

## A late Cretaceous elasmosaurid of the Tethys Sea margins (southern Negev, Israel), and its palaeogeographic reconstruction<sup>‡</sup>

R. Rabinovich<sup>1,\*</sup>, H. Ginat<sup>2</sup>, M. Schudack<sup>3</sup>, U. Schudack<sup>3</sup>, S. Ashckenazi-Polivoda<sup>2</sup> & G. Rogolsky<sup>2</sup>

<sup>1</sup> National Natural History Collections, Institute of Earth Sciences, Institute of Archaeology, The Hebrew University of Jerusalem, Israel

<sup>2</sup> The Dead Sea and Arava Science Center, Israel

<sup>3</sup> Fachrichtung Paläontologie, Institut für Geologische Wissenschaften, Freie Universität Berlin, Germany

\* Corresponding author. Email: rivkar@mail.huji.ac.il

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### Abstract

Recent research on the late Cretaceous (Santonian), Menuha Formation of the southern Negev, Israel, has revealed several unconformities in its exposures, spatial changes in its lithofacies, agglomerations of its carbonate concretions and nodules at a variety of localities. At Menuha Ridge Site 20, portions of a new elasmosaurid skeleton were found within deposits of laminated bio-micritic muddy limestone with thin phosphatic layers. The sediments are rich in microfossils – foraminifera and ostracods preserved in the carbonate mud. Planktic foraminifera species (e.g. *Dicarinella asymetrica*, *D. concavata*, *Sigalia decoratissima carpatica*) appear as well as species indicative of opportunistic life strategies typical of a forming upwelling system in the region. Marine ostracods (e.g. *Brachycythere angulata*, *Cythereis rosenfeldi evoluta*) and many echinoid spines suggest an open marine environment. Using a multidisciplinary approach, we offer here a reconstruction of the micro-regional palaeogeography along a segment of the ancient shoreline of the Tethys Sea during the Santonian, and explain the environmental conditions under which the various fauna lived. This new elasmosaurid is examined in light of the above and compared with evidence from the adjacent areas along the margins of the southern Tethys Sea.

**Keywords:** Arava Valley, elasmosaurid, Menuha Formation, Santonian, Tethys Sea

### Introduction

Multidisciplinary research in the southern Negev endeavours to reconstruct the geological setting of various outcrops of alternating layers of chalk, dolomite and flint, rich in fauna and known as the Menuha Formation. Geological field observations have revealed unconformities, spatial changes in lithofacies, agglomerations of carbonate (or limestone) concretions and other nodules as well as vertebrate remains in select exposures of this formation; indications of various ancient environments.

### Geography and geology background

The research area is located in the central Arava Valley, a segment of the Great Rift Valley in southern Israel (Fig. 1). It is

a 160-km long morphotectonic depression that constitutes the southern extension of the Dead Sea Fault (DSF), which connects the Dead Sea in the north with the Gulf of Elat in the south (Garfunkel, 1981; Garfunkel & Ben-Avraham, 1996). The study area is a segment located along the western central margins of the DSF, where the exposed geological succession is dominated by marine sedimentary rocks of the Mt. Scopus Group (Senonian and Pliocene) and the Avdat Group (Eocene) (Fig. 2). Prevalent rocks in the research area are limestone, chalk, chert, marl and shale. At low altitudes, along 'wadis' (i.e. seasonal water courses) and in nearby terraces, conglomerates from the Dead Sea Group (Pliocene, Pleistocene and Holocene) are either exposed or lie buried at shallow depths. The climate in the area is extremely arid. The altitude of the region is around 300 m above sea level. Mean annual

<sup>‡</sup> The second author's surname was incorrect in the original version of this article. A notice detailing this has been published and the error rectified in the online and print PDF and HTML copies

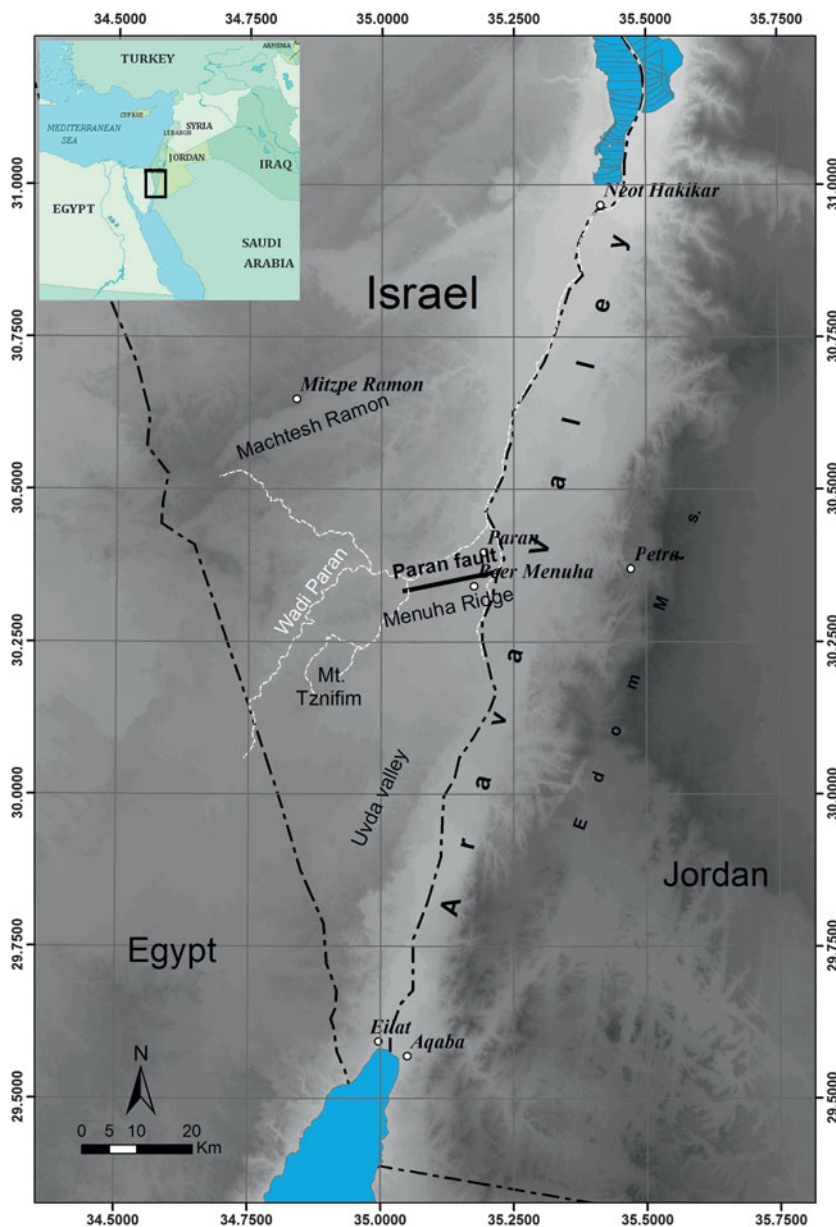


Fig. 1. Location map of the research area and localities mentioned in the text. Note that Site 20 is in the Menuha Ridge.

precipitation is 50 mm, which usually occurs in a few rainfall events, while the mean annual temperature is 23°C (Atlas of Israel, 1985).

The regional, structural setting is dominated by NNE trending sinistral faults of the DSF System along the Arava Valley, with E-W faults of secondary importance (Bartov, 1974). The Paran Fault, located adjacent to Wadi Paran and the Menuha Ridge (Sakal, 1998; Dvory, 2002), is one of those dextral E-W faults. The Menuha Ridge is mostly composed of Middle to late Cretaceous (Late Albian to Coniacian) carbonate sequences and consists of a nearly E-W trending, irregular anticlinal structure whose southern flank is displaced by the Paran Fault. Folding and differential fault movements that produced the exposed structure occurred intermittently from the Senonian to the Miocene (Sakal, 1998).

### Geology of Menuha Formation

The Menuha Formation is a late Cretaceous, marine, mostly Santonian (maximally Late Coniacian to Early Campanian) formation that is exposed in several places in Israel. In eastern areas of the Negev the Menuha Formation represents late Cretaceous platform sequences and the base of the Mount Scopus Group, the most transgressive part of the Upper Cretaceous (mega-cycle III 'Aruma'). The deposition of the group coincided with earlier phases of the Syrian-Arch folding event. Its accumulation therefore conformed to pre-existing topographical formation, with resulting uneven thickness. Synclinal facies are distinguished by thick sections of chalk, marl and chert, while anticlinal sections are much reduced in thickness (Rosenfeld & Hirsch, 2005), therefore many significant hiatuses

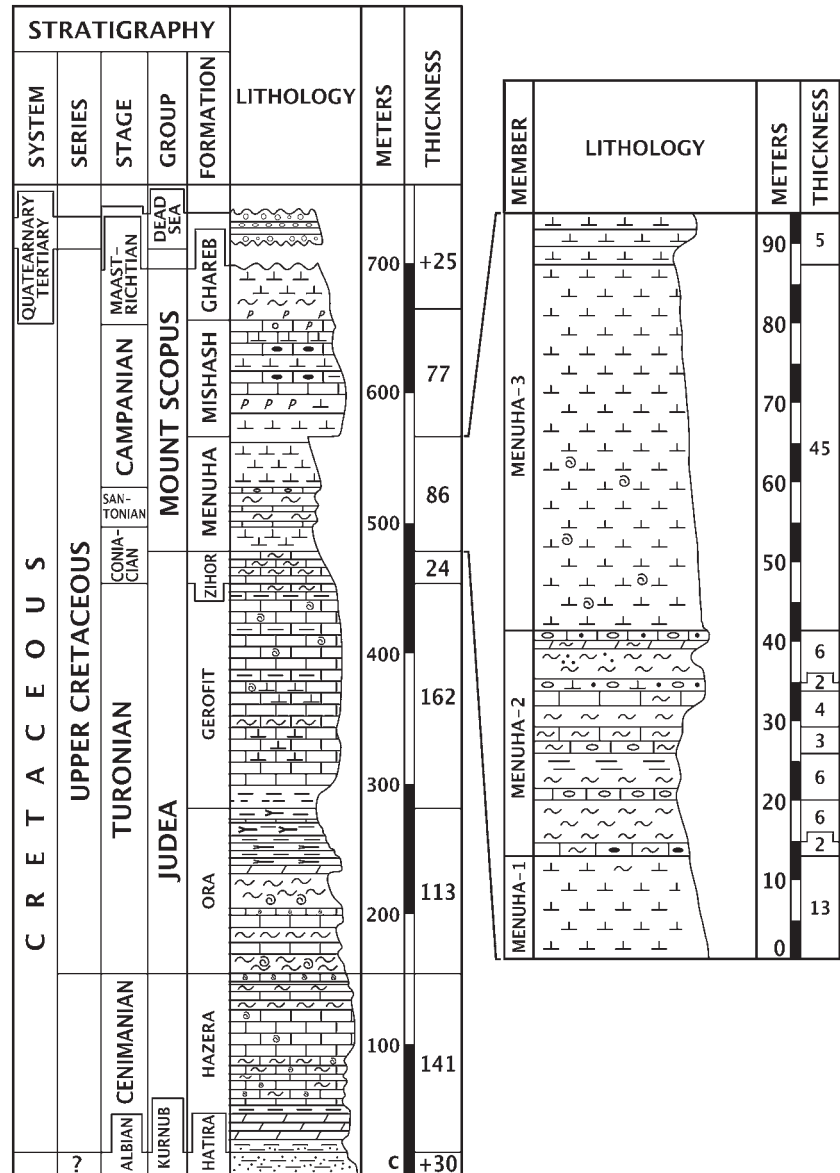


Fig. 2. Geological columnar section of the marine rocks in the Negev. Enlarged: columnar section of the Menuha Formation.

characterise anticlinal sections (as opposed to synclinal facies), which makes extensive biostratigraphical investigations and correlations crucial for understanding this depositional system and its palaeogeographical evolution. In many areas, the Menuha Formation (Santonian) is unconformable and overlies the Turonian (the Coniacian is often missing; see also Rosenfeld & Hirsch, 2005). It is one of the main hiatuses in the Mesozoic succession of Israel. Towards the overlying Mishash Formation (Upper Campanian) the contact is conformable (Fig. 2).

For purposes of mapping, the Menuha Formation in the southern Negev was divided into three members with different lithologies (Ginat, 1991; Shalmon et al., 2009) (Fig. 2):

**Chalk Member (M1):** This member consists of soft white chalk with gypsum and calcite veins. Its thickness is between 13 and 17 m in outcrops not disturbed by tectonic activities causing unconformities.

**Marl Member (M2):** The facies of this member change from north to south. In the north, near the Paran Fault and Hiyyon and Uvda Valleys, they are thinner (c. 30 m thick), composed of soft marls and clays with some layers of limestone and partly silicified limestone concretions. In some instances the layers have phosphorite covers. These concretions are good markers for this member. Towards the southeast their thicknesses increase to c. 60 m. There the sequence includes a c. 10-m layer of limestone and dolostone, some chert, and less marl and clay. There are also fewer limestone concretions and massive chert deposits (c. 0.5 m thick). The chert is mostly reddish, laminar and with lineation; in some locations it is brecciated. Some layers of colourful sandstone are also exposed in that same part of the section.

**Chalk Member (M3):** Mostly of white chalk, its thickness is between 28 and 45 m. Remains of *Pycnodonte vesicularis* are abundant field markers in this unit (Ginat, 1991). In the upper

**Columnar section – site 20, Menuha formation**  
scale 1:20

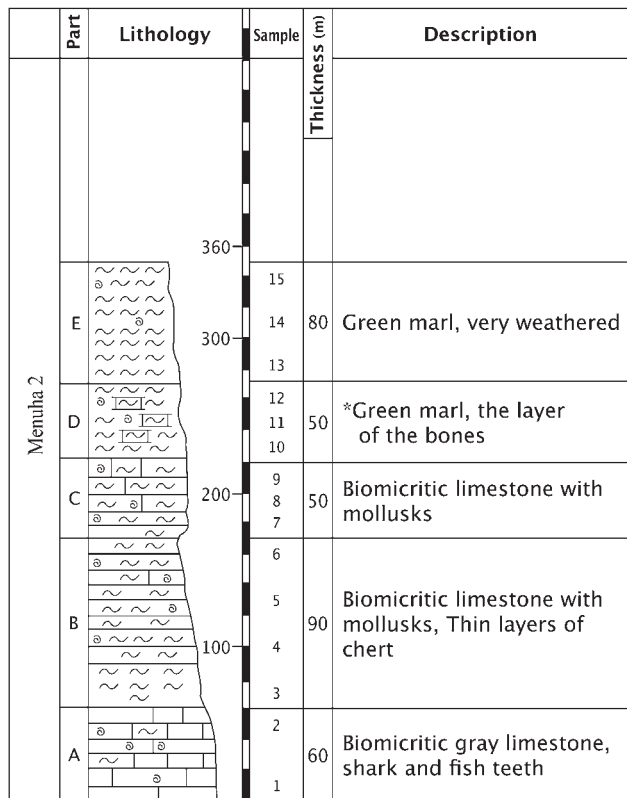


Fig. 3. Detailed geological columnar section of Menuha Ridge Site 20.

reaches of sections at some locations, green and clay marls are found.

**Material and methods**

The research area was mapped (Fig. 1), sections described and samples from several localities along each section were taken



Fig. 4. Menuha Ridge Site 20 general view from the east. Notice the excavation area.

for further sedimentological and faunal analysis. A vertebra found rolling out of the SE slope of the Menuha Ridge at Site 20 (reference grid 35.0573477/30.3005783 UTM, Figs 1–3) induced us to launch an excavation there. Sediment at that site is mostly bio-micritic muddy limestone with thin phosphatic layers (Figs 3–5).

During the excavation parts of an elasmosaurid skeleton were found in the contact zone between marl and marly limestone layers (Unit D). Portions of those layers are of carbonate mud composed of fine silt-size particles. Those laminae are very thin, mostly continuous and indicate deposition without mixing. The sediments are rich in microfossils, foraminifera and ostracods. Our observations on thin sections under a microscope suggest that deposition of faunal elements occurred in an anaerobic marine environment. Associated thin phosphatic layers representing a sea are indicative of slight evidence of activity by benthonic fauna. Very fine grains in the associated marl represent clastic contributions from high biogenic, mostly planktonic activity as well as from a nearby terrestrial environment.

Sediment samples from Site 20 section (see below) revealed a faunal record rich in ostracods, foraminifera, teeth of chondrichthyans and other fishes, as well as echinoid spines, albeit very poor in mollusc remains. The large quantity of fish teeth and thick layers of chert (10 cm) reflect an abundance of fauna with silicate skeletons.

**Micropaleontology of Site 20**

**Ostracods**

The processing of sediment samples from Site 20 followed standard methods. Samples were treated with warm water and if they did not disperse in that medium they were then treated with a solution of 3.5% H<sub>2</sub>O<sub>2</sub>. Samples were washed through sieves (1000, 500, 250 and 125 μm), picked and



Fig. 5. Vertebra HM 104 in situ. Note the surrounding sediments.

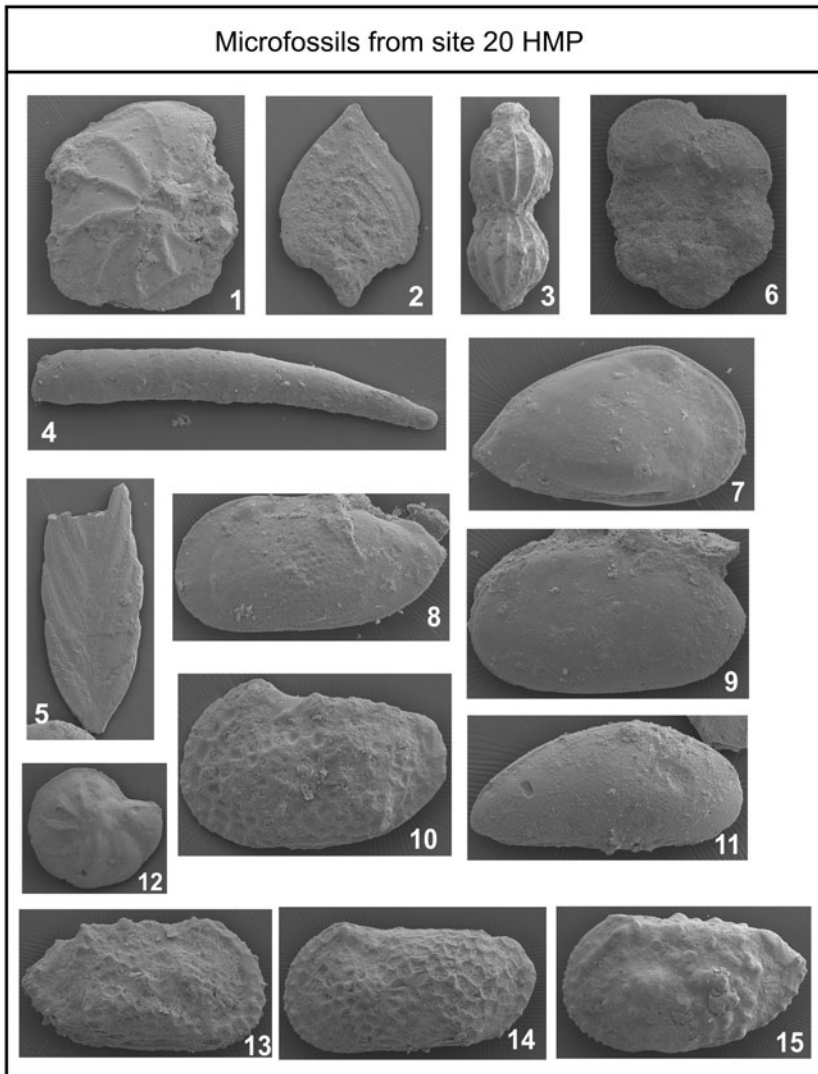


Fig. 6. Ostracoda and foraminifera from Menuha Ridge Site 20. Determinations by U. Schudack and S. Ashckenazi-Polivoda. 1, *Epistomina* sp., Sample HMP 10, length 900  $\mu\text{m}$ ; 2, *Neoflabellina* sp., Sample HMP 10, length 1173  $\mu\text{m}$ ; 3, *Pyramidulina* affinis, Sample HMP 10, length 570  $\mu\text{m}$ ; 4, *Laevidentalina* sp., Sample HMP 10, length 1721  $\mu\text{m}$ ; 5, *Frondiculina* sp., Sample HMP 10, length 642  $\mu\text{m}$ ; 6, *Dicarinella* sp., Sample HMP 10, length 462  $\mu\text{m}$ ; 7, *Brachycythere angulata* (Grekoff, 1951), Sample HMP 10, length 846  $\mu\text{m}$ ; 8, *Protobuntonia numidica* (Grekoff, 1954), Sample HMP 10, length 888  $\mu\text{m}$ ; 9, *Cytherella* sp., Sample HMP 10, length 718  $\mu\text{m}$ ; 10, ?*Cythereis* sp., Sample HMP 14, length 822  $\mu\text{m}$ ; 11, *Paracypris* sp., Sample HMP 14, length 704  $\mu\text{m}$ ; 12, *Lenticulina* sp., HMP section 20, Sample HMP 15, length 786  $\mu\text{m}$ ; 13, ?*Cythereis diversireticulata* (Honigstein, 1984), Sample HMP 15, length 766  $\mu\text{m}$ ; 14, ?*Cythereis* sp., Sample HMP 15, length 926  $\mu\text{m}$ ; 15, *Cythereis rosenfeldi evoluta* (Honigstein, 1984).

afterwards scanned at the Institut für Geologische Wissenschaften, Fachrichtung Paläontologie, FU Berlin, Germany, with a Zeiss Supra 40VP scanning electron microscope. Seventeen samples from the section of Site 20 were investigated in order to provide a general overview of fauna recovered. They included a rich variety, observed mainly at the bottom of the section in Unit D and at the top of Unit E, where the bones were found.

Ostracoda in these samples represent typical Santonian associations with the following species (Fig. 6, 7–11 and 13–15): *Brachycythere angulata* (Grekoff, 1951), *Protobuntonia numidica* (Grekoff, 1954), *Cythereis rosenfeldi evoluta* (Honigstein 1984), ?*Cythereis diversireticulata* (Honigstein, 1984), *Cytherella*

sp., *Paracypris* sp., ?*Cythereis* sp. (preliminary determinations by U. Schudack). Additional analyses suggest that classifications for this group need major revisions.

#### Foraminifera

Three samples (depth 90, 110 and 140 m) were disaggregated for foraminiferal analyses, washed through a > 63  $\mu\text{m}$  sieve and subsequently dried at 50°C. The states of preservation of the foraminiferal tests are generally good throughout the studied sequence. For each sample, foraminiferal specimens were identified and counted. Species identification follows taxonomy common in relevant literature. Ages given are

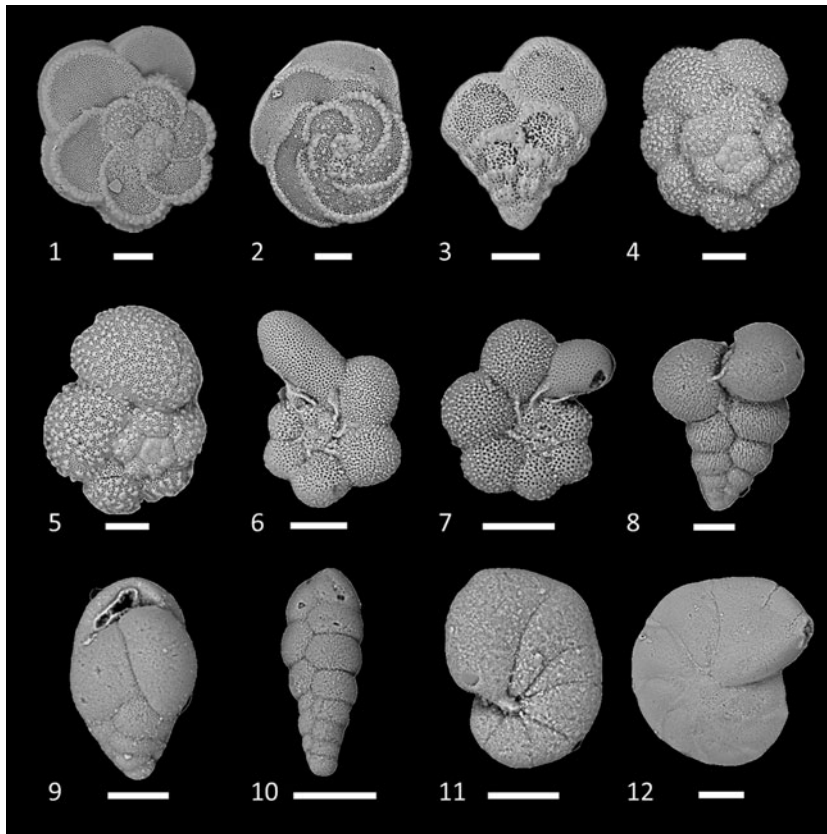


Fig. 7. Selected planktic and benthic foraminifera common at the studied sequence, from depth 110 m. Scale bar 100  $\mu\text{m}$  1-7, 12; scale bar 50  $\mu\text{m}$  8-9, 11. 1, *Dicarinella asymetrica*, spiral side; 2, *Contusotruncana fornicate*, spiral side; 3, *Sigalia decoratissima carpatica*; 4, *Whiteinella paradubia*; 5, *Costellagerina* sp.; 6, *Hastigerinoides calavat*; 7, *Globigerinelloides ehenbergi*; 8, *Heterohelix globulosa*; 9, *Praebulimina hofkeri*; 10, *Neobulimina irregularis*; 11, *Nonionella austiniana*; 12, *Lenticulina* sp.

according to the recent geological time scale (e.g. GTS 2012, in Cohen et al., 2013; Gradstein et al., 2012).

Planktic and benthic foraminiferal assemblages in the samples were alike (see Fig. 7 for selected species). The planktic foraminiferal assemblage is dominated by *Contusotruncana fornicata*, *Costellagerina pilula*, *Archaeoglobigerina cretacea*, *Hedbergella* spp., *Heterohelix* spp., *Whiteinella* spp. and *Globigerinelloides* spp. In addition, the species *Dicarinella asymetrica*, *D. concavata*, *Marginutruncana* spp. and *Sigalia decoratissima carpatica*, which are considered biostratigraphic markers, were also present in all of the studied samples. The benthic foraminiferal assemblage is diversified and dominated by species belonging to the genera *Pyramidulina*, *Neoflabelina*, *Paraebulimina*, *Laevidentalina*, *Gavelinella*, *Nonionella*, *Gabonella* and *Lenticulina*.

## The vertebrate remains

### Systematic palaeontology

SAUROPTERYGIA Owen, 1860  
 PLESIOSAURIA de Blainville, 1835  
 PLESIOSAUROIDEA Welles, 1943

ELASMOSAURIDAE Cope, 1869

Elasmosauridae gen. et sp. indet

### Material

This includes a tooth fragment that was exposed during the excavation but unfortunately was completely shattered following excavations (HM 101; Fig. 8), a possible dentary fragment (HM 7, Fig. 9), a propodial fragment (HM 9, Fig. 10), seven cervical vertebrae (HM 3, HM 4, HM 5, HM 6, HM 104, HM 107, HM 108, Figs 11 and 12) and one dorsal vertebra (HM 2, Fig. 13).

### The locality

The Menuha Ridge (SE slope, Site 20), Arava Valley, a segment of the Great Rift Valley in southern Israel and the Menuha Formation, which are late Cretaceous, mostly Santonian (Late Coniacian to Early Campanian).

### Description of the skeletal elements

Some characteristics of the tooth (HM 101) such as its c. 1-cm wide base, the oval basal cross-section of its crown and its apicobasal running ridges can be observed even in field photos



Fig. 8. Part of a tooth (HM 101) in situ.

(see Fig. 8). A fragment of a dentary (?) (HM 7) has three pits. These pits, in the form of small depressions, appear on the lingual part. As the fragment is not complete we can only suggest that they might be part of dental lamina foramina.

A distal part of a propodial shaft (HM 9) was found eroding from the slope of Site 20. The thickness of the element and its general uncurved shape suggests it is a part of a propodial rather than a girdle element. Its surface is exfoliated and thus it is impossible to determine anything concerning its articular surface. Its preserved size (length 19 cm, width 15 cm) suggests it is a part of a much larger element.

The vertebrae lack the neural arches and the neural spines, and the dorsal vertebra lacks transverse processes. Our identification of the vertebral types was based on characteristics observed on the centra. These are: (1) the location of the rib facets, (2) the presence of ventral foramina subcentralia, located close to each other in the anterior vertebrae, and progressively migrated laterally in the posterior cervicals (Brown, 1981), (3) the existence of a lateral ridge, and to a lesser degree the measurements of the centra, and (4) the existence of a ventral notch. None of these attributes can stand alone as absolute evidence, but combined they suggest the identification of the vertebral types (Tables 1 and 2).

Following definitions summarised in Sachs et al. (2013) and Benson & Druckenmiller (2014), we were able, from



Fig. 9. A dentary(?) fragment (HM 7), anterior view.

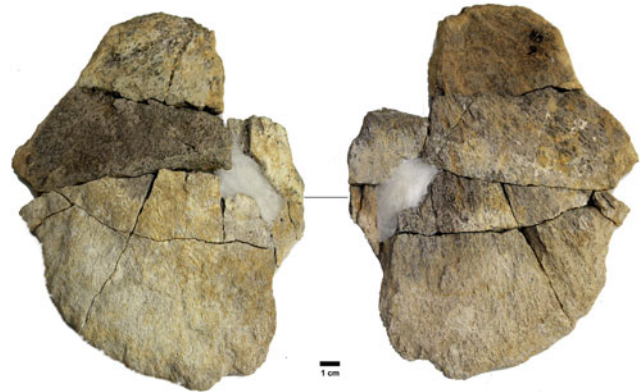


Fig. 10. A propodial fragment (HM 9), dorsal and ventral aspects.

examination of the centra, to identify seven cervical vertebrae. Three are probably from the anterior (HM 3, HM 108, HM 4, Fig. 11) and four from the posterior parts of a neck (HM 107, HM 104, HM 5, HM 6, Fig. 12).

The centra of the anterior vertebrae are longer on their antero-posterior axes than high or wide and they have lateral ridges. Their articulation surfaces are platycoelous with

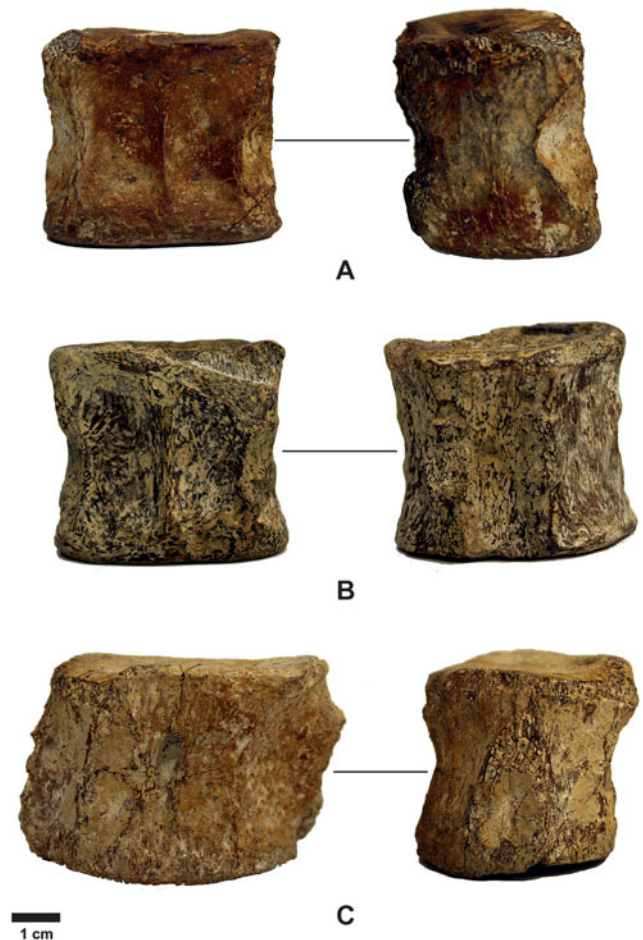


Fig. 11. Cervical vertebrae: A, HM 3, ventral (right) and lateral (left) views - notice the erosion of the lateral aspect; B, HM 108, ventral (right) and dorsal (left) views; C, HM 4, dorsal (right) and lateral (left) views.

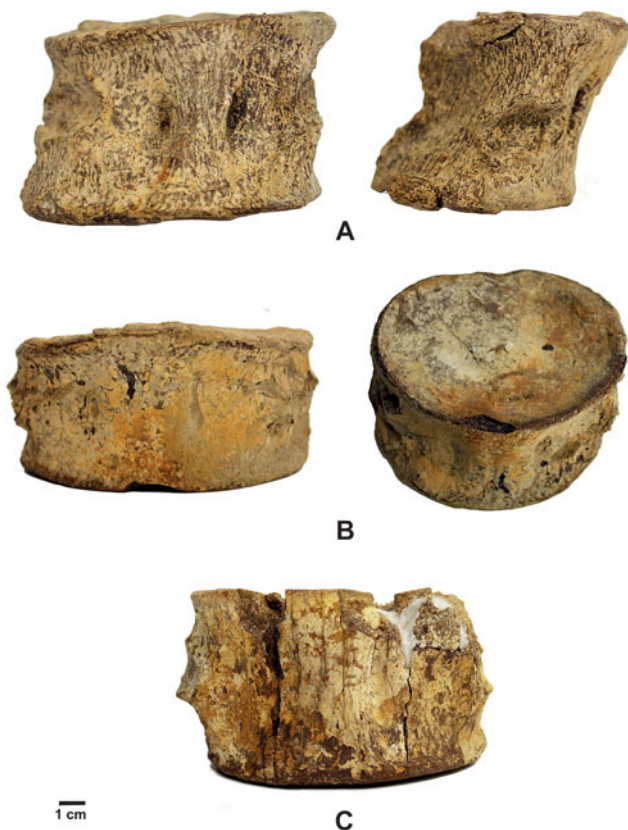


Fig. 12. Cervical vertebrae: A, HM 107, ventral (right) and lateral (left) views; B, HM 104, ventral (right) and articular (left) views; C, HM 6, ventral view.

foramina subcentralia on the ventral surfaces of their centra. The posterior cervical centra are shorter than wide and have wider facets. The centrum of the dorsal vertebra (HM 2, Fig. 13) has circular articular faces, lacking any evidence of lateral rib facets that, had they existed, would have been located on its neural arch (e.g. Bardet et al., 1999).

Based on the above-noted features, those parts of the skeleton under consideration have been designated elasmosaurid. Notably, similar finds of undetermined elasmosaurids have been found in Syria, Jordan, Iran, Egypt (Werner & Bardet, 1996; Bardet & Pereda Suberbiola, 2002; Bardet, 2012) and Morocco (Vincent et al., 2013). Although this is the first time that several elements supposedly of the same individual have been found in a clear context in the Menuha Formation, it is not unexpected that such finds would have been deposited in the Negev.

### Ontogeny

In the absence of neural arches on the vertebrae, it is difficult to determine if they are lacking because they had not yet fused to the centra (following Brown's 1981 age definitions) or because parts of them were broken and/or eroded. The dorsal aspects of the centra are not well preserved in most cases

(Figs 11 and 12) thus a more precise observation on their characteristics is impossible. Whenever visible, cervical ribs seem to have not been ossified with the centrum. However, a slight thickening of their rims is noticeable (e.g. HM 107, HM 104, Fig. 12A and B). Paedomorphism (retention of juvenile features in a mature individual) was suggested as a common phenomena in elasmosaurids (Araújo et al., submitted). Although the remains from Site 20 are clearly of a not very young animal (e.g. in Vincent et al., 2013), a more precise estimation of its age is not warranted based on data presently available.

### Taphonomy

The exposure of the finds provided only primary taphonomical observations, based on merely a few vertebrae and a flat fragment of a bone eroding from the slope of the Menuha Ridge. Subsequent excavation, albeit limited by the outline of the slope, followed the layer that contained the bones for a few metres. That matrix proved to be very hard, while recent gypsum inclusions had penetrated between breaks in the bones exposed.

We attempted to establish whether those remains were *in situ* and represent a single individual. That question can now be partially answered. Although the skeleton is incomplete, the sizes of the bones, their general appearances, states of compaction and positions suggest that they all do indeed belong to the same individual. However, the skeletal elements, although found relatively close to each other, were not in their correct anatomical positions. Possibly a segment of the neck (i.e. several vertebrae) was bent over a more posterior area of the body.

Completeness and articulation of a skeleton can hint at depositional and post-depositional processes (Beardmore et al., 2012), but unfortunately in the current case no articulation and no completeness exist. However, other indications might help in reconstructing the taphonomical history of the elasmosaurid of Site 20. The general state of preservation of its remains is quite good, although parts are missing, possibly resulting from formation processes that created the hard matrix they were recovered from. Careful examination of the skeletal



Fig. 13. Dorsal vertebra HM 2, anterolateral view.



Table 1. Descriptive morphological traits of the vertebrae from Menuha Ridge Site 20.

		Ribarticular surface	Foramina subcentralia	Foramina location (*sizes differ)	Lateral ridge	Fusion to rib	Thickened rim	Asymmetry compaction
HM 3	Cerv	Mid centra	Ventral-centrum	Close to each other*	Present	No		
HM 108	Cerv	Mid centra ?	Ventral-centrum	Close to each other*	Present	No	Present	
HM 4	Cerv	Mid ventral	Ventral-centrum	Distant from each other*	Present	?		Asymmetrical
HM 107	Cerv	Mid centra	Ventral-centrum	Distant from each other*			Present	Asymmetrical
HM 104	Cerv	Mid centra	?				Present?	
HM 5	Cerv	Mid centra	Ventral-centrum	Close to each other*			Weathered rim	Asymmetrical
HM 6	Cerv	Mid centra	Ventral-centrum	Distant from each other*				
HM 2	Dorsal							Asymmetrical

elements' surfaces clearly points to erosion that occurred prior to excavation. Examination of all the elements under a light microscope also failed to indicate any signs of scavenging on the bones. Notably, the states of preservation of the elements are not uniform, indicating they underwent varied degrees of weathering that also altered their appearances. Complex processes of accumulation that influenced the bones resulted in *in situ* exfoliation and compaction. The lateral compression observed on several vertebrae suggests their possible ascription to the same individual (Fig. 12A). The compression is especially severe on the dorsal vertebra (Fig. 13).

## Discussion

Because there is a plethora of marine reptiles, including plesiosaurs, in deposits of the Mesozoic, they have become an enduring subject of research, especially as new finds occur the world over, while known specimens are often restudied (e.g. Powell & Moh'd, 2011; Knutsen et al., 2012; O'Gorman, 2012; Vincent, 2012; Sachs et al., 2013). It is in this scholarly vein that we attempt here to explicate the newly excavated specimen from the Santonian deposit described above; its environment and its faunal context within the confines of the Mediterranean Tethys, and more specifically within the upwelling belt of the southern Tethys Sea (Bardet, 2012).

## Paleoenvironment

Paleoenvironmental indications are based on an accumulation of evidence from several disciplines: structural geology, geochemistry and micropalaeontology. The late Cretaceous marine succession of Israel has been influenced by two major unrelated processes (Ashckenazi-Polivoda et al., 2010):

1. Deposition in tectonically controlled, NE-trending shelf basins associated with the Syrian Arc System (Krenkel, 1924).

This deformation differentiated the outer part of the 'ramp-shelf' (nearly 100 km wide) into sub-parallel NE-SW anticlinal ridges and synclinal basins, resulting in lateral changes in thicknesses and facies.

2. Development of a high-productivity upwelling regime from Santonian to Maastrichtian times along the southern margins of the Tethys Sea (Ashckenazi-Polivoda et al., 2010 and references therein).

Geochemical evidence suggests that the evolution of Tethyan phosphogenesis (phosphatic belt) along the northern edges of the Arabian-African shield during the Cretaceous-Eocene can be deduced from temporal variations of Ca and Nd isotopes and rates of P accumulation. They further suggest that (Soudry et al., 2006, 48; references therein):

'Only in the Late Turonian-Early Santonian, after the entire platform was changed into a subsiding ramp by the compressive deformation which affected the whole Levant (Bentor and

Table 2. Measurements of the vertebrae from Menuha Ridge Site 20: 1, the greatest width (transversally) is measured at the articular face; 2, the greatest length (anteriorposteriorly) is measured at the lateral side; 3, the height (dorsoventrally) measured at the articular face.

		Part present	L	W	H	VLI
HM 3	Cerv	Centra	5	4.8	3.6	69
HM 108	Cerv	Centra	5.2	4.4	3.7	70
HM 4	Cerv	Centra	5	6	5	50
HM 107	Cerv	Centra	7.3	11	7.8	47
HM 104	Cerv	Centra	5.5	11.8	6.5	42
HM 5	Cerv	Centra not complete (bell shape)	7.1	10.5	8.3	43
HM 6	Cerv	Centra incomplete; both facets incomplete	7.5	11	9.5	39
HM 2	Dorsal	Centra, compressed	6	9	8.5	35

Vroman, 1954; Bosworth et al., 1999), would the upwelled nutrient-laden waters be able to penetrate the innermost south Tethys shelves, putting an end to the carbonate platform by excess of nutrients (e.g., Kinsey and Davies, 1979; Hallock and Schlager, 1986) and initiating an unusual sedimentary regime that produces the classic upwelling triad of organic-rich, silica-rich, and phosphate-rich sediments.'

The micropalaeontological record, in particular of the foraminiferal assemblages of the late Cretaceous in Israel, has been studied intensively, mainly by Almogi-Labin et al. (1986, 1991, 1993), Reiss et al. (1985, 1986), Reiss (1988) and lately by Ashckenazi-Polivoda et al. (2010, 2011) and Almogi-Labin et al. (2012). A detailed chronostratigraphy was recently established by Meilijson et al. (2014) for the Coniacian–Maastrichtian of central and southern Israel. Based on their study, three planktic foraminiferal zones were assigned to the Menuha Formation from the Late Coniacian to Early Campanian: the *Dicarinella concavata* Zone, the *D. asymetrica* Zone and the *Globotruncanella elevata* Zone. The studied section at Menuha Ridge Site 20 is dated to Santonian (86.66–83.6 Ma), *D. asymetrica* Zone, based on the presence of the nominated species and other indicative planktic foraminifera species, such as *D. concavata*, *Marginotruncana* spp, and *Sigalia decoratissima carpatica* (Almogi-Labin et al., 1986; Robaszynski & Caron, 1995; Petrizzo, 2000, 2001).

The planktic foraminiferal assemblage of Menuha Ridge Site 20 is dominated by small-sized and simple morphotype species and genera such as *Costellagerina pilula*, *Archaeoglobigerina cretacea*, *Hedbergella* spp., *Heterohelix* spp., *Whiteinella* spp. and *Globigerinelloides* spp. These species, considered to be r-selected and opportunist (r-strategists), are supposed to have had high reproductive potential and have inhabited more nutrient-rich waters close to eutrophy. They are indicators of cooler and/or unstable environments (Petrizzo, 2002; Ashckenazi-Polivoda et al., 2011).

The benthic foraminiferal assemblage at the site is diversified and dominated by buliminid and rotaliid species that are indicative of high food flux and oxygen depletion of the sea floor (Almogi-Labin et al., 1993, 2012; Ashckenazi-Polivoda et al., 2010, 2011). These conditions of increased surface water productivity and decreased sea floor aeration signify the onset of an upwelling regime in the late Santonian in southern and central Israel (Meilijson et al. 2014).

### **Santonian plesiosauids from the southern Mediterranean Tethys**

Most of the marine reptile remains from the southern Mediterranean Tethys are assigned to later periods. They are especially found in the Maastrichtian phosphatic belt (Bardet, 2012). However, as Bardet (2012, 585) has noted: 'Plesiosaurs remain too scarce so that no clear pattern of distribution can be derived from them.'

*Zarafasaura oceanis* and body elements of elasmosaurids from the latest Cretaceous of Morocco, which may be of the same species (Vincent et al., 2013), provide new information about the palaeobiodiversity and palaeobiogeographical distribution of Maastrichtian plesiosaurs (Vincent et al., 2011). Previously described species from the late Cretaceous of North Africa include the polycotyliids *Thililua longicollis* (Bardet et al., 2003), *Manemergus anguirostris* (Buchy et al., 2005), elasmosaurid *Libonectes atlasense* (Buchy, 2006) and *Plesiosaurus mauritanicus* (Arambourg, 1952; considered as a *nomen dubium* in Welles, 1962 and Vincent et al., 2011).

Some isolated finds of elasmosaurid plesiosaurs from phosphate deposits of Rusiefa, Jordan have been identified as *Plesiosaurus mauritanicus* by Arambourg et al. (1959). More recently isolated elasmosaurid teeth, vertebrae and propodial bones have also been noted (Bardet & Pereda Suberbiola, 2002). In the Harrana of Jordan, Kaddumi (2006, 4) has lately reported the find of a plesiosaurid, represented by a well-preserved, but incomplete polycotyliid skull of early Maastrichtian Age.

Al Maleh and Bardet (2003, Fig. 4, 5–7) have described six associated cervical vertebrae of an elasmosaurid in Santonian deposits of the Palmyrides in central Syria. Among other fauna they also noted a Selachian tooth and a primitive chelonoid marine turtle, indicators of a shallow marine environment (Al Maleh & Bardet, 2003). Elasmosauridae gen. and sp. indet. teeth and cervical vertebrae have also been found at several localities in the Palmyrides of Syria of early Maastrichtian age (Bardet et al., 2000).

In addition to our finds, in Israel a plesiosaur vertebra from the Ma'ayan Netafim area near Elat (Haas, 1958) derives from a geological setting, the nature of which is uncertain. Unfortunately, as its exact location is obscure it is difficult to assign it to any particular geological formation. Kolodny and Raab (1988), in a study on oxygen isotope composition that deals with paleothermometry of tropical Cretaceous and Tertiary shelf water, noted the presence of *Plesiosauria* vertebra of Santonian–Lower Campanian Age from Nahal Zin (a seasonal water course debouching into the Arava Valley, southern Negev, Israel). However, those finds have not been described in detail.

### **Morphological characteristics of the elasmosaurid from the southern Negev**

Reports on almost complete specimens or complete skeletal elements offer many data, including details of the skeletal anatomy of elasmosaurid plesiosaurs. They indicate variability in shapes, sizes and proportions, offering a much more complex picture of this taxon than was previously understood. They further indicate variations dependent upon ontogenetic ages of specimens, differences in species and individual characteristics of specimens. Variations, especially in overall skull morphology (e.g. Benson & Druckenmiller, 2014) and post-cranial elements (O'Keefe & Hiller 2006; Sachs et al., 2013;

Benson & Druckenmiller, 2014), have been observed. However, for the present study only morphological variations along the vertebral column are relevant.

Before we are able to properly characterise a detailed skeletal morphology of our specimen, it is first necessary to definitively determine whether or not the remains from the Menuha Ridge are of a single individual and which ontogenetic stage they represent. Unfortunately, the dentary, the broken tooth fragment and the other parts of bones are not diagnostic enough to provide such details. By contrast, the vertebrae are the only body elements that preserve some morphological characteristics.

Variations noted by us in the centra sizes of the cervicals are thought to have three causes: (1) ontogenetic allometry, (2) intracolumn variation and (3) taxonomic variation (Andrews, 1910; Brown, 1981; O'Keefe & Hiller, 2006). Since there are no neural arches and the bone surfaces are not well preserved, it is not possible to definitively determine whether they had been fused to the centrum or became detached because they were of a young individual in which that change would not yet have occurred. In the few cases where ribarticular facies were observed, no evidence of fusion to the ribs was present. The shaft near the distal end of the propodial of our specimen is very eroded and exfoliated, and it is impossible to deduce the individual's age from it.

Determining age based on evidence from the vertebrae is also difficult. Dorsoventral-lateral compression of them, as in our specimens, is not a rare phenomenon and has been observed by Rabinovich (pers. com.) in other collections. It can occur *in vivo* or be the result of post-depositional compression. It can also partially occur in a specimen in a young ontogenetic state (Knutsen et al., 2012).

The cervicals have dumbbell-shaped platycoelous articular surfaces, features considered to be associated with elasmosaurids (Bardet et al., 1999). Because of the variability of cervical dimensions along the neck, the anterior cervicals are longer than they are high (from C15–17, Vincent et al., 2013), while they are shorter than they are high in most posterior cervicals (Sachs, 2005). Based on the above information (Table 2), the Menuha Formation specimen is represented by several anterior and most posterior neck vertebrae. The articular facets of the dorsal vertebra of the specimen are circular (as described by Brown, 1981, 269) and platycoelous, while the centra are medially compressed and have pinched, hourglass-like shapes (as described by Vincent et al., 2013). The tooth with longitudinal ridges has a crown with an oval, basal cross-section c. 1 cm wide (as described by Benson & Druckenmiller, 2014). In the absence of complete specimens, and taking into account ontogenetic variability, there is no definitive relevance to the vertebral length index (VLI) of the vertebrae recovered (O'Keefe & Hiller 2006, but see Knutsen et al., 2012). However, the relatively low values can perhaps exclude the possibility of assigning the Menuha elasmosaurid to a very 'long necked' species.

Based on the bones found, all in close association, and their similar morphologies, we suggest they represent a single specimen. Unfortunately, it is difficult to determine its age, although we suspect, based on the appearance of the bones, that it was not a very young individual.

Although the states of compaction of several vertebrae indicate a connection between them, further examination is necessary for us to be able to determine whether compaction occurred *in vivo* or was due to post-depositional processes (see above). Because the distortion we perceived involves deformation of the complete aspects of the centra, and the sizes of the foramina subcentralia on their ventral surfaces are uneven, we suggest it probably occurred *in vivo*. A paleohistological examination of the centra might provide further information (Talevi & Fernández, 2014).

Unfortunately, based on data currently available, we are unable to contribute to the present vigorous discussion on elasmosaurid vertebral counts (e.g. O'Keefe & Hiller, 2006; Sachs et al., 2013). In our specimen certain differences can be observed in the sizes of the anterior and posterior neck vertebrae, a known characteristic of this group (O'Keefe & Hiller, 2006; Sachs et al., 2013).

Where is the remainder of the animal? Portions probably eroded along the exposed slope as did the rest of the vertebrae, but additional parts may still be imbedded in the ridge. We hope, despite the technical and conservation challenges we may encounter, to be able to extract whatever remains of the individual and any possible others within the deposit.

## Conclusions

The paucity of marine reptiles in the Mediterranean Tethys deposits presently known is a result of limited research rather than of actual fossil availability. Current research in Morocco, where numerous new species are constantly being described (Bardet et al., 2003, 2005, 2010, 2013; Vincent et al., 2011, 2013), emphasises the richness of that country's deposits. Those scholars' work is an example of the wealth of information that may be derived from intensive research within a confined geographic area. A similar potential can be seen in recent work in Jordan (Lindgren et al., 2013).

Paleogeographical variation in the eastern Mediterranean Tethys, within segments of short distance, has been suggested for the Senonian (Lewy & Cappetta, 1989) and recently for the Menuha Formation (Retzler et al., 2013), mainly based on the paleoecology of fish species. These indications suggest to us that additional geological-paleontological research in the same area could well prove to be very rewarding as it is likely to reflect additional evidence of such variation.

The phosphatic belt is dated later than the Santonian in most localities, but the beginning of the unique condition that led to its deposition probably started at the beginning of the Santonian. Thus, our study offers additional evidence of finds

available along the eastern exposure of the Mediterranean Tethys where elasmosaur remains have been found together with those of various fish. They appear in an environment of increased surface water productivity and decreased sea floor aeration, one that presages the onset of the upwelling regime in the late Santonian of our southern Levant.

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