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Artikel: Towards a better definition of the Anisian/Ladinian boundary : new biostratigraphic data and correlations of boundary sections from the Southern Alps

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compared to the 250–350 m of the Latemar time-equivalent. Provided the onset of platform growth was approximately coeval in both areas, the obviously higher rate of creation of accommodation space at Cernera explains the reduced proportion of clinoform deposits there, because little excess carbonate material was available from the platform top and rim. Acceleration of the relative sea-level rise may have induced the inbuilding geometry and drowning at Cernera.

After its submergence the Cernera platform top may have been covered by Hallstatt-type red nodular limestones as suggested by ammonoid bearing reddish limestone clasts within nearby Upper Ladinian megabreccias (Blendinger et al. 1982). Karstification and erosion of parts of the Cernera platform (Assereto et al. 1977a) probably occurred later, i.e. during uplift related to the Upper Ladinian tectonic episode but prior to the ultimate deposition of thick volcaniclastic units.

5. The South Alpine ammonoid record: Its zonal subdivision and the position of the Anisian/Ladinian boundary

5.1. The fossil succession and resulting scheme of ammonoid zones

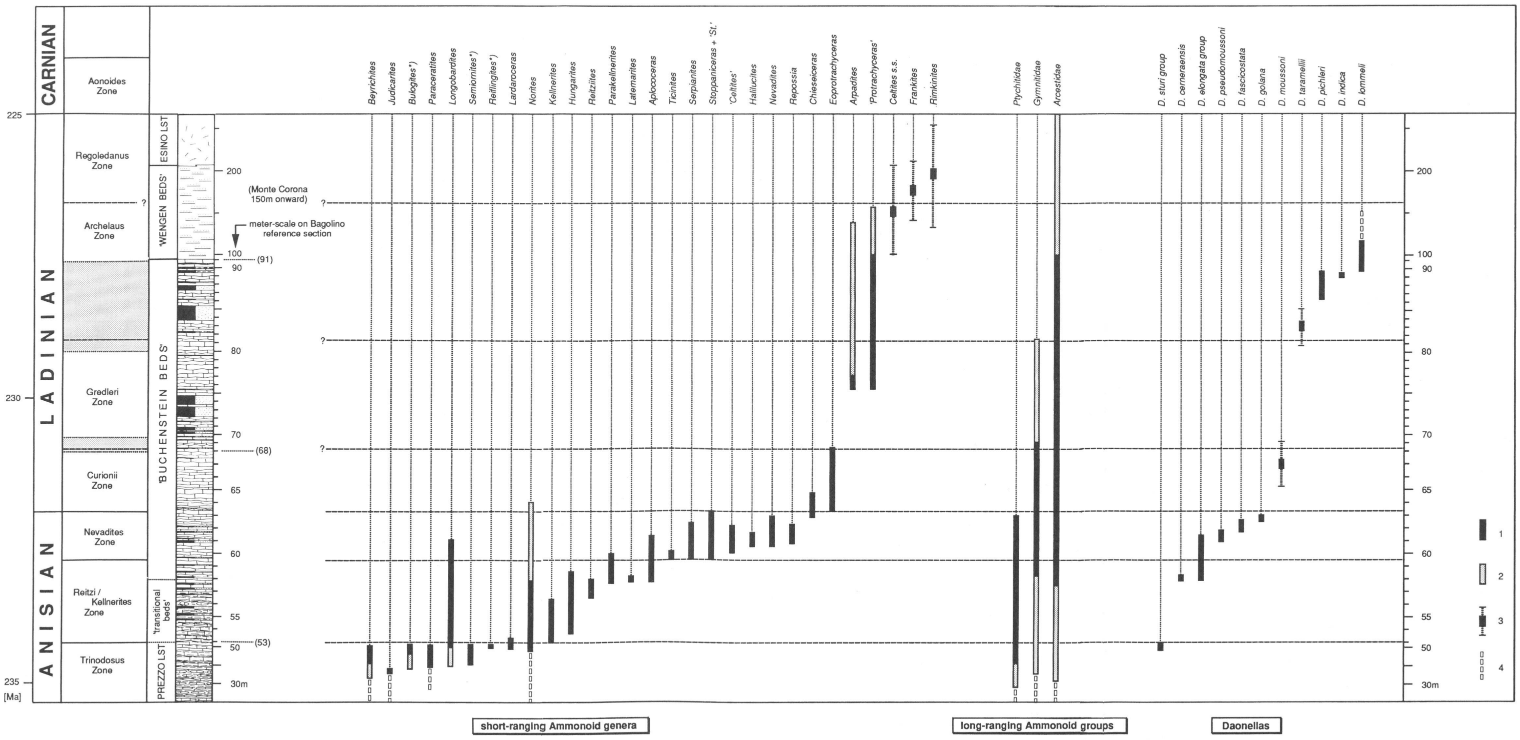
The correlations of South Alpine stratigraphic sections ranging from the Upper Anisian to the Middle/Upper Ladinian are based on the occurrence of macrofossils and are supported by the distribution of volcaniclastic layers. Some of the layers (the supposedly subaerially transported tuff fractions) are excellent time markers in different parts of a irregularly shaped sedimentary basin (Fig. 2). The greatest number of fossil levels positively identified in a continuous succession is at Bagolino (Fig. 7). In this section more than 20 ammonoid and Daonella bearing intervals represent a time span between at least the Trinodosus Zone and the Archelaus Zone. Furthermore, the correlative positions are established for most of the important additional fossil horizons of other South Alpine localities. This site is therefore a suitable reference section for the projection of our own and other data available from the studied areas (Figs. 7, 10–12). Even though improvements are expected for certain intervals, the combined fossil record (Fig. 13) across the Anisian/Ladinian boundary is relatively coherent.

Fig. 13. Range and distribution of Late Anisian to Ladinian ammonoid genera and Daonellas from the studied area. The fossil data are projected on the Bagolino reference section where the greatest number of fossil levels was recognized in a single section (Fig. 7). In order to approximately compensate for highly variable sediment accumulation rates four sectors (20–53 m; 53–68 m; 68–91 m; 91–300 m) are shown at different scales but the meter-levels correspond to those of the other figures of the section. The thickness of the "Wengen Beds" represents the situation at Monte Corona; at Bagolino-Dosso Alto these beds are only 5–50 m thick and overlain by platform carbonates of the Esino Limestone (Brack & Rieber 1986, Fig. 2).

Dotted patterns mark stratigraphic intervals for the Curionii/Gredleri and the Gredleri/Archelaus zone-boundaries. Possible positions are indicated by dashed lines.

*Bulogites**), *Semiornites**) and *Reiflingites**) sensu Assereto (1963); generic and specific names for these and other forms from the Brescian Prealps (e.g. Contrada Gobbia) and Giudicarie are currently under revision (Balini 1992 and pers. comm.). "*St.*" for "*Stoppaniceras*" (including provisionally the group of "*Ceratites*" *ellipticus* of Brack & Rieber, 1986).

Symbols: 1: distribution of fossils as observed in this study; 2: range of fossils according to correlatable South Alpine sections reported in literature; 3: interval for probable position of fossils; 4: supposed range of fossils according to additional information from literature.



CARNIAN
LADINIAN
ANISIAN
Aonoides Zone
Regoledanus Zone
Archelaus Zone
Gredleri Zone
Curionii Zone
Nevadites Zone
Reitzi / Kellnerites Zone
Trinodosus Zone
ESINO LST
'WENGEN BEDS'
'BUCHENSTEIN BEDS'
'transitional beds'
PREZZO LST
(Monte Corona 150m onward)
meter-scale on Bagolino reference section
short-ranging Ammonoid genera
long-ranging Ammonoid groups
Daonellas

Similarly complete and uncondensed ammonoid successions straddling the Late Anisian – Ladinian time interval are rare in the western Tethys. The classical Hungarian sections of the Balaton Highland contain clearly superimposed faunas of the Balatonicus Zone, the Trinodosus Zone and parts of our Reitzi/Kellnerites Zone (Szabo et al. 1980; Balogh et al. 1983; Vörös 1987; Vörös & Palfy 1989; Kovacs et al. 1990). The well documented fossil-rich tuffaceous strata of the lowermost Buchenstein Formation (we shall call it the "Reitzi tuffs") at Felsöörs (Kovacs et al. 1990) and Vászoly (Vörös & Palfy 1989; Kovacs et al. 1990) correspond, however, to only a narrow interval at Bagolino. Neglecting the volcaniclastic beds in the 5 to 25 m thick Hungarian "Reitzi tuffs," the composite thickness of the limestone intercalations does not exceed three meters. This compares well with the pelagic carbonate fraction of the correlative 53–58 m interval at Bagolino. In Hungary the stratigraphical control and spectrum of ammonoids above this level are as yet unsatisfactory. The same probably holds true for the most important sections in the Eastern Alps of Austria (e.g. Gross-Reifling, Hallstatt and surroundings; for a compilation see Tollmann 1985). In the fossil-rich condensed Hallstatt-type limestones at Epidhavros in Greece (Krystyn & Mariolakos 1975; Krystyn 1983) the interval between the Trinodosus Zone and the Archelaus Zone is 2.15 m thick compared to approximately 30 m in the Bagolino section. Nevertheless both faunal successions are apparently in agreement. The number of fossil levels is somewhat higher at Bagolino whereas the condensed cephalopod limestones yielded presumably more specimens. The stratigraphic sections in the Humboldt Range of Nevada (Silberling & Nichols 1982) are thicker by up to a factor of two relative to corresponding intervals in the Bagolino and related stratigraphic sections.

The South Alpine macrofossil record shows an unambiguous sequence of key species of *Judicarites, Paraceratites, Kellnerites, Hungarites, Reitziites, Parakellnerites, Aplococeras, Ticinites, Halilucites, Stoppaniceras, Nevadites, Chieseiceras, Eoprotrachyceras, Arpadites* and *Protrachyceras* among other ammonoids as well as Daonellas. Based on this succession we suggest a redefinition of some ammonoid zones and zone boundaries. Particularly important in this context are the clarified relative positions of *Reitziites reitzi, Parakellnerites, Ticinites polymorphus, Aplococeras avisianum* and *Nevadites* which are index fossils of previously used zones.

Following the current schemes for the Tethyan area, we subdivide the interval between the Trinodosus Zone and the Curionii Zone into two parts. Both units include around four fossil horizons or intervals. More detailed subdivisions would produce much smaller units compared to adjacent zones and are therefore better made on a subzone level.

The South Alpine *Nevadites* which were originally thought to represent the *reitzi* group are indeed younger than *Reitziites reitzi* (Böckh 1872) after which the "Reitzi Zone" was named in Hungary. "Nevadites Zone" [19]) is hence an acceptable term for the zone below the Curionii Zone. At Bagolino its base is provisionally drawn at the 59.5 m-level [20]) corresponding to the appearance of *Ticinites*. Its upper limit and therefore the

[19]) Instead of "Reitzi or Nevadites Zone" as previously suggested (Brack & Rieber 1986).

[20]) The first *Nevadites* were found at Prezzo in strata equivalent to the 60.75 m-level in the Bagolino section (Brack & Rieber 1986, Fig. 7, Pl. 4). The inclusion of *Ticinites* is probably a slight downwards expansion of the Nevadites Zone as defined by Krystyn (1983) but it makes the zone boundary clearly recognisable at Monte San Giorgio, Bagolino and Seceda.

base of the Curionii Zone correspond to the top of the "Chiesense-groove" (Brack & Rieber 1986).

For the interval between the Trinodosus Zone and the Nevadites Zone we think that the name "Reitzi/Kellnerites Zone" is a more suitable term than "Parakellnerites Zone." The "Parakellnerites Zone" was introduced by Krystyn (1983) as a substitute for the "Avisianus-", the "Polymorphus-" and the "Ceratites reitzi Zones." In the Southern Alps the range of *Parakellnerites* is known within a full ammonoid succession at Monte San Giorgio and Bagolino, and falls there in the upper part of our Reitzi/Kellnerites Zone. This zone presumably corresponds to a larger part of the original "Reitzi Zone" in Hungary and the appearance of *Kellnerites* is a useful element for its distinction from the Trinodosus Zone. In the Bagolino reference section the base of the Reitzi/Kellnerites Zone lies at the 53 m-level. According to our correlation (Fig. 10) Balini's (1992) *Lardaroceras* beds at Contrada Gobbia and Monte Corona (Stabol Fresco and Adana sections) are therefore considered as the uppermost part of the Trinodosus Zone in this paper.

Vörös & Palfy (1989) advocate an "Avisianum Zone" followed by a "Reitzi Zone" with the first occurrence of *Reitziites* at its base. Because *Reitziites* (= *Xenoprotrachyceras* in Vörös & Palfy, 1989) is clearly older than *Ticinites* and *Nevadites* this would be a subdivision of our Reitzi/Kellnerites Zone. As mentioned earlier such a subdivision may be acceptable on a subzone level. The index "Avisianum" is unfortunate, however, because the faunas with *Aplococeras avisianum* from Latemar and Cernera appear to be slightly younger than the *Reitziites* horizons at Bagolino.

The definitions of the lower boundaries of the Gredleri- and the Archelaus Zones have to await more thorough documentations of fossils from the middle/upper part of the "Buchenstein Beds". In the Bagolino reference section the base of the Gredleri Zone can be located provisionally within the 68–70 m interval. Its top falls between the 80–91 m levels, depending on which ammonoid zone the Daonellas (*Daonella pichleri, D. indica*) of this and equivalent sections are assigned to.

The allocated positions of the above mentioned ammonoid zone boundaries in the South Alpine Upper Anisian – Ladinian sections closely correspond to the zone boundaries in the Hallstatt Limestone at Epidhavros in Greece (Krystyn 1983).

5.2. The positions of the Anisian/Ladinian and the substage boundaries

Much has been written on what might be the most suitable position for the Anisian/Ladinian boundary (for a compilation of various ideas see e.g. Brugman 1986). The location of a stage boundary is chiefly a matter of convention and practical arguments should therefore outweigh historical reasons. This is especially valid where the latter have become ambiguous and the documentation of the fossil record has improved. This is indeed the case for the stratigraphic interval which includes all proposed Anisian/Ladinian boundaries in western Tethys. Moreover, a widely accepted choice has been made for the stage boundary in North America (e.g. Silberling & Tozer 1968). This boundary also serves as a reference for the most recent sea-level curves (Haq et al. 1988).

Bittner's (1892) original proposal for the Ladinian Stage implies that its lower boundary should be located at the (lithological) base of the "Buchenstein Beds" in the Dolomites. These beds were originally interpreted as equivalents of the "*Protrachyceras reitzi*"-bearing limestones in Hungary. We have shown that what was probably thought to be "*reitzi*" in the Southern Alps (i.e. the *Nevadites*) is distinctly younger than *Reitziites reitzi*. Moreover the age of the lowermost "Buchenstein Beds" in the Dolomites is not sufficiently well constrained. To our knowledge no macrofossils have yet been identified in the first few meters of "Plattenkalke" on top of the barren (regarding ammonoids) Upper Anisian platform carbonates (Contrin Fm.). The frequent occurrence of "Pietra verde" intercalations from the base of the "Plattenkalke" onwards suggests only that they may be close to a level corresponding to the *Reitziites* horizons at Bagolino (Figs. 7, 11). A truly isochronous age for the base of the "Buchenstein Beds" is doubtful, however, even within the Dolomites. Bittner's (1892) implicit definition for the base of the Ladinian lacks a type-section and is therefore ambiguous.

Similarly unclear is the limit between the frequently quoted Anisian and Ladinian substages Illyrian and Fassanian. This is mainly due to the recognition of a significant time-span between the Trinodosus Zone and Curionii Zone after the introduction of these substages. The Illyrian (renamed by Pia, 1930 after the "Bosnian Substage" of Mojsisovics et al. 1895) is based in part on "Hallstatt-type" limestones in Bosnia. The stratigraphic range of these beds exceeds the Trinodosus Zone (Arthaber 1906; Krystyn & Mariolakos 1975) and may reach at least the deeper parts of the Nevadites Zone. According to its original concept the Fassanian is represented by the "Buchenstein Beds" and "Marmolada Limestone" of the Dolomites (Mojsisovics et al. 1895). It thus spans a time interval between the Reitzi/Kellnerites and the lowermost Archelaus Zones. The original Illyrian and Fassanian therefore overlap and the position of the Illyrian/Fassanian boundary at the base of the Nevadites Zone (e.g. Krystyn 1983) is a compromise. The equivalent level in the "Buchenstein Beds" of the northwestern Dolomites is the base of the "Knollenkalke" (e.g. Seceda section) and not of the "Buchenstein Beds" according to Mojsisovics' definition.

It is obvious that these historical concepts are not sufficiently clear to be implemented in a redefinition of the stage boundary. Nevertheless, in view of the newly discovered fossil successions (ammonoids, Daonellas, conodonts, palynomorphs), the Southern Alps may still be regarded as a type area for the Ladinian. It seems reasonable to opt for a biostratigraphical scale with high resolution and wide applicability for the first approximation of the stage boundary prior to the choice of a reference point in a stratigraphic succession. According to the available information the resolution of the ammonoids up to now clearly surpasses alternative scales in the studied interval.

There is general agreement that an ammonoid-based Anisian/Ladinian boundary in the western Tethys area should be drawn somewhere between the Trinodosus Zone and the Curionii Zone. Potentially suitable levels can be associated with the three zone boundaries in this interval (e.g. Krystyn 1983)[21]) all of which can be recognized and

[21]) At least three different Anisian/Ladinian boundary positions have been proposed to date in the Balaton Highland of Hungary. The traditional boundary at the base of the "Reitzi tuffs" at Felsöörs presumably lies close to the boundary between our Trinodosus and the Reitzi/Kellnerites Zones. The recent proposal for an alternative stage boundary just below a *Reitziites*-bearing layer at Vászoly (Vörös & Palfy, 1989) would fall within our Reitzi/Kellnerites Zone. However, as mentioned earlier we think that this zone should not be further subdivided on a zonal level. The first occurrence of *Gondolella trammeri* has also been suggested for the position of the stage boundary (Kovacs et al. 1990). In Hungary this event lacks full ammonoid control. If indeed *G. trammeri* appears at the base of the Nevadites Zone the comparison with the Bagolino section suggests that this boundary is significantly younger than the *Reitziites* horizons (Fig. 13).

assessed in at least one South Alpine section. The full range of the Reitzi/Kellnerites Zone is hitherto only documented at Bagolino. This is thus not a practical level for the stage boundary. The base of the Nevadites Zone is a more suitable alternative but the zone boundary is still insufficiently controlled by fossils. Hence the base of the Curionii Zone is at present the best marker for the Anisian/Ladinian boundary in the Southern Alps. In the stratigraphic successions of the Brescian Prealps and Giudicarie this is equivalent to the top of the "Chiesense groove" (63.3 m-level in the Bagolino reference section; Figs. 7, 8, 10, 11) as discussed in Brack & Rieber (1986). In Epidhavros (Greece) the equivalent boundary is clearly recognizable (Krystyn 1983). In the Balaton Highland of Hungary, however, it lies above the fossil rich "Reitzi tuffs." Certainly our stage boundary concept corresponds most closely to the American convention and thus helps avoiding unnecessary complications in global stratigraphic correlations.

If substages are to be maintained the Illyrian/Fassanian boundary should coincide with the base of the Ladinian Stage. The Fassanian should therefore comprise at least the Curionii Zone but would no longer include the Reitzi/Kellnerites and Nevadites Zones as represented by the lowermost "Buchenstein Beds". Many recent European time scales indicate the Fassanian/Longobardian boundary at the base of the Gredleri Zone (e.g. Krystyn 1983). Again the original concepts of the Fassanian ("Buchenstein Beds" and "Marmolada Lst.") and of the Longobardian ("Wengen Beds") provide no unambiguous definition of their boundaries. However, in the Southern Alps (including the northwestern Dolomites), typical "Wengen Beds" span mainly the Archelaus Zone and in many areas (e.g. eastern Lombardy, Giudicarie) parts of the Regoledanus Zone also (Fig. 2c). This supports an inclusion of the Gredleri Zone into the Fassanian thus restricting the Longobardian to the Archelaus and Regoledanus Zones. The upper limit of the Longobardian is defined by the base of the Cordevolian in the Dolomites (Urlichs 1974, 1977). The resulting homogeneous substage pattern for the Late Anisian and Ladinian is again in good agreement with North American conventions.

5.3. Indications for the Anisian/Ladinian boundary in South Alpine sections

The boundary between the Nevadites Zone and the Curionii Zone (i.e. our Anisian/Ladinian boundary) can be pinpointed or approximated in a number of South Alpine localities in addition to the formerly discussed key sections (Fig. 14).

Parts of the Perledo/Varenna Limestone in a section at **Parlasco**/Val Portone (area of Esino; Pasquarè & Rossi 1969) are here tentatively correlated with the "Grenzbitumenzone" (GBZ) and the "Buchenstein Beds." The lowermost volcaniclastic layers at Parlasco (the "Cestaglia horizon" of Pasquarè & Rossi 1969; Gianotti & Tannoia 1987) seem to correspond to the tuffs in the GBZ at Monte San Giorgio and the T_c–T_e levels at Bagolino. The upper volcaniclastic strata (i.e. the "Parlasco horizon") could represent a tuffaceous succession in the middle portion of the "Buchenstein Beds". The resulting Anisian/Ladinian boundary interval at Parlasco (Fig. 14) is compatible with fossil finds (Gaetani et al. 1987). Conodonts were reported from the lowermost Perledo-Varenna Limestone (*Gondolella constricta, G. trammeri, G.* cf. *longa*) and also occur higher up (*Metapolygnathus hungaricus*) in horizons containing *Daonella moussoni* (Fig. 14). In the same area ammonoids including *Protrachyceras longobardicum, P. steinmanni* and various *Arpadites* are known from lenses in platform carbonates of the Esino Limestone (e.g. Mojsisovics 1882; Rossi Ronchetti 1960 and our own finds). These levels are probably equivalent to the middle/upper portion of the "Buchenstein Beds" at Bagolino and possibly correspond to parts of the Lower Meride Limestone at Monte San Giorgio.

At **Ghegna** (Val Brembana) a rich fauna with ammonoids was found in the scree of the Esino platform carbonates (Tommasi 1913). Our collection from this locality includes representatives of "*Stoppaniceras*" besides *Aplococeras misanii, Chieseiceras chiesense* and other ammonoids, some of which occur close to the boundary between the Nevadites Zone and the Curionii Zone at Bagolino. According to Assereto et al. (1977b, Fig. 3) the lumachella rocks of Ghegna form lenses at the base of the Esino Limestone 15–20 m above typical but thin (< 30 m) Prezzo Limestone. This is in good agreement with the position of distinct tuff markers (corresponding to the T_a tuffs at the 55 m-level at Bagolino) which we identified in equivalent beds at Lenna and Piazza Brembana a few kilometers to the west (Fig. 10). Jadoul et al. (1992) locate the lumachella rocks somewhat higher up in the Esino Limestone (60–100 m from its base). Interestingly these authors also describe several fossil rich lenses in Esino platform carbonates in Val Parina only four kilometers to the southeast of Lenna. In these fossil lenses ammonoids are abundant and include species that are well known from time equivalent "Buchenstein Beds" (*Chieseiceras perticaense, Norites dieneri,* various *Eoprotrachyceras* (*E. rieberi, E. recubariense*) (Fantini Sestini pers. comm.), *Protrachyceras* (*P. longobardicum; P. steinmanni*) among other ammonoids).

In the **Recoaro/Tretto** area, early finds of ammonoids (Tornquist 1898, 1901) include specimens of *Hungarites, Eoprotrachyceras* (*E. curionii* (?), *E. recubariense, E. margaritosum*) and *Arpadites*. These fossils were presumably collected from the scree of nodular limestones, a few meters thick, on top of a prominent "Pietra verde" series (Mietto pers. comm.). Neighboring sections (including the "Pietra verde" interval) provided conodonts (Mietto & Petroni 1979, 1980) indicative of the Nevadites Zone (Krystyn 1983) or a somewhat deeper level for the lowermost samples. Our Anisian/Ladinian boundary falls most probably within the above mentioned nodular limestones. On the basis of the ammonoids these limestones could be a condensed equivalent of the 58–75 m interval of the Bagolino section. The locally thick "Pietra verde" successions at Tretto/Recoaro may thus be tentatively interpreted as equivalents of the T_b–T_e volcaniclastic layers at Bagolino.

At **M. Rite** and **Dont**, Middle/Upper Anisian pelagic successions (Assereto 1971; Farabegoli et al. 1984) continue upwards into typical "Buchenstein Beds." Even though the stage boundary cannot be fixed accurately it probably falls within the lowermost "Knollenkalke." These beds overlie a "Pietra verde" succession above a marlstone unit with Daonellas (known as the "*Daonella* marls"). Similar lithologies with Daonellas in the Prags area (Schadebach section; see Bechstädt & Brandner 1970 for location) are capped by "Plattenkalke" and "Knollenkalke" comparable to those of the Pedraces and Seceda sections. In the area between Prags and M. Rite ammonoids of our Reitzi/Kellnerites Zone were reported from strata just below typical "Knollenkalke" of the "Buchenstein Beds" (Casati et al. 1982; "Stabin" locality).

Further to the east in **Cadore** and **western Carnia**, ammonoids from red nodular limestones (Clapsavon Lst.) date the submergence of platform portions as slightly older than the Anisian/Ladinian boundary (possibly comparable to the drowning of the Cernera platform in the Dolomites). Geyer (1898) found *Chieseiceras chiesense* and *Eopro-*

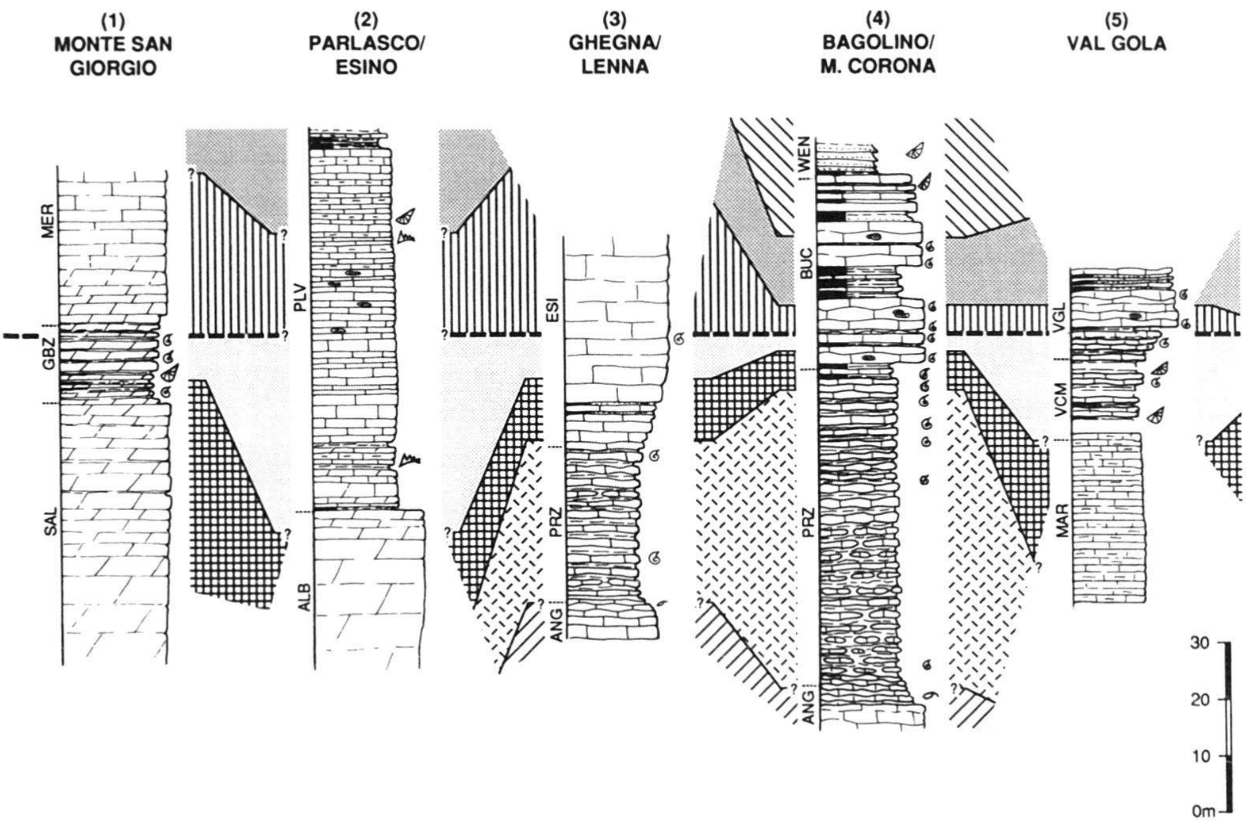


Fig. 14. A correlation of sections straddling the Anisian/Ladinian boundary in various settings along the Southern Alps (see text for discussion and Fig. 1 for locations). The suggested stage boundary (i.e. the limit between the Nevadites and the Curionii Zones) can be pinpointed or approximated in most sections. See Fig. 2b for the large-scale stratigraphic context of individual sections and Fig. 12 and text for details on sections (1), (4), (5) and (7). References for stratigraphic columns which are partly or fully adapted from literature: (2) after Pasquarè & Rossi (1969), bivalve symbol marks position of *Daonella moussoni*, conodonts are mentioned in the text; (3) after Assereto et al. (1977b), faunas indicated are those of the Prezzo Lst. (the *Paraceratites brembanus* fauna e.g. Venzo & Pelosio 1968; the Contrada Gobbia equivalent fauna) and of the lumachella rocks at Ghegna (see text); (5) partly after De Zanche & Mietto (1986, 1989); (6) after De Zanche et al. (1979), Val di Creme section, probable correlative position of the fauna from Tretto (Tornquist 1898, 1901) is indicated; (8) after Pisa et al. (1978) and Assereto (1971); (9) after Lagny (1974) "Casera Plotta" locality with fauna of Geyer (1898); (10) schematic after Pisa (1972, 1974).
Abbreviations of formal and informal stratigraphic units are the same as in Fig. 2.

trachyceras recubariense among other ammonoids in a thin condensed horizon near Sappada (the "Casera Plotta" locality; see also Lagny 1974; Assereto & Pisa 1978). Unpublished specimens of *Chieseiceras chiesense* and *Nevadites* have also been identified at Padova University in De Toni's collections from the Clapsavon Limestone at Valdepena (Lorenzago) and in the M. Clapsavon/M. Bivera area (Brack & Rieber 1986). Interestingly, in the same area, Pisa (1966, 1972) found ammonoids including *Eoprotrachyceras curionii* in platform carbonates 40 m below their top. Provided that the accumulation of fossils is not a fissure fill this would suggest a non-isochronous and presumably tectonically influenced drowning of different platform portions even within a small area. Based on the occurrence of *Protrachyceras gortanii nodato* in the "Buchenstein Beds" at Seceda, the main fauna from M. Clapsavon and Forni di Sotto (Pisa 1966) may correspond to the middle/upper portion of the "Knollenkalke" at Seceda.