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Geometry and chronology of growth and drowning of Middle Triassic carbonate platforms (Cernera and Bivera/Clapsavon) in the Southern Alps (northern Italy)

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ABSTRACT

The depositional architecture and the geometric relationships between platform-slope deposits and basinal sediments along with paleontological evidence indicate the time interval of the younger Anisian *Reitziites reitzi* ammonoid zone to largely represent the main stage of platform aggradation at the Cernera and Bivera/Clapsavon carbonate platforms. Published and new U-Pb age data of zircons from volcaniclastic layers bracketing the stratigraphic interval of platform growth constrain the duration of platform evolution to a time span shorter than 1.8±0.7m.y., probably in the order of 0.5-1m.y., reflecting fast rates of vertical platform aggradation exceeding 500 m/m.y. In the range of growth potentials for shallow-water carbonate systems estimated in relation to the time span of observation, this high rate is in agreement with values for short intervals of 10^5-10^6yrs (e.g., Schlager 1999).

After drowning, the platforms at Cernera and Bivera/Clapsavon were blanketed by thin pelagic carbonates. On the former platform flanks the draping sediments in places comprise red nodular pelagic limestones (Clapsavon Limestone) similar in facies to the Han Bulog Limestones occurring elsewhere in Middle Triassic successions of the Mediterranean Tethys. The drowning of vast areas of former carbonate platforms possibly triggered the onset of bottom-water circulation in adjacent basins as suggested by the abrupt transition from laminated to bioturbated pelagic nodular limestones in the Buchenstein Formation which occurred close to the time of initial platform submergence. During the Late Ladinian the topographic features of the drowned platforms were onlapped by rapidly deposited, predominantly clastic successions including coarse breccias and volcanic rocks sealing and preserving the peculiar stratigraphic setting.

ZUSAMMENFASSUNG

Die Architektur der retrogradierenden Karbonatplattformen der Cernera und des Bivera/Clapsavon Massifs weisen zusammen mit den geometrischen Beziehungen zwischen Plattformabhang- und Beckensedimenten und der Verbreitung von Ammonoideen auf ein kurzes Wachstumsintervall in der späten *Reitziites reitzi* Ammonitenzone (spätes Anisian) hin. Publizierte und neue hoch auflösende U-Pb-Alter von Zirkonen aus vulkanoklastischen Lagen grenzen dieses stratigraphische Intervall ein und ergeben für die Hauptphase des vertikalen Wachstums der Cernera- und der Bivera/Clapsavon-Plattform einen Zeitraum von weniger als 1.8±0.7 m.y., wahrscheinlich in der Grössenordnung von 0.5-1m.y.. In den als Funktion der Beobachtungsdauer geschätzten Wachstumspotentialen für Flachwasserkarbonatsysteme fällt die aus obiger Zeitspanne resultierende hohe Sedimentationsrate von 500 m/m.y. und mehr in den Bereich der Werte für die Bebachtungsdauer 10^5-10^6y (z.B. Schlager 1999).

Nach dem Absinken der Cernera- und der Bivera/Clapsavon-Plattform wurden die markanten untermeerischen Erhebungen von geringmächtigen pelagischen Karbonaten bedeckt, Diese umfassen an den Plattformflanken unter anderem rote Knollenkalke (Clapsavon-Kalk) mit faziellen Ähnlichkeiten mit den in der Mittleren Trias der mediterranen Tethys verbreiteten Rotkalken des Han-Bulog-Typs. Die Absenkung grösserer Bereiche vorheriger Karbonatplattformen ist eine mögliche Ursache für das Einsetzen von Zirkulation und Durchmischung von Bodenwässern in angrenzenden tiefen Beckenbereichen wo in der Buchenstein Formation ungefähr gleichzeitig mit der initialen Plattformabsenkung laminierte, bituminöse Kalke von bioturbierten Kalken abgelöst werden. Im späten Ladinian wurden die Flanken der untermeerischen Erhebungen rasch von vorwiegend klastischen Ablagerungen, Vulkaniten und Breccien eingedeckt und so das besondere stratigraphische Muster konserviert.

Introduction

The accurate quantification of carbonate sediment accumulation is notoriously difficult in ancient platform carbonate systems because this procedure requires reliable age correlation with numerical time-scales. Only in rare cases absolute time and sediment thickness can be measured in the same stratigraphic section. The Late Anisian to Ladinian basinal succes-

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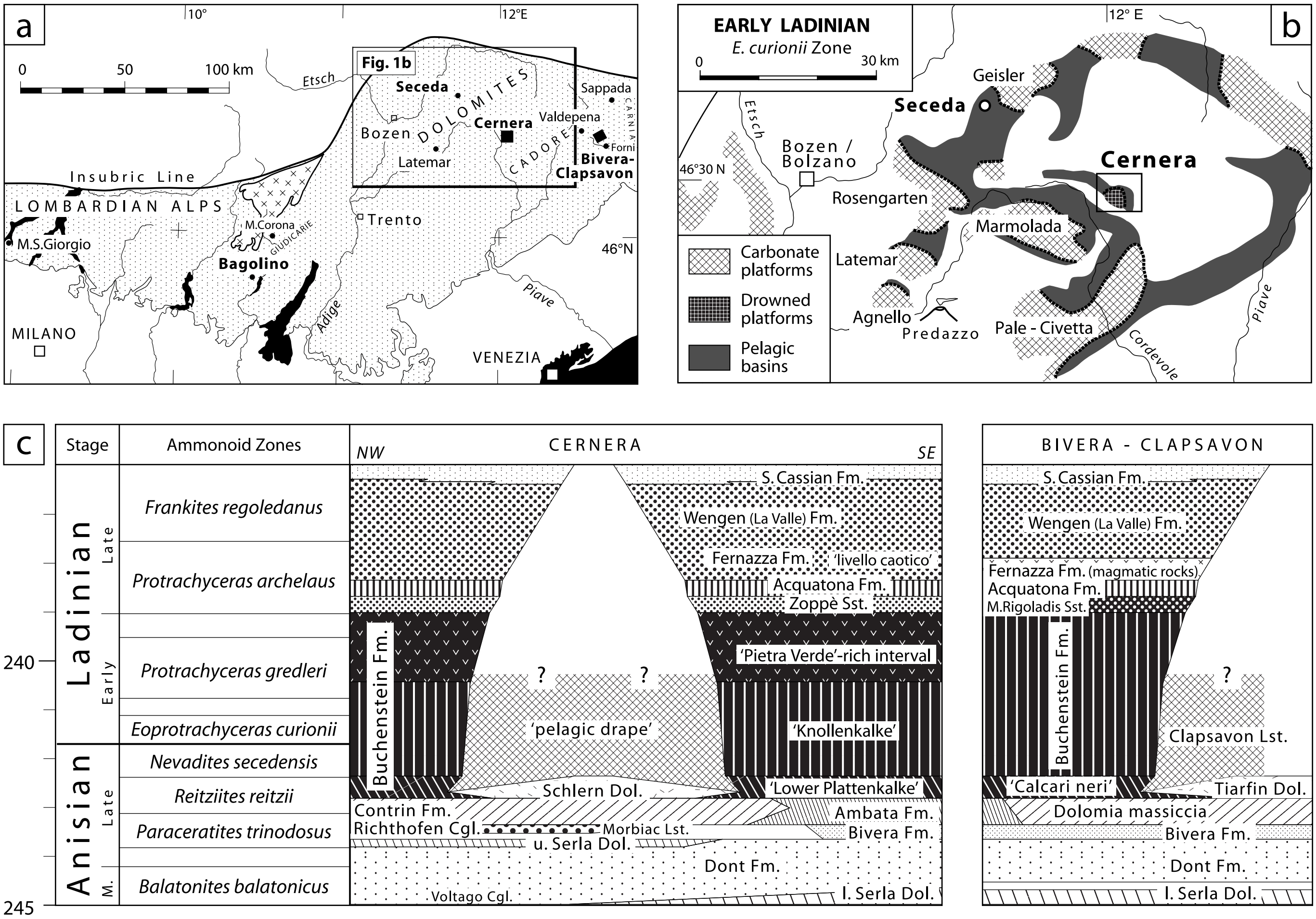


Fig. 1. a) Overview of the central and western Southern Alps. Black rectangles indicate the location of the geological maps of the Cernera (Fig. 2) and the Bivera/Clapsavon-platforms (Fig. 7). b) Distribution of latest Anisian to Early Ladinian carbonate platforms and basinal areas in the central/western Dolomites. c) Chronostratigraphic schemes for the main formations around the Cernera and the Bivera/Clapsavon platforms (Cernera area: compiled and modified after Viel 1979a, b; Blendinger et al. 1982; Brack & Rieber 1993; Stefani et al. 2004. Bivera/Clapsavon area: mainly after Pisa 1972b, 1974; Carulli et al. 1995. Numeric ages and ammonoid zones modified after Brack et al. 2005).

sions of the Southern Alps provide one such exception where both bio- and chronostratigraphic data are available because of the occurrence of age-diagnostic fossils in sufficiently continuous and long stratigraphic sections, which are punctuated by layers of volcaniclastic material containing minerals suitable for radio-isotopic age dating. Moreover, the relevant "pelagic" fossils not only characterise the basinal successions but occur also in the coeval platform carbonates and in the sediments of intra-platform depressions (e.g., Brack & Rieber 1993; Fantini Sestini 1994; Manfrin et al. 2005).

Spectacular exposures and clear geometric relationships between Middle Triassic (Late Anisian to Ladinian) platform carbonates and coeval basin deposits in the Dolomites region of the Southern Alps (Fig. 1a, b) have attracted the attention of generations of geologists in the past decades (among the more recent publications, e.g., Bosellini & Rossi 1974; Gaetani et al. 1981; Bosellini 1984; Bosellini & Stefani 1991; Goldhammer et al. 1993; Brack et al. 1996; Egenhoff et al. 1999; Maurer 1999, 2000; Emmerich et al. 2005). These platforms typically consist of narrow cores surrounded by thick packages of foreslope deposits terminating within thin intervals of starved basinal sediments. Our study focuses on two comparably small platforms in the central Dolomites (Cernera) and in western Carnia (M. Clapsavon - M. Bivera; Fig. 1a-c). Because both platforms apparently grew at the limit of carbonate growth potential and can be constrained in their evolution by geochronological data they provide the rare opportunity for estimating the production capacity of a Middle Triassic platform-carbonate factory.

In this article we briefly outline the geology and geometric relationships and then report new bio- and chronostratigraphic data which help integrating the Cernera and M. Clapsavon - M. Bivera stratigraphies into the high-resolution temporal frame-work available for the Buchenstein Formation in the northwestern Dolomites and Lombardy (see Brack et al. 2005 for references). High-resolution radio-isotope ages from this system and numerically calibrated biostratigraphic data define the chronology of the platform-basin history and allow a first direct assessment of the maximal rates of vertical carbonate accumulation.

The Cernera platform

The Cernera platform is situated in the central Dolomites (Fig. 1b). Topographically the Cernera massif is a minor feature when compared with the surrounding higher Dolomite peaks but its isolated position (Fig. 2) and the deeply eroded southern and western flanks of Cernera and Piz del Corvo provide an almost undisturbed natural section across a single platform cut only by one major fault, the Loschiesuoi fault (Fig. 3).

Since Mojsisovics (1879, figs. p. 312-314) the eastern flank of the Cernera platform is well known for the spectacular onlap of basinal sediments onto platform carbonates as exemplified by numerous illustrations (e.g., Leonardi 1967, fig. 72; Viel 1979a, fig. 5; Blendinger et al. 1982, fig. 4; Cros & Houel 1983, fig. 7; Bosellini 1984, fig. 18; Doglioni 1985, fig. 3; fig. 5; De Zanche et al. 1993, fig. 15; Landra et al. 2000, fig. 11; Blendinger et al. 2004, figs. 4-5). Van Houten (1930) drew a remarkable series of geological sections across the successions onlapping the eastern and northern slopes of the "Cernera reef" but discounted the model of high relief carbonate platforms proposed earlier for Middle Triassic platforms in the Dolomites (Hummel 1928). More recently Viel (1979a, b), Blendinger et al. (1982), and Cros & Vrielynck (1989) provided studies on the local stratigraphy and details related to the Cernera platform. Landra et al. (2000) presented a synthetic seismic model and Blendinger et al. (2004) a geometric model of a fast aggrading and then retrograding platform. The latter model is largely followed here though with some modifications. A recent field-guide summary of the Cernera area is given in Stefani et al. (2004).

Ammonoids from slope portions of the Cernera platform were first mentioned by Cros & Houel (1983) and reported and illustrated by Brack & Rieber (1993), Mietto & Manfrin (1995), De Zanche et al. (1995) and Manfrin et al. (2005). Similar ammonoids are known from clasts in a megabreccia-like interval ("livello caotico") east of Cernera (e.g., Blendinger et al. 1982). The current research yielded additional ammonoids also from other slope portions (Fig. 2).

In the following paragraphs the Cernera platform geometry is briefly outlined (Figs. 2 and 3). The temporal evolution of the platform is discussed in the light of available and new fossil data and an attempt is made to sketch a possible original platform shape.

Pre-platform units and the shape of the platform base

The stratigraphy below the Cernera platform is characterised by a heterogeneous but laterally continuous sedimentary succession including clastic sediments and shallow-marine to basinal carbonates of Early Triassic to Late Anisian age and with clear unconformities and incised surfaces (e.g., Blendinger 1983; Doglioni et al. 1990; Stefani et al. 2004). Although the Contrin Formation at the top of this succession may originally have had a slightly mounded top (Blendinger et al. 2004) these shallow-water carbonates provide a relatively even base for the new and topographically more pronounced Cernera platform-basin system (Fig. 3). Between Valle di Zonia and the Loschiesuoi fault the constructed regional dip of the Contrin surface is around 10-15° towards NNE. East of the Loschiesuoi fault a corresponding plane is more strongly (ca 25°) inclined towards northeast. However, in this sector the Contrin Formation is not clearly resolved from the Upper Serla Dolomite and its separation from the overlying platform interior and slope deposits is vague. Below Piz del Corvo the thickness of this Upper Serla - Contrin interval starts to decrease. Along Rio Sacuz the basinal Ambata Formation onlaps a westerly adjacent slope of the Contrin Formation (Blendinger et al. 1982; Preto et al. 2005).

The main platform interval (Schlern/Sciliar Formation, Marmolada Limestone), basinal deposits (Buchenstein Formation) and pelagic sediments draping the platform flanks

Irregularly spaced but even beds characterise the platform interior in the steep walls flanking the southern peak (2657) of M. Cernera. These beds consist of coarse grainstones with dasycladacean algae, centimetre-sized oncolites and carbonate cement (Cros 1974). North of Cernera this unit can be traced to the southern flank of Col Piombin with a vertical offset in the saddle south of this peak. Between M. Cernera and M. Verdal and east of the Loschiesuoi fault the platform core is replaced laterally by inclined and brecciated but mainly micritic slope deposits, similar in composition to the automicrite described by Keim & Schlager (2001). Beneath and northeast of the northern peak (2664) of Cernera such strata overlie the platform interior beds and clearly indicate a retrograding growth stage. An area of indistinctly bedded light coloured carbonate rocks roughly marks the contact between the platform interior and the slope deposits. Where traceable, this contact area appears to be steep in the lower reaches (east of M. Verdal) and steps back up-section onto former platform interior portions. A mirror image of this geometry is preserved in the cliffs to the east of the Loschiesuoi fault (see fig. 5 in Blendinger et al. 2004). Between Forcella Loschiesuoi and Piz del Corvo the reduced apparent angle of inclination observed for this diffuse plane could be due to the orientation of the exposures oblique to the real dip direction of the platform base and slope. This geometry may also explain the asymmetry (in a map view) of the preserved eastern and western the slope portions. West of Valle di Zonia and southeast of Piz del Corvo the slope deposits are replaced by continuous basinal successions (Fig. 2).

The basinal sediments coeval with the Cernera platform on either side (Fig. 4a, b) comprise pelagic laminated and some-

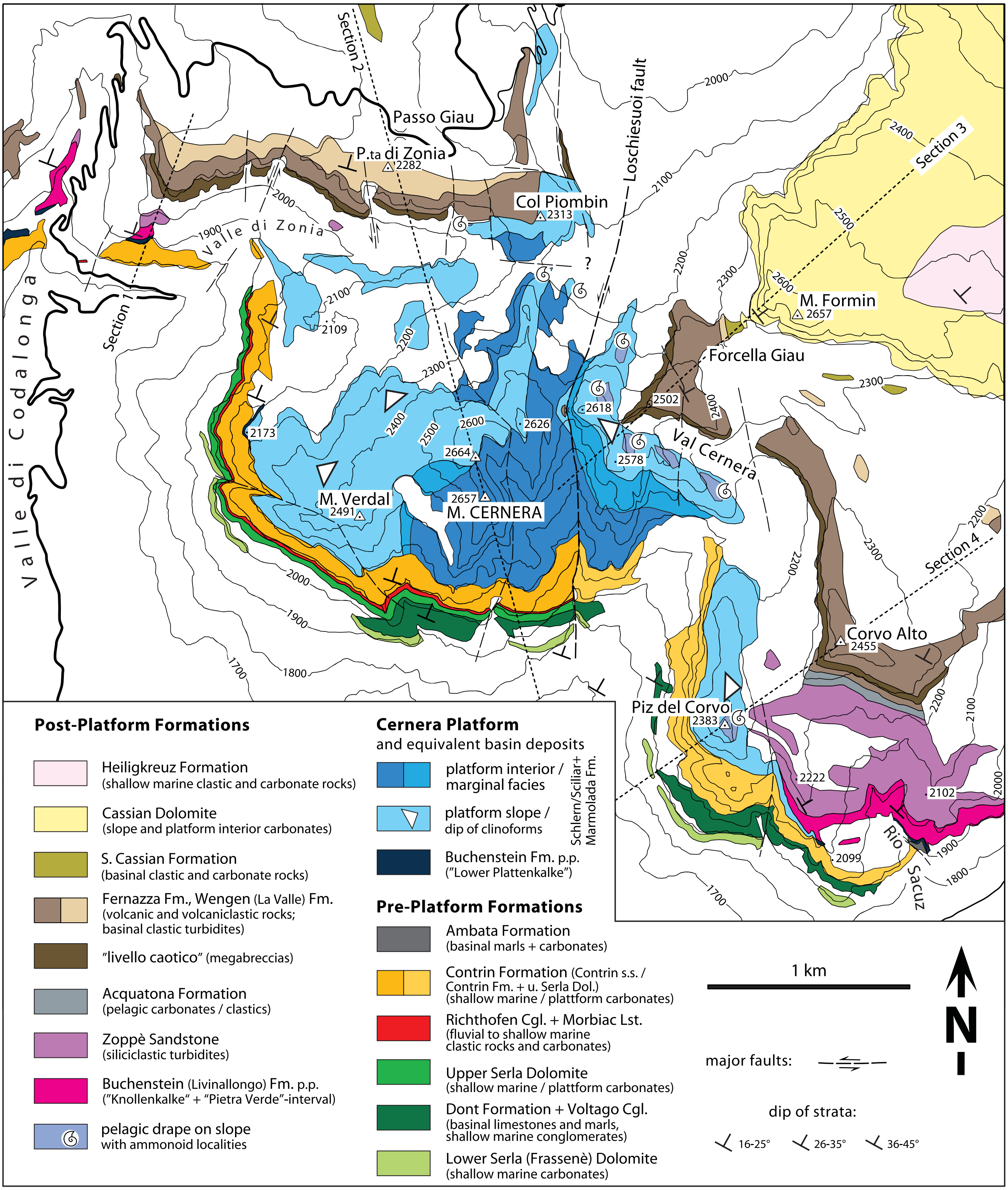


Fig. 2. Geological sketch map of the Middle/Late Triassic formations around Cernera (modified after Blendinger et al. 2004). Outcrops of Early Triassic rocks and Cernera Line below these units are not shown. The traces of sections 1-4 (see Fig. 3c) are indicated.

times bituminous limestones and marls ("Plattenkalke") at the base, followed by siliceous nodular limestones ("Knollenkalke" of the Buchenstein Formation). The pelagic sediments are interbedded with layers of greenish acidic volcaniclastic material (Pietra Verde) and overlain by a prominent Pietra Verde interval, several tens of metres thick.

Northwest of Cernera, the lower part of the Buchenstein succession follows with a sharp contact on top of the Contrin Formation. Along Rio Codalonga (above an altitude of ca 1750 m; Ciampestrin section of Cros & Houel 1983) as well as further east and closer to the platform slope (i.e. on the ridge marking the western termination of Valle di Zonia) the lithological characters of the lower part of the Buchenstein Formation are essentially the same as those of Buchenstein successions of the Livinallongo (Buchenstein) area a few kilometres further west (e.g., the Belvedere section of Brack & Muttoni 2000). On the basis of litho-, bio- and magnetostratigraphy the latter sections are closely tied to the reference Buchenstein outcrop and core section at Seceda. This allows the extrapolation of high-resolution bio-, litho- and chronostratigraphic constraints from Seceda (Brack & Rieber 1993; Brack & Muttoni 2000; Brack et al. 2000; Muttoni et al. 2004) to areas as far as western Cernera. Reference is made to these publications for more details on the volcaniclastic and pelagic marker beds mentioned in the following.

In the Buchenstein outcrop at Valle di Zonia (Fig. 4a) the "Lower Plattenkalke" are poorly exposed but less than 20 metres thick. The Tc-tuff interval in the lower part of the "Knollenkalke" starts around 2.25 m above their sharp base. The Tc and Td-tuffs are strongly reduced in thickness when compared with the corresponding layers in the Livinallongo area. The strata between the top of the "Plattenkalke" and the Tc-level also bear three thin (< 20 cm) volcaniclastic layers. In the Livinallongo area the corresponding "Knollenkalke" host a prominent and up to 13 m thick and predominantly fine-grained Pietra Verde interval (e.g., Belvedere and Castello sections; Brack & Muttoni 2000). Along Rio Codalonga this interval is still ca 10 m thick whereas at Valle di Zonia it corresponds to one of the thin volcaniclastic layers. The thickness reduction of the Tc and Td-tuff horizons and the disappearance of the thick Pietra Verde interval in the lowermost "Knollenkalke" over a distance of a few hundred metres between Rio Codalonga and Valle di Zonia may reflect the onset of a relief on the outermost toe of the Cernera platform slope. South of Valle di Zonia only a few metres of bituminous brownish dolomites are presumably lateral equivalents of the lower part of the "Plattenkalke". These beds are visible in a few places along a grass covered ledge separating the Contrin Formation below from the slope deposits of the western flank of M. Verdal. At an altitude around 2200 m, these layers can be traced eastward through the southwestern cliffs of M. Verdal where they gradually disappear beneath the platform slope.

The Buchenstein succession along Rio Sacuz on the eastern side of the Cernera platform (Fig. 4b) shows differing bedding characteristics and thickness. Only thin tuff layers possibly comprising the Tc-e layers are observed in the lower part of the "Knollenkalke" and similar layers also occur in the underlying beds transitional to the "Plattenkalke" (Preto et al. 2005, 2007 and own observations). According to Cros & Houel (1983) 10 km further east around Zoppè di Cadore the corresponding layers of the so-called "Lower Pietra Verde" reach their maximal thickness values of several tens of metres. The "Plattenkalke" at Rio Sacuz overlie the basinal Ambata Formation but only a few hundred metres further west the equivalent strata and overlying nodular limestones follow above the Contrin carbonates. Similar to the northwestern slope of the Cernera platform a reduced interval of the "Plattenkalke" might continue for some distance between the Contrin top and the outermost platform slope (Blendinger et al. 1982). The "Knollenkalk" portion continues updip and may originally have graded into bedded pelagic strata following on top of the flank deposits east of Piz del Corvo (Fig. 4c). These strata had earlier been interpreted as shallow-water deposits (Blendinger 1985); however, Cros & Vrielynck (1989) identified their pelagic nature. Cros & Vrielynck also recognised the onlap geometry of the Buchenstein intervals against what they described as "a retrograding platform, progressively overlain by basinal deposits". Conodonts (*Paragondolella alpina szaboi*, *Neogondolella longa*) from sediments bracketing the "discontinuity surface" suggested to them a Late Anisian age for the oldest pelagic strata above the slope carbonates at Piz del Corvo. For this reason Cros & Vrielynck (1989) considered the underlying platform carbonates as integral part of the Contrin Formation. In view of the new, representative conodont ranges for the Buchenstein Formation (Muttoni et al. 2004), the mentioned conodont species have their main distributions throughout the *Reitziites reitzi* and *Nevadites secedensis* ammonoid zones, in agreement with ammonoid data from other slope portions (see below).

North of Piz del Corvo, thin intervals of ammonoid-bearing limestones and dolomites are preserved in several places of the outermost platform slope (Fig. 4d). On the northwestern slope of the Cernera platform, i.e. southeast of Punta di Zonia, Cros & Houel (1983) were the first to report ammonoids from the hitherto most prolific fossil locality at Cernera (Figs. 2, 4e). Fossils collected from essentially two horizons of a thin stratigraphic interval were illustrated and discussed in Brack & Rieber (1993) and additional ammonoids were shown in Mietto & Manfrin (1995) and De Zanche et al. (1995). The fossiliferous strata at Punta di Zonia cap a thin slope interval rising eastwards toward Col Piombin (Fig. 4e; for a close-up view see fig. 6 in Blendinger et al. 2004). The downdip extrapolation of this plane joins the Buchenstein Formation of the lower Val di Zonia and indicates an original position of the Punta di Zonia locality relatively high up on the slope, i.e. above the presumed level of onlap of the Zoppè Sandstone. According to Preto et al. (2005) the ca 16 m-thick Punta di Zonia section indeed represents the transition from slope to (hemi)pelagic conditions. For unclear reasons these authors and Stefani et al. (2004) consider the thin succession to partly correspond to the Contrin as well as to the basinal Moena Formation. With the exposures of Contrin Formation in the lower Valle di Zonia and in view of the regular regional dip this would imply a pronounced local uplift of the small platform segment around Col Piombin (Fig. 2).

Biostratigraphic constraints on the age of the platform and its pelagic cover

With the exception of the uppermost fossil horizon, the ammonoids from the Punta di Zonia interval represent the late *Reitziites reitzi* to the early *Nevadites secedensis* zones (Brack & Rieber 1993). Preto et al. (2005) indicate specimens of *Reitziites* sp. and *Kellnerites* sp. from the lower two thirds of the section. Without an adequate documentation the identification of these fossils cannot be evaluated, however.

Specimens of the genera *Halilucites*, *Parakellnerites* (Fig. 5), *Proarcestes* and Gymnitidae were collected from light-coloured limestones and possible fills of fissures in slope sediments on and below the initially descending trail starting on the saddle south of Col Piombin towards Forcella Giau. Additional specimens of *Halilucites* were also found in the slope portion east of the Loschiesuoi fault, i.e. a few tens of metres north of the 2618 peak. Originally these localities were scattered over a palaeorelief that likely exceeded 200 metres. Stratigraphically the genus *Halilucites* has its main distribution in the latest *Reitziites reitzi* to early *Nevadites secedensis* Zone (Brack & Rieber 1993; Brack et al. 2005). In agreement with the conodonts from the oldest layers draping the platform at Piz del Corvo, these data indeed suggest that the platform retreated during the latest *Reitziites reitzi* Zone and drowned during the early *Nevadites secedensis* Zone.

The ammonoids collected from the uppermost fossil horizon at Punta di Zonia include *Chieseiceras chiesense*, *Eoprotrachyceras* cf. *curionii, Falsanolcites* cf. *recubariense, Falsanolcites* sp. along with representatives of *Monophyllites, Epigymnites, Proarcestes*, *Sturia, Sageceras* and *Parapinacoceras.* These taxa document stratigraphic condensation during the late *Nevadites secedensis* to at least the *Eoprotrachyceras curionii* zones. This is compatible with an association of conodonts from the same level at Punta di Zonia (including *Paragondolella excelsa, Neogondolella pseudolonga, N. constricta* and *N. longa*; see Vrielynck 1984) and restricted to the late *Nevadites secedensis* to earliest *Eoprotrachyceras curionii* zones (Muttoni et al 2004; Brack et al. 2005).

The pelagic drape at Piz del Corvo provided specimens of *Gymnites* and *Sturia*. In Val Cernera north of the valley cutting the eastern platform slope *(Eo-)Protrachyceras margaritosum, Protrachyceras* sp. and *Monophyllites* were found on the outermost slope layers at an altitude of ca 2200 m. These data suggest that the preserved remnants of the pelagic drape at least locally may reach the *E. gredleri* Zone (sensu Brack et al. 2005).

Ammonoids possibly derived from the drowned Cernera platform (Fig. 5) are known from clasts of red nodular Clapsavon-type pelagic limestone in a megabreccia interval ("livello caotico") onlapping the eastern slope (e.g., Blendinger et al. 1982). The age of the "livello caotico" clearly postdates the Buchenstein Formation. Its stratigraphic position in the lower part of the Fernazza Formation and ammonoids and daonellas from surrounding clastic sediments constrain the age of this level to the Late Ladinian. Ammonoids from red limestone blocks from these breccias north of point 2502 comprise specimens of *Ticinites* sp., *Celtites* sp., *Protrachyceras* sp.*, P.* cf. *irregulare, Falsanolcites recubariense, Falsanolcites* sp., *Procladiscites* cf. *griesbachi, Sturia forojulensis* along with representatives of *Monophyllites, Megaphyllites, Proarcestes* and Gymnitidae. A specimen of *(Para)Nevadites fedaiae* from presumably similar clasts is shown in Manfrin et al. (2005; Fig. 8/1-2). These taxa again testify an interval ranging from the earliest *Nevadites secedensis* to at least the *Eoprotrachyceras curionii* zones, i.e. equivalent with the age of the in-situ pelagic drape. In analogy with the position of similar coeval ammonoid-bearing limestones at M. Clapsavon, the red limestone clasts of the "livello caotico" likely represent material reworked from the top or from slope portions of a submerged Cernera-type platform.

In conclusion, the main stage of platform aggradation and retrogradation at Cernera is bracketed by the top of the Contrin Formation below and by the widespread pelagic drape on the platform slopes above. The fossil data indicate this growth stage to be largely equivalent in time with the late *Reitziites reitzi* Zone. Correlated with the Buchenstein stratigraphy this largely corresponds to the "Lower Plattenkalke". The lowermost "Knollenkalke" including the Tc-e-tuff markers likely postdate the main period of platform growth. However, without direct evidence we cannot exclude that the last but volumetrically less significant phases of retrogradation and possible capping mounds might overlap also with younger parts of the pelagic drape and corresponding basinal intervals.

Post-platform units

The basinal successions above the thick Pietra Verde interval of the upper Buchenstein Formation on either side of the Cernera platform comprise siliciclastic turbidites of the Zoppè Sandstone, the hemipelagic Acquatona Formation and heterogeneous volcanic and volcano-derived clastic rocks of the Fernazza Formation (Viel 1979a, b) with interbedded megabreccia levels ("livello caotico"). The latter contain a variety of lithologically different metre- to decametre-sized clasts including blocks from the Early Triassic Werfen Formation, and the "Knollenkalke" of the Buchenstein Formation and large boulders of platform derived carbonates. Blocks of ammonoid-bearing red pelagic limestones are known from the Cernera area. In view of the heterogeneous lithological spectrum and of the often very angular shapes of these clasts, the origin of the chaotic layers is not entirely clear. They may represent possibly earthquake-related true channelized megabreccia deposits displaced by gravity flow (e.g., Viel 1979b) or could be ejecta

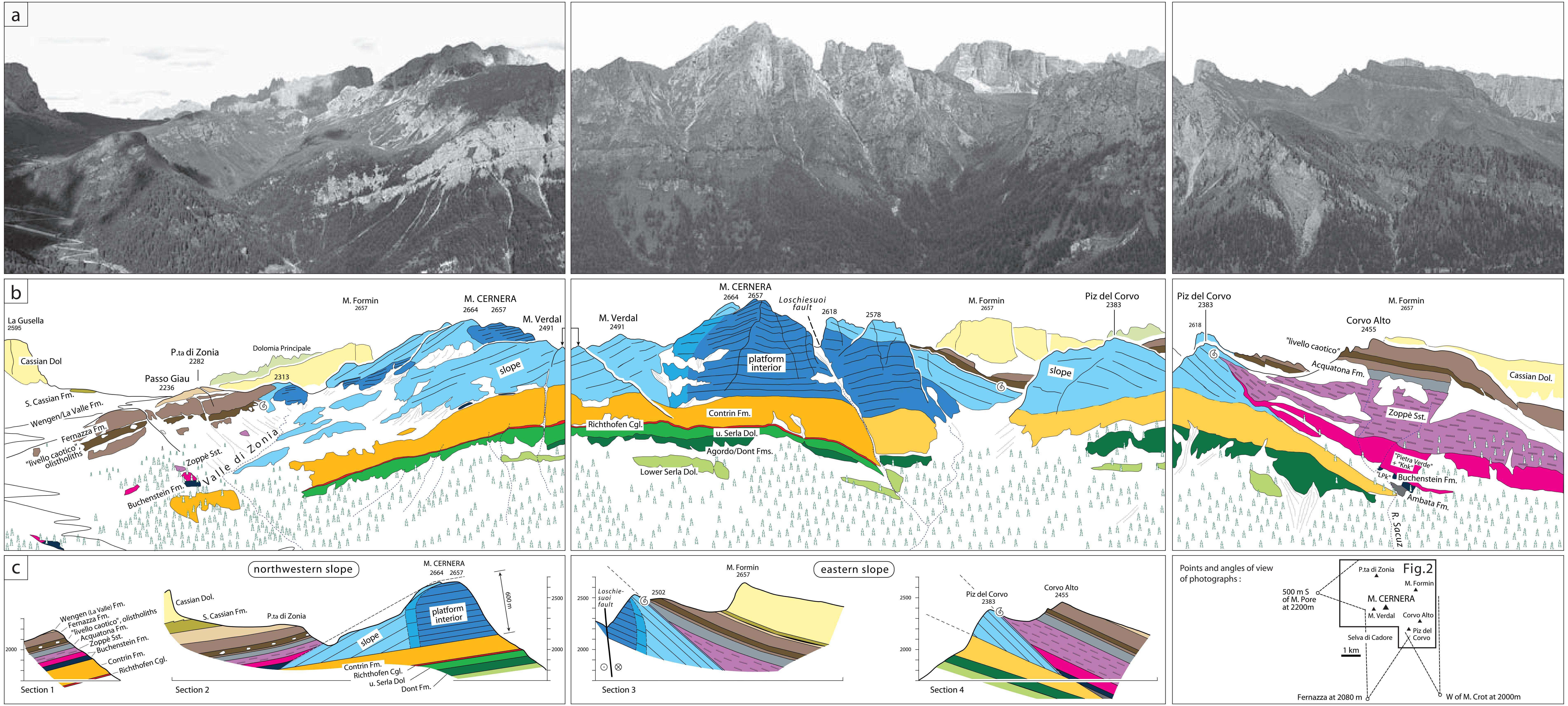


Fig. 3. a, b) Panoramic views and geological sketches of the Cernera mountain as seen from different viewpoints to the west and south (see inset on lower right side) illustrating the geometry of the western and eastern slope areas bordering the platform interior portion of the Cernera platform core. c) Geological sections across the Cernera platform and adjacent basinal successions. See Figure 2 for traces of sections.

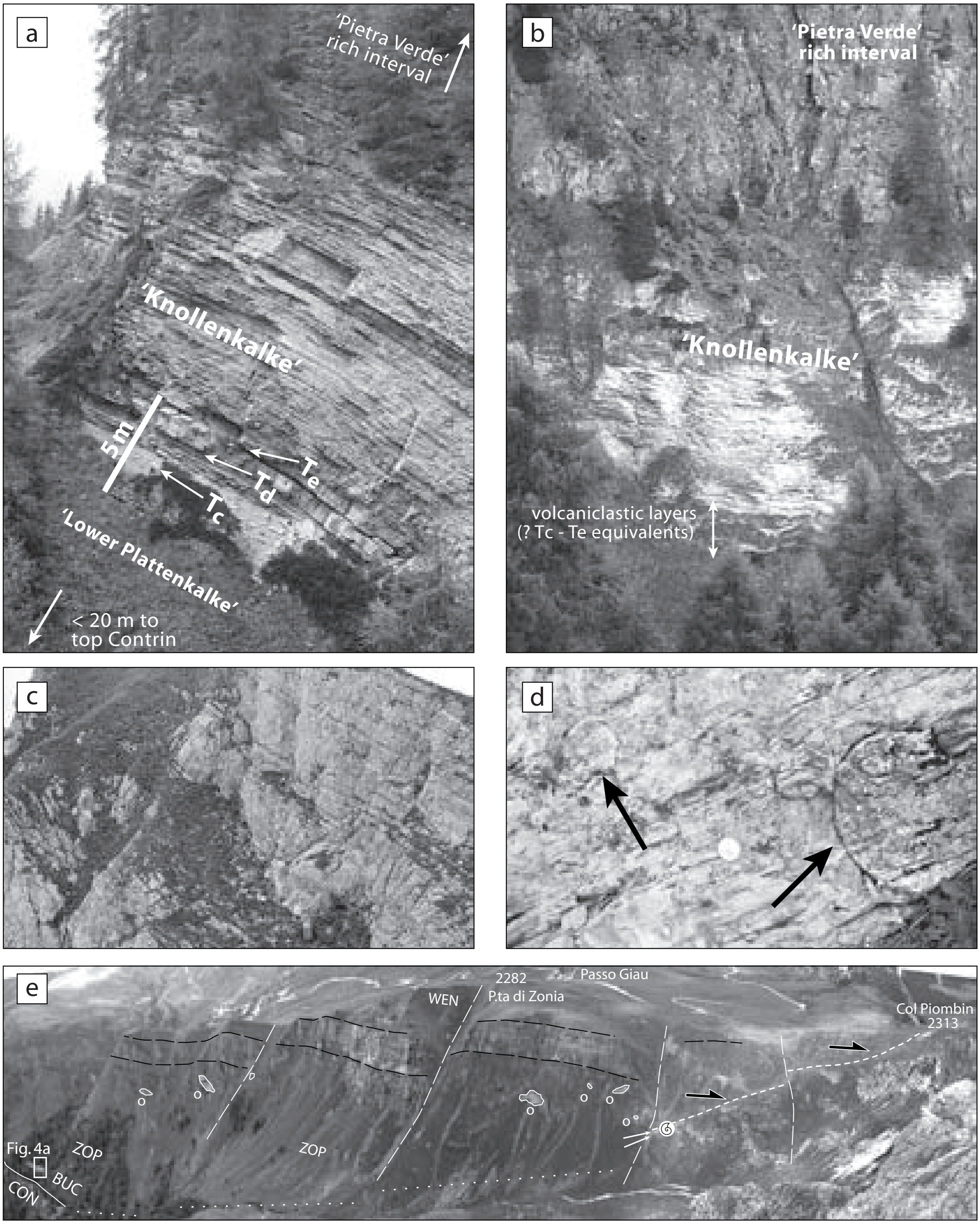


Fig. 4. a) View of the "Knollenkalke"-interval of the Buchenstein Formation at the edge between Valle di Zonia and Valle di Codalonga with the main tuff marker beds Tc-e (see Fig. 4e for location). The "Lower Plattenkalke" are age-equivalent with the main stage of platform growth at Cernera. b) View of the Buchenstein succession in the eastern flank of Rio Sacuz. Thin volcaniclastic layers in the lowermost "Knollenkalke" are possible equivalents of the Tc-e marker beds. The "Plattenkalke" are below these layers and follow above basinal sediments (Ambata Formation, not visible on photo; see Preto et al. 2007 for a log of the lower part of the section). c) Thick-bedded carbonate layers form the pelagic drape above the slope breccias immediately south of Piz del Corvo (person for scale). d) Ammonoids (arrows) oriented parallel to the bedding in the dolomitized carbonates of the pelagic drape north of Piz del Corvo (Val Cernera). e) View of the predominantly (volcani)clastic succession (Zoppè Sandstone [ZOP]; Fernazza Formation; Wengen (La Valle) Formation [WEN]) onlapping (black arrows) the western flank of the Cernera platform west of Col Piombin. The succession is cut only by minor N-S-trending steep faults. Note large carbonate olistoliths (o) in a breccia interval which touches the platform slope above the level of the ammonoid-bearing pelagic drape at the Punta di Zonia fossil locality (white arrows indicate main fossil layers). In the lower left of the photograph the Contrin Formation (CON) and the syn- to post-Cernera platform succession of the Buchenstein Formation (BUC) are visible (see Figure 4a for a close-up).

originating from nearby volcanic eruptions (agglomerates of older authors), or a combination of both. The first option requires a deeply eroded emergent source area. Alternatively, erupting magmas could have lifted the boulders from older stratigraphic levels. Upwards the Fernazza Formation grades into predominantly coarse-grained to silty siliciclastic deposits of the Wengen (La Valle) Formation. These beds are followed by the finer-grained clastic rocks with reworked carbonate material (basinal S. Cassian Formation).

Of this succession the clastic units up to and including the Fernazza Formation are preserved in contact with the slopes at Cernera and their thicknesses show significant variations around the platform. In particular, the turbidic Zoppè Sandstone is much thicker in the eastern succession than to the northwest of Cernera (Viel 1979a; Blendinger et al. 1982).

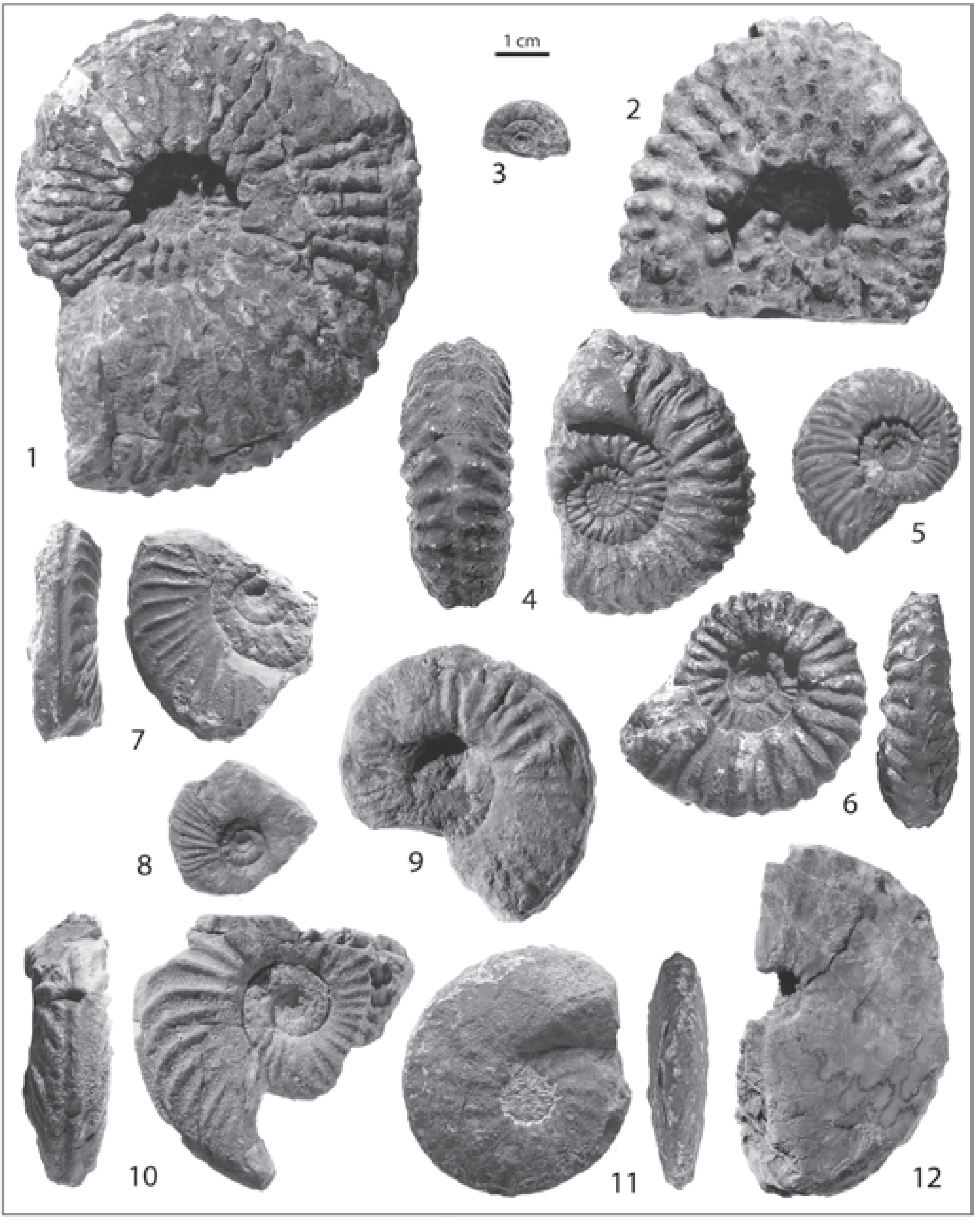
The age of the post-Buchenstein successions is Late Ladinian. It is as yet uncertain if the Zoppè Sandstone is partly coeval with intervals of the Buchenstein Formation as suggested by Viel (1979a) who also reports *Daonella lommeli* from the Zoppè Sandstone. In the reference sections at Seceda and Bagolino (Brack & Rieber 1993) daonellas of the group *D. lommeli* occur only in the uppermost layers of the Buchenstein Formation and higher up. Below Punta di Zonia a specimen of *Frankites* was found in the upper Fernazza Formation. Therefore, the thick and predominantly clastic succession comprising the Zoppè Sandstone, the Fernazza Formation and the overlying coarse clastic sediments accumulated during only a short time span of the late Ladinian.

A model for the reconstructed platform geometry

Figure 6a schematically illustrates the cross sectional appearance of the Cernera platform, reconstructed from the stratigraphies west and east of Cernera, for two time slices prior to and after the deposition of the thick onlapping clastic successions. For simplicity the shown platform sections are more schematic than the reconstructions proposed in Blendinger et al. (2004) and the transition from the aggradational to the retrogradational stages is thought to be more gradual. Any effects of compaction of the thick clastic basinal successions have not been considered. Below the Cernera core the mounded top of the Contrin Formation is depressed possibly due to the load of the subsequent platform whose culmination likely rose to 500-700 metres above the coeval basin floors. Assuming an equivalent depth level for the deposition of the "livello caotico" on both sides of the platform, the varying thickness of basinal sediments indicate that total subsidence and basin depth was greater in the eastern sector where the basinal succession started already in the Middle Anisian. After the submergence of the platform the different bathymetries of the basinal areas may have been levelled through the asymmetric deposition of the turbiditic Zoppè Sandstone.

In Figure 6b an attempt is made to sketch a possible map view of the platform-basin system at a stage just prior to its drowning. The Loschiesuoi fault, an apparent reverse fault with a strike-slip component, is the only major younger discontinuity crossing the Cernera platform and a reconstruction of the original 3d-platform geometry requires its retrodeformation. The contrasting throws of the base and top of an interval comprising the Upper Serla to Contrin Formations (Fig. 2) and the observed thickness variations of this interval across the fault point to a predominantly left-lateral strike-slip movement along the Loschiesuoi fault. Interestingly a translation on the order of several hundred metres brings the northernmost slope portion east of the Loschiesuoi fault into a plausible continuity with remnants of the equivalent platform slope to the west of the fault. These include the relicts of an E-dipping breccia succession capped by brown-weathering (? Zoppè) sandstones at Forcella Loschiesuoi (Fig. 2). In a southern direction the Cernera structure is interrupted at the Cernera Line (reverse fault, not shown on the map) and the extension of the original platform remains unknown. In our model the platform is sketched with a hypothetical northern termination. This may be justified by the absence of unambiguous platform interior strata north of Col Piombin. However, the stratigraphic situation in this sector is unclear and hidden further north. Northerly adjacent and in a steep contact with the carbonates of Col Piombin, a large breccia body with Buchenstein clasts is exposed on its northeastern slope. The enigmatic breccia could either be a downthrown relict of the "livello caotico" or represent a diatreme fill cutting the northern platform flank. Upwards this structure is sealed by the Wengen (La Valle) clastics which also cover the northerly and southerly adjacent carbonates cut by fissures with a galena-dominated mineralisation in its filling matrix (Assereto et al. 1977). The fissures have been considered karst features but the formation of cracks and the circulation of mineralizing fluids could also have been driven by heat related to nearby Late Ladinian magmatic activity.

Fig. 5. Ammonoids from the outermost eastern portions of the Cernera platform and from the Clapsavon-type limestone boulders in the "livello caotico" in contact with the eastern slope (all figures natural size; specimens labelled with PIMUZ-numbers are stored in the collection of the **P**aleontological **I**nstitute and **M**useum of the **U**niversity of **Z**urich). 1: *(Eo-)Protrachyceras margaritosum* (Mojsisovics, 1882), pelagic drape on outermost platform slope, at ca 2250 m altitude on western flank of Val Cernera, PIMUZ 26638; 2: *Protrachyceras cf. irregulare* Fantini Sestini, 1994, red limestone block from "livello caotico" west of Forcella Giau, PIMUZ 26639; 3: *Celtites* sp., red limestone block from "livello caotico" west of Forcella Giau, PIMUZ 26640; 4: *Falsanolcites recubariense* (Mojs.), red limestone block from "livello caotico" west of Forcella Giau, PIMUZ 26641; 5: *Falsanolcites* sp., red limestone block from "livello caotico" west of Forcella Giau, PIMUZ 26642; 6: *Ticinites* sp., red limestone block from "livello caotico" west of Forcella Giau, PIMUZ 26643; 7-9: *Halilucites* sp., (?) fissure fill in white limestone at 2150 m altitude below trail southeast of Col Piombin, 7: PIMUZ 26644, 8: PIMUZ 26645; 9: PIMUZ 26646; 10: *Halilucites rusticus* (Hauer, 1896); white limestone of outermost platform slope at ca 2500 m altitude northeast of peak 2618, PIMUZ 26647. 11: *Parakellnerites* sp., (?) fissure fill in white limestone at 2150 m altitude below trail southeast of Col Piombin, PIMUZ 26648; 12: ? *Hungarites* sp., (?) fissure fill in white limestone a few metres above trail south of Col Piombin, PIMUZ 26649.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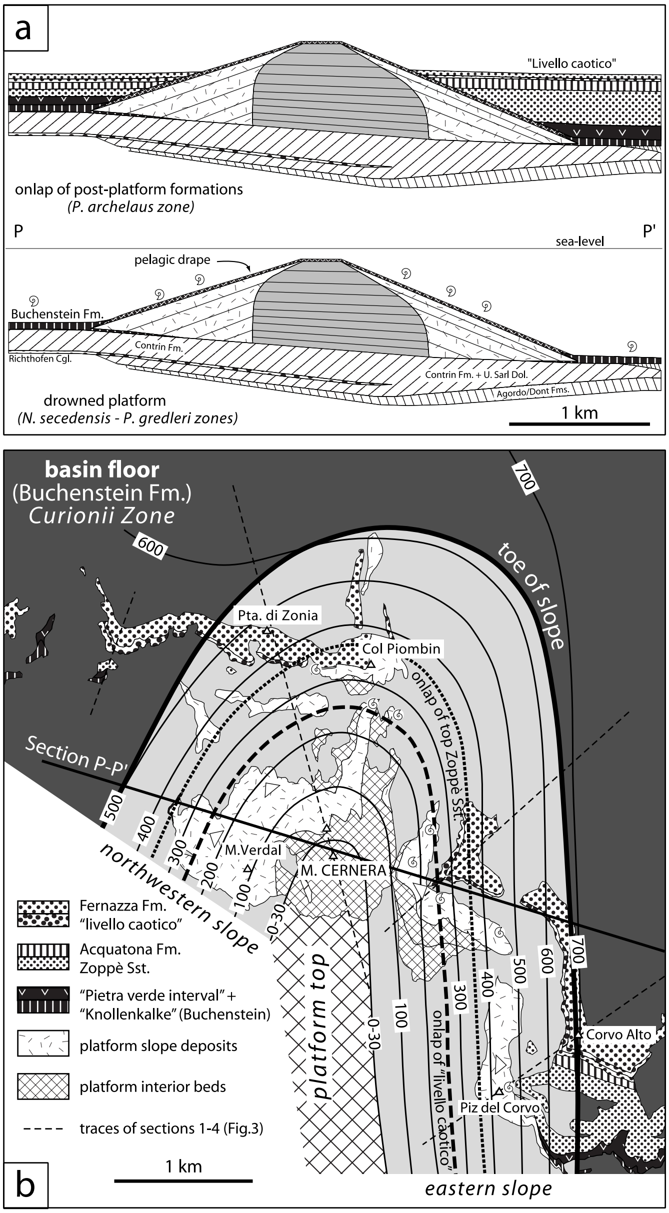

Fig. 6. a) Cross sectional geometry of the reconstructed Cernera platform for two subsequent stages, below: after the drowning of the platform and above: during the onlap of the Late Ladinian clastic succession. b) Tentative reconstruction of the topography of the Cernera platform/sea mount at and after its maximum vertical growth stage with indication of depth-levels reached by onlapping marker intervals (Zoppè Sandstone, "livello caotico"). See text for details of reconstruction. Outcrop contours are as in Fig. 2 but shifted along the Loschiesuoi Fault.

In the proposed map reconstruction, the estimated onlap levels are shown for the top of the Zoppè Sandstone and for the "livello caotico". Along with the depth contours these onlap levels suggest that the currently visible parts of the ammonoid-bearing pelagic drapes formed on the upper two thirds of the platform slopes. Higher up the slopes and mounded platform top may have been covered by ammonoid-bearing red nodular limestones, similar to those at Monte Clapsavon.

The Bivera/Clapsavon platform

The Bivera/Clapsavon platform is located around 50 km east of Cernera (Fig. 1a) in western Carnia in the homonymous mountain range northeast of Forni di Sopra in the upper Tagliamento valley. Of the currently available geological literature and maps the main contributions are from G. Pisa[1] (Pisa 1966, 1972a, b, 1974; Castellarin & Pisa 1973). The geological sketch map (Fig. 7) is based mainly on these studies and complemented with our own observations. More recently, in a study of the Late Ladinian-Carnian stratigraphy of the same area, Carulli et al. (1995) applied new stratigraphic terms, which are partly adopted here.

At Monte Bivera/Clapsavon a transsect from the interior area and slope portions of an originally much larger carbonate platform are preserved. Exposures of equivalent carbonates (Tiarfin Dolomite) also occur in isolated outcrops a few kilometres further northwest and southeast (see e.g., fig. 19 in Pisa 1974). Of these, the platform remnants to the southeast (Clap di Val – M. Tinisa) may originally have been connected with the Bivera/Clapsavon platform but are now separated by a thrusted anticline with stratigraphic older units in its core.

Pre-platform units

The base of the Bivera/Clapsavon platform-basin system corresponds to the top of the "Dolomia massiccia", which is likely a thin equivalent of the Contrin Formation of the Dolomites (Casati et al. 1982). This unit can be traced along the eastern and southern flank of Bivera/Clapsavon (Fig. 8a-c) and the constructed relatively smooth surface dips around 25-30° towards NW. The stratigraphic succession below the "Dolomia massiccia" comprises a heterogeneous interval of basinal carbonates, silts and shales of the Dont and Bivera Formations, with megabreccias and carbonate olistoliths in the latter unit (for details see Pisa 1974). Within a short distance both units strongly vary in thickness, they overlie older platform carbonates with local signs of a karstified surface. Ammonoids including the genera *Balatonites* and *Acrochordiceras* in the uppermost layers of Dont Formation south of peak 2344 unquestionably document the *B. balatonicus* Zone (Pisa 1972a, b and own finds). On the basis of few ammonoids and conodonts, the stratigraphically higher Bivera Formation is considered Late Anisian in age (*Paraceratites trinodosus* Zone according to Farabegoli et al. 1984). Several dm-thick layers of coarse-grained acidic volcaniclastic sandstones are interbedded in the topmost part of the Bivera Formation on the NE-slope of M.

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[1] On the slopes of M. Bivera, in 1976 the geologists Giulio Pisa and Riccardo Assereto and his son were the victims of rock fall triggered by an earthquake.

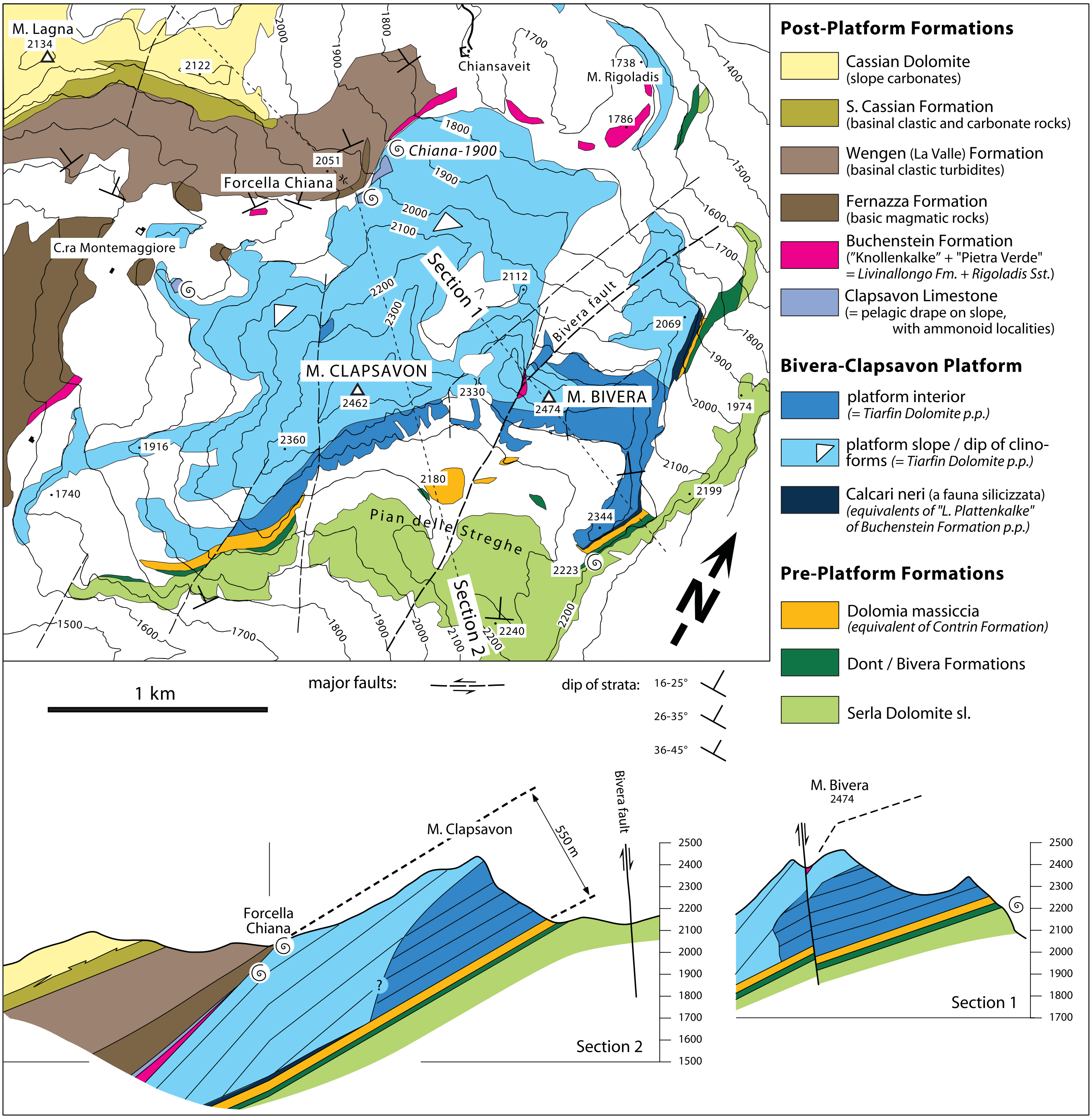

Fig. 7. Geological sketch map of the Bivera/Clapsavon platform and respective sections with their traces indicated on the map (NW sector of map simplified after Tab. 1 in Castellarin & Pisa 1973)

Bivera (sample BIV-1; Fig. 9a). These layers could correspond in age to the oldest known tuff levels of the Prezzo Limestone of eastern Lombardy (i.e. the "Contrada Gobbia" tuff layers of Brack et al. 2005).

The "Dolomia massiccia" is covered by a wedge-shaped unit ("Calcari neri a fauna silicizzata" of Pisa 1974) of dark undulated to nodular basinal limestones (Fig. 9a, b) with abundant terrigenous material and up to dm-thick volcaniclastic sandstones (Pietra Verde). The limestones contain silicified bivalves, brachiopods and abundant plant remains but no ammonoids have as yet been observed. For its stratigraphic position and the occurence of Pietra Verde layers this unit is likely an equivalent of the "Lower Plattenkalke" of the Buchenstein Formation in the Dolomites. The pronounced terrigenous component in the "Calcari neri" may be due to the relative vicinity of exposed land portions in northern Carnia (e.g., Farabegoli et al 1985). At M. Bivera the unit is best developed on its northeastern flank (Fig. 9a, b) and follows with an abrupt contact above the smooth top of the underlying "Dolomia massiccia". This is at variance with Pisa's (1974) interpretation of this plane as a deeply incised erosional relief suggested by the puzzling perspective appearance when seen from below (e.g., Fig. 9a). Further south, i.e. beneath the platform interior beds of the overlying unit, the "Calcari neri" are replaced by a thin interval of bedded carbonates visible in the steep wall east of the 2344 peak (Fig. 8c).

The main platform interval (Tiarfin Dolomite) and its pelagic cover (Clapsavon Limestone)

The interior part of the main platform body at Bivera/Clapsavon is characterised by even but irregularly spaced beds of sometimes oncolithic and dasyclad-bearing mudstones similar to those at Cernera. This succession forms the ridges east of M. Bivera but also extends throughout the southern slope of M. Clapsavon. The platform flank portions are known since Mojsisovics (1880) and occasionally show a coarse breccia-type habit with irregular bedding resembling the clinoforms of Ladinian platforms in the Dolomites.

At a number of places south and north of Forcella Chiana reddish nodular pelagic sediments (Clapsavon Limestone) are preserved as a dm- to m-thick cover of the outermost platform portions. Locally these limestones are rich in ammonoids (Mojsisovics, 1880, 1882; Tommasi, 1899; Pisa 1966; Rieber & Brack 2004). At the contact with the white carbonates the red material is also found to fill fissures and neptunic dykes, up to several decimetres deep. The sediments forming the pelagic drape flanking the Bivera/Clapsavon platform consist of red and grey ammonoid float- to rudstones. Ammonoids are filled with and surrounded by a lime- wackestone to packstone matrix with radiolaria, bivalve shells and crinoid fragments. The originally aragonitic ammonoid shells are replaced by calcite and frequently show sediment-filled borings. Both, ammonoids and surrounding matrix show subsolution. Occasionally thin Fe-Mn crusts document the existence of hardgrounds that probably developed during longer periods of non-deposition. These sedimentologic features are similar to Hallstatt-type pelagic limestones and indicate stratigraphic condensation. This is confirmed by the ammonoid content which comprises elements from the *Nevadites secedensis* Zone up to at least the level of *(Eo-)Protrachyceras margaritosum* (Rieber & Brack 2004). The geological section across the Bivera/Clapsavon platform (Fig. 7) suggests, that the Clapsavon Limestone facies formed on the slope, several hundred metres above the coeval basin floor.

Post-platform units

In the topographically lower reaches along the outermost platform slopes (south of C.ra Montemaggiore and southeast of Chiansaveit) siliceous nodular limestones and Pietra Verde volcaniclastics typical of the Buchenstein Formation occur. Associated with similar basinal carbonates a several tens of metres thick unit of sand-grained acidic volcaniclastics is known from M. Rigoladis (Pisa 1974, Cros 1979). In the creek north of Forcella Chiana the steeply dipping nodular Buchenstein-type limestones and tuffs disappear updip (these strata may be overlain by a few metres of Acquatona Formation) and the clastic rocks of the Fernazza and Wengen (La Valle) Formations directly onlap the platform flank (Fig. 9c). In the lower part of the (volcano)clastic wedge, basalts also occur (Castellarin & Pisa 1973). In a few places these rocks are in a direct contact with the slope carbonates and possibly comprise shallow intrusive bodies. The steep dip of the onlapping strata in the immediate vicinity of the platform flank north of Forcella Chiana could be due to increased compaction away from the platform flank but is likely enhanced by a small fault. At some distance and much higher up on the Bivera/Clapsavon slope an isolated remnant of 10-15 m thick typical siliceous nodular limestones of Buchenstein-type is preserved along a fault immediately west of the M. Bivera peak.

The Wengen (La Valle) clastics northwest of Forcella Chiana are covered by latest Ladinian to Carnian clastic sediments of the basinal S. Cassian Formation and which are seen to interfinger with carbonate platform strings of the younger Cassian Dolomite (Pisa 1974, Carulli et al. 1995).

Platform geometry and age

The cross-sectional dimension and geometry of the Bivera/Clapsavon platform and its pelagic drape and the onlapping clastic wedge indicate a short stage of upbuilding and retrogradation of the platform, most likely during a single (*Reitziites reitzi*) ammonoid zone. The age of the platform base is post-Bivera Formation and the stratigraphic break at the base of the "Calcari neri" likely matches a comparable feature at the base of the "Lower Plattenkalke" of the central/western Dolomites. The oldest faunal elements in the pelagic drape overlying the platform slope are ammonoids of the genus *Ticinites* identified in at least two places in the vicinity of M. Bivera (localities "Chiana-1900" and Clap di Val). *Ticinites* occurs close to the base of the *Nevadites secedensis* Zone and constrains the onset of the main phase of platform drowning in the Bivera/Clapsavon area. We cannot exclude that carbonate production continued for some time in other parts of the platform. According to Pisa (1966), north of Forni di sotto, slightly younger ammonoids occur in Tiarfin carbonates ca 50 m below their top.

Possible comparable settings

Beyond the Bivera/Clapsavon range and possibly the outcrops north of Forni di Sotto (e.g., Clap di Val, Cima Avroni, Malga

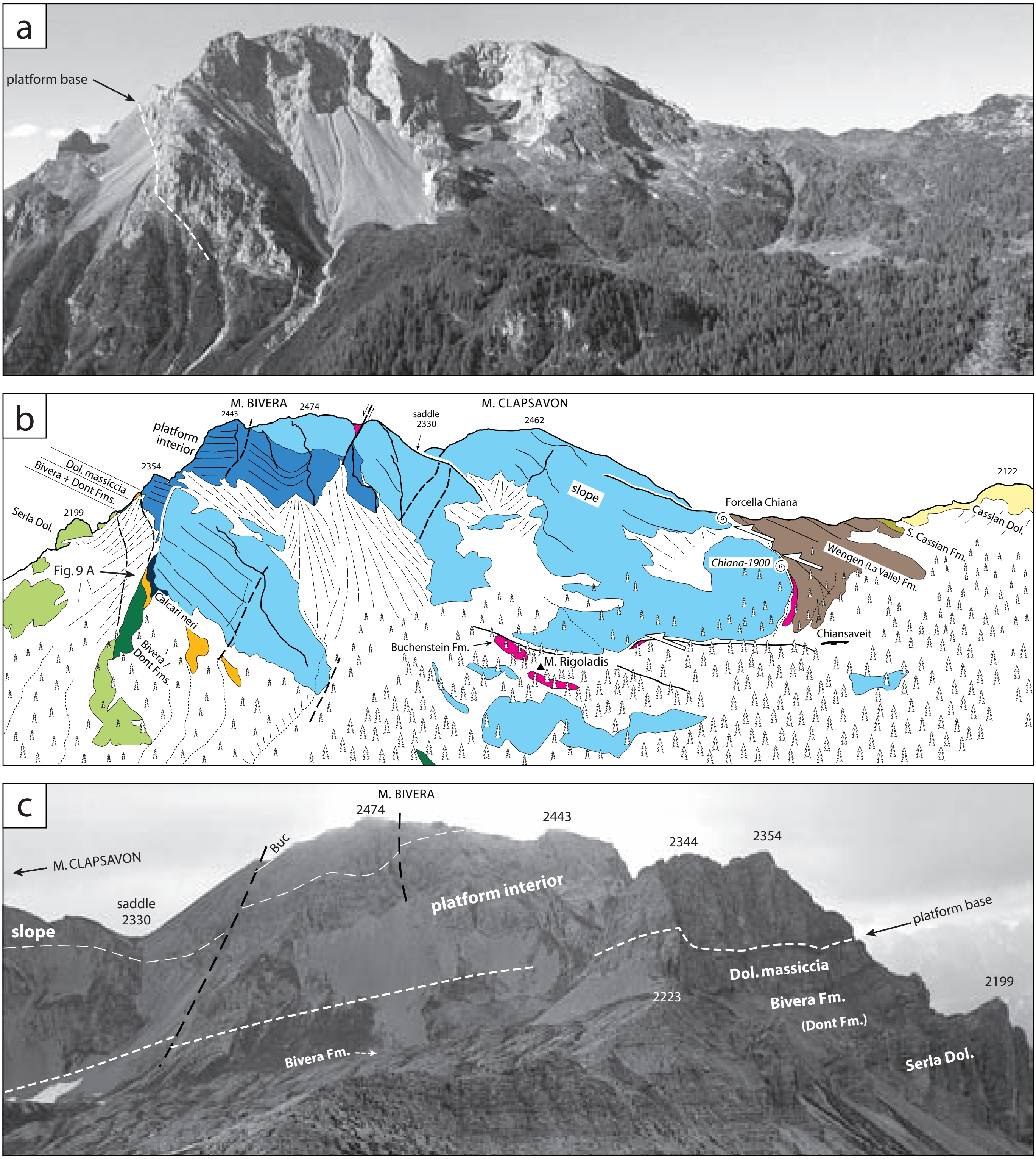

Fig. 8. a, b) View and geological sketch of the northern flank of the Bivera-Clapsavon mountain ridge. The Bivera/Clapsavon platform overlies with a smooth and NW-dipping base the Middle-Late Anisian sediments. On both sides of Forcella Chiana nodular pelagic limestones (Clapsavon Limestone) are preserved as a thin cover of the ultimate slope deposits; these are onlapped by clastic sediments of the Wengen (La Valle) Formation (see Fig. 9c). In the gully south of Chiansaveit volcaniclastic layers associated with "Knollenkalke" of the Buchenstein Formation pinch out on the slope. c) View of the eastern edge of the Bivera/Clapsavon platform as seen from southeast. Note the smooth platform base, which, outside the field of view, can be traced further to the southwest (see also Fig. 7).

Table 1. U-Pb isotopic data of zircons from samples LAT30 at Latemar (Dolomites) and BIV1 at Monte Bivera (western Carnia).

						isotopic ratios								isotopic ages		
Sample	a)	μg[(b)] zirc.	ppm U	Pb$_{c.}$[c)] (pg)	Th[d)]/U	^{206}Pb[e)]/^{204}Pb	^{207}Pb[f)]/^{206}Pb	± %	^{207}Pb[f)]/^{235}U	± %	^{206}Pb[f)]/^{238}U	± %	ρ[g)]	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb
LAT30.Z89	CA	1.0	108	2.0	0.38	150	0.05113	8	0.2712	8.3	0.038474	0.63	.72	**243.4 ± 1.5**	243.7 ± 20.3	247 ± 182
LAT30.Z88	CA	1.3	104	1.9	0.59	187	0.05019	6	0.2662	6.7	0.038464	0.49	.74	**243.3 ± 1.2**	239.6 ± 16.0	204 ± 147
LAT30.Z87	CA	1.2	92	2.1	0.55	148	0.05066	8	0.2684	8.4	0.038431	0.52	.86	**243.1 ± 1.3**	241.4 ± 20.4	225 ± 185
LAT30.Z84	CA	1.4	183	1.7	0.45	403	0.05111	3	0.2707	2.9	0.038421	0.27	.61	**243.0 ± 0.7**	243.3 ± 7.1	246 ± 64
LAT30.Z90	CA	1.2	230	1.6	0.37	447	0.05085	2	0.2694	2.6	0.038421	0.22	.66	**243.0 ± 0.5**	242.2 ± 6.2	234 ± 56
LAT30.Z82	CA	2.2	325	2.8	0.44	642	0.05073	2	0.2686	1.8	0.038407	0.35	.44	**243.0 ± 0.8**	241.6 ± 4.3	229 ± 39
LAT30.Z91	CA	1.1	130	1.9	0.38	197	0.05235	6	0.2770	6.1	0.038375	0.40	.82	**242.8 ± 1.0**	248.3 ± 15.1	301 ± 131
LAT30.Z85	CA	1.1	706	1.1	0.33	1621	0.05113	1	0.2703	0.8	0.038342	0.18	.45	**242.5 ± 0.4**	242.9 ± 2.0	247 ± 18
LAT30.Z83	CA	1.5	453	1.9	0.47	911	0.05090	1	0.2690	1.4	0.038321	0.37	.43	**242.4 ± 0.9**	241.9 ± 3.5	236 ± 30
LAT30.Z86	CA	0.8	167	1.7	0.56	205	0.04951	7	0.2609	7.5	0.038219	0.62	.68	**241.8 ± 1.5**	235.4 ± 17.7	172 ± 166
BIV1.Z03	CA	1.5	104	0.6	0.32	690	0.05133	2	0.2722	1.6	0.038460	0.17	.57	**243.3 ± 0.4**	244.5 ± 4.0	256 ± 36
BIV1.Z08	CA	0.9	73	0.5	0.45	356	0.05087	3	0.2693	3.4	0.038390	0.25	.73	**242.8 ± 0.6**	242.1 ± 8.3	235 ± 75
BIV1.Z12	CA	0.7	130	1.2	0.41	198	0.05230	7	0.2767	7.3	0.038378	0.46	.80	**242.8 ± 1.1**	248.1 ± 18.1	298 ± 158
BIV1.Z05	CA	1.4	87	0.5	0.32	585	0.05095	2	0.2696	2.1	0.038374	0.22	.58	**242.7 ± 0.5**	242.4 ± 5.1	239 ± 46
BIV1.Z02	CA	1.7	139	0.6	0.37	1030	0.05079	1	0.2685	1.1	0.038342	0.22	.44	**242.5 ± 0.5**	241.5 ± 2.7	232 ± 24
BIV1.Z04	CA	0.8	102	0.5	0.36	437	0.05259	3	0.2780	3.0	0.038340	0.24	.59	**242.5 ± 0.6**	249.1 ± 7.5	311 ± 65
BIV1.Z09	CA	0.8	152	0.5	0.24	568	0.05129	2	0.2710	2.1	0.038327	0.17	.67	**242.5 ± 0.4**	243.5 ± 5.1	254 ± 45
BIV1.Z01	CA	0.7	275	0.5	0.32	952	0.05104	1	0.2696	1.2	0.038312	0.13	.56	**242.4 ± 0.3**	242.4 ± 2.9	242 ± 26
BIV1.Z10	CA	0.8	233	0.5	0.36	985	0.05177	2	0.2734	1.7	0.038301	0.18	.53	**242.3 ± 0.4**	245.4 ± 4.1	275 ± 36
BIV1.Z11	CA	0.7	47	0.5	0.36	200	0.05432	6	0.2866	6.8	0.038266	0.46	.84	**242.1 ± 1.1**	255.9 ± 17.3	384 ± 143
BIV1.Z06	CA	0.7	115	1.0	0.31	225	0.05206	5	0.2744	5.3	0.038231	0.34	.85	**241.9 ± 0.8**	246.2 ± 13.1	288 ± 115
BIV1.Z07	CA	2.3	134	0.5	0.28	1362	0.05096	1	0.2683	0.9	0.038183	0.20	.44	**241.6 ± 0.5**	241.3 ± 2.2	239 ± 19

[a)] CA = annealed/chemically abraded

[b)] sample weight is calculated from crystal dimensions and is associated with as much as 50% uncertainty (estimated)

[c)] total common Pb including analytical blank (analytical Pb blank is 0.8 ± 0.3 pg per analysis)

[d)] present day Th/U ratio calculated from radiogenic ^{208}Pb/^{206}Pb and age

[e)] measured value corrected for tracer contribution and mass discrimination (0.15 ± 0.09 %/amu)

[f)] ratios of radiogenic Pb versus U; data corrected for mass fractionation, tracer contibution and common Pb contribution

[g)] correlation coefficient of radiogenic ^{207}Pb/^{235}U versus ^{206}Pb/^{238}U

Uncertainties of individual ratios and ages are given at the 2σ level and do not include decay constant errors.

Ratios involving ^{206}Pb are corrected for initial disequilibrium in ^{230}Th/^{238}U adopting Th/U=4 for the crystallization environment.

Montovo; see Pisa 1972a), comparable occurrences of drowned platforms with a pelagic cover sealed by younger clastic successions may also be suspected for areas with poor exposures further afield in western Carnia and Cadore and whose stratigraphic relationships were usually explained by synsedimentary block faulting. This could hold true for the situation at Valdepena - Col Torondo (ca 10 km NW of M. Bivera) where the Clapsavon Limestone also seems to cover a platform flank possibly onlapped by younger clastic sediments (e.g., fig. 4 in Marinelli 1980). Ammonoids in the red limestones at Valdepena are from presumably similar levels as in the Clapsavon area but also include younger taxa such as *Arpadites* and *Protrachyceras* (De Toni 1914) ranging in age up to the middle/upper Buchenstein Formation (*Protrachyceras gredleri* Zone and younger).

At Sappada (15 km NNE of M. Bivera) Cros & Lagny (1972), Lagny (1974) and Assereto & Pisa (1978) reported rapid variations in the thickness of prominent Pietra Verde successions suggesting the onlap on a relief of platform carbonates covered locally by a condensed ammonoid horizon. Ammonoids collected earlier from the condensed level at Sappada (Rio Lerpa; Geyer 1898) and our own finds (*Nevadites* sp., *Falsanolcites* cf. *rieberi*) document a time span between at least the latest *Nevadites secedensis* to *Eoprotrachyceras curionii* zones. From the same layer Vrielynck (1984) reports a conodont association similar to that of the pelagic drape at Punta di Zonia (Cernera).

If confirmed by more thorough analysis, these settings indicate that platform submergence and drowning in the latest Anisian may have affected a relatively large area east of Cernera.

New radio-isotope age data

Zircons from two volcaniclastic horizons constraining the main stage of platform aggradation at Cernera and Bivera/Clapsavon have been separated by standard mineral separation techniques and analysed by single crystal U/Pb TIMS (thermal ionisation mass spectroscopy) dating techniques. Sample BIV-1 is from a white sandy tuff-layer in the Late Anisian Bivera

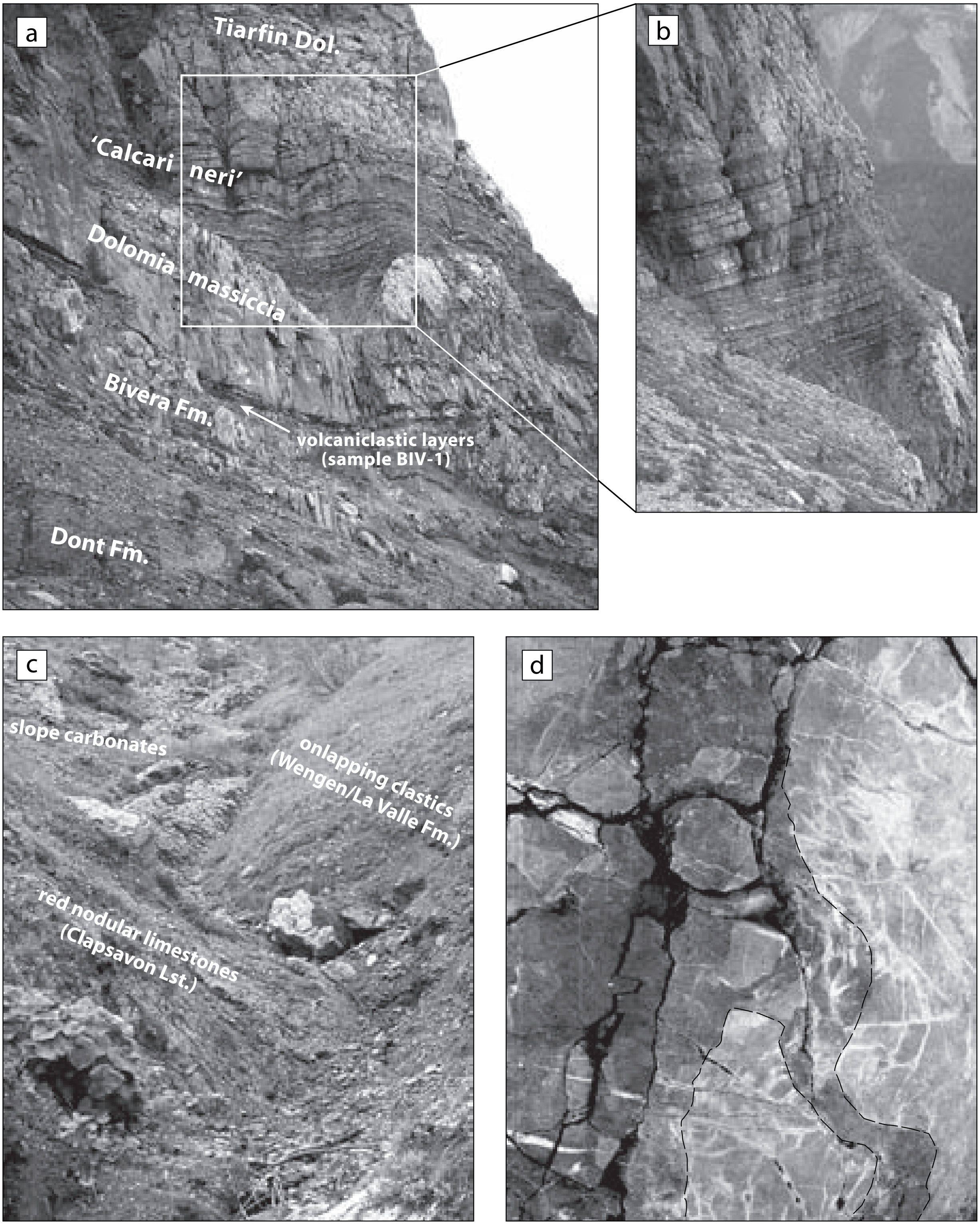

Fig. 9. a, b) View of the stratigraphic succession at the base of the Bivera/Clapsavon platform in the northeastern ridge of M. Bivera. The position of sample BIV-1 from the volcaniclastic layers in the uppermost Bivera Formation is indicated. The apparent erosional relief of the surface of the "Dolomia massiccia" (Pisa 1974; figs. 9, 15, 28) is in reality a smooth surface at the base of the overlying "Calcari neri". c) Outcrop of Clapsavon Limestone on top of light-coloured slope carbonates in the creek northeast of Forcella Chiana. At this place the pelagic limestones are in direct contact with the onlapping clastic sediments of the Late Ladinian Wengen (La Valle) Formation. d) Fissures and sedimentary dykes filled with red pelagic material in the white limestone at the base of the Clapsavon Limestone. Locality as in Fig. 9c.

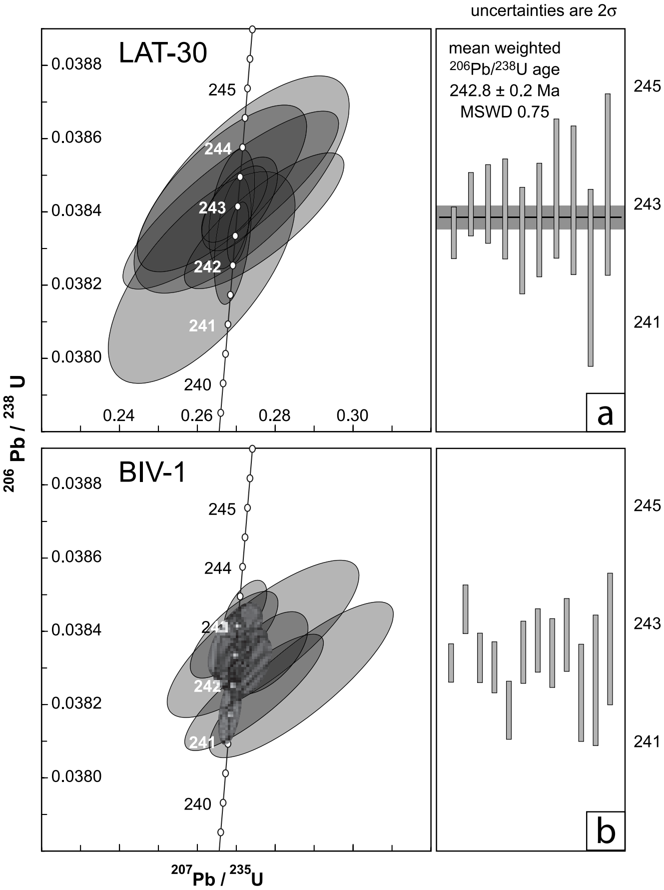

Fig. 10. Concordia diagrams and ^{206}Pb/^{238}U ages ranked by uncertainty: a) Sample LAT-30 is from Latemar (see Mundil et al. 2003); its stratigraphic level is approximately equivalent with the *Ticinites* horizon (i.e. basal *Nevadites secedensis* Zone). b) Sample BIV-1 is from the uppermost Bivera Formation at M. Bivera. See Fig. 9a for its location.

Formation (*Paraceratites trinodosus* Zone according to Farabegoli et al. 1984) at Monte Bivera and sample LAT-30 was collected in the Latemar carbonate platform from a stratigraphic level close to the base of the *Nevadites secedensis* Zone (for details see Mundil et al. 2003).

Previous radio-isotopic dating work on zircons from Middle Triassic volcaniclastic beds indicates that the crystals are affected by varying degrees of secondary Pb loss, resulting in age scatter for zircon populations from individual layers (Mundil et al. 1996; Mundil et al. 2003). In order to eliminate these effects, zircons were treated using the method of thermal annealing at 850°C for 36 hrs, followed by chemical abrasion with conc. HF in pressurized dissolution capsules at 220°C resulting in removal of crystal portions which are affected by secondary Pb loss (Mundil et al. 2004; Mattinson 2005). Application of this pre-treatment procedure has been shown to be superior to the conventional approach of air abrasion. Analytical protocols follow those described in Mundil et al. (2004) unless stated otherwise. The analytical results are listed in Table 1 with graphical representations in Figures 10a, b.

Sample BIV-1

Zircon crystals from BIV-1 are small and characterised by abundant cracks and inclusions. Subsequent to the thermal annealing of the crystals, chemical abrasion for 16 hrs resulted in complete dissolution of the zircons. Although tuning the degree of the HF leaching has proven difficult, 16 hours of leaching has typically resulted in crystals without Pb loss but sufficient material left for TIMS analyses yielding precise ^{206}Pb/^{238}U ages. Total dissolution of the crystals indicates that the zircons from BIV-1 were severely damaged. A second, less aggressive attempt with reduced HF leaching (8hrs) yielded small crystal fragments (median weight of 0.8 μg), but the scatter of the results exceeds the analytical uncertainty of the ^{206}Pb/^{238}U ages (MSWD 3.3) and indicates that the effects of Pb loss were not entirely eliminated. It seems crucial to apply a HF leaching step which results in total removal of Pb loss-affected crystal portions even at the cost of partially dissolving undisturbed parts of the zircons as well. For BIV-1 individual ages from 12 zircons range from *243.3* Ma to 241.6 Ma. Because of Pb loss and the mild leaching step, we interpret the first age to be the minimum age for this sample. Alternatively, rejecting the oldest and the youngest individual age, a coherent weighted mean ^{206}Pb/^{238}U age of 242.4 ± 0.2 Ma (MSWD 0.75) can be calculated but for reasons given below we are prompted to conclude that this age is too young.

Sample LAT-30

Zircons from LAT30 are clear and euhedral and even aggressive HF leaching resulted in crystal fragments with a median

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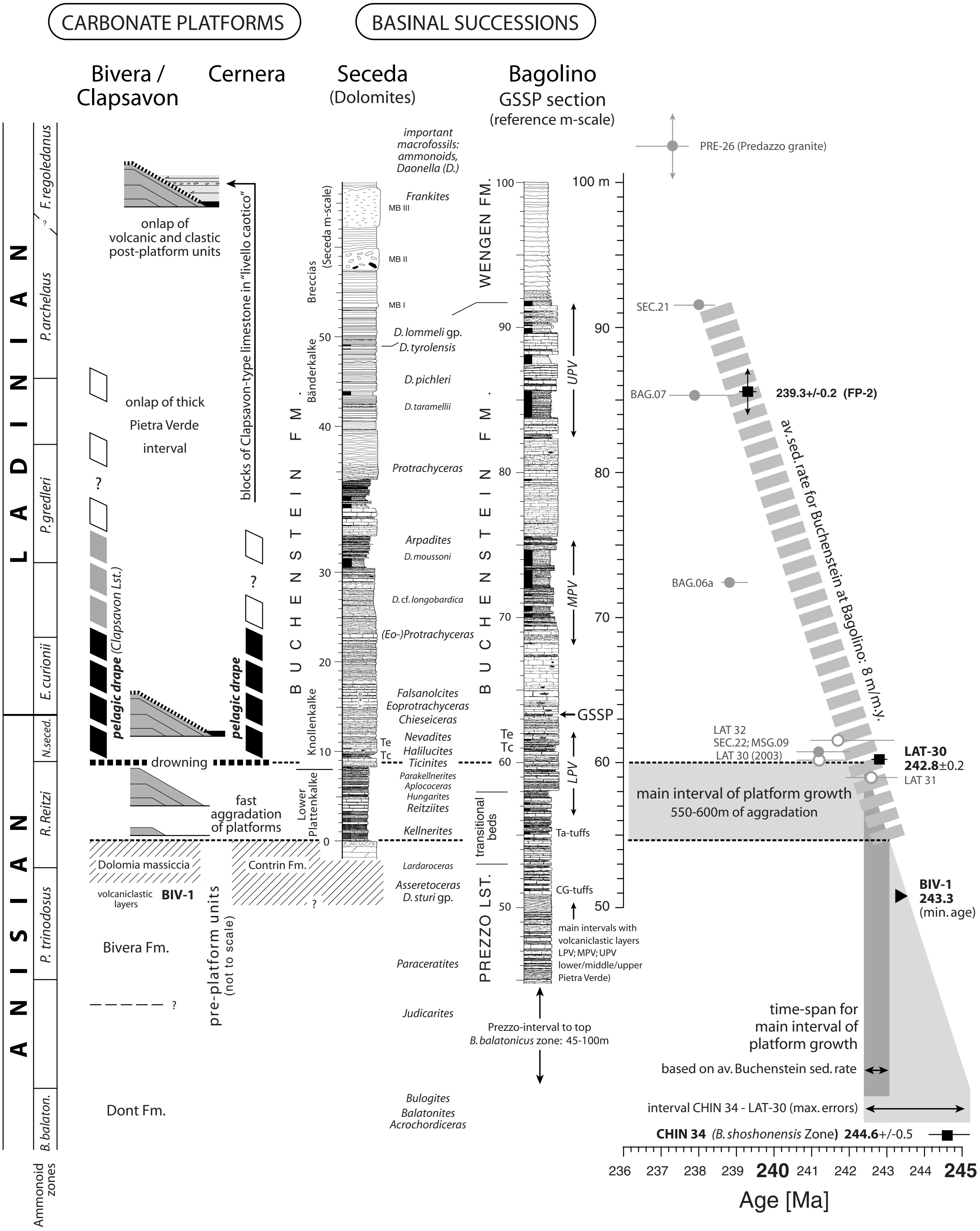
Fig. 11. Time frame and chronology of platform growth, drowning and onlap at Cernera and Bivera/Clapsavon compared with the pelagic reference successions at Seceda and Bagolino (Ladinian-GSSP-section). Only the most important ammonoid genera are indicated in approximately the position of their main occurrences with respect to the Bagolino column; see Brack et al. (2005) for the updated distributions of macrofossils in the *Reitziites reitzi* to *Eoprotrachyceras curionii zones* and Brack & Rieber (1993) and Muttoni et al. (2004) for the correlation of the Bagolino and Seceda columns. The time spans indicated by fossils from the pelagic drapes at Cernera and Clapsavon are shown (black bars). Locally such drapes possibly range higher up (white bars) as suggested e.g., by faunal elements from the Clapsavon Limestone at Valdepena (grey bars).

U-Pb single zircon ages are from Mundil et al. (1996; grey dots), Mundil et al. (2003; grey circles), Ovtcharova et al. (2006; sample CHIN34) and Brühwiler (2004; sample FP-2, zircon data obtained by R. Mundil at Berkeley Geochronology Center). Black squares and triangle indicate new and consistent U-Pb single zircon data obtained after the annealing/leaching pre-treatment procedure. See text for discussion of age data and their allocated stratigraphic positions relative to the Bagolino column.


CARBONATE PLATFORMS
BASINAL SUCCESSIONS
Bivera / Clapsavon
Cernera
Seceda
(Dolomites)
Bagolino
GSSP section
(reference m-scale)
important macrofossils: ammonoids, Daonella (D.)
LADINIAN
ANISIAN
F. regoledanus
P. archelaus
P. gredleri
E. curionii
N. seced.
R. Reitzi
P. trinodosus
B. balaton.
Ammonoid zones
onlap of volcanic and clastic post-platform units
blocks of Clapsavon-type limestone in "livello caotico"
onlap of thick Pietra Verde interval
?
pelagic drape (Clapsavon Lst.)
pelagic drape
drowning
fast aggradation of platforms
Dolomia massiccia
Contrin Fm.
volcaniclastic layers
BIV-1
Bivera Fm.
pre-platform units (not to scale)
Dont Fm.
Breccias
(Seceda m-scale)
Bänderkalke
Knollenkalke
Lower Plattenkalke
BUCHENSTEIN FM.
MB III
MB II
MB I
Frankites
D. lommeli gp.
D. tyrolensis
D. pichleri
D. taramellii
Protrachyceras
Arpadites
D. moussoni
D. cf. longobardica
(Eo-)Protrachyceras
Falsanolcites
Eoprotrachyceras
Chieseiceras
Nevadites
Halilucites
Ticinites
Parakellnerites
Aplococeras
Hungarites
Reitziites
Kellnerites
Lardaroceras
Asseretoceras
D. sturi gp.
Paraceratites
Judicarites
Bulogites
Balatonites
Acrochordiceras
Te
Tc
0
10
20
30
40
50
WENGEN FM.
BUCHENSTEIN FM.
PREZZO LST.
transitional beds
100
90
80
70
60
50
UPV
MPV
LPV
GSSP
Ta-tuffs
CG-tuffs
main intervals with volcaniclastic layers LPV; MPV; UPV lower/middle/upper Pietra Verde)
Prezzo-interval to top B. balatonicus zone: 45-100m
100 m
PRE-26 (Predazzo granite)
SEC.21
BAG.07
239.3+/-0.2 (FP-2)
av. sed. rate for Buchenstein at Bagolino: 8 m/m.y.
BAG.06a
LAT 32
SEC.22; MSG.09
LAT 30 (2003)
LAT-30
242.8±0.2
LAT 31
main interval of platform growth
550-600m of aggradation
BIV-1
243.3
(min. age)
time-span for main interval of platform growth
based on av. Buchenstein sed. rate
interval CHIN 34 - LAT-30 (max. errors)
CHIN 34 (B. shoshonensis Zone) 244.6+/-0.5
236
237
238
239
240
241
242
243
244
245
Age [Ma]

weight of 1.2 μg. TIMS analyses of eleven fragments yielded a coherent weighted mean 206Pb/238U age of *242.8 ± 0.2* Ma (MSWD 0.75). A former study (Mundil et al. 2003) using different leaching and abrasion techniques resulted in an age of 241.2 +0.7/-0.6 Ma from 7 out of 24 analyses, most of which were severely affected by Pb loss (as much as 10%). Although our new age is not agreement with the one from Mundil et al. (2003) we are confident that it is more accurate, as indicated by its coherence.

Discussion

An additional age constraint predating the platform growth considered here comes from a U/Pb zircon age from the *Balatonites shoshonensis* Zone in China (Ovtcharova et al. 2006). In their study, four annealed and chemically abraded crystals yielded a mean ^{206}Pb/^{238}U age of *244.6 ± 0.5* Ma (sample CHIN34). Two air abraded zircons gave slightly younger ages and one age is resolvably younger. The robustness of the ages for CHIN34 (Ovtcharova et al. 2006) and LAT-30 in combination with stratigraphic relations suggest that the age of 243.3 Ma for BIV-1 is a minimum age, in particular in view of the fact that the individual ages for the latter show excess scatter and a mild leaching step was used.

The timing of platform growth and resulting rates of carbonate accumulation

It is as yet unclear what factors beyond accelerated subsidence may have caused the breakdown of carbonate production at Cernera and Bivera/Clapsavon. Both platforms record a stratigraphic interval about twice as thick as age-equivalent intervals in platforms of the western Dolomites (e.g., Brack & Muttoni 2000). Together with the coarse and rather irregular bedding characteristics the 550-600 m thick intervals at Cernera and Bivera/Clapsavon suggest carbonate production and accumulation close to the maximum capacity. The metre-thick equivalent basinal intervals ("Lower Plattenkalke" of the Buchenstein Formation) adjacent to the Cernera platform imply that the export of significant amounts of platform debris did not reach even proximal basin portions. Therefore, the available chrono-biostratigraphic time frame for the Buchenstein Formation (Mundil et al. 1996; Muttoni et al. 2004; Brack et al. 2005) complemented with the new radio-isotope ages allow a direct assessment of the effective potential of carbonate production and accumulation in low-latitude Middle Triassic platforms (Fig. 11).

The base of the platform aggradation interval at Cernera and Bivera/Clapsavon postdates the dated tuff layer in the Bivera Formation (with a minimum age of 243.3 Ma for sample BIV-1). The Bivera Formation follows on top of the Dont Formation with ammonoids (at M. Bivera) corresponding to a level in the *Balatonites shoshonensis* Zone of North America and China (H. Bucher, pers. comm.). In agreement with the age result for the Bivera Formation and values for older (Early Anisian and Early Triassic) stratigraphic levels Ovtcharova et al. (2006) recently obtained a U-Pb-zircon age of 244.6±0.5 Ma for a tuff layer in the *Balatonites shoshonensis* Zone in China (sample CHIN34). The latter value thus serves as a safe constraint for a level pre-dating the platform interval at Cernera and Bivera/Clapsavon. At its top the interval of platform aggradation is constrained by a minimum age close to 242 Ma for the Tc-volcaniclastics (Mundil et al. 1996) and the stratigraphically somewhat older but now re-dated Latemar tuff (LAT-30: 242.8±0.2 Ma) whose level may overlap with the latest stages of platform retrogradation at Cernera. The U-Pb zircon ages of CHIN34 and LAT-30 were both obtained after the annealing-leaching pre-treatment procedure and yield a maximal duration of 1.8±0.7 m.y. for the period of platform aggradation at Cernera and Bivera/Clapsavon. However, this time-span also comprises a stratigraphic interval pre-dating the platform interval and ranging from the top of the *Balatonites balatonicus* Zone (corresponding to the top of the *B. shoshonensis* Zone) to the base of the *Reitziites reitzi* Zone. In continuous pelagic successions of eastern Lombardy and Giudicarie (e.g., Val di Scalve, Monte Corona) this interval largely corresponds to the up to 120 metres thick Late Anisian Prezzo Limestone (e.g., Brack et al. 1999). Therefore, the effective duration of the main period of platform aggradation at Cernera and Bivera/Clapsavon (i.e. the *Reitziites reitzi* Zone or a fraction of it) is probably much shorter than the maximal duration indicated above.

Another way of estimating the time span of the main interval of platform aggradation makes use of sedimentation rates in Buchenstein successions also constrained by recent radioisotope data. Based on the distribution of *Daonella tyrolensis,* a tuff layer (FP-2) in the uppermost Reifling Beds at Flexenpass (Northern Calcareous Alps; western Austria) can be correlated with the youngest layers of the Upper Pietra Verde (UPV) in the Buchenstein Formation at Seceda and Bagolino (Brühwiler 2004 and pers. comm.). Together with the stratigraphic position of the LAT-30 age, these values match an average rate close to 8 m/m.y. for the accumulation of pelagic carbonates at Bagolino (not corrected for volcaniclastic layers and compaction). The extrapolation of this trend to the basal "Knollenkalke" of the Buchenstein Formation and the underlying "transitional beds" (deposited at presumably higher rates) results in a time span of around 1 m.y. for the *Reitziites reitzi* Zone. This value is also in agreement with the minimum age of sample BIV-1.

Consequently the effective time-span available for the main stage of platform growth is in the order of 0.5-1 m.y., resulting in an average rate larger than 500 m/m.y. for the accumulation of the 550-600 m thick platform interior beds at Cernera and Bivera/ Clapsavon. This is close to values of the growth potential estimated for time-spans 10^5-10^6yrs (e.g., Schlager 1999) and probably reflects the exceptional age resolution in this Middle Triassic case history. Moreover the high growth rate indeed indicates that the purportedly "normal" (i.e. lower) values reported for carbonate accumulation on Mesozoic platforms are due to integration over longer and incomplete stratigraphic intervals rather than lower effective growth potentials.

Conclusions

The current survey of two spectacularly exposed, fast-growing and subsequently drowned carbonate platforms in the eastern Southern Alps aimed at integrating litho-, bio and chronostratigraphic data with observations on the platform geometries and platform-basin relationships. The following main points emerge from this study:

– Platform aggradation and retrogradation resulted in high-relief topographic features built on a comparably smooth base whose tops eventually rose to several hundred metres above the coeval basin floors. After drowning the sea mounts were draped by thin pelagic carbonate deposits and finally onlapped by thick piles of volcanic and clastic rocks, locally including chaotic breccia deposits.

– Geometric relationships between the platform slope deposits and coeval basinal sediments along with ammonoids from the ultimate slope portions constrain the main interval of platform growth to a time-span that hardly exceeds the younger part of the Anisian *Reitziites reitzi* Zone (sensu Brack et al. 2005). Only the terminal phases of retrogradation and capping mounds may have continued into the basal *Nevadites secedensis* Zone.

– Modern U-Pb zircon ages constrain the main stage of platform aggradation to a duration of less than 1.8±0.7 m.y. and likely in the range of 0.5-1 m.y., indicating high rates of vertical growth exceeding 500 m/m.y. This high value is a result of the short interval of observation documented by high-resolution bio-, litho- and chronostratigraphic data.

– The red nodular and locally ammonoid-bearing pelagic limestones at M. Clapsavon have formed a consistent layer on inclined platform slope portions also filling (? gravity-induced) fissures in their substrate. In the lower reaches of the platform slopes the red limestones are replaced by less condensed sediments of the Buchenstein Formation of which the younger strata in some places overlap the condensed horizons. In Triassic successions of the Eastern Alps, the Dinarides and Greece, the widespread Middle Triassic Han Bulog Limestones may have formed partly in similar slope environments.

– Stratigraphic settings elsewhere between the eastern Dolomites and western Carnia show evidence for platform drowning in a larger area throughout the latest Anisian. Increased tectonic subsidence is thought to have played a key role in the submergence of platforms. The contemporaneous change from laminated to bioturbated sediments in the basinal Buchenstein Formation could be related to the drowning of a system of shallow thresholds, which likely affected the deep-water circulation patterns in the Buchenstein basins of the Dolomites.

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