**Ammonoid and foraminiferal biostratigraphy from uppermost Valanginian to
lowermost Barremian of the Jebel Boulahouajeb section (northern Tunisia)**

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Abstract

A stratigraphic study was carried out on the Jebel Boulahouajeb section (Lansarine Chain;
Tebourba area, northern Tunisia) in order to establish a relatively detailed biostratigraphic
framework of the Hauterivian pelagic deposits of the Tunisian trough. The limestone–marl
alternations are represented by five limestone-dominated intervals, named calcareous bundles
H1 to H5, separated by thick marly-dominated intervals. The well exposed Jebel
Boulahouajeb section (873 m in thickness) is relatively continuous, rich in ammonoid
macrofauna, and provides an ideal succession for this approach. Concerning the Hauterivian
ammonoid zonal scheme, the following (sub-)zones have been identified: *Acanthodiscus*
radiatus, *Crioceratites loryi*, *Lyticoceras nodosoplicatum*, *Balearites balearis* (with *B.*

balearis, *Balearites binelli*, *Balearites krenkeli* and *Balearites angulicostatus* Subzones) and *Pseudothurmannia ohmi* (with *P. ohmi*, *Pseudothurmannia mortilleti* and *Pseudothurmannia picteti* Subzones) Zones. Thus, except the *Subsarynella sayni* and *Plesiospitidiscus ligatus* Zones, the standard zonation of the Mediterranean Province has been recognized in this area of the Tunisian trough. The boundaries of the Hauterivian stage have been characterized by identifying the last zone of Valanginian (*Criosarasinella furcillata* Zone) and the first zone of Barremian (*Taveraidiscus hugii* Zone). The benthic and planktic foraminiferal assemblages have been used to characterize some stratigraphic levels of the studied section; however the lack of certain data did not allow to well recognize and establish a complete zonal scheme. Mainly on the base of ammonoid biostratigraphy, the Jebel Boulahouajeb section is correlated with the Jebel Oust section (north–west of Zaghouan) that is the Lower Cretaceous reference section of the Tunisia trough.

Keywords: Ammonoids; Foraminifera; Hauterivian; Jebel Boulahouajeb; Jebel Oust; Tunisia

1. Introduction

In his monography on Mesozoic cephalopods of Tunisia, Pervinquière (1907) provided a subdivision of the Early Cretaceous series. This important work was completed by Solignac (1927) who focused his geological survey on the northern Tunisia. Since the middle part of the 20th century, a succession of papers allowed to constraint the bio-lithostratigraphy of this interval using mainly ammonoids and foraminifera, and sometimes calpionellids (Castany, 1951; Bolze et al., 1952; Jauzein, 1967; Memmi, 1965, 1969, 1973, 1979, 1981, 1989; Busnardo and Memmi, 1972; Memmi and Maamouri, 1974; Stranik et al., 1974; Donze et al., 1975; Memmi and Salaj, 1975; Maamouri and Salaj, 1978; Salaj, 1980, 1984; Ben Haj Ali et al., 1993; Maamouri et al., 1994; Ben Haj Ali, 2005, 2006, 2008). Recently Ben Haj Ali and

Memmi (2013) compiled a synthesis presenting a correlation between the ammonoid and foraminifera zonal schemes for the Lower Cretaceous of northern Tunisia. Since Castany (1951), the Jebel Oust locality (north–west of Zaghouan, 40 km South-East of Tebourba, Tunisia trough) has been considered as a reference for the Lower Cretaceous marine succession, and consequently numerous authors quoted previously focused on this section. Due to its relative continuity and richness in micro and macrofauna, Salaj proposed, during the meeting of the working Group on Pelagic Facies in Urbino in 1989, the Jebel Oust section as a standard for marine Lower Cretaceous successions of the Tethyan realm (see Maamouri et al., 1994). In his work on the Lansarine Chain (Tebourba area, northern Tunisia), Zargouni (1975) described and figured two sections for the Lower Cretaceous series: the Jebel Boulahouajeb and Tazega sections. The Jebel Boulahouajeb section appeared interesting for the Valanginian–Aptian interval due to its important thickness and richness in ammonoids that was also sampled by Solignac (1927). Zargouni (1975) underlined the presence in this section of several foraminifera, calpionellid and nannofossil taxa. Considering the literature on the stratigraphy of north Tunisia, it is important to note that, even in the works published during the last decades, the stratigraphic columns of the most sections were generally not detailed as they concerned the Lower Cretaceous period, and the sampling of macrofauna was very sparse. The data was often presented as a species list, and the ammonoids collected were generally not documented (rarely illustrated; as noted by Lehmann et al., 2009).

The aim of this work is to (1) establish a detailed biostratigraphic framework with both ammonoids and foraminifera of the Jebel Boulahouajeb section, mainly for the Hauterivian stage including the characterization of its boundaries, (2) illustrate some ammonoid and foraminifera species of the studied section, and (3) establish correlations with the Jebel Oust reference section using mainly the ammonoid data. The Jebel Boulahouajeb section provides an ideal succession for this approach owing to the expanded, continuous well exposed

outcrops and relatively abundant fossil records, in particular ammonoids which are relatively abundant and well preserved (see Melliti, 2012; Melliti et al., 2013).

2. Geological setting

The Jebel Boulahouajeb section is located in northern Tunisia near Tebourba city, about 40 km west of Tunis (Fig.1). The studied section belongs to the Lansarine Chain, delimited by the vast plain of the Medjerda valley to the south and east, and by the plain of the Oued Ettine to the north and north-west. The Mesozoic stratigraphy, palaeogeography, structures and tectonics of northern Tunisia were described by numerous authors as Burollet (1956, 1991), Bonnefous (1972), Zargouni (1975), Memmi et al. (1989), Bobier et al. (1991), Rais et al. (1991), Souquet et al., (1997), Chikhaoui et al. (1998), Soussi et al. (2000), Kamoun et al. (2001), Bensalem (2002), Piqué et al. (2002), Soussi (2003), Boughdiri et al. (2006), Ben Abdesselam-Mahdaoui et al. (2010, 2011), Masrouhi et al. (2013), Naji et al. (2018a,b). The Jebel Boulahouajeb section belongs the Tunisian trough (“sillon tunisien”, Castany, 1951), a strongly subsiding basin from the Jurassic to Cretaceous time span. It corresponds to a deep marine palaeoenvironment characterized by pelagic-deep deposits. The Lower Cretaceous succession of this area is represented by very thick marly-limestone series with intercalation of some sandstone beds. Large and numerous diapiric intrusions of mainly evaporitic triassic material are also present (Perthuisot, 1981; Burollet, 1991). Zargouni (1975) described the Hauterivian–Aptian interval of the Jebel Boulahouajeb section, suggesting that this pelagic succession could start with the Valanginian; he noted the presence of a Triassic intrusion at its base. In northeastern Tunisia, the Valanginian–Aptian succession is named the M’Chergua Formation (Ben Ferjani et al., 1990; Burollet, 1991). Recently, it was raised to the rank of Group and subdivided into four formations which are from the bottom up (Ben Haj Ali, 2008): El Mergueb (Valanginian to lower Hauterivian), Kef En Nemour (upper Hauterivian to

upper Barremian), Sidi Amor (uppermost Barremian to basal Aptian) and Oued Ellouz (Aptian) formations.

3. Material and methods

3.1. Ammonoids

A preliminary study of macrofauna of the Jebel Boulahouajeb section was started by Melliti (2012) in the El Manar University of Tunis. This palaeontological material has been completed by further samplings made by Melliti, from 2013 to 2016. Sampling of macrofaunal specimens was carried out at fifty four beds. Due to the thickness of the section (873 m, see part 4.1), a bed by bed sampling was not possible for this preliminary study. The marly intervals were not sampled as the outcrop conditions were not favourable. The selected intervals were sampled for their content of pelagic (589 ammonoids representing 95% of macrofauna; 8 aptychi; 15 belemnites) and benthic macrofauna (1 bivalve and 6 echinoids); nautiloids (shells and rhyncholites) were not found.

Dissolution of the ammonoid shells is the norm and specimens are preserved as internal calcareous moulds. The ammonoid fauna is relatively well preserved, but the fragmentation of specimens can be frequent in some beds. The compaction of specimens is relatively important, particularly for the phragmocone. Consequently, some characteristics, such the whorl section, the strength of ribs and tubercules, and how they change between the inner and outer whorls, cannot be observed and compared for some specimens. The palaeontological material was reviewed and taxonomically identified at the University of Lyon (Reboulet and Melliti). The identification of ammonoids at specific level is sometimes difficult or impossible. Some data are here presented at the generic level and some specimens identified with doubt are indicated by a question mark. The material is stored in the palaeontological

collections of the Observatory of Lyon at the Claude Bernard University of Lyon (France, Melliti's collection).

3.2. Foraminifera

One hundred and fifty four samples were collected in the Jebel Boulahouajeb section; most of them (75%) come from the marly beds. Spacing is variable and ranges from less than 5 m to 10 m as the section is very thick. In the laboratory, 300 gr of each sample were analyzed at the University of Tunis by Ben Haj Ali and Melliti. Marly sediments were soaked in tap water and H₂O₂. After twenty four hours, the samples were washed through a set of sieves (63 µm–500 µm). The sieve with mesh opening of 63 µm is recommended. Processed samples, once dried, were stored in closed small plastic bags. The microfaunal assemblage is represented by benthic and planktic foraminifera, ostracods (rare) and echinoid spines (frequent). It is necessary to note that planktic foraminifera were carried out only in the fine fraction. They have a well preserved calcitic test, unlike for the forms described in other sections of the northeastern Tunisia, which are represented by a pyritised test. Due to their very small size, their identification is often difficult. Even if planktic foraminifera are rare, they have been studied for their biostratigraphic interest. The benthic foraminifera are common to frequent in residus and were found in the coarse and fine fraction. Despite of their abundance, just a preliminary study of this group is presented here. The samples were examined under a binocular microscope with optics power twenty times; this magnification is not very adequate to recover easily very small planktic foraminifera. Specimens were mounted in one hundred and sixty cell-slides. Representative specimens illustrated were photographed using Scanning Electron Microscope. The selection of illustrated specimens is based on the stratigraphic importance of the index-species of planktic foraminifera and the importance of associated benthic foraminifera taxa.

4. Results

4.1. Description of the Jebel Boulahouajeb section

The Jebel Boulahouajeb section (JBH; 873 m in thickness) is composed by two complementary sections (sections JBH-A and JBH-B) from the M'Chergua Group (*sensu* Ben Haj Ali, 2008), with abnormal contact of Triassic deposits at the base. On the well-exposed intervals, all beds have been identified and drawn on the field notebook (Melliti, Ben Haj Ali and Sabri Arfaoui); however, due to the important thickness of the section JBH-B, the drawn scheme was simplified. Outcrop conditions are sometime less favorable to make a precise observation as some marly-dominated intervals are more or less affected by scree-cover.

The section JBH-A (Fig. 2; 50 m. thick) starts with a metric bed of red sandstone, followed by an alternation of yellowish limestones and gray marls, attributed to the upper Valanginian.

The section JBH-B (Fig. 3ab; 823 m thick) starts after a lateral displacement of 10 m to north-west from the top of section JBH-A. About 20 m of limestone-marl alternations of the upper Valanginian are exposed at the base of the succession. The Hauterivian is represented by 783 m of thickness, including a 65 m gap of observation. The deposits are made of nodulous limestones, yellow in patina and grey colour when broken, and alternating grey marls. The succession is characterized by calcareous bundles that are limestone-dominated intervals (thick calcareous beds and reduction of marl-bed thickness); they are separated by thick marl-dominated intervals. Starting by a sandstone bed (JBH-B3; 3 m, ochre's color), the lower part of the section JBH-B is composed by two calcareous bundles named H1 (JBH-B5 to B20; 34 m) and H2 (JBH-B22 to B32; 27 m), separated by a marly interval. In the middle part of the section JBH-B, the marly interval is characterized by two calcareous bundles, named H3 (JBH-B86 to B97; 24 m) and H4 (JBH-B163 to B170; 28 m), and several more or less continuous sandstones or siltstones beds (above JBH-B32, JBH-B48-59-65-72-75, above

JBH-B115, and JBH-B181). In the upper part of the section JBH-B, a succession of thick beds allows to recognize a fifth calcareous interval named H5 (JBH-B202 to B219; 26 m), known as the “cornice of Jebel Boulahouajeb” of Zargouni (1975). The uppermost part of the section JBH-B is represented by marls and grey limestones attributed to lowermost Barremian (20 m).

4.2. Ammonoids

4.2.1. Systematics

The ammonoid fauna of the studied section consists of thirty one genera grouped into fourteen families and nine super-families (Appendix 1), mainly using the classification proposed by Klein (2005), Vermeulen and Klein (2006), Klein et al. (2007, 2009), and Klein and Vašíček (2011). As the purpose is not to make a systematic revision, only palaeontological comments are made for some taxa and quantitative data are also given. Further information is available in the papers of Company (1987), Reboulet et al. (1992), Bulot et al. (1993), Bulot (1995), Hoedemaeker (1995, 2013), Reboulet (1996), Cecca et al. (1998), Reboulet and Atrops (1999), Busnardo et al. (2003), Company et al. (2003, 2005), Vermeulen (2003), Ettachfini (2004), Vermeulen et al. (2012, 2013).

Neocomitids are rare to common and they occur in the lower part of the Jebel Boulahouajeb section (section JBH-A, Fig. 2; section JBH-B, Fig. 3a). They are represented by *Teschenites* (12 specimens), *Eleniceras* (3 specimens), *Lyticoceras* (4 specimens; Figs. 4A and 4B), *Jeanthieuloyites* (6 specimens) and *Spitidiscus* (31 specimens). Due to the relatively bad preservation of the material in these beds, the identification of species is difficult for the first three genera; only few *Teschenites subflucticulus* (Fig. 4C) have been recognized in beds JBH-A5 and A7. In this interval also occur *Jeanthieuloyites keyserlingiformis* (Fig. 4D), *Jeanthieuloyites quinquestriatus* (Fig. 4E) and *Jeanthieuloyites solignaci* (Figs. 4F and 4G).

200 The first *Spitidiscus* (identified with doubt) occurs in JBH-B7; the lowest occurrences (LO) of
201 *Spitidiscus lorioli* (Figs. 4H and 4I) and *Spitidiscus meneghini* (Figs. 4J, 4K, 4L) are recorded
202 in beds JBH-B9 and B10, respectively; only one *Spitidiscus rawsoni* (Fig. 4M) have been
203 found in bed JBH-B30. Even though *Himantoceras* is characterized by a cryptoconic shell, this
204 genus should be assigned to the Neocomitinae (the phyletic relation has been shown by
205 Reboulet, 1996, 2007, 2008) and not to the Ancyloceratids as kept by Klein et al. (2007). One
206 specimen of *Himantoceras* cf. *trinodosum* (Fig. 4N) has been found in bed JBH-B4.
207 Olcostephanids are common to frequent in some beds. Among *Olcostephanus* (62 specimens),
208 *Olcostephanus densicostatus* (Figs. 5A and 5B) has been identified in the section JBH-A (Fig.
209 2). *Jeannoticeras jeannoti* (2 specimens; Fig. 5C) has been recorded in beds JBH-B20 and
210 B21 (Fig. 3a).
211 Oosterellids are rare and this family is represented by three species of *Oosterella* (8
212 specimens; Figs 2 and 3a): *Oosterella undulata* (Fig. 5D), *Oosterella cultrata* (Fig. 5E) and
213 *Oosterella cultrataeformis*.
214 Holcodiscids are very rare and only three specimens of *Avramidiscus intermedius* (Fig. 6A)
215 have been found at the uppermost part of the section JBH-B (beds JBH-B232 and B234; Fig.
216 3b).
217 Barremitids are mainly represented by *Plesiospitidiscus* (50 specimens): *Plesiospitidiscus*
218 *fasciger* (Figs. 6B and 6C) have been sampled in beds JBH-B18 and B20 (Fig. 3a); the middle
219 part of the section JBH-B is characterized by *Plesiospitidiscus subdifficilis* (Figs. 6D and 6E;
220 Fig. 3b). In this interval, one *Abrytusites neumayri* (Fig. 6F) has been recorded. Other genera
221 of this family occur in the upper part of the section JBH-B with one *Barremites* gr. *cassida*
222 (Fig. 6G), two *Montanesiceras* cf. *dimboviciorensis* and two *Valdedorsella*? *uhligi* (Fig. 6H).
223 Pulchelliids are very rare in the section JBH-B and only five specimens of *Discoideilia* have
224 been recorded (Fig. 3b): *Discoideilia* cf. *couratieri* (Figs. 6I and 6J) and *Discoideilia favrei*.

225 Haploceratids, with *Neolissoceras grasianum* (Fig. 7A), mainly occurs in the section JBH-A
226 and in the lowermost part of the section JBH-B (13 specimens; Figs. 2 and 3a); only one
227 specimen has been sampled in the middle part of the section JBH-B (bed JBH-B163; Fig. 3b).
228 Phylloceratoids are represented by *Phylloceras* (*Hypophylloceras*) with 16 specimens
229 (*Phylloceras* (*Hypophylloceras*) *tethys*, Fig. 7B; *Phylloceras* (*Hypophylloceras*) *ponticuli*)
230 and *Phyllopachyceras* with 31 specimens (*Phyllopachyceras winkleri*, Fig. 7C;
231 *Phyllopachyceras infundibulum*, Figs. 7D and 7E) which are more frequent in the lower part
232 rather in the upper part of the section JBH-B (Figs. 2 and 3ab). This last species has not been
233 found in the section JBH-A (Fig. 2); it seems that the first specimen (identified with doubt)
234 occurs in bed JBH-B9 (Fig. 3a).
235 Lytoceratids (61 specimens) are represented by *Lytoceras subfimbriatum* (Figs. 7F and 7G);
236 the genus *Lytoceras* is relatively common (Figs. 2 and 3ab).
237 Crioceratitids are represented by *Balearites* (69 specimens) and *Pseudothurmannia* (161
238 specimens) which are relatively abundant, particularly in beds JBH-B163 and B202,
239 respectively (Fig. 3b). In this work, the opinion of Company et al. (2003) is followed:
240 *Balearites balearis*, *Balearites binelli*, *Balearites krenkeli* and *Balearites angulicostatus* could
241 constitute a phylogenetic lineage. These species were included in the genus *Crioceratites* by
242 these authors. More recently, the first three species were considered as belonging to
243 *Balearites* by Vermeulen et al. (2012). However, these both teams have a different conception
244 of the genus *Balearites*; for Vermeulen et al. (2012), some species of *Pseudothurmannia*
245 should be included in *Balearites*, and these authors do not consider *angulicostatus* as a
246 *Balearites*. Taking into account their new data and observations, Matamalas and Company
247 (personnal communication, 2017) suggest that the group/lineage *balearis-binelli-krenkeli-*
248 *angulicostatus* should belong to the genus *Balearites*. According to Company et al. (2003),
249 the evolutionary trend of this group is towards “a stronger ornamentation and a clear

differentiation between main and intermediate ribs in the middle ontogenetic stages”. The ornamentation of *B. balearis* is characterized in the middle stages by uniform and dense ribs lacking distinct umbilical tubercles. In bed JBH-B92 (Fig. 3b), three specimens have been identified as *B. cf. balearis* (Fig. 8A). The second member of the lineage is *B. binelli* (Figs. 8B to 8E); it differs in the appearance of ribs bundles rising from well-defined umbilical bullae. *B. binelli* seems relatively frequent as fifteen specimens have been sampled in bed JBH-B163 and numerous *Balearites* sp. ind. found in this bed probably belong to this species. The next species of the group is *B. krenkeli*; a clear differentiation between main and intermediate ribs from quite early ontogenetic stage can be observed. One specimen belonging to bed JBH-B195 is identified with doubt to this species (Fig. 8F). *Balearites angulicostatus* is the last species of this lineage and the ancestor of *Pseudothurmannia* forms (Hoedemaeker, 1995; Company et al., 2003). In the studied section, two specimens are identified as *Balearites cf. angulicostatus* (Figs. 8G and 8H) in bed JBH-B195. In their work, Company et al. (2003) recognized four species of *Pseudothurmannia*. These authors observed the consecutive appearance of *Pseudothurmannia ohmi*, *Pseudothurmannia mortilleti* and *Pseudothurmannia picteti*; this evolutionary trend is towards a more involute coiling. They noted that *P. ohmi* “differs from its ancestor *angulicostatus* in having the whorls always in touch and having definitively lost the initial trituberculate stage”. In the Jebel Boulahouajeb section, *P. mortilleti* (Figs. 9A to 9E) is well represented and co-occurs with *Pseudothurmannia pseudomalbosi* (Figs. 9F, 9G and 10A). Just above this stratigraphic interval, one specimen of *P. picteti* (Fig. 10B) has been recorded (bed JBH-B219, Fig. 3b). *P. ohmi* has not been recognized. Taking into account the stratigraphic distribution of the last *Balearites* and first *P. mortilleti* found in beds JBH-B195 and JBH-B202, respectively, *P. ohmi* should take place in this interval (from top JBH-B195 to base JBH-B202) in which first specimens of *Pseudothurmannia* sp. ind. have been sampled (bed JBH-B200); indeed,

according to the distribution of species given by Company et al. (2003), *Balearites* (*balearis-binelli-krenkeli-angulicostatus* group) and *Pseudothurmannia* (*ohmi-mortilleti-picteti* group) do not coexist (no overlapping of their ranges). The identification at the specific level was not possible for the three specimens of *Sornayites* found in this part of the section JBH-B characterized by numerous *Pseudothurmannia*. Emericiceratids (2 specimens: *Honnoratia* cf. *thiollieri*; *Paraspiticerias* sp. ind., Fig. 10C), Leptoceratoidids (4 specimens: *Hamulinites* sp. ind.; *Sabaudiella simplex*, Fig. 10D) and Hamulinids (2 specimens: *Anahamulina lorioli*; *Amorina*?) are very rare and restricted in the upper part of the section JBH-B (Fig. 3b). Bochianitids (5 specimens: *Bochianites neocomiensis*) have been found in the section JBH-A and in the lowermost part of the section JBH-B (Figs. 2 and 3a).

4.2.2. Biostratigraphic implications

According to the stratigraphic distributions of ammonoid taxa of the studied section (Figs. 2 and 3ab), the whole Hauterivian stage is represented in the Jebel Boulahouajeb section. Most of the Hauterivian zones of the Standard zonation (Hoedemaeker et al., 2003; Reboulet et al., 2018) have been recognized. All of these are interval zones and their lower boundary is identified by the LO of the index-species (their upper boundary is identified by the base of the next zone). The main references concerning the stratigraphic distribution of taxa allowing to characterize the zones are indicated.

The section JBH-A belongs to the *Criosarasinella furcillata* Zone (Fig. 2), of Valanginian age, taking into account the occurrence of *Teschenites* sp. ind., *T. subflucticulus* (Reboulet, 1996; Reboulet and Atrops, 1999) and *J. keyserlingiformis* (Avram, 1995). This interval is also marked by the occurrence of *Eleniceras* sp. ind., *O. densicostatus*, *O. ondulata*, *J. quinquestriatus* and *J. solignaci*; these taxa are present in the uppermost part of the

300 Valanginian, but they are also known in the lowermost part of the Hauterivian (Reboulet,
301 1996). The Hauterivian is not characterized here due to the absence of *Spitidiscus* and *P.*
302 *unfundibulum*.

303 The Valanginian–Hauterivian boundary can be drawn in the lowermost part of the section
304 JBH-B (Fig. 3a), and is placed at the base of bed JBH-B7 in which a specimen of *Spitidiscus*
305 sp. ind. has been found. When *Acanthodiscus* or *Breistrofferella* are absent (*Acanthodiscus*
306 *radiatus* is the index-species of the first zone of the Hauterivian stage), the LO of *Spitidiscus*
307 can be used to characterize the base of the Hauterivian (Reboulet, 1996; Busnardo et al.,
308 2003). Just below bed JBH-B7, a specimen of *H. cf. trinodosum* has been recorded in bed
309 JBH-B4. According to Reboulet (1996; see also Reboulet and Atrops, 1999), *H. trinodosum* is
310 restricted to the upper Valanginian. Bulot et al. (1993) found in the lowermost part of the *A.*
311 *radiatus* Zone (La Charce section, France) a (or few?) specimen(s) of *Himantoceras* identified
312 as *H. cf. trinodosum*. This/these specimen(s) could correspond to *Himantoceras* n. sp. 2, taxa
313 described by Reboulet (1996) and located in the basal part of the *A. radiatus* Zone (only three
314 specimens found in the Les Sias section, France). Consequently, *H. trinodosum* should be
315 restricted to the upper Valanginian. The *A. radiatus* Zone is characterized by the occurrences
316 of *S. lorioli*, *S. meneghini* and *P. infundibulum* (Bulot, 1995; Reboulet, 1996); all or a part of
317 these taxa are recorded in beds JBH-B9 and B10. The assemblage of the interval JBH-B8 to
318 B10 is also characterized by *Teschenites* sp. ind., *O. cultrata* and *O. cultrataeformis*. The bed
319 JBH-B9 could correspond to the middle part of the *A. radiatus* Zone as the range of these
320 Oosterelid species ends in the lower part of this zone in SE France and the range of *P.*
321 *unfundibulum* starts in its upper part (Reboulet, 1996).

322 The *Crioceratites loryi* Zone is not directly characterized as the index-species has not been
323 found. In the Jebel Boulahouajeb section, the highest occurrence (HO) of *S. meneghini* and *S.*
324 *lorioli* (in bed JBH-B11) is used to put the lower boundary of this zone at the base of bed

JBH-B12 (Fig. 3a). Even if Reboulet (1996) noted the occurrence of *S. meneghini* in the lowermost part of the *C. loryi* Zone, it seems that these both species of *Spitidiscus* are mainly restricted in the *A. radiatus* Zone (see Bulot, 1995).

The *Lyticoceras nodosoplicatum* Zone has been recognized with the LO of *Lyticoceras* sp. ind. in bed JBH-B20 (Fig. 3a). The fact that this taxa co-occurs with *P. fasciger*, in bed JBH-B20, and *J. jeannoti*, in beds JBH-B20 and 21, allows to characterize the lowermost part of the zone (the *Olcostephanus variegatus* Horizon; Bulot, 1995). *Lyticoceras* sp. ind. and *S. rawsoni* have been found in beds JBH-B24 and B30, respectively; according to Bulot (1995) and Reboulet (1996) these both taxa are restricted to the *L. nodosoplicatum* Zone.

The *Subsaynella sayni* and *Plesiospitidiscus ligatus* Zones have not been identified as the interval from the top of JBH-B30 to the base of JBH-B86 has not been sampled for macrofauna (Fig. 3a). Consequently, the upper boundary of the *L. nodosoplicatum* Zone is provisionnaly placed at the top of bed JBH-B30.

The *Balearites balearis* Zone is well identified in the studied section. Its base is placed at the base of bed JBH-B92 in which several specimens of *Balearites* sp. ind. and *B. cf. balearis* have been recorded (Fig. 3b). Two specimens identified with doubt to the genus *Balearites* have been found in beds JBH-B86 and B89. This interval is also characterized by the occurrence of *P. subdifficilis* and *D. cf. couratieri*; according to Company et al. (2003), the LO of these two latter species are at the base of the *B. balearis* Zone. These observations could be in favour to place the base of this zone at bed JBH-B86. However, even if the acme of *D. couratieri* occurs in the *B. balearis* Zone (Vermeulen, 1995), the LO of *D. couratieri* is in the lower part of the *P. ligatus* Zone (Vermeulen, 2003). Due to the difficulty in identifying the different species of *Plesiospitidiscus* and considering that their stratigraphic distribution is not well known around the interval of the *P. ligatus* Zone, it is preferable not to put the base of the *B. balearis* Zone at the LO of *P. subdifficilis*. The lower boundary of *Balearites binelli*

350 Subzone is placed at the base of bed JBH-B163 where its index-species occurs. It is difficult
351 to identify the upper boundary of this subzone. The lower boundary of *Balearites*
352 *angulicostatus* Subzone is drawn at the LO of *B. cf. angulicostatus* sampled in bed JBH-
353 B195. In this bed, there is also *B. krenkeli*?; the specimen probably represents the end of the
354 range of the species. Indeed, according to Company et al. (2003), *B. angulicostatus* and *B.*
355 *krenkeli* co-exist in a short stratigraphic interval of the lowermost part of the *B. angulicostatus*
356 Subzone. Thus, the *B. krenkeli* Subzone can be provisionally assigned to the interval from the
357 top of bed JBH-B170 (just above the range of *B. binelli*) to the base of bed JBH-B195 (just
358 below the LO of *B. cf. angulicostatus*).

359 The *Pseudothurmannia ohmi* Zone is well characterized. Its lower boundary is placed at the
360 base of bed JBH-B200 where one specimen of *Pseudothurmannia* sp. ind. has been recorded
361 (Fig. 3b). As observed by Company et al. (2003) for the SE Spain, the HO of *L.*
362 *subfimbriatum* and *P. subdifficilis* are recorded in the lower part of the zone of the Jebel
363 Boulahouajeb section; a comparison with their work can also be done for *V.?* cf. *uhligi*, *M. cf.*
364 *dimboviciorensis* and *D. favrei* that are sampled in the *P. ohmi* Zone of the studied section.

365 The base of the *Pseudothurmannia mortilleti* Subzone is placed at the base of bed JBH-B202
366 where its index-species first occurs. Its range is similar to that of *P. pseudomalbosi*; this is in
367 accordance with the data of Company et al. (2003). The lower boundary of *P. picteti* Subzone
368 is put at the base of bed JBH-B219. This subzone is difficult to characterize as there is a large
369 stratigraphic interval (65 m in thickness) without observation.

370 The Hauterivian–Barremian boundary is provisionally placed at the base of bed JBH-B232
371 where the LO of *A. intermedius* is recorded (Fig. 3b), even if this species first occurs in the
372 uppermost part of the *P. picteti* Subzone as observed by Company et al. (2003). The base of
373 the Barremian stage is also characterized by the presence of *B. gr. cassida* found in bed JBH-
374 B234.

375

376 4.3. Foraminifera

377 4.3.1. Systematics

378 The micropaleontological study of planktic foraminifera is based essentially on the work of
379 Moullade (1974), Caron (1985), Premoli-Silva and Sliter (2002), Ben Haj Ali (2005; 2006),
380 Ben Haj Ali and Memmi (2013; Appendix 2). Their determination is often difficult due to the
381 very small size of the studied specimens; the problem of the identification of the lowermost
382 Cretaceous planktic foraminifera was also noted by Cecca et al. (1994) and Coccioni and
383 Premoli-Silva (1994). As also underlined by these authors for this interval in Italy and Spain
384 respectively, the planktic foraminiferal assemblages of the Boulahouajeb section is poorly
385 diversified; this was also observed in north-west Tunisia by Ben Haj Ali (2005) and Ben Haj
386 Ali and Memmi (2013). In the studied section (Fig. 11), Favusellids are represented by
387 *Favusella hoterivica* (Figs. 12A and 12B). Praehedbergellids are composed by two genera:
388 *Gorbachikella*, represented by *Gorbachikella kugleri* (Figs. 12C and 12D), *Gorbachikella*
389 *anteroapertura* (Fig. 12E) and *Gorbachikella grandiapertura*, and *Praehedbergella*
390 represented by *Praehedbergella sigali* (Figs. 12F to 12H). Planktic foraminifera occur only in
391 the upper part of the section (Fig 11). They are rare to very rare but *P. sigali* is more abundant
392 in the upper part of its range. The low abundance of the small planktic forms in the
393 Valanginian and Hauterivian stages is also noted by Coccioni and Premoli-Silva (1994).
394 Benthic foraminifera are represented by thirty six taxa, which constitute the main part of the
395 assemblages (Fig. 11). Their palaeontological study is based on Moullade (1974), Neagu
396 (1975), and Holbourn and Kaminski (1995). In the studied section, calcareous taxa are
397 represented by nine genera (*Lenticulina*, *Dentalina*, *Frondicularia*, *Marginulinopsis*,
398 *Catharina*, *Ramulina*, *Marginulina*, *Spirillina* and *Gavelinella*) including twenty two
399 species/taxa. The agglutinated foraminifera, that are generally less frequent, are composed by

five genera (*Dorothia*, *Marsonella*, *Ammodiscidus*, *Bathysiphon* and *Rhizimina*) including fourteen species/taxa. A poor assemblage of benthic foraminifera is recorded in the upper Valanginian interval (6 samples; from JBH-B1 to B6) that is characterized by the occurrence of rare *Lenticulina roemeri* (Fig. 12I). A moderate diversification is observed in the lower Hauterivian of the Jebel Boulahouajeb section. A stronger increase of number of taxa is recorded from the lowermost part of the upper Hauterivian (from level JBH-B76 to the top of the section). The foraminiferal succession for the studied Hauterivian section is subdivided into nine assemblages based on changes in the composition of dominant taxa and on occurrences of species with biochronological interest: *Lenticulina eichenbergi* (Fig. 12J), *Dorothia lilliformis* (Fig. 12K), *Lenticulina multicella* (Fig. 12L), *Dorothia praehauteriviana* (Fig. 12M), *Lenticulina ouachensis ouachensis* (Fig. 12N), *Dorothia kummi* (Fig. 12O), *Dorothia zedlerae* (Fig. 12P), *Lenticulina rotulata* (Fig. 12Q) and *Gavellinella barremiana* (Fig. 12R). These index-species are accompanied by other abundant benthic species (Fig. 11).

4.3.2. Biostratigraphic implications

The planktic foraminifera zonation adopted in this work (Fig. 11) corresponds to the local zonal scheme established by Ben Haj Ali (2005) and Ben Haj Ali and Memmi (2013).

Contrary to Maamouri et al. (1994), benthic foraminifera are not used here to define foraminiferal subzones because the occurrence and distribution of the group is highly controlled by local ecological conditions (see Moullade, 1974).

No planktic forms have been observed in the uppermost Valanginian–lower Hauterivian of the Jebel Boulahouajeb section. This could be partly explained by the difficulty to identify specimens due to their small size. Salaj (1984) and Ben Haj Ali (2005; see also Ben Haj Ali and Memmi, 2013) have noted that the LO of planktic foraminifera are respectively at the base of the lower Hauterivian and the base of the upper Hauterivian. The low diversification

425 of the lowermost Cretaceous foraminiferal planktic assemblages and their scarcity
426 (Coccioni and Premoli-Silva, 1994; Cecca et al 1994; Robaszynski and Caron, 1995) could
427 also explain why these microfossils have not been found in this interval of the studied section.
428 In the Jebel Boulahouajeb section, only five planktic foraminifera species have been recorded
429 in the upper Hauterivian–lowermost Barremian interval. The first bioevent (JBH-B37 at the
430 lowermost part of the upper Hauterivian) is characterized by the LO of *Favusella hoterivica*.
431 The *F. hoterivica* Interval Range Zone is identified by the LO of the index-species (Van
432 Hinte, 1972). In the Cretaceous Mediterranean zonal scheme based on planktic foraminifera,
433 Sigal (1977) indicated that “*Caucasella* gr. *hauterivica-kugleri*” first occurs at the base of the
434 upper Hauterivian (see also Caron, 1985). In Tunisia (Jebel Oust area), *F. hoterivica* first
435 occurs at the base of the Hauterivian (Salaj, 1984). For Maamouri et al. (1994), the
436 “*Globuligerina hoterivica* Zone” characterizes the Hauterivian stage. According to Coccioni
437 and Premoli-Silva (1994), the “mean range” of “*C. hauterivica*” starts at the base of the
438 Hauterivian (synthetic data); however these authors indicated that the LO of this species in SE
439 Spain is at the base of “*Thurmanniceras*” *pertransiens* Zone (base of the Valanginian).
440 According to Ascoli (1988 in Robaszynski and Caron, 1995), the LO of *F. hoterivica* could be
441 lower, in the middle–late Berriasian in the NW Atlantic margin of North America. In the Jebel
442 Boulahouajeb section, only a short part of the stratigraphic range of *F. hoterivica* is recorded
443 corresponding to the lower part of the upper Hauterivian. Consequently, it is not really
444 possible to identify this zone in the studied section.

445 The second set of bioevents concerns the LO of three species belonging to *Gorbachikella*: *G.*
446 *kugleri*, *G. anteroapertura* and *G. grandiapertura* in levels JBH-B73, B91, B109,
447 respectively. As previously evoked, the range of “*Caucasella* gr. *hauterivica-kugleri*” would
448 start at the base of the upper Hauterivian (Sigal, 1977). In north Tunisia, BouDagher-Fadel et
449 al. (1995) indicated that *G. kugleri* occurs in the Hauterivian and its range goes up to the

450 lower Aptian. Ben Haj Ali (2005) recorded the LO of *G. kugleri* at the base of the upper
451 Hauterivian and she defined the *G. kugleri* Interval Zone that characterized this substage (see
452 also Ben Haj Ali and Memmi, 2013). When BouDagher-Fadel et al. (1995) described the new
453 species *G. grandiapertura* and *G. anteroapertura* they did not provide their stratigraphic
454 distribution; the authors indicated that *G. grandiapertura* ranges in Tunisia from Hauterivian
455 to Barremian, and *G. anteroapertura* ranges from the upper Hauterivian to lower Aptian. For
456 Ben Haj Ali (2005), these two species allow to characterize the *G. kugleri* Zone. Referring to
457 the zonal scheme of this author, the LO of *G. kugleri* in the Jebel Boulahouajeb section is
458 used to indicate the base of the *G. kugleri* Zone that is also characterized by *G.*
459 *grandiapertura* and *G. anteroapertura* (Fig. 11).

460 The third bioevent in the planktic distribution of the Jebel Boulahouajeb section is the LO of
461 *Praehedbergella sigali* in level JBH-B221. For Sigal (1977), “*Hedbergella sigali*” first occurs
462 at the base of the Barremian (see also Caron, 1985). It is the index-species of the first planktic
463 foraminifera zone of this stage; this interval zone was defined by Moullade (1966). For
464 Maamouri et al. (1994), *H. sigali* should be put in synonymy with *Hedbergella tuschpsensis*;
465 its LO is recorded at the base of the Barremian and this defined the base of the *H.*
466 *tuschpsensis* Interval Zone. According to Coccioni and Premoli-Silva (1994), the “mean
467 range” of “*H. sigali*” starts at the base of the Barremian (synthetic data); however, these
468 authors indicated that this species first occurs at the base of “*T.*” *pertransiens* Zone in SE
469 Spain. Robaszynski and Caron (1995) underlined that *H. sigali* is rare in the Valanginian and
470 becomes more frequent during the Hauterivian and Barremian. More recently, Premoli-Silva
471 et al. (2017) confirmed that *H. sigali* is already present in the upper Hauterivian of SE Spain.
472 Ben Haj Ali (2005) was the first to recognize the *P. sigali* Zone as the first zone of the
473 Barremian in Tunisia (see also Ben Haj Ali and Memmi, 2013). In the Jebel Boulahouajeb

section, a similar observation is done; the base of the *P. sigali* Zone is placed in the uppermost part of the Hauterivian where the LO of its index-species is recorded.

5. Discussion

5.1. Integrated biostratigraphy: ammonoid and foraminifera zonations

The calibration of the ammonoid and planktic foraminifera zonations proposed here is restricted to the upper Hauterivian–lowermost Barremian of the Jebel Boulahouajeb section (Figs. 3 and 11). The LO of *G. kugleri* and *G. anteroapertura* are in the upper part of the *S. sayni*–*P. ligatus* Zones. *G. grandiapertura* first occurs in the lowermost part of the *B. balearis* (Sub-)Zone. These three foraminifera species also occur in the *P. ohmi* Zone. So, they characterize the upper Hauterivian as observed in other Tunisian sections by BouDagher-Fadel et al. (1995), Ben Haj Ali (2005), and Ben Haj Ali and Memmi (2013). Taking into account the ammonoid distributions of the Jebel Boulahouajeb section, the base of the Barremian is placed at bed JBH-B232 (LO of *A. intermedius*), and so the LO of *P. sigali* (JBH-B221) is recorded in the upper part of the *P. ohmi* Zone (*P. picteti* Subzone). However, the Hauterivian–Barremian boundary could be lowered at level JBH-B221 where the LO of *P. sigali* is recorded. Indeed, as the ammonoid *Taveraidiscus hugii* (index-species of the first Barremian zone) has not been found, this boundary can be placed between the HO of *Pseudothurmannia* (in bed JBH-B219; this genus is restricted in the uppermost part of the Hauterivian; Busnardo et al., 2003; Company et al., 2003; Hoedemaeker, 2013) and the LO of *A. intermedius* (bed JBH-B232). In this interval, ammonoid species with a biostratigraphic interest as *D. favrei* and *B. cf. dimboviciorensis* are rare and they can occur in the *P. ohmi* and *T. hugii* Zones. The proposal to put the base of the Barremian stage at level JBH-B221 could be supported considering that *P. sigali* is the index-species of the first Barremian zone in Tunisia. However, as previously evoked, the LO of *P. sigali* is placed lower in other areas of

the Tethyan realm (base of the Valanginian in Spain). Consequently, the Hauterivian–Barremian boundary is kept at the base of bed JBH-B232.

5.2. Correlations: Jebel Boulahouajeb and Jebel Oust sections

The Jebel Boulahouajeb section is correlated with the Jebel Oust section (Fig. 13) that is considered as the reference section for the northern Tunisian lower Cretaceous series (see Introduction chapter). This correlation is made using the biostratigraphic data (ammonoids and foraminifera), and the lithologic changes.

The ammonoid zonation of the Jebel Oust section was made by Memmi (1981, 1989); it is not complete for some intervals as some zones were not recognized by the author and the boundaries between some zones are not defined. Memmi (1989, p. 64) underlined that her zonal scheme is based on the zonation established for SE France and SE Spain; however she quoted authors who have worked on the Tithonian to lowermost Hauterivian. For the Hauterivian, it seems that Memmi (1989) mainly used the zonal scheme established by Moullade and Thieuloy (1967) and Thieuloy (1977) for SE France; the correlation between this former zonal scheme and a more recent version is established by Bulot et al. (1993; their Table 1). Memmi (1989) replaced the *A. radiatus* Zone by the *Breistrofferella castellanensis* Zone used by Company (1987). Her zonal scheme included the *J. jeannoti* Zone, now considered as the second subzone of the *C. loryi* Zone in the standard zonation (Reboulet et al., 2018). Memmi (1989) considered that the *S. sayni* and *P. ligatus* Zones should be separated but the author grouped them as she was not able to distinguish them in the Jebel Oust section, and also in other northern Tunisian sections (see Memmi, 1981, 1989). For the uppermost Hauterivian, Memmi (1981, 1989) considered the “*Balearites balearis*–*Pseudothurmannia angulicostata* Zone”. For this interval, she recognized in some sections (as Jebel Bou Kornine) ammonoid assemblages with both index-species and also “*Crioceratites*

524 *krenkeli* and *Pseudothurmannia mortilleti*". The *B. balearis* Zone was introduced by
525 Busnardo (1984). In Ben Haj Ali and Memmi (2013), the Hauterivian zonal scheme of
526 Memmi (1989) was slightly modified with the introduction of the *B. balearis* Zone; however,
527 the *B. castellanensis* Zone and the *S. sayni*–*P. ligatus* Zone are kept. For the lower Barremian,
528 Memmi (1989) did not use the zonal scheme established by Busnardo (1965; see also Sornay,
529 1977; Roger, 1980) for the stratotype of Angles section (France) and she replaced the
530 "*Nicklesia pulchella* Zone" by her "*Holcodiscus caillaudi* Zone". For the upper Barremian,
531 Memmi (1989) used the "*Silesites seranonis*–*Barremites strettostoma* Zone" that corresponds
532 to the "*Silesites seranonis* Zone" of Busnardo (1965). This latter author subdivided this zone in
533 three subzones recognized by Memmi (1989) in the Jebel Oust section. For the northern
534 Tunisia, Ben Haj Ali and Memmi (2013) used the Barremian zonal scheme of Memmi (1989).
535 Ammonoid taxa with a biostratigraphic interest for the Jebel Oust locality have been reported
536 on the redrawn section (Fig. 13). Unfortunately, it was impossible to check the identifications
537 of this material; the ammonoids studied by Memmi (1989) are not illustrated, except for few
538 taxa occurring around the lower–upper Valanginian and Valanginian–Hauterivian boundaries
539 (Memmi, 1965, 1970, 1973) and, for the moment, the Memmi's collection is not accessible.
540
541 The interval around the Valanginian–Hauterivian boundary in the Jebel Oust section is
542 relatively well characterized by assemblages allowing to Memmi (1989) to define the
543 uppermost zone of the Valanginian, the "*Teschenites callidiscus* Zone" (= *T. callidiscus*
544 Subzone of the *C. furcillata* Zone in the standard zonation), and the first zone of the
545 Hauterivian, the "*B. castellanensis* Zone" (= *A. radiatus* Zone in the standard zonation). Even
546 if this latter index-species has not been found, Memmi (1989) put the base of the Hauterivian
547 stage at the first bed of Formation 5 (but no ammonoid sampled in this bed; Fig. 13). The
548 genus *Oosterella* is well represented around the boundary and Busnardo and Memmi (1972)

defined a “*Oosterella* interval” corresponding to Formations 4e, 5 to 7 (see also Memmi and Maamouri, 1974; Memmi, 1981, 1989; Maamouri et al., 1994). In SE France, oosterellids are more represented in the upper Valanginian but they also occur in the lowermost Hauterivian (mainly in the *A. radiatus* Zone; Reboulet, 1996, and references therein). The LO of *P. infundibulum* is recorded at the top of Formation 5 of the Jebel Oust section; Memmi (1989, p. 71) suggested that the LO of this species could be in her “*B. castellanensis* Zone”. In SE France, the same observation is made and the LO of *P. infundibulum* is recorded in the upper part of the *A. radiatus* Zone (Reboulet, 1996). The correlative datum (key horizon) for the Jebel Boulahouajeb and Jebel Oust sections is placed at the base of bed JBH-B7 (near the base of the calcareous bundle H1) and the first bed of Formation 5, respectively.

The *C. loryi* Zone was not recognized in the Jebel Oust section (Memmi, 1989). The author underlined (p. 46 and 72) that a fault occurs between the formations 7 (“*B. castellanensis* Zone”) and 8 (“*Olcostephanus (Jeannoticeras) jeannoti* Zone”). In the current standard zonation, *J. jeannoti* is the index-species of the second subzone of the *C. loryi* Zone. In SE France, the LO of *J. jeannoti* is in the upper part of the *C. loryi* Zone and its HO is in the lowermost part of the *L. nodosoplicatum* Zone (Bulot et al., 1993; Reboulet, 1996; Reboulet and Atrops, 1999). Consequently, the lower part of Formation 8 of the Jebel Oust section in which *J. jeannoti* occurs is correlated with the upper part of the *C. loryi* Zone and the lowermost part of the *L. nodosoplicatum* Zone of the Jebel Boulahouajeb section where *J. jeannoti* has been also found (beds JBH-B20 and B21); thus, the upper part of Formation 8 should belong to the *L. nodosoplicatum* Zone (see below).

The *L. nodosoplicatum* Zone was not clearly identified in the Jebel Oust section; this zone was not separated from the *S. sayni* and *P. ligatus* Zones. Memmi (1989) probably used these

574 zones *sensu* Moullade and Thieuloy (1967) or *sensu* Thieuloy (1977). Bulot et al. (1993, p.
575 46) recognized two successive populations of *Subsaynella*: *S. sayni* and *Subsaynella mimica*
576 (see also Thieuloy and Bulot, 1993). In the first interval, they identified an assemblage made
577 of “true” *S. sayni*, *Cruasicerias cruasense* and *Abrytusites juliani*. Consequently, the base of
578 the *S. sayni* Zone *sensu* Bulot et al. (1993) was lowered and *C. cruasense* became the index-
579 species of the first horizon of this zone; these authors underlined (p. 50) that *S. mimica*,
580 classically identified to *S. sayni*, was considered in literature as the index-species to place the
581 base of the *S. sayni auctorum* Zone (see Moullade and Thieuloy, 1967; Busnardo, 1984;
582 Hoedemaecker et al, 1990). In the second interval, Bulot et al. (1993) identified an
583 assemblage characterized by *S. mimica* (= *S. sayni auctorum*), *P. ligatus sensu stricto* (= *sensu*
584 d’Orbigny; not *sensu* Moullade and Thieuloy, 1967) and *S. rotula*. Thus, the base of the *P.*
585 *ligatus* Zone *sensu* Bulot et al. (1993) was lowered and its top was defined by the LO of *B.*
586 *balearis*; *P. ligatus sensu lato* (= *sensu* Moullade and Thieuloy, 1967) occurs higher in the *P.*
587 *ligatus* Zone *sensu* Bulot et al., 1993).

588 Among ammonoids found by Memmi (1989) in the lowermost part of Formation 9, there are
589 “*Neocomites* gr. *nodosoplicatus*”, *S. sayni*, *Abrytusites juliani*, *P. ligatus* and *Spitidiscus*
590 *rotula*. This author probably used the occurrence of “*Neocomites* gr. *nodosoplicatus*” to
591 characterize the lower part of Formation 9 to the *L. nodosoplicatum* Zone. However, it is
592 difficult to use this assemblage of five taxa for correlations with the Jebel Boulahouajeb
593 section. Indeed, according to the stratigraphic distribution of ammonoids given by Bulot et al.
594 (1993) for the interval around the lower–upper Hauterivian boundary in SE France, all these
595 five species cannot co-occur together. *A. juliani* can be found with “true” *S. sayni* in the
596 lowermost part of the *S. sayni* Zone *sensu* Bulot et al. (1993), and *S. rotula* co-occurs with
597 “true” *P. ligatus* in the lower part of the *P. ligatus* Zone *sensu* Bulot et al. (1993). Therefore,
598 the identification of some species made by Memmi (1989) must be interpreted differently. As

L. nodosoplicatum is only present in the lower part of the *L. nodosoplicatum* Zone *sensu* Bulot et al. (1993), it can be considered here that the specimen(s) identified by Memmi as “*N. gr. nodosoplicatus*” could correspond to *Lyticoceras claveli* or *Lyticoceras kiliani*, that occur in the upper part of this zone in SE France (Bulot et al., 1993; Bulot, 1995; Reboulet, 1996; Reboulet and Atrops, 1999), or to *C. cruasense*, that occurs in the lower part of the *S. sayni* Zone in SE France (Bulot et al., 1993; Bulot, 1995). In this case, *P. ligatus* and *S. rotula* were probably also misidentified at the specific level (the identification of these taxa is difficult, more particularly to distinguish the different species of *Plesiospitidiscus*). Consequently, according to this new interpretation, the lower part of Formation 9 in the Jebel Oust section could belong to the *S. sayni* Zone. However, the lowermost part of Formation 9 could belong to the *L. nodosoplicatum* Zone as the assemblage described by Memmi (1989) is located around 35 meters above the base of this formation. For this reason, the stratigraphic interval corresponding to the upper part of Formation 8 and lower part of Formation 9 is correlated with the calcareous bundle H2 of the Jebel Boulahouajeb section in which the boundary between the *L. nodosoplicatum* and *S. sayni* Zones is placed (at the top of JBH-B30). This correlation is also supported by the lithologic change observed above; from the base to the top of Formation 9 of the Jebel Oust section, the sedimentation becomes more marly as observed in the Jebel Boulahouajeb section (between beds JBH-B32 and B86). It is interesting to note that in SE France (Vocontian basin), the limestone–marl alternations are mainly characterized by thick calcareous beds and thinner marly interbeds in the lower Hauterivian, and it is the opposite in the lower part of the upper Hauterivian for which marly interbeds are generally thicker, with relatively thin calcareous beds in the *S. sayni* Zone (see Ferry and Rubino, 1987; Bulot, 1995; Reboulet, 1996).

623 In all sections studied by Memmi (1989), the *S. sayni* and *P. ligatus* Zones have not been
624 separated. The author (p. 72) underlined that both index-species have been found in same
625 beds, as recorded in the uppermost part of Formation 9 at Jebel Oust (Fig. 13) and she
626 suggested that a condensation cannot be excluded. This hypothesis appears unlikely for most
627 of northeastern Tunisian sections, often characterized by dilated series. A misidentification of
628 some taxa could be an alternative; thus, new interpretations of identification can be proposed
629 here for the specimens located in the uppermost part of Formation 9 and three biostratigraphic
630 implications can be evoked as follows (a to c). a) If the identification of *S. sayni* made by
631 Memmi (1989) is correct, that of *P. ligatus* is wrong (see above); in this case, this interval
632 could correspond to the *S. sayni* Zone (its upper part). b) If her identification of *P. ligatus* is
633 correct, the specimen(s) identified as *S. sayni* by Memmi (1989) could be interpreted here as
634 *S. mimica* (see above), for which the LO is in the upper part of the *S. sayni* Zone *sensu* Bulot
635 et al. (1993) and its HO is in the lower part of the *P. ligatus* Zone *sensu* Bulot et al. (1993) in
636 SE France (Bulot et al., 1993; Bulot, 1995). Consequently, the uppermost part of Formation 9
637 (represented by two thick calcareous beds) could belong to the lower part of the *P. ligatus*
638 Zone and the base of this calcareous interval could be correlated with the base of bed JBH-
639 B86 in the Jebel Boulahouajeb section where the sedimentation becomes more calcareous
640 (bundle H3). c) The specimens of *S. sayni* located in the uppermost part of Formation 9 could
641 belong to *Discoideilia*. Indeed, Vermeulen (1998) evoked the great morphological affinities
642 between some species of *Discoideilia* and *Subsaynella*, and their phyletic relation. Taking into
643 account the stratigraphic distribution of *Discoideilia* (Vermeulen, 1995, 1999), this genus can
644 occur in the *B. balearis* Zone with *Plesiospitidiscus*. The specimen(s) of *P. ligatus* occurring in
645 the uppermost part of Formation 9 can be correspond to the *P. ligatus sensu lato*, for which
646 the distribution ends in the lowermost part of the *B. balearis* Zone according to Bulot et al.
647 (1993). These ammonites could be also misidentified and could correspond to *P. subdifficilis*

that occur in the *B. balearis* Zone (Figs. 3b and 13). Consequently, the couple of calcareous beds located in the uppermost part of Formation 9 could belong to the lower part of the *B. balearis* Zone and could be correlated with the couple of calcareous beds JBH-B163 and B170 (bundle H4). In this case, the lithologic changes seem more similar in both sections than those observed in the previous attempt of correlations.

Memmi (1981, 1989) has not used the *B. balearis* Zone in her zonal scheme of the northeastern Tunisian area; she considered the “*B. balearis*–*P. angulicostata* Zone” (see above). In the zonation of the Jebel Oust section, Memmi (1989) indicated the “*P. angulicostata* Zone” (= *P. ohmi* Zone in the standard zonation) for Formation 11 in which she found the index-species and *P. mortilleti*. This allows to correlate the couple of calcareous beds of this formation with the couple of calcareous beds JBH-B202 and B219 of the Jebel Boulahouajeb section as this bundle H5 mainly belongs to the *P. mortilleti* Subzone. Consequently, Formation 10 (no ammonoid sampling) is correlated with the interval belonging to the *B. balearis* Zone in the Jebel Boulahouajeb section.

Above the calcareous bundle of the *P. ohmi* Zone, the sedimentation becomes more argillaceous and a thick marly interval occurs in both sections. In the Jebel Boulahouajeb section, the Hautervian–Barremian boundary is placed in the uppermost part of this interval (bed JBH-B232 corresponding to the base of *T. hugii* Zone), while Memmi (1989) placed this boundary at the base of Formation 12. The author indicated the “*H. caillaudi* Zone” for this formation despite the lack of the index-species. Memmi (1989) underlined that the assemblage of this zone is very poor; among few identified taxa, she recognized the genus *Valdedorsella*. In the Jebel Boulahouajeb section, the LO of *Valdedorsella? uhligi* is at the top of *P. mortilleti* Subzone (top of the calcareous bundle H5). So, the Barremian age of Formation 12 of the Jebel Oust section is probably given by the planktic foraminiferal

Hedbergella sigali Zone reported by Memmi and Maamouri (1974), and Memmi (1989). Classically, this zone is considered as the first zone of the Barremian in Tunisia (see above and Ben Haj Ali, 2005), but some authors as Coccioni and Premoli-Silva (1994) and Premoli-Silva et al. (2017) have recorded this index-species in the Valanginian and Hauterivian of SE Spain. Consequently, Formation 12 could belong to the uppermost Hauterivian (*P. picteti* Subzone) considering that the base of Barremian is put at the base of bed JBH-B232 with the LO of *A. intermedius*. It can be added that the upper part of Formation 12 could correspond to the lowermost Barremian in the case of the Hauterivian–Barremian boundary at the Jebel Boulahouajeb section could be lowered at the level JBH-B221 where the LO of *P. sigali* is observed (see part 5.1).

In the Jebel Oust section, Formation 13 (around 100 m in thickness, mainly represented by thick calcareous beds) corresponds to the Barremian bundle of the literature (“Barre barrémienne”, Memmi, 1981, 1989). According to this author, it is placed in the “*Hemihoplites feraudi* Subzone” of the “*Silesites seranonis*–*Barremites strettostoma* Zone” (upper Barremian), even if these index-species have not been found in this part of the section. The author found only two species of ammonoids: “*Silesites vulpes*” and “*Ancyloceras trispinosum*” (see Fig. 12 in Memmi, 1989). In the Jebel Boulahouajeb section, there is also a thick calcareous bundle (around 200 m of limestone–marl alternations; only the first beds are represented here) that could be correlated with Formation 13. The zonal scheme is not established for this calcareous bundle of the Jebel Boulahouajeb section; only the basal part of this interval belongs to the lower Barremian (bed JBH-B232 and above).

In comparaison with the Jebel Oust section, the study of the Jebel Boulahouajeb section provided a more detailed lithological succession of the uppermost Valanginian–lowermost

Barremian interval of the northern Tunisia, a more complete sampling of macrofauna, a greater set of data on the ammonoid distributions and assemblages, and a greater illustration of this fauna. Contrary to the Jebel Oust section where the boundaries between several ammonoid zones were not identified, the work on the Jebel Boulahouajeb section allowed to update the zonal scheme for the north Tunisia with the recognition of most of the zones of the standard zonation (Mediterranean Province; see Reboulet et al., 2018). Consequently, it appears that the Jebel Boulahouajeb section could be considered as a good reference section for the Tunisian trough, at least for the Hauterivian interval.

6. Conclusion

The study of ammonoids and foraminifera from the uppermost Valanginian to lowermost Barremian of the Jebel Boulahouajeb section of the northern Tunisia has led to three majors results.

1- Most of the ammonoid zones of the standard zonation (Mediterranean Province) have been identified and well characterized by their diversified assemblages: for the uppermost Valanginian, *C. furcilla* Zone; for the lower Hauterivian, *A. radiatus*, *C. loryi* and *L. nodosoplicatum* Zones; for the upper Hauterivian, *B. balearis* and *P. ohmi* Zones (with their subdivisions in four and three subzones, respectively); for the lowermost Barremian, *T. hugii* Zone. The *S. sayni* and *P. ligatus* Zones have not been recognized as the lower part of the upper Hauterivian has not been sampled for macrofauna.

2- The planktic foraminiferal fauna, observed only in the upper Hauterivian and lowermost Barremian, is poorly diversified. Distributions of some species are similar to those recorded in some previous studies done in Tunisia, but not in accordance with data from other Tethyan areas.

3- Correlations between the Jebel Boulahouajeb and Jebel Oust sections are proposed using mainly the ammonoid zonal schemes. The Jebel Boulahouajeb section has to be considered more complete in the lithologic succession, and in the distributions and assemblages of ammonoids. Therefore, it could be a new reference section of the Tunisia trough for the studied interval (mainly Hauterivian).

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1133 **Appendix 1 - Systematic of ammonoids**

1134 This appendix presents the list of ammonoid taxa found in the Jebel Boulahouajeb section; the
 1135 index-species used for the zonation and other taxa evoked in the text have been added. The
 1136 classification is mainly based on Klein (2005), Vermeulen and Klein (2006), Klein et al.
 1137 (2007, 2009), and Klein and Vašíček (2011); some short comments are made for some taxa.

1138

1139 **Perisphinctoidea STEINMANN**

1140 Neocomitidae SALFELD

1141 Neocomitinae SALFELD

1142 « *Thurmanniceras* » COSSMANN

1143 « *Thurmanniceras* » *pertransiens* (SAYN)

1144 *Criosarasinella* THIEULOUY

1145 *Criosarasinella furcillata* THIEULOUY

- 1146 *Himantoceras* THIEULY; see Reboulet, 1996, 2007, 2008; included in Ancyloceratoidea by Klein et al. (2007, p. 31)
- 1147 *Himantoceras trinodosum* THIEULY
- 1148 *Himantoceras* n. sp. 2; see Reboulet, 1996
- 1149 *Teschenites* THIEULY
- 1150 *Teschenites callidiscus* (THIEULY); included in *Neocomites* (*Teschenites*) by Klein (2005, p. 315)
- 1151 *Teschenites subflucticulus* REBOULET; included in *Neocomites* (*Teschenites*) by Klein (2005, p. 320)
- 1152 *Eleniceras* BRESKOVSKI; included in Endemoceratinae by Klein (2005, p. 351)
- 1153 ? Endemoceratinae SCHINDEWOLF
- 1154 *Acanthodiscus* UHLIG
- 1155 *Acanthodiscus radiatus* (BRUGUIERE)
- 1156 *Breistrofferella* THIEULY
- 1157 *Breistrofferella castellanensis* (D'ORBIGNY)
- 1158 *Lyticoceras* HYATT
- 1159 *Lyticoceras claveli* BUSNARDO & THIEULY
- 1160 *Lyticoceras kiliani* REBOULET & ATROPS
- 1161 *Lyticoceras nodosoplicatum* (KILIAN & REBOUL)
- 1162 *Cruasiseras* BUSNARDO
- 1163 *Cruasiseras cruasense* TORCAPEL
- 1164 Spitidiscinae VERMEULEN & THIEULY
- 1165 *Jeanthieuloyites* COOPER
- 1166 *Jeanthieuloyites keyserlingiformis* AVRAM & GRADINARU
- 1167 *Jeanthieuloyites quinquestriatus* BESAIRIE
- 1168 *Jeanthieuloyites solignaci* (MEMMI)
- 1169 *Spitidiscus* KILIAN; this genus is included in Desmoceratidae by Busnardo et al., 2003 (p. 49)
- 1170 *Spitidiscus lorioli* (KILIAN)
- 1171 *Spitidiscus meneghinii* (RODIGHERO)
- 1172 *Spitidiscus rawsoni* BULOT
- 1173 *Spitidiscus rotula* (SOWERBY)
- 1174 Olcostephanidae HAUG
- 1175 Olcostephaninae HAUG
- 1176 *Olcostephanus* NEUMAYR
- 1177 *Olcostephanus densicostatus* (WEGNER)
- 1178 *Olcostephanus variegatus* PAQUIER
- 1179 *Jeannoticeras* THIEULY
- 1180 *Jeannoticeras jeannoti* (D'ORBIGNY)
- 1181 Oosterellidae BREISTROFFER
- 1182 *Oosterella* KILIAN
- 1183 *Oosterella cultrata* (D'ORBIGNY)

1184	<i>Oosterella cultrataeformis</i> (UHLIG)
1185	<i>Oosterella undulata</i> REBOULET
1186	Holcodiscidae SPATH
1187	<i>Taveraidiscus</i> VERMEULEN & THIEULOUY
1188	<i>Taveraidiscus hugii</i> (OOSTER)
1189	<i>Avramidiscus</i> VERMEULEN
1190	<i>Avramidiscus intermedius</i> (D'ORBIGNY); included in <i>Taveraidiscus</i> by Company et al., 2003
1191	<i>Holcodiscus</i> UHLIG
1192	<i>Holcodiscus caillaudianus</i> (D'ORBIGNY)
1193	Desmoceratoidea VON ZITTEL
1194	Barremitidae BRESKOVSKI
1195	<i>Abrytusites</i> NIKOLOV & BRESKOVSKI
1196	<i>Abrytusites juliani</i> (HONNORAT-BASTIDE)
1197	<i>Abrytusites neumeyri</i> (HAUG)
1198	<i>Plesiospitidiscus</i> BREISTROFFER
1199	<i>Plesiospitidiscus fasciger</i> (THIEULOUY)
1200	<i>Plesiospitidiscus ligatus</i> (D'ORBIGNY)
1201	<i>Plesiospitidiscus subdifficilis</i> (KARAKASCH)
1202	<i>Barremites</i> KILIAN
1203	<i>Barremites cassida</i> (RASPAIL)
1204	<i>Montanesiceras</i> BRESKOVSKI
1205	<i>Montanesiceras dimboviciorensis</i> (BRESKOVSKI); Company et al. (2005) included this species in <i>Barremites</i>
1206	<i>Valdedorsella</i> BREISTROFFER
1207	<i>Valdedorsella ? uhligi</i> (HAUG); Company et al. (2003) included this species in “ <i>Barremites</i> ”
1208	<i>Barremiites</i> AVRAM
1209	<i>Barremiites strettostoma</i> (UHLIG)
1210	Silesitidae HYATT
1211	<i>Silesites</i> UHLIG
1212	<i>Silesites seranonis</i> (D'ORBIGNY)
1213	<i>Silesites vulpes</i> (MATHERON)
1214	Pulchelliioidea DOUVILLE (for an alternative classification, see note 96, p. 188 in Vermeulen and Klein, 2006)
1215	Pulchelliidae DOUVILLE
1216	Buergliceratinae VERMEULEN
1217	<i>Subsaynella</i> SPATH
1218	<i>Subsaynella mimica</i> THIEULOUY & BULOT
1219	<i>Subsaynella sayni</i> (PAQUIER)
1220	<i>Discoidellia</i> VERMEULEN
1221	<i>Discoidellia couratieri</i> VERMEULEN

1222	<i>Discoidellia favrei</i> (OOSTER)
1223	<i>Pulchelliinae</i> DOUVILLÉ
1224	<i>Nicklesia</i> HYATT
1225	<i>Nicklesia pulchella</i> (D'ORBIGNY)
1226	Haploceratoidea VON ZITTEL
1227	Haploceratidae VON ZITTEL
1228	<i>Neolissoceras</i> SPATH
1229	<i>Neolissoceras grasianum</i> (D'ORBIGNY)
1230	Phylloceratoidea VON ZITTEL
1231	Phylloceratidae VON ZITTEL
1232	Phylloceratinae VON ZITTEL
1233	<i>Phylloceras</i> (<i>Hypophylloceras</i>)
1234	<i>Phylloceras</i> (<i>Hypophylloceras</i>) <i>tethys</i> (D'ORBIGNY)
1235	<i>Phylloceras</i> (<i>Hypophylloceras</i>) <i>ponticuli</i> (ROUSSEAU)
1236	Phyllopachyceratinae COLLIGNON
1237	<i>Phyllopachyceras</i> SPATH
1238	<i>Phyllopachyceras infundibulum</i> (D'ORBIGNY)
1239	<i>Phyllopachyceras winkleri</i> (UHLIG)
1240	Lytoceratoidea NEUMAYR
1241	Lytoceratidae NEUMAYR
1242	Lytoceratinae NEUMAYR
1243	<i>Lytoceras</i> SUESS
1244	<i>Lytoceras subfimbriatum</i> (D'ORBIGNY)
1245	Ancyloceratoidea GILL
1246	Crioceratitidae GILL
1247	<i>Crioceratites</i> (LEVEILLE)
1248	<i>Crioceratites loryi</i> (SARKAR)
1249	<i>Balearites</i> SARKAR; the opinion of Company et al. (2003) is here followed: <i>B. balearis</i> , <i>B. binelli</i> , <i>B. krenkeli</i> and <i>B.</i>
1250	<i>angulicostatus</i> could constitute a phylogenetic lineage. These 4 species are included in
1251	<i>Balearites</i> following the opinion of Matamalas and Company (personal communication, 2017)
1252	<i>Balearites balearis</i> (NOLAN)
1253	<i>Balearites binelli</i> (ASTIER); included in <i>Binelliceras</i> by Klein et al., 2007 (p. 50)
1254	<i>Balearites krenkeli</i> (SARKAR); included in <i>Crioceratites</i> by Klein et al., 2007 (p. 42)
1255	<i>Balearites angulicostatus</i> (D'ORBIGNY); included in <i>Crioceratites</i> by Klein et al., 2007 (p. 36)
1256	<i>Pseudothurmannia</i> SPATH; the opinion of Company et al. (2003) and the classification of Klein et al. (2007, p. 54) are here
1257	followed: the type species designated by Company et al. (2003) is <i>Ammonites angulicostatus</i>
1258	D'ORBIGNY in PICTET, Pl. 1bis, Fig. 1ab (= <i>Pseudothurmannia picteti</i> SARKAR, holotype by
1259	original designation Pictet, Pl. 1bis, Fig. 1ab)

1260	<i>Pseudothurmannia mortilleti</i> (Pictet & de Loriol); in view of Company et al. (2003), <i>P. mortilleti</i> is here considered as a
1261	senior synonym of <i>P. catulloi</i> (Parona)
1262	<i>Pseudothurmannia ohmi</i> (Winkler)
1263	<i>Pseudothurmannia picteti</i> Sarkar
1264	<i>Pseudothurmannia pseudomalbosi</i> (Sarasin & Schöneldmayer)
1265	<i>Sornayites</i> Wiedmann
1266	Emericeratidae Vermeulen
1267	<i>Honnoratia</i> Busnardo
1268	<i>Honnoratia thiollieri</i> (Astier)
1269	<i>Paraspiticas</i> Kilian
1270	Leptoceratoididae Thieuloy
1271	<i>Hamulinites</i> Paquier
1272	<i>Sabaudiella</i> Vasicek & Hoedemaeker
1273	<i>Sabaudiella simplex</i> Busnardo
1274	Hemihoplitidae Spath
1275	Hemihoplitinae Spath
1276	<i>Hemihoplites</i> Spath
1277	<i>Hemihoplites feraudianus</i> (D'Orbigny)
1278	<i>Hemihoplites? trispinosus</i> (von Koenen)
1279	Ptychoceratoidea Gill
1280	Hamulinidae Gill
1281	<i>Anahamulina</i> Hyatt
1282	<i>Anahamulina lorioli</i> (Uhlir)
1283	<i>Amorina</i> Vermeulen
1284	Bochianitoidea Spath
1285	Bochianitidae Spath
1286	<i>Bochianites</i> Lory
1287	<i>Bochianites neocomiensis</i> (D'Orbigny)

1288

1289 **Appendix 2 - Systematic of foraminifera**

1290 **Alphabetic planktic foraminifera list**

1291	<i>Favusella hoterivica</i> (Subbotina)
1292	<i>Gorbachikella anteroapertura</i> Boudagher-Fadel et al.
1293	<i>Gorbachikella grandiaptura</i> Boudagher-Fadel et al.
1294	<i>Gorbachikella kugleri</i> (Bolli)
1295	<i>Praehedbergella sigali</i> (Moullade)

1296	Alphabetic benthic foraminifera list
1297	<i>Ammodiscus cretaceus</i> (REUSS)
1298	<i>Bathysiphon brosgiei</i> TAPPAN
1299	<i>Catharina</i> sp.
1300	<i>Dentalina deflexa</i> GRZYBOWSKI
1301	<i>Dentalina ejuncida</i> LOEBLICH & TAPPAN
1302	<i>Dentalina gracilis</i> D'ORBIGNY
1303	<i>Dentalina oligostegia</i> (REUSS)
1304	<i>Dorothia gradata</i> (BERTHELIN)
1305	<i>Dorothia hauteriviana</i> (MOULLADE)
1306	<i>Dorothia kummi</i> (ZEDLER)
1307	<i>Dorothia lilliformis</i> (BERTHELIN)
1308	<i>Dorothia ouachensis</i> (SIGAL)
1309	<i>Dorothia oxycona</i> (REUSS)
1310	<i>Dorothia hechti</i> DIENI & MASSARI
1311	<i>Dorothia praeauteriviana</i> DIENI & MASSARI
1312	<i>Dorothia zedlerae</i> MOULLADE
1313	<i>Fronicularia hastata</i> ROEMER
1314	<i>Gavelinella barremiana</i> BETTENSTAEDT
1315	<i>Lenticulina eichenbergi</i> BARTENSTEIN & BRAND
1316	<i>Lenticulina heiermanni</i> BETTENSTAEDT
1317	<i>Lenticulina multicella</i> BARTENSTEIN, BETTENSTAEDT & BOLLI
1318	<i>Lenticulina nodosa</i> (REUSS)
1319	<i>Lenticulina ouachensis</i> (SIGAL)
1320	<i>Lenticulina roemeri</i> (REUSS)
1321	<i>Lenticulina rotulata</i> LAMARCK
1322	<i>Marginulina planiscula</i> (REUSS)
1323	<i>Marginulina striatocostata</i> REUSS
1324	<i>Marginulinopsis</i> .sp.
1325	<i>Marsonella kummi</i> ZEDLER
1326	<i>Nodosaridea</i> sp.
1327	<i>Nodosaria detruncata</i> SCHWAGER
1328	<i>Planularia complanata</i> (REUSS)
1329	<i>Ramulina</i> sp.
1330	<i>Rhizammina</i> sp.
1331	<i>Spirillina minima</i> SCHACKO
1332	<i>Spirillina neocomiana</i> MOULLADE

1333

1334 **Figure captions**

1335 Fig. 1. Geographic map of north Tunisia with location of the Jebel Boulahouajeb and Jebel
1336 Oust sections.

1337

1338 Fig. 2. Jebel Boulahouajeb section (section JBH-A), Tunisia, lithology and ammonoid
1339 distribution; upper Valanginian stage (*Criosarasinella furcillata* Zone *p.p.*).

1340

1341 Fig. 3. Jebel Boulahouajeb section (section JBH-B), Tunisia, lithology and ammonoid
1342 distribution; Fig. 3a: Hauterivian stage (from *Acanthodiscus radiatus* Zone to
1343 *Plesiospitidiscus ligatus* Zone *p.p.*) and its lower boundary (Valanginian *Criosarasinella*
1344 *furcillata* Zone *p.p.* recognized); Fig. 3b: Hauterivian stage (from *P. ligatus* Zone *p.p.* to
1345 *Pseudothurmannia ohmi* Zone) and its upper boundary (Barremian *Taveraidiscus hugii* Zone
1346 *p.p.* recognized). Abbreviations: up. Val.: upper Valanginian; Bar.: Barremian; H1 to H5:
1347 calcareous bundles (limestone-dominated intervals separated by thick marly-dominated
1348 intervals).

1349

1350 Fig. 4. Ammonoids from the Jebel Boulahouajeb section (sections JBH-A and JBH-B),
1351 Tunisia. Scale bar: 1 cm; black arrow: end of phragmocone; SC: Silicone cast. **A**, *Lyticoceras*
1352 sp. ind., JBH-B20, *Lyticoceras nodosoplicatum* Zone. **B**, *Lyticoceras* sp. ind., JBH-B24, *L.*
1353 *nodosoplicatum* Zone. **C**, *Teschenites subflucticulus*, JBH-A5, *Criosarasinella furcillata*
1354 Zone. **D**, *Jeanthieuloyites keyserlingiformis*, JBH-A2, *C. furcillata* Zone. **E**, *Jeanthieuloyites*
1355 *quinquestriatus*, JBH-A7, *C. furcillata* Zone. **F**, **G**, *Jeanthieuloyites solignaci*, JBH-A7, *C.*
1356 *furcillata* Zone. **H**, **I**, *Spitidiscus lorioli*, JBH-B9, *Acanthodiscus radiatus* Zone. **J** (SC), **K**
1357 (SC), *Spitidiscus meneghini*, JBH-B10, *A. radiatus* Zone. **L** (SC), *Spitidiscus meneghini*,

1358 JBH-B11, *A. radiatus* Zone. **M**, *Spitidiscus rawsoni*, JBH-B30, *L. nodosoplicatum* Zone. **N**
1359 (SC), *Himantoceras* cf. *trinodosum*, JBH-B4, *C. furcillata* Zone.

1360

1361 Fig. 5. Ammonoids from the Jebel Boulahouajeb section (sections JBH-A and JBH-B),
1362 Tunisia. Scale bar: 1 cm; black arrow: end of phragmocone; SC: Silicone cast. **A**,
1363 *Olcostephanus densicostatus*, JBH-A5, *Criosarasinella furcillata* Zone. **B**, *Olcostephanus*
1364 *densicostatus*, JBH-A6, *C. furcillata* Zone. **C**, *Jeannoticeras jeannoti*, JBH-B20, *Lyticoceras*
1365 *nodosoplicatum* Zone. **D** (SC), *Oosterella undulata*, JBH-B6, *C. furcillata* Zone. **E**,
1366 *Oosterella cultrata*, JBH-B10, *Acanthodiscus radiatus* Zone.

1367

1368 Fig. 6. Ammonoids from the Jebel Boulahouajeb section (section JBH-B), Tunisia. Scale bar:
1369 1 cm; black arrow: end of phragmocone; SC: Silicone cast. **A** (SC), *Avramidiscus*
1370 *intermedius*, JBH-B232, *Taveraidiscus hugii* Zone. **B** (SC), *Plesiospitidiscus fasciger*, JBH-
1371 B18, *Crioceratites loryi* Zone. **C**, *Plesiospitidiscus fasciger*, JBH-B20, *Lyticoceras*
1372 *nodosoplicatum* Zone. **D**, *Plesiospitidiscus subdifficilis*, JBH-B86, *Subsaynella sayni*–
1373 *Plesiospitidiscus ligatus* Zones. **E**, *Plesiospitidiscus subdifficilis*, JBH-B163, *Balearites*
1374 *balearis* Zone, *Balearites binelli* Subzone. **F**, *Abrytusites neumaryi*, JBH-B163, *B. balearis*
1375 Zone, *B. binelli* Subzone. **G**, *Barremites* gr. *cassida*, JBH-B234, *T. hugii* Zone. **H**,
1376 *Valdedorsella? uhligi*, JBH-B215, *Pseudothurmannia ohmi* Zone, *Pseudothurmannia*
1377 *mortilleti* Subzone. **I**, *Discoideilia* cf. *couratieri*, JBH-B86, *S. sayni*–*P. ligatus* Zones. **J**,
1378 *Discoideilia* cf. *couratieri*, JBH-B89, *S. sayni*–*P. ligatus* Zones.

1379

1380 Fig. 7. Ammonoids from the Jebel Boulahouajeb section (section JBH-B), Tunisia. Scale bar:
1381 1 cm; black arrow: end of phragmocone. **A**, *Neolissoceras grasianum*, JBH-B10,
1382 *Acanthodiscus radiatus* Zone. **B**, *Phylloceras* (*Hypophylloceras*) *tethys*, JBH-B10, *A. radiatus*

1383 Zone. **C**, *Phyllopachyceras winkleri*, JBH-B30, *Lyticoceras nodosoplicatum* Zone. **D**,
 1384 *Phyllopachyceras infundibulum*, JBH-B9, *A. radiatus* Zone. **E**, *Phyllopachyceras*
 1385 *infundibulum*, JBH-B86, *Subsaynella sayni*–*Plesiospitidiscus ligatus* Zones. **F**, *Lytoceras*
 1386 *subfimbriatum*, JBH-B6, *Criosarasinella furcillata* Zone. **G**, *Lytoceras subfimbriatum*, JBH-
 1387 B163, *Balearites balearis* Zone, *Balearites binelli* Subzone.
 1388
 1389 Fig. 8. Ammonoids from the Jebel Boulahouajeb section (section JBH-B), Tunisia. Scale bar:
 1390 1 cm; black arrow: end of phragmocone; SC: Silicone cast. **A**, *Balearites* cf. *balearis*, JBH-
 1391 B92, *Balearites balearis* Zone and Subzone. **B, C, D, E**, *Balearites binelli*, JBH-B163, *B.*
 1392 *balearis* Zone, *B. binelli* Subzone. **F** (SC), *Balearites krenkeli*?, JBH-B195, *B. balearis* Zone,
 1393 *Balearites angulicostatus* Subzone. **G, H**, *Balearites* cf. *angulicostatus*, JBH-B195, *B.*
 1394 *balearis* Zone, *B. angulicostatus* Subzone.
 1395
 1396 Fig. 9. Ammonoids from the Jebel Boulahouajeb section (section JBH-B), Tunisia. Scale bar:
 1397 1 cm; black arrow: end of phragmocone; SC: Silicone cast. **A, B, C, D, E**, *Pseudothurmannia*
 1398 *mortilleti*, JBH-B202, *Pseudothurmannia ohmi* Zone, *P. mortilleti* Subzone. **F** (SC), **G** (SC),
 1399 *Pseudothurmannia pseudomalbosi*, JBH-B202, *P. ohmi* Zone, *P. mortilleti* Subzone.
 1400
 1401 Fig. 10. Ammonoids from the Jebel Boulahouajeb section (section JBH-B), Tunisia. Scale
 1402 bar: 1 cm; black arrow: end of phragmocone. **A**, *Pseudothurmannia pseudomalbosi*, JBH-
 1403 B202, *Pseudothurmannia ohmi* Zone, *Pseudothurmannia mortilleti* Subzone. **B**,
 1404 *Pseudothurmannia picteti*, JBH-B219, *P. ohmi* Zone, *P. picteti* Subzone. **C**, *Paraspiticer*
 1405 *sp. ind.*, JBH-B161, *Balearites balearis* Zone and Subzone. **D**, *Sabaudiella simplex*, JBH-
 1406 B215, *P. ohmi* Zone, *P. mortilleti* Subzone.
 1407

Fig. 11. Jebel Boulahouajeb section (section JBH-B), Tunisia, lithology and Hauterivian foraminifera distribution.

Fig. 12. Scanning Electronic Microscope (SEM) micrographs of selected foraminifera from the Jebel Boulahouajeb section (section JBH-B), Tunisia; the scale bar is indicated in brackets. **A**, *Favusella hoterivica* (50 µm), JBH-B76. **B**, *F. hoterivica* (50 µm), JBH-B109. **C**, *Gorbachikella kugleri* (50 µm), JBH-B91. **D**, *G. kugleri* (10 µm), JBH-B231. **E**, *Gorbachikella anteroapertura* (10 µm), JBH-B172. **F**, *Praehedbergella sigali* (50 µm), JBH-B221. **G**, *P. sigali* (50 µm), JBH-B 225. **H**, *P. sigali* (10 µm), JBH-B236. **I**, *Lenticulina roemeri* (100 µm), JBH-B2. **J**, *Lenticulina eichenbergi* (100 µm), JBH-B44. **K**, *Dorothia lilliformis* (100 µm), JBH-B31. **L**, *Lenticulina multicella* (100 µm), JBH-B94. **M**, *Dorothia praehauteriviana* (100 µm), JBH-B59. **N**, *Lenticulina ouachensis ouachensis* (100 µm), JBH-B120. **O**, *Dorothia kummi* (100 µm), JBH-B111. **P**, *Dorothia zedlerae* (100 µm), JBH-B156. **Q**, *Lenticulina rotulata* (100 µm), JBH- B205. **R**, *Gavelinella barremiana* (50 µm), JBH-B224.

Fig. 13. Correlations between the Jebel Bouahouajeb (JBH) and Jebel Oust (JO) sections for the uppermost Valanginian–lowermost Barremian interval. The Jebel Oust section (lithology, formations 4d to 13, ammonoid taxa and zonation) is after Memmi (1989). For abbreviations see Figure caption 3.

EUROPE

AFRICA

Mediterranean Sea

Bizerte

Tabarka

Gulf of Tunis

Tunis

Tebourba

Jebel Boulahouajeb

Beja

Plain of Oued Ettine

Chain

Plain of Medjerda valley

Lansarine

Jebel Oust

Zaghouan

Nabeul

Gulf of Hammamet

Le Kef

Siliana

Jendouba

Site

50

25

0 Km

A

B

C

D

E

F

G

H

Jebel Boulahouajeb

- Limestone
- Marl
- * Sandstone/siltstone
- ^ ^ ^ ^ Gypsum
- = = Discontinuous bed

Stages - Zonation		
Bar. <i>T. hugii</i>		
upper Hauterivian	<i>Pseudothurmannia ohmi</i>	<i>P. picteti</i>
		<i>P. mortilleti</i>
		<i>P. ohmi</i>
		<i>B. angulicostatus</i>
		<i>B. krenkeli</i>
	<i>Balearites balearis</i>	<i>B. binelli</i>
		<i>B. balearis</i>
		<i>P. ligatus</i>
		?
		<i>S. sayni</i>
lower Hauterivian	?	<i>L. nodosoplicatum</i>
		<i>L. loryi</i>
		<i>A. radiatus</i>
	up. Val.	<i>C. furcillata p.p.</i>
Trias p.p.

Jebel Oust

Formations - Zonation - Stages