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Garrod's Spring in Tabun Cave, Mt. Carmel (Israel): 70 Years Later

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Introduction

Tabun Cave is located on the west slope of Mount Carmel some 20 km south of Haifa (Figure 1). Carved in the cliff on the south side of Nahal (Wadi) Mearot, its entrance faces North-West 45-63 m above mean sea-level. It is a karstic cave formed of three chambers. Each chamber has a swallow hole in its floor. In the inner (southernmost) chamber, the only one with the ceiling preserved, there is a large chimney (Figure 2), some 8 m in diameter. Tabun excavations have revealed an exceptionally thick (25 m) series of human occupation, ranging from the Middle through the Upper Pleistocene, from around 800,000 years to 100,000 years ago (Ron, personal comm.; Grün and Stringer 2000). The initial excavations by D. Garrod, 1929-1934 (Garrod and Bate 1937; Ronen 1982) were followed by A. Jelinek 1967-1972 (Jelinek *et al*. 1973; Jelinek 1977, 1982) and, from 1975 on, by A. Ronen (Ronen and Tsatskin 1995; Shifroni and Ronen 2000; Ronen *et al.* in press).

During the excavations between 1929 and 1934, Garrod had removed a part of the fill of the outer (northern) chamber and most of the fill of the central chamber, where she had reached the deepest deposits and bedrock. In the inner chamber Garrod removed only the top sediments which had filled the chimney. Garrod's major trench was dug between the central and inner chambers across the entire width of the cave, some 18 m. East-West. The south wall of that trench retains the major stratigraphic section at Tabun, ca. 20 m thick. The lower part of the section is composed

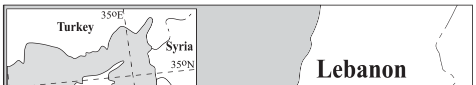

Figure 1: Location map of the Tabun Cave

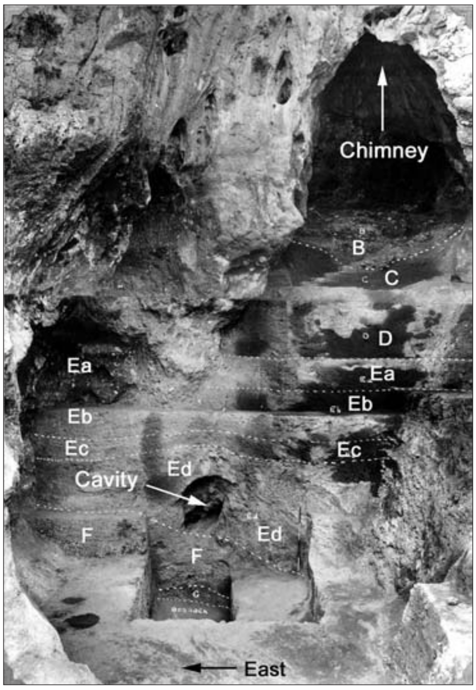

Figure 2: The main stratigraphic section at Tabun cave of Garrod's excavations 1n 1934. H.L. Hamon from the original photograph (Inv. No. 33431), Fonds Suzanne Cassou de Saint Mathurin de la bibliothèque du Musèe des Antiquitès Nationales de Saint-Germain-en-Laye, France

mainly of wind blown, fine quartz sand originating on the sea shore in the west (Jelinek *et al*. 1973; Ronen and Tsatskin 1999). The upper third of the deposits consists of red *Terra-rossa* washed into the cave after the opening of the chimney in the inner chamber, around 130,000 years ago (Grün and Stringer 2000). The opening of the chimney thus marks a radical change of deposition in Tabun, from wind-blown sand prior to the opening to alluvial red clay afterwards (Jelinek *et al*. 1973).

The "spring cavity"

At the base of the central chamber, 12.25 m below datum, Garrod unearthed a large swallow hole into which the layers slumped from all directions. A patch of red earth was discovered in layer Ed (Figure 2), between elevation 8.25 m and 9.75 m below datum. The patch remarkably differed from its surroundings, of brown-grey color. The patch further differed in that it contained a large number of small bones (apparently birds) while the surrounding deposits were entirely devoid of faunal remains. Shortly after its exposure the red patch detached and fell off, revealing a narrow cavity (Garrod and Bate 1937: Plate XXXI, 3). Garrod concluded that the cavity was formed by a spring flowing from the rear rockwall. Travertine deposits found between 6.90 m and 9.00 m below datum seemed to support that interpretation.

Until 1967, when excavation was renewed by Jelinek, erosion had only slightly affected the major section at Tabun. The upper, red clay layers B and C (Figure 2) were especially eroded and had accumulated in the bottom of the central chamber, filling the swallow hole. In order to protect the sediments a 65 sqm roof was built over the chimney in 1967. The roof all but stopped the rain from penetrating the cave. After Garrod, excavations (Jelinek *et al.* 1973; Ronen and Tsatskin 1995) were carried out at a safe distance from the "spring cavity", for fear of collapse of Tabun's major section. The cavity was not studied during the 70 years since its discovery. In the winter of 1997-1998 a large block of sediment detached from the cavity's top part and fell 4.5 m to rest on the bedrock ledge at the base of the section. The block, about 0.8 m x 0.6 m x 0.3 m, contained over 800 lithic artifacts (Ronen *et al.* in press). Establishing the original position of the block became imperative for reconstructing the stratigraphyical position of the collapsed assemblage.

Closely observing the cavity, it became clear that the spring hypothesis cannot explain Garrod's observations. No spring could have transported the red earth with its bone content. In our view (Ronen *et al*. in press), the cavity was not created by a spring, but was part of a subterranean erosion channel leading from the top of the fill down to the swallow hole. As might be expected, the channel was carved along the contact between soft sediment and the vertical rock. Erosion channels exist along all the exposed walls at Tabun. The channel discussed here could have formed only after the opening of the chimney, contemporaneously with the accumulation of the red clay washed into the cave from the mountain top. According to this scenario, the patch of red earth with its bone content would have been transported from the deposits in the upper part of the sedimentological fill at Tabun, 6 m higher. The sole transport of fines and small bones indicates a gentle flow. A weak energy is further suggested by the deposition of travertine, as observed by Garrod.

Methodology

Since the cavity was discovered 70 years ago in layer Ed, the channel has widened to the west, upwards and downwards. At present, the channel's top is in layer Ec, and, cutting across Ed it reaches down into layer F (Figures 2,3). Here we describe the method of measurements that enabled us to reconstruct the cavity's changing contours over time as well as pinpoint the original location of the collapsed block. In the first stage, the area around the cavity's mouth was physically measured in order to obtain accurate dimensions of the present mapping area. Then, using digital measurement techniques with photogrametry and mapping software (Zviely and Klein 2004), five photographs that show the cavity's mouth in 1934, 1975, 1981, 1992, and 2002 were compared. Digital image processing and mapping techniques required scanning and subsequent transformation of analog photographs to digital images. The photographs were scanned at a resolution of 300 dpi in order to obtain surface geometric separation higher than 5 cm.

The raw scanned photographs were imported into a Monoscopic-Photogrametric mapping software program (Microstation Descartes Users Guide, 2002). Then by applying a "Projective" fourth-order transformation module, the 1934, 1975, 1992 and 2002 photographs were superimposed to the geo-referencing 1981 photograph. This photograph previously acquired its planimetric dimensions by using the field measurements from around the cavity's mouth in the first stage. The geometric corrections of each photograph compared to the 1981 photograph, were achieved by using several control points located around the cavity's mouth. Most of the control points were small holes (< 5 cm diameter) made by birds for nesting. The results of the photogrametric process are shown in Table 1. The cavity's mouth contour on each photograph was mapped by using a digital-vector mapping software program (Microstation Java Users Guide 2000). All the contours were combined for comparison into one file. Then by using the "Measure area" application of the Microstation Java software program, the area of the cavity's mouth was measured.

Each stage of the mapping process contributes a vertical error in locating the cavity's mouth contour. The maximum cumulative error due to measurement is:

$$E_{max} = (2R + 2D) /\sqrt{G} = (2x8 + 2x0.45) /\sqrt{16.75} = 4.1 \text{ cm}$$

Where :

R - error due to the photogrametric process (for exaggeration twice the maximum RMS, table 1) RMS-XY 1934 = 8 cm

D - error due to mistakes identifying the cavity's mouth outline (for exaggeration twice the photograph scanning resolution, table 1). 2 x 0.45 = 0.9 m

G - number of the average control points on each photograph. In this study, n = 16.75

Results

The mapping shows that at the end of Garrod's excavations in 1934 the cavity measured 1.9 x 1.3 m, covering 2.3 sqm in layer Ed (Figures 2,3). During the following 41 years, until 1975 (Figure 4), the area grew to 7.7 sqm. Until 1975 the cavity had widened mainly to the west (right in the figures), within layer Ed and downward into layer F (some 30% of the growth). From 1975 to 1981 (Figure 5) the cavity remained stable. Between 1981 and 1992 (Figure 6), the cavity continued to cut into layer F in its lower eastern end and the area grew to 8.3 sqm. The growth continued, and in 2002 the cavity's area reached 15.1 sqm (Figure 7), more than six times its area in 1934. The principal change in recent years is due to a large collapse in the winter of 1997-1998 (Figure 8). That collapse has considerably enlarged the cavity in its upper-western end, mainly in Ed (about 70%) but also penetrating, for the first time, upward into layer Ec (13%). Today the upper end of the erosion channel is 7.2 m below datum, about 1 m higher than in Garrod's time and the lower end is at 10.4 m, 0.65 m lower than in 1934 (Figure 9).

Discussion and Conclusions

Digital photogrametry allowed us to reconstruct the growth pattern of growth of the erosion channel discovered by Garrod in the central chamber of Tabun Cave some 70 years ago, and to analyze the pace of growth. It also enabled us to precisely reconstruct the original position of the large block collapsed in 1997-1998 from the cavity's top. The channel grew in time mainly to the west, upward and down. An eastward growth was prevented by the bedrock. The cavity's enlargement was probably due to erosional processes and minor collapse of the relatively

Table 1: The photogrametric process results

Photo year	1934	1975	1992	2002
Scanning resolution	300dpi	300dpi	300dpi	300dpi
Pixel size (cm)	0.45	0.45	0.45	0.45
Number of control points	17	18	20	12
Standard Deviation -X (cm)	5	0	1	2
Standard Deviation -Y (cm)	2	0	0	2
Standard Deviation -XY (cm)	5	0	0	1
RMS Error - X (cm)	7	1	1	3
RMS Error - Y (cm)	4	1	1	3
RMS Error - XY (cm)	8	1	1	4

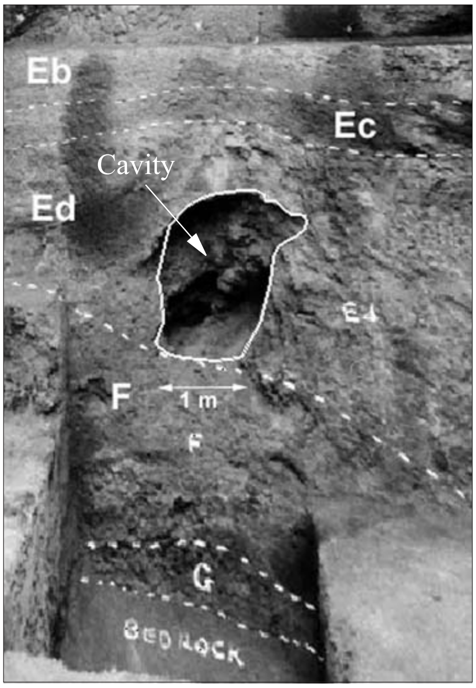

Figure 3: The cavity's mouth in 1934 (source as Figure 2).

Figure 4: The cavity's mouth in 1975.

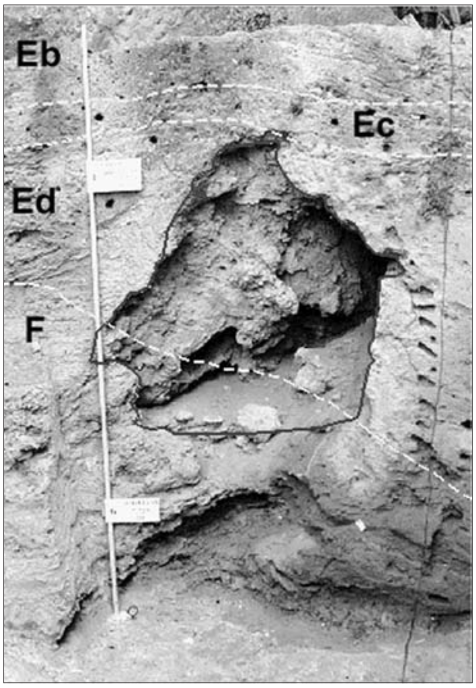

Figure 5: The cavity's mouth in 1981.

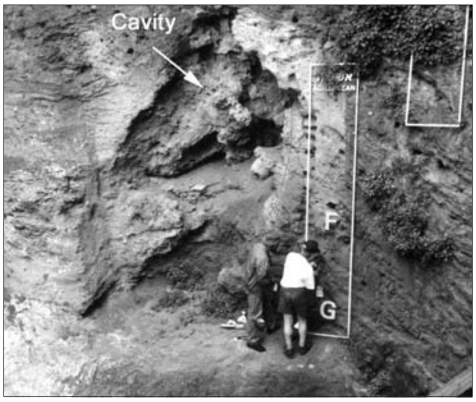

Figure 6: The cavity's mouth in 1992.

soft deposits surrounding the channel on three sides. Signs of trickling water are sometimes seen as thin patches of reddish sediment on the cavity's bottom. Seeking the possible cause for the cavity's enlargement, rain comes first to mind but there is no correlation between the non-linear pattern of growth and the mean annual precipitation measured in Atlit, some 3 km west of Tabun Cave (Table 2). Water also penetrates the cave through fissures in bedrock around which patches of black lichen develop. In places, incipient stalagmites are formed on the cave floor below dripping fissures. On 13 February 2004, in the course of a very rainy winter, the sediments in the major section were wet over a length of about 16 m, from the west

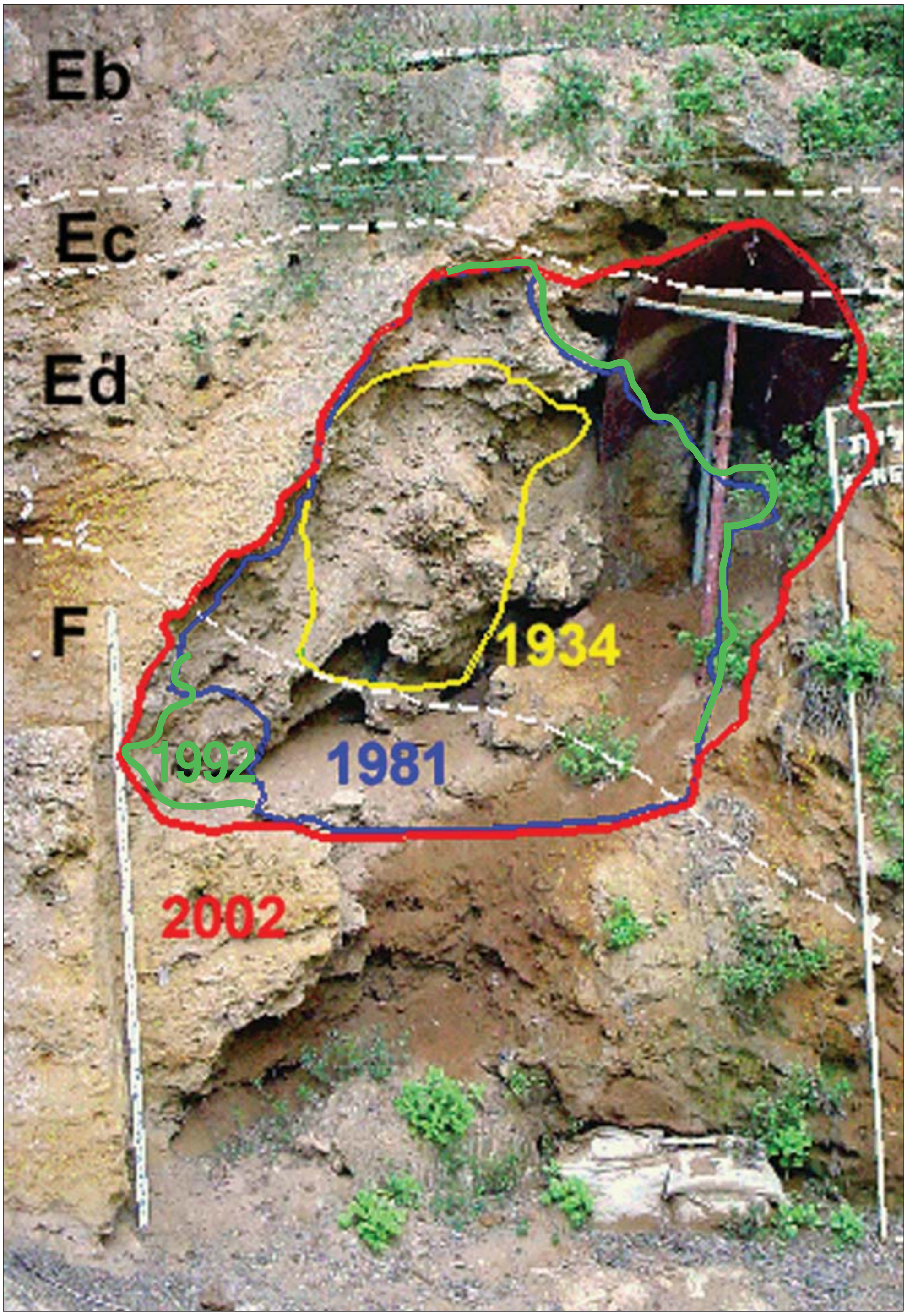

Figure 7: The changing contours of the cavity's mouth 1934-2002.

Figure 8: The cavity's mouth and the fallen block at the beginning of 1998.

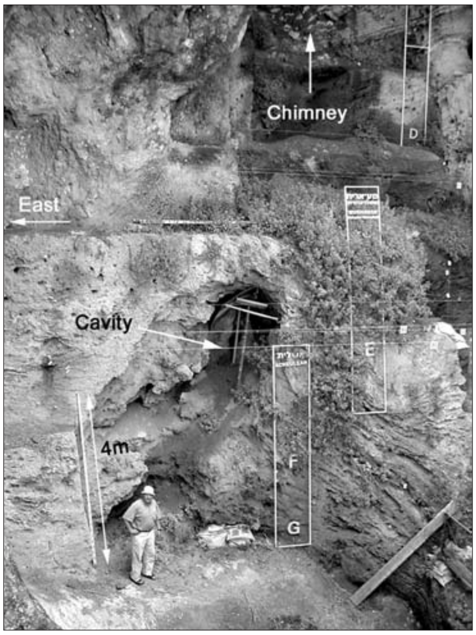

Figure 9: The main stratigraphic section at Tabun Cave in 2002.

Table 2: The growth of the cavity mouth and mean rainfall during 1934-2002

Period	Total cavity area growth (sqm)	Mean cavity area growth (sqm/year)	Average rainfall (mm/year)
1934-1975	5.4	0.13	510
1975-1981	0	0.00	547
1981-1992	0.6	0.05	521
1992-2002	6.8	0.57	478

[Note: The average rainfall during 1934-2000 was 507 mm/year]

wall to a point 2 m short of the east wall. No change was noticed in the cavity outline. Nor did the earthquake of magnitude 5.2, which occurred on 11.2.2004, leave a trace in the cave.

Other factors in addition to precipitation might have contributed to the growth of the cavity: earthquake, vegetation and nesting birds. A rich vegetation governed by *Parietaria judaica* L. grows on the exposed sections of Tabun Cave, especially the sandy parts. The roots penetrate between 5 and 15 cm into the sediment. Birds (Heller, *Coracias garrulus*) occasionally dig their nest in the soft parts of the vertical section. The birds dig a hole 5-10 cm in diameter, preferring sand or silt deposits and avoiding the clay parts. The nesting holes are located in a minimal distance of 15 cm from the cavity's edges, therefore they do not seem to have played a role in the cavity's enlargement.

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