

## Lower Valanginian ammonite biostratigraphy in the Subbetic Domain (Betic Cordillera, southeastern Spain)

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**Abstract:** A new zonation for the lower Valanginian in the Betic Cordillera is presented. It is based on the study of 16 sections located near Caravaca and Cehegín (Region of Murcia). From bottom to top, the following interval zones, defined by the first appearance of the index-species, are distinguished:

- "*Thurmanniceras*" *pertransiens* Zone, which can be subdivided into two subzones, a lower "*Th.*" *pertransiens* Subzone and an upper *Vergolicerias salinarium* Subzone. The latter is characterized by the disappearance of *Olcostephanus drumensis* and the appearance of *Luppovella superba*.
- *Neocomites neocomiensiformis* Zone, also with two subzones, the *Baronnites hirsutus* Subzone below (characterized by the appearance of "*Busnardoites*" *subcampylotoxus* and *Olcostephanus guebhardi*) and the Valanginites *dolioliformis* Subzone above ("*Busnardoites*" *campylotoxus* is restricted to this subzone).
- *Karakaschiceras inostranzewi* Zone, subdivided as well into two subzones, a lower *Karakaschiceras inostranzewi* Subzone and an upper *Saynoceras contestanum* Subzone.

The assemblages characterizing each of these biozones can be recognized throughout the Mediterranean region.

**Key Words:** Lower Valanginian; Cretaceous; ammonite; biostratigraphy; Spain; Mediterranean region.

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**Résumé :** *Biostratigraphie par ammonites du Valanginien inférieur du Domaine Subbétique (Cordillères Bétiques, SE de l'Espagne).*- Une nouvelle zonation pour le Valanginien inférieur de la Cordillère Bétique est présentée. Elle est fondée sur l'étude de 16 coupes localisées près de Caravaca et de Cehegín (région de Murcie). De bas en haut, définies par la première apparition de l'espèce-index, les zones d'intervalle suivantes ont été reconnues :

- une Zone à "*Thurmanniceras*" *pertransiens*, qui peut être subdivisée en deux, une Sous-Zone inférieure à "*Th.*" *pertransiens* et une Sous-Zone supérieure à *Vergolicerias salinarium*. Cette dernière est caractérisée par la disparition de *Olcostephanus drumensis* et l'apparition de *Luppovella superba* ;
- une Zone à *Neocomites neocomiensiformis*, comprenant également deux sous-zones, une Sous-Zone inférieure à *Baronnites hirsutus* (caractérisée par l'apparition de "*Busnardoites*" *subcampylotoxus* et d'*Olcostephanus guebhardi*) et une Sous-Zone supérieure à *Valanginites dolioliformis* (l'espèce "*Busnardoites*" *campylotoxus* est cantonnée à cette sous-zone) ;
- une Zone à *Karakaschiceras inostranzewi*, aussi subdivisée en deux, une Sous-Zone inférieure à *Karakaschiceras inostranzewi* et une Sous-Zone supérieure à *Saynoceras contestanum*.

Les associations qui caractérisent chacune de ces unités biostratigraphiques peuvent être reconnues sur l'ensemble de la région méditerranéenne.

**Mots-clefs :** Valanginien inférieur ; Crétacé ; ammonites ; biostratigraphie ; Espagne ; région méditerranéenne.

### 1. Introduction

Knowledge of the lower Valanginian ammonite biostratigraphy in the Mediterranean region has evolved little during the last two decades. Indeed, the current standard zonation for this interval until very recently (HOEDEMAEKER *et al.*, 2003; REBOULET *et al.*, 2011) was based largely on the proposals of ATROPS & REBOULET (1995a, 1995b), REBOULET (1996), and REBOULET & ATROPS (1999) in SE France. These proposals,

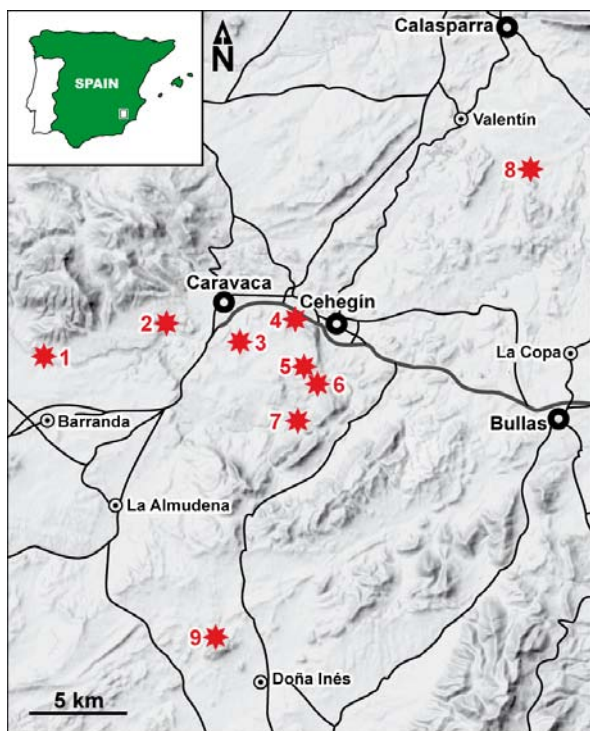
however, differed significantly from the zonal scheme developed, around the same time, by BULOT (1995) and BULOT & THIEULOY (1995). These differences involved not only the bioevents chosen to define the biostratigraphic units, but also the stratigraphic range and even the conception of some key species (KLEIN & HOEDEMAEKER, 1999).

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**Figure 1:** Geographic location of the sections studied. (1) Las Oícas (section Y.O); (2) Miravetes (section Y.Mv); (3) Prado Borda (sections Y.B, Y.B<sub>1</sub> and Y.T); (4) Mai Valera (section Y.P); (5) Puente de la Virgen (section Y.N); (6) Cañada Luenga (sections M.CL, Y.CL<sub>2</sub> and Y.Qp<sub>2</sub>); (7) Barranco del Garranchal (sections Y.G and Y.Q<sub>2</sub>); (8) Cerro Cambrones (section Y.V); (9) Tornajo (sections Y.J<sub>1</sub>, Y.J<sub>2</sub> and Y.J<sub>3</sub>).

In order to resolve these discrepancies, we undertook a detailed analysis of the ammonite stratigraphic distribution throughout the lower Valanginian. To this end, we carried out a systematic sampling of 16 sections in the eastern Subbetic domain (Betic Cordillera, southeastern Spain), some of them previously not studied. This enabled us to accurately identify the sequence of ammonite bioevents and propose a more precise zonation for this interval in the Betic Cordillera. An outline of these results was previously presented (COMPANY & TAVERA, 2013a, 2013b), and some of our proposals were accepted by the attendants to the 5th Meeting of the "KILIAN Group" (Ankara, 31 August 2013) to be included in the last version of the standard Mediterranean zonation (REBOULET *et al.*, 2014). In this paper, we develop this zonal scheme giving a detailed account of the bioevents that define and characterize the different units that compose it and discussing its correlation with the schemes previously proposed by other authors.

## 2. Geological setting and studied sections

All the studied sections belong to the Subbetic Zone, a tectonic domain which corresponds roughly to the pelagic realm of the southern paleomargin of Iberia during the Alpine cycle (Mesozoic and Paleogene). The lithologic successions are made of marl-limestone rhythmites of the Miravetes Formation (VEEN, 1969), in which ammonites are, by far, the main components of the macrofauna. Some slumped intervals are present in the sections of the Sierra de Quipar-Peña Rubia-Mai Valera area, which behaved as a relative topographic high during the Jurassic and the Early Cretaceous (REY, 1993; GEA, 2004).

The sections sampled, all of them located near Caravaca and Cehegín (region of Murcia, SE Spain), are the following (Fig. 1):

- Section Y.O (coordinates: 38°4'26"N 1°57'59"W), on the left bank of the River Argos, 10 km WSW of Caravaca, and 250 m N of the Las Oícas holiday cottage. It corresponds to the uppermost part of section M in HOEDEMAEKER (1982) and HOEDEMAEKER & LEEREVELD (1995);
- Section Y.Mv (coordinates: 38°5'29"N 1°53'43"W), on the right bank of the ravine called Rambla Curiana, 3 km SW of Caravaca, and 500 m of the Miravetes farmhouse. Data on lower Valanginian ammonite biostratigraphy from this classic section were previously published by ALLEMANN *et al.* (1975), HOEDEMAEKER (1982), HOEDEMAEKER & LEEREVELD (1995), and AGUADO *et al.* (2000);
- Sections Y.B (coordinates: 38°4'53"N 1°50'53"W) and Y.B<sub>1</sub> (coordinates: 38°4'51"N 1°51'W), on a gentle slope, 2.7 km SSE of Caravaca, and 300 m S of the Prado Borda farmhouse;
- Section Y.T (coordinates: 38°5'12"N 1°51'14"W), on the eastern side of a small hill, 2.1 km SSE of Caravaca, and 300 m east of the Nueva Caravaca residential area;
- Section Y.P (coordinates: 38°5'40"N 1°49'12"W), on the northeastern slope of the Mai Valera Mountain, 2 km W of Cehegín, and 150 m S of the RM-15 highway;
- Section Y.N (coordinates: 38°4'16"N 1°48'48"W), at the southwestern end of the Peña Rubia Mountain, 2.7 km SW of Cehegín, near a site known as Puente de la Virgen;
- Sections M.CL (coordinates: 38°3'55"N 1°48'43"W) and Y.CL<sub>2</sub> (coordinates: 38°4'N 1°48'48"W), along the ravine named Cañada Luenga, 3.1 km SSW of Cehegín and, respectively, 1.3 and 1.1 km ESE of the Cañada Luenga farmhouse. These sections were formerly studied by ALLEMANN *et al.* (1975), COMPANY & TAVERA (1982), COMPANY (1987), and AGUADO *et al.* (2000);

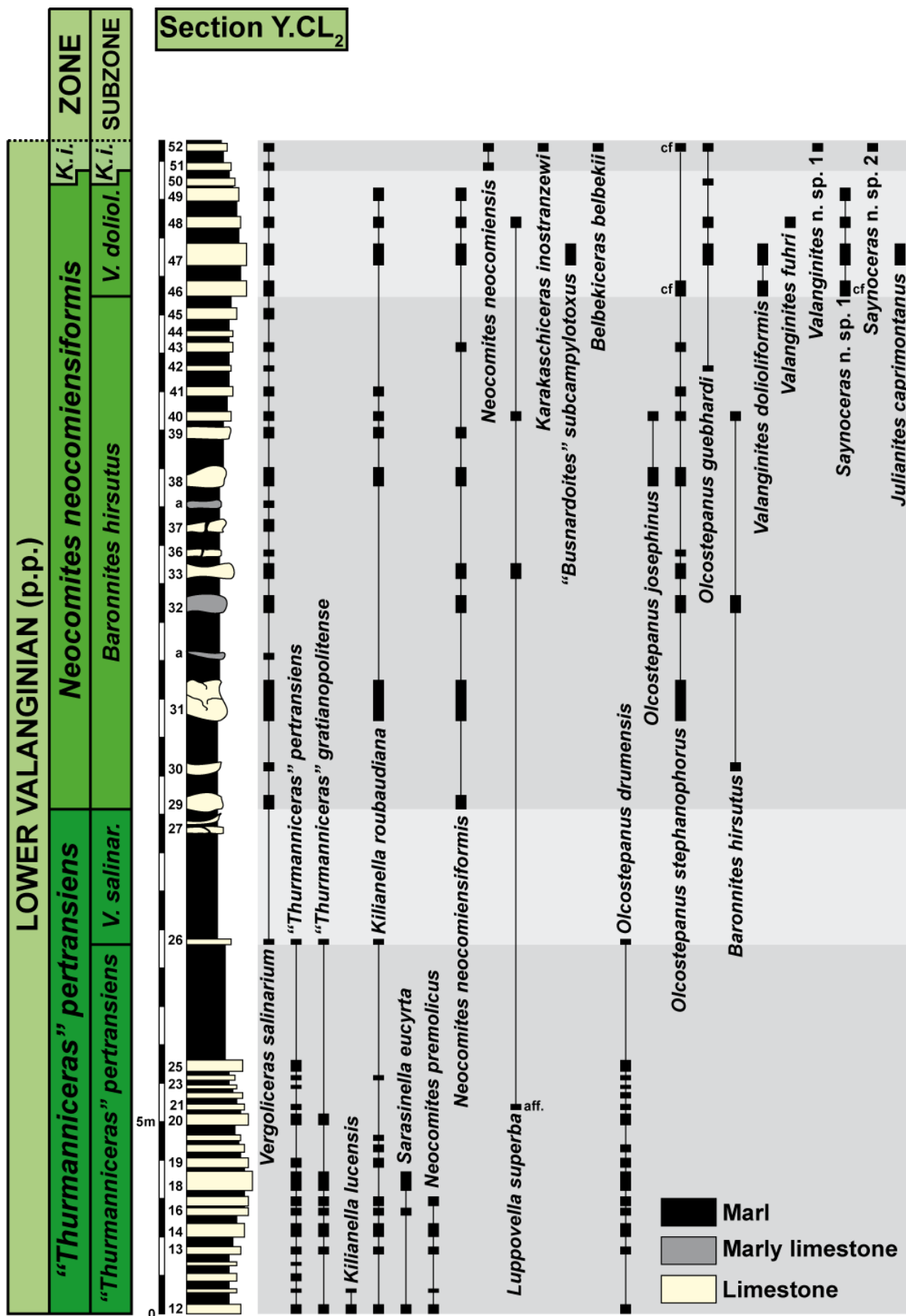


Figure 2: Distribution of the most significant ammonite species in section Y.CL<sub>2</sub>.

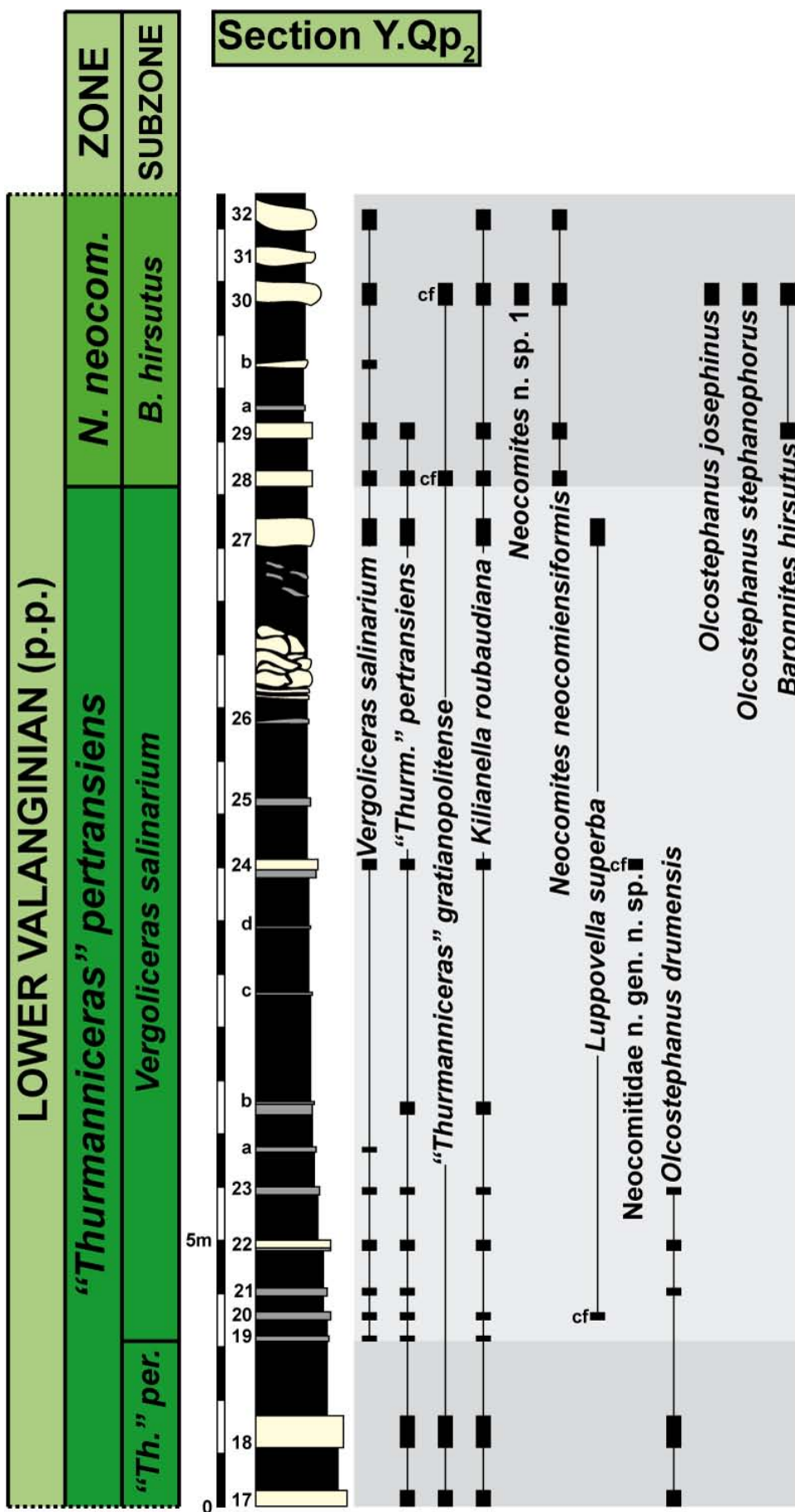


Figure 3: Distribution of the most significant ammonite species in section Y.Qp<sub>2</sub>.

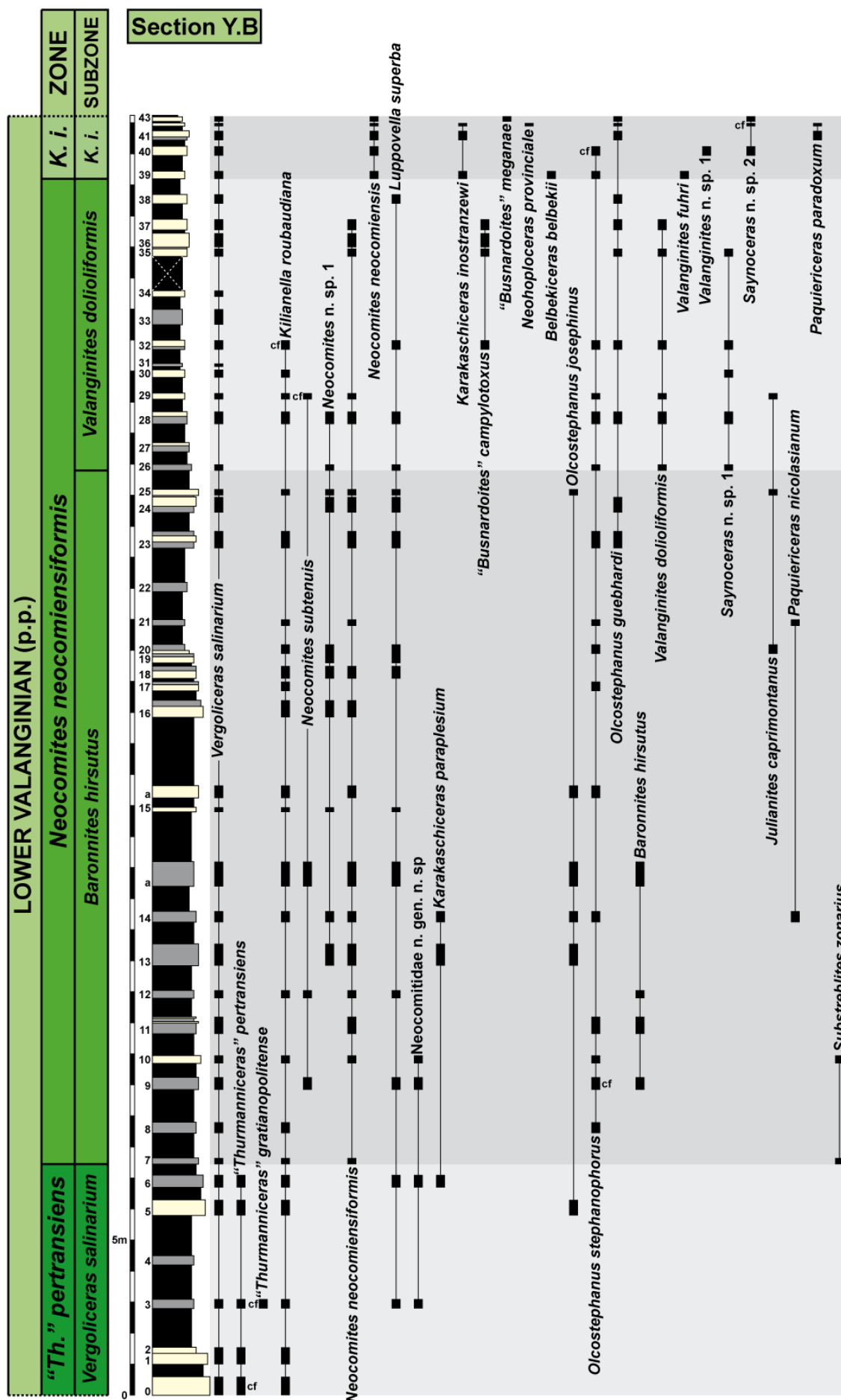


Figure 4: Distribution of the most significant ammonite species in section Y.B.

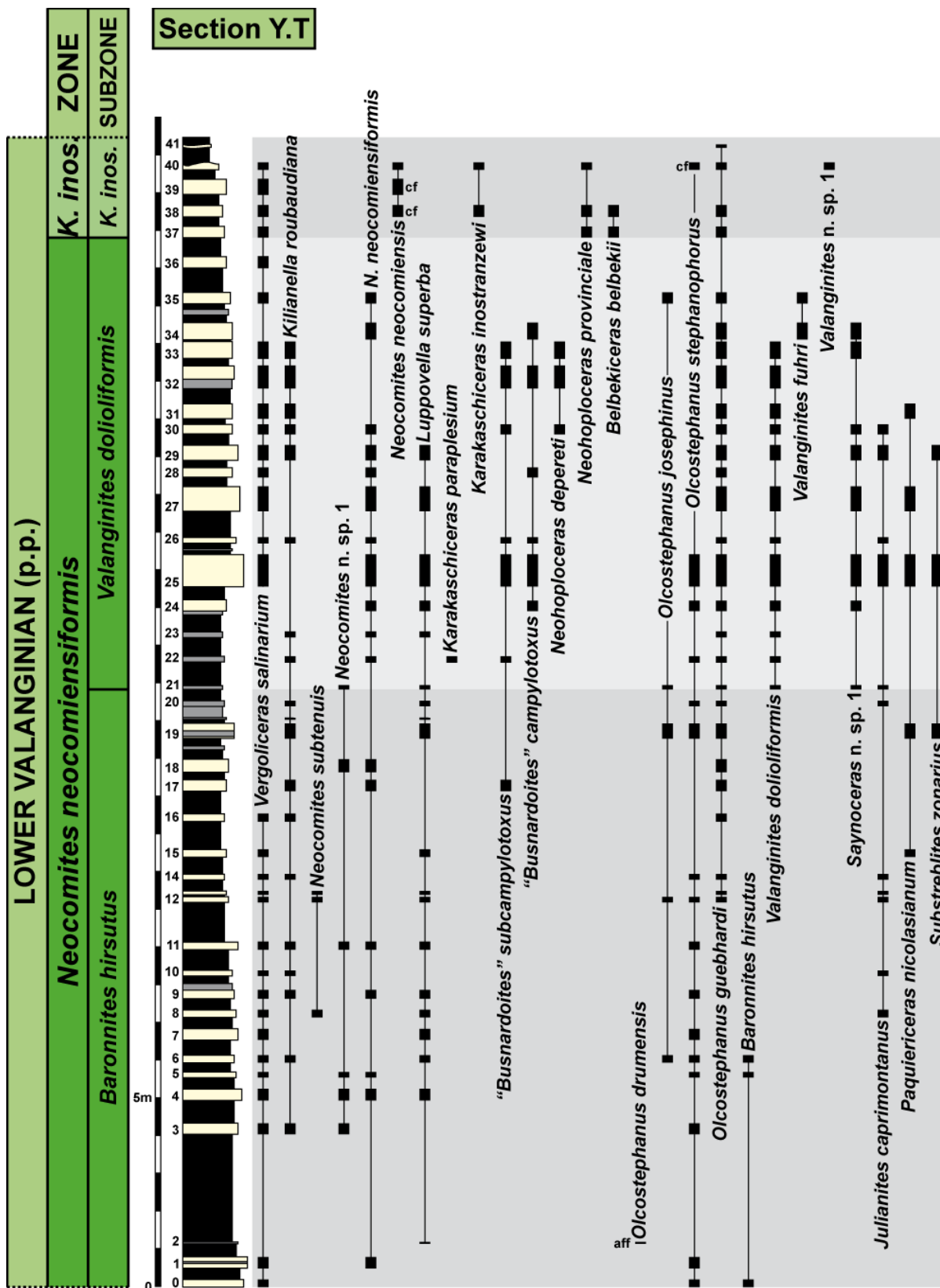


Figure 5: Distribution of the most significant ammonite species in section Y.T.

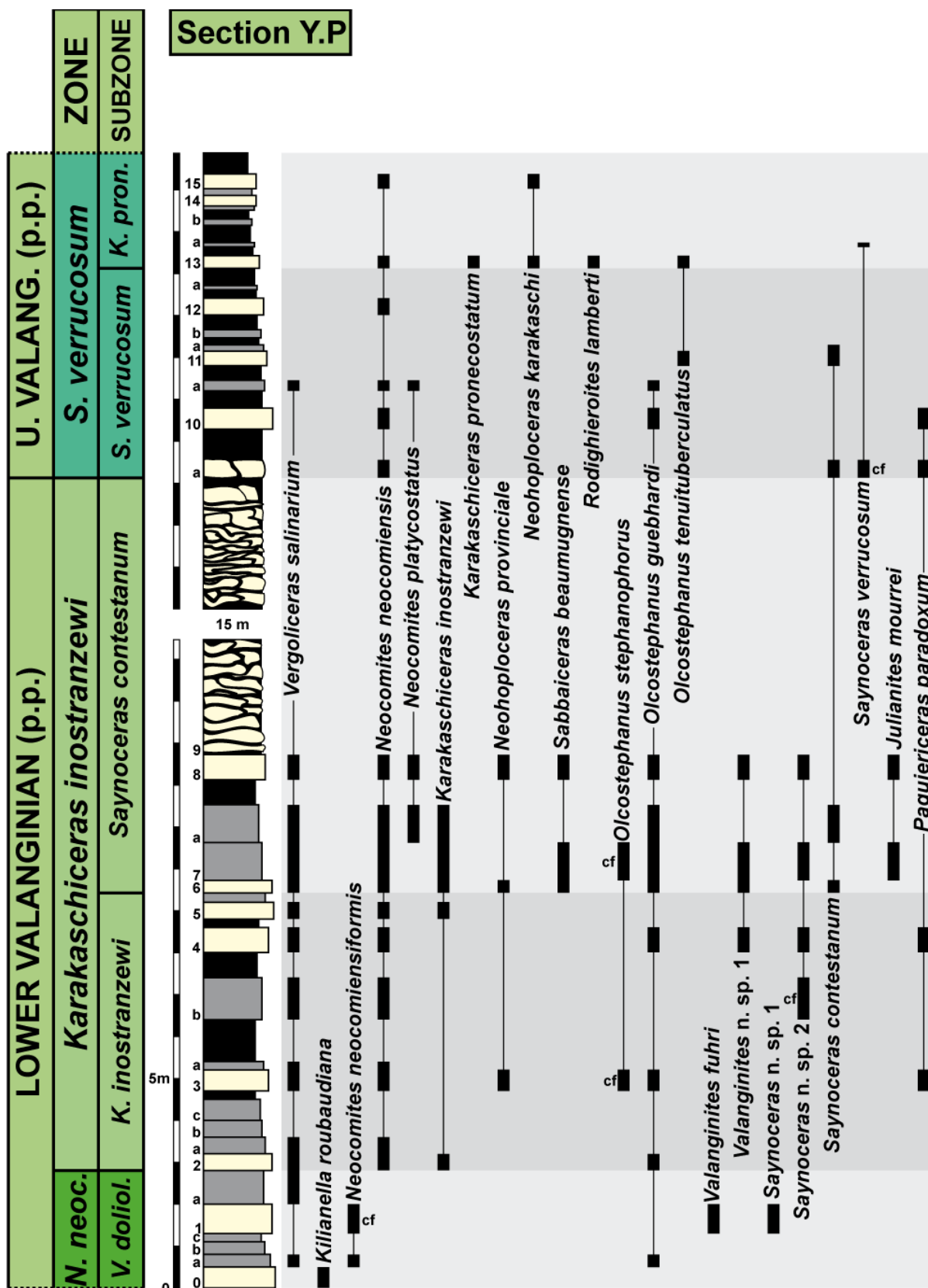


Figure 6: Distribution of the most significant ammonite species in section Y.P.

- Section Y.Qp<sub>2</sub> (coordinates: 38°3'51"N 1°48'24"W), along a small gully on the left bank of Cañada Luenga, 3.2 km SSW of Cehegín and 300 m SW of the Peña Rubia farmhouse. This section was reported upon by COMPANY (1987) and AGUADO *et al.* (2000);
- Sections Y.G (coordinates: 38°2'32"N 1°49'12"W) and Y.Q<sub>3</sub> (coordinates: 38°2'42"N 1°49'03"W), in the environs of the Barranco del Garranchal, on the north-western slope of Sierra de Quípar and,

respectively, 5.5 and 5.8 km SSW of Cehegin. These sections were previously analyzed by PAQUET (1969), COMPANY & TAVERA (1982), COMPANY (1987), and AGUADO *et al.* (2000);

- Section Y.V (coordinates: 38°9'36"N 1°41'8"W), at the northern foothills of the Cerro Cambrones Mountain, 12.5 km NE of Cehegin, and 450 m SW of the Fuente Farín farmhouse;
- Sections Y.J<sub>1</sub> (coordinates: 37°56'36"N 1°51'55"W), Y.J<sub>2</sub> (coordinates: 37°56'35"N 1°52'2"W), and Y.J<sub>3</sub> (coordinates: 37°56'34"N 1°52'11"W), on the northern slope of the Tornajo Mountain, 18 km S of Caravaca and 8.3 km NNW of La Paca. Some biostratigraphic data of this Valanginian outcrop were provided by JANSSEN (2003).

The sections Y.CL<sub>2</sub>, Y.Qp<sub>2</sub>, Y.B, Y.T, and Y.P have been taken as reference sections and are represented, respectively, in Figs. 2 - 6.

### 3. Material and methods

For the present study more than 10,000 ammonites were collected by bed-by-bed sampling from the interval studied in these sections. The fieldwork was carried out by the authors between 1980 and 2012. Most of the specimens are preserved as calcareous internal casts and come from the limestone beds, but some limonitized forms were found in the marly interbeds. Although many of the ammonites are flattened by compaction, their preservation is good enough to allow most of them to be identified to the species level. The assemblages are almost exclusively composed of Mediterranean taxa (Haploceratidae, Neocomitidae, Olcostephanidae, Oosterellidae, Bochianitidae, Phylloceratidae, and Lytoceratidae) and only very few specimens of the typically Boreal Platylenticeratinae were recorded.

The ammonite material is housed at the paleontological collections of the University of Granada. The specimens studied have been numbered following the usual method in these collections. Thus, each specimen is identified with a reference code composed of four elements separated by periods (e.g., Y.T.19.32). The first letter refers to the collector(s) (in this case, Y = COMPANY and TAVERA), the second and third elements indicate respectively the section (T) and the bed (19) where the specimen was collected. The last element is a series number (32 in the example) for each specimen coming from the same bed.

With a few exceptions, the systematic arrangement proposed by KLEIN (2005, 2006) and KLEIN *et al.* (2009) has been followed in this paper. Nevertheless, some generic names will be cited in quotation marks (namely "*Thurmanniceras*" and "*Busnardoites*") indicating that the assignment of the species to that genus is provisional and requires a thorough review. Furthermore, the interpretation of some problematic species (such as *Neocomites neocomiensiformis* or *Karakaschiceras biassalense*) will also be discussed below.

### 4. Ammonite succession and zonation

The analysis of the stratigraphic distribution of the species identified in the studied sections has enabled us to distinguish three interval biozones for the lower Valanginian in the Betic Cordillera (Figs. 7 - 8). These biozones are, from bottom to top, the "*Thurmanniceras*" *pertransiens* Zone, the *Neocomites neocomiensiformis* Zone, and the *Karakaschiceras inostranzewi* Zone, all of them defined at their base by the FAD of the index species. Each of these zones has been, in turn, subdivided into two subzones: a lower one whose base obviously coincides with that of the zone, and an upper one defined at their base by the FAD of its index-species.

#### "*THURMANNICERAS*" *PERTRANSIENS* ZONE

##### Definition and characterization

The lower boundary of this zone is defined by the FAD of "*Thurmanniceras*" *pertransiens*, which, as generally admitted, closely correlates with the FAD of *Calpionellites darderi* (ALLEMANN & REMANE, 1979; BLANC *et al.*, 1994; BULOT *et al.*, 1996; AGUADO *et al.*, 2000; PETROVA *et al.*, 2011; but see KENJO, 2014, for a different interpretation). It is well known that the FAD of *Calpionellites darderi* currently marks the base of the Valanginian stage (BULOT *et al.*, 1996; OGG & HINNOV, 2012).

The base of this zone coincides with a conspicuous faunal renewal. Species that characterized the uppermost Berriasian beds, like *Berriasella calisto*, *Fauriella boissieri*, *Tirnovella alpillensis*, "*Thurmanniceras*" *otopeta*, and *Erdenella paquieri*, disappear and are replaced by new forms such as "*Thurmanniceras*" *pertransiens*, "*Thurmanniceras*" *gratianopolitense* (SAYN), *Neocomites premolicus* SAYN, *Kilianella roubaudiana* (ORBIGNY), and *Sarasinella eucyrta* (SAYN). They are accompanied by several taxa inherited from lower levels such as *Kilianella lucensis* (SAYN), *Olcostephanus drumensis* KILIAN, the last representatives of the genera *Kilianiceras* and *Protancyloceras* and some species of broad stratigraphic distribution. The first specimens of *Luppovella superba* (SAYN) and *Vergolicerias salinarium* (UHLIG) are recorded in the upper part of this zone.



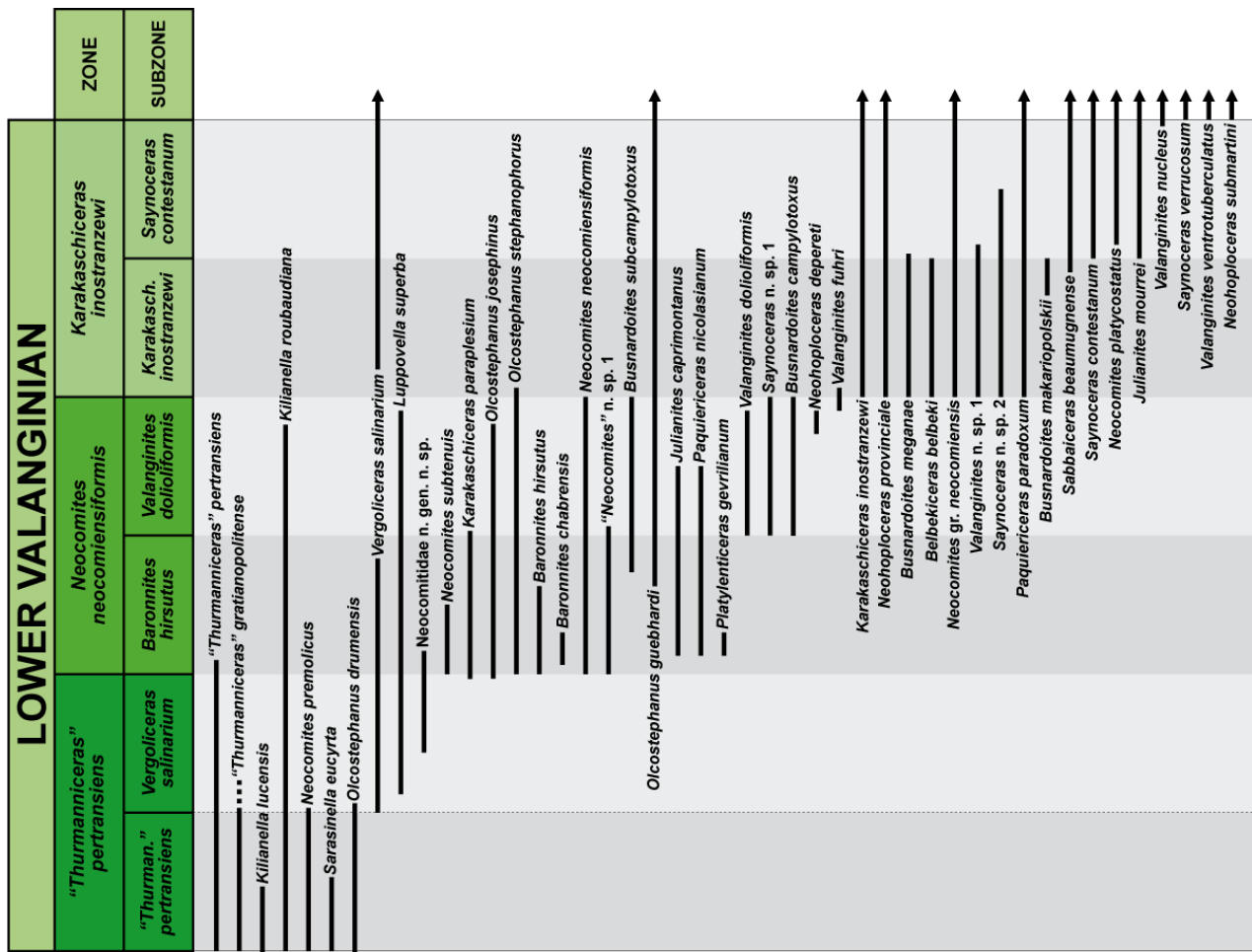


Figure 7: Stratigraphic range of the most significant ammonite species in the framework of the zonation proposed for the lower Valanginian in the Betic Cordillera.

Subdivision

The significant differences between the assemblages from the lower and upper parts of this zone allow it to be subdivided into two subzones: a lower "Thurmanniceras" pertransiens Subzone and an upper Vergoliceras salinarium Subzone. The "Th." pertransiens Subzone is characterized by an abundant and highly diverse fauna dominated by the index species. "Thurmanniceras" gratianopolitense, Kilianella roubaudiana, Neocomites premolicus and Olcostephanus drumensis are also frequent, while Kilianella lucensis and Sarasinella eucyrt are less common and seem to disappear in this interval.

The FAD of Vergoliceras salinarium, here considered a senior synonym of Vergoliceras extracornutum (CECCA), marks the base of the upper subzone. In contrast to the underlying subzone, the assemblage of this unit is little diversified and overwhelmingly dominated by the index species. "Thurmanniceras" pertransiens occurs, although scarcely, throughout this subzone, whereas "Thurmanniceras" gratianopolitense, Neocomites premolicus, and Olcostephanus drumensis become extinct in its lower part. The first, rare specimens of Luppovella superba have been recorded in this interval accompanied by other not yet described

neocomitid taxa.

Discussion

This unit was used for the first time by LE HÉGARAT & REMANE (1968) as a subzone of the classic Kilianella roubaudiana Zone, and elevated to the rank of zone by REMANE & THIEULOY (1973a, 1973b). In its original sense, it included the 'horizon à Kilianella aff. pexiptycha et Thurmannites aff. pertransiens' of MAZENOT (1939), equivalent to the current uppermost Berriasian "Thurmanniceras" otopeta Subzone. Some years later BUSNARDO & THIEULOY (1979a) modified the initial conception by separating the "Th." otopeta beds as an independent zone. Nevertheless, the first formal definition of the "Thurmanniceras" pertransiens Zone was given by COMPANY (1987), who drew its base at the FAD of the index species. It is in this sense that this unit has been employed by most subsequent authors.

"Thurmanniceras" pertransiens is a well-known species that has been reported throughout the Mediterranean region. It is frequent in basinal facies, especially in the lower part of the zone, but becomes rare or even absent in outer shelf paleoenvironments, where Neocomites premolicus and/or "Thurmanniceras" gratianopolitense largely dominate the assemblages.

This led ETTACHFINI (2004) to choose *N. premo-licus* as index of the basal zone of the Valanginian in the western High Atlas. This species has also been employed by KENJO (2014) to characterize the lower subzone of the "Thurmanniceras" *pertransiens* Zone in south-eastern France.

The FAD of *Vergoliceras salinarium* marks the base of the upper subzone of this zone, coinciding with the start of a marl-dominated interval in the lithologic succession. According to the data of AGUADO (1994) the FO of the calcareous nannofossil species *Calcicalathina oblongata*, takes place at the same level. KENJO (2014) has also recognized this subzone in southeastern France. The index species, present all over the Mediterranean area, has a broad stratigraphic range, reaching the upper Valanginian. It has also been occasionally reported from the Berriasian (PATRULIUS & AVRAM, 1976; BULOT & THIEULOY, 1995; KVANTALIANI, 1999; PSZCZÓŁKOWSKI & MYCZYŃSKI, 2004), but in the specimens figured by these authors the keel is only present on the adapertural part of the body chamber, suggesting that they belong to a different species.

#### **NEOCOMITES NEOCOMIENSIFORMIS ZONE**

##### Definition and characterization

The FAD of *Neocomites neocomiensiformis* (UHLIG) marks the base of this zone. A new sharp faunal change takes place around this level, with the extinction of "Thurmanniceras" *pertransiens* and the appearance, besides the index species, of *Baronnites hirsutus* (FALLOT & TERMIER), *Baronnites chabrensis* BULOT, COMPANY & THIEULOY, *Olcostephanus stephanophorus* (MATHERON), *Olcostephanus josephinus* (ORBIGNY), *Karakaschiceras paraplesium* (UHLIG), and *Neocomites subtenuis* SAYN. Other species, such as "Busnardoites" *subcampylotoxus* NIKOLOV, "Busnardoites" *campylotoxus* (UHLIG), *Neohoplloceras depereti* SAYN, *Olcostephanus guebhardi* KILIAN, *Valanginites dolioliformis* (ROCH), *Valanginites fuhri* (BULOT, COMPANY & THIEULOY), *Paquiericeras nicolasianum* (ORBIGNY), and *Julianites caprimontanus* (THIEULOY) have their first records in higher levels within this stratigraphic interval. In addition, some undescribed neocomitid and olcostephanid forms have also been recorded, and the holdover species *Kilianella roubaudiana*, *Luppovella superba* and *Vergoliceras salinarium* are still common in the *Neocomites neocomiensiformis* Zone.

##### Subdivision

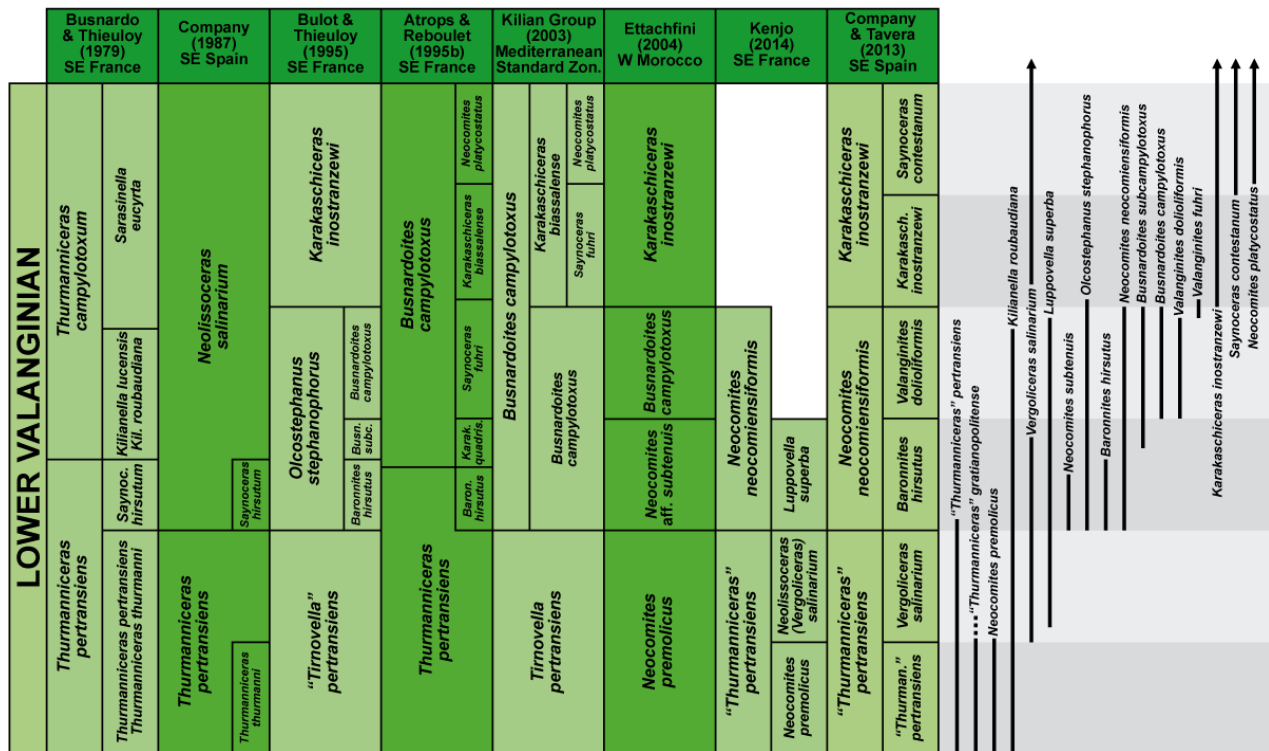
The *Neocomites neocomiensiformis* Zone can be subdivided into two subzones: the *Baronnites hirsutus* Subzone below, and the *Valanginites dolioliformis* Subzone above. The species *Baronnites hirsutus*, *Baronnites chabrensis* and *Neocomites subtenuis*, as well as a few specimens of *Platylenticeras gevrilianum* (ORBIGNY), have been found to be restricted to the lower part of the *B. hirsutus* Subzone. *Paquiericeras nicolasianum*, *Julianites caprimontanus*, "Busnardoites" *subcampylotoxus*, and *Olcostephanus guebhardi* have been first recorded in higher levels of this subzone.

The lower boundary of the *Valanginites dolioliformis* Subzone is identified by the FAD of the index species, accompanied by "Busnardoites" *campylotoxus* and *Saynoceras* n. sp. 1. Some specimens of *Neohoplloceras depereti* have been recorded from the upper part of this stratigraphic interval, whereas *Valanginites fuhri* characterizes a distinctive interval at its top and the base of the overlying *Karakaschiceras inostranzewi* Zone. *Kilianella roubaudiana*, *Luppovella superba*, and most of the species that had appeared in the *Neocomites neocomiensiformis* Zone become extinct throughout this subzone.

##### Discussion

COMPANY & TAVERA (2013a, b) suggested the use of *Neocomites neocomiensiformis* as index species for the middle zone of the lower Valanginian. Their proposal was accepted by the Kilian Group and incorporated into the current version of the standard Mediterranean zonation (REBOULET *et al.*, 2014).

The species *Neocomites neocomiensiformis* has usually been misinterpreted (see synonymy list in KLEIN, 2005). Indeed, most authors have given this name to several late Valanginian and early Hauterivian forms. However, as pointed out by REBOULET (1996) and BUSNARDO *et al.* (2003), the ammonite assemblage described by UHLIG (1902) and revised by VAŠÍČEK (1975) from the Upper Teschen Shales clearly corresponds to the early Valanginian. Despite it, this species has rarely been properly reported from this age (AVRAM, 1995, Pl. 1, fig. 14; FŐZY *et al.*, 2010, Fig. 5A, 5B; VAŠÍČEK, 2010, Pl. 4, fig. 4; KENJO, 2014, Pl. 1, fig. 5, Pl. 2, figs. 1-3), and its representatives have been erroneously attributed to "Busnardoites" *campylotoxus* (COMPANY, 1987, Pl. 11, figs. 12-13; REBOULET, 1996, Pl. 3, figs. 1-2; ETTACHFINI, 2004, Pl. 16, fig. 8), to "Busnardoites" *roberti* (BULOT, 1995, Pl. 11, figs. 1-2), to *Neocomites neocomiensis* (SAYN, 1901, Pl. 3, fig. 6; ARNAUD *et al.*, 1981, Pl. 2, fig. 2), or to "Thurmanniceras" *pertransiens* (BUJTOR, 1993, Pl. 8, figs. D-E; FARAONI *et al.*, 1997, Pl. 3, fig. 11).



**Figure 8:** Correlation of the zonation proposed for the lower Valanginian in the Betic Cordillera with other zonal schemes.

This misinterpretation of *N. neocomiensiformis* underlies the widespread use of "*Busnardoites*" *campylotoxus* to characterize the entire middle and upper parts of the lower Valanginian (COTILLON, 1971; THIEULY, 1973; BUSNARDO & THIEULY, 1979a, 1979b; HOEDEMAEKER, 1982; HOEDEMAEKER & BULOT, 1990; ATROPS & REBOULET, 1995a; HOEDEMAEKER *et al.*, 2003). By contrast, several authors (BULOT, 1995; BULOT & THIEULY, 1995; WIPPICH, 2001, 2003; ETTACHFINI, 2004) have emphasized that true "*B.*" *campylotoxus* has a much shorter stratigraphic range, limited to the interval corresponding to our *Valanginites dolioliformis* Subzone. Our observations (see above) confirm this last point of view and, hence, we consider *N. neocomiensiformis* to be a more appropriate index for the middle part of the lower Valanginian. Its total range entirely covers this stratigraphic interval, and its known paleogeographic distribution spreads over a large part of the Mediterranean region, from Morocco to Romania (see references above).

The *Neocomites neocomiensiformis* Zone would be equivalent to the *Olcostephanus stephanophorus* Zone proposed by BULOT (1995) for the middle part of the lower Valanginian in SE France, and originally conceived as the interval between the FAD of *O. stephanophorus*, which coincides with the FAD of *N. neocomiensiformis*, and the base of the *Karakaschiceras inostranzewi* Zone. There are, however, two main reasons that have led us to choose *N. neocomiensiformis*, instead of maintaining *O. stephanophorus*, as index for this zone. First, *O. stephanophorus* has a more restricted geographic distribution, being known

only from Spain, France, and Hungary (KLEIN, 2005; FÖZY *et al.*, 2010), since the specimen from Pakistan figured by FATMI & RAWSON (1993, Fig. 3n, 3o) does not appear to belong to this species. Second, the markedly cadicone morphology of this species favors a strong dorsoventral crushing by diagenetic compaction in marly sediments (dominant in our sections), which considerably complicates its identification.

The *Baronnites hirsutus* Subzone was introduced by BUSNARDO & THIEULY (1979a, 1979b), and subsequently used as a more or less formal biohorizon by COMPANY (1987), BULOT (1995), BULOT & THIEULY (1995), and REBOULET (1996). For all these authors, the extension of this unit nearly coincided with the total range of the index species. As defined in the present paper, however, it occupies a broader stratigraphic extension corresponding to both the *Baronnites hirsutus* and the *Busnardoites subcampylotoxus* Horizons of the zonal scheme proposed by BULOT (1995). In our sections, the first specimens of "*Busnardoites*" *subcampylotoxus* have, in fact, been recorded shortly above the extinction of *B. hirsutus*. However, "*B.*" *subcampylotoxus* is a rare species, especially in the lower part of its stratigraphic range, as most of the specimens collected by us come from the *Valanginites dolioliformis* Subzone. For his part, BULOT (1995) mentioned the presence of this species in a few particular beds in two platform margin sections (Carajuan and Preynes), but reported only some uncertain juvenile specimens from the Vocontian Basin sections. As can be seen, the records of "*B.*" *subcampylotoxus* are scarce and scattered, hindering

the accurate estimation of its real stratigraphic range, and therefore it does not seem, for the moment at least, advisable to use this species to characterize any stratigraphic unit.

ATROPS & REBOULET (1995a) defined a *Karakaschiceras quadristrangulatum* Horizon at the base of their *Busnardoites campylotoxus* Zone, and overlying the *Baronnites hirsutus* Horizon. In our opinion, the specimens attributed to *K. quadristrangulatum* by REBOULET (1996, Pl. 1, figs. 11-12) are typical morphotypes of "*Busnardoites*" *subcampylotoxus*. Consequently, the *K. quadristrangulatum* Horizon would be equivalent to the *Busnardoites subcampylotoxus* Horizon of BULOT (1995) and to the upper part of our *Baronnites hirsutus* Subzone.

The species *Baronnites hirsutus* has hitherto been found only in France and Spain (see references in KLEIN, 2005). Nevertheless, the presence of *Neocomites subtenuis* in the *Baronnites hirsutus* Subzone allows the direct correlation of this unit with the *Neocomites* aff. *subtenuis* Zone of the zonal scheme established by ETTACHFINI (2004) in Morocco. The *Baronnites hirsutus* Subzone would also equate with the *Luppovella superba* Subzone proposed by KENJO (2014) for the lower part of the *Neocomites neocomiensiformis* Zone. Although *L. superba* has a broader geographic distribution than *B. hirsutus*, we consider that the choice of *L. superba* to characterize this stratigraphic interval is not appropriate, since this species is rare in basin environments (KENJO himself only reported four fragmentary specimens from the Vergol section) and, moreover, it is already present in the upper part of the "*Thurmanniceras*" *pertransiens* Zone.

The *Valanginites dolioliformis* Subzone was erected by COMPANY & TAVERA (2013a, b). We consider *Valanginites paludensis* THIEULOY to be a junior synonym of *V. dolioliformis*. This species has been reported from Morocco, Spain and France. Our *V. dolioliformis* Subzone nearly equates with the *Busnardoites campylotoxus* Horizon as defined by BULOT (1995) (and later used by BULOT & THIEULOY, 1995; WIPPICH, 2001, 2003, and ETTACHFINI, 2004). In fact, the FAD of true "*B.*" *campylotoxus*, the event employed by BULOT (1995) to draw the base of his *B. campylotoxus* Horizon, practically coincides with that of *V. dolioliformis* in our sections (see also BULOT, 1995; WIPPICH, 2001, and ETTACHFINI, 2004). However, we prefer to use *V. dolioliformis* rather than "*B.*" *campylotoxus* as index for this unit because *V. dolioliformis* is much more frequent in our region, and because "*B.*" *campylotoxus* has been previously used as index species for several biostratigraphic units with a quite different sense, which is explicitly against the recommendations of the International Stratigraphic Guide.

ATROPS & REBOULET (1995a) distinguished, in the middle part of their *Busnardoites campylotoxus* Zone, a *Saynoceras fuhri* Horizon, the

extent of which would coincide with the total range of the index species. Nevertheless, as pointed out by REBOULET (1996), they included in *S. fuhri* not only the adult calcareous specimens that matched the original description of the species and that came from two beds situated just below the 'Plaquettes Rousses' in the La Charce section, but also a handful of strongly bituberculate, pyritized nuclei collected in the Vergol section. Thanks to the kindness of our colleague Stéphane REBOULET, we have had the opportunity to examine resin casts of some of these bituberculate nuclei. In fact, they are quite different from the inner stages of true *Valanginites fuhri*, which only have umbilical tubercles and fasciculate ribs (hence justifying the transfer of this last species to the genus *Valanginites*). On the contrary, they are identical to the forms we have here called *Saynoceras* n. sp. 1, an undescribed species, similar to *Saynoceras verrucosum* (ORBIGNY), that occurs throughout the *V. dolioliformis* Subzone (see above and Fig. 7). Therefore, the *S. fuhri* Horizon of ATROPS & REBOULET (1995a) would correlate almost exactly with our *V. dolioliformis* Subzone.

#### **KARAKASCHICERAS INOSTRANZEVI ZONE**

##### Definition and characterization

This zone occupies the stratigraphic interval between the FAD of *Karakaschiceras inostranzewi* (KARAKASCH) and the FAD of *Saynoceras verrucosum* (ORBIGNY). A distinct turnover in the ammonite fauna also occurs around the base of this zone. As mentioned above, most of the species present in the underlying *Neocomites neocomiensiformis* Zone disappear in its upper part, and only a few survive in the *K. inostranzewi* Zone. Among them, *Valanginites fuhri* becomes extinct at the very base of the zone, and *Olcostephanus stephanophorus*, somewhat higher. By contrast, *Olcostephanus guebhardi* and *Vergolicerias salinarium* are still frequent throughout this zone and pass into the upper Valanginian.

Together with the zonal index, other species that appear at the base of the *Karakaschiceras inostranzewi* Zone are *Neocomites* gr. *neocomiensis* (ORBIGNY)-*teschenensis* (UHLIG), *Neohoplaceras provinciale* (SAYN), "*Busnardoites*" *meganae* BULOT, *Belbekiceras belbekii* BARABOSHKIN, *Paquiericeras paradoxum* SAYN, *Valanginites* n. sp. 1, and *Saynoceras* n. sp. 2. Furthermore, *Neocomites platycostatus* SAYN, *Sabbaiceras beaumugnese* (SAYN), "*Busnardoites*" *makariopolskii* NIKOLOV, *Julianites mourrei* (VERMEULEN), and *Saynoceras contestanum* COMPANY have been recorded in higher levels within this zone.

BULOT (1995) and BULOT *et al.* (1995) mentioned the co-occurrence of "*Busnardoites*" *campylotoxus* and *Valanginites paludensis* (= *V. dolioliformis*) with *Karakaschiceras inostranzewi* at the top of formation 7 in some North-Provençal Platform sections. However, we have never found "*B.*" *campylotoxus* or *V. dolioliformis*.

*lififormis* in the *K. inostranzewi* Zone. In Morocco, WIPPICH (2001, 2003) and ETTACHFINI (2004) did not report that association either, except in some strongly condensed sections (ETTACHFINI, 2004, Figs. 20-21). It can be assumed, therefore, that a certain degree of condensation must affect the so called 'bancs à *Karakaschiceras*' in the Arc of Castellane.

#### Subdivision

Two subzones can be distinguished within this zone. The lower *Karakaschiceras inostranzewi* Subzone is characterized by the association of the index species with "*Busnardoites*" *meganae* and *Belbekiceras belbekii*. A few specimens attributable to "*Busnardoites*" *makariopolskii* have also been recorded in the upper part of this unit.

No species has been found to be restricted to the upper *Saynoceras contestanum* Subzone. The index species, together with *Neocomites platycostatus*, *Sabbaiceras beaumugnense* and *Julianites mourrei* appear at the base of this subzone and range into the upper Valanginian. *Valanginites* n. sp. 1 and *Saynoceras* n. sp. 2, which are already present in the previous subzone, have their last records in this interval.

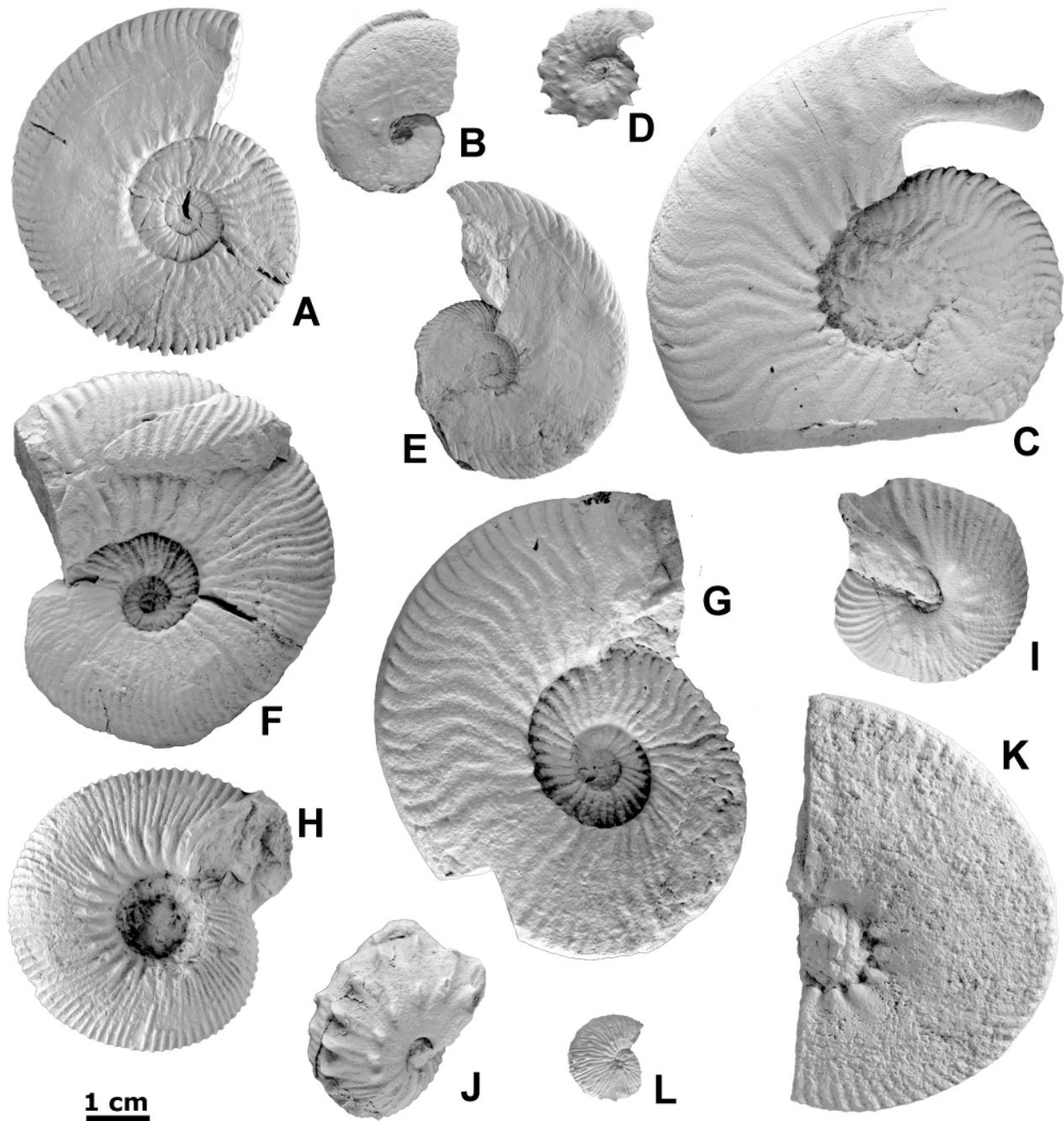
#### Discussion

The *Karakaschiceras inostranzewi* Zone was introduced by BULOT (1995) to replace some previous informally used biostratigraphic units, such as the *Sarasinella eucyrta* Subzone of BUSNARDO & THIEULY (1979b) and the *Karakaschiceras biassalense* Horizon of BULOT *et al.* (1993) and BULOT & THIEULY (1993). Although BULOT (1995) convincingly justified the choice of *K. inostranzewi* as index of this unit, ATROPS & REBOULET (1995a) had already retained *K. biassalense* to characterize the uppermost unit of their lower Valanginian biostratigraphic scheme. This option was subsequently followed by WIPPICH (2001, 2003) and ETTACHFINI (2004), and integrated in the standard zonation proposed by HOEDEMAEKER *et al.* (2003). We agree with BULOT (1995) in considering *K. biassalense* unsuitable to characterize this stratigraphic interval. Actually, we have collected no specimen strictly attributable to *K. biassalense* from these beds. Most of our specimens clearly belong to *K. inostranzewi*, and even the more finely ribbed forms, which superficially resemble *K. biassalense*, do not show the very high whorl expansion rate that is characteristic of this species. The same can be said of most of the specimens coming from this level and assigned in the literature to *K. biassalense* (e.g., BARABOSHKIN & MIKHAILOVA, 2004, Pl. 1, fig. 4; WIPPICH, 2001, Pl. 27, figs. 5-7, Pl. 28, fig. 1; ETTACHFINI, 2004, Pl. 32, figs. 1-5). On the contrary, we have collected specimens very similar to the holotype of *K. biassalense* in the upper part of the *Saynoceras verrucosum* Zone (see also the specimens coming from the same interval figured as *K. pronecostatum* by BULOT, 1995, Pl. 13, figs. 1-

5). In addition, it should be noted that, whereas the holotype of *K. inostranzewi* was found in Mangush (currently Prokhladnoe), that of *K. biassalense* comes from Biassala (currently Verkhorechie), the same locality as the holotype of *Neohoploceras karakaschi* (UHLIG), a species that we have recorded precisely in the upper part of the *S. verrucosum* Zone. We can conclude that the finely ribbed specimens of *Karakaschiceras* found in the uppermost part of the lower Valanginian do not belong to *K. biassalense*, but they would rather be extreme morphotypes of *K. inostranzewi*. Therefore, *K. biassalense* cannot be kept as index species for this interval, and has to be replaced by *K. inostranzewi*. This proposal was accepted by the KILIAN Group and integrated in the last version of the standard Mediterranean zonation (REBOULET *et al.*, 2014).

We consider our *Karakaschiceras inostranzewi* Zone to be equivalent to the *Karakaschiceras biassalense* Subzone of HOEDEMAEKER *et al.* (2003). REBOULET *et al.* (2014) pointed out that some confusion exists about the conception of this last unit, which could be understood to be defined at its base by the appearance of *K. biassalense* (actually *K. inostranzewi*) or, alternatively, by the appearance of *Valanginites fuhri* (species that was selected by HOEDEMAEKER *et al.*, 2003, as index of the lower horizon of this subzone). In any case, the difference would have little significance since, as stated above, the FO of *V. fuhri* only very slightly predates that of *K. inostranzewi*. Nevertheless, it has to be stressed that the *Saynoceras fuhri* Horizon of HOEDEMAEKER *et al.* (2003) is not equivalent at all to the *Saynoceras fuhri* Horizon of ATROPS & REBOULET (1995a) since, whereas the latter nearly correlates with our *Valanginites dolio-lififormis* Subzone (see discussion above), the former would approximately equate our *K. inostranzewi* Subzone.

The *Saynoceras contestanum* Subzone proposed in this paper would correlate in turn with the *Eristavites platycostatus* Horizon of ATROPS & REBOULET (1995a) and HOEDEMAEKER *et al.* (2003). Two reasons lead us to use *S. contestanum* rather than *Neocomites platycostatus* as index for this stratigraphic interval. Firstly, we have serious doubts on the taxonomic status of *N. platycostatus*. In our opinion, most of the specimens assigned to this taxon in the literature could be no more than extreme morphotypes of *Neocomites* gr. *neocomiensis-teschenensis* (see COMPANY, 1987; ETTACHFINI, 2004). Secondly, these morphotypes, which become relatively common in the *Saynoceras verrucosum* Zone, are still extremely rare in the uppermost lower Valanginian beds in our sections. Something similar seems to happen elsewhere, as some authors have found these forms only in the *S. verrucosum* Zone (BULOT, 1995; WIPPICH, 2001, 2003; ETTACHFINI, 2004).



**Figure 9:** A: "*Thurmanniceras*" *pertransiens* (Y.CL<sub>2</sub>.26.1, section Y.CL<sub>2</sub>, "*Th.*" *pertransiens* Zone, *V. salinarium* Subzone). B: *Vergolliceras salinarium* (Y.T.19.32, section Y.T, *N. neocomiensiformis* Zone, *B. hirsutus* Subzone). C: *Neocomites neocomiensiformis* (Y.V.R'.1, section Y.V, *N. neocomiensiformis* Zone, *V. dolioliformis* Subzone). D: *Baronnites hirsutus* (Y.N.5.19, section Y.N, *N. neocomiensiformis* Zone, *B. hirsutus* Subzone). E: *Neocomites subtenuis* (Y.T.8.2, section Y.T, *N. neocomiensiformis* Zone, *B. hirsutus* Subzone). F: "*Busnardoites*" *subcampylotoxus* (Y.V.5.38, section Y.V, *N. neocomiensiformis* Zone, *V. dolioliformis* Subzone). G: "*Busnardoites*" *campylotoxus* (Y.V.6.14, section Y.V, *N. neocomiensiformis* Zone, *V. dolioliformis* Subzone). H: *Olcostephanus guebhardi* (Y.V.5.6, section Y.V, *N. neocomiensiformis* Zone, *V. dolioliformis* Subzone). I: *Valanginites dolioliformis* (Y.V.6.47, section Y.V, *N. neocomiensiformis* Zone, *V. dolioliformis* Subzone). J: *Valanginites fuhri* (Y.V.R'.17, section Y.V, *N. neocomiensiformis* Zone, *V. dolioliformis* Subzone). K: *Karakaschiceras inostranzewi* (Y.V.12.75, section Y.V, *K. inostranzewi* Zone, *K. inostranzewi* Subzone). L: *Saynoceras contestanum* (Y.P.6.45, section Y.P, *K. inostranzewi* Zone, *S. contestanum* Subzone).

## 5. Conclusions

The analysis of the vertical distribution of more than 10000 specimens from 16 sections in the Subbetic Domain has provided an accurate record of the succession of ammonite bioevents occurring during the early Valanginian in the

Mediterranean region. We have identified in this interval three significant faunal turnovers that allow us to distinguish the three biozones, each of them with two subzones, composing the new zonal scheme proposed here.

The "*Thurmanniceras*" *pertransiens* Zone is maintained as defined by COMPANY (1987). At

the lower boundary of this zone, typical upper Berriasian species are replaced by new forms such as "*Thurmanniceras*" *pertransiens*, *Kilianella roubaudiana*, *Neocomites premolicus* and *Sarasinella eucyrta*. The FAD of *Vergoliceras salinarium* defines the boundary between the two subzones of this zone.

The *N. neocomiensiformis* Zone is featured by a strong diversification of the olcostephanids (with the appearance of the genera *Baronnites*, *Saynoceras* and *Valanginites*, together with several new species of *Olcostephanus*), the emergence of the first oosterellids (genera *Paquiericeras* and *Julianites*) and a nearly complete renewal of the neocomitid stock.

Further changes, mainly at the species level, take place at the base of the *Karakaschiceras inostranzewi* Zone, with the disappearance of most of the species present in lower stratigraphic levels and their replacement by new taxa, such as *Karakaschiceras inostranzewi*, *Neohoploceras provinciale*, *Neocomites* gr. *Neocomiensis-teschenensis*, *Neocomites platycostatus*, *Sabbaiceras beaumugnense*, *Paquiericeras paradoxum* and others that already herald the late Valanginian assemblages.

Although the zonation proposed is intended only for the Betic Cordillera, the assemblages characterizing each of the units can be recognized throughout the Mediterranean Region.

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