

## New biostratigraphic data on an Upper Hauterivian–Upper Barremian ammonite assemblage from the Dolomites (Southern Alps, Italy)

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### ABSTRACT

A biostratigraphic subdivision, based on ammonites, is proposed for the Lower Cretaceous pelagic to hemipelagic succession of the Puez area (Southern Alps, Italy). Abundant ammonites enable recognition of recently established Mediterranean ammonite zones from the upper Hauterivian *Balearites balearis* Zone (*Crioceratites krenkeli* Subzone) to the upper Barremian *Gerhardtia sartousiana* Zone (*Gerhardtia sartousiana* Subzone). Ammonites are restricted to the lowermost part of the Puez Formation, the Puez Limestone Member (ca. 50 m; marly limestones; Hauterivian–Barremian). Numerous ammonite specimens are documented for the first time from the Southern Alps (e.g., Dolomites). Ammonite abundances are clearly linked to sea-level changes from Late Hauterivian to mid Late Barremian times. Abundance and diversity peaks occur during phases of high sea-level pulses and the corresponding maximum flooding surfaces (*P. mortilleti*/*P. picteti* and *G. sartousiana* zones). The ammonite composition of the Puez Formation sheds light on the Early Cretaceous palaeobiogeography of the Dolomites. It also highlights the palaeoenvironmental evolution of basins and plateaus and provides insights into the faunal composition and distribution within the investigated interval. The intermittent palaeogeographic situation of the Puez locality during the Early Cretaceous serves as a key for understanding Mediterranean ammonite distribution.

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### 1. Introduction

Lower Cretaceous pelagic to hemipelagic sediments cover relatively small, restricted areas in the higher Dolomites (Southern Alps). In the Southern Alps, cephalopod-bearing deposits are mainly recorded in two different facies (Lukeneder, 2010), the calcareous limestones of the Biancone Formation (= Maiolica Formation in the Appenines; see Weissert, 1981) and the more marly Puez Formation (Lukeneder, 2010).

The stratigraphy of the Lower Cretaceous Puez area is based on microfossils, nannofossils and ammonites (Lukeneder and Aspmair, 2006; Lukeneder, 2010), but a detailed ammonite biostratigraphy and zonation was still missing because ammonites have not been collected bed-by-bed over the last 150 years. This paper presents the results of the systematic ammonite sampling at the Puez section and concludes with a detailed ammonite zonation of that locality. The Mediterranean character of the ammonite fauna is comparable to numerous Lower Cretaceous east-central European (Czech Republic, France, Hungary, Slovakia, Spain), eastern Europe (Bulgaria, Romania) and African (Algeria, Morocco) localities.

The main goal of this paper is to present a valid definition of the Lower Cretaceous ammonite zonation within the Dolomites for the Puez Formation. The Hauterivian and Barremian ammonite faunas from the Puez key-section can be correlated with the most recent ammonite standard zonation for the Lower Cretaceous (Reboullet et al., 2009). Future work will involve palaeomagnetic, isotope and geochemical analyses along with a precise biostratigraphy based on macro-, micro- and nannofossils.

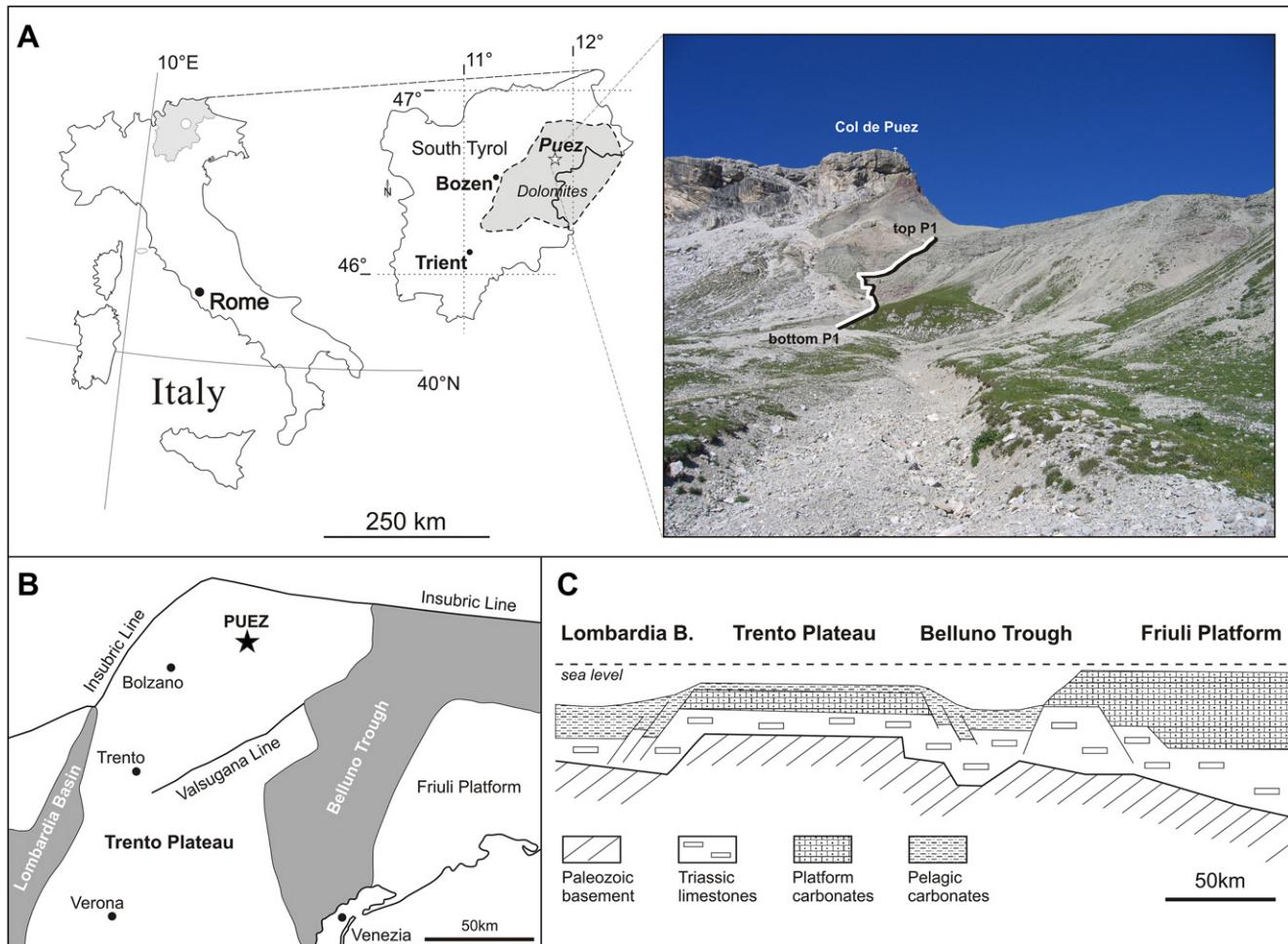
### 2. Geological setting and section studied

The outcrop is situated on the Puez-Odle-Gardenaccia Plateau in the Dolomites (maps Trentino–Alto Adige; South Tyrol; Lukeneder, 2010). The exact position is about 30 km northeast of Bozen (Fig. 1A; E 011°49'15", N 46°35'30"; Lukeneder, 2010). The grey, green to red succession of the Puez Formation is located on the southern side of the Piz de Puez.

#### 2.1. Geological setting and palaeogeography

The studied sites are outcrops on the Puez-Gardenaccia Plateau (Lukeneder, 2010). They are located within the area of the

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**Fig. 1.** Locality map of the Lower Cretaceous Puez area. A, Puez area (white star) and indicated outcrop position (P1) within the Dolomites (South Tyrol, Italy). B, position of the Puez locality on the Trento Plateau. C, east–west transect of the Lower Cretaceous plateau–basinal sequence of the South Alpine region.

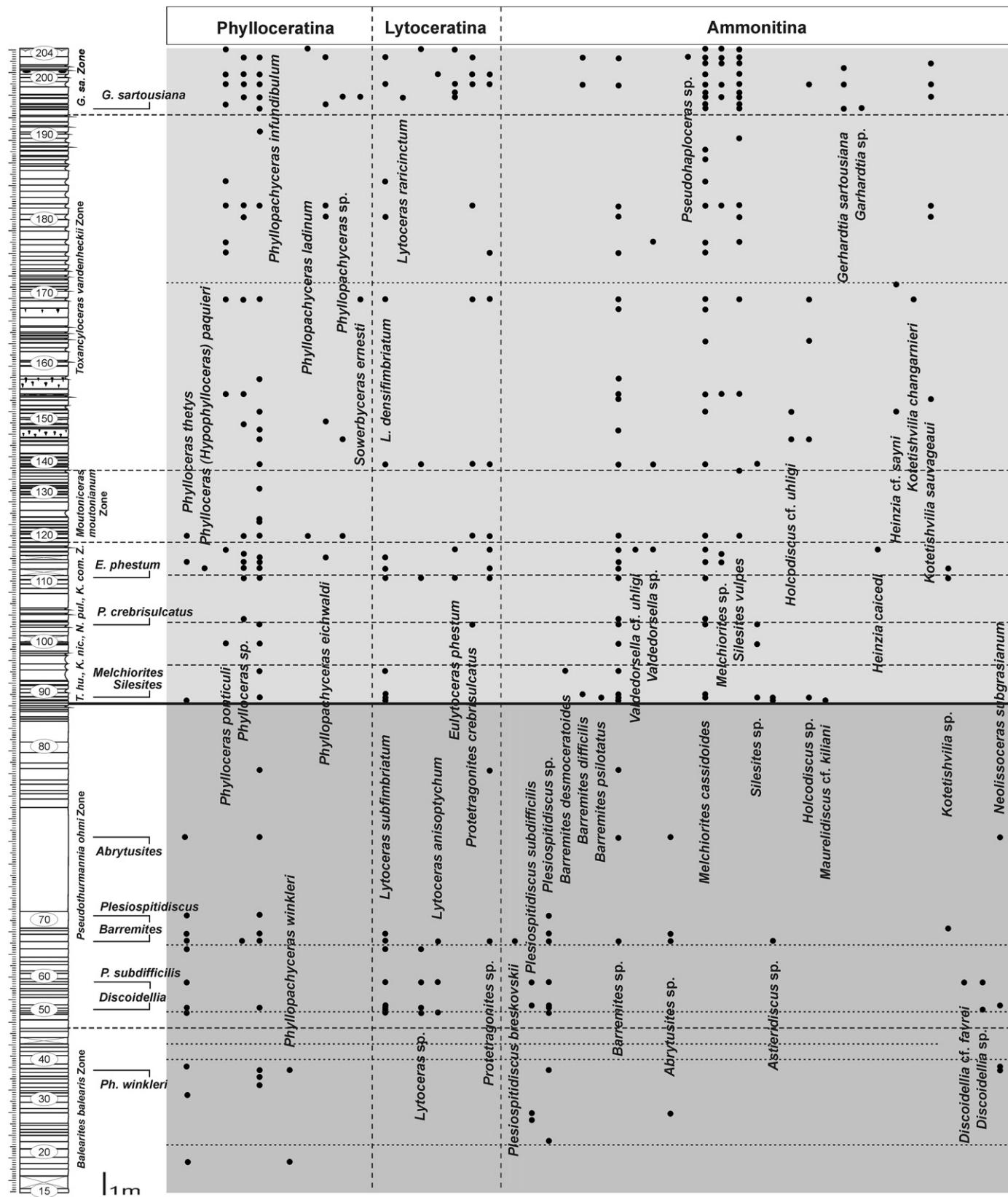
Puez-Odle-Geisler natural park in the northern part of the Dolomites. The Dolomites (Permian–Cretaceous) are an internal part of the Southern Alps; they are a northern Italian chain that emerged during the deformation of the passive continental margin of the Adriatic (= Apulian Plate) of the South Alpine–Apennine Block (Dercourt et al., 1993; Fourcade et al., 1993; Bossellini, 1998; Cecca, 1998; Stampfli and Mosar, 1999; Scotese, 2001; Stampfli et al., 2002; Bossellini et al., 2003). This block was limited by the Penninic Ocean (= Alpine Tethys) to the north and the Vardar Ocean to the southeast (Scotese, 2001; Stampfli et al., 2002). The Puez Formation comprises three members from bottom to top: Puez Limestone, Puez Redbed and Puez Marl (Lukeneder, 2010). The succession shows a transition from limestones and marly limestones into a marl–marly limestone alternation in the upper half of the section. A detailed description of the geology and lithostratigraphy is given in Lukeneder (2010). The complex Mediterranean palaeogeography, and the presence of microplates in the Tethyan oceanic corridor between Africa and Europe, was discussed in detail in Lukeneder (2010, 2011). The Trento Plateau extends from the south (around Trento) up to the Puez region and was formerly surrounded by two basins: the Lombardian Basin to the west and the Belluno Basin to the east (Lukeneder, 2010). According to recent investigations by Muttoni et al. (2005), the Lombardian Basin, and thus the adjacent Trento Plateau to the east, were located at approximately 20°N in Valanginian–Hauterivian times and at almost 30°N in the Aptian.

### 3. Previous work

During the late 19th and early 20th centuries, a rich fauna of cephalopods was collected from Lower Cretaceous sediments from this area by Haug (1887, 1889), Hoernes (1876), Uhlig (1887), Rodighiero (1919) and Pozzi (1993). Additionally, microfacies and ammonites were reported from the “Alpe Puez” by Cita and Pasquare (1959) and Cita (1965), leading them to assume a Hauterivian–Barremian age for the Puez area. After this period, documented by numerous publications on the ammonite fauna of the Puez and adjacent areas by the latter authors, no further investigations were undertaken at the main locality of Puez. This phase of stagnancy in Lower Cretaceous papers was followed by descriptions of small ammonoid faunas from different localities near the Puez area, e.g., from La Stua by Baccelle and Lucchi-Garavello (1967) and Stöhr (1993, 1994). The latter papers compared the faunas from La Stua with the Puez ammonite faunas from Haug (1887, 1889) and Uhlig (1887). The most recent contributions on the Lower Cretaceous of the Puez area were published during the last decade and focused on stratigraphy (Lukeneder and Aspmair, 2006), palaeoecology (Lukeneder, 2008) and lithostratigraphy (Lukeneder, 2010, 2011).

### 4. Material

The ammonites originate from the Puez locality (Dolomites; Fig. 1). Bed-by-bed collecting and a systematic-taxonomic study



**Fig. 2.** Ammonite assemblage from the Puez locality. Phylloceratina, Lytoceratina, Ammonitina within the log (left) and the ammonite zonation indicated. Upper Hauterivian beds shaded in dark grey and Barremian in light grey. Ammonite occurrences and ranges marked by solid black circles. Bold horizontal line, stage boundary; dashed horizontal lines, zonal boundaries; dotted horizontal lines, subzonal boundaries.

provide the basic data for statistical analysis of the investigated ammonite fauna. The material was collected over the last 3 years within the FWF project P20018-N10 and is stored in the South Tyrol Museum of Natural Sciences and the Natural History Museum in Vienna. The preservation of the ammonites is fair (mostly compressed steinkerns without shell) and represents almost the totality of the macrofauna (96%). Some specimens show partly preserved suture lines. During this study, approximately 1209 ammonites, 6 nautilids, 10 lamellaptychi, 6 belemnites, 150 sea urchins, 40 bivalves, 39 brachiopods, and abundant encrusting species (bivalves, corals, serpulids; Lukeneder, 2008) were examined.

The ammonite assemblage consists of 17 families including 44 different Upper Hauterivian–Upper Barremian genera: Phylloceratidae with *Phylloceras*, *Phyllopachyceras*, *Sowerbyceras*; Lytoceratidae with *Lytoceras*, *Eulytoceras*, *Protetragonites*; Desmoceratidae with *Plesiospitidiscus*, *Barremites*, *Valdedorsella*, *Abrytusites*, ?*Pseudohaploceras*, *Melchiorites*; Silesitidae with *Silesites*; Holcodiscidae with *Astieridiscus*, *Holcodiscus*, *Maurelidiscus*; Pulchelliidae with *Gerhardtia*, *Heinzia*, *Kotetishvilia*, *Discoidellia*; Haploceratidae with *Neoliassoceras*; Crioceratidae with *Crioceratites*, *Pseudothurmanna*, *Paracostidiscus*; Emericiceratidae with *Emericiceras*, *Honoratia*, *Paraspiticeras*; Acrioceratidae with *Acrioceras*, *Dissimilites*; Ancyloceratidae with *Toxancyloceras*, *Audouliceras*; Heteroceratidae with *Moutoniceras*; Leptoceratoididae with *Karsteniceras*, *Hamulinites*, *Sabaudiella*; Ptychoceratidae with *Ptychoceras*; Hamulinidae with *Hamulina*, *Anahamulina*, *Vasicekina*, *Ptychohamulina*, *Duyeina*; Megacioceratidae with *Megacioceras*; Macroscaphitidae with *Macroscaphites*, *Costidiscus*.

**Conventions.** NHMV Natural History Museum Vienna, NMB South Tyrol Museum of Natural Sciences. All ammonite specimens in Figs. 3, 6 and 8 were coated with ammonium chloride before photographing. The basic classification of Cretaceous Ammonoidea by Wright et al. (1996), Klein (2005); Vermeulen and Klein (2006) and Klein et al. (2007, 2009) has been followed. The detailed ammonite systematics and taxonomy were adopted and correlated with papers by numerous authors cited in Section 5 below.

## 5. Biostratigraphic ammonite zonation

The ammonite species and resulting ammonite zones identified herein for the Puez Formation allow a correlation of the Hauterivian and Barremian strata at the Puez locality with the recent standard zonation (Reboulet et al., 2009). The ammonite zonation established by the Cretaceous Ammonite Working Group ("Kilian Group") at the international meeting on Lower Cretaceous ammonite zonation in Vienna (Reboulet et al., 2009) is followed. Earlier zonations by Hoedemaeker (1990), Rawson et al. (1999), Hoedemaeker and Rawson (2000), Hoedemaeker et al. (2003) and Reboulet et al. (2006) have been considered for correlation of former and recent literature zonations. If a particular zonal index ammonite is absent the zonal boundary is interpreted by comparison with faunas that characterize the zone elsewhere.

The idea of a *Pseudothurmanna mortilleti* Subzone (middle subzone within the "Pseudothurmanna ohmi" Zone) is accepted. *P. mortilleti* was meant to be a senior synonym of *Pseudothurmanna catullo* (Company et al., 2003, 2005, 2008). A scheme is, therefore, followed that includes a *P. mortilleti* Subzone (Figs. 2, 3, 5, 7). The scheme including a *P. catullo* Subzone as in Reboulet et al. (2009) is not followed because of the contradiction in synonymy mentioned.

The biostratigraphy is compared to sections in Europe (abridged list) from the Northern Calcareous Alps of Austria (Immel, 1978, 1987; Vašíček and Faupl, 1999; Lukeneder, 2003, 2004a), the Gerce and Bakony Mountains in Hungary (Janssen and Fözy, 2005;

Fözy and Janssen, 2006, 2009), the Balkan Mountains of Bulgaria (Dimitrova, 1967; Mandov, 1976), the Silesian Units within the Western Carpathians and Pieniny Klippen Belt of Czech Republic and Slovakia (Uhlig, 1883; Vašíček, 1972, 1994, 1996, 2002, 2008; Vašíček et al., 1994, 2004; Vašíček and Michálik, 1999), the Southern Alps of northern Italy and Umbria-Marche Apennines of central Italy (Uhlig, 1883, 1887; Haug, 1887, 1889; Rodighiero, 1919; Cecca and Pallini, 1994; Cecca et al., 1994a, b; 1995, 1996, 1998; Faraoni et al., 1995, 1996), different districts around the Vocontian Basin of southeast France (Pictet and Loriol, 1858; Lory and Sayn, 1895; Busnardo, 1965, 1984; Thomel, 1964; Autran, 1993; Delanoy, 1994, 1997; Vermeulen et al., 1999, 2002; Vermeulen, 2002, 2005a, 2008, 2009a, b; Vermeulen and Lazarin, 2007; Bert et al., 2008; Delanoy et al., 2008; Clavel et al., 2010), the South and East Carpathians of Romania (Avram, 1990, 1994, 2001; Patrulius and Avram, 2004), the Betic Cordillera in southeast Spain (Barga et al., 1982; Aguado et al., 1992, 2001; Company et al., 1994, 1995, 2002, 2003, 2005, 2008; Hoedemaeker, 1994) and the Swiss Alps and Ultrahelvetic Units of Switzerland (Ooster, 1860; Sarasin and Schöndelmayer, 1901, 1902; Busnardo et al., 2003). The biostratigraphy is compared with sections in North Africa: Algeria (Vermeulen and Lahondère, 2008) and Morocco (Company et al., 2008).

The biotratigraphic zonation at Puez ranges from the Upper Hauterivian *Balearites balearis* Zone up to the Upper Barremian *Gerhardtia sartousiana* Zone (Figs. 2, 3, 7). Not every standard zone or subzone could be detected at the locality using index ammonite species.

### 5.1. Balearites balearis Zone

The *Balearites balearis* Zone is divided into the *Balearites balearis*, *Binelliceras binelli*, *Crioceratites krenkeli* and *Spathicrioceras seitzi* subzones (Reboulet et al., 2009): for correlation, see also Company et al. (2002, 2003). The *B. balearis* Zone is the oldest ammonite zone detected at Puez, where the succession begins within the *B. binelli* Subzone. The dominance of the family Crioceratidae (e.g., *Crioceratites* and *Pseudothurmanna*) hints at the Upper Hauterivian. The presence of *Paracostidiscus radians* (Fig. 4H) and *Plesiospitidicus* strengthens the Upper Hauerivian age for the lowermost parts of the Puez Formation at Puez (Figs. 2–4). Desmoceratidae occur typically with the genera *Plesiospitidiscus* and *Abrytusites* (Fig. 4U), and Haploceratidae with *Neoliassoceras subgrasianum*. The *B. binelli* Subzone is not indicated by the index species but occurs with the family Phylloceratidae comprising *Phylloceras tethys* and *Phyllopachyceras winkleri*. The *B. binelli* Subzone is defined here to be located below the *C. krenkeli* Subzone and characterized by the absence of *C. krenkeli*. The *C. krenkeli* Subzone begins with the first appearance of *C. krenkeli* within bed P1/21 (Fig. 3). The abundance of the index ammonite *C. krenkeli* and the co-occurring ammonite assemblage in beds P1/21 up to bed P1/44 hint at the presence of the *C. krenkeli* Subzone. The *C. krenkeli* Subzone is dominated by the index ammonite *C. krenkeli* (Fig. 4A–C) and is accompanied by *P. radians*, *Anahamulina jourdani* (Fig. 4M), *P. tethys*, *Phyllopachyceras infundibulum* (Fig. 4V), *Phylloceras terverii* (Fig. 4W), *P. winkleri* and *Plesiospitidiscus subdifficilis* (Fig. 4T). As noted by Reboulet et al. (2009), *B. binelli* and *C. krenkeli* occur only in the uppermost part of the *B. balearis* Zone, which is characterized by the range of the index species. The uppermost subzone within the *B. balearis* Zone, the *Sp. seitzi* Subzone, could not be determined so far based on the zonal index ammonite. Its base is tentatively located at the base of bed P1/44 (Figs. 2–4).

Beds within the *B. balearis* Zone display relatively low numbers of species per bed from one to four. The same numbers are shown in families per bed, with lower numbers in the lower parts increasing to the top of the zone (Fig. 7). The mean number of families in the

*B. balearis* Zone is five, the maximum is eight within the *C. krenkeli* Subzone. The minimum is located in the lowermost parts of the zone with one. The evaluation of biodiversity calculated from the ratio between number of species vs. number of individuals per species, the Shannon index, shows a mean value for the *B. balearis* Zone of 0.84 (min. 0.5, max. 1.8; beds with no specimens excluded). This indicates a low species richness and low evenness in their abundance (Fig. 7).

**Discussion.** Company et al. (2003) reported a more intense ammonite diversification and increased abundance in several ammonite groups for Upper Hauterivian faunas within the zone from the Betic Cordillera compared to the subzones below (e.g., *C. balearis* and *C. binelli* subzones). The data provided by Company et al. (2003) broadly correlate with the data presented herein and show that the *C. krenkeli* Zone is characterized by the occurrence of the index ammonites *C. krenkeli*, *Crioceratites majoricensis*, *A. jourdani*, *N. subgrasianum*, *P. subdifficilis*, *A. neumayri*, *P. guerianum*, *D. vermeuleni*, *L. subfimbriatum*, *P. tethys*, *P. winkleri* and *P. infundibulum*.

The same faunal compositions were shown by Fözy and Janssen (2006, 2009) within their *Crioceratites/Pseudothurmannia* assemblage for the *B. balearis* Zone from the Gerecse Mountains in Hungary. The *B. balearis* Zone embraces, according to these authors, *Phylloceras infundibulum* (= *Phyllopachyceras infundibulum*), *Phylloceras* sp., *Lytoceras* sp., *Plesiospitidiscus* spp. and typically *Crioceratites* sp. accompanied by *C. krenkeli*. The same condition can be recognized in the more southwestern Bakony Mountains of Hungary (Fözy and Janssen, 2006) with *P. tethys*, *P. infundibulum*, *P. winkleri*, *L. subfimbriatum*, *Neoliissoceras grasianum*, *Abrytusites* spp., *P. subdifficilis*, *C. krenkeli*, *P. radians*, *Silesites* spp. and *Discoidellia favrei*. This assemblage is equivalent to the fauna corresponding to the interval of the *B. balearis* Zone (*C. krenkeli* Subzone) and “*P. ohmi*” Zone at Puez.

Data from Puez correlate with reported Upper Hauterivian assemblages from the Northern Calcareous Alps in Austria comprising *P. subdifficilis*, *P. cf. mortilleti*, *Megacioceras* cf. *doublieri*, *L. subfimbriatum*, *P. tethys* and *P. infundibulum* (Vašíček and Faupl, 1999). The same situation was shown from the Northern Calcareous Alps by Lukeneder (2003), who established a *C. krenkeli*-abundance zone similar to the *C. krenkeli* beds of Puez comprising also abundant species such as *C. krenkeli*, *P. infundibulum* and *L. subfimbriatum*. Vašíček (1999) reported *M. doublieri* from beds of the *Subsaynella sayni* or *P. ligatus* Zone from the Northern Calcareous Alps in Austria, and therefore appearing earlier than at Puez, where it appears in the *B. balearis* Zone. Delanoy et al. (1987) designated this new genus *Megacioceras* (e.g., *M. doublieri*) for this Upper Hauterivian form of Ptychoceratoidae. They assumed a range for the taxon in southeast France from the *S. sayni* Zone to the *P. angulicostata* Zone.

Equivalent “*Pseudothurmannia* Beds” were detected by Vašíček et al. (1994) in Silesian Units of the Western Carpathians, showing the same dominance in *Pseudothurmannia*. These beds are herein assumed to be equivalent to the *B. balearis* and “*P. ohmi*” Zones (= *Eptychoceras borzai* and *C. binelli* Zones in Vašíček et al., 1994).

Autran (1993) reported faunas from the Upper Hauterivian of the Castellane region (southeast France) by referring to ammonite zonations as H6 (*B. balearis* Zone; see Busnardo, 1984) and H7 (*P. ohmi* Zone). H6 was characterized by the assemblage of *P. infundibulum*, *L. subfimbriatum*, *Acrioceras* sp., *Plesiospitidiscus* spp., *Paraspiticeras* sp., *M. doublieri* and *P. favrei* (= *D. favrei*).

Upper Hauterivian faunas from the historic Veveyse de Châtel section (“Ultrahelvétique des Préalpes externes”) in Switzerland were reinvestigated by Busnardo et al. (2003). The fauna of the

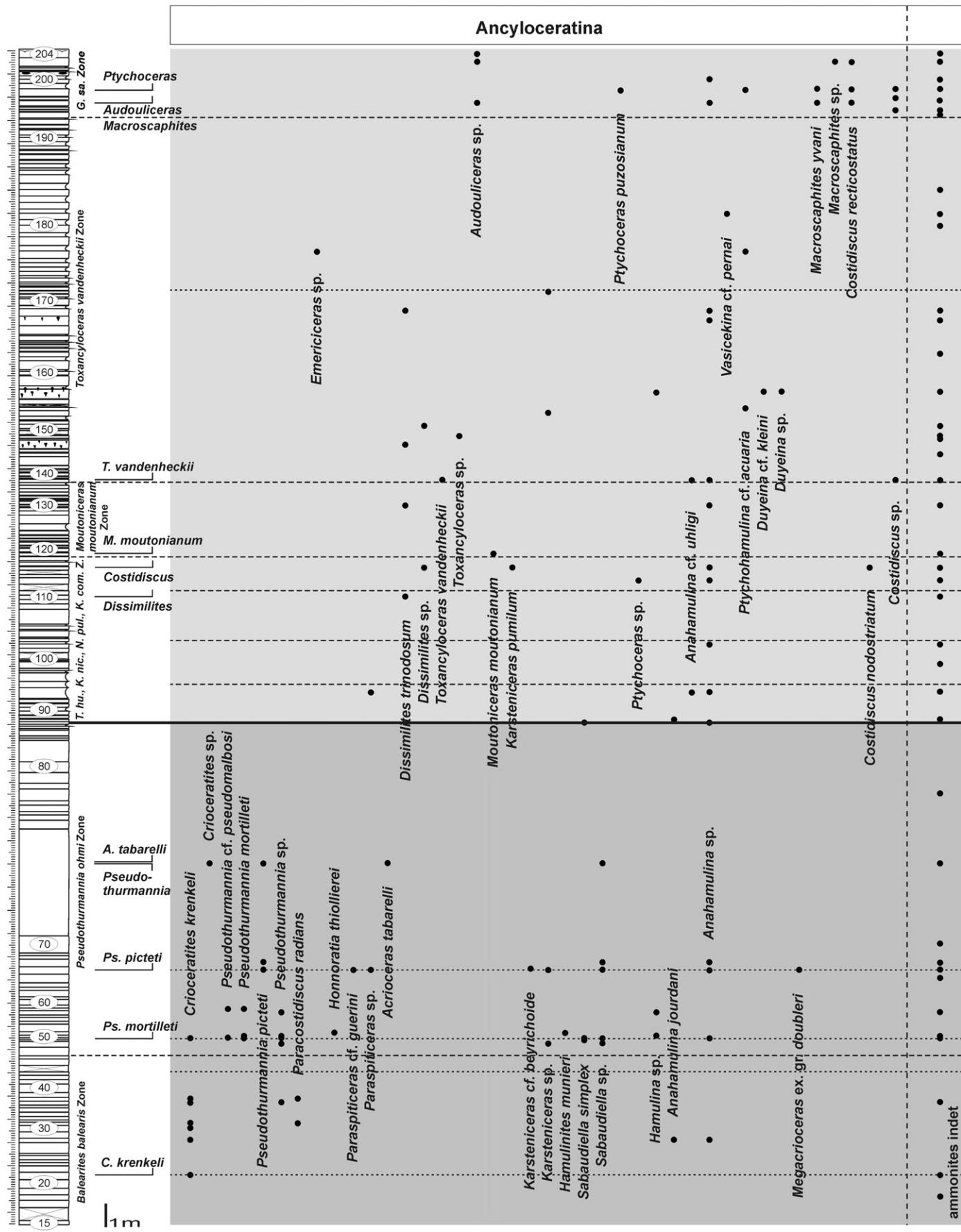
equivalent *B. balearis* Zone comprises *P. tethys*, *P. infundibulum*, *P. winkleri*, *L. subfimbriatum*, *Lytoceras* sp. and *Plesiospitidiscus* spp. The upper boundary of the comparable *B. balearis* Zone at Puez could not be attributed to a single bed and is tentatively located within bed P1/47.

Avram (1994) reported two different and specifiable pseudothurmannid assemblages for the South Carpathian region around Svinia. The lower one is with *Pseudothurmannia pseudomalbosii* from the *B. balearis/P. ohmi* Zone boundary, and the upper is characterized by the mixed assemblage of *P. angulicostata*, *P. picteti* and *P. cf. catullo* (= junior synonym of *P. mortilleti*; see Company et al., 2003, 2008) accompanied by the first *Paraspiticeras* specimens, making it comparable to the *P. picteti* Zone at Puez (Figs. 3 and 4). Avram (1994) also noted the presence of the first *D. favrei* (= Avram's *Psilotissotia favrei*) within the first levels above the *Pseudothurmannia* beds. *D. favrei* starts at Puez with *P. pseudomalbosii* within the *P. mortilleti* Zone. The accompanying lytoceratid and phylloceratid faunas are equivalent in both areas, i.e., Svinia and Puez.

## 5.2. “*Pseudothurmannia ohmi*” Zone

At the Puez section the “*P. ohmi*” Zone (= *P. angulicostata* auct. Zone) could not be determined based on the index ammonite. The lower boundary of the “*P. ohmi*” Zone at Puez has not yet been fixed to a single bed. It is tentatively located at the base of bed P1/47 (Figs. 2–4). The “*P. ohmi*” Zone reaches up to bed P1/86 (Figs. 2 and 3). The “*P. ohmi*” Subzone has so far not been determined using the index ammonite. Its base is tentatively located at bed P1/47 and its upper boundary is assigned to be at the top of the last bed before the overlying *Pseudothurmannia mortilleti* Subzone. This part of the section (i.e., “*P. ohmi*” Subzone) is characterized by the presence of *Pseudothurmannia* sp., *Karsteniceras* sp. and *Sabaudiella simplex* (Fig. 4N, O). The *P. mortilleti* Subzone starts with the first appearance of *P. mortilleti* at bed P1/50 (Fig. 4F). This appearance coincides at the Puez locality with the last occurrence of *C. krenkeli*. *P. mortilleti* typically co-occurs with *P. pseudomalbosii* from beds P1/50 up to P1/58 (Fig. 4D, E). The *P. mortilleti* Subzone from beds P1/50 to P1/65 comprises a characteristic ammonite association of *P. mortilleti*, *P. pseudomalbosii*, *Honoratia thiollierei* (Fig. 4J, K), *Hamulina* sp., *Anahamulina* sp., *Hamulinites munieri* (Fig. 4P) *P. subdifficilis* and *Plesiospitidiscus* sp. The subzone is also marked by the first occurrence of the family Pulchelliidae with *D. cf. favrei* (Fig. 4S), and *Discoidellia* sp. *P. tethys*, *P. infundibulum*, *L. subfimbriatum*, *Lytoceras* sp., and *Lytoceras anisoptychum* occur frequently. The *P. picteti* Subzone starts with its index species *P. picteti* from bed P1/66 and reaches up to the end of the *P. picteti* Subzone, thus to the end of the “*P. ohmi*” Zone with bed P1/86. The *P. picteti* Subzone is characterized by the association of *P. picteti* (Fig. 4G), *Paraspiticeras* cf. *guerini* (Fig. 4L), *Paraspiticeras* sp., *Acrioceras tabarelli* (Fig. 4I), *Sabaudiella* sp., *Anahamulina* sp., *Megacioceras* ex. gr. *doublieri* (Fig. 4Q), *Plesiospitidiscus* cf. *breskovskii*, *Plesiospitidiscus* sp., *Barremites* sp., *Abrytusites* sp., *Astieridiscus* sp. (Fig. 4R) and *N. subgrasianum*. Additionally, representatives of the families Phylloceratiidae and Lytoceratidae occur with *P. tethys* (Fig. 4Y), *Phylloceras* sp., *P. infundibulum*, *L. subfimbriatum*, *L. anisoptychum* (Fig. 4X), and *Protetragonites* sp. Desmoceratidae occur with the first specimens of *Barremites* and *Abrytusites*. Haploceratidae show their last members with *N. subgrasianum* within the *P. picteti* Subzone. Bed P1/86 therefore tentatively marks the upper boundary of the Hauterivian.

Beds within the “*Pseudothurmannia ohmi*” Zone display numbers of species per bed from one to nine. Thirteen families occur within the zone with numbers per bed from zero to ten, with highest values in the *P. mortilleti* and *P. picteti* Zones (Fig. 7). The



mean number of families in the *B. balearis* Zone is 8.6, the maximum is twelve within the *P. picteti* Subzone. The minimum is located in the “*P. ohmi*” Subzone with six families per subzone. The Shannon index shows a mean value for the “*Pseudothurmannia ohmi*” Zone of 1.6 (min. 0.6, max. 2.6; beds with no specimens excluded). This indicates a higher species richness (e.g., twice) than is seen in the *B. balearis* Zone (Fig. 7).

**Discussion.** The *P. ohmi* Zone was defined by Hoedemaeker and Leereveld (1995). The *P. ohmi* Zone with the *P. ohmi*, *P. catullo* or *P. mortilleti* and *P. picteti* Subzones are as proposed by Company et al. (2008) and established by Reboulet et al. (2009). *P. mortilleti* was meant to be a senior synonym of *P. catullo* (Company et al., 2003, 2008). Company et al. (2008) established a scheme with a *P. mortilleti* Zone, which is followed herein (Figs. 2, 3, 5, 7).

Fözy and Janssen (2006, 2009) reported from the “*P. ohmi*” Zone in the Gerecse Mountains in Hungary similar faunas to those of Puez, dominated by *P. infundibulum*, *Phylloceras* sp., *Lytoceras* sp., *Plesiospitidiscus* spp., *Anahmulina* sp. and “*P. ohmi*”.

Similar to the first appearance of *D. favrei* at Puez within the *P. mortilleti* Subzone, Vermeulen (2002) reported first appearances of *D. favrei* and *Psilotissotia* sp. at Angles (Barremian stratotype; Alpes de Haut-Prevence, southeast France) from the same subzone, and additional occurrences within the *P. picteti* Subzone.

Equivalent faunas were reported from Upper Hauterivian sections of Río Argos section in southeast Spain by Hoedemaeker (1994). He reported assemblages with *P. tethys*, *P. winkleri*, *L. subfimbriatum*, *N. subgrasianum*, *D. favrei*, *P. mortilleti*, “*P. catullo*”, *P. subdifficilis*, *C. krenkeli* and first appearances of *L. densifimbriatum*, *P. crebrisulcatus*, *S. vulpes*, *Paraspiticeras* spp. and *H. thiollierei* (Hoedemaeker's *Emericiceras thiollierei*) at the top of Hoedemaeker's “*Pseudothurmannia catullo*” Zone (= top of *P. picteti* Zone in Reboulet et al., 2009). According to Klein et al. (2007), *Honoratia honnoratiana* and *H. thiollierei* are the same species; hence, *H. thiollierei* is the senior synonym and has priority. *H. thiollierei* and *Paraspiticeras* first occur at Puez within the *P. mortilleti* Zone.

Upper Hauterivian sequences were reported by Barga et al. (1982) from the Jaén province (Betic Cordillera), comprising similar components to those of Puez with *P. mortilleti*, *A. tabarelli* and first appearances of *D. favrei* (= *P. favrei* in Barga et al., 1982) within their “*P. angulicostata*”, which is now in parts equivalent to the “*P. ohmi*” auct. Zone and the *P. mortilleti* Zone of Reboulet et al. (2009). *C. krenkeli* occurs a few metres below this level in their “*P. ligatus*” Zone, which corresponds to the upper part of the *B. balearis* Zone (i.e., *C. krenkeli* Subzone) of Reboulet et al. (2009).

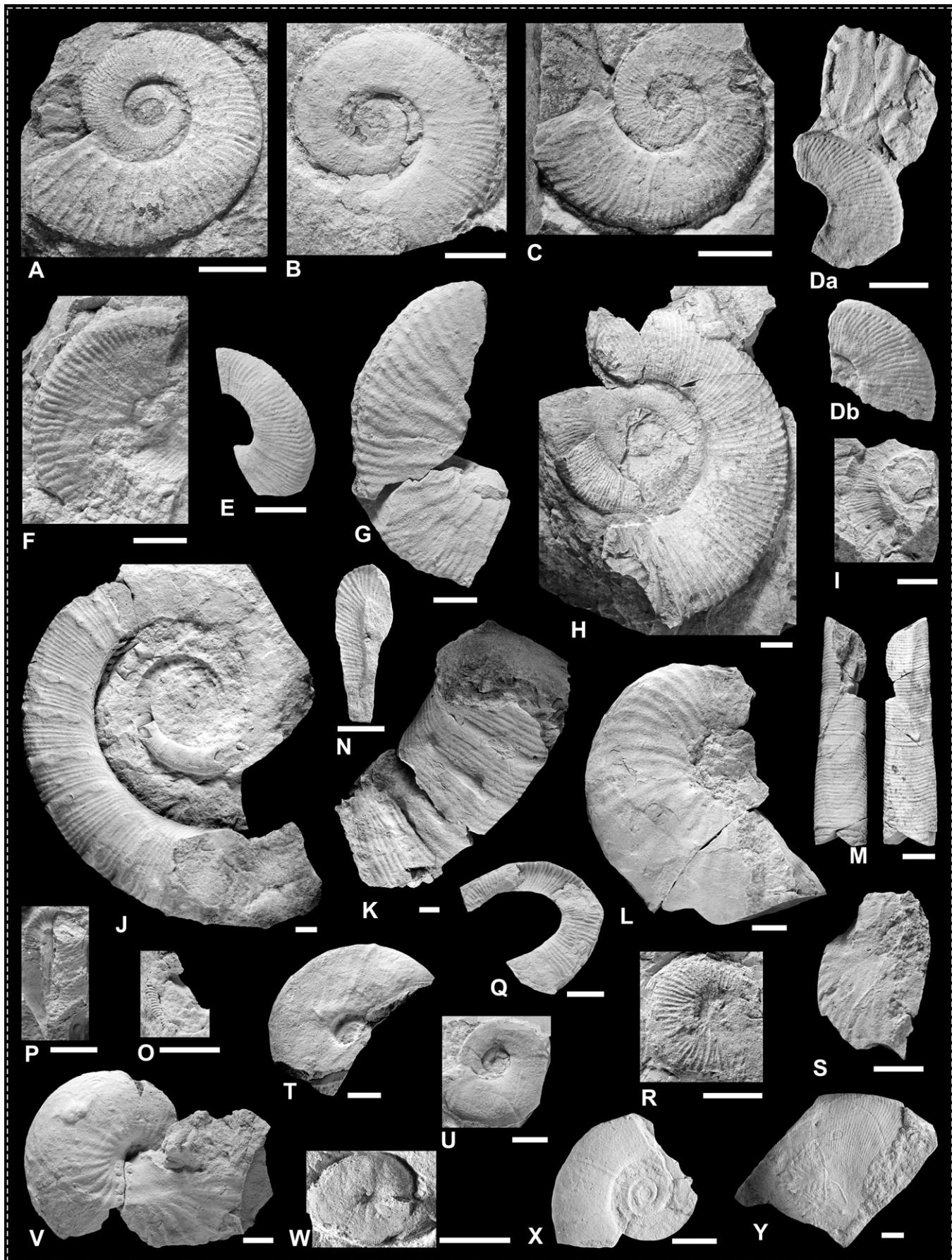
Vašíček (1994) reported *D. favrei* (= Vašíček's *P. favrei*) from the *P. angulicostata* Zone of the Western Carpathians (Czech Republic and Slovakia), which is equivalent to the more recently established “*P. ohmi*” Zone (Reboulet et al., 2009). Vašíček's *D. favrei* derives most probably from the *P. mortilleti* Subzone because he gave the exact range of the appearance of his *P. mortilleti* (= *P. catullo*). This agrees with the occurrence at Puez.

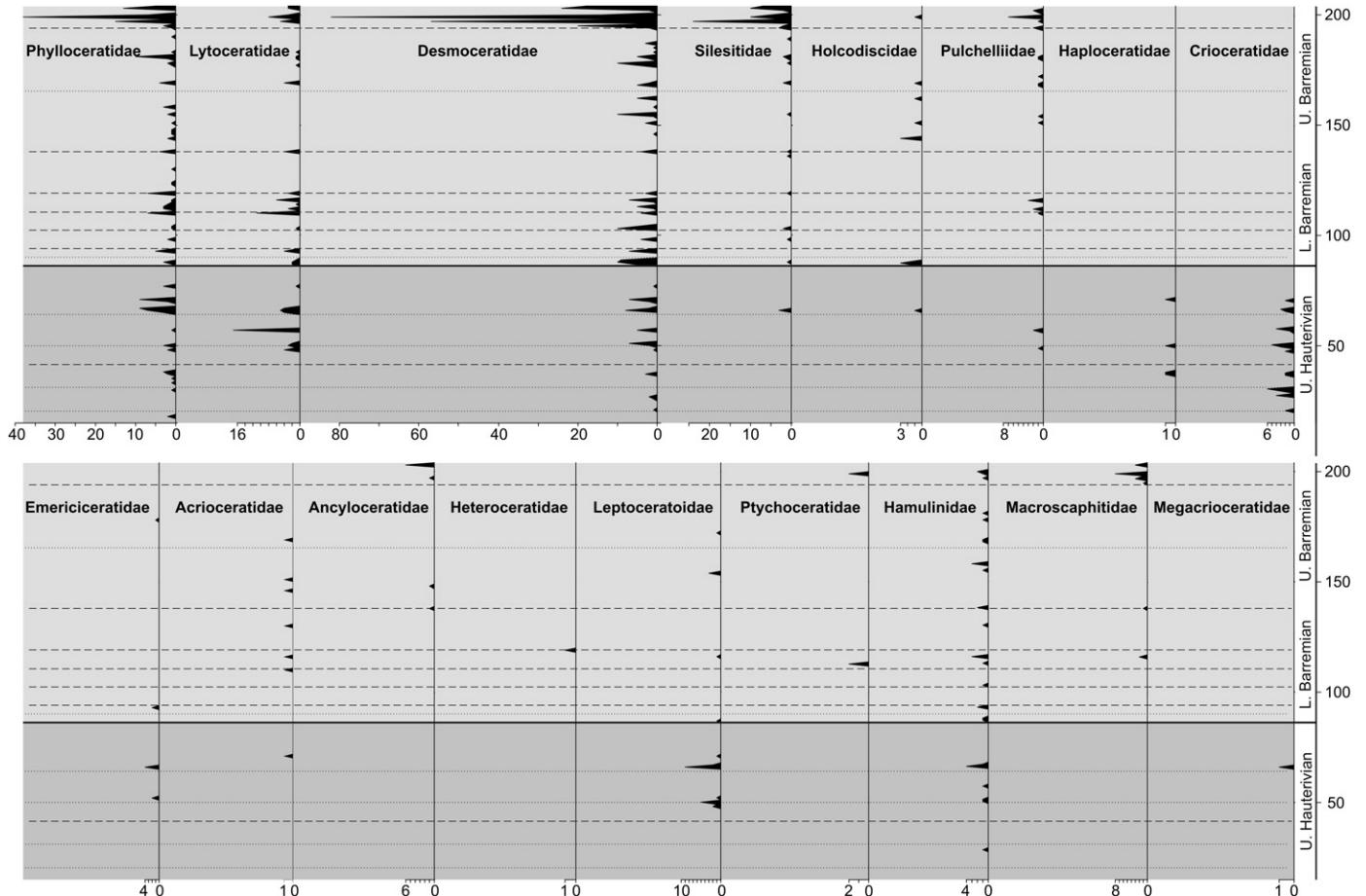
Cecca and Pallini (1994) detected several assemblages from the Umbria-Marche Apennines (Central Italy) with co-occurrences of *P. mortilleti catullo* and *D. favrei* (= Cecca and Pallini's *P. favrei*). They assumed the fauna to be uppermost Hauterivian (i.e., former *P. angulicostata* auct. Zone, now *P. ohmi* auct. Zone and *P. mortilleti* Subzone; Reboulet et al., 2009). The subspecies name of *P. mortilleti catullo* given by Cecca and Pallini (1994) once again shows the confusion within the determination of the members of the

*Pseudothurmannia* group, which is also evident for example in Hoedemaeker (1994), Vermeulen et al. (2002) and Company et al. (2003). Some species determinations made by Cecca and Pallini (1994) seem to be incorrect (see also Vermeulen and Klein, 2006) because *M. moutonianum* cannot occur with or above *Silesites seranonis* and *Gerhardtia provincialis* (= Cecca and Pallini's *Heinzia provincialis*). Uppermost Hauterivian faunas from the Maiolica Formation of the Lessini Mountains and Central Apennines (northeastern and central Italy) were reported from Faraoni et al. (1995, 1996). These faunas were regarded as having been deposited within a guide level, the so-called Mediterranean Faroni Level (see also Galeotti, 1995; Baudin et al., 1997) within the “*P. ohmi* auct.” Zone (i.e., *P. catullo* Subzone = *P. mortilleti* Subzone). Assemblages include the same members as seen at Puez with *P. infundibulum*, *E. anisptychum*, *P. catullo*, *P. favrei* (= *D. favrei*), *Plesiospitidiscus* sp. and *E. thiollierei* (= *H. thiollierei*).

As noted by Company et al. (1994), the transitional interval between uppermost Hauterivian and Lower Barremian strata in southeast Spain is often missing or condensed, depending on the palaeogeographic position during that time. Condensation in deeper environments and concurrent erosion and manifestation of hiatuses were detected in southeast Spain (Company et al., 1994). As they showed in the Sierra del Corque (Capres section CP2; Company et al., 1994), a total loss of sediments from the Upper Hauterivian (*B. balearites* Zone) up to the *Holcodiscus caillaudianus* Zone (sea-level rise) occurs. This was interpreted to mirror a sea-level fall during that time. This fits well with the condensed lower Lower Barremian succession at Puez, which needs more detailed sampling. The Kilian Group replaced the *H. callaudianus* Zone by the topmost *M. moutonianum* Zone (Hoedemaeker and Rawson, 2000). A compilation of the faunal data from Company et al. (2003) described typical assemblages for the *P. mortilleti* Zone, namely the occurrence of *P. mortilleti*, *P. pseudomalbosii*, *E. thiollierei* (= *H. thiollierei*), *Acrioceras meriani*, *Anhamulina subcylindrica*, *P. subdifficilis*, *A. neumayri*, *P. guerianianum*, first *D. favrei*, *L. densifimbriatum*, *P. tethys*, and *P. infundibulum*. As they noted, a prominent faunal turnover or renewal takes place within that zone, often referred to as the Mediterranean Faroni Level (Faraoni et al., 1995, 1996; Galeotti, 1995; Baudin et al., 1997, Cecca, 1998; Company et al., 2003). Company et al. (2003) described typical assemblages for the *P. picteti* Zone, namely the occurrence of *P. picteti*, *E. thiollierei* (= *H. thiollierei*), *Acrioceras ramkrishnai*, *Paraspinoceras morloti*, *A. subcylindrica*, *Hamulinites munieri*, and in the lower parts, the last specimens of *P. subdifficilis* and *A. neumayri*, *Barremites* spp., first appearances of *Silesites* sp., *P. guerianianum*, *D. favrei*, *L. densifimbriatum*, first members of *P. obliquestrangulatum*, *P. tethys*, and *P. infundibulum*. Company et al. (2005) discussed faunal changes linked to the Faraoni Level of the Betic Cordillera. They showed that the ammonite faunal changes (e.g., renewal) from Hauterivian to a more Barremian “face” occurs stepwise during the *P. ohmi* Subzone/*P. mortilleti* boundary period, and at the base of the *P. picteti* Subzone and within the upper part of the *P. picteti* Subzone, both characterized by diversification and replacement of species. The first step occurs during a second-order peak transgression, and the second at a sea-level highstand. By contrast, the third step is more an “extinction event” marked by extinctions of several species which appeared during the first two steps (Company et al., 2005); this is linked to a major sea-level fall. Company et al. (2005) noted the first step as being characterized by the disappearance of *N. subgrasianum*, *P. infundibulum* and

**Fig. 3.** Ammonite assemblage from the Puez locality. Ancyloceratina within the log (left) and the ammonite zonation indicated. Upper Hauterivian beds shaded in dark grey and Barremian in light grey. Ammonite occurrences and ranges marked by solid black circles. Bold horizontal line, stage boundary; dashed horizontal lines, zonal boundaries; dotted horizontal lines, subzonal boundaries.



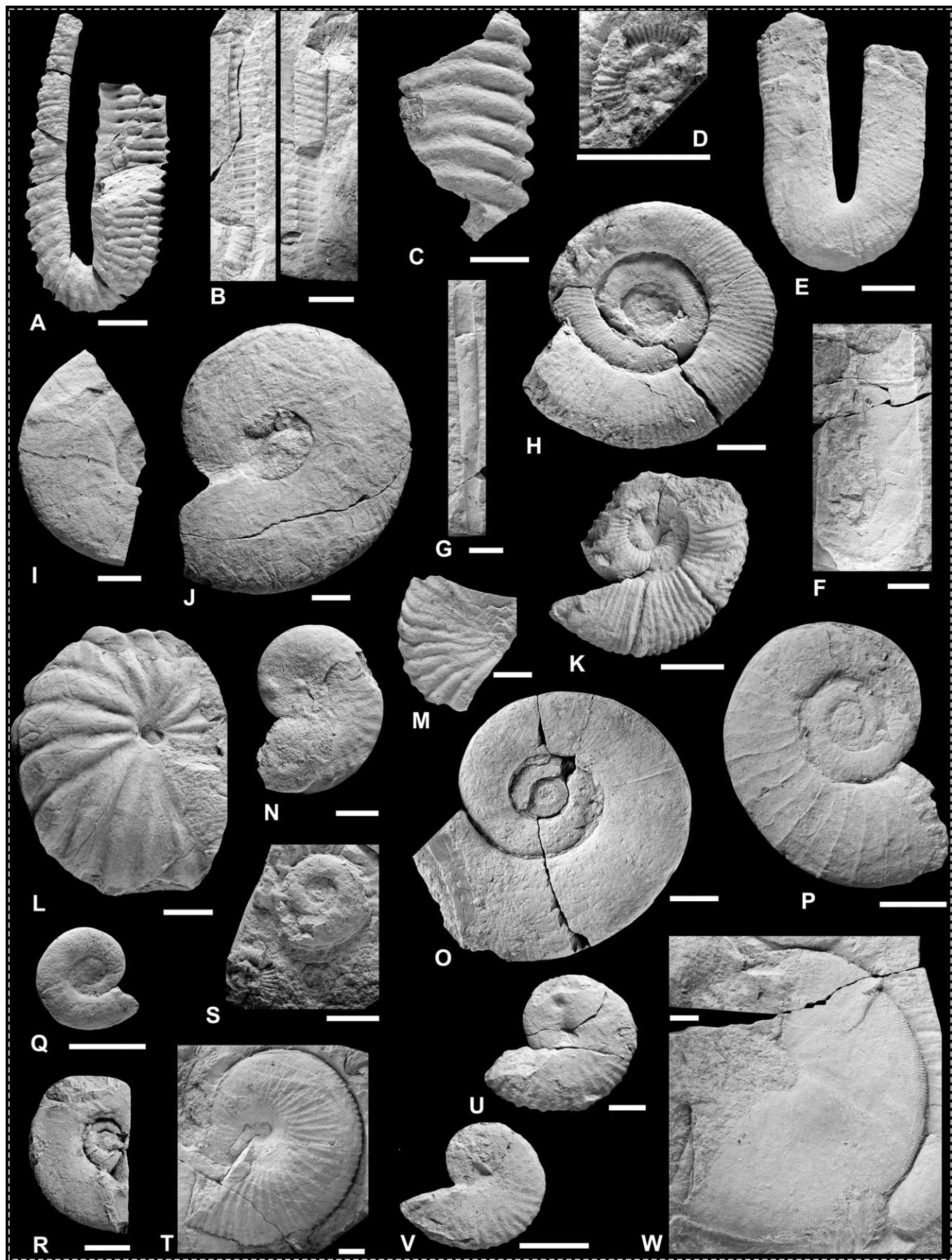


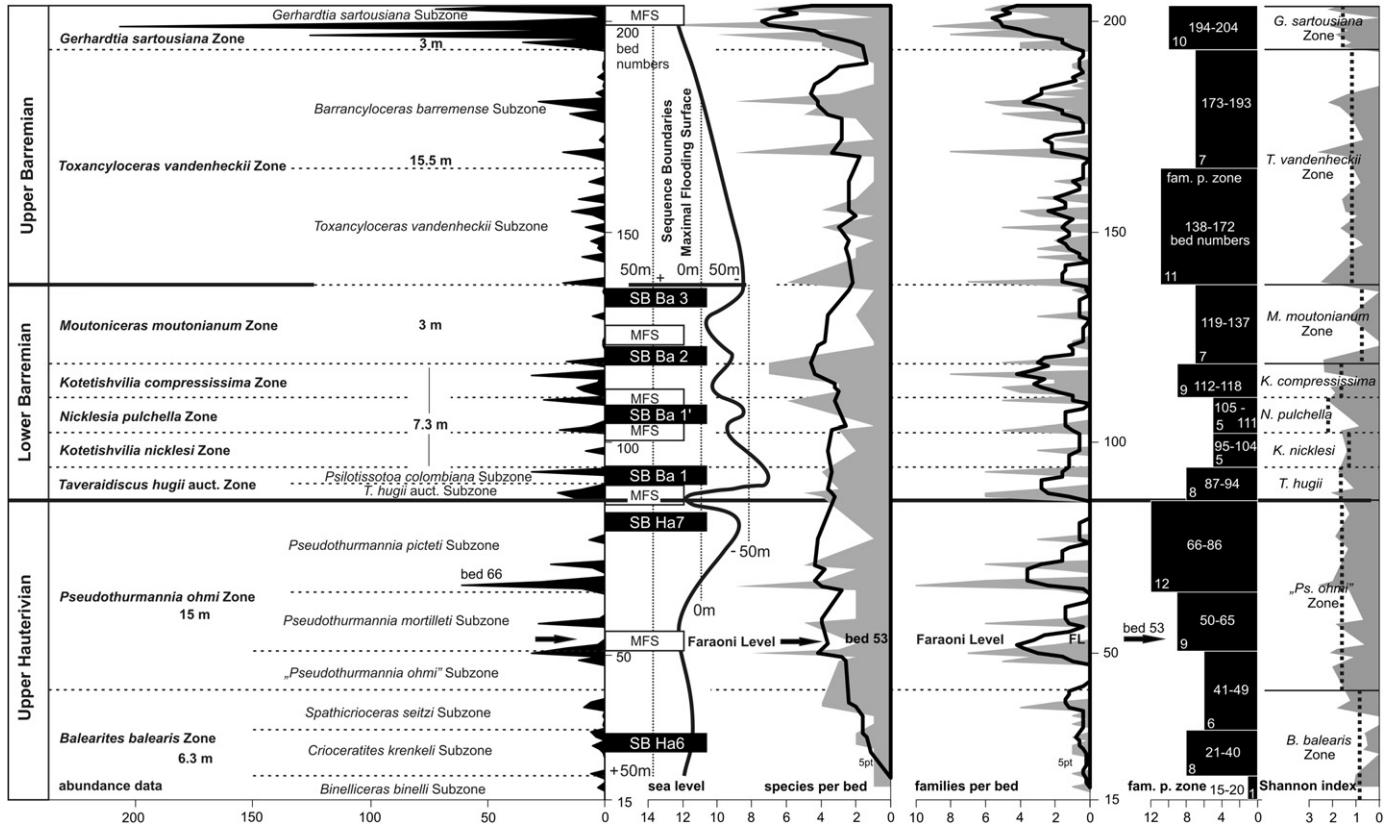
**Fig. 5.** Upper Hauterivian–Upper Barremian abundance data of the ammonite families from the Puez locality. Upper Hauterivian beds shaded in dark grey and Barremian in light grey. Note different scales.

*L. subfimbriatum* around the *P. ohmi* Subzone/*P. mortilleti* boundary, whereas new forms from Pulchelliidae (*D. favrei*) and Leptoceratoidinae (*Hamulinites*) occur. At Puez the situation is similar because *L. subfimbriatum* disappears within the *P. mortilleti* Subzone, and *P. infundibulum* disappears within the *P. mortilleti* Subzone and reappears in the *P. picteti* Subzone. *N. subgrasianum* is very rare within the *P. mortilleti* Subzone, whereas *Hamulinites* and *D. favrei* first appear in this Subzone. The second step is somewhat less spectacular (Company et al., 2005), marked by species changes within genera and appearances of closely related forms at the base of the *P. picteti* Subzone. Examples include *P. mortilleti* and *P. pseudomalbosi* replaced by *P. picteti*, *Acrioceras meriani* by *A. ramkrishnai*, and the occurrence of *Paraspinoceras morloti*. The base of the *P. picteti* Subzone is characterized by the third step, which ranges more or less up to the Hauterivian/Barremian

boundary. Extinctions occur in the Betic Cordillera, for example, in *P. picteti*, *Hamulinites nicklesi*, *Anhamulinina fumisugina*, *P. morloti*, and at Puez in Desmoceratidae, such as *A. neumaryi* in Spain and *Abrytusites*, *P. breskovichii* and *P. subdifficilis*. In contrast, members of Holcodiscidae as *Taveraidiscus* in Spain and *Maurelidiscus* and *Astieridiscus* both a Puez, in addition to Silesitidae with *Silesites* occur within that interval. Desmoceratidae occur with the first “real” *Barremites dimboviciorensis* in Spain, and Emericiceratidae occur with the last *Paraspiticeras guerini* (= *P. guerinianum* in Company et al., 2005) in both areas. Lytoceratidae occur with new *L. obliquestrangulatum* in the *P. picteti* Subzone. An additional zonation was given by Aguado et al. (2001) for the Betic Cordillera region; this is closely similar to the most recent one by Reboulet et al. (2009). Aguado et al. (2001) characterized the *B. balearis* Zone by the presence of *Anahamulinina jourdani* and rare first

**Fig. 4.** Upper Hauterivian ammonites from the Southern Alps, Italy. A–C, *Crioceratites krenkeli*, beds P1/31, P1/28, P1/31, *Balearites balearis* Zone, *C. krenkeli* Subzone; 2011/0159/0001–3. D, E, *Pseudothurmannia pseudomalbosi*, P1/58, P1/50, “*Pseudothurmannia ohmi*” Zone, *Pseudothurmannia catuloi* Subzone; 2011/0159/0004–5. F, *Pseudothurmannia mortilleti*, P1/58, P1/50, “*P. ohmi*” Zone, *P. catuloi* Subzone; 2011/0159/0006. G, *Pseudothurmannia picteti*, P1/67, “*P. ohmi*” Zone, *P. picteti* Subzone; 2011/0159/0007. H, *Paracostidiscus radians*, P1/31, *B. balearis* Zone, *C. krenkeli* Subzone; 2011/0159/0008. I, *Acrioceras tabarelli*, P1/71, “*P. ohmi*” Zone, *P. picteti* Subzone; 2011/0159/0009. J, K, *Honnoratia thiollerei*, P1/52, “*P. ohmi*” Zone, *P. catuloi* Subzone; 2011/0159/0010–11. L, *Paraspiticeras cf. guerini*, P1/66, “*P. ohmi*” Zone, *P. picteti* Subzone; 2011/0159/0012. M, *Anahamulinina jourdani*, P1/28, *B. balearis* Zone, *C. krenkeli* Subzone; 2011/0159/0013. N, O, *Sabaudiella simplex*, P1/49, P1/50, “*P. ohmi*” Zone, *P. catuloi* Subzone; 2011/0159/0014–15. P, *Hamulinites munieri*, P1/52, “*P. ohmi*” Zone, *P. catuloi* Subzone; 2011/0159/0016. Q, *Megacioceras ex. gr. doubleeri*, P1/66, “*P. ohmi*” Zone, *P. picteti* Subzone; 2011/0159/0017. R, *Astieridiscus* sp., P1/86, “*P. ohmi*” Zone, *P. picteti* Subzone; 2011/0159/0018. S, *Discoidellia favrei* P1/57, “*P. ohmi*” Zone, *P. ohmi* Subzone; 2011/0159/0019. T, *Plesiospitiidiscus cf. subdifficilis*, P1/26, *B. balearis* Zone, *C. krenkeli* Subzone; 2011/0159/0020. U, *Abrytusites* sp., P1/27, *B. balearis* Zone, *C. krenkeli* Subzone; 2011/0159/0021. V, *Phyllopachyceras infundibulum*, P1/35, *B. balearis* Zone, *C. krenkeli* Subzone; 2011/0159/0022. W, *Phylloceras tervieri*, P1/30, *B. balearis* Zone, *C. krenkeli* Subzone; 2011/0159/0023. X, *Lytoceras anisoptychum*, P1/48, “*P. ohmi*” Zone, “*P. ohmi*” Subzone; 2011/0159/0024. Y, *Phylloceras tethys*, P1/50, “*P. ohmi*” Zone, *P. catuloi* Subzone; 2011/0159/0025. All specimens are from the Puez log P1. White scale bars represent 1 cm.





**Fig. 7.** Biostratigraphy and faunal assemblages of the Upper Hauerian–Upper Barremian Puez locality. From left to right, ammonite zonal scheme (according to Reboulet et al., 2009), abundance of specimens ( $n$ ); SB, sequence boundaries with Ba Barremian, Ha Hauerian, NFS Maximum Flooding Surface; sequence boundaries and sea-level curves are adapted from basic data after Hardenbol et al. (1998), modified by Adatte et al. (2005) and Arnaud (2005) and adapted in detail to the ammonite zonation herein; species per bed with bold line (5 point smoothing); families per bed, bold line (5 point smoothing); families per zone; Shannon Index for ammonite-bearing beds. For absolute age data, see Ogg et al. (2008).

*Discoidellia*. Additionally, numerous specimens of *P. subdifficilis*, *A. neumayri*, *N. subgrasianum*, *L. subfimbriatum*, *P. infundibulum* and *P. winkleri* occur. They used the *P. mortilleti* Zone (= *P. angulicostata* auct. Zone = “*P. ohmi*” Zone; see Reboulet et al., 2009) and decided to record a subzonation with a lower *P. ohmi*, a middle *P. mortilleti* and an upper *P. morloti* Subzone. The *P. morloti* Subzone is equivalent to the more recent *P. picteti* Subzone (Reboulet et al., 2009). The *P. mortilleti* Zone of Aguado et al. (2001) is characterized by an assemblage with *P. ohmi*, *N. subgrasianum*, *L. subfimbriatum*, *L. densifimbriatum* and first appearances of *Silesites* and *Barremites*. Additionally, numerous specimens of subzonal index ammonites are *P. mortilleti* in the middle and *P. picteti* in the middle (= *P. mortilleti* Subzone) and subsequently in the upper parts (= *P. picteti* Subzone; Reboulet et al., 2009) of their *P. mortilleti* Zone.

In southeast France the main occurrences of *A. tabarelli* were reported by Thomel et al. (1990) to be Lower Barremian, starting from the basal Barremian. At Puez the occurrence appears to be somewhat earlier within the *P. picteti* Subzone. *A. tabarelli*

co-occurs in both areas with *D. favrei*. Clavel et al. (2010) reported similar faunal components from the Upper Hauerian of southeast France with *P. picteti* and *P. pseudomalbosi*, *Plesiospitidiscus* sp. and *A. neumayri*. Busnardo et al. (2003) reinvestigated and collected numerous faunas from the uppermost Hauerian from the historic Veveyse de Châtel section in Switzerland. The fauna of the equivalent “*P. ohmi*” auct. Zone (= *P. angulicostata* auct. Zone of Busnardo et al., 2003) Zone comprises *P. tethys*, *P. infundibulum*, *L. subfimbriatum*, *Lytoceras* sp., *Plesiospitidiscus* spp., *P. guerinianum*, the first *Abrytusites* sp., *Hamulina* sp., *Sabaudiella simplex*, *P. mortilleti* (= *Parathurmanni mortilleti* after Busnardo et al. (2003)), as well as the first *D. favrei* and *H. thiolierei* (= *H. honnoratiana* after Busnardo et al. (2003)). The index ammonite *P. angulicostata* co-occurs.

Company et al. (2008) reported uppermost Hauerian (*P. ohmi* Zone) to Upper Barremian (*G. sartousiana* Zone) faunas from the western High Atlas. They noted that most of the logs are not complete and comprise several hiatuses and condensation phases.

**Fig. 6.** Lower Barremian ammonites from the Southern Alps, Italy. A, B, *Dissimilites trinodosum*, P1/110, P1/130, ?*Nicklesia pulchella* Zone and *Moutoniceras moutonianum* Zone; 2011/0159/0026–27. C, *Moutoniceras moutonianum*, P1/119, M. moutonianum Zone; 2011/0159/0028. D, *Karsteniceras pumilum*, P1/116, ?*K. compressissima* Zone; 2011/0159/0029. E, *Anahamulina* cf. *uhligi*, P1/93, ?*Taveraidiscus hugii* auct. Zone; 2011/0159/0030. F, *Anahamulina jourdani*, P1/88, ?*Taveraidiscus hugii* auct. Zone; 2011/0159/0031. G, *Ptychoceras* sp., P1/113, ?*K. compressissima* Zone; 2011/0159/0032. H, *Costidiscus nodosostriatum*, P1/116, ?*K. compressissima* Zone; 2011/0159/0033. I, *Barremites difficilis*, P1/89, ?*T. hugii* auct. Zone; 2011/0159/0034. J, *Melchiorites desmoceroides*, P1/93, ?*T. hugii* auct. Zone; 2011/0159/0035. K, *Maureliceras cf. kiliani*, P1/87, ?*T. hugii* auct. Zone; 2011/0159/0036. L, M, *Heinzia caicedi*, P1/116, ?*K. compressissima* Zone; 2011/0159/0037–38. N, *Kotetishvilia* sp., P1/110, ?*N. pulchella* Zone; 2011/0159/0039. O, *Lytoceras densifimbriatum*, P1/112, ?*K. compressissima* Zone; 2011/0159/0040. P, *Eulytoceras phestum*, P1/110, ?*N. pulchella* Zone; 2011/0159/0041. Q, *Silesites vulpes*, P1/119, M. moutonianum Zone; 2011/0159/0042. R, *Melchiorites cassidoides*, P1/110, ?*N. pulchella* Zone; 2011/0159/0043. S, *Protetragonites crebrisulcatum* and *Karsteniceras pumilum*, P1/116, ?*K. compressissima* Zone; 2011/0159/0044. T, *Phyllopachyceras infundibulum*, P1/119, M. moutonianum Zone; 2011/0159/0045. U, V, *Phyllopachyceras infundibulum*, juveniles, P1/93, P1/119, ?*T. hugii* auct. Zone and M. moutonianum Zone; 2011/0159/0046–47. W, *Phylloceras paquieri*, P1/112, ?*K. compressissima* Zone; 2011/0159/0048. All specimens are from the Puez log P1. White scale bars represent 1 cm.



They showed that the *P. ohmi* Subzone corresponds to a TST (transgressive system tract) and that the *P. mortilleti* Subzone corresponds to the HST (highstand system tract) of the sequence Ha6 (the MFS, maximum flooding surface, corresponds to the base of the *P. mortilleti* Subzone = Faraoni Level). The sequence boundary Ha7 is missing in most of the western High Atlas localities owing to hiatuses, and followed immediately by the TST and HST of Ha7 in the upper *T. hugii* Zone. Thus, the HST of Ha6 and LST of Ha7 are absent. The exact sequences at Puez from *T. hugii* to *M. moutonianum* remain unclear, but seem quite similar. In Morocco the top of *T. hugii* and base of *K. nicklesi* were correlated to be the LST of Barr1, but missing. The TST and HST (upper part of *K. nicklesi* Zone and lower part of *N. pulchella* Zone) coincided with a maximum flooding during the Barremian. The uppermost part of *N. pulchella* is interpreted as the LST of Barr2. The *K. compressissima* Zone and the lower–middle part of the *C. darsi* Zone (= *M. moutonianum* Zone) would correspond to the TST and HST of sequence Barr2 and the whole of sequence Barr3. The LST of Ba4 corresponds partly to the lower part of the *T. vandenheckii* Zone, and the TST and maximum flooding surface (MFS) are represented in the *G. sartousiana* Zone. The end of Barremian sedimentation is marked in the western High Atlas by an unsynchronous late Early Barremian or early Late Barremian erosive unconformity (see also Hardenbol et al., 1998; Adatte et al., 2005; Arnaud, 2005). According to data from the western High Atlas of Morocco (Company et al., 2008), the *P. ohmi* Zone is characterized by typical faunas with *P. ohmi*, *P. mortilleti*, *P. pseudomalbosi*, *P. subdifficilis*, *A. neumayri* and *Parspiticeras* sp., which broadly correlates with the situation at Puez. By contrast to the situation with *P. picteti*, the *P. picteti* Subzone and the lowermost part of the *T. hugii* Zone are missing in Morocco, marked by a hiatus, and the *P. mortilleti* Subzone is directly overlain by Lower Barremian sediments.

### 5.3. *Taveraidiscus hugii auctorum* Zone

The Hauterivian/Barremian boundary could not be determined based on the occurrence of index ammonites, neither could the index ammonite species be detected for the *T. hugii* auctorum Zone or the *Kotetishvilia nicklesi*, *Nicklesia pulchella* and *Kotetishvilia compressissima* zones (see discussion). The ammonite zonal boundaries are therefore given tentatively (Figs. 2, 3, 6). The base of the Lower Barremian is fixed at the bottom of bed P1/87, which corresponds to the base of the *T. hugii* auct. Zone. It shows first appearances of *Barremites* spp., *Melchiorites* sp., *Silesites* sp., *Holcodiscus* sp., *Maurelidiscus* and *Anahamulina* cf. *uhligi*. The upper boundary of the *T. hugii* auct. Zone is located at the top of bed P1/94.

The *T. hugii* auct. Zone, the lowermost Zone of the Lower Barremian, is marked by an increasing number of members of the family Desmoceratidae. This family shows first appearances of *Barremites desmoceratooides* (Fig. 6J), *Barremites psilotatus*, *Barremites difficilis*

(Fig. 6I), *Barremites* sp., *M. cassidoides*, and *Mechiorites* sp. Silesitidae appear with the first *Silesites* sp. Holcodiscidae show occurrences of the last *Astieridiscus* sp., whereas real *Holcodiscus* appears and the first appearance of *Maurelidiscus* cf. *kilianni* (Fig. 6K) occurs in bed P1/87. The occurrence of *M. kilianni* (within the *M. kilianni* Zone) was interpreted by Vermeulen (2005a, b, 2009b) to mark the basal Barremian. The *M. kilianni* Zone after Vermeulen (2003; see Vermeulen, 2007b, 2009b) was considered to be an equivalent of the *Taveraidiscus hugii* Zone after Hoedemaeker et al. (2003) and Reboulet et al. (2009). Emericiceratidae appear with the last *Parasiticeras* sp. Leptoceratoididae appear with its last *Sabaudiella simplex*. Within the family of Hamulinidae the co-occurrence of *A. jourdani* (last occurrence; Fig. 6F), *Anahamulina* cf. *uhligi* (first appearance; Fig. 6D) and numerous specimens of *Anahamulina* sp. characterize this zone. Representatives of the families Phylloceratiidae (*P. tethys*, *P. infundibulum*; Fig. 6U) and Lytoceratidae (*L. densifimbriatum*) complete the ammonite assemblage of the *T. hugii* auct. Zone at Puez.

Beds within the *T. hugii* auct. Zone display numbers of species per bed from three to five. Eight families occur within the zone with numbers per bed from zero to six, with highest values in lowermost and uppermost parts (Fig. 7). The Shannon index shows a mean value for the *T. hugii* auct. Zone of 1.6 (min. 1.1, max. 2.1; beds with no specimens excluded). This indicates a comparable species richness as seen in the uppermost Hauterivian "*P. ohmi*" Zone (Fig. 7).

**Discussion.** The *T. hugii* auctorum Zone is subdivided into a *T. hugii* auct. Subzone and an upper *Psilotissotia colombiana* Subzone (Reboulet et al., 2009). Rawson (1996) defined this zone and the first occurrence of *T. hugii* as the base of the Barremian Stage. *P. colombiana* was considered as an index species of the zone (Vermeulen, 1996). A detailed discussion on the zone is given by Company et al. (2008).

Correlatable faunas within the *T. hugii* auct. Zone in the Gerecse Mountains of Hungary show an occurrence of *P. infundibulum*, *Phylloceras* *winkleri* (= *Phyllopachyceras* *winkleri*), *Phylloceras* sp., *Lytoceras* sp., *Protetragonites* sp., *Anahumulina* sp., *Hamulina* sp., and typically the pulchelliids *D. favrei*, *T. hugii* and *Taveraidiscus intermedius* (Fözy and Janssen, 2006, 2009).

Lowermost Barremian faunas from the Veveyse de Châtel section in Switzerland (Busnardo et al., 2003) comprise faunal equivalents of the Puez *T. hugii* Zone with *P. tethys*, *P. infundibulum*, *L. subfimbriatum*; in the lowermost beds the last *Plesiosipitiidiscus* and *Abrytusites* specimens occur. *H. thiollierei* shows the last occurrence in the lowermost *T. hugii* beds.

Aguado et al. (1992) described Barremian faunas from the Subbetic domain in the Betic Cordillera. They designated a *Spitiidiscus* *hugii* Zone (= *T. hugii* Zone after Reboulet et al., 2009). This zone was defined by a *P. infundibulum*, *Barremites* and *Spitiidiscus* assemblage. More recently it was defined again by Aguado et al. (2001) for the

**Fig. 8.** Upper Barremian ammonites from the Southern Alps, Italy. A, B, *Toxancyloceras vandenheckii*, P1/138, *Toxancyloceras vandenheckii* Zone, *Toxancyloceras vandenheckii* Subzone; 2011/0159/0049–50. C, *Toxancyloceras* sp., P1/148, *T. vandenheckii* Zone, *T. vandenheckii* Subzone; 2011/0159/0051. D–F, *Audouliceras* sp., P1/203, P1/197, P1/204, *Gerhardtia sartousiana* Zone, *Gerhardtia sartousiana* Subzone; 2011/0159/0052–54. G, H, *Dissimilites trinodosum*, P1/169, P1/146, *T. vandenheckii* Zone, *T. vandenheckii* Subzone; 2011/0159/0055–56. I, *Karsteniceras* sp., P1/154, *T. vandenheckii* Zone, *T. vandenheckii* Subzone; 2011/0159/0057. J, *Anahamulina* cf. *uhligi*, P1/138, *T. vandenheckii* Zone, *T. vandenheckii* Subzone; 2011/0159/0058. K, *Vasicekina* cf. *pernai*, P1/181, *T. vandenheckii* Zone, *Barrancyloceras barremense* Subzone; 2011/0159/0059. L, *Pychohamulina* cf. *acuaria*, P1/178, *T. vandenheckii* Zone, *B. barremense* Subzone; 2011/0159/0060. M, *Duyeina* cf. *kleini*, P1/158, *T. vandenheckii* Zone, *T. vandenheckii* Subzone; 2011/0159/0061. N, O, *Macroscaphites yvani*, P1/197, P1/199, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0062–63. P, *Castidiscus rectostatus*, P1/197, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0064. Q, *Pseudohaploceras* sp., P1/203, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0065. R, *Melchiorites cassidoides*, P1/199, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0066. S, T, *Silesites vulpes*, P1/136, P1, 204, *M. moutonianum* Zone and *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0067–68. U, *Holcodiscus* cf. *uhligi*, P1/144, *T. vandenheckii* Zone, *T. vandenheckii* Subzone; 2011/0159/0069. V, *Heinzia* cf. *sayni*, P1/151, *T. vandenheckii* Zone, *T. vandenheckii* Subzone; 2011/0159/0070. W, *Gerhardtia sartousiana*, P1/, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0071. X, *Kotetishvilia changarnieri*, P1/169, *T. vandenheckii* Zone, *T. vandenheckii* Subzone; 2011/0159/0072. Y, Z, *G. sartousiana*, P1/199, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0073–74. Za, *Gerhardtia sartousiana*, P1/194, lateral and external view, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0075. Zb, Zc, *Kotetishvilia sauvageau*, P1/202, P1/199, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0076–77. Zd, *Eulytoceras phustum*, P1/197, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0078. Ze, *Phylloceras ponticuli*, P1/195, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0079. Zf, *Phyllopachyceras infundibulum*, P1/203, *G. sartousiana* Zone, *G. sartousiana* Subzone; 2011/0159/0080. All specimens are from the Puez log P1. White scale bars represent 1 cm.

Batic Cordillera region. It was characterized by two subzones in accordance with Reboulet et al. (2009). The lower *T. hugii* Subzone was characterized by the presence of *Taveraidiscus* ssp., *Barremites boutini*, *Lytoceras obliquestrangulatum* (= *Protetragonites obliquetsrangulatum*), *Hamulina munieri* and the last occurrence of *D. favrei*. The upper *Psilotissotia colombiana* Subzone is characterized by *P. colombiana*, *Holcodiscus*, *L. anisoptychum* and *Anahamulina paxillosa*.

According to data from the High Atlas of Morocco (Company et al., 2008), two significant hiatuses appear at the Hauterivian/Barremian boundary and in the lower part of the *K. nicklesi* Zone. Both were related to third-order sea-level falls by Company et al. (2008), who pointed to similarities with the lowermost Barremian (*T. hugii* Zone to *K. compressissima* Zone) intervals of the Puez area. In both areas remarkable facies differences, condensation or hiatuses occur. The *T. hugii* Zone in the High Atlas is marked by the occurrence of *Emericiceras koechlini*, *A. tabarelli*, *D. favrei*, *Barremites dimbovi-ciorensis*, *L. densifimbriatum*, *Paraspiticeras* sp. and *Hamulinites* sp. No index ammonites were found. After Company et al. (2008) and Vermeulen (2002), *D. favrei* extends only up to the lower part of the *T. hugii* Zone in Spain, Morocco and France. At Puez, it virtually disappears in the uppermost Hauterivian *P. mortilleti* Zone.

#### 5.4. Kotetishvilia nicklesi Zone

The *K. nicklesi* Zone extends from the bottom of bed P1/95 up to the top of bed P1/104. The overall situation and assemblage composition is a continuation of the underlying *T. hugii* auct. Zone in that it shows Desmoceratidae with numerous specimens of *Barremites* sp. and *M. cassidoides*. Silesitidae appear with further specimens of *Silesites* sp. Hamulinidae occur with *Anahamulina* sp. The Phylloceratidae are characterized by the first appearance of *P. ponticuli* and more specimens of *P. infundibulum*. Lytoceratidae first occur as *P. crebrisulcatus* at the top of the zone.

Beds within the *K. nicklesi* Zone display numbers of species per bed from zero to three. Six families occur within the zone with numbers per bed from zero to five, with highest values in the uppermost parts (Fig. 7). The Shannon index shows a mean value for the *K. nicklesi* Zone of 2.8 (min. 0.0, max. 2.8; single bed with ammonites). This indicates a strongly increased species richness as seen in the *K. nicklesi* Zone but values are shifted because the ammonite occurrence is limited to a single bed (Fig. 7).

**Discussion.** The base of the *K. nicklesi* Zone zone is defined by the first occurrence of *K. nicklesi* (Company et al., 2008). This part is mostly devoid of ammonites and therefore not yet defined at the Puez locality. More sampling is needed to confirm or refute any hiatuses. According to data from the western High Atlas of Morocco (Company et al., 2008), the *K. nicklesi* Zone is only partly preserved there and encompasses only few beds. The index ammonite was detected and additional rare specimens of *E. koechlini*, *A. tabarelli*, *Paraspiticeras* sp., *Hamulinites* sp., *Lytoceras* sp. and *P. ponticuli* were detected, accompanied by new forms such as *Torcapella barremensis*, *Subbpulcellia oehlerti*, *Almohadites camelinus*, *Holcodiscus thomeli* and *Davidiceras* cf. *potieri*. Company et al. (2008) noted that only the upper part of the *K. nicklesi* Zone is represented in the western High Atlas, following a hiatus in the lower part. This example from Morocco shows the complicated situation and sedimentation anomalies within this zone. Species from the Moroccan locality include forms that should be found at Puez for clarification of zonal boundary.

#### 5.5. Nicklesia pulchella Zone

The *N. pulchella* Zone corresponds to the bottom of bed P1/105 up to the top of bed P1/111 (Figs. 2, 3, 6). The ammonite assemblage

is quite similar to that of the underlying *K. nicklesi* Zone. Desmoceratidae occur with *Barremites* sp. and *M. cassidoides* (Fig. 6R). Pulchelliidae occur with *Kotetishvilia* sp. (Fig. 6N) at the top of the zone. The family Acrioceratidae occurs with the first specimens of *Dissimilites trinodosus* (Figs. 3 and 6A, B). Within the *N. pulchella* Zone, Phylloceratidae occur with *Phylloceras* sp. and Lytoceratidae with *E. phestum* (Fig. 6P).

Beds within the *N. pulchella* Zone display numbers of species per bed from one to six. Families occur within the zone with numbers per bed from zero to three, the highest numbers being in the uppermost parts (Fig. 7). The Shannon index shows a mean value for the *N. pulchella* Zone of 1.3 (min. 0.9, max. 1.6; beds with no specimens excluded). This indicates a somewhat lowered species richness as seen in the uppermost Barremian *T. hugii* auct. Zone (Fig. 7).

**Discussion.** The base of the *N. pulchella* Zone is defined by the first occurrence of *N. pulchella* (Company et al., 2008). In accordance with Hoedemaeker et al. (2003) the *N. pulchella* Horizon was elevated to the rank of a Zone. The *N. pulchella* Zone also replaces the upper part of the *K. nicklesi* Zone (Hoedemaeker and Rawson, 2000).

Comparable to the Puez section, the *N. pulchella* Zone described by Fözy and Janssen (2006, 2009) from the Gerecse Mountains are typical, with *K. nicklesi* (determined as *Subpulcellia nicklesi* in Fözy and Janssen (2006, 2009)) and *N. pulchella*. The assemblage is dominated by the first species, but numerous *Silesites* sp., frequent *Holcodiscus* sp. and the first occurrences of the genus *Barremites* were reported. The correlatable interval largely lacks ammonites and is not, therefore, yet defined at the Puez locality.

The last specimens of *E. thiollerei* occur together with *A. subcincta* and *Silesites vulpes* in the lower parts of the *N. pulchella* Zone at Angles (southeast France; Vermeulen, 2002). The *N. pulchella* Zone is dominated in the western High Atlas of Morocco by the index ammonite *N. pulchella* accompanied by members such as *A. tabarelli*, *Paraspiticeras* sp., *Hamulinites* sp., *Lytoceras* sp. and *P. ponticuli* along with forms such as *D. cf. potieri*, the first specimens of *M. nodosum* and still frequent *T. barremensis*, which is replaced towards the top by *T. suessi* (Company et al., 2008).

#### 5.6. Kotetishvilia compressissima Zone

The *K. compressissima* Zone extends from the bottom of bed P1/112 up to the top of bed P1/118. The ammonite assemblage is quite similar to the underlying *N. pulchella* Zone but more numerous in species and specimens. The family Desmoceratidae is represented by *Barremites* sp., *M. cassidoides* and *Mechiorites* sp. and the first specimens of *Valdedorsella* cf. *uhligi* and *Valdesorsella* sp. Pulchelliidae appear with typical *Henizia caicedi* (Fig. 6L, M) and *Kotetishvilia* sp. The Acrioceratidae occur with *Dissimilites* sp. The Leptoceratoididae show appearances of *Karsteniceras* sp. (Fig. 6S) and are accompanied by the first members of Ptychoceratidae with *Ptychoceras* sp. (Fig. 6G). Hamulinidae occur with several specimens of *Anahamulina* sp. *Costidiscus nodosostriatum* (Fig. 6H) is the first member of Macroscaphitidae to occur in the uppermost part of the zone. The topmost part of the *K. compressissima* Zone is marked by typical Phylloceratidae with *P. tethys*, *Phylloceras paquieri* and *Phylloceras* sp. in addition to *P. infundibulum* and *Phyllopachyceras eichwaldi*. *L. densifimbriatum* (Fig. 6O), *Lytoceras* sp., the first specimens of *E. phestum* and numerous specimens of *Protetragonites crebrisulcatus* (Fig. 6S) and *Protetragonites* sp. are the members of Lytoceratidae (Fig. 2).

Beds within the *K. compressissima* Zone display numbers of species per bed from three to seven. Nine families occur within the zone with numbers per bed from zero to eight, the highest values

being in the upper half (Fig. 7). The Shannon index shows a mean value for the *K. compressissima* Zone of 1.6 (min. 0.7, max. 2.3; beds with no specimens excluded). The values indicate a lowering of species richness and a low evenness in their abundance compared to those of the *N. pulchella* Zone (Fig. 7).

**Discussion.** The *K. compressissima* and *Moutoniceras moutonianum* Zones were established after a proposal by Company et al. (1995) and replaced the top part of the *K. nicklesi* Zone and the *Holcodiscus caillaudianus* Zone (Hoedemaeker and Rawson, 2000). After Reboulet et al. (2009) this zone is divided into the *Holcodiscus fallax*, *Nicklesia didayana*, *Heinzia communis* and *Subtorcapella defayae* Horizons (Company et al., 1995, 2008; Vermeulen, 2003, 2007a, b; Vermeulen and Klein, 2006).

As noted by Fözy and Janssen (2006, 2009) this zone can be easily recognised in the Gerecse Mountains by the index ammonite *K. compressissima* (determined as *Subpulchellia compressissima* by Fözy and Janssen (2006, 2009)). Numerous holcodiscids occur throughout the zone, including *Holcodiscus gastaldianus*, *H. nicklesi*, *H. cf. perezianus* and *H. fallax*. The latter species seems to be restricted to the lower parts and *H. caillaudianus* to the upper part of the zone (Company et al., 1995; Fözy and Janssen, 2006, 2009). This is reflected in the zonal sheme shown in Reboulet et al. (2009), where an *H. fallax* Horizon is noted in the lowermost part of the *K. compressissima* Zone. After Fözy and Janssen (2006, 2009), *Moutoniceras* appears within that zone, whereby *Moutoniceras nodosum* is first representative. Similar to the *K. compressissima* Zone from Puez, the assemblage from Bersek Quarry shows additional representatives such as *Barremites* sp., *Melchiorites* sp. and the first specimens within Leptoceratoididae with *Karsteniceras pumilum* (Fig. 6D). These are accompanied by numerous Hamulinidae, including *Anahamulina* spp.

Delanoy and Joly (1995) and Joly (2000) reported *P. ponticuli* (as a typical member of Upper Barremian ammonite assemblages but rare in Lower Barremian) at Puez with the first appearance of *P. ponticuli* in the *K. compressissima* Subzone.

Aguado et al. (1992) described Barremian faunas from the Subbetic domain in the Betic Cordillera, characterizing the *Subpulchellia compressissima* Zone (= *K. compressissima*) by the index ammonite *K. compressissima*, *Subpulchellia nicklesi* (= *K. nicklesi* of the recent *K. nicklesi* Zone; Reboulet et al., 2009), *N. pulchella* (index for the recent *N. pulchella* Zone; Reboulet et al., 2009), *Subpulchellia brevicostata* (*K. brevicostata*), *H. perezianus* and *H. caillaudianus*.

At Angles (southeast France), first *K. changarnieri* occur in the stratotype in the uppermost *K. compressissima* Zone in the lower *S. defayae* Horizon (= *S. defayae* Subzone after Vermeulen, 2002). *Macroscaphites*, *Costidiscus* and *E. phestum* seem to originate in the *K. compressissima* Zone at the Puez locality.

The *K. compressissima* Zone is characterized in the western High Atlas of Morocco by a faunal turnover. This begins in the top of the underlying *N. pulchella* Zone, marked by the new index form *K. compressissima* and other pulchelliids *K. didayana*, *Heinzia communis* and, in upper parts, *K. changarnieri*. At the base of the zone, holcodiscids show a characteristic diversification (Company et al., 2006, 2008) with *H. fallax*, *H. perezianus*, *Avramidiscus gastaldianus* and, higher in the zone, *H. caillaudianus*. Ancyloceratoidea are present with *M. nodosum*, *Dissimilites dissimilis* and members of "Toxoceras" and Hamulinidae.

## 5.7. Moutoniceras moutonianum Zone

The occurrence of the index ammonite *M. moutonianum* (bed P1/119) with the co-occurring ammonite assemblage hints at the presence of the *M. moutonianum* Zone at the Puez section (Figs. 2, 3, 6). The *M. moutonianum* Zone corresponds to the interval from the

bottom of bed P1/119 up to the top of bed P1/137. The family Desmoceratidae is represented by *Barremites* sp. and *M. cassiodoides*. Among the Silesitidae, real *S. vulpes* (Fig. 6Q) occur within this zone for the first time. The Acrioceratidae occur once again with *D. trinodosum*. Heteroceratidae are present at the base of the zone for the first time with the zonal index ammonite *M. moutonianum* (Fig. 6C). Hamulinidae occur with several specimens of *Anahamulina* sp. Phylloceratidae are represented by the last individuals of *P. tethys*, *Phylloceras* sp.; moreover, *P. infundibulum* (Fig. 6T, V), *Phyllopachyceras ladinum* and *Phyllopachyceras* sp. also occur. *P. crebrisulcatum* and *Protetragonites* sp. are the members of Lytoceratidae.

Beds within the *M. moutonianum* Zone display numbers of species per bed from one to seven. Seven families occur within the zone with numbers per bed from zero to five, the highest values being in the lowermost beds (Fig. 7). The Shannon index shows a mean value for the *M. moutonianum* Zone of 0.7 (min. 0.0, max. 2.4; beds with no specimens excluded). Values indicate very low species richness and low evenness of abundance compared to other zones (Fig. 7).

**Discussion.** The *M. moutonianum* Zone is defined by the first appearance of its index species and the co-occurrence in upper parts of *Toxancyloceras vandenheckii* (Company et al., 1995). This zone replaced (Reboulet et al., 2009) the former *Coronites darsi* Zone sensu Vermeulen (1997, 1998) and the *C. darsi* Zone sensu Company et al. (2008). The *Heinzia sayni* Zone of Vermeulen (1997, 1998) is equivalent to the *T. vandenheckii* Zone. According to the data of Vermeulen (2005a, b), the first occurrence of *M. moutonianum* coincides with that of *C. darsi* (Company et al., 2008). Reboulet et al. (2009) assumed that the *M. moutonianum* (sensu Company et al., 1995) and *C. darsi* (sensu Vermeulen (1997, 1998)) zones span the same stratigraphic interval. The *M. moutonianum* Zone (= *Coronites darsi* Zone in Company et al., 2008) is subdivided into a *C. darsi* Horizon and a younger *H. caicedi* Horizon (Reboulet et al., 2009).

Within the Gerecse Mountains, Fözy and Janssen (2006, 2009) noted the presence of the index species *M. moutonianum* and the genus *Heinzia* with *Heinzia* sp. and *Heinzia* cf. *heinzi*. It was accompanied by *Holcodiscus* spp., Hamulinidae with *Anahamulina* and Acrioceratidae with *Dissimilites*. These authors reported the index ammonite co-occurring with abundant *K. changarnieri* and *K. sauvageaui* (= *Subpulchellia changarnieri* and *Subpulchellia sauvageaui* by Fözy and Janssen (2006, 2009)). Numerous specimens of the genus *Heinzia* occur, and *H. caicedi*, when abundant, is typical for that zone. Note that the *H. caicedi* Horizon in Reboulet et al. (2009) encompasses the upper half of the *M. moutonianum* Zone: *H. caicedi* occurs a few beds lower in the *K. compressissima* Zone at Puez. The family Desmoceratidae shows mass occurrences of *Barremites* and *Melchiorites* in single beds (Fözy and Janssen, 2006, 2009). *Macroscaphites* cf. *binodosus* and *Costidiscus* sp. are present together with *Ptychoceras puzosianum* within that zone (Fözy and Janssen, 2006, 2009).

*Ptychoceras puzosianum* occurs somewhat later during the *Toxancyloceras vandenheckii* Zone in the Subbetic region (southeast Spain; Company et al., 1995). In contrast, it was found only much higher at Puez in the *G. sartousiana* Zone. The Acrioceratidae in Spain occur once again with *Dissimilites trinodosum*, and Hamulinidae occur with several species of *Anahamulina* sp.

Avram (1994, 2001) defined the ranges of *D. dissimilis*, *D. trinodosum* and *D. subalternatus* within the Romanian Carpathians. He assumed that *D. dissimilis* was present only in the uppermost lower Barremian, whereas *D. trinodosum* and *D. subalternatus* were characteristic for both the uppermost Lower Barremian and lowermost Upper Barremian. The occurrence of *D. trinodosum* at Puez fits this interpretation. The same situation

was described for southeast France by Ebbo et al. (2000) for a range of *D. trinodosum* starting in the *K. compressissima* Zone and reaching up to the *M. moutonianum* Zone. According to Vermeulen (2007a), species of the genus *Costidiscus* appear from the *T. vandenheckii* Zone and derive from ancestors in the base of the *M. moutonianum* Zone (= *C. darsi* Zone of Vermeulen, 2007a). As noted above, at Puez *Costidiscus nodosostriatum* occurs at the uppermost part of the *K. compressissima* Zone or *K. compressissima/M. moutonianum* boundary interval. Vermeulen (2007a) rejected the idea of *Costidiscus*—*Macroscaphites* being a sexually dimorphic pair owing to their different stratigraphical range, with *Costidiscus* appearing in the *T. vandenheckii* Zone and *Macroscaphites* in the *K. compressissima* Zone in southern France. The same situation is shown herein and strengthens Vermeulen's assumption, which contrasts with the remarks made by Avram (1984), Delanoy et al. (1995), Wright et al. (1996) and Delanoy et al. (2008). Fözy and Janssen (2006, 2009) reported that both *Macroscaphites* and *Costidiscus* were present in the *M. moutonianum* Zone in the Gerecse Mountains of Hungary.

Uhlig (1883) and Vašíček and Wiedmann (1994) noted the typical occurrence of *Karsteniceras pumilium* in the Lower Barremian of the Silesian Unit (Czech Republic), which is in accordance to the specimens found at Puez. Avram (1994) reported a faunal condensation in the lowermost Barremian of the South Carpathian region around Svinia. Nevertheless, the overall assemblages are almost identical to the Puez faunas in that they comprise, from the beginning, *D. favrei*, *Barremites* spp., *Hoclodiscus* sp. and *S. vulpes*. According to Avram (1994) the first representatives of *Macroscaphites* and *Costidiscus* occur together with *E. phestum* in the lowermost Upper Barremian of the Svinia region, i.e., *T. vandenheckii* Zone. *Macroscaphites*, *Costidiscus* and *E. phestum* seem to arise earlier in the *K. compressissima* Zone at the Puez locality.

The *M. moutonianum* Zone of the Subbetic domain in the Betic Cordillera was described by Aguado et al. (1992) based on the presence of abundant *Moutoniceras* sp. specimens and *Subpulchellia* (= *Kotetishvilia*) and *Hoclodiscus*. In Vermeulen's (2002) report on pulchelliids from the stratotype of Angles (southeast France), the *Coronites darsi* Zone (= *M. moutonianum* Zone in Reboulet et al., 2009) contains *K. changarnieri* (throughout) and *K. sauvageaui* (upper part). The base of the Upper Barremian is, according to Vermeulen (2002), marked by the *H. uhligi* Zone (= lower part of the *T. vandenheckii* Zone after Reboulet et al., 2009), which is characterized by the co-occurrence of *H. uhligi*, *K. changarnieri*, *K. sauvageaui*, *T. vandenheckii* and rare specimens of *Moutoniceras* and *Dissimilites*. The *H. uhligi* Zone after Vermeulen (2002) is followed by Vermeulen's *H. sayni* Zone (= upper part of the *T. vandenheckii* Zone after Reboulet et al., 2009), typical in showing *H. sayni*, *Dissimilites* sp., *B. barremense*, *Macroscaphites* aff. *binodosus*, *Ancyloceras vandenheckii* (= *T. vandenheckii*) and *S. seranonis*. The *G. sartousiana* Zone, and especially the comparable *G. sartousiana* Subzone, is characterized by the index ammonite and the co-occurrence of *Camereiceras* cf. *limentinus*, *S. seranonis* and *Ezeiceras janus* (= *Janusites janus*). The *Coronites darsi* Zone (= *M. moutonianum* Zone in Reboulet et al., 2009) is marked in the western High Atlas of Morocco by the rare occurrence of *C. darsi* and more abundant *M. moutonianum*. Additionally, *D. dissimilis*, *Barremites vocontius* and "Melchiorites" *rumanus* are frequent and appear with *C. darsi*, *K. changarnieri*, *T. suessi*, *Hoclodiscus diversecostatus*, *H. perezianus* and *S. vulpes*. *M. moutonianum* is replaced by "Barrancyloceras" *maghrebienne* in the upper part of the Zone.

### 5.8. Toxancyloceras vandenheckii Zone

The *T. vandenheckii* Zone extends from the bottom of bed P1/138 up to the top bed P1/193 (Figs. 2, 3, 7, 8). The appearance of the index ammonite *T. vandenheckii* in bed P1/138 marks the lower

boundary of the *T. vandenheckii* Zone (Figs. 2, 3, 8). The *T. vandenheckii* Zone is subdivided into the *T. vandenheckii* Subzone and the younger *B. barremense* Subzone. Owing to the absence of the subzonal index ammonites, the *T. vandenheckii* Zone is tentatively subdivided into two equal parts at bed P1/172, which corresponds with the last occurrence of *Heinzia* cf. *sayni* (Fig. 8V). The zone occurs with a typical ammonite fauna comprising members of the family Desmoceratidae, with *Barremites* sp., *Valdedorrella* sp., *M. cassiodoides* and *Mechiorites* sp. *Silesitidae* occur with *S. vulpes* (Fig. 8S) and *Silesites* sp. throughout the zone. *Hoclodiscus* cf. *uhligi* (Fig. 8U) and *Hoclodiscus* sp. occur within the *Hoclodiscidae* only in the lower part of the *T. vandenheckii* Zone. *Pulchelliidae* appear with typical *H. cf. sayni*, *K. changarnieri* (Fig. 8X) in the lower part and additional specimens of *K. sauvageaui* in both parts. *Emericiceratidae* occur with *Emericiceras* sp. in the upper part of the zone. *Acrioceratidae* with *D. trinodosum* (Fig. 8G, H) and *Dissimilites* sp. are frequent in the lower part and are accompanied by the zonal index species *T. vandenheckii* (Fig. 8A, B) and an additional specimen of *Toxancyloceras* sp. (Fig. 8C) within the family Ancyloceratidae. Within the family Leptoceratoididae, *Karsteniceras* sp. (Fig. 8I) occurs in the lower part of the zone. *Hamulinidae* occur only in the lower part with *Hamulina* sp., *Anahamulina* cf. *uhligi*, *Anahamulina* sp. and with *Pychohamulina* cf. *acuaria* (Fig. 8L) in both parts. The lower part shows members of *Duyeina* cf. *kleini* (Fig. 8M) and *Duyeina* sp., whereas the upper part is characterized by the occurrence of the hamulinid member *Vasicekina* cf. *pernai* (Fig. 8K). *Macroscaphitidae* occur with only one specimen at the base, along with *Costidiscus* sp. Typical members within the Phylloceratidae occur throughout the zone and include *P. ponticuli*, *Phylloceras* sp., *P. infundibulum*, *P. eichwaldi*, *Phyllopachyceras* sp. and *Sowerbyceras ernesti*. *Lytoceratidae* are represented by *L. densifimbriatum*, *Lytoceras* sp., *P. crebrisulcatum* and *Protetragonites* sp. throughout the *T. vandenheckii* Zone.

Beds within the *T. vandenheckii* Zone display numbers of species per bed from one to nine. Twelve families occur within the zone with numbers per bed from zero to eight, with highest numbers dispersed throughout the zone (Fig. 7). If separated into the *T. vandenheckii* Subzone and *B. barremense* Subzone the former contains eleven families and the latter seven. The Shannon index shows a mean value for the *T. vandenheckii* Zone of 1.1 (min. 0.0, max. 2.6; beds with no specimens excluded). Values indicate slightly higher values of species richness and higher evenness of abundance compared to the *M. moutonianum* Zone (Fig. 7).

**Discussion.** The *T. vandenheckii* Zone is marked by the first appearance datum of the index ammonite (= Lower/Upper Barremian boundary; Rawson et al., 1999) and the co-occurrence *G. sartousiana* in the upper parts (Company et al., 2008; Reboulet et al., 2009). After Reboulet et al. (2009) the *T. vandenheckii* Zone is subdivided into the *T. vandenheckii* Subzone and the younger *Barrancyloceras barremense* Subzone. The former *H. sayni* Subzone (Reboulet et al., 2006) was replaced by the lower *T. vandenheckii* Subzone (Reboulet et al., 2009). After Vermeulen (2005b), *Duyeina kleini* is characteristic for the *G. sartousiana* Zone and *Gerhardtia provincialis* Zone, which were both incorporated into a single *G. sartousiana* Zone with a lower *G. sartousiana* Subzone, a middle *G. provincialis* Subzone and an upper *Hemihoplites feraudianus* Subzone. In southern France the genus *Duyeina* itself appears throughout the Upper Barremian and has its ancestors in the *T. vandenheckii* Zone (Vermeulen, 2005b), which subsequently could be the case with the specimen herein (i.e., *Duyeina* cf. *kleini*; Figs. 3 and 8). The species *K. changarnieri* and *K. sauvageaui* are first present at Puez within the *T. vandenheckii* Zone (lower part = *T. vandenheckii* Subzone). The first specimens of

*K. sauvageaui* in southern France occur in the *M. moutonianum* Zone within the *H. caicedi* Horizon (Vermeulen, 1998), whereas *K. changarnieri* has its acme in southern France within the *K. compressissima* Zone and disappears in the *Heinzia sayni* Zone (uppermost *T. vandenheckii* Zone of Reboulet et al., 2009).

The same range for *K. sauvageaui* was reported from Algeria by Vermeulen and Lahondère (2008). At Puez, *H. cf. syani* is reported only from the *T. vandenheckii* Subzone. In Algeria, *H. syani* occurs in the upper part of the *T. vandenheckii* Zone, which is comparable to the *H. sayni* Zone after Vermeulen (2007a, b). It disappears in the Tethyan region at the base of the *B. barremense* Subzone (after Vermeulen and Lazarin, 2007). Vermeulen and Lazarin (2007) subdivided the *T. vandenheckii* Zone into *T. vandenheckii*, *H. sayni* and *B. barremense* subzones. This scheme was redefined by Reboulet et al. (2009) into a *T. vandenheckii* Subzone and a younger *B. barremense* Subzone.

Upper Barremian ammonite biohorizons for southeast France were discussed by Bert et al. (2008). The biozone is marked by the strong diversification of the Ancyloceratoidae (*Toxan-cyloceras*, *Barrancyloceras*) and Acrioceratidae (*Dissimilites*). The *T. vandenheckii* Zone after Bert et al. (2008) is characterized by the co-occurrence of *Heinzia syani*, *Kotethisvila* sp., *Gassendiceras* sp., *Barrancyloceras* sp. and *T. vandenheckii*. The *T. vandenheckii* Zone after Bert et al. (2008) included the lower *Holcodiscus uhligi*, the middle *H. sayni* and the upper *B. barremense* subzones, and several additional biohorizons were introduced. The lower two subzones are time equivalent to the *T. vandenheckii* Subzone after Reboulet et al. (2009).

According to Fözy and Janssen (2006, 2009) the *T. vandenheckii* Zone is the topmost preserved zone at the Bersek Quarry, shown by the presence of the index ammonite and *H. sayni*. This agrees with the occurrence of *H. sayni* at Puez within the entire *T. vandenheckii* Zone. The authors reported the *T. vandenheckii* Zone by determining *T. vandenheckii*, *H. sayni* and an additional fauna comprising *Kotethisvila* sp. (determined as *Subpulchellia* in Fözy and Janssen (2006, 2009)), *Holcodiscus* spp., *Dissimilites* sp., *Anahamulina* sp., abundant *Melchiorites* and *Barremites* sp., *Barremites* ex. gr. *difficilis* and *Karsteniceras* sp. Both the Puez area and the Gerecse Mountains show the occurrence of small Leptoceratoididae with *Karsteniceras* and Hamulinidae with *Hamulina* sp., *A. cf. uhligi*, *Anahamulina* sp. and *Pychohamulina* cf. *acuaria* (= *Anahamulina* cf. *acuaria* in Fözy and Janssen (2006, 2009)).

Vašíček (1996) also reported *T. vandenheckii* from the central Western Carpathians (Butkov, Quarry, Slovakia). From the Silesian of the Czech Republic, Vašíček (1999), Vašíček et al. (2004) reported a typical Upper Barremian assemblage including *Macroscaphites binodosus* and *M. yvani*, and *C. nodosostriatus* within the *T. vandenheckii* Zone. Vašíček (2008) figured a specimen of *K. ex. gr. sauvageaui*, described as deriving from the Upper Barremian from the Silesian Unit (Western Carpathians). Patrulius and Avram (2004) described but did not figure an assemblage comprising *K. changarnieri* and *Pulchellia caicedi* (= *H. caicedi*) as typical for their *M. moutonianum* Zone.

Company et al. (1994) reported a comparable fauna from the *T. vandenheckii* Zone in the Sierra del Corque (Capres section CP2) from an intermittent zone between the Subbetic and Prebetic Ranges (southeast Spain). The *T. vandenheckii* assemblage at Capres is characterized by the typical co-occurrence of *P. infundibulum*, *M. cassidoides*, *Barremites* spp., *Holcodiscus* spp., *K. sauvageaui* and *K. cangarnieri* (*Subpulchellia sauvageaui* and *S. changarnieri* of Company et al., 1994), *D. trinodosum*, and *T. vandenheckii* (= *Ancyloceras vandenheckii* in Company et al., 1994). Aguado et al. (1992) described Barremian faunas from the Subbetic domain in the Betic Cordillera with *Emericiceras barremense* (= *B. barremense*), *Hemihoplites feraudi* and *Heteroceras astieri* zones for the Upper

Barremian. The Upper Barremian *E. barremense* (= *B. barremense*) Zone was reported with *Heinzia provincialis* (*G. provincialis*, index for *G. provincialis* Subzone: Reboulet et al., 2009), *Subpulchellia* (= *Kotetishvilia*), *Leptoceratoides* and the last members of Holcodiscidae. The *H. feraudi* Zone (= uppermost *H. feraudianus* Subzone of the *G. sartousiana* Zone; Reboulet et al. (2009)) was characterized by the presence of *Macroscaphites yvani* and *M. ectotuberculatus*, *Costidiscus* sp., *B. strettostoma*, *S. seranonis*, *Pseudohaploceras* and *Ptychoceras* sp. Additionally *Hemihoplites* and the last *Subpulchellia* (= *Kotetishvilia*) occur. The *H. astieri* Zone was reported with a specimen of *Heteroceras* sp. The *T. vandenheckii* Zone is not well represented in the western High Atlas area in Morocco (Company et al., 2008); it is marked only by the index ammonite and by several members at the base such as *H. sayni*, the last *M. moutonianum*, *Barremites* sp. and in the upper parts, new forms such as *B. barremense* sp. or *K. sauvageaui*.

### 5.9. Gerhardia sartousiana Zone

The *G. sartousiana* Zone at the Puez section extends from the bottom of bed P1/194 up to the end of log P1 with the top of bed P1/204. The lower boundary is fixed by the first appearance of the zonal index ammonite *G. sartousiana* in bed P1/194 (Figs. 2, 3, 8). Desmoceratidae are represented by *Barremites difficilis* and *Barremites* sp., ?*Pseudohaploceras* sp. (Fig. 8Q), and abundant *M. cassidoides* (Fig. 8R) and *Melchiorites* sp. Silesitidae occur with numerous *S. vulpes* (Fig. 8T). Within the Holcodiscidae, one last specimen of *Holcodiscus* sp. was found. Pulchelliidae appear with the typical genus-pairing of the zonal index species *G. sartousiana* (Fig. 8W, Y, Z, Za), *Gerhardia* sp. and *K. sauvageaui* (Fig. 8Zb, Zc). Representatives of the Ancyloceratinae first appear (*Audouliceras* sp.; Fig. 8D–F). Ptychoceratidae occur with typical *P. puzosianum*. Hamulinidae show *Anahamulina* sp. and *P. cf. acuaria*. Macroscaphitidae appear with their most frequent members, namely *M. yvani* (Fig. 8N, O), *Macroscaphites* sp., *Costidiscus recticostatus* (Fig. 8P) and *Costidiscus* sp. Phylloceratidae show a characteristic assemblage of *P. ponticuli* (Fig. 8Ze), *Phylloceras* sp., *P. infundibulum* (Fig. 8Zf), *P. eichwaldi*, *P. ladinum*, *Phyllopachyceras* sp. and *S. ernesti*. Lytoceratidae are represented by *L. densifimbriatum*, *Lytoceras raricinctum*, *Lytoceras* sp., *E. phestum* (Fig. 8Zd), *P. crebrisulcatum* and *Protetragonites* sp. throughout the *G. sartousiana* Zone.

Beds within the *G. sartousiana* Zone display numbers of species per bed from one to fourteen. Ten families occur within the zone with numbers per bed from one to nine, the highest numbers being in the middle part, but high throughout the zone (Fig. 7). The Shannon index shows a mean value for the *G. sartousiana* Zone of 1.6 (min. 0.0, max. 2.2; beds with no specimens excluded). Values indicate (not significant) slightly higher values of species richness and higher evenness of abundance compared to the *T. vandenheckii* Zone (Fig. 7). Nevertheless, single beds within this zone have yielded abundances of ammonites with over 120 (bed 197) or even more than 200 specimens per bed (bed 199).

**Discussion.** *G. sartousiana* appears in the *G. sartousiana* Zone and disappears within the *G. provincialis* Subzone in Algeria (Vermeulen and Lahondère, 2008) and southern France (Vermeulen, 2002). Delanoy (1994, 1997) described typical assemblages from the *G. sartousiana* Zone from the "Coupe Vergons 2" section (southeast France). The fauna comprises similar assemblages with *K. sauvageaui* (Delanoy's *Psilotissotia sauvageaui*) and members of genera such as *Macroscaphites*, *Costidiscus* and *S. vulpes*, *P. ponticuli*, *P. infundibulum* and *E. phestum*. Delanoy (1997) described the same assemblage as typical for the *G. sartousiana* Zone in southeast France. Upper Barremian ammonite biohorizons for this region were discussed by Bert et al. (2008). They reported the anomalies in

the first occurrence of different sections and therefore had difficulty marking the lower boundary of the *G. sartousiana* Zone. New ammonite biohorizons provided by Bert et al. (2008) were not accepted and transferred to the ammonite zonation scheme for the Mediterranean by the Kilian Group (Reboulet et al., 2009). Bert et al. (2008) summarized the strong diversification in Hemihoplitidae and the coeval decrease in pulchelliids after the acme of *G. sartousiana*. This acme zone is most probably the last ammonite assemblage determined at Puez. The *G. sartousiana* Zone after Bert et al. (2008) included the lower *Camereiceras limentinus*, the middle *Gerhardtia provincialis* and the upper *Hemihoplites feraudianus* subzones. Equivalents are the *G. sartousiana*, the *G. provincialis* and the *H. feraudianus* subzones after Reboulet et al. (2009). The *G. sartousiana* Zone after Bert et al. (2008) is characterized by the co-occurrence of *G. sartousiana*, *G. provincialis*, *C. limentinus*, *Hemihoplites* spp. and *Audouliceras* sp. (in upper parts). Hemihoplitidae with the genera *Hemihoplites*, *Gassendiceras* and *Pseudoshasticriceras* (see Bert and Delanoy, 2009; Bert et al., 2008) are still missing at the top of the Puez section (log P1), implying the absence of the time equivalent beds from the middle part of the *G. sartousiana* Zone, i.e., the *G. sartousiana/provincialis* boundary upwards. It is difficult to correlate with species determined by Cecca and Pallini (1994; see also Vermeulen and Klein, 2006) because no exact zonation is given and the boundaries are therefore uncertain. Nonetheless, faunas seem to appear with same constituents as those of the Late Barremian time intervals detected at Puez.

Reboulet et al. (2009) divided the *G. sartousiana* Zone into the *G. sartousiana* Subzone, the *G. provincialis* Subzone and the youngest *H. feraudianus* Subzone. After Bert et al. (2008) the former zone of *H. feraudianus* was lowered to the rank of a subzone and occupies the upper part of the *G. sartousiana* Zone (Reboulet et al., 2009). Concerning the arguments given by Reboulet et al. (2009), the boundary between the *G. sartousiana* and *Imerites giraudi* zones is characterized by an important faunal turnover marked by the disappearance of Pulchellidae and Hemihoplitinae. Based on the ammonite assemblage and further lithological and microfossil analysis, the upper two ammonite subzones, i.e., the *G. provincialis* and *H. feraudianus* subzones, are probably missing and a hiatus occurs at this time at the top of log P1 after bed P1/204. Bed P1/204 is directly overlain by Aptian sediments. The hiatus in the mid *G. sartousiana* Zone is comparable to situations in southeast Spain (Company et al., 1994), where in the Capres section the *G. sartousiana* (including *H. feraudianus* Subzone) and *Imerites giraudi* zones are condensed within only 2 m. The condensed lower part was determined by the index species of *G. sartousiana* (*Heinzia sartousiana* in Company et al., 1994).

The *G. sartousiana* Zone was reported only from the most distal localities in the western High Atlas. The ammonites are reworked and show signs of condensation there. Company et al. (2008) reported a mixture of lower zone ammonites such as *K. brevicostata*, *Janusites* cf. *janus* and *Camereiceras* sp. with ammonite forms characteristic for the upper part such as *G. provincialis*, *Pachyhemihoplites contei* or *P. gerthi* and *M. cassidoides* (both zones).

Bodin et al. (2006) discussed the Urgonian platform carbonates in the Helvetic Alps (Switzerland). They demonstrated that the time of the *G. sartousiana* Zone is coeval with the increasing productivity of the Urgonian facies around the western Tethyan Realm. Godet et al. (2008) showed that, during the time represented by the *B. balearis* Zone, a change to a more humid climate occurred; this predates the Faraoni Event and the demise of the carbonate platform of the Helvetic zone, lasting from the Late Hauterivian *Spathioceras angulicostatus* and *P. mortilleti* Zone (zonation of Godet et al., 2008; = "P. ohni" Zone in Reboulet et al., 2009) until the late Early Barremian *C. darsi* Zone (= *M. moutonianum* Zone in Reboulet

et al., 2009). From *G. sartousiana* Zone times, the carbonate production on the platforms increased again, subsequently accompanied by a remarkable sea-level rise (Adatte et al., 2005; Arnaud, 2005; Godet et al., 2008). Lithological differences observed around the Puez are clearly consequences of an altered palaeo-oceanography and therefore reflect sea-level fluctuations during the Early Cretaceous, especially within the early Late Barremian (i.e., the *G. sartousiana* Zone). A major rise in sea level took place during the time represented by the *G. sartousiana* Zone (Adatte et al., 2005; Arnaud, 2005) of the uppermost Puez Limestone Member (lower Puez Formation; Puez/log 1), containing the Melchiorites-Level (beds P1/194–204), which is dominated by the genera *Melchiorites* and *Silesites* (Figs. 2, 5, 7). Company et al. (2005) interpreted *Barremites*, comparable to the morphotype *Melchiorites*, as being epipelagic nekton and *Silesites* was described as nektobenthic.

"Faunal turnover", "mass-occurrence", and "migrations" have always been considered as being controlled by transgressive and regressive cycles in various Lower Cretaceous ammonite groups (Rawson, 1981; Hoedemaeker, 1990). This phenomenon was described by Bulot (1993) as Opportunity HUFs (Horizons of Faunal uniformity). Opportunity HUFs were determined to be locally controlled by changing conditions marked by the change in palaeogeographic distribution or of palaeoecological ranges of different ammonite groups. The remarkable assemblage change within the Melchiorites-Level (*G. sartousiana* Zone) reflects a complex of changes in eustasy and in primary bioproductivity (Lukeneder, 2003, 2004b).

## 6. Conclusions

The macrofauna of the Puez Formation at the Puez section, especially of the Puez Limestone Member, is mainly represented by ammonites. Over 1200 ammonite specimens were collected by bed-by-bed sampling. Aptian and Albian members such as the Puez Redbed Member and the Puez Marl Member are almost barren in ammonites and other macrofossils. The ammonite zonation is based on the most recent standard zonation of the international Kilian Group on Lower Cretaceous ammonites (Reboulet et al., 2009). Several zones and even subzones based on the presence of Mediterranean index ammonites, such as the *C. krenkeli*, *P. mortilleti*, *P. picteti*, *M. moutonianum*, *T. vandenheckii* and *G. sartousiana* ammonite zones, were detected. Zones missing in index ammonites are characterized by their typical ammonite associations. The fossiliferous parts of the log begin with the Upper Hauterivian *B. balearis* Zone (*B. binelli* Subzone). The ammonite-rich section ends with a significant hiatus within the lower Upper Barremian *G. sartousiana* Zone (*G. sartousiana* Subzone). This hiatus is marked at the top of bed 204 by an omission horizon, and is directly overlain by the Aptian Puez Redbed Member. The situation is comparable to that of other localities located in southeast Spain and Morocco. The Upper Barremian–Lower Aptian hiatus extends from the middle part of the *G. sartousiana* Zone up to the base of the Aptian, reflecting the absence of at least the topmost part of the *G. sartousiana* Subzone (i.e., *H. feraudianus* Subzone) and the entire *I. giraudi* Zone.

The ammonite assemblage clearly indicates a Mediterranean character, as reported from numerous comparable Lower Cretaceous localities in east-central European (Czech Republic, France, Hungary, Slovakia, Spain), eastern Europe (Bulgaria, Romania) and African localities (Algeria, Morocco). The fauna is dominated by phylloceratids (*P. infundibulum*, *P. tethys*), lytoceratids (*Lytoceras*, *Eulytoceras*, *Protetragonites*), desmoceratids (*Barremites*, *Melchiorites*, *Silesites*) and anycycloceratids (*Anahamulina*, *Crioceratites*, *Dissimilites*, *Karsteniceras*, *Pseudothurmannia*, *Toxancyloceras*).

Ammonite abundances are strongly correlated to single intervals of the section. Ammonite-rich beds were detected within the *C. krenkeli* Zone, the *T. vandenheckii* Zone and the topmost *G. sartousiana* Zone. Abundance peaks occur in bed 66 ( $n > 60$ ) in the *C. krenkeli* Zone and in the *G. sartousiana* Zone in beds 197 ( $n > 120$ ) and 199 ( $n > 200$ ). The evaluation of biodiversity calculated by the ratio between number of species vs. number of individuals per species (Shannon index) shows no clear significance throughout the Puez section, although varying from highstand and maximum flooding phases from the Upper Hauerivian with mean values of 1.6 down to (in steps) values of 0.7 in the Lower Barremian *M. moutonianum* Zone. The Hauerivian is dominated by *Pseudothurmannia*–*Crioceratites*–*Plesiospitiidiscus*, the Barremian by *Kotetishvilia*–*Melchorites*–*Silesites*. Ammonite abundances are clearly linked to sea-level changes from Late Hauerivian to mid Late Barremian times. Abundance and diversity peaks occur during phases of high sea-level pulses and the corresponding maximum flooding surfaces (*P. mortilleti*/*P. picteti* and *G. sartousiana* Zone). The Lower Barremian strata at Puez require more sampling for a more detailed zonation. The uppermost Hauerivian to lowermost Barremian interval has often been reported to be difficult for biostratigraphy because of a potential condensation or a manifestation of a hiatus (Patrulius and Avram, 2004; Company et al., 1994). The ammonite data are the first step in a detailed biostratigraphic scheme for the Puez key-section. More investigations at the stratotype of the Puez Formation will be carried out within the Dolomite project P20018-N10 (project of the Austrian Science Fund FWF). Additional ammonite collections will be carried out in future to determine the exact position of stage-, zone-, and subzone-boundaries. Analyses will include palaeomagnetic, isotope and geochemical analyses along with a detailed biostratigraphy based on micro- and nannofossils.

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