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RESEARCH PAPER

# Biostratigraphic distribution of ammonites and calpionellids in the Tithonian of the internal Prerif (Msila area, Morocco)

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**Abstract** Because of the relatively thick succession exposed in the Msila area, new bed-by-bed sampling has been carried out in order to investigate late Tithonian ammonites and the correlation between biostratigraphic scales based on ammonites and calpionellids. The outcrop begins with Lower Tithonian beds assigned to the Fallauxi Zone. Ammonites have been found that allow recognition in the same section both Fallauxi and Ponti Zones. The most significant species are: *Simoceras admirandum* Zittel, which is the marker of the upper subzone of the Fallauxi Zone, i.e. the Admirandum/Biruncinatum Subzone, and several species of the genus *Lemencia* and *Burckhardticeras peroni* (Roman), that characterize the Ponti Zone. Ammonites that belong to the Microcanthum Zone appear in bed 18. This zone is usually subdivided into two subzones, of which only the lower one, the Simplisphinctes Subzone, has been recognized. The upper Transitorius Subzone has been recognized on the basis of the occurrence of *Moravisphinctes fischeri* (Kilian). The last ammonite unit, the Durangites Zone, is easily recognizable because of the occurrence of species of the genera *Durangites* and *Protacanthodiscus*. The section ends with the beginning of the Berriasian, which is characterized by a well-exposed, ammonite-rich bed of the Jacobi Zone. Correlation of the ammonite zones with calpionellid zones has been investigated. The Chitinoidella Zone is characterized by calpionellids with microgranular tests that appear in the ammonite Admirandum/Biruncinatum Subzone with species of the Dobeni Subzone, which extends up to the Ponti Zone. Representatives of the Boneti Sub-Zone appear in bed 16, which probably correlates with the base of the ammonite Upper Tithonian Microcanthum Zone. Two horizons have been distinguished within the calpionellid Subzone A3.

**Keywords** Jurassic · Cretaceous · Ammonites · Calpionellids · Biostratigraphy · Tethys · Morocco

**Kurzfassung** In der relativ mächtigen Tithon-Abfolge von Msila (Marokko) wurde eine Bank-für-Bank-Neuaufsammlung von Ammoniten durchgeführt, um die Korrelation von Ammoniten- und Calpionelliden-Biostratigraphie zu erreichen. Die Abfolge beginnt mit Untertithon-Schichten der Fallauxi-Zone. Die aufgefunden Ammoniten zeigen im selben Profil sowohl die Fallauxi- als auch die Ponti-Zone. Die wichtigsten Arten sind *Simoceras admirandum* Zittel, dem Index der oberen Subzone der Fallauxi-Zone, d.h. der Admirandum/Biruncinatum-Subzone, verschiedene Arten der Gattung *Lemencia* und *Burckhardticeras peroni* (Roman), welche die Ponti-Zone charackterisieren. Ammoniten der Microcanthum-Zone erscheinen in Schicht 18. Diese Zone wird gewöhnlich in zwei Subzonen unterteilt, von denen nur die untere, die Simplisphinctes-Subzone, mit Sicherheit nachgewiesen werden konnte. Die obere Transitorius-Subzone wird indirekt durch das Vorkommen von *Moravisphinctes fischeri* (Kilian) angezeigt. Die oberste Ammoniten-Zone, die Durangites-Zone, ist anhand des Vorkommens von Arten der Gattungen *Durangites* und *Protacanthodiscus* leicht kentlich. Das Profil endet im basalen Berrias, welches durch

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eine gut aufgeschlossene Ammoniten-Bank der Jacobi-Zone angezeigt ist. Die Ammoniten-Zonen wurden mit denen der Calpionelliden korreliert. Die Chitinoidella-Zone ist charakterisiert durch durch Calpionelliden mit mikrogranularen Gehäusen, die in der Admirandum/Biruncinatum-Ammoniten-Subzone mit Arten der Dobeni-Subzone erscheinen und bis in die Ponti-Zone hinaufreichen. Vertreter der Boneti-Subzone erscheinen in Schicht 16, die wohl mit der Basis der obertithonen Microcanthum-Ammonitenzone korreliert. Zwei Horizonte innerhalb der Calpionelliden-Subzone A3 wurden ausgeschieden.

**Schlüsselwörter** Jura · Kreide · Ammoniten · Calpionelliden · Biostratigraphie · Tethys · Marokko

## Introduction

The end of the Jurassic system is characterized by high endemism of the Tithonian faunas (Cecca 1999; Cecca et al. 2005). In the Mediterranean Tethys the scarcity, or even the lack, of ammonites in pelagic limestones and the frequent sedimentary hiatuses in typical facies like Rosso Ammonitico (Cecca et al. 1992; Cecca 1999) do not allow the stratigraphic succession of Tithonian ammonites to be investigated with the same accuracy as for other Jurassic stages. Around the Jurassic-Cretaceous boundary, the most widespread facies in the Tethys is the usually ammonite-poor and calpionellid-rich Maiolica limestone (Fourcade et al. 1991). This results in rare ammonite-rich localities, which mostly occur in Southern Spain (Enay and Geyssant 1975; Tavera 1985).

For these reasons ammonites are poorly used for correlation of Upper Tithonian successions. Calpionellids are preferred, because of their even occurrence in Tethyan areas (Remane 1985). Correlation between ammonite and calpionellid scales in the Tithonian is still based on data by Enay and Geyssant (1975) and Olóriz and Tavera (1981) (see also Olóriz and Tavera 1989) but additional information on Tithonian ammonites and correlation with calpionellids has been provided by Benzaggagh and Atrops (1995a, b, 1997) and Benzaggagh (2000) after field research on Upper Jurassic-Lower Cretaceous pelagic successions of northern Morocco. Further sampling has been carried out in the Msila area, in the eastern part of the internal Prérif (Fig. 1), where outcrops of ammonite-rich and relatively thick Tithonian successions occur.

## Geological setting

Uppermost Jurassic successions frequently crop out in the western side of the Oued Lakhdar and form the calcareous blocks called "Sofs" (Fig. 2). The section studied, labeled "Y" by Benzaggagh (2000), is located about 2 km west of Msila on the left side of a small gully that runs from the "Sofs" d'Ain el Haoud. It is easily accessible by taking the trail of Douar Kef Mallou. This section shows a relatively complete and fossiliferous succession, whereas Upper Tithonian sediments are rarely preserved in the internal Prérif because of erosion or stratigraphic gaps (Benzaggagh 2000).

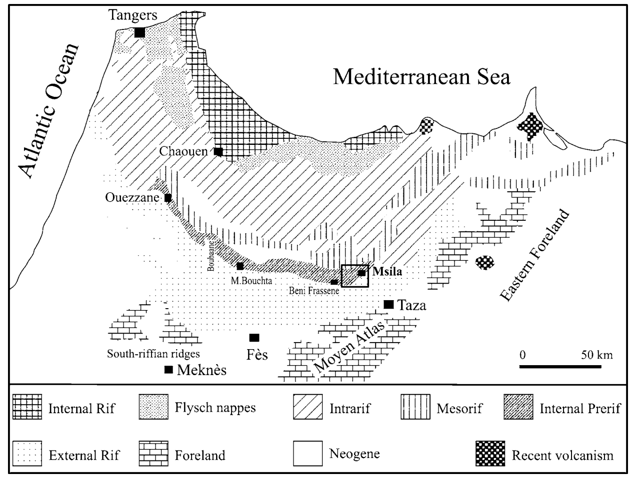



**Fig. 1** Structural sketch of Rif chains (from Leblanc 1979, modified) with the location of the M'Sila area

## Lithology and biomicrofacies

The studied section consists of a 25 m thick succession of limestone and marls that had formed on a submarine slope in a relatively distal depositional environment, as suggested by sedimentary structures and fossils. The lower part is characterized by a slump that laterally grades to a pebbly mudstone, which is cut by a submarine channel (Fig. 3). The stratigraphic succession represented in Fig. 4 was measured on the southern side of the outcrop (the one corresponding to the right side of Fig. 3), which is not disturbed by slumping. The whole succession has been subdivided in three layers, from bottom to top:

*Layer 1*, already named Calcaires de Koudiat Sefha by Benzaggagh (1988), is 4.5 m thick. The lowest rocks consist of unevenly stratified, thin micritic limestones topped by a 40 cm thick limestone bed. This is overlain by a pebbly mudstone (bed 2) and then by beds of 10–20 cm thick limestone alternating with marly interbeds. The latter generally correspond to pebbly mudstones. Ammonites are preserved as internal molds. Most have been found in a quasi-horizontal position. Taphonomic features clearly related to reworking are rare: we have recognized three cases of uncoupling (Olóriz et al. 2002) in beds 5, 6 and 14, and three

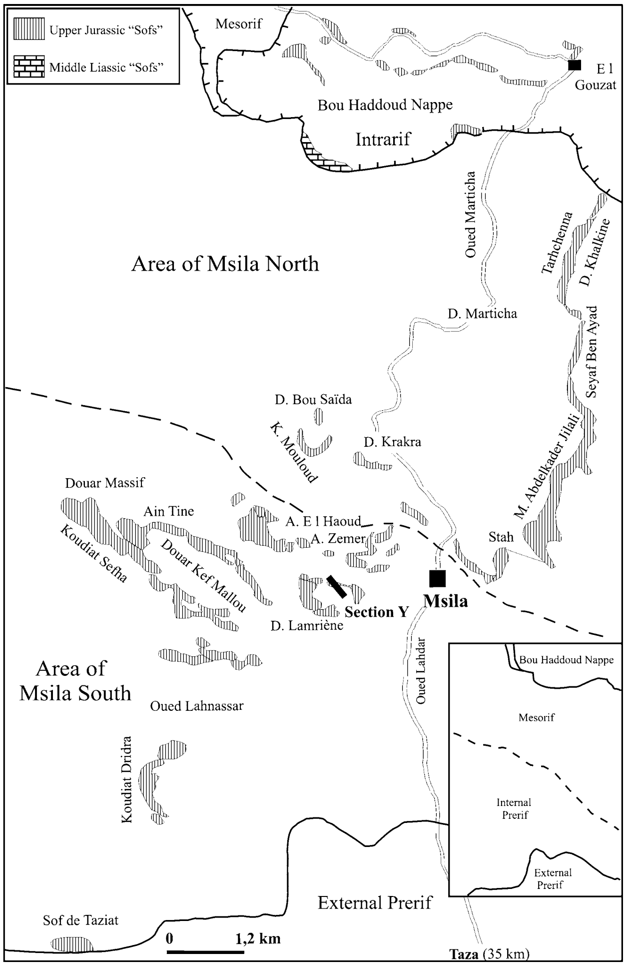



**Fig. 2** Simplified map of the M'Sila area showing the outcrops of the major Upper Jurassic calcareous "Sofs" and the location of the studied section (Y)

molds showing disarticulation surfaces coinciding with septa (Fernandez Lopez 1984) in beds 6, 9 and 12. Intraclast-rich sediments are frequent in all beds from 3 to 14.

*Layer 2* is characterized by marls and is partially covered by the soil. It represents the middle part of the succession. Its thickness is difficult to evaluate because of both soil cover and faulting.

*Layer 3* is 7–8 m thick and represents the upper calcareous part of the succession, with beds dipping towards the South. It consists of a succession of thin beds of micritic, often bioturbated nodular limestones with intercalations of thicker beds (25–50 cm thick) and thin intraclast-rich marly interbeds. Bed 33 is a pebbly mudstone with reworked fossils that laterally passes to a micritic bed with no traces of synsedimentary remobilization.

Marls covered by soil and boulders mask the rest of the succession.

The microfacies of the entire succession varies from mudstone to wackestone that mainly contain pelagic microfossils: *Saccocoma, Globochaete*, radiolarians, calcispheres, *Chitinoidella*, calpionelles, aptychi, small planktic forams with hyaline test, benthic agglutinated and microgranular forams, crinoid debris, rare small bivalves, gastropods, and ostracods.

*Saccocoma,* and calcispheres of the genus *Colomisphaera* Nowak are often abundant. *Saccocoma* abruptly disappears at the top of bed 28 around the boundary between calpionellid A2 and A3 subzones (Fig. 7). This is consistent with observations made in other Tethyan areas (Cecca et al. 2001).

## Ammonites

Ammonites are the most common macrofossils in the Msila section (Figs. 5, 6). Aptychi and belemnites are also frequent. Benthic fossils are represented by sea urchins and brachiopods of the genus *Pygope*. Both groups can be relatively frequent in particular beds. The imacrofossils identified are listed bed by bed. The ammonite zonation is that reported by Geyssant (1997). The number of specimens is given below in brackets.

Lower Tithonian

*Fallauxi Zone, Admirandum/Biruncinatum Subzone*

In the slumped part of the section (see Fig. 3):
Bed 3 (slump): *Simoceras admirandum* Zittel (1ex);
Transition 3/4: *Semisulcatoceras semisulcatum* (d'Orbigny) [pro *Ptychophylloceras ptychoicum* (Quenstedt), see Cecca 2002] (1ex), *Virgatosimoceras* sp. (1ex).
In the succession represented in the log of Fig. 4
Bed 5:Ataxioceratidae sp. indet. (2ex), *Haploceras (Volanites) rhinotomum* Zittel (1ex).

*Ponti Zone*

Bed 6: *Phylloceras* sp. (1ex.), *Protetragonites* sp. (1ex), *Haploceras* sp. (3 ex), Ataxioceratidae sp. indet. (2 ex), *Lemencia* cf. *nitida* (Schneid) (1 ex.), *Lemencia* sp. (2 ex.);
Bed 7: *Phylloceras* sp. (1 ex), *Haploceras* sp. (3 ex), *Lytoceras sutile* (Oppel) (1 ex), Ataxioceratidae sp. indet (4 ex.), *Lemencia* aff. *adeps* (Schneid), *Lemencia* sp. (3 ex), *Burckhardticeras peroni* (Roman) (1 ex), *Aulacosphinctes* n. sp. (3 ex)
Bed 8: *Phylloceras* sp. (1 ex), *Lytoceras sutile* (Oppel) (1 ex), *Protetragonites quadrisulcatus* (d'Orbigny) (2ex), *Haploceras carachtheis* (Zeuschner) morph. *elimatum* (Oppel) M (2 ex) and morph. *carachtheis* m


**Fig. 3** View of the lower part of section Y with the slumped beds cut by deposits filling in a submarine channel. The bed numbers are the same as are used in Figs. 4 and 7

(3ex), *Haploceras* sp. (3 ex), Ataxioceratidae sp. indet (2 ex.), *Parapallasiceras* sp. (3 ex), *Lemencia* cf. *pseudociliata* Olóriz (1 ex.), *Lemencia* sp. (1 ex), ?*Hemisimoceras* sp. (1ex), *Aulacosphinctes* n. sp. (2 ex), Himalayitidae sp indet. (1ex).

Bed 9 (middle): *Pseudiscosphinctes* sp. (1 ex), ?*Lemencia* sp. (1 ex);

Bed 12: *Phylloceras* sp. (2 ex), *Semisulcatoceras semisulcatum* (d'Orbigny) (1ex), *Protetragonites* sp. (1ex), *Haploceras carachtheis* morph. *staszycii* (Zeuschner) M (1 ex) *Haploceras* sp. (2 ex), Ataxioceratidae sp. indet. (1 ex)

Bed 13 (lower part): Oppeliidae indet (1 ex)

Bed 13 (upper part): *Holcophylloceras* cf. *silesiacum* (Oppel) (1 ex)

Bed 14: ?*Phylloceras* sp. (1 ex), *Haploceras carachtheis* morph. *carachtheis* m (2ex)

Bed 16: *Holcophylloceras* cf. *silesiacum* (Oppel) (1 ex)

Bed 17 or 18: *Haploceras carachtheis* morph. *elimatum* M (1 ex)

Upper Tithonian

*Microcanthum Zone, Simplisphinctes Subzone*

Bed 18: ?*Olóriziceras* sp. (1 ex), *Corongoceras* cf. *symbolum* (Oppel) (1 ex)

Bed 20: *Simplisphinctes* cf. *abnormis*? (Roman)

Bed 23: *Micracanthoceras microcanthum* (Oppel) (1 ex)

*Microcanthum Zone, Transitorius Subzone?*

Bed 25: *Paraulacosphinctes* sp. (1 ex), ?*Zittelia* sp. (1 ex); *Pygope catulloi* (Pictet) (1 ex)

Probably from this bed *Aulacosphinctes sulcatus* Tavera (1 ex)

Bed 26: *Phylloceras* sp. (1 ex), *Holcophylloceras* cf. *silesiacum* (Oppel) (1 ex), *Lytoceras liebigi* (Oppel) (1 ex), *Moravisphinctes* cf. *fischeri* (Kilian) (1ex), *Moravisphinctes* sp. (1 ex), ?*Paraulacosphinctes* cf. *senex* (Oppel) (1 ex); *Pygope catulloi* (Pictet) (2 ex)

*Durangites Zone*

Bed 27: *Phylloceras* sp. (1 ex), *Durangites* sp. (1 ex); *Pygope* cf. *janitor* (Pictet) (1 ex).

Bed 27 top: *Protacanthodiscus apertus* (Tavera) (1 ex)

Bed 28: *Phylloceras* sp. (6 ex), *Calliphylloceras kochi* (Oppel) (1 ex), *Holcophylloceras* cf. *silesiacum* (Oppel) (3 ex), *Lytoceras* sp. (1ex), *Substreblites zonarius* (Oppel) (1 ex), *Haploceras carachtheis* morph. *elimatum* M (1 ex), *Haploceras* cf. *tithonium* (Oppel) (1 ex), *Haploceras* sp. (6 ex), *Aspidoceras rogoznicense*

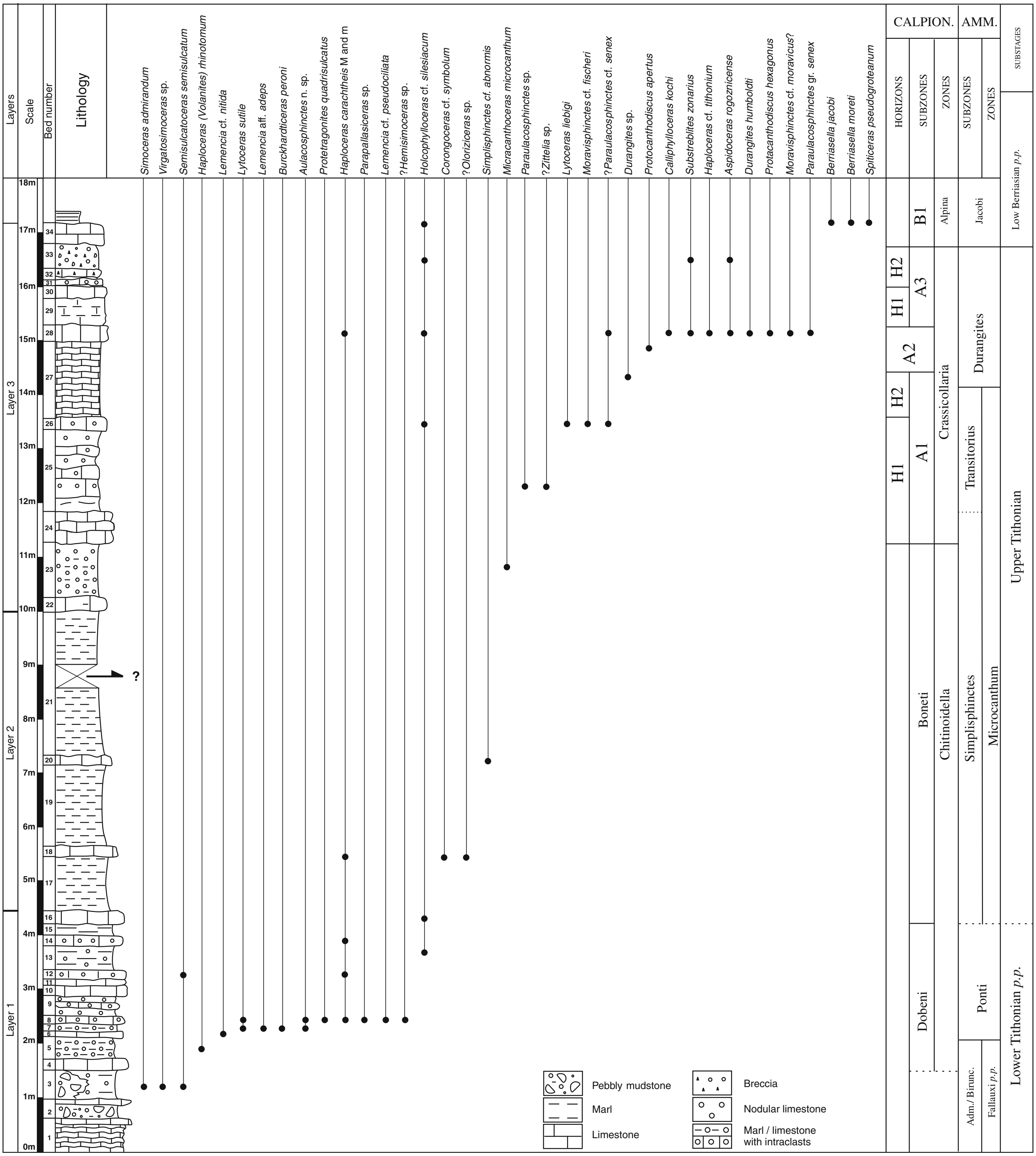



**Fig. 4** Lithostratigraphic log and stratigraphic distribution of the identified ammonite species in section Y of the M'Sila area from the upper part of the Lower Tithonian up to the base of the Berriasian. Ammonites zones are correlated with calpionellid zones

(Zeuschner) (1 ex), *Durangites humboldti* Burckhardt (1 ex), *D.* cf. *humboldti* (1 ex), *Durangites* sp. (1 ex), *Protacanthodiscus hexagonus* (Tavera) (2 ex), *Protacanthodiscus* sp. (1 ex), *Moravisphinctes* cf. *moravicus*? (Oppel) (3 ex), *Moravisphinctes* sp. (3 ex), *Paraulacosphinctes* gr. *senex* (Oppel) (1 ex), ?*Paraulacosphinctes* cf. *senex* (Oppel) (1 ex), ?*Paraulacosphinctes* sp. (1 ex); *Pygope janitor* (Pictet) (1 ex).

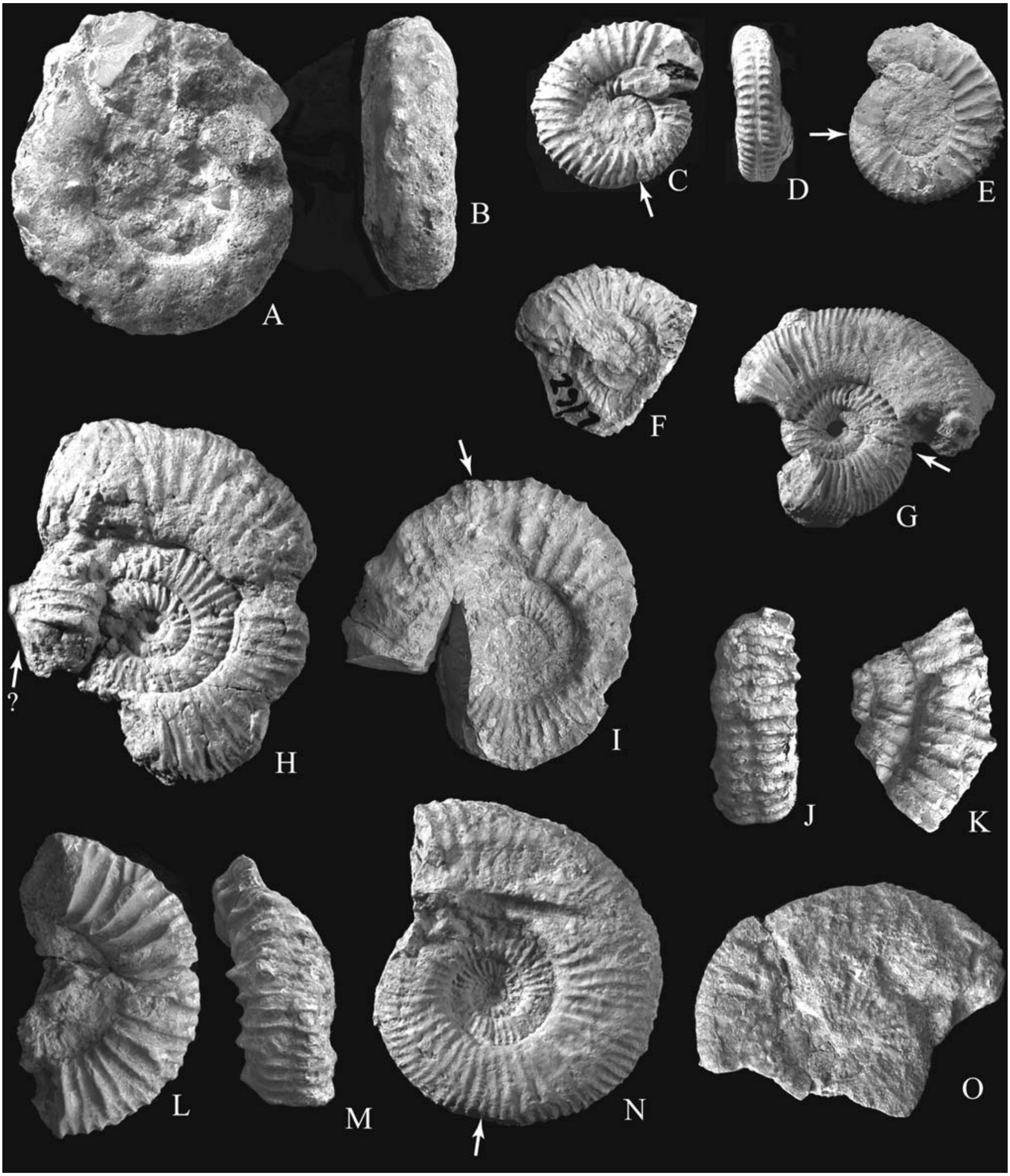



**Fig. 5** Ammonites. **a**, **b**: lateral and ventral views of *Simoceras admirandum* Zittel, bed 3 (slump), Fallauxi Zone, Admirandum/Biruncinatum Subzone. **c**: lateral view of *Burckhardticeras peroni* (Roman), bed 7, Ponti Zone. **d**, **e**: ventral and lateral views of *Aulacosphinctes* n. sp., bed 7, Ponti Zone. **f**: lateral view of *Simplisphinctes* cf. *abnormis*? (Roman), bed 20, Microcanthum Zone, Simplisphinctes Subzone. **g**: lateral view of *Lemencia* aff. *adeps* (Schneid), bed 7, Ponti Zone. **h**: *Lemencia* cf. *pseudociliata* Olóriz, bed 8, Ponti Zone. **i**: *Protacanthodiscus apertus* (Tavera), bed 27 top, Durangites Zone. **j**, **k**: ventral and lateral views of *Corongoceras* cf. *symbolum* (Oppel), bed 18, Microcanthum Zone, Simplisphinctes Subzone. **l**, **m**: lateral and ventral views of *Protacanthodiscus hexagonus* (Tavera), bed 28, Durangites Zone. **n**: lateral view of *Durangites humboldti* Burckhardt, bed 28, Durangites Zone. **o**: lateral view of *Moravisphinctes* cf. *moravicus*? (Oppel), bed 28, Durangites Zone. All figures natural size

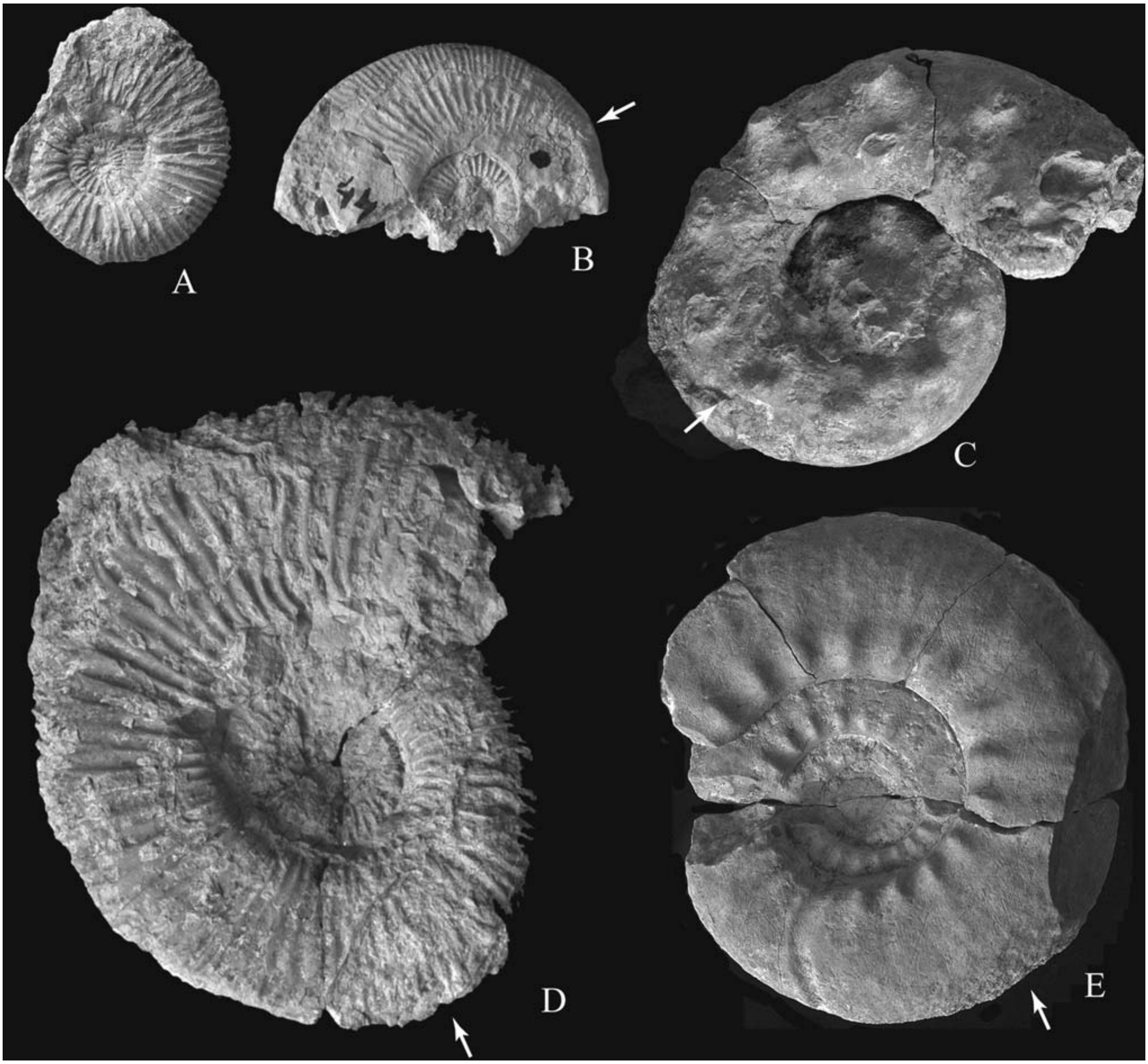



**Fig. 6** Ammonites. **a**: lateral view of *Berriasella jacobi* Mazenot, bed 34 top, Jacobi Zone. **b**: lateral view of *Paraulacosphinctes* gr. *senex* (Oppel), bed 28, Durangites Zone. **c**: lateral view of *Aspidoceras rogoznicense* (Zeuschner), bed 33, Durangites Zone. **d**: lateral view of *Berriasella moreti* Mazenot, bed 34 top, Jacobi Zone. **e**: lateral view of *Spiticeras pseudogroteanum* Djanelidze, bed 34 top, Jacobi Zone. All figures natural size

Bed 30: ?*Moravisphinctes* sp. (1 ex)
Bed 30 top: *Pygope catulloi* (Pictet) (1 ex), *Pygope janitor* (Pictet) (1 ex).
Bed 31: *Pygope* cf. *janitor* (Pictet), *P.* cf. *catulloi* (Pictet) (2 ex) (1 ex).
Bed 33: *Holcophylloceras* cf. *silesiacum* (Oppel) (1 ex), *Substreblites zonarius* (Oppel) (1 ex), *Aspidoceras rogoznicense* (Zeuschner) (1 ex), ? *Berriasella* sp. (1 ex),

Berriasian

*Jacobi Zone*

Bed 34 top: *Phylloceras* sp. (3 ex), *Holcophylloceras* cf. *silesiacum* (Oppel) (1 ex), *Haploceras* sp. (3 ex), *Berriasella jacobi* Mazenot (1 ex), *Berriasella moreti* Mazenot (1 ex), *Spiticeras pseudogroteanum* Djanelidze (1 ex),

## Biostratigraphic results

### The upper Lower Tithonian

In the Prerif, ammonites of the Fallauxi Zone are rarely found and ammonites of the Ponti Zone are generally long-ranging species. The latter ammonite zone has been inferred in previous papers only on the basis of the calpionellid content (Benzaggagh and Atrops 1997; Benzaggagh 2000) and its correlation to late Early Tithonian ammonites (Enay and Geyssant 1975; Cecca et al. 1989).

An important result is the finding in situ of ammonites belonging to both Fallauxi and Ponti Zones in the same section of the Prerif area. The occurrence of the marker *Simoceras admirandum* Zittel in the slumped part of the studied section allows us to recognize here, for the first time, the upper subzone of the Fallauxi Zone, i.e. the Admirandum/Biruncinatum Subzone. The base of the Ponti Zone is tentatively drawn at the base of bed 6 because of the occurrence of *Lemencia* specimens similar to those found in bed 7 where a specimen identified as *Burckhardticeras peroni* (Roman) has been found (Fig. 5c). According to Olóriz (1978), the latter species is one of the alternative markers of the last ammonite zone of the early Tithonian (see also discussion in Geyssant 1997). The occurrence of early himalayitids (*Burckhardticeras, Aulacosphinctes*) is an important feature of the faunal assemblage of this zone.

### The Upper Tithonian

Since Enay and Geyssant (1975) the upper part of the Tithonian has been subdivided in the Microcanthum and Durangites Zones. The former was subdivided by Olóriz and Tavera (1979, 1981) by introducing the Simplisphinctes and Transitorius Subzones. Tavera (1985) subsequently raised these units to the zonal rank in order to replace the Microcanthum Zone. According to Geyssant (1997) we consider these units Subzones of the Microcanthum Zone.

The base of the Microcanthum Zone is not easily recognizable in our section. From bed 9 up to bed 17 only poorly significant ammonites have been found. *Corongoceras* gr. *symbolum,* found in bed 18, occurs in the whole Microcanthum Zone in Southern Spain (Tavera 1985) but the occurrence of *Simplisphinctes* cf.*abnormis* in bed 20 indicates the lower subzone, i.e., the Simplisphinctes Subzone. According to Enay et al. (1998b), in Southern Spain the oldest layers of the Microcanthum Zone are characterized by representatives of the genus *Cordubiceras* Olóriz and Tavera (which has priority over *Baeticoceras* Geyssant, Enay and Busnardo, the name quoted in the paper of Enay et al. 1998b) and are followed by layers containing *Toucasiella*. Because of the absence of representatives of these genera in our section we could not recognize this faunal succession. Because of this, we have drawn the base of the Microcanthum Zone according to Benzaggagh and Atrops (1995a), who showed its correlation with the base of the calpionellid Boneti Subzone. Boughdiri et al. (2005) reported a similar observation from the Jebel Oust (NE Tunisia).

While the Simplisphinctes Subzone has been recognized in several sections of the Prerif (Benzaggagh 2000), the Transitorius Subzone cannot be identified easily because the marker, *Paraulacosphinctes transitorius* (Oppel), is rare. The species *P. senex,* which differs from *P. transitorius* because of the less evolute coiling and a denser ribbing, has been reported from the Transitorius Subzone to the Durangites Zone by Tavera (1985) but Benzaggagh and Atrops (1995a) and Benzaggagh (2000) reported it from the lower part of the Microcanthum Zone. We cannot exclude problems in the identification of ammonites, for example *Paraulacosphinctes*, that have perisphinctid morphology (see also discussion in Cecca et al. 1989, pp. 59–60). Because of poor preservation, only one of our specimens can be ascribed to the group of *P. senex* (Fig. 6b).

The Transitorius Subzone is partly recognized by the occurrence of *Moravisphinctes fischeri* (Kilian). This was observed in Ardèche (SE France) by Cecca et al. (1989) and then confirmed in the Prerif by Benzaggagh (1988, 2000) and Benzaggagh and Atrops (1995a). We have found specimens identified as *M*. cf. *fischeri* in bed 26, ascribed to the upper Microcanthum Zone, Transitorius Subzone, and also in bed 28 together with species of the Durangites Zone. Cecca et al. (1989) suggested that the group of *M. fischeri* is limited to the upper part of the Microcanthum Zone, in an interval corresponding to calpionellid Subzone A1, while *M. moravicus* would occur in the Durangites Zone as suggested by Enay and Geyssant (1975). Because of poor preservation, this suggestion is neither confirmed nor refuted on the basis of the material collected in situ. Specimens of *M. fischeri* have been found in the loose, and a specimen from the Durangites Zone (Fig. 5o) is tentatively assigned, with doubt, to *M*. cf. *moravicus*?

The beginning of the Durangites Zone has been drawn in the middle part of bed 27 because of the occurrence of a specimen showing the characters of *Durangites*. All the identified species that clearly belong to this Zone have been found in beds 27 top and 28, where calpionellids of the A2 Subzone occur. (Fig. 4). *Protacanthodiscus apertus* has been reported by Enay et al. (1998a) in beds correlated with the A3 Subzone. The specimen of *D. humboldti* illustrated here in Fig. 5n is almost identical with that illustrated by Enay et al. (1998a) from La Coronilla (Southern Spain), where it has been found in association with calpionellids of the lower part of the A3 subzone.

*Protacanthodiscus hexagonus*, provisionally ascribed by Tavera (1985) to "*Corongoceras*", occurs in Southern Spain in the Transitorius Subzone and in the Durangites Zone.

Bed 33 is a breccia with reworked ammonites represented by fragments with sharp angles. This feature occurs also in intraclasts and fragments of brachiopods. Bed 34 is rich in species of the Berriasian Jacobi Zone, as already reported by Benzaggagh (2000).

## Calpionellid biostratigraphy

These microfossils are particularly useful for rock-dating in pelagic successions. They are helpful when ammonites are absent or represented by species of poor stratigraphical significance. The coupled use of calpionellid and ammonite biozones is a powerful tool for the biostratigraphy around the Jurassic–Cretaceous boundary (Le Hégarat and Remane 1968; Le Hégarat 1973).

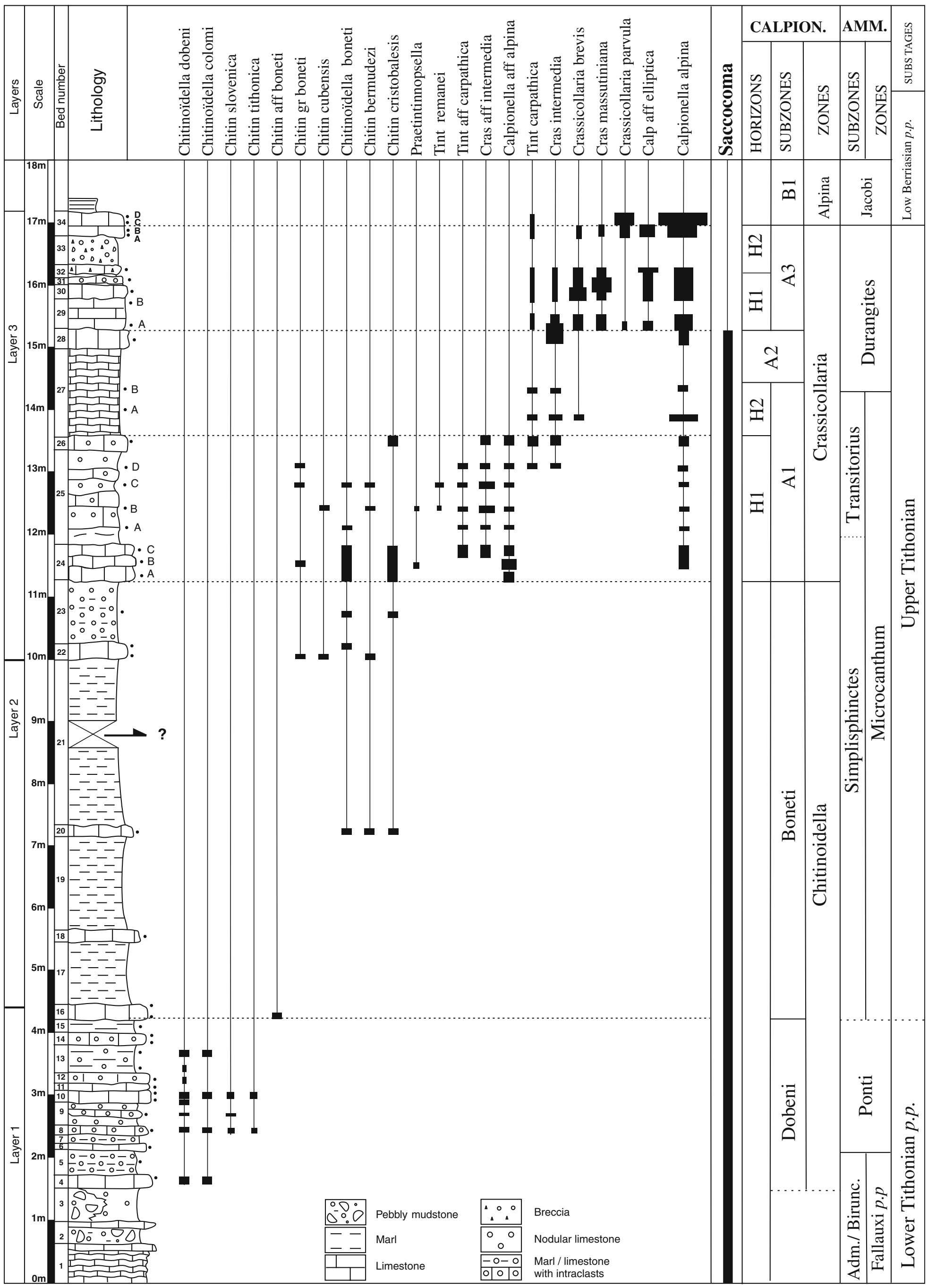



**Fig. 7** Stratigraphic distribution of the identified *Chtinoidella* and calpionellid species in section Y of the M'Sila area from the upper part of the Lower Tithonian up to the base of the Berriasian

The distribution of the identified calpionellid species is presented in Fig. 7. The biostratigraphic results and the zonal assignments are discussed below.

## Chitinoidella Zone

The genus *Chitinoidella* can be subdivided into two major groups of species of different size and different stratigraphic distributions, characterized by microgranular tests: *Chitinoidella* gr. *dobeni* borza and *Chitinoidella* gr. *boneti* doben.

The first group ranges from the upper part of the Fallauxi Zone (Enay and Geyssant 1975) to the Ponti Zone. It gathers species with small-sized loricas (the width is almost 30 µm and the length varies between 40 and 50 µm). The second group occurs in the Microcanthum Zone (Enay and Geyssant 1975; Benzaggagh and Atrops 1995a) up to the boundary between the Simplisphinctes and Transitorious Subzones (Olóriz and Tavera 1989), or to the uppermost part Simplisphinctes Subzone (Boughdiri et al. 2005). It gathers species with larger loricas (the width is almost 50 µm and the length is around 70 µm) whose size equals that of true calpionellids (i.e. calpionellids with hyaline tests). The stratigraphic distribution of species of both groups defines the Dobeni and Boneti Subzones respectively. The boundary between these two subzones is almost coincident with the base of the ammonite Microcanthum Zone (Benzaggagh and Atrops 1995a).

In the whole Msila area *Chitinoidella* gr. *dobeni* Borza, which indicates the late Early Tithonian, always appears in the bed that overlies the breccias of the Calcaires de Koudait Sefha, here called Layer 1 (Fig. 7).

### *Dobeni Sub-Zone*

Specimens of *Chitinoidella* gr. *dobeni* occur from bed 4 to bed 13. They are relatively abundant, except in bed 12 and in the base of bed 13. We have recognized the four species that classically form this group: *Chitinoidella dobeni* Borza (Fig. 8, fig. 2), *Chitinoidella colomi* Borza (Fig. 8, fig. 1), *Chitinoidella slovenica* Borza (Fig. 8, fig. 4) and *Chitinoidella tithonica* Borza (Fig. 8, fig. 3).

### *Boneti Sub-Zone*

Representatives of *Chitinoidella* gr. *boneti* appear in bed 16 and disappear in bed 26, that is, after the appearance of true calpionellids with hyalin tests at the base of bed 24 (sample A in Fig. 7), which is used to draw a boundary with the Crassicollaria Zone.

This group is represented by the following species: *Chitinoidella* aff. *boneti* Doben (Fig. 8, fig. 5), *Chitinoidella* gr. *boneti, Chitinoidella boneti* (Fig. 8, figs. 6 and 7), *Chitinoidella cristobalensis* (Furrazola-Bermudez) (Fig. 8, fig. 8), *Chitinoidella bermudezi* (Furrazola-Bermudez) (Fig. 8, fig. 9), *Chitinoidella cubensis* (Furrazola-Bermudez) (Fig. 8, fig. 10).

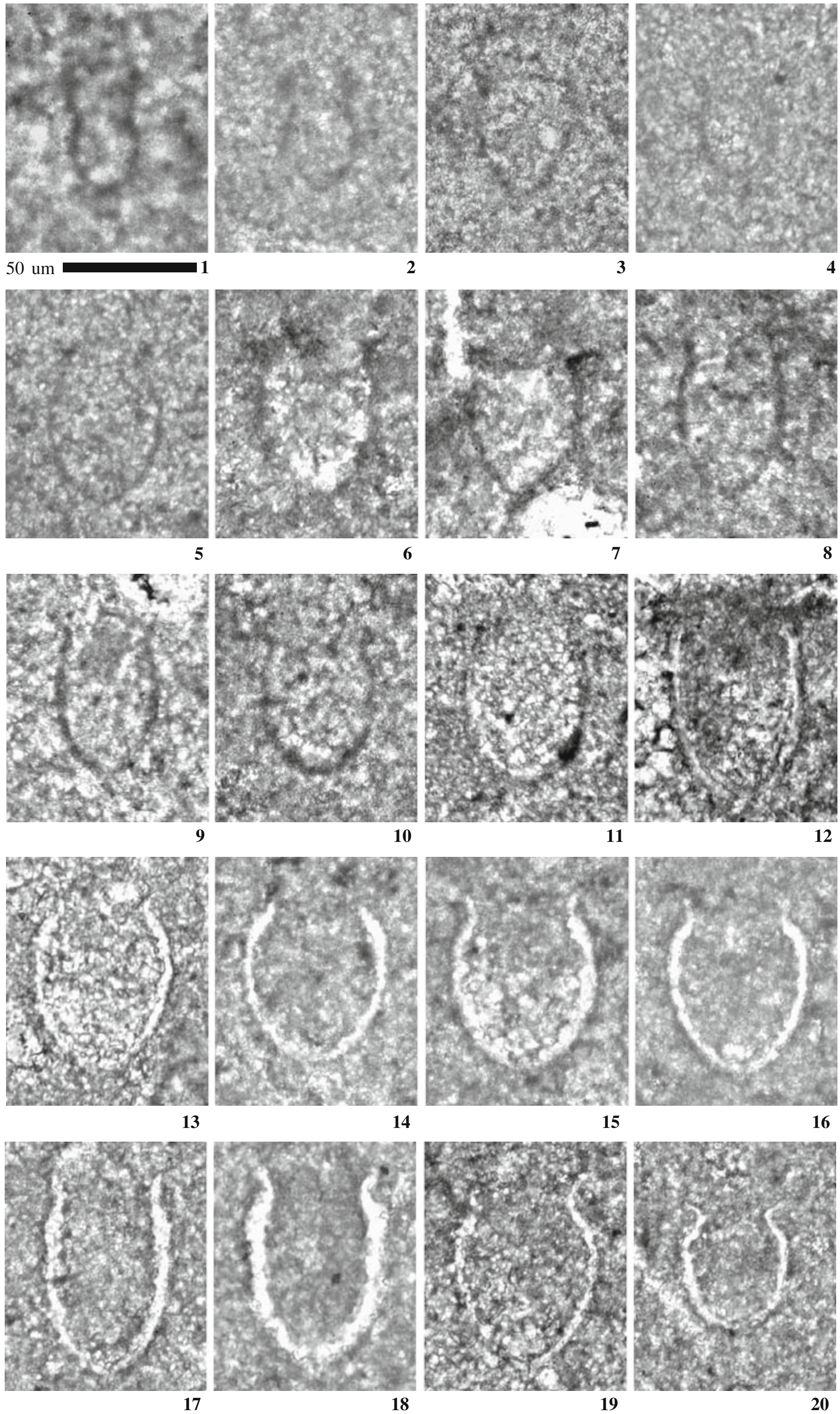
**Fig. 8** **1** *Chitinoidella colomi* Borza bed 4, Chitinoidella Zone, Dobeni Subzone. **2** *Chitinoidella dobeni* Borza, bed 9, Chitinoidella Zone, Dobeni Subzone. **3** *Chitinoidella tithonica* Borza, bed 10, upper sample, Chitinoidella Zone, Dobeni Subzone, Y9 sup. **4** *Chitinoidella slovenica* Borza, bed 8 Chitinoidella Zone, Dobeni Subzone. 5 *Chitinoidella* aff. *boneti* Doben, bed 16 Chitinoidella Zone, Boneti Subzone.**6** *Chitinoidella boneti* Doben, bed 22, lower sample, Chitinoidella Zone, Boneti Subzone. **7** *Chitinoidella boneti* Doben, bed 23, Chitinoidella Zone, Boneti Subzone. **8** *Chitinoidella cristobalensis* (Furrazola-Bermudez), bed 20, Chitinoidella Zone, Boneti Subzone. **9** *Chitinoidella cristobalensis* (Furrazola-Bermudez), bed 25, sample C, Crassicollaria Zone, A1 Subzone, Horizon H1. **10** *Chitinoidella cubensis* (Furrazola-Bermudez), bed 22, lower sample, Chitinoidella Zone, Boneti Subzone. **11** *Praetintinnopsella andrusovi* Borza, bed 24, sample B, Crassicollaria Zone, A1 Subzone, Horizon H1. **12** *Praetintinnopsella andrusovi* Borza, bed 25, sample B, Crassicollaria Zone, A1 Subzone, Horizon H1. **13** *Calpionella* aff. *alpina* Lorenz, bed 24, sample B, Crassicollaria Zone, A1 Subzone, Horizon H1. **14–16** *Calpionella* aff. *alpina* Lorenz, bed 24, sample C, Crassicollaria Zone, A1 Subzone, Horizon H1. **17** *Crassicollaria* aff. *intermedia* (Durand Delga), bed 25, sample C, Crassicollaria Zone, A1 Subzone, Horizon H1. **18** *Crassicollaria intermedia* (Durand Delga), bed 25, sample C, Crassicollaria Zone, A1 Subzone, Horizon H1. **19** *Tintinnopsella carpathica* (Murgeanu and Filipescu), bed 24, sample C, Crassicollaria Zone, A1 Subzone, Horizon H1. **20** *Tintinnopsella remanei* Borza, bed 25, sample B, Crassicollaria Zone, A1 Subzone, Horizon H1. *Scale-bar* in fig. 1 for size reference

## Crassicollaria Zone (A Zone)

After Remane's work (1963, 1985) the Crassicollaria, or A, Zone is classically subdivided in three subzones: A1, A2, and A3. The extent of this zone is almost equivalent to the interval ranging from the upper part of the Microcanthum to the whole Durangites Zones of the ammonite scale (Enay and Geyssant 1975).

New subzones of the Crassicollaria Zone, named with index species have recently been proposed: Remanei and Intermedia subzones (Remane et al. 1986); Remanei, Intermedia, Catalanoi subzones (Grün and Blau 1997); Remanei, Intermedia, Colomi subzones (Pop 1996); Remanei, Brevis, Colomi subzones (Rehakova and Michalik 1997). Unfortunately, these subzones are not easily recognizable in the studied section and, generally, in the preriffian successions. We therefore use the classic zonation of Remane (1963), complemented by new biostratigraphic data for A1 subzone (Benzaggagh 1988; Benzaggagh and Atrops 1995a).

True calpionellids, characterized by hyalin tests, appear in bed 24 of the studied section. The variations of the width and the height of their loricas are from 40 to 65 µm and from 60 to 90 µm, respectively, in the interval spanning the Crassicollaria Zone and the base of the Alpina Zone (bed 24 to the upper part of bed 34).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*A1 Subzone*

According to the reported ammonites, this subzone mostly correlates with the upper part of the ammonite Microcanthum Zone (Fig. 7). In the Internal Prerif two distinct assemblages have been recognized (Benzaggagh and Atrops 1995a; Benzaggagh 2000): Horizon H1, which is characterized by the co-occurrence of both *Chitinoidella* and true calpionellids, and the younger Horizon H2 where both shape and size of calpionellids show the characteristics of the assemblages described by Remane (1963, 1985) for the A1 subzone, i.e. tests, collars, and size typical of *Calpionella*, *Crassicollaria*, and *Tintinnopsella* species. We have recognized H1 from the base of bed 24 (devoid of ammonites) to bed 26 (with ammonites of the Transitorius Subzone), and H2 from the lower to the middle part of bed 27 (samples A and B), which contains ammonites ascribed to the Durangites Zone.

The Horizon H1 has been recognized in different sections of the preriffian and mesoriffian zones (Benzaggagh 2000). True calpionellids are represented by atypical forms of small size, with thin tests and poorly developed collars. We have recognized in the stratigraphical interval from beds 24–26: *Tintinnopsella carpathica* (Fig. 8, fig. 19), *Calpionella alpina* Lorenz also represented by a small-sized form identified as *Calpionella* aff. *alpina* characterized by a short and poorly developed collar (Fig. 8, figs. 14–16), *Crassicollaria* aff. *intermedia* (Durand-Delga) (Fig. 8, fig. 17), small-sized *Crassicollaria intermedia* (Fig. 8, fig. 18), rare *Tintinnopsella remanei* Borza (Fig. 8, fig. 20), *Chitinoidella boneti, Chitinoidella* gr. *boneti*, *Chitinoidella cubensis* (Furrazola-Bermudez) (Fig. 8, fig. 10), *Chitinoidella cristobalensis* (Fig. 8, figs. 8, 9), *Chitinoidella bermudezi* Furrazola-Bermudez) and rare *Praetintinnopsella andrusovi* Borza (Pl. 1, figs. 11, 12). This particular assemblage has been recognized in the Mallorca Island (Spain) and named Association II by Olóriz et al. (1995), who correlate it with the Remanei Subzone. It has been recognized also in several sections of northern Tunisia (S. Ben Abdesselam-Mahdaoui, PhD thesis in progress). *Tintinnopsella remanei* disappears at the top of this horizon.

The Horizon H2 is recognized in a thin stratigraphic interval of the studied section (Fig. 7). It is rich in middle and large sized specimens of *Calpionella alpina* (Pl. 2, 1) and *Crassicollaria intermedia* (Pl. 2, 14) and contains frequent small-sized specimens of *Tintinnopsella carpathica* with thin and short collars.

The calpionellids of the A1 Subzone confirm a previous hypothesis of cladogenetic evolution of early calpionellids (Benzaggagh and Atrops 1995a), instead of the gradual anagenetic evolutionary model proposed by Grandesso (1977) and Remane (1985).

**Fig. 9** **1** *Calpionella alpina* Lorenz, large-sized specimen, bed 28, Crassicollaria Zone, A2. **2** *Calpionella alpina* Lorenz, large-sized specimen, bed 29, sample A, Crassicollaria Zone, A3 Subzone, Horizon H1. **3** *Calpionella* aff. *elliptica* Cadisch (elongated form of *Calpionella alpina* Lorenz), bed 34, sample A, Crassicollaria Zone, A3 Subzone, Horizon H2. **4** *Calpionella* aff. *elliptica* Cadisch (elongated form of *Calpionella alpina* Lorenz), bed 29, sample B, Crassicollaria Zone, A3 Subzone, Horizon H1. **5** *Calpionella alpina* Lorenz (small-sized form, slightly elongated), bed 29, sample A, Crassicollaria Zone, A3 Subzone, Horizon H1. **6** *Calpionella alpina* Lorenz (small-sized ovate form with a slightly pointed aboral pole), bed 34, sample D, Alpina Zone, B1 Subzone. **7** *Calpionella alpina* Lorenz (middle-sized spherical form), bed 34, sample D, Alpina Zone, B1 Subzone. **8** *Tintinnopsella carpathica* (Murgeanu and Filipescu) (badly preserved collar), bed 34, sample D, Alpina Zone, B1 Subzone. **9** *Tintinnopsella carpathica* (Murgeanu and Filipescu), bed 30, Crassicollaria Zone, A3 Subzone, Horizon H1. **10** *Crassicollaria parvula* Remane, bed 34, sample D, Alpina Zone, B1 Subzone. **11** *Crassicollaria parvula* Remane, bed 29, sample B, Crassicollaria Zone, A3 Subzone, Horizon H1. **12** *Crassicollaria brevis* Remane, bed 29, sample A, Crassicollaria Zone, A3 Subzone, Horizon H1. **13** *Crassicollaria intermedia* (Durand Delga), bed 29, sample A, Crassicollaria Zone, A3 Subzone, Horizon H1. **14** *Crassicollaria intermedia* (Durand Delga), bed 28, Crassicollaria Zone, A2 Subzone, **15** *Crassicollaria intermedia* (Durand Delga), bed 27, sample A, Crassicollaria Zone, A1 Subzone, Horizon H2. **16** *Crassicollaria intermedia* (Durand Delga), bed 29, sample B, Crassicollaria Zone, A3 Subzone, Horizon H1. **17** *Crassicollaria massutiniana* (Colom), bed 34, sample A, Crassicollaria Zone, A3 Subzone, Horizon H2. **18–20** *Crassicollaria massutiniana* (Colom), bed 29, sample B; specimen of fig. 20 from bed 30. Crassicollaria Zone, A3 Subzone, Horizon H1. *Scale-bar* in fig. 1 for size reference

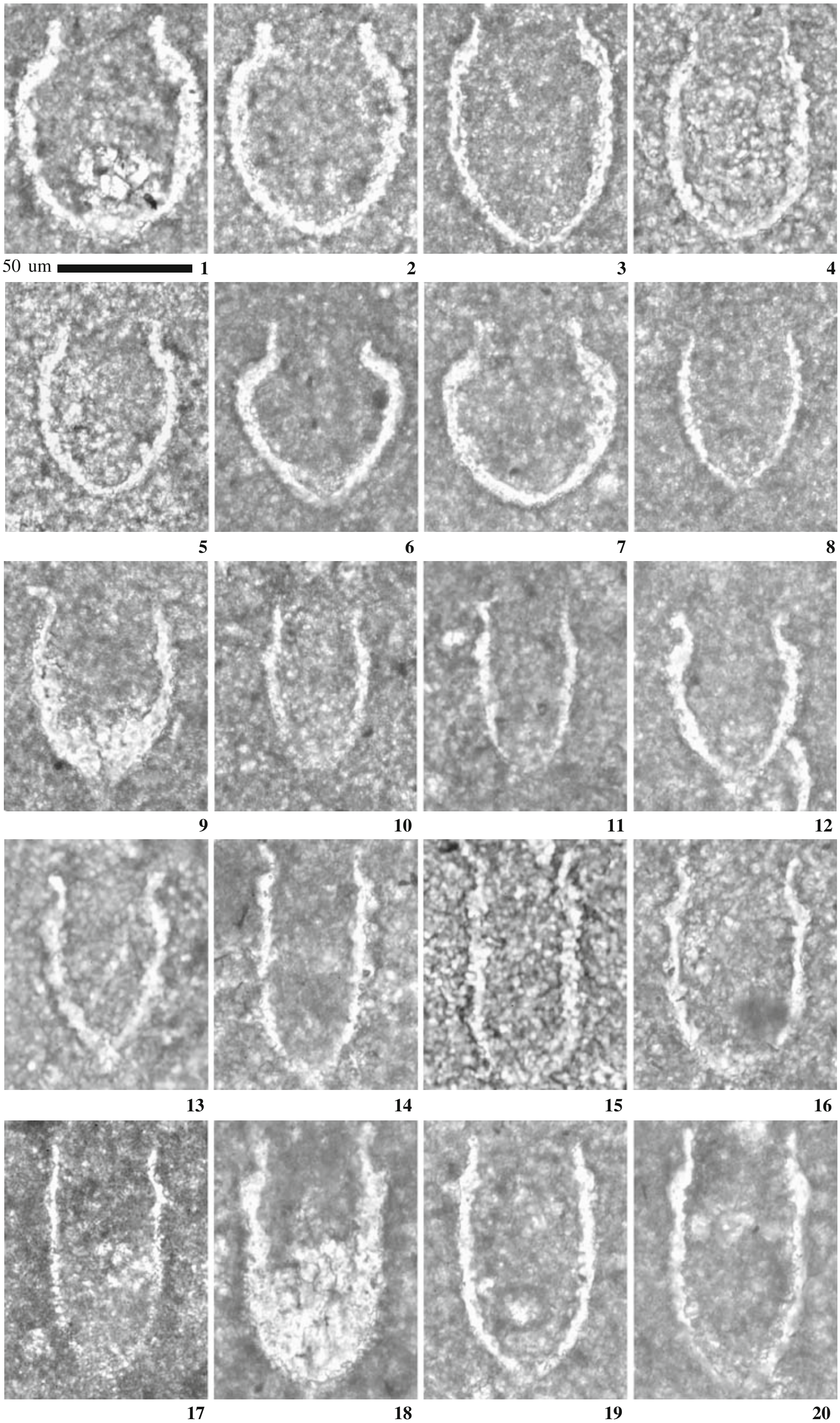
*A2 Subzone*

This subzone shows the same assemblage as the former but here the species *Crassicollaria intermedia* (Fig. 8, fig. 14) is more frequent, whereas *Tintinnopsella carpathica* and middle and large sized specimens of *Calpionella alpina* are less abundant. In our section this subzone is recognized in a thin stratigraphic interval corresponding to the upper part of bed 27 and bed 28 (Fig. 7).

*A3 Subzone*

This is well represented from bed 29 to the lower part of bed 34 (samples A and B). Calpionellas are abundant and assemblages allow the subdivision of this subzone into two Horizons.

In Horizon H1 (bed 29 to bed 31) specimens of *Crassicollaria massutiniana* (Colom) (Fig. 9, fig. 18–20) are abundant and frequently of large size. True specimens of *Crassicollaria brevis* Remane (Fig. 9, fig. 12) appear here together with a peculiar form of *Calpionella alpina,* which is characterized by an elongated shape that we designate with the name *Calpionella* aff. *elliptica* Cadisch (Fig. 9, figs. 3, 4). *Calpionella alpina* of small, middle and large sizes (Fig. 9, figs. 2, 5) are often abundant, whereas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*Crassicollaria intermedia* (Fig. 9, fig. 16) becomes less frequent than in the lower samples. *Tintintinnopsella carpathica* (Fig. 9, fig. 9) is still rare.

Horizon H2 is recognizable from bed 32 to the lower part of bed 34. It is characterized by the abundance of *Calpionella* aff. *elliptica* Cadisch (Fig. 9, fig. 3), the rarity of *Crassicollaria massutiniana* (Fig. 9, fig. 17) and *Crassicollaria brevis*, and also the extinction of *Crassicollaria intermedia.* In contrast, *Crassicollaria parvula* becomes abundant.

## Alpina Zone (B Zone)

### B1 Subzone

Only the very base of the Alpina (or B) Zone is represented in this section. It correlates with the ammonite Jacobi Zone. The calpionellid assemblage has the same characteristics as other Tethyan areas. The abundance of *Crassicollaria parvula* and the absence of *Remaniella ferasini* (Catalano) in the upper part of bed 34 (samples C and D) clearly indicate that we have here the lower part of this Zone, i.e. B1 subzone (Benzaggagh and Atrop 1995b). The explosion of small and middle-sized specimens of *Calpionella alpina* (Fig. 9, figs. 6 and 7), that make 75% of the whole calpionellid assemblage, characterizes this subzone together with the rarity of large-sized specimens of *Calpionella alpina* and the disappearance of *Crassicollaria massutiniana*, *Crassicollaria brevis*, and *Calpionella* aff. *elliptica*. *Crassicollaria parvula* (Fig. 9, fig. 10) is still abundant. *Tintinnopsella carpathica* is always rare (just a very few specimens in each thin section), with rarely well-developed collars (Fig. 9, fig. 8).

The most characteristic element of this subzone is the occurrence of a particular form of *Calpionella alpina* represented by small and middle-sized specimens that bear ovate loricas whose maximum thickness located just below the collar. The aboral pole is pointed (Fig. 6, fig. 6).

## Conclusion

The ammonite faunas from Msila are almost identical with those described from the Subbetic Zone of Southern Spain (Enay and Geyssant 1975; Olóriz 1978; Tavera 1985). There are, of course, common elements with faunas of other Mediterranean areas, for example Algeria (Roman 1936) and Apennines (Cecca et al. 1986; Cecca and Santantonio 1989). The Late Tithonian faunas from the latter area are poorly known and those of the latest Early Tithonian differ because of the abundance and diversity of Simoceratidae (Cecca and Santantonio 1989; Cecca et al. 1994; Cecca 1999).

From the biostratigraphic viewpoint, some of our observations have implications for correlations of ammonite and calpionellid scales. According to Enay and Geyssant (1975, p. 50), representatives of the genus *Chitinoidella* have been found in Southern Spain in the ammonite Ponti Zone and in a section of the Cabra area in the top of the ammonite Fallauxi. These data have been used and reported in subsequent papers. This is the first time, since Enay and Geyssant (1975) and Olóriz and Tavera (1979), that *Chitinoidella* and ammonites of both the upper part of the Fallauxi Zone and the Ponti Zone have been found in the same beds of a single section. In this study the distinction of Horizons I and II within Subzone A3 is proposed. The two horizons are mostly defined on the basis of the abundance of the different species of the genus *Crassicollaria* but Horizon II is also defined by the extinction of the species *C. intermedia*.

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