Ann. Naturhist. Mus. Wien, Serie A	113	9–33	Wien, Mai 2011

The Biancone and Rosso Ammonitico facies of the northern Trento Plateau (Dolomites, Southern Alps, Italy)

By Alexander LUKENEDER[1]

(With 6 figures)

Manuscript submitted on June 18th 2010,
the revised manuscript on November 11th 2010

Abstract

Information is provided about the Rosso Ammonitico and Biancone facies from the Puez area (Col de Puez, Southern Alps) near Wolkenstein (S. Tyrol, Italy). At the Puez locality, the Rosso Ammonitico – a red, nodular limestone facies – shows its latest occurrence (Valanginian) on the northern part of the Trento Plateau. This plateau represents a submarine high during the Lower Cretaceous. The term Rosso Ammonitico Puezzese is established for this Valanginian, red, nodular facies on the Gardenaccia Plateau. The succession of the greyish Biancone Formation and the reddish Rosso Ammonitico facies sheds light on the early Lower Cretaceous tectonic history of the Trento Plateau and the Dolomites. This helps determine to the evolution of plateaus and platforms (Trento Plateau and Friuli Platform) and of the surrounding basins (Lombardian Basin and Belluno Basin).

Keywords: Biancone Formation, Rosso Ammonitico Puezzese, Early Cretaceous, Dolomites, Italy

Zusammenfassung

Die Rosso Ammonitico und Biancone Fazies werden aus dem Puez Gebiet (Col de Puez, Südalpen) nahe Wolkenstein (S. Tirol; Italien) beschrieben. An der Lokalität Puez zeigt die Rosso Ammonitico Fazies das letzte bekannte Auftreten (Valanginium) dieser roten-knolligen Kalk Fazies am nördlichen Teil des Trento Plateaus, einer submarinen Erhöhung zur Zeit des Unterkreide. Der Terminus Rosso Ammonitico Puezzese wird für die rote, knollige Fazies des Valanginiums, auf dem Gardenaccia Plateau eingeführt. Die Abfolge von grauen Biancone und rötlichen Rosso Ammonitco Kalken wirft Licht auf die tektonische Geschichte der frühen Unterkreide des Trento Plateaus und der Dolomiten, und erlaubt somit die Entwicklung von Plateaus (Trento Plateau und

[1] Natural History Museum, Geological-Palaeontological Department, Burgring 7, 1010 Wien, Austria; e-mail: alexander.lukeneder@nhm-wien.ac.at

Friuli Pattform) und der umgebenden Becken (Lombardisches Becken und Belluno Becken) zu erfassen.

Schlüsselworte: Biancone-Formation, Rosso Ammonitico Puezzese, Unter-Kreide, Dolomiten, Italien

Introduction

The geology of the Dolomites and adjacent areas has been described and summarized in detail by Heissel (1982), Doglioni (1987, 2007), Avanzini & Wachtler (1999), Pozzi (1993), Geyer (1993), Bosellini (1998), Bosellini et al. (2003), Lukeneder & Aspmair (2006), and Lukeneder (2008, 2010). Cretaceous sediments cover relatively restricted areas in the Southern Alps (Dolomites) and form a minor element of the higher Dolomites (Hoernes 1876; Mojsisovics 1879; Haug 1887, 1889; Uhlig 1887; Rodighiero 1919; AGIP Mineraria 1959; Baccelle & Lucchi-Garavello 1967a, b; Stöhr 1993, 1994; Costamoling & Costamoling 1994). According to recent investigations of Muttoni et al. (2005), the Lombardian Basin – and thus the adjacent Trento Plateau to the east – were located approx. at 35°N to 25°N in the Early Jurassic, at 10°N in the Middle-Late Jurassic (lowest in the Kimmeridgian), at approx. 20°N in the Early Cretaceous (Valanginian-Hauterivian) time and back to almost 30°N in the Aptian.

The complex Mediterranean palaeogeography of Jurassic and Cretaceous domains (Fourcade et al. 1993) is characterized by microplates in the middle of the Tethyan oceanic corridor between the African and European landmasses. According to numerous authors (Cecca 1998; Dercourt et al. 1993; Scotese 2001; Stampfli & Mosar 1999; Stampfli et al. 2002; Vašíček 1994; Vašíček, et al. 1994; Vašíček & Michalík 1999; Zharkov et al. 1998), the region of the Southern Alps, including the investigated area (e.g. Puez area), was situated at the northern border during the Jurassic and Early Cretaceous. This area represents a passive continental margin of the Apulian Plate (Jud 1994) of the South Alpine-Apennine Block. It was limited by the Penninic Ocean (= Alpine Tethys) to the north-west and the Vardar Ocean to the south-east (Dercourt et al. 1993; Scotese 2001; Stampfli & Mosar 1999; Stampfli et al. 2002).

In the Dolomites, which were a northern part of the Trento Plateau in the Mesozoic, cephalopod-bearing deposits are mainly recorded in three different Lower Cretaceous facies: the calcareous limestones of the Biancone Formation (= Maiolica Formation elsewhere in Italy), the red, nodular Rosso Ammonitico Formation, and marls to marly limestones of the Puez Formation (Lukeneder 2010). Lower Cretaceous relics are situated on the Triassic limestones of the Dolomites and known from successions at the Col de la Soné (2633 m), Muntejela (2666 m), Sassongher (2615 m), and Anderiöl (2510 m). The Piz de Puez (= Puez Spitzen, 2846 m) together with the Col de Puez (Puezkofel, 2725 m) form the major Lower Cretaceous wall starting at about 2400 m above sea level (Lukeneder 2010).

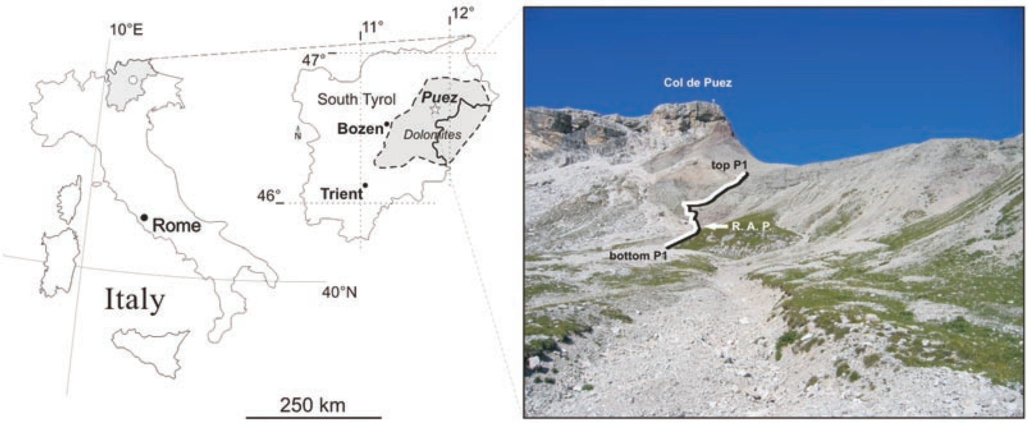


Fig. 1. Locality map of the Puez area with indicated outcrop position of the main log Puez P1/1 (left) within the Dolomites (S. Tyrol, Italy). R. A. P. = Rosso Ammonitico Puezzese.

The studied section is located in the Southern Alps (Dolomites) of northern Italy (CITA & PASQUARÉ 1959; LUKENEDER & ASPMAIR 2006; LUKENEDER 2008, 2010). The stratigraphy of the Lower Cretaceous sediments here is based on micro- and nannofossils (e.g. foraminifera, calpionellids and dinoflagellates; LUKENEDER (2010)). 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), MOJSISOVICS (1879), UHLIG (1887) and RODIGHIERO (1919). This was supplemented by collections of POZZI (1993), LUKENEDER & ASPMAIR (2006) and LUKENEDER 2008). Additionally, microfacies and ammonites were reported from the "Alpe Puez" by CITA & PASQUARÉ (1959) and CITA (1965), leading them to assume a Hauterivian to 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 & LUCCHI-GARAVELLO (1967a, b) and STÖHR (1993, 1994). The latter papers compared the faunas from La Stua with the Puez ammonite faunas described by HAUG (1887, 1889) and UHLIG (1887). FARAONI et al. (1995, 1996) reviewed the papers published on Cretaceous ammonites of the Maiolica Formation from the Venetian Alps (Biancone *Auctt.*), which directly adjoin to the south of the Dolomites, and the real Maiolica Formation of the Central Apennines.

The main goal is to clarify the confusing situation and terminology of reddish limestones in the Southern Alps, especially at the Puez area comprising the stratotype of the Puez Formation. The presented lithological data on the Rosso Ammonitico and Biancone facies types are provided from investigations carried out within the Dolomite project P20018–N10 (project of the Austrian Science Fund FWF).

Geographical and geological setting

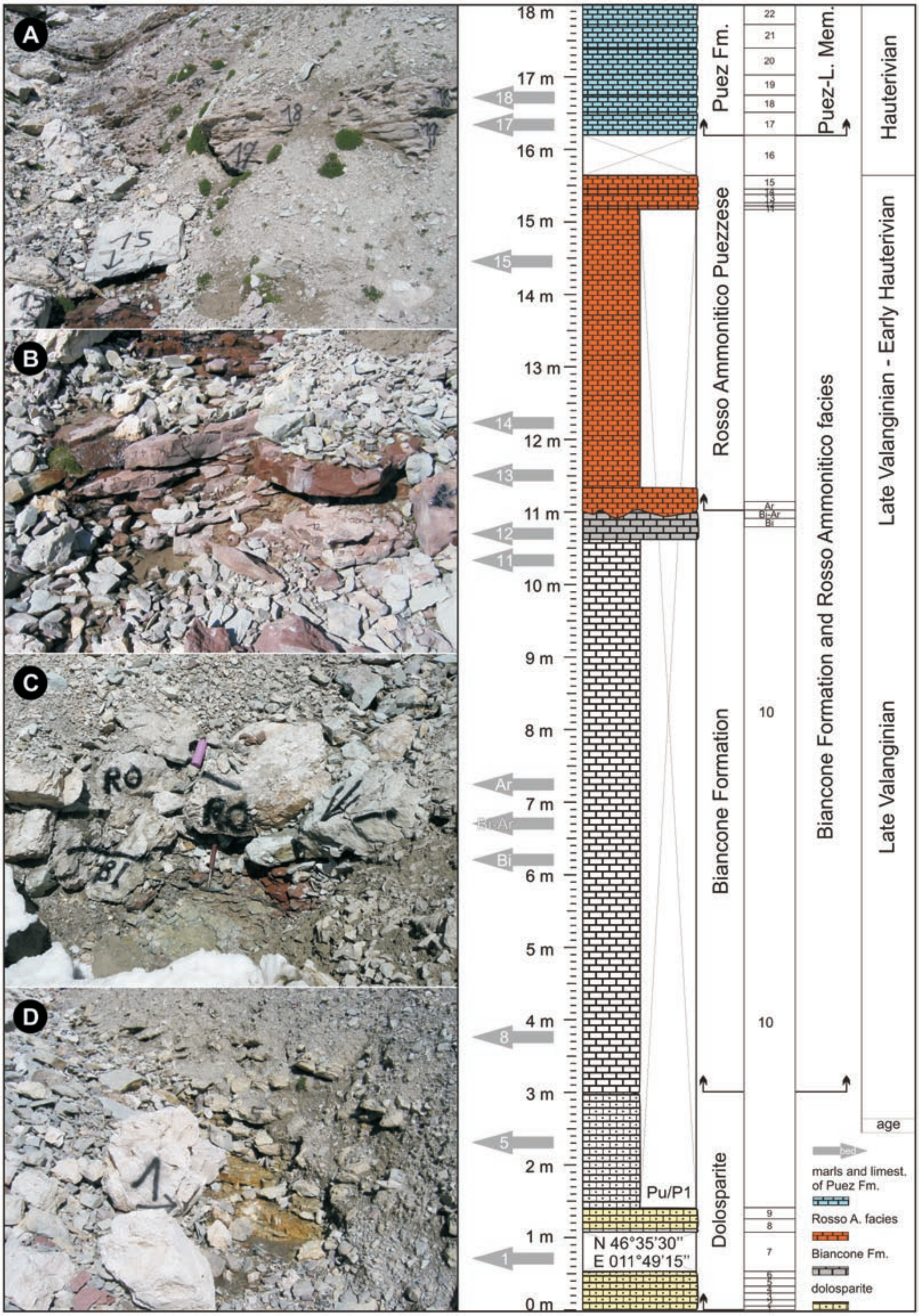
Geography: The outcrop is situated on the Puez-Odle-Gardenaccia Plateau in the Dolomites, 30 km northeast of Bozen, 6 km northeast of Wolkenstein (= Selva in Val. Gardena, = Sölva), in the Department Trentino-Alte Adige (maps Trentino–Alto Adige; South Tyrol, Italy; Tappeiner, 2003; KOMPASS Cortina d'Ampezzo 1: 50 000, 1985). The locality is situated in the heart of the natural park Puez-Odle within the UNESCO world heritage, the Dolomites (Lukeneder 2010). The main section (P1) is located at the southern slope of the Col de Puez (2725 m). The lower boundary of the Puez section is located at 2510 m at the easternmost small stream outcrop: E 011°49'15'', N 46°35'30'' (Fig. 1).

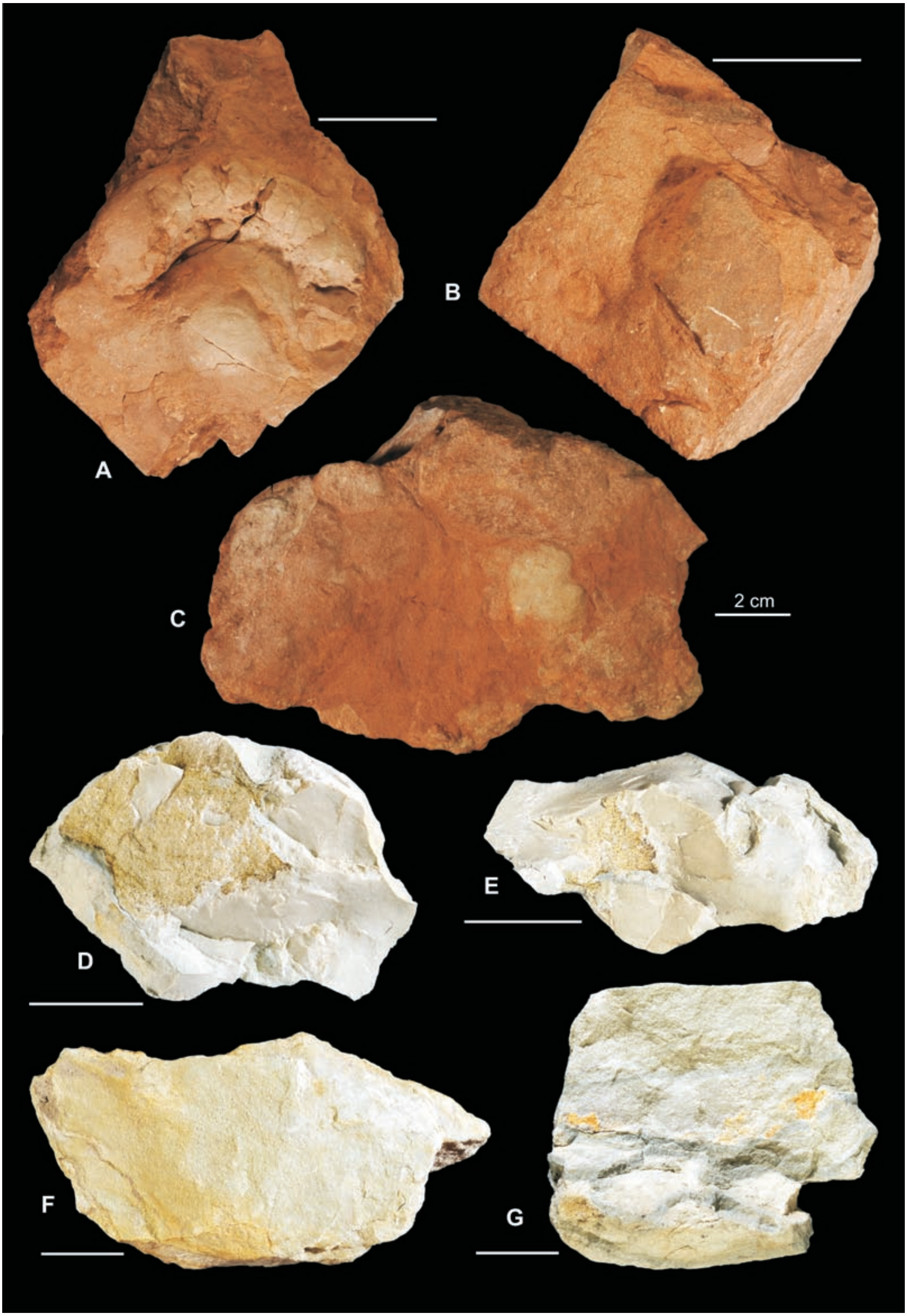
Geological setting : The Puez area is situated on the northernmost part of the Trento Plateau within the Dolomites, formed on a Cretaceous submarine plateau, the Puez-Gardenaccia Plateau (IT 1:50 000, map sheet 55 Cortina d'Ampezzo, geological map western Dolomites, Westliche Dolomiten, 1:25 000, sheet east). The history of this elevation goes back to the Triassic, over the Jurassic and ends with sediments of the Lower to Middle Cretaceous (Weissert 1981; Bosellini 1998; Lukeneder 2010). The Dolomites (Permian to Cretaceous) are an internal part of the Southern Alps, representing a Northern Italian chain that emerged during the deformation of the passive continental margin of the Adriatic (Jud 1994; Bosselini et al. 2003; Castellarin 2006). The geological landscape of the Puez region is dominated by the giant Triassic carbonate platforms (Hautpdolomit). The top of these carbonates bears relics of Lower-Mid Cretaceous sediments which were formerly much more widespread but have been eroded through time (Lukeneder 2010). The Lower Cretaceous sediments are overthrusted ("Gipfelüberschiebung") at the Puez area by the older Triassic Haupdolomit (Doglioni 1985, 1987; Pozzi 1993). For a more detailed geology of the Puez area see Lukeneder (2010).

Material and methods

This study examines 60 rock samples, 30 polished samples and 20 thin sections. Samples derive from the lowermost part of the section Puez/P1 (log P1) and to the west from

Fig. 2. Right: Lower part of the Puez log P1 with beds P1/1-18 (at 0-16 m). Dolosparite (beds 1-10), grey limestones of the Biancone Formation (beds P1/10 - P1/Bi) and the red, nodular limestones of the overlying Rosso Ammonitico facies with beds P1/Ar - P1/15. Left: A, transition from Ammonitico Rosso facies with its last bed P1/15 into the Puez Formation starting with bed P1/17. B, Red nodular beds of the Rosso Ammonitico facies at beds P1/13-15. C, transition from the Biancone Formation (P1/Bi) into the Rosso Ammonitico Puezzese (P1/Ar), at the transition layer P1/Bi-Ar). D, underlying dolosparite bed with the starting point of log with bed P1/1. Puez L. Member = Puez Limestone member. Grey arrows correspond to the bed numbers (samples) indicated in left photographs and given in Figs 4-5. ►


A
B
C
D
18 m
17 m
16 m
15 m
14 m
13 m
12 m
11 m
10 m
9 m
8 m
7 m
6 m
5 m
4 m
3 m
2 m
1 m
0 m
Pu/P1
N 46°35'30''
E 011°49'15''
Puez Fm.
Rosso Ammonitico Puezzese
Biancone Formation
Dolosparite
Puez-L. Mem.
Biancone Formation and Rosso Ammonitico facies
Hauterivian
Late Valanginian - Early Hauterivian
Late Valanginian
age
marls and limest. of Puez Fm.
Rosso A. facies
Biancone Fm.
dolosparite


A
B
C
2 cm
D
E
F
G

Puez/P4 (log P4), where the lithological transition from Biancone to Rosso Ammonitico facies crops out best. Rock samples were sliced and polished. Thin sections were made in vertical directions. Additionally, fossil groups including ammonoids, aptychi, brachiopods and echinoids were collected. Ammonoids are preserved as steinkerns or are represented by calcitic aptychi. No shells are present in ammonoids, restricting determinations to the genus level.

The section at Puez was studied with an integrated approach. Beds were sampled for biostratigraphical (macro-, micro- and nannofossils), and geochemical ($CaCO_3$, TOC) data. Focus is directed to an interval of about 20 m (P1/Bi - P1/15 and P4/0–20) that was studied in detail (Figs 2–5). Macro-, micro- and nannofossil contents were investigated in thin sections. Samples were collected at intervals of 0.2 to metres for total organic carbon (TOC) and calcium carbonate ($CaCO_3$). The microfossil content was analysed for calpionellids, radiolaria, saccocomids (thin sections). Sample numbers, for example P1/Bi, correspond to the sample interval at P1 within the log (for all numbers and figures, P1 = Puez, log 1). All samples are stored at the Natural History Museum of Vienna, in the collection of the Department of Geology and Palaeontology with inventory numbers from NHMW 2010/0127/0018–21.

Calcium carbonate contents ($CaCO_3$; wt% bulk rock, total carbonate) were determined using the carbonate bomb technique. Total carbon content was determined using a LECO WR-12 analyser. Total organic carbon (TOC) contents were calculated as the difference between total carbon and carbonate carbon, assuming that all carbonate is pure calcite. All the chemical analyses were carried out in the laboratories of the Department of Forest Ecology at the University of Vienna.

Facies types at Puez

Biancone facies

The Biancone Formation: traditionally defined as pelagic nannofossil limestone, this formation only occurs at the lowermost part of the section with P1/10 to P1/Bi and P4 (8 metres; Fig. 2). Microfacies types present are radiolaria-wackestones and biogenic-rich mudstones. Radiolaria, ostracods, echinoderms, sponge spiculae and foraminifera are the most prominent constituents of the microfauna. Comparable to typical Biancone Formation limestones (Tithonian), as seen at the La Stua section (STÖHR 1993, 1994).

◄ Fig. 3. Rock samples are positioned in stratigraphical order as found in the outcrop (Biancone lowermost and Rosso Ammonitico facies topmost). A (2010/0127/0001), B (2010/0127/0002), and C (2010/0127/0003), typical rock samples of the Rosso Ammonitico facies at the log P1 at the Puez locality. Note the calcareous ammonoid steinkern (lytoceratid) in A. D (2010/0127/0004) and E (2010/0127/0005), whitish rock samples of the Biancone Formation (P1/Bi). F (2010/0127/0006) and G (2010/0127/0007), rock samples of the underlying dolosparite (P1/6 and P1/9).

The lower boundary: sharp transition (e.g. log. P1/10) from the underlying whitish to light yellow dolosparite. The dolosparite is approx. 3 m thick, extending from beds P1/1 to the lower part of bed 10. The transition of the latter facies types in the lower parts of the section is covered by talus debris most of the year. The lowermost transitional parts had to be excavated before investigations were possible.

The upper boundary: defined at the Col de Puez by an abrupt change from whitish, light grey to reddish limestones from the Biancone Formation- (= Maiolica Formation) like limestone units into reddish limestones of the Rosso Ammonitic facies (red Biancone variation of Lukeneder 2010) (Figs 2–4). A transitional, mixed (due to bioturbation) layer is present at P1/Bi-Ar.

Colour: whitish to light grey; weathering is pale grey.

Geochemistry: TOC values are all approx. 0 %, and $CaCO_3$ displays values between 85.4 and 86.8 %.

Bed thickness: 3–10 cm.

Bed surfaces: straight, sharp to wavy (less).

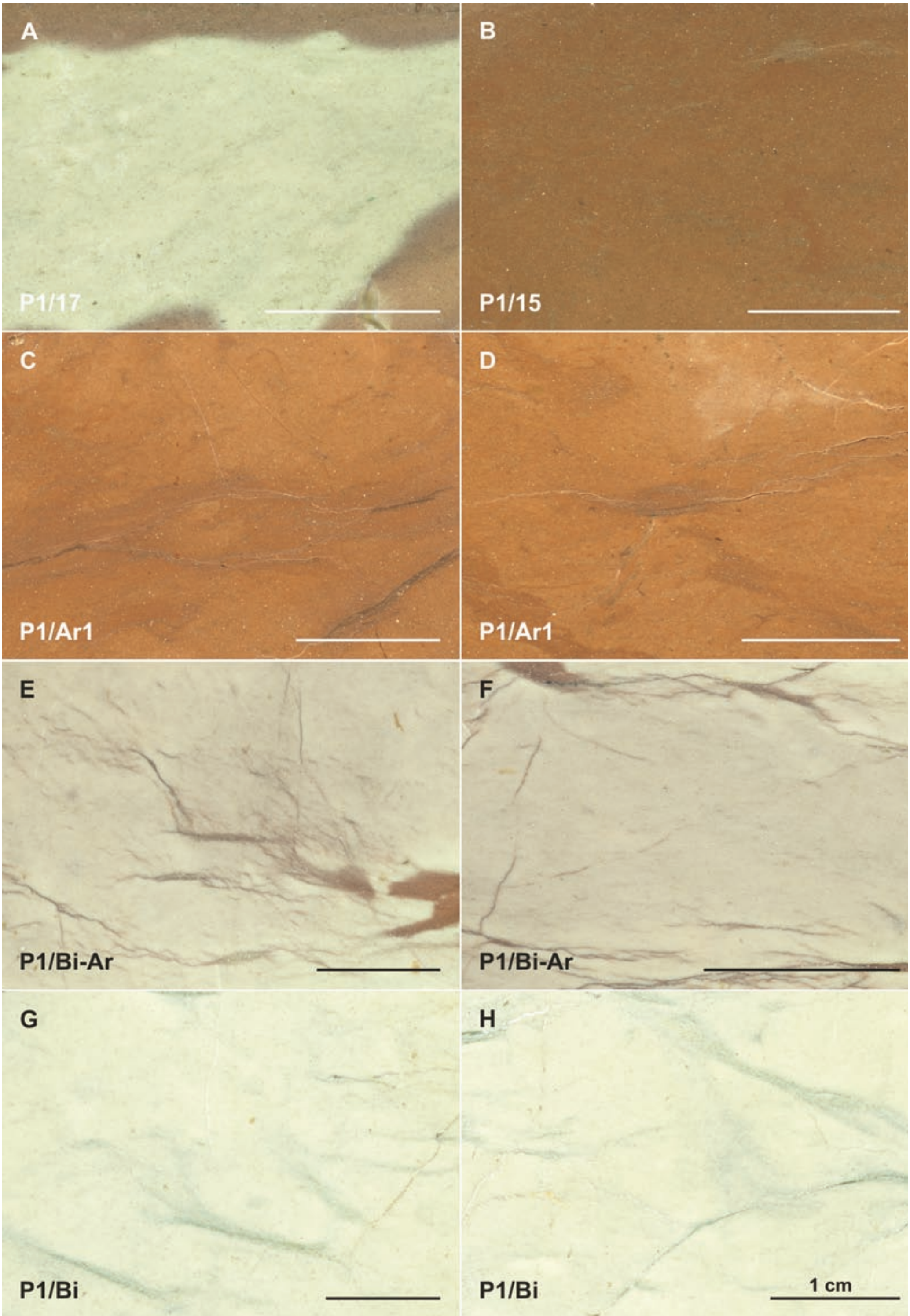
Origin, facies: the Biancone Formation is a pelagic-hemipelagic facies of water depths from approx. 100 m down to 500 m.

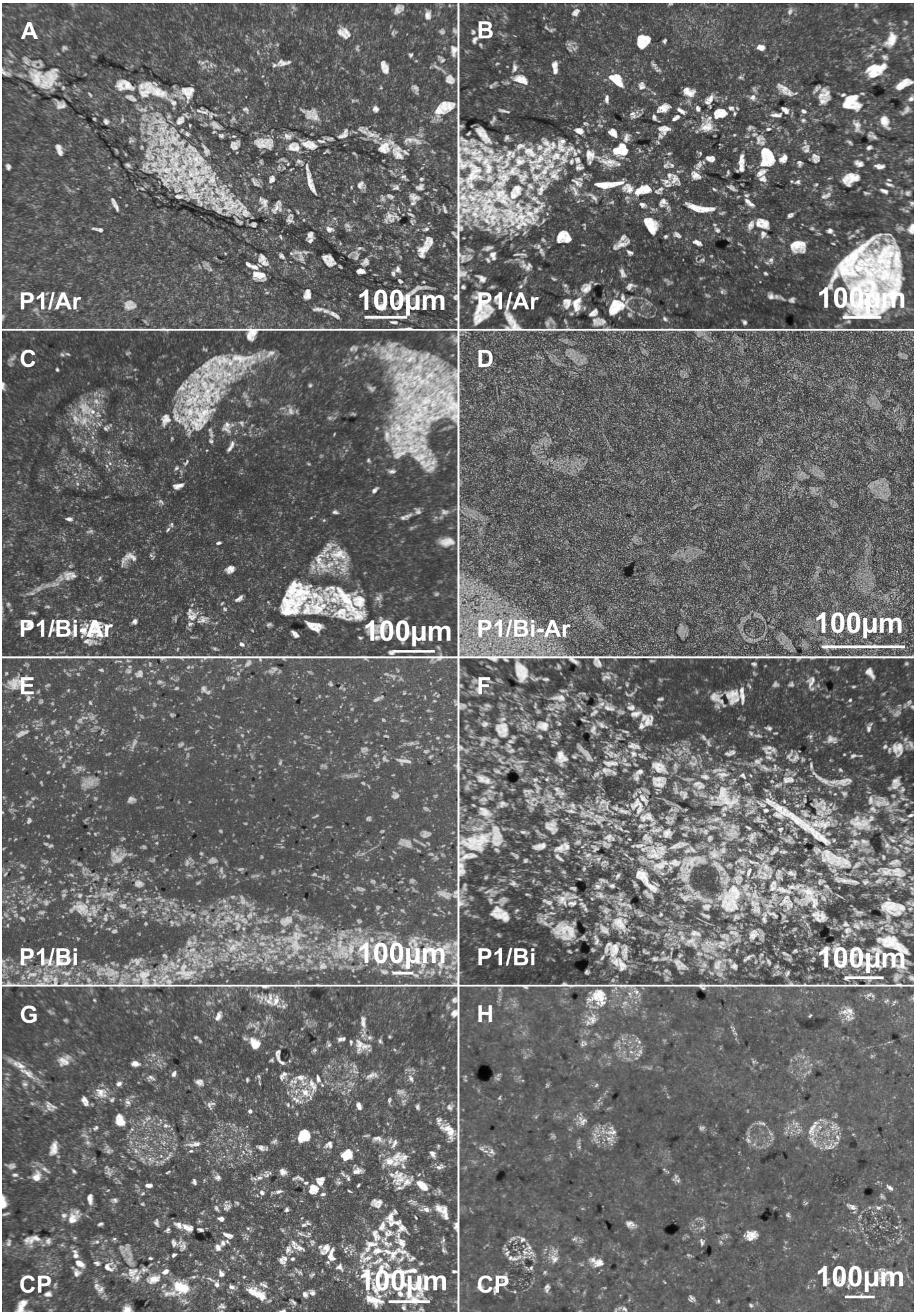
Thickness of formation: approx. 8 m at the section P1 at the southern flank of the Col de Puez. From metre 3 to metre 11 of P1, from the lower part of bed 10 to bed Bi-Ar (Figs 1 and 2).

Occurrence: visible only at the lowermost parts of log P1 and a neighbouring stream-outcrop 100 m to the west of P1 (log P4 is under investigation). An additional small occurrence of the whitish Biancone Formation is located 150 m to the north of the Puez refuge (Rifugio Puez) on the eastern flank of the Col de Puez.

Biostratigraphy: calpionellids are rare and present only in the lowermost part of the Puez section within the Biancone Formation of log P1 with beds P1/Bi and P1/Bi-Ar.

Fig. 4. Polished rock surfaces of the Biancone Formation, the Rosso Ammonitico facies and the Puez Formation (Puez-Limestone Member) from the Puez locality with log 1. Rock samples are positioned in stratigraphical order as found in the outcrop (lowermost Biancone and Rosso Ammonico facies topmost). A, lowermost bed of the Puez Formation (P1/17; 2010/0127/0008). B, final bed of the Rosso Ammonitico facies with beds P1/15 (2010/0127/0009). C and D, typical orange-red limestones of the Rosso Ammonitico facies at bed P1/Ar1 (2010/0127/0010–11). E and F, transitional bed P1/Bi-Ar with pink and incorporated flaser-like parts, caused by bioturbation (2010/0127/0012–13). G and H, final bed with whitish limestones of the Biancone Formation with P1/Bi (2010/0127/0014–15). ►


A
P1/17
B
P1/15
C
P1/Ar1
D
P1/Ar1
E
P1/Bi-Ar
F
P1/Bi-Ar
G
P1/Bi
H
P1/Bi
1 cm


A
P1/Ar
100µm
B
P1/Ar
100µm
C
P1/Bi-Ar
100µm
D
P1/Bi-Ar
100µm
E
P1/Bi
100µm
F
P1/Bi
100µm
G
CP
100µm
H
CP
100µm

Occurrences of *Tintinnopsella carpathica* indicate a Late Valanginian age (*Tintinnopsella* Zone).

Chronostratigraphic age: Late Valanginian (GRADSTEIN et al. 2004; OGG et al. 2008).

Remark: for a discussion on ammonoids and ecology, see LUKENEDER & ASPMAIR (2004) and LUKENEDER (2008, 2010).

Thin section P1/Bi: biomicritic limestone, slightly laminated and bioturbated wackestone. It contains thin laminae consisting of a rich siliciclastic admixture (quartz grains, feldspar, muscovite), rare glauconite and small skeletal fragments. Biogenic fragments belong to rare crinoids, bivalves, ostracods, aptychi, hyaline foraminifers, *Involutina* sp., *Lenticulina* sp., cysts of *Stomiosphaera wanneri*, *Stomiosphaera echinata*, calcified radiolaria and sponge spicules. Pyrite is scattered in the matrix, which is locally stylolitized. Stylolites are impregnated by Fe-hydroxides. *Tintinnopsella carpathica* and several additional sections resembling calpionellid loricas are present (Figs 5E and F).

Age: Late Valanginian (based on calpionellids and dinoflagellates).

Thin section P1/Bi-Ar: biomicritic limestone, slightly laminated and bioturbated mudstone rich in siliciclastic admixure (quartz grains, feldspar, muscovite), rare glauconite and small skeletal fragments concentrated in thin laminae or scattered in matrix. Biogenic fragments belong to rare crinoids, bivalves, ostracods, aptychi, hyaline foraminifers, *Involutina* sp., *Lenticulina* sp., cysts of *Cadosina semiradiata fusca*, *Cadosina semiradiata semiradiata*, *Stomiosphaera echinata*, calcified radiolaria and sponge spicules. Rare calpionellid loricas of ? *Tintinnopsella carpathica* and cysts of *Stomiosphaera echinata* occur. There is also fine clastic admixture with silty quartz grains, muscovite and seldom glauconite. Pyrite is scattered in matrix, which is localy stylolitized. Stylolites are impregnated by Fe-hydroxides (Fig. 5C and D).

Age: Late Valanginian (based on calpionellids and dinoflagellates).

◄ Fig. 5. Thin sections of the Biancone Formation and the Rosso Ammonitico facies and the Puez from the Col de Puez and Col de Pieres localities. For better understanding, rock samples are positioned in stratigraphical order as found in outcrops (lowermost Rosso Ammonitico from Col de Pieres, followed by uppermost Biancone from Puez, and Rosso Ammonico facies from Puez topmost). Note for all sections of the Rosso Ammonitico facies the abundance of biotic fragments with crinoids, bivalves and calcified radiolaria, accompanied by silty quartz grains, muscovite and seldom glauconite. Pyrite is dispersed in the matrix (black grains), which is locally stylolitized. A and B, lowermost bed of the Rosso Ammonitico facies with P1/Ar (same thin sections; 2010/0127/0016). C and D, transitional bed of Biancone and Ammonitico Puezzese Formation with P1/Bi-Ar (same thin section; 2010/0127/0017). E and F, final bed of the Biancone Formation with P1/Bi (same thin section; 2010/0127/0018). Note numerous thin laminae consisting of biogenic fragments of crinoids, bivalves, ostracods, hyaline foraminifera, radiolaria, sponge spicules, and aptychi. G and H, thin section of the Rosso Ammonitico facies from the Col de Pieres with CP (same thin section; 2010/0127/0019).

Rosso Ammonitico facies: Rosso Ammonitico Puezzese (RAP)

The Rosso Ammonitico facies as traditionally defined (Martire 1992, 1996), i.e. as condensed, pelagic, red, nodular limestone, occurs only at the lowermost part of the sections (P1 and P4, Fig. 2). The lithology exhibits nodular, more calcareous light-reddish nodules incorporated in an even more reddish, argillaceous matrix, mainly formed by condensed residues. The latter, more marly parts of the layers form the orange colour after weathering. Corroded ammonoids typically dominate the macrofauna, followed by aptychi, belemnites and brachiopods, best visible on bed surfaces. Microfacies types occur with biogenic-rich bioturbated mudstones, radiolaria-mudstones and foraminifera-radiolaria-wackestones. Radiolaria, ostracods, echinoderms, sponge spiculae and foraminifera are the most prominent constituents.

The lower boundary: defined at the Col de Puez by an abrupt change from the overlying reddish limestones of the Rosso Ammonitico facies (red Biancone variation after Lukeneder 2010) into the older whitish, light grey limestones from the Biancone Formation (= Maiolica). A transitional, mixed (due to bioturbation) layer occurs with P1/Bi-Ar (Fig. 2).

The upper boundary: defined at the Col de Puez by a change from the condensed, nodular, wavy bedded, reddish limestones of the Rosso Ammonitico facies into grey-green-reddish limestones and marly limestones showing even bedding planes, absence of nodules and red clay seams of the Puez-Limestone Member. It appears with Late Valanginian-latest Late Barremian beds (Lukeneder 2010).

Colour: dark reddish, weathering is typical orange-reddish.

Geochemistry: TOC values range from 0–0.1 % and $CaCO_3$ displays values between 71.7 and 86.8 %.

Bed thickness: 5–15 cm.

Bed surfaces: wavy (strong) to nodular.

Origin, facies: the Rosso Ammonitico is a pelagic-hemipelagic facies formed on submarine highs with increased water currents at water depths from approx. 100 m down to 300 m.

Thickness of formation: approx. 5 m at the section P1 at the southern flank of the Col de Puez. From metre 11 to 16 of P1, from bed Bi-Ar to bed 15 (Figs 1 and 2).

Occurrence: only visible at the lowermost parts of log P1 and a neighbouring stream-outcrop 100 m to the west of P1 (log P4 is under investigation). An additional small occurrence of the red Rosso Ammonitico facies is located 120 m north of the Puez refuge (Rifugio Puez) on the eastern flank of the Col de Puez. Most ammonoids of this facies can be found at the Col de Pieres, where this lithology has its laterally most extensive outcrop situation, caused by the flat dipping of beds.

Biostratigraphy: calpionellids are numerous in older parts at the Pieres locality and comparatively rare at the Puez localities. *Calpionellites darderi*, which appears only in sediments of that facies at Col de Pieres, show the Berriasian-Valanginian transition. Occurrences of *Tintinnopsella carpathica* at Puez sections P1 and P4 hint at a Late Valanginian to Early Hauterivian age (*Tintinnopsella* Zone).

Chronostratigraphic age: Late Valanginian to Early Hauterivian at Puez and Early Valanginian at the stratigraphically older Col de Pieres section (GRADSTEIN et al. 2004; OGG et al. 2008).

Remark: for a discussion see LUKENEDER & ASPMAIR (2004) and LUKENEDER (2008, 2010).

Thin section P1/Ar: biomicritic limestone, nannoconid mudstone with thin laminae rich in silty clastics and pyrite. Biogenic fragments of crinoids, bivalves, ostracods, hyaline foraminifers, *Lenticulina* sp., *Involutina* sp., *Spirillina* sp., *Frondicularia* sp., aptychi, *Stomiosphaera wanneri*, *Stomiosphaera echinata*, *Cadosina semiradiata fusca*. Fine clastic admixture with rich silty quartz grains, muscovite and, rarely, glauconite. Pyrite is scattered in matrix which is locally stylolitized. Stylolites are impregnated by Fe-hydroxide (Figs 5A and B).

Age: Valanginian (based on calpionellids and dinoflagellates).

Thin section P1/15: biomicritic limestone, mudstone to wackestone with frequent thin laminae rich in skeletal fragments and abundant pyrite accumulations. Biogenic fragments belong to crinoids, bivalves, ostracods, hyaline foraminifers, calcified radiolaria, sponge spicules, aptychi, rhyncholites, *Tintinnopsella carpathica* and further few calpionellid loricas. There is also a fine clastic admixture with silty quartz grains, muscovite and glauconite. Pyrite is dispersed in a matrix which is locally stylolitized. Stylolites are impregnated by Fe-hydroxide (Fig. 4, B).

Age: Late Valanginian – Hauterivian (based on calipionellids and dinoflagellates).

Thin section CP (Col de Pieres)**:** biomicritic limestone, foraminifera-radiolaria-wackestone with thin laminae rich in silty clastics and pyrite. Biogenic fragments belong to calcified radiolaria and planktonic foraminifers of *Caucasella hoterivica*, which dominate over crinoids, bivalves, ostracods, hyaline foraminifers, *Lenticulina* sp., *Involutina* sp., aptychi, rhyncholites, few calpionellid loricas (*Tintinnopsella carpathica*, *Lorenziella hungarica*) and cysts of *Stomiosphaera echinata*, *Stomiosphaera wanneri*, *Cadosina semiradiata fusca*, *Cadosina minuta*. There is also a fine clastic admixture with abundant silty quartz grains, muscovite and seldom glauconite. Biotic fragments are locally silicified. Pyrite is scattered in a locally stylolitized matrix. Stylolites are impregnated by Fe-hydroxide. On the base of this index marker we can identify the Berriasian-Valanginian transition (boundary) interval. The presence of dinoflagellate cysts of *Stomiosphaera echinata* indicate a somewhat higher biostratigraphic level with Early Valanginian (Figs 5G and H).

Age: Early Valanginian (based on calpionellids and dinoflagellates).

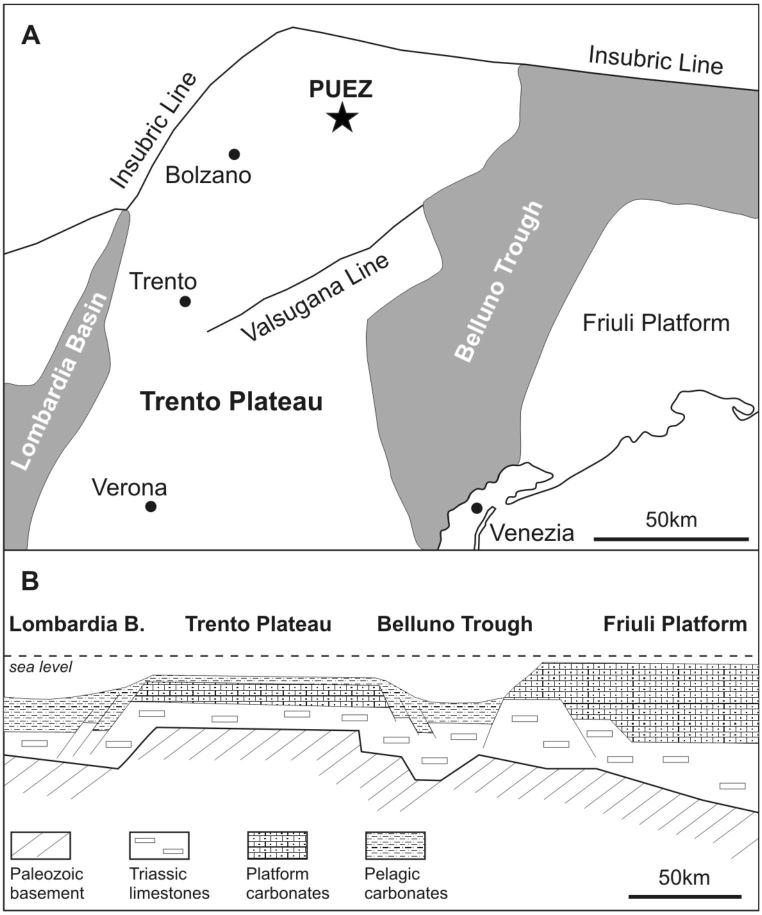


Fig. 6. A, Geographic E-W transect of the Lombardia Basin, Trento Plateau and Belluno Trough (Southern Alps, N. Italy), modified after Martire et al. (2006). B, Palaeogeographic section of the area around the Trento Plateau during the late Jurassic to earliest Cretaceous (not palinspastically corrected), modified after Caracuel et al. (1997) and Préat et al. (2006).

Discussion

The Trento Plateau: Biancone Formation versus Rosso Ammonitico facies

In the Southern Alps and especially in the Dolomites, Upper Jurassic/Lower Cretaceous cephalopod-bearing deposits are mainly recorded in three different facies: the red, nodular carbonates of the Rosso Ammonitico Superiore Formation (Farinacci & Elmi 1981; Geyer 1993; Martire 1992, 1996) formed on submarine highs, the calcareous nannofossil limestones of the Biancone Formation (= Maiolica Formation elsewhere in Italy; Cita 1965; Mayer & Appel 1999), and the more marly Puez Formation (marls-marly limestones; LUKENEDER 2010) formed mainly on slopes and in basins. The formation of these different facies types reflects the mosaic of platforms and submarine rises (e.g. Trento Plateau; WEISSERT 1981; ZEMPOLICH 1993; JUD 1994; STOCK 1994; BOSELLINI 2004) (Fig. 6). Several basins (e.g. Lombardian Basin, Belluno Basin) to the east were established due to Jurassic tectonics, caused by the opening of the Atlantic and Penninic Oceans (BOSELLINI 1998; FOURCADE et al. 1993).

The Lower Cretaceous sequence at Puez mirrors the evolution of the northernmost part of the Trento Plateau at this time (DERCOURT et al. 1993; JUD 1994; BOSELLINI 2004). The Trento Plateau (= Piattaforma Atesina) reaches from the south (around Trento) up to the Puez region and was formerly surrounded by two basins: the Lombardian Basin (= Bacino Italiano) to the west and the Belluno Basin (= Fossa di Belluno) to the east (BOSELLINI et al. 1981; GEYER 1993). The reason for the Upper Jurassic to Lower Cretaceous separation into a basin-plateau-basin succession lies in the rifting history of the opening Mid-Atlantic Ocean, the east adjacent Piemonte-Ligurian Tethys Ocean, and the northeast Penninic Ocean (MAYER & APPEL 1999; MUTTONI et al. 2005).

One of the best known sumarine highs is marked by the North Italian Trento Plateau (Fig. 6), on which regional tectonics and changes in plate geometries are visible (OGG 1981). Morphological highs such as the Trento Plateau (GRANDESSO 1977; MASSARI 1981; DERCOURT et al. 1993; BAUDIN et al. 1997; STOCK 1994; BOSELLINI 2004), located in Lower Cretaceous pelagic environments, were characterised by condensed sedimentation of the typical Rosso Ammonitico facies (AGIP Mineraria 1959; AUBOUIN 1964; JENKYNS 1974; FARINACCI & ELMI 1981; OGG 1981; CECCA et al. 1992, 1993; FOURCADE et al. 1993; ZEMPOLICH 1993; MARTIRE 1992, 1996; MARTIRE et al. 2006).

According to CARACUEL et al. (1997, 1998), the deposition of nodular-marly (lower energy), nodular-calcareous and pseudonodular-calcareous-massive (higher energy) Rosso Ammonitico facies (= Rosso Ammonitico-Veronese Superiore, GEYER 1993; ARV by AVANZINI et al. 2006; or A. R. Veneto of GRANDESSO 1977; MARTIRE 1992, 1996; BECCARO 2006; MARTIRE et al. 2006) was controlled by a combination of carbonate productivity and hydrodynamics. These were related to fluctuations in relative sea level (see also CECCA et al. 1992; FOURCADE et al. 1993, and KROBICKI 1993). After OGG (1981), the variety of nodular textures in Rosso Ammonitico are caused by several processes such as bioturbation, stylolite condensation, and concentration of bioclasts in macro-size (e.g. ammonoids steinkerns) and micro-size (e.g. radiolaria, foraminifera and *Saccocoma*). The ratio of bioclasts, micritic components and clay content is crucial for the formation of red, nodular facies caused by current winnowing (OGG 1981). Most of the larger calcareous nodules are formed of partly dissolved ammonoids (JENKYNS 1974). The age for Biancone (Maiolica) and Rosso Ammonitico was given with Berriasian to Lower Valanginian and with Bajocian to Tithonian consecutively in the captions to the geological map of the Dolomiti Occidentali (2007). Two main facies types can be separated within this condensed Tethyan facies (CITA 1965; CECCA et al. 1993; GEYER 1993; MAYER & APPEL 1999): the more marly Lower Jurassic Rosso Ammonitico Lombardo (R.A.L. Inferiore; Toarcian) and the Middle and Upper Jurassic more calcareous Rosso Ammonitico Veronese (R.A.V. Superiore; Bathonian-Berriasian). The latter is a very distinctive lithostratigraphic unit on the Trento Plateau (Farinacci & Elmi 1981; Ogg 1981). Previous studies were summarised by (Martire et al. 2006). The latter facies type is herein compared to the Rosso Ammonitico facies at the Puez locality, established herein as Rosso Ammonitico Puezzese.

Three main lithological phases are distinguished in the Rosso Ammonitico Veronese *sensu stricto* of the Southern Alps. They were formalised by Martire et al. (2006) at the type section of Monte Kaberlaba and a complementary section at Rabeschini (Ventia; see also Martire 1996, Caracuel et al. 1997; Préat et al. 2006). The petrography and biosedimentology of the Rosso Ammonitico Veronese were analysed by Préat et al. (2006). They concluded that the intensity of the red colour is caused by the abundance of hematite particles (former iron hydroxides) in the sediment. The intensity is a result of micritic diagensis and bacterial-fungal activity reflecting the the degree of sediment-water interface oxygenation (Préat et al. 2006). Thus, good bottom water oxygenation, followed by stronger bioturbation, prevented the formation of bacterial biofilms crucial for the formation of hematite and therefore for the red colours of the Rosso Ammonitic Veronese. After a primary hardground (Bajocian), a basal calcareous and massively bedded part with abundant *Bositra buchi* (thin-shelled pelagic bivalves, "Filamentkalke"), followed by a median, thin-bedded and cherty phase with Rosso Ammonitico Veronese Inferiore (Bathonian-Callovian), overlain regionally by radiolarite-rhyncolite-limestone ("Radiolarit-Rhyncholithen Kalk"; Callovian-Oxfordian) topped by the final ammonite-rich nodular limestone of the Rosso Ammonitico Veronese Superiore (Kimmeridgian-Tithonian). At the type section at Monte Kaberlaba, Martire et al. (2006) distinguished three main units, the Rosso Ammonitico Inferiore (RAI; Lower Unit), the Rosso Ammonitico Medio (RAM; Middle Unit), and the Rosso Ammonitico Superiore (SAI; Upper Unit) comprising 14 different lithozones from Upper Bajocian to Lower Berriasian. The Rosso Ammonitico Superiore occurs with maximal 15–20 m thickness. Depending on the palaeooceanographic situation of different localities, single facies types occur or are absent. On submarine horsts, pelagic ridges and submarine highs (e.g. Trento Plateau; Bosellini 2004), Rosso Ammonitico facies were deposited. In the sourounding basins, however, a more marly facies was sedimented (Grandesso 1977; Cecca et al. 1993). After Cecca el al. (1992, 1993), this red, condensed, nodular facies gradually disappeared in the late Berriasian time. The herein reported Rosso Ammonitico facies from the northernmost part of the Trento Plateau (e.g. Puez locality) represents a younger analogous facies compared to the latest known Rosso Ammonitico occurrences from southern Iberia and the Brianconnais Zone (Cecca et al. 1992). The persistence of that red nodular facies at the Puez locality is mainly caused by its northern position on the Trento Plateau.

The Puez locality

Biancone Formation: Papers on the Cretaceous have dealt with the Maiolica, Lombardian Maiolica and Biancone Formations (Bartolocci et al. 1992; Jud 1994; Lini 1994; Faraoni et al. 1995, 1996, 1997; Baudin et al. 1997; Cecca 1998; Cecca & Landra 1994; Cecca et al. 1994a, b, 1995, 1996; = Venetian Maiolica after WEISSERT 1979, 1981; LINI 1994; MAYER 1999; MAYER & APPEL 1999) from the Venetian Alps, which directly adjoin to the south of the Dolomites, and also dealt with the "real" Maiolica Formation of the Central Apennines. The lithology, weathering and age of some of the localities discussed in the above papers are reminiscent more to the Hauterivian-Barremian parts of the Puez-Limestone Formation than of the almost pure whitish limestone (virtually lacking macrofossils; FOURCADE et al. 1993). The latter part of the Maiolica or Biancone facies occurs at the Puez as the Biancone Formation (e.g. beds P1/10– P1/Bi). Papers on the Maiolica facies, e.g. FOURCADE et al. (1993), MAYER (1999) and MAYER & APPEL (1999), also suggested a duration of that sedimentation type from Late Tithonian up to Aptian in some areas. That interpretation, in the present author's opinion, is a more "sensu lato" one because it includes the younger, more marly upper parts, and is not in the sense of a Maiolica *sensu stricto*. The Maiolica-Biancone Formations occur mainly at Tithonian, Berriasian and Lower Valanginian times. The Biancone Formation at the Puez area is Early to Middle-Valanginian. Twenty kilometres to the east of the Puez area, the locality La Stua described by STÖHR (1993, 1994) and BACCELLE & LUCCHI-GARAVELLO (1967a, b) shows a comparable succession to Puez, comprising "Biancone" (after STÖHR 1993, "Profilabschnitt A", 7 m, Berriasian-Valanginian), red-grey nodular limestones (B, 24 m, Hauterivian).

The Umbria-Marche basinal sequence typically shows the following succession of Upper Jurassic to Upper Cretaceous (CECCA & PALLINI 1994; MONTANARI & KOEBERL 2000): green-grey-red Diaspri Formation (= "Calcari diasprigni") with well-bedded limestones with cherts (Dogger-Malm, 60–120 m), followed by the typical whitish Maiolica Formation *sensu lato* (Berriasian-Aptian, 50–500 m), overlain by the Marne a Fucoidi (Aptian-Albian, approx 70 m), followed by the Scaglia succession with white Scaglia Bianca (late Albian-Cenomanian, approx. 60 m), pink-white-red Scaglia Rossa (Turonian-Eocene, up to 350 m), Scaglia Variegata (middle to late Eocene, approx. 60 m) and the Scaglia Cinerea (Eocene-Oligocene, 80–120 m; see also MAYER & APPEL 1999). As noted by GEYER (1993), Biancone *sensu lato* was often confusingly used for the Biancone *sensu stricto* (Tithonian-Aptian plus the Scaglia Variegata Aptian-Turonian). Former papers on the Lower Cretaceous sediments from the Puez area assumed an Aptian age for these sediments (RODIGHIERO 1919; LUKENEDER & ASPMAIR 2006; LUKENEDER 2008; "Puez Formation with ?Valanginiano-?Aptiano" on the geological map Dolomiti Occidentali 2007). In contrast, LUKENEDER (2010) shows the exclusively Albian age of this member.

As assumed by MUTTONI et al. (2005) the change in palaeolatitudes of the South Alpine blocks from relative low values of 10°N at the Late Jurassic with radiolarites (red and green) to 20–30°N in the Early Cretaceous and the more calcareous sediments of the "Maiolica-Biancone" Formations could have mainly triggered this type of sedimentation (International Association of Sedimentologists (IAS) 2004). A progressive deepening of the Late Jurassic CCD (carbonate compensation depth) is assumed for that timespan (IAS 2004). An increase of terrigenous input and a fluctuation in productivity (cf. ARTHUR & PREMOLI-SILVA 1982) in the higher sea-water column is clearly indicated by the sedimentation of foraminiferal and radiolaria oozes in numerous beds in the Puez-Marl Member. In addition, a change of carbonate dissolution levels could also have triggered these mechanisms (LINI 1994).

Rosso Ammonitico Facies: At the Puez locality, whitish Biancone limestones and the red "Rosso Ammonitico"-facies type (= Biancone var. red after LUKENEDER 2010) occur at the lowermost part of section P1 (see chapter 4; Fig. 2) and more to the west at section P4 (LUKENEDER in prep.). Within the latter sections the Biancone Formation is again overlain by younger, about 5–m-thick Rosso Ammonitco facies with typical red, nodular and ammonite-rich facies. The Rosso Ammonitico facies is most prominent (lateral distribution due to flat dipping of beds) at the Col de la Pieres, 3 km west of the Puez sections, and was termed "calcari cristallino rosso" of Tithonian age by CITA & PASQUARÉ (1959) and later integrated into the group of "Rosso Ammonitico" by CITA (1965). The age was determined based on calpionellids and saccocomids.

The lowermost (?Berriasian to Valanginian) part of the Col de Pieres and Puez localities marks a change in pelagic sedimentation. This change begins at the Biancone Formation, continues over the more energetic red limestone facies shown by the "Rosso Ammonitico" type (P1/10–15), and, at the Puez locality, ends with the more marly, grey Puez Formation (Late Valanginian to Late Albian). This was caused by the reorganisation of the Mediterranean Tethys palaeogeography (CECCA et al. 1992; CARACUEL et al. 1998; DERCOURT et al. 1993; FOURCADE et al. 1993; VAŠÍČEK 1994). After the heterogenous sedimentation (late Jurassic to earliest Cretaceous) on blocks and basins with the "Rosso Ammonitico" type and the "Biancone-Maiolica" type, respectively, a change and homogenisation occurred in the Lower Cretaceous. The change in current patterns and palaeogeography (WEISSERT 1979, 1981) resulted in a new Tithonian-Valanginian 'bloom' in plankton development. This led to deposition of the uniform whitish, fine micritic limestones of the "Biancone - Maiolica" formations (P1/10–Bi-Ar; Fig. 2), dominated by calpionellid, globochaete-calpionellid mudstones, from the Apennines up to the Dolomites in the north of the Trento Plateau. The following Lower Cretaceous sedimentation was much more differentiated in the northernmost part of the Trento Plateau (Dolomites); that part shows the ongoing sedimentation with Maiolica and Biancone formations in the rest of the Southern Alps (e.g. southern Trento Plateau, Lesini mountains etc.; STOCK 1994; BOSELLINI 2004).

The Lower Cretaceous formation of the whitish-grey Biancone Formation (?Berriasian-Late Valanginian, P1/10 to Pl/Bi; Fig. 2) at Puez is followed by the Rosso Ammonitico facies type (Late Valanginian, P1/Ar to P1/15; Fig. 2). Biancone is the local name (on the Trento Plateau) for the more broadly known Italian Maiolica Formation (FARAONI et al. 1995, 1996, 1997; WIECZOREK 1988). Weathered parts of the Rosso Ammonitico type facies are strongly reminiscent of the nodular, ammonite-rich facies of the Rosso Ammonitico Superiore (= Rosso Ammonitico Veronese or R.A. Veneto of GRANDESSO, 1977; Ammonitico Rosso Tridentin, ART of AUBOUIN, 1965). GRANDESSO (1977) and AUBOUIN (1965) showed that the Rosso Ammonitico Veneto reaches up to the lowermost Lower Valanigian in the Lessini Mountains at the Mizzole section and in its eastern occurrences in the Friuli (e.g. locality Claut). CITA (1965) pointed out that the upper boundary of the Rosso Ammonitco Superiore is not synchronous in the Southern Alps (e.g. Venetian region) and occurs at the Tithonian (e.g. La Stua) or Berriasian (e.g. Lago Verde). At the Breggia Gorge section in Southern Switzerland, located within the Lombardian Basin at the Late Jurassic and Early Cretaceous, the Rosso ad Aptici Formation reaches up to the Jurassic-Cretaceous boundary (Jud 1994), overlain by the Maiolica Formation (IAS 2004). This situation is typical for a Lombardian Basin succession, showing the transition from the red Tithonian limestones of the Rosso ad Aptici Formation into the Lombardian Maiolica Formation. That transition starts from the Berriasian (Weissert 1979). In contrast, the latter transition has its equivalents on the Trento Plateau to the east with the Jurassic Rosso Ammonitico Superiore transition into the Cretaceous Biancone Formation. The main difference between the Rosso ad Aptici and Rosso Ammonitico facies is the abundance of chert-nodules and lenses in the former (Aubouin 1964; Cecca et al. 1992). In the Belluno Basin to the east, the situation is somewhat different. Maiolica limestones overlie whitish to grey Jurassic limestones of the “Calcare di Soccher Formation” (Weissert 1979; Lini 1994).

Biostratigraphic data show that the age (Early-Late Valanginian) of the transition from the Biancone formation to the Rosso Ammonitico facies is somewhat younger at the Puez locality than in most other localities. Note also that in most cases Rosso Ammonitico is overlain by Biancone Formation. This is in contrast to the situation at the Puez locality, where the Biancone limestones (whitish to grey varieties) are displaced by reddish, nodular Rosso Ammonitico-like limestones. The red Rosso Ammonitico type occurs most prominently and laterally distributed at the Col de Pieres to the west (Cita & Pasquaré 1959). The bigger part of the succession (approx. 100 m) shows a transition from limestones and marly limestones (Puewz Limestone Member) into a marl-marly limestone alternation in the upper half of the log (Puez Marl Member; Lukeneder 2010). This succession is similar to the Lower Cretaceous of La Stua, which also shows a Rosso Ammonitico, Biancone, and “Ammonitenmergel” succession (comparable to the Puez Formation), and finally grey marls and Aptian marls (Stöhr 1993).

Conclusions

At the lower part of the section (Col de Puez, Dolomites, S. Tyrol), a transition from white limestones into red, nodular limestones occurs. The final deposition of this Lower Cretaceous Biancone Formation and the Rosso Ammonitico facies from the Puez section took place on the northernmost area of the submarine Trento Plateau. Micropalaeontological analyses show a Valanginian age for this transitional interval. The grey to whitish limestones of the Biancone Formation are overlain by a more energetic red, nodular limestone facies of the “Rosso Ammonitico” type. The succession reflects a change of sedimentation during the Valanginian from a “normal” pelagic sedimentation with whitish limestones to a red, condensed, more marly, nodular facies with abundant biogenic residual sediments and abundant ammonoid casts. This probably reflects a tectonically caused sea-level change and therefore current-linked change on the submarine highs of the Trento Plateau during the Early to Late Valanginian. The herein reported Rosso Ammonitico facies from the northernmost part of the Treno Plateau (e.g. Puez locality) represents the youngest analogous red, nodular facies so far. The unique longevity and constancy of this facies on the Puez-Gardenaccia area is mainly caused by its northern position on the Trento Plateau. The term Rosso Ammonitico Puezzese is established for this uppermost red, nodular facies on the Puez-Gardenaccia Plateau.

Acknowledgements

Thanks are due to the Austrian Science Fund (FWF) for financial support (project P20018–N10). I am grateful to Daniela Reháková (Bratislava) for important information on calpionellids and microfacies. Sincere thanks go to Evelyn Kustatscher, Benno Baumgarten and Vito Zingerle (all Museum of Nature South Tyrol) for their help in organisational issues. I thank Arthur Kammerer, Astrid Wiedenhofer and Valentin Schroffenegger (all Office for Natural Parks South Tyrol) for working permits in the Puez-Geisler Nature Park. I am particularly grateful to Monika Sieghardt (Vienna), who provided geochemical analysis. Sincere thanks go to Umberto Uprimny (Neuzeug) for his advice with Italian translations. Special thanks go to Fabrizio Cecca (Paris), Alain Préat (Brussels) and Andreas Kroh (Vienna) for carefully reading and reviewing the manuscript. Preparation work on the rock samples and thin sections were made by Anton Englert (Vienna) and Franz Topka (Vienna). Photographs were taken by Alice Schumacher (Vienna). The publication is dedicated to Oskar Costa (La Villa), who became a friend to us over the years, but died too early in October 2010.

References

AGIP Mineraria (1959): Microfacies Italiane (del Carbonifero al Miocene medio). – San Donato Milanese, Milan, 35 pp., 140 pls.

Arthur, M.A. & Premoli Silva, I. (1982): Development of widespread organic carbon-rich strata in the Mediterranean Tethys. – In: Schlanger, S.O. & Cita, M.B. (eds): Nature and Origin of Cretaceous Carbon-Rich Facies. – Academic Press, London. pp. 7–54.

Aubouin, J. (1964): Réflexion sur le faciés «ammonitico rosso». – Bulletin de la Sociéte Géologique de France, **7**: 475–501.

Avanzini, M., Bargossi, G.M., Borsato, A., Gastiglioni, G.B., Cucato, M., M., Morelli, C., Prosser, G. & Sapelza, A. (2006): Progetto CARG. Foglio 26, Appiano. – Provincia Autonoma di Bolzano-Provincia Autonima di Trento, Bozen, 79 pp.

—— & Wachtler, M. (1999): Dolomiten. Reisen in die Urzeit. – Varlagsanstalt Athesia Ges. m.b.H., Bozen, 150 pp.

Baccelle, L. & Lucchi-Garavello, A. (1967a): Prima segnalazione di Ammoniti Aptiane e Albiane nelle Dolomiti. – Annali dell' Università di Ferrara, **4**/7: 91–101.

—— & —— (1967b): Ammonite dei livelli Cretacici di La Stua (Cortina d'Ampezzo). – Annali dell' Università di Ferrara, Nuova Serie, **4**/9: 117–166.

BARTOLOCCI, P, BERALDINI, M., CECCA, F., FARAONI, P., MARINI, A. & PALLINI, G. (1992): Preliminary results on correlation between Barremian ammonites and magnetic stratigraphy in Umbria-Marche Apennines (Central Italy). – Palaeopelagos, **2**: 63–68.

BAUDIN, F., FARAONI, P., MARINI, A. & PALLINI, G. (1997): Organic matter characterisation of the "Faraoni Level" from Northern Italy (Lessini Mountains and Trento Plateau): comparison with that from Umbria Marche Apennines. – Palaeopelagios, **7**: 41–51.

BECCARO, P. (2006): Radiolarian correlation of Jurassic siliceous successions of the Rosso Ammonitico Formation in the Southern Alps and Western Sicily (Italy). – Eclogae Geologicae Helvetiae, **99**: 21–33.

BOSELLINI, A. (1998): Die Geologie der Dolomiten. – Verlagsanstalt Athesia, Bozen/Bolzano, 192 pp.

— (2004): The western passive margin of Adria and its carbonate platforms. – Special Volume of the Italian Geological Society for the IGC 32 Florence. pp. 79–92.

—, GIANOLLA, P. & STEFANI, M. (2003): Geology of the Dolomites. – Episodes, **26**/3: 181–185.

—, MASETTI, D. & SARTI, M. (1981): A Jurassic "Tongue of the Ocean" infilled witth oolitic sands: The Belluno Trough, Venetian, Alps, Italy. – Marine Geology, **44**: 59–95.

CARACUEL, J., OLORIZ, F. & SARTI, C. (1997): Environmental evolution during the Late Jurassic at Lavarone (Trento Plateau, Italy). – Palaeogeography, Palaeoclimatology, Palaeoecology, **135**: 163–177.

—, — & — (1998): Updated biostratigraphy of the Kimmeridgian and Lower Tithonian at Lavaraone (Trento Plateau). Correlation for epioceanic western Tethys. – Geologica et Palaeontologica, **32**: 235–251.

CASTELLARIN, A., VAI, G.B. & CANTELLI, L. (2006): The Alpine evolution of the Southern Alps around the Guidicarie faults: A Late Cretaceous to Early Eocene transfer Zone. – Tectonophysics, **414**: 203–223.

CECCA, F. (1998): Early Cretaceous (pre-Aptian) ammonites of the Mediterranean Tethys: palaeoecology and palaeobiography. – Palaeogeography, Palaeoclimatology, Palaeoecology, **138**: 305–323.

—, AZEMA, J., FOURCADE, E., BAUDIN, F., GUIRAUD, R., RICOU, L.-E. & WEVER, P. DE. (1993): Early Kimmerdgian (146 to 144 Ma). – In: DERCOURT, J., RICOU, L.E. & VRIELYNCK, B (eds): Atlas Tethys Palaeoenvironmental Maps. Explanatory Notes. – Gauthier-Villars, Paris, pp. 97–134.

—, FARAONI, P. & MARINI, A. (1998): Latest Hauterivian (Early Cretaceous) ammonites from Umbria-Marche Apennines (Central Italy). – Palaeontographia Italica, **85**: 61–110.

—, FARAONI, P., MARINI, A. & PALLINI, G. (1995): Field-trip across the representative sections for the Upper Hauterivian – Barremian ammonite biostratigraphy in the Maiolica exposed at Monte nerone, Monte Petrano and Monte Catria (Umbria-Marche Apennines). – Memorie descrizione della Carta Geologiche d'Italia, **51**: 187–211.

—, FOURCADE, E. & AZEMA, J. (1992): The disappearance of the "Ammonitico Rosso". – Palaeogeography, Palaeoclimatology, Palaeoecology, **99**: 55–70.

—, GÁLEOTTI, S., COCCIONI, R. & ERBA, E. (1996): The equivalent of the "Faraoni Level" (Uppermost Hauterivian, Lower Cretaceous) recorded in the eastern part of Trento Plateau (Venetian Southern Alps, Italy). – Rivista Italiana di Paleontologia e Stratigrafia, **102**/3: 417–424

—— & Landra, G. (1994): Late Barremian-Early Aptian ammonites from the Maiolica Formation near Cesana Brianza (Lombardy Basin, Northern Italy). – Rivista Italiana di Paleontologia e Stratigrafia, **100**/3: 395–422.

——, Marini, A., Pallini, G., Baudin, F. & Begouen, V. (1994a): A guide level of the uppermost (Lower Cretaceous) in the pelagic succession of Umbria - Marche Apennines (Central Italy): the Faraoni Level. – Rivista Italiana di Paleontologia e Stratigrafia, **99**/4: 551–568.

—— & Pallini, G. (1994): Latest Hauterivian – Berremian Ammonite biostratigraphy in the Umbria – Marche Apennines (Central Italy). – In: Bulot, L.G., Argot, M. & Arnaud, H. (eds): Lower Cretaceous Cephalopod biostratigraphy of the Western Tethys. – Géologie Alpine, Mémoire Hors Série, **20**: 205–217.

——, Pallini, G., Erba, E., Premoli-Silva, I. & Coccioni, R. (1994b): Hauterivian – Berremian chronostratigraphy based on ammonites, nannofossils, planktonic foraminifera and magnetic chrons from the Mediterranean domain. – Cretaceous Research, **15**: 457–467.

Cita, M.B. (1965): Jurassic, Cretaceous and Tertiary microfacies from the Southern Alps (Northern Italy). E.J. Brill print, Leiden, 8, 99 pp., + 117 pls.

—— & Pasquaré, G. (1959): Osservationi micropaleontologiche sul Cretaceo delle Dolomiti. – Rivista Italiana di Paleontologia e Stratigrafia, **65**: 385–443.

Kompass (1985): Map of Cortina d'Ampezzo, **55**, 1: 50 000, Kompass-Karten GmbH, Rum/Innsbruck.

Costamoling, H. & Costamoling, W. (1994): Fossilien des Gardertales. – Verlagsanstalt Athesia GmbH., Bozen/Bolzano, 111 pp.

Dercourt, J., Ricou, L.E. & Vrielynck, B. (eds) (1993): Atlas Tethys Palaeoenvironmental Maps. Explanatory notes. – Gauthier-Villars, Paris, 307 p. (14 maps, 1 pl.).

Doglioni, C. (1985): The overthrusts of the Dolomites: ramp-flat systems. – Eclogae Geologicae Helvetiae, **78**/2: 335–350.

—— (1987): Tectonics of the Dolomites (Southern Alps, Northern Italy). – Journal of Structural Geology, **9**: 181–193.

—— (2007): Tectonics of the Dolomites. Bulletin für angewandte Geologie, **12**/2: 11–15.

Dolomiti Occidentali (2007): Carta Geologica of the Dolomiti Occidentali. 1:25 000, sheet **28**. – Litografia artistica Cartografica, Florence.

Faraoni, P., Flore, D., Marini, A., Pallini, G. & Pezzoni, N. (1997): Valanginian and early Hauterivian ammonite successions in the Mt Catria group (Central Apennines) and in the Lessini Mts (Southern Alp), Italy. – Palaeopelagos, **7**: 59–100.

——, Marini, A. & Pallini, G. (1995): The Hauterivian ammonite succession in the Central Apennines, Maiolica formation (Petrano Mt., Cagli -PS). Preliminary results. – Palaeopelagos, **5**: 227–236.

——, Marini, A., Pallini, G. & Pezzoni, N. (1996): The Maiolica Fm. of the Lessini Mts and Central Apennines (North Eastern and Central Italy): a correlation based on new bio-lithostratigraphical data from the uppermost Hauterivian. – Palaeopelagos, **6**: 249–259.

Farinacci, A. & Elmi, S. (eds) (1981): Rosso Ammonitico Symposium Proceedings. – Editioni Tecnoscienza, Rome, pp. 602.

Fourcade, E., Azema, J., Cecca, F., Dercourt, J., Guiraud, R., Sandulescu, M., Ricou, L.-E., Vrielynck, B., Cottereau, N. & Petzold, M. (1993): Late Tithonian (138 to 135 Ma). – In: Dercourt, J., Ricou, L.E. & Vrielynck, B (eds): Atlas Tethys Palaeoenvironmental Maps. Explanatory Notes. – Gauthier-Villars, Paris, pp. 113–134.

Geyer, O.F. (1993): Die Südalpen zwischen Friaul und Gardasee. – Sammlung Geologischer Führer, **86**: Bornträger, Berlin-Stuttgart, 576 p.

Gradstein, F.M., Ogg, J. & Smith, A. (2004): A Geologic Time Scale 2004. – Cambridge University Press, New York, Melbourne, Cambridge, 589 pp.

Grandesso, P. (1977): Gli strati a Precalpionellipi del Titoniano e I loro rapporti con il Rosso Ammonitico Veneto. – Mémoires Science Géologie (University of Padova), **32**: 3–14.

Haug, E. (1887): Die geologischen Verhältnisse der Neocomablagerungen der Puezalpe bei Corvara in Südtirol. – Jahrbuch der Kaiserlich-Königlichen Geologischen Reichs-Anstalt, **37**/2: 245–280.

—— (1889): Beitrag zur Kenntniss der oberneocomen Ammonitenfauna der Puezalpe bei Corvara (Südtirol). – Beiträge zur Paläontologie und Geologie Österreich-Ungarns, **7**/3: 193–229.

Heissel, W. (1982): Südtiroler Dolomiten. – Sammlung Geologischer Führer, **71**, Gebrüder Borntraeger, Berlin-Stuttgart, 172 pp.

Hoernes, R. (1876): Neocomfundorte in der Gegend von Ampezzo und Enneberg in Südtirol. – Verhandlungen der kaiserlich-königlichen Geologischen Reichs-Anstalt, **7**: 140–141.

IAS, International Association of Sedimentologists (2004): Super Sedimentological Exposures (compiled by Weissert, H.). – IAS Newsletter, **194**, www.iasnet.org.

Jenkyns, H.C. (1974): Origin of red nodular limestones (Ammonitico Rosso, Knollenkalke) in the Mediterranean Jurassic: a diagentic model. – In: Hsü, K.J. & Jenkyns, H.C. (eds): Palagic Sediments: on Land and under the Sea. – Special Publication Number 1 of the International Association of Sedimentologists, **1**: 249–271.

Jud, R. (1994): Biochronology and Systematics of Early Cretaceous radiolaria of the Western Tethys. – Mémoires de Géologie, Lausanne, **19**: 1–147.

Krobicki, M. (1993): Tithonian-Berriasian brachiopods in the Niedzica succession of the Pieniny Klippen belt (Polish Carpathians); Paleoecological and paleobiogeographical implications. – In: Palfy J. & Vörös A. (eds): Mesozoic Brachiopods of Alpine Europe. pp. 69–77.

Landra, G., Cecca, F. & Vašíček Z. (2000): Early Aptian ammonites from the top of the Maiolica and the anoxic “Selli Level” (Lombardy, Southern Alps). – Bolletino della Società Paleontologica Italiana, **39**: 29–45.

Lini, A. (1994): Early Cretaceous carbon isotope stratigraphy of the maiolica Formation, Southern Alps (Northern Italy and Southern Switzerland): Stratigraphic and palaeoenvironmental significance. – Unpublished PhD Thesis, ETH Zurich, 120 pp.

Lukeneder, A. (2008): The ecological significance of solitary coral and bivalve epibionts on Lower Cretaceous (Valanginian-Aptian) ammonoids from the Italian Dolomites. Acta Geologica Polonica, **58**/4: 425–436.

—— (2010): Lithostratigraphic definition and stratotype for the Puez Formation: formalisation of the Lower Cretaceous in the Dolomites (S. Tyrol, Italy). – Austrian Journal of Earth Sciences, **103**, 138-158.

—— & Aspmair, C. (2006): Startigraphic implication of a new Lower Cretaceous ammonoid fauna from the Puez area (Valanginaian - Aptian, Dolomites, Southern Alps, Italy). – Geo.Alp, **3**: 55–91.

Martire, L. (1992): Sequence stratigraphy and condensed pelagic sediments. An example from the Rosso Ammonitico Veronese, northeastern Italy. – Palaeogeography, Palaeoclimatology, Palaeoecology, **94**: 169–191.

—— (1996): Stratigraphy, Facies and Synsedimentary Tectonics in the Jurassic Rosso Ammonitico Veronese (Altopiano di Asiago, NE Italy). – Facies, **35**: 209–236.

——, Clari, P., Lozar, F. & Pavia, G. (2006): The Rosso Ammonitico Veronese (Middle-Upper Jurassic of the Trento Plateau): a proposal of lithostratigraphic ordering and formalization. – Rivista Italiana di Paleontologia e Stratigrafia, **112**: 227–250.

Massari, F. (1981): Cryptalgal fabrics in the Rosso Ammonitico sequences in the Venetian Alps. – In: Farinacci, A. & Elmi, S. (eds): Rosso Ammonitico Symposium Proceedings. – Tecnoscienza, pp. 435–469.

Mayer, H. (1999): Calibration of the Early Cretaceous time scale by integration of magnetostratigraphy and cyclostratigraphy: Study of the Cismon section (Southern Alps, Italy) and review. – Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, **212**: 15–83.

—— & Appel, E. (1999): Milankovitch cyclicity and rock-magnetic signatures of palaeoclimatic change in the Early Cretaceous Biancone Formation of the Southern Alps, Italy. – Cretaceous Research, **20**: 189–214.

Mojsisovics, E. v. (1879): Die Dolomitriffe von Südtirol und Venetien. – Beiträge zur Bildungsgeschichte der Alpen. Hölder, Wien, 552 pp.

Montanari, A. & Koeberl, C. (2000): Impact Stratigraphy. The Italian Record. – Lecture Notes in Earth Sciences Series, 93. Springer-Verlag, Berlin, 364 pp.

Muttoni, G., Erba, E., Kent, D.V. & Bachtadse, V. (2005): Mesozoic Alpine facies deposition as a result of past latidudinal plate motion. – Letters to Nature, **434**: 59–63.

Ogg, J.G. (1981): Middle and Upper Jurassic sedimentation history of the Trento Plateau (Northern Italy). – In: Farinacci, A. & Elmi, S. (eds): Rosso Ammonitico Symposium Proceedings. – Editioni Tecnoscienza, Rome, 479–503.

——, Ogg, G. & Gradstein, F.M (2008): The Concise Geologic Time Scale. – Cambridge University Press, Cambridge, 177 pp.

Pozzi, E. (1993): Die Fossilien der Dolomiten. – Tappeiner Verlag, Lana. 176 pp.

Préat, A., Morano, S., Loreau, J.-P., Durlet, C. & Mamet, B. (2006): Petrography and biosedimentology of Rosso Ammonitico Veronese (middle-upper Jurassic, north-eastern Italy). – Facies, **52**: 265–278.

Rodighiero, A. (1919): Il sistema Cretaceo del Veneto Occidentale compreso fra l'Adige e il Piave con speziale reguardo al Neocomiano dei Sette Comuni. – Palaeontographica Italica, **25**: 39–125.

Scotese, C.R. (2001): Atlas of Earth History. Paleomap project. – Arlington, 52 pp, Texas.

Stampfli, G.M., Borel, G.D., Marchant, R & Mosar J. (2002): Western Alps geological constraints on western Tethyan reconstructions. – In: Rosenbaum, G. & Lister, G.S. (eds): Reconstruction of the evolution of the Alpine-Himalayan Orogen. – Journal of Virtual Explorer, **8**: 77–106.

—— & MOSAR, J. 1999. The making and becoming of Apulia. – Mémoires Science Géologie (University of Padova). Special volume, 3rd Workshop on Alpine Geology **51**/1, Padova.

STOCK, H.W. (1994): Stratigraphie, Sedimentologie und Paläogeographie der Oberkreide in den nordöstlichsten Dolomiten(Italien) – Jahrbuch der Geologischen Bundes-Anstalt, **137**: 383–406.

STÖHR, D. (1993): Die Ammoniten der Kreide von La Stua (Dolomiten, Norditalien). Unpublished PhD thesis, University of Giessen, 173 pp.

—— (1994): Ammonoidea aus Schwarzschiefern von La Stua (Norditalien, Provinz Belluno) – Giessener Geolgische Schriften, **51**: 291–311.

TAPPEINER (2003): Naturpark Puez-Geisler. – Panoramakarte. Tappeiner, Lana.

UHLIG, V. (1887): Ueber neocome Fossilien von Gardenazza in Südtirol nebst einem Anhang über das Neocom von Ischl. – Jahrbuch der kaiserlich-königlichen geologischen Reichsanstalt, **37**/1: 69–108.

VAŠÍČEK, Z. (1994): Early Cretaceous ammonite biostratigrapy in the Western Carpathians (The Czech and Slovak Republics). – Géologie Alpine, Mémoires Hors Série, **20**: 169–189.

—— & MICHÁLIK, J. (1999): Early Cretaceous ammonoid paleobiogeography of the west Carpathian part of the Paleoeuropean shelf margin. – Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, **212**: 241–262.

——, MICHALÍK, J. & REHÁKOVÁ, D. (1994): Early Cretaceous stratigrapy, palaeogeography and life in Western Carpathians. – Beringeria, **10**: 1–169 pp.

WEISSERT, H.J. (1979): Die Palaeoozenographie der südwestlichen Tethys in der Unterkreide. – Unpublished PhD Thesis, ETH Zurich, 174 pp.

—— (1981): Depositional processes in an ancient palagic environment: the Lower Cretaceous Maiolica of the Southern Alps. – Eclogae Geologicae Helvetiae, **74**: 339–352.

WIECZOREK, J. (1988): Maiolica – a unique facies of the western Tethys. – Annales Societatis Geologorum Poloniae, **58**: 255–276.

ZEMPOLICH, W.G. (1993): The drowning succession in Jurassic carbonates of the Venetian Alps, Italy: a record of supercontinent breakup, gradual eustatic rise, and eutrophication of shallow-water environments. – In: LOUCKS, R.G. & SARG, J.F. (eds): Carbonate Sequence Stratigraphy – Recent Developments and Applications. American Association of Petroleum Geologists Memoir, Tulsa, **57**: 63–105.

ZHARKOV, M.A., MURDMAA, I.O. & FILATOVA, N.I. (1998): Peleogeography of the Berriasian-Barremian Ages of the Early Cretaceous. – Stratigraphy and Geological Correlation, **6**: 47–69