

# Early Oligocene benthic Foraminifera from the Lower Inn Valley area: implications for the paleoenvironmental evolution of the Inneralpine Molasse

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**Abstract:** Two early Rupelian (Early Oligocene) sections of the Lower Inn Valley area have been analyzed for their benthic foraminiferal faunas to assess the paleoenvironmental evolution of the Inneralpine Molasse as part of the Western Paratethys. At both sections the sediment successions start with fluvial and deltaic conglomerates and sandstones of the Häring Formation overlain by the clayey marls of the Paisslberg Formation (“Fish Shale”) that were deposited under marine conditions. Changes in benthic foraminiferal assemblages of the Paisslberg Formation can be related to the basin evolution. They allow semi quantitative estimates of water depth, temperature, organic matter fluxes, and oxygenation. Bathymetric estimates range from littoral water depths at the base of the sections to outer neritic water depths (maximum values around 200 m) within the middle Paisslberg Formation. High proportions of miliolid foraminifera occur at the base and top of the investigated sections and indicate a shallow water environment with warm-temperate climatic conditions. The faunas of the deeper shelf within the Paisslberg Formation comprise mainly infaunal species and indicate enhanced organic matter fluxes and moderate oxygen concentrations in the bottom water. The faunal results mirror a transgression-regression cycle that is most likely linked to the subsidence of the basin combined with eustatic sea level fluctuations during the Early Oligocene. The transgressive part of this cycle can be correlated with the late Paleogene successions of the Slovenian Basin and points to a contemporaneous basin evolution in the Eastern Alpine realm.

**Zusammenfassung:** Zur Rekonstruktion der Umweltveränderungen im Bereich der Inneralpinen Molasse während des Älteren Oligozäns wurden zwei Profile aus der Unterinntal-Region hinsichtlich ihrer benthischen Foraminiferenfauna untersucht. An beiden Lokalitäten beginnt die Abfolge mit deltaischen Konglomeraten und Sandsteinen der Häring-Formation, die von den marinen tonigen Mergelsteinen der Paisslberg-Formation (“Fischschiefer”) überlagert werden. Die Verbreitung der benthischen Foraminiferen spiegelt die regionale Beckenentwicklung wider und erlaubt Rückschlüsse auf Wassertiefe, Temperatur, Nahrungssituation und Sauerstoffgehalt. An der Basis der Paisslberg-Formation herrschten vermutlich litorale aber normal-marine Bedingungen, wogegen im mittleren Profilabschnitt maximale Wassertiefen um 200 m (tieferer Schelf) angenommen

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werden. Hohe Anteile von Milioliden im unteren und oberen Bereich der Abfolgen weisen auf einen flachen warm-temperierten Ablagerungsraum hin. Die Faunen des tieferen Schelfes werden durch infaunale Arten dominiert und belegen hier eutrophe Bedingungen am Meeresboden und mäßig abgereicherte Sauerstoffkonzentrationen im unteren oxischen Bereich. Die faunistischen Ergebnisse spiegeln einen Transgressions-Regressions-Zyklus wider, der mit eustatischen Meeresspiegelschwankungen im Älteren Oligozän korreliert werden kann. Der transgressive Abschnitt läßt sich mit Profilen im Slowenischen Becken vergleichen und belegt somit eine überregional zeitgleiche Beckenentwicklung während des Älteren Oligozäns im Ostalpenraum.

**Keywords:** Benthic Foraminifera, Austria, Oligocene, Paratethys, Paleoecology, Paleoceanography

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## 1. INTRODUCTION

The late Paleogene and Neogene evolution of the Paratethys is closely associated with both tectonic and climatic changes. At the Eocene-Oligocene boundary, the northward drift and rotation of the Indian and African continents, respectively, resulted in the separation of the Tethys Ocean into the Eurasian intercontinental Paratethys Basin and the Mediterranean Sea (BÁLDI, 1984; RÖGL, 1998; STEININGER & WESSELY, 2000) (Fig. 1). While the seaway from the Indo-Pacific to the Atlantic persisted, the Turgai Strait closed and enabled continental migrations from the Eocene-Oligocene boundary on. During the Rupelian, the Rhine Graben opened and established a narrow marine connection between the western Paratethys and the North Sea Basin (RÖGL, 1998). However, repeated disconnections between the Paratethys and adjacent oceans and increased river run-off from the surrounding landmasses resulted at times in a strongly stratified water column and dysoxic to anoxic conditions in the deeper basins (e.g., BÁLDI, 1984; KRHOVSKY et al., 1993; POPOV & STOLYAROV, 1996). These drastic oceanographic changes are responsible for the repeated deposition of laminated, organic-rich sediments, the occurrence of low-diversity plankton assemblages, and benthic faunas adapted to low-oxygen conditions (BÁLDI, 1984; RÖGL & STEININGER, 1984; KRHOVSKY et al., 1993; UJETZ,



Fig. 1: Palinspastic reconstruction of an early stage of the beginning of the Paratethys in the Early Oligocene (Middle Kiscellian), 32 to 30 Ma (redrawn from RÖGL, 1998). Asterisk indicates the deposition site of the investigated sediment sections.

1996; SCHERBACHER, 2000; SCHMIEDL et al., in press; KRHOVSKY et al., this volume). As part of the Western Paratethys, synorogenic late Paleogene sediments were deposited in several areas on top of the Eastern Alpine orogenic wedge. Facies and subsidence histories of these sediment successions (including deposits in Slovenia and the Lower Inn Valley area) closely resemble those from the western Molasse Basin and the Central Paratethys (JELEN et al., 1998; ORTNER & STINGL, this volume).

In addition to tectonic events, the paleoceanographic evolution of the Paratethys was influenced by eustatic sea level changes caused by fluctuations of the East Antarctic ice volume. First evidence for the existence of an East Antarctic ice shield occurs near the early-middle Eocene boundary (EHRMANN, 1991; HAMBREY & BARRETT, 1993). The composite stable isotope record shows that this ice shield experienced major phases of growth during the Late Eocene and middle Oligocene, followed by a volume decrease in the Early Miocene (ABREU & ANDERSON, 1998). At the Eocene-Oligocene boundary a major drop in  $\delta^{18}\text{O}$  values occurs at different ODP sites at high and low latitude locations and indicates the increase in the size of the East Antarctic ice sheet (e.g., SHACKLETON & KENNETT, 1975; MILLER et al., 1987; ZACHOS et al., 1992). The global climate deterioration of the Late Eocene is followed by a reduction of the East Antarctic ice sheet during the early Rupelian associated with a pronounced eustatic sea level rise (HAQ et al., 1987; ABREU & ANDERSON, 1998) (Fig. 2). This sea level high-stand is reflected by marine

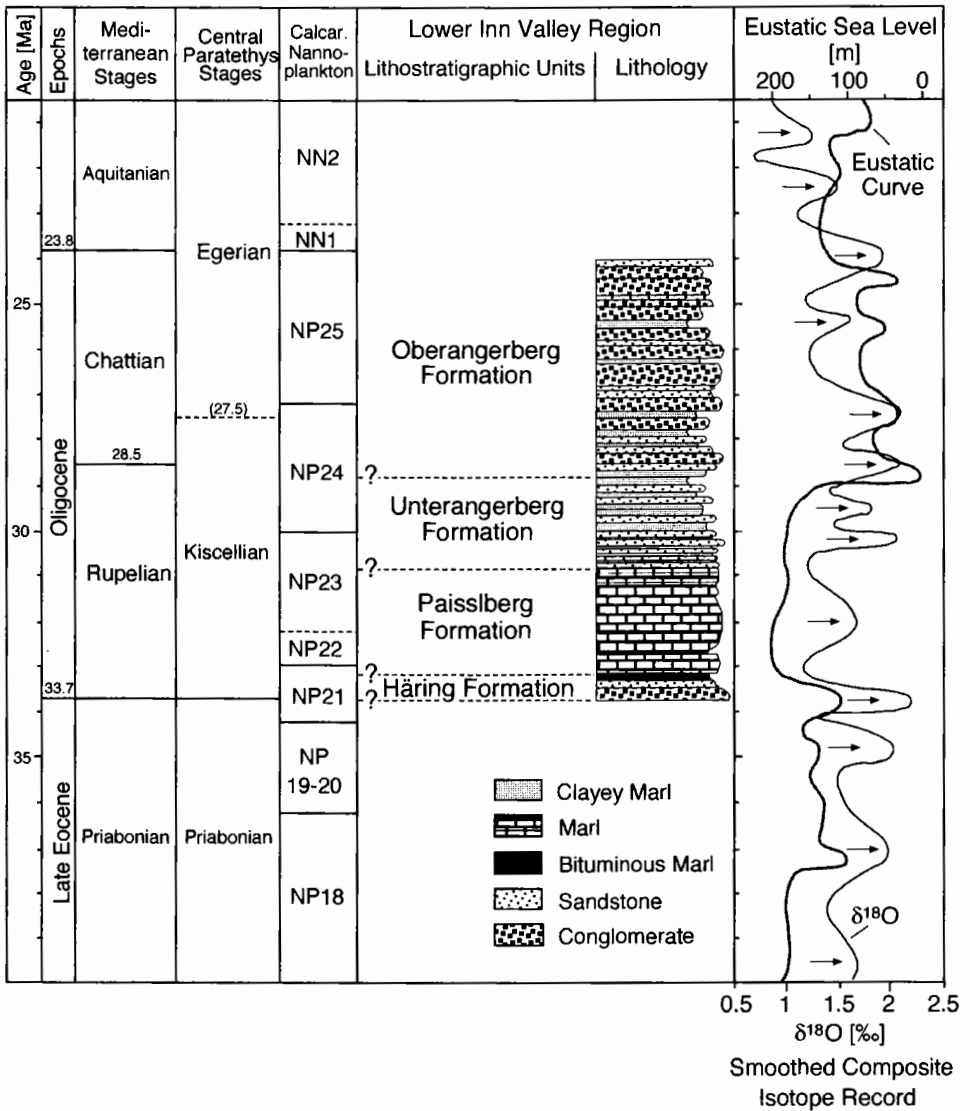


Fig. 2: Simplified standard profile of early Oligocene deposits in the Lower Inn Valley area (after ORTNER & STINGL, this volume). Stratigraphy according to BERGGREN et al. (1995) and RÖGL (1996). The eustatic sea level curve of HAO et al. (1987) and the composite smoothed  $\delta^{18}\text{O}$  record of ABREU & ANDERSON (1998) are given for comparison. Arrows indicate major glacioeustatic events.

Rupelian sediments that are widely distributed throughout the Paratethys realm and is followed by several drops and rises of sea level during the late Rupelian.

Timing and correlation of events within the Paratethys and Tethys realms are often hampered by a poor age control and the superimposition of global (eustatic) and regional (basin subsidence) environmental signals (SCHMIEDL et al., in press). However, the interregional correlation between the eastern, central and western parts of the Paratethys was considerably improved by a number of recent papers including new nannoplankton datings, the establishment of ecostratigraphical zones, and the consideration of sequence stratigraphic results (e.g., NAGYMAROSY, 1991; KRHOVSKY et al., 1993; POPOV et al., 1993; KRHOVSKY, 1995). These studies indicate a superregional increase of nutrient supply and decrease in surface water salinity in the whole Paratethys during the Early Oligocene. This change is considered to be due to both climatic and paleogeographic changes that gradually restricted the connection with the open ocean and finally caused the isolation of the Paratethys in the early NP 23 zone (BALDI, 1984; RUSU, 1988; POPOV et al., 1993; KRHOVSKY et al., 1993; KRHOVSKY et al., this volume).

In order to distinguish between global and regional signals paleoenvironmental investigations based on sediment successions from the Paratethys require the evaluation of stratigraphy, water depth and oceanography at the time of deposition. Benthic foraminifera are known to be very suitable for the reconstruction of past marine basin environments. They have been successfully used to assess Cenozoic changes in water depth, oxygenation, and organic matter fluxes in deep and shallow marine ecosystems (e.g., MACKENSEN & BERGGREN, 1992; DIESTER-HAASS & ZAHN, 1996; THOMAS & GOODAY, 1996; SCHERBACHER, 2000). Benthic foraminifera have been described previously from the Oligocene successions of the Lower Inn Valley area (e.g., LÜHR, 1962; LINDENBERG, 1966). However, these investigations focussed on stratigraphic and phylogenetic aspects. Little information is available on the paleoecologic significance of foraminifera from this region (HAGN et al., 1981; REISER, 1987; DOHMANN, 1991).

In our study we present benthic foraminiferal data from two early Rupelian sections of the Lower Inn Valley area. The main objective of our study is to apply the paleoecological potential of benthic foraminifera to the reconstruction of the Early Oligocene paleoenvironmental history of the Western Paratethys in the northeastern Alpine realm. Moreover, the regional impact of eustatic sea level fluctuations and tectonic changes on the marine ecosystems is assessed.

## 2. STUDY AREA

The Lower Inn Valley extends SW-NE from Innsbruck to the northern margin of the Eastern Alps. The Oligocene deposits of the Lower Inn Valley area overlie Mesozoic sediments of the East Alpine zone and are exposed along the Inn Valley shear zone between the towns of Häring, Kössen, and Reit im Winkel (Fig. 3). Deposition and facies evolution of the Oligocene deposits are associated with NW-directed shortening and sinistral activity that occurred along the Inn Valley shear zone (ORTNER, 1996; ORTNER & STINGL, this volume). These tectonic movements were caused by orogen-parallel extension in more internal parts of the orogen. Diachronous facies development and distribution of benthic foraminifera in the Rupelian successions indicate a marine advance from

north to south (LINDENBERG, 1966; KROIS, 1992). This transgression was caused by the Rupelian sea level rise (HAQ et al., 1987) and was probably amplified by the regional basin subsidence and tectonic movements of the Eastern Alpine region. It has even been speculated that during the Oligocene a trans-alpine deep-marine connection existed between the Paratethys marginal sea and the Tethys Ocean (WAGNER, 1980; DOHMANN, 1991).

The Oligocene succession of the Lower Inn Valley is divided into four formations: Häring Formation, Paisslberg Formation, Unterangerberg Formation, and Oberangerberg Formation (ORTNER & STINGL, this volume) (Fig. 2). The Häring Formation represents transgressive sediments comprising deltaic conglomerates and sandstones (Lengerergraben Member) overlain by lacustrine bituminous marly sandstones and coal measures (Bergpeterl Member). While older studies indicate a Late Eocene age (e.g., LÜHR, 1962), more recent micropaleontological and sequence stratigraphic observations suggest an Early Oligocene age (CICHA et al., 1971; HOCHULI, 1978; KROIS, 1992; ORTNER, 1996). The Paisslberg Formation consists of deeper marine marls and marly limestones ("Cement Marls", "Fish Shale") and the locally exposed shallow water carbonates of the Werlberg Member (ORTNER & STINGL, this volume). The Paisslberg Formation was deposited during the Early (to middle) Oligocene, representing nannoplankton zones NP21–NP22 (LÜHR, 1962; CICHA et al., 1971; STEININGER et al., 1976; RÖGL et al., 1979; DOHMANN, 1991). It probably extends into NP23 in the upper part of the formation (CICHA et al., 1971; SCHERBACHER, 2000) (Fig. 2). Based on micropaleontological results, a transgressive trend from water depths of 50–200 m in the lower part to 200–600 m (possibly up to 1000 m) in the higher part is suggested within the Paisslberg Formation (HAGN et al., 1981). The onset of sedimentation of the Unterangerberg Formation occurs in the upper part of the middle Oligocene and it interfingers laterally with the Paisslberg Formation (LÜHR, 1962; KROIS, 1992; ORTNER, 1996; ORTNER & STINGL, this volume). This transition is marked by a significant increase of terrigenous components. The Unterangerberg Formation consists of alternating sandstones and silty to clayey sediment layers. The youngest depositional unit of the Lower Inn Valley Oligocene is the Oberangerberg Formation which was deposited during the Late Oligocene (Chattian) and comprises fluvial conglomerates, sandy marls and sandstones containing small-scale coal measures (KROIS & STINGL, 1991; ORTNER & STINGL, this volume).

### 3. MATERIAL AND METHODS

This study is based on two Lower Oligocene (Lower Rupelian) sections from the Lower Inn Valley area (Fig. 3). The section "Buchaugraben" is exposed along a creek between the village of Bichlach and the Buchau estate (Tyrol, Austria). It comprises a 25 m thick succession of sediments. The approximately 40 m thick section "Pötschbichl" is located north of the village of Entfelden near Reit im Winkl (Bavaria, Germany). Both investigated successions comprise the uppermost part of the Häring Formation and the overlying clayey marls of the Paisslberg Formation ("Fish Shales"). The correlation of lithology and different faunal parameters (Fig. 4, 5) suggest that the 25 m thick "Buchaugraben" section corresponds to approximately the lower 34 m of the "Pötschbichl" section. Hence, sedimentation rates at the "Pötschbichl" section exceeded those at the "Buchaugraben" section.

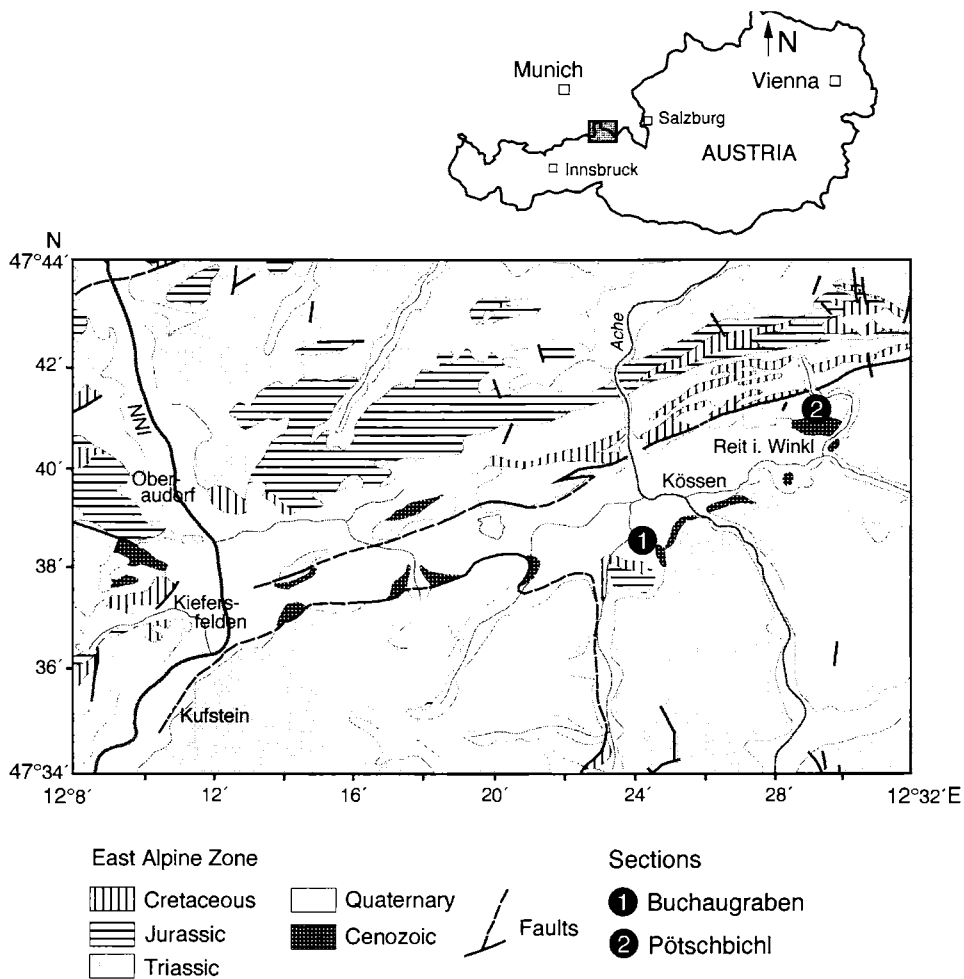
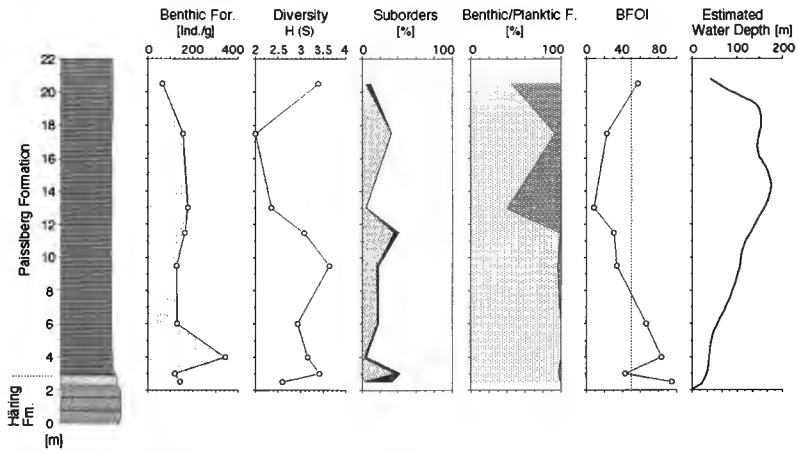


Fig. 3: General geologic map and studied localities in the Lower Inn Valley area, Austria / Germany. The geologic information is based on GANSS & ZITZMANN (1980).

**a) Section "Buchaugraben"**



**b) Section "Pötschbichl"**

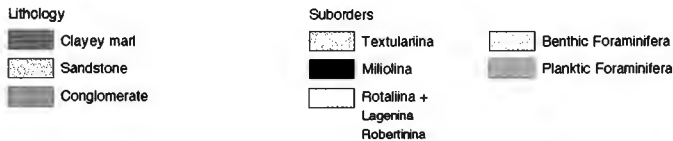
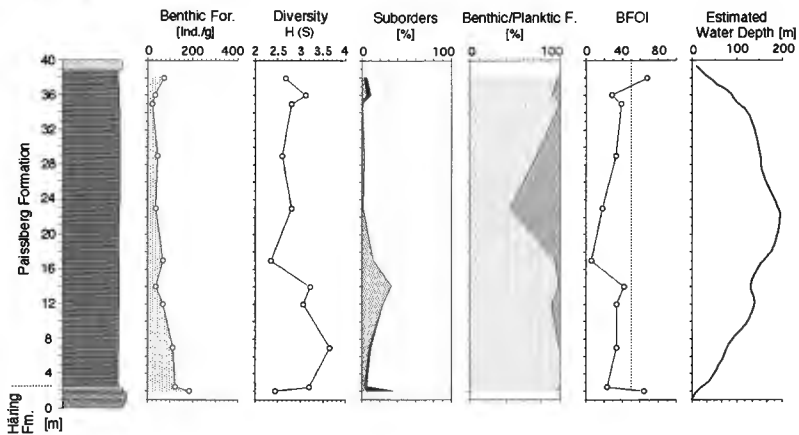


Fig. 4: Lithology, benthic foraminiferal number, diversity, relative proportion of benthic foraminiferal suborders, relative abundance of planktic and benthic foraminifera, estimated bottom water oxygenation, and estimated water depth of the lower Oligocene sediment sections at a) "Buchaugraben" and b) "Pötschbichl" in the Lower Inn Valley area. The Benthic Foraminiferal Oxygen Index (BFOI) was estimated according to KAIHO (1994). Index values between 0 and 50 correspond to dissolved oxygen concentrations between 1.5 and 3 ml l<sup>-1</sup>, values >50 correspond to concentrations >3 ml l<sup>-1</sup>. The water depth was assessed according to the Plankton/Benthos ratios and the bathymetric significance of the different benthic foraminiferal species and assemblages (for details see text).



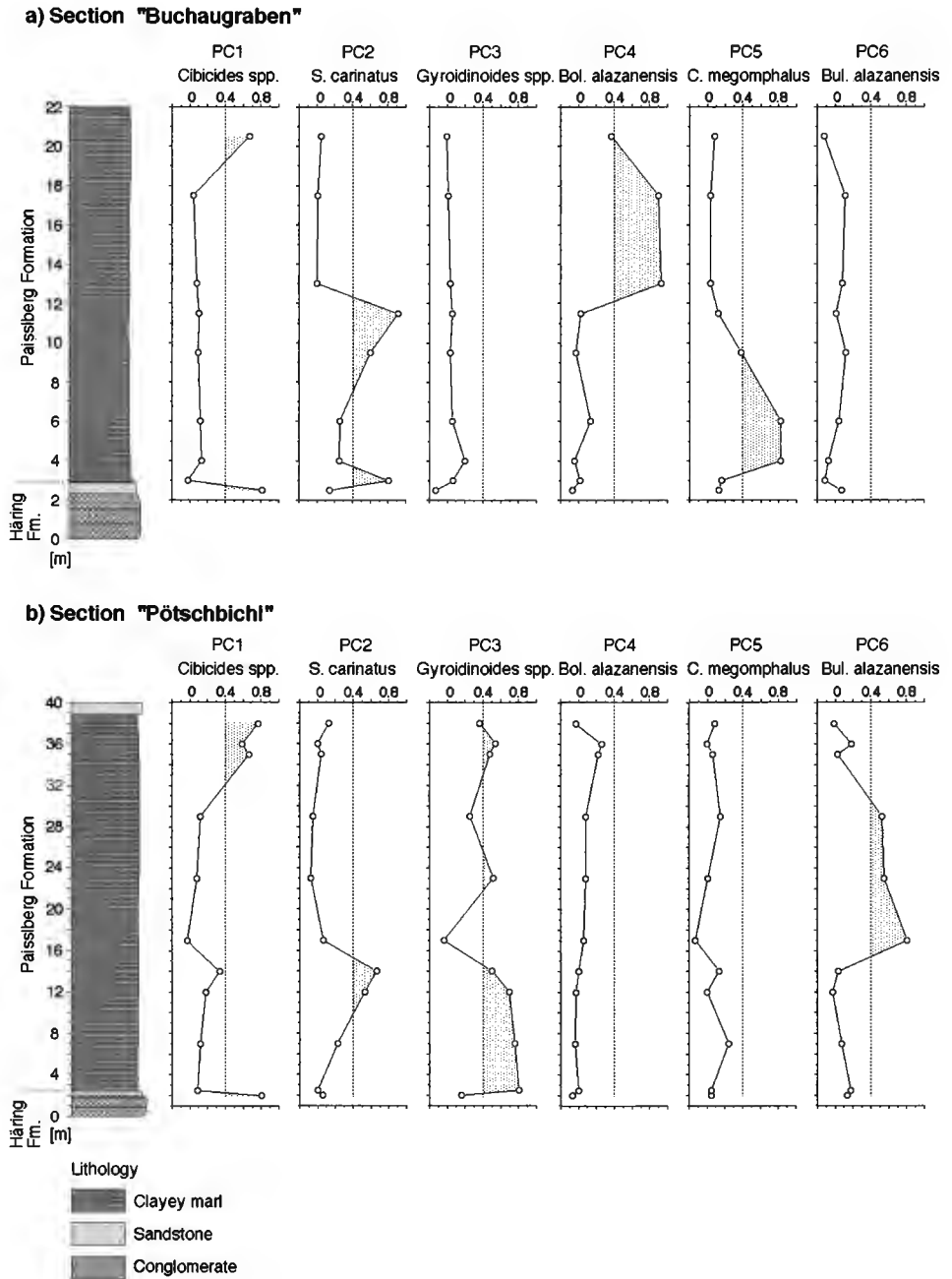


Fig. 5: Lithology and Q-mode benthic foraminiferal assemblages of the lower Oligocene sediment sections at a) "Buchaugraben" and b) "Pötschbichl" in the Lower Inn Valley area.

In total, 20 samples were collected from the two sections. For the micropaleontological studies 200–300 g sediment were dried and weighed. Subsequently, samples were treated with an alcohol-detergent (Rewoquad) mixture and washed over a 63  $\mu\text{m}$  mesh size. The coarse residue was dried and weighed. The investigation of the benthic foraminiferal fauna was carried out on representative splits of the size fraction  $>125 \mu\text{m}$ . At least 300 specimens were counted for each sample. Species determination was mainly based on SZTRÁKOS (1982), PAPP & SCHMID (1985), REISER (1987), and CÍCHA et al. (1998). The refined taxonomy of CÍCHA et al. (1998) based on the generic classification of LOEBLICH & TAPPAN (1988) was adapted. Diversities were determined following the Shannon-Wiener information equation (BUZAS & GIBSON, 1969). Faunal assemblages were calculated by Q-mode (Varimax-rotated) principal component analyses (PCA) as applied by SCHERBACHER (2000). Rare species that occurred only in one sample or never exceeded 2 individuals per sample were summarized in the respective genera (spp.) or in the category “all other species”. PC loadings  $>0.4$  were regarded as statistically significant (MALMGREN & HAQ, 1982). PC scores  $>3$  were assigned to dominant taxa and PC scores between 1 and 3 to important associated taxa of an assemblage. For the evaluation of changes in bottom water oxygenation the approach of KAIHO (1994) was applied to the species matrix. The assessment of the microhabitat preference of the different taxa is based on the comparison with morphologically similar extant taxa according to CORLISS (1991), GOODAY (1994), KAIHO (1994, 1999) and own data from the Mediterranean Sea (e.g., SCHMIEDL et al., 2000). Benthic Foraminiferal Oxygen Index (BFOI) values between 0 and 50 are based on high ratios of dysoxic and suboxic species and low ratios of oxic species and correspond to oxygen concentrations between 1.5 and 3  $\text{ml l}^{-1}$  (low oxic). BFOI values  $>50$  are based on high ratios of oxic species and low ratios of suboxic and dysoxic species and correspond to concentrations  $>3 \text{ml l}^{-1}$  (high oxic). A detailed description of the BFOI calculation is given in SCHERBACHER (2000).

## 4. RESULTS

### 4.1. Numerical faunal parameters

At the “Buchaugraben” locality benthic foraminiferal numbers (BFN) vary between 65 and 342 (mean: 158) individuals  $\text{g}^{-1}$  dry sediment (Fig. 4). The highest values are observed in the lowermost samples of the section. At the “Pötschbichl” locality BFN are considerably lower when compared to the “Buchaugraben” samples and vary between 21 and 184 (mean: 72) individuals  $\text{g}^{-1}$  dry sediment. Numbers are highest near the base of the Paisslberg Formation and decrease from bottom to the upper part of the section. A slight increase of the BFN occurs at the top of this section.

The relative abundance of benthic and planktic foraminifera shows similar trends at both locations. Planktic foraminifera are almost absent at the base of the sections and exhibit a significant increase of up to 60% in the middle part. While the proportions of planktic foraminifera stay high in the upper part of the “Buchaugraben” section, they return to values below 10% in the upper part of the “Pötschbichl” section (Fig. 4).

Benthic foraminiferal diversities exhibit H (S) values between 2 and 3.7 at both locations. Maximum values are observed in the lower part of the sections. Significant

decreases of H (S) values in the middle part of both sections coincide with increases of planktic foraminiferal tests (Fig. 4). The benthic foraminiferal fauna is dominated by rotaliids in all samples (57–98%). The relative abundance of textulariids varies between 2 and 38%. At the “Buchaugraben” locality textulariid tests are more abundant (3–38%, mean 18%) than at the “Pötschbichl” locality (2–24%, mean 9%). Miliolids exhibit relative abundance between 0 and 30%. At both localities elevated numbers occur near the base and top of the sections (Fig. 4; Tab. 1; App.).

At both sections the BFOI values never drop below 0. This suggests that oxic conditions (above 1.5 ml l<sup>-1</sup>) persisted throughout the investigated time interval at both sections. Highest oxygen concentrations above 3 ml l<sup>-1</sup> are estimated for the base and top of the sections. Low oxic conditions between 1.5 and 3 ml l<sup>-1</sup> occur in the middle parts of the sections coinciding with lowest benthic foraminiferal diversities and high proportions of planktic foraminifera (Fig. 4).

#### 4.2. Benthic foraminiferal assemblages

On the base of a Q-mode principal component analysis the Rupelian benthic foraminifera were grouped into six main assemblages accounting for 71.3% of the total variance of the data set (Fig. 5, Tab. 1). Communalities vary between 0.53 and 0.83. SEM images of selected dominant and associated species of these faunas are figured on Plates 1 and 2.

Significant loadings of the *Cibicides* spp. fauna (PC1) occur at the base and top of both investigated sections. Important species of this fauna include *Quinqueloculina* spp. (mainly *Q. seminula*), *Cibicides* sp. 1, *Uvigerina gracilis*, and *Asterigerinata* spp. The *Spirorutilus carinatus* fauna (PC2) exhibits statistically significant factor loadings in the lower to middle part of both sections where it is mainly associated with *Cibicidoides ungerianus* and *Hansenisca soldanii*. The *Gyroidinoides* spp. fauna (PC3) is restricted to the lower part of the “Pötschbichl” section where it occurs between PC1 and PC2. Important associated taxa of this fauna are *Cibicides* spp., *Bolivina* spp., *Bolivina vaceki*, *Nonion* spp., *Nodosaria* spp. and *Bulimina* spp. The *Bolivina alazanensis* fauna (PC4) is restricted to the upper part of the “Buchaugraben” section and occurs above PC2. Important and associated constituents are *Recurvoides* spp., *Uvigerina gracilis* and *Bolivina* spp. The *Cibicides megomphalus* fauna (PC5) is also restricted to the “Buchaugraben” locality where high PC loadings of this fauna are observed in the lower part of the section between the two peaks of PC2. This fauna resembles PC3 at the “Pötschbichl” section. Dominant and associated species include *Cibicidoides pseudoungerianus*, *Stilostomella nuttalli*, *Cibicidoides ungerianus*, and *Melonis affinis*. Finally, the *Bulimina alazanensis* fauna (PC6) occurs in the middle part of the “Pötschbichl” section. It resembles PC4 at the “Buchaugraben” section and contains *Bolivina* spp., *Rosalina* spp., *Bulimina* spp., *Uvigerina gallowayi*, and *Bigenerina* spp. as important constituents. Both faunas (PC6 and PC4) are associated with low values of the oxygen index and elevated abundance of planktic foraminifera (Figs. 4, 5).

No.	Dominant Species	Score	Important Associated Species	Score	Explained Variance, %
PC1	<i>Cibicides</i> spp.	7.8	<i>Uvigerina gracilis</i>	2.4	16.9
	<i>Quinqueloculina</i> spp.	5.2	<i>Asterigerinata</i> spp.	2.3	
	<i>Cibicides</i> sp.1	3.9	<i>Reussella</i> spp.	1.8	
			<i>Globocassidulina</i> spp.	1.6	
			<i>Discorbis</i> spp.	1.2	
PC2	<i>Spirorutilus carinatus</i>	8.9	<i>Hansenisca soldanii</i>	2.0	14.0
	<i>Cibicoides ungerianus</i>	5.3	<i>Stilostomella nuttalli</i>	1.8	
			<i>Cibicides</i> sp.1	1.7	
			<i>Cibicides</i> spp.	1.6	
			<i>Bolivina beyrichi</i>	1.1	
PC3	<i>Gyroidinoides</i> spp.	5.4	<i>Nonion</i> spp.	2.3	15.2
	<i>Cibicides</i> spp.	4.6	<i>Nodosaria</i> spp.	2.2	
	<i>Bolivina</i> spp.	3.4	<i>Bulimina</i> spp.	2.1	
	<i>Bolivina vaceki vaceki</i>	3.1	<i>Uvigerina</i> spp.	1.7	
			<i>Hoeglundina elegans</i>	1.4	
			<i>Siphonina</i> spp.	1.1	
PC4	<i>Bolivina alazanensis</i>	9.2	<i>Globocassidulina</i> spp.	1.2	9.8
	<i>Recurvooides</i> spp.	4.2			
	<i>Uvigerina gracilis</i>	3.9			
	<i>Bolivina</i> spp.	3.3			
PC5	<i>Cibicides megomphalus</i>	8.1	<i>Cibicoides ungerianus</i>	2.7	8.4
	<i>Cibicoides pseudoungerianus</i>	3.7	<i>Melonis affinis</i>	2.0	
	<i>Stilostomella nuttalli</i>	3.1	<i>Oridorsalis umbonatus</i>	1.8	
			<i>Hoeglundina elegans</i>	1.7	
			<i>Hansenisca soldanii</i>	1.6	
			<i>Cibicides</i> spp.	1.5	
			<i>Lenticulina cultrata</i>	1.2	
			<i>Cibicides</i> sp.1	1.2	
			<i>Discorbis</i> spp.	1.1	
PC6	<i>Bulimina alazanensis</i>	5.5	<i>Bigenerina</i> spp.	2.5	6.9
	<i>Bolivina</i> spp.	5.4	<i>Stilostomella nuttalli</i>	1.6	
	<i>Rosalina</i> spp.	4.8	<i>Angulogerina cf. selseyensis</i>	1.1	
	<i>Bulimina</i> spp.	3.7	<i>Discorbis</i> spp.	1.0	
	<i>Uvigerina gallowayi</i>	3.1			

Tab. 1: Composition of benthic foraminiferal assemblages from the investigated lower Oligocene sections. Principal Component No., dominant taxa and important associated taxa with Varimax Principal Component Scores, and explained variance in percent of total variance are given.

## 5. DISCUSSION

The distribution patterns of benthic foraminifera from the investigated sections can provide a variety of valuable paleoenvironmental information on the basin evolution in the Lower Inn Valley area during the Early Oligocene. In the following the available environmental information will be discussed focusing on the reconstruction of water depth, temperature and salinity, trophic conditions, and bottom water ventilation. In this context, important environmental information can be derived from the comparison of the fossil faunas with equivalents from modern marine environments. This comparison focuses on the general faunal structure (e.g., diversity) and life strategies (e.g., microhabitat) of the dominant taxa.

### 5.1. Bathymetry

In near-shore marine environments the influence of water depth on the occurrence of planktic foraminifera persists even when physicochemical conditions are equivalent to an open marine setting (HEMLEBEN et al., 1989; ARNOLD & PARKER, 1999). In shelf waters, planktic foraminifera are often small-sized and usually sparsely distributed (GIBSON, 1989). This is especially true of inner neritic environments on broad continental shelves and epicontinental seas where they may be entirely absent. Consequently, the occurrences of frequent planktic foraminifera in the middle part of the "Pötschbichl" and the middle through upper parts of the "Buchaugraben" sections suggest at least an outer neritic environment with water depths exceeding 150–200 m (Fig. 4).

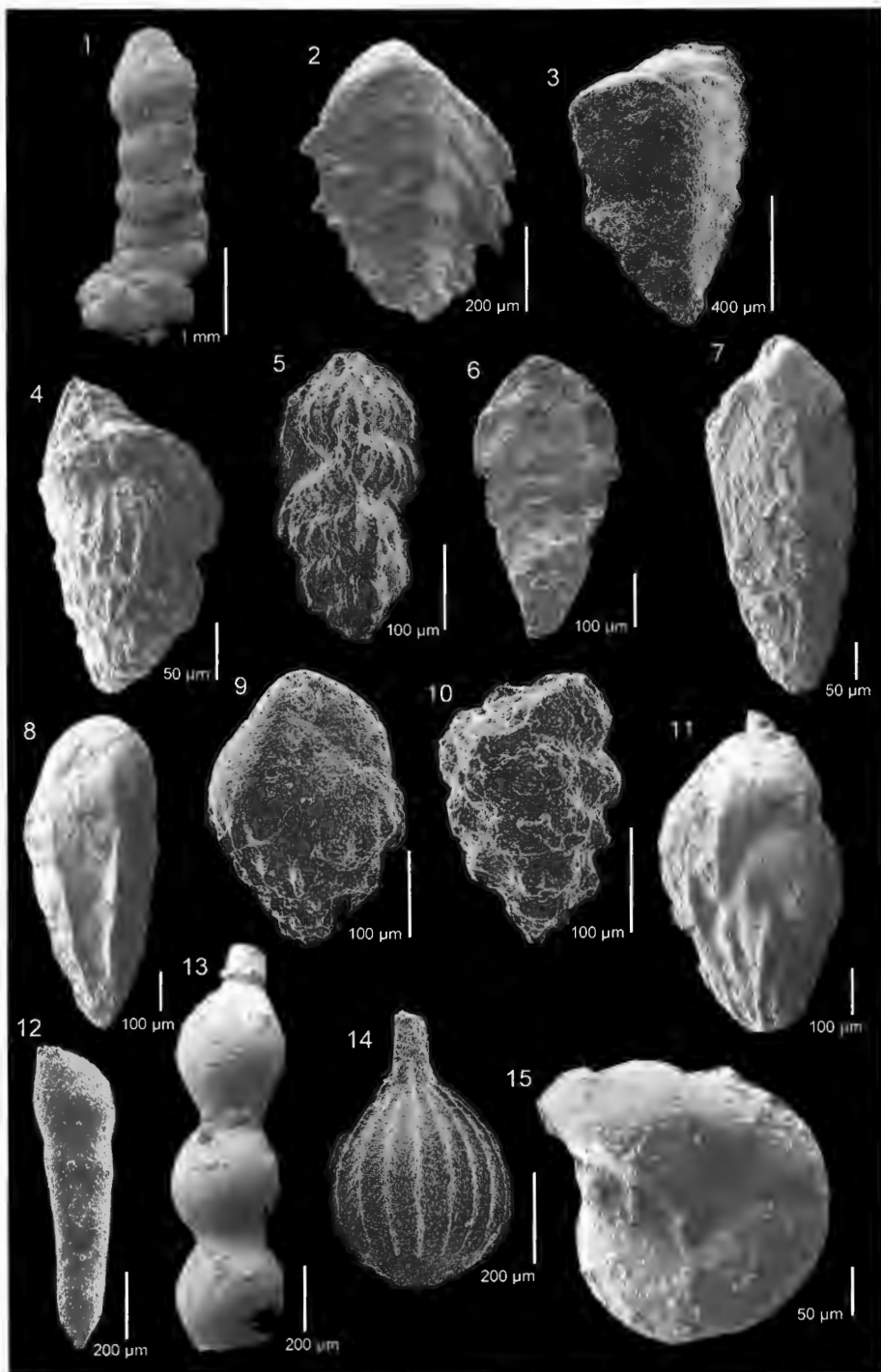
This depth estimate is in accordance with the distribution of the different benthic foraminiferal faunas. At the base of both investigated sections, where almost no planktic foraminifera are observed, the fauna consists of up to 30% miliolids (mainly *Quinqueloculina seminula*) that are dominant taxa of the *Cibicides* spp. fauna (PC1) (Figs. 4, 5). Significant loadings of PC1 are also observed in the three uppermost samples of the "Pötschbichl" section and the topmost sample of the "Buchaugraben" section. At the "Buchaugraben" section different species of the genus *Elphidium* are associated with this fauna and exhibit maximum abundance of 6%. Assemblages rich in miliolids and elphidiids are characteristic of warm inner neritic environments (0–30 m water depth) (BOTOVSKOY & WRIGHT, 1976; CULVER et al., 1996; SEN GUPTA, 1999). Similar conditions seem to have prevailed during the deposition of the lower and uppermost parts of the Paisslberg Formation in the investigated area.

The faunas (PC 2 to PC 6) that occur between the two maxima of the *Cibicides* spp. fauna (PC 1) are characteristic for middle neritic to upper bathyal environments (approximately 30 to 1000 m water depth). This estimate is based on numerous studies on the distribution of Recent benthic foraminiferal faunas at continental shelves and adjacent slopes of the Atlantic Ocean and Mediterranean Sea dominated by species related to the fossil ones of this study (e.g., LUTZE, 1980; SGARRELLA & MONCHARMONT ZEI, 1993; DE STIGTER et al., 1998; DE RIJK et al., 1999). Consequently, faunal evolution should allow a rather accurate estimation of water depths during the deposition of the Paisslberg Formation. Typical faunal elements of middle to outer neritic environments (30 to 200 m water depth) include the species *Lobatula lobatula*, *Cibicides megomphalus*, *Cibicides* spp., *Melonis affinis*, *Gyroidinoides umbonatus*, *Hansenisca soldanii*, *Spirorutilus carinatus*,

and several bolivinids (mainly *B. vaceki vaceki*, *B. beyrichi*) that are important constituents of PC2, PC3 and PC5 (Fig. 5, Tab. 1). In contrast, the dominance of the species *Bulimina alazanensis*, *Uvigerina gallowayi*, and *Bolivina alazanensis* within PC4 and PC6, points to outer neritic to upper bathyal water depths. In the present open oceans, faunas dominated by these genera are characteristic for oxygen minimum zones at upper continental slopes between approximately 200 and 1000 m water depth (LUTZE, 1980; SEN GUPTA & MACHAIN-CASTILLO, 1993). *Uvigerina gallowayi* closely resembles the extant *U. mediterranea* which in the Mediterranean Sea is common at upper bathyal water depths, mainly between 300 and 1200 m (SGARRELLA & MONTCHARMONT ZEI, 1993; DERIJK et al., 1999).

## Plate 1

- Fig. 1: *Sabellovoluta humboldti* (REUSS 1851).  
Fig. 2: *Spirorutilus carinatus* (D'ORBIGNY 1826).  
Fig. 3: *Semivulvulina pectinata* (REUSS 1850).  
Fig. 4: *Uvigerina gracilis* (REUSS 1851).  
Fig. 5: *Angulogerina* cf. *A. selseyensis* (HERON-ALLEN & EARLAND 1909).  
Fig. 6: *Bolivina alazanensis* CUSHMAN 1926.  
Fig. 7: *Bolivina vaceki vaceki* SCHUBERT 1902.  
Fig. 8: *Bulimina alazanensis* CUSHMAN 1927.  
Fig. 9: *Bulimina alsatica* CUSHMAN & PARKER 1937.  
Fig. 10: *Bulimina kasselensis* BATJES 1958.  
Fig. 11: *Uvigerina gallowayi* CUSHMAN 1929.  
Fig. 12: *Dentalina inornata* D'ORBIGNY 1846.  
Fig. 13: *Stilostomella nuttalli* (CUSHMAN & JARVIS 1934).  
Fig. 14: *Lagena amphora* REUSS 1863.  
Fig. 15: *Melonis affinis* (REUSS 1851).



Based on micropaleontological results, HAGN et al. (1981) suggested a transgressive trend from 50–200 m in the lower part to 200–600 m (possibly up to 1000 m) in the upper part for the Paisslberg Formation. This seems to be in accordance with our benthic foraminiferal data. However, in marginal seas and semi-enclosed basins (e.g., fjords) the depth zonation of benthic foraminifera can be influenced by telescoping effects (ALVE, 1990; SEN GUPTA & MACHAIN-CASTILLO, 1993). As a consequence, faunas typical for open ocean bathyal environments may occur at neritic water depths around 100 to 200 m controlled by organic matter fluxes and oxygen concentration similar to those on the continental slope. Telescoping effects may explain the occurrence of “bathyal” faunal elements also in Rupelian basin environments of Slovenia (SCHMIEDL et al., in press) and the Lower Inn Valley. This assumption is corroborated by the proportions of planktic foraminiferal tests that never exceed 60% of the total foraminiferal fauna in the investigated samples (Fig. 4). This ratio is characteristic for outer shelf areas and appears too low for a more pelagic environment (GIBSON, 1989; HEMLEBEN et al., 1989). This bathymetric estimate of maximum water depths around 200 m for the Early Oligocene of the Lower Inn Valley is supported by foraminiferal data of REISER (1987) and DOHMANN (1991). They reported neritic conditions for the early Rupelian of the Lower Inn Valley and shallow bathyal conditions with maximum water depths between 400 and 600 m during deposition of the more distal Rupelian sediments (“Fish Shale”) of the South German Molasse Zone.

The regressive trend in the topmost part of the Paisslberg Formation identified in our study (Fig. 4) has been previously reported by HAGN et al. (1981) and is based on the presence of more numerous benthic foraminiferal tests in this interval. The composite oxygen isotope record of ABREU & ANDERSON (1998) shows several fluctuations related to eustatism. These fluctuations in the Rupelian seem to occur during a sea level high stand (HAQ et al., 1987) (Fig. 2). The observed regressive trend during the younger part of the Paisselberg Formation is probably related to an eustatic sea level drop associated with an extension of the East Antarctic continental ice shield. However, it is not clear how much the regional signal of basin subsidence (ORTNER & STINGL, this volume) biased the global signal of eustatic sea level change in the Inneralpine Molasse.

## Plate 2

Fig. 1: *Cibicides* sp. 1, umbilical view.

Fig. 2: *Cibicides* sp. 1, spiral side.

Fig. 3: *Cibicides megomphalus* (GÜMBEL 1861), umbilical side.

Fig. 4: *Cibicides megomphalus* (GÜMBEL 1861), spiral side.

Fig. 5: *Cibicoides ungerianus* (D'ORBIGNY 1846), umbilical side.

Fig. 6: *Cibicoides ungerianus* (D'ORBIGNY 1846), spiral side.

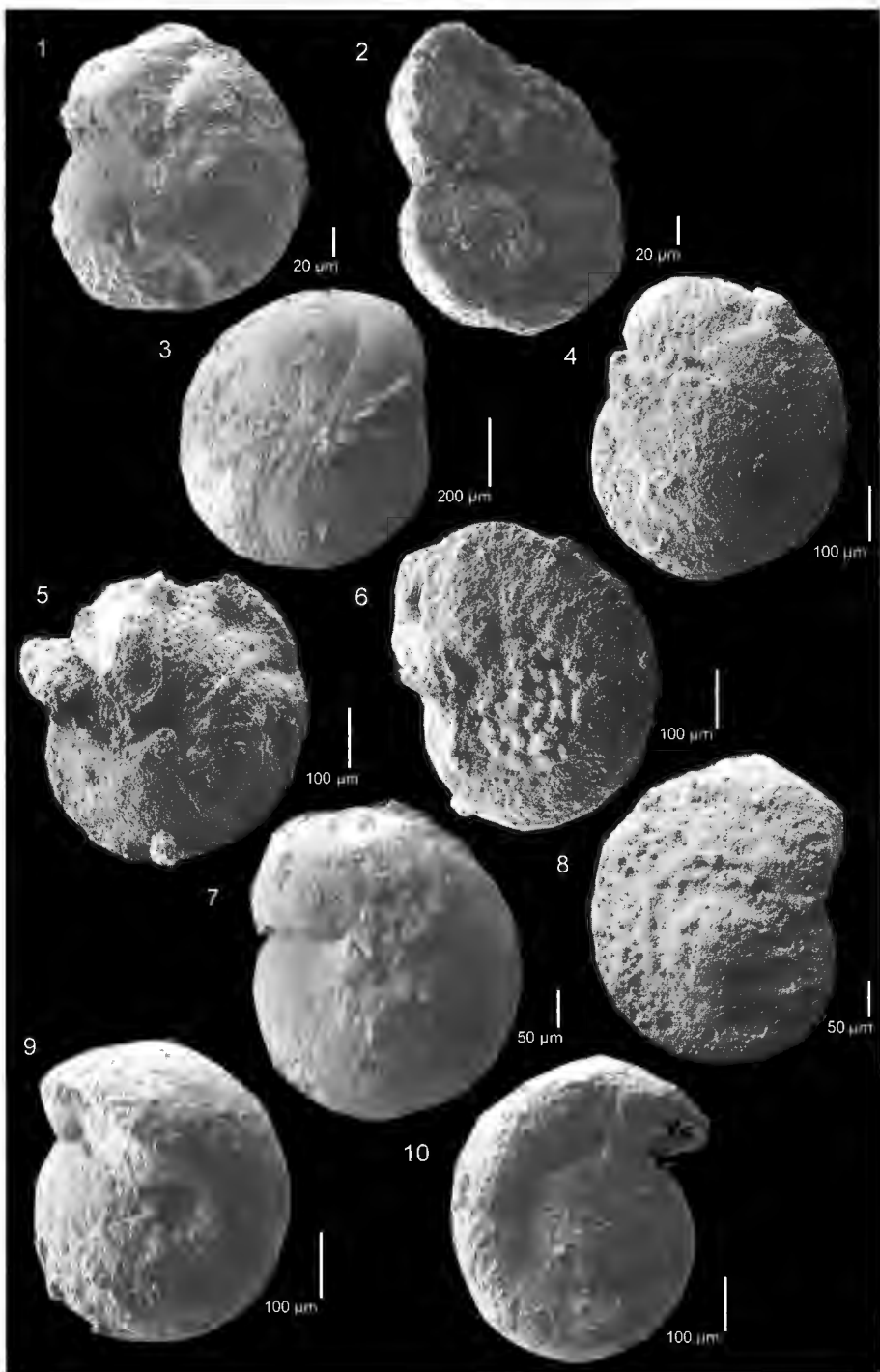
Fig. 7: *Cibicoides pseudoungerianus* (CUSHMAN 1922), umbilical side.

Fig. 8: *Cibicoides pseudoungerianus* (CUSHMAN 1922), spiral side.

Fig. 9: *Hansenisca soldanii* (D'ORBIGNY 1826), umbilical side.

Fig. 10: *Hansenisca soldanii* (D'ORBIGNY 1826), spiral side.





## 5.2. Water temperature and salinity

Species composition and diversity of benthic foraminiferal faunas from shallow water environments are strongly dependent on temperature and salinity of the water mass (CULVER et al., 1996; SENGUPTA, 1999). Consequently, the shallow water faunas from the base and top of the investigated sections may give estimates of the water temperature and salinity (see above; Figs. 4, 5). The *Cibicides* spp. fauna contains elevated percentages of miliolids (mainly *Quinqueloculina seminula*) which account for up to 30% of the total fauna. Low-diverse faunas with a dominance of large miliolids are characteristic for warm and often hypersaline environments, like subtropical and tropical lagoons (MURRAY, 1991). However, the *Cibicides* spp. fauna exhibits rather high diversities of  $H(S) = 2.5$  or above. Moreover, the percentage of miliolids is rather low when compared with tropical shallow water ecosystems (e.g., 40–60% miliolids in inner neritic environments of tropical Brazil, LEVY et al., 1995). Also test sizes are well within the average of all investigated samples. This indicates warm-temperate to tropical and normal-marine conditions without significant environmental stress such as strong temperature and salinity fluctuations (MURRAY, 1991; CULVER et al., 1996; SENGUPTA, 1999) or hypersaline conditions. Our temperature estimate is in accordance with high abundance of bryozoans and the local presence of zooxanthellate corals with moderate diversity within the calcareous Werlberg Member of the Paisslberg Formation (LÖFFLER & NEBELSICK, this volume). These macrofaunas indicate a transitional environment between warm-temperate and tropical conditions with water temperatures ranging between approximately 16° and 23° C (following BETZLER et al., 1997). This temperature range is well in accordance with the estimates based on the composition of the benthic foraminiferal fauna.

These results suggest that no significant variations in salinity occurred during the deposition of the lowermost and upper parts of the Paisslberg Formation at both investigated sections. However, the environmental significance of the results is limited due to the low temporal and spatial resolution of the investigated samples. Thus, similar to the Early Oligocene Slovenian sections (SCHMIEDL et al., in press), more extreme environments (e.g., lagoons, brackish environments) might have occurred but evidence of their presence was not identified in the investigated samples. Therefore, it is not possible to determine more accurately the full range in physical properties of the water masses.

The regressive trend represented by shallow water faunal elements in the topmost parts of the investigated sections was probably accompanied by more restricted basin conditions and enhanced fresh water influence (HAGN et al., 1981). This assumption is corroborated by elevated abundance (up to 6% of the total fauna) of *Elphidium* spp. (among others *E. aff. hauerinum*) in the uppermost part of the "Buchaugraben" section. Most species of the genus *Elphidium* (including the common species *E. advenum* and *E. excavatum* morphologically resembling the extinct *E. aff. hauerinum*) are abundant in euryhaline ecosystems such as estuarine and deltaic environments that experience marked fluctuations in fresh water input and thus, salinity changes (MURRAY, 1991). Significant fresh water fluxes were reported from the Central and Eastern Paratethys starting at the Eocene / Oligocene boundary with maximum influence on the marine ecosystems (decrease of surface water salinity, stratification) during the early NP23 biozone (BÁLDI, 1984; KRHOVSKY et al., 1993; KRHOVSKY et al., this volume).

### 5.3. Organic matter fluxes and bottom water oxygenation

During the last two decades, a number of studies revealed that distribution and microhabitat of benthic foraminifera are strongly related to the organic carbon flux rate to the sea floor and oxygen content of the bottom and pore water (e.g., CORLISS, 1985; JORISSEN, 1987; ALTENBACH & SARNTHEIN, 1989; MACKENSEN & DOUGLAS, 1989). In food-limited environments, commonly characterized by oxic conditions, both foraminiferal standing stock and diversity are rather low and the fauna mainly comprises epifaunal species. In mesotrophic environments standing stocks are moderately high and faunal diversity is at a maximum. The corresponding faunal assemblages comprise a variety of epifaunal, shallow infaunal and deep infaunal species. Low-diversity faunas with high standing stock prevail in eutrophic and oxygen-limited environments and mainly comprise deep-infaunal species that are adapted to dysoxic conditions (JORISSEN et al., 1995).

This dynamic concept can be applied to the fossil faunas of the investigated sections in order to assess changes in trophic conditions and ventilation at the Early Rupelian sea floor of the Lower Inn Valley area. This approach is aided by further data on the distribution and microhabitat preferences of equivalent Recent species (e.g., CORLISS, 1985; CORLISS, 1991; SEN GUPTA & MACHAIN-CASTILLO, 1993; GOODAY, 1994; DE STIGTER et al., 1998; SCHMIEDL et al., 2000). For a number of Oligocene species no closely related extant equivalents exist that would provide direct ecological information. For these species the microhabitat preference is assessed based on their morphological characteristics according to CORLISS (1991) and GOODAY (1994).

The *Gyroidinoides* spp. fauna (PC3) and *Cibicides megomphalus* fauna (PC5) that occur stratigraphically above the inner neritic *Cibicides* spp. fauna (PC1) comprise mainly epifaunal (e.g., *C. megomphalus*, *C. ungerianus*, *C. pseudoungerianus*) and several shallow infaunal species (e.g., *Hansenisca soldanii*, *G. umbonatus*, *Bolivina vaceki*, *Melonis affinis*). Therefore, these faunas indicate oligotrophic to mesotrophic conditions and well-aerated bottom and pore waters (Fig. 5, Tab. 1). This interpretation is corroborated by rather high diversities ( $H(S) = 3$  to 3.5) and elevated BFOI values (Fig. 4). The *Spirorutilus carinatus* fauna (PC2) that succeeds PC3 and PC5 in the "Pötschbichl" and "Buchaugraben" sections, respectively, is characterized by high diversities ( $H(S) = 3.1$  to 3.6) and contains shallow infaunal (e.g. *S. carinata*) and epifaunal species (e.g., *C. ungerianus*) in similar proportions. The genus *Cibicides* is very common in well-aerated shelf ecosystems (MURRAY, 1991). In contrast, *Spirorutilus carinatus* is reported from Eocene to Early Oligocene outer shelf and upper slope environments (JONES & CHARNOCK, 1985; CHARNOCK & JONES, 1989). Its morphology suggests an infaunal life strategy in organic-rich habitats (CORLISS, 1991; GOODAY, 1994). Related extant taxa (e.g., several species of the genera *Spiroplectamina* and *Spiroplectinella*) are known from eutrophic shelf and slope environments in restricted fjords or upwelling areas where they tolerate low or seasonally changing bottom and pore water oxygenation (LUTZE & COULBOURN, 1984; ALVE, 1990). These results suggest a slight increase of organic matter fluxes or seasonally oxygen-depleted bottom waters during the time of *S. rutilus* dominance (Fig. 4).

A shift to more persistent eutrophic and lower oxic conditions is marked by the *Bolivina alazanensis* and *Bulimina alazanensis* faunas (PC4, PC6) in the "Buchaugraben" and "Pötschbichl" sections, respectively (Fig. 5, Tab. 1). This interpretation is

based on the dominance of shallow to intermediate infaunal species in these faunas (according to CORLISS, 1985, 1991; GOODAY, 1994) and a drop in diversities ( $H(S) = 2$  to 2.8). At the same time, the highest proportions of planktic foraminifera are observed indicating maximum basin depths around 200 m (Fig. 4). Low-diversity faunas that are dominated by a few shallow to deep infaunal taxa (mainly of *Bolivina*, *Brizalina*, *Bulimina*, *Uvigerina*, *Globobulimina*) usually occur in organic-rich sediments along with bathyal oxygen minimum zones in high productivity areas (CORLISS, 1985; SEN GUPTA & MACHAIN-CASTILLO, 1993; BERNHARD & SEN GUPTA, 1999). The modern *Bulimina alazanensis* inhabits mesotrophic and rather well oxygenated environments at bathyal to abyssal water depths in the South Atlantic Ocean (LUTZE & COULBOURN, 1984; SCHMIEDL et al., 1997). Similar ecological preferences are assessed for *Uvigerina gallowayi* closely resembling the extant and widely distributed *U. mediterranea*. This shallow infaunal species dominates outer neritic and upper bathyal assemblages in mesotrophic to eutrophic environments of the Mediterranean Sea and the West African Continental margin characterized by organic-rich fine-grained sediments and moderately to well oxygenated bottom waters (LUTZE, 1986; DERUIK et al., 1999; SCHMIEDL et al., 2000). The morphology of *Bolivina (Brizalina) alazanensis* resembles those of Recent brizalinids (e.g., *Brizalina alata*) characteristic for eutrophic and low-oxygenated environments at outer neritic to upper bathyal water depths (BERNHARD & SEN GUPTA, 1999; DE RIJK et al., 1999).

In addition to these infaunal species, faunas PC4 and PC6 of the Early Oligocene sections contain several epifaunal taxa (e.g., *Rosalina nana*, *Discorbis* spp.) and estimated oxygen concentrations never drop below oxic conditions (Fig. 4; Tab. 1). These observations suggest that environmental stress was limited and ecosystems were rather stable throughout the deposition of the Paisslberg Formation. Similar faunal patterns occur in modern shelf-water hypoxia that are characterized by larger variations in the distribution and diversity of benthic foraminifera (SEN GUPTA & MACHAIN-CASTILLO, 1993).

Our data suggest that moderate to high organic carbon fluxes prevailed during the deposition of the main parts of the Paisslberg Formation at the investigated sections. This conclusion is supported by high bryozoan abundance in contemporaneous carbonates of the Werlberg Member that also indicate eutrophic conditions (LÖFFLER & NEBELSICK, this volume). At deepest water depth (in an outer neritic environment) represented in the middle part of the Paisslberg Formation the *Bolivina alazanensis* (PC4) and *Bulimina alazanensis* (PC6) faunas indicate eutrophic and low-oxic conditions. This observation suggests a decrease of oxygen and increase of organic matter fluxes with increasing water depths during the deposition of the Paisslberg Formation. However, the lack of suboxic to anoxic conditions proves that shelf waters were rather well ventilated throughout the investigated time interval.

#### 5.4. Small-scale variability within the basin environment

The faunal patterns of both investigated sections mirror a transgression-regression trend of the basin evolution in the Lower Inn Valley area during the Early Oligocene (see chapter 5.1). Besides this general trend, differences in the composition and distribution of the benthic foraminiferal faunas are observed. They are probably due to spatial environmental gradients within the basin at the time of deposition. Relative differences of sedimentation rates between the two sections can be assessed based on the faunal

pattern. At the "Buchaugraben" section the drastic increase of planktic foraminifera and the onset of the *Bol. alazanensis* fauna (as indicator for eutrophic and low oxic conditions) occur approximately 9 m above the lower boundary of the Paisslberg Formation (Fig. 4, 5). In contrast, at the "Pötschbichl" section the drastic increase of planktic foraminifera and the onset of the *Bul. alazanensis* fauna (pointing to eutrophic and low oxic conditions, similarly to the *Bol. alazanensis* fauna) occur approximately 13 m above the lower boundary of the Paisslberg Formation. This observation suggests higher sedimentation rates at the "Pötschbichl" section relative to the "Buchaugraben" section.

Lower relative sedimentation rates at the "Buchaugraben" section are accompanied by higher BFN, higher proportions of miliolids, higher abundance of elphidiids, slightly higher BFOI values, and differences in the composition of the deeper shelf assemblages when compared with the "Pötschbichl" section (Figs. 4, 5). Sedimentation rates are normally influenced by distance from the source area, sea floor topography, and current velocities (KENNETT, 1982). Higher sedimentation rates often occur in small depressions that act as a trap for fine sediment particles. Elevated accumulation rates of sediment particles and organic carbon at the "Pötschbichl" section could have favored the abundant occurrence of *Bulimina alazanensis*, *Bulimina* spp. and *Uvigerina gallowayi* that are less abundant at the "Buchaugraben" section. In modern oceans, morphologically similar species (e.g., *U. mediterranea*, *U. peregrina*, *B. elongata*, *B. aculeata*, *B. striata*) occur in high numbers in fine-grained and organic-rich sediments (e.g., LUTZE & COULBOURN, 1984; JORISSEN, 1987; SCHMIEDL et al., 2000). At the "Buchaugraben" section lower sedimentation rates and slightly elevated BFOI values are probably a result of enhanced bottom currents. This assumption is corroborated by the occurrences of *Uvigerina (Trifarina) gracilis* and *Globocassidulina* spp. as constituents of PC4 (Tab. 1). On hydrodynamically exposed positions in the modern South Atlantic Ocean the species *Angulogerina angulosa* and *Globocassidulina subglobosa* are adapted to an elevated energy state (high current velocities) at the benthic boundary layer (MACKENSEN et al., 1995).

These sedimentological and faunal characteristics point to a more proximal or hydrodynamically exposed position at the "Buchaugraben" section and a more distal and probably slightly deeper position at the "Pötschbichl" section. The more proximal character of the "Buchaugraben" section is also corroborated by the occurrence of elphidiids (see above) and elevated abundance of miliolids (MURRAY, 1991) relative to the "Pötschbichl" sediments. The distribution of the different sediment facies within the Lower Inn Valley indicates a pronounced small-scale variability within the basin. This variability is probably the result of complex tectonic activities along the Inn Valley shear zone (ORTNER & STINGL, this volume).

## 5.5. Implications for the paleoenvironmental evolution of the Inneralpine Molasse and the western Paratethys

Our faunal results indicate a transgression-regression trend most likely linked to eustatic sea level changes that occurred during the Early Oligocene (ABREU & ANDERSON, 1998). Contemporaneous sediment successions representing transgressive system tracts occur at different locations in the Eastern Alps and demonstrate a super-regional control of the basin evolution in the Inneralpine Molasse superimposed on the local subsidence histo-

ries. The Paisslberg Formation of the Lower Inn Valley area can be correlated with the lower part of the Tegel Unit in the Slovenian Basin (SCHMIEDL et al., in press). In both areas the distribution and species composition of the faunas are very similar and indicate a basin evolution from deltaic to inner neritic to outer neritic conditions.

However, the faunal comparison points to a gradient in water temperatures between the two areas. In the Slovenian Basin a rich zooxanthellate coral fauna and the dominance of larger foraminifera and large miliolids in carbonate buildups and lagoonal deposits, respectively, suggest tropical water temperatures (with minimum winter temperatures above 18° C) (NEBELSICK et al., in press; SCHMIEDL et al., in press). In the Lower Inn Valley area, lower size and abundance of miliolids (this study), a less-diverse coral fauna and the high abundance of bryozoans (LÖFFLER & NEBELSICK, this volume) univocally indicate a temperature range between warm-temperate and tropical marine climates. According to the distribution of comparable faunas in the modern oceans temperatures of approximately 16–23° C can be estimated (BETZLER et al., 1997). The assumed temperature differences between the two regions suggest a boreal influence (via the Rhine Graben) in the Lower Inn Valley area while the Slovenian Basin may have experienced a more tropical climate due to marine connections with the Indopacific realm (RÖGL, 1998). This assumption is corroborated by the occurrence of cool water planktic foraminiferal faunas of small test sizes and low diversities in Early Oligocene sections from the northern Alpine margin and Rhine Graben (e.g., HUBER, 1994; UJETZ, 1996). These faunas indicate that cooler conditions prevailed north of the Alps in comparison to more southerly regions that bear a stronger Tethyan influence (UJETZ, 1996).

At both locations BFOI values never drop below 0 ("low oxig") values. However, no regressive trend is observed in the Slovenian Basin during the Early Oligocene. This difference can be explained by a locally strong subsidence of the Slovenian Basin overprinting eustatic fluctuations (SCHMIEDL et al., in press). Several studies have demonstrated that at upper bathyal depths of the Molasse and Pannonian basins bottom waters experienced more extreme oxygen depletions during the Early Oligocene when compared to the inneralpine shelf environments. In both areas, the faunas are often characterized by very low diversities and small individuals and at times even the entire benthic fauna is absent, indicating dysoxic to anoxic conditions (e.g., SZTRÁKOS, 1982; BÁLDI, 1984; REISER, 1987; DOHMANN, 1991; UJETZ, 1996). This biofacies comparison shows that in the Western and Central Paratethys oxygen concentrations obviously decreased with increasing water depth. Similar oceanographic conditions are assumed for the marginal basin of the eastern Mediterranean Sea during the Pliocene and Quaternary. At times of sapropel formation, the shelf areas were bathed by low oxig to suboxic water masses. In contrast, the bathyal and abyssal basin ecosystems experienced dysoxic to anoxic conditions (ROHLING, 1994; SCHMIEDL et al., 1998). These oceanographic conditions occurred during pluvial times when freshwater input from the borderlands was increased. This again probably triggered high primary productivity and enhanced fluxes of organic carbon to the seafloor. Simultaneously, the rate of deep water formation drastically decreased due to the stratification of the water column (ROSSIGNOL STRICK, 1983; CRAMP & O'SULLIVAN, 1999; EMEIS et al., 2000). In the late Paleogene Paratethys similar oceanographic situations repeatedly occurred during times of isolation from the surrounding oceans (BÁLDI, 1984; POPOV & STOLYAROV, 1996; SCHMIEDL et al., in press). These environmental changes were likely a response to eustatic sea level fluctuations and

the tectonic evolution of the Alpine and Carpathian orogens (RÖGL, 1998). However, also climatic changes resulting in fluctuations between more and less humid conditions (fresh water input) have to be considered (KRHOVSKY et al., 1993; KRHOVSKY et al., this volume; SCHMIEDL et al., in press).

## 6. CONCLUSION

The benthic foraminifera of the early Rupelian (Early Oligocene) successions at the "Buchaugraben" and "Pötschbichl" localities in the Lower Inn Valley area reflect the regional basin evolution and allow semiquantitative estimates of bathymetry, water temperature, organic matter fluxes, and oxygen content in the bottom and pore waters:

- 1) The faunal successions mirror a transgression-regression cycle that can be linked to the basin subsidence and eustatic sea level fluctuations of the early Rupelian. The bathymetric evolution starts with littoral to inner neritic conditions (0–30 m water depth) and reaches a maximum water depth of approximately 200 m within the Paisslberg Formation. Higher upsection, the water depth decreases again to inner neritic conditions (10–30 m).
- 2) Elevated proportions of miliolid foraminifera (up to 30% of the total fauna) in the inner neritic deposits indicate a transitional environment between warm-temperate and tropical conditions (16–23° C following BETZLER et al., 1997). Estimated temperatures are slightly lower than those reconstructed for the Slovenian Basin (minimum temperatures around 18° C). This temperature gradient is probably due to the prevalence of boreal and Indopacific influence north and south of the Eastern Alps, respectively.
- 3) Changes in oxygenation of the bottom water and organic matter fluxes accompany the bathymetric changes. Shallow and mid-shelf assemblages are dominated by epifaunal and shallow infaunal species indicating oligotrophic to mesotrophic conditions and well oxygenated bottom water. In contrast, deeper shelf assemblages are dominated by shallow to intermediate infaunal benthic foraminifera indicating a transition to eutrophic and low oxic conditions. Benthic foraminiferal diversities never drop below  $H(S) = 2$ . This points to normal marine conditions lacking severe environmental stress, such as strong oxygen deficiency.
- 4) The faunal differences at the two sites investigated are explained by a complex coastal topography and differential current system causing small-scale variations in sedimentation rates and organic matter fluxes. These factors, in turn, controlled energy state, food and oxygen gradients at the sea floor.
- 5) Benthic foraminiferal faunas of the transgressive sections can be correlated with Early Oligocene successions of the Slovenian Basin and thus point to a similar basin evolution in the Eastern Alpine realm. The comparison of these shelf faunas with bathyal faunas from the Molasse and Pannonian basins suggests that oxygen concentrations in the Early Oligocene Paratethys decreased with increasing water depth. Here, oxygen deficiencies were probably caused by the repeated isolation and stratification resulting from the combined effects of eustatic sea level variations, tectonic changes and pluvial times of enhanced fresh water run-off.

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	Section "Buchaugraben"									Section "Pötschbichl"												
	[m in section]	2.5	3	4	6	9.5	11.5	13	17.5	20.5	2	2.5	7	12	14	17	23	29	35	36	38	
<i>Adelosina longirostra</i>			x																			
<i>Ammobaculites agglutinans</i>					x	x	x															
<i>Ammodiscus incertus</i>			x																			
<i>Ammoscalaria pseudospiralis</i>			x			x																
<i>Amphicoryna badenensis</i>				x	x				x				x									
<i>Angulogerina angulosa</i>			x																		x	
<i>Angulogerina cf. selseyensis</i>					x	x	x	x					x			x		x				
<i>Anomalinoides affinis</i>			x	x	x	x	x					x										
<i>Anomalinoides badenensis</i>			x	x	x	x	x					x						x				
<i>Arenobulimina cf. cuskleyae</i>			x																			
<i>Asterigerinata planorbis</i>	x					x																
<i>Bolivina alazanensis</i>					x	x		x	x	x						x		x				
<i>Bolivina beyrichi</i> - group				x		x	x	x	x			x			x			x				x
<i>Bolivina budensis</i>								x														
<i>Bolivina carinata</i>						x		x							x							x
<i>Bolivina crenulata</i>													x	x	x				x			
<i>Bolivina elongata</i>										x			x	x								x
<i>Bolivina molassica</i>									x													
<i>Bolivina prion</i>													x			x						x
<i>Bolivina rhomboidalis</i>																x		x				
<i>Bolivina semistriata</i>													x									
<i>Bolivina striatula</i>					x																	
<i>Bolivina vaceki vaceki</i>								x	x	x		x	x	x	x						x	x
<i>Bolivina compressa</i>								x														
<i>Bulimina alazanensis</i>						x	x			x						x						
<i>Bulimina alsatica</i>						x	x					x	x		x				x	x		
<i>Bulimina elongata</i>																					x	x
<i>Bulimina kasselensis</i>				x																		
<i>Bulimina ovata</i>													x			x						
<i>Buliminella carteri</i>							x						x									
<i>Cassidulina alabamensis</i>							x															
<i>Ceratobulimina contraria</i>						x	x	x		x	x											
<i>Ceratocancris haueri</i>			x	x	x	x	x		x		x											
<i>Chilostomella cylindroides</i>								x														
<i>Cibicides megomphalus</i>			x	x	x	x	x		x	x			x	x	x						x	
<i>Cibicidoides pseudoungerianus</i>			x	x	x	x																
<i>Cibicidoides ungerianus</i>			x	x	x	x	x					x	x	x	x							
<i>Cornuspira involvens</i>								x														
<i>Cyclamina miocenica</i>			x		x		x															
<i>Dentalina inornata</i>					x	x	x									x						
<i>Discorbis globularis</i>			x						x													
<i>Discorbis limbata</i>			x	x						x												
<i>Eggerella bradyi</i>			x	x	x																	
<i>Elphidium aff. hauerinum</i>										x												
<i>Epistominella cf. smithi</i>						x								x	x			x				
<i>Eponides polygonus</i>													x							x		
<i>Favulina hexagona</i>									x													x
<i>Fursenkoina acuta</i>			x			x										x						
<i>Glandulina laevigata</i>				x		x																
<i>Globobulimina pacifica</i>			x		x	x	x		x			x	x		x	x						
<i>Globocassidulina globosa</i>			x	x	x	x	x	x	x	x												x
<i>Globulina gibba</i>			x		x																	
<i>Grigelis pyrula</i>							x															
<i>Guttulina problema</i>			x																			
<i>Gyroidinoides guayabalensis</i>				x		x																
<i>Hansensca soldanii</i>			x	x	x	x	x			x					x							x
<i>Hemirobulina hantkeni</i>			x				x															x
<i>Heterolepa cf. dutemplei</i>					x								x									

Appendix 1: Range chart of benthic foraminiferal species from the "Buchaugraben" and "Pötschbichl" sections.

[m in section]	Section "Buchaugraben"									Section "Pötschbichl"										
	2.5	3	4	6	9.5	11.5	13	17.5	20.5	2	2.5	7	12	14	17	23	29	35	36	38
<i>Hoeglundina elegans</i>			x	x	x	x	x		x		x	x	x	x	x		x			
<i>Karrerella hantkeniana</i>			x	x	x	x	x		x			x	x							
<i>Karrerella siphonella</i>								x												
<i>Laevidentalina boueana</i>			x			x						x								
<i>Lagena amphora</i>			x						x	x										
<i>Lagena asperoides</i>								x												
<i>Lagena laevis</i>			x																	
<i>Lagena sulcata</i>																				x
<i>Lenticulina arcuatostriata</i>				x			x						x							
<i>Lenticulina articulata</i>						x														
<i>Lenticulina cultrata</i> - group			x	x	x	x	x		x			x	x	x						
<i>Lenticulina ellisori</i>				x		x	x													
<i>Lenticulina gerlachi</i>			x		x	x	x													
<i>Lobatula lobatula</i>	x	x	x	x	x	x	x	x	x											
<i>Martinottiella communis</i>			x																	
<i>Melonis affinis</i>	x	x	x	x	x	x	x		x		x	x		x						
<i>Neoeponides schreibersii</i>			x	x	x	x	x													
<i>Nodosaria hispida</i>			x	x																
<i>Oridorsalis umbonatus</i>			x	x	x	x	x		x		x	x		x						x
<i>Pararotalia canui</i>		x								x										
<i>Pararotalia rimosa</i>				x		x														
<i>Percultazonaria pseudodecorata</i>	x		x			x				x					x					
<i>Planulina costata</i>						x														
<i>Planulina marialana</i>			x	x	x	x	x		x	x			x		x					
<i>Planulina venezuelana</i>							x	x												
<i>Plectofrondicularia vauhani</i>													x							
<i>Pleurostomella incrassata</i>								x												
<i>Pseudoglandulina aequalis</i>													x	x						
<i>Pseudoglandulina elongata</i>				x	x									x						
<i>Pyramidulina raphanistrum</i>			x	x	x	x	x						x		x					
<i>Quinqueloculina seminula</i>			x						x											
<i>Quinqueloculina triangularis</i>	x	x			x	x														
<i>Ramulina cf. kittlii</i>					x															
<i>Reophax grandis</i>			x																	
<i>Reussella spinulosa</i>									x											
<i>Reussella terquemi</i>			x					x		x			x						x	x
<i>Rosalina nana</i>							x													
<i>Saccamina difflugiformis</i>			x																	
<i>Saracenaria pygmaea</i>			x		x	x														
<i>Semivulvulina pectinata</i>			x		x	x	x						x							
<i>Sigmoilinita tenuis</i>			x	x		x	x													
<i>Siphonina prima</i>													x	x						
<i>Sphaeroidina bulloides</i>				x									x							
<i>Spiroloculina badenensis</i>							x													
<i>Spiroloculina excavata</i>			x																	
<i>Spirorutilus carinatus</i>			x		x	x	x		x				x	x	x					x
<i>Stilostomella adolphina</i>			x	x									x							
<i>Stilostomella nuttalli</i>				x	x	x	x	x	x	x			x	x						x
<i>Textularia gramen</i>			x								x									x
<i>Textularia lontensis</i>				x																
<i>Triloculina gibba</i>			x																	
<i>Triloculina tricarinata</i>			x																	
<i>Tritaxia szaboi</i>												x	x	x	x					
<i>Turrilina alsatica</i>				x	x		x								x					
<i>Uvigerina carapitana</i>													x							
<i>Uvigerina gallowayi</i>						x			x	x		x	x	x	x	x	x			
<i>Uvigerina gracilis</i>			x	x	x	x	x	x	x				x							x
<i>Vulvulina haeringensis</i>			x		x	x	x													

Appendix 1: continued.