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# The Cenomanian (Late Cretaceous) *Konservat-Lagerstätte* of en Nammoûra (Kesrouâne Province), northern Lebanon

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**KEY WORDS** – Konservat-Lagerstätten, Plants, Pisces, Birds, Reptilia, Cretaceous, Middle-late Cenomanian, African-Arabian plate, Lebanon.

**ABSTRACT** – The fossil association and the stratigraphical and geological setting of the Lebanese Konservat-Lagerstätte of en Nammoûra (= Ain-el-Gârboûr) are described. Fossils in the site are relatively rare, but well-preserved and sometimes show traces of soft tissues. The fossil association is somewhat different from that of the famous Cenomanian sites of Hjoûla and Hâqel where fish and crustacean remains are dominant. Terrestrial plants are common at en Nammoûra and reptiles, although rare, are present. The site also yields isolated feathers and important skeletal remains of birds. The age of the en Nammoûra Lagerstätte is considered latest middle Cenomanian based on foraminiferan biostratigraphy and local stratigraphic relationships. The depositional setting was in a small, non-tectonic and restricted marine basin bordered to the ENE by a clinoform and was not deeper than 50 m. Bottom conditions possibly including hypersalinity and anoxia allowed exceptional preservation of biota from a variety of different habitat.

**RIASSUNTO** – [Il Konservat-Lagerstätte cretaceo di en Nammoûra (Provincia di Kesrouâne, Libano settentrionale)] – Vengono descritte l'associazione fossile e le condizioni geologiche e stratigrafiche del giacimento per conservazione (Konservat-Lagerstätte) di en Nammoûra (= Ain-el-Gârboûr) in Libano. I fossili in questo sito sono relativamente rari, ma sono ben conservati e talvolta presentano tracce di tessuti molli. L'associazione fossile è in parte diversa da quella dei famosi giacimenti Cenomaniani di Hjoûla e Hâqel, caratterizzati da una prevalenza di pesci e crostacei. A en Nammoûra sono comuni i resti di piante terrestri e, sebbene rari, sono presenti pure i rettili. Il sito ha fornito anche piume isolate e importanti resti scheletrici di uccelli. L'età del Lagerstätte di en Nammoûra viene considerata tardo Cenomaniano medio sulla base della biostratigrafia a foraminiferi e della stratigrafia locale. L'ambiente deposizionale era un piccolo bacino ristretto di origine non tettonica, bordato a est-nord est da un clinomorfo e non più profondo di 50 m. Le particolari condizioni al fondo, forse dovute a ipersalinità delle acque e anossia, hanno permesso l'eccezionale conservazione di organismi morti provenienti da habitat diversi.

## INTRODUCTION

The Cretaceous of Lebanon is famous for the fossil *Lagerstätten* of Hjoûla (= Hadjoula), Hâqel (= Hakel) and the less well-known Dahr el Kelb and Maïfouq (Mont-Liban, Jbail Province) deposits. All are of Cenomanian age, and situated about 35-40 km NNE of Beirut. They have yielded a rich fauna dominated mainly by fishes and crustaceans. A list of the fossils found at the Hjoûla and Hâqel sites is reported by Hückel (1970), but it is out of date as a considerable number of new fossils have been excavated over the last years. In fact the sites of Hjoûla and Hâqel are intensely excavated for fossils to be sold to tourists and collectors. Another famous *Lagerstätte* rich in fossil fish, crustaceans and coleoid cephalopods is known further south, at Sâhel Aalma (20 kilometres NNE of Beirut) and its age is reported as late Santonian (Ejel & Dubertret, 1966).

Recently another site, named in the literature as "Nammoura" (see Pinna & Dal Sasso, 1997; Bannikov & Bacchia, 2000; Krassilov & Bacchia, 2000), has also yielded a fossil association typical of the fossil *Konservat-Lagerstätten* and was briefly described by Dalla Vecchia & Venturini (1999).

Specimens from "Nammoura" can easily be distinguished from those of Hjoûla by their characteris-

tic greenish or pale blue-grey colour of the rock (pale yellow to beige only if very weathered), the rarity of fossil remains and the presence of small lenses of chert, absent in Hjoûla (F. M. Dalla Vecchia, pers. obs.). There is some resemblance with cherty levels in Hâqel where, however, the lithology is made of grey limestone with grainy bedding surfaces, which are highly fossiliferous (containing abundant, scattered fragmentary fish remains, crustaceans and coprolites) (FMDV, pers. obs.).

The geology of the "Nammoura" site is undescribed and its age remains to be established.

One of us (F. M. Dalla Vecchia, FMDV) had the chance of visiting the site for four days in September 1998. A primary goal of the fieldwork was to undertake a preliminary geological report and a palaeontological survey, with emphasis on sampling for microfossils analysis in order to date the succession which has yielded important bird remains. The spectacular exposition of the geometry of the sedimentary bodies enabled aspects of the genesis of the fossiliferous levels to be investigated.

The general palaeontological description of the site, its dating and a preliminary description of its stratigraphic and sedimentological context are the object of this paper.

Thin sections are deposited at the Museo

Palaeontologico Cittadino of Monfalcone, and the following abbreviations are used: FLST = floatstone; GRST = grainstone; MDST = mudstone; PKST = packstone; WKST = wackestone.

Abbreviations of institutional names: MCSNM = Museo Civico di Storia Naturale di Milano; MPC = Museo Paleontologico Cittadino, Monfalcone (Gorizia); PIM = Palaeontological Institute, Moscow.

#### LOCATION AND TOPOGRAPHY REMARKS

An introduction to the problem of local names of the sites is appropriate. The original names are written in Arabian characters and are translated into Latin characters when they need to be reported in the Western literature. The translation is not codified and, as a consequence, there is a plethora of different translations for the name of each locality. This creates problems in the scientific literature, as we show below.

We use here the names of Lebanese towns and villages as reported in the Map of Lebanon at scale 1:200.000 in the Stephan Guide "Liban" (without date, but recently published).

The site known as "Nammoura" is represented by two quarries opened near the bed of the Ouadi (Valley) "al Gabour", near the en Nammoûra village, Kesrouâne Caza (Caza corresponds to our Province), Mohafazat (corresponding to our Region) of Mont-Liban. The name "al Gabour" is not reported on the map and has been spelled for us by Lebanese people from the original Arabian name (this name creates a little misunderstanding, see below). The site is ten kilometres SSE of Hjoûla and 25 kilometres NNE from Beirut (Text-fig. 1). The narrow

and deep valley is ESE-WNW trending and cuts a succession of gently dipping and tectonically undisturbed Cretaceous limestones (Text-fig. 2). The same succession is present on both flanks of the valley, but corresponding levels are topographically higher on the left flank (at the top of which is en Nammoûra village) because of the dip.

The quarries are mined for thin slabs of building stone and fossils are occasionally found by quarry workers.

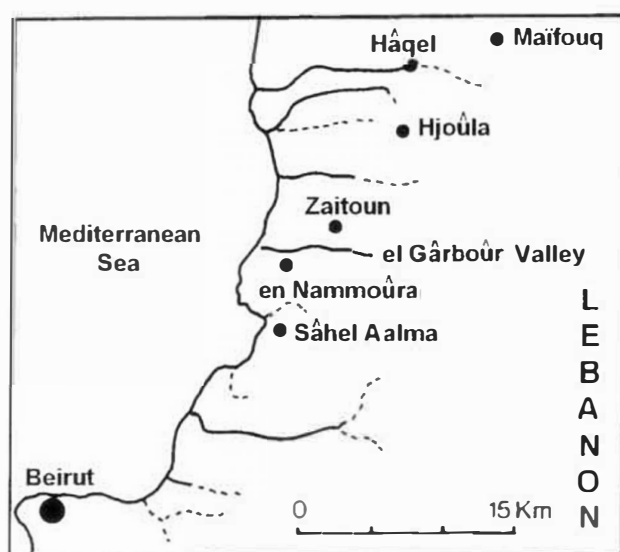
Fossils from this site are present in the Roland Anhour collection, which was donated to the MCSNM in the early 80's (Giorgio Teruzzi, pers. comm.) and in a recently acquired collection at the PIM (Krassilov & Bacchia, 2000). The first quotation of this site is probably that of Gayet (1988) on a "new fossiliferous site of Lebanon". In fact Gayet (1988, p. 199) described "four specimens of a small fish, coming from a Lebanese locality named Aïn-el-Gârboûr, situated south of Zaitoun in the Mount Liban". The specimens were collected in 1974 by Prof. I. A. Kafescioglu who stated that "the fossiliferous outcrop does not present the same richness of fossils of the classic outcrops of Hakel and Hadjoula, of which has the same late Cenomanian age" (our translation from French).

Bannikov & Bacchia (2000) consider as different sites that of Aïn-el-Gârboûr reported by Gayet (1988) and "Nammoura". They write (p. 4) "one further Lebanese locality, Aïn-el-Gârboûr, ..., is known for the only fish discovered there, the "salmoniform" *Gharbouria libanica* (Gayet 1988)..... A new locality with marine fishes was discovered recently by private collectors in the Nammoura quarries.....the Nammoura locality is represented by two limestone quarries opened in the bed of the Ouadi (Valley) Al Gabour". However, the similarity between the names "Aïn-el-Gârboûr" and "Ouadi (= Wadi) Al Gabour" suggests the localities are the same (in Arabic Aïn means "spring" and "wadi" is an ephemeral stream). On the map of Lebanon Zaitoun is the village in front of en Nammoûra, on the opposite side of the valley. Thus the new site of Gayet (1988) is that described here and is the same as the new site of Bannikov & Bacchia (2000). As an aside, Dilcher & Basson (1990) who described fossil leaves from en Nammoûra, though they had discovered "a new fossil locality in Lebanon".

Gayet (1988, p. 199) reported the age of Hâqel and Hjoûla as late Cenomanian, but in succeeding pages, as in her preceeding works (e.g. Gayet, 1980a, b), she quoted the age as "early Cenomanian".

#### THE MACROFOSSILS OF THE LAGERSTÄTTE

A fossil assemblage comprising articulated vertebrate skeletons with preserved soft-tissues, non-mineralised invertebrates, and plants, characteristic of the fossil *Konservat-Lagerstätten*, was found in the quar-



Text-fig. 1 - The region NE of Beirut with the location of the Cenomanian *Lagerstätten*.



Text-fig. 2 - Panoramic view of the al el-Gârboûr valley from WSW (toward the Mediterranean sea) to ENE. The two quarries opened into the Lagerstätte are in the background (arrow).

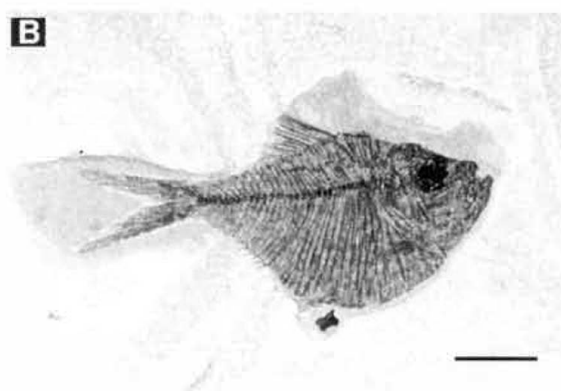
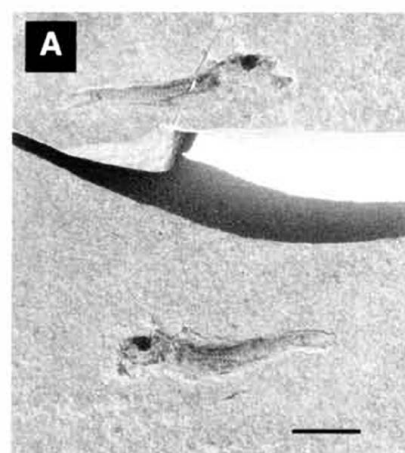
ries. The unit containing the fossil assemblage is exploited by quarry workers because rock splits easily into thin slabs.

Most of the fossils discovered in the site are kept in private collections in Lebanon and elsewhere around the world, since the fossils are sold by the quarry owners and workers to Lebanese and foreign fossil dealers.

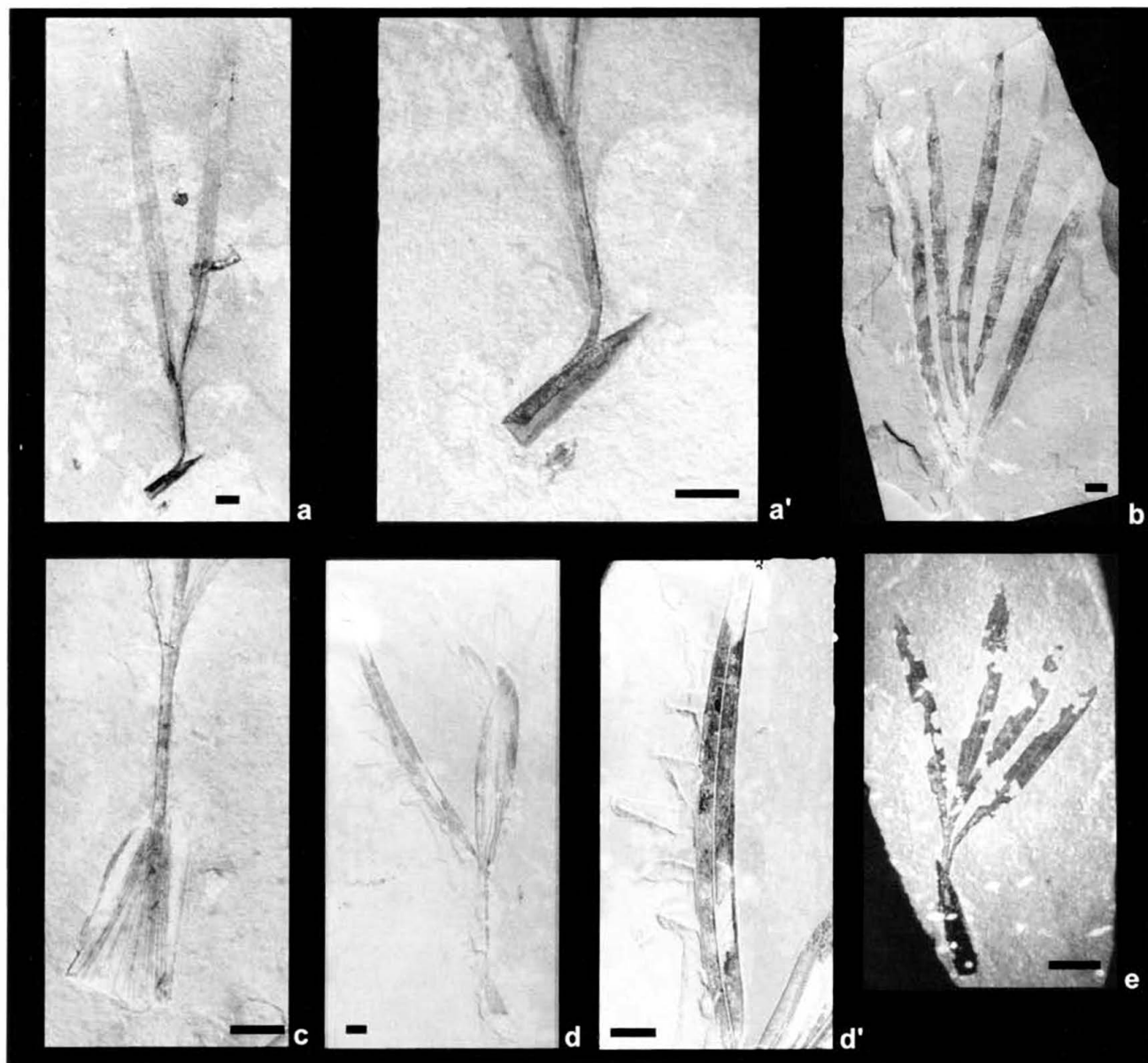
Visits to the site, and to view private collections in Lebanon along with discussion with a quarry owner allows us to confirm that fossils are rather rare (as previously noted by I. A. Kafescioglu in 1974), but are extraordinarily well-preserved. Levels, pockets or "hot-spots" with high concentrations of fossils were not found.

The most common fossils are small teleost fishes two to four centimetres long, usually complete (Text-fig. 3A), but it is also possible to find isolated heads or the anterior part of the body only.

The second most frequent group are terrestrial plants (Text-figs 4-5) which are represented by single leaves or small branches. The characteristic composite leaves of the dicotyledon angiosperm *Sapindopsis* (Text-fig. 4) are by far the most common. According to Krassilov & Bacchia (2000) two species, *S. anhourii* Dilcher & Basson (Text-fig. 4d-d') and *S. lebanensis* Krassilov & Maslova (Text-fig. 4e), are present. The first species has been reported from this site since 1990 (Dilcher & Basson, 1990). According to a recent description of a florule from en Nammoûra (Krassilov & Bacchia, 2000) the angiosperms dominate the floral association. Other dicotyledons include *Nuphranthus cretacea* Krassilov (represented by a flower, Text-fig. 5a), *Nammourophyllum altin-gioides* Maslova & Krassilov (Text-fig. 5b), *Aryskumia*



Text-fig. 3 - Fishes from en Nammoûra: A) A small teleost fish, the most common fossils in the site; B) Clupeomorph fish (MCSNM V 1997). The scale bar equals 10 mm.

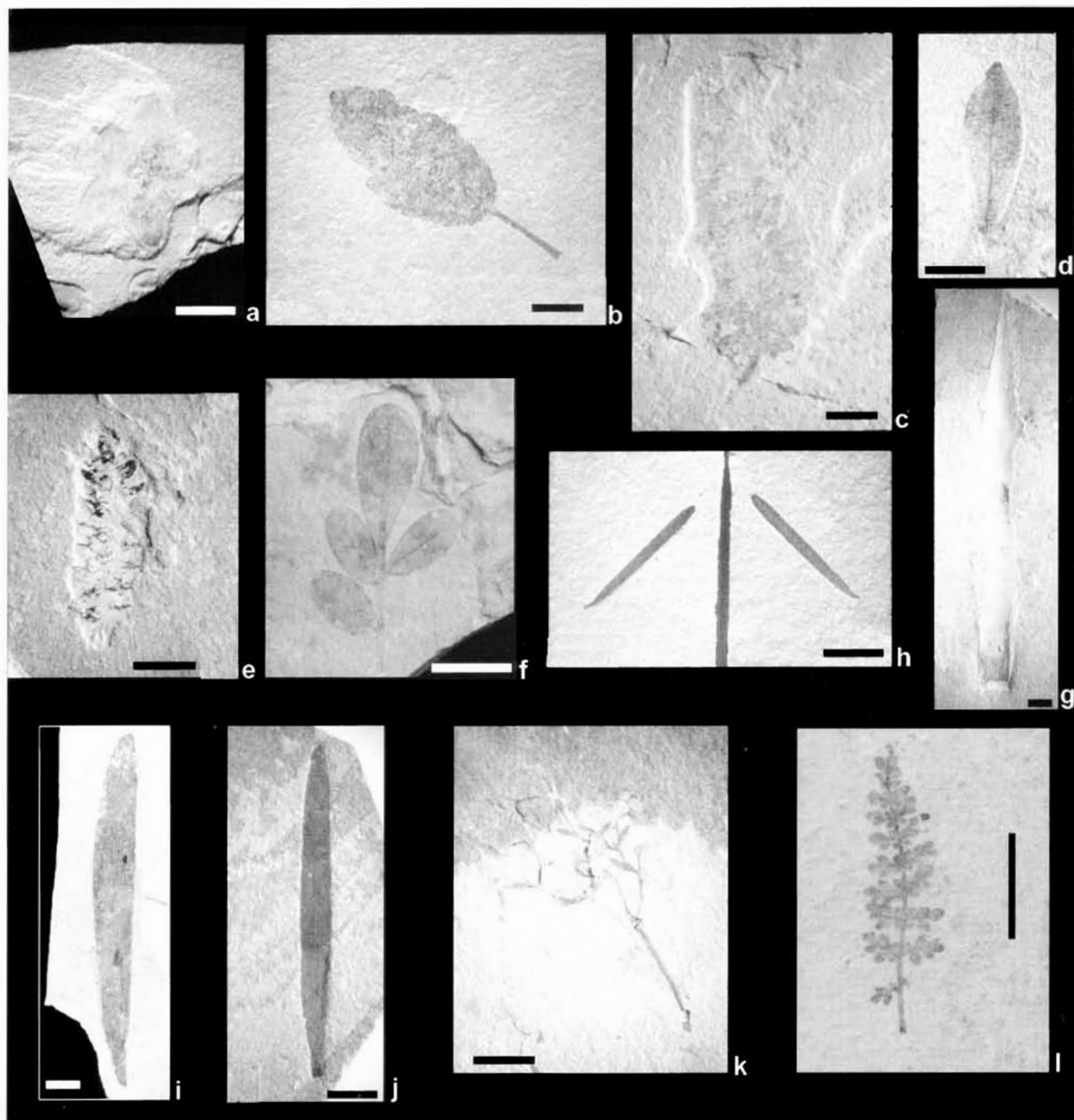


Text-fig. 4 - Plant remains from en Nammoûra. The angiosperm dicotyledon *Sapindopsis*: a-a') *Sapindopsis* sp., the specimen MCSNM B 129 and the particular of the sheathing stipule at the leaf base, with the head of a small fish nearby; b) *Sapindopsis* sp., specimen with 5 leaflets, MCSNM B 128; c) Particular of the stipule of another specimen of *Sapindopsis* sp., MCSNM B 132; d-d') *S. anhourii*, MCSNM B 201, d) the whole specimen, d') particular of a leaflet, with the very distinct venation; e) *S. lebanensis*, PIM4799/7. The scale bar is 10 millimetres.

cf. *A. zelkovifolia* Shilin (Text-fig. 5c), *Parvileguminophyllum* sp. (Text-fig. 5d) and Platicaryaceae indet. (Text-fig. 5e). The monocotyledon "*Phragmites*" (Text-fig. 5g) is also reported. Gymnosperms are represented by the conifer needle *Pseudolarix* sp. (Text-fig. 5h) and the ginkgophyte leaf *Pseudotorellia* sp. (Text-fig. 5i-j). The Pteridophytes *Nammouria gracilis* Krassilov (Text-fig. 5k) and *Pteris* sp. (Text-fig. 5l) also occur.

Leaves with grey prismatic-elongated crystals up to 20 mm long and tufts of whitish, needle-like crys-

tals have been observed. Some composite leaves of *Sapindopsis* were completely covered by the tufts. Unfortunately, it was not possible to take a sample of these crystals for mineralogical studies. It is unlikely that the leaves were transported into the marine environment by rivers as suggested by Krassilov & Bacchia (2000, p. 798), as evidence of fluvial influence (e.g. terrigenous sediments) is lacking in the entire el-Gârboûr section (see below) and the continental palaeoshoreline was hundreds of kilometres away (see below).



Text-fig. 5 - Plant remains from en Nammoûra. Angiosperm dicotyledons: a) *Nuphranthus cretacea* (flower), PIM4799/9; b) *Nammourophyllum atingioides*, PIM4799/11; c) *Arjaskumia* cf. *A. zelkovifolia*, PIM4799/12; d) *Parvileguminophyllum* sp., PIM4799/2; e) *Platicaryae* indet., PIM4799/8; f) *Dicotyledon* indet., MCSNM B 577. Monocotyledons: g) "*Phragmites*", PIM4799/13. Gymnosperms: h) *Pseudolarix* sp., PIM4799/4; i-j) *Pseudotorellia* sp., MCSNM B 574 and PIM4799/1. Pteridophytes: k) *Nammouria gracilis*, PIM4799/10a; l) *Pteris* sp., MCSNM B 133. The scale bar is 10 millimetres.

Medium to large actinopterygian and elasmobranchian fishes appear to be the most diverse animal group of the assemblage. A quarry owner and other local and international collectors have shown to one of us (FMDV) ray-fishes, ichthyodectiform-like fish-

es, *Rhynchodercetis* or *Belenostomus*-like fishes (e.g. MCSNM V-3837), pycnodonts, eel-like fishes, and others that were indeterminate. A tooth of a large shark was also found (Krassilov & Bacchia, 2000). Clupeomorphs (Text-fig. 3B) and other undeter-

mined fishes, including large specimens, are deposited in the collection of the MCSNM. Unfortunately, this ichthyofauna has never been the object of systematic study. Only the "Salmoniforme" *Gharbouria libanica* Gayet (Gayet, 1988) and the clupeomorph *Sorbinichthys elusivo* Bannikov & Bacchia (Bannikov & Bacchia, 2000) [recte *Sorbinichthys elusivus*] have been described. Specimens are usually complete and very well preserved, with a characteristic black spot in the orbit representing the pigment of the eye (Text-fig. 3).

Crustaceans appear to be rare. One of us (FMDV) had an opportunity to examine a relatively large astacid-like discovered by a man cutting the slabs; a small shrimp and a palinurid are in the collection of the MCSNM (Alessandro Garassino, pers. comm.).

The only shelled invertebrates are some *Pteria*-like pseudoplanktonic bivalves preserved on a single small slab (MPC, without number) and an isolated, small radiolitic rudist seen in longitudinal cross-section on a slab (FMDV, pers. obs.). A pteropod is deposited at the MCSNM (I-25146; FMDV, pers. obs.).

Small coprolites and gastric ejecta (millimetric pellets comprised mainly of thin bones) are present, and the gastric ejecta are relatively common.

Tetrapods are represented mainly by articulated skeletons of aquatic reptiles. Chelonians are the most common (we have notice of at least six specimens, and FMDV saw one just discovered by the workers in the quarry). A complete small marine chelonian is deposited in the MCSNM (V-3933).

The holotype of the dolichosaur *Aphanizocnemus libanensis* Dal Sasso & Pinna most probably comes from this site (Dal Sasso & Renesto, 1999). Other two varanoid lizards, a new dolichosaur very close to *Pontosaurus* from the Cenomanian of Lesina/Hvar (Dalmatia), and a *Pachyrachis*-like ophiomorph were also found (Dal Sasso & Renesto, 1999) and are at present at the MCSNM. The new dolichosaur preserves skin remains with small, still connected scales (Dal Sasso & Renesto, 1999).

Articulated phalanges, with a very elongate penultimate phalanx and a relatively short ungual, on exhibit in an antiquities shop in the town of Jbail, possibly belong to the manus of a large theropod dinosaur. The "forearm of a large theropod dinosaur" has been reported by Krassilov & Bacchia (2000, p. 785), and is probably the same specimen.

Some small feathers were found at en Nammoûra quarries, but are deposited in private collections (Flavio Bacchia, pers. comm.) and have never been figured. Two small feathers are deposited at the MCSNM (V-3932, V-3883; Text-fig. 6). The presence of feathers is of note because they are rather rare in the Mesozoic. Schlee (1973) reported the presence of feathers in the Neocomian-early Aptian amber from Jezzini (Southern Lebanon). The skeletal remains of an Enanthiornite bird (Text-fig. 7) have been found in the unit 3b of the upper quarry (Dalla



Text-fig. 6 - A small feather (MCSNM V 3883) from the en Nammoûra site. The scale bar is in centimetres.

Vecchia & Chiappe, in press). The en Nammoûra Enanthiornite bird appears to be a predated bird about the size of a pigeon, with feather remains and small drops of plant resin (amber) inside the skeleton. The structure of the foot and the amber inclusions suggest it was an arboreal bird (Dalla Vecchia & Chiappe, in press). The skeletal remains with feathers of a second bird are present in a private collection in Lebanon (FMDV, pers. obs.). Thus, the en Nammoûra site reveals to be relatively rich in bird remains. These remains, together with the feathers in amber from Jezzini and small tridactyl footprints from the Maastrichtian of Morocco (see Chiappe, 1995) are the only evidence for birds from the Cretaceous African-Arabian continent.

According to the quarry workers and owners the reptiles and birds are all discovered in the subunit 3b (see below) in the upper quarry.

#### THE STRATIGRAPHICAL SECTION AND ITS PALAEOENVIRONMENTAL INTERPRETATION DESCRIPTION

Here we describe the stratigraphic succession from the bottom of the valley where the bridge crosses the el-Gârboûr creek to the top of its flanks (Text-figs 8-11). Our geological survey was undertaken rapidly, given the limited time available in site. An absence of



Text-fig. 7 - An enantiornithine bird with remains of feathers (MCSNM V 3882a) from the en Nammoûra site. The scale bar is in centimetres.

roads and tracks, a covering of thorny vegetation, and the inaccessibility of vertical cliffs and, last but not least, a vegetation fire which was burning in the upper valley, made this survey difficult. Therefore, the description of the stratigraphic section is somewhat schematic.

**Unit 1** - A section 7-8 metres-thick is exposed, but the full thickness is not seen. It comprises laminated but non-stratified, fine-grained, intraclastic WKST-PKST with chert concretions and is very similar to the base of unit 5 (see below).

**Unit 2** - At the base there are about 10 metres of grey, non-stratified and non-laminated fine-grained bioclastic PKST with *Calcisphaerulidae*, fragments of pelagic crinoids, bivalves and small planktonic foraminifers. Above there are about 20 m of whitish, fine intraclastic PKST-WKST with remains of pelagic crinoids. The upper part comprises of 2-3 m of whitish-grey, fine intraclastic-bioclastic PKST/WKST with remains of pelagic crinoids, *Calcisphaerulidae*, rare *Ataxophragmiidae* and small planktonic foraminifers (*Hedbergella* sp.) (Pl. 1, fig. 1).

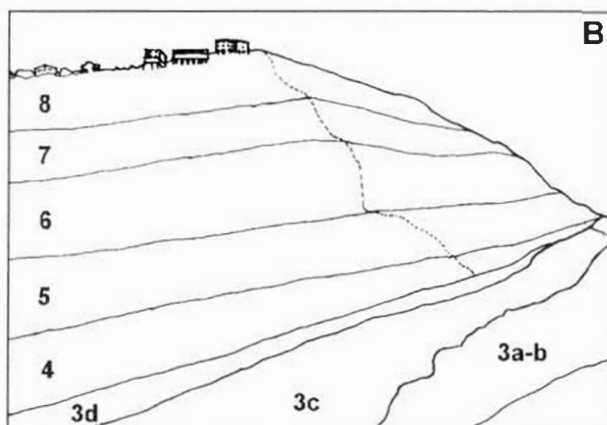
Moving to NNE-ESE, along the right flank of the valley a clinoform (i.e. a wedge-like lithosome) against which the overlying units 3-4 onlap, is clearly visible (Text-figs 10-11). Unfortunately, during our time there,

a fire was burning in the upper part of the valley, not reached by tracks, and thus direct sampling was impossible. The wedge closes distally (WSW) on unit 2.

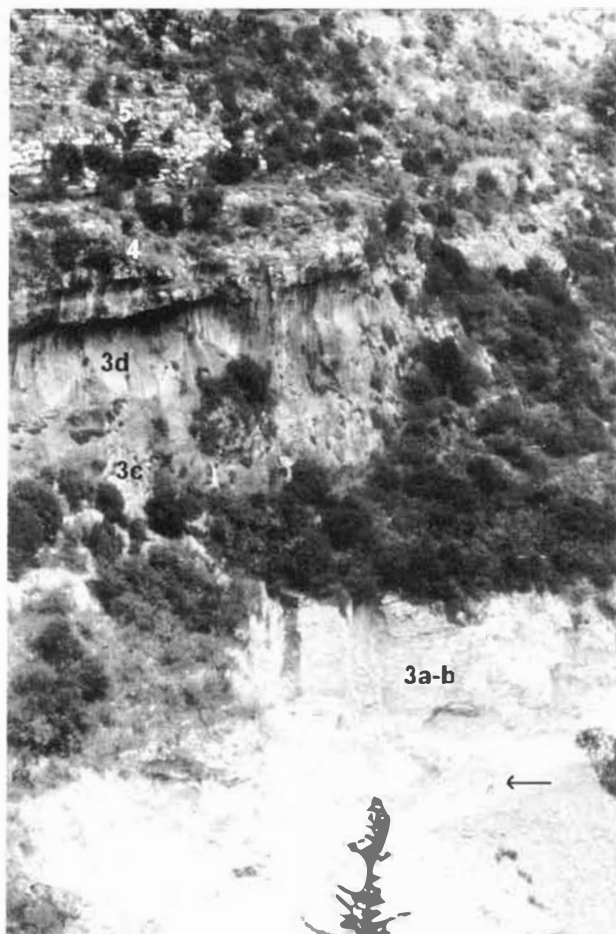
**Unit 3** - This is the unit containing the *Lagerstätte* and has been subdivided vertically into four subunits (3a-d). Two main quarries have been opened in the subunits 3a-b, one topographically higher on the left side of the valley and the second at the bottom close to the level of the stream in the right side of the valley (Text-figs 2, 10). The thickness of subunits 3a-b is 10-12 metres in the lower quarry (Text-fig. 9) whereas it is at least twice as thick in the upper quarry. Thus, the lithosome closes rapidly to west or northwest.

The subunits 3a-b are pale blue-grey to greenish (pale yellow to beige when strongly weathered) "lithographic" limestones with tabular bedding and plane-parallel lamination (Text-fig. 12). They are very fine-grained, "varved", intraclastic MDST-WKST-PKST, without microfossils (Pl. 1, figs 2-3).

The lamination/fissility is similar to that of the well-known Solnhofen lithographic Limestone, with fissile beds splitting into wide, millimetres-thick slabs ("lami-



Text-fig. 8 - Panoramic view of the stratigraphic sequence in the el-Gârboûr valley just above the lower quarry. A) Photo; B) Interpretative drawing. For scale note the buildings in the upper side of the photo. Legend: 3-8 = units 3-8.



Text-fig. 9 - Detail of the lower quarry and the overlying stratigraphic section. For scale note the man in the lower right corner of the photo (arrow). Legend: 3-5 = units 3-5.

nae"). The thickness of single splitting "laminae" are generally 3-10 mm in 3a and 10-40 mm in 3b. Thin-sections reveal a sub-millimetric lamination within each split "lamina" (Pl. 1, figs 2-3). Bedding and lamination are undisturbed, with no evidence for bioturbation, soft-sediment deformation (slumps, load casts etc.) or traces of syndimentary tectonics. The whitish, grey to light brown chert forms mainly millimetric-centimetric lenses. Sometimes they include fossils; a leaf has been observed partly preserved enclosed in chert.

The subunit 3a is characterized by higher fissility and a lesser amount of chert with respect to 3b. Subunit 3b produces thicker slabs and for this reason it is preferred for quarrying. Chert lenses and thin layers are sometimes very densely packed. The direction (azimuth) of bedding is  $12^\circ$  with a westward dip of  $14^\circ$  in the lower quarry,  $8^\circ$  with a westward dip of  $15^\circ$  in the upper quarry.

The subunit 3c is made of beige to cream-coloured, massive limestone (faint bedding is identifiable in a few places) with very frequent rounded

chert concretions. Like subunits 3a-b, it is a fine-grained intraclastic WKST-PKST. The concretions are, on average, decidedly larger than those in 3b, with the main axis of elongation over 150 mm. Because of the absence of fissility and abundance of large concretions this subunit is not quarried. Generally speaking in subunits 3a-c there is an upward increase in chert content and a decrease in fissility. On the right flank of the valley (lower quarry) subunits 3a-b and 3c have a similar thickness.

The subunit 3d is composed of beige-coloured, massive limestone without chert. It is a very fine-grained intraclastic WKST-PKST with thin-shelled bivalves, *Calcispherulidae* and fragments of pelagic crinoids (Pl. 1, fig. 4). Being "softer" than the underlying 3c and the overlying unit 4, this subunit forms an evident niche below the base of the latter (Text-figs 8-9) which marks its position along the flank of the valley. This subunit appears to close just ENE of the lower quarry, where unit 4 is directly above 3c.

**Unit 4** - This is an unit of whitish, poorly-bedded limestone with local accumulations of radiolitic rudists (Text-fig. 13). It is composed mainly of fossiliferous WKST (Pl. 1, figs 5-7). This unit diminishes in thickness to NNE or ENE and therefore appears to close against the large wedge which borders the basin to NNE. The thickness just above the lower quarry is about 6-7 m (see Text-fig. 9). Scattered remains of radiolites, among which *Praenadiolites*, are present in the lower part of the unit, whereas in the upper part small (maximum length 50 mm) entire valves of radiolites can be found (FLST with rudists; Pl. 1, fig. 5). The top of unit 4 is composed of a 0.8 m thick layer of RDST-GRST with rounded fragments of mollusc shells (Pl. 1, fig. 8).

A relatively rich foraminifer fauna is found in the samples from this unit (Pl. 1, figs 6b, 7): *Pseudodonia drorimensis* Reiss, Hamaoui & Ecker (Text-fig. 14B), *Prealveolina* gr. *cretacea* (D'Archiac), Orbitolinidae (*Conicorbitolina* cf. *conica* (D'Archiac), found in just a sample, Text-fig. 14A), *Pseudorhapydionina dubia* (De Castro), *Pseudorhapydionina laurinsensis* (De Castro) (relatively infrequent), *Biconcava* sp., *Cuneolina* sp., *Nezzazata* sp., Ophthalmitidae and Miliolidae. Also monaxon sponge spicules are present.

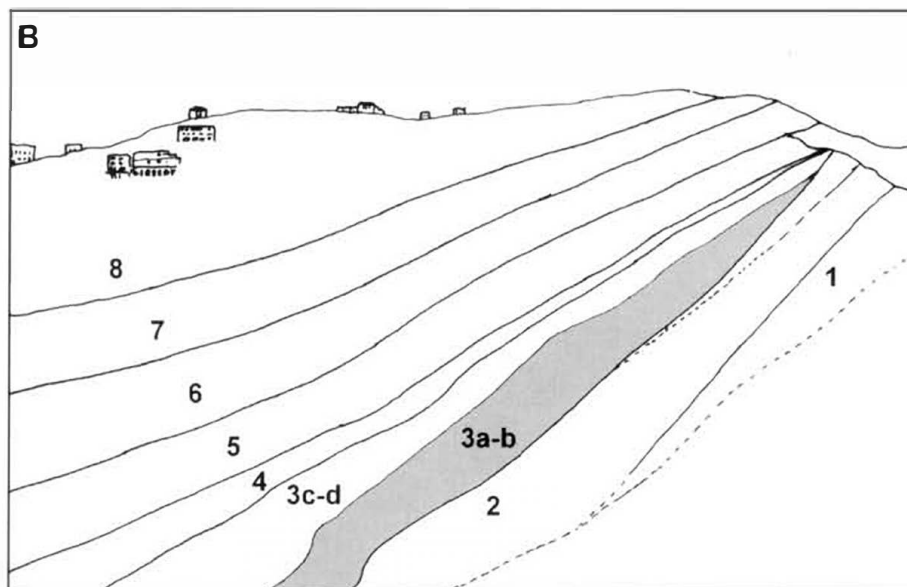
**Unit 5** - About 30 m of grey-blue to pale brown limestone with chert (Text-figs 8-10). At the base it is well-bedded, with centimetric, thinly-laminated layers and thin layers of chert. Rare small slumps have been observed. They are very finely grained intraclastic MDST-WKST(PKST), sometimes graded and with erosive bases; millimetric levels of bioclastic PKST with remains of pelagic crinoids and rolled fragments of bivalve shell, are present (Pl. 1, figs 9a-b). Stratification is less evident in the upper part of the unit, where chert-bearing horizons become more frequent and chert nodules also appear.

The upper part of the el-Gârboûr valley section is better exposed along the road which leads from the main road of en Nammoûra to the quarries.

A



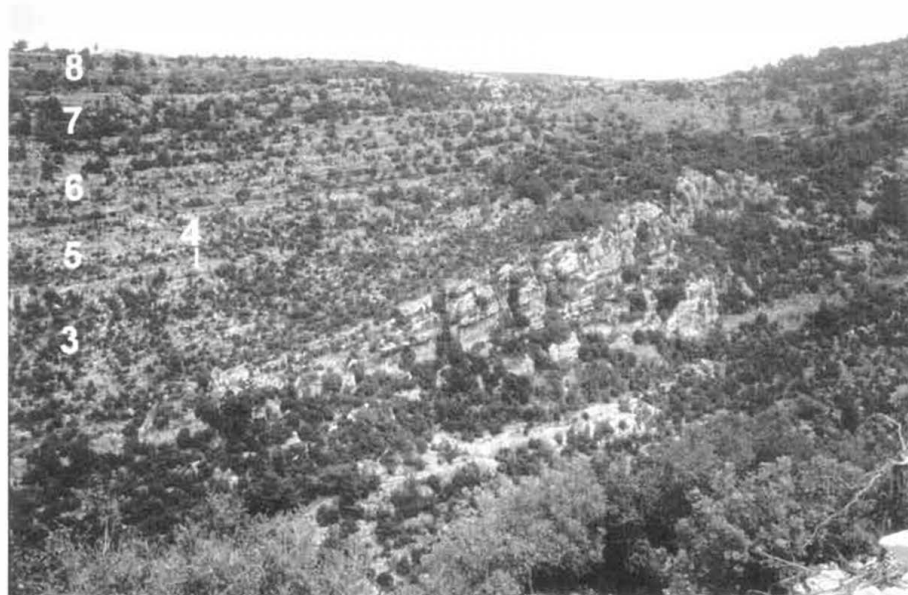
B



Text-fig. 10 - Panoramic view of the el-Gârboûr valley from en Nammoûra village, with the two quarries (the two white spots in A, lower quarry to the left), the "wedge" and the stratigraphic section described in the text. A) Photograph; B) interpretative drawing. Dotted lines indicates the bottom of the valley. The shadowed area in B represents the outcrop of the *Lagerstätte* subunits. Legend: 1-8 = units 1-8.

**Unit 6** - Well-bedded pale brown and grey limestone, with centimetric-decimetric, tabular layers of WKST and MDT-WKST often with abundant microfauna, mainly foraminifera (Pl. 2, figs 1-2). The unit is about 60 m thick. Approximately in the middle of the unit there are layers rich in alveolinids (*Ovalveolina* cf. *ovum*; Pl. 2, fig. 2, Text-fig. 14C). The macrofossils observed in this unit include fragments of bivalves and gastropods. Foraminifera in the samples are represented by *Ovalveolina* cf. *ovum*, *Pseudorhapydionina laurinensis*, *Pseuduolituonella reicheli*, *Biplanata* sp., *Biconcava* sp., *Cuneolina* sp., *Nezzazata* sp., very rare *Vidalina* sp., Nubecolariidae, Miliolidae (often very frequent) and Ophthalmitidae. Other microfossils are represented by sponge spicules and ostracods.

**Unit 7** - This unit is approximately 50 m thick. At the base there are about 25-30 metres of grey to whitish, poorly stratified limestone (fossiliferous, bioclastic WKST and PKST; Pl. 2, figs 3-4), with levels rich in oysters (Text-fig. 15) and less common levels with rudists. Gastropods are occasionally present. A level with chert nodules has also been observed. Foraminifera are represented by often abundant Nubecolariidae, Ophthalmitidae, Miliolidae, *Trochospira* sp., *Nummuloculina* sp., *Cuneolina* sp., *Biplanata peneropliformis* Hamaoui & Saint-Marc, *Pseuduolituonella* sp., *Pseuduolituonella reicheli*, *Pseudorhapydionina dubia*, *Biconcava* sp., *Pseudorhapydionina laurinensis*, *Peneroplis* ? *parvus*, *Dicyclina* sp., *Nezzazata* sp., *N. picardii*, *Chrysalidina gradata* and very rare *Vidalina* sp. (Pl. 2, figs 4a-b). *Pseudorhapy-*



Text-fig. 11 - The wedge (clino-form) against which the units 3 and 4 onlap (see also Text-fig. 10). Legend: 3-8 = units 3-8.

*dionina laurinensis* (Text-fig. 14D) becomes very frequent.

About five metres of thick beds of bioclastic PKST with gastropods, Miliolidae and Ataxophragmiidae are found above, and are intercalated with thinner beds with chert nodules.

Five metres of thinly-bedded limestones with chert nodules follow. These beds are sometimes thinly laminated, and sometimes more massive PKST-FLST with frequent non-rudist bivalves. Small planktonic foraminifera are present (?*Rotalipora* sp., *Hedbergella* sp.).

Finally, there are about 15 metres of stratified, intraclastic and bioclastic PKST-WKST (Pl. 2, figs 5a-b), with levels of FLST rich in small bivalves (horizons with small oysters are seen). The microfauna consists of Miliolidae, Ataxophragmiidae, Ophthalmiidae, *Nummofallotia* sp., *Pseudorhapydionina lau-*

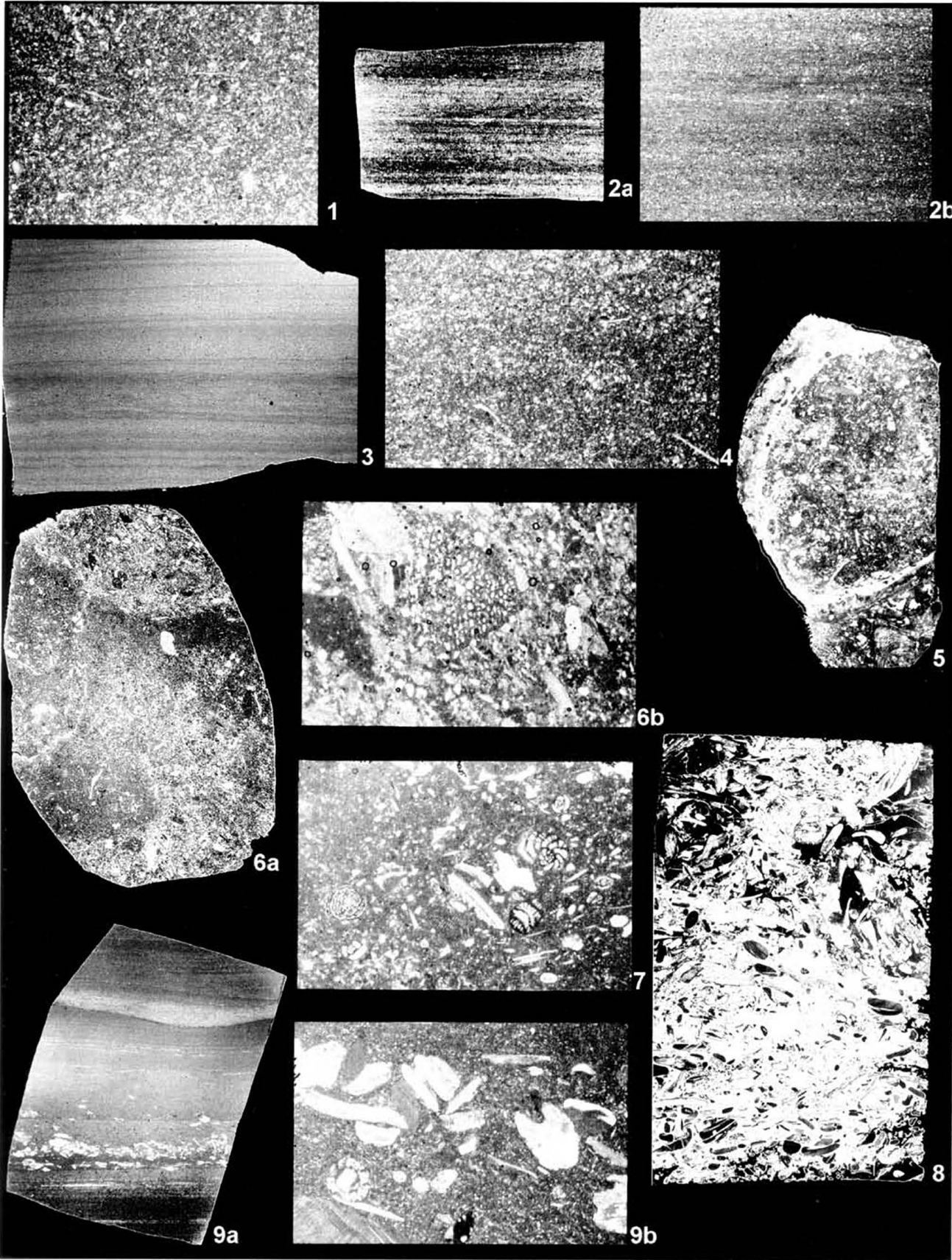
*rinensis*, *Chrysalidina gradata*, *Cuneolina* sp., *Merlingina* sp., *Pseuduolituonella* sp., *Dicyclina* sp., *Nezzazata* sp. and ostracods (Pl. 2, figs 5a-b).

**Unit 8** - Well-bedded yellowish to grey marly limestone, with prevailing centimetric-decimetric tabular beds, and at least six thicker limestone beds. Its total thickness is over one hundred metres and it forms the upper slopes of the valley. At the base of the unit there are intercalations of thinly-bedded, sometimes nodular, fine-grained intraclastic MDST-WKST with chert. Intraclastic MDST-WKSTs and WKSTs rich in foraminifers and ostracods (Pl. 2, fig. 6) prevail in the thick beds above. Foraminifera in a sample from the top of the valley section include *Nezzazata* sp., *Pseudorhapydionina laurinensis*, *Biconcava* sp. and Nubecolariidae.

#### EXPLANATION OF PLATE 1

Figs. 1-9 - Microfacies of the el-Gârboûr Valley section.

- 1) Upper part of unit 2. Thin section NAM-3: Fine-grained intraclastic WKST-PKST with *Calcisphaerulidae* and fragments of pelagic crinoids (x 12.5).
- 2) Subunit 3a. Thin section NAM1a: a) inner lamination of a single split "lamina" (x 4); b) particular of the inner lamination (x 12.5).
- 3) Subunit 3b. Thin section NAM1b: indisturbed lamination of the fine-grained intraclastic MDST-WKST (x 2).
- 4) Subunit 3d. Thin section NAM2: intraclastic WKST-PKST with thin-shelled bivalves, fragments of pelagic crinoids and possible *Calcisphaerulidae* (x 12.5).
- 5) Unit 4. Thin section NAM3 representing the infilling of a small rudist (x 2).
- 6) Unit 4. Thin section NAM3+: a) fossiliferous WKST with several specimens of *Orbitolina* in the upper part (x 2), b) particular of the upper part of the thin section with *Orbitolina* (x 12.5).
- 7) Unit 4. Thin section NAM3+++: fossiliferous WKST (x 12.5).
- 8) Uppermost unit 4. Thin section NAM4: bioclastic RDST-GRST made of rounded fragments of mollusc shell (x 2).
- 9) Lower part of unit 5. a) Thin section NAM5a: MDST- thin-grained WKST with a bioclastic horizon (x 1.33), b) particular of the bioclastic horizon (x 10).





Text-fig. 12 - The laminated cherty limestone of subunits 3a-b, the *Lagerstätte* level. Hammer for scale.

## INTERPRETATION

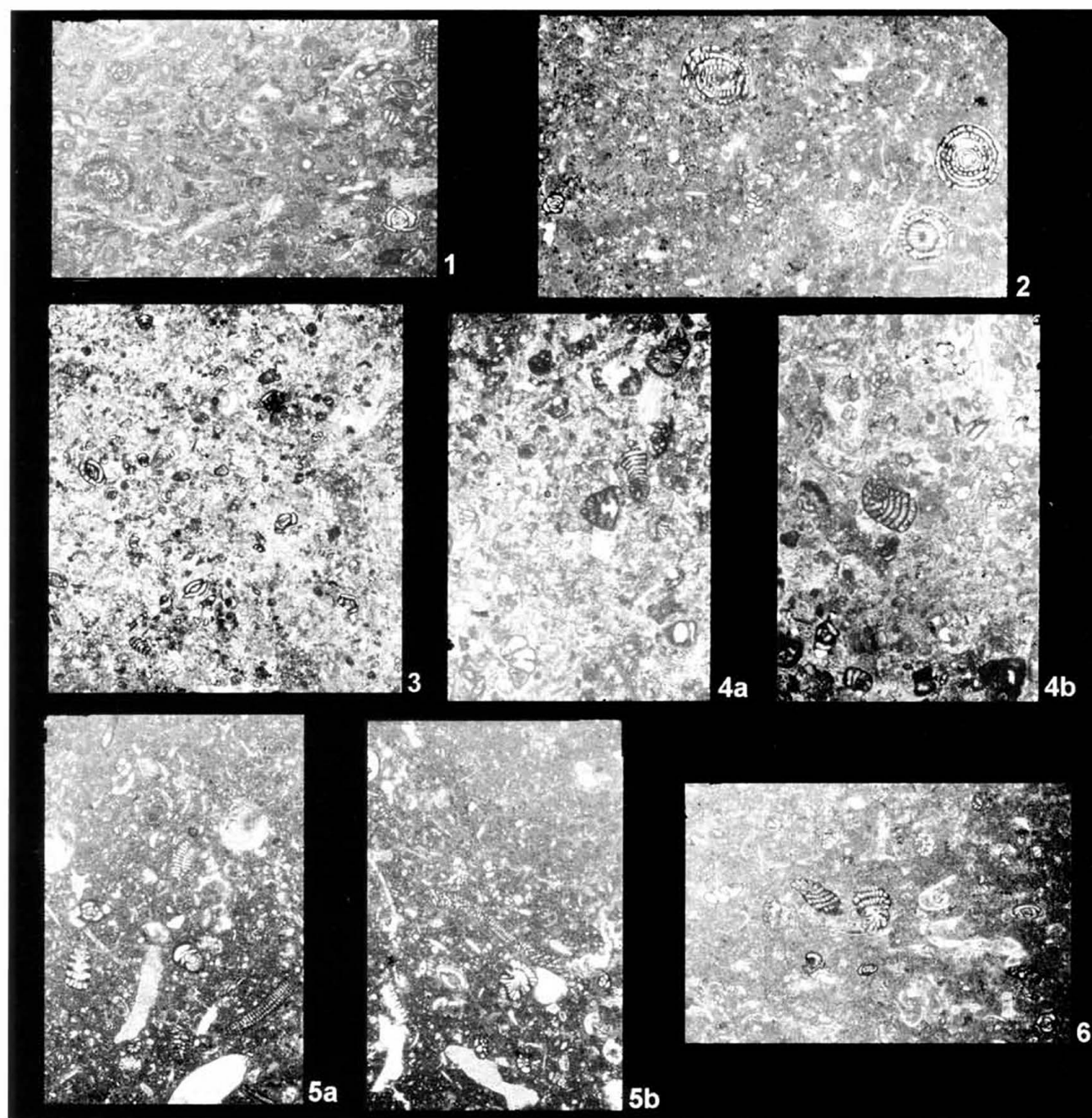
### ORIGIN OF THE *LAGERSTÄTTE*

The absence of autochthonous benthos and of bioturbation suggests an environment hostile to macrofauna. Usually this condition is attributed to water



Text-fig. 13 - Radiolitic rudists in the unit 4.

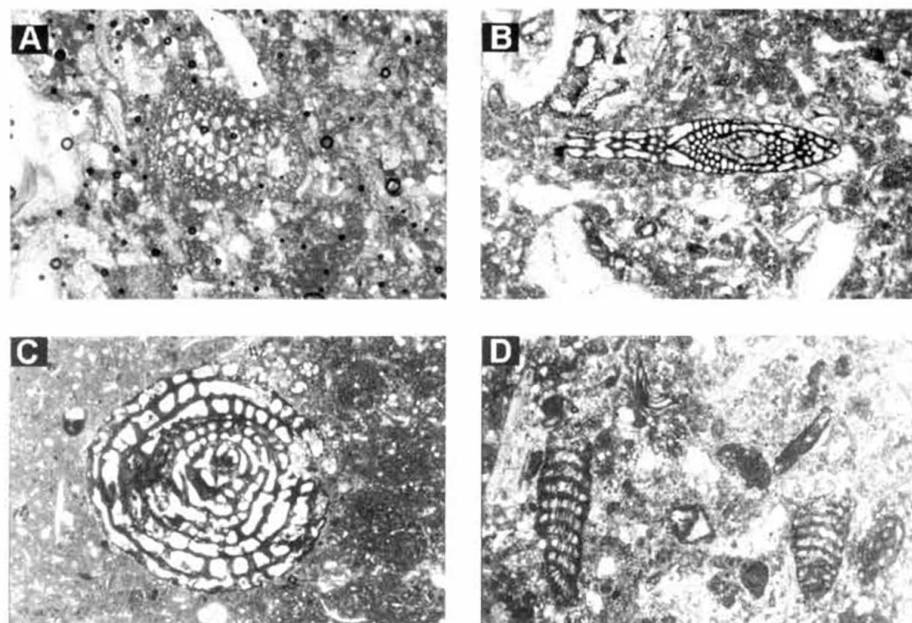
stagnation and consequent oxygen depletion (disoxic to anoxic conditions) and high salinity (Seilacher *et al.*, 1985; Barthel *et al.*, 1990). The absence of predators and scavengers contribute to the preservation of the organisms usually found in *Konservat-Lagerstätten* (articulated vertebrate skeletons sometimes with soft tissue remains, arthropods, soft-bodied invertebrates, plants (see for examples Sorbini, 1980; Grande, 1984; Seilacher *et al.*, 1985; Conway Morris & Whittington, 1988; Pinna, 1988a, b; Gall, 1988; Barthel *et al.*, 1990), which under normal conditions are completely destroyed. A rapid burial by fine sediment is also considered important for the fossilisation, because it avoids scavenging by the epifauna (Seilacher *et al.*, 1985) and disaggregation of decomposing carcass by currents (Allison, 1988b). In the case of en Nammoûra the "varved" pattern of lamination suggests that the bottom waters were still and the input of sediment was punctuated and scarce, thus a rapid burial cannot be the cause for the preservation of the organisms. The sealing by prokaryotic scums is considered the chief factor of preservation in some *Lagerstätten* (Hemleben & Freels, 1977; Seilacher *et al.*, 1985). Cyanobacteria form a mat on



#### EXPLANATION OF PLATE 2

Figs. 1-6 - Microfacies of the el-Gârboûr Valley section.

- 1) Unit 6. Thin section NAM6sin-1: fossiliferous WKST (x 12.5).
- 2) Unit 6. Thin section NAM6sin medio: fossiliferous WKST with Alveolinidae (x 6).
- 3) Lower part of unit 7. Thin section NAM7sin B: fossiliferous WKST (x 6).
- 4a-b) Lower part of unit 7. Thin section NAM7sin B-1: fossiliferous WKST- PKST (x 12.5).
- 5a-b) Upper part of unit 7. Thin section NAM7sinx: fossiliferous WKST(x 12.5).
- 6) Uppermost part of unit 8. Thin section NAM8K: fossiliferous WKST (x 12.5).



Text-fig. 14 - Foraminifera from the el-Gârboûr Valley section. A) *Conicorbicolina* cf. *conica*, unit 4 (thin section NAM+; x 20); B) *Pseudedomia drorimensis*, unit 4 (thin section NAM+++; x 20); C) *Ovalveolina* cf. *ovum*, unit 6 (thin section NAM6sin medio; x 15); D) *Pseudorhapydionina laurinenensis*, unit 7 (thin section NAM7sin B-1; x 20).

the surface of the sediment, which encapsulates the carcasses lying on the surface, protecting them and the sediment from bioturbation. Today cyanobacterial mats are restricted mainly to hypersaline environments. According to Seilacher *et al.* (1985), the presence of a fossil prokaryotic scum is testified macroscopically by the preservation of a variety of marks (roll, drag and landing marks, reticulate ridges) on the bed surface. No traces of such marks have been observed at en Nammoûra site.

The bacterial decomposition of vertebrate carcasses is slowed but not halted by the scarcity of oxygen because putrefaction is caused mainly by anaerobic bacteria (Allison, 1988a; Weigelt, 1989; Briggs, 1993) which are less efficient biodegraders than aerobic bacteria (Allison, 1988b). Allison (1988a) has shown that the anaerobic decay of soft-bodied and lightly skeletized organisms is relatively rapid in a geological sense and cannot promote soft-part preservation. Low water pH and high salinity are more important than oxygen depletion in slowing putrefaction and permitting the preservation of the dead organisms, because all putrefactive bacteria are sensitive to acid and salty solutions (Klinkhammer & Lambert, 1989; Weigelt, 1989; Briggs, 1993). According to Allison (1988b) the early diagenetic mineralisation promoted by anoxia and controlled by rate of burial, amount of organic matter, and salinity, is the most important factor for soft-tissue preservation in the *Konservat-Lagerstätten*.

The needle-like crystals covering some fossil leaves are reminiscent of minerals which forms under hypersaline conditions, like barite, celestine and gypsum, and could be related to a high salinity of the basinal waters. Further study is needed on those crystals to confirm this hypothesis.

## ENVIRONMENTAL EVOLUTION

At the base of the sequence, cherty limestones and limestones with planktonic foraminifera and pelagic crinoids occur, indicating basinal conditions (units 1-2). A wedge, probably of bioclastic material, prograded from NE to SW onto the basinal deposits (Text-figs 10-11). This wedge appears to be significant in the platform evolution as the wedge generated the restricted basin where the *Lagerstätte* was deposited. The *Lagerstätte* subunits (3a-b) onlaps onto the wedge. This lens-like, small basin was starved of coarser sediment, had restricted circulation and possibly became hypersaline during the deposition of subunits 3a-b. The extreme rarity of planktonic and nektonic organisms (foraminifera, pelagic crinoids, pelagic bivalves, ammonites) suggests the presence of a barrier separating the basin from the open sea.



Text-fig. 15 - Oyster level in the lower part of unit 7.

The episodic input of carbonate mud originated from the platform, where it was suspended by storms or tidal currents and redeposited by fall-out in the basin bottom. Open pelagic sedimentation returned for subunits 3c-d.

The overlying unit 4 shows a rapid shallowing-upward to platform conditions, indicated by an abundant benthic fauna and by an increase of environmental energy (waves, currents and water turbulence in general). The uppermost bioclastic level shows modification by waves and currents. Subunits 3c-d and unit 4 also overlap the wedge. The geometry of the section shows that the infilling of the small basin is less than 50 m thick (see Text-figs 9-11) and roughly corresponds to the depth at which the *Lagerstätte* began to form.

The unit 5 shows the return to basinal conditions and thus marks a transgression. However, the presence of a nearby platform is suggested by sporadic thin bioclastic intercalations. Above, units 6 to 8 present prevailing platform facies, with short-duration pelagic intercalations in unit 7, possibly becoming more frequent in unit 8.

Therefore the en Nammoûra *Lagerstätte* probably formed at the bottom of a shallow, restricted basin related to the development of a clinoform probably caused by eustatism (the late middle Cenomanian transgression noted by Saint Marc, 1974, p. 202), since there is no evidence of a tectonically-controlled margin.

#### AGE

Unit 4, approximately 15 metres above the top of the en Nammoûra *Lagerstätte* in the lower quarry (Text-fig. 9) contains *Pseudorhapydionina laurinesis*, *Pseudorhapydionina dubia*, *Prealveolina* gr. *cretacea*, *Pseudedomia drorimensis*, and *Conicorbitolina* gr. *conica*. The presence of orbitolinids shows that the unit is within the middle Cenomanian (e.g. Schroeder & Neumann, 1985). Following Saint-Marc (1974, p. 284) the range of *Pseudorhapydionina laurinesis* in Lebanon covers exclusively the base of the late Cenomanian (*Pseudorhapydionina laurinesis* Biozone); *Pseudorhapydionina dubia* appears at the base of the late Cenomanian and *Pseudedomia drorimensis* is present throughout the middle-upper Cenomanian. On the other hand, *Orbitolina conica* and *Prealveolina cretacea cretacea* are considered to extend only to the top of the middle Cenomanian.

The presence of *Biplanata peneropliformis*, *Pseudorhapydionina dubia*, *Pseudorhapydionina laurinesis*, *Vidalina* sp. in unit 6, and the absence of orbitolinids in this unit are in agreement with a late Cenomanian age (cf. Saint-Marc, 1974, pl. 3). *Ovalveolina* cf. *ovum*, very common in this unit, is not reported by Saint-Marc (1974, pl. 3). According to many authors (e.g. Schroeder & Neumann, 1985) the stratigraphic distribution of *Ovalveolina ovum* is limited to the middle-late Cenomanian.

The microfossil associations of unit 7 include very frequent *Pseudorhapydionina laurinesis*, *Pseudorhapydionina dubia*, *Biplanata peneropliformis* and rare *Vidalina* spp. The abundance of *Pseudorhapydionina laurinesis*, the presence of *Pseudorhapydionina dubia*, *Biplanata peneropliformis* and *Vidalina* spp. and the absence of orbitolinids indicate a definitive late Cenomanian age. Furthermore, according to Saint-Marc (1974, p. 202) the base of the upper Cenomanian in the region of Jbail presents "littoral facies" and a rich benthic microfauna with Miliolidae, Soritidae and Alveolinidae and a macrofauna with rudists, oysters and gastropods characteristic of shallow waters, which were absent during the middle Cenomanian.

Those data suggest that unit 4 corresponds to the middle Cenomanian / upper Cenomanian boundary and the *Lagerstätte* is situated in the upper part of the middle Cenomanian (according to Hückel, 1970, fig. 3, the Cenomanian section in the nearby Hjoûla region is at least 550 m thick).

The upper part of the el-Gârboûr section (unit 8) is still within the lower part of the upper Cenomanian as indicated by the presence of *Pseudorhapydionina laurinesis*.

#### COMPARISON WITH THE OTHER CENOMANIAN LAGERSTÄTTEN OF LEBANON

The site en Nammoûra differs from other Cenomanian *Lagerstätten* of Lebanon in several respects and are discussed below.

#### AGE

According to Hückel (1970, fig. 3) the Hjoûla site is placed within Cenomanian IVd subdivision. (The Cenomanian is locally divided into seven subdivisions, I-VII). The Hjoûla site is stratigraphically about 20 metres below the nearby Hâqel *Lagerstätte* site, but this age difference cannot be resolved biostratigraphically. According to Hückel (1970) the stratigraphic subdivision containing the Hâqel *Lagerstätte* site (Cenomanian Va) presents *Orbitolina concava concava* and the ammonite "*Acanthoceras mantelli*". The presence of this ammonite is reported by Zumoffen (1926) but Hückel (1970) just mentions it. *Orbitolina concava concava* has been also found in the section at Hjoûla (Hückel, 1970).

Dalla Vecchia & Venturini (1999) and Dalla Vecchia *et al.* (2001) considered these sites as early Cenomanian on the basis of Saint-Marc's (1974) and Hückel's (1970) studies. In fact, according to these papers, both sites are latest early Cenomanian. The late early Cenomanian age (or boundary between early Cenomanian and middle Cenomanian) was accepted by Gayet (1980a,b; 1988), Garassino (1994) and Dal Sasso & Pinna (1997). However, Hemleben (1977, p. 244) reported biostratigraphic

data suggesting a different dating for Hâqel and Hjoûla sites. According to Hemleben, Hückel (1970) based his stratigraphy and dates of the Lebanese Cenomanian on Zummofen (1926) and the ammonite identifications by the latter were not revised. However Hemleben confirms that ammonite nuclei found by Hückel do belong to the group of *Acanthoceras* (*Acanthoceras*-Formenkreis; Hemleben, 1977, p. 244). Actually, we do not find any mention of "*Acanthoceras mantelli*" in Basse (1952), Thomel (1980) and Wright *et al.* (1996). The taxon identified by Zummofen (1926) is probably the Acanthoceratid *Mantelliceras mantelli* (Sowerby). According to Wright *et al.* (1996) *M. mantelli* has a lower Cenomanian range and has been found in Europe, northern and eastern Africa, Madagascar, southern India, Texas and Brazil. The *mantelliceras* Zone is the lower of the two biochronozones of the lower Cenomanian (Gradstein *et al.*, 1995, fig. 8).

Hemleben (1977, p. 244) reports the presence of the planktonic foraminifers *Praeglobotruncana stephani* (Gandolfi), *Rotalipora cushmani* (Morrow) and *Rotalipora greenhornensis* (Morrow) in the marly intercalations of the Cenomanian IVd and V. *Praeglobotruncana stephani* ranges from the late Albian (*Rotalipora appenninica* Zone) to middle Turonian (*Helvetoglobotruncana helvetica* Zone). According to Caron (1985) and Bralower *et al.* (1995) *Rotalipora cushmani* marks the last planktonic foraminifer biozone of the Cenomanian, which begins in the middle of the mid Cenomanian and ends in the upper Cenomanian (the uppermost Cenomanian-lower Turonian is represented by the *Whiteinella archaeocretacea* Zone); *Rotalipora greenhornensis* has a similar range, disappearing just before the top of the upper Cenomanian. According to Bralower *et al.* (1995) the *R. greenhornensis* Subzone represents the lower half of the *R. cushmani* Zone. According to Saint Marc (1974, pl. 3) *Rotalipora cushmani* and *Rotalipora greenhornensis* are found in the entire upper part of the upper Cenomanian and in the lowermost Turonian of Lebanon but do not occur in the lower part of the upper Cenomanian.

Hemleben (*ibidem*) also reports the presence of *Pseudolituonella reicheli*, *Pseudodedomia viallii* (= *Sellialveolina viallii* Colalongo), *Nummofallotia apula* Luperto Sinni and *Rhapydionina lauriniensis* (= *Pseudorhapydionina lauriniensis*) in the Cenomanian IIIb, which according to Hückel (1970) is placed more than 50 metres stratigraphically below the Hjoûla site. Following Saint Marc (1974) *Pseudodedomia viallii* does not reach the upper Cenomanian in Lebanon, while *Pseudorhapydionina lauriniensis*, as already reported above, is found only in the lower part of the upper Cenomanian.

A sample collected by FMDV from a massive lithological body which contacts the well-bedded fossil-bearing level at Hjoûla undoubtedly has the foraminifer *Orbitolina* sp. in the matrix. According to Hückel (1970, see fig. 7) this massive body is a sub-

marine sin-sedimentary slide (debris flow) which involved the fossil-bearing level. If this is the case, the age of the fossil-bearing level cannot be younger than middle Cenomanian. However, this cannot be the case if the contact between the massive lithosome and fossil-bearing level is of tectonic (fault) origin.

The analysis of the nannoplankton undertaken by Eliana Fornaciari on samples from the upper part of units 2, 3b, 3d, 5 and on samples from Hjoûla and Hâqel has been unsuccessful: the samples are barren or with forms not useful for biostratigraphy.

A conclusive dating of Hjoûla and Hâqel sites remains to be achieved.

Thus the en Nammoûra site could be coeval with Hjoûla and Hâqel sites or even older, contrary to our previous statement (Dalla Vecchia & Venturini, 1999) which was based on data from Hückel (1970) and Saint Marc (1974) only.

#### PALAEOTOPOGRAPHIC SETTING

The fossiliferous levels of Hâqel and Hjoûla were formed in tectonic basins produced by transpressive tectonics according to Hückel (1970), in deep silled basins at the transition outer platform-basin following Saint-Marc (1974) or developed in a deep trench along the shelf margin according to Hemleben (1977, fig. 7). In agreement with all these interpretations, gravity flow deposits are common in these basins, unlike the en Nammoûra basin which had a distinct origin, related to the presence of the clinoform.

#### FOSSIL ASSEMBLAGES

Fossils, mainly decapod crustaceans and fishes, are extraordinarily common at Hjoûla and Hâqel and this has been related to frequent mass deaths caused by algal proliferation due to deep water upwelling (Hemleben, 1977). However, such fossils are very rare at en Nammoûra, suggesting a normal death rate. The provenance of dead organisms was from different environments, even relatively far away as the emergent areas (terrestrial plants and birds). Hjoûla and Hâqel sites partly differ from each other in the composition of the faunal association, as shown by Hückel (1970). For example, ophiurids and pelagic crinoids are present only at Hâqel, while ammonites occur only at Hjoûla. Plants are rare at Hâqel and are unknown at Hjoûla. No terrestrial vertebrates (excluding a pterosaur from Hâqel; Dalla Vecchia *et al.*, 2001) have been found so far (Hückel 1970; FMDV, pers. obs.). According to Bannikov & Bacchia (2000, p. 4) "the composition of fish fauna... [of en Nammoûra]...clearly differs from those of Cenomanian...and Senonian [Lebanese] localities". Preservation of soft tissues (e.g. skin, eye ball) is more frequent at en Nammoûra than at the other sites.

The distinctive fossil assemblages of the Cenomanian Lebanese *Lagerstätten* could be due

mainly to the different sedimentological settings, relationships with the carbonate platform and open sea, distance from coastline and short-term eustatic oscillations. As a consequence, distinguishing the site of provenance of fossils is necessary at least for palaeoecological analysis. The microfacies seen in thin section are all rather similar, but the comparison of the gross lithological features of the slabs containing the fossils can in many cases help to distinguish the provenance of the specimens.

#### PALAEOENVIRONMENTAL AND PALAEOGEOGRAPHICAL REMARKS

Krassilov & Bacchia (2000) surprisingly recognize affinities with the approximately coeval floras of North America, Central Europe and Crimea and noted a marked difference with Early Cretaceous and Turonian floras of the Middle East. The prevalence of xeromorphic plants suggests arid climatic conditions similar to those of the present-day Mediterranean (*ibidem*, p. 797). This would be in agreement with the hypothesized hypersalinity at the bottom of the basin where the *Lagerstätte* formed.

According to Hückel (1970, p. 120) the Cenomanian coastline was 400 kilometres away in south Jordan. According to the palaeogeographical maps of Saint-Marc (1978) and Philip *et al.* (2000) the nearest land, at least during the late Cenomanian marine highstand, was hundreds of kilometres to the south east in the Arabian Peninsula. Therefore, the terrestrial material probably came from emergent parts of the carbonate platform, probably on islands. The wide carbonate platform present during Cenomanian times in Lebanon and nearby regions (see Philip *et al.*, 2000) had very low relief and eustatic oscillations would have had dramatic effects on the environment.

Middle Cenomanian terrestrial plants (angiosperms) are reported from the Aanjar locality of the western flank of the M. Hermon of southern Lebanon (Saint-Marc, 1974, p. 201) and are relatively common in the upper part of upper Cenomanian of the Antilebanon (*ibidem*, p. 203). This also suggests repeated emergence of the carbonate platform.

The absence or extreme rarity of terrestrial plants and the absence of terrestrial vertebrates in Hjoûla and Hâqel suggest a greater distance from the coastline with respect to the en Nammoûra site.

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