only yield runoff unto the farm after relatively prolonged rainfall, whereas the smaller conduit catchments (1-7 ha) will already produce some runoff after more gentle rain. However, when runoff does flow in the wadi of the eastern catchment, it usually contributes the largest amounts of water unto the farm in absolute quantities (Photo 3). These variations in reaction time, frequency of flow, and absolute quantity of runoff produced, must all be considered in proper runoff farming design and management.

The conduits that divide the southern catchment of the Avdat farm into smaller sub-catchments (Evenari et al., 1971, 1982) were built by man in



PHOTO 3. Large quantities of runoff water flow through the wadi of the sizable eastern catchment (345 ha) into the Avdat farm.

antiquity (the hillside conduit system, p. 49), presumably for some of the hydrological reasons stated above and below. The differences in runoff yields between the seven sub-catchments of the southern drainage basin are not only determined by individual catchment size, as is clear from Table 6. Variations in surface cover, vegetation, slope angle, length of overland flow, landscape irregularities, quality of the conduits, etc. have their respective influence upon the ultimate runoff yield.

Runoff from catchments is, according to Shanan (1975), adversely affected by overland flow length. An increase in the length of overland flow from 20 to 100 m causes a 50 % reduction in runoff. Small catchments are likewise more efficient producers of runoff. Shanan considers initial water losses, i.e. rainfall required to initiate and transmit runoff, as the most important reasons for these differences. Initial water losses in the investigated catchments amount to 2.5 mm for the small plots of 80 square meters, 5.5 mm for the southern conduit catchments of 1 to 7 hectare, and 7 to 8 mm for the third order eastern drainage basin of 345 hectare. The initial losses in the latter

basin are accounted for by Shanan in the following manner: crust wetting 2.5 mm, overland flow losses 3.0 mm, wadi channel losses 2.5 mm.

These figures from the Avdat area in the Negev are comparable to those found for parts of North Africa. A minimum rainfall of 5 mm is required to initiate runoff in the Mزاب basin in Algeria, and in Egypt a rainfall of 8 mm is necessary to cause a flood (Dubief, 1953; qf. Shanan, 1975).

The flow velocity of shallow runoff overland flows is a key to grasp the significance of the concept of partial area contribution (Yair et al., 1978). In a rough stony environment like the Negev hills runoff flow velocities are low, being in the order of 3-6 cm/sec, seldom exceeding 10 cm/sec (Emmett, 1970; Lavee, 1973). As rainfall duration is usually short in the central Negev hills, surface runoff generated at the upper part of slopes exceeding some 50 m in length probably has little or no chance of reaching the slope base. Only the lower part of the slopes may contribute runoff to a related wadi channel during most rainfall events (Yair et al, 1978).

This principle was apparently well understood by the ancient runoff farmers who designed the conduit system to overcome this particular problem in certain landscape situations. A large catchment can be divided into several smaller ones through the building of conduits, thereby shortening the length of overland flow considerably. Since channel flow in a conduit is much faster than overland flow, more runoff water can thus be harvested from the hillslopes unto the arable fields (p. 49, photo 6).

Whereas the runoff farmer aims to minimize infiltration in the runoff producing-parts of his catchment(s), his strategy changes completely when the runoff water finally flows into the farm lands proper. Here the precious water has to be conserved as good as possible.

The fields are therefore terraced, while check-dams retain the harvested runoff water. Notwithstanding the positive effect of ploughing, infiltration of the runoff water into the loessial soil is a slow process and usually takes one to three days. The height of the lowest part of the check-dam above the ground level, often made up by a spillway, determines the amount of water that is kept on the field. According to experiments, 1 mm of water suffices to moisten 8-10 mm of loessial soil to its water-holding capacity. If 300 mm of water is retained by a check-dam, a loess soil of 2 to 3 meter deep will be fully moistened. After the water has completely infiltrated into the soil, the surface crust will dry out in about 24-36 hours. Once the crust is dry, the soil is rather well sealed to keep the moisture inside for agricultural purposes (Evenari et al., 1971).

RUNOFF FARMING SYSTEMS

A proper understanding and analysis of the landscape is an essential prerequisite in the design of runoff farming systems. Apart from the climate, the landscape must also be suited for rainwater-harvesting agriculture. Man sometimes needs to reshape or alter the landscape in order to improve the setting for runoff farming. The following minimal requirements have to be present in the landscape:

- a) Geomorphic surface conditions must be such that runoff is relatively easy generated by rainfall.
- b) Differences in elevation must be present, so that runoff waters can be concentrated in the lower parts of the landscape.
- c) The runoff receiving landscape parts must have sufficiently deep soils, of suitable texture and structure, to retain and store the received runoff water for agricultural purposes.

Runoff farming systems were classified by the author (Bruins et al., 1986a) in relation to specific landscape properties, as each runoff farming system has to be adapted to a certain geomorphic situation:

1. Micro-catchment system
2. Terraced wadi system
3. Hillside conduit system
4. Liman system
5. Diversion system

The order in which the five systems distinguished here are described is not arbitrarily chosen. It begins with the system of the smallest geomorphic scale and continues successively with increasingly larger systems in landscape settings of greater dimension (Bruins et al., 1986a). From a historic perspective, it should be noted that the micro-catchment system is apparently a new development in the Negev, having been introduced in the last 25 years of this century (Shanan et al., 1970; Evenari et al., 1971, 1982). A kind of liman system already functioned in the area in antiquity, though detailed case studies are lacking. This latter system is used today in the Negev in particular to establish green areas along the roads, planted with trees that provide both shade and improve the architecture of the landscape.

1. MICRO-CATCHMENT SYSTEM.

Rather flat or slightly undulating landscapes often lack a natural distribution of runoff-producing and runoff-receiving areas. These type of landscapes seem, therefore, less suited for rainwater-harvesting agriculture. However, if the soil has the right texture (gravel or coarse sand are out of the question) and is capable of producing runoff, then micro-catchments (Shanan et al., 1970; Shanan and Tadmor, 1979) may be introduced successfully.

Micro-catchments have to be made artificially by man, involving earth movements to create a runoff-producing area and a related infiltration basin. The size of micro-catchments is generally less than one hectare, whereby the infiltration basin, usually a large pit (Photo 4), is dug at the lowest spot.



PHOTO 4. Micro-catchment with fruit tree in the Avdat area. The infiltration basin is filled with runoff water from the glistening runoff-producing part.

In a very flat landscape relatively more work is required to make a runoff-producing and runoff-receiving area, in which trees, pasture or food crops can be planted. When even slight natural slopes exist, and the surface is capable of producing runoff, then a runoff-producing area is already present. It is important to design and built the micro-catchments according to the best fit with the existing landscape contours.

Crop requirements also influence micro-catchment design. Square, rectangular or circular micro-catchments are generally better suited for trees, although food crops or pasture plants can also be grown in this way, appearing as little green islands in the landscape. Longitudinal micro-catchments, following the contour lines, enable mechanization and are often preferred for field crops. Various types and shapes of micro-catchments are reported in the literature, reviewed by Boers and Ben-Asher (1982), who define micro-catchments as having a runoff flow trajectory of less than 100 m from runoff contributing area to the receiving area or infiltration basin.

Of paramount importance is the relationship in size and design between runoff-producing and runoff-receiving area. Enough runoff water must be generated and stored for proper agricultural production. The above relationship depends upon climate, geomorphology, soil and type of crop. A noteworthy advantage of micro-catchment systems is the high specific runoff yield as compared with larger catchments (Shanan, 1975; Shanan and Tadmor, 1979). A disadvantage is the low number of crops per unit area and the enhanced oasis effect as a result.

2. TERRACED WADI SYSTEM.

A terraced wadi system involves the building of a series of low check-dams across a wadi to retain the runoff waters in the stream channel and enable the water to be stored in the wadi soil. The check-dams or dikes were built from local stones put together without cement in single-line or double-line walls. Each individual terrace behind a check-dam ought to be levelled to ensure proper water spreading and storage in the soil. This terracing of the wadi had the effect of transforming a certain part of the valley into a continuous stairway, with stairs perhaps 10-20 meters wide and 20-50 cm high (Hillel, 1982). Hundreds of terraced wadis can be found in the runoff farming district. Suitability of a wadi for this system depends mainly upon the following three factors:

- a) Hydrology of the wadi and its catchment.
- b) The ratio between catchment area and the width (area) of the wadi bed, in which the agricultural fields are to be located.
- c) Soil depth and texture of the wadi bed.

The terraced wadi is probably the most ancient type of a man-made runoff farming system in the central Negev hills by which stream valleys were changed considerably. The profile of a terraced wadi differs markedly from the original shape of the stream channel. Erosion and deposition processes were profoundly changed as a result of terracing. A number of terraced wadis seem to date back to the Israelite Period, nearly 3000 years ago (Evenari et al., 1958; Aharoni et al., 1960; Cohen, 1976). The system does not appear to be confined, however, to a specific age. The investigated wadi of Nahal Mitnan seems to have been terraced in Byzantine times. Bedouin have also engaged in the terracing of small wadis, according to Mayerson (1960b).



PHOTO 5. A terraced wadi, now being eroded, upstream from the Shivta farm.

Small and medium-sized wadis, situated in rather narrow valleys, are generally most suited for this system of runoff farming. The runoff-producing hillslopes ought to rise directly from the sides of the terraced wadi bed. The possible presence of colluvium is a clear disadvantage, which may prevent runoff from reaching the wadi. The terrace dams in the smaller wadis usually lack a spillway and the floodwaters were allowed to overtop the entire length of the check-dam. In the somewhat wider wadis, however, a special spillway was built in the check-dam to prevent erosion. The spillway overflow level from one wadi terrace to the next may be 15 to 30 cm high, depending upon the average frequency and magnitude of runoff events as well as upon the crops to be grown. A spillway level of 25 cm above the field ensures the retention and storage of about 250 mm of water when runoff has filled the wadi terraces.

3. HILLSIDE CONDUIT SYSTEM.

The hillside conduit system is a useful rainwater-harvesting agricultural system in geomorphic situations, by which rather wide stream valleys with good agricultural soils are surrounded by hills having long slopes or colluvium (Bruins et al., 1986a). This system is found regularly in the central Negev hills and seems to date back to the Nabatean-Byzantine period.

When the length of runoff overland flow over a slope is long, water is being lost (Shanan, 1975) or may not even reach the valley fields at all due to the low velocity of overland flow (Yair et al., 1978). Channel flow, on the other hand is rather fast and very little water is lost en route. By building simple ditches as conduits on the hillslopes, the length of overland flow is considerably shortened. Thus a number of sub-catchments are formed. The overland flow in each sub-catchment is determined by the spacing of the conduit channels. The conduits themselves are low walls, simply built from loose stones and soil, having a slope of no more than 1%. The conduits also enable the runoff to bypass possible colluvial deposits, which otherwise might have absorbed (Yair, 1983) part of the runoff waters.

In a number of geomorphic situations more runoff can be harvested through the introduction of conduits. The runoff waters drained by the conduits from the respective sub-catchment (Photo 6) can be directed specifically towards certain agricultural fields, or into cisterns and other storage reservoirs. This regulating aspect of conduit channel flow is another advantage of the system.

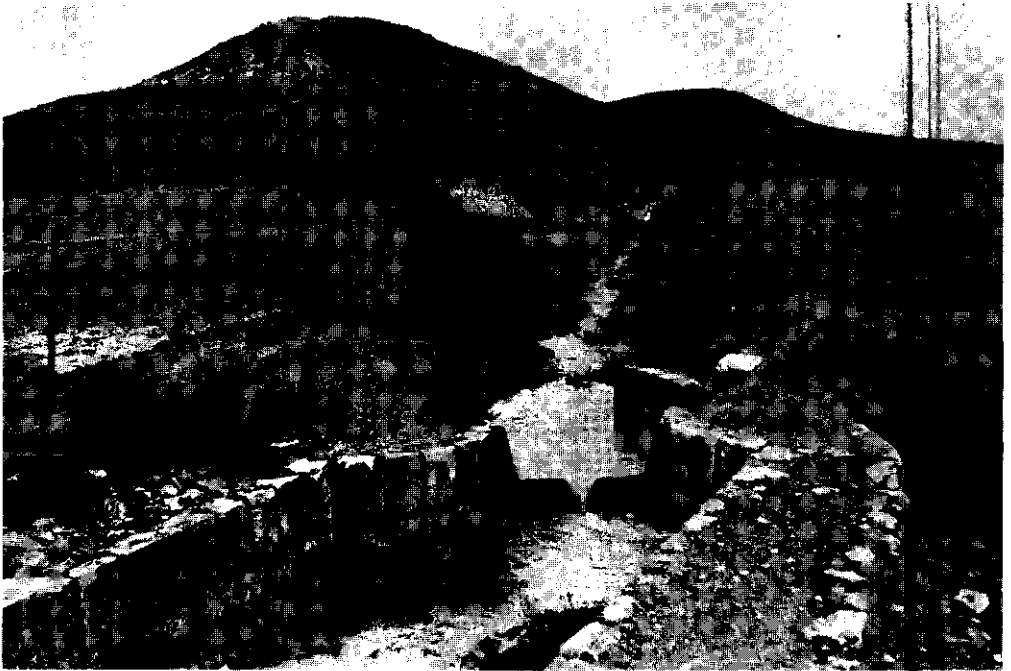


PHOTO 6. Runoff water drained by a hillside conduit flows into the Avdat farm.

The valley soils that receive the runoff water from the conduits for agricultural purposes must obviously be terraced, whereby check-dams and spillways are used to regulate, retain and store the harvested water. The Avdat experimental runoff farm (Evenari et al., 1971, 1982) exhibits a nice example of the hillside conduit system (Photo 6), which is more complicated and generally of a larger geomorphic scale than the terraced wadis.

4. LIMAN SYSTEM.

Wherever tributary wadis, known to carry runoff floodwaters in due season, widen or come unto a large plain with good soils, limans may be constructed. A check-dam is built around the levelled arable land to retain the runoff waters from the wadi. A spillway regulates the level of the water in the liman to prevent the destruction of the check-dam. In larger wadis a series of limans may be built after each other. When the first liman has filled up, the water will flow through the spillway into the second liman and so forth, provided enough runoff water is generated in the catchment area.



PHOTO 7. Limans filled with runoff water at the Wadi Mashash farm.

The term liman is derived from the Greek word "LIMNE" which means lake. A liman just filled up with runoff water looks like a lake indeed (Photo 7). The catchment size of a liman is generally larger than in the preceding systems, though not always. Mini-limans can also be made (Bruins et al., 1986a).

At the Wadi Mashash experimental runoff farm in the Negev, altogether 10 hectares of limans have been established, planted with fruit and fuel trees (Evenari et al., 1982). Most of the limans function in a successful manner. Many more limans have been constructed in the Negev by the authorities, generally along the main roads for landscaping purposes.

5. DIVERSION SYSTEM.

In landscape situations where large areas of potential arable land are found at an elevated position with respect to the stream bed of an adjacent wadi, it becomes necessary to build more intricate structures in order to divert the runoff floodwaters onto the fields. For this purpose a dam must be constructed in the wadi, upstream from the planned fields, at a point where

the level of the wadi bed is at a sufficiently higher elevation than the fields under consideration. At this point a dam is built to raise the floodwaters. A low threshold dam may often be sufficient. A diversion channel is excavated from the dam towards the planned agricultural fields. The gradient of the diversion channel must obviously be less than the actual wadi and the adjacent terrace plains. If this precondition is successfully implemented, the diversion channel will emerge further downstream unto the surface of the arable lands, which, from hereon, can be irrigated with diverted floodwaters.

Three ancient diversion systems in the runoff farming district, along Nahal Lavan, Nahal Avdat, and Nahal Mamshit, were studied in detail by Shanan et al. (1961). The largest and most striking example of a diversion system in the Negev is that of Nahal Lavan, near the Nabatean-Byzantine town of Shivta. The terraced agricultural fields comprise here an area of about 200 hectares, showing massive ancient walls with spillways of 30-60 meter in length.

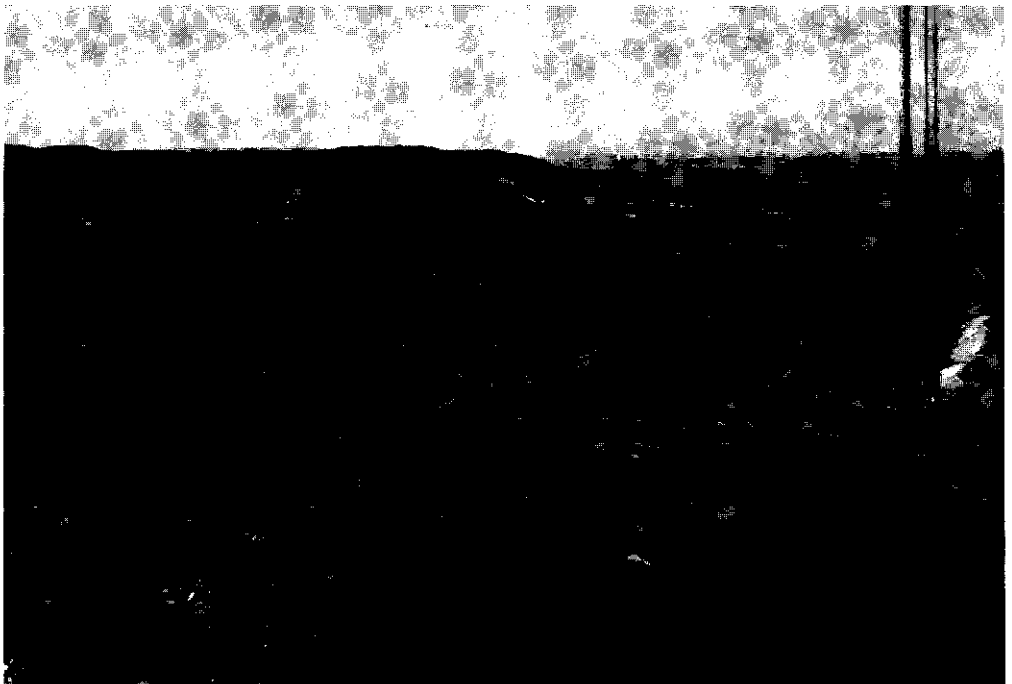


PHOTO 8. Modern diversion channel, 700 m long, departing from Nahal Avdat onto a cultivated area of 6 ha, amidst many remains of ancient runoff farming, as well as modern micro-catchments, belonging to the Avdat runoff farm.

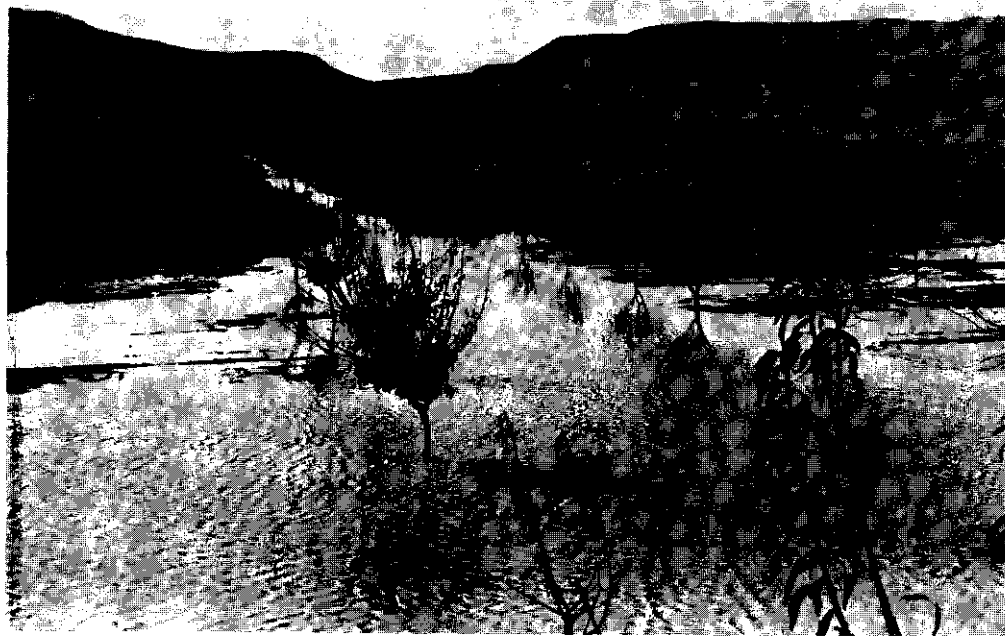


PHOTO 9. Runoff water flowing from this diversion channel into the farm lands.

The handling of large flows of diverted water in these diversion systems required undoubtedly greater skill and sophistication than the operation of small runoff farms. Maintenance of these systems often became increasingly difficult due to silting up problems, necessitating the construction of new diversion structures, beginning higher upstream, to ensure the gravity flow of diverted floodwaters toward the fields (Shanan et al., 1961; Hillel, 1982).

In the last ten years a diversion system has been set up near the Avdat experimental farm, constructed by David Mazig (Evenari et al., 1982). An approximately 50 cm high threshold dam was built at an appropriate place in Nahal Avdat. From this dam a 700 meter long diversion channel was excavated into the Late Pleistocene loessial terrace deposits of Nahal Avdat (Photo 8). Since the diversion channel has a smaller gradient than the wadi and its adjacent terrace plain, the channel bottom reaches the surface of the cultivable lands after about 700 m (Photo 9). A loessial serozem soil, exhibiting a well developed calcic horizon, can be seen in certain parts along the sides of the diversion channel.

When there is a flood in Wadi Avdat, the threshold dam raises the level of

the water, enabling the precious liquid to flow into the diversion channel. The diverted floodwaters flow through the diversion channel and finally emerge onto the farm lands of the Late Pleistocene loessial terrace of Wadi Avdat (Photo 9). In addition, runoff water from a tributary wadi of Nahal Avdat is also conducted onto the same arable lands. The agricultural fields are surrounded by check-dams and interconnected via spillways. An area of 6 hectare of desert land is cultivated in this manner, planted with pistachio and almond trees. A desert park has also been laid out for recreational purposes (Evenari et al., 1982).

Micro-catchments surrounded by low earth bunds were constructed alongside of the diversion channel, particularly in the terrain that gradually descends towards the channel. The infiltration basins of the various micro-catchments appear as little dots on Photo 8. Apart from the agricultural objectives, the micro-catchments help to check erosion caused by undesired runoff flows from this sloping land toward the side of the channel. In this manner, different runoff farming systems are not only adapted to local conditions, as dictated by the geomorphic make-up of the area, but also may protect each other in erosion control.

4 Pastoralism

NOMADIC PASTORALISM AS A SPECIALIZED FORM OF A FOOD-PRODUCING ECONOMY

Pastoralism has been an important form of land-use in the arid Negev during historical times. However, the practising of livestock herding, either by a nomadic, semi-nomadic or sedentary population, is often hard to grasp in archaeological and historic terms. As a food-producing system in the area, pastoralism cannot be disregarded in the context of this dissertation. Besides the available data from the Negev, mentioned below, the origins and various forms of pastoralism in the region at large are treated in a somewhat wider historic and geographic perspective.

Nomadic and semi-nomadic livestock rearing has been practised widely in the great arid belt that stretches from the Atlantic coast of the Sahara to the steppes of Mongolia. In terms of man-land relationships extensive livestock rearing often developed in marginal environments where food production through crop cultivation is either impossible or a rather risky undertaking. Hence the natural vegetation is harvested through the grazing animals and is thus transformed into milk, meat and other useful products for man. As such, mobile extensive pastoralism can be fully regarded as a specialized form of a food-producing economy (Khazanov, 1985).

There are, however, a large number of possible interrelationships between livestock rearing and crop cultivation. This ratio of pastoralism and agriculture not only depends upon the environment, but also upon various economic, social and political factors. The influence of these latter aspects is exemplified by the fact that pastoral nomads may live in areas fit for cultiva-

tion, while not engaging significantly in agriculture if at all (Cunnison, 1966; Marx, 1982). "Pure" pastoralists can only develop within a complex economic system, of which they are an integral part. They produce luxury food for an urban or well-to-do rural population. This kind of pastoralism is quite distinct from "subsistence pastoralism", which is usually a combination of livestock rearing and farming (Marx, 1986, personal communication).

Pastoralists hardly ever subsist directly on their animals, as far as their diet is concerned. If their food was only composed of eating their livestock and its products, they would require very large herds indeed (Marx, 1982). Pastoral specialization has meant more or less economic one-sidedness and no autarky, as pointed out by Khazanov (1985:3) in an excellent and comprehensive study about nomads and the outside world. He states that nomads could never exist on their own without the outside world and its sedentary societies and different economies. Marx (1982) argues that animals are not merely produced in a pastoralist society, because they contribute to the diet of their owners, but rather for sale or for exchange against grain or other goods. Cereals often constitute the staple food of many pastoralists.

Khazanov (1985:16) defined the most important characteristics of pastoral nomadism:

1. Pastoralism is the predominant form of economic activity.
2. Its extensive character is connected with the maintenance of herds all year round on a system of free-range grazing without stables.
3. Periodic mobility in accordance with the demands of a pastoral economy in specific grazing territories.
4. The participation in pastoral mobility of all or the majority of the population.
5. The orientation of production towards the requirements of subsistence. (Khazanov remarks that this fifth characteristic today no longer applies in many cases, as pastoral nomads have been drawn into the world market system.)

The most important problem of pastoral nomadism is the balance between availability of natural resources, number of livestock and population-size (Barth, 1964; Khazanov, 1985). The thesis is put forward by Barth (1959/60:8) that: "Unless techniques for the storage of fodder are developed, absolute population-size is limited by the carrying capacity of the pastures in the least productive period of the year." (cf. Khazanov 1985:70). Not only the

intra-annual shortages of pasture should be taken into account, but also the inter-annual frequency of drought years.

Pastoralism in the central Negev without any feed reserves or supplementary supplies has led to overgrazing, in the absence of a coordinated policy. In good years the flocks would multiply, and in drought years their numbers would exceed the dry range's carrying capacity. During a succession of droughts the Bedouin flocks would be decimated, while their owners would be impoverished for years. Their plight could be so desperate that the semi-nomads or nomadic desert dwellers, driven by starvation, would enter more humid sedentary areas in search for food (Hillel, 1982). An example of such an incident, although not necessarily related to a drought, is reported by Bailey (1980) to have occurred during the Ottoman period in 1877: "troops fired upon the bedouins as they were carrying off crops near Gaza..."

In a larger perspective, that includes Africa, Le Houérou (1985) is pessimistic about the present impact of man in pastoral areas. Many factors, such as overstocking, wood cutting, human and animal population expansion, contribute to intensify the pressure on grazed ecosystems. These, in turn, become less resilient and less able to absorb climatic droughts, which they used to do under the light exploitation conditions of the past centuries.

Le Houerou (1985), who wrote the article in 1982, remarked that if this situation persists, one can only predict a gloomy future for pastoralism. Nomadic pastoralism will either have to disappear quietly or evolve towards other systems of animal production with increased reliance on supplementary feedings for longer and longer periods. Khazanov (1985:71,76) is equally pessimistic: "Pastoral nomadism is doomed to stagnation because its economy is extensive... Increased production in nomadic society as a whole is, to any significant extent, impossible".

PASTORALISM AND AGRICULTURE

Pastoral nomadism proper is in its most pure manifestation characterized by the total absence of agriculture. Semi-nomadic pastoralism is much more widespread throughout the world. Its predominant activity is also composed of extensive pastoralism and the periodic changing of pastures, but agriculture is practised as well in a secondary and supplementary capacity. There are, however, many other forms of pastoralism, which are somehow integrated with agricultural practices. Although there seems to be a clear lack of

detailed historic and archaeological information about these relationships in the Negev in antiquity, some of the systems described by Khazanov (1985:19) may actually have existed here in the past, used either by the Bedouin (Marx, 1967) or by the sedentary runoff farmers:

1) SEMI-SEDENTARY PASTORALISM differs most fundamentally from semi-nomadic pastoralism in the sense that agriculture plays the predominant role in the general economic balance.

2) HERDSMAN HUSBANDRY or DISTANT PASTURE HUSBANDRY describes the situation in which the majority of the population leads a sedentary life and is occupied for the most part with agriculture. The livestock or, more often, some of it, is tended all year round by herdsman especially assigned to this task. They maintain the herds on pastures, sometimes quite far from the settlements. For part of the year the animals are usually kept in enclosures, pens and stalls, which entails the laying-in of fodder.

3) SEDENTARY ANIMAL HUSBANDRY usually supplements agriculture and has different variants.

a) HOUSEHOLD-STABLE ANIMAL HUSBANDRY is one of these variants. It is characterized by the grazing of livestock in pastures adjacent to the settlement for part of the year, whereby the animals usually return every day. For the other part of the year the livestock are kept in stables and enclosures and fed accordingly.

b) SEDENTARY HOUSEHOLD HUSBANDRY WITH FREE GRAZING is yet another variant of sedentary animal husbandry. This is genetically one of the most primitive and ancient forms of pastoralism in which the laying-in of fodder and the maintenance of livestock in enclosures or stables is generally absent or very limited (Khazanov, 1985).

The technical problems and organizational requirements of a possible integration between runoff farming and animal husbandry in the central Negev in antiquity are eloquently described by Hillel (1982:187):

"All the evidence at hand leads to the conclusion that the ancients, especially during the Nabatean-Roman-Byzantine epoch, maintained a diverse agricultural economy in the central Negev, with cultivation and grazing carried out simultaneously. Since roaming livestock could devour and trample crops, destroy runoff-collecting conduits, accelerate erosion of slopes, and induce

silting and pollution of cisterns, undisciplined grazing has always been a menace to farming. Only an organized and coordinated society could resolve and integrate such potentially contradictory activities as farming and grazing, as well as land and water rights, so as to avoid conflict and damage."

No such coordination existed, in the opinion of Hillel (1982), from the Early Arab period until the establishment of the State of Israel. The tribes of Bedouin that inhabited the region could not be certain of long-term land ownership, because of intermittent struggles over territorial rights. Bailey (1980) collected material about such situations of internal warfare between the Bedouin tribes during the 19th century, based upon oral traditions of the Bedouins themselves.

THE ORIGINS OF PASTORALISM

Most authorities agree that pastoral nomadism did not evolve from hunting and food gathering societies. It rather developed as a specialization out of sedentary agriculture (Grigg, 1974). Its sources go back to the Neolithic revolution and the emergence of a food-producing economy, which basically always consisted of two forms of economic activity: crop cultivation and animal husbandry. As pointed out by Khazanov (1985), only groups leading a relatively sedentary way of life with definite surpluses of vegetable food at their disposal could domesticate animals.

In a study about the emergence of specialized pastoralism in the southern Levant, Levy (1983) points out that during the Late Neolithic, some 6000-7000 years ago, crop cultivation and livestock grazing in the northern Negev is clustered around springs, in year-round grazing areas. The maximum grazing range of sheep away from these springs is about 5-8 km. This might be considered as a form of household animal husbandry with free-range grazing, as described above.

With population growth and the development of a new agro-technology, the subsequent Chalcolithic settlements moved further into the more arid inland valleys, probably using runoff floodwaters for crop cultivation. It would have been a physiological necessity for village communities in the inland valleys to move sheep or goat herds to the more humid coastal plain on the arrival of the dry summer season. The temporary nature of Chalcolithic settlement on the coastal plain indicates, according to Levy, the primarily pastoral nature of these camps as part of a newly developed subsistence strategy, in which sheep

and goat herds owned by permanent villages were moved north-westward for grazing during the late summer and early winter months. This development of sedentary pastoralism during the Chalcolithic (4000-3200 B.C.) marked the emergence of the traditional system of land-use and herd-management in the Northern Negev, which matured during the Early Bronze Age (3200-2200 B.C.) and lasted until the 20th century (Levy, 1983).

This system has the following characteristics:

1. Grazing by mobile herds of small livestock (sheep and goat) combined with the dry-land cultivation of winter cereals (wheat and barley) whenever and wherever possible.
2. No significant use of irrigation water, fertilization or supplementary feeds.
3. The grain and livestock products are primarily used for the subsistence of the local population, although surpluses are traded or exchanged in favourable years (Noy-Meir and Seligman, 1979; cf. Levy, 1983).

The adaptation of a food-producing economy to a specific habitat led, especially in arid zones (Le Houérou, 1985) to the predominance of pastoralism over other forms of agriculture. Apart from social and political factors, it can be said (Khazanov, 1985:69) that pastoral nomadism and semi-nomadic pastoralism developed and functioned in the first instance in those regions where they had economic advantages over all other kinds and forms of economic activity. Khazanov considers that climatic changes played an important role in the emergence of many types of pastoral nomadism, but economic and cultural preconditions were also necessary.

The Arabian peninsula was the major centre of nomadization in south-west Asia and its role was similar to that of the Sahara to the development and dissemination of African nomadism. Just as in the Sahara, cattle appears in Arabia in the sixth millennium B.C. and small stock appears in the fourth and third millennia B.C., when pastoralism becomes the predominant economic activity. Sheep and goat definitively replaced cattle in Central Arabia from the end of the third millennium B.C. Herdsman husbandry and semi-nomadic pastoralism existed in the Near East during the third and second millennia B.C., but in no way was there real nomadism.

The climate of Arabia altered at about the same time as the climate in the Sahara did (McClure, 1971). It is not known how the desiccation which began about 2500 B.C. and *grosso modo* continues until the present (Pearse, 1971;

Maley, 1973; Flohn and Nicholson, 1980; Nicholson and Flohn, 1980) affected the ancient pastoralists of Arabia. Perhaps one consequence of it was the movement of pastoralists to the borders of agricultural areas (Oates, 1976). What is clear, however, is that the "bedouinization of Arabia" or the final stage of the formation of real pastoral nomadism in Arabia was linked to the beginning of the utilization of the camel as a riding animal (Khazanov, 1985):

"It was only specialized camel-herding, which began in Arabia somewhere in the middle of the second millennium B.C. and was possibly stimulated by the desiccation of the peninsula, which led to the dissemination of real pastoral nomadism in the inner regions of Arabia and Syria. Already in the eleventh century B.C. the Midianites, Amalekites and "children of the East" stormed through Jordan into Palestine (Judges 6:1-6), "...for both they and their camels were without number" (Judges 6:5). According to Dostal (1959:22) their invasion was linked to the perennial problems faced by nomads: the desire to extend grazing territory for the increasing numbers in their herds, the need of agricultural products and of trade with sedentary societies, etc." (Khazanov, 1985:100).

Le Houérou (1985) wrote an excellent article about the impact of climate on pastoralism, dealing with specific quantitative aspects of pastoral man-land relationships. The development of pastoral nomadism in the Near East is summarized by Khazanov (1985:102) in the following way. Nomadic pastoralism evolved out of a mixed economy of crop cultivation and animal husbandry, passing through the stage of extensive herdsman husbandry and/or semi-nomadic pastoralism. The earliest forms of extensive pastoralism were in the first instance based upon the herding of small livestock. The camel gradually gained an important position in the economy as food, as well as for transport and riding purposes. The immediate transition to pastoral nomadism in its traditional economic forms, at least with regard to species-composition of herds and methods of their utilization, was probably linked to specific changes or variations of climate. Finally, nomads were linked right from the beginning in a complex system of peaceful and hostile relations with sedentary states (Khazanov 1985:102).

The rather scanty historic information about the interrelationships in the Negev between nomadic or semi-nomadic Bedouins and the sedentary runoff farming population, including travellers, is described by Mayerson (1963, 1964) for the Byzantine and Early Arab period. Marx (1967, 1977, 1982) and Baily (1980) have studied contemporary Bedouin life in the Negev and its recent history.

5 Horvat Haluqim

ENVIRONMENT

GEOMORPHOLOGY AND GEOLOGY

The site of Horvat Haluqim exhibits a classic example of an ancient terraced wadi system (p. 47), constructed for runoff farming purposes well before the Nabatean period, as indicated by archaeological excavations (Cohen, 1976) and investigations by the author in one of the terraced fields. The remains of the ancient agricultural village are situated on the southern slopes of the Haluqim anticlinal range, some 4 km to the north of the canyon-like Zin Valley which constitutes the most dramatic geomorphic feature in the area. The hills of Har Haluqim, rising to an altitude of 618 m, are part of the Southwest-Northeast trending fold belts of the northern Central Negev.

Two modern settlements, Kibbutz Sede Boqer and Midreshet Ben-Gurion, are situated to the south of Horvat Haluqim in the adjacent synclinal plain of Sede Zin, at an altitude of 470-475 m. Their respective distances to the site are about 1.5 km and 4.5 km. The road from Sede Boqer to Yeroham forms the de facto southern border of the site. The synclinal plain of Sede Zin is largely covered by Late Quaternary loessial deposits (Issar et al., 1984) of the Netivot Formation (Bruins et al., in preparation).

The site of Horvat Haluqim comprises three small tributary wadis (Photos 1, 10, 12; Fig. 9) of Nahal Haroa, which drain part of a hill composed of Upper Cretaceous carbonate rocks. The wadis are of the first to second order and begin at an altitude of about 530-540 m at the upper slopes of a rather flat, east-west trending hill top axis, which is about 200 m wide. The length of the wadis from their inception until the road is in the range of 500 to 600 m.

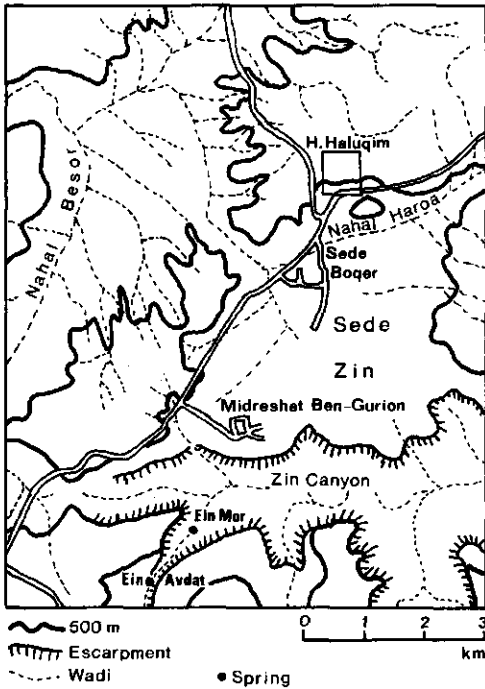


FIG. 8. Location of Horvat Hалуqim.

Their average width ranges from less than 5 m up to 25-30 m. Initially the stream beds are narrow as the wadis descend from about 540 to 520 m. When the wadi beds widen and their gradient diminishes, ancient agricultural terraces appear, usually beginning at an altitude of some 515-520 m. Henceforth the wadis are terraced until the vicinity of the road, whilst their beds gradually descend to an altitude of about 495 m.

The lithology of the hill drained by the three wadis is dominated by the Nezer Formation of Late Turonian age, characterized by well bedded lithographic limestone and minor chalk layers (Arkin and Braun, 1965), having a southward dip of about 6°.

The natural jointing pattern and the individual thickness (about 30 cm) of the hard micritic limestone layers makes the Nezer Formation suited for local building stones that are easily quarried and handled (Photo 11), and which were used in the past. Turonian rocks of the underlying Shivta Formation are exposed along the lower part of the stream-valley slopes, above the three mentioned wadis. The Shivta Formation consists of poorly bedded calcarenitic limestone layers.

CLIMATE

The site is situated in close proximity to the nearby meteorological station of Sede Boqer. Climatic data from the latter station, belonging to the Israel Meteorological Service, are quoted from Arzi (1981). The average annual rainfall is 94 mm, measured in the period from 1951/1952 to 1979/1980. Inter-annual variations fluctuated from a minimum of 30.9 mm to a maximum of 167.3 mm per year. The average number of rainy days amounts to 26 per year; the range of annual variation lies in between 11 and 36 rainy days. The yearly temperature average is 18.2 degrees Celsius. Average daily temperatures in the coldest month (January) range from 3.9 °C at night to 15.4 °C in the daytime,

TABLE 7. CLIMATIC DATA FROM THE SEDE BOQUER METEOROLOGICAL STATION. *

	OCT	NOV	DEC	JAN	FEB	MAR	APR
RAINFALL (mm)	2.6	9.5	22.4	23.3	15.7	11.9	7.2
RAINY DAYS	0.8	2.8	5.3	6.5	4.3	3.8	2.0
TEMPERATURE (°C)	20.6	16.0	11.4	9.6	11.6	13.6	17.0
RELATIVE HUMIDITY (%)	60	62	68	70	64	58	53
EVAPORATION (mm/day)	6.0	4.0	2.9	3.1	3.8	5.1	7.3
EVAPORATION (mm/month)	186	120	90	96	107	158	219
WIND DIRECTION	N	N	NE	W	W	N	NW

	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL OR AVERAGE
RAINFALL (mm)	0.7	0.2	0	0	0	93.5
RAINY DAYS	0.4	0.1	0	0	0	26
TEMPERATURE (°C)	20.9	24.2	24.8	25.3	23.6	18.2
RELATIVE HUMIDITY (%)	43	45	53	57	62	58
EVAPORATION (mm/day)	9.4	11.0	10.7	10.1	8.3	6.8
EVAPORATION (mm/month)	291	330	332	313	249	2491
WIND DIRECTION	N	NW	NW	NW	NW	NW

* Modified from Arzi (1981).

All data are average figures, derived from the Israel Meteorological Service (Climate Department): Rainfall data and the number of rainy days are from a 29 year period (1951/1952 to 1979/1980). Temperature and relative humidity data are from a 10 year period (1952-1956 and 1964-1969). Evaporation data of an open water surface were measured in a Class A Evaporation Pan, up-to-date until 1972/73 (Last, 1978). Wind direction data are from 1974-1975.

and in the hottest month (August) from 17.8 °C at night to 32.8 °C in the day. Maximum temperatures reach sometimes values of over 40 °C.

The relative humidity is on the average 58 %, ranging from a monthly low of 43 % in May to a maximum of 70 % in January. Total annual evaporation from an open water surface amounts to some 2500 mm, measured in a Class A Evaporation Pan (Last, 1978, qf. Arzi, 1981). The potential annual evapotranspiration is 1917 mm (Arzi, 1981), calculated according to Stanhill (1961). Detailed monthly climatic data are presented in Table 7, modified from Arzi (1981).

HYDROLOGY

The hillslope hydrology of a somewhat similar area as Horvat Haluqim, situated on the same anticlinal range, has been studied in detail by Yair (1981) and his collaborators. Their main conclusions from the Sede Boqer experiment site, some 4 km southwest of Horvat Haluqim, about runoff generation and its flow down the hillslope can be summarized as follows: (1) Bedrock areas respond more quickly to rainfall than do soil covered areas. (2) An integrated flow of runoff along the entire slope, that includes a colluvial part toward the bottom, is quite rare under the present rainfall conditions in the area (Yair, 1983).

On the hillslopes studied by Yair, three geological formations are successively exposed from top to bottom: the Nezer, Shivta, and Drorim Formations. Deep colluvial deposits occur at the base of the slopes. Although the two sites appear in a similar landscape setting, there are some important differences.

The Drorim Formation, which appears to be less runoff productive than the other geological formations (Yair, 1981:242), does not crop out at the Horvat Haluqim site. Colluvial deposits at the base of the slopes are virtually absent at Horvat Haluqim and thus cannot obstruct runoff flows from reaching the wadi bed. Moreover, the upper part of the Shivta Formation, which shows the best runoff production at the Sede Boqer experimental site, is exposed at an advantageous geomorphic position at Horvat Haluqim: at the lower part of the hillslopes just above the three wadis. The shape of the hillslopes at Horvat Haluqim is usually convex, having a maximum gradient of about 20-25 degrees, generally at their lower part toward the wadis. Average slope length from interfluvium to wadi bed is about 100 m on the hilly spurs that separate the three wadis from each other.

Considering the outcome of the research conducted by Yair and his colleagues at the Sede Boqer site, it seems that the three wadis of Horvat Haluqim are endowed with an advantageous runoff-producing and runoff-conducting catchment. Although the catchments are relatively small, obvious for stream channels of the first and second order, their geologic and geomorphic properties appear well suited for runoff farming.

SOILS AND VEGETATION

This preliminary conclusion seems substantiated by the dense wadi vegetation, which is in sharp contrast to the scattered shrubs on the rather barren hillslopes (Photo 1, p.30). The sedimentology and soil development of the

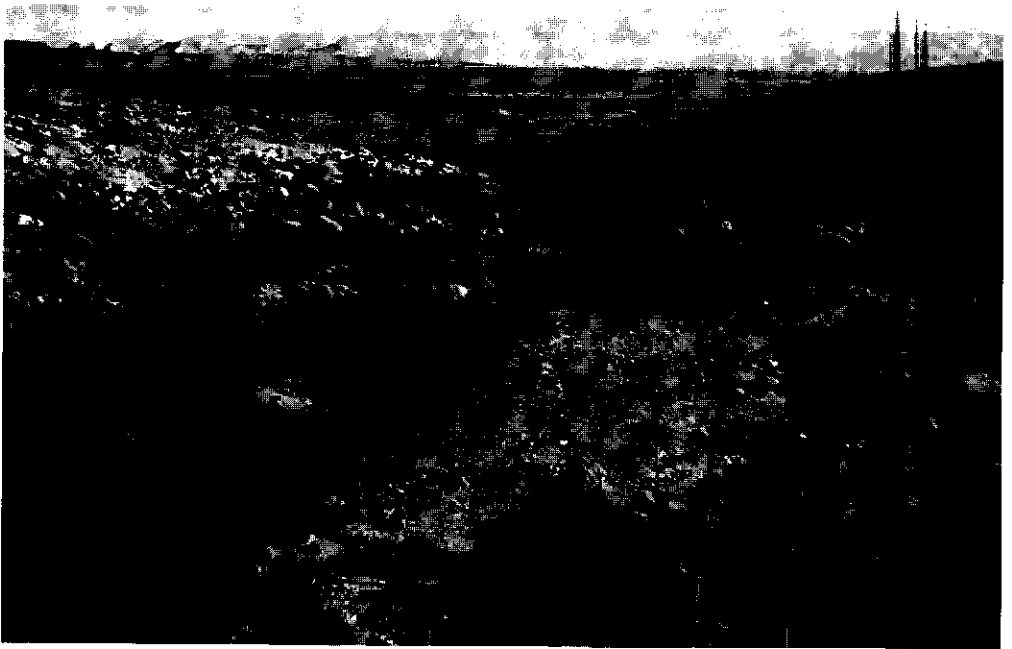


PHOTO 10. View from one of the terraced wadis at Horvat Haluqim, overlooking the synclinal Zin plain towards the elevated Eocene Avdat plateau.



PHOTO. 11. Hard limestone beds of the Nezer Formation, easily quarried.

alluvial wadi deposits at Horvat Haluqim were investigated in detail in one of the man-made terraces. The results are presented in a following sub-chapter.

The soil cover on both the Nezer and Shivta Formations is limited, patchy and shallow. Bare rock outcrops occur frequently throughout the hilly catchment of the three wadis. The shallow lithosols on the hills are dominated by the *Artemisia herba-alba* - *Gymnocarpos decander* and *Hammadetum scopariae* associations, the latter being characteristic for the driest habitats with the worst moisture-retention regimes.

Deeper brown lithosols with significant soil moisture amounts exist in patchy rock crevices near bare rock outcrops, as a natural mini-variety of the micro-catchment system in runoff farming. The *Varthemia iphionoides* - *Origanum dayi* association occurs at these most favourable runoff receiving "mini infiltration basins" on the hillslopes (Yair and Danin, 1980; Danin, 1983:40-41).

The salinity (EC) of lithosol A-horizons at the Sede Boqer site, investigated by Arzi (1981), ranges from 0.4-3.9 mS/cm. The salinity usually increases somewhat in the subsoil, if there is a subsoil at all.

The serozems that developed in the colluvium at the base of the slopes are much more saline in the deeper subsoil. The electrical conductivity (EC) reaches here a maximum value of 26 mS/cm (Arzi, 1981). An article about similar colluvial deposits at the Haluqim anticlinal range, which includes soil stratigraphic data and their paleoclimatic implications, is currently in press (Issar et al., 1986).

The Late Quaternary Serozem soils developed in the loessial deposits of the Sede Zin syncline are also very saline. The A-horizon has an EC of about 1.4 mS/cm, whilst values of 42 mS/cm already occur at a depth of 25 cm. Gypsic horizons are also found in these soils. Young alluvial loess soils on the Sede Zin plain have a very low salt content (Dan et al., 1973; Dan, 1981).

ARCHAEOLOGY OF HORVAT HALUQIM

The site extends along the three mentioned tributary wadis of Nahal Haroa (Figure 9). Archaeological excavations at the site were conducted by Rudolph Cohen (1976). The remains consist of a small fortress and a settlement which includes 25 buildings, 4 cisterns and related agricultural terraces. Apart from two buildings ascribed to the 2nd-3rd centuries A.D. (Roman period), most of the other remains are attributed by Cohen (1976) to the 10th century B.C. (Israelite period).

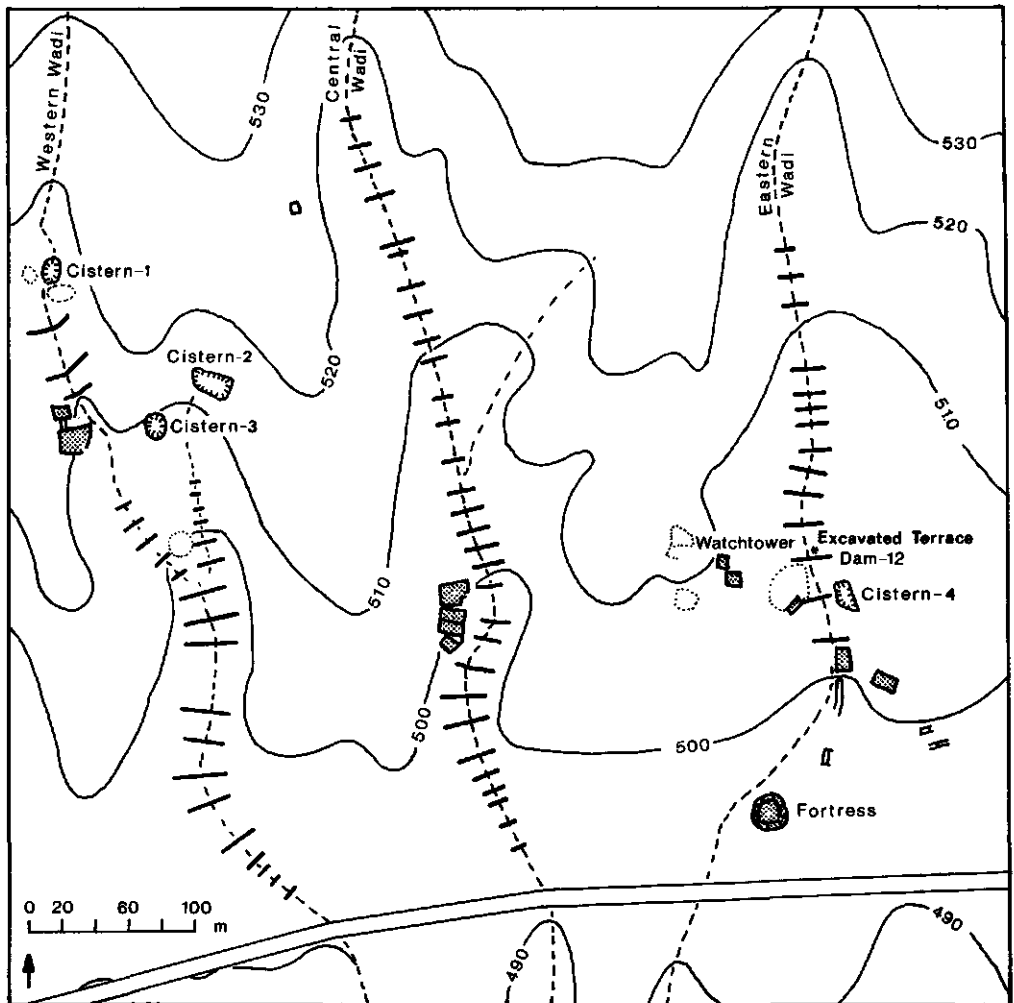


FIGURE 9. Plan of the Horvat Haluqim site (modified after Cohen, 1976, 1981), showing the location of the fortress, the watch-tower, various buildings, cisterns, and the three wadis with their terraced fields (surveyed by the author). The geography of the site can be summarized as follows:

ALONG THE EASTERN WADI:

Fortress	23 x 21 m	40 m N of the road	10 m East of the wadi bed
Building	8 x 8 m	90 m NE of the fortress	25 m East of the wadi bed
Building	14 x 9 m	90 m NNE of the fortress	Just East of the wadi bed
Cistern	18 x 8 m	130 m NNE of the fortress	10 m East of the wadi bed
Building	10 x 10 m	140 m NNW of the fortress	45 m West of the wadi bed

ALONG THE CENTRAL WADI:

Several buildings 180 m NW of the fortress Just West of the wadi bed

ALONG THE WESTERN WADI:

Cistern 22 x 12 m 420 m NW of the fortress 65 m East of the wadi bed

Cistern 11 x 11 m 440 m NW of the fortress 25 m East of the wadi bed

Cistern 14 x 9 m 540 m NW of the fortress Inside the wadi bed

Building 10 x 8 m 480 m NW of the fortress Just West of the wadi bed

Some of the 25 recorded buildings, belonging to the settlement, were excavated by Cohen (1976). The fortress has a roughly oval plan (about 21-23 m in diameter) and includes 7 casemate rooms around a central courtyard (Photo 12). Only the foundations of the fortress walls of Horvat Haluqim were found to be preserved, resting on the limestone bedrock of the Nezer Formation. The walls are built from local, roughly-hewn limestone blocks. The size of the casemate rooms varies from 1.5-2 m in width to 5.5-8 m in length (Cohen, 1976). The shape of its ground-plan is similar to the Early Fortress at Kadash-Barnea and other fortresses in the region (Cohen, 1980, 1981, 1983).



PHOTO 12. The western casemate room of the fortress at Horvat Haluqim.

Cohen (1980:77) admits that "the fundamental problem of the early fortress network is its date". Radiocarbon dates from the tell at Kadesh-Barnea, partly published in Chapter 8, seem to suggest that the Early Fortress at the latter site may have been erected in the Late Bronze or Early Iron age. The apparent similarity in architectural style and shape of the groundplan between the Early Fortress at Kadesh-Barnea and the fortress at Horvat Haluqim (Cohen, 1980) raises the question whether the early fortress network might date to the Late Bronze or Early Iron age. Cohen (1980) mentions the different archaeological opinions in this matter, by which Rothenberg (1972) seems to favour a Late Bronze age for the ceramic complexes involved.

Recent advances in the calibration of radiocarbon dates from conventional C-14 years into historical years (Chapter 8; Pearson, 1986), may lead to a situation in which the outcome of controversial stratigraphic problems in archaeology, based on ceramics or architecture, will be resolved by radiocarbon dating on the basis of chrono-stratigraphy. The dimension of time is indeed the absolute basis in stratigraphy and the impartial arbitrator in all aspects of stratigraphic research. Only time allows for the juxtaposition of contemporaneous events in history, archaeology, climate, and landscape.

In the absence of such a detailed chrono-stratigraphy for Horvat Haluqim, the age of the site will be referred to in accordance with the general opinion of Cohen (1976), as Iron age, bearing in mind the raised question that some parts of the site may be older perhaps. Two buildings at the site are actually younger and belong to the Roman period. The Roman watch-tower, situated 140 m NNW of the fortress, is the best preserved building at Horvat Haluqim. The walls are built of large hewn stones and are 1 m wide.

WATER SUPPLY IN THE PAST

The nearest spring in the vicinity, fed by a natural flow of shallow groundwater, is the brackish spring of Ein Mor in the Zin Valley, some 7 km south of Horvat Haluqim. The water of this spring is all right for animals, but is considered too saline for regular human consumption. The necessary water supply for the former inhabitants of Horvat Haluqim, therefore, had to come from runoff rainwater, caught and stored in cisterns.

The four cisterns located in the settlement are built of large rough stones. All cisterns, except the one located inside the wadi bed of the western stream valley, are silted up to the brim. Three large piles of silt

next to the latter cistern, which still may fill with water in the rainy winter season, indicate that it was cleared a number of times in the past. This cistern is oval in shape (9 x 14.5 m), with walls 1 m wide and preserved to a height of 4 m. Its estimated water-holding capacity amounts to some 300 cubic metres of runoff water (Cohen, 1976).

As the other three cisterns are completely silted up, it is more difficult to assess their water holding capacity. Their combined volumes are conjectured to be some 1100 cubic metres. If all the cisterns would have filled up during the rainy season, approximately 1400 cubic metres of water could have been stored within the settlement in the past. In a drought year, probably much less runoff water could be harvested and stored, perhaps less than a third of the estimated storage capacity, e.g. some 300 cubic metres. How many people could have lived on such amounts?

Assuming a daily water requirement of 10 liter per capita (Evenari et al., 1971; Broshi, 1980), which is a rather low quantity, 300 cubic metres of water might have supported the minimal needs of some 80 people. An amount of 1400 cubic metres, possibly stored in wet years, might have been sufficient for a population of 380. An assessment of past population levels must be based, however, apart from other considerations, upon minimal figures in dry years (Mayerson, 1967; Broshi, 1980), as it was difficult to bring in any significant quantities of water in antiquity. Moreover, the water needs of possible flocks and other animals in the village must also be taken into account, besides evaporation losses that can amount to 2.5 meter/year (Table 7), if the water surface of the cisterns was fully exposed. It seems, therefore, that the past population of Horvat Haluqim was probably less than 80 people.

ANCIENT RUNOFF-FARMING WADI TERRACES AT HORVAT HALUQIM

The terraced fields in the wadis are in all likelihood contemporaneous with many of the other structures within the settlement. The siting of a number of houses at Horvat Haluqim seems to have been chosen to facilitate easy access to the cultivated fields in the terraced wadis, as already noted by Cohen (1976). If not for the practising of runoff farming, there appears to be no logical explanation for the location of these houses in the settlement. Horvat Haluqim seems to have been a small agricultural village with a defensive posture, if the fortress is contemporaneous with the terraced fields.

The number and dimensions of the check-dams and terraced fields in the

three wadis were surveyed by the author. Beginning at the head of each stream valley, the dams and terraced fields in the respective wadis were successively numbered, while going downstream. It is theoretically possible that a very few dams are hidden from view, completely buried by alluvial sediments. This would not affect, however, the determined outcome of both the combined length of the terraced fields and the calculated cultivable area in each respective wadi:

- (1) The EASTERN Wadi exhibits 14 check-dams and terraced fields, having a total cultivable area of 0.53 hectare. The wadi is terraced over a length of 250 m.
- (2) The CENTRAL Wadi contains 30 check-dams and related terraced fields, having a total cultivable area of 0.75 hectare. This wadi is terraced over a length of 454 m.
- (3) The WESTERN Wadi exhibits 20 check-dams and related terraced fields, having a total cultivable area of 0.73 hectare. The wadi is terraced over a length of 411 m.

This latter figure includes a possible break in terracing over some 60 m between check-dam 3 and 4. It is not clear whether this stretch of wadi was never terraced because of an apparently steeper wadi gradient or that erosion has removed once existing dams and terraces.

The Western Wadi contains a cistern in its stream bed just above the beginning of the first terraced field. This set-up might have enabled intensive vegetable cultivation, even during the summer season, in the first terraced fields below the cistern, irrigated by its stored runoff rainwaters. The very existence of houses, situated just below the first three terraced fields (Cohen, 1981:60), seems to strengthen this hypothesis of an intensive and perennial vegetable-herb-fruit garden near home, watered from the cistern in addition to natural runoff flows.

A very small tributary of the Western Wadi joins the main stream bed some 90 m below the mentioned building remains, in between dam 8 and 9. The fact that even this little and narrow wadi was terraced, shows the determination of the ancient village population to cultivate every little plot of soil suited for runoff farming. The wadi has 6 small check-dams and related terraced fields with a total cultivatable area of 0.05 hectare (497 square metres). The little wadi is terraced over a length of 56 m.

The total area of terraced fields in the three wadis amounts to 2.07 ha, whilst the total catchment area of the three wadis combined is estimated at

about 36 ha. The ratio of the runoff receiving area of cultivated fields to the runoff producing catchment area can, therefore, be put at approximately 1:17 for the Horvat Haluqim site. This local datum is very near the average figure of 1:18 for the entire Runoff Farming District in the central Negev desert (Kedar, 1967).

TABLE 8. Number and size of dams and terraced fields in the three wadis * of Horvat Haluqim, descending from the head of the valleys downstream.

TERRACED FIELD and DAM NUMBER	DAM LENGTH = WIDTH (m) OF TERRACED FIELD			LENGTH (m) OF TERRACED FIELD (upstream from dam)			FIELD AREA (square metre)		
	wadi WEST	wadi CENTRAL	wadi EAST	wadi WEST	wadi CENTRAL	wadi EAST	wadi WEST	wadi CENTRAL	wadi EAST
1	15.5	12.5	12.0	30.5	12.0	12.0	398	132	160
2	24.0	13.0	14.7	28.4	16.8	16.8	560	214	224
3	18.0	15.2	15.7	15.4	12.0	18.0	323	169	274
4	10.0	18.0	19.3	(72.0)	17.3	38.7	224	287	677
5	13.0	19.4	18.6	12.5	31.0	14.4	143	579	273
6	14.5	13.0	20.0	12.6	5.6	9.6	173	33	185
7	11.0	16.0	19.6	13.7	21.0	9.6	174	304	190
8	10.0	17.5	20.0	12.3	16.0	15.7	129	268	311
9	28.5	15.6	22.0	17.4	15.6	13.7	335	258	288
10	32.5	15.7	24.0	14.2	13.0	14.7	433	203	338
11	31.5	11.5	24.1	14.6	21.3	18.3	467	289	440
12	29.0	13.5	23.5	40.0	14.5	20.0	1210	181	476
13	24.0	13.5	38.0	16.8	23.0	22.3	445	310	686
14	32.0	17.5	25.0	20.0	18.2	26.0	560	282	819
15	25.8	20.0		17.5	11.2		505	210	
16	24.3	20.0		27.0	12.2		676	244	
17	13.0	20.0		17.0	10.3		317	206	
18	9.0	19.3		7.2	10.1		79	198	
19	8.0	15.9		9.5	12.0		80	211	
20	10.0	15.7		12.2	18.8		109	297	
21		15.8			11.7			184	
22		23.0			19.2			372	
23		26.7			17.7			439	
24		26.4			14.8			392	
25		22.5			20.5			501	
26		17.0			13.0			256	
27		13.3			9.8			148	
28		11.2			7.5			91	
29		9.5			13.0			134	
30		10.3			15.2			150	

The field width of a certain terrace, used to calculate its field area, is based upon the average length of the two dams bounding that terraced field.

* Data about the little tributary of the Western Wadi appear in Table 9.

TABLE 9. Number and size of dams and terraced fields in the little tributary of the Western Wadi of Horvat Haluqim (measured from the head of the valley downstream).

TERRACED FIELD AND DAM number	DAM LENGTH = WIDTH (m) OF TERRACED FIELD	LENGTH (m) OF TERRACED FIELD upstream from dam	FIELD AREA (metre square)*
1	6.0	6.0	30
2	5.5	7.5	43
3	5.5	9.0	49
4	8.0	7.8	52
5	13.0	12.2	128
6	17.0	13.0	195

* The field width of a certain terrace, used to calculate the field area of that terrace, is generally based upon the average length of the two dams bounding that terraced field.

The average ratio between the length of a terraced field and its width (= the length of the dam across the wadi) in the runoff-farming terraced wadi system at Horvat Haluqim is 0.90. Thus the average length of the terraced fields is slightly less than the average width of the wadi bed. However, the individual terrace length/width ratio's at the site vary considerably and range grosso modo in between 0.5 and 2.0.

For an equal distribution of runoff water within each terraced field, it is important that the fields are levelled. In a proper design of a terraced wadi system, the gradient of a wadi, therefore, determines how often and at which points check-dams are to be constructed across the wadi bed. It is obvious that the steeper the gradient of the wadi the more check-dams and terraces are required per unit of wadi-length to enable each terraced field to be levelled, in analogy to a staircase. Apart from the wadi gradient, the depth of soil within the wadi bed is a determining factor as well. A relatively shallow soil will not allow much room for levelling. In the case of two similar wadis, having an equal gradient but different overall soil depth, more check-dams might be necessary in the wadi with the shallower soil. It remains to be investigated how level the ancient terraces actually were.

The three wadis of Horvat Haluqim, including the little tributary of the Western Wadi, contain a total of some 72 terraced fields. The combined length of all the measured dams put together amounts to 1234 meter, which is quite a

constructional achievement for such a little village in order to wrestle a living from the desert.

TABLE 10. Data about runoff farming fields at the Horvat Haluqim site.
(Terraced wadi system)

	TRIBU- TARY	WADI WEST	WADI CENTRAL	WADI EAST	TOTAL OR AVERAGE
a) Number of dams and terraced fields	6	20	30	14	72
b) Average length of terraced field	9.3	17.5	15.1	17.8	15.4 (m)
c) Average dam length = field width	9.2	19.2	16.6	21.2	17.1 (m)
d) Ratio b/c = Ratio e/f	1.01	0.91	0.91	0.84	0.90
e) Total length of terraced wadi fields	55.5	350.8	454.3	249.8	1110.4 (m)
f) Total length of dams	55.0	383.6	498.5	296.5	1233.6 (m)
g) Total area of fields	497.0	7284	7542	5340	20663 (m ²)

STRATIGRAPHY AND SOIL DEVELOPMENT OF A WADI TERRACE AT HORVAT HALUQIM, CONSTRUCTED AND USED FOR RUNOFF FARMING IN ANTIQUITY

THE DISCOVERY OF AN ANCIENT TERRACE LAYER

In November 1982 an excavation was made by the author into a terrace of the Eastern Wadi, some 150 m north of the fortress, just upstream from dam 12 near the Roman watchtower (Figure 9, Table 8). The dam has a length of 23.5 m and a width of 1.60 m. It is built across the wadi in a southwest-northeast direction, its azimuth being 62 degrees. Although the architecture of the dam was not investigated, its rather complex and somewhat dilapidated appearance is unlike the precise and neatly layered dams, so often characteristic for the Nabatean-Roman-Byzantine period. It is possible that the dam was first built during the Israelite period, in accordance with the age attributed to the site by Cohen (1976).

New evidence for the pre-Nabatean origin of these agricultural terraces was found during the present excavations, as described below. Independent carbon-14 dating may be possible in a later stage. It seems likely that the dam may

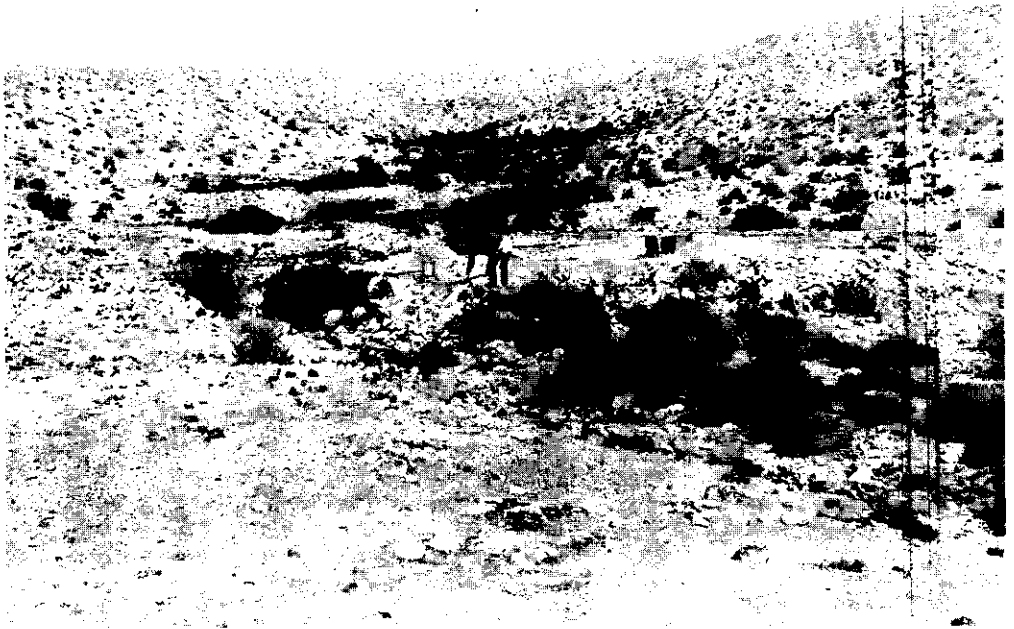


PHOTO 13. Excavation into terrace 12 of the Eastern wadi of Horvat Haluqim.

also have been repaired and expanded for runoff farming in later periods, as indicated by some Roman remains at the site. Thus the dam probably reflects a composite archaeological and architectural history.

The terrace upstream from the dam is slightly affected by erosion. A very shallow but discernible erosion channel winds its way through the terrace, and has made an opening into the somewhat dilapidated terrace dam described above. The first pit into the terrace was excavated from 0-250 cm upstream from the dam, just east from the very shallow present stream channel. The location of this pit proved to be well chosen, as, rather surprisingly, a stone wall was discovered below the surface at a depth of 50-100 cm.

This wall begins at the contact with the dam, and runs perpendicular from the dam in an upstream direction in the middle of the terraced wadi bed. The wall is built of two courses, being only one stone wide and about 50 cm high. Local natural limestone blocks were used in the construction of this wall, which might have been part of an ancient spillway, buried by alluvial loessial sediments after the site was abandoned. The wall has so far been excavated until 4 m upstream from the dam. Its upper course consists of 12 stones.

PHOTO 14. Exhumed wall and former terrace surface, in the middle of the wadi bed, perhaps dating back to the Israelite period (Iron age).

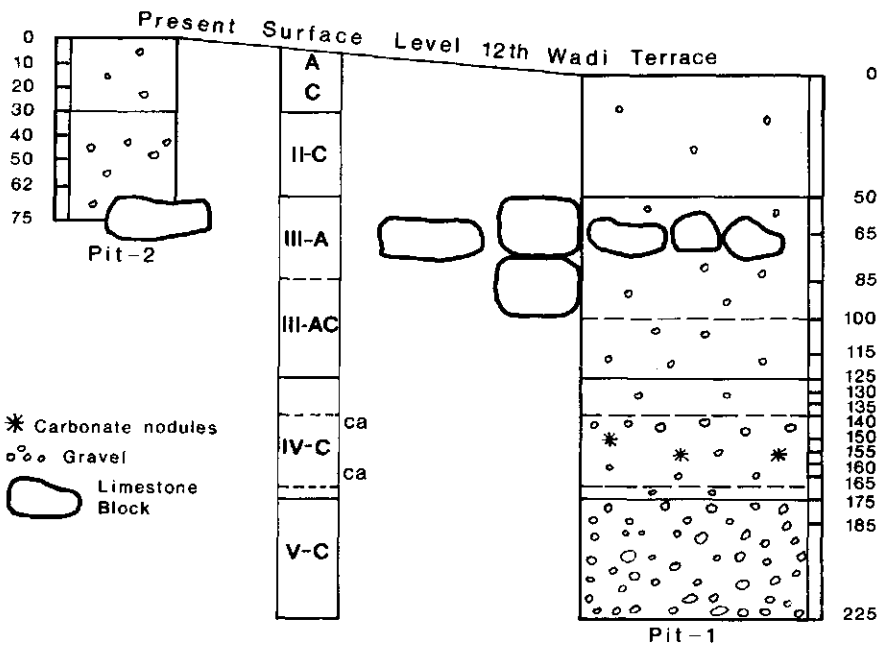


FIGURE 10. Excavated and sampled soil pits in the 12th terrace of the Eastern wadi of Horvat Haluqim (related to Photo 14).

The average length of the limestone blocks making up the wall is some 33 cm, similar to their width, whilst their thickness (height) is about 25 cm.

Natural blocks of limestone were found on both sides of the wall at about the same depth, sometimes appearing to form a protective cover for the underlying loessial sediment, that could otherwise have been affected by erosion and piping, as a result of runoff flows, by which the dam might have been undercut. If this interpretation is correct, then these horizontally spread limestone blocks are likely to have formed part of an ancient spillway system, together with the two-course high wall. However, since this wall has not yet been excavated over its entire length, the above conclusion remains tentative.

The alluvial loessial soil shows a somewhat different character from about 50-100 cm, at the same depth as the buried wall. The colour becomes more greyish, the structure more compact, and a few black and brick-red spots appear occasionally. A few tiny pieces of bone were also discovered. This is evidently a layer disturbed by man in the past, a buried surface horizon. Pottery sherds found in this layer are attributed by Cohen (1983, personal communication) to the Israelite period. It thus seems clear that, approximately in the middle of the wadi bed, a pre-Nabatean, possibly Iron age soil surface has been discovered in relation to the two-course high wall and adjacent rough pavement.

The wall is built on alluvial loessial sediments, of a silt loam texture, which below a depth of about 100 cm do not appear to have been disturbed by man. Small mounts of gravel and a few stones occur in the fine-grained alluvial loessial deposits. At a depth of 140-170 cm a weakly developed calcic horizon occurs, showing small but distinct orthic carbonate nodules (Wieder, 1977; Wieder and Yaalon, 1974), making up about 1-3 volume per cent of the soil matrix. Below a depth of 175 cm the amount of gravel increases considerably, but at 225 cm depth the bedrock surface has still not been reached.

A second pit was excavated unto a depth of 75 cm, a few meter east of the former one. The silt loam loessial profile is rather uniform in its appearance. Apart from a few small sherds of pottery of doubtful origin, no archaeological objects of stratigraphic value were found in this pit, although some natural limestone blocks appeared scattered at about the same depth as the upper part of the discovered wall in pit-1 (Photo 14). The second pit lies somewhat closer to the hillside edge of the terrace, and farther away from the very shallow erosion channel. The surface of the terraced field is slightly higher near pit-2 than around pit-1, as erosion has apparently removed part of the surface layer near the latter pit.

LABORATORY DATA

Soil samples were collected from both pits. The samples in pit-1 were taken some 70 cm west of the wall discovered in the subsoil, and 245 cm upstream from the dam. The samples in pit-2 were taken at a distance of 250 cm east of the buried wall, and 80 cm upstream from the dam (Fig. 10). The actual distance between the sampled profiles is 350 cm. The depth of the samples is stated with respect to the adjacent surface of the terrain next to the two pits, which appears to be somewhat lower near pit-1.

The content of organic carbon and nitrogen can be rated as very low (Ilaco, 1981) for the entire alluvial soil profile of this ancient runoff-farming terrace, which is characteristic for arid regions. Despite these deficiencies, negatively affecting natural soil fertility, the loessial soil is physically and structurally well suited for runoff-agriculture, having a good water-holding capacity.

The most striking contrast between the two pits is the large difference in the respective contents of soluble salts. Pit-1 can be regarded as having an extremely low salinity content (Ilaco, 1981): its electrical conductivity ranges from 0.23-0.38 mS/cm. The samples from pit-2, at a distance of only 3.50 m east of the sampled profile of pit-1, exhibit, on the other hand, a medium to moderately high salinity. The electrical conductivity gradually increases from 5.95 mS/cm in the upper 10 cm to 9.00 mS/cm at a depth of 70 cm.

The proximity of pit-1 to the present, very shallow, erosion channel suggests that, (1) either accumulated salts have been leached here by recent runoff stream flows from the entire profile beyond a depth of 1.85 m, or (2) no salt accumulation could ever take place on this particular spot since the end of runoff farming at this terrace. The fact that pit-2, at a sampling distance of only 3.50 m (!), does contain almost 30 times more salts is quite extraordinary. The alluvial loessial sediments in pit-2 seem for the most part to post-date the Iron-Age. Thus the salts must also have accumulated since that period, after the final termination of runoff farming. The accumulation of salts in soils may require considerable time (Yaalon, 1964; Dan and Yaalon, 1982), whereas leaching may occur within a few years.

Since the original salt content of the alluvial deposits is unknown, it is hard to assess how long a period it took for this salinity profile to develop. The much higher salinity of pit-2, as compared to pit 1, does make it clear, however, that runoff flows have not been able to flood this part of the terraced field, which is only slightly higher than the area around pit-1, for

a certain period of time until today.

TABLE 11. Granulometry and soil chemistry of alluvial loessial sediments in an ancient runoff-farming terrace of the Eastern Wadi at Horvat Hалуqim
1) Upper sediments - Pit-2.

HORIZON	DEPTH (cm)	CLAY <0.002 mm (%)	SILT 0.002- 0.063 (%)	SAND 0.063- 2 mm (%)	TEXTURE	GRAVEL >2 mm (%)	CARBONATES CaCO ₃ (%)
A	0-10	17.1	55.8	27.1	SILT LOAM	2	30.0
C	10-20	16.4	60.7	23.0	SILT LOAM	5	26.9
C	20-30	14.9	62.4	22.7	SILT LOAM	2	30.6
II-C	30-40	20.2	58.8	22.0	SILT LOAM	8	30.3
II-C	40-50	19.3	51.7	29.0	SILT LOAM	12	29.6
II-C	50-62	20.6	54.0	25.4	SILT LOAM	9	29.1
II-C	62-75	26.1	50.4	23.4	SILT LOAM	4	29.4

HORIZON	DEPTH (cm)	pH	EC(1:1) (mS/cm)	SAR	ORGANIC CARBON (%) C	NITRO- GEN (%) N	TOTAL PHOSPHORUS (%) P ₂ O ₅
A	0-10	7.4	5.95	47.9	0.56	0.05	0.23
C	10-20	7.4	7.59	77.1	0.56	n.d.	0.24
C	20-30	7.4	7.70	83.7	0.52	0.04	0.28
II-C	30-40	7.5	7.90	79.5	0.56	n.d.	0.35
II-C	40-50	7.4	7.99	66.7	0.53	n.d.	0.34
II-C	50-62	7.4	8.70	72.7	0.57	n.d.	0.33
II-C	62-75	7.3	9.00	74.9	0.58	n.d.	0.32

HORIZON	DEPTH (cm)	SOLUBLE SALTS IN 1:1 SOIL/WATER EXTRACT (meq/kg soil)							
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
A	0-10	1.7	<0.10	52.0	0.8	0.9	53.0	0.4	0.4
C	10-20	1.6	<0.10	70.0	0.8	1.9	65.0	5.9	0
C	20-30	1.4	<0.10	70.0	0.8	0.8	65.0	5.4	0.2
II-C	30-40	1.5	<0.10	70.0	0.8	0.9	58.0	7.5	0
II-C	40-50	2.1	0.10	70.0	0.5	0.8	55.0	13.5	<0.1
II-C	50-62	2.3	0.15	80.5	0.8	0.7	68.0	14.0	<0.1
II-C	62-75	2.5	0.20	87.0	0.8	0.6	75.0	16.0	0

Percentages in weight % of the fine earth <2 mm; only gravel in weight % of the total soil. EC = electrical conductivity. SAR = sodium adsorption ratio. n.d. = not determined.

Sampling depth in both pits is with reference to the surrounding surface, which seems to be somewhat higher near pit-2. This should be taken into account when both pits are compared stratigraphically; in that case some 15 cm must probably be added to the sample depths of pit-1 (Table 12).

TABLE 12. Granulometry and soil chemistry of alluvial loessial sediments in an ancient runoff farming terrace of the Eastern Wadi at Horvat Haluqim
2) Buried Iron-Age soil, overlying Late Quaternary alluvium - Pit-1.

HORIZON	DEPTH (cm)	CLAY <0.002 mm (%)	SILT 0.002- 0.063 (%)	SAND 0.063- 2 mm (%)	TEXTURE	GRAVEL >2 mm (%)	CARBONATES CaCO ₃ (%)
III-A	50- 65	14.7	50.0	35.3	SILT LOAM	6	30.9
III-A	65- 85	13.1	58.2	28.7	SILT LOAM	7	33.1
III-A(C)	85-100	14.9	63.6	21.5	SILT LOAM	5	29.4
III-A(C)	115-125	18.0	62.3	19.7	SILT LOAM	5	31.3
IV-C	130-135	12.2	61.9	25.9	SILT LOAM	6	30.1
IV-Cca	140-150	17.8	56.6	25.6	SILT LOAM	11	30.4
IV-Cca	150-155	17.9	57.5	24.6	SILT LOAM	7	31.5
IV-Cca	160-165	17.3	67.7	15.1	SILT LOAM	6	29.3
V-C	175-185	20.1	61.1	18.7	SILT LOAM/GRAVEL	17	29.6

HORIZON	DEPTH (cm)	pH	EC(1:1) (mS/cm)	SAR	ORGANIC CARBON (%) C	NITRO- GEN (%) N	TOTAL PHOSPHORUS (%) P ₂ O ₅
III-A	50- 65	7.8	0.34	3.2	0.69	0.04	0.55
III-A	65- 85	7.9	0.23	4.5	0.74	n.d.	0.52
III-A(C)	85-100	7.8	0.26	5.6	0.46	n.d.	0.36
III-A(C)	115-125	7.8	0.30	8.1	0.65	n.d.	0.40
IV-C	130-135	7.7	0.25	6.3	0.35	n.d.	0.13
IV-Cca	140-150	7.7	0.33	9.6	0.23	n.d.	0.14
IV-Cca	150-155	7.7	0.33	8.9	0.23	n.d.	0.13
IV-Cca	160-165	7.7	0.37	12.8	0.42	n.d.	0.15
V-C	175-185	7.6	0.38	14.1	0.46	n.d.	0.13

HORIZON	DEPTH (cm)	SOLUBLE SALTS IN 1:1 SOIL/WATER EXTRACT (meq/kg soil)							
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
III-A	50- 65	0.5	<0.10	1.8	<0.1	2.1	0.5	0.2	<0.1
III-A	65- 85	0.5	<0.10	2.5	<0.1	2.4	0.2	0.4	0.2
III-A(C)	85-100	0.4	<0.10	2.8	<0.1	2.6	0.2	0.3	<0.1
III-A(C)	115-125	0.3	<0.10	3.2	0.2	2.9	0.3	0.4	<0.1
IV-C	130-135	0.3	<0.01	2.5	0.2	2.2	0.4	0.2	0
IV-Cca	140-150	0.3	<0.10	3.7	0.6	3.5	0.5	0.2	0
IV-Cca	150-155	0.2	<0.10	3.2	0.4	3.3	0.3	0.4	0
IV-Cca	160-165	0.1	<0.10	3.5	0.4	3.5	0.2	0.3	0
V-C	175-185	<0.1	<0.10	3.2	0.3	3.5	0.2	0.4	0

Percentages in weight % of the fine earth <2 mm; only gravel in weight % of the total soil. EC = electrical conductivity. SAR = sodium adsorption ratio. n.d. = not determined.

SOIL MICROMORPHOLOGY

Microscopic studies of thin sections from the buried Iron-Age soil layer of Horvat Haluqin, showed unequivocally that wet conditions have existed in the past, presumably as a result of runoff farming. This conclusion is based on the occurrence of ferric nodules or concentrations of iron-(hydro)oxides in the Iron age soil horizon (Photos 15 and 16). Ferric nodules can only develop under an alternating wet-dry reduction-oxidation regime, which is quite abnormal for aridic soils in dry regions.

These observed gley features seem to be convincing evidence of runoff farming practices in the past, in the time before the silting up of the terrace and the subsequent salinization. Runoff farming must have been successful in the sense, that the built terrace dam was able to keep a substantial amount of runoff water on this particular terraced field, during occasional flooding in the rainy season, which caused a temporary reduction environment in the soil.



PHOTO 15. Dark ferric nodule in the centre of the photo, with a diameter of about 0.25 mm, situated in the ancient terrace layer (probably Iron age), at a depth of 60 cm. Note a land-snail shell remnant at the right-hand side. This microscope-photo was taken with plain polarized transmitted light (without crossed polarizers). The length of the picture equals 0.5 mm.

Iron, which is usually present in the alluvial loessial soils under consideration, can become mobile in a wet, reduced environment. Through diffusion processes the iron may move to certain micro-sinks in the soil, near spots where voids facilitate the entry of air (oxygen). Here the iron is again oxidized and immobilized as a result. These diffusional micro-sinks may develop into concentrations of iron(hydro)oxides or ferric nodules after a certain period of time.

The formation of ferric nodules may take place within a relatively short time range in the order of one hundred to a few hundred years, depending upon various circumstances (Brinkman, 1986, personal communication). For more soil-chemistry information on this issue, the reader is referred to Brinkman (1979) and Van Breemen (1986). A more detailed account of the soil micromorphology of this terraced field at Horvat Haluqim will be published elsewhere.

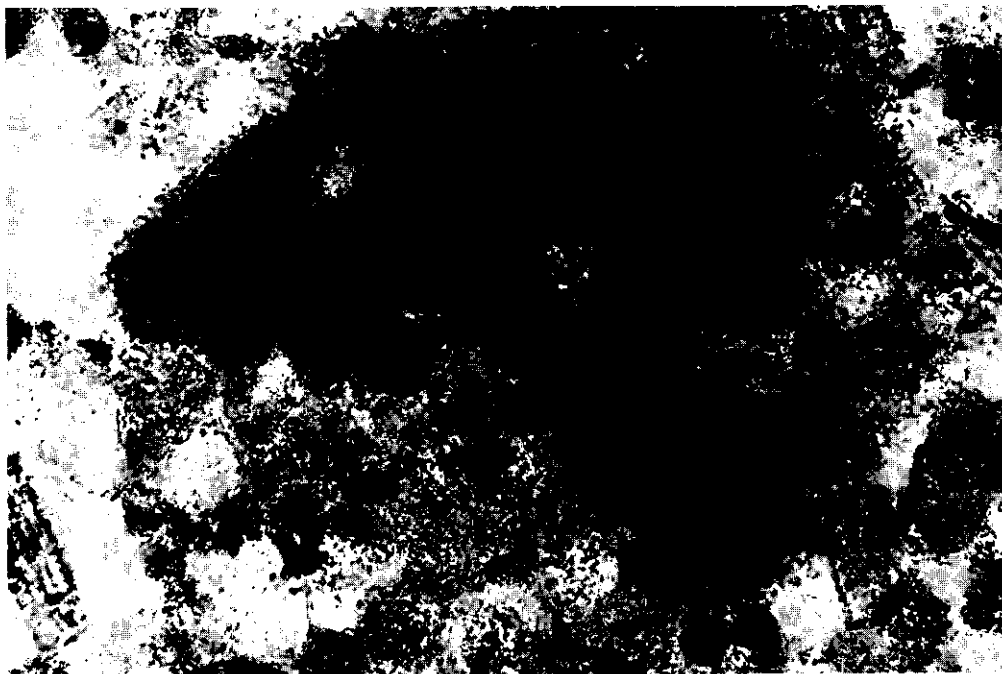


PHOTO 16. Dark ferric nodule in the centre of the photo, with a diameter of about 0.35 mm, situated in the ancient terrace layer (probably Iron age), at a depth of 75 cm. This microscope-photo was taken with plain polarized transmitted light (without crossed polarizers). The length of the photo equals 0.5 mm.

STRATIGRAPHIC CONCLUSIONS

On the basis of the field and laboratory data a fivefold stratigraphic division is made within the investigated deposits, arranged in a soil-sedimentary sequence from the terrace surface downward. The stratigraphic indices are similar to those appearing in the soil horizon designation of Tables 11 and 12.

I. POST IRON-AGE SEDIMENTATION PHASE-2. The upper 30 cm of alluvial loessial sediment (pit-2) has an average clay content of 16.1 %, whereas the amount of total phosphorus (0.25 % P_2O_5) is lower than in the subsoil. The phosphorus content, very stable in a calcareous environment, is understood to reflect the influence of human activity.

II. POST IRON-AGE SEDIMENTATION PHASE-1 (RUNOFF-FARMING PERIOD-??). The alluvial loessial deposits at a depth from 30-75 cm (pit-2) contain on the average more clay (21.6 %) than the overlying layer, whilst the phosphorus content suddenly rises to about 0.34 %. It seems likely that the lower part of this layer is transitional to the Iron Age soil, exhibited in pit-1.

III. IRON-AGE LAYER (RUNOFF-FARMING PERIOD-1). The buried Iron-Age horizon appears in pit-1 at a depth from about 50-100 cm. The lower clay content of the alluvial loessial sediment may be due to the closer proximity of pit-1 to the main part of the stream channel. The phosphorus and organic C content reaches peak values in this horizon of 0.55 % and 0.74 %, respectively.

IV. PRE-TERRACING (PRE-RUNOFF-FARMING) ALLUVIAL LOESSIAL SEDIMENTS. Below the buried Iron-Age horizon, the phosphorus and organic C contents show a significant decline to 0.13 % and some 0.30 %, respectively. This clearly indicates the beginning of an alluvial loessial layer, predating the period of runoff farming and the influence of man. A weakly developed calcic horizon (140-175 cm depth) is present in this layer.

V. GRAVELLY ALLUVIAL SEDIMENTS. The amount of gravel increases sharply at a depth of 175 cm, which marks the upper boundary of coarser alluvial sediments, mixed with silt loam. At 225 cm depth, bedrock was not yet reached.

A number of significant stratigraphic conclusions can be drawn from this excavation in the 12th terraced field of the Eastern Wadi of Horvat Haluqim.

Since the Iron Age soil surface appears at an average depth of about 70 cm, it seems beyond any doubt that loessial soil already existed in this wadi, when the terraced wadi system was first built for runoff farming purposes. More than 155 cm of soil was already present at this particular spot, when the ancients decided to terrace the wadi. The upper 100 cm consisted of fine loessial soil, whilst the gravel content increased below this level. The more gravelly subsoil, also mixed with silt loam, was still capable of keeping moisture in its profile. Thus the entire 155+ cm of soil, already present at the onset of the ancient runoff-farming period, could have stored runoff water to sustain field crops or trees.

Kedar (1957) expressed the view that one of the main purposes of the ancients to built the many thousands of dams across the wadis in the Negev was to enable soil to accumulate, so that agriculture could be practised in a later stage. Kedar apparently assumed that no soil or not enough soil was present in many wadis designated for runoff farming by the ancients, when they first decided to built these dams. This view clearly does not seem to fit the stratigraphy of the terraced field described above. Enough soil was already present, when the ancients, presumably the ancient Israelites (Cohen, 1976), built dams across the little wadi(s) at Horvat Haluqim.

The main and probably sole purpose to terrace the wadis was the retention of runoff water rather than soil. The fact that more sediment also began to accumulate as a result of damming, was a secondary factor, not always welcome perhaps, as it necessitated the building of new layers of stones on top of the dams in the course of time. On the other hand, the annual addition of some new sediment with every flood onto the wadi terraces might have contributed to rejuvenate soil fertility and keep it at a higher natural level than without this seasonal accumulation of eroded surface material from the slopes of the surrounding catchment.

6 Estimated wheat yields under runoff-farming conditions in antiquity, related to Horvat Haluqim

INTRODUCTION

How many people might have been fed at Horvat Haluqim in the past with locally produced food, grown in the three small terraced wadis? It is impossible to give an accurate answer to that important question without modern research data from the actual site about yields of food crops in relation to year-to-year climate, crop rotation systems and manuring practices.

In modern research about runoff farming in the Negev (Evenari et al., 1971, 1982) the Terraced Wadi System has not been investigated, whilst agricultural examinations of the Hillside Conduit System (Avdat and Shivta), Diversion System (Avdat) and Liman System (Wadi Mashash) were largely concentrated on fruit trees. Some data about wheat yields are available from the Avdat experimental runoff farm for the period from 1961/62 to 1966/67. These data, though quite interesting, are of limited value to assess yields in antiquity, since chemical fertilizers were used, except for the first year 1961/62.

An initial beginning has been made by the author to investigate the crucial question of climatic variability in dry regions and self-sufficient food production based on runoff farming (Bruins et al., 1986b). Future research on this subject should involve systematic year-to-year food crop production, evaluated in relation to climate, rainfall and runoff amounts, crop rotation, cropping patterns, and soil fertility (manuring). Such knowledge is vital to assess the viability of runoff farming in the Negev as a food-crop producing system, in past and present. Research on this issue may help to resolve some

historic-archaeologic related questions, and will provide know-how on climate-defensive measures that might be taken with regard to runoff farming in developing countries.

Despite all the shortcomings in our knowledge today, a rough estimation can be made about the magnitude of past food production at Horvat Haluqim, as well as the amount of people that might have subsisted on this local produce.

WHEAT YIELDS BASED ON ANCIENT LITERARY SOURCES

About 73 % of the average food basket today is composed of cereals (Buringh, 1977). This percentage was probably even higher in the past, when cereals and legumes (pulses) made up the major part of the diet. Noteworthy is the remark made by Pliny (Nat. Hist. 18.21.94-95; Loeb ed., vol 5, p.249): "Nothing is more prolific than wheat - Nature having given it this attribute, because it used to be her principal means of nourishing man". It thus seems reasonable to base the following calculations entirely on cereal production and consumption data.

The unique Nizzana papyri of the 6th and 7th century A.D. are the only historical documents that provide actual data on ancient yields of food crops in the Runoff Farming District of the Negev. Document 82 (Mayerson, 1955; Kraemer, 1958) mentions the yields of wheat, barley, and aracus (a legume) during a certain year in the 7th century in the Nizzana area. Apart from the fact that aracus is a legume, its specific typological meaning is unknown

TABLE 13. Yields of wheat, barley and aracus in the Nizzana area, grown in a certain year during the 7th century A.D. under runoff farming conditions (after Mayerson, 1955).

PLACE	CROP	Modii SOWN	Modii REAPED	YIELD
Ragorios to Kat	Wheat	40	270	6.8 -fold
Malalkani	Wheat	40	288	7.2 ,,
Alphag	Wheat	180	1225	6.8 ,,
Alphag	Barley	50	402	8.0 ,,
Berain	Barley	40	350	8.8 ,,
Berain	Aracus	30	97	3.2 ,,

(Mayerson, 1955). Yields are usually stated in ancient literary sources as the volume amount harvested with respect to the volume amount sown. The yields in the Nizzana papyri are expressed in terms of modii sown and modii reaped (Table 13). One modius is 8.7 litres (Mayerson, 1955:271).

Today crop yields are generally presented as the weight of the harvested crop per unit of field area, often in kg or ton per hectare. Whereas a liter of water is always a kg, a liter of wheat will not always have the same weight, as this depends on the size of the grains and their specific weight. Variations in the weight of a liter of wheat are, therefore, likely between different wheat varieties. A liter of barley or aracus will likewise have different respective weights. Thus we are faced with a problem to translate ancient yields, expressed in volumes, accurately into kg, or into kg/ha, for comparison with present yields.

Mayerson (1955:55) estimates 4 modii to be the approximate equivalent of one U.S. bushel, which means that in his opinion one modii of wheat is about 6.8 kg. In an article on wheat-farming during Roman times, White (1963) appears to have used the following equation: 1 modii = 5.88 kg of wheat. This latter figure is used in the following calculations, to facilitate comparison with modern yields. Few other literary data exist about yields in antiquity in the Mediterranean region. Wheat is usually the only crop on which some ancient information is available (White, 1963; Feliks, 1963; Sperber, 1978).

The question arises how much seed of wheat was sown per unit of area in antiquity? Information on this matter may enable the translation of ancient sowing amounts and yields into kg/hectare. In addition it is important to know what the ancients thought about sowing practices with respect to climatic and soil conditions. The Nizzana papyri do not contain information on this matter. White (1963) studied both of these aspects from ancient Roman literary sources. Despite the fact that the available Roman sources do not touch upon runoff farming as such, their data are quite instructive and may serve as a basis to estimate the likely amount of wheat sown under rather dry conditions.

The report by Cicero (In Verr., II, iii, 112) about wheat yields in the Leontini district of Sicily in the year 70 B.C. is most useful. Cicero does not only report the ancient wheat yields in that region in the usual volumetric comparative way, as being 8- to 10-fold the amount sown, but also states the amount of wheat sown per unit of area.

This important historical text enabled White (1963) to calculate the yield reported by Cicero as 48 modii per iugerum. This is either an 8-fold or a 10-fold yield according to whether the seed is sown at the rate of 6 or 5 modii

per iugerum. An iugerum is 0.252 hectare (Mayerson, 1955:271). White (1963) translated this past wheat yield in Sicily of the 1st century B.C. into the more modern expression of 11.2 quintals per hectare, which is 1120 kg/ha. Hence one modii of wheat is estimated to be 5.88 kg, whereby one modii per iugerum equals 23.33 kg/ha. The amount of wheat sown per hectare in Sicily during the 1st century B.C. seems, therefore, to have ranged in between 112 and 140 kg/ha.

THE QUANTITY OF WHEAT SOWN IN RELATION TO SOIL AND CLIMATE

White (1963) reports the following information from ancient literary sources about variations of the quantity of seed sown per hectare with respect to soil and climate conditions in Roman times:

Varro merely recommends the farmer to adapt the quantity of seed sown to local soil conditions. Columella (*De Re Rust.*, II, IX, 5-6) provides a more comprehensive account of the matter:

"If the field is moderately stiff (*cretosus*) or wet (*uliginosus*) you need for winter wheat (*siligo*) or common breadwheat (*triticum*) rather more than five modii... But if the ground is dry (*siccus*) and loose in texture (*resolutus*), no matter whether it be rich or lean, only four; for conversely, lean land requires the same amount of seed; unless it is sown thinly, it produces a small and empty head. But when it branches out into several stalks from one seed it makes a heavy stand from a light sowing."

From this passage it is clear, as pointed out by White (1963), that the dominant consideration in deciding whether to sow thinly or thickly is the moisture content and texture of the soil. The same distinction is made by Pliny (*Nat. Hist.* XVIII, 199):

"In dense, chalky or moist soil sow six modii of winter wheat or common wheat, but in loose, dry and fertile soil, four: A meagre soil produces a small and empty ear unless it has the stalks far apart, whereas fields with a rich soil produce a number of stalks from a single seed and yield a heavy crop from thinly-sown seed."

It was customary in Greece and Italy to sow either early in autumn (light

rains) or immediately before the onset of winter (White, 1963) with its heavy rains. In early autumn the seed would be sown thinly, whilst just before the winter it was sown thickly (Theophrastus, Caus. pl., III, 25; cf. White, 1963). Columella (De Re Rust., II, IX, 6) points out that the thin early sowing enables the plant to form stools during the winter and branch out.

Inter-cropping of cereals with olives and vines was extensively practised in Roman Italy (White, 1963). It is not known whether inter-cropping of this kind was also carried out in the arid Negev desert under runoff farming conditions in antiquity. From the Nizzana papyri a threefold land division can be deduced in the 7th century A.D. (Mayerson, 1955; Kraemer, 1958):

- (1) Seedland, mainly used for food crops like wheat and barley.
- (2) Vineyard.
- (3) Garden or orchard.

This differentiation seems to suggest a division of cropping in the central Negev desert rather than the example of inter-cultivation in Roman Italy.

ESTIMATED AMOUNT OF WHEAT SOWN IN THE CENTRAL NEGEV DESERT AND CORRESPONDING YIELDS

Considering the advice of Columella (De Re Rust., II, IX, 5-6) and Pliny (Nat. Hist. XVIII, 199) to sow 4 modii of wheat, presumably per iugerum, in dry soil, it is assumed that a similar amount of 4 modii/iugerum, which is about 93.3 kg/ha, was sown in antiquity in the dry Negev desert. This is one modii less than the amount of 5 modii per iugerum, as suggested by Mayerson (1955). The amount of 93.3 kg seed per hectare fits very well within the range advised by the agricultural compendium for rural development in the tropics and subtropics (Ilaco, 1981), put at 70-100 kg/ha for line sowing, and 25 % more where broadcasting is practised, i.e. 88-125 kg/ha.

The number of hectares sown and the wheat yields in kg/ha can thus be calculated from document 82 of the Nizzana papyri, for a certain year in the 7th century A.D. in the Nizzana area, grown under runoff farming conditions (Table 14). The average yield amounts to 646 kg/ha, which is considerably less than the figure of 943 kg/ha calculated by Mayerson (1955). The difference is caused by his assumption of a sowing rate of 5 modii per iugerum, and one modii of wheat being equal to 6.8 kg.

TABLE 14. Calculated yields of wheat and the amount of hectares sown in three individual historic cases in the Nizzana area (central Negev) * , compared with past yields from selected other regions. #

PLACE	TIME	Modii SOWN	Modii REAPED	HECTARES sown	YIELD (kg/ha)
Nizzana area	7th cent. A.D.	40	270	2.52	630
Nizzana area	7th cent. A.D.	40	288	2.52	672
Nizzana area	7th cent. A.D.	180	1225	11.34	635
Roman Sicily	70 B.C.				1120
Sicily	1959				1060
Italy	Varro (+ 30 B.C.)				1200
Italy	Columella (+ 50 A.D.)				500
Syria	1949-1957				700
Tunisia	1949-1957				500
Israel	1910-1930				531

* Based on document 82 of the Nizzana papyri (Mayerson, 1955; Kraemer, 1958) # and data from White (1963) and Stanhill (1978). The assumed sowing rate is 4 modii/iugerum (93.3 kg/ha), whereby 1 modii of wheat is assumed to have a weight of 5.88 kg.

EVALUATION OF ANCIENT WHEAT YIELDS IN THE LIGHT OF MODERN RESEARCH

The calculated average wheat yield of 646 kg/hectare from the Nizzana area is slightly above the outcome of modern field experimentation of wheat yields in Israel from unfertilized plots, being on the average 580 kg/ha (J. Ephrat, 1977, personal communication, cf. Stanhill, 1978). This is considered to be a confirmation of the realistic value of the calculated Nizzana yield. For it is rather unlikely that any significant fertilization could have been accomplished in antiquity on the runoff farming fields of the central Negev desert.

Notwithstanding the unique system of runoff farming, the desert environment does have a limited carrying capacity with regard to the amount of people and

accompanying animals that can be supported per unit of desert area. Moreover, extensive livestock rearing, common for arid regions, is not quite a system which allows manure to be concentrated for use on the arable lands for food crop production. Therefore, apart from what the animals drop during their allowed grazing of certain stubble fields, no animal manure was probably added to the fields.

It is clear from the studies by De Wit (1958) and his colleagues (Van Keulen and De Wit, 1975; Van Keulen, 1979, Penning de Vries and Djitaye, 1982; Penning de Vries, 1983) that lack of fertilization is, apart from water, the main reason of low yields in arid regions. This is also the conclusion from Stanhill (1978) in his research about an autarkic agro-ecosystem of a typical fellah's farm in the Yizreel Valley of Israel, based on data from the first decades of the 20th century. The average rainfall in the area is at present about 483 mm per year. Average wheat yields amounted to 531 kg/ha (Table 14, last figure), whereby wheat was the most important crop in this agro-ecosystem. Stanhill (1978) concludes "that the main factor limiting wheat yields on the fellah's farm was the complete absence of fertilization".

WHEAT YIELDS FROM THE AVDAT EXPERIMENTAL RUNOFF FARM

The comparatively few data acquired by Evenari and his colleagues on wheat yields at the Avdat experimental runoff farm are not representative of ancient runoff farming conditions, since modern fertilizers were used in all cases, except for the first year. It seems nevertheless worthwhile to quote their interesting results:

1961/1962 SEASON (Rainfall 64.7 mm)

The first flood was on December 6, 1961, and penetrated to a depth of 120 cm, which corresponds to 2000 cubic meter of available moisture per hectare or 200 mm of effective rainfall. This proved to be the only flood of the rainy season and the wheat developed without any additional water. The wheat varieties Ethit and Florence Aurore 8/39 were sown on 17-12-1961 by broadcasting on a field that had received an amount of 35 cubic meter of manure per hectare. The plants emerged on 29-12-1961. Full ripening and harvesting of Florence occurred on 21-4-1962 and 20-5-1962, respectively; and of Ethit on 30-4-1962 and 17-5-1962. The yields of the two varieties were 950 kg/ha and 600 kg/ha, respectively (Evenari et al., 1963).

1962/1963 SEASON (Rainfall 29.5 mm)

The research program for field crops was not carried out because of the drought conditions. All available water was diverted to the orchard and the range plants and the plots for the annual field crops were left dry (Evenari et al., 1964).

1963/1964 SEASON (Rainfall 183.3 mm)

There were three large and prolonged floods in December 1963, on 1-4, 10-11 and 30-31 of that month. During each of these floods the field crop plots were inundated for 24-48 hours. The plots received 9200 cubic meter of water per hectare, which is equal to 920 mm of effective rainfall. Moisture filled the soil several times to a depth of more than 3 meter. Prior to seeding the plots were prepared with a roto-tiller 5 days after the (second?) flood and fertilized with 300 kg/ha ammonium sulfate (21% N) and 800 kg/hectare superphosphate (15% P₂O₅). Two wheat varieties, Florence Aurore 8/39 and Ethit, were sown on 25-12-1963 in rows 20 cm apart, with a seed rate of 130 kg/ha. Good but slow emergence started 11 days after sowing; bird damage was severe and could not be controlled. The dates of full ripening and harvesting of Florence are 6-4-1964 and 20-5-1964, respectively; and of Ethit 14-4-1964 and 8-5-1964. The yield of Florence was 1950 kg/ha and of Ethit 1390 kg/ha (Evenari et al., 1965).

1964-1965 SEASON (Rainfall 144.2 mm)

Since the first flood of the rainy season was late, on 12-1-1965, no wheat was sown this year. Runoff flows were recorded on 14 days (Evenari et al., 1968).

1965-1966 SEASON (Rainfall 91.5 mm)

An early flood occurred on 5-10-1965. The field plots for wheat received prior to sowing 500 kg/ha superphosphate (26% P₂O₅), 400 kg/ha ammonium sulphate (21% N), and 40 cubic-metre/ha organic manure. Sowing (150 kg/ha) of the Florence wheat variety and the Thesera 41 dwarf variety was carried out on 23-10-1965, by which the latter variety received an additional top dressing of 200 kg/ha ammonium sulphate (21% N). Harvesting took place on 7-5-1966, but the published results are somewhat confusing: p. 27 mentions a yield of the Florence variety of 4380 kg/ha, whereas table 85 gives a figure of 2670 kg/ha for Florence and 4380 kg/ha of the Nanasit wheat variety, not mentioned earlier. The yield of Thesera 41 is not stated (Evenari et al., 1968)

1966-1967 SEASON (Rainfall 80.7 mm)

Seven very small floods occurred and field crops did not develop at all during this season (Evenari et al., 1968).

ESTIMATED WHEAT YIELDS AND RELATED POPULATION LEVELS AT HORVAT HALUQIM

In the only year that no chemical fertilizers were given to the wheat sown at the Avdat experimental runoff farm, but "only" 35 cubic-metre/ha of manure, yields were 600 kg/ha and 950 kg/ha, respectively, for two different wheat varieties. It is unlikely that such an amount of manure could have been supplied yearly to the ancient seedlands in the Runoff Farming District of the Negev in antiquity. During the 6 years from 1961/62 to 1966/67, no wheat was sown or harvested during 3 years, for lack of runoff water or the first seasonal flood being too late. The average wheat yield at the Avdat experimental runoff farm during these 6 consecutive years, including the years without any yield, is 995 kg/ha, obtained with the stated amounts of chemical fertilizers and manure.

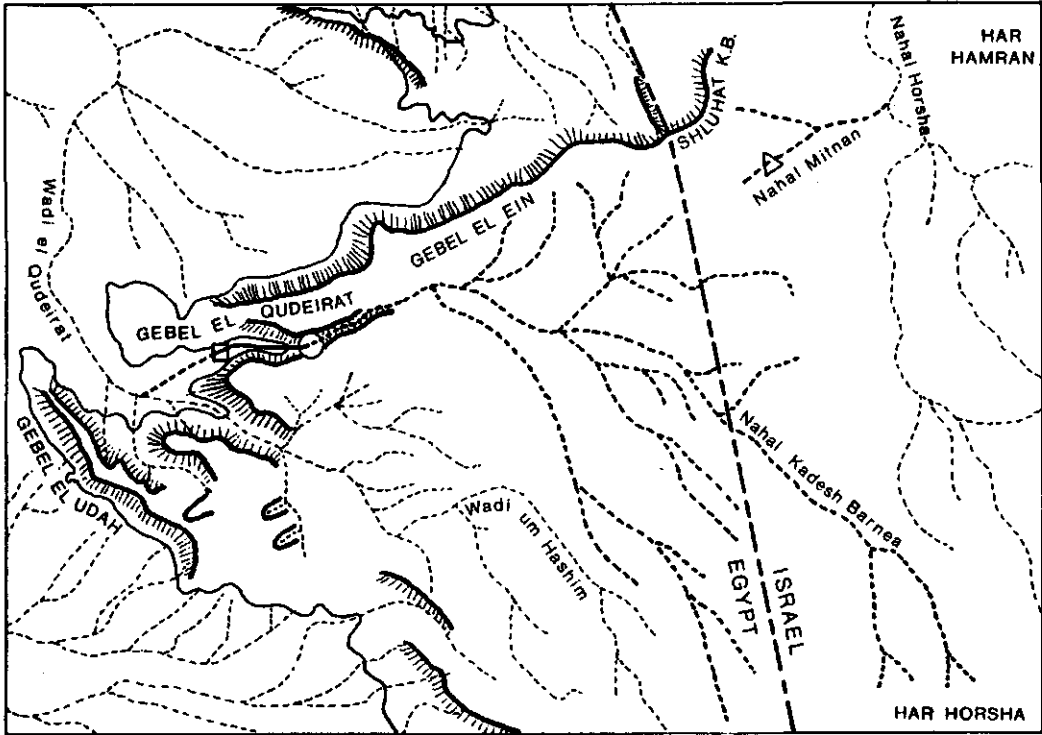
Average runoff water supply to the runoff farming system in the Nizzana desert area (present annual rainfall about 86 mm) during the 7th century A.D. might also have been 200-500 mm in the year that the yields were recorded. It seems unlikely that fertilization was much better in this desert region than in the semi-arid Yizreel Valley. Hence it seems also unlikely that wheat yields were much higher than 500 to 600 kg/ha in the Runoff Farming District during the 7th century A.D. The average yield of 646 kg/ha, calculated from the Nizzana papyri on the suppositions described above (Table-14), does not seem too low an estimate, therefore.

If conditions during the functioning of the runoff farming village at Horvat Haluqim, roughly 3000 years ago, were more or less similar to the farming situations described above, the 2.07 hectare of terraced fields in the three wadis may have yielded some 1242 kg of wheat per year, based on an assumed average yield of 600 kg/ha.

This quantity has to be reduced by the seed stock required for next year (about 200 kg) and post-harvest losses (Hall, 1970; Van der Lee, 1978) of some 10 % (125 kg), which leaves an estimated 917 kg/year for human consumption. Broshi (1980) takes the figure of 250 kg grain/person/year as an overall minimum average required for human subsistence. These aspects of human food requirements are treated in more detail in chapter 11. Thus only about 4

people could have lived on the food production of the three terraced wadis. Even assuming the possibility of high average yields of 1200 kg/ha, not more than 8 people could have been nourished by the local produce.

As past population figures at Horvat Haluqim were certainly higher, considering the amount of houses and other buildings (Cohen, 1976), the conclusion has to be that either much more terraced wadis in the vicinity of the site were incorporated in the local food economy, or food was regularly supplied from outside, e.g. from the wetter northern part of the country.







-  ESCARPMENT
-  SPRING
-  TELL
-  NAHAL MITNAN SITE

FIGURE 11. Area of Kadesh-Barnea and Nahal Mitnan

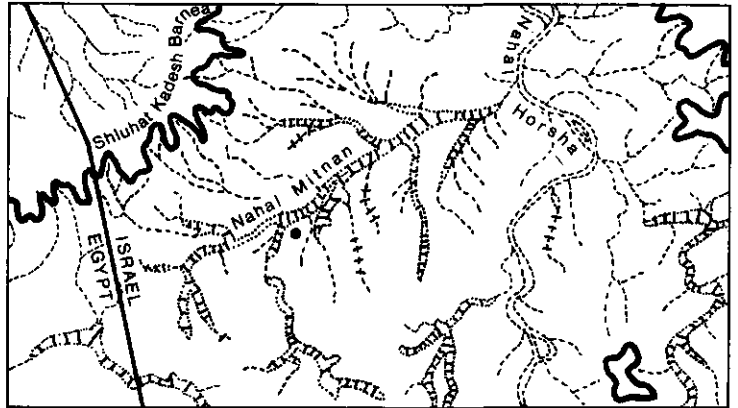





FIGURE 12. Area of Nahal Mitnan in more detail.

-  FARMSTEAD
-  TERRACED WADI
-  600 m Contour

7 Nahal Mitnan

ENVIRONMENT

The terraced wadi of Nahal Mitnan is situated close to the border with Sinai (Egypt), at a distance of about 37 km south-west of Horvat Haluqim, as the crow flies. Some 9 km farther to the south-west, already in Sinai, lies the Valley of Ein el Qudeirat, considered to be the area of Kadesh-Barnea (Figure 11), extensively dealt with in the next chapter.

Nahal Mitnan is a tributary of Nahal Horsha, lying in the Loz-Horsha zone of the runoff farming district, south of the Nizzana zone (Kedar, 1967). The wadi flows from south-west to north-east and is about 3.5 km long, over which length it is joined by its own tributaries of the first to third order (Figure 12). Nahal Mitnan is terraced over most of its length. The terraced parts of the wadi descend from about 540 m to 475 m, when it joins Nahal Horsha. Its average gradient is nearly 2%. Many of its tributaries are also terraced. Nahal Mitnan drains part of Sheluhat Kadesh-Barnea, a mountainous range situated to the north-west, which rises to an altitude of 682 m.

This range forms part of a complex folding structure, together with Har Hamran (704 m) to the east (Figure 3), that seems to be connected with the east-west trending Saad-Nafha-Hallal fault lineament (Bartov, 1974; Zilberman, 1981). A structural saddle, through which Nahal Mitnan and Nahal Horsha are able to flow northward, separates Sheluhat Kadesh-Barnea from Har Hamran (Zilberman, 1981).

The area drained by Nahal Mitnan is largely composed of well-bedded limestones, with some silicified horizons, belonging to the Nahal Yeter Formation of Middle Eocene age (Benjamini, 1979; Zilberman, 1981). The Early Eocene

Nizzana Formation is exposed along the entire south-eastern hillslope flank of Sheluhat Kadesh-Barnea, built of limestones and chalky limestone with some chalk lenses. The soft marls of the Late Cretaceous to Early Tertiary Taqiye Formation, cropping out just over the top of this mountainous range (Zilberman, 1981), are apparently not drained by upper, first order, tributaries of Nahal Mitnan, with a few possible exceptions.

The average annual rainfall for the area is estimated at about 75 mm (p. 110). The hillsides are characterized by shallow desert lithosols and bare rock outcrops, which support a very scattered shrub vegetation dominated by *Zygophyllum dumosum*, *Reaumuria negevensis*, and *Artemisia herba-alba* (Danin, 1983). Most vegetation is concentrated in the terraced wadis, dominated by the *Thymelaea hirsuta* - *Achillea fragrantissima* association. The alluvial loessial soils in two adjacent wadi terraces were investigated by the author, the results of which are presented below.

ARCHAEOLOGY

A farmstead, situated along Nahal Mitnan, at a distance of some 2 km upstream (south-west) from the confluence with Nahal Horsha, was excavated by Mordechai Haiman (1982). The farmstead is located on a natural terrace south of the stream bed of Nahal Mitnan, at an altitude of about 510 m, near the edge of limestone hills made up by the Eocene Nahal Yeter Formation. As the farmstead lies somewhat higher than the wadi-bed below, its former inhabitants could keep an eye on the terraced fields (Photo 17).

The following data from the excavated farmstead, which has a size of 50 x 20 m, are quoted from Haiman (1982): The farm comprises 11 rooms and courtyards. The rooms are square (4 x 4 m), whereas the courtyards are rectangular, measuring about 7.5 x 5.5 m. The walls, 60 cm wide, were built of two parallel rows of limestone blocks (30 x 20 cm) with a filling in the intervening spaces. Haiman noted the high building quality with carefully laid courses and precise right angles.

The pottery found at the site, e.g. delicate bowls painted with a net design, cooking pots, juglets, and an undamaged oil lamp, dates to the 7th and 8th century A.D. An Arabic inscription was found on both sides of a glass disc. Other finds included fragments of iron and copper tools, mortar pieces, pounders, grinding stones, and a large number of millstones, which might suggest that cereal food crops were an important part of local runoff agricul-

ture in the terraced wadi systems. It seems that a Byzantine to Early Arab age can be attributed to the farmstead, as well as to other complexes along the banks of Nahal Mitnan and its tributaries (Haiman, 1982).

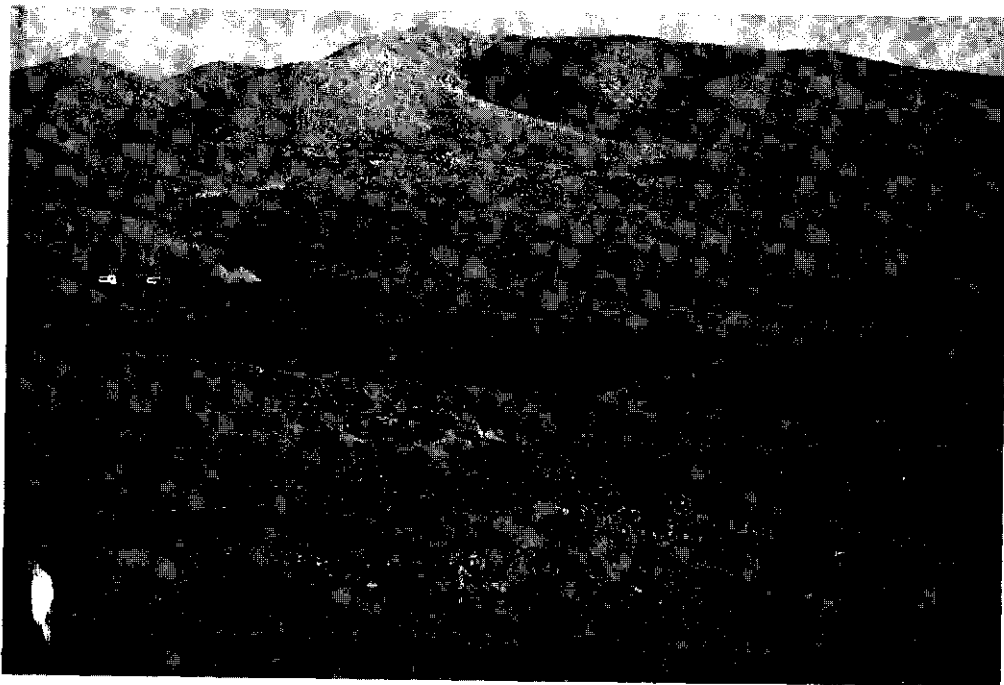


PHOTO 17. Nahal Mitnan with the Byzantine-Early Arab farmstead in the foreground, overlooking the terraced fields toward the hills of Shluhat Kadesh-Barnea. The dam and terraced fields nearest to the farmstead were investigated (pointed out by the arrow).

STRATIGRAPHY AND SOIL DEVELOPMENT IN BYZANTINE WADI TERRACES OF NAHAL MITNAN

STRATIGRAPHY

The terraced stream bed of Nahal Mitnan is flanked on both sides by natural wadi terraces, which presumably date back to the Late Pleistocene. The fine loessial sediments of these natural terraces were deposited when the wadi bed was situated at a higher level than today. A serozem soil with a well developed calcic horizon has formed in these natural terrace deposits. The farmstead is actually located on the upper part of such a Late Pleistocene terrace near the Eocene hillside edge.

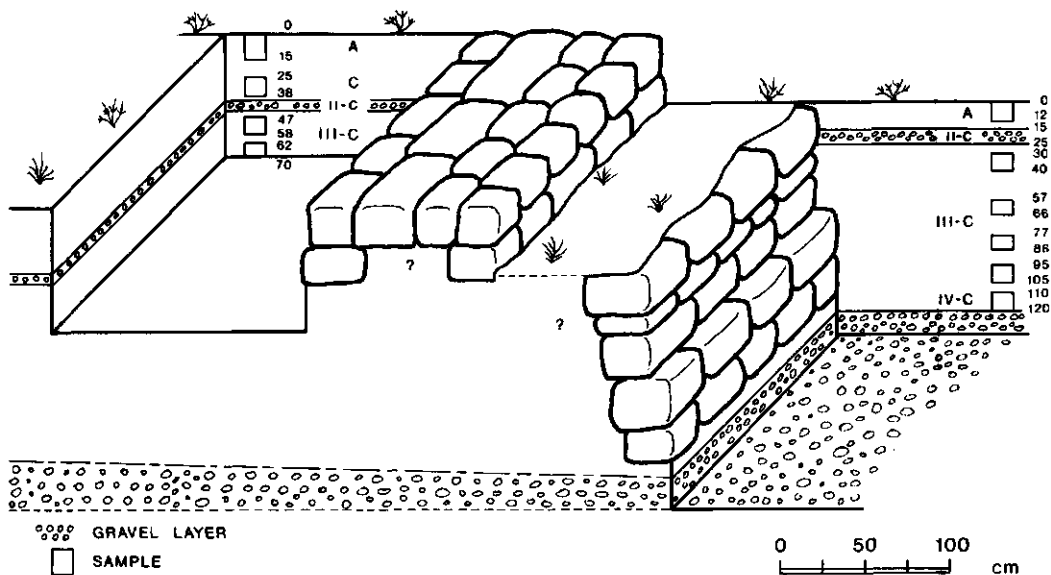


FIGURE 13. Stratigraphy of a check-dam and two adjacent terraced fields in the wadi bed of Nahal Mitnan.

Two pits were excavated into the man-made historical terraces within the wadi bed, on both sides of a check-dam that is located nearest to the farmstead described above. The dam, built for runoff farming purposes, is in all likelihood related to the adjacent farmstead and seems, therefore, to date back to the Byzantine period. Only one small piece of ribbed pottery, apparently Byzantine, was found during the excavations inside the two terraces.

The dam is silted up unto its brim with respect to the upper terrace, whilst it rises some 40 cm above the surface of the lower terrace, downstream of the dam. As the prime object of the excavation was to study the sedimentary stratigraphy and soil development of the man-made terraces, the dam was not excavated from inside and its architecture not thoroughly investigated. It is, however, quite clear that the building style of this dam is much more precise and orderly than the dams at the site of Horvat Haluqim, which may date back to the Iron age or even earlier.

The pit, excavated into the terrace downstream of the dam (Figure 13), surprisingly revealed a hidden lower part of the dam, buried below alluvial

loessial wadi sediments. The dam is thus more complex and wider than initially anticipated, having a width of about 2 meter. This lower part of the dam is 110 cm high, built of 5 courses of limestone blocks, arranged in neat layers (Figure 13). The base of the lower dam rests on alluvial loessial sediments. A gravel layer appears some 10 cm below the base of the dam. The pit was not excavated beyond this gravel layer. The upper part of the alluvial deposits exposed in this pit, including a thin gravel layer at a depth of 15-25 cm, are obviously younger than the lower dam itself.

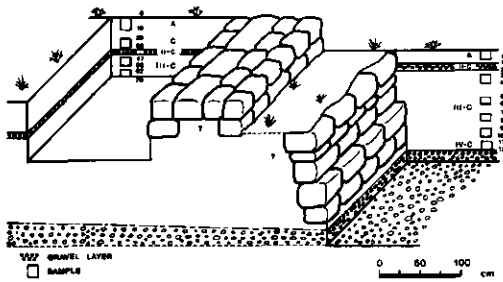
The other pit, excavated into the terrace upstream from the dam (Figure 13), exposed the base of the upper dam at a comparatively shallow depth of about 40 cm below the present surface of this upper terrace. A thin gravel layer occurs at a similar depth of 38-43 cm. As the terrace surface upstream from the dam is about 40 cm higher than the terrace surface downstream from the dam, it thus seems that these upper gravel layers, found in both pits, constitute one and the same stratum. The sedimentary stratigraphy and appearance of the dam complex suggest that the upper part of the dam was built in a later stage.

The reason for this addition was apparently the gradual silting up of the terraced field unto the upper courses of the lower (then only) dam. The upper gravel layer, indicative of more rapid stream flow in the wadi, was apparently deposited at the end of this first aggradational period since the wadi was terraced. In this stage the holding up function of the dams, by which the runoff floods were arrested and sedimentation induced, had apparently been overcome. Hardly any runoff flood waters could have been retained on the field, as the dam was nearly buried below the aggradational deposits. This necessitated the building of an addition to the dam on top of the alluvial sediments that had accumulated.

However, the previous process repeated itself (the past is the key to the future!) as alluvial sedimentation subsequently raised the level of the terraced field unto the brim of the upper dam. This is the situation at present. It is noteworthy that more alluvial loessial sediment has accumulated upstream from the dam on top of the upper gravel layer, than downstream from the dam (Figure 13).

SOIL DEVELOPMENT

The sediments downstream of the dam are somewhat finer textured than upstream, presumably because of hydraulic differences in the flow of runoff water on both sides of the dam. The alluvial soils in the terraced fields of



Nahal Mitnan, which accumulated and developed during and since the Byzantine period, contain more clay than the alluvial soils in the first order wadi of Horvat Haluqim, apparently terraced during the Israelite period.

TABLE 15. Granulometry and soil chemistry of alluvial loessial sediments in an ancient runoff-farming terrace in the wadi bed of Nahal Mitnan.
1) Terraced field upstream from a check-dam of apparent Byzantine origin.

HORIZON	DEPTH (cm)	CLAY <0.002 mm (%)	SILT 0.002- 0.063 (%)	SAND 0.063- 2 mm (%)	TEXTURE	GRAVEL >2 mm (%)	CARBONATES CaCO ₃ (%)
A	0-15	21.1	56.1	22.8	SILT LOAM	1	43.0
C	25-38	19.5	47.8	32.8	SILT LOAM	0	45.4
II-C	38-43 *				GRAVEL		
III-C	47-58	26.7	52.6	20.7	SILT LOAM	2	44.9
III-C	62-70	27.2	51.8	21.0	SILTY CLAY LOAM	1	45.5

HORIZON	DEPTH (cm)	pH	EC(1:1) (mS/cm)	SAR	ORGANIC CARBON (%) C	NITRO- GEN (%) N	TOTAL PHOSPHORUS (%) P ₂ O ₅
A	0-15	7.4	0.45	5.8	0.79	0.06	0.16
C	25-38	7.4	0.34	3.9	0.56	n.d.	0.13
II-C	38-43 *						
III-C	47-58	7.4	0.46	5.9	0.46	n.d.	0.15
III-C	62-70	7.4	0.54	7.0	0.58	n.d.	0.15

HORIZON	DEPTH (cm)	SOLUBLE SALTS IN 1:1 SOIL/WATER EXTRACT (meq/kg soil)							
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
A	0-15	1.0	<0.10	4.2	<0.1	4.3	0.4	0.6	0
C	25-38	0.7	<0.01	2.4	<0.1	2.7	0.5	0.6	<0.1
II-C	38-43 *								
III-C	47-58	1.6	<0.10	5.3	<0.1	2.4	3.2	1.1	0
III-C	62-70	1.6	<0.10	6.3	<0.1	2.6	3.2	1.8	0

Percentages in weight % of the fine earth <2 mm; only gravel in weight % of the total soil. EC = electrical conductivity. SAR = sodium adsorption ratio. n.d. = not determined. * Gravel layer at 38-43 cm depth.

TABLE 16. Granulometry and soil chemistry of alluvial loessial sediments in an ancient runoff-farming terrace in the wadi bed of Nahal Mitnan.

2) Terraced field downstream from a check-dam of apparent Byzantine origin.

HORIZON	DEPTH (cm)	CLAY <0.002 mm (%)	SILT 0.002- 0.063 (%)	SAND 0.063- 2 mm (%)	TEXTURE	GRAVEL >2 mm (%)	CARBO- NATES CaCO ₃ (%)
A	0- 12	25.0	54.6	19.6	SILT LOAM	2	40.9
II-C	15- 25 *				GRAVEL		
III-C	30- 40	25.9	55.2	18.9	SILT LOAM	0	41.1
III-C	57- 66	36.1	49.6	14.3	SILTY CLAY LOAM	0	44.1
III-C	77- 86	34.5	56.6	8.9	SILTY CLAY LOAM	0	44.2
III-C	95-105	28.2	47.3	24.6	CLAY LOAM	4	43.9
IV-C	110-120	21.8	53.7	24.5	SILT-LOAM/GRAVEL	15	46.8

HORIZON	DEPTH (cm)	pH	EC(1:1) (mS/cm)	SAR	ORGANIC CARBON (%) C	TOTAL PHOSPHORUS (%) P ₂ O ₅
A	0- 12	7.4	0.70	4.4	1.37	0.18
II-C	15- 25 *					
III-C	30- 40	7.4	0.30	2.9	0.73	0.15
III-C	57- 66	7.4	0.28	2.9	0.72	0.18
III-C	77- 86	7.5	0.63	6.2	0.67	0.18
III-C	95-105	7.4	0.28	4.1	0.67	0.14
IV-C	110-120	7.4	0.25	2.9	0.72	0.11

HORIZON	DEPTH (cm)	SOLUBLE SALTS IN 1:1 SOIL/WATER EXTRACT (meq/kg soil)							
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
A	0- 12	2.8	<0.10	5.3	0.2	7.5	0.7	0.7	0
II-C	15- 25 *								
III-C	30- 40	1.1	<0.10	2.2	<0.1	3.3	<0.1	0.2	0
III-C	57- 66	1.1	<0.10	2.2	<0.1	3.0	<0.1	0.2	0
III-C	77- 86	2.0	<0.10	6.3	<0.1	2.7	4.4	0.9	0.3
III-C	95-105	0.8	<0.10	2.6	<0.1	2.5	0.3	0.4	0
IV-C	110-120	0.8	<0.10	1.8	<0.1	2.4	0.1	0.3	0

Percentages in weight % of the fine earth <2 mm; only gravel in weight % of the total soil. EC = electrical conductivity. SAR = sodium adsorption ratio.

* Gravel layer at 15-25 cm depth.

The soils in Nahal Mitnan are virtually free of soluble salts. The electrical conductivity ranges in between 0.30 and 0.70 mS/cm. Sodium is the predominant cation throughout the profiles, whilst hydrogen-carbonate is usually dominant amongst the anions, often exceeding the amount of chloride, particularly in

the top-soil. As HCO_3^- is generally the dominant anion in rainwater (Yaalon, 1963, 1964; Nativ et al., 1983) and runoff floodwaters (Nativ et al., 1983), there appears to be a causal relationship in this respect.

The terraced wadi soils at Nahal Mitnan are considerably more calcareous, containing an average amount of 44 % carbonates, than the sampled agricultural wadi terrace at Horvat Haluqim, which contains 30 % carbonates on the average. The difference is largely attributed to the different lithology in the respective catchments. Comparatively softer limestone rocks with more intervenient chalk layers make up the catchment of Nahal Mitnan, whereas harder Turonian limestone rocks predominate in the catchment area of the Horvat Haluqim wadis.

The terraced wadi soils of Nahal Mitnan have a low organic C and nitrogen content, typical for arid regions. The amounts concerned are slightly more advantageous, however, than in the investigated agricultural wadi terrace at Horvat Haluqim, perhaps related to a comparatively better soil moisture regime in the more recent past.

The amount of total phosphorus in the studied soils of Horvat Haluqim is, however, considerably higher than in Nahal Mitnan. Past human activity on the former terrace appears to have been more pronounced, as indicated by the reported finds. The phosphorus distribution in Nahal Mitnan is nevertheless internally consistent with the past influence of man, as the content of horizon-IV, which predates human activity, is even lower than the overlying layers that developed after the beginning of runoff farming.

The stratigraphic picture of the investigated check-dam and adjacent terraced fields in the wadi bed of Nahal Mitnan can be summarized as follows, in accordance with the horizon nomenclature used in the Tables 15 and 16:

- I. The present surface layers of the terraced wadi (A and C horizons), consisting of alluvial sediments that accumulated after the construction of the upper part of the check-dam.
- II. The upper gravel layer, which was deposited before the upper part of the dam was added.
- III. Alluvial sediments that accumulated after the terracing of Nahal Mitnan for runoff farming purposes, i.e. after the building of the lower part of the check-dam across this stretch of the wadi bed.
- IV. Alluvial sediments predating the terracing of the wadi.

8 Kadesh-Barnea: environment, history and the tell

ENVIRONMENT

GEOMORPHOLOGY AND GEOLOGY

The Highlands of the Central Negev continue for some 10-20 km across the border into Egypt. Further to the west stretches the barren expanse of Northern and Central Sinai, characterized by wide plains, plateaus, valleys, individual hills, and isolated mountainous domes. Viewed from Sinai, the Central Negev highlands, ranging in altitude from about 400 to 1000 meter, look like an impressive mountainous plateau.

The Kadesh-Barnea area is situated at the western edge of these Highlands, about 6 to 10 km inside Egypt (Figure 2, 14). The spring of Ein el Qudeirat, arising in the gorge-like valley of Wadi el Qudeirat, is the most important feature of the Kadesh-Barnea area in terms of man-land relationships. It is apparently the richest spring of the entire Sinai and Negev desert region, producing water of a relatively good quality. The average discharge of the spring is about 61 cubic meters of water per hour, flowing as a perennial stream in the channel of Wadi el Qudeirat over a distance of 2 km.

The rather narrow valley plain, in which the wadi has cut a steeply banked stream channel, ranges in altitude from about 350 m at its mouth, near the confluence with Wadi Um Hashim, to about 405 m at the actual site of the spring's major outlet. The valley is enclosed by a series of spiny ridges and escarpments that emanate from the highlands. Gebel el Udah (522 m) limits the area in the southwest, whereas Gebel el Qudeirat (500 m) bounds the Kadesh-Barnea valley to the north (Figure 14). The width of the valley plain ranges from about 400 m at its western entrance to some 40 m near the spring.

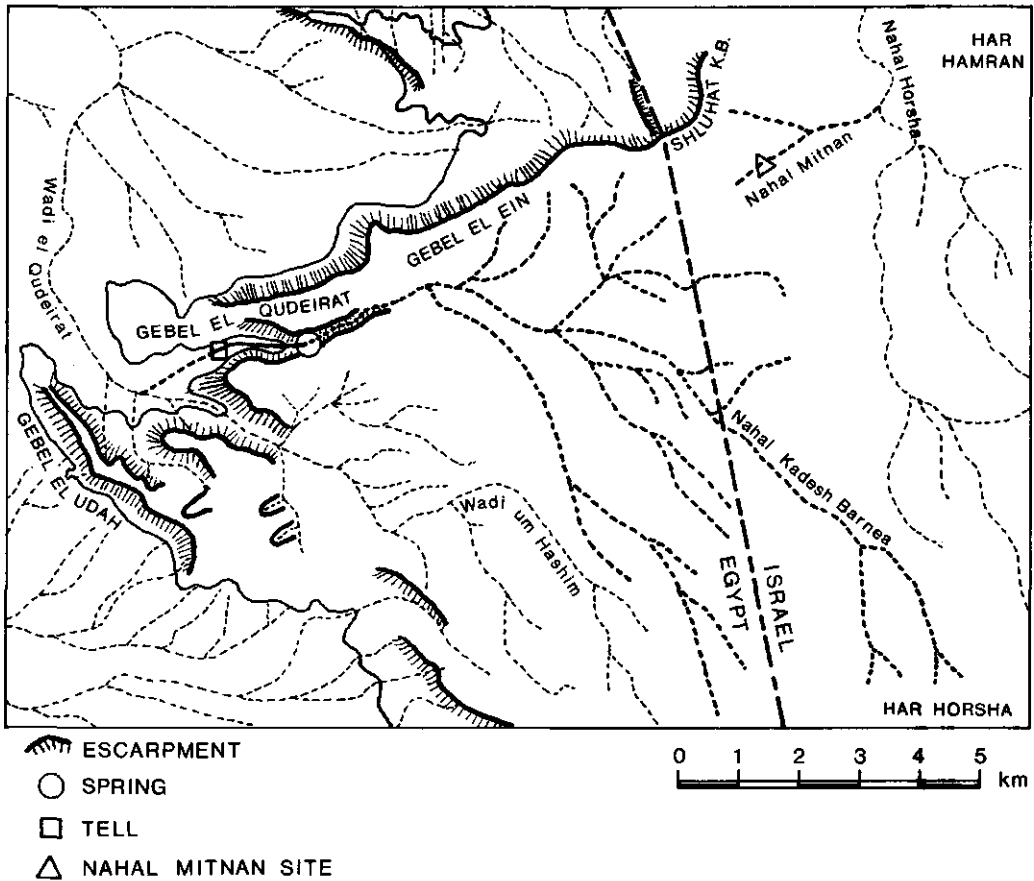


FIGURE 14. The catchment of Nahal Kadesh-Barnea and the valley oasis of Ein el Qudeirat, showing the location of the spring and the tell.

Viewed in a somewhat wider geological perspective, Gebel el Qudeirat forms part of a complex folding structure related to the Saad-Nafha-Hallal fault lineament. This is the main, east-west trending, linear fault system in the northern part of the so-called Central Negev and Sinai shear belt, situated in between the two main faulting zones of the Negev-Sinai region: the Dead Sea Rift Valley in the east and the Suez Rift in the west (Bartov, 1974; Zilberman, 1981). The ridge of Gebel el Qudeirat continues eastward as Gebel el Ein and Shluhat Kadesh Barnea, which together form the southern flank of a complex, east-west trending, fold structure that includes Har Hamran farther to the east. A structural saddle, through which Nahal Horsha and its tributary

Nahal Mitnan run northward, separates Har Hamran from Sheluhat Kadesh-Barnea (Zilberman, 1981). Just north of Gebel el Qudeirat and Gebel el Ein exists a complex fault system, which is related to the folding structure described above, forming part of the Saad-Nafha-Hallal lineament (Bartov, 1974).

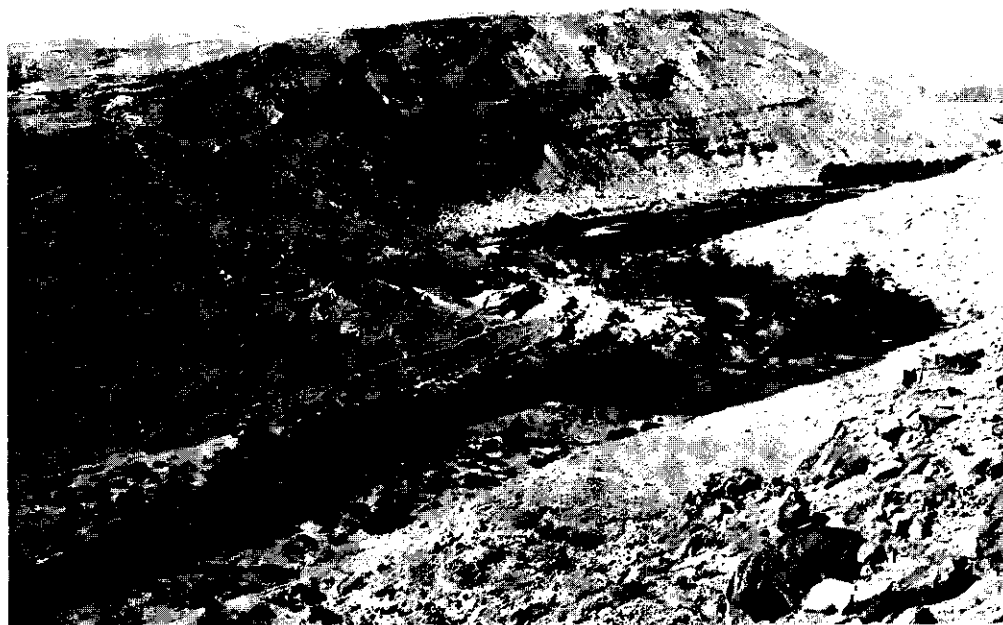


PHOTO 18. The Kadesh-Barnea valley and the beginning of agricultural cultivation (date-palms) near the broken Jarvis Dam, some 400 m downstream from the spring proper. The mountainous ridge south of the valley is built of Eocene calcareous rocks.

The steep, mountainous ridges north and south of the Kadesh-Barnea valley are mainly built of hard limestones, as well as chalk, of the Eocene Avdat Group, overlying the soft marl and chalk of the Mount Scopus Group in the subsurface. The Lower to Middle Eocene Nahal Yeter Formation (Benjamini, 1979) forms the upper part of the ridges, overlying the Lower Eocene Nizzana Formation, which in turn overlies the Paleocene Taqiye Formation.

The Nahal Yeter Formation is composed of well-bedded limestone with some silicified horizons. Large-scale deformations characterize the top of this formation, formed by collapsed units of well-bedded limestone layers, 10-20 m thick. These sedimentary structures may have been caused by Eocene earthquakes

(Zilberman, 1981). The Nizzana Formation consists of limestones and chalky limestone with some chalk lenses. The layers exhibit small to moderate intra-formational sedimentary disturbances, like small folds, detached layers, sedimentary conglomerates and small sedimentary faults. The underlying Taqiye Formation is mainly composed of marl, cropping out at the lower part of the northern and western slope of Gebel el Qudeirat, as well as across the entrance of the Kadesh-Barnea valley near the confluence with Wadi Um Hashim.

GEO-HYDROLOGY

The main upper aquiclude of the Central Negev Highlands is the Taqiye Formation, mainly consisting of impervious marl. This formation underlies the entire Eocene Avdat Plateau from Kadesh-Barnea in the west until the Zin Valley in the east. Runoff rainwaters that have infiltrated into the underground may concentrate as shallow groundwater on top of the Taqiye marls. As a result of this hydro-geological situation, some springs arise at favourable locations on the outskirts of the Highlands, near outcrops of the Taqiye Formation.

The gorge-like valley of Wadi el Qudeirat is incised into the Eocene Avdat Group and actually cuts into the marls of the Taqiye Formation some 3 km downstream from the point where the spring of Ein el Qudeirat emerges in the wadi bed. The relation seems obvious, but the local fold and fault structures of the Saad-Nafha-Hallal lineament, to which the Kadesh-Barnea area is connected, may also have an important influence on the position of the spring.

The latter view seems concurrent with the existence of the nearby spring of Quseima, 7 km west-northwest of Ein el Qudeirat, situated on the Saad-Nafha-Hallal lineament. This spring appears to be almost as copious as Ein el Qudeirat, having a discharge of about 50-60 cubic meter of water per hour, as reported by Karschon (1984). The water of the Ein Quseima spring appears to be of even better quality than the spring of Ein el Qudeirat. Its reported chloride content of 250-300 mg/liter (7.1 - 8.5 meq/liter) is only half the quantity occurring in the latter spring.

Data about the water of Ein el Qudeirat are shown in the following table. The spring is flowing all year round and the differences in discharge between the various months and years are relatively small, ranging in between 48 and 73 cubic meters of water per hour. The average discharge is about 61 cubic meter/hour. This suggests a considerable relaxation time between rainfall events in the catchment area and spring flow, probably caused by the buffering effect of a sizeable natural storage of shallow groundwater.

TABLE 17. Discharge data and chemical analysis of the spring water of Ein el Qudeirat.
(based upon data from the Israel Hydrological Service)

SAMPLE DATE	DISCHARGE	
	(cubic meter/24 hours)	(cubic meter/hour)
1926	1500	63
23-08-1951	1400	58
21-10-1969	1750	73
19-01-1970	1150	48
18-05-1970	1600	67
16-07-1970	1450	60
21-09-1970	1400	58
17-02-1971	1400	58

Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺		HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
89	45	330	4	(mg/liter)	212	509	226
4.44	3.70	14.35	0.10	(meq/liter)	3.47	14.36	4.71

AGRICULTURAL EVALUATION OF THE SPRING WATER

The chemical composition of the water appeared to be fairly constant during the years from 1926 to 1971. The chloride content ranged in between 500-580 mg/liter (14.1 - 16.4 meq/l). The amount of dissolved salts is about 1.42 g/l and the electrical conductivity (EC) of the spring water is estimated at 2 mS/cm. The sodium adsorption ratio (SAR) is 7.11, showing the sodicity (alkali) hazard of the water to be low. This is confirmed by the negative value (-4.67) of the RSC (residual sodium carbonate and bicarbonate), another criterion to judge the sodium hazard of irrigation water (ILACO, 1981).

For irrigation purposes the water from the spring can be classified as having a medium-high salinity hazard (Thorne and Peterson, 1964). The water is suitable to irrigate crops with a moderate to good salt tolerance. Irrigation is allowed on soils with a moderate to poor permeability. The crusting loam to silt loam soils in the Kadesh-Barnea valley are, therefore, suited to this type of irrigation water. Leaching with excess water is required, however, to prevent a built-up of salts in the root zone.

RAINFALL

The average annual rainfall today in the Kadesh-Barnea area has to be estimated from data of nearby locations. Mean annual rainfall at Quseima, situated about 7 km west of Ein el Qudeirat at an altitude of some 300 m, is

64 mm (Israel Meteorological Service, 1967). Nizzana receives a mean annual rainfall of 86 mm and lies 26 km north of Ein el Qudeirat at an altitude of 250 m. The average rainfall in the Kadesh-Barnea area (altitude of the Ein el Qudeirat valley and of the surrounding ridges and highlands is 350-425 m to over 500 m, respectively) can therefore be estimated at about 75 mm/year.

SOILS and VEGETATION

In terms of man-land relationships, the Kadesh-Barnea valley is not only endowed with a copious spring, flowing all year round, but also with cultivable soils formed in alluvial loessial sediments. These young alluvial soils show little or no profile differentiation in the field. However, on close examination, including microscope studies and chemical analysis, remarkable features of soil development were discovered in the valley soils adjacent to the steep banks of the narrow wadi channel.

Loessial serozems, usually exhibiting calcic, gypsic and saline horizons, are found on more elevated Pleistocene terraces in the valley. Calcareous desert lithosols and Brown lithosols occupy the surrounding hillslopes and highlands, covered by a desert vegetation dominated by *Zygophyllum dumosum*, *Artemisia herba-alba*, *Salsola tetranda*, *Suaeda vera* var. *desertis*.

The vegetation along the stream channel, fed by the flow of spring-water, includes *Tamarix nilotica*, *Nitraria retusa*, *Typha australis* and *Phragmites australis* (Danin, 1983, personal communication, cf. Goldberg, 1984).

HISTORY AND GEOGRAPHY

Kadesh-Barnea appears to be the principal place where the people of Israel sojourned in the desert for some 40 years under the leadership of Moses (Num. 14:33-34), after the Exodus from Egypt and before they entered the promised land. Most references in the Bible to Kadesh-Barnea are indeed related to this period within the Late Bronze Age (1550-1200 B.C.), when the Israelites "abode in Kadesh many days" (Deut. 1:46). However, the site is already mentioned in the time of Abraham, in the Middle Bronze Age, around 1900 B.C., when Kadesh is equated with En-mishpat, "The Spring of Judgement" (Gen. 14:7).

The location of Kadesh-Barnea can be inferred from the description of the southern border of the Land of Israel (Num. 34:1-6; Ezech. 47:19; 48:28) and of the southern border of the territory allocated to the tribe of Judah (Josh.

15:1-4). Numerous scholars of past generations have attempted to identify biblical Kadesh-Barnea with sites in Sinai, the Negev, or even more distant places, as summarized by Cohen (1981). A general scholarly consensus emerged early in the 20th century, relating Kadesh-Barnea to the oasis of Ein el Qudeirat.

Woolley and Lawrence (1914-15) regarded the region around Quseima (Fig. 2) with its springs and arable soil, at the crossroads of two of antiquity's major desert routes, as the likely area of Kadesh-Barnea from a more broad perspective. The sheltered valley-oasis of Ein el Qudeirat, in the eastern part of the Quseima region, is considered by them as the most likely candidate for Kadesh-Barnea in a more restricted sense, by which they focussed special attention to the Tell.

The authors made their observations in January and February of 1914. The following quotations eloquently describe the area and some of the reasons for relating it to Kadesh-Barnea (Woolley and Lawrence, 1936:88, 87): "These roads running out to north, south, east, and west... together with its abundance of water and wide stretch of tolerable soil, distinguish the Kossaima plain from any other district in the Southern Desert, and may well mark it out as the headquarters of the Israelites during their forty years of discipline... only in the Kossaima district are to be found enough water and green stuffs to maintain so large a tribe for so long, and that therefore the Wilderness of Zin and Kadesh-Barnea must be the country of Ain el Guderat, Kossaima, Muweilleh, and Ain Kadeis".

In their description of the springs in the Quseima region, they contrast the barren and rugged area around Ein Qadeis with the more cultivable Quseima plain and the oasis of Ein el Qudeirat. The latter site is clearly distinguished as the most outstanding spot in the entire region (p. 75):

"In place of the solitary Ain Kadeis are Ain Muweilleh, in a soft wady bed; Ain Kossaima, a plentiful running of water in the sand; and Ain Guderat, a great spring, not set in a dung-heap like Ain Kadeis, or sand-choked like all other Negeb springs, but bursting straight from the rock, and running down a deep green valley of lush grass in swift irrigation channels, or in a long tree-shaded succession of quiet pools many feet deep. This plain about Kossaima runs from Muweillah on the west to the foot of the great pass of Ras Seram on the east. In fortunate years it might be very fruitful; and in the worst seasons its crops cannot entirely fail, thanks to the irrigated valley of Ain el Guderat - the only stretch of corn-land under running water which we saw in all the southern waste."

ARCHAEOLOGY OF THE TELL

Woolley and Lawrence were the first scholars with solid archaeological training to study the Tell in the valley of Ein el Qudeirat, situated some 1600 meter downstream from the spring, "commanding the finest water-supply in all the desert" (p. 84). They described the tell as a little mound rising above the surrounding corn-fields. After brief excavations, they found the tell to be made up by the remains of an ancient fortress and contemplated the possibility that it might have existed already during the time of the Exodus, and perhaps be linked specifically to Kadesh-Barnea.

The excavations by Dothan in 1956 further clarified the ground plan of the fortress, dating its construction to the Judean kings of the 8th-7th centuries B.C. (Dothan, 1965). Thus, the tempting possibility posed by Woolley and Lawrence (1936:88) "that the fort was already built when Moses came" turned out to be unreal for this particular stronghold. A reliable stratigraphy was, however, still lacking for the tell.

Rudolph Cohen conducted thorough excavations at the site during ten seasons from 1976-1982. These extensive investigations revealed the remains of two other fortresses. Thus the tell is not made up by just one stronghold of one period, i.e. the Late Iron age, but by three superimposed fortresses, each one built over the remains of its predecessor. A concise description of these fortresses, quoted from Cohen (1981, 1983), follows at page 116. The Early Fortress and a number of related buildings and silos appear to be the oldest archaeological structures found at the site, attributed by Cohen to the 10th century B.C. (Cohen, 1980, 1981, 1983).

CARBON-14 DATE (GrN-12330) - LATEST BRONZE TO EARLY IRON AGE

A charcoal sample was taken by the author in collaboration with Cohen from one of the lowermost ash layers, some 5 meter below the surface of the tell-mound. This layer seems stratigraphically connected with the destruction of the Early Fortress. The sample was investigated at the Isotope Physics Laboratory of Prof. Mook (University of Groningen) and yielded a date of 2,930 \pm 30 BP in conventional Carbon-14 years (GrN-12330). When this date is translated into historical years, calibrated against the high precision curve of Pearson (1986), for reasons explained in the following section, the resulting age of the ash layer is surprisingly early: 1255-1055 Cal B.C.

The natural level of carbon-14 in the atmosphere has not been constant with time, as first reported by De Vries (1958) who made this important observation

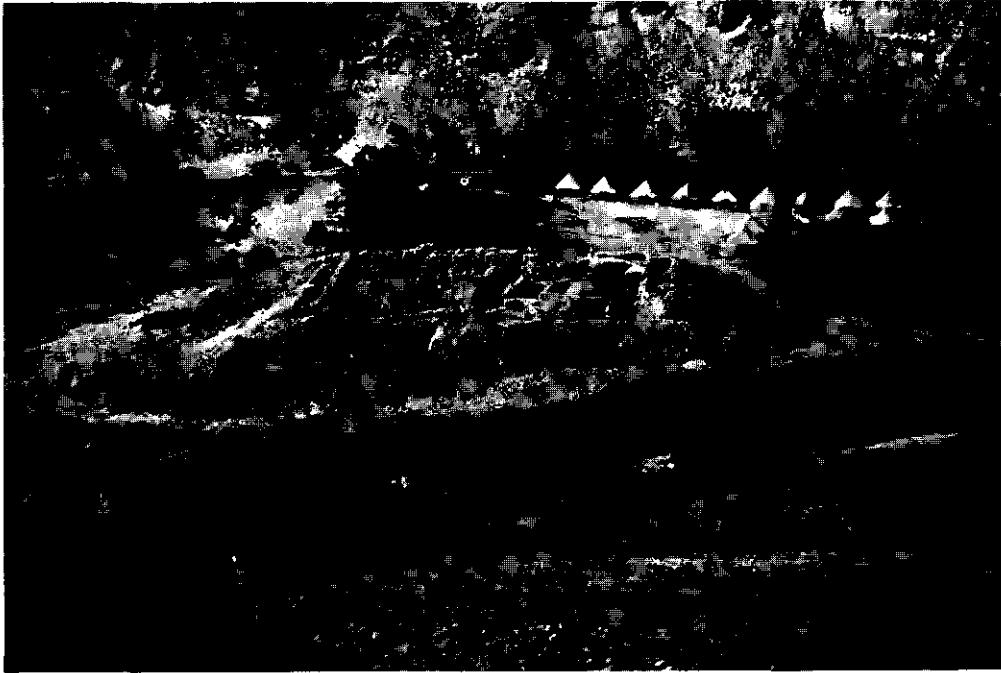


PHOTO 19. The excavated tell in the valley of Ein el Qudeirat, exhibiting primarily the outline of the Upper Fortress (Late Iron Age). The stream channel carries the water from the spring along the southern part of the tell.

indirectly through C-14 measurements of tree-rings from European and North American wood. A radiocarbon date, as a consequence, although consistent in its own timescale, cannot simply be placed into a historical time framework. First the carbon-14 date, expressed in conventional C-14 years, has to be translated into astronomical years. The resulting calibrated C-14 date can then be correlated with historically dated events (Mook, 1983).

In order to make this calibration possible, very detailed and precise C-14 analyses were carried out on wood of known astronomical age, dated by dendrochronology. Research on oak wood from Ireland has resulted in a high precision radiocarbon calibration curve, published by Pearson (1986).

A conventional C-14 date is always presented with a range of uncertainty, called standard deviation (σ). The probability that the actual date is situated within this time period is 68 %. If the age range is enlarged to about 3 σ , the probability becomes virtually 100 %. It should also be realized that a charcoal sample, in most cases, does not represent a single

year, like a tree-ring, but comprises a certain time-width. In an ideal situation, the amount of detail in a calibration curve ought to be adapted to the time-width of the C-14 sample (Mook, 1983).

When a radiocarbon date is translated from conventional C-14 years into historical years, not just the median year of the C-14 date, but the entire sigma related age range of the date has to be plotted against the calibration curve. Apart from sigma (σ), the standard deviation of the calibration curve, being 15 years, has to be taken into account as well in order to determine the correct age range for calibration: (a) Calculate $\sqrt{\sigma^2 + 15^2}$; (b) The resulting number X is added to the median year of the C-14 date, which gives the upper time limit of the date's range to be calibrated; (c) X is subtracted from the median year of the C-14 date, which gives the lower time limit of the C-14 date to be calibrated (Mook, personal communication, 1985).

The age range of the charcoal sample under discussion (GrN-12330; 2930 ± 30 BP), to be used in the calibration plotting, is 2965-2895 BP in conventional C-14 years. This sigma related time range of the date is plotted (Fig. 15) against the high precision radiocarbon timescale calibration curve of Pearson (1986). The resulting calibrated date for the black ash layer in historical years is 1255-1055 Cal B.C.

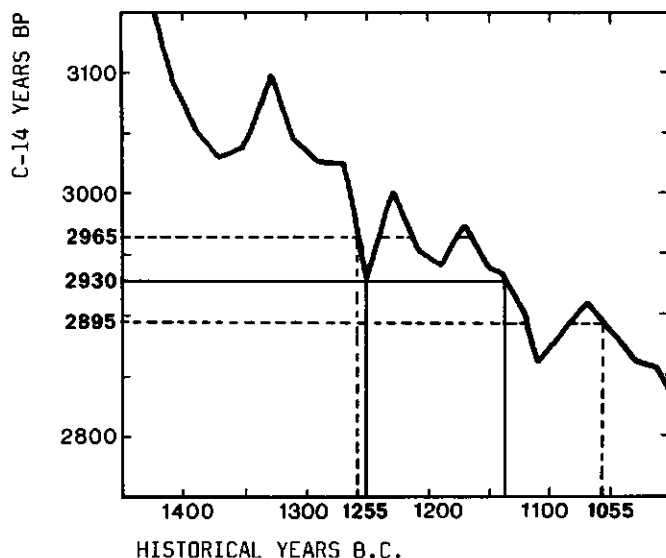
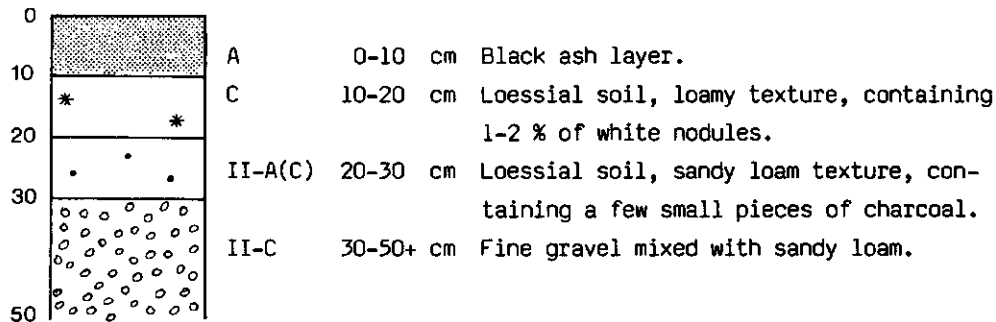


FIGURE 15. Calibration of the above C-14 date (GrN-12330) into historical years (apparently related to the time of destruction of the Early Fortress).

Taken at face value this surprising outcome might indicate that the Early Fortress is perhaps older than anticipated. If the ash layer is indeed related to the time of destruction of the latter stronghold, then the radiocarbon date of this ash layer suggests this to have occurred during the very end of the Late Bronze Age or Early Iron Age. The logical implication is, that the time of construction of the Early Fortress must be even older than the above C-14 date, pointing to the Late Bronze Age, perhaps.

The result of this radiocarbon date and its ramifications, touching upon the dramatic transition from the Canaanite to the Israelite period in the Negev and Sinai, as well as the outcome and stratigraphic context of other C-14 dates from the tell, will be discussed and evaluated in a joint publication.

The dated ash layer covered a soil profile with the following stratigraphy and characteristics:



The ash layer can be regarded as a disturbed A horizon, overlying a C horizon that consists of loess with a loamy texture. About 1-2 % of white nodules, composed of gypsum or secondary carbonates, appear in this C horizon. These nodules were formed by natural soil forming processes under the influence of rainfall, which caused influx, dissolution, concentration and recrystallization of these chemical compounds in the upper part of the soil.

It is obvious that nodule formation could only take place when the soil was still situated at the former landscape surface, during the period before and/or in the time after the formation of the C-14 dated ash layer. With the building of the Middle Fortress, if not already during the time of the Early Fortress, the soil became buried below the rainfall penetration depth, which is about 30 cm for a loamy soil in the average arid climate of the region.

The next II-A(C) soil horizon has a texture of sandy loam. It contains some small pieces of charcoal, probably older than the dated black ash layer. It is

apparently another buried A horizon. The charcoal remains may have originated from human activity at the site, perhaps during the Bronze Age, by which no artifacts were apparently left behind.

The underlying II-C horizon consists of virgin soil, composed of a natural mixture of fine gravel and sandy loam.

EARLY FORTRESS

The Early Fortress has an oval groundplan with a diameter of 27 m, and is similar to the other Israelite fortresses in the Central Negev such as at Horvat Haluqim: p. 69, photo 12 (Cohen, 1976, 1980). The ash-covered floors of the casemate rooms contained a rich assemblage of pottery, attributed to the 10th century B.C. (Cohen, 1981, 1983). Unlike other similar strongholds in the Central Negev, which were not rebuilt after their destruction, the site at Kadash-Barnea is unique in the sense that a new fortress was erected over the ruins of the former one (Cohen, 1980).

MIDDLE FORTRESS

The Middle Fortress had a completely different, rectangular, ground plan with a size of about 60 x 40 m. It had a solid wall, about 4 meter thick, and eight projecting towers. The fortress was entirely surrounded by an earthen glacis that rested against a buttress wall, 2.50 m high. This wall was surrounded by a moat, about 4 m wide, except on the southern side where the wadi channel functioned as a natural moat. A big cistern, ca. 10 m across and with a capacity for about 180 cubic meters of water, was uncovered inside the fortress. A plastered conduit, running underneath the southern rampart walls toward the side of the wadi, facilitated the filling of the cistern with water from the spring. Silos and granaries were also discovered (Cohen, 1981, 1983).

UPPER FORTRESS

The Upper Fortress at Kadash-Barnea was erected a short time after the destruction of the Middle Fortress and its ground plan, already outlined by Woolley and Lawrence (1914-15) and Dothan (1965), is almost identical to that of the latter. Casemate walls, however, replaced the thick, massive walls. The earthen glacis was adapted to the new walls, whereby the buttress wall and moat continued to function, as well as the cistern and its conduit, that runs underneath the southern rampart walls toward the side of the wadi (Photo 20). On the ash-covered floors of the the casemate and interior rooms a large assemblage of ceramic vessels was uncovered, the wheel-made pottery being



PHOTO 20. A plastered conduit, running underneath the southern rampart wall of the Upper (and Middle) Fortress toward the side of the wadi, facilitated the filling of the large cistern inside the latter fortresses.

characteristic for the 7th to 6th century B.C. One jar was still full of burnt wheat. The third and last fortress at Kadesh-Barnea was probably destroyed by the Babylonian army of Nebuchadnezzar at about the same time as the First Temple in Jerusalem - 586 B.C. (Cohen, 1981, 1983).

PERSIAN PERIOD

After the destruction of the Upper Fortress, there was evidently limited reoccupation on the site during the Persian Period (587-332 B.C.) in the form of an unwalled settlement (Dothan, 1965; Cohen, 1981, 1983).

ENVIRONMENT AND SITING OF THE TELL

The tell-mound rises some 6 meter above the surrounding valley plain, which is 164 meter wide at this point. The mountain edge of Gebel el Qudeirat bounds the valley some 78 m to the north of the tell (Photo 19, 22),

measured from the northern wall of the upper and middle fortress. The perennial desert stream, fed by the spring, flows along the southern side of the tell (Photo 19). The mountain edge that bounds the valley in the south (Photo 18, 22) lies about 46 m from the southern wall of the upper and middle fortress. These fortresses themselves had a width of some 40 m (Cohen, 1983), as a consequence of which the upper part of the tell is about 40 m wide as well.

The tell is made up by the remnants of the three fortresses that were successively built on the site. Probably throughout its history the tell functioned as a sedimentation trap for dust, mixed in with the remnants and debris of successive cycles of building and destruction. Studies about soil development at the tell in relation to its stratigraphy will be published elsewhere.

The tell is situated on a slightly elevated hillock, a stony remnant of a Pleistocene terrace in the middle of the valley of Ein el Qudeirat. This hillock is primarily composed of coarse gravel and well-rounded boulders up to 40 cm in diameter (Photo 21), being somewhat cemented. These coarse sediments were deposited during the Late Pleistocene, when the stream bed of the wadi was situated well above the present level of the valley.



PHOTO 21. Late Pleistocene deposits, consisting of slightly cemented coarse gravel and well-rounded boulders up to 40 cm in diameter, below the base of the southern wall of the Upper Fortress.

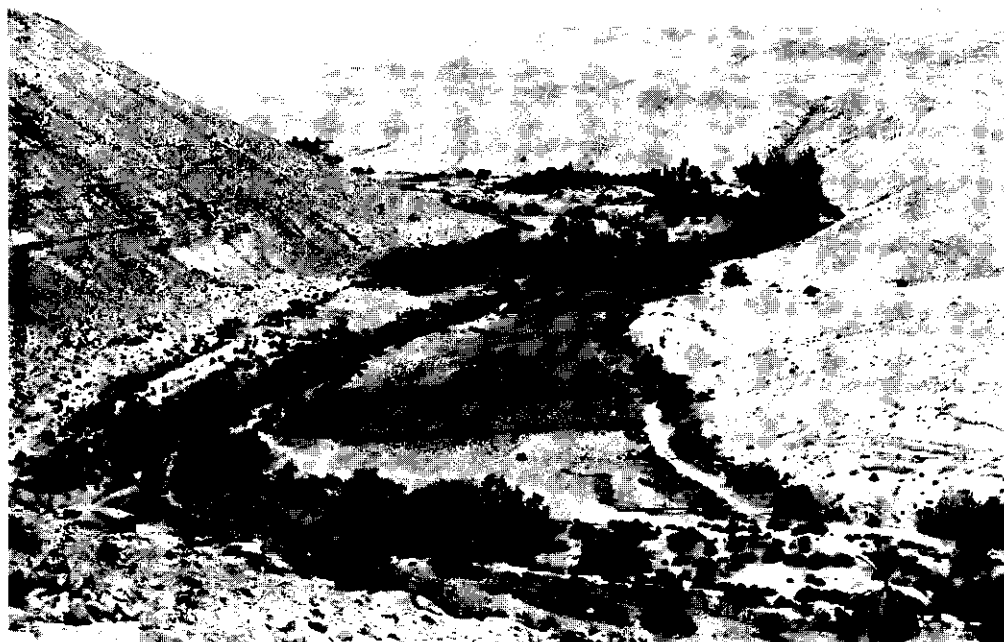


PHOTO 22. The valley of Ein el Qudeirat widens here, just downstream from the Jarvis Dam; the excavated Tell is visible farther downstream, located in the centre of the valley oasis, more westward.

Goldberg (1984) found Middle Paleolithic discoid cores in a similar terrace remnant, presumably dating back 90.000-40.000 BP (Schwarcz et al., 1980), about 1700 m downstream from the tell, at the entrance of the valley near the confluence with Wadi Um Hashim.

Before the construction of the Early Fortress, the site must have looked like a low, natural hillock, rising some 3 meter above the general level of the valley plain. This stony hillock constituted the natural foundation on which the Early Fortress and subsequent fortresses were built, right in the middle of the valley, yet firmly established on the stony underground (Photo 21) to withstand the seasonal floods. A shallow soil with a loam to sandy loam texture, found below some of the ancient man-made structures, covered part of the stony hillock.

It is noteworthy that the ancients did not built their strongholds next to the actual spring itself, but farther downstream where the valley is wider (164 m) and suited for irrigation agriculture. The site selected by the people

who built the Early Fortress and subsequent fortresses was apparently the only elevated stony foundation within the loamy valley plain, situated at a very strategic position: about half-way between the entrance of the Kadash-Barnea valley (which could be kept in view some 1500 m westward) and the actual location of the spring (some 1600 m eastward). The precious water from the spring is flowing naturally to the site of the tell all year round, carried by the narrow stream channel, which is incised below the valley plain and passes the tell just 10-20 meter south of the main southern fortress wall. A few hundred meter farther downstream, however, this unique perennial stream in the desert disappears below the surface of the wadi bed.

The position of the tell thus has the following advantages:

1. It commands the westernmost access to the spring-water.
2. It is situated amidst suitable farming lands in the wider part of the valley.
3. The elevated stony underground provides a firm foundation against seasonal runoff floods.
4. It gives a view unto the western entrance of the valley.

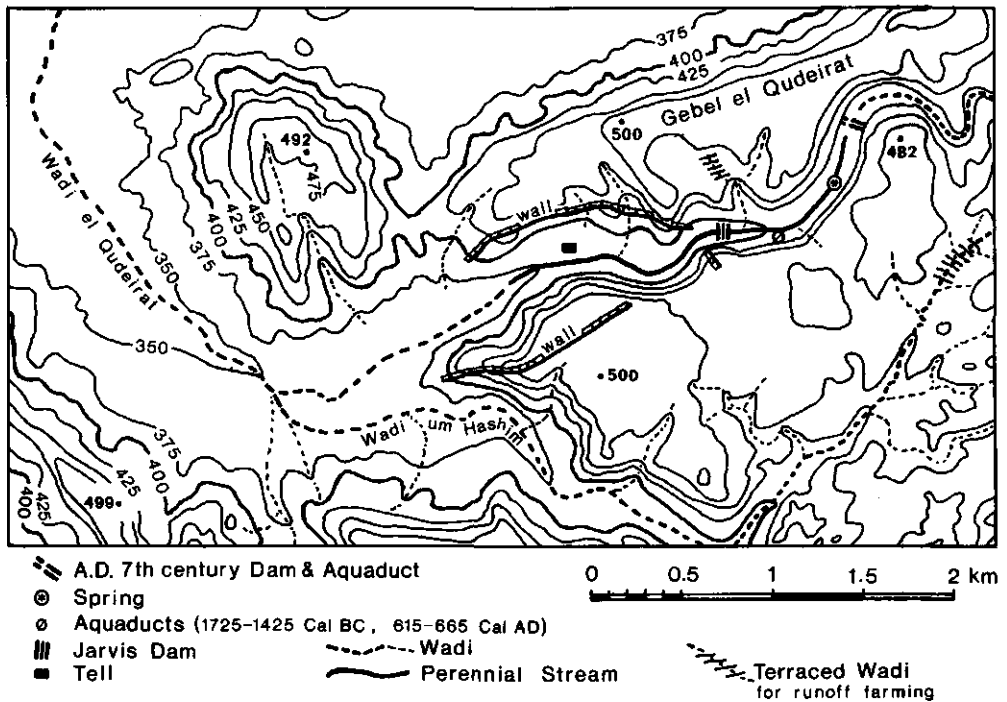


FIGURE 16. The valley of Ein el Qudeirat or Kadash-Barnea

9 Kadesh-Barnea: irrigation agriculture

SYSTEMS OF IRRIGATION AGRICULTURE IN THE KADESH-BARNEA VALLEY

The occurrence of a copious spring, whose water is flowing freely all year round in the middle of the desert, in a valley also endowed with cultivable soils, may suggest the practise of agriculture to be a natural and simple matter. In reality the situation is somewhat more complicated, essentially due to obstacles of a geomorphic nature. The main problems for farmers to practise agriculture in the valley of Ein el Qudeirat are essentially twofold:

1. The water from the spring arises and flows in the stream channel of Wadi el Qudeirat (Nahal Kadesh-Barnea), situated below the level of the cultivable valley plain.
2. Although the average annual rainfall in the area is low, being about 75 mm today, powerful runoff floods may occasionally develop in Nahal Kadesh-Barnea during the rainy season, causing damage or destruction to irrigation systems and crops.

In order to solve the first problem, the farmers had to bring the water from the spring unto the level of the cultivable valley plain. The remains of former and present irrigation systems in the valley show two principal solutions:

(a) AQUADUCTS THAT BEGIN AT THE NATURAL LEVEL OF THE STREAM BED, either having their intake of water near the main outlet of the spring or farther down the wadi bed. This type of aquaduct must initially have a gradient which is less than the slope of the stream channel and valley plain. As the aquaduct

descends less steep than the latter, it will seemingly rise with respect to the channel bluff and will appear at some point downstream onto the level of the valley plain as a result. The point of emergence of the aquaduct onto the valley plain is obviously the highest level where irrigation and agriculture can take place. From this point the aquaduct may have the same, steeper, gradient as the valley. A low threshold-dam that raises the water-level somewhat behind it will considerably facilitate the intake of water into the aquaduct(s), thus improving this system.

(b) THE BUILDING OF A MAJOR DAM that raises the water level until the height of the valley plain, as a significant artificial pond will form behind such an obstruction wall in the stream channel. Aquaducts can thus begin at the level of the valley plain right from their beginning, which may allow the valley plain to be irrigated farther upstream, depending of course upon the location of the dam. This system enables a better control and more efficient use of the spring-water for agricultural purposes.

It seems obvious that aquaducts which have their beginning in the wadi bed (type a) are susceptible to destruction by powerfull runoff floods, occasionally roaring through the stream channel in the rainy season. Aquaducts connected with high dams that raise the water until the level of the valley plain, can be built right from their beginning point of water intake on the edge of the valley against the mountain side. In these high dam systems the aquaducts are rather safe, but now the dam itself may be destroyed by runoff floods, historic examples of which will be discussed in the following sections.

At present the stream channel only occupies a small part of the Kadesh-Barnea valley. The channel is about 5 to 15 meter wide. It has steep banks and its bed is well incised to a depth of 3 to 6 meter below the partly cultivated valley plain. Within historical times the stream channel has experienced dramatic changes, extensively dealt with in Chapter 10.

Each irrigation system in the Kadesh-Barnea valley necessarily comprises two different aspects. The first aspect involves the conduction or raising of water from the spring onto the valley plain, and has already been discussed. The second aspect involves the equal distribution of irrigation water over the agricultural fields. Possible distribution systems that were probably used at various times in the past can be characterized as wild flooding, border, and basin irrigation (Booher, 1974).



PHOTO 23. Unlined irrigation ditch against the hillside edge, made by local Bedouin.

These systems may have been integrated or combined in various local adaptations.

The main irrigation aqueducts or ditches were usually placed along both high edges of the valley plain, against the hillsides. By making outlets at desired points into these main aqueducts, the water would flow onto that part of the valley plain requiring irrigation. Each part of the valley plain is sloping down both laterally towards the stream channel and longitudinally in a general downstream direction. The farmer had several options in distributing the flow of water as equally as possible over his fields. The likely systems used are outlined below:

WILD FLOODING SYSTEM

This method, described by Booher (1974:108), consists of spilling water at frequent intervals from a grade ditch constructed along the high edge of a sloping field. The water is allowed to flow freely down the slope, irrigating the soils the water moves across. Interceptor ditches are placed at intervals down the slope to collect the water, which will tend to concentrate in swales, and to redistribute it more uniformly. This system is used primarily on steep lands or valley lands with an uneven topography, where uniformity of water distribution is not a major consideration. The system is also important for flatter lands having shallow soils, which, for that reason, cannot be levelled.

Success with this method depends on the skill to release water at the correct points from the grade ditches, and in adjusting the size of openings so that the correct amount of water is released to cover the area without causing soil erosion. A minimum of land grading is required with this method of irrigation, which is an important advantage where soil depths are shallow

and only a limited amount of earth can be moved (Booher, 1974). Shallow soils covering a stony underground do occur in parts of the Kadesh-Barnea valley.

BORDER IRRIGATION SYSTEM

This method (Booher, 1974:93) requires a series of parallel ridges of earth or stone, positioned in a lateral direction across the valley plain. There appear to be ancient remains of stony ridges in the Kadesh-Barnea valley which might have been used for such an irrigation method. The land in between these parallel ridges is called a border-strip or gravity-check. The ridges guide and check a sheet of flowing irrigation water moving down the valley-slope, the water being released from aqueducts at the edge of the hillside. The land should have a uniform moderate slope and careful land preparation is necessary for this method to be efficient.

Where conditions are suitable for border irrigation it is often the most efficient method for the irrigation of close-growing crops such as cereals, pasture or other field crops. The system is also used for irrigating orchards and vineyards (Booher, 1974).

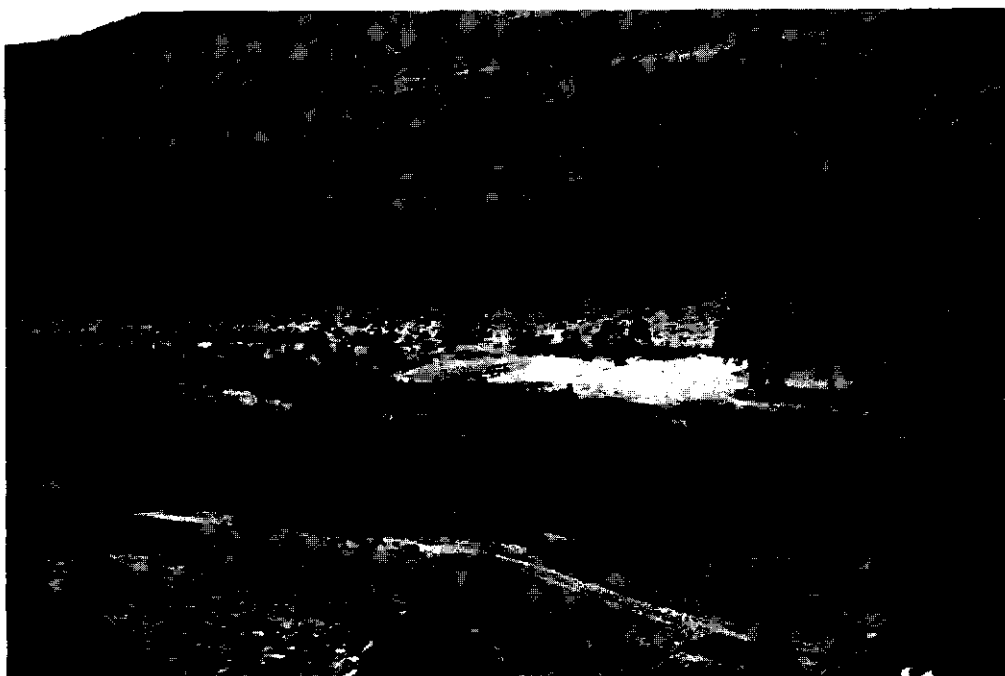


PHOTO 24. A combination of wild flooding and border irrigation for field crops, next to the date-palms, carried out by local Bedouin in the valley of Ein el Qudeirat, upstream from the tell, south of the stream channel.

BASIN IRRIGATION SYSTEM

This method (Booher, 1974) is generally most widely used. There are many variations in its application, but the principle is simple: dividing the land into small units so that each has a nearly level surface. Levees (ridges, bunds or dikes) are constructed around each individual unit or basin, which are filled with irrigation water to the desired depth.

Basins may vary in size from 1 square metre, used for growing vegetables and other intensive crops, to several hectares for cereals or other field crops (Booher, 1974). The size not only depends upon the type of crops but also upon the geomorphology of the landscape. The latter factor determines the maximum size of the basin that can be levelled.

Unlined ditches and ridges of earth are usually not preserved. In many cases these have to be rebuilt every year on account of natural deterioration or plowing. Moreover, the setting up of a new field alignment, because of crop rotation or a change in ownership, may also alter existing field and irrigation distribution systems periodically. In archaeological or historic reconstructions it is, therefore, often impossible to relate hard remnants, like stone aqueducts, to soft agricultural field systems. Remains of the latter are usually not found. In case ridges are preserved, their dating is generally problematic, hence their correlation with remains of known age.

Evidence from hard but often fragmentary remnants of irrigation farming that served as the basis for this outline, together with more recent historic descriptions, is presented in the following section. The position in the valley of ancient aqueducts and dams was pointed out to the author by Yosef Porat, who investigated these remains as an archaeologist (Porat, personal communication, 1981).

ARCHAEOLOGIC AND HISTORIC EVIDENCE OF IRRIGATION AGRICULTURE IN THE KADESH-BARNEA VALLEY.

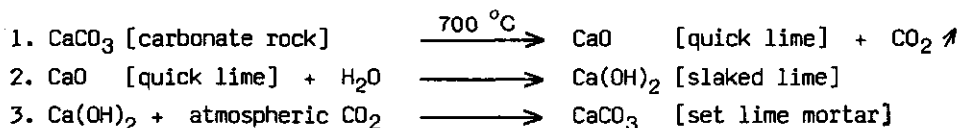
BRONZE AGE AQUADUCT: CARBON-14 DATE (GrN-12327)

An aquaduct remnant lined with stones and lime mortar is situated at an estimated distance of about 400 m downstream from the spring of Ein el Qudeirat. The aquaduct is buried below the present surface of the valley plain to a depth ranging from 2.30 m for its upper stones to 3.10 m for its bottom part (Photos 25, 35). The mortar contains small pieces of charcoal.

The radiocarbon content of both the lime mortar and the charcoal were investigated at the Isotope Physics Laboratory of Prof. Mook (University of Groningen). The resulting dates in conventional C-14 years (BP), as well as in calibrated historical years for the charcoal date (Fig. 17), are as follows:

Mortar (GrN-12381)	12.250 ± 230 BP	
Charcoal (GrN-12327)	3.270 ± 100 BP	1725-1425 Cal B.C.

The discrepancy between the two dates is obviously due to contamination of the lime mortar with "dead" carbon, probably of Eocene age. The lime mortar apparently contains both C derived from the atmosphere at the time of the construction of the aquaduct, and Eocene C from the surrounding rocks. It seems likely that the ancients produced lime mortar for the aquaduct by the burning of local Eocene carbonate rocks:



Either incomplete burning of the carbonate rocks or intentional mixing of the mortar with fine rock fragments resulted in a C content of mixed origin and age in the mortar. Clear evidence for the presence of "dead" carbon in mortar, probably of Eocene age, was obtained by microscopic studies of thin sections from other aquaduct mortar samples in the Kadesh-Barnea valley (p. 138). Hence the unrealistic C-14 date of 12.250 ± 230 BP, which does not reflect the true age of the aquaduct.

The carbon-14 date of the charcoal (3.270 ± 100 BP; GrN-12327) was calibrated against the high precision timescale calibration curve of Pearson et al. (1985), resulting in a historical date of 1725-1425 Cal B.C. (fig. 17). This date is admittedly older than expected, which suggests the aquaduct to have been constructed during the Middle or Late Bronze Age. The laboratory pre-treatment of charcoal and the physical and chemical aspects of radiocarbon dating in general are discussed by Mook and Streurman (1983). The stratigraphy of the valley profile in which the aquaduct remnant appears is presented on page 151, 152.

If the charcoal date reflects the true age of the aquaduct, it seems likely that irrigation agriculture was practised in the Kadesh-Barnea valley during part of the Bronze Age.



PHOTO 25. Remnants of a Bronze age aquaduct (1), a Late Byzantine-Early Arab aquaduct (2), both radiocarbon dated; and of a recent Bedouin pipeline (3).

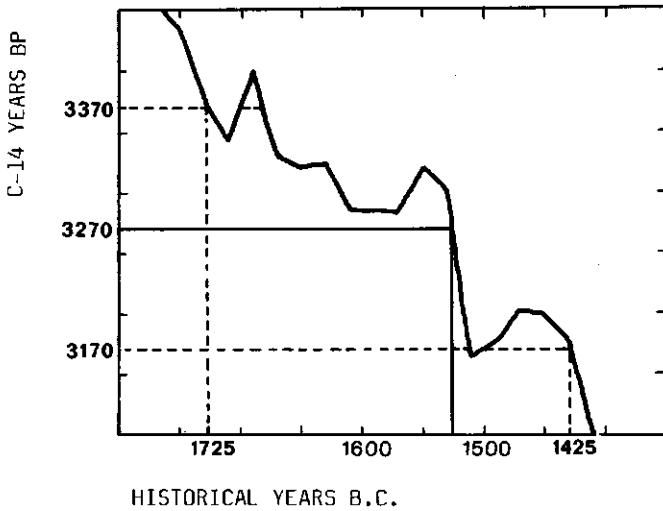


FIGURE 17. Calibration of the C-14 date of the (1) aquaduct (3270 ± 100 BP; GrN-12327) into historical years: 1725-1425 Cal B.C.

IRON AGE

No structural remains have yet been found of Iron Age irrigation agriculture. The plastered conduit, that facilitated the cistern inside the Middle and Upper Fortress to be filled with spring water, may have been connected with a so far unknown aquaduct system upstream. The level of the conduit was about 2 metre above the Iron Age level of the valley plain in the immediate vicinity of the tell. If there ever was such a connection, then the unknown aquaduct must have been built on pedestals or an artificial ridge for the last hundred metre or so upstream from the fortress.

The silos and granaries of the successive fortresses, as well as the jar full of burnt wheat (Cohen, 1983) are of course no proof of agricultural practice in the area. These discovered food storage facilities were either filled with imported grains and/or local agricultural produce.

Circumstantial evidence, however, like the position of the successive fortresses in the wider part of the cultivable valley and the occurrence of Israelite runoff farming in the adjacent highlands and various other parts of the Central Negev (Aharoni et al, 1960; Cohen, 1976), makes it illogical to assume that no agriculture was practised during the Iron Age in the well-watered valley of Ein el Qudeirat.

BYZANTINE PERIOD

Woolley and Lawrence, who visited the area in January-February 1914, described remains of irrigation systems, which in their opinion belong to the Byzantine period. On both the northern and southern edge of the valley appear the abandoned ditches of two old irrigation channels against the hillside. The northern aquaduct is built of masonry and very poor mortar. It is nearly destroyed and very difficult to trace. Maybe it went to the cultivable valley of Wadi el Ain, which forms the north-western continuation of Wadi el Qudeirat in the direction of Quseima, "but more probably it was made only to bring water to a little Byzantine village whose remains yet exist in a bay of the northern slope" (Woolley and Lawrence, 1936:78,80), situated about 1 km downstream from the tell on the lower hillslope of Gebel el Qudeirat. Woolley and Lawrence estimated the remains at about 15 to 20 small houses.

The aquaduct on the south side "is only a dug ditch, winding along the contour of the hills, till it comes to an end in a great Byzantine reservoir, situated in the very mouth of the valley" (Woolley and Lawrence, 1936:78), near the junction with the valley of Wadi Um Hashim.

"The reservoir is a great work, four-square, and about twenty yards each

way, built in the usual style of the precise Greek masonry, laid in line, and it still preserves in one corner the opening of the sluice, which let out its water as required to gardens on the flat land round the elbow of the hills. The reservoir is, however, now long abandoned, half filled with earth and stones" (Woolley and Lawrence, 1936:78). More precise measurements of the reservoir were published by Elgabaly (1954): 20 x 20 x 3.5 m. Thus the maximum capacity of the reservoir is 1400 cubic meters of water.

It seems likely that the reservoir was used by the ancients to store the flow of spring water during the night. Irrigating at night is usually not practical for various reasons (Horst, 1983), e.g. no control of irrigation, difficult rotation between various fields, farmers are reluctant to work during the hours of darkness. However, as the spring continues to flow at night, this water would be lost for agricultural production unless it is stored and subsequently released for irrigation during the daytime. The average discharge from the spring at present is 61 cubic meters of water per hour. In a night of 12 hours, during which no irrigation is practised by the farmers, 732 cubic meters of water would flow out of the spring. This amount could easily be stored in the reservoir that has a capacity of up to 1400 cubic meters.

Major Jarvis was the British governor of Sinai during the years 1922-1936. He first visited the valley of Ein el Qudeirat in 1922, attracted as a sportsman by the number of desert partridges in the area. His book *Desert and Delta* describes his discovery of the reservoir, which he ascribed to the Romans, being unaware of the 1914-15 publication of Woolley and Lawrence who considered it of Byzantine age. Since Jarvis (1938:245) considered the Byzantine period in the southern Levant as "the later Roman period, between the third and sixth centuries A.D.", there does not seem to be a contradiction between these opinions.

"One day whilst resting high on the hillside overlooking the valley after a hard morning's shoot, I noticed a big square mass of old masonry on the southern slope of the hill that was obviously an old Roman reservoir. It was filled to the top with silt and the sides had fallen away in places, so that previously I had imagined it was the ruins of a large building, but from my position above I now saw it for what it was, a stone water-tank. The question then arose as to how the Romans managed to fill it as it was nearly fifty feet [15 m] above the level of the valley. Gradually as my eyes got used to the uniform greyish-yellow of the limestone rocks I traced the line of the ancient water-course that had brought water to the reservoir a thousand years ago and,

following it up on foot, I came at the head of the valley to the remains of the dam that had at one time raised the level of the stream." (Jarvis, 1938:244).



PHOTO 26. Remains of a dam and connected aquaduct in the valley of Ein el Qudeirat (upstream from the spring), dating to the 7th century A.D.

These dam remains were pointed out to the author in 1981 by Porat, who considered them to be of Byzantine age. The dam probably had an opening in its upper part to allow the raised water to flow into the very beginning of the aquaduct that is situated on top of it. The aquaduct continued from the dam along the southern edge of the valley and hillside. Once it carried precious irrigation water to the fields and probably also to the reservoir, some 3 km down the valley. It is rather intriguing, however, that the position of the dam is upstream from the spring in the dry part of the valley. Woolley and Lawrence (1936:79) did not mention the remnants of the dam as such, but also noticed beyond the spring "a built aquaduct of stone and lime leading out of the hill-side and running across the valley. It probably points to another, but now forgotten, spring which watered these upper fields."

CARBON-14 DATING OF THE DAM (GrN-12326)

The dam and its aquaduct are built of masonry. Pieces of charcoal are usually present in the lime mortar, enabling carbon-14 dating. The author collected samples of mortar with charcoal from various parts of the dam on both sides of the valley to get a sufficient quantity. The charcoal was extracted from the lime mortar in the Isotope Physics Laboratory of Prof. Mook (University of Groningen), undergoing the usual pretreatment (Mook and

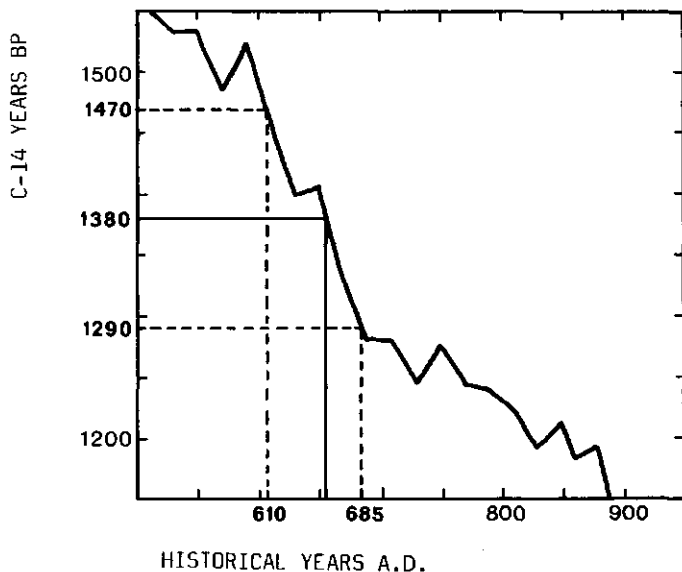


FIGURE 18. Calibration of the C-14 date of the dam (1380 ± 90 BP; GrN-12326) into historical years: 610-685 Cal A.D.

Streurman, 1983).

The extracted charcoal was dated as well as a piece of mortar, taken from underneath the aquaduct surface about 110 cm below the highest part of the dam. The resulting dates in conventional C-14 years (BP), as well as in calibrated historical years for the charcoal date (Fig. 18), are as follows:

Mortar (GrN-12379)	5.330 ± 130 BP	
Charcoal (GrN-12326)	1.380 ± 90 BP	610-685 Cal A.D.

The charcoal date seems realistic, giving a Late Byzantine or Early Arab age to the dam and its aquaduct. The outcome for the mortar, on the other hand, does not reflect the age of the dam, probably due to, either incomplete burning by the ancients of local Eocene carbonate rock for the production of quick lime, or subsequent contamination with "dead" carbon. A microscopic study of mortar from the dam's aquaduct not only revealed the presence of "inherited" carbonate rock fragments, but also yielded convincing evidence of the past flow of water in the aquaduct on top of the dam.

MORTAR MICROMORPHOLOGY AND PALEO-ENVIRONMENT OF THE DAM'S AQUADUCT BOTTOM

The mortar sample was taken from the bottom part of the aquaduct, about 1 meter below the highest part of the dam and about 5.30 meter above the lowest part of the adjacent wadi bed. The micromorphological terminology used is mainly from Brewer (1964), apart from the term calciasepic, introduced by Mulders (1969).

The mortar is mainly composed of fine plasma, skeleton grains and voids, in decreasing order of their respective volumes. Voids of various sizes appear in the mortar matrix. The size of the skeleton grains is usually in the range of coarse silt (0.04-0.06 mm), as well as very fine sand (0.06-0.1 mm). The skeleton grains are angular and subrounded in shape, appearing randomly, sometimes clustered, in the mortar matrix. Quartz grains are most common, followed by calcite, whilst hornblende, feldspars and other heavy minerals appear occasionally.

The mortar plasma is primarily composed of a crystic calcic fabric, showing micrite to sparite calcite crystals. This crystic fabric sometimes occurs in distinct rounded grains of up to 1 cm in diameter, which may either be rock relicts or newly formed mortar pieces with a sharp boundary. A small fossil composed of sparite proved that rock fragments containing "dead" carbon are present in the mortar. This caused the C-14 date derived from the carbonate part of the mortar to be unrealistic.

Plasma that consists of a calciasepic fabric, essentially made up by micrite mixed with fine clay, also occurs. Some parts of the mortar, appearing as aggregates up to 1 cm in size, are reminiscent of the micromorphology of loessial soil (Bruins, 1976). Many pieces of charcoal of various sizes appear randomly in the mortar matrix.

The microscopic discovery of the following micromorphological phenomena in the mortar unequivocally proved the actual functioning of the dam and its aquaduct for a considerable time period:

AUTHIGENIC PYRITE

The discovery of a large cluster of pyrite framboids (photos 27, 28) in the mortar is outstanding evidence of a reduced environment in the past, caused by a rather continuous flow of water in the aquaduct during the time of its functioning in antiquity. The microscopic identification as pyrite became possible through the suggestions of Jongmans and Miedema (1985, personal communication). The cluster is up to 0.8 mm in diameter and consists of about a hundred black to reddish brown pyrite framboids, composed of microcrystals.



PHOTOS 27. Incident light.

PHOTO 28. Plain transmitted light.

Identical microscopic pictures of the pyrite framboid cluster. The width of the pictures is equal to 0.5 mm. Pyrite is opaque for transmitted light (Photo 28), but shows a typical shining lustre with incident light (Photo 27).

The pyrite is partly weathered to iron-oxide. Each pyrite framboid has a size of 0.02-0.04 mm. The pyrite cluster can be regarded as a filled crystal chamber. The pyrite framboids have partly penetrated the surrounding mortar matrix, showing crystal overgrowth of pyrite over micrite. For more specific aspects about the micromorphology of pyrite in soils, the reader is referred to the publications by Pons (1964), Van Dam and Pons (1972), and Miedema et al., (1974). The soil-chemical aspects of pyrite formation are discussed by Van Breemen (1972).

Apart from the described cluster, more pyrite framboids occur in the mortar. Some gypsum crystals, 0.2 mm in length, may have been formed as a result of partial oxidation of the pyrite into iron-(hydro)oxides. A number of ferrans and iron-oxide nodules appear in the mortar. A neoferran-ferran with a size of 0.7 mm is particularly well developed, partly in a vugh against the

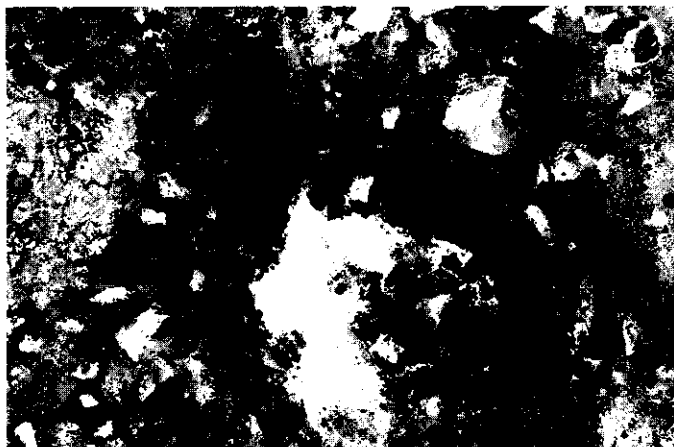


PHOTO 29. Neoferran-ferran in the mortar of the 7th century aquaduct on the dam (length photo is 0.9 mm; plain polarized light).

voidsides and partly inside the matrix (photo 29). Such a concentration of iron-oxides is due to a rather wet environment with alternating oxidation-reduction conditions. It is not clear whether these ferric nodules formed in a different archaeological phase, characterized by a less continuous flow of water in the aquaduct.

After the dam was destroyed, probably by a powerful runoff flood in Nahal Kadesh-Barnea, the irrigation system was suddenly put out of action. This resulted in a very sharp environmental change, by which the mortar became as dry as the prevailing desert climate, except for some occasional rainfall during the winter season. As a consequence of this sudden change from an aquatic to an arid environment, the pyrite has been preserved so well during the last millennium.

CARBON-14 DATING OF AN AQUADUCT BEGINNING IN THE WADI BED (GrN-12328)

The remains of this aquaduct appear in the same channel bluff profile, about 400 meter downstream from the main outlet of the spring of Ein el Qudeirat, in which the aquaduct remnant occurs (Photo 25) that yielded a Bronze Age C-14 date of 1725-1425 Cal B.C. (GrN-12327). Whereas the latter aquaduct was a lined surface ditch, the aquaduct now under discussion had its beginning point in this stretch of the stream channel, tapping the water from the wadi bed (Porat, 1981, personal communication).

The aquaduct remnant consists of widely spaced stones and lime mortar, which facilitated the entry of spring-water flowing over the wadi bed. The vertical dimension of the aquaduct is 1 m, its upper stones are situated at a depth of 4.10 m and its bottom part lies 5.10 m below the present surface of the valley plain adjacent to the stream channel (Photo 25).

The present level of the wadi bed lies at a depth of 5.25 m and today the water from the spring flows below the aquaduct. The aquaduct mortar contains small pieces of charcoal. The carbon-14 content of both the lime mortar and the charcoal were investigated at the Isotope Physics Laboratory of Prof. Mook (University of Groningen). The resulting dates in conventional C-14 years (BP), as well as in calibrated historical years for the charcoal date, are as follows:

Mortar (GrN-12380)	14.250 ± 350 BP	
Charcoal (GrN-12328)	1.395 ± 50 BP	615-665 Cal A.D.

The unrealistic outcome of the mortar is certainly due to the presence of "dead" carbon, for reasons described previously. The charcoal date seems to represent the age of the aquaduct correctly, which is virtually the same as the C-14 date for the dam (1380 ± 90 BP; 610-685 Cal A.D.; GrN-12326). This strongly suggests that, either at the end of the Byzantine period or at the beginning of the Early Arab period, two different systems were constructed simultaneously to tap the water from the spring for irrigation agriculture during the 7th century A.D.

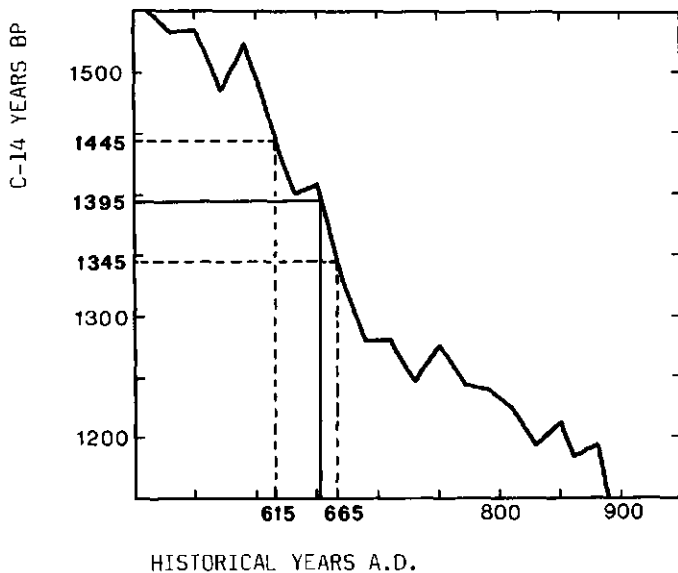


FIGURE 19. Calibration of the C-14 date of the wadi-bottom aquaduct (1395 ± 50 BP; GrN-12328) into historical years: 615-665 Cal A.D.

The position of the Late Byzantine - Early Arab wadi-bottom aquaduct below the Bronze Age dated aquaduct seems an apparent stratigraphic problem. If these radiocarbon dates are correct, and the labeling of the two respective samples were not accidentally exchanged, either in the field or in the laboratory, how is it possible to find a younger aquaduct below an older one? A key to a possible answer may be the different ways by which the two aquaducts were constructed in relation to their respective functions. The older Bronze Age dated aquaduct was built on the former valley surface to conduct the spring-water from upstream. The beginning of this aquaduct and the manner by which the spring-water entered this system is unknown.

The Late Byzantine - Early Arab aquaduct was not situated at the former valley surface during the 7th century A.D., but at the level of the wadi bed to tap the flow of spring-water. It had to be constructed, therefore, either by (1) digging a channel from the valley-plain surface down unto a possible groundwater level adjacent to the natural stream channel, or (2) by carving out the lowest part of the existing stream channel bank in a slight lateral excavation at the level of the wadi bed and below the Bronze Age dated aquaduct (if this aquaduct was already present indeed):

The former possibility (1) seems unlikely for the following reasons: The stream channel of Wadi el Qudeirat is the natural aquaduct that carries the water from the spring downstream on its bed. The amount of water seeping, per unit of time, below the wadi bed in a lateral direction is too little to be caught in any useful quantity, if at all, by a subsurface seepage collecting type of aquaduct. As a matter of fact, the author made an excavation near the tell, 6 m aside from the present stream channel, virtually unto the same level as the wadi bed with its flow of spring-water, finding the soil to be dry.

Only the direct inflow of water from the wadi bed into the aquaduct can tap this perennial stream of spring-water effectively for agricultural purposes. Hence the aquaduct had to be built inside the 7th century stream channel. It seems, however, unpractical to built such an aquaduct in the middle of the wadi bed, making it an easy prey for erosion during runoff floods in the rainy season. The solution of the ancients, as interpreted and envisaged by the author, might have been as follows: the construction of such an aquaduct partly inside one of the existing stream channel banks, by carving away only some sediment at its lowest part at the level of the wadi bed and leaving the upper part of the bluff intact. A low temporary dam was perhaps built in the wadi bed, parallel to the aquaduct under construction, to prevent the entry of water that would have made the work impossible.

The loessial material making up the channel bank will not easily collapse upon the removal of some material from its lowest part. The Bronze Age dated aquaduct remnant in the upper part of the bluff would, therefore, not necessarily have been completely destroyed during the construction of the 7th century aquaduct. In fact only a small part of the Bronze age dated aquaduct has actually been preserved (Photo 35), as compared to the large stretch of the 7th century wadi-bed aquaduct still in situ.

The side of the latter aquaduct that faced the flow of water in the wadi bed was obviously built with openings in between the stones, whilst it had to be closed on all other sides, also from above, to prevent water losses as well as the entry of sediment that might block the flow of water inside the aquaduct. Upon completion of the aquaduct, perhaps carried out in stages, its closed upper part could be covered again with some of the excavated sediment, so that the bluff might have been restored as a relatively firm natural wall with the water tapping aquaduct anchored inside.

Somewhat farther downstream, a low threshold dam might have existed to raise the water level slightly. This would have facilitated the intake of water into the aquaduct considerably. From the point where the aquaduct became situated above the flow of water in the wadi, as it eventually had to descend with a smaller gradient than the stream channel to emerge onto the valley plain, its character and make-up necessarily changed from a water-intake aquaduct to a mere water conducting channel.

MORTAR MICROMORPHOLOGY OF THE 7th CENTURY WADI-BED AQUADUCT

The mortar is mainly composed of fine plasma, skeleton grains and voids, in decreasing order of their respective volumes. Voids of various sizes and shapes, like skew planes, vughs and some rare channels, appear in the mortar matrix. The related distribution of plasma and skeleton grains is porphyroskeletal. The skeleton grains, angular and subrounded in shape, are mainly of coarse silt (0.04-0.06 mm) and very fine sand size (0.06-0.1 mm), usually occurring randomly in the mortar matrix. Quartz grains are most common, followed by calcite, whilst hornblende, feldspars and other heavy minerals appear occasionally.

A number of large lime grains, 2-10 mm in diameter and rounded to subrounded in shape, appear in the mortar matrix. These grains consist of a rather uniform crystic calcic or calciasepic fabric, in which virtually no skeleton grains occur. Because of their rounded shape, it is not entirely clear whether these grains are inherited rock fragments or newly formed mortar particles.



PHOTO 30. A fossil and charcoal in the mortar (photo width = 0.32 mm) (plain polarized light)



PHOTO 31. Charcoal in the mortar (photo width = 2.6 mm) (plain polarized light)



PHOTO 32. Pyrite framboid (0.04 mm) inside charcoal (incident light)

The mortar plasma has a predominant crystic calcic fabric, showing micrite to sparite calcite crystals. A calciaspic plasmic fabric also occurs. Small marine fossils, probably of Eocene age, appear randomly in the mortar (Photo 30). This proves the presence of inherited "dead" carbonate, which caused the unrealistic C-14 date derived from the carbonatic part of the mortar.

Many charcoal pieces of various sizes (0.005 - 8 mm) appear randomly scattered through the mortar matrix (Photo 31, 32).

AUTHIGENIC PYRITE

The presence of pyrite framboids in the mortar, in relation to voids, provides unequivocal evidence of a reduction environment in the past, when the aquaduct was tapping the water flowing over the wadi bed during the Late Byzantine-Early Arab period. One distinct pyrite framboid, glittering when observed under the microscope with incident light, has formed inside a void of a large charcoal fragment (Photo 32).

Concentrations of iron oxides (ferrans and neoferrans) also occur in the mortar, sometimes as a weathering product of pyrite. This seems to be indicative of a period with alternating wet-dry reduction-oxidation circumstances in the past. Fine gypsum needles appear in association with weathered pyrite as well.

BEDOUIN IRRIGATION FARMING IN THE KADESH-BARNEA VALLEY

The Late Byzantine to Early Arab dam and aquaduct systems, described in the preceding sub-chapters, were probably destroyed by powerful runoff floods in Nahal Kadesh-Barnea during the Early Arab period. There is no evidence whether these irrigation systems were abandoned before or after their apparent natural collapse.

Since the Early Arab period, there seems to be no archaeological or historic information about irrigation agriculture in the Kadesh-Barnea valley until the dawn of the 20th century. During their visit in Januari-Februari of 1914, Woolley and Lawrence made a number of observations about Bedouin irrigation farming in the valley, which appear scattered through the pages of their book (Woolley and Lawrence, 1936, p. 75-84).

At that time the Bedouin's system for irrigation agriculture involved a simple dam across the stream bed, about 800 m downstream from the spring proper, and some 400 m downstream from the previously described ancient aquaduct remnants. This dam was probably made of earth and stones. It probably had to be repaired or rebuilt regularly after the runoff floods in the rainy season. The dam raised the water level somewhat in the stream channel. Here the irrigation ditches of the Bedouin Arabs belonging to the Guderat tribe had their start. These unlined ditches "are only ephemeral, a deeper furrow among the crops, as such canals must always be, made each spring and destroyed each winter in the Arab yearly interchange of plough and fallow" (Woolley and Lawrence, 1936, p. 78).

From this dam the valley was cultivated in a downstream direction until the

fields fade out at the valley mouth. The two distinguished British surveyors made an elucidating description of the hydraulic characteristics of the stream channel and its functioning during runoff floods in the rainy season, as well as during Bedouin irrigation practices in their time.

"The water-course ... is a clear channel, cut five to fifteen feet [1.50 - 4.50 m] into the ground, steep banked, and generally from three to ten yards [2.70 - 9 m] in width. It thus wastes only an inconsiderable part of the valley space, and its depth gives it content enough to carry off all ordinary floods without damage to the fields on each side. An occasional great flood may sweep the whole place, levelling trees and washing out the soil, as happened two years ago [1911-1912]; but normally the lower reaches of the torrent-bed are dry except when it is raining, or when the cultivators, having finished the watering of their land, turn the stream of their little canals back into the proper bed." (Woolley and Lawrence, 1936, p. 77-78).

The British authors do not mention the growing of fruit trees by the local Bedouin, but only field crops. This is corroborated by Jarvis who found a similar situation in 1922, as shown in a picture in his book (Jarvis, 1938:272). The cultivated part of the valley appeared green or yellow with the crop according to the season. Acacia trees stood at intervals along the edge of the valley. Woolley and Lawrence described the tell-mound as rising above the adjacent corn-fields, where barley and/or wheat was probably growing at the time.

In front of the ruins of the Byzantine village, mentioned earlier, are the threshing floor and corn pits of the Guderat tribe. The Bedouin moved their camp to the old village site for a few weeks in each year. Apart from farming, the British surveyors also noted semi-nomadic livestock rearing as part of the food producing economy of the Bedouin. They mention the flocks and herds at Ain el Gudarat, while calling attention to the tribesman as a great maker of flint tools, used for the animals.

"There is no permanent settlement of Arabs in the valley, through their fear of the climate. It is believed that anyone who lies there in summer (whether man or beast) will be attacked by an intermittent fever of peculiar strength; indeed even the cooked meat of animals which have fed in the valley is declared dangerous by the local authorities in hygiene. As a matter of fact, the large deep pools of the upper river must be admirable breeding places for mosquitoes" (Woolley and Lawrence, 1936, p. 80).

About eight years later, in 1922, Major Jarvis first visited the area as the British Governor of Sinai, a function in which he continued to serve until

1936. "When I first saw the Wadi Gedeirat there were about six acres [2.4 ha] of cultivated land which the local Arabs irrigated by means of a small mud dam that they constructed every year after the winter floods" (Jarvis, 1938:243). This type of dam and its location was probably the same as referred to by Woolley and Lawrence, described above.

After discovering the remnants of the ancient irrigation systems in the valley of Ein el Qudeirat, as described on p. 129, it occurred to Jarvis "that it would be most interesting and fascinating, not to say useful, to reconstruct in some way the old Roman system of irrigation... The need for something of the sort was apparent, for the Arabs of this area depend for their existence on rain crop barley which is only a definite success once in five years" (Jarvis, 1938, p. 244-245).

This remark by Jarvis is not entirely correct, as the Bedouins were not self-sufficient in their crop farming, which constituted only an addition to their extensive livestock husbandry. The semi-nomadic Bedouin usually trade their animals for food grains grown by sedentary farmers in the wetter parts of the region (Marx, 1982). However, the note that rainfed barley farming in the area during the twenties and thirties was only successful once in 5 years, is a valuable datum. Jarvis (1938:245) continued his reasoning: "If they were provided with an irrigation system that would enable them to make certain of their winter barley, and to grow also a summer crop of maize or millet, it would constitute a very definite bettering of their lot".

Inspired by the ancient example, Jarvis decided to have a dam constructed in the stream valley for irrigation farming purposes. Funding of the dam came from the budget allotted to Sinai for anti-malaria work, as the construction of a dam would "kill two birds with one stone" (Jarvis, 1938:247): both advancing irrigation farming and fighting malaria in the area. The dam would hold the water back of the perennial stream fed by the spring and this would prevent the formation of isolated pools downstream. "One could easily cope with the mosquito larvae in the big pond that would form by the introduction of that jolly little Egyptian fish, the Bolti... immediately after his introduction to a stream or pool, he makes himself at home and proceeds to breed to such an extent that in a few short months the water is a moving mass of small fry. The fry, which are in a constant state of ravenous hunger, work their way up into the grassy fringes of the pools and round the stems of the reeds and rushes, so that it takes a most redoubtable mosquito larva to escape their attentions" (Jarvis, 1938:247).

The dam was constructed of cut limestone blocks and masonry at the head of

the wider part of the valley in 1926. Its position is about 700 m downstream from the spring, apparently near the place where the Bedouins used to make their small mud dam. The carbon-14 dated ancient dam and aquaduct remnants are situated upstream from the Jarvis dam. Haj Ali, the government mason at El Arish, constructed the dam, whereby he sometimes manufactured home-made lime on the spot, if there was a lack of cement (Jarvis, 1938:248). This suggests that the ancients could also have made their lime from local Eocene carbonate rock.

When the dam was completed, a huge pond, about 90 m long and 27 m wide, formed behind the dam in a day and a half. The barrier was not absolutely water-tight, as some one-sixth of the water supply was finding its way through the coarse gravel beneath the concrete foundations. Haj Ali, therefore, constructed a much lower second dam, some 45 m downstream from the first. From this second dam the escaping water was led "into the big channels that ran from the dam to the reservoirs, so that by this means we harnessed the whole flow of the stream" (Jarvis, 1938:249).

It appeared that excellent cast-iron pipes, 20 cm in diameter, and with a combined length of nearly 5 km, had remained in the area since the time of their use by the Turkish army. By employing these pipes it became not only possible to run the water from the dam to the reservoir without seepage losses, but also to carry subsidiary channels across gorges to good land beyond, while the irrigation system was extended to about 800 m below the reservoir at the mouth of the valley (Jarvis, 1938:250-251).

"The reservoir was then cleaned of the silt of ages, which filled it to the brim, and the old Roman plaster lining, which had fallen away in patches, was stripped off and a layer of twentieth-century concrete substituted. The concrete was later faced with a lining of cement and 'Pudlo', a patent waterproofing mixture, and the reservoir was ready for the flow from the stream" (Jarvis, 1938:251). The British governor admitted that he "felt something of a Philistine" when he lined the age old construction "of vast cut stones with the prosaic and unpleasant-coloured concrete of to-day, but I consoled myself with the thought of the acres of dun-coloured deserts that would become green as the result." It took a day to fill the reservoir of about 20 meter square and 3.5 m deep, which fits the calculation made on page 127, in relation to the average discharge of the spring of 61 cubic meter per hour.

Jarvis described all kind of social and human-psychological problems which had to be overcome, as well as the need for instruction, before the potential of the irrigation system was tapped by the local Bedouin population. A govern-

ment garden was established, both as an object lesson and for experimenting with various crops and fruit trees. The olive trees made the most prolific growth, attaining the height of over 3.50 meter in their third year. The vines were also exceptional in every way, producing a remarkable quantity of grapes with a very fine flavour. Citrus trees proved less successful. Concerning vegetables, the growth of asparagus was phenomenal in every respect.

The irrigation scheme in the valley of Ein el Qudeirat was started by Jarvis in 1926 and it had been in existence for ten years when he left Sinai in 1936. Some 120 hectare had come into cultivation with thousands of olive trees in varying stages of growth. "As I expected, there was no real enthusiasm for the work until the first Beduin had marketed his crop of olives and turned the cash proceeds over wonderingly in his palm. Then, when it transpired that there was real money to be made over these queer bitter fruits, every man proceeded to extend his plot, and to level off fresh desert land until finally one found irrigated orchards a mile away from the dam" (Jarvis, 1938:268). Apart from olives, the bedouins also cultivated vines, winter grains, and some maize in summer.

Some twenty years later, in the fifties, the system still seemed to function properly, according to Elgabaly (1954) who noted that the water was carried in iron pipes and cement canals to irrigate the area below the dam. During the night water was collected and stored in a reservoir with a capacity of about 1000 cubic meters. He reported orchards of olives, pomegranates and figs growing on the water from the spring, and considered the olives as the most successful trees.

What Jarvis (1938:269) had feared that "the dam may crack with a heavy flood" happened in 1956, thirty years after its construction. However, the Egyptians repaired the dam, which, as a result, continued to function until 1969, when another powerful runoff flood broke the dam again (Fromkin, 1981). Since that event, the Jarvis dam has not been reconstructed (Photo 33), and the local Bedouin farmers use the cast-iron pipes to tap the water from the spring in order to irrigate their orchards and field crops (Photo 24). The remaining structure of the Jarvis dam functions today as a kind of aqueduct-bridge for the cast-iron pipes to cross the valley (Photo 33).

In a talk with a local Bedouin in December 1981, I asked whether they manure their fields. "Only water" was his answer, as he denied any use of whatever kind of fertilizer. The goats and sheep drop, nevertheless, a certain amount of manure, as they are allowed to graze on uncultivated plots and various other fields.

10 Kadesh-Barnea: valley stratigraphy and soil development

THE VALLEY SECTION NEAR THE LATE BYZANTINE - EARLY ARAB DAM

Historic reconstruction of landscape and soil development in the Kadesh-Barnea valley became possible through the presence of archaeological remains and radiocarbon dating. The valley sections which supplied useful data are dealt with in order of their respective location in the stream channel, starting with the C-14 dated Late Byzantine to Early-Arab dam, upstream of the present position of the spring, and successively continuing down the valley.

Remnants of the dam appear on both sides of the stream channel, as can be seen on Photo 26. A cross section of the valley (Figure 20) shows the stratigraphic position of the dam remains in relation to the accumulated sediment and present level of the stream bed. It is evident from this stratigraphic relationship that, some time after the destruction of the dam, sediments were deposited in the valley during a remarkable period of aggradation, followed by a period of incision that seems to continue even today. This relatively recent period of downcutting exposed the above sedimentary profile for examination.

Some sediment samples were taken for laboratory analysis from this profile, which is precisely located in between the two remnants of the 7th century dam (Photo 26, Figure 20), situated at opposite sides of the valley. In other words, once the dam in its full length blocked the valley at this spot where now sediments appear in its place.

Most of the sediments exhibited in the studied profile are rather uniform in texture, being of a loess-like nature without macro-structural elements, until a depth of 3.95 m, when a lithological break appears. The baselevel of the Late Byzantine-Early Arab dam coincides with a depth of about 2.55 m.

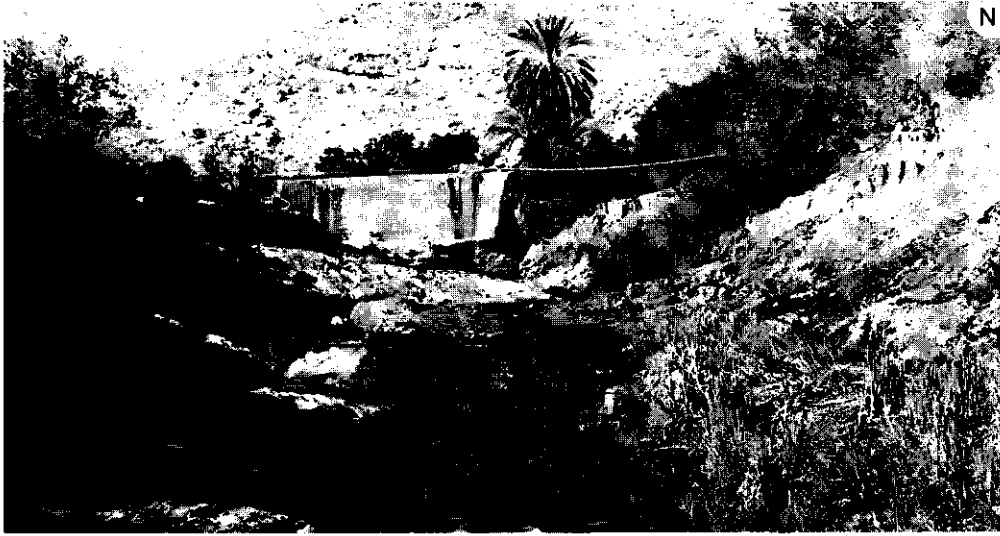


PHOTO 33. The broken Jarvis Dam as a modern example how the 7th century dam might have looked after its partial collapse and before the unique historic period of wadi aggradation, during which the dam became nearly buried.

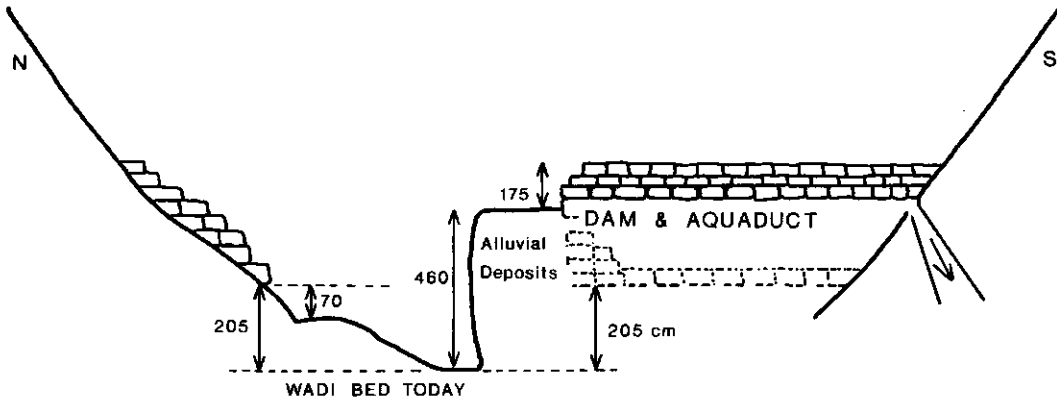


FIGURE 20. Cross-section of the stream channel in relation to the remains of the 7th century dam in the valley of Ein el Qudeirat.

It seems likely that the entire alluvial loessial sequence appearing above the lithological change at 3.95 m postdates the destruction of the 7th century dam, deposited during the period of extraordinary aggradation.

This stratigraphic conclusion implies a phase of downcutting and erosion, following the destruction of the dam but prior to the aggradational period, which removed some 1.50 m of sediments below the base level of the dam, from a

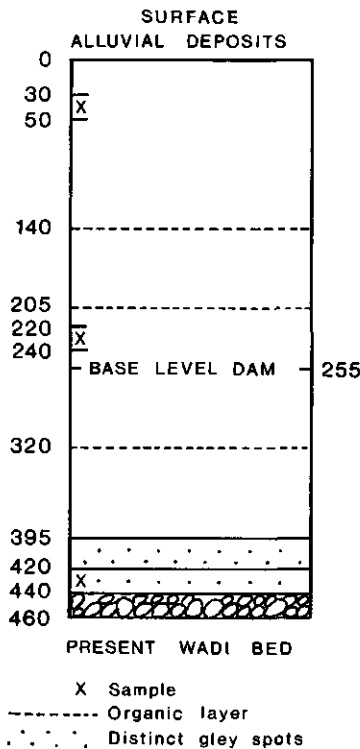


FIGURE 21. Sampled profile in between the dam remains.

a date of 665 ± 115 BP in conventional C-14 years. Calibrated against Pearson's curve (Pearson, 1986), this date corresponds to a historical date of 1260-1400 Cal A.D. (Figure 22). The lowermost prominent organic layer in the alluvial sediments, situated between the 7th century dam remains, occurs at a similar depth of 3.20 m and is presumed to be of identical age.

At a depth of 3.95 m a lithological change is visible, marked by very clear orange-brown gley spots, indicative of alternating oxidation-reduction circumstances in the past, due to aquatic conditions in this part of the stream channel. Another distinct lithological change occurs at a depth of 4.20 m, the upper boundary of a more sandy layer, 20 cm thick, that contains many mollusc shells. At 4.40 m a stony layer appears at the base of the profile, exhibiting subrounded stones up to 30 cm in diameter. The average size of the stones is 10-20 cm, while the interlocking packing voids are filled with smaller gravel. The stones are imbricated in a downstream direction.

level of about 2.50 until a depth of 3.95 m.

Many dark organic layers occur in the sediment profile at intervals of about 10 to 20 cm. Most of these dark layers are faint and thin, less than 1 cm in thickness. Three more prominent layers were distinguished at a depth of 1.40, 2.05 and 3.20 m below the surface edge of the channel bluff. The dark layers must have been ancient surface levels (paleo A-horizons), once covered with vegetation, apparently fed by water from the spring. These surface horizons were successively formed and subsequently buried during the gradual process of valley aggradation. Today vegetation mats cover little surface areas within the stream channel from the first emergence of spring water in the wadi bed.

A few hundred meters down the valley, some 50 m upstream from the main outlet of the spring proper, Goldberg (1984) was able to collect enough charcoal for carbon-14 dating from a pocket or lense at a depth of 3 m below the valley plain. The charcoal yielded

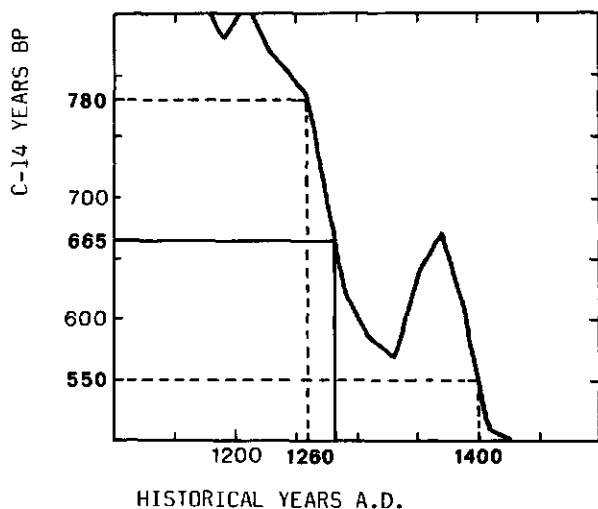


FIGURE 22. Calibration of the C-14 date of a charcoal sample (665 ± 115 BP; Goldberg, 1984), collected from a depth of 3 m below the valley plain, into historical years: 1260-1400 Cal A.D.

The lithological change at 3.95 or 4.20 can be regarded as an erosional discontinuity, that marks the depth of wadi incision after the destruction of the dam and prior to the following period of aggradation. The above mentioned carbon-14 date, being younger than the age of the 7th century dam, fits this picture very well indeed. It thus seems likely, that by the 13th or 14th century A.D., the wadi had already deposited its first 75-100 cm of alluvial sediments: the onset of the unique historic period of wadi aggradation. Another 3 m of sediment was yet to be deposited in the following centuries.

Two sediment samples were taken in the alluvial loessial deposits at respective depths of 30-50 cm and 220-240 cm. Another sample was collected from the more sandy layer at 420-440 cm, which contains mollusc shells. The laboratory results are displayed in Table 18. The alluvial loessial sediments are rich in carbonates and appear to be moderately saline throughout the profile. Sodium and chloride make up the bulk of the salts. The amount of sulphate is relatively high in the layer near the base of the section, which also shows a comparative decrease in chloride. The higher nitrate value in the middle of the profile, may have been derived from some of the dark coloured organic layers.

TABLE 18. Granulometry and chemical analysis of alluvial sediments in between the remnants of the radiocarbon dated 7th century dam in the valley of Ein el Qudeirat.

DEPTH (cm)	CLAY <0.002 mm (%)	SILT 0.002- 0.063 (%)	SAND 0.063- 2 mm (%)	TEXTURE	GRAVEL >2 mm (%)	CARBONATES CaCO ₃ (%)
30- 50	15.8	44.7	39.5	LOAM	0	43.6
220-240	10.4	38.6	51.1	LOAM	0	44.3
420-440	17.1	19.6	63.4	SANDY LOAM	1	56.5

DEPTH (cm)	pH	EC(1:1) (mS/cm)	SAR	ORGANIC CARBON (%) C	TOTAL PHOSPHORUS (%) P ₂ O ₅
30- 50	7.1	9.5	49.0	0.70	0.13
220-240	7.2	9.3	49.4	0.27	0.14
420-440	7.4	8.8	71.6	0.36	0.09

DEPTH (cm)	SOLUBLE SALTS IN 1:1 SOIL/WATER EXTRACT (meq/kg soil)							
	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
30- 50	6.1	0.2	87.0	0	1.0	91.0	5.0	0
220-240	6.0	0.2	87.0	0	0.9	89.5	5.0	1.2
420-440	1.6	<0.1	65.0	0	0.4	35.0	33.0	<0.1

Percentages in weight % of the fine earth <2 mm; only gravel in weight % of the total soil. EC = electrical conductivity. SAR = sodium adsorption ratio.

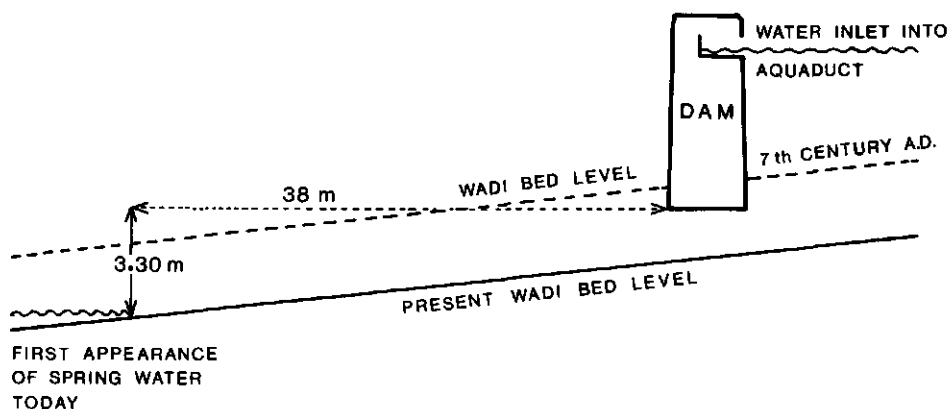


FIGURE 23. Longitudinal valley section through the 7th century dam, showing past and present hydro-geomorphic relationships.

Figure 23 shows the location of the dam with respect to the present position of the water level from the spring, as well as the likely situation in antiquity, when a pond must have accumulated behind the dam, so that the spring-water could flow into the aquaduct on top of the dam. The height of the dam was about 4.30 m. From the studied stratigraphic interrelationships the following conclusions seem warranted about the evolution of this part of the stream channel in historical times:

1. The level of the wadi bed at the time of the dam's construction (7th century A.D.) was about 2 meter higher than its lowermost present level.
2. The nearest and highest occurrence of spring-water today appears at a distance of 38 m downstream from the dam, 3.30 m below the base-level of the 7th century dam.
3. If the dam was to be reconstructed today, it would serve no other purpose than the temporary retention of some runoff water during floods in the rainy season.
4. The apparent function of the dam, in antiquity, was to raise the waters from the spring to the level of the aquaduct system that began on top of the dam, for irrigation farming purposes.
5. Hence an important outlet of the spring was in all likelihood situated upstream from the dam in the 7th century A.D. There is none today.
6. At some time during or after the 7th century A.D. the dam was destroyed by a powerful runoff flood in Nahal Kadesh-Barnea, comparable to the destruction of the Jarvis dam in the 20th century.
7. The destruction of the dam was followed, during a certain period of time, by a regime of stream channel incision.
8. This period of downcutting was terminated by a remarkable change in the hydraulic and geomorphic behaviour of Nahal Kadesh-Barnea. Sediments began to aggragate in this part of the stream channel, as a result of which the position of the wadi bed became higher and higher. Eventually, the remnants of the 7th century dam were almost completely buried by alluvial loessial sediments.
9. Another environmental change caused the cessation of this quite extraordinary period of wadi aggradation. Nahal Kadesh-Barnea began to cut into its own bed, removing a considerable part of its previous deposits. This period of incision is still continuing today and has advanced to such a degree that the present level of the wadi bed is well below the level of the 7th century A.D.



PHOTO 34. (1) Location of the 7th century dam. (2) The first emergence of spring-water in the wadi-bed. (3) The main outlet of the spring at present.

with its appearance in 1914, as described by Woolley and Lawrence (1936:79): "The spring proper is... where a buttress of limestone runs into the valley... From the foot of it the water gushes out strongly in three little spouts thick as a man's arm, from deep, narrow fissures in the rock... Ain el Guderat means the spring of the earthenware kettles, or small spouted pots. Whether it refers to the rush of water, in contrast to the slow welling up of Ain Kadeis, or to actual pottery, we know not".

Since the reference to the limestone buttress is unclear today, one wonders whether the principal outlet of the spring has actually changed since 1914?

It thus seems that the position of the spring in the valley of Ein el Qudeirat has shifted since the 7th century A.D. Concerning the actual site of the spring today, one has to be aware of the two manners in which the spring-water emerges in the stream channel.

The first quiet appearance of spring-water in the wadi bed begins 38 m downstream from the location of the 7th century dam. This very gentle emergence and quiet flow of water in the wadi bed continues for a few hundred meter further down the stream channel, until the major present outlet of the spring is reached (Photo 34).

Here the water rises naturally with some force through a concrete pipe, vertically placed into the wadi bed. This "concrete" sight of the spring is, admittedly, rather disappointing today, compared

THE CHANNEL BLUFF PROFILE THAT EXHIBITS TWO C-14 DATED AQUADUCT
REMNANTS (BRONZE AGE AND LATE BYZANTINE-EARLY ARAB PERIOD)

Two different aquaduct systems appear in the southern bluff of the stream channel, about 400 meter downstream from the main outlet of the spring. These remnants were radiocarbon dated by Mook at the University of Groningen (GrN-12327, GrN-12328), and have already been described (p. 134). The lower aquaduct near the base of the profile, situated somewhat above the present level of the wadi bed, formed the beginning of a water transport system in the 7th century A.D. This stretch of aquaduct had the function to tap the spring-water flowing over the wadi bed.

The remains of the aquaduct are still visible over some tens of meters (Photo 35). It was built at the edge of the stream-channel bottom existing at the time and its position indicates that the wadi bed of the 7th century A.D. was, at this part of the valley, perhaps one meter higher than at present. This conclusion fits the evidence from the 7th century dam site, some 700 m upstream, which also indicated a higher level of the wadi bed in those times.

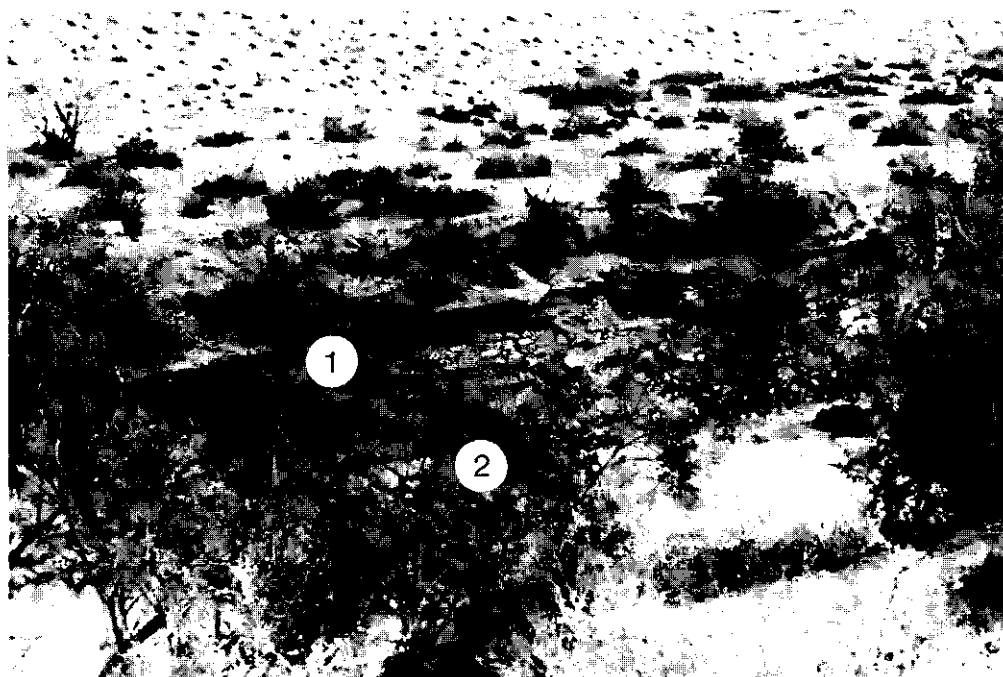


PHOTO 35. A partly collapsed remnant of a Bronze age dated aquaduct (1) above extensive remains of a 7th century (A.D.) aquaduct (2) near the wadi bed.

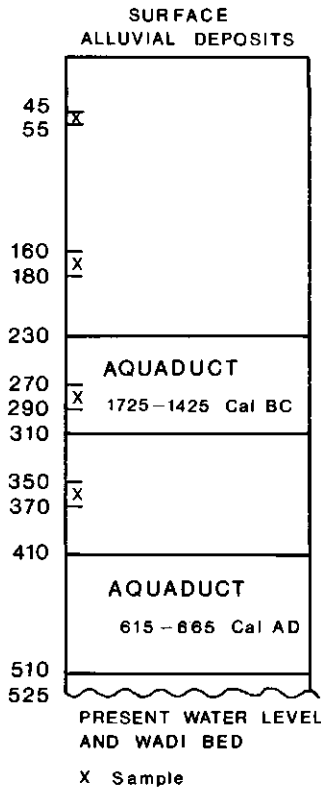


FIGURE 24. Sedimentary profile of the channel bluff, in which the ancient aquaducts appear.

The laboratory results are presented in Table 19.

The clay content of 7 % inside the Bronze age dated aquaduct is the lowest value encountered in the investigated valley sediments. The two samples from the alluvial sediments overlying the Bronze age dated aquaduct remnant, apparently deposited during the main period of historic wadi aggradation, have a somewhat different granulometry than the deeper layers. The layer above the wadi-bottom aquaduct is likely to have been disturbed by man during the construction of the latter aquaduct in the 7th century A.D.

The entire sediment profile is moderately affected by salinity, which has a tendency to increase slightly in an upward direction. The same trend is also perceptible in the sediment profile in between the remnants of the 7th century dam. This kind of distribution of salts through the profile suggests their

The aquaduct remnant in the middle part of the profile, of which only a small part is still preserved (Photo 35), yielded a surprisingly early carbon-14 date (GrN-12327) of 1725-1425 Cal B.C. (Late-Middle to Late Bronze Age). It is a type of aquaduct that probably was situated at the former surface level of the valley during the time of its functioning in the past (Porat, 1981, personal communication). The upper 2.30 to 3.00 meter of sediment above this aquaduct (Photo 35) must, therefore, have been deposited since the Late Bronze Age during a period of wadi aggradation.

The alluvial sediments of the entire profile (5.25 m) are of a loess-like nature, consisting of silt loam to clay loam in the lower part of the section. The deposits have a somewhat finer texture than the loamy sediments near the 7th century dam, some 700 m farther upstream. Sediment samples were taken at respective depths of 45-55 cm, 160-180 cm, 270-290 cm (inside the sediment-filled Bronze Age dated aquaduct), and 350-370 cm (in between the two aquaduct remains).

TABLE 19. Granulometry and chemical analysis of alluvial sediments in the channel bluff profile that exhibits the C-14 dated aquaduct remnants (* 1725-1425 Cal B.C. and # 615-665 Cal A.D.) @ in the valley of Ein el Qudeirat.

DEPTH (cm)	CLAY <0.002 mm (%)	SILT 0.002- 0.063 (%)	SAND 0.063- 2 mm (%)	TEXTURE	GRAVEL >2 mm (%)	CARBONATES CaCO ₃ (%)		
45- 55	20.2	58.9	21.2	SILT LOAM	0	41.7		
160-180	23.9	59.6	16.5	SILT LOAM	0	44.9		
* 270-290	7.1	67.4	25.4	SILT LOAM	0	38.1		
350-370	27.3	35.2	37.5	CLAY LOAM	2	46.9		
#								
DEPTH (cm)	pH	EC(1:1) (mS/cm)	SAR	ORGANIC CARBON (%) C	TOTAL PHOSPHORUS (%) P ₂ O ₅			
45- 55	7.3	10.4	92.6	0.52	0.12			
160-180	7.3	12.8	145.0	0.52	0.14			
* 270-290	7.3	11.2	99.2	0.54	0.14			
350-370	7.4	9.9	56.5	0.52	0.11			
#								
DEPTH (cm)	SOLUBLE SALTS IN 1:1 SOIL/WATER EXTRACT (meq/kg soil)							
	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
45- 55	3.7	0.35	131.0	<0.1	0.50	107.0	27.0	0.6
160-180	1.7	0.30	145.0	0	0.20	133.0	11.0	0.3
* 270-290	5.8	0.35	174.0	0	1.15	134.0	46.0	0.1
350-370	4.5	0.25	87.0	0	0.40	54.0	39.5	0.2
#								

Percentages in weight % of the fine earth <2 mm. Only gravel in weight % of the total soil. EC = electrical conductivity. SAR = sodium adsorption ratio. @ Note peculiar stratigraphy: younger aquaduct below older remnant (p.134).

origin to be related to a capillary rise of spring-water from the wadi bed (Kamphorst, 1986, personal communication; Kamphorst and Bolt, 1978). However, the level of the wadi bed, and with it the level of the flow of spring-water, has experienced dramatic changes since the Byzantine period. The salt distribution, therefore, cannot be related to Byzantine or earlier periods. Salts are easily leached and their present distribution in the sediments adjacent to the stream channel probably reflects the more recent local environmental history, i.e. the main period of wadi aggradation and the subsequent period of downcutting.

The amount of dissolved salts in the spring water is about 1.42 g/liter. Sodium and chloride are the main salt constituents in the spring-water as well as in the sediment. Both of these components decrease in quantity in the lower part of the sediment profile, accompanied with an increase in sulphate. A similar salt distribution occurs in the sediment profile in between the 7th century dam remnants, some 700 m upstream.

VALLEY AGGRADATION AND ITS RADIOCARBON DATING NEAR THE TELL

Going downstream from the channel bluff site that exhibits the remains of the two ancient aquaducts, one passes the partly destroyed Jarvis dam after about 250 m. The tell of the fortresses lies further down the valley at a distance of some 1200 m from the former aquaduct site.

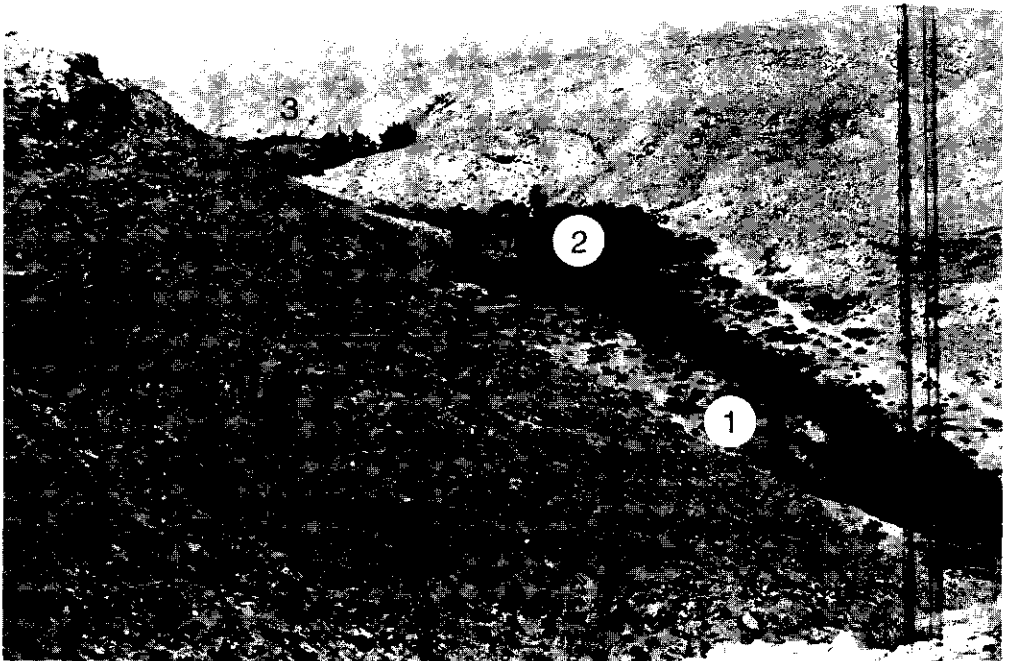


PHOTO 36. A large stretch of the valley of Ein el Qudeirat, displaying the location of: (1) the channel bluff site with the ancient aquaducts, (2) the broken Jarvis Dam, (3) the tell of the fortresses.

About 200 m upstream from the tell, a charcoal pocket was found in the southern channel bluff, approximately 2.50 m below the valley plain and 1.50 m above the present stream bed with its perennial flow of spring-water. A charcoal sample was taken (GrN-11946) for carbon-14 dating.

Some 60 m southwest of the tell, another charcoal sample (GrN-11947) was collected from the northern channel bluff, at a level of about 3 m below the valley plain and 1.30 m above the present stream bed with its gentle flow of water. Both charcoal samples were investigated at the Isotope Physics Laboratory of Prof. Mook (University of Groningen). The resulting dates in conventional C-14 years and calibrated historical years (Figure 25) are as follows:

GrN-11946	540 ± 45 BP	1310-1430 Cal A.D.
GrN-11947	445 ± 25 BP	1440-1460 Cal A.D.

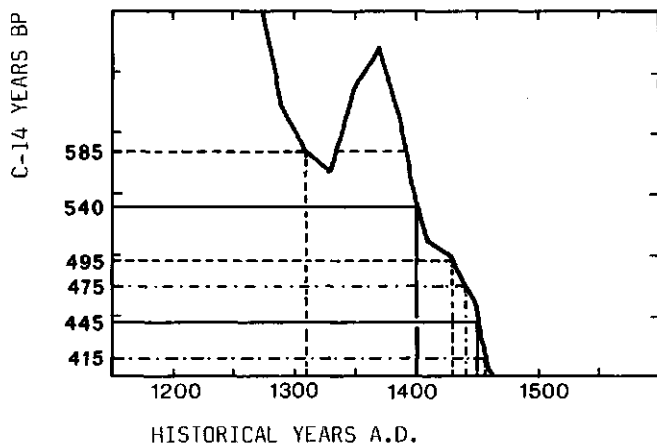


FIGURE 25. Calibration of the C-14 dates of two charcoal samples, collected from different channel bluff sections near the tell, into historical years.

These data give important information about wadi aggradation during the Mamluk Period, in addition to the detailed picture already obtained from the 7th century dam site, upstream from the spring. However, more information is yet needed to establish more precisely the duration of the extraordinary period of aggradation after Byzantine-Early Arab times. Moreover, is there any available evidence about stream channel evolution in the valley of Ein el Qudeirat during earlier historic periods?

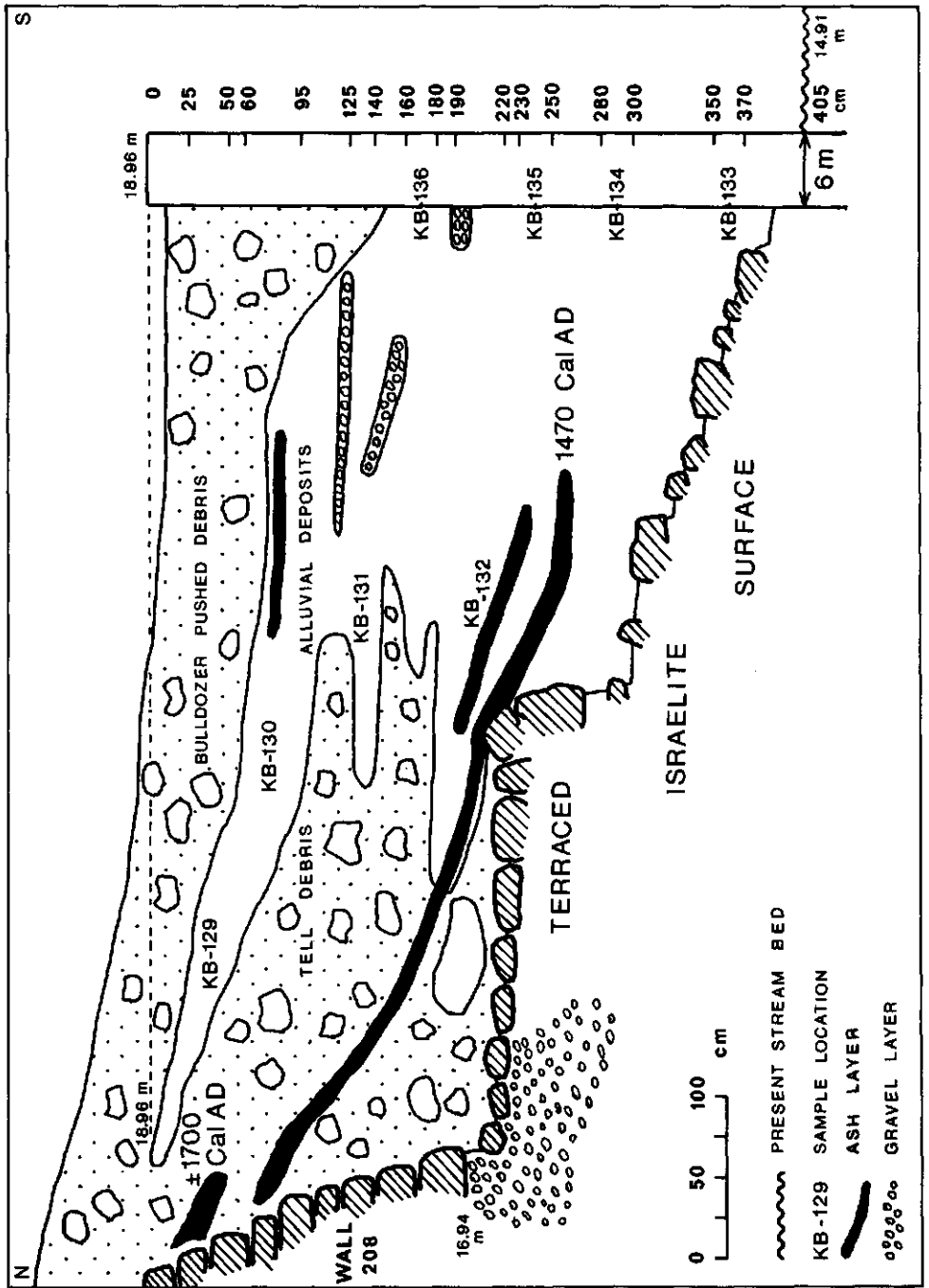


FIGURE 26. Stratigraphy of valley deposits at the southern edge of the tell.

As the wadi flows along the southern edge of the tell, it was assumed by the author that this part of the valley might contain stratigraphic information about the position and evolution of the stream channel and its wadi bed during the Late Bronze, Israelite and subsequent periods. Therefore, a trench was dug from the base of the southern buttress wall in the direction of the stream channel in the winter of 1981/1982, during the last seasons of excavations by Rudolph Cohen before the Israeli withdrawal from Sinai.

It was discovered that a terraced slope, lined with large stones, descends from the buttress wall of the Middle and Upper Fortress toward the former position of the wadi bed during the Iron Age. The obvious purpose of this terraced slope, covered with stones, was to protect the ancient Israelite fortresses from being undercut by powerful runoff floods in the rainy season.

The stratigraphic relationships between the terraced slope, the various dark ash layers, accumulated debris and sedimentary layers deposited by the wadi at this part of the tell, are shown in Figure 26.

The base of the buttress wall lies 2 meter higher than the present level of the stream bed. The distance between the buttress wall and the stream channel is 12 m, when measured along the trench. The terraced and stone covered slope, descending from the base of the buttress wall in the direction of the wadi, marked the landscape surface between the tell and the stream channel during the Iron Age. A natural gravel deposit, probably of Late Pleistocene age, underlies the base of the buttress wall and the first part of the terraced slope.

The position of the stream channel during the Iron Age was similar as today, but the level of the wadi bed might have been somewhat lower than at present. Alluvial loessial deposits cover the terraced Iron Age slope and appear unto a height of about 4 meter above the level of the present wadi bed.

A sloping dark ash layer, about 5 meter in length, descends from the buttress wall, passes just over the top of the first man-made Iron Age terrace step, and ends within the alluvial loessial sediment at a height of 1.50 m above the present stream bed level. This dark ash layer marks the landscape surface at a time when the wadi aggradation had already begun, since at least some 1.50 m of sediment was already deposited. Three charcoal samples from different parts of this ash layer were dated at the Isotope Physics Laboratory of Prof. Mook (University of Groningen).

The resulting dates in conventional carbon-14 years as well as in historical or dendro years, after calibration with the curve of Pearson et al. (1985), are as follows (Figure 27):

GrN-11949	395 ± 45 BP	1450 - 1485 Cal A.D.
GrN-12331	340 ± 40 BP	1470 - 1530 Cal A.D.
GrN-12333	410 ± 35 BP	1450 - 1480 Cal A.D.

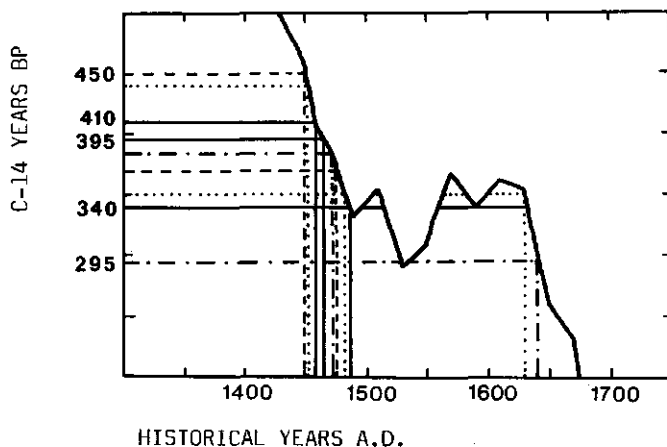


FIGURE 27. Calibration of the above C-14 dates into historical years.

The actual calibration of the three C-14 dates is shown in Figure 27, which exhibits the particular swings of the high precision curve of Pearson (1986) in this particular time stretch. The inclusion of the youngest swing of the graph into the calibration seems unrealistic and has, therefore, been omitted, as the dates show a distinct tendency to belong to the earlier time section of the graph. A clear consensus results from the three different charcoal samples of this dark ash layer. An age of about 1470 Cal A.D. appears to be the weighed average outcome, dating this ancient surface layer to the latest part of the Mamluk Period.

Another dark ash lense, only 40 cm long, is situated against the buttress wall above the former ash layer at a very important stratigraphic position. The lense lies some 30 cm above the upper part of the former ash layer and some 30 cm below the highest aggradation level of alluvial loessial sediments. Charcoal from the lense was investigated by the Isotope Physics Laboratory of Prof. Mook (University of Groningen). The resulting date in conventional C-14 years and in calibrated historical years, according to the high precision curve of Pearson (1986), is as follows:

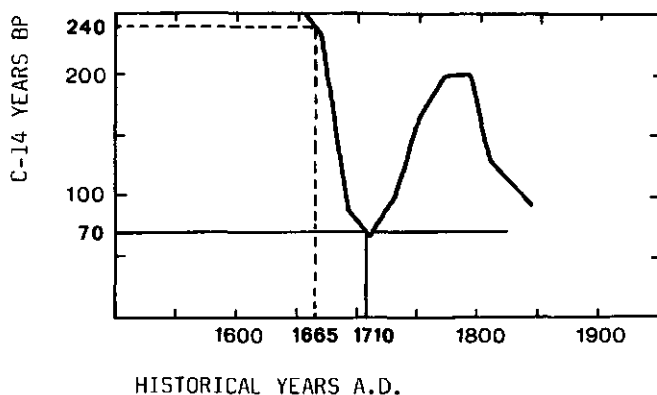


FIGURE 28. Calibration of the above C-14 date into historical years.

This result indicates that the wadi aggradation was probably at its highest level during the 17th and 18th century, when the wadi bed was about 4 meter above its present level. As a matter of fact, an abandoned stream channel exists just west of the tell, exhibiting a paleo-wadi bed at a level of 4.33 m higher than the adjacent present stream bed. This abandoned stream channel branches off the present wadi course near the southwestern corner of the tell, some 5 m south of the southern buttress wall, and bends away from the present stream channel before rejoining it some 200 m farther to the west (Photo 37 and 38).

The gravel lenses appearing in the upper part of the alluvial sediments in the studied section (Figure 26), lie at a distance of 4 to 6 meter south of the buttress wall. These gravel lenses show how the wadi bed moved gradually closer to the tell during its upward aggradation, as compared to its position during the Iron Age and today.

When did the period of aggradation come to an end? The former C-14 date (GrN-12332) indicates this to have occurred after the 17th century. From the observations of Woolley and Lawrence (1936:77) it is clear that the downward incision of the wadi and the formation of the present stream bed had already largely taken place before 1914. It seems, therefore, likely that this remarkable period of stream channel aggradation came to an end in the 18th century.



PHOTO 37. The present stream channel (1) and the abandoned paleo-wadi bed (2) downstream from the tell, which functioned during the main aggradational period. The level of the paleo-wadi bed is 4.33 m higher than the present stream bed. Note the ancient man-made wall on Gebel el Qudeirat to the north.

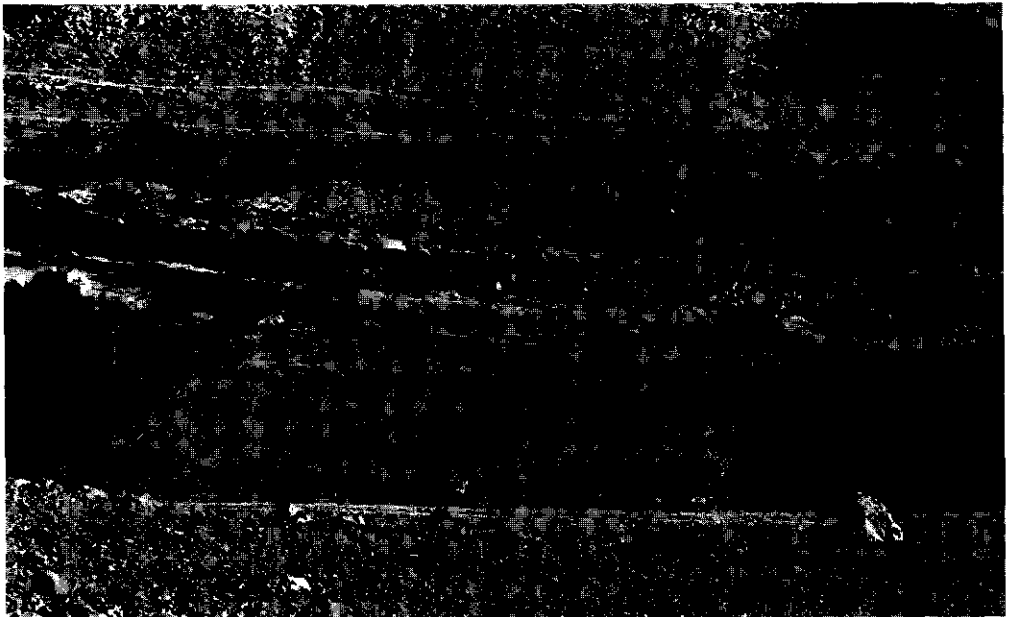


PHOTO 38. Close-up of the abandoned paleo-wadi bed (2), which functioned during the main aggradational period; viewed from Gebel el Qudeirat.

Very striking is the sudden change in the hydraulic or geomorphic behaviour of Nahal Kadesh-Barnea from aggradation to incision at the end of this period, as well as the rapid rate of downcutting that followed this marked environmental change.

SOIL DEVELOPMENT

If aggradation took place in the stream channel during the Mamluk and Ottoman periods, by which the wadi reached a level of about 4 meter higher than today, then the flow of spring-water carried by the wadi bed from farther upstream, must also have streamed up to about 4 meter higher than today. Is there any evidence of these former wet conditions in the sediment as a result of post-depositional processes of soil development, proving wet conditions in the past? The answer is a very definite yes.

Thin sections of three samples from the alluvial loessial sediments, deposited during the period of wadi aggradation, were investigated under the microscope. Sample KB-129 was collected from the uppermost, sandwiched alluvial loess layer (Figure 26), representing the highest level of aggradation during the 17th or 18th century. The other two samples are from somewhat greater depth. The approximate ages of the micromorphology samples, as well as their precise position with respect to the Iron Age buttress wall and the present wadi bed, are shown in Table 20.

TABLE 20. Position and approximate age of alluvial loessial sediment samples in the Kadesh-Barnea valley, south of the tell, investigated microscopically from thin sections, in order to study their post-depositional soil development.

Sample	Depth (cm)	Height above base-level of the Iron Age buttress wall (cm)	Distance		Approximate time of sedimentation
			South of buttress wall (cm)	North of present wadi-bed (cm)	
KB-129	30- 60	140-170	125	1050	17-18th century A.D.
KB-131	120-140	60- 80	350	825	16-17th century A.D.
KB-132	190-220	10- 0-(-)20	300	875	15-16th century A.D.

MICROMORPHOLOGY AND PALEO-ENVIRONMENT OF KB-129

The general appearance of the matrix is relatively loose, which is not surprising for such a young sediment, less than 300 years old, near the valley surface. Three slaking crusts in the thin section are apparently remnants of sedimentary layering from the time of deposition, which seems to have been largely destroyed within a remarkable short period by biological pedoturbation. The soil matrix is composed of fine plasma and skeleton grains in about equal volume amounts, as well as voids. The related distribution between skeleton grains and plasma varies, being intertextic, agglomeroplasmic, or porphyro-skelic. The plasma has a calciasepic to very fine crystic calcic fabric.

The skeleton grains, angular and subrounded in shape, are generally of coarse silt to very fine sand size (0.04-0.1 mm); some sand grains are up to 0.3 mm. The arrangement of the grains is random, sometimes clustered. Their mineralogy is dominated by quartz, followed by calcite, whilst feldspars, hornblende, glauconite and other heavy minerals appear occasionally.

Remains of fossils, from silt to sand sizes, are very common. Most of these small fossils appear to be of marine origin, apparently derived from the omnipresent calcareous marine rocks in the catchment of Nahal Kadesh-Barnea. Charcoal remnants, varying from silt size up to 1 mm, occur randomly in the matrix. A few angular to subrounded limestone fragments, up to 3.2 mm in diameter, are the largest components inside the sediment sample, together with a piece of pottery of similar size.

Voids of various sizes and shapes, like channels, compound packing voids, vughs and some skew planes, appear at random in the matrix. Evidence of biological activity since the time of sediment deposition, about 250 years ago, is apparent from the existence of channels, occurring regularly in sizes of up to 0.2 mm, root remains, and pedotubules (aggroutubules and isotubules) up to 10 mm in diameter. This already points to wetter soil conditions in the past, due to the perennial flow of spring-water carried by the wadi bed, when the stream channel had aggradated to its maximum level, some 4 meter higher than today, during the Ottoman period.

AUTHIGENIC PYRITE

Conclusive evidence of such a high level of the wadi bed is provided by the presence of pyrite, which can only form under reduced water-logged conditions. A cluster of pyrite framboids (Photo 39), 0.01-0.04 mm in diameter, obviously formed in situ, is situated in a channel with root remnants. A weakly developed neoferran (growth of iron-oxides inside the soil matrix)



PHOTO 39. Pyrite framboids (0.03 mm) in the uppermost sedimentary layer (incident light).

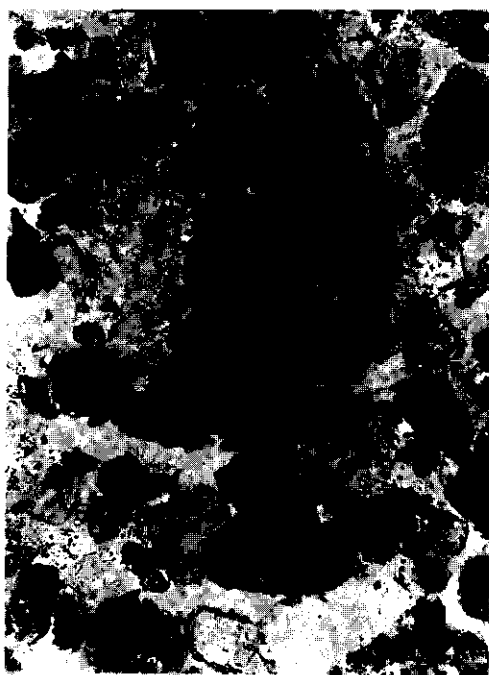


PHOTO 40. Ferric nodule (0.3 mm) in the uppermost sedimentary layer (plain polarized light).

adjacent to the pyrite cluster and the channel edge, probably formed as a result of partial oxidation of the pyrite. Other ferric nodules (Photo 40) in the matrix confirm this picture of wet conditions in the recent past. To the trained eye, weak gley features are even visible macroscopically in the field.

The observed gley phenomena, neo-ferrans and ferric nodules, are usually associated with an alternating oxidation-reduction environment. Such conditions may have occurred at a certain level X: (a) during aggradation, just before the stream bed and the water flow arrived at level X, or (b) when the stream bed and water flow were at some vertical distance above level X, so that downward seepage of water was not sufficient to fully saturate the soil and exclude the entry of air (oxygen); (c) during downcutting, as the position of the stream bed moved slightly below level X.

A full reduction environment with pyrite formation in the Kadesh-Barnea valley could only occur in those sediments situated at the actual level of water flow or to some depth below this level, as long as the soil matrix remained saturated with water, excluding the entry of air.



PHOTO 41. Small pedogenetic calcite crystals around a root remnant in a deposit less than 300 years old (crossed polarizers).

Some secondary crystallization of calcium carbonate has clearly taken place in the recently deposited uppermost alluvial loessial sediments. Apart from a very few incipient carbonate nodules, some nice calcitans occur in channels, often related to roots. Newly formed calcite crystals, 0.002-0.03 mm in size (fine silt), completely surround a root remnant having a diameter of 0.3 mm (Photo 41). Even smaller micrite crystals (0.002-0.01) appear in a cluster, 0.1 mm in diameter, attached to a root.

The occurrence of gypsum is not very apparent, but very small, newly formed crystals (0.005-0.02 mm) seem to make up a cluster with a size of 0.06-0.15 mm.

The degree of soil development in such a short period of time of about 250 years is certainly remarkable for a desert region. However, one should take into account the very large contrasts in environmental circumstances: First water-logged to wet from the perennial flow of water in the wadi bed during a certain period after deposition, when aggradation in the stream valley reached its highest level. Later, probably in the 18th century, the process of downcutting followed the relatively long period of aggradation. Suddenly the soil environment became as dry as the surrounding desert, when the stream channel lowered its bed. Only some capillary rise of water may have moistened this upper part of the alluvial loess deposit in the beginning period of progressive downcutting, apart from the periodic wetting of occasional heavy rainfall that penetrated into the somewhat deeper part of the soil. No irrigation farming seems to have taken place at this particular spot in the valley.

Because of this sudden transition from aquatic to arid conditions, the pyrite has been preserved so well in this soil, as well as in the mortar of the aqueducts already described previously. In case of prolonged moist oxida-

tion conditions during the transition from wet to dry, the pyrite should probably have disappeared already (Van Breemen, 1986, personal communication).

MICROMORPHOLOGY AND PALEO-ENVIRONMENT OF KB-131

The age of this alluvial loessial layer is about 400 years. The soil matrix is denser than in the uppermost sedimentary layer (KB-129) described above. The related distribution of plasma and skeleton grains is, accordingly, mostly porphyroskelic and occasionally agglomeroplasmic. The clay content appears to be higher and there is, consequently, more plasma than skeleton grains. The latter particles are similar in composition, size and shape as in the previous sample. A few pieces of charcoal, up to 2 mm, and fossiliferous carbonate grains appear randomly in the matrix. The largest solid component is a subrounded piece of limestone, 2.2 x 4.6 mm in size.

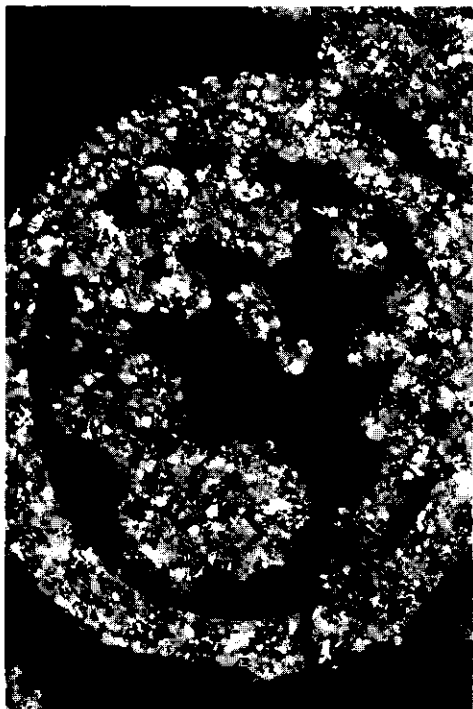


PHOTO 42. Pedotubule 3 mm in diameter (crossed polarizers).

Past biological activity in the soil must have been intense, as indicated by the many channels, root remnants and pedotubules. The latter features are caused by small digging and burrowing creatures that moved through the soil. The following types of pedotubules can be distinguished in the sampled layer: granotubules, isotubules and aggotubules, varying in diameter from 0.7-3.0 mm (Photo 42). Apart from channels, various other types of voids, like vughs and skew planes occur at random or clustered in the soil matrix.

AUTHIGENIC PYRITE

Conditions of a water-logged reduction environment in the past is clearly indicated by the presence of pyrite framboids, which regularly occur in the matrix, usually related to voids. The pyrite crystals are often weathered. Evidence of wet conditions and alternating oxidation-reduction circumstances is also provided by the occurrence of neo-ferran cutans,

0.02-0.05 mm thick, and small diffuse ferric nodules. Gley features are somewhat more developed and pyrite appears in a more advanced stage of weathering, as compared to the upper sedimentary aggradational layer.

Some neo-formation of calcite has taken place, usually in the matrix as very small-scale incipient concentrations, not easily identified as such. One crystal chamber was observed in a vugh of 0.4 x 0.5 mm, containing fine micritic and sparitic calcite crystals, 0.005-0.05 mm in size. Considerably more widespread in this layer is the crystallization of gypsum in voids. Several channels and vughs are filled up by gypsum crystals, both in needle and more equilateral shapes. Not all the gypsum is necessarily derived from pyrite oxidation, as it may also have crystallized above the level of stream flow from capillary rising water.

MICROMORPHOLOGY AND PALEO-ENVIRONMENT OF KB-132

This layer was approximately deposited in 1500 A.D., just above the first step of the terraced Iron Age slope, at the same level as the base of the buttress wall. The micromorphology is in many respects similar to the former sample from a layer 75 cm higher. Therefore, only the remarkable features or differences with the former sample will be described.

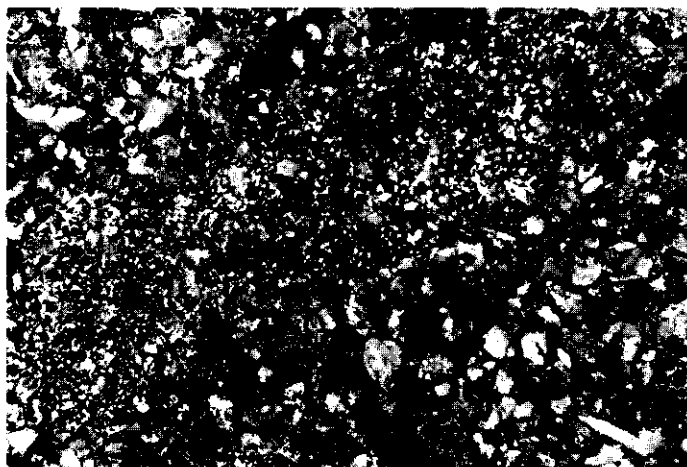


PHOTO 43. Channels filled with fine gypsum crystals (length photo = 1.5 mm; crossed polarizers).

A very large striotubule, 2 cm wide and 11 cm long, appears in the middle part of the entire thin section. Biological activity and pedoturbation has clearly been intense in the past.

The amount of gypsum is markedly higher than in the former sample. Many channels and other voids are completely filled in with fine gypsum

crystals, 0.005-0.04 mm in size (Photo 43). As some voids within the very large striotubule, mentioned above, are also filled with gypsum crystals, it

can be concluded that the phase of intense biological activity preceded the period of gypsum crystallization.

Apart from two large, weathered pyrite framboids, 0.08 mm and 0.12 mm in diameter, less pyrite seems to occur as compared to the samples above. Since this layer is closer situated to the present water level, moist oxidation conditions appear to have persisted for a longer period of time at this level during the successive phases of aggradation and downcutting. Most of the pyrite has probably disappeared as a result. The widespread occurrence of gypsum may underline this viewpoint, although most of the gypsum has probably been derived from capillary rising water and subsequent crystallization.

From the micromorphology samples so far described, it can be concluded that the transition from a water-logged reduction environment to the very dry regional desert environment has been particularly sharp, within a short period of time, in the aquaduct on top of the 7th century dam, upstream from the spring, and in the uppermost aggradational sedimentary layer in the profile south of the tell. Pyrite, formed in the latter aquaduct (Photo 27, 28) during the time of functioning of the 7th century dam, or formed in the uppermost aggradational deposits (Photo 39), in the 17th-18th century A.D., has clearly been best preserved because of this sharp transition.

GRANULOMETRY AND CHEMICAL ANALYSIS OF THE AGGRADATIONAL DEPOSITS SOUTH OF THE TELL

Eight samples were taken from the alluvial loessial deposits south of the tell (Figure 26) for granulometric and chemical analysis. Three of these samples are from the same respective positions as the micromorphology samples (KB-129, KB-131, KB-132), already described above, and have, therefore, kept the same respective sample numbers. The following table defines the location of the various samples with respect to the buttress wall, the present wadi bed, the vertical grid-system used during the archaeological excavations by Rudolph Cohen, and the depth below the former valley plain surface at the time of maximum aggradation.

The former valley plain surface near the stream channel was at a level of about 19.00 m during the phase of maximum aggradation, expressed within the vertical grid-system used during the excavations. The upper surface near the stream channel has been eroded since the onset of the period of downcutting and incision. Very recently a layer of debris from the excavations was pushed over the eroded surface by a bulldozer (Figure 26).

The particle size analysis reflects the loessial character of the alluvial

TABLE 21. Position and approximate age of samples from the alluvial loessial fill sediments in the Kadesh-Barnea valley, south of the tell, deposited during the period of stream channel aggradation from the 13-18th century A.D.

Sample	Depth (cm)	Height within the vertical grid-system of the excavations (m)	Distance		Approximate time of sedimentation (A.D.)
			South of buttress wall (cm)	North of present wadi-bed (cm)	
KB-129	25- 50	18.75-18.50	125	1050	17-18th century
KB-130	60- 95	18.40-18.05	225	950	17-18th century
KB-131	120-140	17.80-17.60	350	825	16-17th century
KB-132	190-220	17.10-16.80	300	875	16-17th century
KB-136	160-180	17.40-17.20	600	575	16-17th century
KB-135	230-250	16.70-16.50	600	575	15-16th century
KB-134	280-300	16.20-16.00	600	575	14-15th century
KB-133	350-370	15.50-15.30	600	575	13-14th century
*	409	14.91	1175	0	Present wadi-bed
#		16.94	0	1175	

* Water flow in present 20th century wadi-bed.

Base-level of Iron-Age buttress wall.

fill deposits, in which silt is the dominant component. The lower section of the fill is somewhat more clayey than its upper part, although a layer of clay loam (KB-131) exists within the upper section as well.

The total amount of salts in the alluvial fill sediments south of the tell gradually decreases with depth (Table 22). The salinity of the upper layers can be rated from moderately high (EC 8.4 mS/cm) to medium (EC 5.8 mS/cm), further decreasing downward to a low salinity (EC 1.1 mS/cm) in the deeper layers. Such a characteristic distribution evidently shows the salts to be derived from capillary rising spring-water flowing over the wadi-bed, as suggested by Kamphorst (1985, personal communication).

Sodium and chloride are the dominant salts in the fill sediments, followed by sulphate. This seems to be compatible with the composition of the spring-water (Table 22), from which most of the salts are thought to be derived.

Samples KB-136 and KB-135 are situated near recent erosional surfaces, now covered by a layer of bulldozer-pushed debris from the excavations. This proximity to an erosional stream channel surface might perhaps relate to the relatively larger contents of bicarbonate anions and sodium-carbonates. The pH is higher as a result. The microscopically observed presence of gypsum fits with the measured sulphate content, being highest in sample KB-132 (Photo 43).

TABLE 22. Granulometry and chemical analysis of alluvial loessial fill sediments in the Kadash-Barnea valley, south of the tell, deposited during the aggradational period from the 13-18th century A.D.

SAMPLE	DEPTH (cm)	CLAY	SILT	SAND	TEXTURE	GRAVEL	CARBONATES
		<0.002 mm (%)	0.002- 0.063 (%)	0.063- 2 mm (%)		>2 mm (%)	CaCO ₃ (%)
KB-129	25- 50	14.4	41.4	44.3	LOAM	2	42.8
KB-130	60- 95	14.7	47.1	37.9	LOAM	0	42.7
KB-131	125-140	28.4	48.3	23.2	CLAY LOAM	0	45.3
KB-132	190-220	15.2	49.1	35.8	LOAM	0	41.9
KB-136	160-180	15.9	50.8	33.3	SILT LOAM	0	45.4
KB-135	230-250	23.6	40.9	35.5	LOAM	0	46.0
KB-134	280-300	25.9	47.3	26.8	LOAM	0	48.1
KB-133	350-370	23.4	45.0	31.5	LOAM	0	46.6

SAMPLE	DEPTH (cm)	pH	EC(1:1)	SAR	ORGANIC CARBON	TOTAL PHOSPHORUS	NITROGEN
			(mS/cm)		(%) C	(%) P ₂ O ₅	(%) N
KB-129	25- 50	7.8	8.40	52.9	0.64	0.16	0.03
KB-130	60- 95	7.1	6.58	31.4	0.27	0.14	n.d.
KB-131	125-140	7.4	5.98	48.6	0.81	0.18	n.d.
KB-132	190-220	7.4	5.78	47.9	0.84	0.17	n.d.
KB-136	160-180	7.8	3.62	54.1	0.27	0.15	n.d.
KB-135	230-250	8.1	1.10	30.0	0.83	0.17	n.d.
KB-134	280-300	7.7	1.08	30.3	0.88	0.18	n.d.
KB-133	350-370	7.7	1.85	33.3	0.43	0.15	n.d.

SAMPLE	DEPTH (cm)	SOLUBLE SALTS IN 1:1 SOIL/WATER EXTRACT (meq/kg soil)								
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
KB-129	25- 50	3.5	<0.10	70.0	0	0	3.7	56.0	12.0	5.0
KB-130	60- 95	3.8	<0.10	43.5	0	0	1.2	33.0	14.0	0.6
KB-131	125-140	1.6	<0.10	43.5	0	0	1.5	34.0	11.0	0.6
KB-132	190-220	1.6	<0.10	43.5	0	0	0.9	30.5	17.5	0.2
KB-136	160-180	1.2	<0.10	42.8	0	0.2	2.2	30.5	9.0	1.8
KB-135	230-250	0.3	<0.01	10.6	0	0.2	3.6	5.8	1.1	0.4
KB-134	280-300	0.3	<0.01	10.7	0	0	2.8	6.7	1.8	0.2
KB-133	350-370	0.6	<0.10	19.0	0	0	2.1	14.0	3.6	<0.1
SPRING-WATER	405	4.4	3.7	14.4	0.1	n.d.	3.5	14.4	4.7	n.d.

Percentages in weight % of the fine earth <2 mm. Only gravel in weight % of the total soil. EC = electrical conductivity. SAR = sodium adsorption ratio. n.d. = not determined.

AN EXCAVATED SOIL PIT WEST OF THE TELL

The pit was excavated to determine the stratigraphy of the upper sediments at this part of the valley, as well as the particle size distribution and main soil chemistry. The location of the pit is 38 m west of the tell and some 60 m north of the stream channel. From an agricultural point of view, the pit lies next to a field with olive trees (Photo 37), farmed by the Bedouin. The surface of the pit is situated at a level of 18.29 m, expressed within the vertical grid-system used during the archaeological excavations.

The sedimentary stratigraphy until the depth of excavation (1.50 m) is essentially twofold:

- 1) 0- 75 cm Fine loessial deposits with a texture of loam, containing some scattered stones.
- 2) 75- 150+ cm Gravel with stones up to 10 cm in size.

Another excavated soil pit, located at a distance of about 10 m east from the north-eastern corner of the tell, exhibits a similar sedimentary stratigraphy. The boundary between the loessial sediments and the underlying gravel lies here at a depth of 60 cm. The surface of this pit is situated at a level of 18.61 m, expressed within the vertical grid-system of the archaeological excavations.

The resulting stratigraphic picture of this part of the valley, as elucidated by the investigated pits and channel sections, clearly shows the blanket of alluvial loessial sediments to increase in thickness toward the stream channel, whilst the loam-gravel boundary descends accordingly.

The particle size distribution of the upper two horizons in the soil pit west of the tell is rather similar to the granulometry of the upper fill sediments adjacent to the stream channel, south of the tell (Table 22, 23). This might indicate that some alluvial loessial sediment was also deposited farther away from the stream channel, during the period of maximal aggradation in the 17-18th centuries A.D. Sediment laden floods probably covered the entire Kadesh-Barnea valley when channel aggradation reached its highest levels in historical times.

Even in the beginning of the 20th century large runoff floods could occasionally sweep the whole valley, as reported by Woolley and Lawrence (1936:77). The marked difference being, that the flood reported by the British authors caused erosion, whereas the floods during the period of aggradation had the opposite effect, causing sedimentation!

TABLE 23. Granulometry and chemical analysis of an excavated soil pit in the Kadesh-Barnea valley, next to an irrigated field with olive trees, 38 m west of the Tell.

HORIZON	DEPTH (cm)	CLAY <0.002 mm (%)	SILT 0.002- 0.063 (%)	SAND 0.063- 2 mm (%)	TEXTURE	GRAVEL >2 mm (%)	CARBONATES CaCO ₃ (%)
A	0-15	12.5	48.1	39.4	LOAM	1	45.0
C-I	25-35	14.0	45.8	40.2	LOAM	2	45.5
C-I	45-55	19.8	31.3	48.9	LOAM	8	46.4
C-II	70-80	20.0	26.1	53.8	SANDY-LOAM/GRAVEL	24	49.4

HORIZON	DEPTH (cm)	pH	EC(1:1) (mS/cm)	SAR	ORGANIC CARBON (%) C	TOTAL PHOSPHORUS (%) P ₂ O ₅
A	0-15	8.3	0.63	15.8	0.69	0.11
C-I	25-35	8.2	1.22	39.1	0.69	0.16
C-I	45-55	7.9	1.25	43.0	0.71	0.14
C-II	70-80	7.2	7.00	51.3	0.80	0.14

HORIZON	DEPTH (cm)	SOLUBLE SALTS IN 1:1 SOIL/WATER EXTRACT (meq/kg soil)								
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
A	0-15	0.5	<0.01	7.9	<0.10	0	5.4	3.0	0.5	<0.1
C-I	25-35	0.2	<0.01	10.7	<0.01	0.8	0.1	5.2	4.6	<0.1
C-I	45-55	0.2	<0.01	13.6	<0.01	0	2.5	6.2	5.0	0.1
C-II	70-80	5.7	<0.10	87.0	<0.10	0	1.0	49.0	38.5	0

Percentages in weight % of the fine earth <2 mm. Only gravel in weight % of the total soil. EC = electrical conductivity. SAR = sodium adsorption ratio.

The amount of soluble salts in the upper 60 cm of the soil profile can be rated very low to low, increasing slowly with depth, until the salt content shows a very sharp increase at the loam-gravel boundary, at a depth of 70 cm. Such a salt distribution is in marked contrast to that of the fill profile south of the tell (Table 22), and reflects the influence of leaching, due to irrigation farming by the Bedouin on the adjacent field.

Sodium is the dominant cation throughout the profile, whereas the amount of bicarbonate surpasses the chloride anion content in the A horizon. The amount of sulphate anions in the three subsoil horizons is nearly as large as the chloride anion content, which is also understood to be a result of leaching with irrigation water from the spring. The nitrate content is consistently lower than in the fill profile south of the tell.

STREAM CHANNEL EVOLUTION IN THE KADESH-BARNEA VALLEY
DURING HISTORICAL TIMES

In conclusion of the detailed descriptions about the stratigraphy, radiocarbon dating, mortar micromorphology and soil development of various investigated sections in the valley of Ein el Qudeirat, the most relevant stratigraphic information is brought together in Table 24. On the basis of these data, an attempt is made to reconstruct the evolution of the stream channel since the Late Bronze Age.

TABLE 24. Geomorphic, archaeological, and C-14 data about stream channel evolution in the Kadash-Barnea valley during historical times, in chrono-stratigraphic sequence.

Object	Below present valley plain (cm)	Above present wadi-bed (cm)	C-14 charcoal sample	Conventional C-14 date (BP)	Calibrated C-14 date (historic years)
Surface aquaduct	230-310	215-295#	GrN-12327	3270 + 100	1725-1425 BC
Iron Age wadi-bed	>400	<0			
Basis dam	257-400	73-203*	GrN-12326	1380 + 90	610- 685 AD
Wadi-bed aquaduct	410-510	15-115#	GrN-12328	1395 + 50	615- 665 AD
Charcoal lense	300	?	QC-491	665 + 115	1260-1400 AD
Charcoal pocket	250	150	GrN-11946	540 + 45	1310-1430 AD
Charcoal pocket	300	130	GrN-11947	445 + 25	1440-1460 AD
Charcoal lense	250	150	GrN-12333	410 + 35	1450-1480 AD
idem	idem	idem	GrN-11949	395 + 45	1450-1485 AD
idem	idem	idem	GrN-12331	340 + 40	1470-1530 AD
Charcoal lense	30	375	GrN-12332	70 + 170	1665-1950 AD

The range in heights expresses the vertical thickness of the aquaduct.

* The range in heights expresses maximum and minimum levels of present wadi bed and valley plain levels.

During the Late Bronze and Iron Age, the surface of the valley plain was apparently somewhat lower than today, particularly in its narrow part upstream of the Jarvis dam and in proximity to the stream channel. The level of the stream bed appears also to have been somewhat lower than at present. This status quo or dynamic equilibrium in the stream channel of the valley of Ein

el Qudeirat may have continued, albeit with presumed small fluctuations, since the Iron Age probably until Late Hellenistic or Roman times.

During the Late Byzantine period the stream bed level was about one meter higher than today, taking into consideration the basis-level of the 7th century (A.D.) dam, as well as the level of the 7th century wadi-bottom aquaduct that tapped the water flowing over the stream bed.

Since the wadi bed seems to have been below the present level during the Iron Age, stream channel aggradation is likely to have occurred at some time before the Late Byzantine Period. A charcoal sample collected by Goldberg (1984) from a fill deposit 3 km northwest of Quseima, about 9 km northwest of Ein el Qudeirat, seems to fit this picture. The sample (QC-492) yielded a C-14 date of 1755 ± 105 BP in conventional carbon-14 years. When calibrated against the high precision calibration curve of Pearson et al. (1985), the resulting outcome (Figure 29) in historical years is 125-405 Cal A.D.

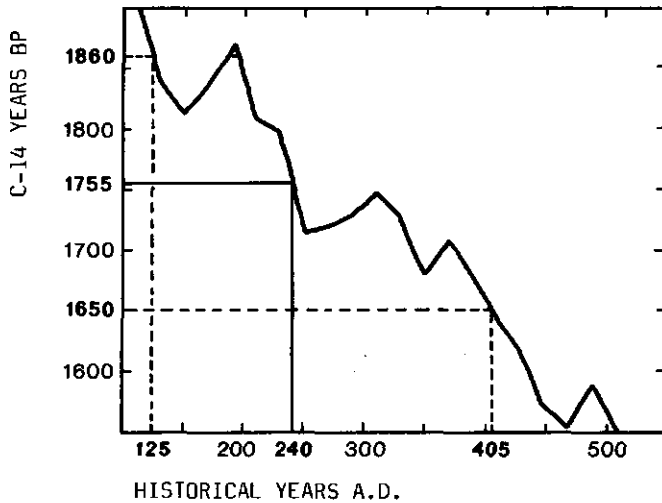


FIGURE 29. Calibration of the above C-14 date (QC-492) into historical years.

The destruction of the 7th century dam coincided perhaps with a period of stream channel incision during the Early Arab period, by which the stream bed was lowered with about 1-1.50 m below the Late Byzantine level. This can be concluded from the sedimentary stratigraphy near the 7th century dam.

The most extraordinary period of stream channel aggradation during historical times apparently began in the 13th century A.D., during the latter part of the Crusader period or very beginning of the Mamluk period, and lasted until about the 18th century. The stream bed rose with about 4 meter during this aggradational period!

This remarkable regime of aggradation in Nahal Kadesh-Barnea came to an end apparently in the 18th century. It was followed by a dramatic change that led to rapid downcutting and incision during the last few centuries, which lowered the stream bed with about 4 meter to its present level. This process of incision and erosion seems to continue even today.

TABLE 25. Summary conclusions of stream channel evolution in the Kadesh-Barnea valley during historical times. *

HISTORIC PERIOD	APPROXIMATE TIMING	STREAM CHANNEL BEHAVIOUR
Late Bronze Age to Late Hellenistic-Roman times	1500 - 100 B.C.	Dynamic equilibrium of the stream channel, with small fluctuations.
Late Hellenistic - Roman Period	100 B.C. - 400 A.D.	Stream channel aggradation and dynamic equilibrium
Byzantine Period and Early Arab Period	400 - 700 A.D.	Dynamic equilibrium
Early Arab Period to Late Crusader Period	700 -1200 A.D.	Incision and dynamic equilibrium
Late Crusader Period to Late Ottoman Period	1200 -1700 A.D.	Major aggradational period
Late Ottoman Period until the present	1700 -1986 A.D.	Rapid incision and erosion

* This summary framework is based upon available evidence in the present state of knowledge and understanding. New data may refine or alter this picture.

11 Water, food production and population in the Kadesh-Barnea area

INTRODUCTION

There are usually several criteria to assess past population levels in a certain area. The number of building structures is commonly used in this respect (Broshi, 1980). However, in cases of tent-dwelling communities, like the ancient Israelites during their sojournment in the desert after the Exodus from Egypt, or other nomadic and semi-nomadic inhabitants of arid regions, the latter criterium is generally of no practical value. The pitching of tents and their subsequent removal will hardly leave any trace, if at all. In these circumstances an assessment of the natural food producing capacity of a certain dry region, in combination with the availability of water, may be the only helpful criterium as a paleo-population indicator.

With regard to the Kadesh-Barnea valley, it is possible to make an estimation of food production levels based upon irrigation agriculture with water from the spring of Ein el Qudeirat. Such an approach is in a sense hypothetic and tentative. It seems, nevertheless, very useful to assess the carrying capacity of the area in terms of food production. The number of people that can be fed maximally in the Kadesh-Barnea valley, exclusively relying on a self-sufficient type of subsistence farming, does not necessarily coincide, however, with actual population numbers in certain historic periods.

The spring was certainly not used to its full potential for food production in most periods in the past, as this would require full control over the water flow from the spring, night storage, and two food crops per year, both in the winter and the summer season. It seems, therefore, likely that population levels directly supported by food produced with water from the spring were

usually below the maximum potential. On the other hand, population numbers might have been well above the maximum carrying capacity of the valley, as food could have been supplied through imports or by other means.

The major food crops, both in antiquity and at present, are the cereals. About 75 % of our food today is derived, one way or the other, from cereals (Buringh, 1977). Leguminous pulses or beans (Westphal, 1974, 1982) are second in importance, both for their significant protein content and for their importance in crop rotation to maintain a certain level of soil fertility.

Apart from the two-field system (one year a field is sown, the next year it is left fallow), used in the Mediterranean area (Slicher van Bath, 1960:68), the so-called three-field system was also known in the region in antiquity, especially since its promotion in Roman times. In this system one part of the land was sown with cereals, a second with legumes and the third was left fallow. This fallow land was used for pasturage and became thus fertilized in a natural way by animal manure. The next year this division was rotated, by which legumes, usually lentils, were sown in the fallow land of the former year; wheat or barley was sown in the part occupied the year before by legumes; and the land in which cereals had grown was left fallow. This traditional system of land use and crop rotation persisted in the Southern Levant for many centuries into modern times (Turkowski, 1969).

Food crops like wheat, barley, lentils and chick peas are known in the region at large from antiquity (Zohary, 1973; Zohary and Hopf, 1973; Hopf, 1978). Most of these food crops grow in the winter and spring season, and would require some 300 mm of water, well distributed during their life cycle. The average annual rainfall at present is about 75 mm, usually concentrated in the winter months. It seems that summer cereals like sorghum were mainly introduced in the Southern Levant by the Arabs (Watson, 1983), at some time after the Muslim-Arab conquest in the 7th century A.D. Summer crops would require more irrigation water than winter crops, due to the higher temperatures in summer and the total lack of rainfall. Some over-irrigation beyond the actual need of the crop is required, due to the slight salt content in the spring water of Ein el Qudeirat (1.42 g/l).

ESTIMATED MAXIMAL FOOD PRODUCING CAPACITY AND RELATED POPULATION LEVELS OF THE KADESH-BARNEA VALLEY IN ANTIQUITY AND TODAY.

The purpose of the following hypothetical calculations is to assess

the maximal possible carrying capacity of the area in historical times, relating food production levels to population numbers, based on a rather autarkic food economy. Rainfall amounts during historical times have naturally varied, as will be discussed in the last chapter, but it seems unlikely that the average annual amounts deviated with more than about 50 % from the present average quantity. The discharge of the spring may, likewise, have varied in the past, but these variations are probably also within a 50 % range from the present values. The 20th century precipitation and discharge data served as a basis for the calculations. Such oversimplifications are inevitable in this kind of assessments, by which care is taken not to underestimate the carrying capacity of the area. The outcome of the calculations can, therefore, be regarded as a likely maximum indeed.

The spring has an average discharge of about 60 cubic meter of water per hour. This amounts to 525.600 cubic meter of water per year. If a rotational food crop pattern could be arranged that would allow for an evenly distributed consumptive water use of the spring water throughout the year (without summer cereals or summer pulses this is actually a problem), then the 525.600 cubic meters of annual spring water might be distributed over an area of 131.4 hectare, by which each field would receive 400 mm/year as an average. Full control of the spring flow and a system of either night irrigation or night storage is imperative to use the total yearly discharge of the spring for irrigation agriculture.

The Jarvis irrigation scheme in the area, already described, which concentrated on cash crops, mainly olives trees, brought some 120 ha into cultivation (Jarvis, 1938:267). This shows that enough potentially arable land exists in the area in relation to the capacity of the spring. Hence soil is not the limiting factor in the Kadesh-Barnea valley and the adjacent valleys downstream.

In antiquity, a yield of 1000 kg/hectare of cereals or pulses was considered to be a good figure, which could only have been obtained through proper crop rotation and maintenance of soil fertility. The average yields of wheat and winter legumes amounted to only 530 kg/ha on a rainfed fellah's farm in the Yizreel Valley (483 mm/year on the average), during the second and third decades of the 20th century, in a non-optimal autarkic agro-ecosystem (Stanhill, 1978). The Nizzana papyri of the 6th and 7th century A.D. mention the yield of wheat, grown in a runoff farming system in the Nizzana area during a certain year, to be 6.9 times the amount sown (Kraemer, 1958). In the chapter on Horvat Haluqim, it was already extensively discussed that average

wheat yields under runoff farming conditions in antiquity probably did not exceed 600 kg/ha.

With proper irrigation farming in the Kadesh-Barnea valley, and a secured supply of about 400 mm of water per growing season (about half a year), a yield of 1000 kg/ha of cereals and leguminous pulses might have been possible in the past. If food crop production and agricultural water use from the spring of Ein el Qudeirat could have been distributed evenly throughout the year (winter and summer crop), then about 130,000 kg of cereals and legumes might have been harvested from some 130 hectares.

This quantity has to be reduced by the seed stock required for next year (about 13,000 kg) and post-harvest losses (Hall, 1970; Van der Lee, 1978) of some 10 % (13,000 kg), which leaves an estimated 100,000 kg/year for human consumption. The rather optimistic yield ratio of 1:10 underlines the purpose of the calculation to assess the maximum carrying capacity of the area. A detailed study of historic yield ratios in several European countries was made by Slicher van Bath (1963a,b). The average nutritional value of cereals and pulses is about 3000-3500 cal/kg (Westphal, 1974, 1982; Ilaco, 1981). A reasonably well-fed human being needs some 2500 cal/day or 912,500 cal/year. If all his/her energy requirements were to be supplied by the 100,000 kg of cereals and pulses, $3250 \times 100,000 = 325$ million food calories would be available per year. The number of human beings that could live on this amount would be $325,000,000 : 912,500 = 356$ people (about 280 kg of cereals and pulses per person/year).

Assuming a lower consumption of 2000 cal/person/day, which was approximately the average for India in 1958 (Weitz and Rokach, 1968), 445 people could have lived on this amount (225 kg of cereals and pulses for one person per year). These figures of 280 and 225 kg/year per capita are comparable with the figure of 250 kg grain/person/year, taken by Broshi (1980) as an overall minimum average. However, apart from food calories, also the amount of food protein has to be taken into consideration, as well as the need for vitamins and minerals from fruits and vegetables. Van der Woude (1963) studied the consumption of cereals, meat and butter, in relation to calory requirements, in Holland at the end of the 18th century.

The average daily protein requirement for a human being is about 80 g/day or 29.2 kg/year. A rough estimate of the protein content in the mixture of 100,000 kg of cereals and pulses would be about 12 %, which amounts to 12,000 kg protein. This quantity seems sufficient for the yearly requirements of about 411 people, showing that quantitatively enough protein would be present

in the cereals and pulses for about 400 people. However, qualitatively, certain amino acids necessary for the human body are usually lacking in a diet entirely composed of cereals and pulses. With a limited choice of food crops, soya bean was not known in the area in antiquity, some 25 % of the daily protein intake ought, therefore, to be animal protein (Weitz and Rokach, 1968).

Sheep and goats were certainly kept in the area in the past, grazing the stubble of harvested field crops, fallow land, and the surrounding countryside. Animal manure would have been important to keep soil fertility and cereals/pulses production on a level of one ton per hectare. The relation between agriculture and pastoralism during historical times might have varied in between the semi-nomadic pastoralism of the Bedouin, to forms of herdsman husbandry and sedentary animal husbandry, as defined by Khazanov (1985). In order to feed the herds in the difficult months from the second part of the summer until the early winter, in which there is virtually no natural pasture (Hillel, 1982:196), some of the irrigation water is likely to have been used for the growing of forage crops.

A certain amount of vegetables and fruits were probably also grown to enlarge the dietary composition, thereby satisfying taste and nutritional requirements. The food basket was perhaps for 75-90 % composed of cereals and pulses, the remainder made up by animal products, fruits and vegetables. It is, therefore, unlikely that all the available irrigation water, during certain periods in the past, was entirely used for the growing of cereals and pulses. The latter production was, therefore, probably somewhat lower than calculated above. Moreover, a certain percentage of the food grains might necessarily have been given to the flocks as supplementary feed. It thus seems likely that with a more varied dietary composition, population levels would have been somewhat lower, than the number of 400 calculated on the basis of cereals and pulses alone. However, the grazing of herds outside the valley in winter and spring might have compensated somewhat for the loss in cereal production, because part of the naturally produced biomass of an adjacent area is harvested through the animals.

The maximum possible population level fed by the varied produce of irrigation farming in the Kadesh-Barnea valley in antiquity, including the keeping of some flocks, can thus be estimated at less than 400 people. This calculation is based on the ideal situation of two harvests of food crops per year, a yield of one ton/hectare and a fully effective use of all the water produced by the spring, supplying an average amount of 400 mm to each crop.

In modern times, assuming free access to the necessary chemical fertilizers and an ideal fertilizer-water management, yields of 8000 kg/ha may be possible in the region with the same quantity of about 400 mm of water (De Wit, 1958; Van Keulen, 1979, 1980). Thus the "absolute" maximum food producing capacity of the Kadesh-Barnea valley might be sufficient to feed about 3000 people.

Concerning the direct use of water by man, for drinking, washing, and cooking, the amounts required are relatively low for a population of 400 people. Personal water requirements are estimated at 10 liter per capita per day as a minimum (Evenari et al., 1971:148-150). For 400 people this amounts to 1460 cubic m of water/year, which is produced by the spring in 24 hours.

COMPARISON OF ESTIMATED FOOD PRODUCTION AND RELATED POPULATION LEVELS WITH ARCHAEOLOGIC DATA OF LATE BYZANTINE - EARLY ARAB TIMES

It seems highly unlikely that full control of the spring's annual discharge for agricultural food production was actually realised in antiquity. Perhaps a 75 % efficiency might have been attained, which would have reduced the calculated maximum carrying capacity from about 400 to 300 people. In case food crops, like cereals and pulses, were only grown in winter, due to the absence of suitable summer varieties in the region in the past, then the carrying capacity would have been reduced further from about 300 to perhaps 150 people. The former Byzantine village in the valley of Ein el Qudeirat apparently consisted of about 20 houses (Woolley and Lawrence, 1936:80). If each house had 6 inhabitants, the population might have numbered some 120 people, which is not far off the latter estimated figure of 150.

From the remnants of irrigation systems, attributed to the Byzantine period, Woolley and Lawrence (1936:79,80) concluded that most of the valley of Ein el Qudeirat and beyond was cultivated in those times. The Early Arab period ought to be included in this period, as indicated by the carbon-14 dates published in this thesis. The British authors suggested that the local population was in those times probably more numerous than the Bedouins in 1914, who cultivated only part of the valley. Their statement "One can well imagine that in years of drought Ain el Guderat fed all the saints of Central Sinai" might indicate, however, an exaggerated expectation of the food producing potential of the valley and its spring. If the latter estimated figure of 150 is somewhere near the truth, as well as the estimated population for the local village, only 30 people could have been fed in addition to the villa-

gers. Nevertheless, it was certainly the only reliable food producing area in the region during drought years.

In the early part of the 20th century, night storage was not part of the irrigation system anymore, and fruit trees and summer vegetables were absent, apparently because of the malaria hazard, as reported by Woolley and Lawrence (1914/15) and by Jarvis (1938). In such a situation only a quarter of the spring's annual discharge could possibly have been used, being 131,400 cubic meter of water. If 50 % of this water (65,700 cubic meters) was used effectively for winter cereals by the local Bedouin, some 16 hectare could have been cultivated with winter cereals, whereby each plot would receive 400 mm of irrigation water. Assuming a yield of 700 kg/ha, some 11000 kg of winter grains might have been produced. When this amount is reduced with 40 % for next year's seed stock, animal feed and post-harvest losses, approximately 6600 kg would have remained to feed about 33 people, if the grain composed 80 % of their diet.

REMAINS OF RUNOFF FARMING IN THE VICINITY OF KADESH-BARNEA

From the preceding part it is clear that agricultural food production through irrigation farming with the relatively copious spring of Ein el Qudeirat was only sufficient to feed a rather limited number of people: from a few tens to a few hundred people at the most, depending upon the degree of water control and farming efficiency. It is, therefore, not surprising to find other agricultural systems based on runoff farming in the immediate vicinity of the Kadesh-Barnea valley. In certain periods in antiquity, there was apparently both an incentive and the capability to develop the two farming systems side by side in the same region. The present Bedouin population also uses both systems for farming in this part of the desert, albeit in a low key manner.

THE PLATEAU SOUTH OF THE KADESH-BARNEA VALLEY

A number of terraced wadis appear on the undulating plateau to the south-east of the spring of Ein el Qudeirat. From the remains of an apparent four room ancient farm house (coordinates 09695-00675) one overlooks a terraced wadi lying to the south of it. The terraced wadi, a tributary of Wadi Um Hashim, contains about 20 check-dams spaced at regular intervals across its stream bed. Only the two lowermost terraced fields have been ploughed by the Bedouin.

GEBEL EL QUDEIRAT, NORTH OF THE KADESH-BARNEA VALLEY

A small but neatly terraced wadi appears on the middle slopes of Gebel el Qudeirat, above the Jarvis Dam. This runoff farming system consists of 5 check-dams, the latter dam being almost 2 meter high (Photo 44). The check-dams are orderly built of naturally shaped stones of approximate similar size. There is no clear evidence as to the age of the system, which, judged from the amount of silt accumulated behind the terrace dams, must date back to antiquity. The absence of natural vegetation inside the terraces and the appearance of plough-marks, shows that the system is used for food crops by the local Bedouin. The position of this runoff farm on the slopes above the valley of Ein el Qudeirat, so close to the spring and its perennial stream, demonstrates the determination in certain periods of antiquity to develop and use every possible part of the desert for agricultural purposes.



PHOTO 44. An ancient runoff farm on Gebel el Qudeirat, above the Jarvis Dam.

GEBEL EL EIN

Continuing from Gebel el Qudeirat to Gebel el Ein, in the direction of Sheluhat Kadesh-Barnea, a very isolated runoff system appears on the upper south-facing slopes of this mountainous ridge. The system, composed of only four check-dams, is situated in a slightly flat and concave part of the

hillslope. The runoff farming system is not used at present by the Bedouin. The following table shows the measures of dams and fields.

TABLE 26. Runoff farming system on Gebel el Ein near Sheluhat Kadesh-Barnea, having a cultivable area of only 675 square meter.

	LENGTH (m)	WIDTH (m)	HEIGHT (m)	FIELD WIDTH (m)	FIELD AREA (m ²)
DAM 1	30.80	0.60	0.30	6	185
DAM 2	22.00	0.70	0.50	8	210
DAM 3	17.30	0.70	0.30	7	140
DAM 4	16.20	0.90	0.65	8.50	140

WADI EL HALUFI

Quite a large number of runoff farming systems occur between Sheluhat Kadesh-Barnea and Ein el Qudeirat along Wadi el Halufi, a tributary of Nahal Kadesh-Barnea. These systems are partly eroded, because of incision. The Bedouin use some of the remaining fields for wheat or barley cultivation. They generally do not repair the ancient runoff systems, which, as a result receive only direct rainfall, since runoff water cannot reach these fields any more. In this way a barley crop may only be a successful in an occasional very wet year, perhaps once in five years, as noted by Jarvis (1938:245). On the other hand, there are also examples of Bedouins who have repaired or constructed runoff catching dams.

THE WESTERN PART OF GIVAT BARNEA

This area, a plateau some 5 km to the east of Kadesh-Barnea, at an average altitude of about 550 m, is dissected by tributary wadis of Nahal Kadesh-Barnea, many of which were terraced for runoff farming in antiquity. The mountainous ridge of Sheluhat Kadesh-Barnea bounds the area to the north. A very nice terraced wadi, not eroded, is fully used by the local Bedouins, who have ploughed the fields. The author visited the area on February 21, 1982, when the cereal crop sown was just beginning to emerge from the soil. This particular wadi was probably terraced in the Byzantine period. From the remains of a Byzantine farm-house one has a clear view over the terraced fields (Photo 45). Its dams were built with large stones in distinct rows. The first dam in focus is 1.80 high and has a width of 2 m. The average size of its building stones is 40-50 cm, but huge blocks of 1.20 m also occur. This first dam is partly built upon bedrock.

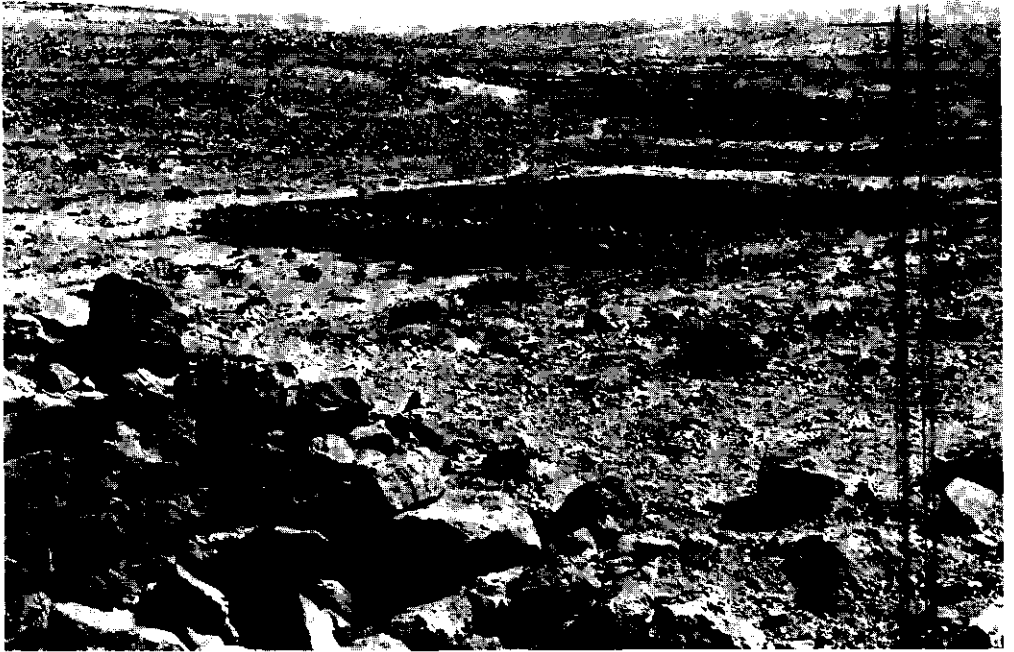


PHOTO 45. A tributary wadi of Nahal Kadesh-Barnea, probably terraced in the Byzantine period, farmed today by local Bedouin for food crops.

A beautiful circular threshing floor (Photo 46) with a diameter of 19.50 m is situated south of the former wadi on a somewhat higher part of the plateau. The threshing floor is used by the Bedouin, as indicated by the adjacent heaps of ensilaged grain stocks, covered with earth and branches (Photo 47). On a nearby fairly level plateau are the remnants of an ancient fortress, another circular threshing floor (19.70 m diameter), and ancient circular silo pits (1.30 m diameter). One of these pits was excavated and appeared to be lined with stones to a depth of 50 cm below the surface. Large upright standing stones at the edge of the circular threshing floors, may have served as a kind of fence in the past.

From the remnants of runoff farming systems, threshing floors and silo pits in the vicinity of Kadesh-Barnea, it seems clear that cereal food crops were grown in the area in the past with runoff rainwater, only a few kilometers to the east of the valley oasis of Ein el Qudeirat with its spring and totally different system of irrigation farming. Both systems of desert farming are also used today by the Bedouin.

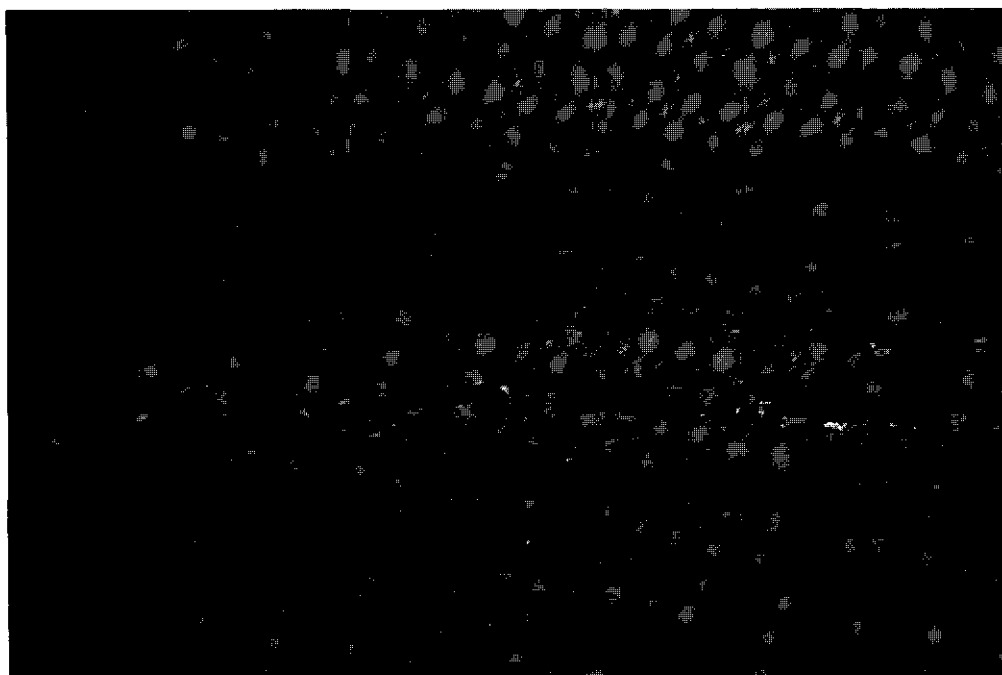


PHOTO 46. Circular threshing floor and ensilaged grain mound at the right-hand side. The mountainous ridge of Shluhat Kadesh-Barnea rises in the background.



PHOTO 47. Ensilaged cereal stocks, produce of local Bedouin runoff farming.

THE POST-EXODUS SOJOURNMENT OF THE ANCIENT ISRAELITES IN THE DESERT

Finally, some remarks about the matter of encampment, water and food supply of the ancient Israelites after the Exodus and their 40 years in the desert. The area of Ein el Qudeirat and Ein Quseima is generally accepted as the most likely region in which Kadesh-Barnea was probably situated.

It seems unlikely, though, that the actual encampment of the Israelites was in the valley plain of Ein el Qudeirat, because of the danger of flooding in the rainy season. The whole valley was swept by a flood in 1911/12, as mentioned by Woolley and Lawrence (1936:78). During the recent excavations of the tell by Rudolph Cohen (1976-1982), runoff water was occasionally flowing through the tents standing on the valley plain near the tell. The excavated fortresses (Cohen, 1981, 1983) were not built on the general level of the valley plain, but on a somewhat elevated natural hillock. The Byzantine village and the Bedouin encampment are also situated on higher grounds, on the footslope of Gebel el Qudeirat.

As already estimated, the valley of Ein el Qudeirat might have produced in antiquity food for about 400 people at the most. If the nearby springs of Quseima and of Ein Qadeis were also fully used for food production, perhaps enough food might have been grown for 700 people. If runoff farming was practised in the surrounding area during the Late Bronze Age, maybe enough food for about 1000 people and their livestock might have been grown in years without drought. This number is, however, very remote from the large number of people mentioned in the Torah (Exodus 12:37; Numbers 11:21).

A food producing economy based on extensive livestock rearing seems out of the question, as these Israelites were, according to the Scriptures, not dispersed throughout the Sinai peninsula, but were living together in the desert in an organized manner. Moreover, the widespread assumption that pastoral nomads can or could survive in a self-sufficient autarkic way is a myth, masterly refuted by Khazanov, who states "pastoral specialization has meant more or less economic one-sidedness and no autarky... nomads could never exist on their own without the outside world and its non-nomadic societies... the important phenomenon of nomadism really consists in its indissoluble and necessary connection with the outside world" (Khazanov, 1985:3).

It seems likewise out of the question that the Israelites, sojourning in the desert, could depend for their food supply on the non-nomadic outside world, on Edom, Moab, or on the Canaanite inhabitants of the promised land, which they intended to conquer. If they had to feed themselves by agricultural

and pastoral food production in the region of Quseima and Ein el Qudeirat, their numbers could not possibly have exceeded a mere 1000 people at the most. However, the surrounding enemy nations would not have feared such a small group of people, advancing toward their borders.

Although the high population numbers mentioned in the Bible are often discounted as mere symbolic or typological expressions (Broshi, 1980), the context in which these numbers are placed cannot easily be dismissed. The Biblical narrative does not portray the ancient Israelites, having come out of Egypt, as a small band of some 1000 Bedouins. The Torah clearly exhibits another picture: "And Moab was sore afraid of the people, because they were many...". Balak, the king of Moab went to Balaam, saying: "Behold, there is a people come out from Egypt: behold, they cover the face of the earth, and they abide over against me... they are too mighty for me" (Numbers 22:3-6).

Apart from food supply, there is the problem of water. If virtually all the waters of the springs in the region were fully used for agricultural production, there would have been no drinking water left for so large a community. In terms of drinking water the area of Ein el Qudeirat and Ein Quseima might have sustained a significant population. However, in terms of food supply, by which it is unlikely that the surrounding enemy nations would have exported food to the advancing Israelites, there seems indeed no alternative but the unique food provision described in the Torah: manna.

The practical problem how so large a community could have been sustained and fed for some 40 years in the desert, or even for one year, cannot be simply removed by scepticism and scorn for the subject as such. The matter touches upon the very existentialism of Israel's history. With regard to the demand for meat alone, the problem is well expressed by Moses himself: "...thou hast said, 'I will give them meat, that they may eat a whole month!' Shall flocks and herds be slaughtered for them, to suffice them? Or shall all the fish of the sea be gathered together for them, to suffice them?" (Numbers 11:21-22).

On the one hand, the region of Kadesh-Barnea and Quseima, possibly the most favourable agricultural area in the entire Sinai-Negev desert, could not have fed more than 1000 people at the most. On the other hand, the historical context clearly requires a large Hebrew population at the dramatic transition from the Canaanite period to the Israelite period. The food provisioning of so large a migrating community in the hyper-arid Sinai desert is far beyond the regional carrying potential. Something very extraordinary must have occurred indeed, about which the Scriptures are very definite and clear.

12 Relationships between the landscape, climatic, and agricultural history of the region

VALLEY CHANGES IN RELATION TO CLIMATE AND AGRICULTURE

INTRODUCTION

In the sphere of historic landscape studies the assessment of possible causal relationships between valley history, climate history and land-use history, should first and foremost be grounded on the absolute basis of stratigraphy: TIME. Only time is the impartial dimension that allows for a juxtaposition of various aspects of the history of earth and man.

If there appears to be a connection between climatic history and landscape history, on the basis of time, it does not necessarily mean that we understand this relationship in terms of climatic and geomorphic processes. The extrapolation of knowledge about present climatic and geomorphic processes may vice versa lead to a mistaken interpretation of certain landscape properties, considered to be in equilibrium with the present, but in fact formed in a different environment of the past, or over a long period of time. The age of the landscape properties under consideration ought to be determined before relations are made with present processes. The dimension of time should never be underestimated and the present does not always hold the proper key to unravel the past.

The influence of man is beyond doubt with regard to the wadis terraced for runoff farming purposes, in whatever historical period. It is clear that man had a decisive influence in this respect on geomorphic wadi processes. By building thousands of check-dams across hundreds of wadis, man did put the breaks on the occasional runoff floodwaters that turn a dry river bed into a

stream in the desert on some rainy days during the year, usually in the winter season. Aggradation took place in the terraced wadi courses as a result, as shown in the examples of Horvat Haluqim and Nahal Mitnan. There is no need here to invoke climatic causes. Man did the job that caused aggradation, although (!) in certain historic periods more sediment may have been supplied from the catchment to the wadis than in other periods, like today.

The possible influence of man is, however, much more difficult to prove, if at all, when a cut-and-fill stratigraphy is found in a valley that lacks a staircase of runoff farming terraces in its stream bed. The investigated Kadesh-Barnea valley is an excellent example in this respect. During the Late Bronze and Iron Age, as well as during the subsequent Persian and Hellenistic periods, no discernible evidence was discovered about sweeping changes in the valley of Kadesh-Barnea and its stream channel. The wadi bed was apparently at about the same level as today or somewhat lower, in a kind of long-term dynamic equilibrium, not much fill and not much cut. The possibility is always there, of course, that significant changes did occur during those periods, but either left no trace for detection today or were overlooked by the author.

THE CLIMATIC RELATIONSHIP

The studied cut-and-fill history of the Kadesh-Barnea valley is in the following section first compared with the climatic history, juxtaposed as good as possible on the basis of time:

ROMAN FILL DEPOSIT. The first detectable aggradational period during the last three millennia predates the Late Byzantine period. Aggradation may have taken place in Roman times, as indicated by a C-14 date (Figure 29, Table 25). The precise beginning of this aggradational phase could not be determined, however. With regard to regional paleo-climatic data, it is noteworthy that a dramatic rise in the level of the Dead Sea occurred during the 1st century B.C., which is understood to reflect an increase in rainfall (Klein, 1982). A time-relationship between this rainy period and pre-Byzantine aggradation in the Kadesh-Barnea valley cannot be substantiated, as the dating of the Roman fill lacks sufficient detail.

INCISION DURING THE EARLY ARAB PERIOD. Downcutting took place after the 7th century A.D. and prior to the next aggradational period, which apparently began around 1200 A.D. With regard to climate, Lamb (1977:428) quotes evidence of widespread drought in the eastern Mediterranean during the 7th and 8th

centuries.

MAIN FILL DEPOSIT (LATE CRUSADER - MAMLUK - EARLY OTTOMAN PERIOD). The most remarkable period of aggradation in the Kadesh-Barnea valley during historical times occurred from about 1200-1700 A.D., when progressive sedimentation caused the level of the wadi bed to rise with some 4 meter.

It is a great advantage that well-dated and detailed proxy-climatic rainfall data of local origin exist over this period of time. These data have been derived from variations in the level of the Dead Sea (Klein, 1981) and the width of tree rings from a *Juniperus Phoenica* tree (Waisel and Liphshitz, 1968). This tree, dating back from 1115-1968, grew just 40 km west of Kadesh-Barnea on Gebel Halal, at a similar altitude of about 400 m as the Kadesh-Barnea valley. The data from the tree rings and Dead Sea level support each other very well indeed (Klein, 1981). From 1170-1700 the climate was generally wetter than usual, especially in the periods from 1170-1320, 1360-1430, and from 1470-1650 (Klein, 1981).

It is noteworthy that many charcoal samples collected for carbon-14 dating, date back to the interventient period between 1320-1470, when the climate was less wet, alternating with drier periods. Perhaps there was a pause in aggradation during this stage. The valley surface near the stream channel may have remained unchanged as a result for some 150 years, enabling relatively more ash or charcoal to develop upon it.

INCISION SINCE THE LATE OTTOMAN PERIOD UNTIL TODAY. Rapid incision lowered the wadi bed again with some 4 meter during the last two or three centuries. From 1700-1880 the climate was very dry, but improved somewhat at the end of the 19th century and during the first decades of the 20th century. Several periods of drought have since occurred in the rather dry present century (Klein, 1961, 1981).

This pattern of aggradation and incision during historical times in the Kadesh-Barnea valley appears to be more complex, as a detailed case study, than the results published by Vita-Finzi (1969) about the widespread occurrence of a historic fill in the Mediterranean valleys in general. The principal difference is that a period of incision during the Early Arab period seems to separate the historic fill into two parts:

- 1) A Roman fill of moderate proportions.
- 2) The main historic fill, deposited from about 1200-1700.

The results from the Kadesh-Barnea valley do, nevertheless, corroborate the basic trend of Vita-Finzi's pioneering research in this field, as far as historical aggradation is concerned. Although various valleys may have their own specific pattern of cut-and-fill processes, the widespread occurrence of stream valley aggradation in the Mediterranean region and the Near East around the time of the Middle Ages seems to suggest a general climatic cause, also favoured by Vita-Finzi (1969:115). The influence of man cannot be ruled out (Davidson et al., 1976; Butzer, 1980; Wagstaff, 1981) and may be the dominant factor in certain cases, e.g. the terraced wadis in the Negev. Each valley should be examined within its own sphere and upon its own merits.

Concerning the valley of Ein el Qudeirat, the conclusion seems justified that the influence of climatic variations appears to be the predominant cause of the cut-and-fill history of this particular valley. Periods of aggradation coincide with a climate that is wetter than usual, whereas periods of incision seem to occur during particularly dry climatic periods. This conclusion verifies the working hypothesis adopted by Goldberg (1984), based upon his studies of the Late Quaternary valley stratigraphy in the Kadesh-Barnea area, in which he concentrated on the Late Pleistocene.

ASSESSMENT OF POSSIBLE ANTHROPOGENIC INFLUENCES ON THE CUT-AND-FILL HISTORY OF THE KADESH-BARNEA VALLEY

Changes in land-use did occur in this remote and very thinly populated desert area, but the juxtaposition of the cut-and-fill evolution of the valley and the history of runoff farming settlement periods in the Negev (Israelite period, Late Nabatean-Roman-Byzantine-Early Arab period) does not seem to make much sense. It seems highly unrealistic to explain the periods of aggradation and incision in the valley of Ein el Qudeirat as the result of man.

On the first face a tentative coincidence might be contemplated between the poorly dated Roman fill and the possible onset of runoff farming in the catchment area of Nahal Kadesh-Barnea in Nabatean-Roman times. However, there is so far no evidence of settlement in the area during Nabatean-Roman times, as most historic archaeological remains in the area belong primarily to the Bronze and Iron age or the Byzantine-Early Arab period (Haiman, 1982, personal communication), which is substantiated by the outcome of the C-14 data published in this thesis.

Moreover, historical documents studied by Mayerson (1963) seem to indicate that there was no runoff farming south-west of Shivta in the late 4th century A.D. The settled area or oecumene had its boundary in those days near Shivta,

whilst the inner desert began south-west of Shivta, according to the narrations of Nilus the Ascetic. By the Late Byzantine period the limit of the inhabited part of the central Negev desert had extended itself west and south for a considerable distance, as indicated by the itinerarium (ca. A.D. 570) of Antoninus of Placentia and the Nizzana papyri (Mayerson, 1963). The carbon-14 results of the described aqueduct remains in the Kadesh-Barnea valley, dating to the Bronze age and 7th century A.D., give additional support to the view that post-Iron age settlement and agricultural land-use of this area south-west of Shivta mainly began in the Late Byzantine period.

Most authorities agree that the sedentary runoff farming civilization in the central Negev and north-eastern Sinai ceased to exist during the Early Arab period, when towns and farms were abandoned because of political, economic and religious changes. How should this have led to incision in the valley of Ein el Qudeirat? A possible deterioration of runoff farming terraces in the various tributaries of Nahal Kadesh-Barnea upstream from the Valley of Ein el Qudeirat, might have supplied more sediment, perhaps causing aggradation downstream rather than incision?

Let us continue, for the sake of argument, to consider possible human causes for aggradation or incision in later periods as well. What could man have done in the catchment of Nahal Kadesh-Barnea during the Late Crusader period, to cause the onset of the most remarkable period of aggradation in historical times and to maintain it for many centuries? Was there any dramatic change in land-use during those days in the above catchment? There is no indication in that direction. In which way did man behave differently in the catchment of Nahal Kadesh-Barnea during the later part of the Ottoman (Turkish) period, that might explain the termination of this extraordinary aggradational period and the start of rapid incision?

Moreover, it seems worth noting, that the significant changes that followed the First World War (the British Mandatory period and the establishment of the State of Israel) did not cause any notable alteration in the current phase of incision and erosion, notwithstanding the building of the Jarvis dam in the Kadesh-Barnea valley and its functioning from 1926-1969.

REFLECTIONS ABOUT THE RELATION BETWEEN CLIMATE AND VALLEY HISTORY

How then should a relatively wet climatic period lead to aggradation? Although the time-stratigraphic relation seems irrefutable, it appears rather difficult to explain this relation in terms of landscape processes. More rainfall may lead to a differential increase in vegetation: a slight increase

on the hillside catchment and a much more dramatic increase in the stream channels, due to the different soil depths and moisture storage capabilities on the hill-slopes and valleys, respectively. Such a development might help to slow down silt laden runoff streams in the wadis, thereby perhaps inducing aggradation.

This is, however, but one possible aspect of the complex and intricate reaction of the landscape to more rainfall. Another important question is to what extent the rainfall regime varied in wet and dry periods, with regard to rainfall intensity and duration? A certain amount of rain may come down in many light showers or in a few heavy downpours, which has a rather different effect in terms of infiltration, runoff, erosion, and length of stream flow in the drainage system. Did the aggradational sediments only originate from soil stripping of the hill-slopes in the catchment, or was there a more intensive dust input from outside the region as well? During the wet climatic periods of the Late Pleistocene large amounts of loess were deposited in the Central and Northern Negev (Yaalon and Dan, 1974; Bruins, 1976; Bruins and Yaalon, 1979, 1980; Issar and Bruins, 1983).

Is there any similarity in climatic and landscape processes between the wet climatic periods in Historical and Late Pleistocene times? As climatic processes ought to be studied in a wider geographical context, the possible relation between Southern Levantine conditions during the last Ice Age in the Late Pleistocene and during the so-called Little Ice Age in historical times deserves more attention. There occurred a general turn towards colder climates in Europe, according to Lamb (1977:449; 1984), from A.D. 1200-1400 onwards until the 18-19th century. This was accompanied by shifts of the zones of most cyclonic activity, as the polar cap and the circumpolar vortex expanded.

It seems clear that during a period of aggradation more sediment is supplied to the landscape drainage system than it can handle. The sediment thus accumulates in the wadis, whereas during a period of incision sediment is eroded from the stream channels and subsequently removed. The possibility that incision and erosion in the upper part of the drainage system may cause contemporaneous aggradation in the lower part of the drainage system, is a further complicating factor that requires attention, not just in terms of single events but also in stratigraphic terms over long periods of time. More research is needed to unravel the intricate processes that cause aggradation and incision in relation to wet and dry periods, respectively.

CLIMATIC VARIATIONS AND THE VIABILITY OF RUNOFF FARMING

PALEO-CLIMATE IN THE REGION DURING HISTORICAL TIMES

Climate expresses the integrated atmospheric state of our planet in time and space. The study of changes in climate and its possible impact on human society, by which the relation of climate to food production is probably most important, is necessarily tied to time and a certain geographic locality. As instrumental records of climate are limited to the last centuries only, paleo-climatic data can only be obtained indirectly from proxy-climatic indicators, like historical documents, changes in lake levels, and the width of tree rings dated by dendrochronology.

Information deduced from the Bible about climatic conditions in the Land of Israel and its surroundings does not suggest sweeping long-term changes since the time of Abraham until the 1st century A.D. The general fabric of climate has apparently remained rather similar during this period of time. From the perception of human experience, however, drastic short-term climatic variations seem to have occurred within Biblical times, like the famine during the Middle Bronze age in the days of Jacob and Joseph for example. It is a matter of semantics and time-scale whether to call these climatic events changes, variations, or fluctuations. The ice ages are also mere fluctuations of the climate of the earth within geological or astronomical times.

Proxy-climatic data from tree rings prior to 1115 A.D (Waisel and Liphshitz, 1968) are apparently not available yet. Relatively high levels of the Dead Sea, implying a wetter than average climate, appear to have occurred in historical times during part of the Bronze Age, although reliable dating seems to be a problem (Neev and Emery, 1967; Neev and Hall, 1977). Subsequent medium to long-term periods with a wetter than average climate in historical times occurred in the 1st century B.C., as indicated by a sharp rise and fall of the Dead Sea level (Klein, 1982), and particularly during the rather unique climatic period from about 1170-1700 A.D. (Waisel and Liphshitz, 1968; Klein, 1981).

RELATIONS BETWEEN CLIMATE AND RUNOFF FARMING

Considering the possible relations between these wetter than average climatic conditions and the history of runoff farming, there is a bit of irony in the fact that this unique form of arid zone agriculture was not practised

in the Negev by a sedentary population when the climatic environment seemed to have been most ideal, i.e. during the 1st century B.C. and from A.D. 1200-1700. In other words, there is no apparent relationship between long-term climatic trends and runoff farming settlement patterns in the central Negev desert during the last three millennia.

The viability of runoff farming does not only relate to long-term climatic trends, but is also very much dependent upon annual rainfall variability and the frequency of drought years. Runoff farming enables agricultural production in certain arid regions based upon local rainfall. Yet, runoff farmers have to cope with drought years, as arid regions are characterized by large yearly fluctuations in the amount of runoff producing precipitation. How did the ancient farmers and the sedentary population in the central Negev in general cope with annual rainfall variations and droughts?

In the present state of knowledge we can only guess about annual data on rainfall variability and droughts during the two distinct historic phases of sedentary runoff farming in the central Negev, i.e. the Iron Age and the composite Late Nabatean-Roman-Byzantine-Late Arab period (Mayerson, 1955; Evenari et al., 1958; Aharoni et al., 1960; Cohen, 1976; Negev, 1982a, 1982b; Haiman, 1982).

The data acquired since 1960 at the three experimental runoff farms of Avdat, Shivta, and Wadi Mashash, established by Evenari, Shanan and Tadmor (Evenari et al., 1971, 1982) give valuable information about annual rainfall and runoff variations in present times. On the basis of these available data a rough estimation was made about the frequency of drought years, in which food production would probably have been a failure (Table 27, Bruins et al., 1986a,b). More or less similar frequencies of drought years probably formed a part of normal climatic patterns in the past during similar dry-to-average climatic phases, as in the period from 1960-1984.

The pioneering research about runoff farming by Evenari and his colleagues was not designed to investigate long-term viability with respect to food crops in a self-sufficient food economy. Their data can, therefore, only serve as a basis for additional and different investigations, specifically designed to study the yields of food crops in relation to rainfall, runoff, soil fertility and various cropping patterns on a continuous long-term basis. Such research can give more detailed and firm answers about the viability of food production through runoff farming in a dry arid climate on the border of the hyper-arid zone.

With regard to the rainfall and runoff data from the farms mentioned above,

it is easy to distinguish between a very rainy year and a bad drought year. It is difficult, however, to draw the dividing line between a moderately good year, in which agricultural production is perhaps just above the limit of economic or nutritional survival and a moderately bad year, just below that red line. Another aspect of viability, that cannot be grasped in terms of overall annual rainfall and runoff data, is the distribution of the incoming runoff water over the farm fields. At the Avdat farm, for example, largely based on the conduit system, a choice can be made out of several options as to how many fields should receive the incoming runoff water.

In very rainy years all the fields can be saturated with runoff water. But in moderate to bad years some fields have to be closed off for the incoming runoff waters to ensure that at least part of the cultivable area is saturated with moisture, if at all. An even water spreading over all the fields, in such a situation, could result in a total crop failure. The terraced wadi system, as found at Horvat Haluqim for example, seems to be less flexible in this respect. The hydrological and agricultural functioning of this latter system has not been investigated so far and different catchment properties preclude simple and possibly misleading comparisons to be made on the sole basis of runoff water management flexibility.

The timing and frequency of runoff floods during the growing season is another significant climatic factor of direct importance in viability studies. The season 1964-65 was a very rainy year at Avdat (144.2 mm). Since the first flood came late, however, it was decided by Evenari and his colleagues (1968) not to sow wheat, but other field crops and vegetables, like chick pea, carrots, asparagus and artichokes. There are no data how the ancient runoff farmers selected their field crops with regard to the timing of the first flood. Neither do we have such detailed paleo-climatic data about rainfall and runoff distribution in the central Negev in antiquity.

THE FREQUENCY OF DROUGHT YEARS

The modern rainfall and runoff data of the three experimental runoff farms enable an assessment of the frequency of runoff drought years at present. A runoff drought year usually coincides with a rainfall drought year, though not necessarily. More runoff is sometimes produced in years with less rainfall than in wetter years, because of annual differences in rainfall intensity and duration. Detailed runoff data for the Avdat and Shivta farms are only available from 1960-61 until 1966-67. Although the runoff data from the Mashash farm are less precise, as they were measured in a simple way,

TABLE 27. Runoff drought years at the Avdat, Shivta, and Wadi Mashash experimental runoff farms, based upon available rainfall and runoff data (after Bruins et al., 1986a,b).

RAINY SEASON	AVDAT RUNOFF FARM hillside conduit system			SHIVTA RUNOFF FARM hillside conduit system			MASHASH RUNOFF FARM liman system		
	Rain (mm)	Runoff (m ³)	Drought year	Rain (mm)	Runoff (m ³)	Drought year	Rain (mm)	Runoff (m ³ /ha)	Drought year
1960-61	70.0	1932		102.5	594				
1961-62	64.7	4471		50.6	280	*			
1962-63	29.5	792	*	24.8	44	*			
1963-64	183.3	51875		145.3	6293				
1964-65	144.2	6115		160.8	9444				
1965-66	91.5	6905		67.1	1297				
1966-67	80.7	1827		94.4	2285				
1967-68	86.9			75.4					
1968-69	70.3			73.2					
1969-70	58.4		*	43.6		*			
1970-71	82.0			115.2			142.0	7000	
1971-72	162.6			172.4			207.0	10000	
1972-73	53.5		*	41.0		*	55.0	0	*
1973-74	132.6			105.8			180.5	4000	
1974-75	84.9			77.7			93.0	3000	
1975-76	77.1			62.6		*	79.5	0	*
1976-77	64.1		*				101.0	2000	
1977-78	68.0						75.0	1500	
1978-79	56.0		*				90.7	5000	
1979-80	100.6						166.0	16500	
1980-81	100.8						120.7	10000	
1981-82	68.8		*				75.5	0	*
1982-83	124.2						170.0	3500	
1983-84	29.3		*				84.5	0	*
Average	86.8	10560		88.3	2891		117.2	4464	
Drought year frequency (once every ... years)			3.4			3.2			3.5

their consistent yearly determination is of great value to assess long-term viability.

Data from the Avdat runoff farm suggest that approximately 7 out of 24 years can be classified as drought years. Thus the average frequency of runoff droughts at the Avdat farm is once in 3.4 years. The Shivta runoff farm, another example of a conduit system with possibilities to manipulate the

incoming runoff waters, experienced about 5 drought years during 16 years of measurements, an average drought frequency of once in 3.2 years. At the Wadi Mashash runoff farm, largely based on the liman system fed by larger catchments which show clear zero runoff yields in drought years (Table 27), 4 out of 14 years were absolute runoff drought years, an average of once in 3.5 years.

As there appears a remarkable similarity between the resulting figures from the three runoff farms, the preliminary conclusion seems justified that in the 80-120 mm winter rainfall zone of the central Negev, shortage of runoff water seems a severe limiting factor in agricultural production once every 3 to 4 years in the present rainfall regime. From a farm management point of view, it is obviously a must to overcome these runoff drought years if runoff farms are to be viable. The question immediately arises how individual farmers and society as a whole managed to cope with runoff drought years in antiquity.

DROUGHTS AND THE VIABILITY OF RUNOFF FARMING

It should first of all be realized that, apart from zero yields, it is difficult to define a drought in absolute terms. A drought in agricultural production is associated with a certain economic and socio-technical framework within a certain society. Apart from natural environmental factors, the fabric of that society and the amount of people that depend upon a certain area of agricultural land for their provisioning, determines when a drought threshold is crossed, so that the system can no longer function in the usual way for a certain time.

When thrown out of equilibrium because of drought, the system tends to draw on internal reserves of energy, and/or resorts to external energy that actually forms the reserve of a socio-economic or political framework wider than the system initially described. The restored balances and their thresholds of tolerance are not necessarily the same as the initial balances or thresholds of tolerance (Spitz, 1980).

The forming of internal reserves was probably a significant strategy of the sedentary population that engaged in runoff farming to overcome drought years during the Israelite period, as well as during the composite Late Nabatean-Roman-Byzantine-Early Arab period. Reserves could have been accumulated in three principal commodities: water, food, or money (Bruins et al, 1986b). It seems unlikely that any significant quantities of water might have been stored in wet years for irrigation in dry years. The capacity of the available cisterns seems to have been sufficient only for direct water requirements of

man and his animals, not for agriculture, with possible exceptions like one of the cisterns at Horvat Haluqim. Even in the latter case, water was probably not stored for agricultural use in drought years, but for supplementary irrigation of a few fields in the same year only. During drought years, all water reserves were probably necessary to sustain man and his animals.

It remains a matter of uncertainty whether these stockpiles of food or money could have been acquired through runoff agriculture in the central Negev desert during the good years as a reserve for the drought years, thereby maintaining a self-sufficient equilibrium. There are several archaeological (Cohen, 1976, 1980) and historic indications (Gihon, 1967) that a central government outside the Negev, to which the latter region belonged, had an interest in establishing and maintaining a sedentary population in the central Negev desert for defensive purposes, both during the Israelite and Roman-Byzantine period.

In that perspective it seems likely that the central government and its economic power constituted the principal buffer on which the sedentary population of the central Negev could rely for its provisioning in times of drought. The imperial government, of which the central Negev was a part during Roman and Byzantine times, apparently had a clear interest in the activity of runoff farming in the area and probably gave guarantees for food supplies and/or financial compensation in years of drought when crops failed.

Runoff farming was practised for many centuries during the composite Late Nabatean-Roman-Byzantine-Early Arab period, and the system obviously functioned despite the inevitable occurrence of droughts. The integration of the region in a larger political and economic order must have been the key to overcome the drought years. An assured supply of food (and water if necessary) must have been guaranteed to some extent as an incentive to settle the region.

Such a background does not rule out, however, the development of complex economic relations within the runoff farming district itself. The basic principle of economic integration in a larger political setting during Roman-Byzantine times as the key of viability seems indisputable, because in no way could the runoff farming district have produced enough food to sustain its population, as indicated in the following and final part of this dissertation.

However, in transitional periods and other special cases, when the wider political and economic integration collapsed, individual farmers might have been able to operate in a self-provisioning way. This important matter of self-sufficient runoff farming viability in such a dry area as the central Negev desert requires further investigation.

FOOD PRODUCTION AND POPULATION IN THE RUNOFF FARMING DISTRICT

In historical times the Negev was settled by a sedentary population that engaged in runoff farming during the Israelite period and during the composite Late Nabatean-Roman-Byzantine-Early Arab period (Mayerson, 1955; Evenari et al., 1958; Aharoni et al., 1960; Cohen, 1976; Negev, 1982a, 1982b; Haiman, 1982). The possible existence of runoff farming communities during the Bronze Age cannot be ruled out, but the picture is far from clear (Cohen and Dever, 1980). The survey carried out by Kedar (1967) determined the extent of the runoff farming district in the central Negev (about 2000 square km), as well as the total area of terraced fields (about 4000 hectare). It is not known, however, how much wadi land was actually cultivated within each historical period.

There seems to be a general consensus amongst scholars that the sedentary population of the central Negev, as well as the extent of runoff farming, reached its peak during the Byzantine period. The population level in this period was estimated by Avi-Yonah (1964; cf. Broshi, 1980) to have ranged between 52,000-71,000 people. Broshi (1980) arrived at a more conservative figure. In his opinion the population of the central Negev did not exceed 30,000 people during Roman-Byzantine times.

The question arises to what degree the sedentary population of the central Negev desert could have been self-sufficient in terms of food production. In order to approach this matter in a quantitative manner, it is first necessary to make a number of suppositions that are not entirely realistic but, nevertheless, required as a basis for calculations:

- 1) All the 4000 ha of terraced wadi fields were used for runoff farming during Byzantine times.
- 2) All farming land was used for wheat production.
- 3) The average yield of wheat amounted to some 600 kg/hectare, as extensively discussed in chapter 7.
- 4) The average annual bulk food requirement per capita is equal to about 250 kg of wheat (Broshi, 1980), discussed in chapter 11.

Based on these suppositions, it can be calculated that annual wheat production in the runoff farming district was probably not higher than about 2,400,000 kg. Such an amount of wheat would have been sufficient to feed some 9600 people. If someone would consider an average annual yield of 600 kg/ha

too low, let's be optimistic and base our calculation on a runoff-farming bumper harvest, for those days, of 1000 kg/ha. The resulting 4,000,000 kg of wheat could have fed some 16,000 people, which is still only half the conservative population estimate made by Broshi (1980). Moreover, this latter wheat-yield figure seems highly unrealistic as an annual average, because the drought years must also be taken into account.

Even the lower figure of 2,400,000 kg wheat has to be reduced by the quantity of seed needed for next year (about 400,000 kg) and some 10 % (Hall, 1970) of post-harvest losses (about 240,000 kg), which leaves some 1,760,000 kg for human consumption. This quantity would be sufficient to feed about 7000 people. The inclusion of the Kadesh-Barnea valley and the runoff-farming areas in north-eastern Sinai, which belonged to the district in Byzantine times, might have added food for another 1000 people (Chapter 11). As it is unlikely that all available farm land could have possibly been devoted to wheat farming each year, it can safely be assumed that less than 8000 people could have been fed in the runoff farming district in a self-sufficient food economy.

This means that less than a quarter of the conservative population estimate of 30,000, made by Broshi (1980), could have been fed by locally produced food in the runoff farming district. The conclusion seems therefore justified, that runoff farming during the Byzantine period could not have matched the direct food requirements of the sedentary population in the central Negev. An assured food supply to this population from outside the region must have been an integral part of political and economic realities in Byzantine times. Local runoff farming seemed to have played a supplementary function in this respect.

However, during changing, transitional phases of sedentary agriculture in the runoff farming district, e.g. in Early Arab times, it is nevertheless possible that the remaining farmers, struggling to cope with the new political and economic situation, were able to subsist on their own produce. Also in other periods with low population levels, a kind of self-sufficiency might have been attained. This latter aspect requires further research.

APPENDIX 1

ARCHAEOLOGICAL AND HISTORICAL PERIODS IN ISRAEL, WITH EMPHASIS ON THE NEGEV

Period	Approximate date B.C. or A.D.
NEOLITHICUM	7500 - 4000 B.C.
CHALCOLITHICUM	4000 - 3200 B.C.
CANAANITE or BRONZE AGE	Early Bronze Age 3200 - 2200 B.C. Middle Bronze Age 2200 - 1550 B.C. Late Bronze Age 1550 - 1200 B.C.
ISRAELITE or IRON AGE	Early Iron Age 1200 - 1020 B.C. Middle Iron Age 1020 - 842 B.C. Late Iron Age 842 - 587 B.C.
BABYLONIAN AND PERSIAN PERIODS	587 - 332 B.C.
HELLENISTIC PERIOD	332 - 37 B.C.
In the Negev:	
NABATEAN PERIOD *	Early Nabatean Period 300 - 100 B.C. Middle Nabatean Period 25 BC- 50 A.D. Late Nabatean Period 70 - 106+ A.D.
Annexation of the Nabatean kingdom to the Roman empire 106 A.D.	
ROMAN PERIOD	37 BC-324 A.D.
BYZANTINE PERIOD	324 - 634 ,,
ARAB PERIOD	634 - 1099
CRUSADER PERIOD	1099 - 1291
MAMLUK PERIOD	1291 - 1516
OTTOMAN PERIOD	1517 - 1917
BRITISH MANDATORY PERIOD	1917 - 1948
STATE OF ISRAEL	1948 -

* Based on Negev (1982a).

A P P E N D I X 2

LABORATORY METHODS OF SEDIMENT AND SOIL ANALYSIS

Particle size analysis of the sediment and soil samples was carried out at the Stichting Technisch Centrum voor de Keramische Industrie in Arnhem. The samples were treated with HCl, so that the carbonate components were removed prior to the grain size determinations. Some large carbonate grains may not have been dissolved entirely.

All other chemical analyses were carried out by Mr. F.J. Lettink at the Chemical Laboratory of the Department of Soil Science and Geology (Agricultural University of Wageningen), headed by Mr. L. Th. Begheijn. The methods for the quantitative determination of organic carbon, nitrogen, carbonate, soluble salts, electrical conductivity and pH are described in *Methods of Chemical Analyses for Soils and Waters* (Begheijn, 1980). The method used to determine the total phosphate content is described by Begheijn and Schuylenborgh (1971:136).

The pH, soluble salts and electrical conductivity were measured in the liquid extract of a 1:1 soil/water solution. All analyses were carried out on the natural soil or sediment fraction < 2 mm. In case gravel (> 2 mm) was found to be present, the weight percentage of the gravel fraction was determined, which includes the carbonate grains as well.

Large size thin sections for the microscopic investigation of soil, sediment and ancient aqueduct-mortar samples were made at the Micromorphological Laboratory of the Department of Soil Science and Geology (Agricultural University of Wageningen), headed by Ir. R. Miedema. The thin sections were prepared by Mr. O.D. Jeronimus, according to the method described by Jongerius and Heintzberger (1963).

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S A M E N V A T T I N G

WOESTIJN MILIEU EN LANDBOUW IN DE CENTRALE NEGEV EN KADESH-BARNEA GEDURENDE DE HISTORIE

Ongeveer een derde deel van het oppervlak der aarde bestaat uit droge gebieden, die meestal worden onderverdeeld in hyper-aride, aride en semi-aride streken. Er bestaat een groot verschil in potentieel land-gebruik tussen deze drie droge zones, uitgaande van het gebruik van locale regenval. In Israel ligt de semi-aride zone, waar landbouw m.b.v. directe regenval in de meeste jaren mogelijk is, net ten noorden van de Negev woestijn. De grens tussen de semi-aride en aride zone valt hier samen met de 300 mm regenval isohyët. De noordelijke Negev en het tamelijk hoog gelegen centrale deel van de Negev liggen grotendeels in de aride zone. De hyper-aride zuidelijke en oostelijke Negev hebben een gemiddelde jaarlijkse regenval van minder dan 60 mm. Landbouw en veeteelt gebaseerd op locale regenval is in de hyper-aride zone niet mogelijk, behalve in oases.

De aride zone is meestal geschikt voor extensieve veehouderij, maar is te droog voor normale regenafhankelijke landbouw. Runoff landbouw, eveneens gebaseerd op locale regenval, is echter wel mogelijk in de aride zone, indien het milieu zich hiervoor leent: De geomorfologische, lithologische en bodemkundige eigenschappen van het landschap, alsmede het regenval regime, moeten zodanig zijn dat regenwater relatief snel gaat afstromen en vervolgens kan worden opgeslagen in het bodemprofiel van de lagere delen van het landschap. Een dergelijk milieu is aanwezig in het "Runoff Landbouw District" van de centrale Negev, waar zich zeer veel cultuur-technische restanten van runoff landbouw bevinden, daterend uit het verleden.

Runoff landbouw is hierbij gedefinieerd als landbouw in droge gebieden met behulp van afstromend regenwater (runoff) in een natuurlijk of geprepareerd drainage gebied, of vanuit een wadi.

Op hydro-geomorfologische gronden worden vijf vormen van runoff landbouw onderscheiden:

- 1) Micro-vanggebied systemen
- 2) Geterrasseerde wadi systemen
- 3) Helling-aquaduct systemen
- 4) Liman systemen
- 5) Wadi-aftakkingskanaal systemen

Het gebruik van runoff landbouw in het aride deel van de Negev woestijn gaat mogelijk terug naar het Chalcolithicum, zo'n 5500 jaar geleden. In de Israelitische periode of IJzer tijd (circa 1000 voor Christus) werden een aantal runoff landbouw nederzettingen gevestigd in de centrale Negev. De archeologische datering van de vele cultuur-technische overblijfselen van runoff landbouw die in de Negev worden gevonden is echter een moeilijke en complexe zaak, waar nog niet zo veel systematisch onderzoek aan is verricht. Een duidelijke chrono-stratigrafie ontbreekt in de meeste gevallen.

In een wadi-terras te Horvat Haluqim, aangelegd voor runoff landbouw in de Israelitische periode of nog daarvoor, werd microscopisch de aanwezigheid vastgesteld van ijzer-oxide concentraties in een ongeveer 3000 jaar oude bodem-horizont. Dit is een duidelijk bewijs van een periodiek nat en gereduceerd bodem milieu in het verleden. Het practiseren van runoff landbouw in de oudheid, waarbij het afstromend regenwater in de betreffende wadi werd vastgehouden door een reeks van lage keer-dammen en aldus in het bodemprofiel werd opgeslagen, moet hiervoor verantwoordelijk zijn geweest. Dergelijke bodemvorming in dit droge aride gebied is normaal niet mogelijk.

Gedurende de historie zijn in het heuvelland van de centrale Negev, in een gebied van ongeveer 200.000 hectare, zo'n 4000 hectare cultiveerbare grond in de wadis en valleien geschikt gemaakt voor runoff landbouw. Hiertoe werden duizenden dammen gebouwd in de wadis. Bovendien werden op vele hellingen eenvoudige doch functionele aquaducten aangelegd om meer afstromend regenwater te kunnen verzamelen, hetgeen blijk geeft van een zeer goed ontwikkeld geomorfologisch-hydrologisch begrip van het landschap in de oudheid. Ook werden kanalen gegraven die de runoff waterstromen in de wadis ten dele konden aftakken en geleiden naar cultiveerbare velden.

Tijdens de Byzantijnse periode, van de 5e-7e eeuw na Christus, bereikte de runoff landbouw in de centrale Negev woestijn zijn hoogtepunt. De gemiddelde tarwe en gerst oogsten zullen waarschijnlijk niet hoger zijn geweest dan circa 600 kg/hectare. Op grond van schattingen en berekeningen lijkt het erop dat minder dan een vierde deel der bevolking in de Byzantijnse tijd kon worden gevoed met lokaal verbouwde granen en peulvruchten. Dit bevestigt de indruk dat het verder in cultuur brengen van de aride centrale Negev (grenzend aan de hyper-aride zone) d.m.v. runoff landbouw werd gestimuleerd en mogelijk gemaakt door de Byzantijnse autoriteiten. In dit verband moet worden gedacht aan het strategische voordeel van een sedentaire bevolking in dit zeer droge gebied ter verdediging van de zuid-oost grens van het Byzantijnse rijk.

Agrarische zelfvoorziening gebaseerd op runoff landbouw is misschien wel

mogelijk geweest met veel lagere bevolkingsaantallen in voorgaande en latere perioden. Dit aspect vereist echter meer onderzoek. Interne voedsel reserves moeten een integraal onderdeel hebben gevormd van runoff landbouw systemen ter overbrugging van de onvermijdelijke jaren van extreme droogte en misoogsten.

Er lijkt geen relatie te bestaan tussen variaties van het klimaat in het verleden en de geschiedenis van sedentaire runoff landbouw in de centrale Negev. In een deel van de eerste eeuw voor Christus en in de periode van circa 1200-1700 A.D. was de gemiddelde regenval relatief hoger in dit gebied, en het milieu derhalve beter geschikt voor runoff landbouw, dat echter in die eeuwen niet werd bedreven door een sedentaire bevolking. De mogelijke activiteiten van semi-nomadische Bedoeïnen op het gebied van runoff landbouw is historisch gezien niet te achterhalen voor de genoemde tijdvakken.

Opmerkelijke geomorfologisch-geologische veranderingen hebben zich in de laatste twee millennia voorgedaan in de vallei-oase van Kadesh-Barnea, gelegen in de noord-oostelijke Sinai. Sedimentaire ophoging (aggradatie) in de Kadesh-Barnea vallei vond plaats in de Romeinse tijd, en vooral in de periode van 1200-1700 A.D. Tijdens de aggradatie in dit laatste tijdvak werd het wadi-bed met circa 4 meter opgehoogd. Het permanente beekje in een deel van de wadi, gevoed door een van de grootste bronnen van de Negev-Sinai woestijn, stroomde hierdoor ook op een hoger niveau. Deze landschappelijke interpretatie werd overtuigend gestaafd door de microscopische ontdekking van authigene pyriet in het bovenste deel van de aggradatie sedimenten. Na 1700 heeft de wadi zich opnieuw in zijn eigen afzettingen ingesneden en is het niveau van het wadi bed in korte tijd met zo'n 4 meter verlaagd.

Deze dramatische veranderingen in de vallei van Ein el Qudeirat (Kadesh-Barnea) vallen chronologisch samen met bepaalde paleo-klimatologische perioden: (a) sedimentaire ophoging in de vallei vond plaats tijdens een relatief nat klimaat; (b) insnijding en erosie viel samen met een relatief droog klimaat. De geomorfologisch-geologische evolutie van de Kadesh-Barnea vallei in het Laat-Holoceen kan ongeveer als volgt worden samengevat:

1500 - 100 B.C.	Dynamisch evenwicht
100 B.C.- 400 A.D.	Enige aggradatie en dynamisch evenwicht
400 - 700 A.D.	Dynamisch evenwicht
700 -1200 A.D.	Insnijding en dynamisch evenwicht
1200 -1700 A.D.	Omvangrijke aggradatie
1700 -1986 A.D.	Snelle insnijding en erosie

Irrigatie landbouw in de vallei-oase van Kadesh-Barnea of Ein el Qudeirat werd kennelijk reeds bedreven in de Bronstijd omstreeks 1600 voor Christus. Deze conclusie is gebaseerd op grond van de C-14 datering van een aquaduct restant. De overblijfselen van een dam met aquaduct aan het begin van de vallei-oase dateren volgens de C-14 methode uit de 7e eeuw A.D. De aanwezigheid van authigene pyriet in de mortel van dit aquaduct, dat zich bovenop de dam bevindt, is overtuigend bewijs van natte gereduceerde omstandigheden in het verleden tijdens het functioneren van dit Laat-Byzantijns - Vroeg-Arabisch irrigatie systeem.

Het maximale aantal mensen dat in vroegere tijden kon worden gevoed in de vallei-oase van Kadesh-Barnea, d.m.v. irrigatie landbouw met water van de bron, bedroeg hooguit 300-400 personen. In het hele gebied van Quseima en Ein el Qudeirat, door velen beschouwd als de meest waarschijnlijke streek van het Bijbelse Kadesh-Barnea, kunnen in de oudheid niet meer dan zo'n 1000 mensen geleefd hebben in systemen van agrarische zelfvoorziening.

Aangezien de menigte der Israelieten, onder aanvoering van Mozes, zeer zeker uit een veel grotere bevolking bestond tijdens het verblijf in de grotendeels hyper-aride Sinai woestijn, na de Exodus uit Egypte, zou het volk zonder de unieke voedsel-voorziening van manna zeker zijn omgekomen. Noch locale landbouwkundige productie, noch extensieve veehouderij, noch voedselimporten van de vijandige volken in de omgeving bieden enig wetenschappelijk alternatief in dit opzicht. Deze kwestie raakt de existentiële kern van de geschiedenis van het volk Israel in die kritieke periode van haar bestaan.

Nomadisch pastoralisme is een gespecialiseerde vorm van een voedsel producerende economie, die door z'n eenzijdigheid bijna niet tot autarkie kan leiden en in sterke mate afhankelijk is van de niet-nomadische sedentaire buitenwereld. Nomadisch pastoralisme leidt bij een gelijkblijvend territorium tot stagnatie, omdat een wezenlijke toename van de productie in een puur nomadische maatschappij vrijwel onmogelijk is. Er zijn archeologische aanwijzingen dat runoff landbouw systemen in de aride Negev werden gecombineerd met veehouderij. Met betrekking tot zelfvoorzienende voedsel productie gebaseerd op locale regenval in aride streken verdient het aanbeveling de levensvatbaarheid te onderzoeken van mogelijke combinaties van veehouderij met de enige vorm van regenafhankelijke landbouw geschikt voor de aride zone *sensu stricto*: runoff landbouw. Voedselreserves voor jaren van extreme droogte zijn echter onmisbaar in dergelijke systemen.

CURRICULUM VITAE

The author was born in 1948 in Zeist, The Netherlands. In 1966 he completed secondary school (HBS-b) at the Openbaar Lyceum "Schoonoord" in Zeist and began his studies at the Agricultural University of Wageningen. The author first studied landscape architecture, and later switched to soil science and geology, in which field he continued at The Hebrew University of Jerusalem. In 1975 he received the Dicker-Shraga Award from the Geological Society of Israel and the Department of Geology of The Hebrew University for his studies on the desert loess of the Negev. He graduated cum laude in 1978.

Since 1976 he has been teaching soil science at the Ben-Gurion University of the Negev, and also worked for brief periods at The Hebrew University of Jerusalem and at Haifa University. In 1979-1980 he was a research fellow at the Department of Soil Science and Geology at the Agricultural University of Wageningen, and investigated the paleomagnetic stratigraphy of the Maas terraces. From 1981-1984 he worked for the Archaeological Survey of Israel to study ancient man-land relationships in the Negev desert and at Kadesh-Barnea. Since 1982 he has been connected with the Jacob Blaustein Institute for Desert Research of the Ben-Gurion University of the Negev. In 1984 he was co-organizer of the Third International Course on Runoff Farming in Arid Regions, held at the Sede Boqer Campus, Israel.