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THE SECEDA DRILL HOLE IN THE MIDDLE TRIASSIC BUCHENSTEIN BEDS (LIVINALLONGO FORMATION, DOLOMITES, NORTHERN ITALY) A PROGRESS REPORT

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Riassunto. Sono qui riportati i primi risultati e le informazioni essenziali riguardanti il progetto di perforazione a scopo scientifico denominato "Seceda Coring". La carota ottenuta è attualmente in studio da parte di un gruppo internazionale di ricercatori appartenenti a diverse università. Obbiettivi fondamentali del progetto sono una accurata analisi sedimentologica e ciclostratigrafica della intera successione pelagica di età medio Triassica riferibile alla Formazione di Buchenstein nelle Dolomiti Nord-occidentali (Alpi Meridionali, Italia), così come le relazioni cronologiche con le piattaforme carbonatiche coeve. Studi complementari vertono sugli strumenti di correlazione stratigrafica, quali bio-, lito- e magnetostratigrafia.

Abstract. First results and basic geological information of the Seceda Coring Project are reported. The Seceda project started with drilling of a well for scientific purposes. The core material is currently studied by an international group of geoscientists from different universities. Fundamental topics of the project are a thorough sedimentological and cyclostratigraphic analysis of the complete succession of Middle Triassic pelagic Buchenstein Beds in the northwestern Dolomites (Southern Alps, Italy) as well as their temporal relationship with coeval carbonate platforms. Complementary studies focus on stratigraphic correlation tools including bio-, litho- and magnetostratigraphy.

Introduction.

The Triassic of the Southern Alps has recently become the object of an intense debate that revolves around two fundamental topics of geology – time and the origin of depositional rhythms.

The background is as follows. In the late 1980's and early 90's, a group from John Hopkins University, Baltimore, USA, led by L.A. Hardie, studied the Latemar platform in the Dolomites, producing - among others – detailed documentations of the slope and margin (Goldhammer & Harris, 1989; Harris, 1993, 1994) and the platform interior (Hardie et al., 1986; Goldhammer et al., 1987, 1990, 1993). The platform interior was found to consist of a hierarchy of bedding rhythms. Hinnov & Goldhammer (1991) showed that most of these rhythms are compatible with orbital control if one assumes a duration of at least 12 Ma for the late Anisian-Ladinian interval during which the Latemar platform was formed.

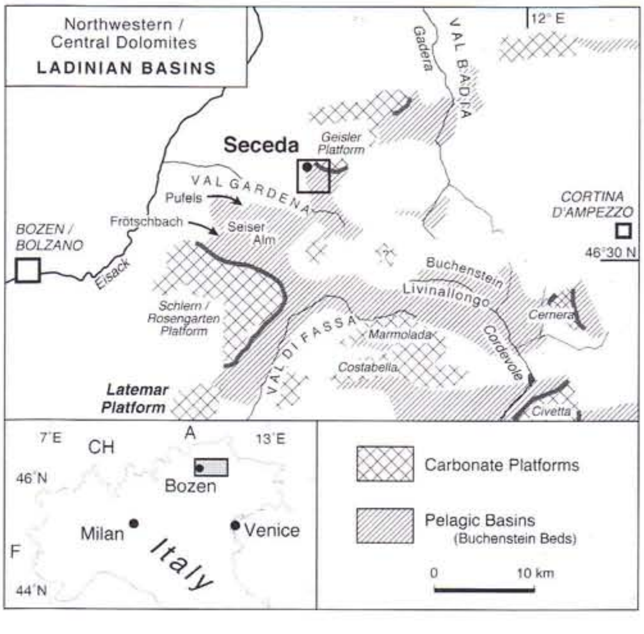

Fig. 1 - Carbonate platforms and basins in the Dolomites during the early Ladinian. Dark lines mark approximate positions of the platform-basin-transition. Area of Fig. 2 is indicated.

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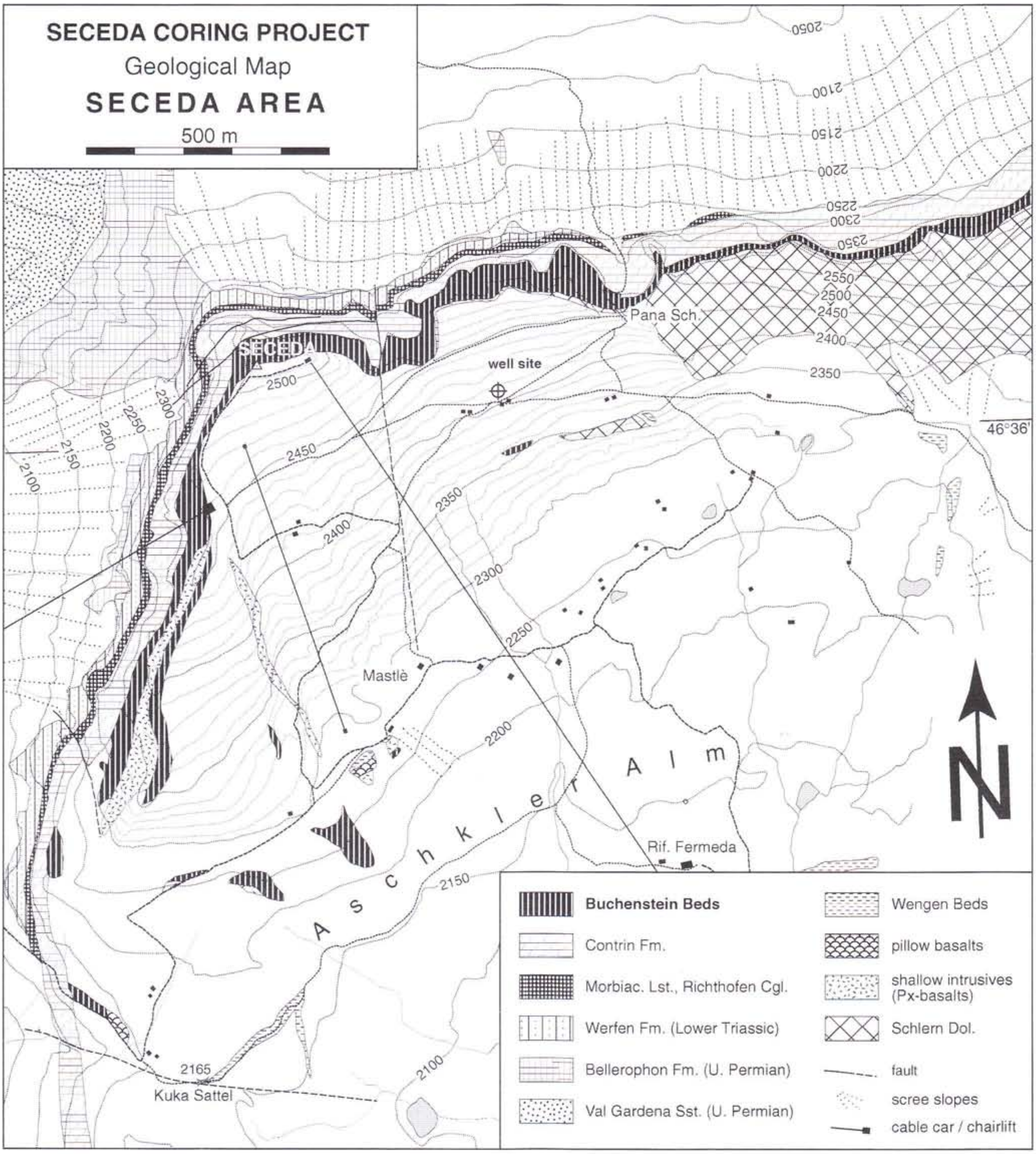


Fig. 2 - Map of outcrops around the Seceda peak (see text for further information). The site of Seceda drilling is indicated.

Almost simultaneously with the work on the Latemar platform, the coeval basinal Buchenstein Beds (or Livinallongo Fm.) were studied from a sedimentologic, petrographic and stratigraphic point of view (Bosellini & Ferri, 1980; Cros & Houel, 1983; Brack & Rieber, 1993). The last paper is a monographic documentation of the formation in Lombardy and the Dolomites that presents lithostratigraphy along with biostratigraphic dates. When radiometric age results from zircons in volcaniclastic layers (Mundil et al., 1996) were added to this detailed stratigraphic framework, the discrepancy with current Triassic time scales and with the orbital interpretation of the Latemar succession became immediately obvious and led to different interpretations of Middle Triassic stratigraphy (Brack et al., 1996, 1997; Hardie & Hinnov, 1997). The debate carries added weight because the data are from the type area of the Ladinian stage and are tied to the standard

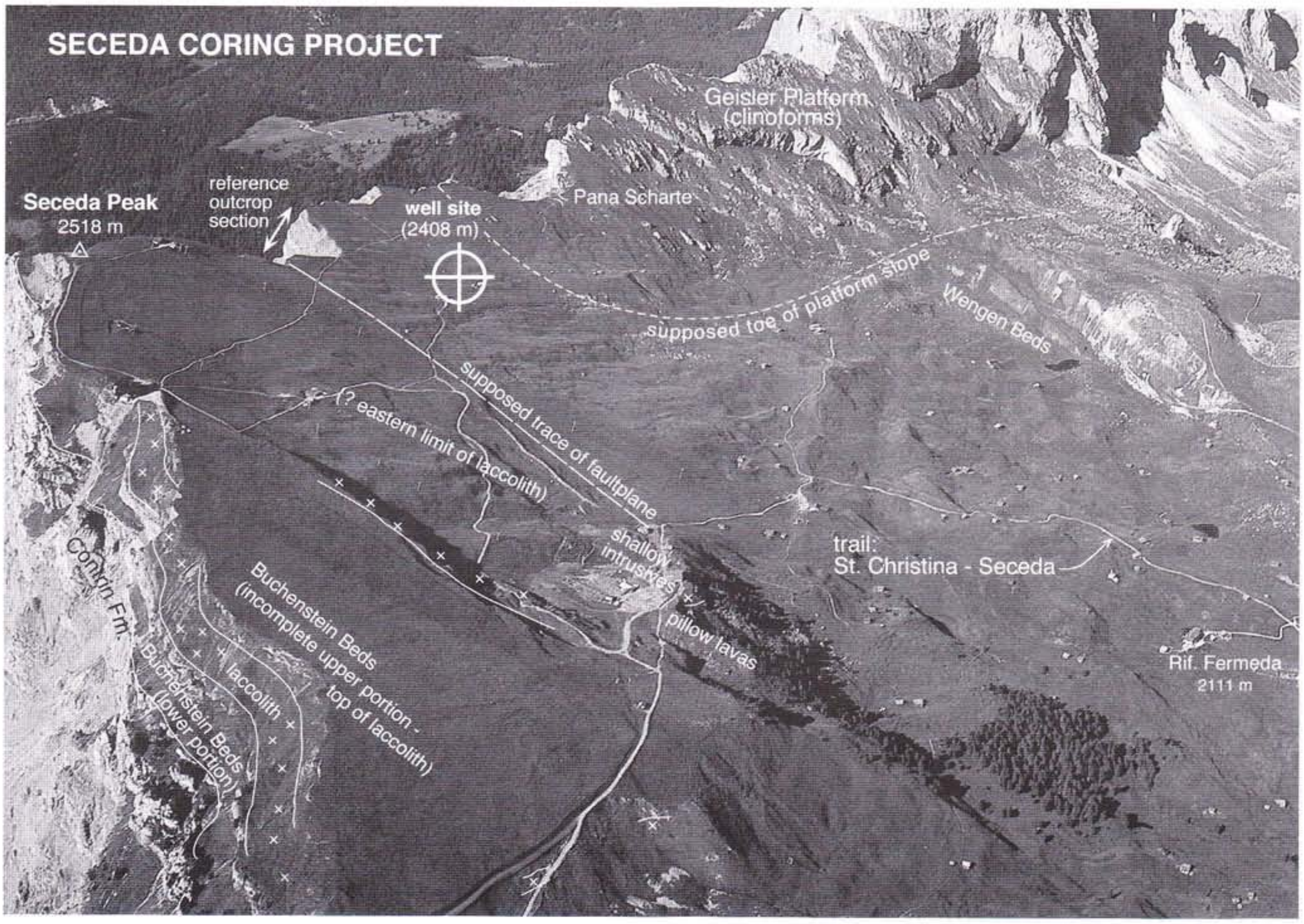


Fig. 3 - Air-view of the Seceda area with location of the drill site (airphoto by Tappeiner AG, Lana; reproduced with permission).

ammonoid zones; thus they directly affect the chronological framework of the Triassic.

Attempts to resolve the dispute are of two kinds. One group of studies concentrated on the origin, lateral persistence and age of the platform cycles in the Latemar (Heidelberg group; Egenhoff et al., 1999, Zühlke et al., 2000) and on accurate platform-basin correlations (e.g. Maurer, 1999, 2000). This paper reports on a second group of studies that focuses on the bedding rhythm of the Buchenstein Beds. If strong orbital rhythms were to be found, so the argument, then direct comparison of the zircon ages with the orbital chronology would be possible. In 1997, an informal working group was set up to carry out such a study with the first three authors of this paper as founding members. Presently, the working group includes 18 researchers of nine institutions: the Free University of Amsterdam, the ETH and University of Zürich, the University of Ferrara, the Johns Hopkins University at Baltimore, the Lamont-Doherty Earth Observatory, the University of Milan and the Universities of Kiel and Köln. A decisive step could be taken in 1998 when the Province of Bolzano/Bozen (Amt für Geologie und Baustoffprüfung, Dr. Ludwig Nössing) agreed to drill a well in the Buchenstein Beds for research purposes.

This paper presents a progress report on the results of the drilling campaign and explains the plans and strategies for further study.

The Buchenstein Beds: general outline and geology around the drill site at Seceda.

Successions of basinal Buchenstein Beds (= Livinallongo Fm. of Viel, 1979) are found in a wide area throughout the Dolomites (Fig. 1) and in adjacent areas. In general, the Buchenstein Beds consist of pelagic carbonates such as laminated siliceous and nodular cherty limestones as well as layers of acidic fine to coarse grained volcaniclastic material. In the upper part of complete Buchenstein successions, reworked debris derived from adjacent carbonate platforms is abundant. The stratigraphic range of Buchenstein Beds is subject to variations, however. In areas of platform growth, parts or the entire basinal succession are replaced by coeval platform carbonates. Towards the central and eastern Dolomites volcaniclastic intervals are increasingly thicker and the successions are often affected by alpine tectonic deformation.

Slimhole logging tools	Depth range (m) (a)	Sampling interval (b)	Remarks
Gamma-gamma density (g cm^{-3})	00.00 - 87.23	1 cm	Bottom casing at 22.34 m; standard density tool
Neutron porosity (fraction)	00.00 - 87.90	1 cm	Standard neutron porosity tool
Natural gamma ray (counts per second)	06.55 - 105.03	1 cm	Standard natural gamma tool
Single Point resistivity (SP)	00.00 - 85.04	1 cm	Bottom casing at 21.22 m standard resistivity tool
Resistivity (ohm-m)	00.00 - 85.04	1 cm	Bottom casing at 21.22 m standard resistivity tool
Acoustic televiewer*)	20.00 - 85.10	2 mm	Bottom casing at 20.74 m

*) acoustic televiewer system deploys fast rotating piezo-electric crystal that emits and recieves acoustic signal; high resolution recording of 3D borehole dimension and acoustic hardness of borehole wall formations (dependent on amplitude variation of reflected wave).

Tab. 1 - Logging tools and measured intervals (top casing is 0.00 m).

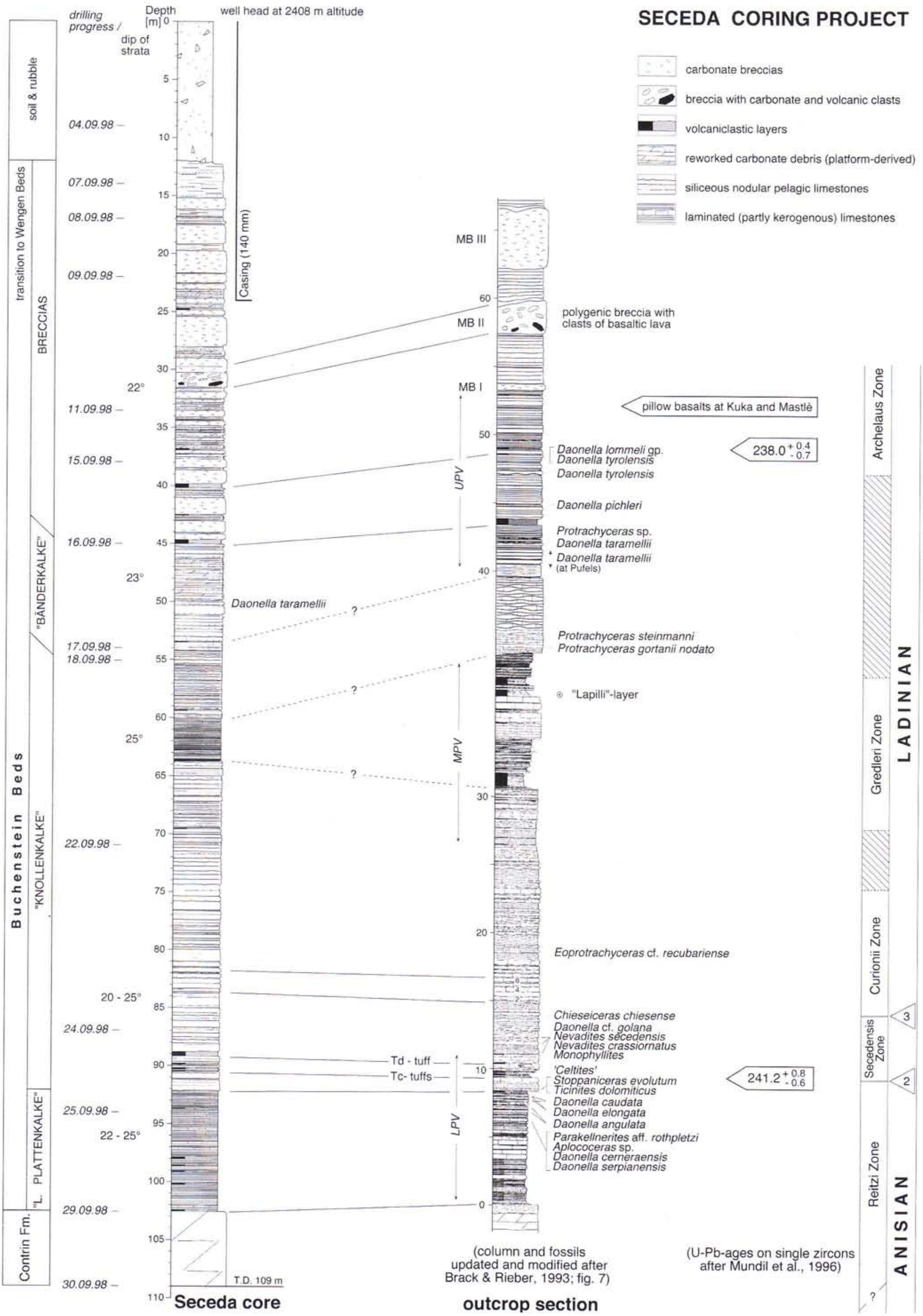
	core interval (metre)	approx. stratigraphic thickness (m)	dominant lithologies
A	12 - 15	2.6	marls and sandstones with plant remains
B	15 - 44	26.3	"breccias" (interval with coarse-grained carbonate breccias)
C	44 - 53	8.1	calcareous turbidites with platform debris
D	53 - 92.15	35.8	pelagic nodular lst. with thin interval of laminated siliceous limestones
E	92.15 - 102.55	9.4	laminated kerogenous lst.
F	102.55 - 109	5.8	dolomitised platform carbonates

Tab. 2 - The main straigraphic units of the Seceda core.

At some distance from coeval platform slopes, the Buchenstein successions in the northwestern Dolomites are remarkably invariable (e.g. Brack & Rieber, 1993) and sets of pelagic strata can be traced in detail over long distances (Brack & Muttoni, 2000). A full section of Buchenstein Beds is exposed in a steep cliff east of the Seceda peak (Brack & Rieber, 1993, fig. 4). In this area the Buchenstein Beds have yielded so far the most significant succession of macrofossils (ammonoids, *Daonella*) of uppermost Anisian to Ladinian age from the Dolomites. Moreover, Seceda is located close to classical outcrops such as Frötschbach (see Muttoni et al., 1996, 1997) and the Pufels gorge to the southwest of Seceda, i.e. the area where the Buchenstein Beds had been described for the first time (Von Richthofen, 1860).

At Seceda (Fig. 2, 3) the Buchenstein Beds follow on top of upper Anisian platform carbonates (Contrin Fm.) with an apparently smooth upper surface. The regional dip of strata is around 20 - 25° towards southeast. To the east the Buchenstein Beds are gradually replaced by slope deposits (Schlern Dolomite) of the Geisler platform whereas near Kuka Sattel in the southwest, the succession is overlain by pillow basalts and siliciclastic basinal Wengen Beds. These basinal siliciclastics also interfinger with slope carbonates of the Schlern Dolomite to the southeast of Pana Scharte. The lavas and clastic sediments at Seceda belong to the lowermost part of a thick pile of volcanic and clastic rocks which is preserved to the south of Col Raiser (2 km southeast of Seceda) and in the slopes around Seiser Alm. Along the ridge south of the cable car station at Seceda a laccolith is found at the level of the middle Buchenstein Beds. The nearby basaltic extrusive rocks were possibly fed

Fig. 4 - Drilling progress and startigraphic log of the Seceda core. Lithological breaks and marker beds allow precise correlation with the outcrop section. See Brack & Rieber, 1993; Brack et al., 1996 and Mundil et al., 1996 for additional information on (bio-)stratigraphy, ammonoid zones and isotopic age data from Seceda. Positions currently in evaluation for the Anisian/Ladinian-boundary are indicated by numbers (2, 3; 1 being the base of the Reitzi Zone); main intervals with volcaniclastic layers: Lower (LPV), Middle (MPV), Upper (UPV) Pietra Verde. MB I-II: distinct megabreccia bodies in outcrop section.


SECEDA CORING PROJECT
carbonate breccias
breccia with carbonate and volcanic clasts
volcaniclastic layers
reworked carbonate debris (platform-derived)
siliceous nodular pelagic limestones
laminated (partly kerogenous) limestones
drilling progress / dip of strata
Depth [m]
well head at 2408 m altitude
Casing (140 mm)
soil & rubble
transition to Wengen Beds
BRECCIAS
"BÄNDERKALKE"
"KNOLLENKALKE"
"L. PLATTENKALKE"
Buchenstein Beds
Contrin Fm.
04.09.98
07.09.98
08.09.98
09.09.98
11.09.98
15.09.98
16.09.98
17.09.98
18.09.98
22.09.98
24.09.98
25.09.98
29.09.98
30.09.98
22°
23°
25°
20 - 25°
22 - 25°
Daonella taramellii
Td - tuff
Tc- tuffs
T.D. 109 m
Seceda core
MB III
MB II
MB I
UPV
MPV
LPV
polygenic breccia with clasts of basaltic lava
pillow basalts at Kuka and Mastlè
Daonella lommeli gp.
Daonella tyrolensis
Daonella tyrolensis
Daonella pichleri
Protrachyceras sp.
Daonella taramellii
Daonella taramellii (at Pufels)
Protrachyceras steinmanni
Protrachyceras gortanii nodato
"Lapilli"-layer
Eoprotrachyceras cf. recubariense
Chieseiceras chiesense
Daonella cf. golana
Nevadites secedensis
Nevadites crassiornatus
Monophyllites
'Celtites'
Stoppaniceras evolutum
Ticinites dolomiticus
Daonella caudata
Daonella elongata
Daonella angulata
Parakellnerites aff. rothpletzi
Aplococeras sp.
Daonella cerneraensis
Daonella serpianensis
238.0 +0.4 -0.7
241.2 +0.8 -0.6
(column and fossils updated and modified after Brack & Rieber, 1993; fig. 7)
outcrop section
(U-Pb-ages on single zircons after Mundil et al., 1996)
Archelaus Zone
Gredleri Zone
Curionii Zone
Secedensis Zone
Reitzi Zone
LADINIAN
ANISIAN

through this subvolcanic body as suggested by the outcrop relationships near Mastlè.

The location of the drill site (Figs. 2, 3) was chosen as close as (logistically) possible to the reference outcrop section, in a narrow area between the toe of the Geisler platform slope and a N-S running fault between Seceda peak and Pana Scharte. The area to the west of this fault is elevated by a few tens of metres and only the lower half of the Buchenstein succession is preserved here.

Drilling and logging operations.

On September 1 - 2, 1998 a mobile drilling rig was transported to and installed on the final drill site at 2408 m altitude. Water supply was from the nearby chairlift station close to Seceda peak. Drilling started on the following day and ended on September 30, when a total depth of 109 m was reached. Drilling operations were interrupted during weekends and were severely obstructed by low temperatures and snow in mid September. Drilling first penetrated an unexpectedly thick soil cover. Due to downhole loss of water while drilling through the uppermost karstified carbonate breccia bodies, a 140 mm casing was pushed to a depth of 24 metres. Thereafter coring progress was steady, reaching a maximum of 9 m/day. A drill bit with 97 mm diameter leaving a 93 mm wide core was employed over the entire length of the hole.

Acquisition of wire line logs was completed in cold weather during October 1 - 2. A set of slimhole logging tools was deployed (Table 1). Circulation problems hampered logging in the interval of 85 - 109 m. Only the natural gamma tool could be run over the entire section of Buchenstein Beds.

Recovery, handling and storage of core material.

Average recovery was better than 95% (between 25 - 103 m levels) and even the most friable lithologies (marls and certain ash layers) were recovered with only minor losses. After completion of drilling, the core material was transported to Bozen/Bolzano for further processing. Broken cores were carefully re-assembled and glued; subsequently, the entire suite of cores was cut in two equal halves and digitally photographed. The entire Seceda core is now archived at the Natural History Museum in Bozen/Bolzano.

Results of preliminary core inspection and comparison with outcrop.

The bore hole penetrated and continuously cored 109 m of rock and soil (Fig. 4). The top 12 m consist of soil. The bedding of the Triassic units dips fairly uniformly at 25° so that the penetration amounts to recovery of around 88 m of stratigraphic thickness. From top to bottom the following main units are distinguished (Table 2): Interval A represents a transitional unit close to the base of the Wengen Beds. Interval B is characterised by abundant coarse-grained, platform-derived carbonate material (breccias). Intervals C - E are typical members of the Buchenstein Beds, i.e. the "Bänderkalke", the "Knollenkalke" and the "Lower Plattenkalke" respectively. Interval F is the topmost part of the Contrin Formation.

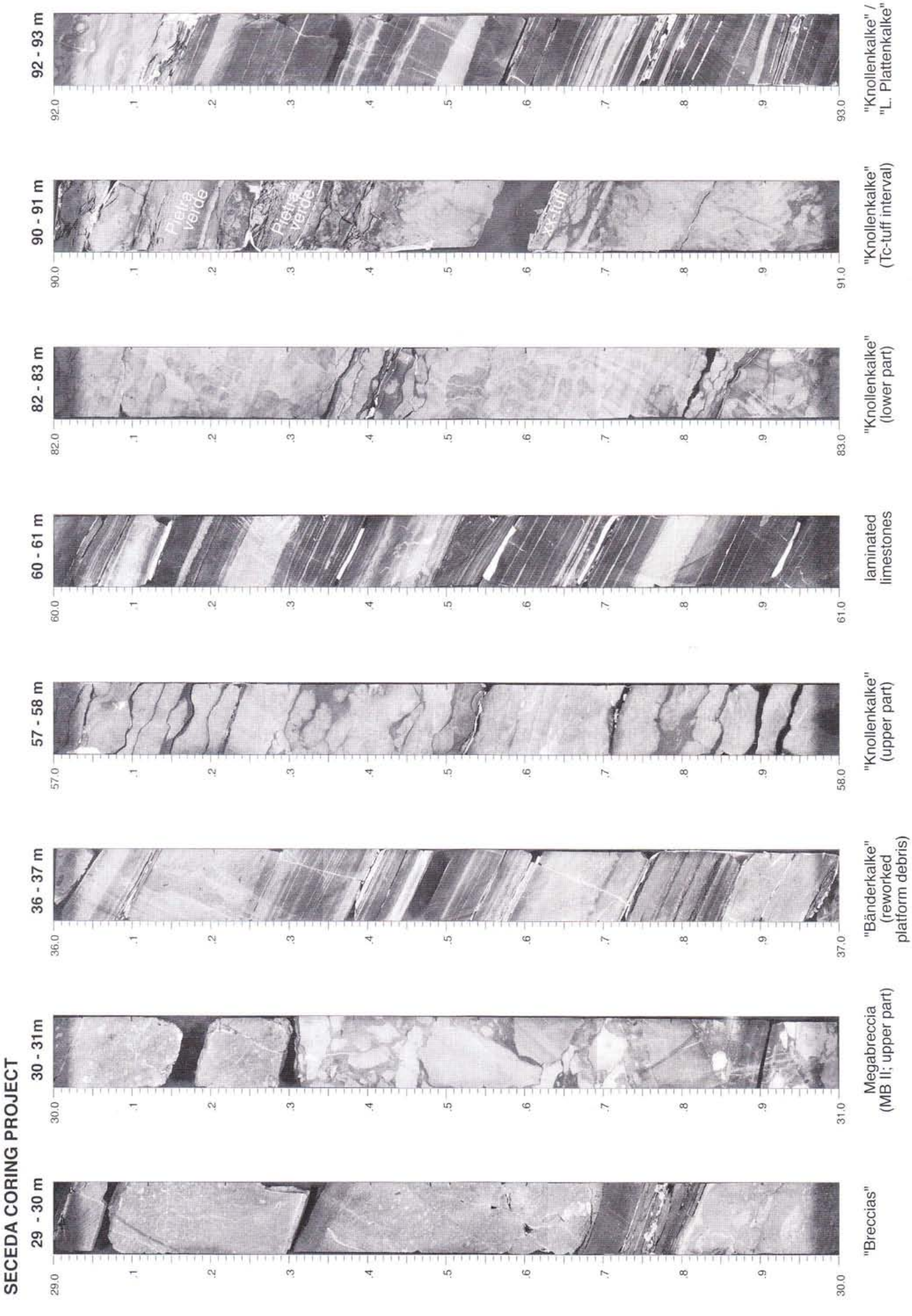
The drill site was only 200 m away from the Buchenstein outcrops in the north-facing cliffs of Seceda (Figs. 2, 3). The subdivision into members observed by Brack & Rieber (1993) in the outcrop matches very well with the cores. The comparison also shows a high degree of correspondence at the level of individual beds, such as the "Lower Plattenkalke"/"Knollenkalke"-boundary, the Tc and Td and additional tuff layers in the reference outcrop section of Brack & Rieber (1993, figs. 4, 7) as well as conspicuous pelagic limestone beds and breccia layers (Fig. 4).

A first cursory examination of the slabbed cores (see Fig. 5 for representative examples) shows that the resolution of the fine layering is distinctly superior to that of the nearby outcrop. Particularly clear is the alternation of bioturbated and unbioturbated, finely laminated intervals that were deposited during anoxic (or nearly anoxic) conditions at the sea floor.

Also well resolved are the layers of sand and rubble shed by the surrounding platforms. These layers are scarce at the base of the Buchenstein succession (Plattenkalke, unit E), they become frequent in the middle part (Knollenkalke, unit D), and increase to over 30% in unit C (Bänderkalke). In the breccia interval (unit B) platform derived debris make up over 60% of the sediment volume. This distribution probably reflects the upbuilding and subsequent progradation of the nearby Geisler (Odle) platform.

The core interval above the 35 metre level is characterised by the occurrence of thick breccia layers with platform derived carbonate clasts. The amount of coarse breccia layers observed in the core, when compared with the outcrop section, suggests a closer vicinity of the drill site with respect to the toe of the Geisler platform slope.

Fig. 5 - Photos of representative intervals of slabbed Seceda core.


SECEDA CORING PROJECT
29 - 30 m
"Breccias"
30 - 31m
Megabreccia (MB II; upper part)
36 - 37 m
"Bänderkalke" (reworked platform debris)
57 - 58 m
"Knollenkalke" (upper part)
60 - 61 m
laminated limestones
82 - 83 m
"Knollenkalke" (lower part)
90 - 91 m
Pietra verde
Pietra verde
xx-tuff
"Knollenkalke" (Tc-tuff interval)
92 - 93 m
"Knollenkalke" / "L. Plattenkalke"

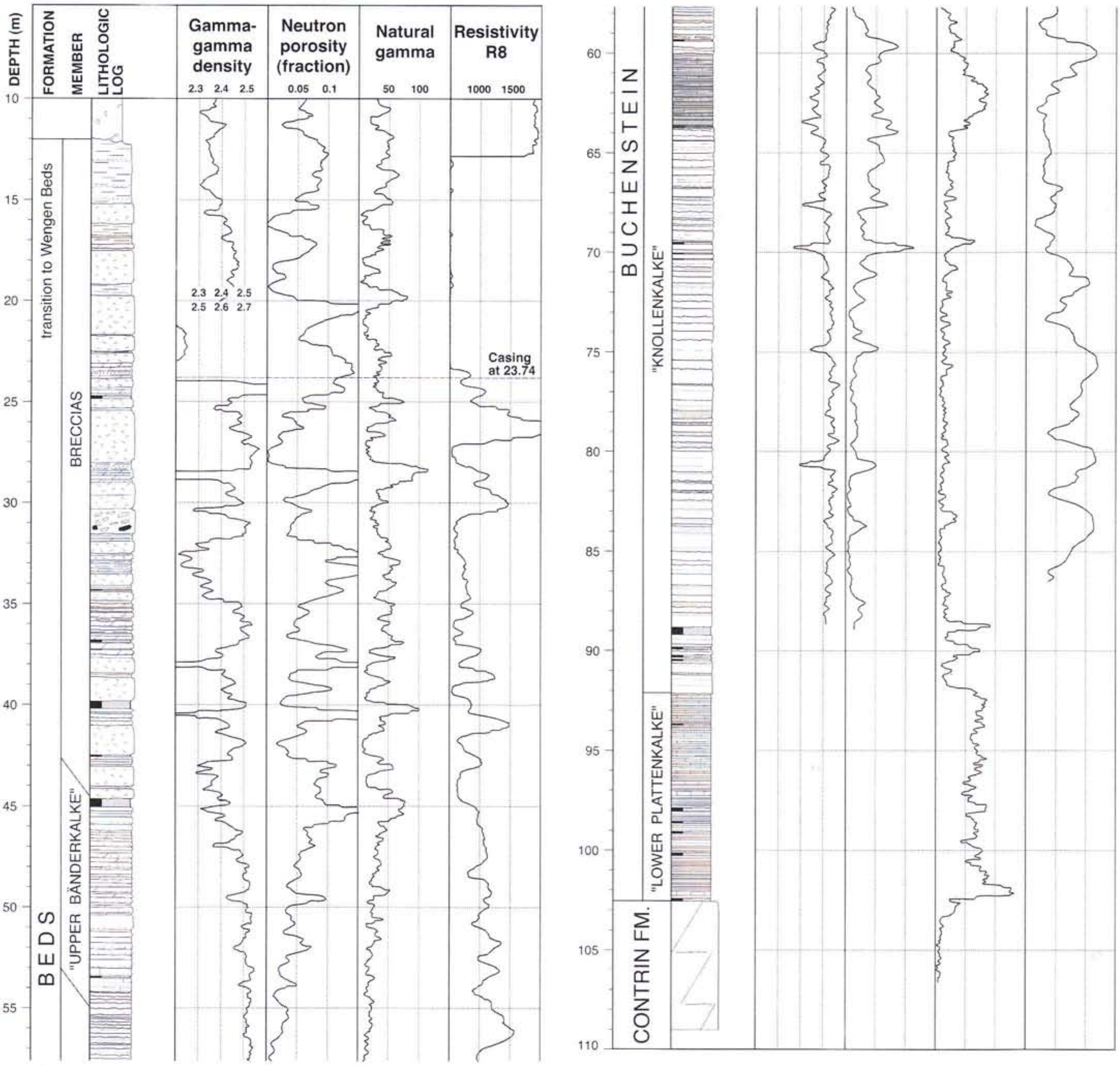


Fig. 6 - Diagram showing slimhole wire line logs that were collected alongside a simplified lithologic log; gamma-gamma density ($g\ cm^{-1}$), neutron porosity (fractional), natural gamma (counts per second) and resistivity ($ohm\ s^{-1}$).

A conspicuous and unique polygenic breccia in the 30.3 - 31.45 metre interval of the core contains clasts of basinal limestones as well as basaltic volcanics. This important marker bed is easily recognised in the outcrop section (MB II). It lies at a position postdating the level of pillow basalts which follow on top of a several metres thick chaotic breccia immediately above the horizons with *Daonella pichleri* and *Daonella tyrolensis* in stratigraphic successions to the southwest (Mastlè; Kuka Sattel) and southeast (close to the Cisles creek south of Col Raiser). The occurrence of carbonate breccias above the MB II horizon and the interfingering of basinal siliciclastics with slope deposits to the southeast of Pana Scharte suggest that platform carbonate growth continued at least during the initial stages of basaltic volcanism and deposition of Wengen Beds in this area.

Wire line logs.

A qualitative examination of the logs shows a number of general patterns that bode well for more detailed (and quantitative) analyses in the future (Fig. 6).

Volcanic material correlates well with maxima in natural gamma radiation. The amount of terrigenous clay in the background sediment seems to be small and will have to be determined by X-ray diffraction analysis.

The upward-increasing amount of rubble and sand shed from the platform shows up well in the neutron-porosity log where breccia beds appear as high-porosity intervals (probably due to dolomitic clasts with high vuggy porosity).

Natural gamma, neutron porosity and resistivity tools all indicate that the lower part of the section (between 103 m and 45 - 50 m) is characterized by small-amplitude variations whereas the upper part shows high-amplitude oscillations, indicating frequent interruptions of the basinal background sedimentation by sediment-gravity flows from the platform and, probably, also detritus from the Ladinian volcanism.

Outlook.

The data set accumulated to date represents the rock column in several different ways: a continuous column of cores, their photographic images, plus the various physical properties measured by the wireline logs. This should provide an excellent basis for statistical analysis of the bedding rhythms.

As stated in the introduction, the main purpose of the project is to document and analyse the sedimentary rhythms of the Buchenstein Beds with special emphasis on evidence for orbital control of certain rhythms. As the Earth's orbital perturbations are quasi-periodic oscillations in time, any test for orbital control of bedding rhythms involves the critical step from bed thickness to time. This transformation is fraught with uncertainties and has no ideal solution. However, in this instance certain characteristics of the formation work in our favour:

Despite the debate on the absolute time scale of the Middle Triassic, there is general consensus that the cored section represents at least several millions of years of geologic time; thus we can search for a wide range of orbital frequencies, including the eccentricity cycles at about 0.4 and 1.2 Ma.

Layers in the Buchenstein Beds of the Dolomites have been traced over 30 - 40 km, there is no evidence for major erosion by turbidity currents or contour currents. Field geology indicates a deposition in a silled basin with variable sediment input but without significant erosion.

A complicating attribute of the Buchenstein Beds is that deposition was fed from at least three different sources: (a) detritus from surrounding carbonate platforms; (b) planktic material, consisting of organic matter, siliceous and possibly also calcareous tests of micro-organisms; (c) volcanic detritus.

It is likely that statistical analysis will be meaningful only after sedimentologic studies have succeeded in separating the three lithosomes and (approximately) quantifying the variations of input through time. The time-series analyses will have to be done for a number of different scenarios. We imagine using several different assumptions for the duration of the Buchenstein Beds. Furthermore, a variety of statistical techniques will be applied.

Available and new preliminary results on bio- and magnetostratigraphy confirm that the Seceda core and the related outcrop section is not only of importance for a better understanding of Triassic sedimentary rhythms but also provides an important stratigraphic reference for the Late Anisian to Late Ladinian time interval.

Acknowledgments.

The drilling of the Seceda core would have been impossible without the support of the Geological Survey of Bozen. We would like to thank Dr. L. Nössing for offering logistical support, drilling equipment and team. Dr. J. Schweigel and Ing. E. Engel gave us further advice and helped with the organisation. Most important was the excellent performance of the drillers Ludwig Planer and Walter Pignater. Their careful handling of the drilling equipment in even the worst weather conditions was absolutely essential for obtaining the high quality core now available for research. The communities of St. Christina and St. Ulrich/Ortisei gave us access to the drill site. The Funivie Seceda SpA. with director J. Comploj allowed us to use water for drilling from a pool at Seceda top. During the drilling operations the Vinatzer family at Seceda restaurant kindly offered the survey geologists to stay at Seceda top. Jakob Tappeiner (Tappeiner AG, Lana) gave the permission to publish the photograph on Fig. 3. Michel Groen and Marieken Overdijk were crucial for the success of the logging operations. We also acknowledge Ludovich Baron and Dominique Chapellier (University of Lausanne) for density/porosity log acquisition. Philip Cleaver (ALT, Luxembourg) provided the acoustic televiewer. Winch, natural gamma and electric probes were supplied by MountSopris (Colorado, USA); special thanks to John Stowell for generous support and advice.

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