Austrian Journal of Earth Sciences | Volume 103/1 | 138 - 158 | Vienna | 2010

Lithostratigraphic definition and stratotype for the Puez Formation: formalisation of the Lower Cretaceous in the Dolomites (S. Tyrol, Italy)

Alexander LUKENEDER

KEYWORDS

Valanginian-Albian
Early Cretaceous
Puez Formation
Stratotype
Dolomites
Italy

Natural History Museum, Geological-Palaeontological Department, Burgring 7, 1010 Wien, Austria;

alexander.lukeneder@nhm-wien.ac.at

Abstract

Although pelagic to hemipelagic Lower Cretaceous sediments only cover restricted areas in the Dolomites (Southern Alps, Italy), they form a significant element of the mountainous areas of the higher Dolomites. Unfortunately, many of the formations within this area lack a precise definition (type section and detailed lithostratigraphic log). Here, a stratotype for the newly formalised Puez Formation is fixed in the Puez area (Col de Puez) near Wolkenstein (S. Tyrol) at E 011°49'15'', N 46°35'30''. The Puez Formation (approx. 121 m thick) is subdivided into three members from Valanginian to Albian age: the Puez Limestone Member (approx. 50 m; marly limestones; Late Valanginian-Late Barremian), the Puez Redbed Member (approx 9 m; foraminiferal wackestone-packstones; Aptian) and the Puez Marl Member (approx. 57 m; marl to limestone alternations; Early Aptian-Late Albian). The newly formalised Puez Formation sheds light on the Lower Cretaceous tectonic history of the Dolomites, and allows the paleoenvironmental evolution of basins and plateaus to be better understood, as well as the faunal composition and distribution within the investigated interval.

Obwohl pelagische und hemipelagische Sedimente der Unterkreide nur eng begrenzte Areale in den Dolomiten (Südalpen, Italien) bedecken, bilden sie ein wesentliches Element des gebirgigen Gebietes der höheren Dolomiten. Für zahlreiche lithologische Formationen fehlen allerdings präzise lithostratigraphische Definitionen (Typ-Lokalitäten oder detaillierte Profile). In dieser Arbeit werden unterkretazische Abfolgen aus den Dolomiten erstmals formalisiert. Eine Typ-Lokalität für die neu aufgestellte Puez Formation wird im Puez Gebiet (Puezkofel) nahe Wolkenstein (Südtirol) mit E 011°49'15'', N 46°35'30'' fixiert. Die Puez Formation (ca. 121 m) wird in drei Subformationen vom Valanginium bis in das Albium unterteilt: die Puez-Kalk-Subformation (ca. 50 m; mergelige Kalke; spätes Valanginium-spätes Barremium), die Puez-Redbed-Subformation (ca. 9 m; Foraminiferen wackestone-packstones; Aptium) und die Puez-Mergel-Subformation (ca. 57 m; Mergel bis Kalk Wechselfolge; frühes Aptium-spätes Albium). Die neu formalisierte Puez Formation erlaubt es, die tektonische Geschichte der Unterkreide aus den Dolomiten zu interpretieren, die Entwicklung der Umweltbedingungen von Becken und Plateaus aufzuspüren und zusätzlich die Zusammensetzung und Verbreitung der Fauna dieser Zeit zu verstehen.

1. Introduction

Cretaceous pelagic to hemipelagic sediments cover relatively small, restricted areas in the Dolomites (Southern Alps). Lower Cretaceous deposits form a major element of the mountainous area of the higher Dolomites (Hoernes, 1876; Mojsisovics, 1879; Haug, 1887, 1889; Uhlig, 1887; Rodighiero, 1919; AGIP Mineraria, 1959; Baccelle and Lucchi-Garavello, 1967a, b; Stöhr, 1993, 1994; Costamoling and Costamoling, 1994). The geo-logy of the Dolomites and adjacent areas has been described and summarized in detail by Heissel (1982), Doglioni (1987, 2007), Avanzini and Wachtler (1999), Pozzi (1993), Geyer (1993), Bosellini (1998), Bosellini et al. (2003), Lukeneder and Aspmair (2006), and Lukeneder (2008).

In the Dolomites, which form in the Lower Cretaceous a part of the Trento Plateau (Geyer, 1993; Bosellini et al., 2003; Lukeneder, 2008), cephalopod-bearing deposits are mainly recorded in two different facies, the calcareous limestones of the Biancone Formation (= Maiolica Formation elsewhere in Italy; Weissert, 1979, 1981; Channell et al., 2000; Lukeneder and Aspmair, 2006) and the Puez Formation (marls-marly limestones). 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 Valanginian-Hauterivian time and back to almost 30°N in the Early Cretaceous (Aptian).

Lower Cretaceous relics are situated on the Triassic limestones of the Dolomites (Hauptdolomit, up to 1000 m thick), covered at the Puez area by Dachsteinkalk (= Calcare di Dachstein; up to 10 m) with abundant, small megalodonts. At most localities with Lower Cretaceous sediments in the Dolomites, we also observed a relatively thin red, nodular limestone of the Rosso Ammonitico Formation type (= Ammonitico Rosso Fm.; 10-20 m; Flügel, 2004) between the Triassic and Lower Cretaceous (Lukeneder and Aspmair, 2006). The Triassic-Jurassic succession is then overlain by small areas formed by Lower Cretaceous sediments. These occasionally “conus shaped” relics (up to 150 high) of the Puez Formation are especially evident on the Puez-Odle-Gardenaccia Plateau (= Gherdenacia). The successions are well known 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 Puez (Puezkofel, 2725 m) form the major Lower Cretaceous outcrop starting at about 2400 m above sea level. Other well-known Lower Cretaceous localities in this area are the Piz Boè (Sella Group), as well as the plateaus of the area around Ampezzo ("Rote Wand" Fosses, Fanes), near Cortina d'Ampezzo at Ra Stua (= La Stua), and nearby Antruilles.

The studied section is located in the Southern Alps (Dolomites) of northern Italy (Cita and Pasquaré, 1959; Cita and Rossi, 1959; Lukeneder and Aspmair, 2006; Lukeneder, 2008). The stratigraphy of the Lower Cretaceous sediments here is based on ammonites and microfossils (e.g. foraminifera). During the late 19th and early 20th century, a rich fauna of cephalopods was collected from Lower Cretaceous sediments from this area by Haug (1887, 1889), Hoernes (1876), Mojsisovics (1879), Uhlig (1887), Rodighiero (1919), and Pozzi (1993). Additionally, microfacies and ammonites were reported from the "Alpe Puez" by Cita and 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 and Lucchi-Garavello (1967a, b) 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). 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 of this paper is to present a formalized lithostratigraphic definition and a stratotype for the Lower Cretaceous strata within the Dolomites, the Puez Formation. The presented lithological data and preliminary results on the Puez Formation are provided from investigations within the Dolomite project P20018-N10 (project of the Austrian Science Fund FWF). Future work will involve palaeomagnetic, isotope and geochemistry analyses in addition to a precise biostratigraphy based on macro-, micro- and nannofossils. In this paper, preliminary data especially on biostratigraphy, are included for the sake of completeness; detailed data, i.e. on macro- and microfossils, will be published elsewhere.

2. Geographical and Geological Setting

Geography. The outcrop is situated on the Puez-Odle-Gardenaccia Plateau in the Dolomites (maps Trentino – Alto Adige; South Tyrol; Tappeiner, 2003; KOMPASS Cortina d'Ampezzo 1: 50 000, 1985). The exact position is about 30 km northeast of Bozen (Fig. 1; E 011°49'15'', N 46°35'30''). The localities are accessible from the village Wolkenstein (1560 m) in the Val Gardena (= Grödner Tal) by following the Val Lunga (= Langental) to its eastern end and then hiking on path 16 up the steep dolomite wall. The outcrops are located near the Rifugia Puez (= Puez Hütte, 2475 m). The Lower Cretaceous crops out running between the Col da la Pieres (2747 m) at the west flank, the middle Col de Puez (2725 m), and at the eastern border with the Sassongher (2615 m; Fig. 2). The grey, green to red succession of the stratotype is located on the southern side of the Piz de Puez (2846 m, 1:25 000, sheet 05 Val Gardena). The occurrence is well exposed on the steep southern flanks. Almost 3000 m high mountains and steep terrain made sampling very difficult.

Geological setting. The new formation and members described herein occur at outcrops located on the Puez-Gardenaccia Plateau (map Dolomiti Occidentali, 2007). They are located within the area of the Puez-Odle-Geisler natural park in the northern part of the Dolomites. The Dolomites (Permian to Cretaceous), an internal part of the Southern Alps, are a Northern Italian chain that emerged during the deformation of the

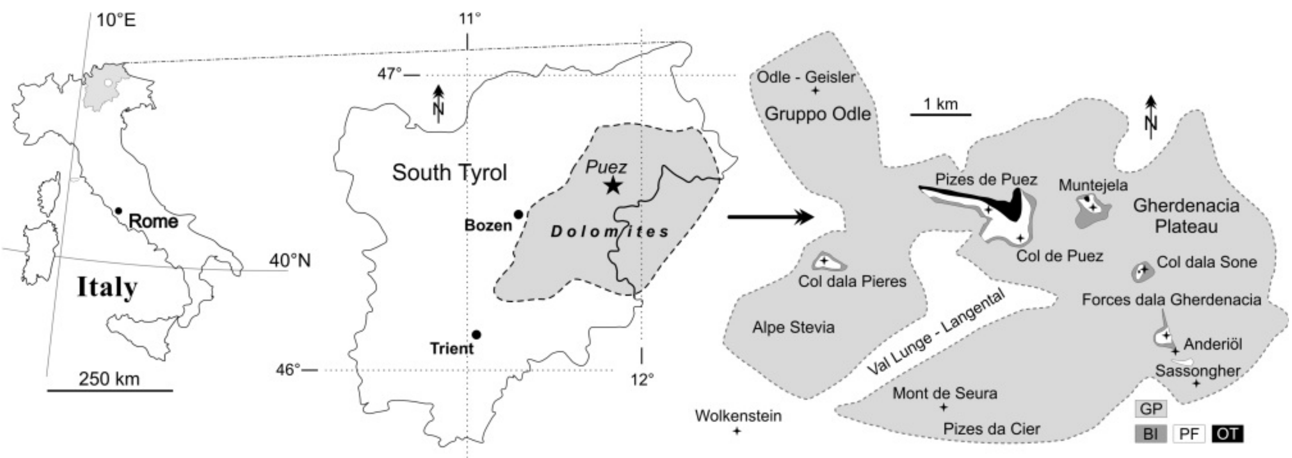


Figure 1: Locality map of the Puez area (left) with indicated outcrop position (black star) within the Dolomites (S. Tyrol, Italy). Lower Cretaceous localities on the Gherdenacia Plateau mentioned in the text (right). GP Gherdenaccia Plateau, BI Biancone Formation, PF Puez Formation, OT Overthrust.

passive continental margin of the Adriatic plate (Jud, 1994; Bosellini et al., 2003; Castellarin, 2006).

The geological landscape of the Puez region is dominated by the giant Triassic carbonate platforms. The top of these carbonates bears relics of Lower Cretaceous sediments which were formerly much more widespread but have been eroded through time. The Lower Cretaceous sediments are overthrusted ("Gipfelüberschiebung") by the Upper Triassic Hauptdolomit (Doglioni, 1985, 1987; Pozzi, 1993). This phenomenon can be observed only at the Puez-Gardenaccia Plateau and the Sella area located directly to the south (Heissel, 1982). The thickness of the overthrusting dolomite (Doglioni, 1985) differs markedly at different localities (approx. 0-150 m). The Hauptdolomit is overlain by Jurassic, strongly dolomitized (granulated structure), whitish to yellow, dolosparitic beds. The latter beds developed most probably by dolomitization of former Biancone limestone beds (see Geyer, 1993). This type of dolomitized sediments was called, in the Umbria-Marche region, "Maiolica with saccharoidal structure" (Cecca et al., 1995). On the Puez-Gerdenaccia geological map (Dolomiti Occidentali, 2007) it is known as dolosparites of the Gardenacia Formation. The Lower Cretaceous succession starts with pure limestones of the reddish to grey Biancone Formation (?Berriasian-Late Valanginian) (Fig. 3). The lowermost parts show similarities to the Rosso Ammonitico (A.R. Superiore). Biancone is the local name (Trento Plateau) for the more broadly known Italian Maiolica Formation (Faraoni et al., 1995, 1996, 1997; Wieczorek, 1988). The Puez Biancone type limestone appears to be somewhat different from this normally uniform Maiolica facies. The former shows numerous changes from grey to red beds within approx. 20 m of thickness. Weathered parts of this 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). Grandesso (1977) showed that the Rosso Ammonitico Veneto reaches up to the Lower Valanigian in the Lessini Mountains at the Mizzole section and in its eastern occurrences in the Friuli (e.g. locality Claut). The situation in these lowermost formations on the Puez-Gardenaccia Plateau is not completely clear due to the bad outcrop conditions (talus debris and, most of the year, snow cover) in the lower parts of the Upper Jurassic and Lower Cretaceous. Biostratigraphic data show that the age – Early-Late Valanginian – might be somewhat younger at the Puez locality as in most other localities, showing the transition of Rosso Ammonitico Superiore like limestones into Biancone limestones (red and grey varieties). The red R. A. type and red Biancone limestones occur most prominent at the Col de Pieres to the west (Cita and Pasquaré, 1959). The Biancone facies is followed by the Puez Formation with its single three members as defined here (Puez-Limestone, Puez-Redbed and Puez-Marl Member). The succession shows a transition from limestones and marly limestones into a marl-marly limestone alternation in the upper half of the log. This succession is similar to the Lower Cretaceous of La Stua, which also shows Rosso Ammonitico, Biancone, "Ammonitenmergel" (comparable to the herein formalised Puez Formation), grey marls and Aptian marls (Stöhr, 1993).

The Lower Cretaceous sequence shows the evolution of the northernmost part of the Trento Plateau at this time (Dercourt et al., 1993; Jud, 1994). 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;

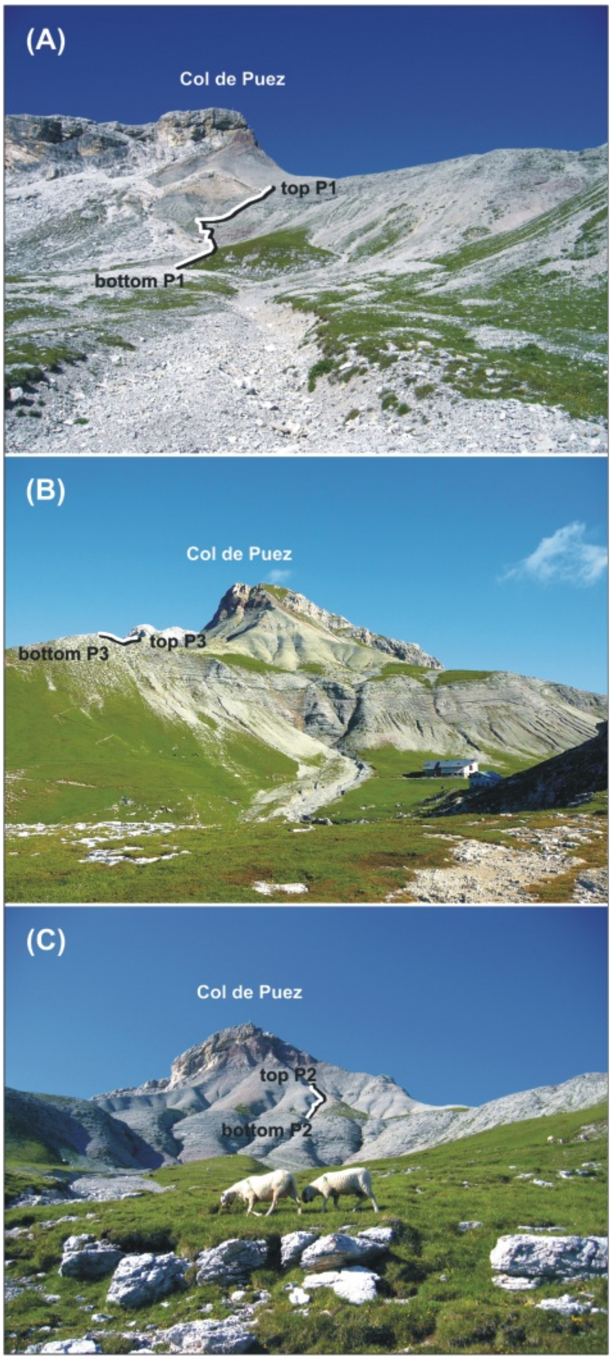


Figure 2: Locality and stratotype of the Puez Formation with logs P1-P3 at the Col de Puez (Puezkofel). A, log P1 of the Puez-Limestone Member. B, log P3 of the Puez-Redbed Member. C, log P2 of the Puez-Marl Member.

Geyer, 1993). The reason for the Late Jurassic to Early 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 and Appel, 1999; Muttoni et al., 2005).

3. The Puez Formation

Invalid former designations of this unit due to a missing accurate reference section or lithostratigraphic description include early publications from Mojsisovics (1879), Uhlig (1887), to more recent papers of Costamoling and Costamoling (1994), Doglioni (2007) or latest by Lukeneder and Aspmair (2006), and Lukeneder (2008). All the latter authors have used the Puez marls in some manner but did not formalize the formation (no type-log, no GPS data etc.). No logging, detailed stratigraphy or precise description of a type section is available.

Type area: IT 1:50 000, map sheet 55 Cortina d'Ampezzo, geological map western Dolomites (Westliche Dolomiten) 1:25 000, sheet east. Area north of Wolkenstein in the Department Trentino-Alte Adige (South Tyrol, Italy, Fig. 1). The locality is situated in the heart of the natural park Puez-Odle within the UNESCO world heritage, the Dolomites.

Type section: the type section is located at the southern slope of the Col de Puez (2725 m) at the eastern end of the SW-NE striking Langental valley (= Vallunga), 6 km north-north-east of Wolkenstein (= Selva in Val. Gardena, = Sölva; Figs. 2-7). 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''. The refuge Rifugio Puez (= Puez Hütte) is located 700 m to the south-east (2475 m).

Reference sections: reference sections of the Puez Formation are in the same area of the Puez-Gardenaccia Plateau, the Pizes de Puez with its easternmost summit the Col de Puez (2725 m; E 011°49'29'', N 46°35'38''), Col de la Sone (2633 m; E 011°51'00'', N 46°35'06''), the Muntejela (2666 m; E 011° 50'23'', N 46°35'42''), the Forca de Gardenaccia (2598 m; E 011°51'21'', N 46°34'53''; = Anderiöl in Costamoling and Costamoling, 1994), the northern part of the Sassongher (2615 m; E 011°51'18'', N 46°34'30''), the western Col de la Pieres (2747 m; E 012°05'33'', N 46°37'58''), and the area around the neighbouring localities Antruilles (2000 m; E 012°04'14'', N 46°36'45'') and La Stua (1739 m; E 011°49'15'', N 46°35'30''), all situated within the Dolomites region. For geological details see the geological map of the western Dolomites (Dolomiti Occidentali, 2007; 1:25 000, sheet east).

The lower boundary: defined at the type locality at the Col de Puez by an abrupt change into more marly limestones and calcareous marls (65-70% $CaCO_3$) from grey to reddish, cherty limestones (80-87% $CaCO_3$) from the Biancone Formation- (= Maiolica-) like limestone units at the boundary (Figs. 3 and 4).

The upper boundary: defined at the type locality at the Col de Puez by an overthrusting ("Gipfelüberschiebung") by Triassic Haupdolomit (Pozzi, 1993); observed at the Puez-Gardenaccia and Sella area. The thickness of the overthrusting dolomites differ in all localities from Col Pieres with 0 m, the Pizes de Puez with 120-150 m, and Col de la Sone, Muntejela and Sassongher with approx. 0-10 m, which differs markedly from all other Lower Cretaceous localities (Fig. 7).

Subdivision: lower part defined herein as Puez-Limestone Member (log P1 with beds P1/17-204; Figs. 3 and 4), middle part as Puez-Redbed Member (log P3 with beds P3/1aa-1h; Fig. 5), and the upper part as Puez-Marl Member (uppermost part of log 3 with beds P3/2-28 and log P2 with beds P2/1-268; Figs. 5-7).

Derivation of name: after the mountain Col del Puez (= Puezkofel; 2725 m; E 011°49'15'', N 46°35'30''; Fig. 1); 6 km NNE of Wolkenstein and 7 km NWW of La Villa (= Stern).

Synonyms: invalid terms such as "Puez-Mergel" (Avanzini and Wachtler, 1999; Bosellini, 1998), "Marna di Puez" (Castellarin et al., 2006), "Puez Marls" (Doglioni, 2007), "Puez-Schichten" (Costamoling and Costamoling, 1994), "Puez Marls and Marne del Puez" (Genevois, 1999), "Puez-Mergel" (Pozzi, 1993), "Neocommergel" (Hoernes, 1876), "Neokom-Mergel" (Heissel, 1982), "graue Mergelkalke" (Mojsisovics, 1879; Uhlig, 1887), "oberneocome Mergel und Mergelkalke" (Haug, 1889), "Ammoniten-Mergel und Apt-Mergel" (Stöhr, 1993; Stock, 1994), "ammonite-marls" (Cita, 1965) "calcari grigio-rossastri and calcari marnosi grigio-verdi" (Cita and Pasquaré, 1959), "marne e calcari nodulosi rosso e calcari grigi" (Rodighiero, 1919), the "pseudo-formalized" term "Puez Formation" by Lukeneder and Aspmair (2006), Lukeneder (2008), and the "Puez Formation – Formazione di Puez" on the geological map Dolomiti Occidentali (2007; sheet east 1:25 000).

Lithology: the Puez section consists essentially of red to grey calcareous marls and grey, silty marlstones of the Puez Formation (100-150 m) underlain by green-grey calcareous limestones of the Biancone Formation (= Maiolica type) and red-nodular limestones of the "Rosso Ammonitico" type. A very unique feature of the middle section of the Puez Formation is the numerous cherty and calcareous concretions with their characteristic "bulb" shape (beds P/146-168, Fig. 3; Fig. 4, F). They appear in different shapes, but pear-shaped forms up to 20 centimetres in height dominate. Here, we refer to the whole sequence of Lower Cretaceous marly limestones and marls as the Puez Formation (Puez marls plus limestones) excluding the lowermost formation, the Biancone Formation. The Biancone Formation as traditionally defined (pelagic nannofossil limestone) occurs only in the lowermost part of the section. The outcrops are generally exposed on steep walls up to the Piz de Puez (= Puezspitzen) and Col de Puez (= Puezkofel). Microfacies types recognized include radiolarian-wackestone, biogenic-rich mudstone and radiolarian-wackestone, biogenic-rich radiolarian mudstones. Radiolarians, ostracods, echinoderms, sponge spiculae, and foraminifera are the most prominent constituents of the microfauna and can appear to be rock-forming.

Geochemistry: TOC (total organic carbon) values reach from 0.0-2.28 % and S (sulfur) values display contents from 0.3-0.6%. $CaCO_3$ (calcium carbonate contents, equivalents calculated from total inorganic carbon) displays values between 50.1 and 95.8 %.

Macrofossils: from abundant ammonoids (see below) and echinoids (Disasteroida), over rare nautilids (*Cymatoceras*), belemnites, aptychi (*Lamellaptychus*), rhynchoteuthids (*Rhynchoteuthis*), bivalves (*Propeamussium*), and brachiopods (*Pygope*) to beds, or even parts of the log barren in macrofossils (e.g. Puez-Redbed Member and Puez-Marl Member). Most common ammonoid genera derive from the Puez-Limestone Member, with *Phylloceras*, *Phyllopachyceras*, *Lytoceras*, *Barremites*, *Melchiorites*, *Abrytusites*, *Neocomites*, *Olcostephanus*, *Pulchellia*, *Silesites*, *Acrioceras*, *Anahamulina*, *Hamulina*, *Macroscaphites*, *Crioceratites*, *Ancyloceras* and others. Ammonites and echinoids can be very abundant in single fossiliferous beds. Microfossils are most frequent, with radiolaria, foraminifera and calpionellids and in the lowermost sediments from the Biancone (grey and red variety) and Puez Formation limestones. Foraminifera are dominant in the middle and upper part of the Puez Formation within the marls and limestones of the Puez-Redbed Member and the Puez-Marl Member (Figs. 5-7). Bioturbation and ichnofossils such as *Chondrites*, *Zoophycus*, *Halimedides*, and *Thalassinoides* can be frequent and are most visible on the top of marker beds as P1/204 and in the Albian Puez-Marl Member.

Microfossils: foraminifera (*Lenticulina*, *Involutina*, *Praehedbergella*, *Rotalipo*ra, *Thalmanninella*, *Biticinella*, *Planomalina*, *Ticinella*, *Paraticinella*, *Globigerinelloides*, *Hedbergella* etc.), tintinnids (*Calpionella*, *Tintinnopsella*), radiolaria (*Thanarla*, *Archaeodictyomitra*, *Sethocpsa* etc.), ostracods, sponge spicules and other groups.

Nannofossils: calcareous nannofossils with nannoconids (*Nannoconus*), coccoliths (*Watznaueria*, *Eiffellithus*, *Chiastozygus*), murolithids (*Rhagodiscus*), nannolithids (*Assipetra*) and others.

Origin, facies: the Puez Formation is a pelagic-hemipelagic facies (Lukeneder and Aspmair, 2006; Lukeneder, 2008).

Chronostratigraphic age: Late Valanginian – Late Albian with an approx. duration of 35 million years (Gradstein et al., 2004; Ogg et al. 2008).

Biostratigraphy: calpionellids are comperatively rare and appear only in the lowermost part of the Puez section within the Biancone Formation of log Puez/P1, and the lowermost beds of the Puez Formation show mainly a ?Berriasian and Late Valanginian zonation (*Tintinnopsella* Zone). Characteristic foraminifera (up to the *Thalmanninella globotruncanoides* Biozone), and calcareous nannofossils (up to latest Albian CC9 Zone) hint at a Late Berriasian to Late Albian age (Albian/Cenomanian boundary). Ammonoids occur only in the lower half (Puez-Limestone Member) of the log (e.g. Puez/P1) and hint at a Late Valanginian to latest Barremian duration (*Criosarsinella furcillata* Zone, Toxancyloceras vandenheckii Zone), in accordance with Reboulet et al. (2009). No ammonoids have yet been found in the Puez-Marl Member.

Thickness: approx. 121 m at the type section of the Puez Formation at the southern flank of the Col de Puez (2725 m).

Lithostratigraphically higher rank: northernmost Trento Plateau within the Dolomites (Southern Alps).

Lithostratigraphic subdivision: limestone-dominated lower part defined herein as Puez-Limestone Member (P1/17-204, Figs. 2A, 3 and 4), red beds of the middle part as Puez-Redbed Member (P3/1aa-1h; Figs. 2B and 5) and the marl-limestone alternation in the upper part as Puez-Marl Member (P3/2-28 and P2/1-268; Figs. 2C, and 5-7).

Underlying units: reddish to grey Biancone Formation (?Berriasian-Valanginian) at the type locality at Puez (e.g. log. P1/10-17, lowermost part not yet known). Comparable to typical Biancone Formation limestones (Tithonian), as seen at the La Stua section (Stöhr 1993, 1994).

Overlying units: younger sediments are eroded in the Puez-Odle region. Overlying turbiditic series of the Scaglia variegata Formation occur at La Stua (Stöhr 1993, 1994). The Puez Formation is at the Puez locality overthrusted by Triassic Hauptdolomit (Doglioni, 1985, 1987; Pozzi, 1993).

Geographic distribution: area of the Dolomites in South Tyrol but only preserved at relic areas due to erosive processes. Puez-Odle area (Bosellini, 1998; Bosellini et al., 2003; Lukeneder and Aspmair, 2006; Lukeneder, 2008) and La Stua (= Ra Stua; Cita and Rossi, 1959; Stöhr 1993. 1994).

Complementary references: Hoernes (1876), Mojsisovics (1879); Haug (1887, 1889), Uhlig (1887), Rodighiero (1919), Cita and Pasquaré (1959), Baccelle and Lucchi-Garavello (1967a, b), Doglioni, 1985, 1987), Pozzi (1993), Costamoling and Costamoling (1994), and Jud (1994). The geology of the Dolomites and adjacent areas has been described and summarized in detail by Pozzi (1993), Geyer (1993), and Heissel (1982).

The Puez Formation is subdivided into single members due mainly lithology differences, as given by the rules of the International Stratigraphic Committee (International Committee of Stratigraphy, 2009). The derivation of names for the members was in accordance to this international code. The Puez Formation is subdivided into the lowermost Puez-Limestone Formation, followed by the Puez-Redbed Formation and overlain by the Puez-Marl Formation. The locality name is followed by the characteristic lithological feature (lithology and color) of the described part of the log.

3.1 The Puez-Limestone member

The Puez-Limestone Member constitutes a new member, erected herein. This member comprises the lower, limestone-dominated part of the “Puez Formation” defined herein (see also Uhlig, 1887, Rodighiero, 1919, Stöhr, 1993, 1994, Costamoling and Costamoling, 1994, Bosellini, 1998, Bosellini et al., 2003, Lukeneder and Aspmair, 2006, Lukeneder, 2008, and Gaillard and Olivero, 2009).

Type area: As for the herein-defined Puez Formation. IT 1:50 000, map sheet 55 Cortina d’Ampezzo, (South Tyrol, Italy).

Type section: Formed by the lower part (log Puez/P1; Figs. 2A, 3 and 4) of the Puez Formation. The Puez-Limestone

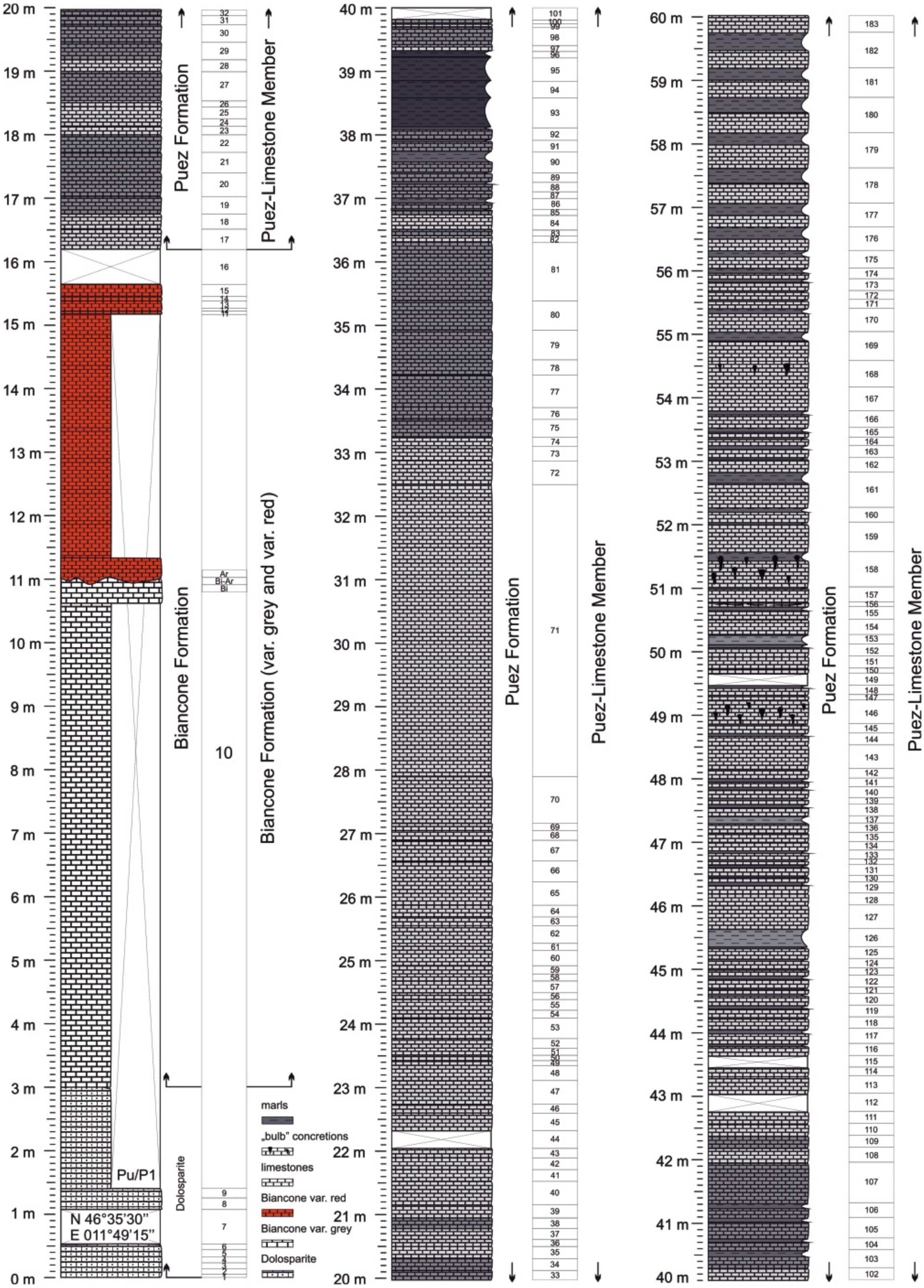
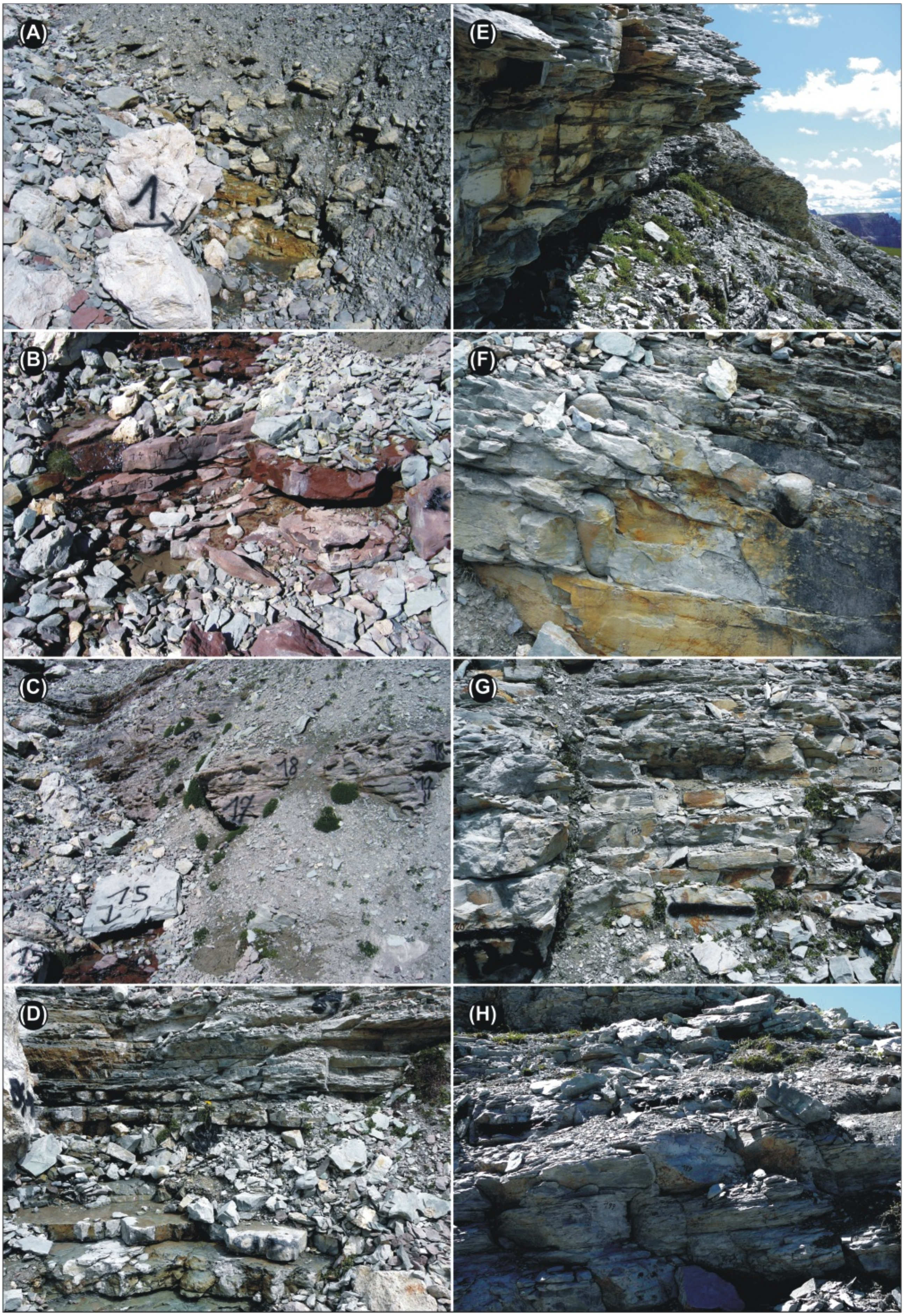


FIGURE 3: Lower and middle part of the Puez log P1 with beds 1-183 (at 0-60 m). Underlying units are the Dolosparite (beds 1-10) and the red and grey limestone varieties of the Biancone Formation (beds 10-15). The Puez Formation starts with the Puez-Limestone Member at bed P1/17 (at 16.2 m) and reaches bed P1/183, ending at bed P1/204 (at 66 m) on Fig. 5 (Fig. 5D).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(E)
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18
17
15
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Member appears with beds P1/17-204 at E 011°49'15'', N 46°35'30''.

Reference sections: reference sections of the Puez Formation are in the same area (Puez-Gardenaccia Plateau), the Pizes de Puez, Col de la Sone, the Muntejela, the Forca de Gardenaccia, the northern area of the Sassongher, and additionally age equivalents at La Stua, all situated within the Dolomites region.

The lower boundary: defined by the gradual change from red cherty, nodular limestones from the red Biancone Formation (weathering similar to Rosso Ammonitico Superiore) into dark grey reddish limestone with higher marl contents of the Puez-Limestone Member at bed P1/17 (Figs. 3 and 4C).

The upper boundary: defined by the abrupt change from light to dark grey marly limestone and marls into red, coarser foraminiferal limestones (sandy weathering) of the Puez-Redbed Member (defined herein), fixed at the top of the marker bed P1/204 (= P1/210 and P2/210, Figs. 5 C and D) appearing with numerous red trace fossils on the top (*Halimedides*, *Thalassinoides*, *Chondrites*).

Derivation of name: after the limestone dominated facies of the member.

Synonyms: invalid terms such as "Puez-Mergel" (Avanzini and Wachtler, 1999; Bosellini, 1998), "Marna di Puez" (Castellarin et al., 2006), "Puez Marls" (Doglioni, 2007), "Puez-Schichten" (Costamoling and Costamoling, 1994), "Puez Marls and Marne del Puez" (Genevois, 1999), "Puez-Mergel" (Pozzi, 1993), "Neocommergel" (Hoernes, 1876), "Neokom-Mergel" (Heissel, 1982), "graue Mergelkalke" (Mojsisovics, 1879; Uhlig, 1887), "oberneocome Mergel und Mergelkalke" (Haug, 1889), "Ammoniten-Mergel und Apt-Mergel" (Stöhr, 1993; Stock, 1994), "ammonite-marls" (Cita, 1965).

Lithology: the Puez-Limestone Member consists of red, grey and grey-green limestones, marly limestones and calcareous marls. In the middle part (beds P1/146-169; Figs. 3 and 4F) of this member, frequently bulb-shaped chert-carbonate concretions occur. Concretions appear in different shapes (horizontal layers, spherical etc.) dominated by a bulb-shaped morphology up to 20 cm in height. The concretions are mostly formed around biogenic components dominated by ammonites and trace fossils. Microfacies types are the same as for the Puez Formation.

Geochemistry: TOC values reach from 0.0-0.28% and S values display contents from 0.3-0.4%. $CaCO_3$ displays values between 50.1 and 90.9%.

Macrofossils: From abundant ammonoids (see below) and echinoids (Disasteroida), over rare nautilids (*Cymatoceras*), belemnites, aptychi (*Lamellaptychus*), rhynchoteuthids (*Rhynchoteuthis*), bivalves (*Propeamussium*), and brachiopods (*Pygope*) to almost beds, or even parts of the log barren in macrofossils. The most common ammonite genera are *Phylloceras*, *Phyllopachyceras*, *Lytoceras*, *Barremites*, *Melchiorites*, *Abrytusites*, *Neocomites*, *Olcostephanus*, *Pulchellia*, *Silesites*, *Acrioceras*, *Anahamulina*, *Hamulina*, *Macroscaphites*, *Crioceratites*, and *Ancyloceras*. Ammonites and echinids can be very abundant in single fossiliferous beds (e.g. P1/17, P1/65, P1/93).

Microfossils: foraminifera (*Spirillina*, *Involutina*, *Praehedbergella* etc.), tintinnids (*Calpionella*), radiolaria (*Thanarla*, *Archaeodictyomitra*, *Sethocpsa* etc.), ostracods, sponge spicules and other groups.

Nannofossils: calcareous nannofossils with nannoconids (*Nannoconus*) and others.

Origin, facies: the Puez-Limestone Member is a pelagic-hemipelagic facies Lukeneder and Aspmair, 2006; Lukeneder (2008).

Chronostratigraphic age: Late Valanginian – latest Late Barremian.

Biostratigraphy: calpionellids are extremely rare and appear only in the lowermost part of the Puez-Limestone Member (up to P1/17) and show Late Valanginian zonation (*Tintinnopsella* Zone). Characteristic foraminifera (*Praehedbergella*) and calcareous nannofossils (*Nannoconus* ssp., up to latest Barremian) hint at a Late Valanginian to Late Barremian age. Ammonoids occur throughout the Puez-Limestone Member (Puez/P1) and hint at a Valanginian to uppermost Barremian range (*Criosarsinella furcillata* Zone, *Toxancyloceras vandenheckii* Zone).

Thickness: approx. 50 m at the type section of the Puez-Limestone Member (Puez Formation) on the southern flank of the Col de Puez (Figs. 3-5).

Lithostratigraphically higher rank: The Puez Formation formalized herein, on the Trento Plateau within the Dolomites (Southern Alps).

Underlying units: reddish to grey limestones of the Biancone formation (?Berriasian-Valanginian) at the type locality on the Puez Plateau.

Overlying units: foraminiferal wackestone-packstones of the Aptian Puez-Redbed member, formalized herein.

Geographic distribution: as for the Puez Formation, the area of the Dolomites in South Tyrol (Lukeneder 2008), but only preserved at relic areas due to erosive processes.

Figure 4: Beds of the Dolosparit, the Biancone Formation and the Puez Formation (Puez-Limestone Member) at the stratotype. A, the Jurassic Dolosparite at beds P1/1-8. B, red and grey limestones of the Biancone Formation at beds P1/12-15. C, the Puez Formation starts with the Puez-Limestone Member at bed P1/17. D, The Puez-Limestone Memer with well bedded, reddish limestone beds P1/80-87. E, typical marly limestones of the middle part of the Puez-Limestone Member at beds P1/120. F, unique bulb-shaped, calcareous chert concretions at the middle part of the Puez-Limestone Member at bed P1/146. G, marly limestones of the middle part (Barremian) of the Puez-Limestone Member at beds P1/120-128. H, uppermost part of the Puez-Limestone member with fossiliferous, grey-violet limestones at P1/198-204.

3.2 The Puez-Redbed member

The newly defined Puez-Redbed Member encompasses the middle part of the Puez Formation defined herein. This member was not noticed by earlier authors or in more recent papers by Lukeneder and Aspmair (2004) and Lukeneder (2008).

Type area: as for the Puez Formation. IT 1:50 000, map sheet 55 Cortina d'Ampezzo, (South Tyrol, Italy).

Type section: the middle part (log Puez/P3; Figs. 2B and 5) of the Puez Formation. The Puez-Redbed Member appears with beds P3/1aa-1h at E 011°49'34'', N 46°35'24''.

Reference sections: reference sections of the Puez Formation are in the same area (Puez-Gardenaccia Plateau), the area around the Pizes de Puez, but badly exposed due to covering by debris cones from the above marly Puez-Marl Member.

The lower boundary: defined by the abrupt change from grey limestones from the underlying Puez-Limestone Member (after ?hiatus) into the red, coarser-grained sediments of the Puez-Redbed Member at bed P1(204 (see Puez-Limestone Member above).

The upper boundary: defined by the abrupt change from red, coarser sediments (foraminiferal limestones of the Puez-Redbed Member into the typical bright grey to almost black marl-limestone alternations of the overlying Puez-Marl Member (Fig. 5).

Derivation of name: after the reddish color of the member.

Synonyms: no equivalents to this unique facies known yet.

Lithology: the Puez-Redbed Member consists of red, foraminiferal limestones and red, intercalated calcareous marls with strong bioturbation (beds P3/1aa-1h; Fig. 5).

Geochemistry: TOC values reach from 0.0-2.78% and S values display contents from 0.2-0.6%. $CaCO_3$ displays values between 50.6 and 84.8%.

Macrofossils: Only rare crinoid and bivalve fragments (not determined) have been detected. The Puez-Redbed Member is barren of ammonites, echinids and other macrofossil groups.

Microfossils: abundance of foraminifera such as *Paraticinella*, accompanied by other groups.

Nannofossils: calcareous nannofossils with nannoconids (*Nannoconus*) and others.

Origin, facies: the Puez-Redbed Member is a pelagic-hemipelagic facies (Lukeneder and Aspmair, 2006; Lukeneder, 2008).

Chronostratigraphic age: Early Aptian – Late Aptian.

Biostratigraphy: preliminary data with characteristic foraminifera (*Paraticinella eubejaouaenisi*) and calcareous nannofossils (*Nannoconus truitti truitti*) hint at an Aptian age (see Premoli Silva et al., 2009).

Thickness: approx. 9 m at the type section of the Puez-Redbed Member (middle part of the Puez Formation) at the southern flank of the Col de Puez.

Lithostratigraphically higher rank: Puez Formation on Trento Plateau within the Dolomites (Southern Alps).

Underlying units: grey limestones and marly limestones of the Puez-Limestone Member (Late Valanginian-latest Late Barremian) at the type locality at Puez.

Overlying units: light-grey limestones to almost black marls of the marl-limestone alternations of the Puez-Marl Member (formalized herein).

Geographic distribution: only observable at the Puez area of the Dolomites.

3.3 The Puez-Marl member

The Puez-Marl-Member encompasses the marl-rich upper part of the Puez Formation, defined herein (for a discussion see also Lukeneder and Aspmair, 2004, and Lukeneder, 2008; complementary references are Uhlig, 1887, AGIP Mineraria, 1959, Geyer, 1993, Stöhr, 1993, 1994, Costamoling and Costamoling, 1994, Bosellini, 1998, and Bosellini et al., 2003).

Type area: as for the Puez Formation. IT 1:50 000, map sheet 55 Cortina d'Ampezzo, (South Tyrol, Italy).

Type section: the upper part (log Puez/P2; Figs. 5-7) of the Puez Formation. The Puez-Marl Member appears with beds P2/1-268 at E 011°49'29'', N 46°35'29'' and the upper part of log P3 with P3/2-28 at E 011°49'34'', N 46°35'25'', occurring at the lowermost part of this member.

Reference sections: several sections in the same area (Puez-Gardenaccia Plateau) at the Pizes de Puez. Due to erosional processes this member is mostly missing at other sections and only weathered remnants and relics are visible at the Col de la Sone, the Muntejela, the Forca de Gardenaccia, the northern area of the Sassongher, and additionally age equivalents at La Stua, all situated within the Dolomites region.

The lower boundary: defined by the abrupt change at P3/2 (Fig. 5) from the red, coarser sediments of the Puez-Redbed Member into the typical bright grey to almost black marl-limestone alternations of the overlying Puez-Marl member.

The upper boundary: defined at the Col de Puez by an overthrust ("Gipfelüberschiebung") of the older Triassic Hauptdolomit and Dachsteinkalk.

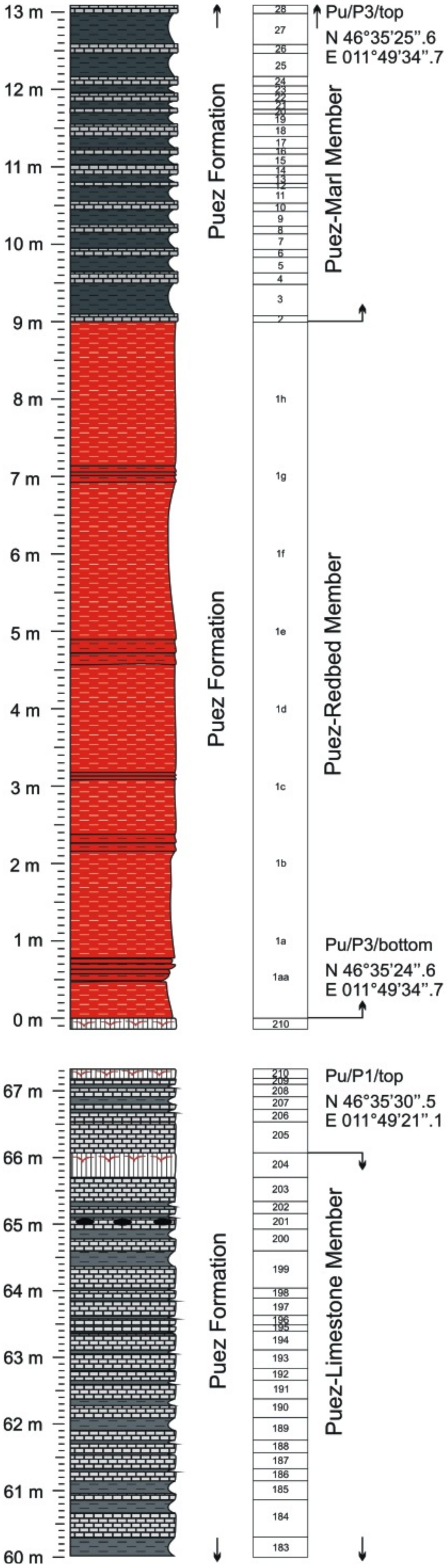
Derivation of name: after the strongly pronounced, marl-dominated alternation of dark grey to black marls with intercalated limestone beds of the member.

Synonyms: the upper parts of Stöhr's (1993, 1994) "Ammonitenmergel" and "Aptmergel" at the La Stua locality.

Lithology: the Puez-Marl Member consists of a strongly pronounced alternation of dark grey to black marls with intercalated grey limestones, marly limestones and calcareous marls. In the lower parts (beds P3/2-28 and P2/1-248; figs. 5-7) the darker marl beds (up to 0.1-1 m) dominate over the intercalated limestone beds (up to 0.01-0.5 m) in this member. The bed-thickness and marl content varies throughout the member. The quantity and thickness of intercalated limestone beds increases in the upper part of the Puez Marl Member (P2/249-268; Figs. 6 and 7). Limestone beds are strongly burrowed by dark burrows from the corresponding, overlying darker marl bed. Microfacies types are foraminiferal- to radiolarian-dominated packstones to wackestones. Abundant foraminifera occur also in the darker marls.

Geochemistry: TOC values reach from 0.0-0.74% and S val-

Figure 5: On the left: uppermost part of the Puez log P1 with beds P1/183-210 (at 0-67 m). The Puez-Limestone Member ends at bed P1/204 (at 66 m; D). Beds P1/205-210 illustrate an overthrusted, tectonical doubling of beds P1/199-204. Bed P1/204 (= P1/210 and P3/210) marks the last bed of the Puez-Limestone Member and shows mumerous penetrating trace fossils (*Halimedides*, *Thalassinoides*, *Chondrites*), filled with red sediments from the overlying Puez-Redbed Member (C). The red foraminiferal wackestones-packstones derive from beds P3/1aa-1h (B). The lowermost part (A) of the Puez-Marl Member starts with beds P2/1-28 (at 9-13 m), ending at bed 268 (at 57 m) on Fig. 6.


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
Puez Formation
Puez-Marl Member
Pu/P3/top
N 46°35'25".6
E 011°49'34".7
Puez Formation
Puez-Redbed Member
Pu/P3/bottom
N 46°35'24".6
E 011°49'34".7
1h
1g
1f
1e
1d
1c
1b
1a
1aa
210
67 m
66 m
65 m
64 m
63 m
62 m
61 m
60 m
Puez Formation
Puez-Limestone Member
Pu/P1/top
N 46°35'30".5
E 011°49'21".1
210
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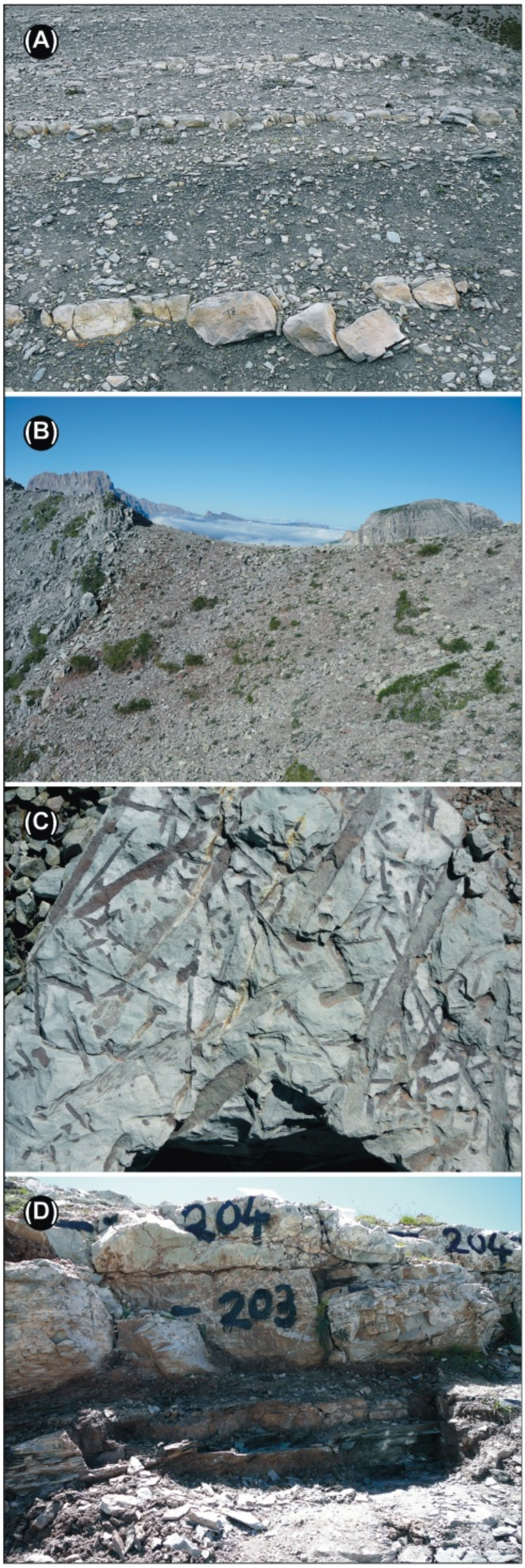
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204
203
204

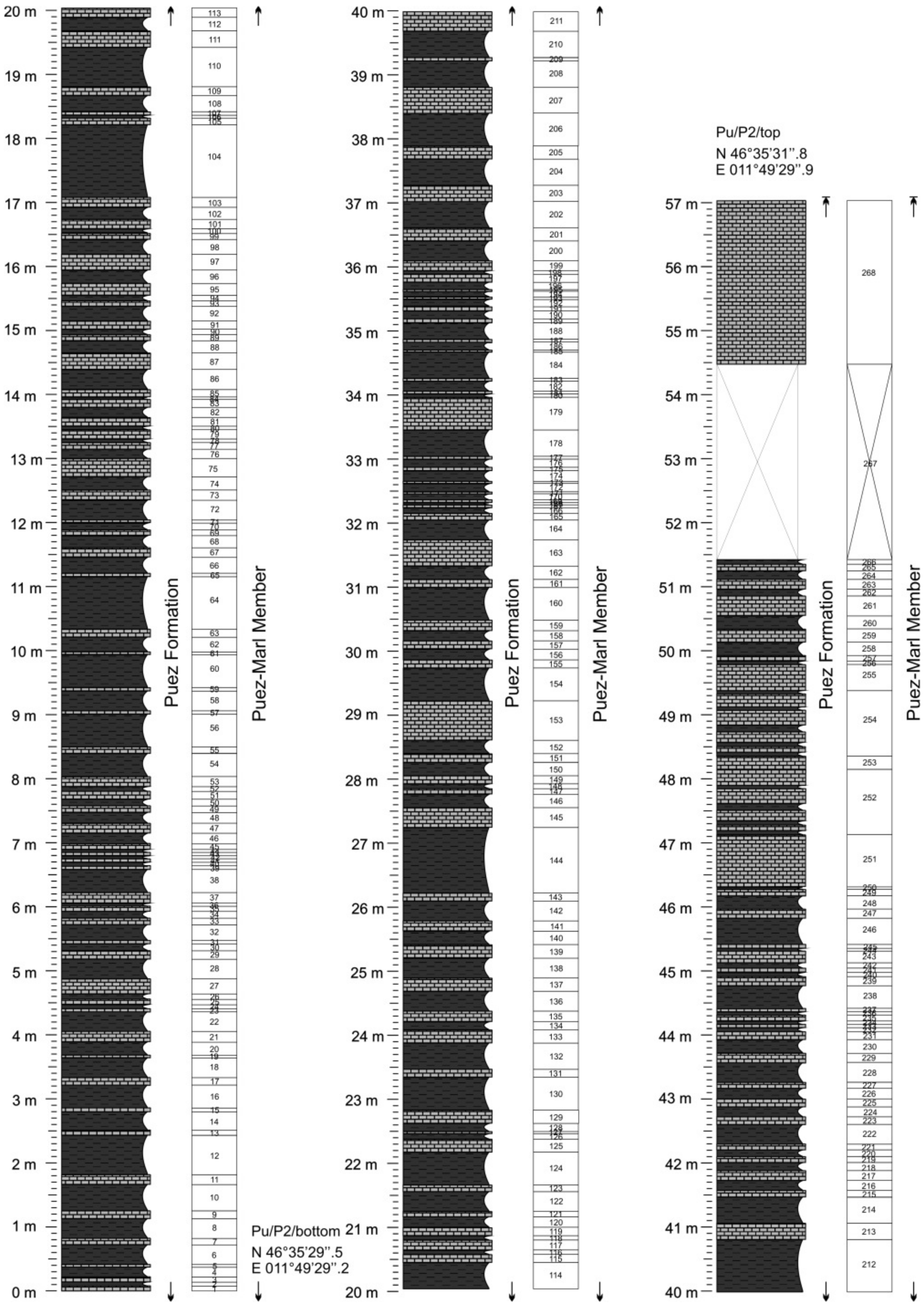


Figure 6: Log of the Puez Marl-Member with its marl-limestone alternation from beds P2/1-268 (at 0-57 m). Note the increasing limestone content in bed numbers and increasing thickness, as seen in Fig. 7.

ues display contents from 0.2-0.6%. $CaCO_3$ displays values between 41.8 and 95.8%.

Macrofossils: only larger trace fossils (*Chondrites*, *Zoophycos* etc.) have been observed. No ammonites or echinids could be detected so far.

Microfossils: foraminifera (*Spirillina*, *Involutina*, *Thalmanninella*, *Planomalina*, *Biticinella*, *Ticinella*, *Paraticinella*, *Rotalipora*, *Praehedbergella*, *Hedbergella* etc.), radiolaria (*Thanarla*, *Archaeodictyomitra*, *Sethocpsa* etc.), ostracods, sponge spicules and other groups.

Nannofossils: calcareous nannofossils with nannoconids (*Nannoconus*), coccoliths (*Watznaueria*, *Eiffellithus*, *Chiastozygus*), murolithids (*Rhagodiscus*), nannolithids (*Assipetra*) and others.

Origin, facies: the Puez-Marl Member is a pelagic-hemipelagic facies (Lukeneder and Aspmair, 2006; Lukeneder, 2008).

Chronostratigraphic age: Early Albian – Late Albian (?Albian-Cenomanian boundary).

Biostratigraphy: preliminary data indicate *Hedbergella* ssp. and *Rotalipora* ssp. (up to the *Thalmanninella globotruncanoides* Biozone), and calcareous nannofossils such as *Eiffellithus* ssp. (up to latest Albian CC9 Zone) and hint at an Early Albian to Late Albian age (maybe up to the Albian/Cenomanian boundary). No ammonites have yet been found in the Puez-Marl Member. Since the recent investigations herein, this member was thought to be of Aptian age (Rodighiero, 1919; Lukeneder and Aspmair, 2006; Lukeneder, 2008).

Thickness: approx. 57 m at the type section of the Puez-Marl Member (Puez Formation) on the southern flank of the Col de Puez.

Lithostratigraphically higher rank: the Puez-Formation on the Trento Plateau within the Dolomites (Southern Alps).

Underlying units: the Puez-Redbed Member with its red foraminiferal limestones and marls (see Puez Redbed Member).

Overlying units: the overthrusting ("Gipfelüberschiebung") Triassic Haupdolomit. Younger sediments do not occur.

Geographic distribution: as for the Puez Formation, the area of the Dolomites in South Tyrol (Lukeneder and Aspmair, 2006; Lukeneder 2008), but only preserved at relic areas due to erosion.

4. Discussion

4.1 Early Cretaceous Palaeoenvironments and Facies in the Dolomites

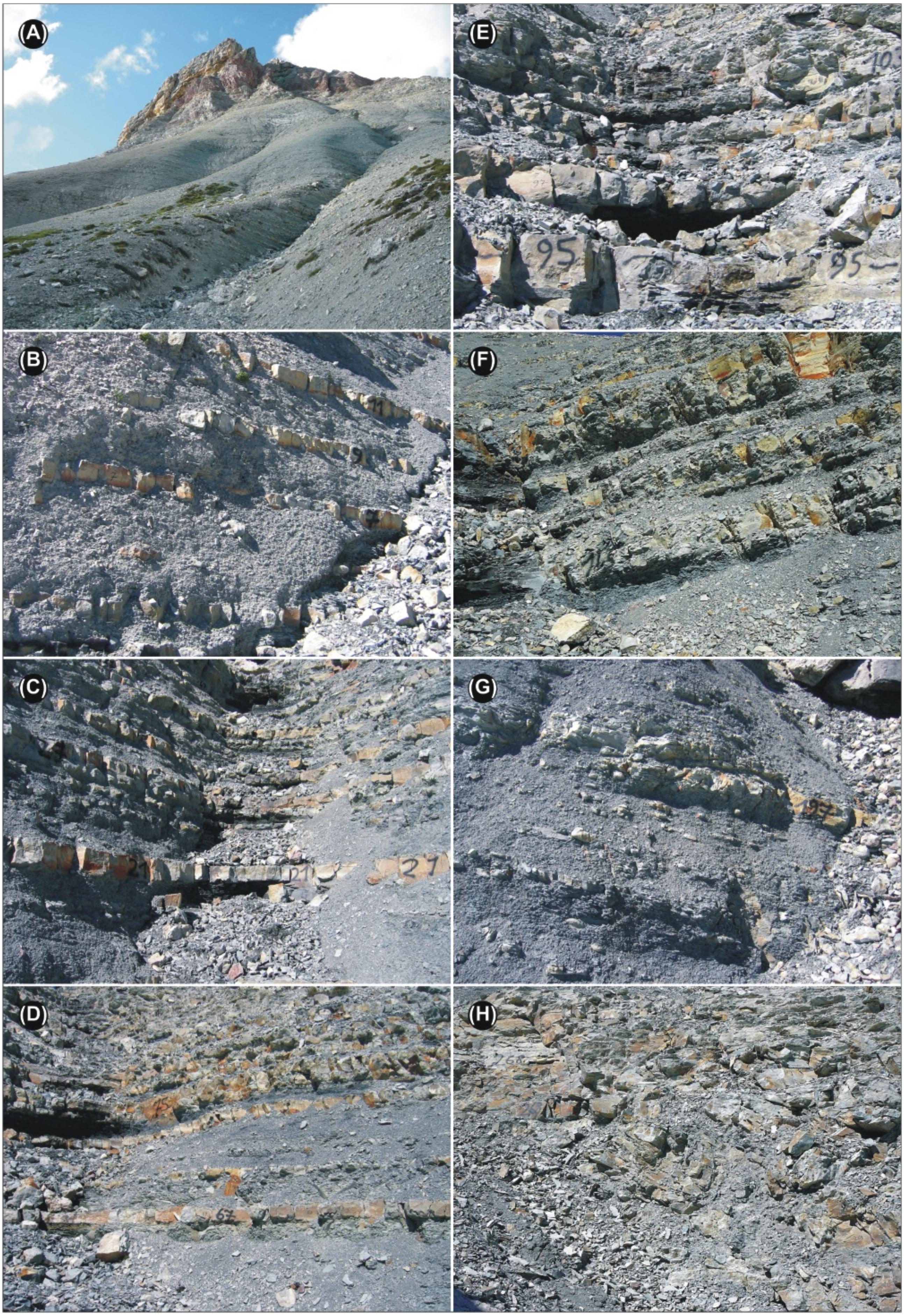
The complex Mediterranean palaeogeography of the Jurassic and Cretaceous western Tethys Ocean (Fourcade et al. 1993) is characterized by the presence of microplates situated in the middle of the Tethyan oceanic corridor between the African and European landmasses. According to numerous authors (e.g. Cecca, 1998; Dercourt et al., 1993; Scotese, 2001; Stampfli and Mosar, 1999; Stampfli et al., 2002; Vašíček, 1994; Vašíček, et al., 1994; Vašíček and Michalík, 1999; Zharkov et al., 1998), the region of the Southern Alps, including the investigated area (i.e. Puez area), was situated during the Jurassic and Early Cretaceous at the northern border, 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 and the Vardar Ocean to the South-East (Dercourt et al., 1993; Scotese, 2001; Stampfli and Mosar, 1999; Stampfli et al., 2002).

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 formed on submarine highs, the calcareous nannofossil limestones of the Biancone Formation (= Maiolica Formation elsewhere in Italy; Mayer and Appel, 1999), and the more marly Puez Formation (marls-marly limestones; formalized herein) formed mainly on slopes and in basins. Morphological highs such as the Trento Plateau (Grandesso 1977; Massari, 1981; Dercourt et al., 1993; Baudin et al., 1997; Stock, 1994), located in Lower Cretaceous pelagic environments, were characterized by condensed sedimentation of the typical 'Rosso Ammonitico' facies (AGIP Mineraria, 1959; Aubouin, 1964; Farinacci and Elmi, 1981; Ogg, 1981; Cecca et al., 1992; Fourcade et al. 1993; Zempolich, 1993; Martire et al., 2006). According to Caracuel et al. (1997), the deposition of nodular-marly (lower energy), nodular-calcareous and pseudonodular-calcareous-massive (higher energy) Rosso Ammonitico facies (= Rosso Ammonitico-Veronese Superiore, Geyer, 1993; or A. R. Veneto of Grandesso, 1977; Martire, 1992, 1996; Beccaro, 2006; Martire et al. 2006) was controlled by a combination of 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).

The formation of these different facies types reflects the mosaic of platforms and submarine rises (e.g. Trento Plateau; Weissert, 1981; Zempolich, 1993; Stock, 1994). 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 history of this area reflects the evolution of the Circum-Tethyan area, especially the easternmost Tethys part.

The evolution of marine biota on the Southern Alpine microplate and the southern European shelf was influenced by continuing disintegration of carbonate platforms during the Early Cretaceous. Pelagic influence also became more pronounced in former reef and shallow areas. Sea-floor spreading occurred during the Jurassic within the Neotethys (Scotese, 2001; Stampfli and Mosar, 1999; Stampfli et al., 2002). The central Atlantic, the western adjacent Ligurian Ocean, and the newly formed Penninic Ocean were opening during Early Middle Jurassic (Cecca et al., 1992; Fourcade et al., 1993; Muttoni et al., 2005; Castellarin, 2006). The Puez area is situated on the northernmost part of the Trento Plateau within the Dolomites, located on one of the so formed submarine plateaus, the Puez-Gardenaccia Plateau. 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).

At the Puez locality the transition from the nannofossil lime-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stones of the Biancone Formation (?Berriasian-Upper Valanginian; = Biancone var. red, see Geyer 1993) to the more marly Puez Formation (marls-marly limestones) appears gradually. The boundary between the latter formations is located at bed P1/17 (Fig. 3). The change in carbonate content and red color is evident at this point. A similar gradual transition between such facies types is reported from the Umbria-Marche Apennines from the Maiolica Formation into the Marne a Fucoidi by Cecca et al. (1995). The similar red "Rosso Ammonitico"-type to red Biancone limestones occur most prominently at the Col de la Pieres and were called "calcari cristallino rosso" of Tithonian age by Cita and 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 part of the Puez log P1 does not yet outcrop, but the age determinations by the latter authors seem to be correct. The Puez Formation marks a change in pelagic sedimentation, beginning from the latter, more energetic and probably somewhat shallower red limestone facies shown by the "Rosso Ammonitico" type (visible in rock falls) and the red, in parts very similar Biancone Formation (P1/10-15) at the Puez locality up to the more marly, grey Puez Formation (Late Valanginian - Late Albian).

A reorganization of the Mediterranean Tethys palaeogeography took place at the Jurassic-Cretaceous transition (Cecca et al., 1992; Caracuel, et al. 1998; Dercourt et al., 1993, Fourcade et al., 1993; Vašíček 1994). After the inhomogeneous sedimentation (late Jurassic to earliest Cretaceous) on blocks and basins with the "Rosso Ammonitico" type and the "Maiolica-Biancone"type, respectively, a change and homogenization occurred in the Lower Cretaceous. During Early Cretaceous times, microplanktonic assemblages prevailed both in the eupelagic and hemipelagic environments over the extensive sea floor, characterized by diversified sedimentation. Hemipelagic to pelagic marine environments were characterized by a uniformly soft, unconsolidated muddy bottom during sedimentation of the Puez Formation and comparable Lower Cretaceous Mediterranean localities (Vašíček et al., 1994). A change in current patterns and paleogeography (Weissert, 1979; 1981) resulted in a new Tithonian-Valanginian 'boom' in plankton development. This led to deposition of the uniform whitish, fine micritic limestones of the "Maiolica - Biancone" formations 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 Biancione formations in the rest of the Southern Alps /e.g. southern Trento Plateau, Lesini mountains etc.; Stock, 1994). The latter formations are followed by the sedimentation of the Puez Formation (Puez-Limestone Member), in which nannoconid wackestones dominated at the beginning of the Cretaceous (Vašíček et al., 1994; Michalík and Vašíček, 1989; Reháková, 1995; Reháková and Michalík, 1997; Reháková, 2000a, b). Nannoconids persisted in dominance during the Valanginian, Hauterivian and Barremian (e.g. Puez-Limestone Member at Puez), while the calpionellids decreased in abundance among the microplankton communities until the Late Valanginian at log Puez P1/15 in the Puez Formation (Reháková, 2000a, b).

The Aptian Puez-Redbed Member (P3/1aa-1h; Fig. 5) at the Puez is characterized by an abrupt change in lithology and, thus, by a palaeoenvironmental change from nannoconid mudstone to red, foraminiferal-packstones also marked by the widespread Early Aptian nannoconid crisis (the Selli Level; see Coccioni et al., 1992, Cecca et al, 1995; Barrera and Johnson, 1999; Bralower et al., 1999; Premoli-Silva and Sliter, 1999; Luciani et al., 2001; Sano, 2003) as reported for example by Cecca et al (1994), Landra et al. (2000), Erba (2004), Méhay et al. (2009), and Tejada et al. (2009). Although different in lithology (e.g. Puez-Redbed Member), probably forced by the submarine elevated position of the Trento Plateau block, this facies change could be related to one of the Mesozoic oceanic anoxic events (OAE), the Aptian OAE1a. The Puez-Redbed Member is strongly reminiscent of the situation with the Late Aptian-earliest Albian *Hedbergella* limestone reported by Wagreich (2009) from the Northern Calcareous Alps (Austria). As shown for the Breggia Gorge (Lombardian Basin, Switzerland, however, the top of the Maiolica can exhibit a hardground and a following hiatus of Late Barremian to Early Aptian (IAS, 2004). Thus, the black shale deposits (OAE1a, Selli Level) could be missing at the Puez section because this is observed in the Breggia Gorge. This abrupt change at the end of the Barremian, with a hiatus often marked by abundant trace fossils (*Rhizocorallium*, *Halimedides*) on the top of the last Maiolica bed, below the Scaglia Formation of late Aptian-Albian age, is also observed in the Vocontian Basin and the Breggia Gorge (Gaillard and Olivero, 2009). Albian parts of the Puez-Marl Member (P2/1-268; Figs. 6 and 7) succession show an increasing terrigenous influx marked by abundant, dark marl beds and wood occurrences (e.g. tree trunks). The terrigenous influx (e.g. clay minerals) is triggered by the erosion of the first islands created by Alpine tectonics (Bosellini, 1998). Intercalated limestone beds consist partly of radiolarian and foraminifera oozes. These reflect the different nutrification of the prevailing ocean currents and the sea-level fluctuations within the Albian. A further deepening of the northern Trento-Plateau in the Albian is indicated by the radiolarian oozes in numerous beds of the Puez-Marl Member.

Figure 7: Marly limestones and marl beds of the Puez-Marl Member (upper Puez Formation) A, the Puez-Marl Member within the ditch of Puez log P2 at the Col de Puez. B, The lowermost Puez-Marl Member with dominating marl at beds P2/1-11 (at 0-2 m), C, with marl-limestone alternations at beds P2/21-40 (at 4-7 m), D, with increasing limestone content in the upper half at P2/67-80 (at 11.5-13.5 m), E, with thicker limestone beds at P2/95-103 (at 15.5-17 m), F, with up to 1-meter-thick limestone beds at P2/145-153 (at 27.5-29 m), with a marl-dominated part and thin limestone beds at P2/164-200 (at 32-36 m), and F, uppermost part of the Puez-Marl member with final limestone bed P2/268 (55-57 m).

4.2 Regional Correlations and Environments of the Puez Formation

The Puez area and its Cretaceous sediments are well known (Haug, 1887; 1889; Uhlig, 1887; Lukeneder and Aspmair, 2006; Lukeneder, 2008) but, so far, not accurately documented. The main aim of the presented lithostratographic study is to formalize well-known Lower Cretaceous sediments within the Southern Alps (e.g. the Dolomites). The result is a stratotype for the formalised Puez Formation with a reference section (bed-by-bed) marked by GPS data fixation. A detailed lithostratigraphy with geochemical and photographic documentation is provided as a tool for a better correlation within Cretaceous formations in the Dolomites, but also for the Lower Cretaceous in the Mediterranean region. In most papers and reports noted above, fossils were described only from rock falls but not from bed-by-bed sampling (Lukeneder and Aspmair, 2006; Lukeneder, 2008). The succession at the Puez area can best be correlated with other Lower Cretaceous localities in the Dolomites such as La Stua (Stöhr, 1993, 1994), except for the Aptian Puez-Redbed Member, which is so far reported only herein and not known elsewhere.

The locality La Stua described by Cita and Rossi (1959), Stöhr (1993, 1994) and Baccelle and Lucchi-Garavello (1967a, b) shows a similar succession comprising "Biancone" (after Stöhr, 1993 "Profilabschnitt A" (7 m, Berriasian-Valanginian), red-grey nodular limestones (B, 24 m, Hauterivian), "Ammonitenmergel" (C, 42, late Hauterivian-late Barremian; "calcari marnoso molto fossilifere" by Baccelle and Lucchi-Garavello, 1967b), red-grey-green limestones and marls (D, 53 m, early Late Barremian-latest Barremian), red and dark-green claystones "Aptmergel" (E 10.6 m, Aptian), red and green limestones and marls (F, 16.6 m), cherty limestones with chert concretions (G 13 m), alternation of limestones and marls (H, 13 m, Aptian), radiolarite (I, 1.6 m), black claystones (K, 1.5 m, Albian) and finally green and red limestones and marls (L, 8.25 m, Albian). The Biancone at Puez is comparable with Stöhr's Biancone type; his red-grey nodular limestones are quite similar with the lowermost Puez-Limestone Member and his "Ammonitenmergel" is correlated with the middle and upper parts of the Puez-Limestone Member (up to beds P1/204; Fig. 3). Stöhr's red-grey-green limestones and marls are similar in lithology but have a different age. After the latter author, this marl-limestone alternation ("Profilabschnitt D") is of Aptian age (if correctly determined; see also Cita and Rossi 1959), whereas the Puez-Marl Member is of Albian age. Comparable is the thickness of similar lithological successions occuring with Biancone with approx. 6 m at Puez and 7 m at La Stua, over red-grey nodular limestones of the Puez locality (Biancone red var.; "calcari cristallino rosso" of Cita and Pasquaré, 1959; "calcari nodulosi color rosso" of Rodighiero, 1919) with 5 m to 24 m at La Stua. The overlying Puez-Limestone Member with 50 m at the stratotype of the Puez Formation is equivalent in age (Hauterivian-Barremian) and its lithology to La Stua's "Ammonitenmergel", which measures 42 m plus the limestones and marls with 53 m (all early Late Hauterivian-latest Barremian). This would mean that the sedimentation rate of the same lithology was approx. twice as high as at the Puez area in the same time. Stöhr's (1993) "Profilabschnitte H-L" are of Albian age (see Cita and Rossi, 1959), which can be correlated to the whole Puez-Marl Member, but differs remarkably in lithology and thickness, as noted above. Although different in lithology, the intermittent black shales (= "Schwarzschiefer", 10 m) of "Profilabschnitt E" (Stöhr 1993, 1994) at La Stua mark a lithological change at the beginning of the Aptian (lowermost 2 m in the latest Barremian); this could be compared to the lithological incision at the Puez with the Puez-Redbed Member (P3/1aa-1h, Aptian; Fig. 5).

Other Cretaceous successions such as described by Weissert (1979, 1981), Bartolocci et al. (1992), Jud (1994), Lini (1994), Faraoni et al. (1995, 1996, 1997), Baudin et al. (1997), Cecca (1998), Cecca and Landra (1994), and Cecca et al. (1994a, b, 1995, 1996) include the Maiolica, Lombardian Maiolica and Biancone Formations (= Venetian Maiolica after Weissert, 1979, 1981 and Lini, 1994; Mayer, 1999; Mayer and 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. Some of the localities discussed in the above papers are remiscent in lithology, weathering and age more of the Hauterivian-Barremian parts of the Puez-Limestone Formation of the Puez Formation and less of the almost pure limestone virtually lacking macrofossils (Fourcade et al., 1993) of the Maiolica or Biancone facies, as occurring at the Puez as the Biancone Formation (e.g. beds P1/10-15). Papers on the Maiolica facies, e.g. Fourcade et al. (1993), Mayer (1999) and Mayer and 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 shows Early to Middle-Valanginian age.

Marly sediments of the upper Puez-Marl Member (Albian; Figs. 5-7) at the Puez Plateau show some features similar to the Marne a Fucoidi of the Umbrian March Region (Cecca et al., 1994a, b, 1995) The Puez-Marl Member show also similarities to the Aptian-Albian parts of its South Alpine equivalent, the Scaglia Variegata in the southern Trento Plateau (between Trento and Verona; Lini, 1994). The transition from the Puez-Limestone Member into the Puez-Marl Member is not gradual at the Puez area. This differs from the situation reported for the transition between Biancone sensu stricto and Scaglia Variegate (Geyer, 1993), or the gradual transition into the lowermost Aptian between the Maiolica Formation into the Marne a Fucoidi in the Umbria-Marche Apennines (Cecca et al., 1995). The transition between the Maiolica Formation and the Scisti a Fucoidi from the Umbria-Marche Apennines (e.g. Gorgo a Cerbara) is described from the earliest Aptian as coinciding with the above nannoconid crisis (Cecca et al., 1994; Channell et al., 2000). In contrast to the monotonous marly lithology of the Marne a Fucoidi (Aptian-Albian, green-red marls and marly limestones) and the Scaglia Variegata limestone with its cherty nodules (in most localities younger in age), the Puez-Marl Member (beds P2/1-268, dark grey marls) shows numerous intercalations of thin (0.02 m) to thick limestone beds (1 m). Some parts of the limestone beds comprise strong bioturbation similar to the Marne a Fucoidi. The Umbria-Marche basinal sequence shows typically the following succession of Upper Jurassic to Upper Cretaceous (Cecca and Pallini, 1994; Montanari and Koeberl, 2000): green-grey-red Diaspri Formation 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, approxx 60 m) and the Scaglia Cinerea (Eocene-Oligocene, 80-120 m; see also Mayer and 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 and Aspmair, 2006; Lukeneder, 2008; “Puez Formation with ?Valanginiano-?Aptiano on the geological map Dolomiti Occidentali, 2007). In contrast, the recent paper shows the exclusively Albian age of this member.

The Lower Cretaceous succession at Puez reflects a deepening of the area at the time of sedimentation, ranging from limestones of the Puez-Limestone Member (Late Valanginian) with mudstones over red foraminiferal wackestone-packstones of the Red-Bed Member (Aptian) up to the uppermost marl-limestone alternation of the Puez-Marl Member (Late Albian) with foraminifera-radiolaria-dominated mudstones-wackestones and packstones (see Jud, 1994 for radiolarians in the Maiolica Formation). The transition from a limestone-dominated Puez-Limestone Member to a marl-dominated Puez-Marl Member seems to be the local expression on the Treno Plateau of a global change in the oceanic and current system (Bernoulli, 1972) of hemipelagic and pelagic environments (see Lini, 1994). Muttoni et al. (2005) discussed the change in paleolatitudes of the South Alpine blocks from relative low values of 10°N in the Late Jurassic with radiolarites (red and green) to 20-30°N in in the Early Cretaceous. The change in paleolatitudes could have mainly triggered the type of sedimentation to more calcareous sediments of the “Maiolica-Biancone” Formation (Muttoni et al., 2005; 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 and Premoli-Silva, 1982) in the higher sea-water column is clearly indicated by the sedimentation of foraminiferal and radiolarian 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).

5. Conclusions

A new formation, the Puez Formation (approx. 107 m) is established and formalized. Three new sub-members within the Puez Formation are erected, the Puez-Limestone Member, the Puez-Redbed Member, and the Puez-Marl Member. The type section is located at the southern slope of the Col de Puez (2725 m) on the Puez-Gardenaccia Plateau, 6 km north-east of Wolkenstein. The lower boundary of the Puez type section is located at 2510 m within a small stream outcrop at E 011°49’15’’, N 46°35’30’’.

The deposition of the Lower Cretaceous sediments (Late Valanginian - Late Albian) from the Puez section took place on the northernmost area of a submarine plateau, the approximately north-south directed Trento Plateau, surrounded by the deeper Lombardian Basin to the west and the Belluno Basin to the east. The Puez Formation marks a change in pelagic sedimentation. More energetic and probably somewhat shallower environments represented by the red limestone facies of the “Rosso Ammonitico” type were displaced by the grey to red parts of the very similar, deposited in deeper aeas, Biancone Formation at the Puez locality. The succession is finally overlain by the more marly, grey Puez Formation (Late Valanginian - Late Albian). The succession reflects a deepening of the area at the time of sedimentation. This ranges from the lower parts with the limestone-dominated Puez-Limestone Member (Late Valanginian-latest Late Barremian), followed by the red foraminiferal limestones of the Puez-Redbed Member (Aptian) and capped by the the uppermost parts with marl-limestone alternations of the Puez-Marl Member (Albian) with foraminifera-radiolaria-dominated mudstones-wackestones and packstones.

The preliminary stratigraphy (Valanginian-Albian) was obtained from correlations on micro- (foraminifera etc), nanno- (nannoconids etc.) and macrofossils (ammonites etc.). For the succession of the Puez Formation, this revealed an approx. Late Valanginian - Late Albian age with a duration of at least 35 million years. This age is reflected by the Puez-Limestone Member (Late Valanginian to latest Late Barremian), the Puez-Redbed Member (Aptian) and the Puez-Marl Member (Early Albian to Late Albian) (?Cenomanian boundary). This is the first documentation that the stratigraphic extent of the Puez Formation is much younger than expected. The Puez-Marl Member is of Albian age and most probably reaches the Albian-Cenomanian boundary.

The macrofauna of the Puez section, especially the Puez-Limestone Member, is represented by ammonites and echinids, and rare brachiopods. The other members as the Puez-Redbed Member and the Puez-Marl Member are almost barren in ammonites and other macrofossil groups. Contrastingly, the microfossils (foraminifera and radiolaria) are abundant in the latter members. The ammonite standard zonation is based, at least for some zones, on the presence of index ammonites such as *Criosarasinella furcillata* and *Toxancyloceras vandenheckii* for the *Criosarasinella furcillata* and *Toxancyloceras vandenheckii* ammonoid Zone, respectively.

More investigations at the stratotype of the Puez Formation will be done, especially on biostratigraphy and isotope geochemistry.

Acknowledgements

Thanks are due to the Austrian Science Fund (FWF) for financial support (project P20018-N10). I am grateful to Daniela Reháková (Bratislava), Eva Halasová (Bratislava), Ján Soták (Banská Bystrica) for important information and preliminary results on microfacies, nannofossils and forminifera. Sincere thanks go to Evelyn Kustatscher, Benno Baumgarten and Vito Zingerle (all Museum of Nature South Tyrol) for their help in organisatory issues. I thank Arthur Kammerer, Astrid Wiedenhofer and Valentin Schroffenegger (all Office for Natural Parks South Tyrol) for a work permit in the Puez-Geisler natural park. I am particularly grateful to Monika Sieghardt (Vienna), who provided geochemical analysis. Very special thanks go to Michael Wagreich (Vienna) and an anonymous reviewer for carefully reading and reviewing the manuscript. Photographs were taken by Alice Schumacher (Vienna).

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Received: 15. February 2010
Accepted: 12. May 2010

Alexander LUKENEDER
Natural History Museum, Geological-Palaeontological Department, Burgring 7, 1010 Wien, Austria;
alexander.lukeneder@nhm-wien.ac.at