
A Candidate Of The Global Boundary Stratotype Section And Point For The Base Of The Carnian Stage (Upper Triassic):

GSSP at the base of the canadensis Subzone (FAD of Daxatina) in the Prati di Stuoeres/Stuoeres Wiesen section (Southern Alps, NE Italy)

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Introduction

This paper is a slightly modified version of the proposal for the GSSP of the base of the Carnian Stage presented by Broglio Loriga et al. (1998, 1999) for discussion among the members of the L/C working group of the STS (M. Gaetani chairman), concerning the Prati di Stuoeres/Stuoeres Wiesen candidate section.

This proposal and its contents follow the guidelines published on p. 61 of Albertiana 26. Of the items listed in these guidelines, the discussion of cycle stratigraphy and point 4B are excluded here. About the latter, no other candidate sections have been proposed.

1. Stratigraphic Rank Of Boundary

Base Of The Carnian Stage And The Upper Triassic Series

2. Proposed Gssp - Geographic And Physical Geology

2a Geographic Location

The GSSP candidate at Prati di Stuoeres/Stuoeres Wiesen (Province of Belluno, Veneto Region, NE Italy) is located on the left side of the Cordevole Valley, on the southern slope of the crest separating the Badia/Abtei and the Cordevole valleys (Dolomites, Southern Alps).

The Prati di Stuoeres section (German: Stuoeres Wiesen) lies few hundreds meters east of Pralongià, a locality sited NE of Arabba (Cordevole Valley). The section extends from an altitude of 1980 m and reaches the crest at 2150 m a.s.l., within a vast gully-eroded depression, deeply incised

within the slope. Upwards, it continues inside the overlying meadows and ends at the toe of the vertical walls of the Piccolo Settsass (the well-known Richtigshofen Riff of Mojsisovics, 1879) and of the Settsass (Fig. 1).

The section can be easily reached from Rif. Pralongià following C.A.I. footpath n. 23 towards Settsass, a few hundreds meters ESE of Piz Stuoeres (2181m). Pralongià is easily attainable by many footpaths (C.A.I.n.22, n. 23, n.3) from all the surrounding localities, San Cassiano/St. Kassian, Corvara/Kurfar (Badia/Abtei Valley) and from Campolongo Pass, but also by gravel roads from Corvara/Kurfar (intersection at km 35, SP 244) and Renaz (intersection at km 88, SR 48) and by chair-lift from Rifugio Chertz near Campolongo Pass.

2b Geological Location

The Prati di Stuoeres/Stuoeres Wiesen section (Fig. 2) is located in the Dolomites that constitute the central-northern portion of the Southern Alps (Doglioni, 1987; Castellarin and Cantelli, 2000). The Southern Alps derived from the comparatively gentle deformation of the passive continental margin of the Mesozoic Tethys Ocean into a non metamorphic, south-vergent thrust belt belonging to the Alpine Belt. In the Dolomites, the sedimentary succession spans from late Permian to Cretaceous time, but it is a worldwide reference area for the Triassic (Bosellini et al., 2003).

The Dolomites stratigraphy records several tectonic and magmatic events including the Late Ladinian emplacement of epicrustal intrusions (Monzoni, Predazzo, Cima Pape) and shoshonitic volcanism (Sloman, 1989). This is a key event in the stratigraphic record of the Dolomites and it

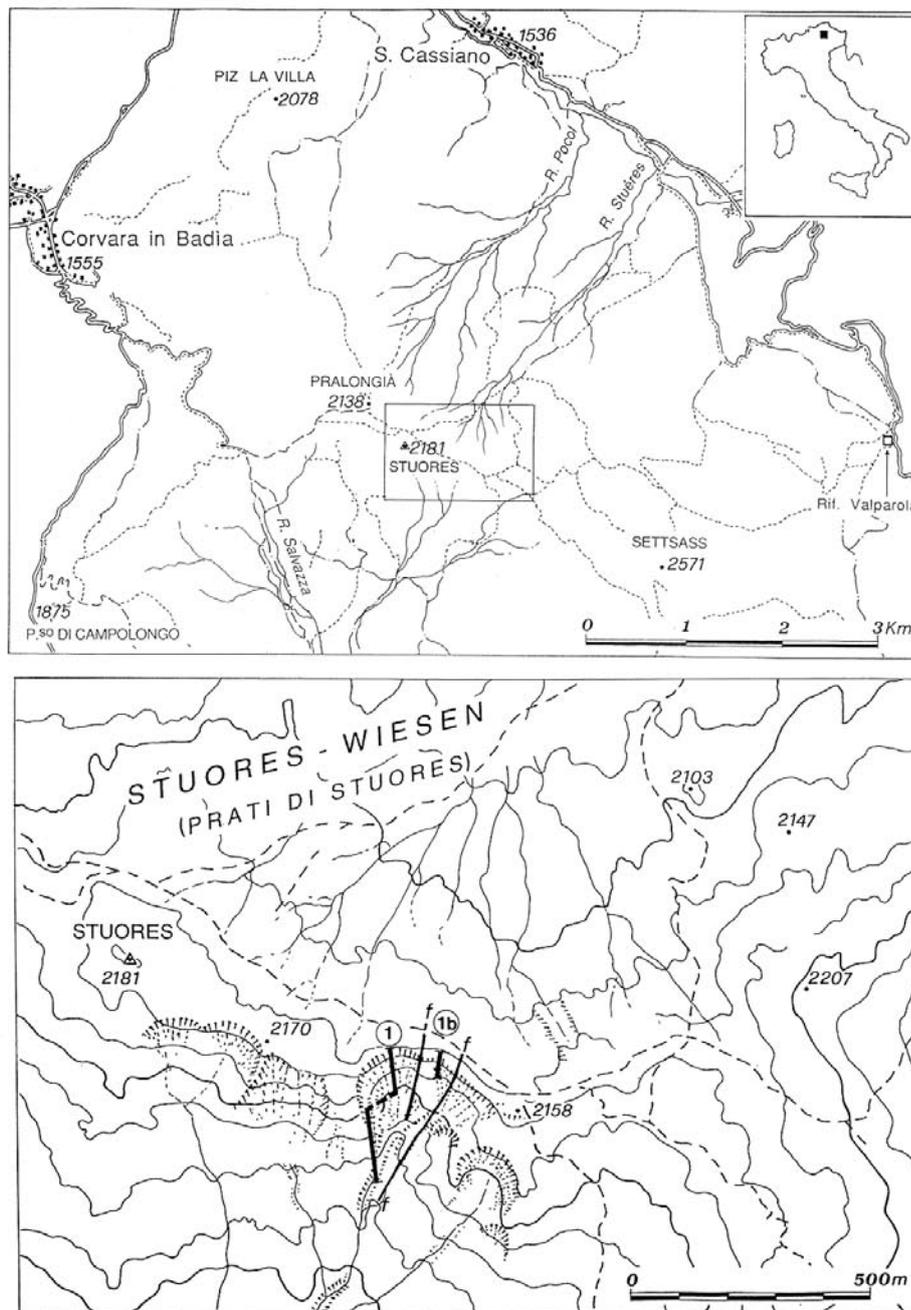


Figure 1: Location map of the Prati di Stuores/Stuores Wiesen section (from Broglio Loriga et al., 1998, mod.).

is responsible of huge input of volcanoclastics and lava flows both in subaerial and marine conditions (Fernazza Fm). The tectonic activity related to the volcanic event also triggered submarine collapses of the pre-volcanic succession, and their embodying as megabreccias into the coeval volcanoclastics. These units constitutes the base of the described succession at Prati di Stuores (Broglio Loriga et al., 1999). After the rapid emplacement of the volcanic edifices, the stratigraphic succession records their erosion as a thick volcanodetritic unit (Wengen Fm) enhanced by a sea level fall. The Wengen Fm shows an internal organisation controlled by the progradation of turbiditic lobes towards deeper basins, lithofacies are thus controlled by the distance from source areas. Locally, small carbonate platforms are documented (mostly with fringing reef geometries):

they are responsible for the exportation of carbonatic boulders called “Cipit” as well as finer biocalcarenites. The reduced rates of erosion, related to the sea level rise and the start-up of rimmed carbonate platforms (Cassian Dolomite), lead to a reduced siliciclastic input in favour of carbonate sediments in the basins (San Cassiano Fm). The typical organisation of this interval, exhibiting strong volcanoclastic input, sharp reduction and again increase in siliciclastic and shallow water-derived carbonates, is well documented in the area of Prati di Stuores/Stuores Wiesen. The subsequent basin evolution is characterized by a progressive shallowing, resulting in a complete closure of the basin itself during Late Carnian time (Heiligkreuz, Travenanzes Fms).

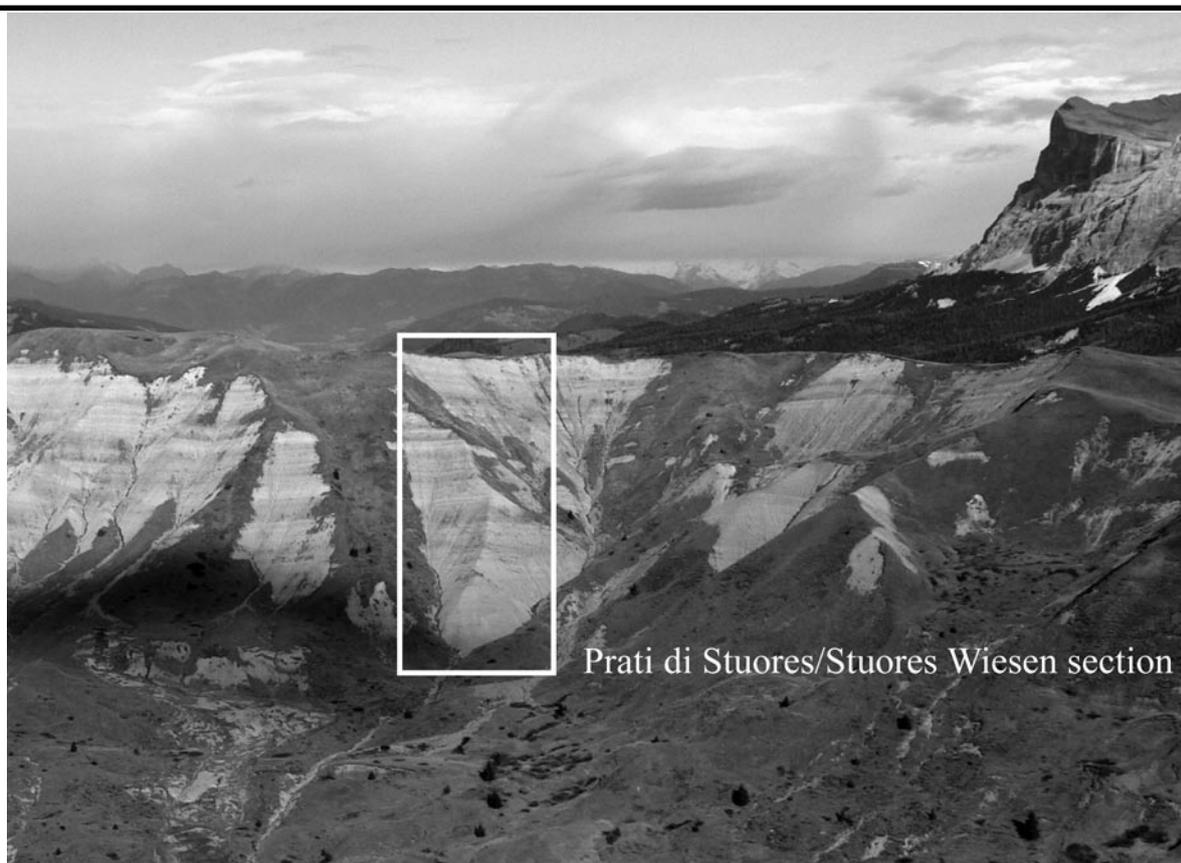


Figure 2: Picture of the Prati di Stuores/Stuores Wiesen section.

2C Location of level and specific point

Several outcrops exposing the upper Wengen and the San Cassiano Formations are present at Prati di Stuores/Stuores Wiesen. Most of them expose long sections, which are easily correlated by tracing conspicuous beds. The section, exposed at 46°31'37"N and 11°55'49"E; 1980 m a.s.l., WGS84 datum, is indicated as Standard Section, because it exposes the longest succession (Figs 1, 3). This section is represented on Italian topographic map at scale 1:25000 number 11-I-SE "Corvara in Badia", 5th ed., 1963, published by the Istituto Geografico Militare Italiano.

The proposed GSSP is located at the base of bed SW4, at 45 m from the base of the San Cassiano Fm in the Prati di Stuores/Stuores Wiesen stratigraphic section (Figs 1, 4, 5). Bed SW4 is a marly limestone immediately underlying an arenite bed in the lower San Cassiano Formation. The bed yields ammonoids, including *Daxatina canadensis* (Whiteaves), proposed as the principal marker to identify the boundary.

2D Stratigraphic completeness

The Prati di Stuores/Stuores Wiesen section is characterized by a thick interval of marine sediments deposited below storm wave-base. The depositional motif consists of hemipelagites and thin turbidite beds (both siliciclastic and from nearby carbonate platforms) documenting high but variable sedimentation rates. In detail, a slight increase in sedimentation rate is noticed towards the upper part of the section accordingly to the overall regressive trend. Taking as a whole, terrigenous sedimentation seems to decrease

upwards in favour of the carbonate supply coming from the progradation of carbonate platforms (Cassian Dolomite).

Slumps and slump scars are recognized in the upper part of the section, but are absent around the proposed GSSP level. Such slumps-slump scars do not involve considerable thickness and therefore do not correspond to significant stratigraphic gaps. Hard-ground and non-depositional and/or condensed levels are absent in the studied interval.

2E Adequate thickness and stratigraphic extent

The Prati di Stuores/Stuores Wiesen section encompasses 180 meters of hemipelagic beds of the Wengen and San Cassiano Fms, which become more than 200 once the physically correlated section 1bis is considered (Fig. 5). Lateral continuity of the outcrops is also in the order of many hundreds of meters (Fig. 3). Ammonoids are common throughout the section.

Below the proposed GSSP, 45 m of marls and arenites referred to the San Cassiano Fm and ca. 20 m of Ladinian shales are exposed in the section; this interval represent the top of the Upper Ladinian *regoledanus* Subzone.

The first biozone of the Carnian, the *canadensis* Subzone, is well represented in the section up to m 194.30, where the boundary with the overlying *aon* Subzone is documented in section 1bis.

The Prati di Stuores/Stuores Wiesen section thus encompasses three ammonoid subzones. This stratigraphic interval is relatively short, if compared with the thickness of the succession; this is a consequence of the high sedimentation

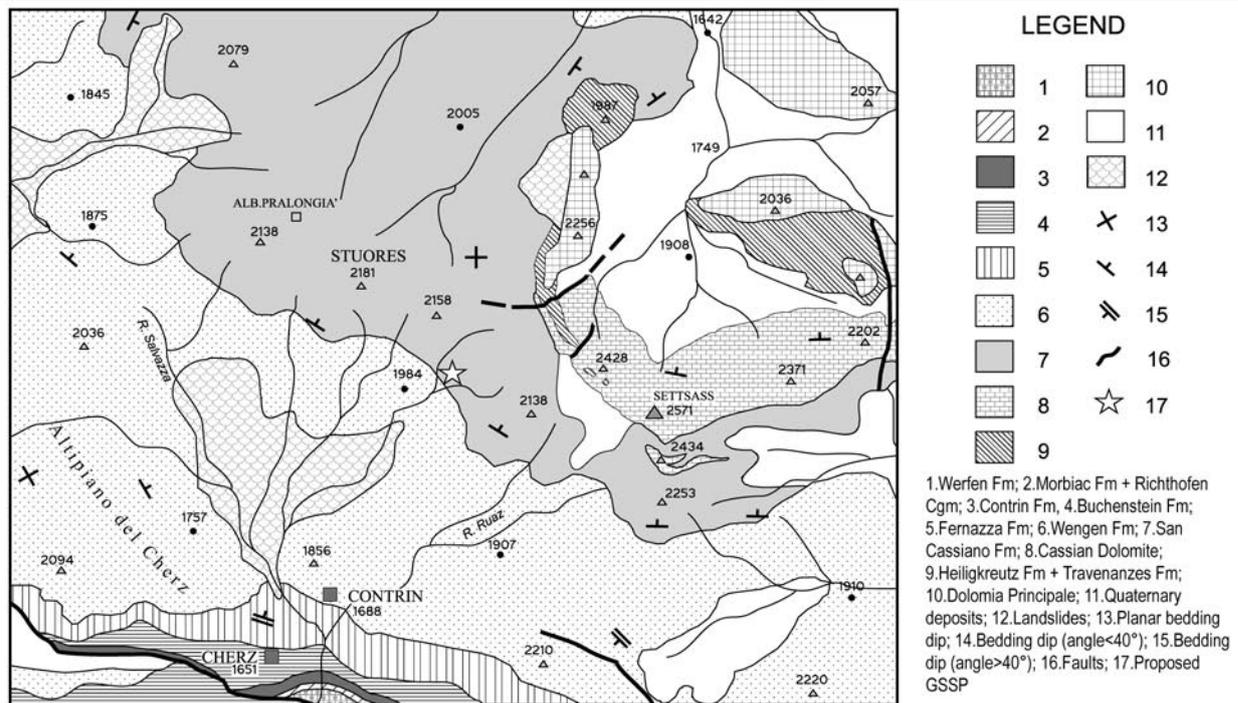


Figure 3: Geologic map of the type area of the proposed GSSP for the base of the Carnian.

rate that characterized the Cassian basin between the late Ladinian and early Carnian. The considerable stratigraphic extent below and above the proposed boundary level is then sufficient to ensure a stable definition of the GSSP.

2F Provisions for conservation and protection

The accessibility of the Prati di Stuoeres/Stuoeres Wiesen section is historically documented from the early XIX Century, thanks to the classical works by Münster (1834), Wissmann and Münster (1841), Klipstein (1845), Laube (1869), Mojsisovics (1882), Ogilvie (1893), Ogilvie Gordon (1900, 1929), Urlichs (1974, 1994), and others. This historical record clearly documents a long-lasting persistence of the natural outcrops. The section area is involved in small but frequent landslides, due to the steep exposure and the lithological nature of the involved unit, consisting of marls, volcanoclastic arenite and thin bio-calcarenite alternations. The chosen section, however, lies on a steep rise, about 75 metres above the slope base, a high-standing location preventing the landslide and debris flow deposits from accumulating on the section outcrop. The large lateral continuity of the outcrop also support a good preservation potential of the proposed GSSP.

The Prati di Stuoeres/Stuoeres Wiesen area belongs to a Dolomites area nominated for subscription to the UNESCO World Heritage List. The area benefits from significant degree of environmental protection, supporting its long-lasting preservation. The area is protected by the Law 8/8, 1985, n. 431 (Galasso), preserving the whole of the territories above 1600 m, and it extends within the Col di Lana - Settsass - Chertz protected area (ZPSIT3230086), related to the directive Natura 2000 (92/43/CE, 79/409/CE). The local administrations (Comune di Livinallongo del Col di Lana and Provincia di Belluno) intend to maintain and label the section access and to disseminate the related information to the general public.

3. Primary and secondary markers

3A principal correlation event (marker) at gssp level

The proposed GSSP-level at Prati di Stuoeres/Stuoeres Wiesen is defined by the first appearance of the ammonoid genus *Daxatina* (i.e. *Daxatina canadensis*), as recognized in the bed SW4.

The genus *Daxatina* is documented in several sections of the Southern Alps: Prati di Stuoeres/Stuoeres Wiesen, Bec de Rocces near Campolongo Pass, Antersass in Badia Valley, Rio Cuzze near Borca di Cadore and Pista Nera near Sappada (Mietto and Manfrin, 1995a, 1995b; Broglio Loriga et al, 1998, 1999; Manco et al., 2004; Mietto et al., 2007). After the early findings in British Columbia (Whiteaves, 1889), in the Svalbard Archipelago (Böhm, 1903, 1904) and in Alaska (Martin, 1926), more recently the new occurrences in the Himalayas region (Spiti valley: Balini, Krystyn and Torti, 1998; Krystyn, Balini and Nicora, 2004) and in Nevada (New Pass Range: Balini and Jenks, 2007; Balini et al., 2007) testify the worldwide distribution of the quoted genus.

For this reason the proposed GSSP-level provides an excellent tool for trans-Panthalassan correlations, between low to middle-high palaeolatitude domains.

3B Other stratigraphy

3B.1 Biostratigraphy

Ammonoids

In the Prati di Stuoeres/Stuoeres Wiesen section, three ammonoid subzones have been recognized: *regoledanus*, *canadensis* and *aon*. The *regoledanus* Subzone is documented from the base of the section (Wengen Fm) to 45 m

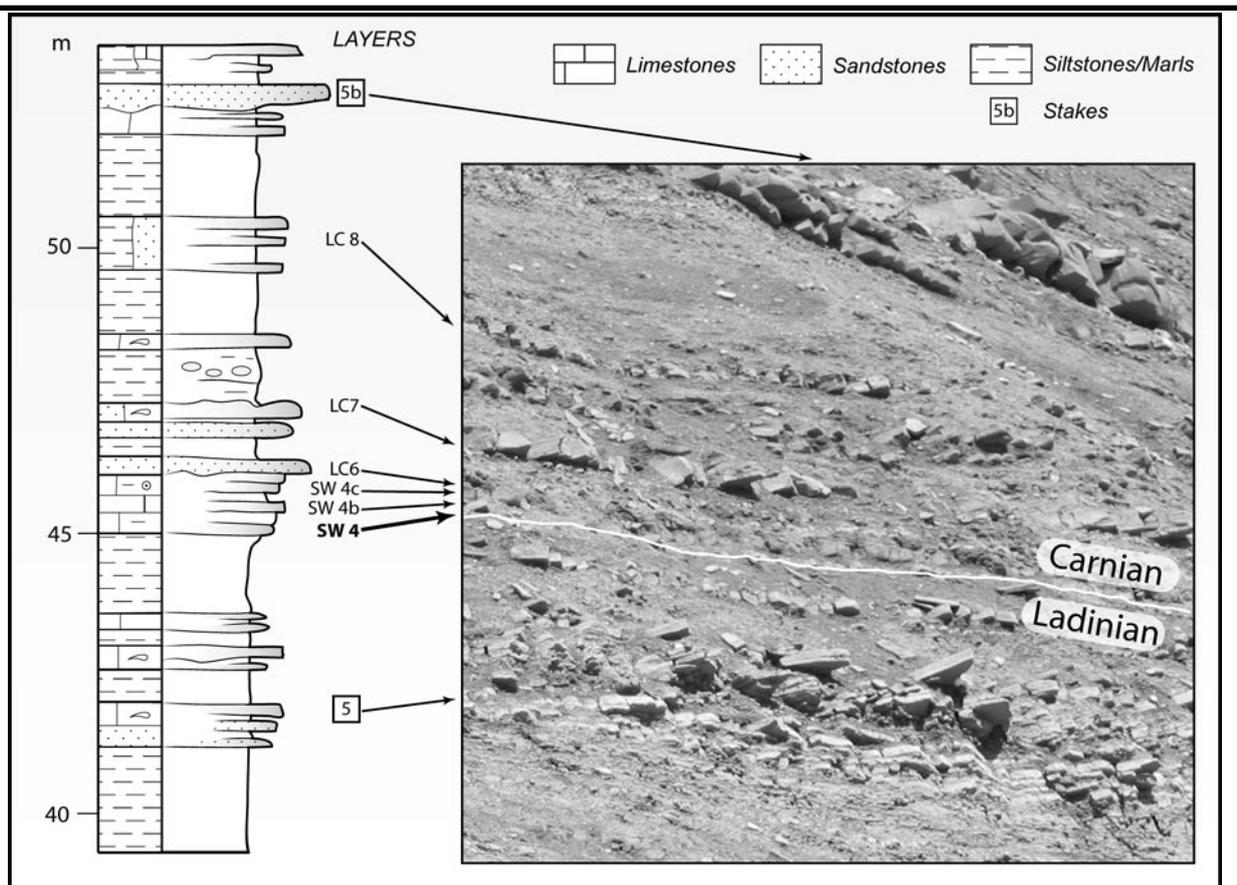


Figure 4: Log and photograph of the Prati di Stuores/Stuores Wiesen section showing the Ladinian/Carnian boundary in detail.

from the base of the San Cassiano Fm. Within this interval (Fig. 5) cf. *Protrachyceras* and *Zestoceras* cf. *enode* Tozer occur. The latter species is also documented in other stratigraphic sections of the Southern Alps, always associated with longobardian ammonoid fauna (Mietto et al., submitted). The *canadensis* Subzone starts from the base of the bed SW4 in which, with the strongly ornamented species *Daxatina canadensis*, the genus *Daxatina* firstly appears. Successively, 16.50 m above the same bed a finely ornamented trachyceratid specimen occurs. This specimen was previously attributed to *Trachyceras bipunctatum* (Münster) (Mietto and Manfrin, 1995a, 1995b; Broglio Loriga et al., 1999; Mietto et al., 2007) but is now attributed to *Daxatina* cf. *laubei* Tozer, 1994 (Mietto et al., submitted). Above, representatives of *Daxatina* (chiefly *D. canadensis*) are scattered along 145 m of the Prati di Stuores/Stuores Wiesen section. Above this interval, the first appearance of *Trachyceras* cf. *aon* (Münster) is checked in bed SW24. The interval zone comprised between the first occurrence of *D. canadensis* and the first occurrence of *T. aon* was originally defined as *Daxatina* cf. *canadensis* Subzone. Later on, based on the direct comparison with type material from Canada, this unit is formally named *canadensis* Subzone. In the past, this biozonal interval was considered equivalent to the *sutherlandi* Zone (Urlichs, 1974, 1977) then comprised in the tethysian *regoledanus* Zone (Urlichs, 1994). Almost 34 m above the bed SW4, the first occurrence of genus *Trachyceras* is recorded by the species *T. muensteri* (Wissmann). In particular, this taxon is characterized by a subammonitic suture line, but less indented

than, e.g., in *T. aon*. After the attribution of most specimens to *D. cf. laubei*, the occurrence of *T. bipunctatum* in the *canadensis* Subzone at Prati di Stuores/Stuores Wiesen cannot be confirmed anymore. Nevertheless, this species has been found in the Antersass section, in the uppermost part of the biozone (Mietto et al., 2007, submitted).

Two species of *Frankites* are documented at Prati di Stuores/Stuores Wiesen: the most abundant and widespread is *Frankites apertus* (Mojsisovics). This taxon, which is considered synonymous of *Frankites sutherlandi* (McLearn) from North America by Mietto et al. (submitted), occurs from the upper part of the *regoledanus* Subzone to the lower part of the *canadensis* Subzone at least. A second species, *Frankites johnstoni* Mietto and Manfrin (in Mietto et al., submitted), occurs sparsely in the lower part of the latter subzone, but its total range comprises, in other sections, also most of the *regoledanus* Subzone.

The best documented genus in the *canadensis* Subzone is *Zestoceras*. In bed SW5b, 7.40 m above SW4, *Zestoceras lorigae* Mietto and Manfrin (in Mietto et al., submitted) occurs. This species is widespread along the *canadensis* Subzone, where its seems to be confined. A second species, *Zestoceras barwicki* (Johnston), originally assigned by Johnston (1941) to the genus *Clionites* (sic!), is equivalent to *Zestoceras cerastes* Tozer. We consider these taxa as synonyms (Mietto et al., 2007, submitted).

Moreover, the bed SW4 yields also *Sirenotrachyceras thusneldae* (Mojsisovics), which is scattered, at present,

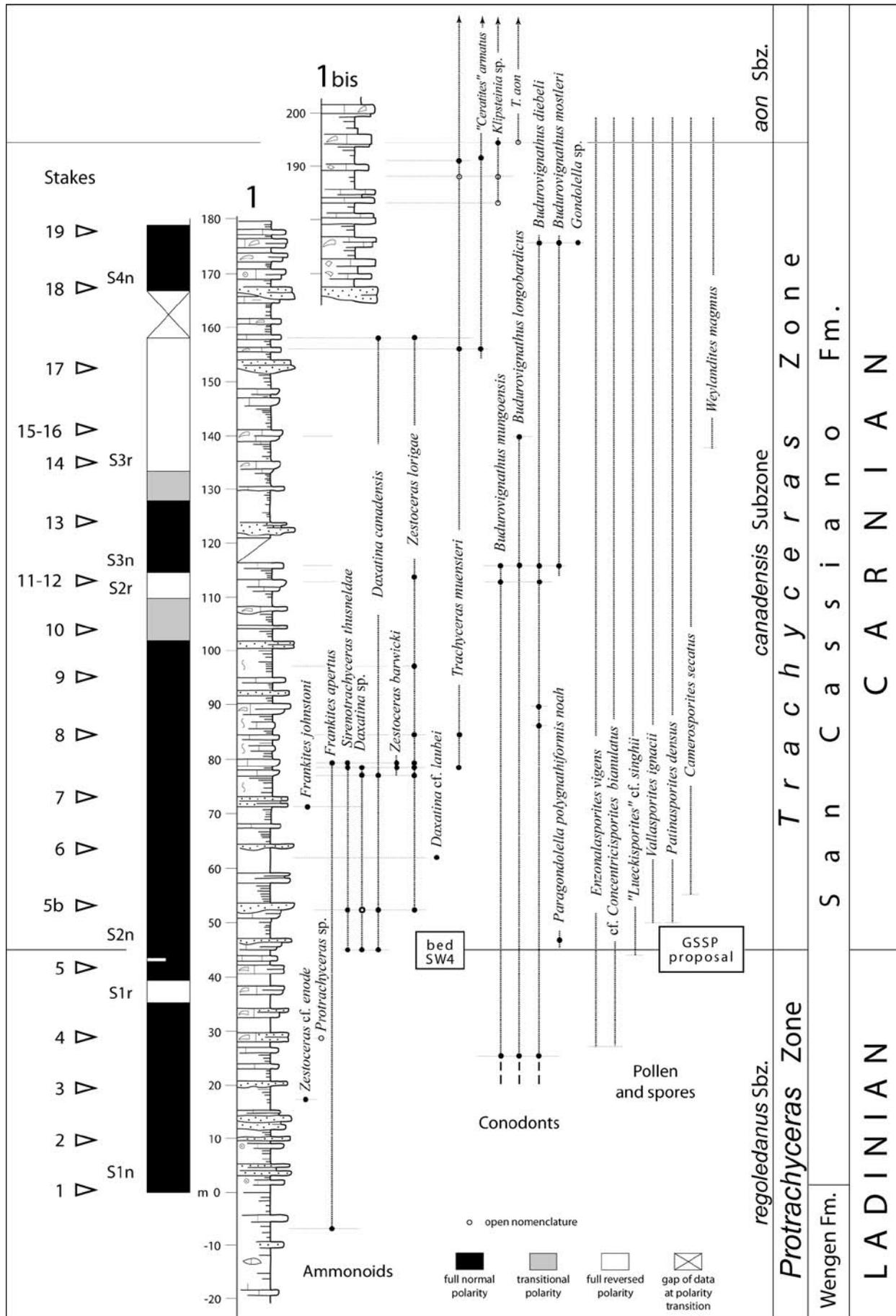


Figure 5: Stratigraphic column of the Prati di Stuores/Stuores Wiesen section with distribution of main fossils and magnetostratigraphy (from Broglio Loriga et al., 1998, mod.).

within the lower part of the subzone.

In the last ten meters of the biozone, taxa documented also in the *aon* Subzone [e.g. *Klipsteinia* cf. *achelous* (Münster), “*Ceratites*” *armatus* (Münster)] occur. In a bed of a nearby section (SW 11), correlated with the uppermost part of the Prati di Stuoeres/Stuoeres Wiesen section, *Badiotites eryx* (Münster) is also recorded. The *canadensis* Subzone is directly overlaid by the *aon* Subzone; the latter is marked by *Trachyceras* cf. *aon* (Münster), as documented in the section 1b (Fig. 5), at 194,30 m from the base of the San Cassiano Fm (bed SW24). The *canadensis/aon* subzones boundary is better exposed in the Antersass section (Fig. 10) and is marked, in particular, by *Trachyceras aon* (Münster), *Brotheotrachyceras* spp. and *Hannaoceras* sp. (Mietto et al., 2007; submitted).

Conodonts

Although the Prati di Stuoeres/Stuoeres Wiesen section has been investigated several times for conodont biostratigraphy, a poor fauna has been recorded. This fauna is composed of *Budurovignathus mungoensis* (Diebel), *Budurovignathus mostleri* (Kozur), *Budurovignathus diebeli* (Kozur and Mostler), *Budurovignathus longobardicus* (Kovács) and by the long-ranging species *Gladigondolella malayensis malayensis* Nogami and *Gladigondolella tethydis* (Huckriede) (Mastandrea in Broglio Loriga et al., 1999). All these species range at least from the upper part of the Longobardian (late Ladinian) to the lower part of the Julian (early Carnian).

Other coeval sections, Antersass and Bec the Roces sections, have been studied both for ammonoid and conodont biostratigraphy (Mietto et al., 2007). A similar conodont fauna have been recovered from both sections with the addition of *Paragondolella foliata* Budurov and the two subspecies *Pseudofurnishius murcianus praecursor* Gullo and Kozur and *Pseudofurnishius murcianus murcianus* Van den Boogaard from Antersass section (Mietto et al., 2007). Recently, *Paragondolella polygnathiformis noah* (Hayashi) has been recovered in the Prati di Stuoeres/Stuoeres Wiesen section (Manco et al., 2004; Mietto et al., 2007; and Fig. 5).

Paragondolella polygnathiformis noah (Hayashi) lies on the phylogenetic lineage of *Paragondolella inclinata* – *Paragondolella polygnathiformis polygnathiformis* – *Paragondolella polygnathiformis noah*, a branch of the *excelsa*-stock which evolved during the late Ladinian – early Carnian (Kovács, 1983). During the last years, the species here named *Paragondolella polygnathiformis* (Budurov and Stefanov) has been ascribed into different genera by various authors, e.g. *Neogondolella*, *Paragondolella*, *Metapolygnathus*. Considering the phyletic evolution and considering the peculiarities which distinguish the above-mentioned genera, as summarized by Kozur (1989), this species has been here interpreted as belonging to genus *Paragondolella*.

Paragondolella polygnathiformis noah (Hayashi) is characterized by a geniculation point or an abrupt anterior step on both the anterior lateral margins. The presence of this

feature on only one of the anterior margins is typical for the transitional forms between *Paragondolella inclinata* (Kovács) and *Paragondolella polygnathiformis polygnathiformis* (Budurov and Stefanov) during the latest Ladinian. *Paragondolella polygnathiformis polygnathiformis* (Budurov and Stefanov) differs from *Paragondolella polygnathiformis noah* (Hayashi) for the absence of a free blade since the platform tends to reach the point of the blade.

Historically, the FO of *Paragondolella polygnathiformis* has been used to define the base of the Carnian, the occurrence of which was considered coincident with the base of the *Trachyceras aon* Subzone (Krystyn, 1983). Later, it has been demonstrated a downward extension of the range of *Paragondolella polygnathiformis* below the FAD of *Trachyceras aon* (Kozur, 1980, 1989; Kovács et al., 1991; Gallet et al., 1998; Rigo et al., 2007), that means within the *canadensis* Subzone. At Spiti (India), the FO of *Paragondolella polygnathiformis noah* along with *Paragondolella polygnathiformis polygnathiformis* is some meters below the FO of *Daxatina canadensis*.

At Prati di Stuoeres/Stuoeres Wiesen, *Paragondolella polygnathiformis noah* (Hayashi) has been collected from sample SW 4c, 70 cm above the first occurrence of *Daxatina canadensis* (Whiteaves) in bed SW 4. The FAD of *Paragondolella polygnathiformis noah* (Hayashi) is practically coincident with the FAD of *Daxatina canadensis*, and might be an useful additional marker event for the base of the Carnian stage.

Halobiids and other macrofossils

The lower San Cassiano Fm deposited within a deep basin, well below the photic zone, with a high sedimentary rate and oxygen-deficient bottom conditions (e.g. Fürsich and Wendt, 1977; Broglio Loriga et al., 1999). These conditions only permitted the proliferation of posidonioids, an opportunistic bivalve group, well adapted to low-oxygen benthic habitats (e.g. Wignall, 1994; Aberham, 1994). Posidonioids are common throughout the whole *canadensis* Subzone, where they generally occur in the laminated dark grey clay and argillaceous marls alternated with turbidites. For these reasons, bivalves of the lower San Cassiano Fm of Prati di Stuoeres/Stuoeres Wiesen section (uppermost *regoledanus* and *canadensis* subzones) are mainly represented by members of the superfamily Posidonioidea (sensu Waller in Waller & Stanley, 2005), while gastropods and brachiopods are rarer. Specimens of the latter two groups mostly occur since the middle *canadensis* Subzone (Posenato in Broglio Loriga et al. 1999: tab. 6).

The posidonioids of the *canadensis* Subzone were distinguished into three groups (Posenato in Broglio Loriga et al., 1999): a) “*Posidonia*” *wengensis* (Wissmann); b) “*Posidonia*” cf. *wengensis*; c) ?*Halobia* sp.

On the base of the recent revision of T. R. Waller (in Waller & Stanley 2005), the first species is attributed to *Bositra*, although this author include in the Family Posidoniidae those posidonioids with the “hinge line generally much shorter than shell length” (op. cit., p. 19), while “*Posidonia*” *wengensis* is characterized by a long hinge margin (see

also Wissmann in Münster 1841, pl. 16, fig. 12), thus the attribution of Wissmann's species to *Bositra* is not completely convincing. The species is common in the Longobardian Wengen beds Auct. of the Dolomites, from which the type-material was found (Wissmann in Wissmann and Münster, 1841). The second group (b) yields "*Posidonia wengensis*" - like valves with weak radial costellae. Radial plications characterise *Daonella* and *Halobia* and for this reason the hypothesis that the group B) "could represent juvenile stage of *Daonella* or a transition to *Halobia*" was proposed (Posenato in Broglio Loriga et al., 1999: p. 60). Both the just above quoted genera have species groups which show transitional features to "*Posidonia*" such as the *Gruppe der posidonoiden Daonellaformen* and *Gruppe der schwach verzierten Halobien* and *Gruppe der Halobia styriaca* (Kittl, 1912). Also the specimens reported by Mietto et al. (2007) from the *canadensis* Subzone of Bec de Rocces section, and classified as "praehalobids", belong to this group. However, radial ribbing may also occur in the family Posidoniidae, to which *Bositra* belongs (Waller and Stanley, 2005). Fine radial ribs were also noted by Kittl (1912: p. 19) in some shells by him referred to Wissmann's species. However, in absence of an abundant population, which depicts the sculpture variability and in absence of unquestionable features of possible derived genera (i.e. the anterior auricle/tube of *Halobia*), we again refer to *Bositra* both the groups and distinguish them only at specific level (*Bositra wengensis* and *Bositra* cf. *wengensis*).

The third group (c) consists of very rare specimens collected from two beds (7SW6.1 and 5SW8.0, see Broglio Loriga et al. 1999: tab. 6). The reason of this classification is discernible in the left specimen of pl. 9, fig. 2 of Broglio Loriga et al. (1999): it is a left valve with prevailing comarginal folds and a slight curved anterior tube/ear - like process, which induced us to refer tentatively it to *Halobia* (?*Halobia* sp., Posenato in Broglio Loriga et al., 1999).

According to several authors (e.g. Mojsisovics, 1874; Kittl, 1912; Gruber, 1976; Mc Roberts, 2000), *Halobia* (an halobiid with the anterior auricle -or tube- separated from the disk), derived directly from *Daonella* (a D-shaped and radially plicated halobiid lacking of the anterior auricle), or through the intermediate genus *Aparimella* Campbell, 1994. According to this hypothesis, the ancestral species have well developed radial plications, which have to be considered a primitive, plesiomorphic feature of the Halobiidae, considering this family as a natural, monophyletic taxon (Campbell, 1994; McRoberts, 2000). However, *Halobia* contains more than 300 species and subspecies (McRoberts, 1993), and many authors consider this genus a polyphyletic group (e.g. Kittl, 1912; Ichikawa, 1958; Gruber, 1976; Polubotko, 1988; McRoberts, 2000). Among the eleven *Halobia* species-groups proposed by Kittl (1912), two are characterized by a reduced radial ribbing. They are the *Gruppe der schwach verzierten Halobien* and *Gruppe der Halobia styriaca*. Some species of the former group (e.g. *H. disperseinsecta* Kittl) are closely related to species of the second group [e.g. *H. lenticularis* (Gemellaro): Cafiero and De Capoa Bonardi (1980, 1982)] for which the new genus *Perihalobia* Gruber, 1976 was

proposed. According to Gruber (1976), *Halobia* derived from *Daonella*, while *Perihalobia* from "*Posidonia*" as indicated by the outline and sculpture pattern of the early species *H. lenticularis* from the late Carnian - lower Norian of Sicily and Montenegro (Cafiero and De Capoa Bonardi, 1980, 1982). A direct origin of *Halobia* from "*Posidonia*" was also sustained by Polubotko (1984, 1988), who considered *Halobia*, with seven subgenera, as derived from "*Posidonia*", while he erected the new genera *Zittelhalobia* and *Indigirohalobia*, and respectively two and three subgenera, for those halobiids derived from *Daonella*. A group of halobiids with feeble or without radial plications was also recognized by Campbell (1994), who classified it as *Halobia* (*Parahalobia* Yin and Hsu).

The early sure Halobiids of the Prati di Stuoeres/Stuoeres Wiesen occur in the middle *aon* Subzone (*Halobia cassiana* Mojsisovics, bed 13b) and across the *aon-aonoides* subzones boundary (*Halobia fluxa* Mojsisovics, beds 18-19) (Urlich 1974, 1994). The latter species belong to the *Halobia rugosa* group of Kittl (1912), which also contains *H. zitteli* Lindström and *H. vixaurita* Kittl, two species with a well developed radial ribbing, and restricted, in the western Tethys, to the *aon* Subzone (Gruber, 1976; Krystyn, 1978). Both the *Halobia* species from the upper San Cassiano Fm of Prati di Stuoeres/Stuoeres Wiesen have a well developed radial sculpture, thus the early sure Halobiids of the Prati di Stuoeres/Stuoeres Wiesen section do not belong to a group with reduced sculpture, hypothetically derived from "*Posidonia*". In conclusion, the lacking of posidonioids with an undisputable anterior ear impedes the sure identification of *Halobia* in the *canadensis* Subzone of the Prati di Stuoeres/Stuoeres Wiesen, although the specimen of the group c) could contribute to the debate on the phyletic connection between *Bositra*, *Daonella* and *Halobia*.

Palynomorphs

The distribution of spores, pollen grains and marine elements (acritarchs, foraminiferal linings and tasmanites) in the Prati di Stuoeres/Stuoeres Wiesen section reflects the evolution of the terrestrial and marine flora before and after the proposed boundary. Thirtyfour samples have been studied in order to define the distribution and the main LADs and FADs present along the succession.

Typical upper Ladinian-lower Carnian sporomorphs as *Uvaesporites gadensis*, *Kuglerina meieri*, *Ovalipollis pseudoalatus*, *Todisporites* spp., *Aratrisporites* spp., *Reticulatisporites dolomiticus*, *Sellaspora rugoverrucata* and the circumpolles form *Partitisporites novimundanus* are present throughout the section.

In the upper part of the *regoledanus* Subzone, *Concentricisporites* cf. *C. bianulatus*, *Enzonasporites vigens*, *Kyrtomisporis ervii*, *Gordonispora fossulata* and *Duplicisporites granulatus* have their first occurrence (Fig. 6). "*Lueckisporites*" cf. *singhii* firstly appears very close to the top of the *regoledanus* Subzone.

Moreover, *Nevesisporites vallatus*, *Todisporites marginales*, *Calamospora* sp. A, *Apiculatisporites parvispinosus* and *Densosporites* cf. *variomarginatus* are, in the Prati di

Stuores/Stuores Wiesen section, restricted to the *regoledanus* Subzone. *Nevesisporites vallatus* has its last occurrence at the proposed boundary.

Above the proposed boundary, in the lower part of the *canadensis* Subzone, *Vallasporites ignacii*, *Patinasporites densus* and *Aulisporites* cf. *A. astigmus*, together with *Duplicisporites verrucosus* and *Camerosporites secatus*, have their first occurrence.

In the samples from the uppermost part of the *canadensis* Subzone, the first occurrences of *Weylandites magnus*, *Camerosporites pseudoverrucatus* and *Samaropollenites speciosus* are found. No other significant bioevents are documented in the overlying *aon* Subzone.

The palynological content of the Prati di Stuores/Stuores Wiesen section supports the proposal to place the boundary at the FAD of *Daxatina canadensis*. This ammonoid event occurs very closely to significant changes of the palynological association, consisting in the replacement of upper Ladinian sporomorphs by typical Carnian microflora.

The first appearance of *Patinasporites densus* marks the base of the *vigens-densus* phase and is associated with the first appearance of *Vallasporites ignacii* (Van der Eem, 1983); their common occurrence has been traditionally considered to be close to the base of the Carnian (Van der Eem, 1983, Fisher, 1972; Visscher and Brugman, 1981; Fisher and Dunay, 1984; Warrington, 1996; Hochuli and Frank, 2000; Roghi 2004).

On the base of a previous palynological work (Van der Eem, 1983), the Ladinian/Carnian boundary was placed in the Prati di Stuores/Stuores Wiesen section at sample Stu 2-09 AL, corresponding to the base of the author's *vigens-densus* phase and, always in the same section, to sample 3 of Urlichs (1994). Van der Eem's sample Stu 2-09 AL is located above our uppermost sample (sw af, metres 193.5), thus, the base of the *vigens-densus* phase in the Prati di Stuores/Stuores Wiesen section is lowered by at least 130 metres with respect to Van der Eem (1983). In fact, the occurrence of the typical Carnian species *Vallasporites ignacii* and *Patinasporites densus* very close to the proposed GSSP boundary, in association with *Enzonalasporites vigens*, allows to refer the palynological associations from the lower part of the *canadensis* Subzone to the *vigens-densus* phase of Van der Eem (1983). These data reinforce the proposal to place the base of the phase close to the base of the *canadensis* Subzone (Broglia Loriga et al., 1999).

On the basis of the first occurrence, in the Prati di Stuores/Stuores Wiesen section, of *Concentricisporites* cf. *C. bianulatus* within the *regoledanus* Subzone, the base of the *Concentricisporites* cf. *C. bianulatus* assemblage (Roghi, 2004) is late Ladinian (Longobardian) in age.

Other microfossils

There are no new data about foraminifers, microcrinoids and holothurian sclerites besides those exposed in Broglia Loriga et al. (1998, 1999). Benthic foraminifers in particular were studied by C. Broglia Loriga, R. Rettori

and D. di Bari (Broglia Loriga et al., 1999). In a preliminary proposal (Broglia Loriga et al., 1998), these authors concluded that:

1. A Carnian affinity in the portion of section belonging to the lower *canadensis* (m. 45 to 145) ammonoid subzones is suggested by taxa observed in thin sections.
2. The assemblages recognized in isolated material and thin sections in this lower interval are, however, closely comparable to those of the upper *canadensis* Subzone (m 145 to 180).
3. Most of the species occurring in the Prati di Stuores/Stuores Wiesen section 1 (Fig. 4) are quoted in the Carnian of the Taurus, Carpatho-Balkans, Transadnanubian Central Range, Serbia, Northern Calcareous Alps, Julian Alps, China and Israel.
4. Change in taxonomical compositions may strongly depend on ecological factors.

Microcrinoids and holothurian sclerites were studied by G.F. Laghi and M. Rechichi (Broglia Loriga et al., 1999). Again, the conclusions of the preliminary proposal (Broglia Loriga et al., 1998) can be summarized as follows:

1. Between m 20 to 45, the first occurrences of many microcrinoids are documented.
2. From m 120 to 150, a short peak of abundance in both microcrinoids and sclerites can be recognized.
3. Above this peak, the taxonomic diversity decreases. According to Bizzarini (1993), holothurian sclerites increase again upwards.
4. Close to the top of the section, a few species disappear. The last occurrence of *Osteocrinus acus* is the most prominent event.

The microcrinoid and holothurian sclerites association seems to be rather typical of the *canadensis* Subzone; with minor modifications, it also extends upwards into the *aon* Subzone.

The variations in taxonomic diversity can probably be referred to ecological factors.

3B.2 Magnetostratigraphy

A total of 96 paleomagnetic core samples were analyzed for magnetostratigraphy (Broglia Loriga et al., 1999). A bipolar characteristic component of magnetization oriented in geographic coordinates north and positive or south and negative was isolated in 72% of the specimens in the temperature range comprised usually between about 200°C and 450°C up to 550-580°C. In 10% of the specimens the characteristic component could be followed up to maximum unblocking temperatures of 600-630°C. An additional 11% of the samples show transitional directions associated with polarity excursions or acquired during field polarity reversals. The bipolar and transitional characteristic component directions become shallower upon correction for bedding tilt. Rock-magnetic experiments point to magnetite as the main carrier of the magnetic remanence; subsidiary sulphurs and haematite are occasionally present. The

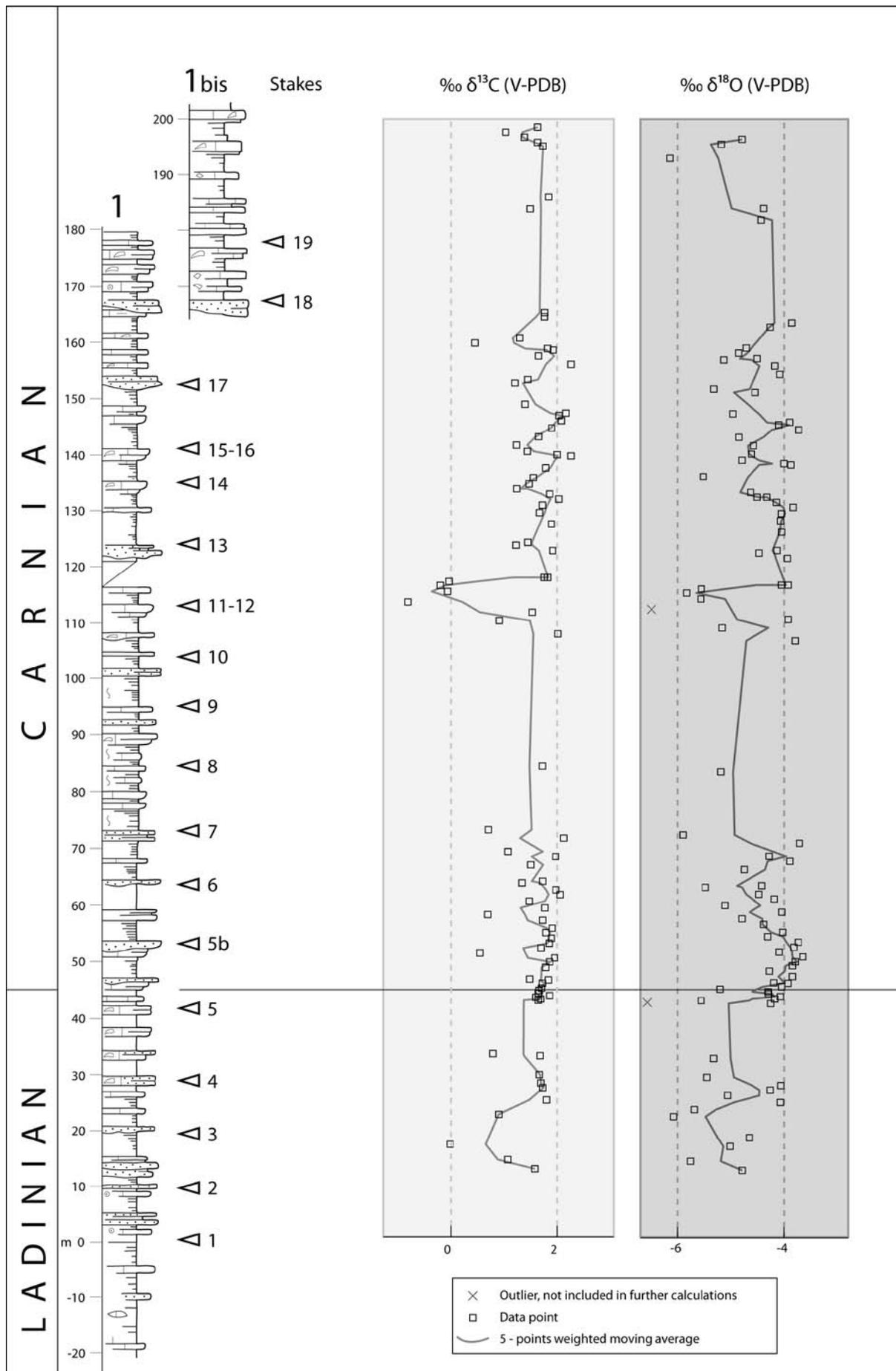


Figure 7: Chemostratigraphic data from the Prati di Stuores/Stuores Wiesen section

latitude of the specimen virtual geomagnetic pole (VGP) with respect to the overall mean north paleomagnetic pole was used to delineate magnetic polarity stratigraphy. The latitude of the VGPs defines, from bottom to top, a lower normal (S1n)-reverse (S1r)-normal (S2n)-reverse (S2r)-normal (S3n)-reverse (S3r)-normal (S4n) polarity sequence. The base of the Carnian, as defined by the FAD of *Daxatina canadensis*, falls towards the base of S2n. The Prati di Stuores/Stuores Wiesen section can be tentatively correlated with the coeval Mayerling section from Austria of Gallet et al. (1998). According to this correlation (Broglia Loriga et al., 1999), the first appearance of *Daxatina canadensis* at Prati di Stuores/Stuores Wiesen would fall at Mayerling within the *diebeli* conodont Assemblage Zone.

3B.3 Chemical stratigraphy

Prati di Stuores/Stuores Wiesen section has never been investigated in detail with the purpose of describing stable Carbon, Oxygen, and Strontium isotopes variations. To improve our knowledge in this time interval 102 samples have been collected so far along the whole section of Prati di Stuores/Stuores Wiesen for analyse Carbon and Oxygen stable isotopes' ratios. Samples are unequally spaced (see Fig. 7), being collected exclusively from siltitic marls that were not potentially involved in turbidites. From each sample, a small amount of rock (few grams) has been hand-drilled, avoiding macrofossils (like bivalves shells), intraclasts or fractures filled by calcite. The drilled powder is thus considered representative of the bulk composition of the sample.

Powders were reacted with phosphoric acid and analyzed using an automated continuous-flow isotope ratio mass spectrometer at the University of Innsbruck. Results were calibrated against NBS and IAEA standards and have been reported relative to VPDB scale. The long-term analytical uncertainties are $\pm 0.07\%$ for $\delta^{13}\text{C}$, and $\pm 0.08\%$ for $\delta^{18}\text{O}$ (reported at the 1σ level, Spötl and Vennemann, 2003).

Preliminary results of our analyses are plotted in Fig. 7: for graphical purposes, in $\delta^{13}\text{C}$ box seven *mild* outliers* are not shown being lower than -2% and clearly isolated from the data cloud. For the same reason, six mild outliers are not shown in $\delta^{18}\text{O}$ box, being lower than -7% or greater than -2% $\delta^{18}\text{O}$. Oxygen isotopes values are strongly drifted towards very low values, being potentially overprinted by diagenesis. $\delta^{13}\text{C}$ values appear to be constant albeit sensibly scattered along the whole section, with no evidence of excursions close to the proposed Ladinian/Carnian boundary, or anywhere else throughout the section except close to Stakes 11-12. $\delta^{13}\text{C}$ values, ranging between $0 \div 2\%$ VPDB, seem compatible with the expected values for this time interval (Korte et al., 2005, Veizer et al., 1999). It is necessary, however, to highlight the preliminary nature of these data: further analyses both at Prati di Stuores/Stuores Wiesen and in correlated sections seem necessary to identify diagenetic influences and ultimately unravel the primary geochemical trend within this interval.

*: *mild* outliers are defined as data points whose values are $< Q_1 - 1.5 \cdot (Q_3 - Q_1)$ or $> Q_3 + 1.5 \cdot (Q_3 - Q_1)$, where Q_1 and

Q_3 are the first and third quartiles for the given dataset, respectively.

3B.4 Sequence stratigraphy

Comparing to Broglia Loriga et al. (1999), there are no significant variations of the sequence stratigraphic interpretation across the proposed boundary, as well as its global correlation (Fig. 8). The only differences are related to the slightly younger age of the supposed sequence boundary defining the base of the sequence Car 1. New biostratigraphic data from the Southern Alps (Dolomites and Lombardy) and Transdanubian Range (Hungary), allows us to put it in the lower part of the *regoledanus* Subzone instead of the *neumayri* Subzone.

The proposed GSSP is placed at the beginning of the regressive trend just after the Car 1 (sensu Gianolla et al., 1998) or Lad 3 (sensu Hardenbol et al. 1998) maximum flooding surface (*mfs*), dated to the upper *regoledanus* Subzone, in a section presenting very high sedimentation rates (Gianolla, 1995). This *mfs* is one of the best traceable surfaces for basin-wide correlation. Thus the potential for correlation of the proposed boundary is enhanced by sequence stratigraphic interpretation, specially when compared with sections characterized by lower sedimentation rates.

3B.6 Other event stratigraphy

Up to now, no other physical or chemical surfaces have been recognized that could be used for correlations outside the Dolomites area. Tephra layers of latest Ladinian age have been discovered recently in some sections of the Dolomites (cf. chapter 3B.8), but are not yet been identified at Prati di Stuores/Stuores Wiesen. Their correlation potential, however, should be limited to the eastern Southern Alps. No cyclostratigraphic analyses have been carried out in Prati di Stuores/Stuores Wiesen section. Masetti et al. (1991) studied a slightly younger succession of the San Cassiano Fm. some kilometres from Stuores (Lavarella section, near San Cassiano village). There, these authors recognized a cyclic organisation of stratal patterns. Such regular organization was not observed at Prati di Stuores/Stuores Wiesen, probably because of the greater distance of this section from carbonate slopes of the Cassian carbonate platforms.

3B.7 Marine-land correlation potential

The palynological association of Prati di Stuores/Stuores Wiesen allows correlation of the proposed boundary in terrestrial sections.

In Switzerland, *Vallasporites ignacii* and *Patinasporites densus* appear in the upper part of the middle Gipskeuper (interval F in Scheuring, 1970 and Mostler and Scheuring, 1974). In south Germany (Franken), *Vallasporites ignacii* appears in the upper "Myophorienschichten" both in outcrop and in the Obersees borehole, while *Patinasporites densus* in the overlying "Estherienschichten". On the base of these first appearances, the proposed GSSP level can be correlated to in the upper part of the Myophorienschichten (Van den Berg, 1987, Brack et al., 1999).

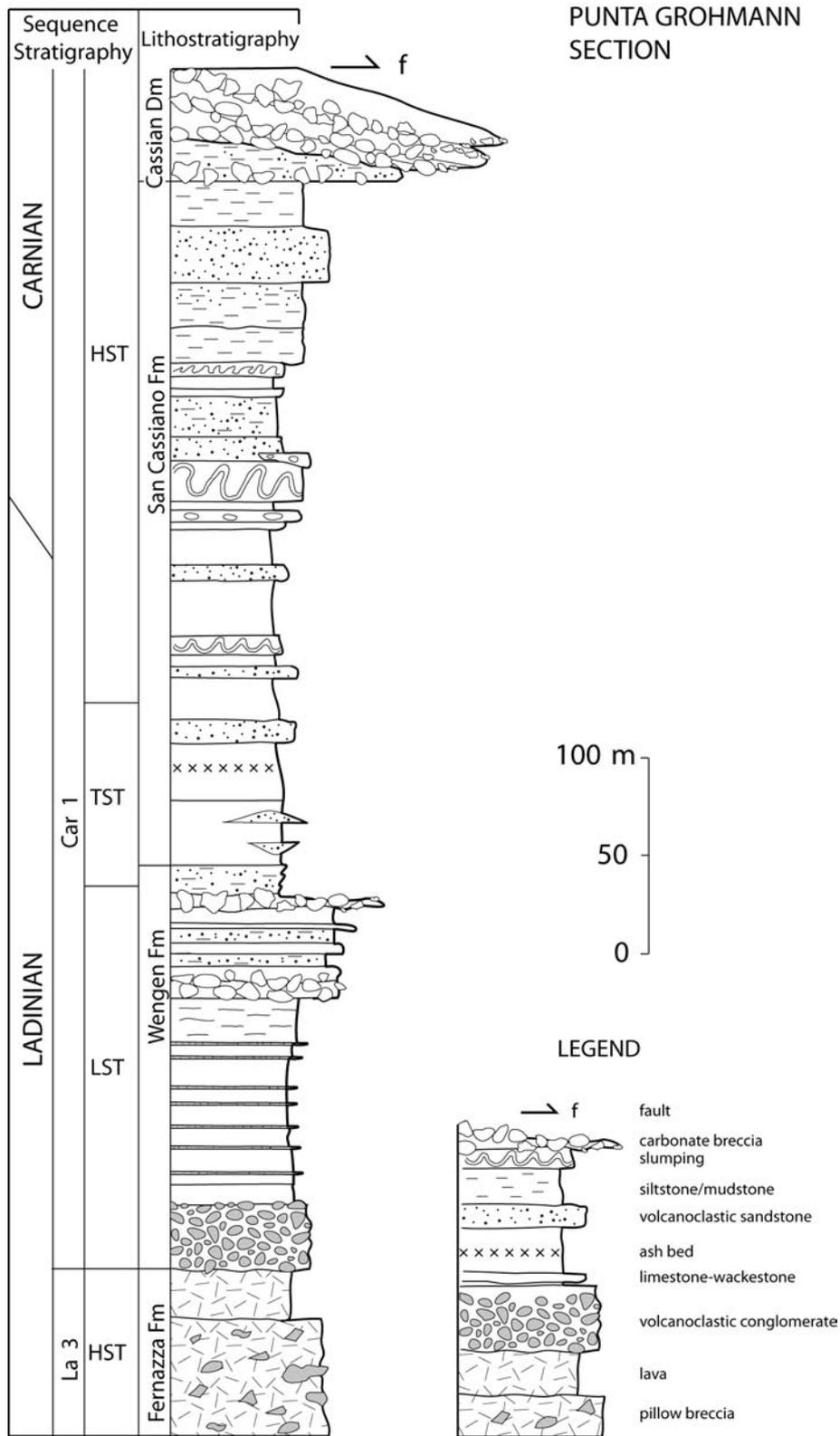


Figure 8: Lithostratigraphy and sequence-stratigraphic interpretation around the Ladinian/Carnian boundary at the Punta Grohmann section, 14 km westward from Prati di Stuares. This section is representative of the sedimentary evolution in this time interval in the Dolomites.

In England, on the base of the occurrences of *Camerosporites secatus* and *Enzonasporites vigens*, the boundary lies within the “Keuper marl” (Warrington, 1970).

In the Temple Mountain Member of the Chinle Formation (southwestern U.S.A.), typical Carnian associations are described from the base of the succession but the proposed boundary is not identifiable (Litwin et al., 1991; Litwin and Ash, 1993).

In the Newark Supergroup (eastern U.S.A.), *Vallasporites ignacii* and *Patinasporites densus* appear in the Stockton Formation; on the base of these findings the boundary was placed inside this formation. (Fowell et al., 1994). Recent magnetostratigraphic studies, however, questioned this correlation and rather suggest the GSSP level should lie below the succession of the Newark Supergroup (e.g., Muttoni et al., 2004).

3B.8 Amenability to geochronometry

No datable layers are known from the Prati di Stuoeres/Stuoeres Wiesen section. Recent studies have recognized several primary and reworked ash beds in correlatable sections from the surroundings of the proposed stratotype section (Furin, 2007), further ash beds have been sampled during summer 2007. Among all the studied primary ash beds, only one layer yielded enough zircon crystals for radiometric dating. This bed, collected in the Alpe di Siusi area (24 km west of Prati di Stuoeres/Stuoeres Wiesen) has good biostratigraphic control based on ammonoids and conodonts. With the reference to ammonoids, the ash bed is within the lower part of the *regoledanus* Subzone (sensu Mietto and Manfrin, 1995), below the Car1 sequence boundary (see paragraph 3B.4). Chemical Abraded, ID-TIMS radiometric age of the mentioned layer is expected to be published in 2008. Further ash beds have been collected in the Punta Grohmann section (14 km westward from Prati di Stuoeres) from ash beds between the Car1 sequence boundary and the first occurrence of *Frankites apertus* (Mojsisovics), but data are still preliminary. No radiometric ages are known so far in this area above the proposed boundary. Published radiometric ages bracketing the proposed Ladinian/Carnian boundary are 238.0 +0.4 -0.7 Ma (Mundil et al., 1996) and 230.91±0.33 Ma (Furin et al. 2006). The two ages are excessively older/younger than the proposed boundary (see above) so any interpolation between these two pinpoints is extremely inaccurate (and potentially erroneous). The older age is obtained by U/Pb TIMS analyses on eight air-abraded Zircon crystals from an ash bed collected at Seceda (17 km NE from Prati di Stuoeres/Stuoeres Wiesen). The layers belong to the *archelaus* Zone (sensu Brack and Rieber, 1993, i.e., corresponding to the *longobardicum* to *neumayri* subzones in Mietto and Manfrin, 1995a), based on the presence of *Daonella lommeli*. The younger age is obtained by Chemical Abrasion ID-TIMS technique on eight zircon crystals from a layer collected in the Southern Apennines (Southern Italy – more than 700 Km SE). Biostratigraphic control on the latter layer is given by conodonts and palynomorphs: according to Kozur and Weems (2007) the layer belongs

to the *Carnepigondolella zoeae* conodont zone, leading to middle to upper Tuvalian (Upper Carnian) age. According to many Authors (Gallet et al., 2003; Kozur and Weems, 2007) the expected age for the Ladinian/Carnian boundary should fall approximatively at 237 Ma.

3C Demonstration of regional and global correlation

3C.1 Regional correlation

The litho-, sequence-, magneto- and biostratigraphic correlation of Ladinian/Carnian boundary interval within the Southern Alps is widely illustrated and discussed in De Zanche et al. (1993), De Zanche and Gianolla (1995), Mietto and Manfrin (1995b) and Broglio Loriga et al. (1998, 1999). From a biostratigraphic point of view, several stratigraphic sections and localities in the Southern Alps provide ammonoid faunal assemblages referred to the *canadensis* Subzone. Bed-by-bed distributions of ammonoids, conodonts and palynomorphs in selected key sections are showed in Mietto et al. (2007, submitted).

3C.2 Long distance and global correlation

The succession of ammonoid faunas in the Prati di Stuoeres/Stuoeres Wiesen section and in other correlated localities in the Southern Alps, records some bioevents which occur in homotaxis also in the Tethys and extra-tethysian domains (Himalayas, Nevada, British Columbia, Svalbard). With reference to Mietto and Manfrin (1995b) and Broglio Loriga et al. (1999), the occurrence of taxa with widespread distribution allows the tethysian biozones to be correlated with those defined in British Columbia by Tozer (1967, 1994). In particular, the *canadensis* Subzone has been considered nearly equivalent to the *sutherlandi* Subzone 2 of Canada for the concurrent occurrence of *Daxatina canadensis* and *Frankites apertus* (= *sutherlandi*), and correlatable by the first appearance of the former taxon. Nevertheless, the uppermost Ladinian to lowermost Carnian part of the North America ammonoid Standard Scale needs to be revised because of the partial overlapping between the *sutherlandi* and *desatoyense* Zones, demonstrated in Nevada (Balini, in press). The “*Daxatina canadensis* Zone”, defined in the Svalbard Archipelago (Bjørnøya, see Mørk et al., 1992), is also correlated with the *canadensis* Subzone. Magnetostratigraphic correlation based on ammonoids vs conodonts calibration between Prati di Stuoeres/Stuoeres Wiesen and Mayerling in Northern Calcareous Alps is showed in Broglio Loriga et al (1999), and is now confirmed by the finding of *Paragondolella polygnathiformis noah* in the bed SW4c (Mietto et al., 2007).

The ammonoid succession recently reported from the *canadensis* Subzone in Himalayas (Guling 1 and Muth 3 sections in Spiti Valley: Balini, Krystyn and Torti, 1998; Krystyn, Balini and Nicora, 2004) and in Nevada (New Pass Range: Balini and Jenks, 2007; Balini et al., 2007; Balini, in press) is consistent with the ammonoid succession at Prati di Stuoeres/Stuoeres Wiesen. The correlation is illustrated in detail by Balini et al. (in prep.).

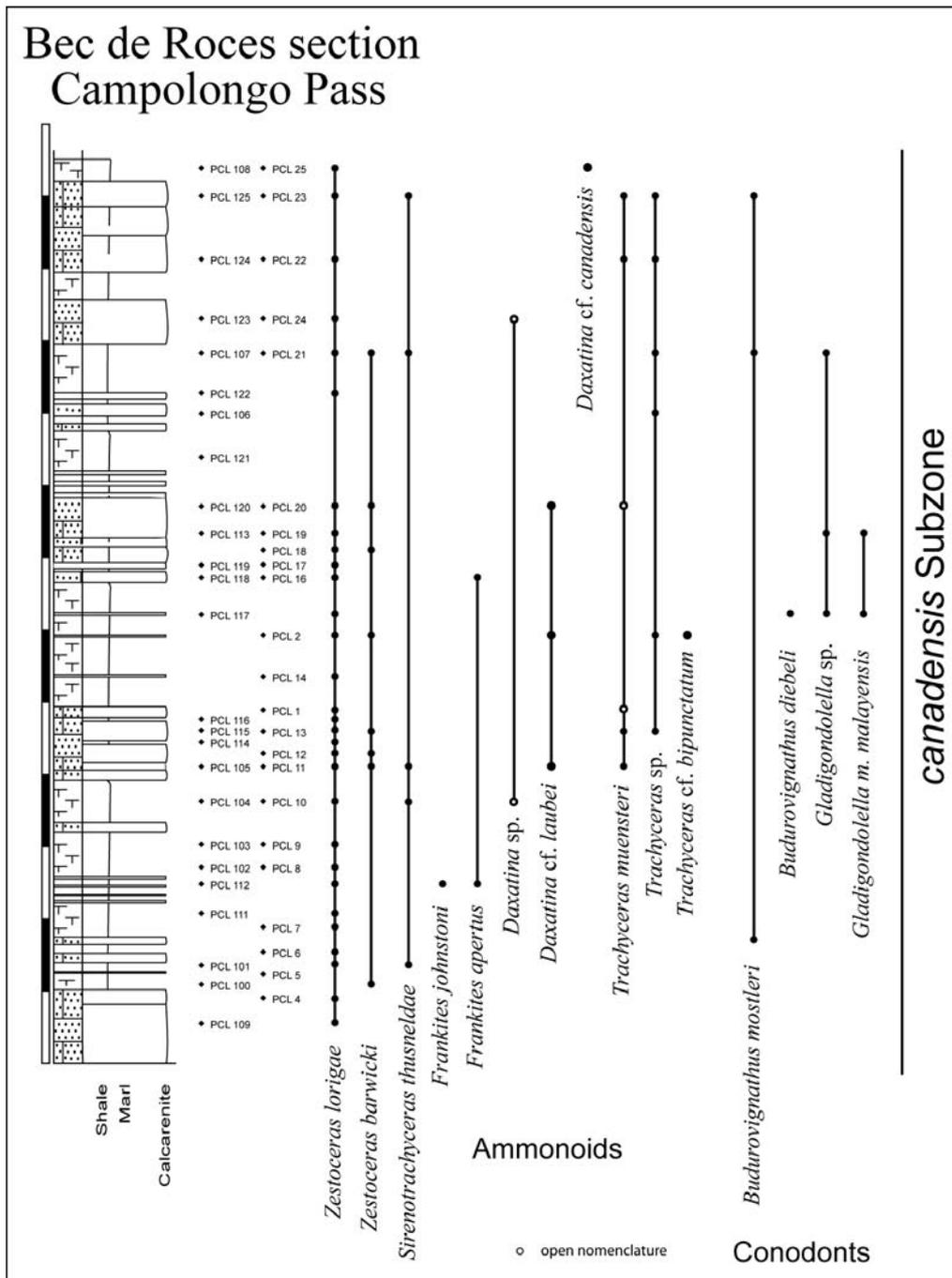


Figure 9: Stratigraphic column of the Bec de Rocès section, with distribution of main fossils.

4. Selection process

4A Relation of the GSSP to historical usage

The history of concepts regarding the Ladinian/Carnian boundary is summarized in Gaetani (1995) and Broglio Loriga et al. (1999). As well known, the base of the Carnian traditionally coincides with the appearance of *Trachyceras aon*, considered the first representative of the genus. *Trachyceras* is documented at Prati di Stuores/Stuores Wiesen by *Trachyceras muensteri* that occurs associated with *Daxatina canadensis*; in the Antersass section *T. bipunctatum* also occurs in the *canadensis* Subzone. This implies the predation of genus *Trachyceras* and allows to consider the *canadensis* Subzone Carnian in age (Mietto and Manfrin, 1995a, 1995b). Also conodonts, palynomorphs and

halobiids corroborate this assumption.

4C votes

During “The Global Triassic” Conference in Albuquerque (23-28 may, 2007), the STS session voted that the primary marker for the definition of the GSSP for the base of the Carnian Stage is the first appearance of the genus *Daxatina*. Voted secondary markers are the first appearance of *Paragondolella polygnathiformis noah* and halobiids. The Prati di Stuores/Stuores Wiesen section in the Southern Alps (NE Italy), and the bed SW4 in which *Daxatina canadensis* firstly appears, were considered a good candidate for the GSSP of the base of the Carnian.

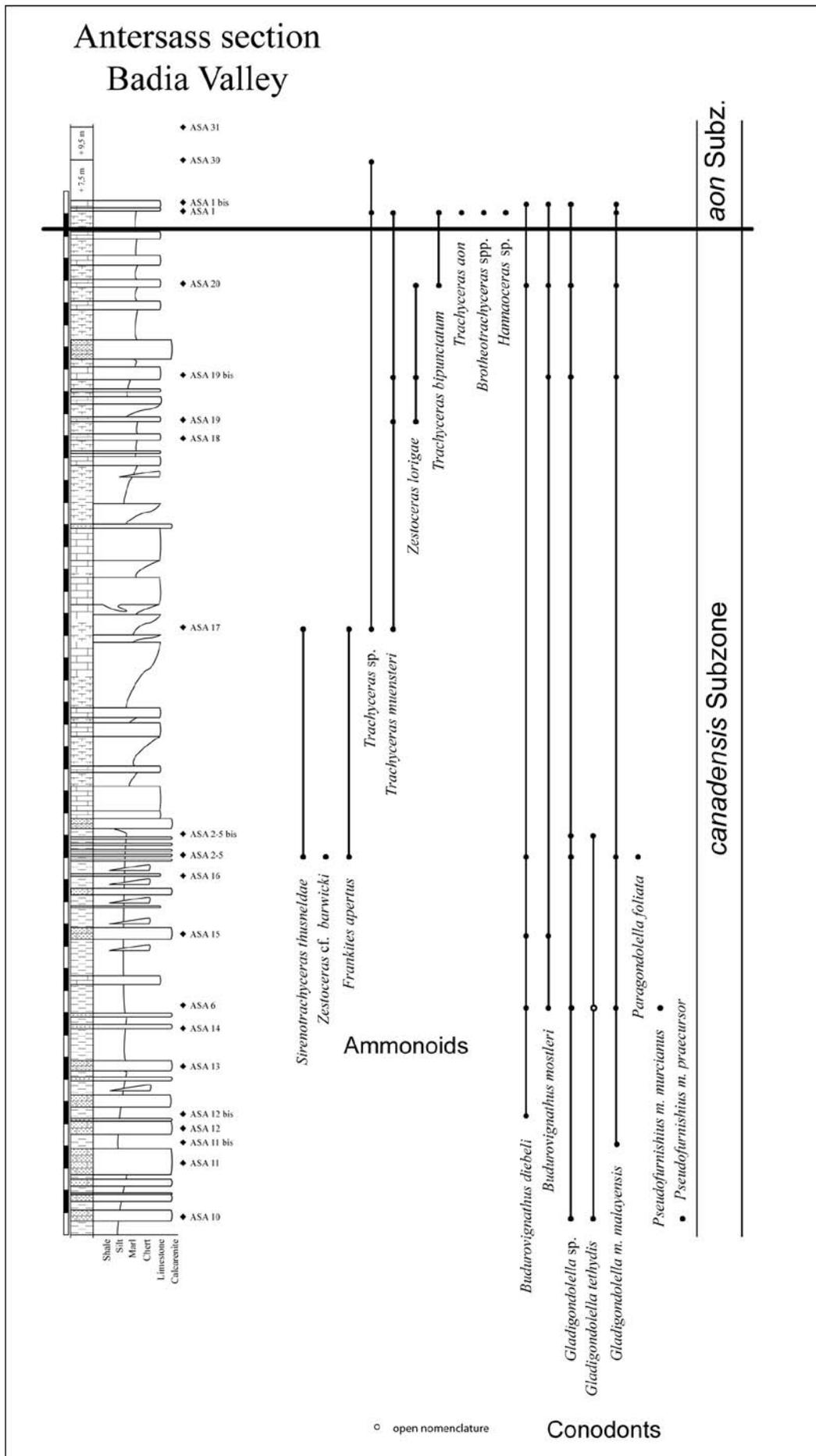


Figure 10: Stratigraphic column of the Antersass section, with distribution of main fossils.

4D selected publications

- Balini, M., in press - Discovery of Upper Ladinian ammonoids at the type locality of the Lower Carnian Desatoyense Zone (South Canyon, New Pass Range, Nevada). *J. Paleont.*, 82/1(2008), 162-168.
- Balini, M., and Jenks, J.F., 2007 - The Trachyceratidae from South Canyon (Central Nevada): record, taxonomic problems and stratigraphic significance for the definition of the Ladinian-Carnian boundary. *New Mex. Mus. Nat. Hist. & Sci. Bull.*, 41, 14-22.
- Balini, M., Jenks, J.F., McRoberts, C.A., and Orchard, M.J., 2007 - The Ladinian-Carnian boundary succession at South Canyon (New Pass Range, Central Nevada). *New Mex. Mus. Nat. Hist. & Sci. Bull.*, 40, 127-138.
- Balini, M., Krystyn, L., Manfrin, S., McRoberts, C.A., Mietto, P., Nicora, A., Orchard, M.J., Richoz, S., and Rigo, M., in prep. - Ladinian/Carnian boundary marine correlation between North America and Tethyan realm.
- Balini, M., Krystyn, L., and Torti, V., 1998 - In search of the Ladinian-Carnian boundary: perspectives from Spiti (Tethys Himalaya). *Albertiana*, 21, 26-32.
- Bizzarini, F., 1993 - Microfossili al limite Ladinico-Carnico nella Successione dei Prati di Stuoeres (Dolomiti Orientali). *Ann. Musei Civici, sez. Arch. St. Sci. Nat.*, 8, 141-168.
- Broglio Loriga, C., Cirilli, S., De Zanche, V., di Bari, D., Gianolla, P., Laghi, M.F., Lowrie, W., Manfrin, S., Mastandrea, A., Mietto, P., Muttoni, C., Neri, C., Posenato, C., Rechichi, M.C., Rettori, R., and Roghi, G., 1998 - A GSSP candidate for the Ladinian/Carnian boundary: the Prati di Stuoeres/Stuoeres Wiesen section (Dolomites, Italy). *Albertiana*, 21, 2-18.
- Broglio Loriga, C., Cirilli, S., De Zanche, V., di Bari, D., Gianolla, P., Laghi, M.F., Lowrie, W., Manfrin, S., Mastandrea, A., Mietto, P., Muttoni, C., Neri, C., Posenato, C., Rechichi, M.C., Rettori, R., and Roghi, G., 1999 - The Prati di Stuoeres/Stuoeres Wiesen Section (Dolomites, Italy): a candidate Global Stratotype Section and Point for the base of the Carnian stage. *Riv. Ital. Paleont. Strat.*, 105/1, 37-78.
- Gaetani, M., 1995 - Criteri per la definizione della base del Piano Carnico. *Ann. Univ. Ferrara, Sci. Terra*, v. 5(suppl.), 9-12.
- Gallet, Y., Krystyn, L. and Besse, J., 1998 - Upper Anisian to Lower Carnian magnetostratigraphy from the Northern Calcareous Alps (Austria). *J. Geophys. Res.*, 103, 605-621.
- Krystyn, L., Balini, M., and Nicora, A., 2004 - Lower and Middle Triassic stage and substage boundaries in Spiti. *Albertiana*, suppl. 30, 39-52.
- Mietto, P., Buratti, N., Cirilli, S., De Zanche, V., Gianolla, P., Manfrin, S., Nicora, A., Preto, N., Rigo, M., and Roghi, G., 2007 - New constraints for the Ladinian-Carnian boundary in the Southern Alps: suggestions for global correlation. *New Mex. Mus. Nat. Hist. & Sci. Bull.*, 41, 275-281.
- Mietto, P., and Manfrin, S., 1995a - A high resolution

Middle Triassic ammonoid standard scale in the Tethys Realm. A preliminary report. *Bull. Soc. Géol. France*, 1995/5, 539-563.

Mietto, P., and Manfrin, S., 1995b - La successione delle faune ad ammonoidi al limite Ladinico-Carnico (Sudalpino, Italia). *Ann. Univ. Ferrara, Sci. Terra*, 5(suppl.), 13-35.

Mietto, P., Manfrin, S., Preto, N., and Gianolla, P., submitted - Selected ammonoid fauna from Prati di Stuoeres/Stuoeres Wiesen and related sections in the Ladinian-Carnian boundary interval (Southern Alps, NE Italy). *Riv. It. Paleont. Strat.*, Milano.

Tozer, E.T., 1994 - Canadian Triassic Ammonoid Faunas. *Geol. Surv. Canada Bull.*, 467, 1-663.

5. Other useful sections

The most relevant complementary sections in the Southern Alps, significative for the definition of the Ladinian/Carnian boundary have been described in Mietto et al. (2007, submitted).

The Bec de Rocces section is located on the eastern flank of the Sella Massif, near Passo Campolongo not far from Stuoeres (**Fig. 9**). It is a short section that best illustrates the ammonoid association typical of the *canadensis* Subzone. The Anterass section is located on the northern flank of Gardenaccia in the middle Badia Valley. This section is noticeable for the abundance of fairly well preserved ammonoids that best records the boundary between the *canadensis* and *aon* subzones (**Fig. 10**).

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References

- Aberhan, M., 1994 - Guild-structure and evolution of Mesozoic benthic shelf communities. *Palaios*, 9, 516-545.
- Böhm, J., 1903 - Über die Obertriadische fauna der Bäreninsel. *K. Svenska Vet.-Akad. Handl.*, 37/3, 2-76.
- Böhm, J., 1904 - Über *Nathorstites* und *Dawsonites* aus der arktischen Trias. *Zeit. Deutsch. Geol. Gesell.*, 56, b.m. 96-97.
- Bosellini, A., Gianolla, P., and Stefani, M., 2003 - Geology of the Dolomites: Episodes, v. 26, p. 181-185.
- Brack, P., and Rieber, H., 1993 - Towards a better definition of the Anisian/Ladinian boundary: New biostratigraphic data and correlations of boundary sections from the Southern Alps. *Ecl. Geol. Helv.*, 86/2, 415-527.

- Brack, P., Rieber, H., and Urlichs, M., 1999 - Pelagic succession in the Southern Alps and their correlation with the Germanic Middle Triassic. *Zbl. Geol. Paläont.*, 1998,/7-8, 853-876.
- Cafiero, B., and De Capoa Bonardi, P., 1980 - Stratigraphy of the pelagic Triassic in the Budva-Kotor area (Crna-Gora, Montenegro, Yugoslavia). *Boll. Soc. Paleont. Ital.* 19(2), 179-204.
- Cafiero, B., and De Capoa Bonardi, P., 1982 - Biostratigrafia del Trias pelagico della Sicilia. *Boll. Soc. Paleont. Ital.*, 21(1), 35-71.
- Campbell, H.J., 1994, The Triassic bivalves *Halobia* and *Daonella* in New Zealand, New Caledonia, and Svalbard. *Inst. Geol. Nucl. Sciences Monograph*, 4, 1-166.
- Castellarin, A., and Cantelli, L., 2000 - Neo-Alpine evolution of the Southern Eastern Alps. *Journal of Geodynamics*, 30, 251-274.
- De Zanche, V., and Gianolla, P., 1995 - Litostratigrafia al limite Ladinico-Carnico (Sudalpino orientale). *Ann. Univ. Ferrara, Sci. Terra*, 5(suppl.), 41-48.
- De Zanche, V., Gianolla, P., Mietto, P., Siorpaes, C., and Vail, P.R., 1993 - Triassic sequence stratigraphy in the Dolomites (Italy). *Mem. Sc. Geol.*, 45, 1-27.
- Dogliani, C., 1987 - Tectonics of the Dolomites (Southern Alps - NE Italy). *Journ. Struct. Geol.*, 9, 181-193.
- Fisher, M.J., 1972 - The Triassic palynoflora succession in England. *Geoscience and Man.*, 4, 101-109.
- Fisher, M.J., and Dunay, R.E., 1984 - Palynology of the Petrified Forest Member of the Chinle Formation (Upper Triassic), Arizona, U.S.A., *Pollen et Spores*, 26/2, 241-284.
- Fowell, S.J., Cornet, B., and Olsen, P.E., 1994 - Geologically rapid Late Triassic extinctions: Palynological evidence from the Newark Supergroup. *Geol. Soc. Am. Sp. Pap.* 288, 197-206.
- Furin, S., 2007 - Temporal constraints to major events of the Triassic of the Dolomites (Southern Alps, Italy). Unpublished Ph.D. Thesis. University of Ferrara (Italy).
- Furin, S., Preto, N., Rigo, M., Roghi, G., Gianolla, P., Crowley, J.L., and Bowring, S.A., 2006 - High-precision U-Pb zircon age from the Triassic of Italy: Implications for the Triassic time scale and the Carnian origin of calcareous nannoplankton and dinosaurs: *Geology*, 34, 1009-1012.
- Fürsich, F.T., and Wendt, J., 1977 - Biostratigraphy and palaeoecology of the Cassian Formation (Triassic) of the Southern Alps. *Palaeogeogr., Palaeoclim., Palaeoecol.*, 22, 257-323.
- Gallet, Y., Krystyn, L., and Besse, J., 1998 - Upper Anisian to lower Carnian magnetostratigraphy from the Northern Calcareous Alps (Austria). *J. Geophys. Res.*, 103, 605-621.
- Gianolla P., 1995 - Stratigrafia sequenziale al limite Ladinico-Carnico (Sudalpino orientale). *Ann. Univ. Ferrara, Sci. Terra*, v. 5(suppl.), 49-57.
- Gianolla, P., De Zanche, V., and Mietto, P., 1998 - Triassic Sequence Stratigraphy in the Southern Alps (Northern Italy). In: de Gracianky, P.Ch., Jacquin Th., and Vail, P.R. (eds) - *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins*. S.E.P.M. Spec. Publ. 60, 719-747.
- Gruber, B., 1976, Neue Ergebnisse auf dem Gebiete der Ökologie, Stratigraphie und Phylogenie der Halobien (Bivalvia). *Mitt. Geol. Ges. Bergbaustud. Österr.*, 23, 181-198.
- Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., de Graciansky, P.C., and Vail, P.R., 1998 - Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. In: P.C. de Graciansky, J. Hardenbol, T. Jacquin, P.R. Vail and D. Ulmer-Scholle (Eds.): *Mesozoic and Cenozoic sequence stratigraphy of European basins: SEPM Special Publication*, 60, 3-13.
- Hochuli, P.H., and Frank, S.M., 2000 - Palynology (dinoflagellate cysts, spore-pollen) and stratigraphy of the Lower Carnian Raibl Group in the Eastern Swiss Alps. *Eclogae geol. Helv.*, 93, 429-443.
- Ichikawa, K., 1958 - Zur Taxonomie und Phylogenie der triadischen „Pteriidae“ (Lamellibranch.), mit besonderer Berücksichtigung der Gattungen *Claraia*, *Eumorphotis*, *Oxitoma* und *Monotis*. *Palaeontographica A*, 111, 131-212.
- Johnston, F.N., 1941 - Trias at New Pass, Nevada (New Lower Karnic Ammonoids). *Journ. Paleont.*, 15/5, 447-491.
- Kittl, E., 1912 - Materialien zu einer Monographie der Halobiidae und Monotidae der Trias. *Res. Wiss. Erforsch. Balatonsees*, I Band, I Teil, 229 pp.
- Klipstein, A.v., 1845 - Beiträge zur Geologischen Kenntniss der östlichen Alpen. *Mitt. Gebiete Geol. Paläont.*, 1(1843-1845), 1-311.
- Korte, C., Kozur, H.W., and Veizer, J., 2005 - $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of Triassic brachiopods and carbonate rocks as proxies for coeval seawater and palaeotemperature: *Palaeogeography, Palaeoclimatology, Palaeoecology*, 226, 287-306.
- Kovács, S., 1983 - On the evolution of *excelsa*-stock in the Upper Ladinian-Carnian (Conodonta, genus *Gondolella*, Triassic). *Osterr. Akad. Wiss., Schriften. Erdwiss. Komm.*, 5, 107-120.
- Kovács, S., Krystyn, L., Szabò, S., Dosztály, L., and Budai T., 1991 - The Ladinian/Carnian boundary in the Balaton Upland, Hungary. *Symp. Trias. Strat. Abstr. Booklet*, p. 39, Lausanne.
- Kozur, H., 1980 - Revision der Conodontenzonierung der Mittel und ober Trias des tethyalen Faunenreich. *Geol. Paläont. Mitt.*, 10, 79-173.
- Kozur, H., 1989 - The Taxonomy of the Gondolellid Conodonts in the Permian and Triassic. *Courier Forsch. Inst. Senckenberg*, 117, 409-469.
- Kozur, H.W., and Weems, R.E., 2007 - Upper Triassic conchostracan biostratigraphy of the continental rift basins of the eastern North America: its importance for correlating Newark supergroup events with the Germanic Basin and the International Geologic Time

- Scale, in Lucas, S.G., and Spielmann, J.A., eds., The Global Triassic: New Mexico Museum of Natural History & Science Bulletin, 41, 137-188.
- Krystyn, L., 1978 - Eine neue Zonengliederung im alpin-mediterranen Unterkarn. In H. Zapfe (ed.), The stratigraphy of the Alpine-Mediterranean Triassic. 4. Schrif. Erdwiss. Komm., Österr. Akad. Wiss., 37-75.
- Krystyn, L., 1983 - Das Epidaurus-Profil (Griechenland) - ein Beitrag zur Conodonten-Standardzonierung des tethyalen Ladin und Unterkarn. Schr. Erdwiss. Komm., Öster. Akad. Wiss. 5, 231-258.
- Laube, G.C., 1869 - Die Fauna der Schichten von St. Cassian. Ein Beitrag zur Paläontologie der Alpenen Trias. V. Abtheilung. Cephalopoden. Schlusswort. Denk. K. Ak. Wiss., Mathem.-naturwiss. Cl., 30, 49-105.
- Litwin, R.J., and Ash, S.R., 1993 - Revision of the biostratigraphy of the Chatam Group (Upper Triassic), Deep River Basin, North Carolina, USA. Rev. Palaeobot. Palin., 77, 75-95.
- Litwin, R.J., Traverse, A., and Ash, S.R., 1991 - Preliminary palynological zonation of the Chinle Formation, southwestern U.S.A., and its correlation to the Newark Supergroup (eastern U.S.A.), Rev. Palaeobot. Palynol., 68, 269-287.
- Manco, S., Mietto, P., Nicora, A., Preto, N., Rigo, M., and Tognon, M., 2004 - Conodont fauna at the Ladinian/Carnian boundary interval in the Southern Alps. Albertiana, suppl. 30, 9.
- Martin, G.C., 1926 - The Mesozoic Stratigraphy of Alaska. U.S. Geol. Surv. Bull., 776, 1-489.
- Masetti, D., Neri, C., and Bosellini, A., 1991 - Deep-water asymmetric cycles and progradation of carbonate platforms governed by high frequency eustatic oscillation (Triassic of the Dolomites). Geol., 19, 336-339.
- McRoberts, C.A., 1993 - Systematics and biostratigraphy of Halobiid bivalves from the Martin Bridge Formation (Upper Triassic), northeast Oregon. J. Paleont., 67(2), 198-210.
- McRoberts, C.A., 2000 - A primitive *Halobia* (Bivalvia: Halobioidea) from the Triassic of northeast British Columbia. J. Paleont., 74(4), 599-603.
- Mojsisovics, E.M. von, 1874 - Über die triadischen Pelecypoden-Gattungen *Daonella* und *Halobia*. Abh. k.k. Geol. Reich., 7(2), 1-35.
- Mojsisovics, E.M. von, 1879 - Die Dolomit-riffe von Südtirol und Venetien. Beiträge zur Bildungsgeschichte der Alpen. 552 pp., A. Hölder, Wien
- Mojsisovics, E.M. von, 1882 - Die Cephalopoden der mediterranen Triasprovinz. Abh. K. K. Geol. Reichsanst., 10, 1-332.
- Mørk, A., Vigran, J.O., Korchinskaya, M.V., Pchelina, T.M., Fefilova, L.A., Vavilov, M.N., and Weitschat, W., 1992 - Triassic rocks in Svalbard, the Arctic Soviet islands and the Barents Shelf; bearing on their correlations. In: Vorrent T.O., Bergsager E., Dahl-Stamnes Ø.A., Holter E., Johansen B., Lie E. and Lund T.B. (eds) - Arctic Geology and Petroleum Potential. NPF Spec. Publ., 2, 457-479.
- Mostler, H., and Scheuring, B.W., 1974 - Mikrofloren aus dem Longobard und Cordevol der Nördlichen Kalkalpen und das Problem des Beginns der Keuperse-dimentation im Germanischen Raum. Geol. Paläontol. Mitt., 4, 1-35.
- Mundil, R., Brack, P., Meier, M., Rieber, H., and Oberli, F., 1996 - High resolution U-Pb dating of middle Triassic volcanics: tile-scale calibration and verification of tuning parameters for carbonate sedimentation. Earth Planet. Sci. Lett., 141, 137-151.
- Münster, G.G. von, 1834 - Über das Kalkmergel-Lager von St. Cassian in Tyrol und die darin vorkommenden Ceratiten. N. Jb. Miner. Geogn. Geol. Petrefactenk., jhg. 1834, 1-15.
- Muttoni, G., Kent, D.V., Olsen, P.E., Di Stefano, P., Lowrie, W., Bernasconi, S.M., Hernández, F.M., 2004. Tethyan magnetostratigraphy from Pizzo Mondello (Sicily) and correlation to the Late Triassic Newark astrochronological polarity time scale. GSA Bull. 116, 1043-1058.
- Olgivie, M.M., 1893 - Contributions to the Geology of the Wenhen and St. Cassian Strata in the Southern Tyrol: Quarterly Journal of the Geological Society, 49, 1-78.
- Ogilvie-Gordon, M.M., 1900 - On the Fauna of the Upper Cassian Zone in Falzarego Valley, South Tyrol. Geol. Mag., n.s. IV, 7, 337-349.
- Ogilvie-Gordon, M.M., 1929 - Geologie des Gebietes von Pieve (Buchenstein), St. Cassian und Cortina d'Ampezzo. Jhb. Geol. Bundesanst., 79, 357-424.
- Polubotko, I.V., 1984 - Zonal an correlation significance of Late Triassic halobiids. Sovetskaya Geologiya, 6, 40-51 (in Russian).
- Polubotko, I.V., 1988 - On the morphology and systematics of the Late Triassic Halobiidae (bivalve molluscs). Annual of the All-Union Palaeontological Society, 31, 90-103 (in Russian).
- Rigo, M., Preto, N., Roghi, G., Tateo, F. & Mietto, P., 2007 - A CCD rise in the Carnian (Upper Triassic) of western Tethys, deep-water equivalent of the Carnian Pluvial Event. Palaeogeogr. Palaeoclimatol. Palaeoecol., 246, 188-205.
- Roghi, G., 2004 - Palynological investigations in the Carnian of Cave del predil area (once Raibl, Julian Alps). Rev. Palaeob. Palynol., 132, 1-35.
- Scheuring, B.W., 1970 - Palynologische und palynostratigraphische Untersuchungen des Keupers im Bolchentunnel (Solothurner Jura). Schweiz. Palaontol. Abh., 88, 2-119.
- Slovan, L.E., 1989 - Triassic Shoshonites from the Dolomites, Northern Italy - Alkaline Arc Rocks in a Strike-Slip Setting: Journal of Geophysical Research-Solid Earth and Planets, 94, 4655-4666.
- Spötl, C., and Vennemann, T.W., 2003 - Continuous-flow isotope ratio mass spectrometric analysis of carbonate minerals: Rapid Communications in Mass Spectrometry, 17, 1004-1006.

-
- Tozer, E.T., 1967 - A standard for Triassic Time. Geol. Surv. Canada Bull., 156, 1-103.
- Urlichs, M., 1974 - Zur Stratigraphie und Ammonitenfauna der Cassianer Schichten von Cassian (Dolomiten/Italien). Schrift. Erdwiss. Komm. Österr. Ak. Wiss., 2, 207-222.
- Urlichs, M., 1977 - Zur Alterstellung der Pachycardientuffe und der Unteren Cassianer Schichten in den Dolomiten (Italien). Mitt. Bayer. Staatsslg. Paläont. Hist. Geol., 17, 15-25.
- Urlichs, M., 1994 - *Trachyceras* Laube 1869 (Ammonoidea) aus dem Unterkarn (Obertrias) der Dolomiten (Italien). Stuttgarter Beitr. Naturk., ser. B (Geol. Paläont.), 217, 1-55.
- Van den Bergh, J.J., 1987 - Aspects of Middle and Late Triassic palynology. Palynological investigation in the Keuper (Upper Ladinian, Karnian, Norian and Rhaetian) and Lower Jurassic (Lias alfa1 + alfa2) of Franken, SE West-Germany. Stuijfmil, 5, 26-33, Utrecht.
- Van der Eem, J.G.L.A., 1983 - Aspects of Middle and Late Triassic Palynology. 6. Palynological investigations in the Ladinian and Lower Karnian of the Western Dolomites, Italy. Rev. Palaeobot. Palynol., 39, 189-300.
- Veizer, J., Ala, D., Azmy, K., Bruckschen, P., Buhl, D., Bruhn, F., Carden, G.A.F., Diener, A., Ebner, S., Goddard, Y., Jasper, T., Korte, C., Pawellek, F., Podlaha, O.G., and Strauss, H., 1999 - $^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ evolution of Phanerozoic seawater: Chemical Geology, 161, 59-88.
- Visscher, H. and Brugman, W.A., 1981 - Ranges of selected palynomorphs in the Alpine Triassic of Europe. Rev. Palaeobot. Palynol., 34, 115—128.
- Waller, T.R., and Stanley, G.D., 2005 - Middle Triassic Pteriomorphian Bivalvia (Mollusca) from the New Pass Range, west-central Nevada: systematics, biostratigraphy, palaeoecology, and paleobiogeography. J. Paleont. 79, suppl.1, Memoir 61, 64 pp.
- Warrington, G., 1970 - The stratigraphy and palaeontology of the 'Keuper' series of the central Midlands of England. Q. Jl. geol. Soc. Lond., 126, 183-223.
- Warrington, G., 1996 - Chapter 20A, Triassic spores and pollen; in: Jansonius J. and McGregor, D.C. (ed.), Palynology: principles and applications. American Association of Stratigraphic palynologists Foundation, Vol. 2, p. 755-766.
- Whiteaves, J.F., 1889 - On some Fossils from the Triassic Rocks of British Columbia. Geol. Nat. Hist. Surv. Canada, Contrib. Canad. Palaeont., 1, 127-149.
- Wignall, P.B., 1994 - *Black shales*. Geology and Geophysics Monographs, Oxford University Press, **30**, 130 pp.
- Wissmann, H.L., and Münster, G.G.v., 1841 - Beiträge zur Geognosie und Petrefacten-Kunde des Südöstlichen Tirol's vorzüglich der Schichten von St. Cassian. Beitr. Petrefacten-Kunde, 4, 1-152.

First detailed carbon isotope curve through the Ladinian-Carnian boundary : The Weissenbach section (Austria).

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Abstract - We present here a preliminary carbon isotope curve of the Ladinian-Carnian Boundary Interval from the Weissenbach-Mayerling section, Northern Calcareous Alps (NCA). The $\delta^{13}\text{C}_{\text{carb}}$ data measured in hemipelagic limestones record two negative excursions of small amplitude immediately below and above the boundary interval. If confirmed by data from other sections these two negative excursions might be relevant chemostratigraphic markers for the Ladinian-Carnian boundary.

1. Introduction

Carbon isotope curves have been widely used as correlation tool and their application is recommended by the ICS within the frame of GSSP definitions. But up to now, there is no detailed carbon isotope curve available for the Ladinian-Carnian boundary (LCB). Prati di Stuoeres/Stuoeres Wiesen in the Southern Alps (Italy), the currently only candidate GSSP (Broglia Loriga et al., 1998; 1999; Mietto et al., 2007), has no published carbon isotopic records. The only available $\delta^{13}\text{C}_{\text{carb}}$ curves for this time slice are from Romania (Atudorei, 1999) and Oman (Hauser et al., 2001), but without adequate biostratigraphic control for this interval and a low isotopic resolution for the Oman section (Hauser et al., 2001). The Weissenbach section in the Northern Calcareous Alps of Austria is important because of its reliable magnetostratigraphy (Gallet et al., 1994, 1998; in these papers the section is named Mayerling) and is approximately correlative to the Stuoeres Wiesen section using conodonts and magnetostratigraphy. We present here a preliminary carbon isotope curve through the LCB.

2. Geological setting

The Weissenbach section is located approximately 30 km southwest of Vienna, in the vicinity of the village of Weissenbach near Mayerling (Fig. 1). Gallet et al. (1994) used the name ‘Mayerling’ (rather than Weissenbach) because of its well-known historical background. From a paleogeographical point of view, this section belongs to the Northern Calcareous Alps (NCA), which are considered as a part of the northwestern Tethyan continental margin (e.g. Bosselini et al., 1980). The section is situated along a railway cutting (1, Fig. 1), with beds dipping 55° towards southeast (Gallet et al., 1994). The section sampled consists of 22 m of thick-bedded, whitish, fine-grained, deep-water pelagic limestones (Fig. 2). This uniform lithology is best suited for carbon isotopic studies (Atudorei, 1999).

3. Method

Twenty-four samples were taken within 15 m of the presumed LCB. For isotopic analyses, powders were produced from selected micritic samples using a diamond-tipped drill. Hand specimens were carefully examined to avoid cracks, veins and weathering features and drilled on the

counterpart of thin sections. The samples were analyzed using an automated carbonate preparation system connected to a Delta^{plus}XL mass spectrometer (Spötl and Venemann, 2003) at Innsbruck University. Reproducibility of replicate analyses was better than $\pm 0.1\text{‰}$ for standards and $\pm 0.15\text{‰}$ for sediment samples for both carbon and oxygen isotope values. All isotope results are reported using the conventional δ notation, defined as per mil (‰) deviation vs. VPDB.

4. Results and discussion

4.1 Biostratigraphy

The biostratigraphy of the sequence is based exclusively on conodonts, a difficult task in absence of a modern revision of Upper Ladinian to Lower Carnian faunas and

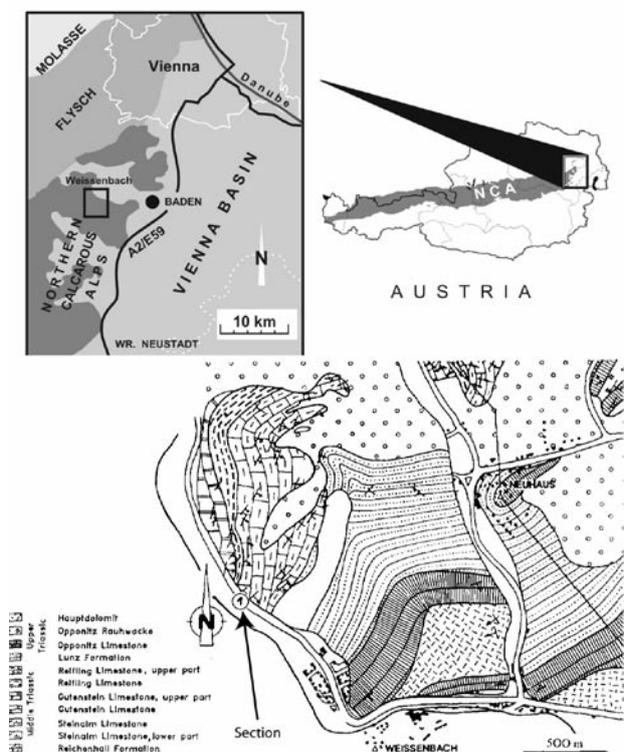


Figure 1: Location, simplified geological and structural maps of the Weissenbach section (modified after Gallet et al., 1994).

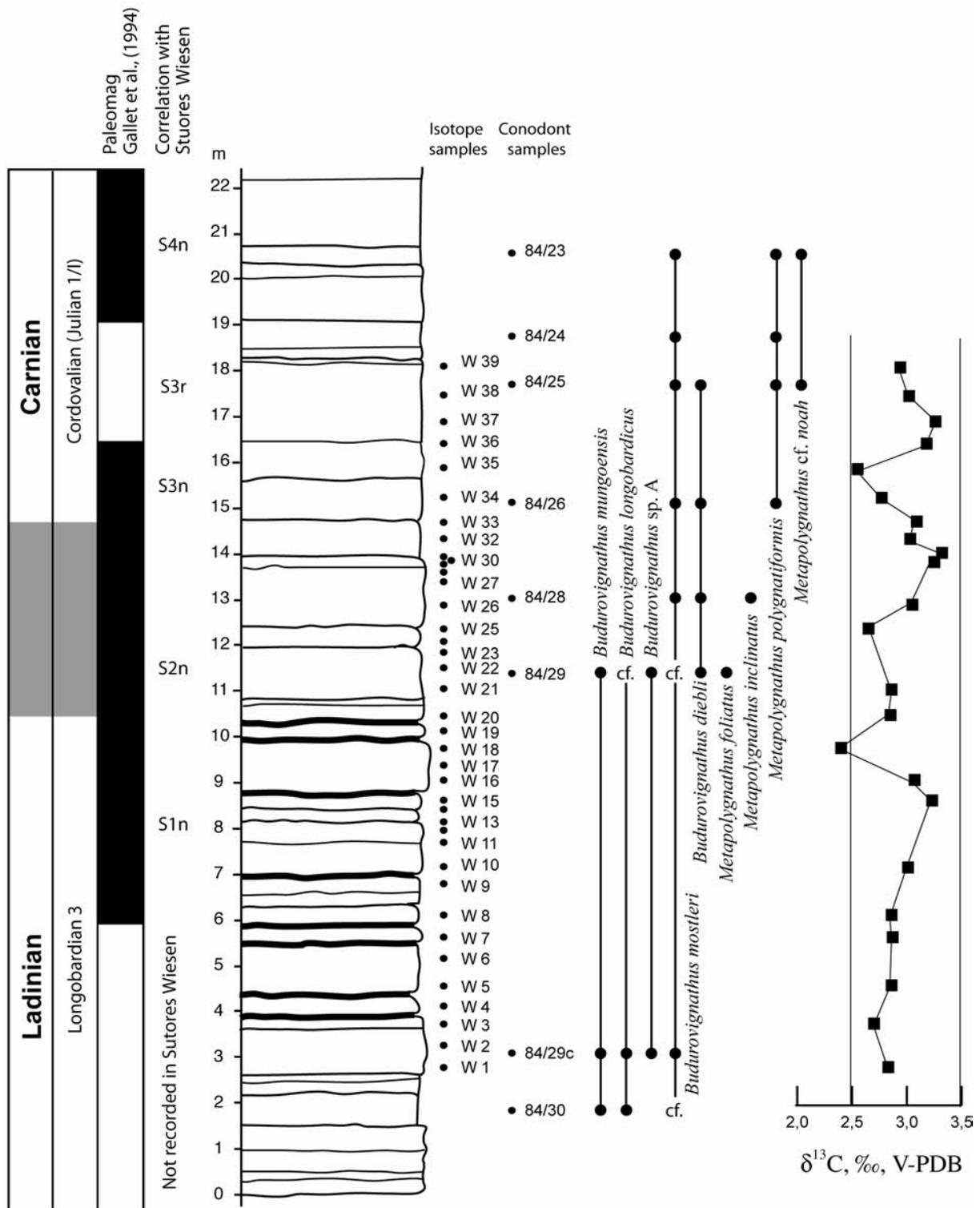


Figure 2: The Ladinian-Carnian boundary interval in Weissenbach showing the possible location of the boundary (in grey), conodont ranges, $\delta^{13}\text{C}_{\text{carb}}$ data and magnetic polarity zones with assumed correlations to the GSSP candidate Stuores Wiesen (Italy).

considering the highly contradicting views on the taxonomy of the time-diagnostic genera *Budurovignathus* and *Metapolygnathus*. Published species ranges of the mentioned taxa are therefore highly subjective and may vary considerably rendering a comparison and correlation difficult. A high-resolution stratigraphic interpretation of the Weissenbach section is further hampered by two other factors, i.e. discontinuous data below the indicated LCB interval (Fig. 2), and the apparent difference in faunal

composition of the exclusively *Budurovignathus*-bearing samples in the lower part of the section versus the mixed budurovignathid-gondolellid associations above.

In absence of generally accepted definitions, we provide the here used defining criteria for *Budurovignathus* and *Metapolygnathus* species. Forms with a short rectangular, terminally rounded to slightly squared platform and a lower un-bifurcated keel are included in a morphologically expanded *Budurovignathus longobardicus* (Kovacs)

Sam- ple	meter	d13C, ‰	d18O, ‰
W 1	2.75	2.8	-3.4
W 3	3.70	2.7	-2.8
W 5	4.55	2.9	-1.9
W 7	5.60	2.9	-3.9
W 8	6.10	2.9	-2.0
W 10	7.15	3.0	-2.4
W 15	8.60	3.2	-2.1
W 16	9.05	3.1	-2.8
W 18	9.75	2.4	-2.4
W 20	10.50	2.9	-2.5
W 21	11.10	2.9	-3.8
W 25	12.40	2.6	-3.4
W 26	12.90	3.0	-2.7
W 30	13.85	3.3	-2.4
W 31	13.95	3.3	-1.7
W 32	14.30	3.0	-2.6
W 33	14.70	3.1	-2.9
W 34	15.25	2.8	-3.9
W 35	15.90	2.6	-3.8
W 36	16.40	3.2	-3.3
W 37	16.90	3.3	-2.4
W 38	17.50	3.0	-2.8
W 39	18.10	2.9	-2.9

Table 1: $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of the Weissenbach section.

with an extended range from the Upper Ladinian to the lowest Carnian (cf. *aon*-Zone specimens from Stuores Wiesen figured *Budurovignathus diebeli* in Neri et al., 1995). Specimens with an elongated rectangular, posteriorly squared platform and a well bifurcating, Y-shaped terminal keel are assigned to *Budurovignathus diebeli* (Kozur & Mostler) and might - in this restricted sense - become a valuable marker for the new LCB. The *Metapolygnathus polygnathiformis* group is differentiated in *M. polygnathiformis* s. str. (plus newly described species in Orchard & Balini, 2007), and *M. cf. noah* for morphotypes close to Hayashi's type figure of this species. Orchard & Balini (2007), however, argues to restrict this name to Upper Carnian representatives and not to use it for Lower Carnian ?homoeomorphs.

Neglecting long-ranging species occurring throughout the late Ladinian and basalmost Carnian (*B. mungoensis*, *B. longobardicus*, *M. inclinatus*, *M. foliatus*) there remain three taxa (*B. diebeli*, *M. polygnathiformis*, *M. cf. noah*), which may be of time-significance for the LCB in Weissenbach. These three forms share successive appearances in the section within a 6 m interval starting with *B. diebeli* followed by *M. polygnathiformis* and closely above by

M. cf. noah. Such a low-resolution record does not allow any direct correlation with the Stuores Wiesen sequence, though our gray shaded "boundary interval" (see Fig. 2) may come close to the ammonoid-defined LCB in the candidate GSSP.

4.2 Magnetostratigraphy

The section contains four magnetic polarity intervals with the second one being much longer than the other three (Fig. 2). Muttoni's magnetostratigraphic comparison of Weissenbach-Mayerling with Stuores Wiesen (in Broglio Loriga et al., 1998) lacked a proper chronostratigraphic time frame. He equated a rather long time interval in Weissenbach (complete *regoledanus*-Zone = Longobardian 3 in Gallet et al., 1994) with a much shorter one in Stuores (*Daxatina* cf. *canadensis* Zone = upper part of *regoledanus*-Zone sensu Gallet et al., 1994). The magnetic correlation used in the present paper fits the biostratigraphic data much better. The sedimentation rate, which is 15 to 20 times lower in Weissenbach than in Stuores Wiesen, has as consequence that the sampling interval in Weissenbach (30-60 cm) is in proportion much coarser than in Stuores (< 5-9 m). This might explain the absence of the two thin Stuores Reversals S1r and S2r in the Weissenbach section. Consequently, we correlate the first long Weissenbach Normal with the three Stuores Normals S1n to S3n. At Stuores Wiesen, the base of the *Daxatina* cf. *canadensis* Zone is located low in S2n (Broglio Loriga et al., 1998). Translating this position into the long Normal of Weissenbach would lead to a LCB close to the base of the gray shaded LCB interval in Fig. 2, the probably most realistic value achievable.

4.3 Chemostratigraphy

The lithology, which is rich in carbonate (>99%) and very poor in organic matter, the study of thin-sections, the low thermal overprint (Conodont CAI 1) and the absence of a significant correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values, strongly suggest that diagenesis did not alter the $\delta^{13}\text{C}$ values. The uniform lithology permits to record isotope variations, which would most likely be difficult to identify in a less homogenous limestone. Within the measured interval the $\delta^{13}\text{C}$ values vary between 2.4‰ and 3.3‰. $\delta^{13}\text{C}$ values are slightly increasing from 2.7‰ to 3.2‰ in the first 6 m. The curve then records two negative excursions of 0.7‰ in amplitude, one beginning just below the interval presumably comprising the LCB (shaded interval in Fig. 2) and the second one beginning immediately above it. If confirmed by subsequent studies the suggested position of the LCB at the base of the shaded interval will provide a possibility to correlate this boundary within the first negative excursion.

In Dobrogea (Romania) Atudorei (1999) showed constant values in the two lower thirds of the Ladinian followed by an increase of 1.5‰ to 2‰ and again constant values in the Lower Carnian. Unfortunately, the available biostratigraphic data do not allow to decide if this increase occurred in the Upper Ladinian or in the Lower Carnian. Our results suggest that this increase did not occur around the boundary, but either below or above it and thus cannot serve as marker for the LCB. Further isotope studies are

necessary to 1) define the exact biostratigraphic position of the $\delta^{13}\text{C}$ increase recorded in Dobrogea, and 2) confirm the reproducibility and the wider correlation of the two small negative excursions around the LCB in the Weissenbach section.

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References

- Atudorei, N.-V., (1999) - Constraints on the Upper Permian to Upper Triassic marine carbon isotope curve. Case studies from the Tethys: PhD Thesis: Lausanne University, 155p.
- Broglio Loriga, C., Cirilli, S., De Zanche, V., di Bari, D., Gianolla, P., Laghi, M.F., Lowrie, W., Manfrini, S., Mastandrea, A., Mietto, P., Muttoni, C., Neri, C., Posetano, C., Rechichi, M.C., Rettori, R. and Roghi, G., (1999) – The Prati di Stuoeres/Stuoeres Wiesen section (Dolomites Italy) : A candidate Global Stratotype section and Point for the base of the Carnian stage. *Rivista Italiana di Paleontologia e Stratigrafia*, v. 103, p. 605-621.
- Broglio Loriga, C., Cirilli, S., De Zanche, V., di Bari, D., Gianolla, P., Laghi, M.F., Lowrie, W., Manfrini, S., Mastandrea, A., Mietto, P., Muttoni, C., Neri, C., Posetano, C., Rechichi, M.C., Rettori, R. and Roghi, G., (1998) – A GSSP candidate for the Ladinian/Carnian boundary : The Prati di Stuoeres/Stuoeres Wiesen section (Dolomites Italy), *Albertina*, v. 21, p. 2-18.
- Bosselini, A., Lobitzer, H., Brandner, R., Resch, W. and Castellarin, A., (1980) - The complex basins of the Calcareous Alps and paleomargins, *Abh. Geol. Bunderanst.* V. 34, p. 287-325.
- Gallet, Y., Besse J., Krystyn L., Théveniaut, H. and Marcoux, J., (1994) - Magnetostratigraphy of the Mayerling section (Austria) and Erenkolu Mezarlik (Turkey) section: Improvement of the Carnian (late Triassic) magnetic polarity time scale *Earth and Planetary Science Letters* V. 125, p. 173-191.
- Gallet, Y., Krystyn L., Besse J., (1998) - Upper Anisian to lower Carnian magnetostratigraphy from the northern Calcareous Alps (Austria) *Journal of Geophysical Research-Solid Earth* V.103/B1, p. 605-621.
- Hauser, M., Martini, R., Burns, S., Dumitrica, P., Krystyn, L., Matter, A., Peters, T. & Zaninetti, L., (2001) - Triassic stratigraphic evolution of the Arabian-Greater India embayment of the southern Tethys margin. *Eclogae Geologicae Helvetiae*, V. 94(1), p. 29-62.
- Mietto, P., Buratti, N., Cirilli, S., De Zanche, V., Gianolla, P., Manfrini, S., Nicora, A., Preto, N., Rigo, M., Roghi, G., (2007) – New constraints for the Ladinian-Carnian Boundary in the Southern Alps : Suggestions for global correlations. *New Mexico Museum of Natural History and Science, Bulletin* 41, 275-281.
- Neri, C., Russo, F., Mastandrea, A. and Baracca, A., (1995) – Litostratigrafia, ammonoidi e conodonti della Formazione di San Cassiano : la sezione dei Prati di Stuoeres (Stuoeres Wiesen, Dolomiti). *Ann. Univ. Ferrara, Sci. Geol.*, v. 5 (suppl.), p. 59-74.
- Orchard, M.J. and Balini, M., (2007) – Conodonts from the Ladinian-Carnian Boundary Beds of South Canyon, New Pass Range, USA. *New Mexico Museum of Natural History and Science, Bulletin* 41, 333-340.
- Spötl, C., & Vennemann, T.W., (2003) - Continuous-flow isotope ratio mass spectrometric analysis of carbonate minerals. *Rapid Communications in Mass Spectrometry*, V.17, p. 1004-1006.