**GEOCHRONOMETRIA** 28 (2007), pp 47-53
DOI 10.2478/v10003-007-0030-1

Available online at
versita.metapress.com and www.geochronometria.pl

# THE ABSOLUTE CHRONOLOGY OF THE ZOOGENIC DEPOSITS FROM THE NEGEV DESERT (ISRAEL)

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Received 2 July 2007 Accepted 26 September 2007

**Abstract:** Zoogenic deposits are one of the most important sources of the information on the history of arid ecosystems. Different organic materials form the deposit thus offering an opportunity for palaeobotanic analysis as well as for radiocarbon dating. However, many obstacles arise while dating zoogenic deposits. Some layers can be readily dated by radiocarbon as dung layers, but some of them do not contain any organic material preserved.
Three zoogenic deposits from the central part of the Negev Desert (Israel) were investigated. Azmaut deposit was accumulated more then 5000 years. This deposit is a key object of this research. The Ramon I deposit was accumulated for the last 8000 years.
The observed coincidence of the changes of the deposits and the pollen spectra testifies the presence of common causes driving them. It allows us to compare the spectrum of sufficiently dated Azmaut deposit with that of the poorly dated Bsor one. The bottom layers of the Ramon I deposit were formed 2000 years earlier than that of Azmaut. Combining the results of the pollen analysis and the radiocarbon dating of the three deposits enables us to reconstruct the vegetation history of the region during the last 8000 years.

**Keywords:** holocene, pollen analysis, zoogenic deposit, Israel, radiocarbon dating.

## 1. INTRODUCTION

The Middle East is one of the most ancient centres of animal domestication. Yet the impact of pastoralism on its ecosystems as well as Holocene vegetation history is still poorly understood. Conventional data sources of palaeoecology as peat and lake deposits can be rarely found in arid environments. This is the main cause of the lack of the ecosystem's history information. One of the most promising lines of investigation addressing these questions is research of zoogenic deposits accumulated in caves and niches. Different species of animals have used such shelters for thousands of years. Dung, bones, feathers and other organic materials form the deposit layer by layer from the bedrock of the shelters (Knyazev, 1979).

In the central part of the Negev Desert (Israel), we uncovered seven zoogenic deposits consisting of alternating dung, ash and mineral layers. Identification of preserved faeces showed that ibexes (*Capra ibex*) as well as sheep and goats used these rock shelters (Rosen *et al*., 2005). Unfortunately it is impossible to tell faeces of wild animals apart from those of ancient domestic ones. The presence of the latter is indicated by a high rate of deposit accumulation. Ibexes do not gather into big flocks and use rock shelters for short periods of time only, so they cannot form thick layers of dung deposit (Dinesman *et al*., 1989). Ash layers indicate not only the presence of hearths. Humans often burned accumulated dung in order to clean the cave floor. Shepherds of North Caucasus and other regions frequently utilize this method even today (Gamkrelidze, 1986). Evidence obtained in southwest Jordan shows that Middle Eastern shepherds also used to burn dung deposits in rock shelters (Simms and Russell, 1997).

Organic material accumulated at the cave bottom offers an opportunity for analysis of different kinds of plant and animal remains like pollen (Navarro Camacho *et al*., 2000; Navarro *et al*., 2001; Scott *et al*., 2005), macrofossils (Hansen, 2001; Holmgren *et al*. 2001), phytoliths (Wallis, 2001; Scott, 2002), bones (Andrews, 1990; Tomek and Bocheński, 2005), charcoal (Cowling *et al*.,

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ISSN 1897-1695 (online), 1733-8387 (print) 

1999; Asouti, 2003) and many others. Reconstructions of ecosystem history based on these analyses must rest on a firmly established absolute chronology. But many obstacles arise while dating zoogenic deposits. Abrupt changes of the deposition rate, including complete interruptions, are frequently found in cave deposits due to different ways of rock shelter utilizations. Events of burning form ash layers. As a result, rather complicated stratigraphy represented by alternating dung, ash and mineral layers can be encountered in cave deposits. Some of these layers, e.g. dung layers, can be readily dated by radiocarbon, but others do not contain any preserved organic material.

The current research is dedicated to the construction of absolute chronology of three zoogenic deposits by combining radiocarbon dating with pollen analysis. The investigated deposits were exposed in the central part of the Negev desert (**Fig. 1**). Hot summers (average daily air temperature in July is 26.48°C) and relatively cold winters (average daily temperature in January is 10.18°C) characterize this region. Relative humidity is about 40-60% (Babaev *et al*., 1986). Atmospheric precipitation usually occurs between October and May; the average annual rainfall does not exceed 100 mm (Hillel, 1982; Shenbrot, 2004). The central part of the Negev desert is covered with sparse vegetation. *Artemisia herba-alba* (Compositae), *Zygophyllum dumosum* (Zigophyllaceae) and *Reaumuria negevensis* (Tamaricaceae) are abundant on the slopes; while *Anabasis siriaca* and *Hammada scoparia* (Chenopodiaceae) dominate over the valley bottoms (Danin, 1983).

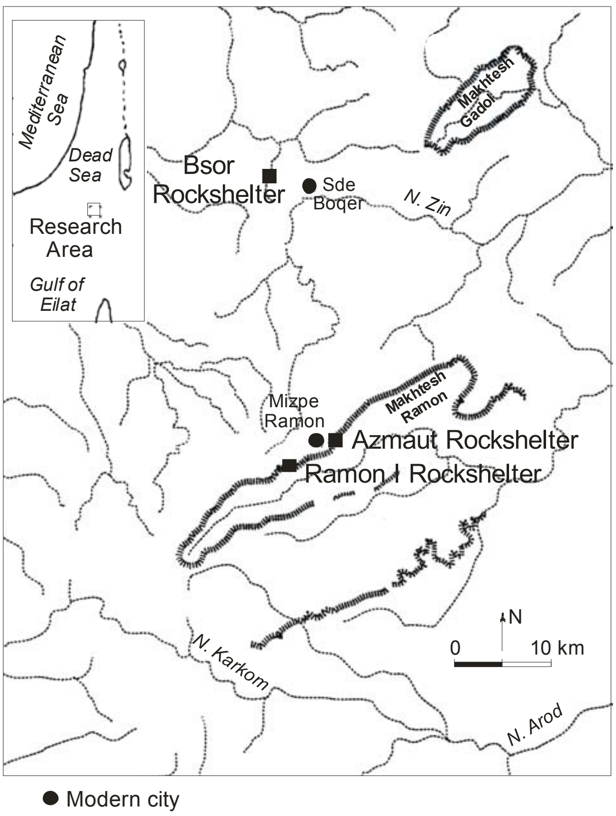


**Fig. 1.** *The central part of the Negev desert, and location of rock shelters.*

## 2. DESCRIPTION OF THE ZOOGENIC DEPOSIT PROFILES

The Azmaut rock shelter is located in the upper cliff face of the north wall of the Ramon Crater at the head of the Azmaut Ascent, on the edge of the town of Mitzpe Ramon (N 30°36,458'; E 34°48,438'). It faces south and geologically occupies the seam between two limestone formations. The shelter was partially destroyed in the 1950s with the construction of the paved road leading through the crater. This destruction left an open section, visible from the road now. Azmaut deposit is well stratified due to an alternation of the ash, dung and gravel layers. Its depth is 108 cm (**Fig. 2**).

The Azmaut zoogenic deposit consists of:

- 17-20 cm – pressed dung with abundant plant remains,
- 20-29 cm – friable ash layers with charcoal and gravel,
- 29-31 cm – layers of burnt dung with charcoal and gravel,
- 31-51 cm – consolidated sediment of gravel with inclusions of dung,
- 51-64 cm – consolidated sediment of gravel and fine-grained material without apparent inclusions of dung,
- 64-79 cm – pressed dung with abundant plant remains,
- 79-95 cm – layers of burnt dung with charcoal and gravel,
- 95-101 cm – pressed dung with abundant plant remains,
- 101-102 cm – friable ash layers with charcoal and gravel,
- 102-111 cm – pressed dung with abundant plant remains,
- 111-113 cm – layers of burnt dung with charcoal and gravel,
- 113-116 cm – pressed dung with abundant plant remains,
- 116-120 cm – friable ash layers with charcoal and gravel,
- 120-123 cm – layers of burnt dung with charcoal and gravel,
- 123-125 cm – friable layer of gravel without apparent inclusions of dung.

Thus, gravel layers represent one third of Azmaut deposit, while ash horizons, meaning all thermally processed ones, occupy 35% of it. The remaining portion of the deposit consists of layers of pressed dung.

The Ramon I zoogenic deposit is located in the upper cliff face of the north wall of the Ramon crater as the Azmaut rock shelter (N 30°35,022'; E 34°44,006'). It is situated about 5 km from the latter. Ramon I deposit is of 90 cm in depth; ash layers represent 98% of it (**Fig. 2**).

Ramon I zoogenic deposit:

- 7-9 cm – pressed dung with inclusion of gravel,
- 9-18 cm – layers of burnt dung with charcoal and gravel,
- 18-23 cm – friable ash layers with charcoal and gravel,
- 23-37 cm – consolidated sediments of ash and gravel,

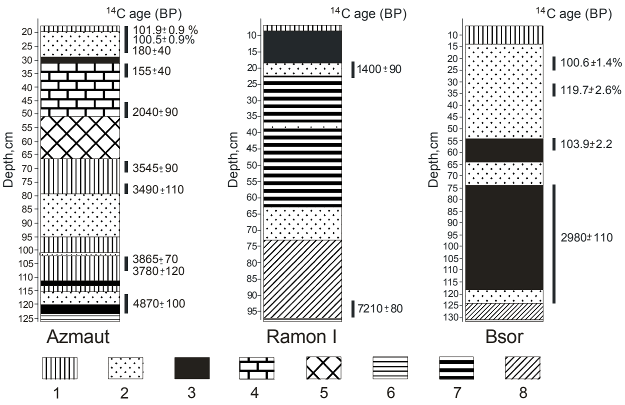


**Fig. 2.** *The profiles of zoogenic deposits. Layers: 1 – pressed dung; 2 – friable ash; 3 – burned dung with inclusions of charcoal; 4 – consolidated sediment of gravel and dung; 5 – consolidated sediment of gravel and fine-grained sediments; 6 – gravel layer; 7 – consolidated sediment of ash and gravel; 8 – gravel with ash and charcoal.*

- 37-39 cm – friable ash layers with charcoal and gravel,
- 39-63 cm – consolidated sediments of ash and gravel,
- 63-74 cm – friable ash layers with charcoal and gravel,
- 74-97 cm – friable gravel with inclusion of bones, charcoal and plant remains.

The Bsor zoogenic deposit is located about 40 km to the north from Azmaut (N 30°55,608'; E 34°41,939'). (**Fig. 1**). It is 126 cm deep and the ash layers represent 94% of it (**Fig. 2**).

Bsor zoogenic deposit:

- 6-13 cm – pressed dung with inclusion of gravel,
- 13-54 cm – friable ash layers with inclusion of faeces, charcoal and gravel,
- 54-64 cm – layers of burnt dung with charcoal and gravel,
- 64-74 cm – friable ash layers with inclusion of faeces, charcoal and gravel,
- 74-118 cm – layers of burnt dung with charcoal and gravel,
- 118-131 cm – friable gravel with inclusion of charcoal,
- 131-132 cm – friable gravel.

## 3. METHODS

Sections were cut through the all three deposits and samples for radiocarbon dating and pollen analysis were collected. Charcoal and plant remains extracted from the layers were used for dating. The radiocarbon was measured in the Group of Historical Ecology (A.N. Severtsov Institute of Ecology and Evolution, RAS, former Institute of Evolutionary Morphology and Animal Ecology). Radiocarbon dates were calibrated with OxCal 3.10 computer program (Bronk Ramsey, 1995) with using IntCal 04 calibration curve (Reimer *et al.*, 2004a). CaliBomb computer program was used to calibrate modern $^{14}C$ data (Reimer *et al*., 2004b) with the curve for NH zone 2 (Hua and Barbetti, 2004) and smoothing in years 1.0. The pollen analysis was conducted following Faegri and Iversen (1989). Pollen concentration values were obtained by adding *Lycopodium clavatum* tablets (batch № 938934) to a specific volume of sediment (Benninghoff, 1962). Pollen diagrams were drawn and a subdivision of pollen sequences into zones was conducted with computer programs TILIA 2.0 (Grimm, 1991-1993) and TILIA-GRAPH 1.25 (Grimm, 1991). Stratigraphically, the constrained sum-of-squares (CONISS) cluster analysis (Grimm, 1987) was used.

## 4. RESULTS AND DISCUSSION

The Azmaut deposit was accumulated over more then 5000 years, which was inferred from 10 radiocarbon dates conducted (**Table 1**). The Azmaut deposit is a key object of this research; it is also being the best dated one. 25 samples were collected for pollen analysis. Total pollen concentration (further TPC) noticeably varies through the Azmaut deposit: from 7000 to 4 300 000 grains/cm$^3$. The following palynomorphs are dominant in spectra: Chenopodiaceae, Cruciferae, Gramineae, Liliaceae s.l., and Compositae, including *Artemisia.*

Two pollen zones (A and B) and five subzones were

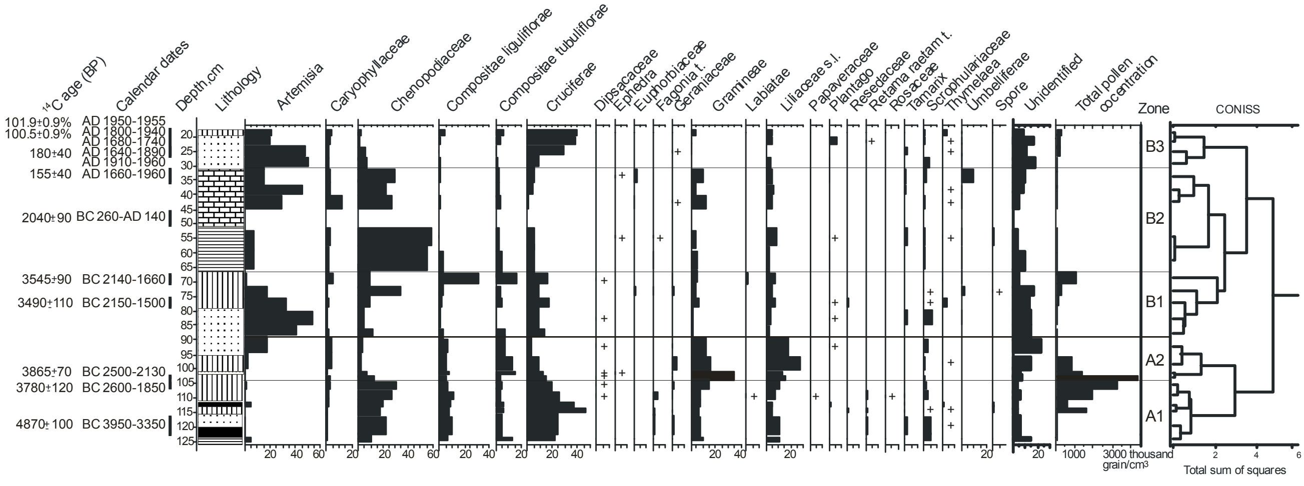


**Fig. 3.** *The profile and the pollen diagram of the Azmaut zoogenic deposit. See legend of Fig. 2.*

**Table 1.** *Radiocarbon and calibrated dates of Azmaut, Ramon I and Bsor zoogenic deposits. Ranges of calendar ages – ranges with confidence level 95% (IntCal04 Programme, Reimer et al. 2004a).*

| Depth (cm) | Lab No. | $^{14}$C age (BP) | Ranges of calendar ages (AD/BC) | | Dated material |
|---|---|---|---|---|---|
| | | | **Azmaut** | | |
| 17-20 | IEMAE-1331 | 101.9±0.9% | AD 1950-1955 | (97.9%) | Plant remains |
| 20-23 | IEMAE-1330 | 100.5±0.9% | AD 1680-1740<br>AD 1800-1940 | (24.5%)<br>(66.9%) | Plant remains |
| 23-27 | IEMAE-1329 | 180±40 | AD 1640-1890<br>AD 1910-1960 | (77.6%)<br>(17.8%) | Plant remains |
| 31-36 | IEMAE-1348 | 155±40 | AD 1660-1960 | (95.4%) | Plant remains |
| 45-51 | IEMAE-1342 | 2040±90 | BC 360-270<br>BC 260-AD 140 | (7.2%)<br>(88.2%) | Plant remains |
| 67-71 | IEMAE-1328 | 3545±90 | BC 2140-1660 | (95.4%) | Plant remains |
| 75-79 | IEMAE-1327 | 3490±110 | BC 2150-1500 | (95.4%) | Plant remains |
| 102-104 | IEMAE-1326 | 3865±70 | BC 2500-2130 | (93.7%) | Plant remains |
| 104-107 | IEMAE-1325 | 3780±120 | BC 2600-1850 | (95.4%) | Plant remains |
| 116-123 | IEMAE-1298 | 4870±100 | BC 3950-3350 | (95.4%) | Humic acid |
| | | | **Ramon I** | | |
| 18-23 | IEMAE-1352 | 1400±90 | AD 430-820<br>AD 840-860 | (94.3%)<br>(1.1%) | Plant remains |
| 92-97 | IEMAE-1358 | 7210±80 | BC 6250-5970 | (95.4%) | Plant remains |
| | | | **Bsor** | | |
| 19-25 | IEMAE-1357 | 100.6±1.4% | AD 1670-1780<br>AD 1800-1945 | (34.3%)<br>(62.3%) | Plant remains and charcoal |
| 31-36 | IEMAE-1383 | 119.7±2.6% | AD 1958-1962<br>AD 1980-1990 | (23.4%)<br>(76.6%) | Plant remains |
| 54-59 | IEMAE-1380 | 103.9±2.2% | AD 1650-1960 | (99.9%) | Charcoal |
| 74-124 | IEMAE-1355 | 2980±110 | BC 1450-900 | (95.4%) | Charcoal |

distinguished on the base of cluster analysis (**Fig. 3**). Zone A is distinguished from zone B by both a higher TPC, and a greater proportion of Gramineae and Liliaceae, and consists of two subzones. Zone B is characterized by high share of *Artemisia* and Chenopodiaceae and consists of three subzones.

Subzone A1 was formed until about 23$^{rd}$ century BC. Crucifers dominate the spectrum, proportions of grasses and liliaceous pile up to 10%. We found the same spectrum in the bottom layers of Ramon I zoogenic deposit.

Only two radiocarbon dates were obtained for Ramon I deposit: one from the upper part and the other from the bottom layer (**Table 1**). It was accumulating for about eight thousand years. 18 samples were collected for pollen analysis, but pollen concentration in 10 ash layers was too small to conduct reliable counting. There is not a lot of pollen in ash layers because of burning (Brooks and Shaw, 1972).

The bottom layers of Ramon I deposit let us extend pollen spectra of Azmaut deposit back in time. The results of pollen analysis of these two deposits allow us to suggest that from 5$^{th}$ till 3$^{rd}$ millennium BC, the vegetation of the Negev desert differed from that of today in being much more diverse. This difference probably reflects climatic change. Climatic reconstructions show that these three thousand years were unstable but comparatively wetter than nowadays (Bar-Matthews *et al*., 1998, Migowski *et al*., 2006).

Considerable increase of proportion of grass pollen along with a peak of total pollen concentration can be seen in the layers of the Azmaut deposit which were dated back to about the 23$^{rd}$ century BC (**Fig. 3**). These features in pollen spectrum coincide with period of significantly increased precipitation reconstructed on the base of various climatic proxies. It lasted from the 27$^{th}$ until the 23$^{rd}$ century BC (Bar-Matthews *et al*., 1998; Migowski *et al*., 2006). We can suppose that vegetation in the investigated area in this period was close to that of northern Negev today.

The mean amount of annual precipitation in the vicinity of Beer Sheba is about 200 mm, i.e. twice as much as in central Negev (Hillel, 1982). Grasses, mainly annual ones, dominate the vegetation of the northern Negev (Zaady *et al*., 2001). In spite of the dominance in vegetation, their presence in recent pollen spectra is minor due to low pollen production. It is explained by the fact that most desert species of grasses flower during a short period of precipitation in spring. The maximum of precipitation fell on summer during early and middle Holocene in contrast to recent conditions. Grasses, which are blooming during summer, have much more high pollen productivity (El-Moslimany, 1990). Therefore, the observed changes of vegetation were governed not only by changes of the amount of precipitation alone but also by its seasonal shift.

The same changes in pollen spectra can be seen in Bsor deposit. Three modern radiocarbon dates were obtained for the uppermost part of this deposit (**Table 1**). 27 samples were collected for pollen analysis. TPC strongly varies through the Bsor deposit: from 6 to 113 grains/cm$^3$. TPC in one ash layer (105-111 cm) was too small to conduct reliable counting. Two pollen zones (A and B) and five subzones were distinguished on the base of cluster analysis. Zone A is characterized by high proportion of Gramineae and consists of two subzones.

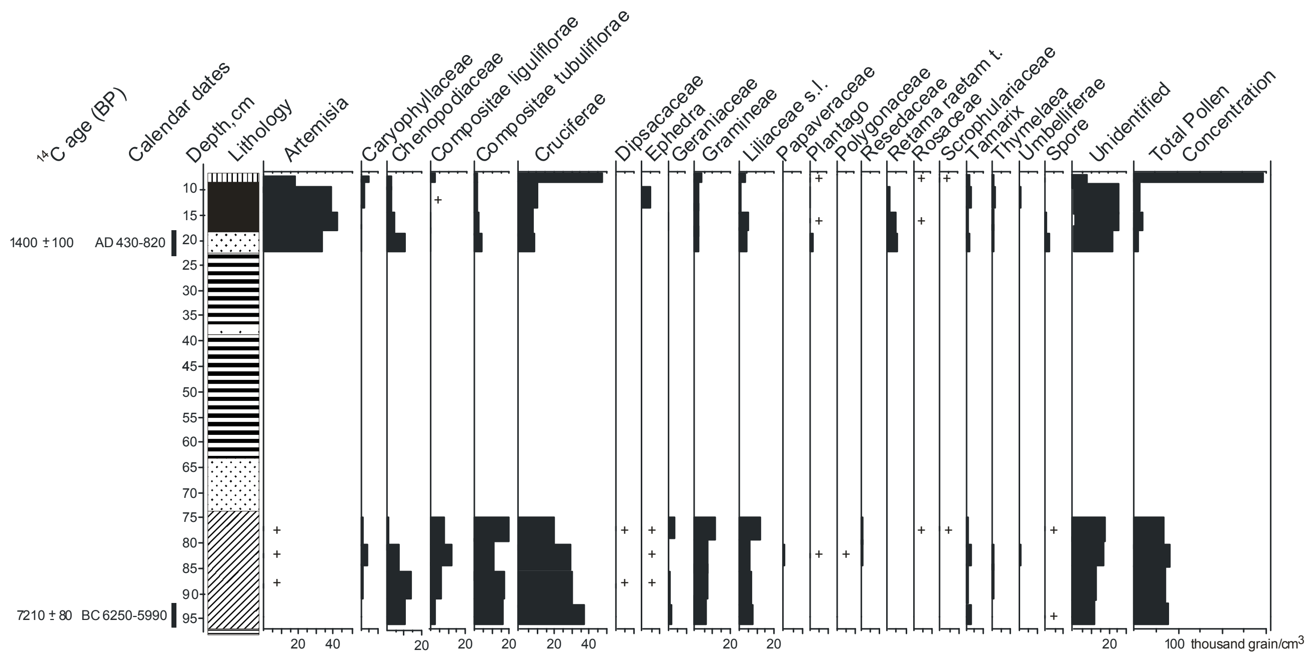


**Fig. 4.** *The profile and the pollen diagram of Ramon I zoogenic deposit. See legend of Fig. 2.*

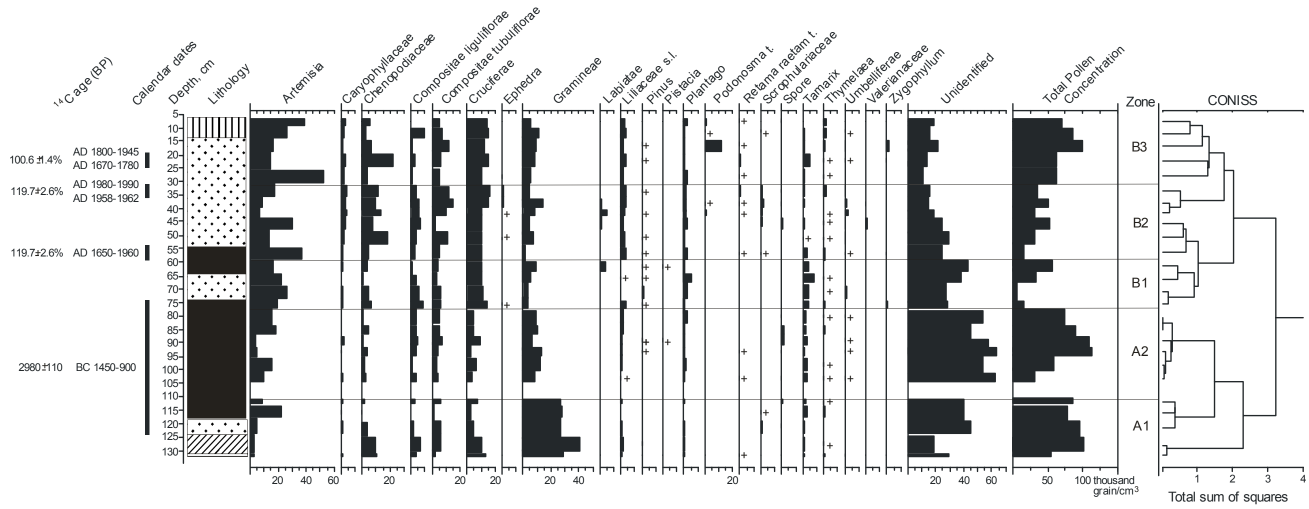


**Fig. 5.** *The profile and the pollen diagram of Bsor zoogenic deposit. See legend of Fig. 2.*

Zone B is characterized by high share of *Artemisia* and Cruciferae and consists of three subzones.

The similarity of pollen spectra of Azmaut and Bsor deposits allows dating the layers of the latter. Lowermost layers of Bsor are characterized by high total pollen concentration and significant proportion of grasses. The same features are distinctive to zone A2 of Azmaut deposit. The latter were formed around 23rd century BC.

In the next four centuries till 19th century BC pollen spectra of the Azmaut deposit were characterized by following features: TPC and the proportion of grasses decreased while the proportion of wormwood reached a high value (**Fig. 3**). The upper part of subzone A1 and the lower part of subzone A2 of the Bsor deposit display the same changes (**Fig. 5**). Climatic reconstructions show that at the same time, the amount of precipitation decreased by 20-30% (Bar-Matthews *et al.*, 1998). This event was not restricted to Middle East only but covered many Mediterranean regions as well as Asian and African ones (Staubwasser and Weiss, 2006).

Significantly increased TPC with an extended proportion of Cruciferae and Compositae and a reduced proportion of Artemisia mark Azmaut deposit layers which were formed about 19th century BC (**Fig. 3**). The same features characterize subzone A2 of the Bsor deposit (**Fig. 5**). More wet conditions are reconstructed for the period from the 20th till the 16th centuries BC (Bar-Matthews *et al.*, 1998; Migowski *et al.*, 2006).

Comparison of pollen spectra of the Azmaut and Bsor deposits allows us to propose that the lower half of the latter was formed from 23rd century BC till the middle of the second millennium BC. This interpretation does not contradict the radiocarbon dates obtained for this horizon (**Table 1**). Apparently, the accumulation of the Bsor deposit was interrupted from the middle of the second millennium BC till recently.

It is also interesting to compare upper layers of the Azmaut, Ramon I and Bsor deposits. They also share common features: significant proportions of wormwood, crucifers and plantain pollen (**Figs 3-5**).

The increased amount of *Artemisia* and *Plantago* pollen can reflect overgrazing (Ward and Olsvig-Whittaker, 1993; Mirkin *et al*., 2001). It is worth noting that a sharp increase of *Artemisia* and *Plantago* pollen concentration is detected in the two uppermost layers of the Azmaut deposit (**Fig. 3**). The radiocarbon dates obtained for them are modern but they do not show the bomb effect. The still lower dates allow us to suggest that these layers were formed from the end of the 18th till the middle of the 20$^{th}$ century (**Table 1**). A big group of Bedouins had come in the Negev desert at the end of 18-19 centuries (Bailey, 1985). The same dynamics of wormwood and plantain-rose pollen can be seen in the upper layers of the Bsor deposit (**Fig. 5**).

## 5. CONCLUSIONS

Radiocarbon dating and pollen analysis of these three deposits let us draw the following conclusions:

1) Changes of proportion and concentration of pollen of various plant taxons are synchronous with climatic oscillations and events of anthropogenic impacts.
2) It allows us to compare features of pollen spectra of different zoogenic deposits with each other in order to date layers which cannot be dated by the radiocarbon method.
3) Different zoogenic deposits had different duration of accumulation. Furthermore at least some of them had interruptions in deposition. That is why only investigation of several deposits from given location and an accurate comparison of the results will develop into reliable reconstructions of vegetation.

## ACKNOWLEDGEMENTS

The authors are very grateful to the Ramon Science Centre, Dr. B. Krasnov, Dr. I. Khokhlova and Dr. G. Shenbrot for the help and the organization of field investigations. We are much indebted to Dr. A. Savinetsky and Dr. N. Kiseleva (A.N. Severtsov Institute of Ecology and Evolution of Russian Academy of Sciences), Prof. S.A. Rosen and Dr. J. Plakht (Ben-Gurion University, Israel) for fruitful discussions.

Our study was supported by the Russian Foundation for Basic Research (grant 06-04-48531), Program "The origin and evolution of Biosphere" and Program of basic research DES the Russian Academy of Sciences "Development of technologies of monitoring ecosystem modelling and forecasting in studies of natural resources in arid climate conditions", and also a grant from the Ministry of Science of Israel.

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