The Global Boundary Stratotype Section and Point (GSSP) for the Base of the LADINIAN STAGE (Middle Triassic)

A proposal for the GSSP at the base of the *curionii* zone in the Bagolino section (Southern Alps, Northern Italy)

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ABSTRACT
The Global boundary Stratotype Section and Point (GSSP) for the Base of the LADINIAN STAGE (Middle Triassic) is defined at the top of a distinctive 20-cm-thick groove (= "*Chiesense* groove") of limestone nodules in a shaley matrix, located about 5 m above the base of the Buchenstein Beds in the Caffaro river bed (45°49'09.5''N, 10°28'15.5''E), south of the village of Bagolino (Province of Brescia, northern Italy). The lower surface of the overlying thick limestone bed has the lowest occurrence of the ammonoid *Eoprotrachyceras curionii* (base of the *E. curionii* zone; onset of the Trachyceratidae ammonoid family). Secondary global markers in the uppermost Anisian include the lowest occurrence of conodont *Neogondolella praehungarica* and a brief normal-polarity magnetic zone. The GSSP level is bracketed by U-Pb single zircon age data, indicating that the boundary age is ~ 240 to 242 Ma.

STRATIGRAPHIC RANK OF BOUNDARY
Base of the Ladinian Stage in the Middle Triassic Series.

Relation of the GSSP to historical usage
The long history of concepts regarding the Anisian/Ladinian boundary is summarized and illustrated in Brack & Rieber (1994). These views have been further discussed by Kozur (1995).
The first formal recognition of a stratigraphic interval comprising what is now called Ladinian goes back to the subdivisions of the Triassic System proposed by E.v.Mojsisovics. Ammonoids served as the main biostratigraphic tool for these divisions. By 1874 and with later modifications (e.g., 1882), Mojsisovics used the name "Norian" for a stratigraphic interval including, at its base, the South Alpine Buchenstein Beds and siliceous limestones of Bakony (Hungary). Because Mojsisovics erroneously equated this interval with parts of the ammonoid-rich Hallstatt-limestones, he used the term "Norian" as the stage name. "Norian" refers to the Norian Alps around Hallstatt near Salzburg (Austria). Later, the Hallstatt-ammonoids turned out to be much younger. Bittner (1892) therefore proposed the term "ladinisch" (Ladinian) as a new label of the stratigraphic interval of South Alpine Buchenstein and Wengen Beds. Although not accepted by Mojsisovics et al. (1895), "Ladinian" was subsequently a generally adopted stage name (e.g., Arthaber, 1906).
In the time of Mojsisovics, knowledge of ammonoid successions in the Anisian/Ladinian boundary interval was still fragmentary and correlations were rather speculative. For instance, the South Alpine Buchenstein Beds and siliceous limestones in Bakony were considered age equivalents and both attributed to the *R. reitzi* zone. However, recent biostratigraphic results on ammonoids, conodonts and radiolaria (see further on) clearly document that the main ammonoid bearing interval of Mojsisovics' "yellow siliceous limestones of Bakony" slightly predates and overlaps in age with only the lowermost South Alpine Buchenstein Beds. Moreover the base of the Buchenstein Beds is diachronous and the lower part of this unit has sometimes also been considered Anisian. In the light of a modern definition of the base of the Ladinian Stage, the original concepts and historical usage of the Anisian/Ladinian boundary provide no unambiguous basis for the positioning of the GSSP. What still may be considered of particular relevance in this context is that in his introduction of the term "ladinisch" (Ladinian), Bittner (1892) specifically referred to stratigraphic successions

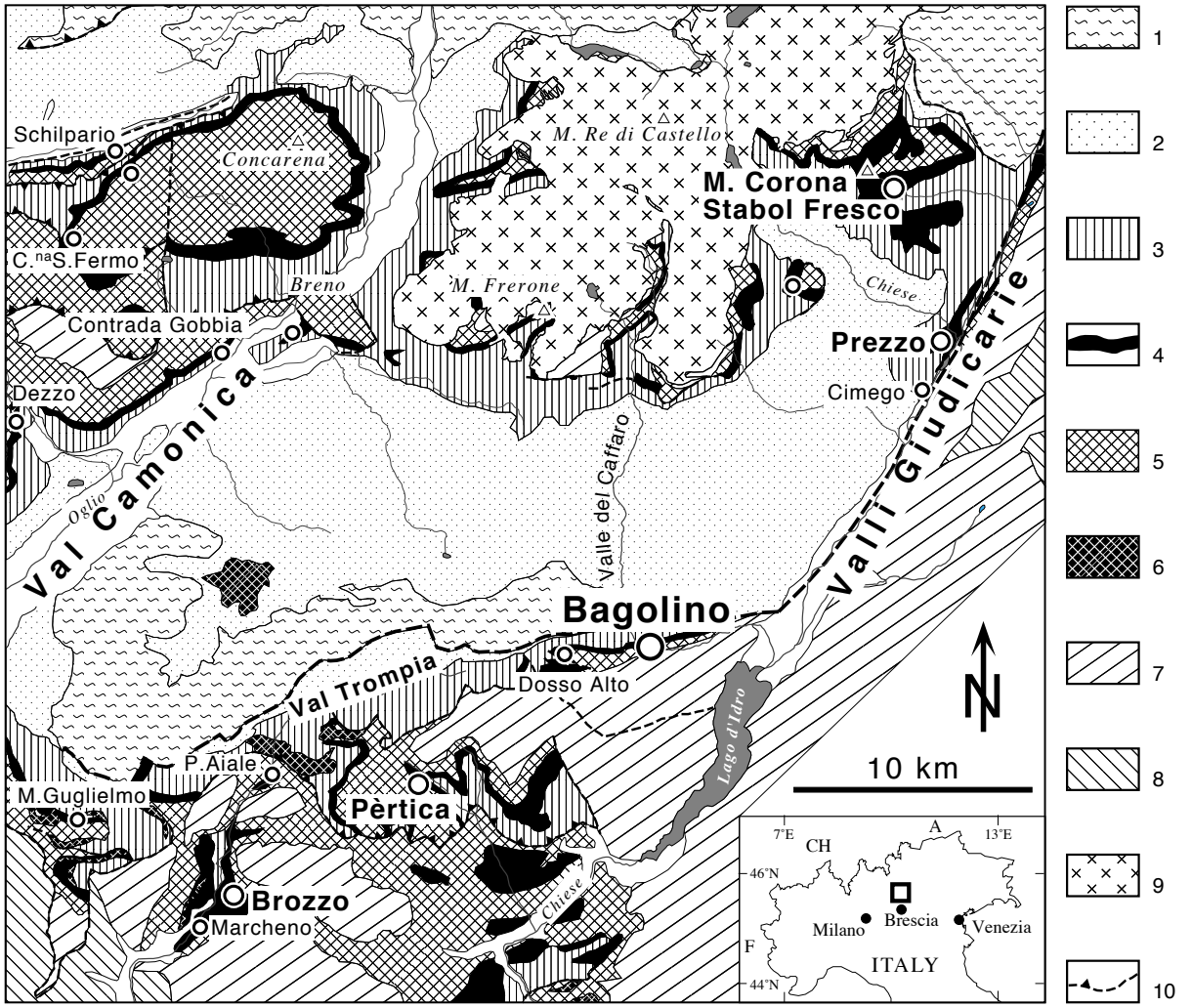

Figure 1: Geological sketch map of the area with classical localities of Middle Triassic stratigraphy in eastern Lombardy and Giudicarie (Trentino). 1: Pre-Permian basement; 2: Permian to Lower Triassic including lowermost Anisian units; 3: Mainly lower/middle Anisian units (Angolo Lst.; Dosso dei Morti - Camorelli Lst.); 4: Upper Anisian - Ladinian pelagic successions (Prezzo Lst., Buchenstein- and Wengen Beds); 5: Ladinian / Carnian platform carbonates and age-equivalent intra platform deposits (Pratotondo Lst., Lozio Shales); 6: Ladinian - Carnian shallow intrusive rocks; 7: Norian - Rhaetian shallow water carbonates and basinal equivalents; 8: Jurassic - Cretaceous units; 9: Tertiary Adamello plutonics; 10: major tectonic lines (faults and thrusts).

in the Southern Alps, with the Buchenstein Beds as the oldest unit. The lower part of the South Alpine Buchenstein Beds is thus an appropriate stratigraphic interval for establising the GSSP for the base of the Ladinian Stage.

PROPOSED GSSP - GEOGRAPHIC AND PHYSICAL GEOLOGY

Geographic location

The GSSP-candidate at Bagolino (Province of Brescia, Northern Italy) is located in the Brescian Prealps portion of the Southern Alps, and more precisely, in Valle del Caffaro between Val Camonica and Valli Giudicarie (Fig.1). The Anisian/Ladinian boundary succession is well exposed at three sites in the bed of the river Caffaro, in the surroundings of the Romanterra bridge, south of the village of Bagolino (Sites A - C; see Fig.2). The GSSP-Site is situated close to eastern end of Site B and its coordinates are 614.276 / 5075.118 (UTM-grid) and Long./Lat. 45°49'09.5''N, 10°28'15.5''E respectively.

Bagolino can be reached by car or by public transport from Brescia. A bus station is located at short distance from the Romanterra bridge. The bridge can also be reached by car and its coordinates are 45°49'11.1''N, 10°28'8.6''E and the altitude is 646m. From this point the main exposures lie within walking distance along the banks and in the

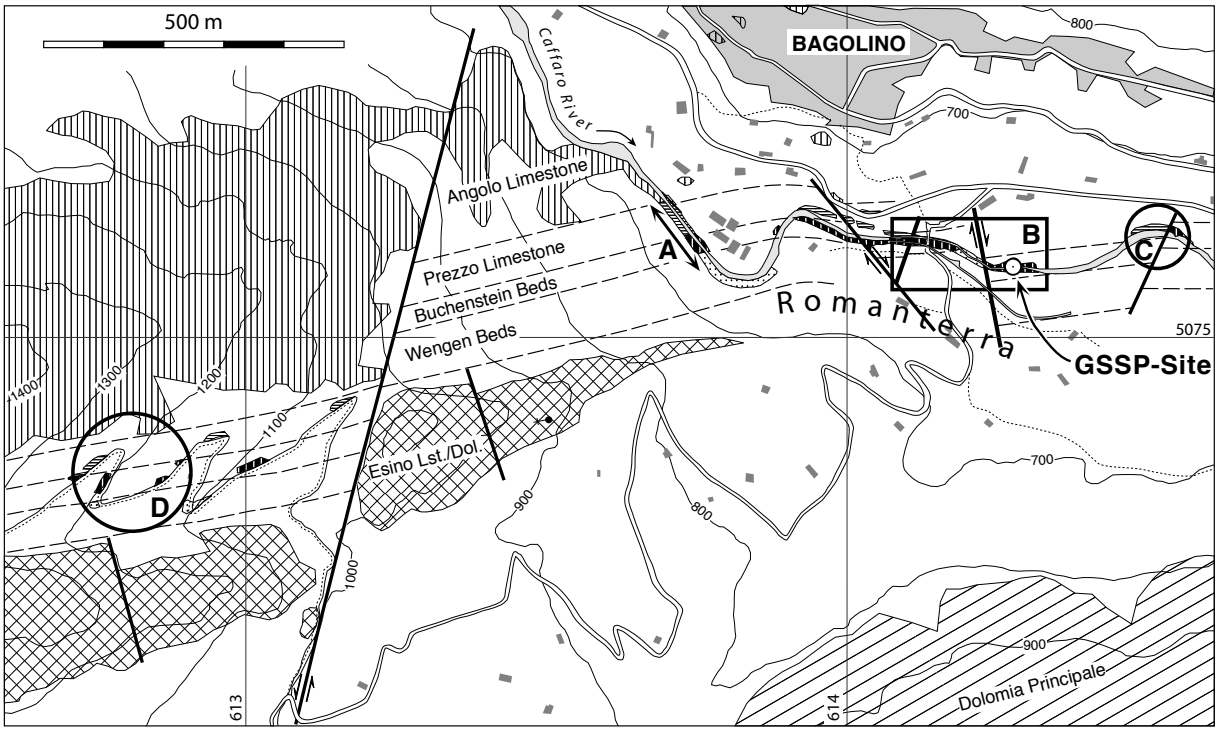

Figure 2: Geological sketch map of the vertical to slightly overturned Middle Triassic succession in the surroundings of Bagolino. The main sites (A - D) with exposures of the Anisian/Ladinian boundary interval are indicated. The stratigraphic ranges of the intervals exposed at each site are shown in Fig.3. A continuous succession ranging from the uppermost Angolo Limestone to the Wengen Beds is exposed at Site A. The frame at Site B outlines the area of a detailed map of this outcrop as illustrated in fig.4 of Brack & Rieber (1986). Coordinates of GSSP-Site: Long./Lat. N 45°49'09.5", E 10°28'15.5".

bed of the Caffaro river. The GSSP-Site (= Site B) is situated approximately 150m ESE of the bridge. Site B lies downstream of a dam deviating the river waters. Parts of the outcrops may be submerged during high river waters in spring or after heavy showers. The other sites are inaccessible only with extreme winter conditions.

Geological setting

The Middle Triassic succession at Bagolino is part of a thick sediment prism comprising Lower to Upper Triassic strata, which are turned upright in front of an uplifted portion of the Brescian Prealps. The latter area is situated to the north of a bounding fault (Val Trompia Line) and consists of pre-Permian metamorphic basement and Lower Permian - Triassic cover rocks. Alpine deformation of the Middle-Upper Triassic rocks south of the Val Trompia Line was the result of south-directed tectonic transport of basement and cover rocks which occurred in two phases, prior and after the emplacement of the Eocene-Oligocene Adamello intrusives respectively.

Pelagic successions of Middle Triassic age are also exposed at various places south and west of Bagolino (Fig.1), including the classical locality at Dosso Alto and important complementary sections at Pèrtica, Brozzo and Marcheno. To the north of Bagolino, Middle Triassic pelagic sediments occur along the southern margin of the Adamello intrusives. This area hosts important sections in Giudicarie (Prezzo, at the eastern termination of Val di Daone; Monte Corona - Stabol Fresco) and in Val Camonica (e.g., Contrada Gobbia).

At Bagolino, the pelagic succession consists from bottom to top of the Prezzo Limestone, the Buchenstein Beds and the Wengen Beds. The succession is well exposed at different places in the Caffaro river bed at Romanterra (Fig.2). The same lithologies occur in scattered outcrops on the southern slopes of M. Pizza (Site D). Additional exposures of these strata are also accessible along the Rio Ricomassimo creek around 3km east-northeast of Romanterra.

The stratigraphic succession at Romanterra, as documented in Figure 3, starts in the uppermost Angolo Limestone with a distinct brachiopod lumachella at its top. The pelagic Prezzo Limestone consists of limestone-shale alternations with nodular to wavy bedding in the lower and

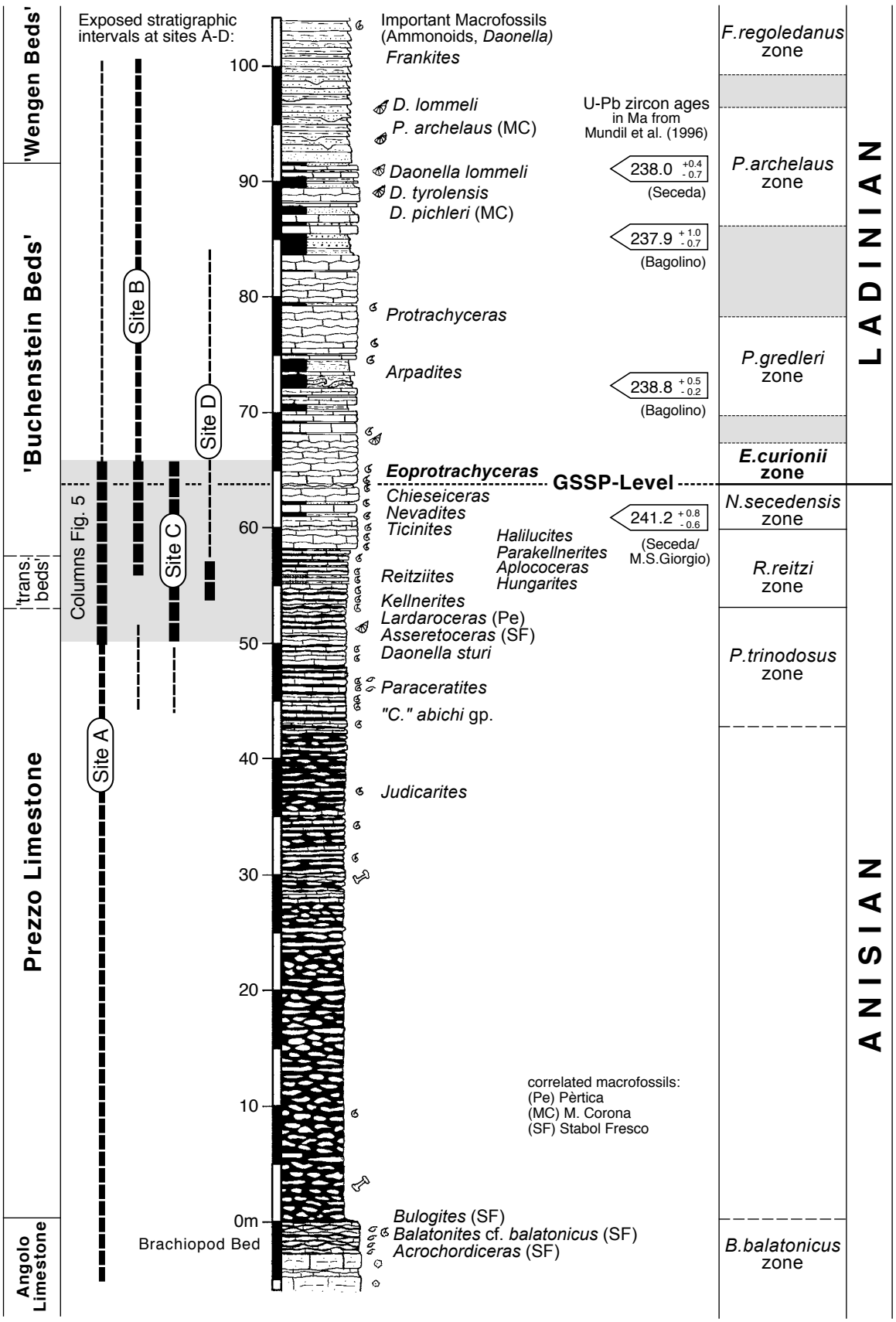

Figure 3: Summary log of the Middle Triassic pelagic succession at Bagolino. The stratigraphic intervals exposed at Sites A - D as well as the main macrofossil horizons and the scheme of ammonoid zones are indicated. Isotopic age data are weighted mean U-Pb-ages (uncertainties at 95% confidence level) on single grain zircon from volcaniclastic layers at Bagolino and Seceda (from Mundil et al., 1996).

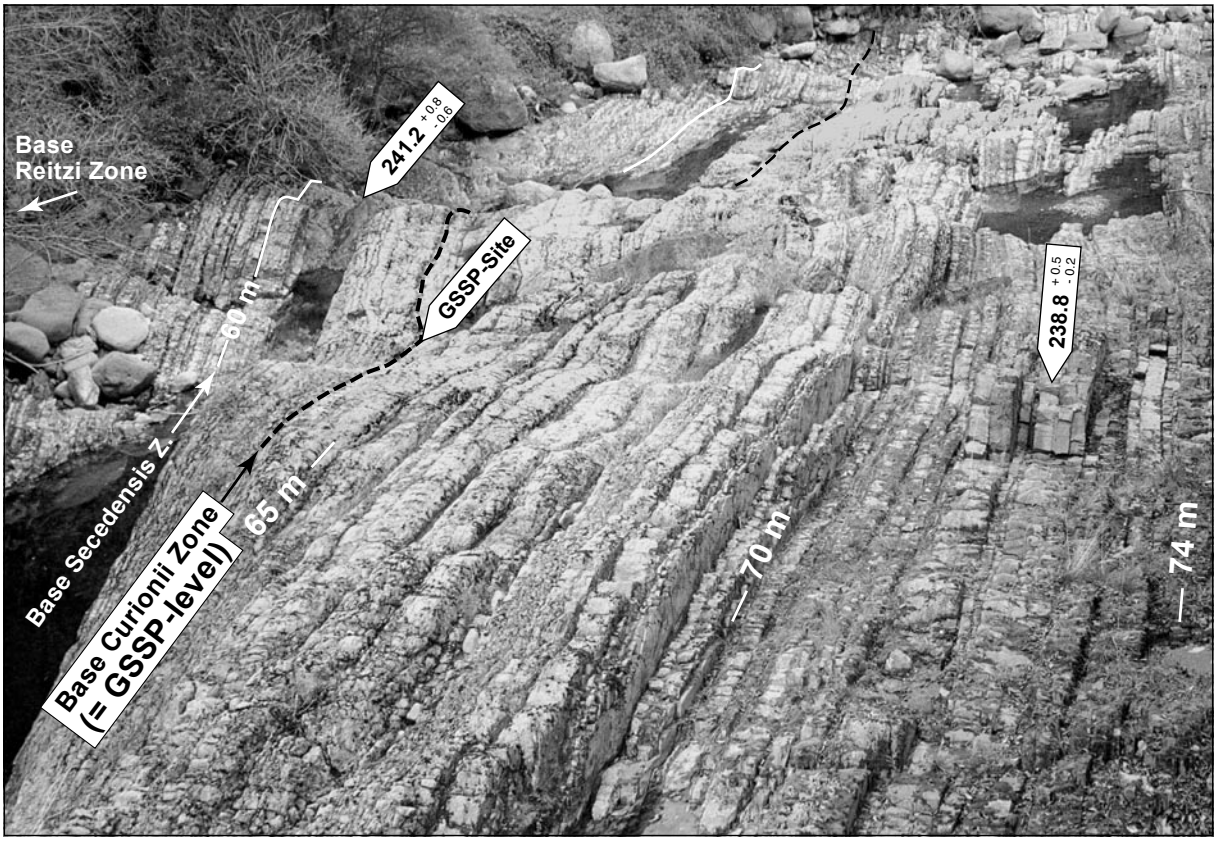

Figure 4: View of the spectacular outcrop of Buchenstein Beds at Site B (eastern end; = GSSP-Site) with a continuous exposure of strata between the *reitzi* zone and the *archelaus* zone (base of Wengen Beds).

more regular and thicker bedding in the upper part. In an interval transitional to the Buchenstein Beds, the first significant volcaniclastic layers are interbedded with increasingly siliceous limestones and shales. The Buchenstein Beds consist of siliceous pelagic nodular limestones and up to a few decimetres thick volcaniclastic layers which can be traced laterally on a regional scale. A marked change in sedimentation is observed at the top of the Buchenstein Beds with the abrupt switch to the predominantly siliciclastic Wengen Beds.

The Anisian/Ladinian boundary interval comprises the "transitional beds" and the lower part of the Buchenstein Beds and is best exposed at Sites A - C. In particular, at the eastern end of Site B (Fig.4; for a detailed map of this outcrop see fig.4 in Brack & Rieber, 1986), the fully exposed strata from the 57m-level upward can be traced over several tens of metres along strike. At Site C, until recently, an undisturbed succession was exposed of the 51-65m-interval and which comprised all boundary positions hitherto discussed as potential base of the Ladinian Stage. Unfortunately the lower part of this section is now partly covered by a recent slide of the river bank

Location of Level and Specific Point

The proposed GSSP-level at Bagolino is defined in the lower part of the Buchenstein Beds, around 5m above its base, at the top of a distinct 20-25cm-thick interval of limestone nodules in a shaly matrix in contact (upwards) with several thick limestone beds (Fig.5b). The nodular limestone interval is known as the "*Chiesense* groove" and bears ammonoids such as *Chieseiceras chiesense* and '*Stoppaniceras' (ellipticum*-group). On the lower surface of the overlying thick limestone bed *Eoprotrachyceras curionii* has its lowest occurrence. Macrofossils were found at this level at all sites mentioned for Bagolino (Figs.2,3,5). Because of the particularly vast exposure, the eastern end of Site B (Fig.4) is designated as the principal outcrop / section for the GSSP.

Stratigraphic completeness

No signs of stratigraphic gaps have been detected so far in the pelagic part of the Middle Triassic sediment succession at Bagolino. The reduction of

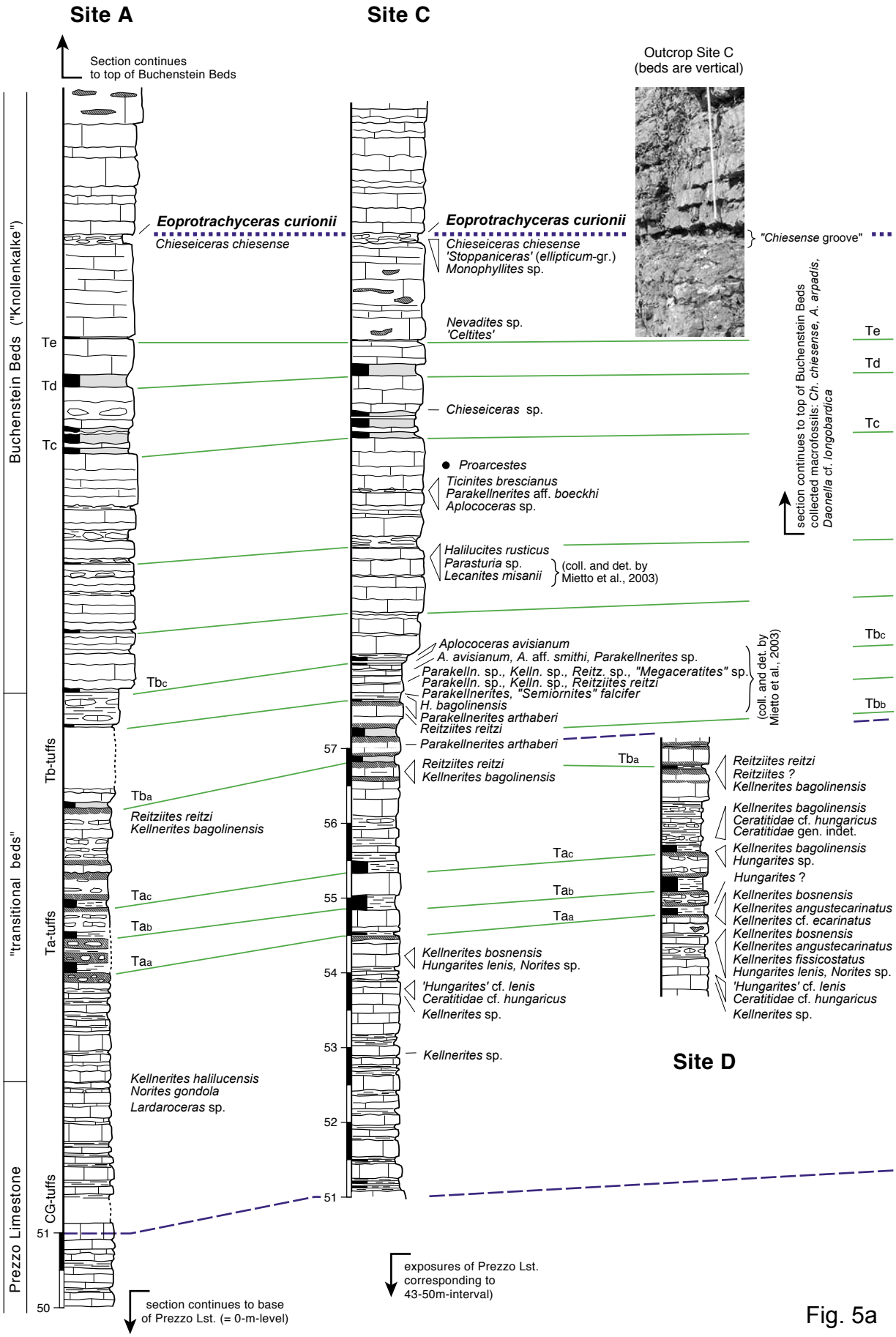
Site A
Site C
Site D
Section continues to top of Buchenstein Beds
Outcrop Site C (beds are vertical)
"Chiesense groove"
Buchenstein Beds ("Knollenkalke")
"transitional beds"
Prezzo Limestone
Eoprotrachyceras curionii
Chieseiceras chiesense
Eoprotrachyceras curionii
Chieseiceras chiesense
'Stoppaniceras' (ellipticum-gr.)
Monophyllites sp.
Nevadites sp.
'Celtites'
Chieseiceras sp.
Proarcestes
Ticinites brescianus
Parakellnerites aff. boeckhi
Aplococeras sp.
Halilucites rusticus
Parasturia sp.
Lecanites misanii
(coll. and det. by Mietto et al., 2003)
section continues to top of Buchenstein Beds collected macrofossils: Ch. chiesense, A. arpadis, Daonella cf. longobardica
Aplococeras avisianum
A. avisianum, A. aff. smithi, Parakellnerites sp.
Parakelln. sp., Kelln. sp., Reitz. sp., "Megaceratites" sp.
Parakelln. sp., Kelln. sp., Reitziites reitzi
Parakellnerites, "Semiornites" falcifer
H. bagolinensis
Parakellnerites arthaberi
Reitziites reitzi
(coll. and det. by Mietto et al., 2003)
Parakellnerites arthaberi
Reitziites reitzi
Kellnerites bagolinensis
Kellnerites bosnensis
Hungarites lenis, Norites sp.
'Hungarites' cf. lenis
Ceratitidae cf. hungaricus
Kellnerites sp.
Kellnerites sp.
Kellnerites halilucensis
Norites gondola
Lardaroceras sp.
Reitziites reitzi
Reitziites ?
Kellnerites bagolinensis
Kellnerites bagolinensis
Ceratitidae cf. hungaricus
Ceratitidae gen. indet.
Kellnerites bagolinensis
Hungarites sp.
Hungarites ?
Kellnerites bosnensis
Kellnerites angustecarinatus
Kellnerites cf. ecarinatus
Kellnerites bosnensis
Kellnerites angustecarinatus
Kellnerites fissicostatus
Hungarites lenis, Norites sp.
'Hungarites' cf. lenis
Ceratitidae cf. hungaricus
Kellnerites sp.
Te
Td
Tc
Tbc
Tbb
Tb-tuffs
Tba
Tac
Tab
Taa
Ta-tuffs
CG-tuffs
57
56
55
54
53
52
51
50
exposures of Prezzo Lst. corresponding to 43-50m-interval)
section continues to base of Prezzo Lst. (= 0-m-level)

Fig. 5a

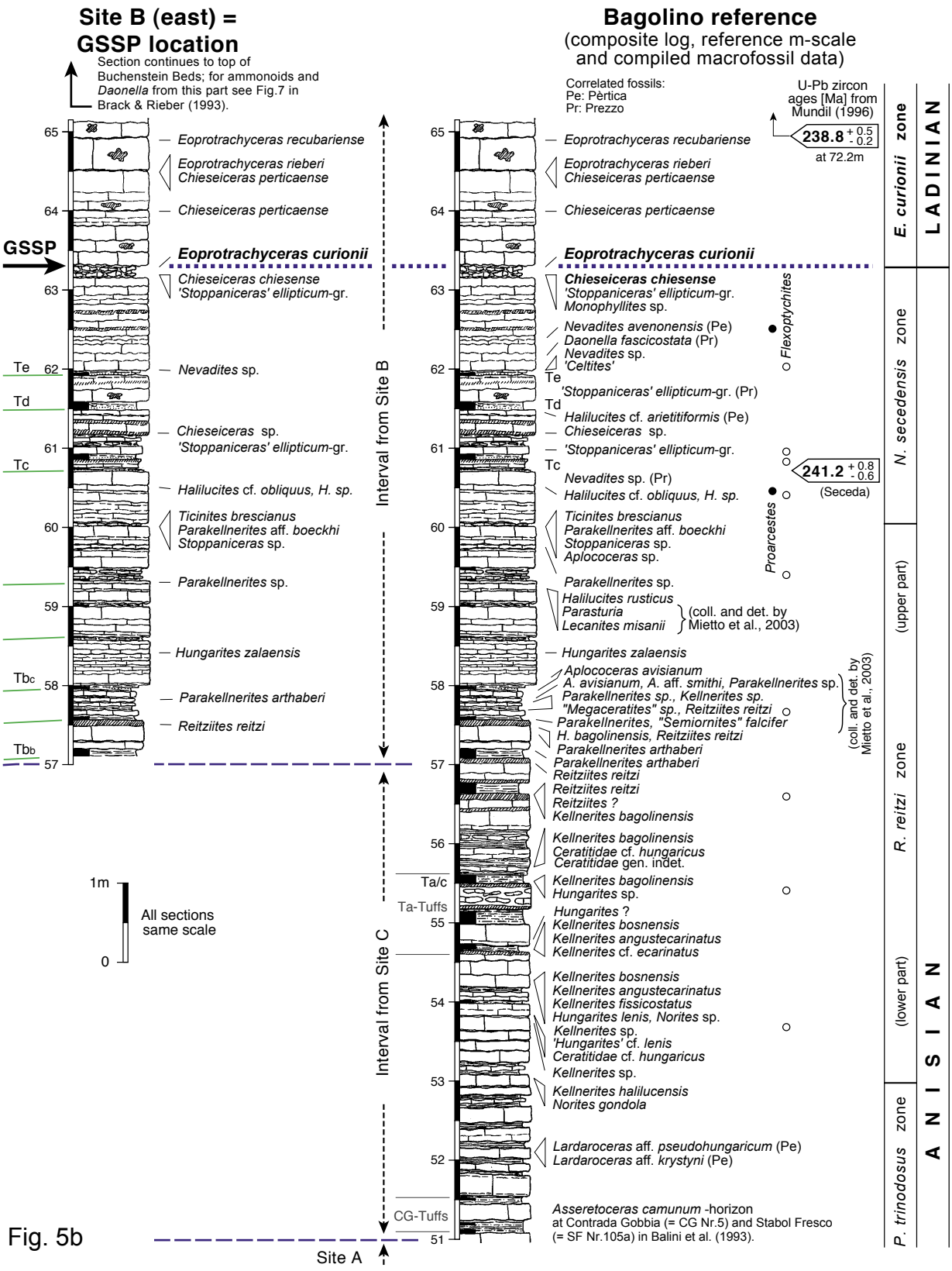

Fig. 5b

Figure 5a,b: Detailed stratigraphic logs with distribution of ammonoids in intervals around the Anisian/ Ladinian boundary at sites A-D and resulting composite log with integrated age information for Bagolino. Specific volcaniclastic marker beds used for bed-by-bed correlation are indicated and labelled. The designated GSSP-section is at Site B (eastern end), i.e. at the base of the *curionii* zone corresponding to the top of a distinctly recessive weathered interval with limestone nodules in a shaly matrix ("*Chiesense* groove").

clay content at the base of the Buchenstein Beds suggests a decrease of the sedimentation rate from moderately high values in the Prezzo Limestone to low values in the Buchenstein Beds. On the basis of isotopic age constraints, the average sedimentation rates in the (non-decompacted) siliceous pelagic nodular limestone of the Buchenstein Beds in the Dolomites are estimated to be in the order of 10m/m.y. (Brack & Muttoni, 2000). In comparison with the Dolomites the thickness of corresponding intervals of Buchenstein Beds in sections of eastern Lombardy (including Bagolino) and Giudicarie is reduced by 40-50% and the rates of sedimentation are accordingly lower. The layers with predominantly airborne volcaniclastic material obviously represent short-lived deposition on the scale of duration of volcanic eruptions. The siliciclastic Wengen Beds again represent rapid sediment accumulation.
In spite of the somewhat reduced thickness of the Anisian/Ladinian boundary interval at Bagolino its ammonoid record seems to be exceptionally complete (Fig.5).

Adequate thickness and stratigraphic extent
The entire pelagic succession exposed at Bagolino (Fig.3) is more than 100m thick and ranges in age from the middle/late Anisian to the late Ladinian. Ammonoid faunas of the *balatonicus* zone and from a stratigraphic level corresponding to the Brachiopod Bed at Bagolino are known from Giudicarie (e.g., Balini et al., 1993; Brack et al., 1999). The Prezzo Limestone at Bagolino bears ammonoids from the *Judicarites*-horizon upwards. Nearby sections of Prezzo Limestone (e.g., Stabol Fresco, Contrada Gobbia; see Balini et al., 1993; Balini, 1998) bear one of the richest ammonoid faunas reported so far for the *trinodosus* zone in Western Tethys. At Bagolino the ammonoid record shows a particularly high resolution in the *reitzi, secedensis* and *curionii* zones. Ammonoids and *Daonella* are known from the upper Buchenstein and from the Wengen Beds, with representatives of *Frankites* (*regoledanus* zone) being the youngest ammonoids found to date.
In the Southern Alps and beyond, the Bagolino section is thus arguably one of the most extensive not condensed and macrofossil-bearing Middle Triassic succession known so far. Moreover, the Anisian/Ladinian boundary interval at Bagolino (i.e. the interval corresponding to 51-65m of the reference scale; Fig.5) is the only place in the realm of western Tethys where, in a single section, all levels discussed as potential Anisian/Ladinian boundary have been identified on the basis of ammonoids (Fig.6b)!
Comparable sections elsewhere in the Southern Alps are either condensed (e.g., Clap di Val: see Mietto & Manfrin, 1995), show a much lower number of ammonoid horizons (e.g., Seceda, Margon / Val Gola; Fig.6a) or have a limited stratigraphic range (e.g., M.S.Giorgio; Fig.6b) and/or a punctuated fossil record in non-pelagic settings (e.g., storm-layers in the plaform-interior carbonate succession at Latemar; e.g. Mundil et al., 2003; Manfrin et al., in press).

Provisions for conservation and protection
The existence of exposures of Buchenstein Beds south of the village of Bagolino (Site B) was indicated by Bittner (1881). Mariani (1906) documented the first ammonoids from these beds. This is sufficient guarantee for a long persistence of the natural exposures in the Caffaro river bed. Moreover, a good portion of the outcrop surface is periodically cleaned by high river waters.
The authorities of Bagolino are prepared to maintain and label an easy access to the river bed of the main outcrop (Site B) and to fix appropriate posters with information also for the public.

OTHER USEFUL SECTIONS

Stratigraphic results from the most relevant South Alpine sections complementary to Bagolino and of significance for the definition of the base of the Ladinian Stage are shown in Figure 6a,b.
New stratigraphic data are now also available from a multidisciplinary study of the Seceda core (Brack et al., 2000). So far these efforts have resulted in a detailed sedimentological characterisation of Buchenstein lithologies (Maurer & Schlager, 2002) as well as in detailed information on its magnetostratigraphy and conodonts (Muttoni et al., 2004). For the GSSP here proposed, Seceda is therefore the principal auxiliary section, mainly because it adds magnetostratigraphy, isotope and complementary conodont data to the information from Bagolino. However, the stratigraphic range and number of macrofossil levels known from Seceda is clearly inferior to the resolution of the fossil record in the proposed GSSP-section at Bagolino (Fig.6a,b).

PRIMARY AND SECONDARY MARKERS

Principal correlation event (marker) at GSSP level

The proposed GSSP-level at Bagolino is defined with the first appearance of the ammonoid genus *Eoprotrachyceras*, i.e. with the species *Eoprotrachyceras curionii* (MOJS.) as indicated above. In all sections studied thoroughly in eastern Lombardy (including Bagolino) and Giudicarie *E. curionii* occurs in a single layer. To date there is no evidence for the occurrence of older representatives of the genus *Eoprotrachyceras*.

In western Tethys *E. curionii* is thus the oldest known representative of the genus *Eoprotrachyceras* and marks the onset of the family Trachyceratidae. The genus '*Anolcites'* shares some morphological characters with, and its FAD predates that of *Eoprotrachyceras*. However, the stratigraphically oldest representatives of *'Anolcites'* seem to be descendants of *Nevadites,* which is considered to belong to the Ceratitidae (Tozer, 1994a; Rieber & Brack 2002).

The proposed GSSP-level allows an excellent correlation of sections not only in the Southern Alps but also the recognition of a corresponding level in Greece (Epidavros). Representatives of the genus *Eoprotrachyceras* have been reported from numerous places including the Triassic successions in North America (Nevada, British Columbia) and is therefore a suitable marker for trans-Panthalassan correlation.

The narrow interval with *Chieseiceras chiesense* immediately below the layer with *E. curionii* is another most suitable marker for correlation of sections in the Southern Alps and Greece.

Other stratigraphy

Biostratigraphy

Other Ammonoids and definition of ammonoid zones

Apart from the macrofossils mentioned above and proposed for the collocation of the GSSP, the record of ammonoids is particularly well established also above and below the GSSP-level. Within the Brescian Prealps and Giudicarie firm correlations are evident for ammonoids with a short range such as *Eoprotrachyceras recubariense, E. rieberi, Chieseiceras perticaense* above, and the last Ceratitidae ('*Stoppaniceras' ellipticum*-gp.), *Nevadites* and *Ticinites* below the GSSP-level (Brack & Rieber, 1986, 1993; Brack et al., 1995). The fossil record below the layers with *Ticinites* provides an excellent correlation of sections in the Southern Alps with those in Hungary (Figs.6,8).

The ammonoid zones referred to in this proposal are understood as assemblage zones and are named after a typical ammonoid species. Following Brack & Rieber (1993, 1994) and Rieber & Brack (2002) the base of the *reitzii* zone (= *Reitziites reitzi* zone) is defined by the FAD of the genus *Kellnerites*, the base of the *secedensis* zone (= *Nevadites secedensis* zone) by the FAD of the genus *Ticinites* and the base of the *curionii* zone (= *Eoprotrachyceras curionii* zone) by the FAD of the genus *Eoprotrachyceras* respectively. In western Tethys the genus *Eoprotrachyceras* is the oldest representative of the ammonoid family Trachyceratidae. Note, however, that alternative schemes with ammonoid zones and subzones proposed for the Anisian/Ladinian boundary interval differ from these definitions. Until recently (e.g., Vörös et al., 1996; Vörös, 1998) the Hungarian stratigraphers used a corresponding *reitzi* zone (including four subzones, named *felsoeoersensis, liepoldti, reitzi, avisianum*) with its base placed at the FAD of *Kellnerites*. However, without a specific explanation, Vörös et al. (2003) have reduced the range of the *reitzi* zone to only comprise the *reitzi* and *avisianum* subzones. The scheme of ammonoid zones and subzones used by Mietto et al. (2003a,b) refers to a succession of the following subzones: *reitzi*, *avisianum, crassus*. In this scheme the *reitzi* and *avisianum* subzones largely correspond to the lower and upper parts of our *R. reitzi* zone respectively. With respect to Mietto & Manfrin (1995), the base of the *crassus* subzone (lowermost subzone of their *Nevadites* zone) is redefined by Mietto et al. (2003a,b) with the FAD of *Halilucites*, i.e. at a level slightly above the 59m-level of the Bagolino reference scale but clearly below the base of the *secedensis* zone at the 60m-level.

Conodonts

Conodont data are available from Bagolino (Nicora & Brack, 1995; Brack & Nicora, 1998) and closely correlated sections (Pèrtica, Brozzo: Nicora & Brack, in prep.; Stabol Fresco: Kovács et al., 1990 and updates). New results from the Dolomites (Muttoni et al., 2004) provide a significant

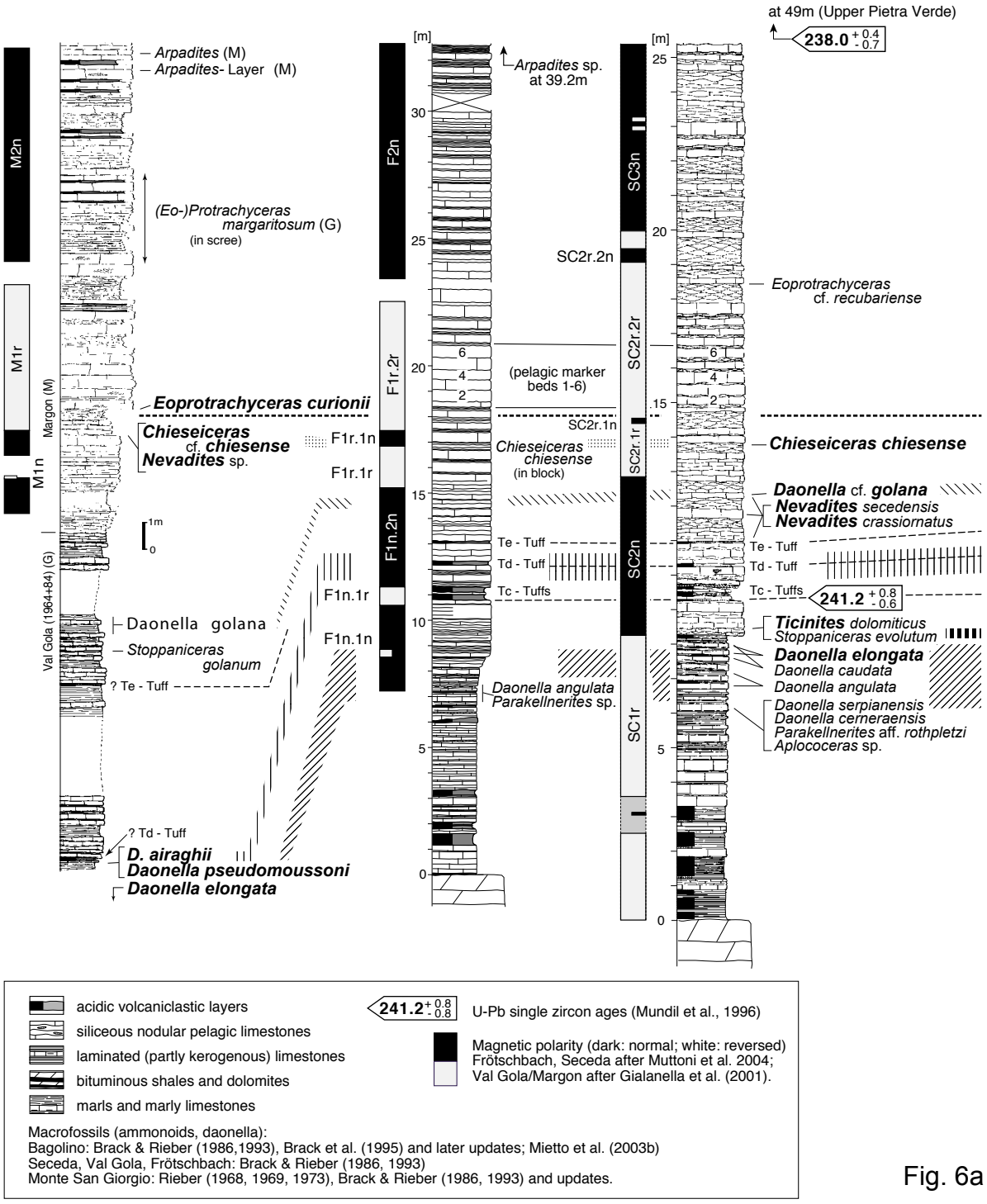

Fig. 6a

Figure 6a,b: Compilation of important stratigraphic results from correlated South Alpine sections in the Anisian/Ladinian boundary interval (updated after Brack et al., 2001) with indication of lithological markers (volcaniclastic layers, bedding patterns), magnetic reversals, isotopic age data and the ranges of macrofossils (ammonoids, *Daonella*). The Seceda section is the main auxiliary section in the Dolomites. The correlation of key fossils and the proposed GSSP-level at the base of the *curionii* zone are highlighted. Also shown is the correlation with the zonal scheme and important fossil horizons of the Balaton Highland (Felsöörs; Vörös et al., 2003). Triangles with numerals mark the positions of various proposals for the base of the Ladinian Stage: 1-3 correspond to the GSSP-proposals in Albertiana 28; 1b and 2b are older alternatives.

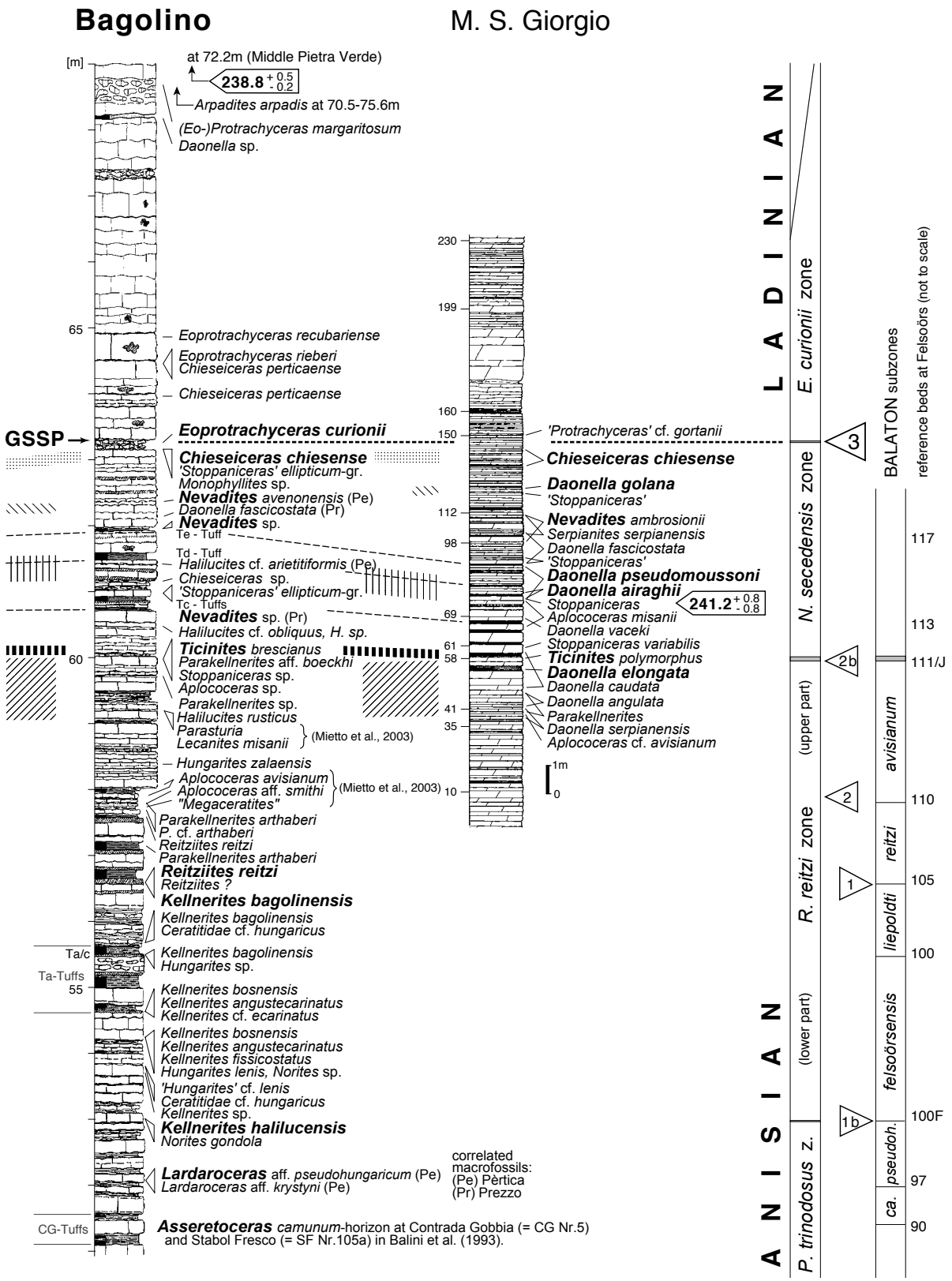
Bagolino
M. S. Giorgio
[m]
at 72.2m (Middle Pietra Verde)
238.8 +0.5 -0.2
Arpadites arpadis at 70.5-75.6m
(Eo-)Protrachyceras margaritosum
Daonella sp.
65
Eoprotrachyceras recubariense
Eoprotrachyceras rieberi
Chieseiceras perticaense
Chieseiceras perticaense
GSSP
Eoprotrachyceras curionii
Chieseiceras chiesense
'Stoppaniceras' ellipticum-gr.
Monophyllites sp.
Nevadites avenonensis (Pe)
Daonella fascicostata (Pr)
Nevadites sp.
Te - Tuff
Td - Tuff
Halilucites cf. arietitiformis (Pe)
Chieseiceras sp.
'Stoppaniceras' ellipticum-gr.
Tc - Tuffs
Nevadites sp. (Pr)
Halilucites cf. obliquus, H. sp.
60
Ticinites brescianus
Parakellnerites aff. boeckhi
Stoppaniceras sp.
Aplococeras sp.
Parakellnerites sp.
Halilucites rusticus
Parasturia
Lecanites misanii
(Mietto et al., 2003)
Hungarites zalaensis
Aplococeras avisianum
Aplococeras aff. smithi
"Megaceratites"
(Mietto et al., 2003)
Parakellnerites arthaberi
P. cf. arthaberi
Reitziites reitzi
Parakellnerites arthaberi
Reitziites reitzi
Reitziites ?
Kellnerites bagolinensis
Kellnerites bagolinensis
Ceratitidae cf. hungaricus
Ta/c
Kellnerites bagolinensis
Hungarites sp.
Ta-Tuffs
55
Kellnerites bosnensis
Kellnerites angustecarinatus
Kellnerites cf. ecarinatus
Kellnerites bosnensis
Kellnerites angustecarinatus
Kellnerites fissicostatus
Hungarites lenis, Norites sp.
'Hungarites' cf. lenis
Ceratitidae cf. hungaricus
Kellnerites sp.
Kellnerites halilucensis
Norites gondola
Lardaroceras aff. pseudohungaricum (Pe)
Lardaroceras aff. krystyni (Pe)
correlated macrofossils:
(Pe) Pèrtica
(Pr) Prezzo
CG-Tuffs
Asseretoceras camunum-horizon at Contrada Gobbia (= CG Nr.5) and Stabol Fresco (= SF Nr.105a) in Balini et al. (1993).
230
199
160
150
112
98
69
61
58
41
35
10
'Protrachyceras' cf. gortanii
Chieseiceras chiesense
Daonella golana
'Stoppaniceras'
Nevadites ambrosionii
Serpianites serpianensis
Daonella fascicostata
'Stoppaniceras'
Daonella pseudomoussoni
Daonella airaghii
Stoppaniceras
241.2 +0.8 -0.8
Aplococeras misanii
Daonella vaceki
Stoppaniceras variabilis
Ticinites polymorphus
Daonella elongata
Daonella caudata
Daonella angulata
Parakellnerites
Daonella serpianensis
Aplococeras cf. avisianum
1m
0
LADINIAN
ANISIAN
E. curionii zone
N. secedensis zone
(upper part)
R. reitzi zone
(lower part)
P. trinodosus z.
3
2b
2
1
1b
BALATON subzones
reference beds at Felsoörs (not to scale)
avisianum
reitzi
liepoldti
felsoörsensis
pseudoh.
ca.
117
113
111/J
110
105
100
100F
97
90

Fig. 6b

extension of the conodont record reported earlier for Frötschbach (Muttoni et al., 1996, 1997).
Figure 7 shows the conodont distribution at Bagolino and compiled data from additional sections accurately correlated with Bagolino on the basis of bio- and lithostratigraphy.
In the Anisian/Ladinian boundary interval, the most significant "conodont events" are the following: (1) Close to the base of the *reitzi* zone, *Neogondolella cornuta postcornuta* and the group of *Paragondolella alpina* appear among other taxa; (2) In the upper *reitzi* zone, *Neogondolella pseudolonga, Paragondolella fueloepi* and *Paragondolella trammeri* appear for the first time; (3) In the upper part of the *secedensis* zone, *Neogondolella praehungarica* appears together with a precursor form of *Budurovignathus gabriellae* provisionally referred to here as *Neogondolella* sp. A; (4) *Budurovignathus truempyi* and *B. hungaricus* occur in layers corresponding to the 66m-level of the Bagolino reference column or higher up.
The appearance of *N. praehungarica* and its co-occurrence with *P. fueloepi* in the upper part of the *secedensis* zone, just below the proposed GSSP-level, seems at present to be the only suitable marker for conodont-based correlation with data from Nevada and British Columbia (Bucher & Orchard, 1995; Orchard & Tozer, 1997).

Daonella
Only a few well preserved specimens of the biostratigraphically relevant thin shelled bivalves *Daonella* have been extracted from the Anisian/ Ladinian boundary interval in sections around Bagolino. Of these, *Daonella fascicostata* was found in the upper *secedensis* zone just above the Te-tuff layer at Prezzo. Figure 6a,b highlights the close match of the distribution of *Daonella* in other South Alpine sections. In particular, the levels with representatives of the group of *Daonella elongata (D.serpianensis-angulata-caudata-elongata-airaghii)* at M.S.Giorgio, Seceda and Val Gola are in excellent agreement. Because of the occurrence of undisputed representatives of the *D. elongata*-group in China (*D.* cf. *airaghii*) and in the *meeki* zone of Nevada (*Daonella* cf. *elongata;* Silberling & Nichols, 1982 and new unpublished own finds), these bivalves are of particular interest for far reaching correlation.
No determinable *Daonella* are known so far from the *curionii* zone. Higher up, different species of *Daonella* are precisely located in layers of the middle (*D.* cf. *longobardica, D. moussoni*) and upper Buchenstein Beds *(D. taramellii, D. pichleri, D. tyrolensis)* at Bagolino, M. Corona and Seceda (Brack et al., 2000; Schatz, 2001a,b; Maurer & Rettori, 2002).

Radiolarians
Numerous, but hitherto unreported species of radiolarians have been detected in samples from Buchenstein Beds from Seceda and Frötschbach (H. Kozur, pers. commun.). Of these, the radiolarians from the uppermost Plattenkalke with *Daonella* of the *elongata*-group (lower Buchenstein Beds; Fig.6) can be attributed to the *Oertlispongus inaequispinosus* subzone (upper *Spongosilicarmiger italicus* Zone). In agreement with the correlation based on macrofossils (Seceda-Bagolino, Bagolino-Felsöörs; Figs.6 and 8), at Felsöörs (Fig.8) this radiolarian subzone comprises the layers 110-111C (Vörös et al., 2003). This radiolarian subzone is known throughout the Tethys and has also been recognised in radiolarites of Panthalassa (Japan, Philippines) thus allowing a correlation with ammonoid-free and mostly conodont-free low latitude oceanic radiolarite successions.
The most complete available uppermost Anisian to lower Ladinian radiolaria succession (beginning with the *reitzi* zone) is known from the Recoaro area (Kozur & Mostler, 1994). However, for the stratigraphic interval above the *reitzi* zone this succession lack a detailed ammonoid calibration.

Palynomorphs
First results on palynomorphs from Buchenstein Beds of the Seceda core (Dolomites) along with revised data from Val Gola suggest a distinct change in the microflora between assemblages observed in the Lower Plattenkalke (upper *reitzi* zone) and in the Knollenkalke corresponding to the upper *curionii* zone (Hochuli & Roghi, 2002).

Magnetostratigraphy
Samples taken for magnetostratigraphic analysis at Bagolino show remagnetised Tertiary components (G. Muttoni, pers. commun.). However, the succession of magnetic reversals is well established for almost the entire succession of Buchenstein Beds in correlated sections in the Dolomites (Muttoni et al., 1996, 1997, 2004; Brack & Muttoni 2000) and at Val Gola (Gialanella et al.,

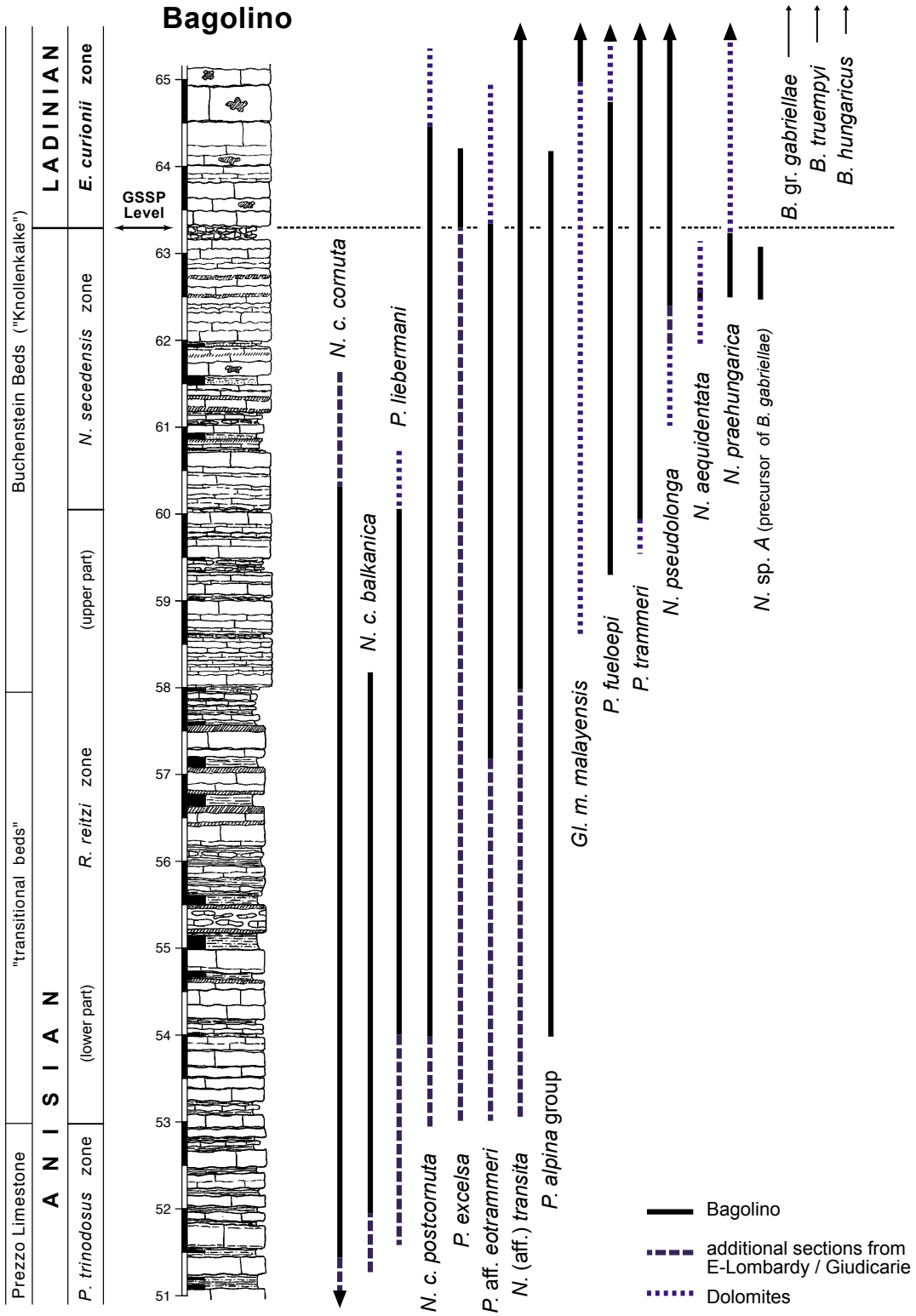

Figure 7: Detailed stratigraphic log of the Anisian/Ladinian boundary interval at Bagolino with the distribution of conodonts. Average sample spacing is around 18cm above and 50cm below the 58m-level respectively (for details see Brack & Nicora, 1998). Also shown are correlated complementary data from additional sections in eastern Lombardy (Brozzo, Pèrtica) and Giudicarie (Stabol Fresco) as well as in the Dolomites.

2001; see also discussion by Brack et al., 2001). In this record of magnetic reversals (Fig.6a), the proposed GSSP-level lies close to the base of the reversed magnetozone SC2r.2r at Seceda and correlative magnetozones F1r.2r, P2r, M1r, at Frötschbach, Pedraces and Margon respectively. This magnetozone is preceded by the short normal polarity interval SC2r.1n (corresponding to Fr1r.1n and P2n).

The new data from the Seceda core (Muttoni et al., 2004) not only confirm the previous results but also provide a stratigraphic expansion of this record. Remarkable is the existence of a long zone of reversed polarity in the Lower Plattenkalke below the base of the *secedensis* zone (*Ticinites* horizon). The comparison with the Hungarian data as reported in Vörös et al. (2003) casts doubts on the reliability of a long normal polarity interval in the corresponding interval at Felsöörs (upper part of Vàszoly Fm.).

Chemical stratigraphy

No systematic studies on stable isotopes and other chemical markers are available for Bagolino. Unpublished results of a pilot study of stable isotopes (C, O) on 30 outcrop samples evenly distributed over the entire succession of Buchenstein Beds at Seceda show lithology-related variation in the carbon isotopes (R. Abart, pers. commun.). Throughout the entire column no significant excursion is evident in the oxygen isotopes with a mean value of $\partial^{18}O$(PDB) of -2.82+/-0.78‰. $^{87}Sr/^{86}Sr$-ratios of conodonts from the *secedensis* to *curionii* zone interval in equivalent Buchenstein-type lithologies (Knollenkalke) in Hungary (Felsöörs, Köveskal) fall in the range between 0.707664-0.707716, with a tendency of (stratigraphically) upwards decreasing values (Korte et al., 2003).

Sequence stratigraphy

The deposition of the pelagic Buchenstein Beds occurred in deep marine conditions. The age calibration of platform-basin settings in the Dolomites (Maurer 1999, 2000; Brack & Muttoni, 2000) indicates a maximum basin depth close to the base of the *curionii* zone (i.e. close to the proposed GSSP-level). Comparison of the pelagic successions of the Southern Alps with the Germanic Middle Triassic suggests that the "Cycloides gamma"-horizon identified as a maximum flooding surface in the Germanic realm (Aigner & Bachmann, 1992) may indeed correspond to a level at around or just above the base of the *curionii* zone (Brack et al., 1999).

Cycle stratigraphy

No cyclostratigraphic data are available for Bagolino.

The spectral analysis of bedding rhythms in distinct intervals of Buchenstein Beds of the Seceda core and section (Maurer et al., in press.) may point to the existence of hierarchical stacking patterns possibly related to variations in orbital parameters. If confirmed and extended, these results could potentially provide a significant refinement of the age resolution in the Knollenkalk-interval of the Buchenstein Beds, i.e. from the *secedensis* zone upwards and including the proposed GSSP-level.

Tephrastratigraphy

At Bagolino volcaniclastic layers occur in the uppermost Prezzo Limestone and throughout the entire Buchenstein succession as a few millimetres up to a few decimetres thick acidic ash beds often with a greenish colour ("Pietra verde"). In the Buchenstein Beds the volcaniclastic layers show increased frequencies in three stratigraphic intervals. Individual beds and characteristic stacks of layers can be traced over tens of kilometres and have been identified as far away as in the Dolomites and Southern Switzerland (Fig.6a,b; see also figs.7,10,11 in Brack & Rieber, 1993 and figs.2,3,11 in Brack & Muttoni, 2000) The lateral persistence of volcaniclastic layers points to an airborne origin of the silt to sand-sized ash particles, probably originating from eruption centres outside the present Southern Alps.

Beyond their occurrences in South Alpine basinal sediments and platform interior carbonates (e.g., at Latemar; Mundil et al., 2003), comparable volcaniclastic ash layers are well known and show potential for isotopic age dating and stratigraphic correlation in the Reifling Beds of the Eastern Alps as well as in sedimentary successions further afield (e.g., Hungary, Dinarids, Greece).

Geochronometry

High-resolution U-Pb age data obtained on single zircon grains from volcaniclastic layers are available for four distinct stratigraphic horizons in Buchenstein and corresponding layers at Bagolino, Seceda and M.S.Giorgio (Figs.3,5,6; Mundil et al., 1996; Brack et al, 1996). The proposed GSSP-

level is bracketed by the age values for the Tc-tuff interval (secedensis zone; SEC.22: 241.2+0.8/-0.6Ma and MSG.09: 241.2±0.8Ma; uncertainties at 95% confidence level) below and for a volcaniclastic layer with accretionary lapilli at the 72.2m-level of Bagolino (BAG.06a: 238.8+0.5/-0.2Ma) above. Sanidine Ar-Ar data (239.3±0.6Ma, obtained by incremental CO_2 laser heating of approximately 100 grains; Renne et al., in prep.) of the lower level (secedensis zone) with U-Pb data at M.S.Giorgio conform with the ca. 1% age bias between the Ar-Ar and U-Pb geochronometric systems (e.g., Min et al., 2000). Moreover, the error bars of the zircon ages of this level overlap with multigrain U-Pb-ages from stratigraphically somewhat older tuff layers at Felsöörs (Pálfy et al., 2003; Vörös et al., 2003). An independent U-Pb zircon study on crystals from volcaniclastic layers in South Alpine Buchenstein sections (including Bagolino) yields results which are in agreement with the above mentioned U-Pb data (S. Bowring, pers. commun.).

Regional and global correlation

The accurate litho-, tephra- and biostratigraphic correlation of Anisian/Ladinian boundary intervals of sections in the Brescian Prealps (including Bagolino) and Giudicarie has been discussed above. With a comparable bed-scale resolution, distinct intervals of Buchenstein Beds in the Dolomites have been correlated on the basis of stratal patterns and magnetostratigraphy (Brack & Muttoni, 2000; Muttoni et al., 2004). Selected key sections from these areas and Southern Switzerland are shown in Fig.6a,b and comprise the most important macrofossils, magnetic reversals and lithostratigraphic markers (see Brack & Rieber, 1993; Brack et al., 2001 for additional information and references).

The comparison of ammonoids also documents a good correspondence of fossils (ammonoids, conodonts) below the *Ticinites* horizon at Bagolino and in the Balaton Highland (e.g., Felsöörs; Figs.6b,8). The apparent expansion of the stratigraphic interval of the *reitzi* zone at Felsöörs (Vörös, 1998; Vörös et al., 2003) is due to dilution with abundant volcaniclastic material. The cumulative thickness of fossil-bearing limestone layers is comparable in both sections (Fig.8). The proposed GSSP-level (i.e. the base of *curionii* zone) has not yet been identified at Felsöörs.

The ammonoid records straddling the Anisian/Ladinian boundary at Bagolino and in the condensed section of red Hallstatt-type limestone at Epidavros (Krystyn, 1993; unpublished own data) are also in good agreement (e.g., representatives of *Kellnerites, Nevadites, Chieseiceras, Eoprotrachyceras, Arpadites*). The proposed GSSP-level can be identified but the comparison also suggests particularly strong condensation in the *curionii* zone interval at Epidavros.

The correlation of South Alpine pelagic successions (including Bagolino) with the Germanic Middle Triassic is discussed in Brack et al. (1999). A detailed fossil-based correlation is hampered by endemism of the faunas in the Germanic upper Muschelkalk. The resulting old correlation problem might be overcome in future by the recognition of corresponding magnetic reversals in Muschelkalk successions. To date, magnetostratigraphic results are available only for an incompletely preserved succession of upper Muschelkalk in Poland (Navrocki & Szulc, 2000). This record ends presumably at around the proposed GSSP-level.

Correlations of South Alpine sections with sediment successions in North America are discussed in Brack & Rieber (1994) and Bucher & Orchard (1995). In the Anisian/Ladinian boundary interval the correlation is established on the basis of corresponding ammonoid genera (*Nevadites, Eoprotrachyceras*), *Daonella* (*D. elongata*-gp.) and conodonts (*N. constricta* + *N. alpina, N. praehungarica, P.* (aff.) *fueloepi*). These elements document the close correspondence of the interval upper *reitzi* zone - *curionii* zone of western Tethys with the upper part of the *meeki* zone - lower *subasperum* zone of Nevada. In North America (Nevada, British Columbia) the proposed GSSP-level is recognised by the onset of representatives of the genus *Eoprotrachyceras*. Tozer (1994b) emphasized that a base of the Ladinian at a stratigraphically deeper level would be unrecognizable in British Columbia. Because of the affinities of ammonoids with those of the Arctic and also with those of Nevada, the Triassic successions of northeastern British Columbia are of crucial importance for the biostratigraphic link with the Arctic Middle Triassic (Dagys & Weitschat, 1993). Nevertheless, a precise macro- and microfossil-based correlation of upper Anisian to lower Ladinian successions at low latitudes and in the Arctic realm are still problematic and magnetostratigraphy has to our knowledge not been established with sufficient detail in

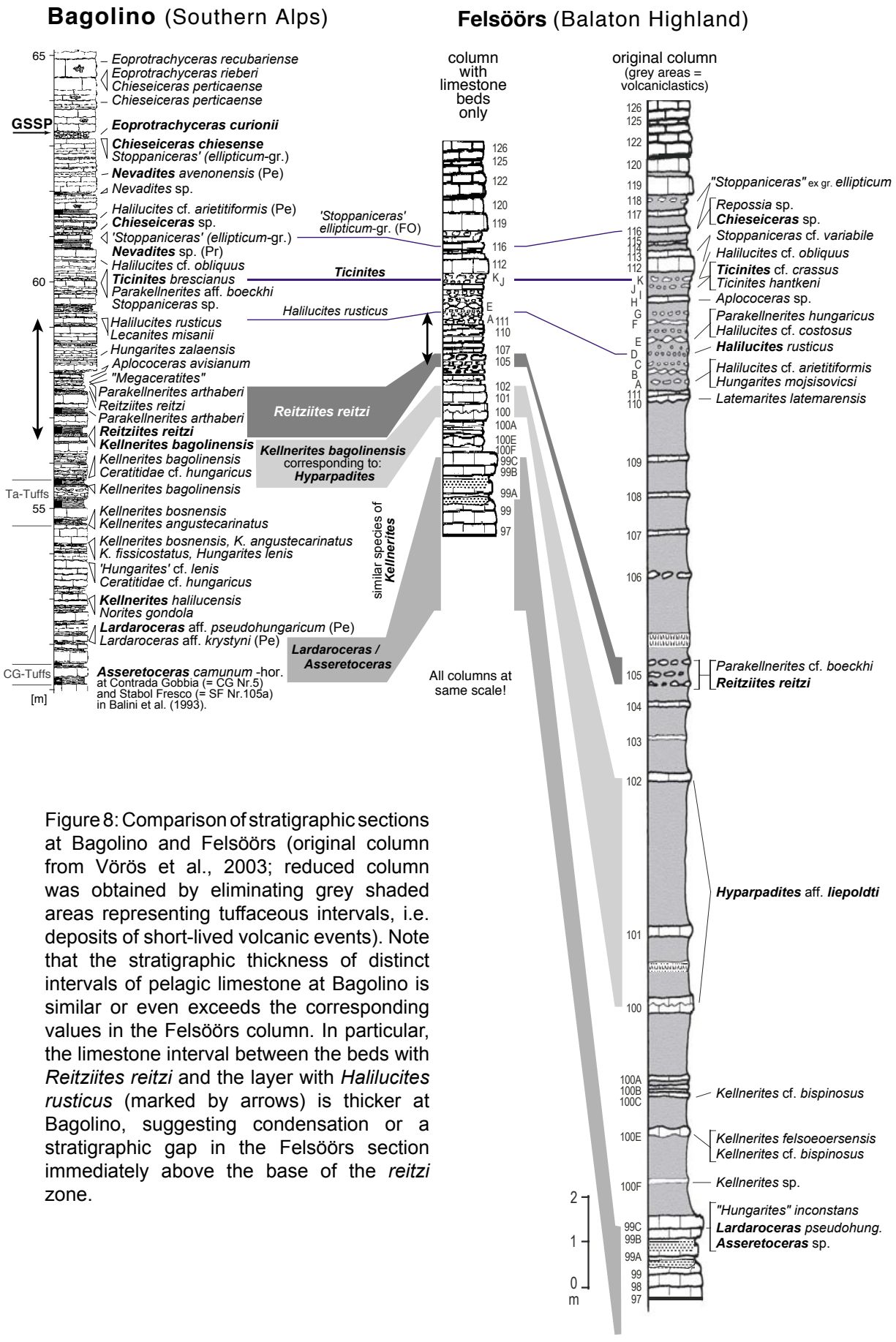

Figure 8: Comparison of stratigraphic sections at Bagolino and Felsöörs (original column from Vörös et al., 2003; reduced column was obtained by eliminating grey shaded areas representing tuffaceous intervals, i.e. deposits of short-lived volcanic events). Note that the stratigraphic thickness of distinct intervals of pelagic limestone at Bagolino is similar or even exceeds the corresponding values in the Felsöörs column. In particular, the limestone interval between the beds with *Reitziites reitzi* and the layer with *Halilucites rusticus* (marked by arrows) is thicker at Bagolino, suggesting condensation or a stratigraphic gap in the Felsöörs section immediately above the base of the *reitzi* zone.

Arctic intervals. Conversely, the correlation of stratigraphic sequences between low and high latitude successions still lacks sufficiently precise age control.

Elsewhere, fossiliferous pelagic sediment successions straddling the Anisian/Ladinian boundary seem to be quite rare. At present we are unaware of successions with appropriate records of either ammonoids, *Daonella* or conodonts. Himalayan successions (e.g. Spiti) seem not to bear ammonoids attributable to the upper *secedensis* to *curionii* zone. *Daonella* and/or ammonoids of this interval presumably occur in places throughout south-east Asia (e.g., Vietnam) but hitherto lack appropriate stratigraphic and paleontologic documentation. *Daonella*-bearing marine sediments of Middle Triassic age and from higher-paleolatitudes are known from volcaniclastic-rich successions in New Zealand.

If confirmed and properly positioned with respect to the proposed GSSP-level, the distinct change in microflora assemblages observed between the upper *reitzi* zone and the upper *curionii* zone in Seceda and associated sections (Hochuli & Roghi, 2002) may have potential for correlation of marine and non-marine sections of comparable climate zones.

OTHER CANDIDATES AND REASONS FOR REJECTION

Two alternative formal proposals for the GSSP of the base of the Ladinian Stage have been published in Albertiana 28 (marked 1 and 2 in Fig.6b).

Vörös et al. (2003) advocate a GSSP at the base of the *reitzi* zone with a repositioned base, i.e. at layer 105 in the Felsöörs section. Unambiguous specimens of *Reitziites reitzi* have been documented so far only from Hungary and from the Southern Alps. Moreover, no species assigned to *Reitziites* have as yet been indicated from sections in North America or Canada. Therefore we consider the distribution of *Reitziites* as being too restricted and unsuitable for a GSSP definition. Finally, the comparison of the Felsöörs section with the Bagolino column (Fig.8) documents the existence of a strongly condensed or even incomplete interval immediately above the *Reitziites* horizons at Felsöörs.

Mietto et al. (2003b) propose the GSSP at the base of their *avisianum* subzone at Bagolino. For reasons given in Brack & Rieber (2003) we still consider the species of *Aplococeras* as bearing too few distinctive characters for a ready identification. In agreement with Silberling & Nichols (1982), we repeat our conviction that the Tethyan ammonoid *A. avisianum* and the North American *Lecanites vogdesi* are not co-specific. Unfortunately, Site C proposed by Mietto et al. (2003b) as GSSP-section at Bagolino is now partly covered by a recent landslide.

Older alternatives for the Anisian/Ladinian boundary are indicated in Fig.6b (1b and 2b) but have been rejected for similar reasons, i.e. the restricted distributions of key taxa (*Kellnerites, Ticinites*) used in their definitions.

Acknowledgments:

We would like to thank all people involved in the long process of defining the base of the Ladinian for stimulating discussions and scientific and moral support. In 1993, M. Gaetani initiated the formal discussion and decision process. Later on A. Baud led the Anisian/Ladinian boundary working group whose discussions significantly contributed to the current proposal. STS-chairman Mike Orchard and ICS-officer James G. Ogg thoroughly reviewed this proposal.

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(Several key references describing aspects of the Bagolino stratigraphy are marked with an asteriks). Muttoni et al. (2004) provide the most up-to-date stratigraphic information on the auxiliary section at Seceda including the reference succession of magnetic reversals).

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