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Carnian stratigraphy in the Raibl/Cave del Predil area (Julian Alps, Italy)

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Key words: Carnian, Julian, Tuvalian, ammonoids, palynomorphs, sequence stratigraphy, Dolomia Principale margins, Julian Alps

ABSTRACT

The analysis of the type-sections of Tor Formation and Carnitza Formation in the neighbourhood of Raibl/Cave del Predil (Tarvisio area, Julian Alps, Italy) allows a better definition of the Carnian stratigraphic and sequence stratigraphic framework in this classical area. Ammonoids and palynomorphs confine the age of the Conzen Formation and of most of the Tor Formation to the Julian, while the uppermost Tor Formation, the Carnitza Formation and the base of the Dolomia Principale are Tuvalian in age. In the Tarvisio area, a margin-foreslope system of the Dolomia Principale, interfingering with basinal sediments (Carnitza Formation), is exceptionally well preserved at a seismic-scale. This setting allows a better comprehension of the start-up of the Dolomia Principale carbonate platform.

RIASSUNTO

Lo studio delle sezioni tipo della Formazione di Tor e della Formazione di Carnitza nei dintorni di Raibl/Cave del Predil (Tarvisio, Alpi Giulie) hanno consentito una migliore definizione dell'assetto stratigrafico e stratigrafico-sequenziale del Carnico in quest'area classica. Ammonoidi e palinomorfi assegnano età Julica alla Formazione di Conzen e a gran parte della Formazione di Tor mentre sono tuvaliche la parte superiore della Formazione di Tor, la Formazione di Carnitza e la porzione inferiore della Dolomia Principale. Nei dintorni della Portella è eccezionalmente conservato a scala sismica un sistema margine-*slope* della Dolomia Principale che si interdigita con depositi bacinali (Formazione di Carnitza). Questa struttura consente di comprendere meglio la nascita della Dolomia Principale.

Introduction

The Cave del Predil (formerly Raibl) area (Fig. 1), near Tarvisio, has historically been considered the type-area of the Carnian stage (Mojsisovics 1869). Much geological work has been carried out in this area since the first half of the XIX century; many studies concerned the Portella and Sella delle Cave sections, on opposite sides of the Rio del Lago Valley, to the east and west of Cave del Predil respectively.

Previously, the "Raibl beds" in the neighbourhood of Raibl were taken to comprise the beds between the Mount Re metalliferous limestones (Sciliar Dolomite) below and the Dolomia Principale above (Fig. 2).

In this succession, Suess (1867, p. 579) distinguished the following units:

1) a lower group, comprising the "fish bearing beds" and the "barren beds", separated by coral beds;
2) an intermediate group, or "Raibler Schichten" *s.str.*, characterized by *Myophoria kefersteini* and *Solen caudatus* in the lower part, by *Arcestes joannisaustriae*, *Pinna* sp. and *Spiriferina gregaria* in the middle and, in the upper part, by *Megalodon* banks;
3) an upper group, or "Torer Schichten", containing *Corbula rosthorni*, *Myophoria whateleyae* and other bivalves.

Assereto et al. (1968), following the stratigraphic scheme in Allasinaz (1966), revised the lithostratigraphic succession and defined the Raibl Group, as follows:

1) Predil Limestone, corresponding to the "fish-bearing beds", containing *Trachyceras aon* and including the coral beds;
2) Rio del Lago Formation, including the "barren beds" and the *Myophoria* beds. According to Assereto et al. (1968), the latter correspond to the "Raibl Beds" *s.str.*;

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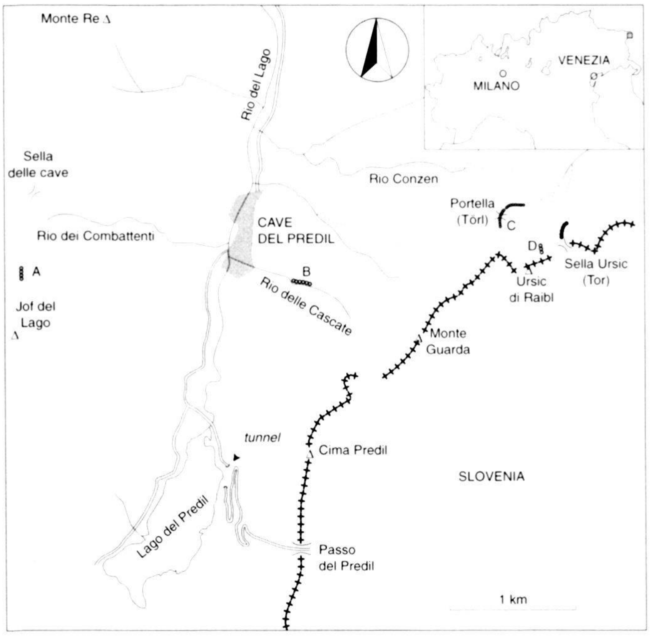

Fig. 1. Locations of the measured sections (A=Jof del Lago; B=Rio delle Cascate; C=Portella; D=Sella Ursic).

3) Rio Conzen Limestone, consisting of thick bedded dolomites, limestones and dolomitic limestones and corresponding to the *Megalodus*-Kalk Auct.;
4) Tor Formation, comprising a lower unit of alternating limestones and marls, with numerous bivalves; a middle, ca. 25 m-thick, dolomite, and an upper unit of grey to dark-grey micritic limestones.

Lieberman (1978a) separated the upper part of the Tor Formation as the Carnitza Formation, because it is lithologically distinct from the underlying marls and marly limestones.

Lithostratigraphy

In this paper, the Carnian succession from the Conzen Formation to the lower Dolomia Principale, cropping out in the neighbourhood of the Portella (formerly Törl, Fig. 1), is described (Fig. 3, 4, 5). Further indications can be found in Allasinaz (1966), Assereto et al. (1968), Schulz (1970, with particular regard to microfacies analysis) and Lieberman (1978 a, b).

The succession comprises the following units from bottom to top:

Conzen Formation

The unit corresponds to the Calcare di Rio Conzen of Assereto et al. (1968), thick mainly calcareous-dolomitic interval. In the study area, subtidal dolomites bearing megalodontids of the basal Conzen Formation sharply overlie basinal marls of the Rio del Lago Formation (Sella delle Cave section, Fig. 1). The boundary between thick-bedded dolomites and dolomitic limestones, rich in megalodontids and other bivalves, of the Conzen Formation and silty marls and siltstones of the overlying Tor Formation is also sharp.

The Conzen Formation shows lateral variation of facies: eastward it is more carbonate, westward it frequently includes terrigenous intercalations. In the neighbourhood of Sella Ursic (Fig. 1), about 30 m of pale grey-bluish limestones, rich in large bivalves, sharply rest on strongly dolomitized beds. The boundary between the two units is irregularly ondulated.

In the Rio delle Cascate section (Fig. 1-B; Fig. 4), the lower portion of the unit consists of whitish dolomites and dolomitic limestones, mainly metre-thick, cropping out in correspondence to the waterfall. This interval is overlain by a lithozone formed by decimetre- to metre-thick terrigenous-carbonate asymmetric cycles. At the base, every cycle is made up of dark laminated pelites and marls; upwards, bioturbated nodular micritic limestones follow; the upper part of the cycle consists of centimetre- to decimetre-thick limestones and dolomitic limestones (wackestones-packstones), often amalgamated. Alternating grey wackestones-packstones with coated grains and foraminifers and coquinas with large bivalves follow upwards. These are overlain by a well-defined terrigenous interval comprising alternating nodular marly limestones, black siltstones, marls and grey limestones. Upwards, the formation becomes mainly dolomitic and contains wavy to planar stromatolite beds and fenestral dolomites.

In the type-area, the Conzen Formation is interpreted as a carbonate-terrigenous platform (Assereto et al. 1968). Its lower part is mainly subtidal; towards its top, it is characterized by intra-peritidal influences. This unit definitely closed the Ladinian-Carnian basins in the eastern Southern Alps (Jadoul & Nicora 1986; Gianolla et al. 1998a)

Tor Formation

The Tor Formation, as defined by Assereto et al. (1968), corresponds to the *Torer Schichten* (Auct.), but the name has been used in Lieberman's (1978a) restrictive sense (Fig. 2). The formation is named after the ancient name of Sella Ursic (Tor), some hundred metres east of the Portella (Fig. 1).

The Tor Formation is a thin-layered shallow-water fossil-rich terrigenous-carbonate unit (Fig. 5). In the study area, the boundaries with the underlying Conzen Formation and the overlying the Portella dolomite are sharp.

The main portion of the unit consists of alternating marls, siltstones, marly limestones and limestones rich in bivalves, gastropods, foraminifers and *Bactrillium*. The monotonous succession is interrupted by levels of graded bioclastic calcarenites (storm layers). Bioturbation is common in these rocks. In the upper part of the Portella section (Fig. 5), corals in life position, growing on bivalve biostromes, are preserved. Alternating thin limestones, marls and siltstones form the

Suess (1867)		Assereto et al. (1968)	Lieberman (1978a, 1980)	This paper
Hauptdolomit		Dolomia Principale	Dolomia Principale Formation	Dolomia Principale
Torer Schichten	Gruppo di Raibl	Formazione di Tor	Carnitza Formation	Carnitza Formation
			Dolomia Principale Formation	Portella dolomite
			Tor Formation	Tor Formation
Raibler Schichten s.str. -Megalodonten-Bänke		Calcare di Rio Conzen	Conzen Formation	Conzen Formation
-Lagen mit *Arcestes Johannis Austriae, Pinna, Spiriferina gregaria* -Lagen mit *Myophoria Kefersteini* und *Solen caudatus*		Formazione di Rio del Lago	Rio del Lago Formation	Rio del Lago Formation
-Tauben Schiefern -Korallenbänke -Pflanzen- und fishreiche Schiefern		Calcare del Predil	Predil Limestone	Predil Limestone
Erz-führend Kalk von Raibl		Dolomia dello Schlern	Schlern Formation	Sciliar Dolomite

Fig. 2. Lithostratigraphic subdivisions in the Portella area.

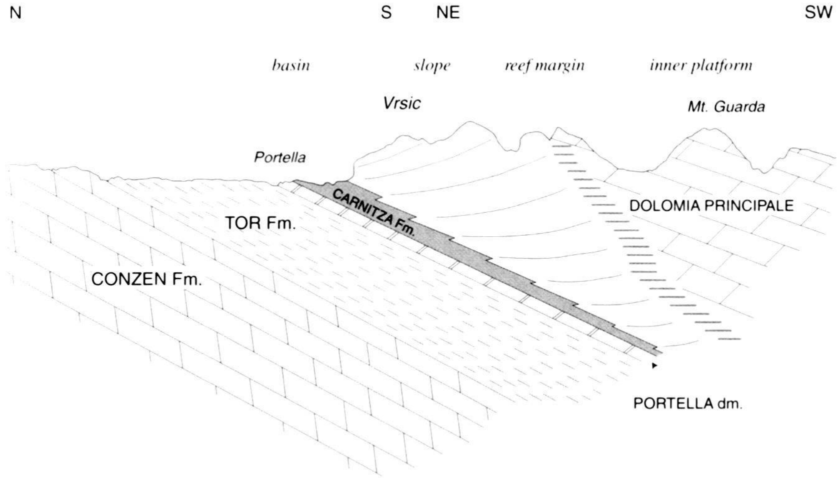

Fig. 3. Stratigraphical relationships of Carnian units in the Portella area.

upper portion of the unit, in which bivalves, ostracods and foraminifers are frequent. Upwards, ostracods become more and more abundant. Plant debris and low-angle cross-laminations are present near the top of the unit.

The variety and the abundance of the infauna are well-known. For a thorough illustration, see Wöhrmann (1894), Allasinaz (1966), Lieberman (1979). In the Portella area, the formation is about 120 m thick, and extends at least 15–20 km westwards into the Dogna Valley (westernmost Julian Alps, Jadoul et al. 1995).

The depositional environment appears to be related to a shallow-water terrigenous-carbonate ramp, characterized by low energy conditions interrupted by frequent storm events. As shown by the increasing abundance in ostracods, a decrease in salinity is suggested in the upper part of the unit.

Portella dolomite

This informal name is introduced here for a 25 m-thick whitish or pale-grey dolomitic unit which overlies the Tor Formation (Fig. 5, 6). It separates the Tor Formation from the overlying Carnitza Formation. Lieberman (1978a, 1978b, 1980) regarded it as a tongue of the Dolomia Principale but it is here considered to be distinct from that formation. As a matter of fact, throughout the Julian Alps the basinal Carnitza Formation, or the laterally corresponding Monticello Formation (see below), separates the Portella dolomite from the overlying Dolomia Principale. The unit is well exposed at Portella (Fig. 1–C), in Rio delle Cascate (Fig. 1–B), at Sella Ursic (Fig. 1–D) and in the Dogna Valley, about 15 km west of Cave del Predil. The unit is also recognizable in the southern Karawanken, directly

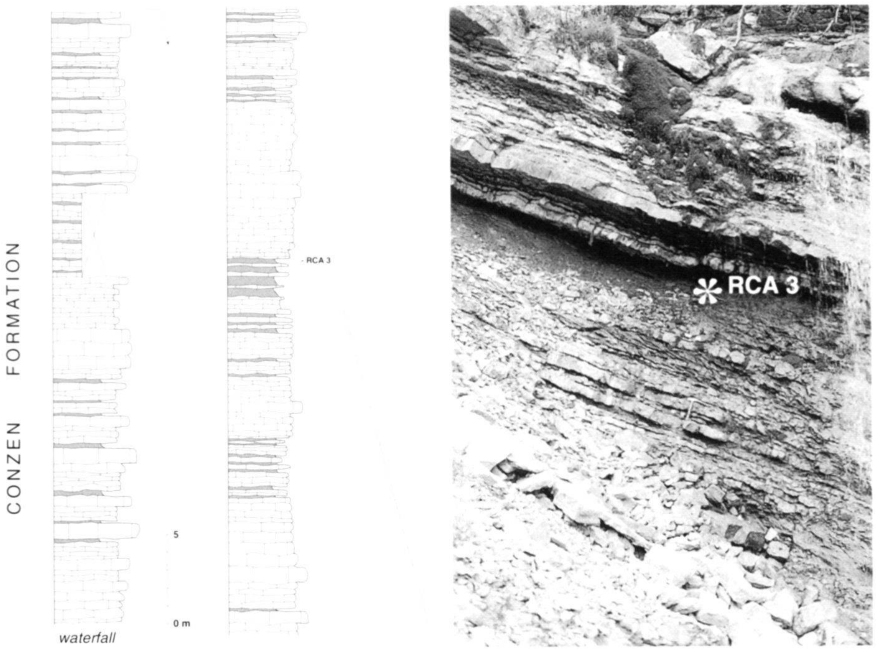

Fig. 4. Rio delle Cascate section. The lower part of the Conzen Formation (about 180 m) is exposed in correspondence to the waterfall of Rio delle Cascate, west of Cave del Predil. The measured interval includes a large amount of fine-grained terrigenous material. Legend as in Fig. 4.

below the Carnitza Formation (cf. Schlaf 1996). A few kilometres farther west, it is overlain by the Monticello Formation. This demonstrates the possibility of correlating the lower part of the Carnitza Formation (see below) and the Monticello Formation, as recently suggested also by Carulli et al. (1987, 1998). As a consequence, the Portella dolomite could correspond to one of the dolomitic horizons locally named Dordolla, Lunze or Mestri horizon (Carulli et al. 1987; Jadoul et al. 1995). In the future, as the Monticello Formation overlies the "dolomie cariate" formation (Carulli et al. 1998), the correspondence between the latter and the Portella dolomite should also be verified.

The unit consists of whitish or grey dolomites. In the Portella section, bedding is ill-defined, generally decimetre-thick. At Rio delle Cascate the lower part of the unit has a very clear centimetre-thick bedding, in the middle it appears massive and becomes evident in the upper part. With the exception of rare planar to wavy stromatolites and thin intercalations of dark laminated dolomites, fossils and sedimentological structures have been obliterated by dolomitization.

The lower and upper boundaries of the Portella dolomite, respectively with the underlying Tor Formation and the overlying Carnitza Formation, are sharp (Fig. 5).

The Portella dolomite is interpreted as a carbonate bank deposited in a shallow water environment.

Carnitza Formation

The Carnitza Formation was examined along the same profile (Fig. 3, 5) as the type-section in Lieberman (1978a), close to the Italian-Slovenian border, about two hundred metres to the west of Sella Ursic (Fig. 1–D, 7). In this area, it is 80 m thick.

The lower boundary with the Portella dolomite is sharp (Fig. 5); dark grey dolomitic limestones, containing thin-shelled bivalves and radiolarians, rest on whitish or grey dolomites.

In the study area, the formation consists of well bedded grey to dark-grey faetid limestones (wackestones to packstones), in 5 to 15–20 cm-thick beds with parallel, planar to wavy bedding, commonly separated by centimetre-thick black marly-siltstone interlayers. In the lowermost and uppermost parts, beds are often dolomitized. Limestones show a pelagic facies, rich in thin-shelled bivalves and radiolarians and with relatively abundant ammonoids. Due to the interfingering with the prograding slope of the Dolomia Principale (Figs. 3, 8), interbeds of bioclastic packstones and grainstones bearing crinoids, brachiopods, foraminifers, *Tubiphytes* and large bivalves increase in abundance upwards through the upper half of the formation (Fig. 5). Slumps, slump-scars and decimetre to metre-thick intercalations of breccias (Fig. 9) with centimetre to decimetre-sized clasts of both dolomites belonging to the Dolomia Principale margin and slope, and intrabasinal black pelagic limestones, become more and more abundant upwards.

Shelfward, this unit is partially heteropic with the Monticello Formation and the lower part of the Dolomia Principale; basinward it should correspond to the "dolomia con selce" (cf. Assereto et al. 1968; Schlaf 1996). On the basis of its stratigraphic position, the lower part of the Carnitza Formation seems to be replaced by the Monticello Formation in westward direction. A similar conclusion was recently drawn by Carulli et al. (1998) which recognized the Monticello Formation

Fig. 5. Lithostratigraphic sections of the Upper Carnian succession in the Portella area.

Fig. 6. A view of the Portella saddle from the south-east. On the left the contact between the basinal Carnitza Formation and the toe of the slope of the prograding Dolomia Principale. T = Tor Formation; Pd = Portella dm.; Ca = Carnitza Formation; DP = Dolomia Principale.

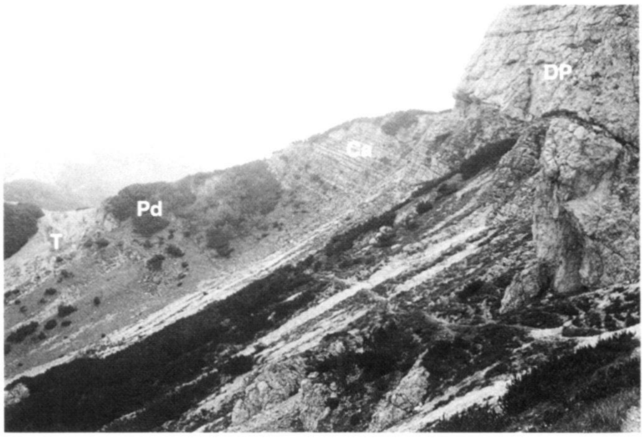

Fig. 7. A view of Sella Ursic from the south-west, with the type section of the Carnitza Formation. T = Tor Formation; Pd = Portella dm.; Ca = Carnitza Formation; DP = Dolomia Principale.

throughout the Carnian Alps and in the Amanda 1 bis AGIP well. In this work, on the basis of the lithological features of the lower part of the Dolomia Principale in the Cadore area, the extension of the Monticello Formation to at least a part of the eastern Dolomites is suggested.

The Carnitza Formation is a basinal unit deposited on top of a carbonate bank which, due to the rise in sea-level, to the concurrent increase in subsidence and to the birth of a rimmed shelf (Dolomia Principale platform), rapidly evolved to deep ramp, then to open pelagic shelf and finally to deep shelf margin.

Dolomia Principale

The Dolomia Principale forms the crest of mountains that marks the border between Italy and Slovenia. In this sector of the Southern Alps, a basinward prograding margin-slope system of the Dolomia Principale carbonate platform is exceptionally and spectacularly exposed (Figs. 3, 8). These geometrical relationships were first suggested by Assereto et al. (1968) and Doglioni (1988). The peculiarity of this situation is that the first phases of Late Carnian platform initiation are preserved.

The Tuvalian platform margin in the Portella area is quite different from the margins of the Middle-Upper Norian (Jadoul 1986; Jadoul et al. 1992; Roghi et al. 1995; Carulli et al. 1997; Gianolla et al. 1998a) intra-platform basins inside the Dolomia Principale both in the Southern Alps and Northern Calcareous Alps. In fact, such younger margins are strongly tectonically controlled and are the effect of platform dissection during initial phases of the Tethyan rifting (Jadoul 1986; Cirilli & Tannoia 1988; Ciarapica et al. 1987; Jadoul et al. 1992; Trombetta & Bottoni 1993; Carulli et al. 1997). The platform-slope-basin system (Dolomia Principale-Carnitza Formation) exposed at Portella seems more likely to be an example of preservation of the marginal setting of the Slovenian Basin (cf. Cousin 1973; Buser 1989; Schlaf 1996).

A section, nearly perpendicular to the direction of the margin progradation, is exposed along the cliff extending from the Portella to Rio delle Cascate (Fig. 8). Here, clinoforms of the Dolomia Principale slope clearly interfinger with basinal deposits (Carnitza Formation). The clinoforms are sigmoidal, decimetre- to metre-thick and dip basinward at about 30–35 degrees. They consist of coarse breccias and calcarenites, generally separated by one to two metres of pelagic black limestones (Fig. 7).

Due to the steep cliffs of the Dolomia Principale (Fig. 8), the nature of the margin has been investigated in only a few places. However, a good outcrop is easily accessible along the road Cave del Predil to Passo del Predil, on the external flank of the tunnel, just east of Lake Predil (Fig. 1). Here, the superposition of the layered back-reef facies above the massive dolomite of the margin is visible. The latter consists of some ten metres of massive dolomites with scanty centimetre-sized cavities; the pervasive dolomitisation has almost completely obliterated traces of organic structures. However, selective surface erosion emphasizes dasycladaceans and serpulids. The back-reef facies sharply overlie the massive margin and consist of cross-bedded doloarenites, dolomites bearing pisolitic caliche- or laminated caliche-crusts, subtidal dolomitic mudstones and breccias infilling tidal channels.

The interior platform facies are cyclic and made up of alternating mainly stromatolitic dolomites, grey, green and pink aphanitic dolomites, grey and green shales. Upwards, stromatolitic dolomites with tepee are almost universally present.

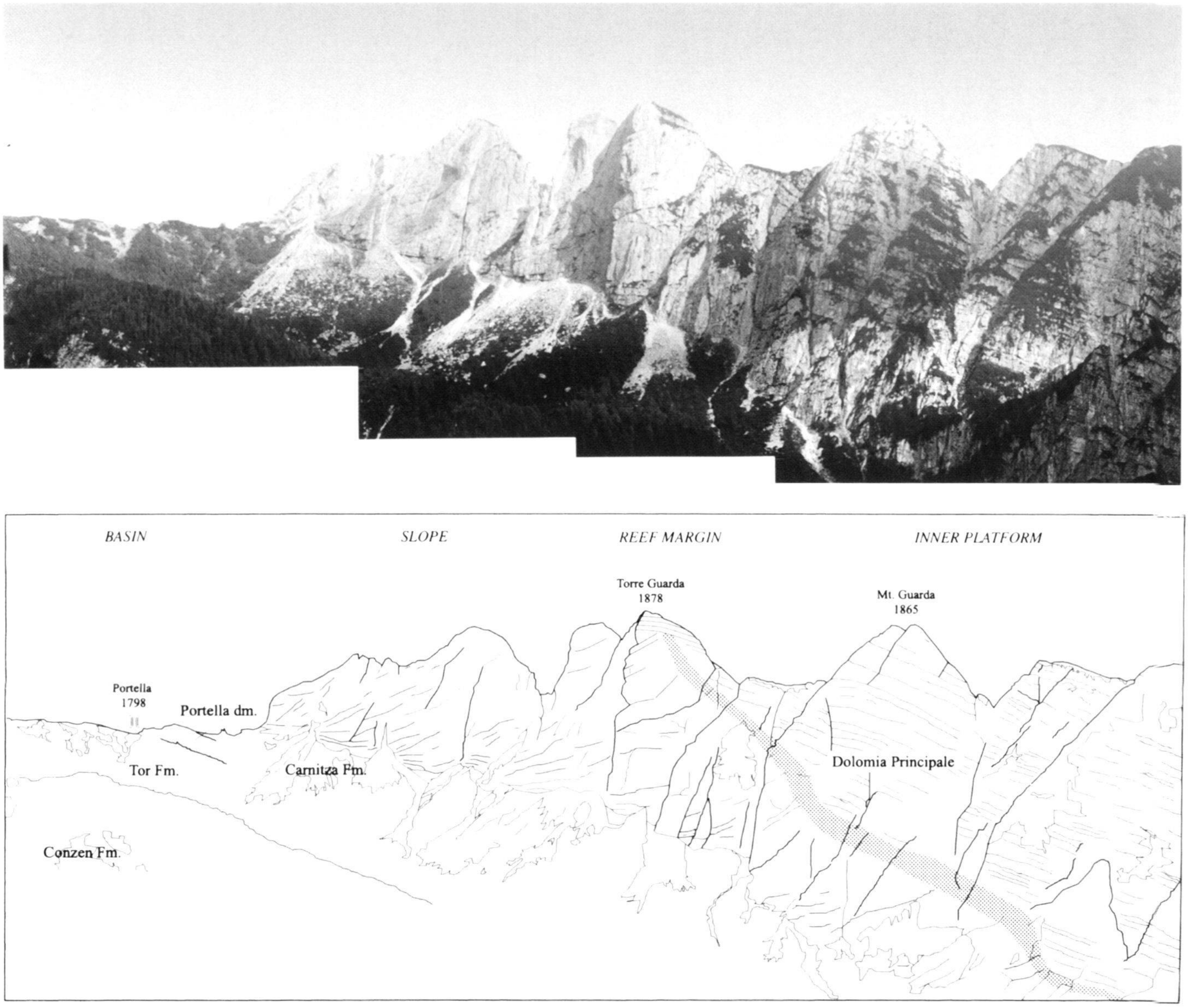

Fig. 8. View of the cliff made up of the Dolomia Principale foreslope between the Portella and Rio delle Cascate. Clinoforms interfinger with limestones of the basinal Carnitza Formation. The dotted area indicates the probable extension of the reef margin. Photo taken from near Sella delle Cave (see Fig. 1).

3. Biostratigraphy and age

In the past, the age of the Conzen Formation to Dolomia Principale succession was established on the basis of the rich bivalve and gastropod fauna; the *Torer Schichten*, until the end of the 60's, were generally regarded as Tuvalian (late Carnian) in age (Arthaber 1906; Pia 1937; Allasinaz 1966; Assereto et al. 1968).

More recently, Lieberman (1978a, 1979, 1980) suggested a Julian age for most of the Tor Formation; the majority of the bivalves, and all of the ostracods, indicate a Julian age, but conodonts indicate a post-Julian age for the uppermost Tor Formation. Lieberman (1978a) noted the ammonoids *Proarcestes gaytani* (Klipstein) and *Joannites* cf. *styriaca* (Mojsisovics), probably from the lower and the middle part of the unit respectively; these species are unknown in the Tuvalian (Lieberman 1978a, 1980). In the overlying Carnitza Formation, Lieberman (1978a) found *Projuvavites* sp. (in debris) and *Discophyllites* sp.; these ammonoids indicate a Tuvalian age. On the basis of the presence of the conodont *Epigondolella nodosa* (Hayashi) in the Carnitza Formation, Lieberman (1978a) stated that its lower part is Tuvalian 2 (sensu Krystyn 1980), and the remainder is Tuvalian 3.

Fig. 9. A coarse-grained dolomitized breccia interfingering with the basinal Carnitza Formation at the toe of the slope of the prograding Dolomia Principale. Photo taken some hundred metres south-west of Portella.

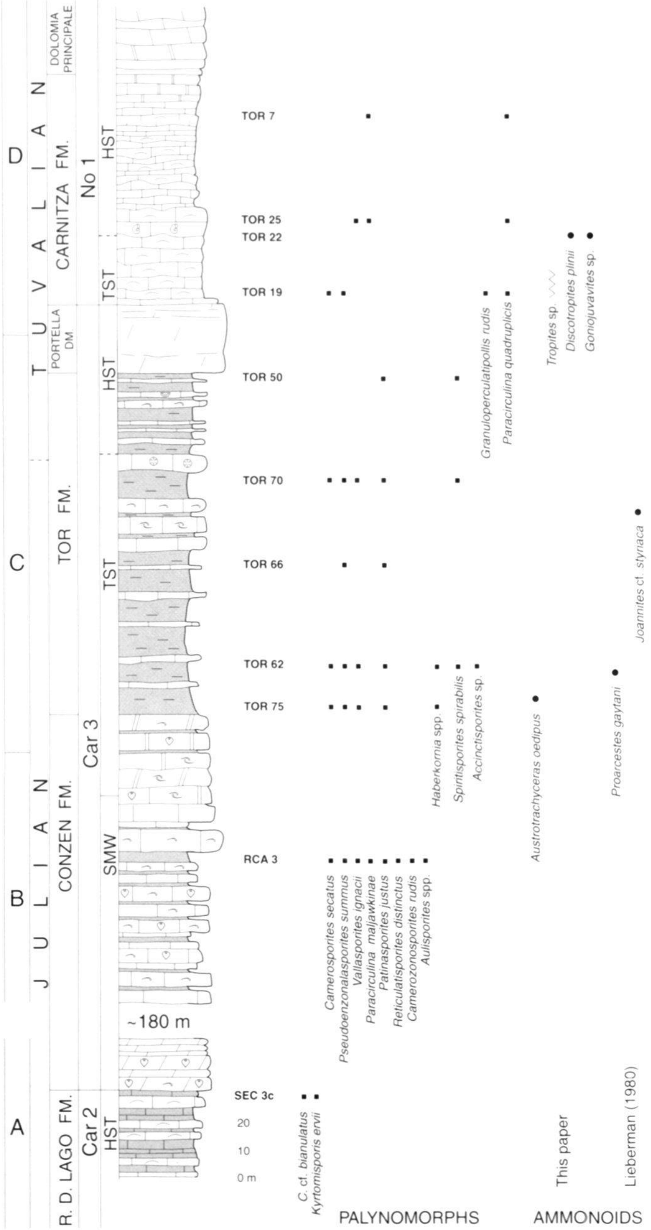

Fig. 10. Composite schematic upper Julian-Tuvalian lithostratigraphy, biostratigraphy and sequence stratigraphy in the Cave del Predil area: A=Jof del Lago section; B=Rio delle Cascate section; C=Portella section; D=Sella Ursic section.

The results of our studies confirm Lieberman's conclusions. The presence of Julian ammonoids in the lower-middle part of the Tor Formation is also corroborated by the presence of a fragment of *Austrotrachyceras oedipus* (Mojsisovics) (det. L. Krystyn) in the basal Tor Formation at Rio delle Cascate.

Stratigraphically significant ammonoids have been collected from the Carnitza Formation in the Sella Ursic section (Pl. 1). *Discotropites plinii* (Mojsisovics), and *Goniojuvavites* sp. Krystyn have been found about 25 m above the base in the type section (Fig. 5). This association is typical of the Plinii Subzone (lower part of the Anatropites Zone, Tuvalian 3, Krystyn 1982). Moreover, in the neighbourhood of the Portella, *Tropites* sp., *Goniojuvavites* sp., *Discotropites* ex gr. *sandlingensis* (Hauer) and *Projuvavites* sp. have been collected from debris. As debris with *Tropites* sp. probably originated from the lowermost part of the Carnitza Formation, the presence of the ammonoid does not preclude the base of the unit from belonging to the underlying Subbullatus Subzone (Tuvalian 2).

Palynological samples from the succession, extending from the top of the Rio del Lago Formation to the upper part of the Carnitza Formation, yielded rich assemblages of spores, pollen and acritarchs, the most important of which from the biostratigraphic point of view are:

Aulisporites spp.
Camerosporites secatus Leschik in Kräusel & Leschik 1956
Camerozonosporites rudis Leschik in Kräusel & Leschik 1956
Concentricisporites cf. *bianulatus* (Neves 1961) Antonescu 1970

Granuloperculatipollis rudis (Venkatachala & Goczan 1964) Scheuring 1978
Haberkornia spp.
Kyrtomisporis ervii van der Eem 1983
Paracirculina quadruplicis Scheuring 1970
Paracirculina maljawkinae Klaus 1960
Patinasporites densus Leschik in Kräusel & Leschik 1956
Patinasporites justus Klaus, 1960
Porcellispora longdonensis (Clarke 1965) Scheuring 1970
Pseudoenzonalasporites summus Scheuring 1970
Reticulatisporites distinctus Orlowska-Zwolinska 1985
Sellaspora rugoverrucata van der Eem 1982
Spiritisporites spirabilis Scheuring 1970
Vallasporites ignacii Leschik in Kräusel & Leschik 1956

Selected taxons are illustrated in Plate 2 and the distribution is shown in Figure 10.

A palynoflora from the top of the Rio del Lago Formation includes the common upper Fassanian to Julian forms *Kyrtomisporis ervii* and *Concentricisporites* cf. *bianulatus*, however never found in the Tuvalian (cf. van der Eem 1983).

The association of *Pseudoenzonalasporites summus*, *Patinasporites* spp., *Vallasporites ignacii*, *Paracirculina maljawkinae* in miospore assemblages from the Conzen Formation to the Carnitza Formation succession is considered indicative of a Carnian age (Dunay & Fisher 1978; Góczán & Oravecz-Scheffer 1996; Klaus 1960; Leschik 1956; Orlowska-Zwolinska 1983; Scheuring 1970; Visscher & Krystyn 1978, van der Eem 1983). Inside this Carnian association, a distinctive Julian miospore assemblage, which does not occur in the overlying Tor Formation, is found in the terrigenous intercalation within the Conzen Formation (sample RCA3, Fig. 4). This assemblage includes *Camerozonosporites rudis*, *Reticulasporites distinctus* and a great number of species of *Aulisporites*, among which *A. astigmosus*, *A. circulus* and *A. canalis*. It is well correlatable with the *astigmosus* zone of Poland (Schilfsandstein – Reed Sandstones; Orlowska-Zwolinska 1983; Fijalkowska-Mader, 1999) and with the lower part of the *densus-maljawkinae* phase (Brugman 1983) in the Germanic and Alpine domains.

The most typical and common elements found in the Tor Formation are *Spiritisporites spirabilis*, *Haberkornia* spp. and *Accinctisporites* spp. (Fig. 10). *Spiritisporites spirabilis* (sensu Scheuring in Mostler et al., 1978) was first described by Scheuring (1970) from the topmost Schilfsandstein in a tunnel southeast of Basel. It has also been found in the Opponitz Limestones in the neighbourhood of Lunz, and considered, by Dunay & Fisher (1978), to be Tuvalian in age. Moreover, *S. spirabilis* was found in the Dolomites in the Dürrenstein and Raibl Formation ("Raibl Formation" and "San Cassian Formation" in Blendinger 1988), while its first occurrence was recently documented some metres below a bed containing *Shastites* cf. *pilari* (Diener) (Gianolla et al. 1998b), characteristic form of Dilleri Zone, Tuvalian 1 (cf. Krystyn 1973) (Pl. 1, Fig. 8, 9). *Accinctisporites* was recorded from the Arden Sandstones (Mercia Mudstone Group) in England (Clarke 1965; Warrington 1970, 1971) and the Reed Sandstones in Poland (Orlowska-Zwolinska 1983). Species of *Haberkornia* were recorded from the North Curry Sandstones (Mercia Mudstone Group) in England and were given a Julian/Tuvalian age (Warrington & Williams 1984).

The microspore assemblage from the Carnitza Formation is characterized by a great number of circumpolles (*Paracirculina quadruplicis*, *P. maljawkinae*, *P. tenebrosa*, *Camerosporites secatus*, *Granuloperculatipollis rudis*) associated with monosaccate form (*Pseudoenzonalasporites summus*, *Patinasporites densus* and *Vallasporites ignacii*); the bryophyte spore *Porcellispora longdonensis* is also common. *G. rudis* (sensu Scheuring in Mostler et al. 1978) was also found in the Monticello Formation (Carulli et al. 1998), in the Upper Gypsum Beds of south-eastern Poland (Fijalkowska-Mader 1999) and is a characteristic constituent in Norian and Rhaetian assemblages throughout Europe (cf. Heunisch 1996, Warrington 1974, Hochuli et al. 1989).

Ammonoids constrain the pollen association in the Carnitza Formation to the upper Tuvalian (Fig. 10). A similar assemblage from the Upper Carnian cherty limestones ("calcari con selce") at Mt. Triona (Sicily, Visscher & Krystyn 1978) was constrained, by ammonoids and conodonts, to the Tuvalian 2/3 transition (= boundary between Subbullatus and Anatropites Zones).

4. Sequence stratigraphy

Two 3rd-order depositional sequences (DS) are recognized in the study area (Fig. 10, 11). The first DS comprises the Conzen Formation, the Tor Formation and the Portella dolomite; the second one comprises the Carnitza Formation and a part of the Dolomia Principale.

The sequence boundary (SB) of the first DS is well exposed south of Sella delle Cave (Figs. 1, 10). It corresponds to the sharp boundary between the basinal marly limestones and marls of the Rio del Lago Formation and the overlying megalodont-bearing dolomites and dolomitic limestones of the Conzen Formation, thus documenting the downward shift of the facies.

The thick carbonate interval, which forms the Conzen Formation, is considered to be a shelf margin systems tract (SMST). The uppermost Conzen Formation, made up of pale-blue limestones, large-pelecypod coquinas and calcarenites interbedded with very thin brown siltstone layers, and lying with a sharp contact on strongly dolomitized beds (top SMST) of the upper Conzen Formation, is to be interpreted as the beginning of the transgressive systems tract (TST). The TST also includes the lower to middle Tor Formation, comprising fossiliferous marls, shales and limestones deposited in shallow environment. A coral bed (Fig. 5), documenting normal salinity and open shelf conditions, defines the maximum flooding surface (mfs), around which bioturbation is very strong, thus documenting a slowing down in sedimentation. The decrease in salinity, suggested by the increase in ostracod abundance and the increase in biocalcarenites (upper Tor Formation) document the highstand systems tract (HST). The upward shallowing trend is concluded by the reappraisal of the carbonate deposition (Portella dolomite).

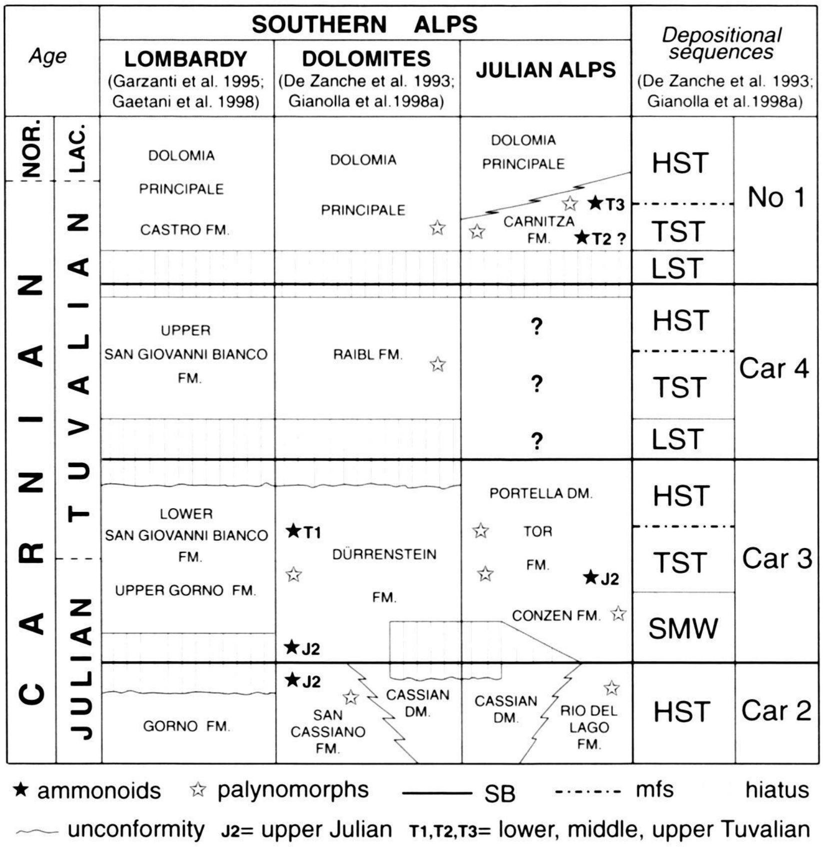

Fig. 11. Carnian sequence chronostratigraphic framework in the Southern Alps.

Black or dark-grey anoxic pelagic limestones of the Carnitza Formation rest in sharp contact on the Portella dolomite. The contact is here interpreted as a drowning unconformity and is considered to be the SB of the second DS. Therefore, a hiatus is expected in that position. The lower part of the Carnitza Formation consists largely of bioclastic, low-scale cross-laminated, packstones-grainstones testifying to an increase in energy during the initial transgressive phase. The TST continues upwards, as indicated by the clearer and clearer pelagic character of the limestones, the decrease in terrigenous input and finally the appearance of a more diversified open water fauna. The mfs is placed in a bed (Tor 22, Fig. 3, 10) with abundant ammonoids, radiolarians, thin-shell bivalves and brachiopods. Above the mfs, the basinal sediments are characterized by a slight increase in terrigenous supply and distal neritic turbidites, attesting to the early HST. The late HST is clearly documented by the basinward prograding geometries of the Dolomia Principale.

5. Discussion and conclusions

New data on Carnian lithostratigraphy, biostratigraphy and sequence stratigraphy in the Raibl/Cave del Predil area lead to conclusions which state the stratigraphic framework more exactly but, in the same time, paves the way for further problems especially in the definition and correlation of the 3rd-order DSs throughout the Southern Alps and Tethyan domain.

Ammonoids collected inside the Carnitza Formation confirm the dating by Lieberman (1978a) and definitely fix a Tuvalian 3 age for the unit. On the basis of ammonoids found in debris, its lower part could exceed the boundary of the underlying Subbullatus Zone (Tuvalian 2). These biostratigraphical data allow a Tuvalian 3 age to be assigned to the lower part of the Dolomia Principale, whose slope interfingers with the middle-upper part of the Carnitza Formation (Fig. 3 and 8). The Julian age of the lower and middle part of the Tor Formation, defined by Lieberman (1978a) mainly on the basis of conodonts and ammonoids, is confirmed by the presence of *Austrotrachyceras oedipus* (Mojsisovics) (det. L. Krystyn).

Palynostratigraphical analysis of the succession has defined (Fig. 10): 1) at the top of the Rio del Lago Formation, a microflora which is not younger than the Julian; 2) in the Conzen Formation a peculiar Julian palynoflora; 3) within the Tor Formation, an assemblage of Julian-Tuvalian age; 4) in the Carnitza Formation, a Tuvalian palynoflora association. A further conclusion from the palynostratigraphical point of view, is the peculiarity of *Spiritisporites spirabilis* (*sensu* Scheuring in Mostler et al. 1978). *S. spirabilis* has been used to define the vigens-spirabilis phase (van den Bergh 1987; Köppen 1997) in the Germanic basin; in Switzerland, it appears at the top of the Schilfsandstein (Scheuring 1970); in France, at the top of the Grès à Roseaux (Courel et al. 1984) and in the middle-upper part of the Dürrenstein Formation in the Dolomites (some metres below the first appearance of *Shastites* cf. *pilari*, Dilleri Zone, lower Tuvalian) (Gianolla et al. 1998b). Moreover, it is also characteristic and frequent in the Opponitz Limestones (Dunay & Fischer 1978). In the Portella section, *S. spirabilis* has been found throughout the Tor Formation; however, in the Dolomites, on the basis of a check and redefinition of the stratigraphical position of samples in Blendinger (1988), *S. spirabilis* has been pointed out both within the Dürrenstein Formation (productive sample H117) and the Raibl Formation (productive samples A12 and H57). Therefore, on the basis of available data, the vertical range of *S. spirabilis* seems to extend from the uppermost Julian to close to the Tuvalian 2/3 boundary. The palynostratigraphical analysis also confirms the difference between *S. spirabilis* and *Granuloperculatipollis rudis* (Scheuring in Mostler et al., 1978); furthermore the two forms seem to have a different vertical range.

Biostratigraphy constrains the correlation of the interval Conzen Formation to Portella dolomite with the Dürrenstein Formation (Dolomites). In spite of their remarkable diversity in thickness, both successions also document the same evolutionary trend. In fact, both the Dürrenstein Formation and the Conzen to Portella sequence may be divided into three parts. The lower one overlies basinal deposits (San Cassiano Formation – Rio del Lago Formation, upper Julian in age) and documents the infilling of previous basins. It consists of subtidal dolomites, dolomitic limestones and locally terrigenous-carbonate facies and, on the whole, shows a shallowing up evolution. It is worth to underline that Pia (1937) suggested that the lower bedded dolomites (Dürrensteindolomit) could correspond to the limestones bearing megalodontids (Megalodus kalk, Conzen Formation) in the Raibl area. The middle part shows a progressive deepening setting and is characterized by a widespread fine- to coarse-grained terrigenous input, which pollutes the carbonate sedimentation. In the Dolomites, it corresponds to the terrigenous interval within the Dürrenstein Formation (Areniti del Dibona, Bosellini et al. 1982), while in the study area it corresponds to the transgressive part of the Tor Formation. The age of this second interval is upper Julian and the Julian/Tuvalian boundary falls in its upper part (Figs. 10, 11). The third part of the sequence (upper Tor Formation and Portella dolomite – upper Dürrenstein Formation, Tuvalian in age) documents a generalized phase of shallowing and progradation of carbonate facies. The above stratigraphic correlations give a first answer to the aged question (Bittner 1885; Koken 1913) about the correspondence of the Torer Schichten and the Heiligkreuz Schichten (local German name of the Dürrenstein Formation in Badia Valley, northern Dolomites, cf. Gianolla et al. 1998b).

The new biostratigraphical data permit to correlate the first DS (Conzen Formation-Tor Formation-Portella dolomite) with the Car3 DS, corresponding to the Dürrenstein Formation in the Dolomites. Moreover, the second DS in the Julian Alps (Carnitza Formation and lower part of the Dolomia Principale) is correlatable with the No1 DS. However, De Zanche et al. (1993) and Gianolla et al. (1998a), respectively in the Dolomites and throughout the Southern Alps, also defined a DS (Car4), corresponding to the Raibl Formation, interposed between Car3 and No1. At this point, the Car4 DS is not recognizable in the Julian Alps and there is no evidence of erosion at the top of the Portella dolomite. Therefore, the bulk of the problem is if the Car4 DS, as defined by De Zanche et al. (1993) in the Dolomites and by Garzanti et al. (1995) and Gaetani et al. (1998) in Lombardy is a local sequence erroneously extended by Gianolla et al. (1998) to the eastern Southern Alps. In such a case, as suggested by Neri & Stefani (1998), the Raibl Formation should be considered as belonging to the TST of the No1 DS.

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Plate 1.

Tuvalian ammonoids from the Julian Alps and from the Dolomites (all figures natural size; all material is curated in the Dipartimento di Geologia Paleontologia e Geofisica, Università di Padova).

Figs. 1a–b. *Discotropites plinii* (Mojsisovics), TOR 22.2a, Carnitza Formation, Sella Ursic section; 1a lateral view, 1b ventral view.
Fig. 2. *Goniojuvavites* sp., TOR 22.1, Carnitza Formation, Sella Ursic section.
Fig. 3. *Goniojuvavites* sp., TOR 203 dt., Carnitza Formation, Portella area.
Fig. 4a. *Discotropites* ex gr. *sandlingensis* (Hauer), TOR 204.a, Carnitza Formation, Portella area, positive view.
Fig. 4b. *Discotropites* ex gr. *sandlingensis* (Hauer), TOR 204.b, Carnitza Formation, Portella area, negative view.
Fig. 5. *Projuvavites* sp., TOR 202, Carnitza Formation, Portella area.
Fig. 6. *Tropites* sp., TOR 201, Carnitza Formation, Portella area.
Fig. 7. *Austrotrachyceras oedipus* (Mojsisovics), RCA 30, lower Tor Formation, Rio delle Cascate section, negative view.
Fig. 8. *Shastites* cf. *pilari* (Diener), SCS.dt1.c, Dürrenstein Formation, Santa Croce/Heiligkreuz section (Peraguda, Badia Valley, Dolomites).
Fig. 9. *Shastites* cf. *pilari* (Diener), SCS. dt1, Dürrenstein Formation, Santa Croce/Heiligkreuz section (Peraguda, Badia Valley, Dolomites).
Figs. 10a–b. *Shastites pilari* (Diener), BRV5, Dürrenstein Formation, Rio Verde section (Lozzo di Cadore, eastern Dolomites), 10a lateral view, 10b ventral view.

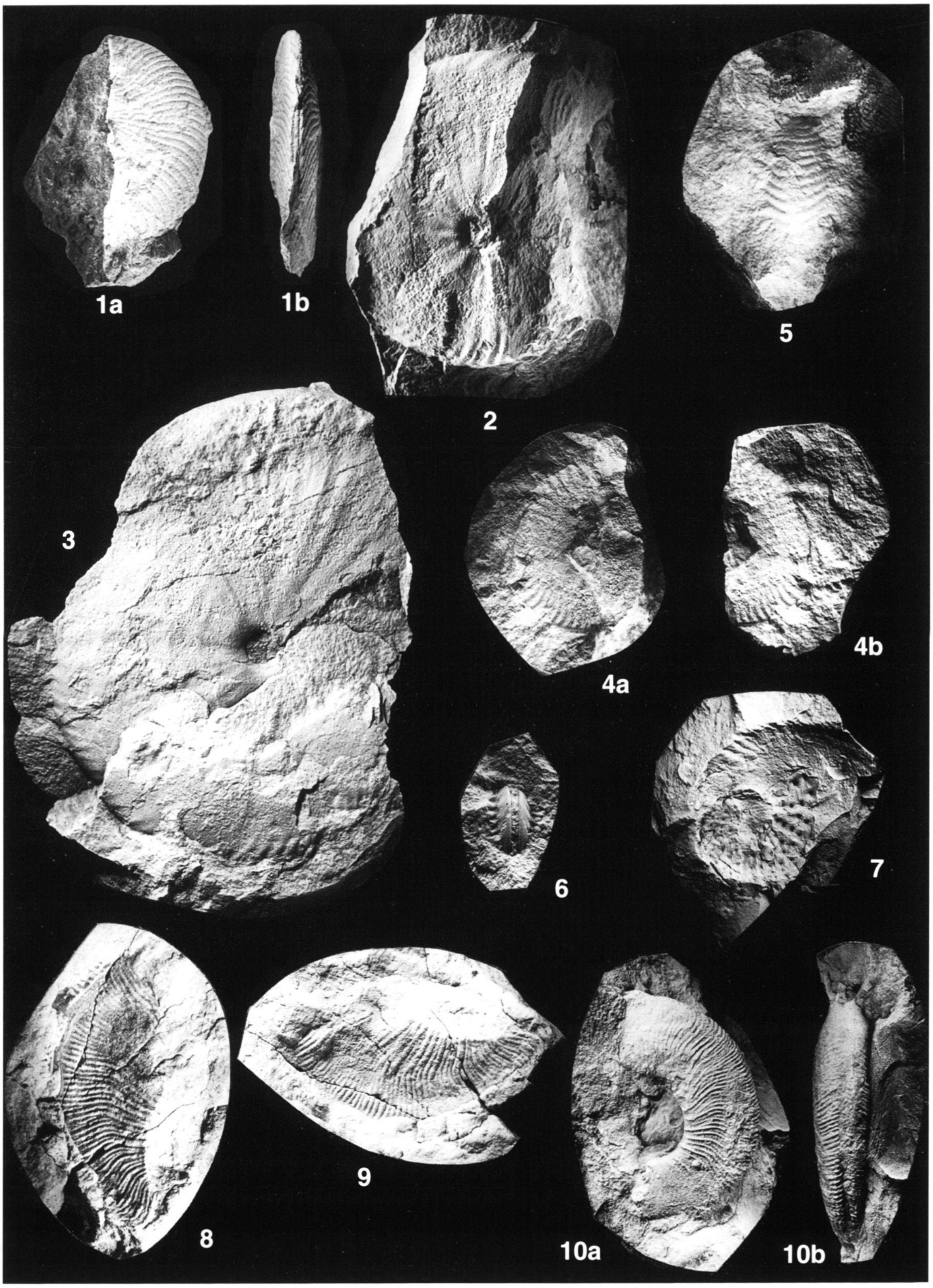
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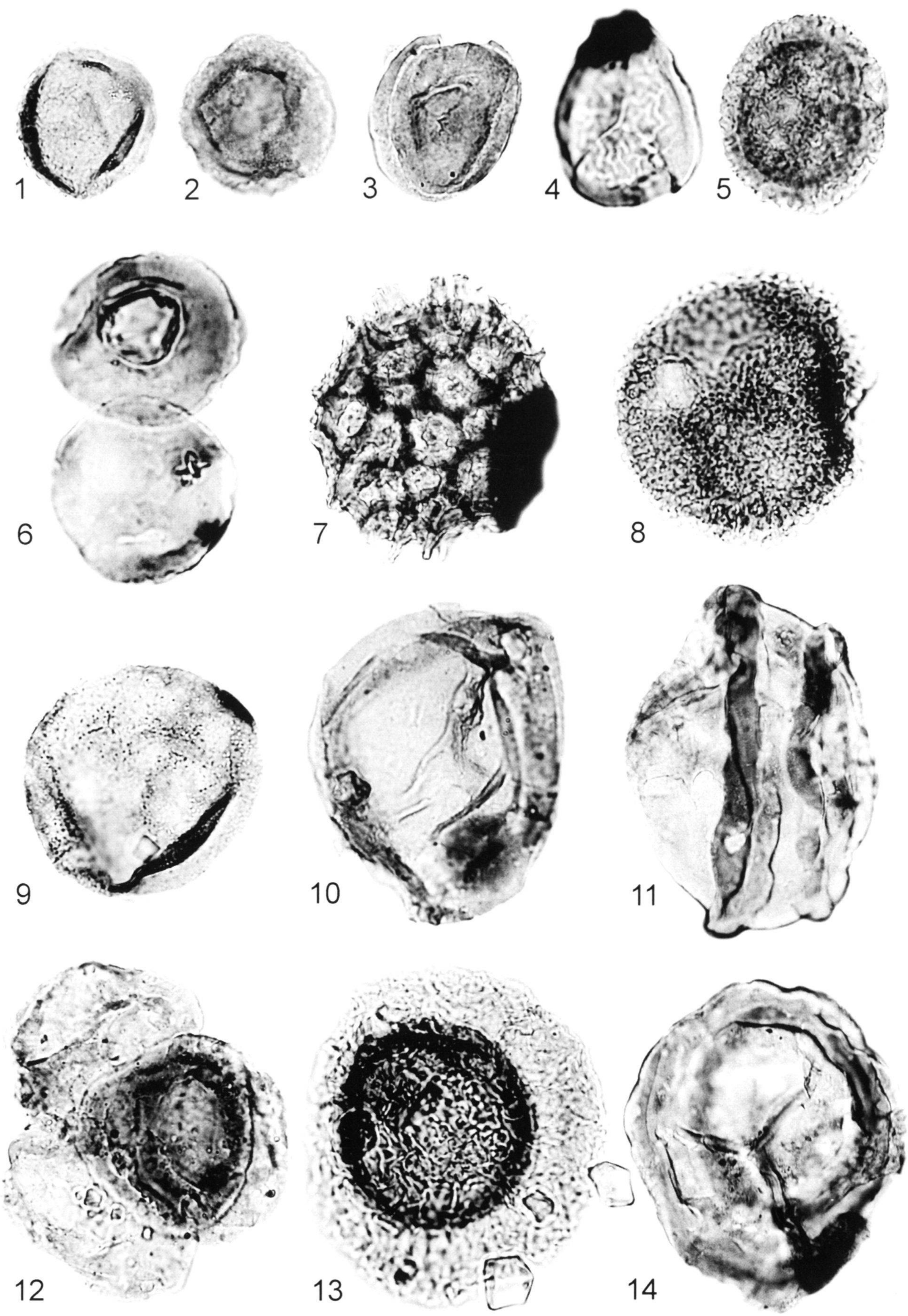
Plate 2

Carnian palynomorphs in the Portella area. All slides are housed in the Dipartimento di Geologia, Paleontologia e Geofisica of the Università of Padova. Coordinates of the figured specimens were taken with the England Finder using Leitz Wetzlar no. 5345 with attached camera.

Fig. 1. *Haberkornia* sp., (31,5 µm), Tor Formation, Portella section, slide TOR 62 I, N 30.
Fig. 2. *Granuloperculatipollis rudis* (Venkatachala & Goczan 1964) Scheuring 1978 (34 µm), Carnitza Formation, Portella section, slide TOR 19 I, M 30/1.
Fig. 3. *Paracirculina maljawkinae* Klaus, (34 µm), Tor Formation, Portella section, slide TOR 70 I, F 28/2.
Fig. 4. *Camerozonosporites rudis* Leschik, (36 µm), Conzen Formation, Rio delle Cascate section, slide RCA 3 IV, E 41/1.
Fig. 5. *Vallasporites ignacii* Leschik, (38 µm), Tor Formation, Portella section, slide TOR 70 II, N 30.
Fig. 6. Couple of *Aulisporites circulus* Starke, (single specimen 27 µm), Conzen Formation, Rio delle Cascate section, slide RCA 3 II, L 33/2.
Fig. 7. *Reticulatisporites distinctus* Orlowska-Zwolinska, (63 µm), Conzen Formation, Rio delle Cascate section, slide RCA 3 VI, H 42.
Fig. 8. *Pseudoenzonalasporites summus* Scheuring, (50 µm), Tor Formation, Portella section, slide TOR 62 I, M 31.
Fig. 9. *Spiritisporites spirabilis* Scheuring, (54 µm), Tor Formation, Portella section, slide TOR 70 I, M 20/3.
Fig. 10. *Aulisporites astigmosus* (Leschik) Klaus, (55 µm), Conzen Formation, Rio delle Cascate section, slide RCA 3 II, W 35/1.
Fig. 11. *Concentricisporites* cf. *bianulatus* (Neves) Antonescu, lateral view, (wide 126 µm), Rio del Lago Formation, Jof del Lago section, slide SEC 3c IV, M 30.
Fig. 12. *Paracirculina quadruplicis* Scheuring, (single specimen 40 µm), Carnitza Formation, Ursic saddle section, slide TOR 19 II, Q 31/2.
Fig. 13. *Patinasporites justus* Klaus, (65 µm), Tor Formation, Portella section, slide TOR 62 II, T 40/3.
Fig. 14. *Concentricisporites* cf. *bianulatus* (Neves) Antonescu, proximal view, (110 µm), Rio del Lago Formation, Jof del Lago section, slide SEC 3c II, 7 40/4.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