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STRATIGRAPHY AND GEOCHEMISTRY OF AN EARLY CAMPANIAN DEEPENING SUCCESSION (BIBERECK FORMATION, GOSAU GROUP, AUSTRIA)

奥地利 Gosau 群 Bibereck 组 Campanian 早期海水变深序列的地层学和地球化学

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Abstract: The Bibereck Formation of the Schmidsippl section in the type area of the Gosau Group (Northern Calcareous Alps, Austria) records a transgression and deepening of the depositional area from shallow neritic to bathyal depths. The Bibereck Formation overlies the sandstones of the Upper Santonian Hochmoos Formation (Sandkalkbank Member). It is characterized by sandy to silty grey bioturbated marls and marlstones, including minor amounts of mollusc debris, overlain by grey marls and marly limestones. The lower part of the Bibereck Formation indicates a deepening to nearshore-offshore transitional areas, Higher up, the marls indicate offshore deposition of fine-grained mud at palaeowater depths of about 50 to 150 m, overlain by marly limestones with more than 90% of planktonic foraminifera which point to a bathyal depositional environment. Biostratigraphic dating indicates that the whole sampled interval belongs to the *asymetrica-elevata* Zone of the planktonic foraminifera zonation, defined by the concurrent range of *Globotruncanita elevata* and *Dicarinella asymetrica*, and nannofossil standard zone CC17b/UC12 with the marker species *Calculites obscurus*, *Lucianorhabdus cayeuxii* (both normal and curved forms) and *Arkhangelskiella cymbiformis*, which can be correlated to the Early Campanian. The plot of Ca/Al and Ca_{tot} over depth shows that the influence of marine derived Ca is close to zero between 0 and 5 m and increases significantly up section. (Fe/Al)/calcite display two peaks of more reducing conditions, one at 4 m and the second at 10 m. The decrease in K/Al is interpreted as a shift towards more humid conditions. Ba increases in the upper part of the profile indicating a shift towards lower primary production. Terrigenous minerals stay fairly constant above 7 m and decrease further towards the top of the profile. Biostratigraphic data indicate a duration of less than 500 000 years for the sedimentation of the Bibereck Formation, during which a deepening of the sedimentation area from a few meters water depths to about 800 to 1 500 m is recorded. Geochemistry identifies two pulses of sea level change over the profile. These data give a base for comparison with overlying oceanic red beds.

Key words: Campanian; Ca/Al ratio; sea level change; deepening succession; Austria

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摘　要：Schmidsippl 剖面位于奥地利北钙质阿尔卑斯构造带内 Gosau 群典型地区。剖面出露的 Bibereck 组记录了一个海侵和沉积区海水变深过程。Bibereck 组之下是 Santonian 晚期 Hochmoos 组（Sandkalkbank 段），主要为砂质、粉砂质灰色生物扰动构造发育的泥灰岩，含少量双壳类碎片。Hochmoos 组之上为灰色泥灰岩和泥灰质灰岩。Bibereck 组下部显示变深到近滨—远滨过渡带区域；向上，泥灰岩指示细粒泥质远滨沉积，水深大致 50～150 m；之上出现浮游有孔虫含量超过 90％的泥灰质灰岩，代表着半深海沉积环境。生物地层数据显示采样层位整体位于浮游有孔虫 *asymetrica-elevata* 带，由 *Globotruncanita elevata* 和 *Dicarinella asymetrica* 的共同出现来界定。钙质超微化石 *Calculites obscurus*、*Lucianorhabdus cayeuxii*、*Arkhangelskiella cymbiformis* 的出现指示属于钙质超微化石带 CC17b/UC12，相当于 Campanian 初期。地层深度剖面上，Ca/Al 比值和 Ca_{tot} 含量显示海水来源的 Ca 在 0～5 m 地层内几近于零，向上快速增加；(Fe/Al)/碳酸盐显示两个峰值，代表更还原条件，分别位于 4 m 和 10 m 位置；K/Al 比值的下降被解释为更潮湿气候条件；剖面上部 Ba 含量的增加显示向更低原始生产条件的变化；陆源矿物在剖面 7 m 以下保持稳定，之上一直到剖面顶部不断下降。生物地层数据表明在约 50 万年短暂的时间间隔内水深由几米深浅水环境变深为 800～1 500 m 深半深海环境。地球化学数据显示在海侵过程中出现两个海平面变化波动过程。这些数据为与上覆大洋红层进行对比提供了基础。

关键词：Campanian；Ca/Al 比值；海平面变化；海水变深序列；奥地利

0 Introduction

The Santonian to Early Campanian was a time of major changes in the earth's system, especially in plankton evolution (Premoli-Silva and Sliter, 1999), tectonism (Larson, 1991; Reicherter and Pletsch, 2000) and palaeoceanography (Hu et al., in press). During this time, the Northern Calcareous Alps (Eastern Alps, Austria) underwent important changes that resulted in a significant deepening and palaeogeographic rearrangement of basins and source areas (Wagreich and Faupl, 1994). The subsidence was ascribed to tectonic erosion along the active Penninic-Austroalpine continental margin at the northern border of the Adriatic plate (Wagreich, 1993, 1995). During and after the deepening event, sedimentation of CORBs (Late Cretaceous oceanic red beds; Hu et al., in press; Wagreich and Krenmayr, in press) indicates major palaeoceanographic changes within this northwestern Tethys branch (for palaeogeographic overview see Stampfli et al., 2002).

Descriptions of the sediments deposited during the times of considerable change from terrestrial-shallow-water to deep-water in the Northern Calcareous Alps are comparatively rare (e. g. Butt, 1981; Wagreich, 2003), especially from the type area of the Gosau Group, the Gosau Valley in Upper Austria. This paper describes the stratigraphy of an Early Campanian deepening succession which grades into deep marine red beds (CORB) further up section. An overview of geochemical changes is given as a reference for future detailed geochemical and isotope work on the transition from grey to red beds of the Upper Cretaceous.

1 Geological setting and lithostratigraphic overview

The Upper Cretaceous to Eocene Gosau Group of the Northern Calcareous Alps was deposited after a major deformational phase (Eoalpine orogeny, Faupl and Wagreich, 2000). The Northern Calcareous Alps were situated at a palaeolatitude of about 30°N, at the northern, active margin of the Adriatic plate in a subtropical climate belt (Wagreich and Faupl, 1994; Sanders et al., 1997). The Gosau Group records early regional transtensional strike-slip and pull-apart basin subsidence (Wagreich and Decker, 2001), followed by a diachronous deepening event (Wagreich, 1995).

The Gosau basin in the Gosau Valley area (Upper Austria) and near Abtenau-Russbach (Salzburg) is the type area of the Gosau Group (Fig. 1). The basin fill comprises about 1 000 m of Upper Turonian to lowermost Campanian terrestrial and shallow-water sediments of the lower Gosau Subgroup, which are unconformably overlain by more than 1 200 m thick deep-water deposits of the upper Gosau Subgroup of Campanian to Eocene age. The deep-water deposits seal pull-apart basin structures of the Upper Turonian-Early Campanian (Wagreich and Decker, 2001).

The basin fill is subdivided into an up to 350 m thick interval of red alluvial conglomerates (Kreuzgraben Fm.) of Late Turonian age at the base, which is overlain by a transgressive succession of marine paracycles of the Upper Turonian to

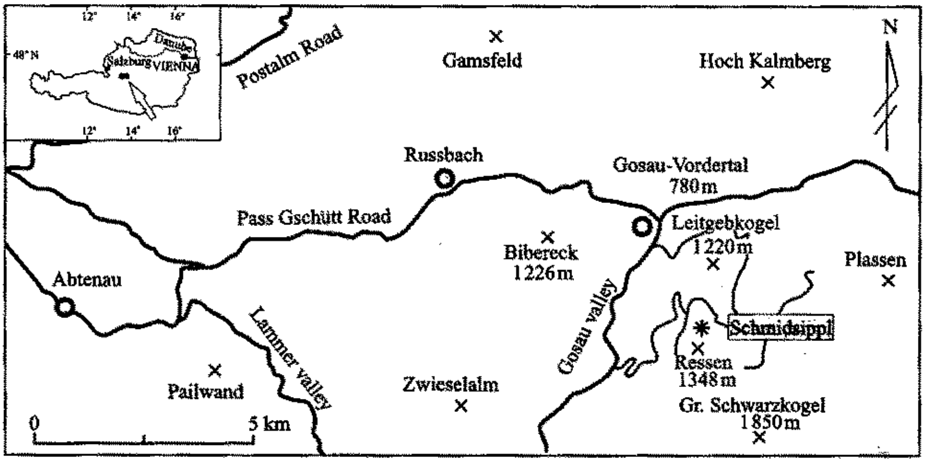

Fig. 1 Schematic road map of the Gosau area in the Northern Calcareous Alps, indicating the geographic position of the Schmidsippl section to the southeast of the village Gosau-Vordertal (Upper Austria)

Coniacian Streiteck Fm. Storm-influenced shelf and near-shore sediments of up to 500 m, including rudist bioherms, filled the basin in Santonian times (Grabenbach Fm., Hochmoos Fm.), and record a gradual shallowing during the Late Santonian. The latest Santonian sandstones of the Sandkalkbank Member (part of Hochmoos Formation; e.g. Kollmann, 1982; Summesberger, 1985) indicate extreme shallow-water conditions and even subaerial exposure along the northwestern basin margin. The overlying marls of the Bibereck Formation record a sudden deepening of the Gosau basin into bathyal depths and the onset of pelagic and turbidite deposition, which predominate in the following Ressen Formation, a small, high efficient deep-water fan system. The overlying marls and marly limestones of the Nierental Formation (Campanian-Maastrichtian) and the turbidites of the Zwieselalm Formation (Maastrichtian-Early Eocene) complete the deep-water part of the succession (Krenmayr, 1996).

Sedimentary thicknesses of the lower Gosau Subgroup decrease from the depocentre around Gosau-Russbach to the SE basin margin, due to synsedimentary normal faulting (Wagreich and Decker, 2001). Consequently, the section at the Schmidsippl southeast of Gosau-Vordertal comprises a reduced Upper Turonian-Lower Campanian succession of only about 50 to 80 m in contrast to up to 1 000 m thick successions in the depocentre of the basin (Fig. 2). The section at the Schmidsippl consists of up to 30 m Upper Turonian to Coniacian red alluvial conglomerates, which are overlain by a few metres of Upper Santonian shallow-water sandstones and marls that include a rudist limestone layer (Trenkwalder, 1999). Above a bioturbated sandstone bed, which has been correlated to the Upper Santonian Sandkalkbank Member in the basin centre, a 21 m marly section of the Bibereck Formation follows, which is described in detail below. Deep water turbidites of the Late Campanian Ressen Formation cover both, the sediments at the Schmidsippl and at the depocentre at Gosau. Further to the south up to 30 m of Upper Santonian neritic bioclastic limestones (Untersberg Fm.; Trenkwalder 1999) mark the Late Santonian/Early Campanian transgression at the basin margin onto a cliffed coast near a fault scarp.

2 Methods

Bulk geochemical analyses were executed on all 12 samples after HF-HNO_3 digestion of the total sample by DCP-OES (Spectraspan III B Emission Spectrometer, Institute for Geological Sciences, Vienna) and ICP-MS (Perklin Elmer Sciex Elan 6100, Department of Geological Sciences, Vienna). Mg, Al, P, Ca, Ti, Mn, and Fe were analysed by DCP. Further, elements analysed by ICP-MS are those named above and Na, K, and the trace elements Li, Be, V, Cr, Ni, Co, Cu, Zn, Ge, As, Rb, Sr, Mo, Cd, Ba, Pb, and U. Concurrent measurements of internal standards ensured that both techniques could be compared. The reproducibility of all data lies below 3% for ICP measurements of main elements and below 5% for trace elements except for V, which is considerably higher (10%) because its concentrations are close to detection limit. The reproducibility for DCP measurements lies below 5% for all elements mentioned. The mineralogical composition was investigated by XRD (Philips PW 1820 diffractometer with PW control and a PW 1830 generator at the

Institute for Applied Geology, BOKU Vienna). To estimate mineral abundances the individual intensity of texture free samples (quartz, feldspar, sheet silicates, calcite, dolomite) was normalized by the total intensity signal of all identified phases (Schultz, 1964).

The carbonate content was additionally determined by volumetric CO_2 liberation after HCl treatment using a Scheibler apparatus. This method distinguishes calcite and dolomite and has a reproducibility of 5%.

All reagents used were p. a. grade or higher and all solutions were prepared with ultra-pure water.

Foraminifers for biostratigraphical analysis were investigated in the fractions 160～300 μm and 300～600 μm, which were sieved, dried, and sonicated. Nannoplankton smear slides for light microscope investigations were prepared after sonication of scratched-off powder and a two hour settling interval to remove clay particles.

3 Sedimentology

The Bibereck Formation in the Schmidsippl section overlies bioturbated fine sandstones and marly sandstones of the uppermost Hochmoos Formation (Sandkalkbank Member, Fig. 2).

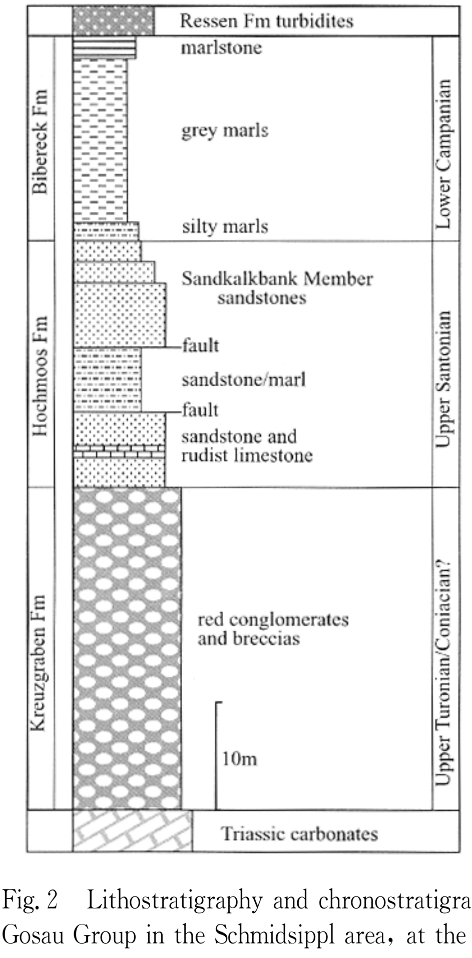

Fig. 2 Lithostratigraphy and chronostratigraphy of the Gosau Group in the Schmidsippl area, at the southeastern margin of the Gosau Basin; modified from Trenkwalder (1999) and Wagreich and Decker (2001)

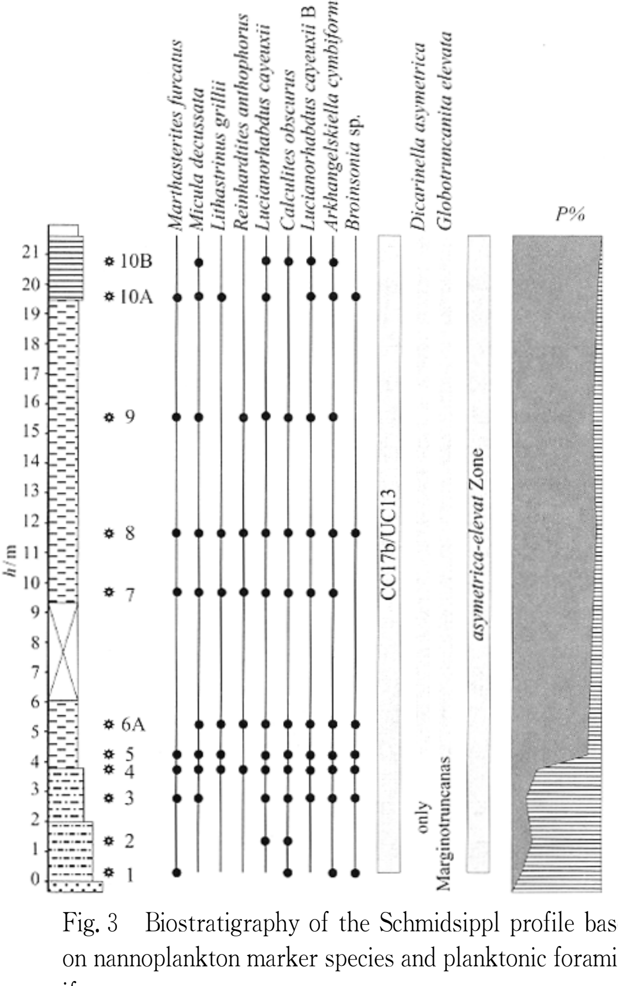

Fig. 3 Biostratigraphy of the Schmidsippl profile based on nannoplankton marker species and planktonic foraminifera

Planktonic ratio $p\% = \text{planktonic}/(\text{planktonic}+\text{benthic})$ foraminifera (100 specimen counted in sieve fraction > 0.3 mm)

Small plant debris and minor amounts of macrofossils such as bilvalve-and gastropode fragments characterize the sandstones of the Hochmoos Formation. The change from indurated sandstones to softer, sandy to silty grey marls and marlstones (Fig. 3) defined the base of the Bibereck Formation. These grey silty marls of the Bibereck Formation include some minor amounts of small bivalves, gastropods, and mollusc debris, and are heavily bioturbated. Above, the sand content of the marls decreases and they display a stronger susceptibility to weathering. At and above 19.5 m, a higher carbonate contents causes the marls to become more compact.

The interpretation of the depositional environment of the Bibereck Formation is based on Wagreich（1988），Wagreich and Faupl（1994）and Trenkwalder（1999）. The underlying sandstones of the Hochmoos Formation show clear signs of shallow-water deposition，e.g. strong bioturbation including *Ophiomorpha*-type burrows，a shallow-water mollusc fauna，solitary corals，and minor laminations and ripple stratification. Foraminifers are rare and restricted to a few genera such as *Quinqueloculina*，*Nummofallotia*，and *Lenticulina*. This suggests a shallow nearshore to shoreface depositional environment（Wagreich，1988）. The transition to the bioturbated sandy to silty marls indicates deepening to nearshore-offshore transitional areas，where waves only rarely influenced the sediment-water interface，and soft，muddy bottom sedimentation from suspension prevailed. Comparable sections in the depocentre of the basin to the north，at the Bibereck，include sandy tempestites in the lower part of the Bibereck Formation，which hints a depth of deposition between fair weather and storm wave base of these marls (about 5 to 30 m water depths). Higher up in the section，the marls indicate offshore deposition of fine-grained mud at palaeowater depths of about 50 to 150 m，corroborated by plankton-rich foraminiferal assemblages. Marls and marly limestones with more than 90% of planktonic foraminifera on top of the section indicate a bathyal depositional environment.

4 Biostratigraphy and paleoecology

4.1 Foraminifers

Although the foraminiferal assemblages change strongly within the successions，planktonics indicate that the whole interval of the Bibereck Formation sampled belongs to the *asymetrica-elevata* Zone of the planktonic foraminifera zonation. This concurrent range zone（Wonders，1980；Dowsett，1984）is defined by the first occurrence（FO）of *Globotruncanita elevata*（Brotzen）（base of zone）and the last occurrence（LO）of *Dicarinella asymetrica*（top of zone）. This zone marks a rather short time interval of probably not more than 1～2 Ma. According to Gale et al.（1995），the Santonian-Campanian boundary is situated within the *elevata-asymetrica* Zone. The exact position of the lower boundary of the Campanian is still under debate，as no GSSP is approved yet（e.g. Hancock and Gale，1996；Küchler and Wagreich，2002）and correlations of the boundary criterion，the LO of the crinoid *Marsupites testudinarius*（Schlotheim），to planktonic zonations are still arbitrary or even missing. Thus，several authors placed the lower boundary of the Campanian at the first appearance datum of *G. elevata*（e.g. Dowsett，1984），others at the extinction level of *D. asymetrica* or the *Dicarinella asymetrica-concavata* group（e.g. Robaszynski et al.，1984；Caron，1985；Premoli-Silva and Sliter，1999）. According to Dowsett（1984）the *elevata-asymetrica* Zone（his *Globotruncana elevata-Globotruncana concavata* concurrent range zone) can be subdivided into a lower part with *Sigalia deflaensis* and an upper part without *Sigalia*. In the Schmidsippl material no *Sigalia* was found，which is in accordance with the assumption，that the Schmidsippl succession represents the upper part of the *elevata-asymetrica* Zone.

The microscopical analysis shows abundant coral fragments，ostracode shells and lithic fragments from the bottom up to 1.3 m of the profile. Inoceramus fragments are abundant. Sparse planktonic forams，mainly small Marginotruncanas，can be found up to 3.8 m only. Benthic foraminifera include species of the genera *Hoeglundina*，*Gavelinella*，*Anomalina*，and *Tritaxia*. The degree of preservation varies greatly above 2.8 m.

Above 3.8 m a sharp increase in the amount of planktonic foraminifera is observed and the planktic forms *Globotruncanita elevata* and *Dicarinella* occur. Benthics are mainly represented by *Gavelinella*，*Dorothia pupa*，*Vaginulina gosae*，*Stensioeina pommerana*，and *Lenticulina* sp.

Above 9.7 m the benthic foraminiferal assemblage changes slightly towards more deep-water benthic forms such as *Eponides* sp. and small *Dentalina* sp. together with *Marsonella* sp. and *Ammodiscus* sp. Occasionally fish teeth can be found and ostracode shells are nearly absent at and above this level.

The appearance of the strongly umbilicoconvex *Globotruncana elevata* and *Dicarinella* at 2.8 m indicates that the sea level reached a depth at which the living conditions favour large，deep-dwelling planktic foraminifers. The first appearance of *Eponides* sp. at 9.7 m indicates an increase in water depth. This compares well to the geochemical data，which also show a significant influence of marine signals from 9.7 m upward.

4.2 Nannofossils

Subdivisions at the Santonian-Campanian boundary interval based on calcareous nannoplankton use the standard zonations introduced by Sissingh（1977），Perch-Nielsen（1985：CC zones）and Burnett（1998：UC zones）. Perch-Nielsen（1985）recognized the FO of *Calculites obscurus*（Deflandre）in the Late Santonian，defining the base of standard zone CC17, and the FO of *Broinsonia parca parca* (Stradner) at the base of CC18. Most of nannofossil workers place the base of the Campanian within CC17 or at the base of CC18 (e. g. Perch-Nielsen, 1985; Wagreich, 1992; Cunha et al., 1997; Küchler and Wagreich, 2002). In the northwestern Tethys, Wagreich (1992) recognized the FO of curved *Lucianorhabdus cayeuxii* within CC17, near the ammonite defined Santonian-Campanian boundary, and thus divided this zone into two subzones, CC17a and CC17b. According to Lantos et al. (1997) the base of magnetochron 31r is above CC17b, near the base of CC18.

According to Burnett (1998) the following Santonian to basal Campanian zones can be distinguished: zone UC12, base defined by the LO of *Lithastrinus septenarius* (middle to Late Santonian), UC13, base defined by the FO of *Arkhangelskiella cymbiformis* Vekshina, and UC14a, base defined by the FO of *Broinsonia parca parca*. Based on Burnett (1998), the Santonian-Campanian boundary is situated within the uppermost part of UC12, just below the FO of *Arkhangelskiella cymbiformis*.

In the Schmidsippl section nannoplankton samples are characterized by the following marker species (Fig. 3): *Calculites obscurus*, *Lucianorhabdus cayeuxii* (both normal and curved forms), *Micula decussata*, *Lithastrinus grillii*, *Arkhangelskiella cymbiformis*, *Broinsonia enormis*, *Broinsonia* cf. *parca expansa*, *Marthasterites furcatus*.

These marker species indicate that the whole sampled interval belongs to CC17 of the Perch-Nielsen (1985) zonation. The presence of curved *L. cayeuxii* marks the regional zone CC17b of Wagreich (1992). A latest Santonian to early Early Campanian age can be inferred from these results (e. g. Wagreich, 1992; Lantos et al., 1997). According to the zonation by Burnett (1998) the presence of *A. cymbiformis* from the lowermost sample onwards indicates UC13 and thus also early Early Campanian, clearly above the Santonian-Campanian boundary.

Nannofossil assemblages of the Schmidsippl section display only moderate to bad preservation and low abundances, especially in the lower part of the section. Thus, nannofossil assemblages have not been quantitatively evaluated. However, some qualitative trends within the section can be recognized. Assemblages of the genera *Watznaueria*, *Chiastozaygus*, *Glaukolithus*, *Stradneria*, *Cribrosphaerella* and *Eiffellithus* characterize the lowermost, shallower part. *Micula decussata* and larger holococcoliths such as *Lucianorhabdus* are extremely rare or absent. Thus a preference for more open marine conditions for these genera is suspected.

5 Geochemistry

The bulk geochemical analysis divides the elements into those of terrigenous origin such as Al, Li, Be, V, Cr, Ni, Co, Zn, Ge, As, Rb, Ti, Fe, and K which correlate positively with each other. The marine signal is mainly linked to Ca, which correlates positively with Sr and Ba in particular in the upper part (above 10 m) of the profile.

Element/Al ratios were calculated to remove the detrital component of the geochemical data. Ca/Al ratios remove the terrestrial Ca signal mainly derived from plagioclase. The difference between total Ca and Ca/Al ratios (Fig. 4) represents the marine signal compared to the terrigenous input. This qualitative plot of Ca/Al and Ca_{tot} over depth shows that the influence of marine derived Ca is close to zero between 0 and 5 m and increases significantly in the central part of the profile. The marine Ca signal decreases toward the top. This is caused by a shift to more dolomite in the carbonates of the upper part of the profile (see Fig. 5).

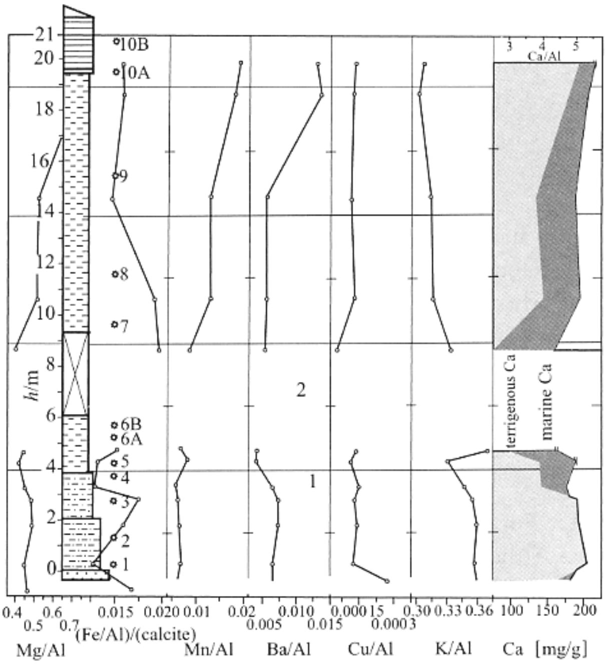

Fig. 4 Geochemistry of the Schmidsippl profile

Fe/Al ratios indicate two episodes (1, 2) of suboxic diagenesis where Fe/Al ratios increase. Ba/Al builds up significantly at the top of the profile whereas Cu/Al stays fairly constant. K/Al indicates a shift to more humid conditions in the source area with one aridity peak right at the onset of the second suboxic event. Ca and Ca/Al shows a first increase of marine derived Ca at 4 m

Mg/Al ratios represent the carbonate bound Mg and therefore correlate with the dolomite content (compare Fig. 4 and 5).

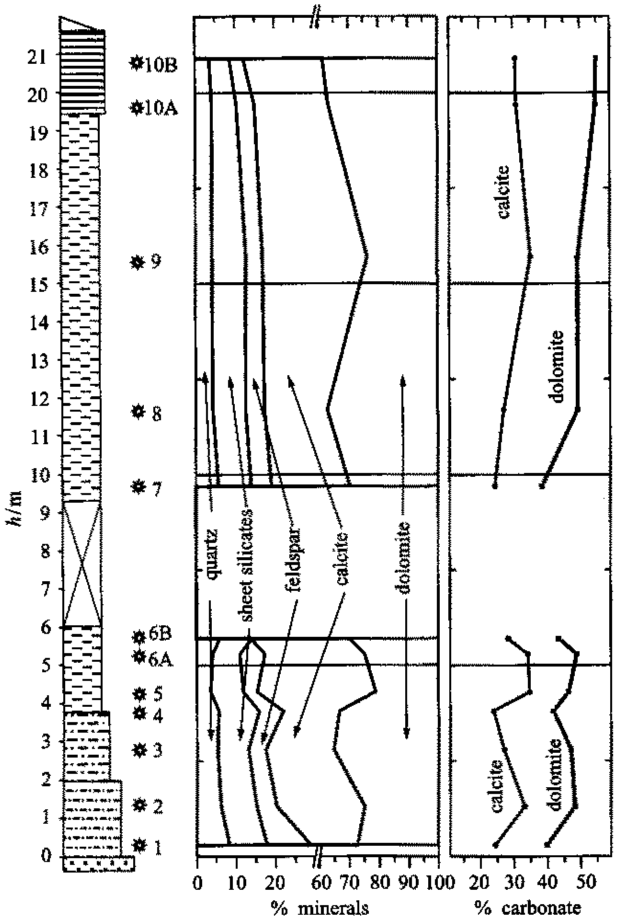

Fig. 5 Mineralogy of the Schmidsippl profile

Bulk mineralogy determined by XRD shows a decrease of terrigenous minerals at 4 m which continues towards the top of the profile. The carbonate content resolved by CO_2 liberation shows two increases in the lower part of the profile where both dolomite and calcite behave similarly. The increase is very pronounced at 4 m. At the top, no major changes are observed but the calcite and dolomite distribution in the carbonate phase is antithetic

In the same fashion, Fe/Al ratios were calculated to remove the terrestrial signal (mainly in the form of clay minerals, micas, and iron oxides) from the total Fe content. Fe/Al ratios hence correspond to carbonate bound iron. Because only divalent ions such as Fe^{2+} can be incorporated into the carbonate lattice, a rough estimate on the redox state during early diagenesis employing this ratio is possible. An increase in Fe^{2+} corresponds to a shift towards more reducing conditions. Different amounts of calcite contribute to the total carbonate content in the profile. For that reason, the Fe/Al ratio was normalized by the calcite content. (Fe/Al)/calcite display two peaks of more reducing conditions, one at 4 m and the second at 10 m.

K/Al data represent the mechanisms of weathering in the source area. Since both elements are of terrigenous origin, variations in K are commonly attributed to relative shifts in the clay mineral content (i. e. kaolinite vs. smectite, illite and chlorite) (e. g. Rehfeld et al., 1998). Low K/Al periods represent episodes of increased chemical weathering (increased humidity) where all ions are removed and kaolinite forms. The gradual decrease in K/Al over the profile with two "aridity" peaks corresponds to a shift towards more humide (less K, less illite chlorite and possibly smectite) conditions.

Ba/Al ratios follow the K/Al ratios in the lower part of the profile (up to 16 m) but then, once K/Al continues to decrease, Ba/Al starts to increase. This increase follows a decrease in Fe/Al. A similar relationship between Ba and Fe/Al development was also observed in samples of Upper Cretaceous rhythmic marl-limestone deposits (Rehfeld et al. 1998) and in our own data (Rehkogelgraben profile, unpublished data).

In summary the geochemistry of the Schmidsippl profile shows the following succession from older to younger: (1) increase in marine Ca; (2) decrease in K/Al; (3) increase of Fe/Al ratios; (4) increase in Ba in the upper part of the profile.

6 Mineralogy

Bulk X-ray diffraction pattern identifies quartz, muscovite and other sheet silicates namely iron rich chlorite (sudoite) and illite, as well as feldspars (microcline) as main mineral phases. The content of terrigenous minerals such as sheet silicates, quartz, and feldspar is highest at the onset of the profile and decreases rapidly in the first 2. 7 m. Above 2. 7 m carbonates (especially dolomite) increase before quartz and sheet silicates increase slightly at 3. 3 m. Terrigenous minerals stay fairly constant above 7 m and decrease further towards the top of the profile. The total carbonate content lies between 40% and 55 %.

7 Discussion and conclusions

Mineralogy, geochemistry, sedimentology, and palaeontology indicate a transgression and a rapid deepening in the Bibereck Formation. The mineralogical evidence for instance the increase in carbonate and simultaneous decrease in detrital minerals places the onset of strong subsidence above 3 m whereas geochemistry places a definite deepening with a qualitative increase of marine derived Ca above 4 m. Paleontology (planktonic foraminifer ratios) also suggests a strong deepening event at 4 m and a second deepening event with the increase of bathyal benthic foraminifera from 9.4 m onward. The first increase in (Fe/Al)/calcite ratios simultaneously with the transgression could indicate higher input of nutrients from the flooded landmass that result in suboxic conditions in the basin (Hilbrecht et al., 1989).

K/Al ratios suggest an increase in humidity and a shift to more kaolinite-dominated detrital material. This long-term trend is interrupted by a slight increase in K/Al at 4 m and with the onset at 5.5 m right below the gap. Both increases in K/Al occur simultaneously with both (Fe/Al)/calcite pulses towards more reducing conditions. This could indicate large-scale erosion during transgression, which not only introduces a high amount of organic matter but also significant amounts of clay minerals such as illite and chlorite. XRD scans identify sudoite next to illite as one sheet silicate phase, which could also serve as Fe source during the early diagenetic reduction of iron which then gets incorporated into the calcite lattice.

Concerning the Ba/Al profile, we have to distinguish between terrestrial derived Ba and marine Ba that is widely used as a paleonutrient proxy (Gingele et al., 1999). In the lower part of the profile Ba/Al and K/Al ratios display similar trends. This indicates Ba derived from terrestrial sources (clays) similar to K. In the upper part of the profile (from 16 m upward) the Ba/Al ratio deviates from K/Al ratios. This can be attributed to a higher marine influence on the Ba distribution. Ba/Al can be used in full marine systems to infer the cycling of nutrients within the water column (Lea and Boyle, 1989). The increase in Ba in the uppermost part of the profile hence indicates a shift towards low primary production where more nutrient like elements are released and preserved in the sedimentary record. The continuous decrease of K/Al ratios suggests the trend towards a more humid climate in the source area.

The duration of the deepening cannot be assessed directly as geochronologically dateable tuff layers etc. are missing in the sections of the Bibereck Formation. However, indirect dating by fossil evidence and chronostratigraphic correlations is possible. Based on the time scale of Gradstein et al. (1995) the duration of CC17 is less than 2 Ma. This is also indicated by a direct dating of a tuff in the lower part of CC18 (81.67 Ma, Bernoulli et al., 2004). As only subzone CC17b was recognized, a total duration of about 1 Ma for this subzone can be assumed.

The *asymetrica-elevata* planktonic foraminifer Zone represents a short concurrent range zone which, due to its short duration, is not recognized in some planktonic zonation scale (e.g. Caron, 1985). As Late Santonian ammonites are present in the Sandkalkbank Member below the base of the Bibereck Formation, the lower boundary of the Campanian is probably situated at the base of the Bibereck Formation. This gives an age of about 83.5 Ma for the base of the Bibereck Formation. The top of the *asymetrica-elevata* Zone (corresponding to the top of the *asymetrica* Zone of other authors) is dated as 83 Ma (e.g. Bralower et al., 1995). This indicates a duration of less than 500.000 years for the sedimentation of the Bibereck Formation of the Schmidsippl section, during which a deepening of the sedimentation area from a few meters water depths to about 800 to 1 500 m is recorded.

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