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Short Paper

Reevaluating the tectonic uplift of western Mount Carmel, Israel, since the middle Pleistocene

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ABSTRACT

Reevaluation of geological and archaeological evidence from western Mount Carmel constrains its maximal tectonic uplift since the Middle Pleistocene. Tabun Cave, presently 45 m above sea level (asl), revealed human occupation from about 600 ka to 90 ka before present. The 25 m thick archaeological strata at Tabun are composed of laminated fine sand, silt and clays. Moreover, no marine deposits were found in Tabun or nearby caves. Since sea level in the last 600 ka reached a maximal of 5 to 10 m asl, Tabun Cave could not have been uplifted since then by more than 35 to 40 m, that is a maximal average rate of 58 to 67 mm/ka.

Introduction

From Egypt to northern Israel, Mount Carmel is the only elevated structure that reaches to the eastern Mediterranean coast (Fig. 1). The northern slopes of the Carmel are home to the city of Haifa, and the Zevulun Plain, just northeast of the mountain (Fig. 2), accommodates several urban centers and a heavy petrochemical industry.

Seismicity and neotectonic evidences were recently reported along and around the Carmel fault at the northeastern margins of Mount Carmel (Figs. 1, 2), thus putting the city of Haifa and the industrial and urban centers of the Zevulun Plain at seismic risk. Therefore, estimating rates of neotectonic activity of the Carmel Mountain and fault is of great importance.

Mount Carmel area also played a major role in the study of human evolution and the exit from Africa. Humans have occupied this region since the Middle Pleistocene (Olami, 1984); in the Late Pleistocene, modern humans and Neanderthals lived there simultaneously (Garrod and Bate, 1937; Rak, 1998).

The current study focuses on integrating and reevaluating the existing geological and archaeological findings from the western Mount Carmel, and estimates the possible uplift of that area since the Middle Pleistocene. The results provide crucial evidences for the rate and timing of uplift of Mount Carmel, one of the most prominent structural features in this region.

Geological setting

The Carmel range is a triangle, stretching 33 km along the Mediterranean coast, 12 km wide at its maximum and 546 m above sea-level (asl) at its peak. It is bordered by Haifa Bay in the northeast, Zevulun Plain and Yizre'el Valley in the east, Carmel coastal plain in the west, and the Menashe hills in the south (Figs. 1, 2). The Carmel is part of the elongated deformation belt that bifurcates northwestwards from the Dead Sea Transform and cuts to the Mediterranean Sea (Fig. 1). This belt marks an abrupt change in the landscape style of northern Israel, a northward increase of its seismicity, a considerable thinning of the crust and a change in the magnetic and gravimetric properties (Ben-Avraham et al., 2002).

The Carmel Mountain is composed mostly of a Cenomanian–Turonian–Senonian carbonate complex of dolomite, limestone and chalk, locally intruded by soft volcanic rocks (Picard and Kashai, 1958; Karcz, 1959; Kashai, 1966; Sass and Bein, 1978; Sass, 1980; Segev and Sass, 2006). Younger rocks are rare, and limited to small exposures along the mountain's periphery. The present configuration of the mountain and the adjacent plains may have started in the Early Miocene (e.g., Achmon and Ben-Avraham, 1997) or the mid-Oligocene (Schattner et al., 2006).

The steep northeastern slopes of Mount Carmel accommodate the major Carmel (Yagur) fault (e.g. Picard and Kashai, 1958; Rotstein et al.,

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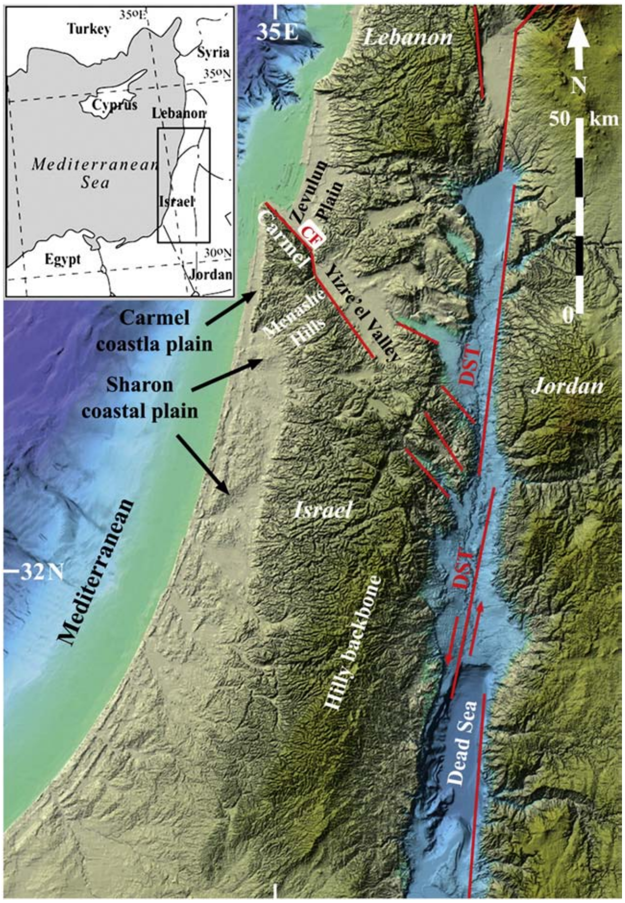

Figure 1. Location map of the study area. Shaded relief modified after Hall and Calvo (2005). CF — Carmel fault; DST — Dead Sea Transform.

1993; Hofstetter et al., 1996; Achmon and Ben-Avraham, 1997). Its southeastern margins dip towards the wide Menashe syncline, and its southernmost narrow tip is sharply terminated by the Or-Akiva fault (Fig. 2). The western slopes, however, incline gently westwards with a steep cliff facing the Mediterranean. No fault is known to exist there (Sneh et al., 1998; Bartov et al., 2002), and the cliffs are considered an abrasion form (Picard and Kashai, 1958; Michelson, 1970). On structural maps the Carmel resembles a half horst (Fig. 2) (Picard and Kashai, 1958; Karcz, 1959; Fleischer and Gafsou, 2003) bounded by the Carmel fault in the northeast and dipping moderately southwestwards (Kafri, 1970; 1988).

Uplift of Mount Carmel

Researchers have previously discussed the timing of the last phase of Mount Carmel's uplift (Table 1). Based on Miocene fauna found on the eastern slopes of the Carmel at 400 m asl, Picard and Kashai (1958) concluded there was a "… post-Miocene uplift of the Carmel of several hundred meters." Karcz (1959) suggested a general uplift during the upper Tertiary-Quaternary period, Kafri and Ecker (1964) related the uplift to the end of the Miocene, Kafri (1969) argued for a post Tyrrhenian uplift of 40 to 50 m., and Michelson (1970) suggested that Mount Carmel was already uplifted from at least the Neogene. Recently, Vita-Finzi and Stringer (2007) suggested an uplift of about 40 m in the last 110 ka, implying a rate of 400 mm/ka. However, Ronen et al. (2007) ruled out this rate.

Using Interferometric Synthetic Aperture Radar (InSAR) measurements, Novitzky (2006) noted a negligible motion of the Carmel, below the threshold of resolution (vertical displacement of 1000 mm/ka), in the last decade (Table 2). Geodetic studies from recent decades, on the other hand, suggested an uplift rate of more than 1 mm/yr (i.e. 1000 mm/ka) (Table 2). These rates are ten times greater than those inferred from geological markers for the nearby mountain backbone of Israel during the Pleistocene (Begin and Zilberman, 1997) (Fig. 1).

The Carmel coastal plain

The Carmel coastal plain (Fig. 2) is a narrow elongated strip of land built mainly of calcareous aeolianite sandstone ridges of the Upper Pleistocene (locally named kurkar). The ridges run parallel to the coastline; clays and alluvial sediments fill the troughs in between (Issar, 1968; Gvirtzman et al., 1998; Neber, 2002; Frechen et al., 2004; Galili et al., 2005). The kurkar layers are interbedded with red loamy soils (locally named hamra) as well as clay and alluvial material (Farrand and Ronen, 1974; Ronen, 1975a; 1975b; 1977; Ronen et al., 1999; Neber, 2002; Frechen et al., 2004).

The Pleistocene sequence, several tens of meters thick, covers the carbonates of the Carmel complex (Kafri, 1970; Michelson, 1970). East–West oriented ephemeral streams that cross the coastal plain and the kurkar ridges on their way to the Mediterranean Sea, drain the western slopes of Mount Carmel. Recent studies of the Carmel coastal plain suggest an average uplift rate of about 48 mm/ka for the last 125 ka (since MIS 5e) (Galili et al., 2007; Ronen et al., 2007).

Sea-level since Middle Pleistocene

Global sea-level curves indicate that during the last 600 ka, the sea reached the maximum elevation of 5 to 10 m above the present level

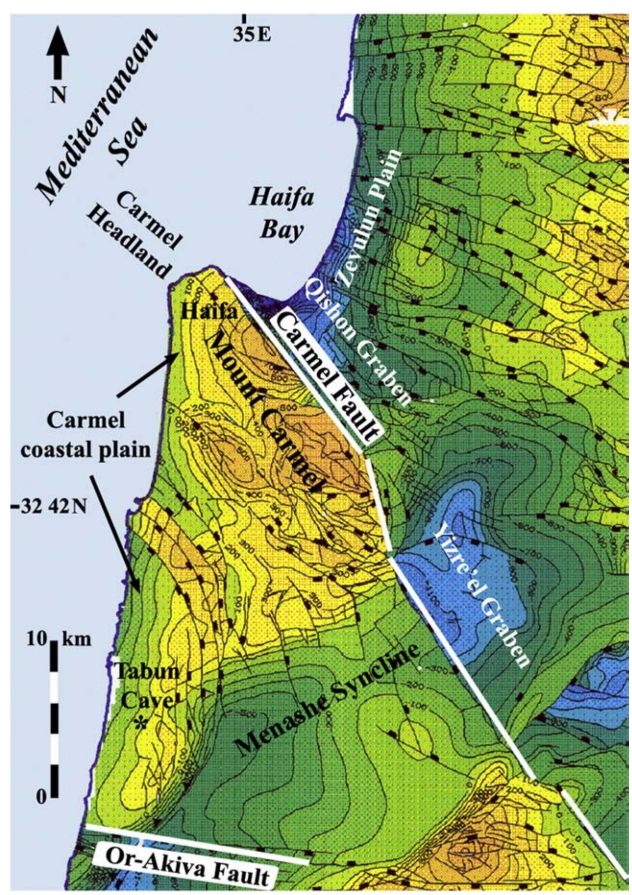

Figure 2. Structural contour map of the study area. Key-horizon is Top Judea Group, Turonian, elevation interval of 100 m. Modified after Fleischer and Gafsou (2003).

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Table 1
Proposed tectonic uplift rates for western Mount Carmel during the Pleistocene, from previous geological studies

Reference	Geologic marker and time frame	Vertical displacement (m)	Rate of uplift (mm/ka)
Kafri (1969)	40 to 50 m uplift of Tyrrhenian strata 100 ka old	40 to 50	400 to 500
Kafri (1970; 1988)	a) Pleistocene terraces on slopes of western Mount Carmel.	100 to 125	~50 to 60
	b) Tyrrhenian strata 13 m asl in northern Mt. Carmel	13	130
	c) Raised terraces correlated with subsurface strata	6°–7° tilt	~2°/Ma
Michelson(1970)	Limited local tectonic uplift (10 to 20 m) post Tyrrhenian I. High marine terraces reflect eustatic sea level changes	–	–
Begin and Zilberman (1997)	Uplift of Mount Carmel in the last 1 to 2 Ma	200	100
	Uplift of Early Pleistocene beach terraces	120	~50
Vita-Finzi (2002)	40 m tectonic uplift of western Carmel caves in last 110 ka;	~40	~360
Vita-Finzi and Stringer (2007)	Tectonic uplift of the coast during the Holocene		200
Mashiah (2005)	40 to 50 m uplift of abrasion surfaces of interglacial 7	40 to 50	200 to 250

at least three times, and dropped to more than 100 m below present level (bsl) at least five times (Waelbroeck et al., 2002; Schellmann and Radtke, 2004; Rabineau et al., 2006; Siddall et al., 2006). During the last 250 ka, sea-level rose above its present level only once, at the peak of the last interglacial at ~125 ka (MIS 5e) (Fig. 3: inset). Studies in tectonically stable regions in the Mediterranean coasts (e.g., in western Sicily and southern Sardinia, Italy) indicate that the last interglacial sea reached approximately 6±3 m asl (Lambeck et al., 2004; Ferranti et al., 2006). This is contrary to the view held previously, namely that Quaternary sea-level changes stretched over some 100 m asl (e.g., Michelson, 1970).

Archaeological setting in the Carmel area

Numerous prehistoric open sites and caves were surveyed and excavated on Mount Carmel (Olami, 1984). Middle Palaeolithic occupation was found in many of these places, as well as in hamra soils and beach deposits along the Carmel coastal plain (Ronen, 1977; Galili et al., 2007). The oldest, Lower Paleolithic archaeological remains were recovered in a few cave sites along the western slopes of the mountain (Garrod and Bate, 1937; Ronen, 1984; Weinstein-Evron, 1998), including the Tabun Cave.

Tabun Cave

Tabun has the longest sequence of human habitation in the Mount Carmel area. Situated on the western slope about 45 m asl (Figs. 2–5), it faces northwest. Excavations at Tabun were initiated by Garrod (between 1929 and 1934) (Garrod and Bate, 1937; Ronen, 1982), followed by Jelinek (between 1967 and 1972) (Jelinek et al., 1973; Jelinek, 1977; 1982), and were continued from 1975 onward by Ronen (Ronen and Tsatskin, 1995; Shifroni and Ronen, 2000). The excavations revealed 25 m thick archaeological strata ranging from at least 600 ka (Laukhin et al., 2000; Ronen et al., 2000) to about 90 ka (Grün and Stringer, 2000; Mercier et al., 2000; Mercier and Valladas, 2003; Rink et al., 2004; Coppa et al., 2005) (Table 3). The lower part of the strata (Fig. 5: layers G, F and E) is composed of wind-blown, very fine Nile-derived quartz sand and silt (Jelinek et al., 1973; Goldberg, 1973; Ronen and Tsatskin, 1995). As a general trend, grain size gradually decreases with time while the silt component increases until reaching layer D. The upper third of the section (Fig. 5: layers C, B and the Chimney), consists of Terra Rossa clayey soil washed into the cave through the large, open chimney in the ceiling of the inner chamber.

Table 2
Proposed recent vertical tectonic rates for western Mount Carmel, from previous geodetic and interferometric studies

Reference	Methods, time frame and rates of Mt. Carmel vertical motions
Kafri (1969)	Geodetic leveling: 1) Uplift of a few mm/yr in northeastern Carmel. 2) Subsidence of 5 mm/yr in southern margins.
Even-Tzur (2003)	GPS and precise leveling: The Carmel range uplifted at a rate of 5 mm/yr relative to its surroundings.
Even-Tzur and Agmon (2005)	GPS and precise leveling: 5 mm/yr in the west. 2 mm/yr in the east.
Shahar and Even-Tzur (2005)	High precision leveling: Oscillatory movements, different velocities (~1 mm/yr uplift) in different periods
Novitsky (2006)	Interferometric Synthetic Aperture Radar (InSAR): No motion detected within the resolution of vertical component of 1 mm/yr.

Marine sediments and mollusks from western Mount Carmel caves

Comprehensive sedimentological studies were carried out inside the western Mount Carmel caves: el-Wad (Weinstein-Evron, 1998); Gamal (Weinstein-Evron et al., 1999); Skhul (Ronen, 1976); Tabun (Goldberg, 1973; Jelinek et al., 1973; Farrand, 1979; Ronen and Tsatskin, 1995; Tsatskin et al., 1995) (Fig. 4) and Kebara (Goldberg and Bar-Yosef, 1998). These caves are all situated between 25 and 60 m asl; yet none of them yielded sediments of marine origin.

Marine mollusks are common in coastal and inland Paleolithic sites in the southern Levant (Bar-Yosef, 1988–89; 2005), some of which were recovered from the Tabun, Skhul and el-Wad caves (Garrod and Bate, 1937). They included (Bate, 1937): *Acanthocardia deshayesi* (Payraudeau, 1826), *Laevicardium crassum* (Gmelin, 1791), *Nassarius gibbosulus* (Linnaeus, 1758), *Pecten jacobeus* (Linnaeus, 1758) and *Ostrea crenulifera* (Sowerby, 1871). The shells are dispersed and scattered across the archaeological strata in patterns not typical of marine or coastal deposits. Moreover, they are common in the southeastern Mediterranean today and are not considered Quaternary index fossils (H.K. Mienis, personal communication, June 2007). Although taken recently as evidence for a 40 m rise of western Mount Carmel since MIS 5e (Vita-Finzi and Stringer, 2007), it is more likely that the marine mollusks were brought into the cave by the inhabitants, either as ornaments or as food (Bate, 1937).

Sedimentation patterns of the coastal caves of Israel

The Israeli coast is exposed to highly destructive winter storms typical of 5 m wave height significant, and once every two decades

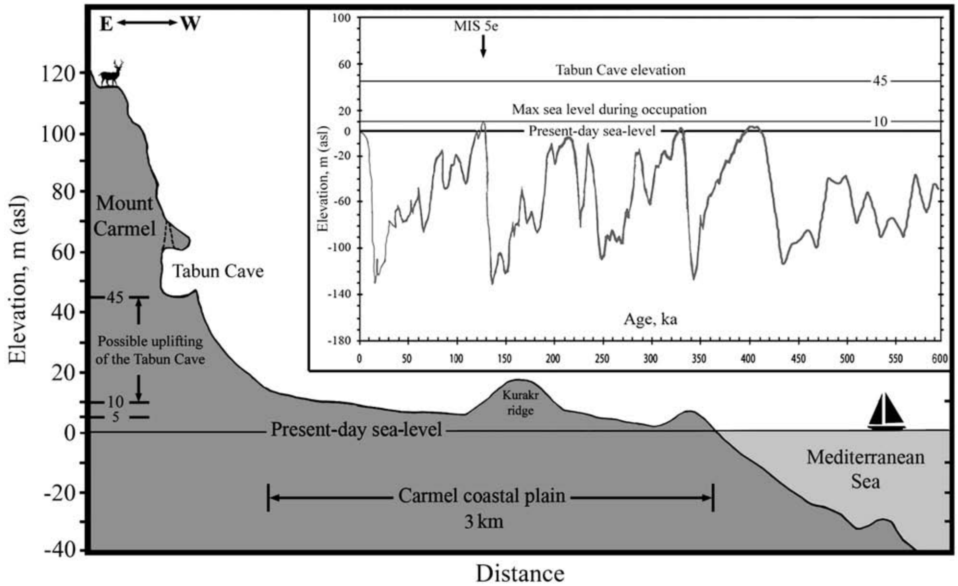

Figure 3. Schematic East–West cross section of the study area exemplifies the possible range of uplift of western Mount Carmel in the last 600 ka. Inset: Global sea-level changes in the last 600 ka and the relative position of the Tabun Cave since the Middle Pleistocene. Modified after Waelbroeck et al. (2002), Rabineau et al. (2006) and Siddall et al. (2006).

the waves reach 7.3 m high significant (Rosen and Kit, 1982; Zviely et al., 2001; 2007). Coastal caves partly flooded by the sea area found today along the Galilee and the Carmel coastal plains, and the sediments found there consist solely of boulders, pebbles and very coarse particles.

The fine sediments preserved in the western Mount Carmel caves, and in particular the very fine, laminated sand that embedded at Tabun Cave (Layers G, F and E), are therefore highly significant. Had the sea penetrated the cave during the occupation period, the waves would have washed out the fine material. Adding to this the absence of marine deposits in any of the western Mount Carmel caves, it can be concluded that the caves were all times above sea level in the last 600 ka.

Maximal possible uplift of the Tabun Cave

As sea level in the last 600 ka has not reached above 5 to 10 m asl (Waelbroeck et al., 2002; Schellmann and Radtke, 2004; Rabineau et al., 2006; Siddall et al., 2006) (Fig. 3), the Tabun Cave presently 45 m

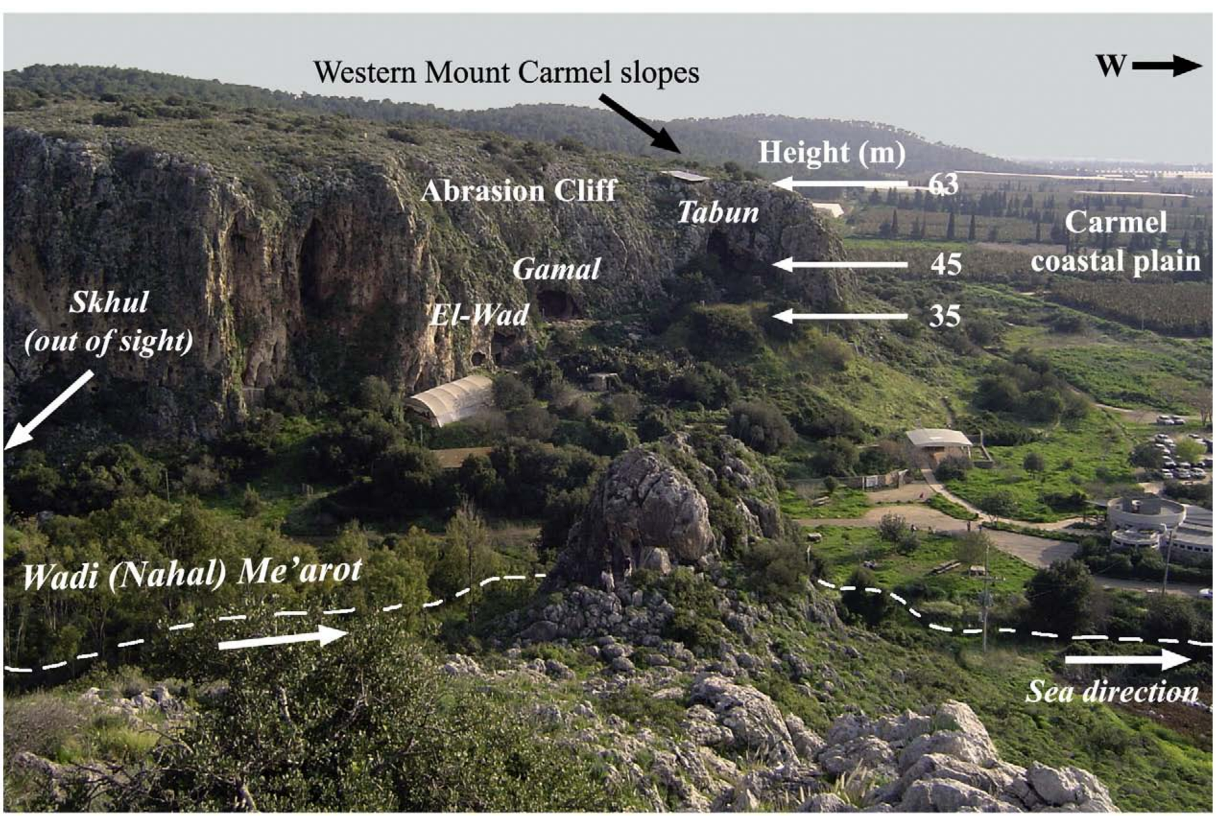

Figure 4. Panoramic view of the western Mount Carmel slopes and the Carmel coastal plain, south of Wadi (Nahal) Me'arot. Note the height of the caves above the present sea level.

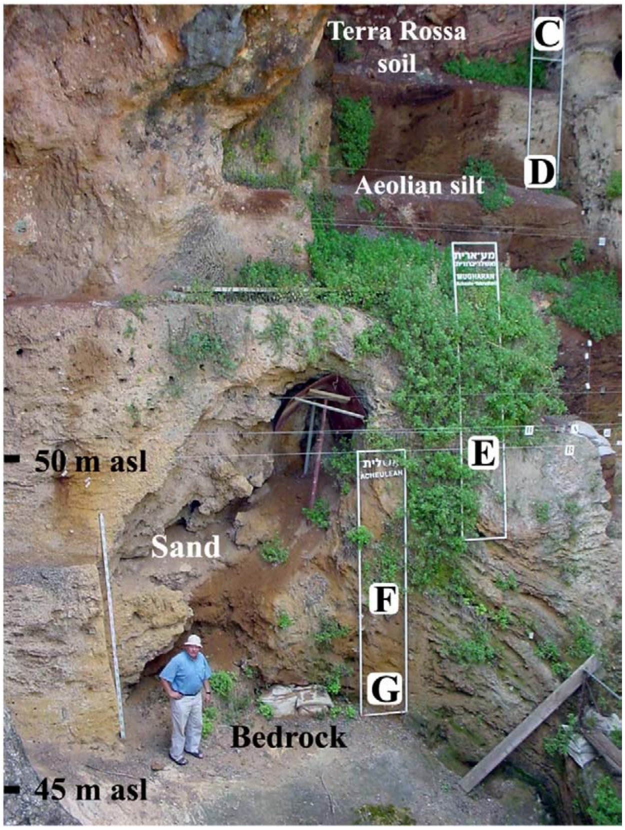

Figure 5. The main part of the stratigraphic section in the Tabun Cave (layers G to C) in 2002. The section is composed mainly of wind-blown, fine quartz Nile-derived sand.

asl, could not have been uplifted within that period by more than 35 to 40 m., i.e. an average uplift rate less than of 58 to 67 mm/ka. However, episodic higher rates or even temporary subsidence within that time frame cannot be ruled out. Obviously, it is also possible that at 600 ka the Tabun Cave was higher than 5 to 10 m asl (even already at its present position). Thus, these results should be considered as the maximal rise and uplift rates of the western Carmel Mountain since the Middle Pleistocene.

Discussion and conclusions

Geological and archaeological considerations, based on evidence from Tabun and nearby caves, indicate that the western Mount Carmel was not uplifted by more than 35 to 40 m in the last about 600 ka, that is a maximal average rate of 58 to 67 mm/ka. This is in accordance with Kafri (1970) and Begin and Zilberman (1997), but in contrast to the higher rates previously suggested (Table 1). The recent hypothesis that the MIS 5e transgression of about 125 ka penetrated the Skhul and el-Wad (Vita-Finzi and Stringer, 2007) caves, is also ruled out.

Comparing the maximal uplift rate suggested here for western Mount Carmel with that of the Carmel coastal plain (approximately 48 mm/ka, by Galili et al., 2007), there could be no more than a small (10 to 19 mm/ka) relative vertical displacement during the last 125 ka, if at all. Since no tectonic fault is known to exist between the two regions, the relative motion, if did occur, could be accommodated by a tilting.

Interestingly, Michelson (1970) mapped several sets of marine terraces along the western slopes of Mount Carmel at various heights, up to 125 m asl. Based on altimetry, he correlated these terraces with Pleistocene high sea levels and assumed that they provide records of interglacial periods. However, as modern studies show that during the last 600 ka the sea level reached a maximum elevation of only 5 to 10 m asl (Waelbroeck et al., 2002; Schellmann and Radtke, 2004; Rabineau et al., 2006; Siddall et al., 2006) (Fig. 3: inset), these terraces seem to antedate the occupation of the Tabun Cave and therefore are older than the Middle Pleistocene.

Comparing the limited uplift of the western Mount Carmel since the Middle Pleistocene (estimated here) with the recent GPS and high-precision geodetic measurements (Table 2), there is a discrepancy of about one order of magnitude. Had the geodetic rates been consistent for the last 600 ka, western Mount Carmel would have reached an elevation of some 600 m or higher.

The quantitative results obtained here shed light on the vertical tectonics of the western Carmel slopes, a long debated issue regarding one of the most prominent structural features in the region. Yet this cannot be simply extrapolated onto the Carmel fault at the eastern Carmel foothills. The many faults and folds existing in the Carmel structure (Fig. 2) are able to absorb the deformation imposed on its western side, without transferring it to the eastern side. Thus, the neotectonics of the Carmel fault should not be simply derived from the present tectonics of the western Carmel slopes.

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Table 3
Tabun Cave chronology

Garrod layer	Jelinek unit	Mean EU ESR age (ka)	Mean LU ESR age (ka)	Combined ESR and US data age (ka)	TL mean age (ka)	RTL	Sediment
Chimney		–	–	–	–	–	Terra Rosa soil
B		082 ± 14 (6)	092 ± 18 (6)	090^{+30}_{-16} (6)	–	–	
		102 ± 17 (1)	122 ± 16 (1)	104^{+33}_{-18} (1)			
C	I	120 ± 16 (1)	140 ± 21 (1)	135^{+60}_{-30} (1)	165 ± 16 (4)	–	
D	II	133 ± 13 (1)	203 ± 26 (1)	143^{+41}_{-28} (1)	196 ± 21 (4)	–	Silt
	V				222 ± 27 (4)	–	
	IX				256 ± 26 (4)	–	
Ea	X	176 ± 22 (1)	213 ± 32 (1)	208^{+102}_{-44} (1)	267 ± 22 (4)	–	Sand
	XI				264 ± 28 (4)	–	
Eb	XII	180 ± 32 (1)	195 ± 37 (1)	–	324 ± 31 (4)	–	
Ec		198 ± 51 (1)	220 ± 63 (1)	–	–	–	
Ec-Ed	XIII	262 ± 32 (5)	330 ± 43 (5)	387^{+49}_{-36} (5)	302 ± 27 (4)	–	
F	XIV	–	–	–	415 ± 27 (3)	–	
G		–	–	–	–	610 ± 150 (2)	
						630 ± 160 (2)	

Reference: (1) Grün and Stringer (2000); (2) Laukhin et al. (2000); (3) Mercier et al. (2000); (4) Mercier and Valladas (2003); (5) Rink et al. (2004); (6) Coppa et al. (2005).

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