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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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Kapitel: 2: Middle Triassic stratigraphy and fossiliferous Anisian/Ladinian boundary sections

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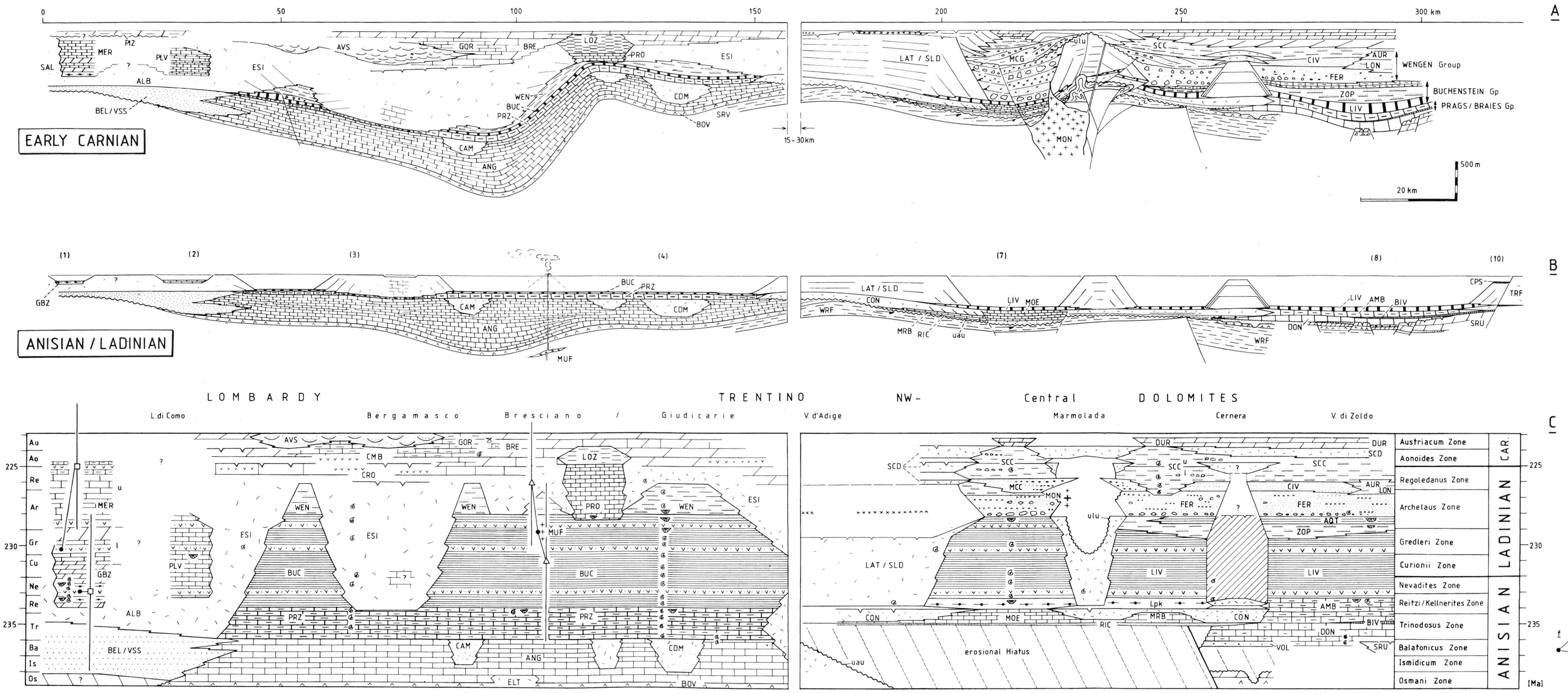
tions at different scales and periods do already exist from rocks of the South Alpine Middle Triassic.

Details on new and revised ammonoid and Daonella genera and species are presented in the paleontological part.

2. Middle Triassic stratigraphy and fossiliferous Anisian/Ladinian boundary sections

The Middle to Upper Triassic rocks of the Southern and Eastern Alps formed prior to the Late Triassic-Jurassic breakup of the western Tethys in a tectonically mobile framework of repeatedly uplifted and subsiding blocks to the south of central Europe. Heterogenous Anisian to Carnian stratigraphic successions (Fig. 2) and Triassic tectonic structures indicate distinct periods of volcanism and tectonism, the latter with both, compressional and extensional components. Strike-slip movements were suggested in plate reconstructions for the Triassic western Tethyan area (e.g. Brandner 1984; Ziegler 1989) and wrench fault systems are indeed apparent in parts of the Southern Alps (Doglioni 1984a). Nevertheless, the large-scale geodynamic context of Triassic movements throughout the Southern Alps and formerly adjacent areas still remains largely obscure. Both rift-related and subduction-related models have been proposed (for discussions see e.g. Bechstädt et al. 1978, Brandner 1984, Castellarin et al. 1988, Sloman 1989).

Fig. 2. A, B) Simplified reconstructions of the cross sectional stratigraphy along the northern sector of the Southern Alps (see Fig. 3b for the trace of the section).
C) Chronostratigraphic chart for the South Alpine Middle Triassic.
The compilation is based on numerous references most of which are mentioned in the text. Unclear stratigraphic relationships are deliberately left vague. Scales are only approximate. In the Lombardian sector the depocenter of the Angolo Limestone lies in fact 30 km south of the section. Scheme of ammonoid zones modified after Krystyn (1983) (new Reitzi/Kellnerites Zone). See text for information on time-scale.
(1)–(10): Projected positions of sections in Fig. 14.
Special symbols: a: biostratigraphic calibration points (ammonoids, Daonellas); b: volcanic rocks, megabreccias/olistoliths; c: supposed stratigraphic position of shallow intrusives (M. Muffetto, Monzoni/Predazzo); d: typical successions of volcaniclastic layers; e: tectonically induced "diapirs" (Late Ladinian tectonism) of Upper Permian to Lower Triassic strata (central Dolomites); f: stratigraphic positions (full symbol) and age values (open symbol) with 2 sigma error bars of radiometrically dated rocks (see text for references).
Formal and informal stratigraphic units (in alphabetical order; abbreviations used in Figs. 2 and 14): ALB: Albiga Dol.; AMB: Ambata Fm.; ANG: Angolo Lst.; AQT: Aquatona Fm.; AUR: Auronzo Fm.; AVS: Val Sabbia Sst.; BEL: Bellano Fm.; BIV: Bivera Fm.; BOV: Bovegno "Cargneules"; BRE: Breno Fm.; BUC: Lombardian "Buchenstein Beds"; CAM: Camorelli Lst.; CDM: Dosso dei Morti Lst.; CIV: Civetta Sst.; CMB: Metallifero Bergamasco Lst.; CON: Contrin Fm. (= Upper Sarl Dol. auct.); CPS: Clapsavon Lst.; CRO: "Calcare Rosso"; DMR: "Daonella Marls"; DON: Dont Fm.; DUR: Dürrenstein Dol.; ELT: Elto Dol.; ESI: Esino Lst.; FER: Fernazza Hyaloclastites; GBZ: Grenzbitumenzone; GOR: Gorno Fm.; Knk: "Knollenkalke" (= "Buchenstein Beds" p.p.); LAT: Latemar Lst.; LIV: Livinallongo Fm. (= "Buchenstein Beds" of Dolomites); LON: Longiarin Sst.; LOZ: Lozio Shales; Lpk: "Lower Plattenkalke" Mb. (= "Buchenstein Beds" p.p.); MAR: Margon Lst.; MCG: Marmolada Cgl.; MER: Meride Lst.; MOE: Moena Fm.; MON: Monzoni & Predazzo intrusives; MRB: Morbiac Lst.; MUF: Muffetto subvolcanic rocks; PIZ: Pizella Marls; PLV: Perledo-Varenna Lst.; PRO: Pratotondo Lst.; PRZ: Prezzo Lst.; RIC: Richthofen Cgl.; SAL: Salvatore Dol.; SCC: basinal San Cassian Fm. (l: lower, u: upper); SCD: San Cassian Dol.; SLD: Schlern Dol.; SPZ: M. Spitz Lst.; TRF: Tiarfin Dol.; Ubk: "Upper Bänderkalke" (= "Buchenstein Beds" p.p.); VCM: Val di Centa Marls; VGL: Val Gola Lst.; VOL: Voltago Cgl.; VSS: Valsassina Clastics; WEN: Lombardian "Wengen Beds"; ZOP: Zoppè Sst. Main unconformities resulting from tectonic uplift and erosion: uau: "Upper Anisian Unconformity"; ulu: "Upper Ladinian Unconformity".


A
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50
100
150
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250
300 km
SAL
MER
PIZ
PLV
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BEL/VSS
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PRO
WEN
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ANG
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15-30 km
LAT / SLD
MCG
ulu
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SCC
CIV
AUR
LON
FER
ZOP
LIV
WENGEN Group
BUCHENSTEIN Gp
PRAGS / BRAIES Gp.
500 m
20 km
EARLY CARNIAN
B
(1)
(2)
(3)
(4)
(7)
(8)
(10)
GBZ
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WRF
MRB
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CPS
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ANISIAN / LADINIAN
C
LOMBARDY
TRENTINO
NW-
Central
DOLOMITES
L.di Como
Bergamasco
Bresciano
/
Giudicarie
V. d'Adige
Marmolada
Cernera
V. di Zoldo
Au
Ao
Re
Ar
Gr
Cu
Ne
Re
Tr
Ba
Is
Os
225
230
235
CMB
CRO
ELT
SCD
DUR
MCC
AQT
Lpk
VOL
erosional Hiatus
Austriacum Zone
Aonoides Zone
Regoledanus Zone
Archelaus Zone
Gredleri Zone
Curionii Zone
Nevadites Zone
Reitzi / Kellnerites Zone
Trinodosus Zone
Balatonicus Zone
Ismidicum Zone
Osmani Zone
CAR.
LADINIAN
ANISIAN
[Ma]
a
b
c
d
e
f
Rb/Sr
K/Ar

The shoshonitic character of the igneous products is in conflict with a conventional rift model. No unambiguous reminders of Triassic oceanic crust or clearly subduction-related structural and sedimentological features have been reported from the Southern Alps or its original surroundings.

The South Alpine Anisian to Ladinian rocks originated during a long, overall transgression between a period of distinct sea-level lowstand in the basal Anisian and a period of multiple fluctuations in the Carnian. The overall transgressive trend was locally disturbed and overprinted by coeval volcanism and tectonic movements. As a result, a rapidly changing pattern of emergent areas, carbonate platforms, shallow marine shelves and pelagic basins evolved. This area lies to the north of an elongated "mobile belt", a site of repeated uplift and volcanism as documented from the subsurface of the Po plain (e.g. Brusca et al. 1981).

The area between Lombardy and the Dolomites includes the most important stratigraphic sections that will be discussed in this paper. The Anisian to Ladinian evolution of this sector shall therefore be rapidly outlined in a generalized and simplified way (Figs. 2, 3). No attempts have yet been made to restore the Alpine deformations although this would definitely improve the emerging picture of the Triassic paleogeography (for a rough sketch see Trümpy 1992). As a first approximation the strongly squeezed Lombardian sector has to be stretched and shifted by some 30–50 km (equivalent to the pre-43 Ma alpine shortening of the Lombardian Alps) in a northerly direction relative to the Dolomites. The transect of Fig. 2 was therefore approximately a straight line across the South Alpine realm during the Triassic.

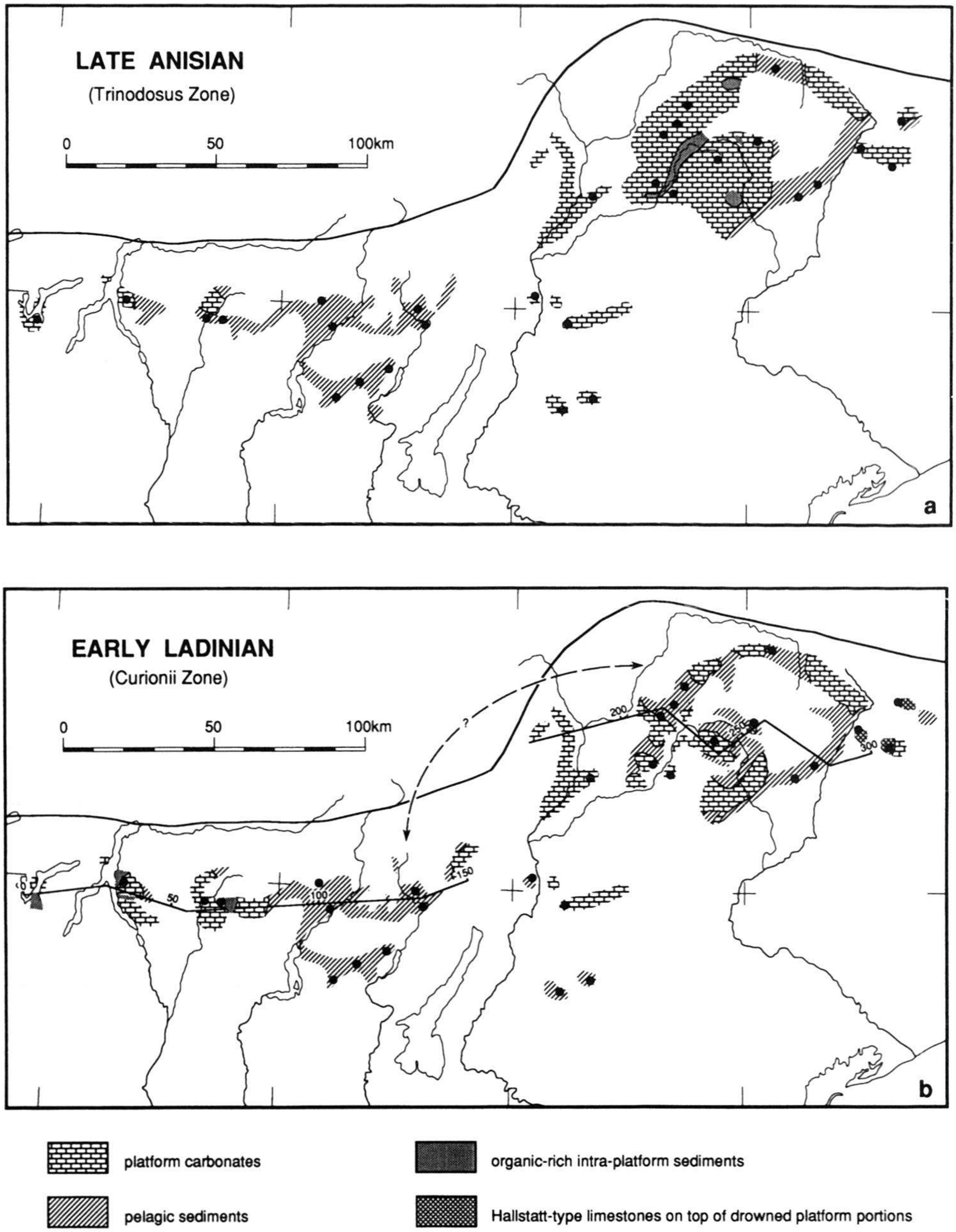
2.1. A few steps in the Anisian to Ladinian evolution

2.1.1. Early to Middle Anisian

Peritidal carbonates and mixed carbonate/evaporite deposits were laid down over most of the Southern Alps during a marked regression in the Early Anisian (Bovegno Cargneules, Lower Serla Fm.; e.g. De Zanche & Farabegoli 1982; Brandner 1984).

Monotonous successions of neritic and often nodular marly limestones (Angolo Lst.) interspersed with algal banks (Dosso dei Morti Lst. and equivalent shallow water carbonates) formed in the Middle Anisian in a shallow basin throughout eastern Lombardy. Pronounced thickness variations (50–700 m) in these shallow marine deposits clearly indicate tectonically controlled subsidence. Areas close to basin margins (Lake Como area, De Zanche & Farabegoli 1983; Gaetani et al. 1987; Recoaro/Tretto and Valsugana areas, De Zanche & Mietto 1981, 1989) still received clastic detritus with components from Permian and basement rocks.

In the eastern Dolomites carbonate platforms, flanked by shallow lagoons and tidal channels initially bordered a deepening, narrow basin (Pisa et al. 1978). In areas distant enough from the main clastic sources, basinal conditions persisted throughout most of the Anisian and Ladinian (Fig. 3a, b) as documented by a continuous pelagic succession of mixed siliciclastics and carbonates (Dont Fm., Bivera Fm., Ambata Fm., Daonella-Marls, Buchenstein Beds). Strata equivalent to the lower part of this succession might have extended into parts of the western Dolomites which were subject to erosion during Upper Anisian tectonic movements.



Figs. 3a, b. Actual distribution of basinal successions and platform carbonates in the Anisian/Ladinian boundary interval (area of Dolomites after Gaetani et al. 1981). The approximate trace of cross section Fig. 2 is indicated in Fig. 3b. Note that basinal conditions persisted throughout the Late Anisian into the Ladinian only in two areas: a wide basin in eastern Lombardy and a narrow N-S trending depression in the eastern Dolomites. A northern connection may have existed between these areas possibly via the Reifling and similar basins in the Northern Calcareous Alps or other areas inbetween (? Bakony).
Black dots mark the fossil localities indicated in Fig. 1.

2.1.2. Late Anisian to Early Ladinian

From late Middle Anisian time a large area of the western Dolomites was tilted (westward-dipping) and up to 400 m of strata, mainly of the Werfen Fm., were removed (Bosellini 1968; Brandner 1984). This erosional surface is unconformably covered by a thin sheet of fluviatile clastics (Peres Beds, Richthofen Cgl.). The resumption of subsidence allowed subtidal algal banks to build up and advance laterally over neritic limestones (Morbiac Lst.). The shallow water carbonates finally coalesced to a vast platform (Contrin Fm.) with some narrow basinal fingers or ponds (Moena Fm.; Masetti & Neri 1980). A more or less coherent platform may have ultimately reached to the south as far as the Recoaro/Tretto area (Monte Spitz Lst.; Fig. 3a).

The drowning of Anisian carbonate platforms in the Lombardian and eastern adjacent sector (Dosso dei Morti and equivalent carbonates) may have been related to the above mentioned westward tilting of the western Dolomites. Pelagic conditions persisted in this area throughout the rest of the Late Anisian and Early Ladinian (Prezzo Lst.; "Buchenstein Beds"). In western Lombardy basinal carbonates transgressed distal portions of a clastic succession. Further to the west these clastic deposits formed the substratum of Upper Anisian platform carbonates (Albiga and equivalent Dolomites; Farabegoli & De Zanche 1984, De Zanche & Farabegoli 1988).

In the Latest Anisian the large carbonate platform extending from the western Dolomites southwards was fragmented and portions of it collapsed (Figs. 2–5). Along its indented eastern margin platform carbonates continued to grow on (? fault bounded) topographic ridges (Dolomites area; Bosellini 1984). Bordering initially starved and silled but rapidly deepening basins, up to 800 m of small-cyclic platform carbonates and talus deposits (Marmolada- & Latemar Lst., Schlern Dol. p.p.) aggraded and eventually prograded (Bosellini & Rossi 1974; Bosellini 1984). In the intervening basins siliceous pelagic carbonates ("Buchenstein Beds") similar to coeval sediments in eastern Lombardy accumulated at low rates throughout the Latest Anisian and Early Ladinian. Basinal areas closer to carbonate platforms and volcanic sources received locally increased amounts of platform debris and reworked acidic volcanic detritus.

Red nodular limestones (Hallstatt-type limestones) were deposited on submerged platform portions especially in the eastern Dolomites and Cadore (Clapsavon Lst. p.p.; Pisa 1972; Marinelli 1980).

Anoxic conditions existed in bottom waters of depressions ("Grenzbitumenzone"; Perledo-Varenna Lst.; part of Meride Lst.) in the interior of larger carbonate platforms in western Lombardy (Salvatore Dol.; Esino Lst.). Organic-rich muds and reworked platform carbonates accumulated in these shallow basins but at rates that exceeded pelagic sedimentation in distal portions of the Buchenstein basins further to the east. Only subdued topographic relief thus existed in the intra-platform depressions and the carbonate platforms eventually migrated again across such areas.

2.1.3. Late Ladinian to Early Carnian

Vigorous tectonic and volcanic events affected the area of the Dolomites during the Late Ladinian (Bosellini et al. 1977, 1982; Doglioni 1982, 1984a, b; Blendinger 1985). Movements along a WSW-ENE-trending sinistral wrench-fault zone in the western and central Dolomites produced a high ridge thus triggering coarse gravity flows. Megabreccias and olistoliths accumulated in the adjacent basins. Carbonate platforms close to this ridge were exposed and suffered karstification and in places deep erosion (e.g. Blendinger 1985). During a short period of predominantly basic magmatism, the originally deep (600–800 m) interplatform-basins and collapsed areas around the main volcanic centers (Monzoni, Predazzo) were filled with volcanic rocks and their erosional products. Only after the volcanism had ceased did widespread subsidence resume. New generations of carbonate platforms (Cassian Dol.) then nucleated along the rims of remaining topographic highs and prograded rapidly across the depressions which were still being filled at high rates with reworked volcanic and increasingly with carbonate detritus (Bosellini 1984; Brandner 1984).

Between the basins of the western Dolomites and eastern Lombardy a wide carbonate platform persisted throughout most of the Ladinian. In the Late Ladinian the eastern Lombardian basins suddenly received increased amounts of siliciclastic material in the form of storm deposits and turbidites ("Wengen Beds"; ? southern source). However, volcanic rocks and tectonic structures comparable to those of the Dolomites are almost entirely absent. Small platforms (Esino Lst.) expanded rapidly and ultimately filled a significant portion of the former basins. The northernmost Lombardian platforms (e.g. the Concarena) reached locally exceptional thicknesses of up to 1300 m. Unlike the "Lower Ladinian" buildups and deep intervening basins in the Dolomites, some of the thick, younger platforms in Lombardy were confined to elongated (? pull-apart) zones of rapid subsidence and much smaller reliefs existed towards the adjacent basins (Pratotondo Lst.; "Wengen Beds"; Brack 1984). Similar geometries have been proposed for coeval platforms in the Northern Calcareous Alps (Sarnthein 1967; Brandner 1984). Indeed the latter may have been located close to the Lombardian sector in Triassic times.

Towards the end of the Ladinian and in the Early Carnian the Esino platform tops in Lombardy were subject to repeated emergences (Assereto et al. 1977a). Drowned or inactive platform portions were onlapped and covered by small cyclic sub- to peritidal carbonates (Gorno Fm.; Breno Fm.) and locally by fine-grained siliciclastic rocks (Lozio shales). Several Carnian delta systems, sourced by a new subaerial volcanic belt, advanced temporarily northward into the shallow lagoons and depressions of central and eastern Lombardy (e.g. Gnaccolini & Jadoul 1988, 1990; Garzanti & Jadoul 1985).

2.2. *Nature of fossiliferous Anisian/Ladinian boundary successions*

Fossiliferous pelagic successions spanning the entire Anisian and Ladinian time interval do not exist in the Southern Alps. Fossil bearing Anisian/Ladinian boundary sections are found mainly in the following settings: (a) continuous pelagic successions, (b) pelagic sediments overlying drowned platform carbonates and (c) internal and flank portions of carbonate platforms.

Sections straddling the complete stage boundary interval are restricted to those of type (a). They are found in two basinal zones (Figs. 2, 3), a narrow depression in the eastern Dolomites (Ambata Fm., Buchenstein and Wengen Groups of the respective type areas) and a wider basin in eastern Lombardy (Prezzo Lst., "Buchenstein Beds," "Wengen Beds"). The stratigraphy of the latter will be dealt with in some detail below.

Pelagic strata on top of drowned platform carbonates (Type b sections) are mainly the classical "Buchenstein Beds" which are present throughout the northwestern Dolomites and in the Trento and Recoaro/Tretto areas. Hallstatt-type limestones are also found locally (e.g. to the east of the Dolomites; Clapsavon Lst. of Cadore and Carnia). The base of these beds may not be isochronous in all settings, reflecting onlap relationships and/or different times of (tectonically induced) drowning of sometimes previously exposed platforms.

Fossil bearing intervals in carbonate platform areas (Type c sections) are usually of restricted vertical and lateral extent. Nevertheless they host some important and exceptionally rich faunas on flank and interior portions of small platforms (e.g. Latemar, Cernera) as well as in deposits of larger intra-platform depressions (e.g. "Grenzbitumenzone" at Monte San Giorgio).

In the following chapters we will present new stratigraphic and fossil data from representative successions in all these settings. The sections studied in detail are located in the Dolomites, in the eastern Lombardian Prealps and adjacent territories (Bergamask- and Brescian-Prealps, Giudicarie, Trento area) and in southern Switzerland (Fig. 1).

3. Anisian/Ladinian boundary intervals in basinal "Buchenstein Beds"

In 1892 Bittner proposed the Ladinian Stage with the "Buchenstein Beds" at its base. In the Southern Alps these are the most widespread fossiliferous pelagic sediments straddling or approaching the stage boundary. However, their fossil content is usually poor, they are lithologically variable and exhibit lateral facies changes with coeval platform carbonates. Opinions therefore diverged through time about the stratigraphic range of the "Buchenstein Beds." Some of the most important ideas are summarized in roughly chronological order before details are presented on the main lithologies, the depositional settings and the studied sections.

3.1. Opinions on the stratigraphy and range of the "Buchenstein Beds"

The "Buchenstein Beds" were defined by Richthofen (1860) in a section near Pufels[3]) in the northwestern Dolomites (Fig. 1) as a lithologically characteristic succession of evenly bedded and nodular siliceous limestones with greenish shaly intercalations. A few non-diagnostic fossils were mentioned from this unit at Pufels and Seceda by Richthofen (1860) and Stur (1868). Ammonoid finds from the Pufels section include "*T.* cf. *reitzi*" (Mojsisovics 1873), later referred to as "*T. reitzi*" and "*Trachyceras curionii*" (Mojsisovics 1882). This led the latter to correlate these beds with the "*Trachyceras reitzi*"-bearing limestones in the Balaton Highland of Hungary. Mojsisovics (1879) also extended and generalized the lithostratigraphical range to consist of two series of evenly bedded, dark limestones (the lower and upper "Bänderkalke", also called "Plattenkalke" by other authors) separated by a stack of nodular limestones with greenish volcaniclastic intercalations ("Pietra verde"). Similar nodular limestones associated with "Pietra verde" were recognized also in other parts of the Southern Alps, in the Eastern Alps and Bakony.

No relevant additional fossils were known from the "Buchenstein Beds" in the Dolomites when Bittner (1892) introduced the "Ladinian Stage[4])" (called "Norian" by Mojsisovics until 1902) and fixed its base with this lithologically defined unit. Thereafter the term "Buchenstein Beds" was frequently used in a chronostratigraphic

[3]) The name "Buchenstein" is derived from another locality near Andraz in the Livinallongo area of the central Dolomites where the homonymous beds are typically developed (e.g. Leonardi 1967).

[4]) After the Ladini people in the Dolomites.