A quantitative look on northwestern Tethyan foraminiferal assemblages, ~~late~~ Campanian Nierental Formation, Austria

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The *R. calcarata* Taxon Range Zone at Postalm section, Northern Calcareous Alps (Austria), is examined quantitatively for foraminiferal assemblages, especially the planktonic group. This study focuses on establishing a high resolution record spanning an 800 ka long stratigraphic interval from the active continental margin of the Penninic Ocean. Postalm section displays reddish limestone-marl alternations representing precession cycles. For this study, 26 samples from limestones as well as marls were examined for foraminiferal assemblages. Data suggest a typical, open marine late Campanian foraminiferal community. The >63 µm fraction is dominated by opportunist taxa, i.e. members of *Hedbergella* and *Heterohelix*. *Archaeoglobigerina* and *Macroglobigerinelloides* appear frequently and benthic foraminifera are very sparsely found. The share of globotruncanids, representing more complex morphotypes amongst planktonic foraminifera, is recorded with 5 to 10 ~~percent.~~ The state of preservation of foraminifera from Postalm section ~~can be considered as~~ moderate to poor. Differences between samples from marls and samples from limestone are evident, but do not reveal ~~facts that could be interpreted as~~ a diagenetic ~~impact~~ on microfossil communities. However, data from microfossils ~~suffering from only~~ moderate to bad preservation can still offer valuable insight in palaeoecology and biostratigraphy. Information gathered on the ~~constitution~~ of the planktonic foraminiferal assemblage confirms a low to mid-latitude setting for the Postalm section. As well resolved records of Late Cretaceous foraminifera assemblages are rare, the examination of the *R. calcarata* Taxon Range Zone provides some insights in variations and short term changes during the very short period of 800 ka.

A quantitative look on northwestern Tethyan foraminiferal assemblages, late Campanian Nierental Formation, Austria

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1. Introduction

The Late Cretaceous is a period recording major changes in the Earth’s climate system. Trends in climate evolution reflect the transition from a mid-Cretaceous hothouse to a more moderate greenhouse during the later part of the Late Cretaceous (e.g. Barrera and Savin, 1999, Huber et al., 2002, Friedrich et al., 2009, 2012, Hay and Floegel, 2012, Jung et al., 2013, Price et al., 2013, Linnert et al., 2014). Fundamental palaeoenvironmental changes triggered by climate and palaeoceanographic changes can also be recognised as drivers behind modifications in the composition of foraminiferal assemblages - and especially - planktonic foraminiferal communities, as discussed in this paper (Premoli Silva and Sliter, 1999, Abramovich et al., 2003, Falzoni et al., 2013).

The late Campanian time interval is generally considered a period with a highly diversified planktonic foraminifera fauna (Premoli Silva and Sliter, 1999, Ambramovich et al., 2003). Prolonged evolution and development ~~in~~ foraminiferal communities is known from the late Campanian to Maastrichtian, coinciding with the onset of the general end-Cretaceous cooling trend (Hart, 1999, Premoli Silva and Sliter, 1999, Georgescu, 2005). The radiation of ~~a~~rchaeoglobigerinidae and ~~r~~ugoglobigerinidae, the ~~further~~ diversification of biserial planktonic taxa, the appearance of complex morphotypes in globotruncanids – all are developments during the late Campanian to Maastrichtian (Hart, 1999, Premoli Silva and Sliter, 1999, Georgescu, 2005).

Few high resolution studies on general evolutionary trends, visible in the quantitative data from Campanian foraminifera communities exist. In general, most quantitative studies on Late Cretaceous foraminiferal assemblages focus on developments around stage boundaries and/or events (e.g., Huber et al., 1999, Arz and Molina, 2001, Odin and Lamaurelle, 2001, Petrizzo, 2002, Caron et al., 2006, Elamri and Zaghbib-Turki, 2014, Elamri et al., 2014, Reolid et al., 2015). The vast majority deals with the Cretaceous- Paleogene turnover (e.g.: Abramovich et al., 1998, Li and Keller, 1998, Arenillas et al., 2000, Abramovich and Keller, 2002, Karoui-Yaakoub et al., 2002, Premoli Silva et al., 2005, Gallala et al., 2009, Beiranvand and Ghasemi-Nejad, 2013, see also Pardo and Keller, 2008, for a compilation of selected quantitative databases on the Cretaceous-Palaeogene boundary).

An almost complete Santonian-lower Maastrichtian succession is recorded in pelagic to hemipelagic deposits at Postalm section, Austria, at the NW margin of the Tethys. The study of Wagreich et al. (2012) addresses biostratigraphy as well as the astronomical calibration of the *R. calcarata* Zone in the late Campanian at Postalm. With its rather short duration of only 800 ka (806,3 ka in the study of Wagreich et al., 2012, Robaszynski and Mzoughi, 2010, give a mean duration of 790 ka), and the distinct morphology of the nominative taxon, the *Radotruncana calcarata* Taxon-range Zone is considered a well-established, easily recognisable and reliable time interval in Late Cretaceous chronostratigraphy of the Tethyan realm (e.g. Robaszynski et al., 1984, Chungkham and Jafar, 1998, Premoli Silva et al., 1998, Puckett and Mancini, 1998, Huber et al., 2008, Wendler et al., 2011).

In this work we present a quantitative study on ~~the~~ planktonic foraminiferal assemblage in the *R. calcarata* Zone at Postalm section. With 26 samples in the 803.6 ka long interval, this high-resolution study gives information on the composition of typical Tethyan pelagic assemblages. This work deals with subtle changes in northwestern-Tethyan planktonic foraminiferal communities on the brink of the Late Cretaceous cooling and major faunal turnover events (Premoli Silva and Sliter, 1999). Wolfgring et al. (2015) reported biostratigraphy and qualitative foraminiferal data based on presence-absence data from two sections on opposite margins of the Penninic Ocean, including data from the Postalm section.

2.1. Geological setting

Units forming the Northern Calcareous Alps (NCA) were deposited along the northern margin of the Austroalpine domain on the Adriatic microplate (Wagreich, 1993)– at the southern margin of the Penninic Ocean ("Alpine Tethys" of Stampfli and Borel, 2002; Handy et al., 2010), which was a north-western part of the Tethys oceanic system (see also Neuhuber et al., 2007).

Within the system of the NCA, the Upper Cretaceous to Paleogene Gosau Group is characterised by the terrestrial to shallow marine Lower Gosau Subgroup and the deep-water deposits of the Upper Gosau Subgroup. The Lower Gosau Subgroup of Turonian to Santonian age filled pull-apart basins alongside an oblique subduction – strike-slip zone (Wagreich and Decker, 2001). After a short phase of tectonically induced uplift of the NCA, rapid subsidence processes resulted in the sedimentation of the pelagic, hemipelagic and turbiditic Upper Gosau Subgroup, comprising strata of Santonian/Campanian to Eocene age (Wagreich, 1993, Krenmayr, 1999, Wagreich et al., 2011, Hofer et al., 2011).

The Postalm section (coordinates WGS 84 013° 23' 11" E; 47° 36' 44" N) belongs to the Nierental Formation of the Upper Gosau Subgroup (Fig. 1) (Krenmayr, 1996, Wagreich and Krenmayr, 2005, Wagreich et al., 2012). The Nierental Formation was originally deposited at palaeolatitudes of approximately 35 - 30°N, alongside the southern margin of the Penninic Ocean (Fig. 2). The Santonian to Maastrichtian succession at Postalm is characterised by distinct marly limestone – marl cycles and records an upper to middle bathyal depositional environment (Wagreich et al., 2012) (Fig.3). Marly limestones can be classified as foraminiferal packstone. The Postalm section is interpreted as a pelagic to hemipelagic depositional environment well above the CCD. The section was part of a northward deepening slope within the NCA with bathyal water depths (Wagreich and Krenmayr, 2005, Wolfgring et al., 2015).

The deposits recorded at the Postalm section are interpreted as Cretaceous Oceanic Red Bed (CORB), indicating overall well oxygenated bottom waters (Hu et al., 2005, Wagreich and Krenmayr, 2005). The sediment accumulation rate is estimated to be 20 mm/ka (Wagreich et al., 2012).

For more detailed information on the geological setting at Postalm section, the reader is referred to Wagreich et al. (2012).

##Fig1

##Fig2

##Fig 3

3. Material and methods

3.1 Sampling and samples preparation

The *Radotruncana calcarata* Taxon Range Zone (TRZ) was sampled bed-by-bed, following biostratigraphic investigation of Wagreich et al. (2012) and Neuhuber et al. (unpublished data). No standard sampling distance was applied. Fig. 4 gives an overview on the stratigraphic framework and the location of sample spots. 26 samples from marls and marly limestones were processed to obtain quantitative data. Marl and marly-limestone samples were ~~dissolved~~ with hydrogen peroxide and ~~the~~ tenside Rewoquad©. Firm foraminifera packstone required intense treatment; in addition to the application of tensides, cooking these samples in hydrogen peroxide was mandatory.

Samples and microslides are stored in the Earth Science collections at the Department of Geodynamics and Sedimentology, University of Vienna.

Quantitative data were assessed using the >63 µm size fractions. “Larger" foraminifera (>125 µm) were assigned genus and species, while the 63 - 125 µm fraction is mostly discussed on genus level, as, in some cases, the state of preservation did not permit the identification of taxonomically relevant features. According to micropalaeontological standard procedures, some 300 specimens per sample were counted. Data were obtained from marls as well as marly limestones.

The tool PanPlot 2 (Sieger and Grobe, 2013) was used to visualise foraminifera abundances in Postalm section.

##fig.4

3.2. Palaeodepth estimates

Depositional palaeo waterdepth was calculated applying the methods published in Van der Zwaan et al. (1990) and Hohenegger (2005).

The palaeodepth in meters according to Van der Zwaan et al. (1990) is estimated as:

$$D(m) = e^{3.58718 + (0.03534xPc)} \qquad (1)$$

where *D(m)* is the estimated palaeodepth in metres, *e* is Euler's number and *Pc* the corrected ratio of planktonic/benthic foraminifera. The calculation of *Pc* excludes taxa that are not directly dependent on the flux of organic matter to the seafloor from the analysis (Van der Zwaan et al., 1990, Kopecká, 2012).

In addition, presence-absence data of benthic foraminifera recorded at Postalm section (Wolfgring et al., 2015) was used to calculate palaeo waterdepth applying the method of Hohenegger (2005). The basic formula for estimating the depth gradient is given as:

$$g = \sum_{i=1}^{m} l_i d^{-1}_{i} / \sum_{i=1}^{m} d^{-1}_{i} \qquad (2)$$

where i_i is the mean depth, d_i the distribution range along the taxon's depth range and *g* the estimated palaeodepth.

3.3. Taxonomic remarks/methods and the preservation of microfossils

With few exceptions, the state of preservation in the investigated samples can be considered moderate to poor. Most spiral and trochospiral planktic and benthic forms appear with fully intact tests. Elongated forms frequently appear fragmented. However, the state of preservation did not allow the definite taxonomic assignment of some individuals to species level. Thus, morphogroups for certain taxa were established.

Some double keeled, biconvex globotruncanid taxa (*Globotruncana arca, G. lapparenti, G. orientalis*) have subsequently been merged to *Globotruncana arca-lapparenti-orientalis,* as morphological transitions were observed. Some biserial planktonic specimens displayed a very bad state of preservation, rendering the identification of some individuals on species level impossible. These specimens were aggregated into the group “*Heterohelix”* spp.~~.~~ Biserial planktonic taxa with reniform chambers were pooled under “*Laeviheterohelix”* spp.~~.~~

Planktonic foraminiferal taxonomy predominantly follows Nederbragt (1991), Robaszynski and Caron (1995) and Premoli Silva and Verga (2004). Some significant taxa of the section are pictured in Wolfgring et al. (2015).

To define the trophic characteristics of the investigated area, we determined the distribution of r- and K-strategists. r-strategists are generally considered to be opportunists and adapted to eutrophic or unstable conditions; K-strategists represent more complex morphotypes that favour stable, rather oligotrophic environments (Premoli Silva and Sliter, 1999, Petrizzo, 2002, Gebhardt et al., 2010).

4. Results

4.1. Quantitative data

The quantitative investigation of the *R. calcarata* TRZ displays the composition of a typical late Campanian low to mid-latitude Tethyan foraminiferal community (Fig. 5). Table 1 displays relative abundances of foraminiferal species. The foraminiferal assemblage at Postalm is dominated by members of *"Heterohelix"* and *Hedbergella.* These two groups account for up to 80 percent of the total assemblage. Small heterohelicid taxa are dominated by ~~*Heterohelix*~~ *globulosa.* We can confirm the presence of *Pseudotextularia nuttalli, H. rajagopalan, H. striata, H. navarroensis* and *Guembelitria* sp. However, the groups "*Heterohelix"* spp. and "*Laeviheterohelix"* spp. ~~have~~ a relatively high ~~share~~ of the assemblage. Multiserial or flaring heterohelicids were not detected.

The genus ~~*Hedbergella*~~ is represented by the species *H. holmdelensis* and *H. monmouthensis* in varying numbers*.* The share of this group ~~is~~ slightly increasi~~ng~~ towards the top of the *R. calcarata* TRZ.

Globotruncanids are less abundant and represent between 1 and 12 percent. This group is represented by the genera *Globotruncana, Globotruncanella, Globotruncanita, Contusotruncana* and *Radotruncana.* The group *Globotruncana arca-lapparenti-orientalis* comprises several double keeled, biconvex taxa, and was, as expected, most frequently detected within the globotruncanid lineage. Other globotruncanid taxa, such as *G. linneiana*, *G. ventricosa. G. mariae, G. falsostuarti,* as well as *C. patelliformis* and *C. fornicata* are present throughout the section. The zonal marker~~,~~ *Radotruncana calcarata*~~,~~ is a comparatively rare element at Postalm that accounts only ~~to~~ a maximum of 1 percent of the assemblage.

The genus *Macroglobigerinelloides* is present in numbers up to 15 percent, including *M. bolli*, *M. ultramicrus* and *M. multispinus*. *Archaeoglobigerina* is mainly represented by two taxa, *A. cretacea* and *A. blowi*. Rugoglobigerinids (presumably *R. rugosa*?) are less abundant.

The planktic/benthic foraminifera ratio is very high throughout the section. Benthic foraminifera never display a higher share than 6 percent. Quantitative data show a peak in benthic foraminifera abundance in the lower part of the section (samples 7/38 and 7/39). High abundance in 7/39 is inferred by high numbers of tubular agglutinating taxa (presumably *Nothia* spp.).

##Table 1

##Fig 5

4.2. Life strategies of planktonic foraminifera

Life strategy reconstructions (classifications) of Cretaceous planktonic foraminifers follow Premoli Silva and Sliter (1999). K-strategists are mostly keeled, predominantly larger taxa that are interpreted as open marine, deep dwelling species. This group comprises complex morphotypes that prefer oligotrophic environments. Both, heterohelicids as well as hedbergellids are considered opportunistic taxa, thus regarded as r-strategists. Table 2 provides information on the life strategy of planktonic foraminiferal taxa rec~~re~~ded at Postalm section.

Upon examination of the >63 μm fraction, the foraminiferal assemblage displays opportunistic r-strategists as the dominant element, as small biserial and trochospiral taxa account for an overwhelming majority of individuals. K-strategists, which are exclusively represented by globotruncanids at Postalm, are mostly recorded with less than ten percent. Taxa showing a life strategy that cannot be clearly assigned, "r/K-intermediate" selected taxa such as *Macroglobigerinelloides*, show a similar frequency pattern as K-selected species. Fig. 6 displays the distribution of taxa ~~in~~ respect to their life strategy and the inferred environmental characteristics.

##Table 2

Fig. 6

5. Discussion

Examining foraminiferal assemblages from a bathyal environment of a ~~fossil~~ active continental margin preserved in a mountain belt ~~is faced with~~ some drawbacks. This study has to deal with ~~considerably~~ poor preservation of microfossils due to strong diagenetic overprint and minor folding and faulting of the sections. Still, records restricted ~~in terms of~~ taxonomical resolution (especially with smaller foraminifera, i.e. ~63-125 μm) can give some indication o~~n~~ palaeoecology and biostratigraphy;

conspicuous biostratigraphic~~al~~ marker species are still clearly identifiable. If the loss of taxonomic~~al~~ information only permits the identification at genus level, especially ~~in~~ small (<125 µm) morphotypes, compari~~ng~~ the relative abundance of foraminiferal taxa is still possible. Likewise, the distribution of r- and K-strategists is ~~an information~~ that can typically be determined at genus level (Hart, 1999, Premoli Silva and Sliter, 1999, Petrizzo, 2002, Gebhardt et al., 2010).

5.1 Biostratigraphy – implications from quantitative data

The *Radotruncana calcarata* Zone was first introduced by Herm (1962) and defines the interval between the first occurrence (FO) and the last occurrence (LO) of the nominate taxon. For a long time the top of the *R. calcarata* interval was defin~~ing~~ the Campanian – Maastrichtian boundary in plankton biostratigraphic zonations for the Late Cretaceous (e.g., Salaj and Samuel, 1966, Caron, 1985, Sliter, 1989). Today, chronostratigraphic correlations ~~locate~~ this interval in the mid to late Campanian (Robaszynski and Caron, 1995 - as *Globotruncana calcarata* TRZ, Premoli Silva and Sliter 1999, Berggren and Pearson, 2005, Huber et al., 2008, Robaszynsky and Mzoughi, 2010; Ogg and Hinnov, 2012).

Other studies concerned with the *Radotruncana calcarata* TRZ also recorded *G. angulata* (as *G.* cf. *angulata* in Hart, 1987), *Pseudoguembelitria costulata* (Li and Keller, 1998), *Rugoglobigerina hexacamerata*, *Globigerinelloides yaucoensis* (Arz and Molina, 2001), *Globotruncana aegyptiaca* (Arz and Molina, 2001, Chacón et al., 2004), *Globigerinelloides messinae* and *Pseudoguembelina costualta* (Premoli Silva et al., 2005) and *Globotruncana rosetta* (Robaszynski and Mzoughi, 2010). These taxa were not identified in the *R. calcarata* Zone at Postalm section.

In our section from the Northern Calcareous Alps, we ~~seem to witness~~ the extinction of *Globotruncanita elevata* within the *R. calcarata* TRZ. Generally, the LO of this taxon is considered to ~~be~~ shortly before or within the *R. calcarata* interval (e.g., Robaszynski and Caron, 1995, Chacón et al., 2004, Cetean et al., 2011, Petrizzo et al., 2011)

It is difficult to compare the results of different quantitative studies on Late Cretaceous planktonic foraminiferal assemblages ~~from~~ other locations, as different environments are studied and different methods are applied (starting with the examination of different size fractions and different ways of sample preparation). For instance, Li and Keller (1998) document an analysis of the foraminiferal assemblage in the >63 µm fraction from the South Atlantic DSDP site 525A (Walvis Ridge), together with an examination of the >105 µm fraction of Site 21 (Rio Grande Rise).

The works of Petrizzo (2001) on planktonic foraminifera from Kerguelen Plateau, ODP Leg 183 and Petrizzo (2002), from Exmouth Plateau (ODP Sites 762 and 763), examine the >40 µm size fractions. Both the studies of Li and Keller (1998) and Petrizzo (2001, 2002) discuss fully pelagic sections.

Arz and Molina (2001) describe the foraminiferal fauna from the Tercis GSSP - this study examines the >106 µm size fraction from a shelf environment. Elamri and Zaghbib-Turki (2014) deal with the >100 µm fraction from a pelagic section recording the Santonian- Campanian boundary (Kalaat Senan area in Tunisia).

Nevertheless, it is possible to follow proportional distribution patterns of planktonic foraminifera during and close to the *R. calcarata* TRZ. Foraminiferal assemblages in Cretaceous ~~p~~eriod are characterised ~~in~~ respect to the distinct sequence or succession of dominant planktonic foraminiferal taxa and lineages.

During the Early Cretaceous, hedbergellids and towards the end of the Cretaceous ~~p~~eriod, heterohelicids represented the dominant element in planktonic foraminiferal communities (Hart, 1999, Premoli Silva and Sliter, 1999). At Postalm, hedbergellids and heterohelicids, in varying numbers, still represent the vast majority of the foraminiferal assemblage. This ~~concurs~~ with the assumption that during the ’mid‘ to late Campanian, these groups ~~were most abundant~~ (Premoli Silva and Sliter, 1999).

We find a similar distribution of genera in other quantitative and semi-quantitative studies on Late Cretaceous communities. Arz and Molina (2001) correlate the *Rugoglobigerina hexacamerata* Zone at Tercis to the *R. calcarata* TRZ. Reflecting the distribution pattern visible in the relative abundance of foraminiferal genera, the similarity to Postalm section is conspicuous, although palaeoenvironmental conditions are quite different, contrasting a pelagic bathyal setting to the Tercis shelf setting. There, heterohelicids and hedbergellids, together with globigerinelloids are dominant elements whereas globotruncanids are represented by 10-20 %.

Li and Keller (1998) also report ~~a~~ predominan~~t~~ ~~presence~~ of ~~the genus *Hedbergella*~~ (~~*H.*~~ *monmouthensis* and *H. holmdelensis*) around the *R. calcarata* interval at DSDP Site 21 (South Atlantic). Heterohelicid taxa are also represented in high numbers (*H. globulosa, H. planata, H. pulchra* and *P. costulata*) and globotruncanids are represented there by 20 %. As hedbergellids and heterohelicids are predomina~~ntly~~ ~~present in~~ smaller size fractions (<125 µm), the comparatively high ~~share~~ of globotruncanids in the studies of Li and Keller (1998) and Arz and Molina (2001) might result from the use of the >105 µm fraction.

The quantitative studies of Petrizzo (2001, 2002), both localities from the southern high latitudes, show few similarities in the relative abundance of taxa. The upper Santonian to lower Campanian assemblage of Site 183 displays a very strong dominance of heterohelicids. The species *H. globulosa* alone sometimes accounts for 40 percent of the assemblage (Petrizzo, 2001), a feature that is not so prominently expressed in foraminifera assemblages of Postalm section.

Postalm and Tercis (Arz and Molina, 2001) present both~~,~~ heterohelicids and hedbergellids as dominant faunal elements. The semi-quantitative study of Premoli Silva et al. (2005) also indicates similar abundance patterns as Postalm section. While ~~the taxa~~ *Hedbergella holmdelensis* and *H. monmouthensis* are distributed equally at Postalm section, the study from ODP Hole 160-967E only records *Hedbergella holmdelensis* as a common element during the *R. calcarata* interval.

A further comparison of the distributi~~ve~~ pattern of foraminiferal lineages ~~visible~~ in quantitative studies from the southern high latitudes shows that hedbergellids are not as abundant, and globotruncanids are less diverse.

Postalm displays a sparse record of the genus *Rugoglobigerina.* On examination of the isotopic signatures of this taxon, a habitat in the upper, warmer layers of the ocean appears likely (Abramovich et al., 2003, Falzoni et al., 2014, Petrizzo et al., 2015).

5.2 Benthic foraminifera

Benthic foraminifera appear as rare faunal elements in quantitative data but play a significant role using absence-presence data (see Wolfgring et al., 2015).

The Postalm section yields a highly diverse “Deep Water Agglutinating Foraminifera”-assemblage (Kuhnt and Kaminski, 1990), as well as abundant calcareous benthic foraminifera. Genera like *Dorothia* or *Marssonella* occur together with abundant calcareous benthic foraminifera, especially nodosarids and lenticulinids. We interpret these assemblages as typical for a “Slope-Marl” fauna or an upper to middle bathyal assemblage (following Kuhnt et al., 1989, Koutsoukos and Hart, 1990, Widmark and Speijer, 1997, Kaminski and Gradstein, 2005).

Two minor peaks in benthic foraminifera abundance were recorded. These peaks are based on the high frequency of the taxon *Nothia* sp. However, as a result of this taxon’s epifaunal mode of life (Kuhnt et al., 1989, Kuhnt and Kaminski, 1990), mostly fragmented individuals were recovered and counted. Thus, we cannot eliminate the possibility that an accumulation of fragmented individuals of *Nothia* sp*.* ~~is rather~~ caused by episodic current activity rather than by a bloom in this taxon. However, if this taxon indeed ha~~s~~ episodic blooms at the bottom of the bathyal slope basin reconstructed for the Postalm section, an increased flux of nutrients downslope ~~that~~ would have positive influence on epifaunal detritivore species, such as *Nothia* (Geroch and Kaminski, 1992, Kaminski and Gradstein, 2005). These favourable palaeoecological conditions could have been triggered by several factors, ~~i.e.~~: turbiditic events, changes in bottom water currents, etc.

5.3 Depositional water depths

The tectonic evolution ~~in~~ the Penninic oceanic realm ~~and particularly the situation~~ recorded ~~in~~ Gosau Group sediments suggest certain constraints for the reconstruction of palaeodepths in parts of the Nierental Formation (Wagreich and Krenmayr, 2005, Wagreich et al., 2009).

The base of Postalm section as well as some other Gosau sections record the transition from a neritic setting to a pelagic environment (Wagreich and Krenmayr, 2005, Butt, 1981). Changes in faunal composition reflect changes in the palaeoenvironment. To sketch a possible palaeodepth model several approaches were considered.

The application of a planktic/benthic foraminifera ratio (P/B– ratio) is a popular and reliable method to estimate palaeo waterdepths in modern, oligotrophic environments (Van der Zwaan et al., 1990, 1999, Gebhardt et al., 2009). With respect to the benthic foraminiferal fauna at Postalm section, we assume slightly dysoxic habitat conditions (see Wolfgring et al., 2015). On that score, a mesotrophic regime should be taken into consideration (according to the TROX model by Jorissen et al., 1995). Therefore, calculating palaeo waterdepths using the P/B-ratio without considering local environmental properties is likely to lead to inaccurate conclusions in this section (as, according to Van der Zwaan et al., 1999, P/B ratios are sensitive to oxygen deficiency).

Results from the quantitative assessment show a maximum of 6 percent assigning to benthic foraminiferal taxa. Thus, appl~~ying~~ the formula of Van Zwaan et al. (1990) would result in palaeo waterdepths around 1200 m (as this method requires the use of the “corrected” benthos ratio, mono-specific mass occurrences of taxa were excluded from the calculations). This method has certain constraints – Van der Zwaan et al. (1990) state that it is useful to estimate paleodepths between 30 and 1250 m. At Postalm section we record up to 100-% planktonic foraminifera in standard quantitative data and therefore stretch this method to the limits.

The characteristics of benthic foraminiferal communities resemble those of “Slope-Marl” assemblages (Kuhnt et al., 1989, Kaminski and Gradstein, 2005), or “Upper to Middle

Bathyal” communities (Widmark and Speijer, 1997). Widmark and Speijer (1997) document this particular assemblage type from various localities recording palaeo waterdepths from upper slope to abyssal.

Using the palaeoslope model of Nyong and Olson (1977) with depth ranges for Campanian-Maastrichtian benthic foraminifera along the Atlantic coast, as well as the bathymetric ranges of benthic foraminifera of Sliter and Baker (1972), Speijer and Van der Zwaan (1996), Kaminski and Gradstein (2005), Valchev (2006), Holbourn (2013) in combination with the calculation method by Hohenegger (2005), a mean (theoretical) depositional water depth of 695 m can be calculated. An average minimum water depth of 349 m at sample POST 7/35 and an average maximum water depth of 914 m at sample POST 6/07 were recorded. Although this method has severe limitations in its application to fossil and extinct taxa, and depth ranges for the Penninic Ocean active margin assemblages may differ considerably from estimates from the North Atlantic passive margin slope model, the estimates of water depth gradients is within the principally inferred depth range.

Fig. 7 compares the two methods used for the calculation of palaeo-waterdepths at Postalm. The depth ranges of benthic foraminiferal taxa and the calculated palaeo waterdepths for each sample can be found in Appendix 1.

In addition to the information provided by the benthic foraminiferal record, valuable data are also provided on the assessment of the composition of the planktic foraminiferal assemblage: According to data from planktonic foraminifera we consider the Penninic Ocean during the Campanian-Maastrichtian a non-restricted environment in terms of faunal exchange. The assemblage recorded at Postalm ~~does~~ neither seem to lack essential elements of the planktonic foraminiferal community, nor can we record any hints towards an endemic foraminiferal fauna in the Penninic Ocean.

Apart from the preference for warmer water layers (as suggested by Abramovich et al., 2003, Falzoni et al., 2014, Petrizzo et al., 2015), Olsson (1977), Hart (1980) and Georgescu (2005) speculate on *Rugoglobigerina* as a taxon preferring shallow water as rugoglobigerinids are frequently a common element or even dominant in shallow water deposits. Rugoglobigerinids are a rare faunal element at Postalm section. Thus, this fact also supports the reconstruction of a hemipelagic to pelagic setting in the *R. calcarata* Zone.

Summarising the information on foraminiferal assemblages and on the tectonic evolution of the active margin of the Penninic ocean (see Butt, 1981, Wagreich, 1993), we can reconstruct the depositional environment during the *R. calcarata* Zone as an upper to middle slope setting with palaeo waterdepths of at least 500 – 800 m. We interpret the minor differences in calculations of water depths within a depth range of 300 m using the approach by Hohenegger (2005) as artificial, being a result of the low (and thus sometimes erratic) numbers of benthic foraminifera recorded and the inaccuracy of depth habitat estimates for Cretaceous foraminifera. Thus, both applied quantitative methods of palaeodepth estimates are not able to record and resolve 3rd order sea-level changes which may be in the range of up to 75 m within the late Campanian (Haq, 2014).

5.4 Palaeoecology

Cretaceous ocean systems are characterised by well stratified water masses, offering niches for a variety of life strategies (Leckie, 1989, Huber and Watkins, 1992, Price et al., 1998, Norris et al., 2001, Leckie et al., 2002). Reconstructing the palaeoecology of planktonic foraminifera from pelagic environments ~~always~~ relies on the use of recent analogues in morphotypes (as found in Hemleben et al., 1989). Indications of the environmental properties, prevailing in the preferred habitat of planktonic foraminifera, can be found by the examination of stable isotope ratios (e.g., D'Hondt and Arthur, 1995, Price et al., 1998, Abramovich et al., 2003). The variety of life strategies is neither fully understood yet, nor easy to summarise. Premoli Silva and Sliter (1999) apply the ecological concept of K- and r-strategists for Cretaceous planktonic foraminifera.

Heterohelicids are opportunistic taxa, indicating unstable conditions and generally preferring eutrophic environments, and are presumed to be indicators for stress environments (Leckie, 1987, Nederbragt, 1991, Premoli Silva and Sliter, 1999, Boudagher-Fadel, 2013). There is evidence that this group thrives in the oxygen minimum zone – a model that explains the interpretation of heterohelicid dominance within an assemblage, sees this group as indicat~~or~~ ~~for~~ a locally well-developed oxygen minimum zone (Leckie, 1998, Pardo and Keller, 2008, Reolid et al., 2015).

~~E~~xamining the habitat patterns of planktonic species during the latest Cretaceous (late Campanian to late Maastrichtian), the study of Abramovich et al. (2003) ~~sees~~ some ~~members of Heterohelix~~ as inhabitants of the subsurface layers, or water masses close to the thermocline (*Heterohelix globulosa, H. planata, H. punctulata*). Bornemann and Norris (2007) report a habitat close to the surface for the genera *Heterohelix* and *Hedbergella*.

K-strategists represent specialist taxa that thrive in oligotrophic environments. This group is often represented by keeled forms~~,~~ assign~~ing~~ to the *Globotruncana* ~~or~~ *Glonotruncanita* lineage. The ecological characteristics of K-strategists and the functional morphology of keels also permit the interpretation of globotruncanids as deep-dwelling forms, favouring colder waters and requiring an oligotrophic environment (Hart, 1980, Premoli Silva and Sliter, 1999).

Hedbergellids are generally considered open marine species (Leckie, 1987, Koutsoukos and Hart, 1990, Norris and Wilson, 1998, Premoli Silva and Sliter, 1999, Petrizzo, 2002, Gebhardt, 2004), and exhibit similar ecological preferences as heterohelicids. Studies on planktonic foraminifera that integrate information from stable isotope data, interpret hedbergellids as surface dwellers, occupying the upper mixed layer (e.g., Price et al., 1998, Fassel and Bralower, 1999, Norris et al., 2002, Ando, 2009, 2010). Norris and Wilson (1989) and Petrizzo (2002) suggested a wider depth distribution for mid-Cretaceous hedbergellids~~.~~ ~~Also~~ Huber et al. (2011) indicate hedbergellids to be highly flexible and to show a dynamic behaviour.

As most biserial planktonic foraminifera, the trochospiral hedbergellids ~~are known to be~~ opportunistic taxa that prefer eutrophic environments and occupy the upper mixed layer (Premoli Silva and Sliter, 1999, Gebhardt et al., 2004). Both groups are considered r-strategists in the literature. Gebhardt et al. (2010) characterise hedbergellids from the Cenomanian to Turonian of the Austrian Alps~~,~~ as intermediate forms between r and K strategists. The genus *Schackoina* is often considered as an indicator for poorly oxygenated environments, but ~~does overall not display an adequately investigated~~ life strategy (Magniez-Jannin, 1998, Premoli Silva and Sliter, 1999, Petrizzo, 2002). Therefore, we exclude this taxon from palaeoecological analyses.

The distribution of r- and K-selected taxa at Postalm section does not only ~~give~~ information on the palaeoecological regime. The relationship between r- and K-selected taxa can be characteristic for the latitudinal distribution. Moreover, with the ongoing evolution of more complex morphotypes as a driving force, the relative abundance of the two groups follows a distinct pattern throughout the Cretaceous (Hart, 1980, Leckie, 1989, Premoli Silva and Sliter, 1999). According to Premoli Silva and Sliter (1999), Late Cretaceous planktonic foraminifera communities are, in contrast to foraminifera communities from the Early Cretaceous, highly diversified and dominated by K-selected taxa. With a palaeolatitude of approximately 35°N, we consider Postalm, and the north-western Tethys in general, to represent a low to mid-latitude setting.

Quantitative data helped to document at least 15 planktonic foraminiferal genera. Therefore, we consider the assemblage at Postalm as diverse and dominated by r-selected taxa. The number of K-selected specialists diminishes polewards and r-selected taxa prevail (Premoli Silva and Sliter, 1999) but no similarities to a species- or morphogroup- distribution pattern known from higher latitudes, boreal assemblages (i.e. chalk facies), were identified. Postalm section yields single and double- keeled K-selected taxa~~,~~ that are typical elements of Campanian tropical to mid-latitude foraminifera communities. At Postalm section, K-selected specialists, which are dominant in low latitude faunas, are present, but only few in number. Therefore, the foraminiferal assemblage at Postalm, ~~although typical~~ Tethyan, ~~can be interpreted to represent a significant trend towards~~ mid-latitudes (following Malmgren, 1991, Premoli Silva and Sliter, 1999, Nishi et al., 2003)~~. Compared to low latitude assemblages from, Tunisia or Italy, Postalm section displays~~ fewer K-strategists (i.e. globotruncanids) and more opportunistic taxa (hedbergellids, heterohelicids).

5.5. Implications for Palaeoceanography of the late Campanian Penninic Ocean

Some works describe the Penninic Ocean (or the Alpine Tethys) as a restricted environment during mid-Cretaceous ~~times~~ (e.g., Mort et al., 2007 and Gebhardt et al., 2010 from the Cenomanian/Turonian). The Late Cretaceous foraminiferal assemblage examined in this study shows all fundamental elements of a well-developed low to mid-latitude planktonic foraminiferal community. Although few taxa recorded in other studies ~~could~~ not ~~be~~ identified at Postalm, the planktonic foraminiferal assemblage with its high diversity (see also Wolfgring et al., 2015) does not give indications for a restricted oceanic environment. From the investigated section we ~~can~~ record members of the *Globotruncana* lineage as alleged deep dwellers, heterohelicids, ~~that are~~ thriv~~ing~~ ~~o~~n oxygen minimum zones, as well as Hedbergellae that ~~presumably~~ prefer surface water~~s~~. ~~Given~~ the ~~all~~ Cretaceous sea-level ~~high~~ at the Cenomanian-Turonian boundary (see Haq, 2014) we interpret the ~~changing~~ ~~restriction status~~ of the Penninic Ocean as a result of tectonic processes that opened seaways from the southern main Tethys Ocean system into the northwestern Tethys and its continuation into the Atlantic, probably due to plate tectonic rearrangements and subsidence events from Turonian to Campanian (e.g., Wagreich, 1993; Reicherter and Pletsch, 2000).

A direct comparison with other quantitative studies on Late Cretaceous planktonic foraminiferal assemblages is difficult. However, considering the low to mid-latitude setting of the Northern Calcareous Alps, the frequency and distribution of taxa and ecological groups approaches results from other studies on Late Cretaceous planktonic foraminiferal assemblages from bathyal or hemipelagic to pelagic sections (e.g., Chacón et al., 2004, Robaszynski and Mzoughi, 2010, Elamri and Zaghbib-Turki, 2014). Furthermore, the cyclostratigraphically dated synchronous appearance and disappearance of the zonal marker fossil *R. calcarata* in the Alpine sections and in Tunisia indicates good connections to the tropical Tethys Ocean (Robaszynski and Mzoughi, 2010, Wagreich et al., 2012).

Foraminiferal data from Postalm give little information ~~for~~ fluctuations in sea-level during the *R. calcarata* interval. There are some minor changes, easily overlooked in standard quantitative data, and/or hard to interpret at the fringes of the assemblages in the 1-3 percentage range. Changes in the relative abundance of keeled globotruncanids towards the top of the section and the continuous presence of *Schackoina* in the stratigraphically younger part of the *R. calcarata* interval could ~~rather be a hint towards~~ subtle changes in the palaeoceanography of the Penninic Ocean than a robust sea-level or water-depth signal.

A similar situation is recorded from other proxy data: Minor carbon isotope peaks (Wagreich et al., 2012; Wendler, 2013) or geochemical proxy data (Neuhuber et al., subm. 2015), could also imply small scale changes in sea level but have to be interpreted with caution (Neuhuber et al., subm. 2015).

~~It can be~~ conclude~~d~~ that~~,~~ although major changes and cycles (sequences) in the range of several Ma may influence foraminiferal communities, those short-term changes within the 800 ka long calcarata Zone ha~~ve~~ minimal impact on planktonic foraminiferal communities in a well connected, bathyal setting of water depths over 500 m.

5.6. Differences in limestones and marls and the preservation of microfossils – how does cyclic sedimentation affect the foraminiferal record?

The effects of diagenesis on the cyclic pelagic rock record is a ~~strongly~~ discussed subject (Westphal and Munnecke, 2003). Postalm shows limestone- marly limestone alternations that were interpreted to reflect precession cycles (Wagreich et al., 2012). For this study, both stronger indurated marly limestones as well as marls from within the same precession cycle were disintegrated with hydrogen peroxide and tensides, and subsequently examined quantitatively for foraminifera. In contrast to marly samples, firm foraminifera packstone required repeated cooking in hydrogen peroxide, as well as the application of tensides to dissolve. Marly samples were dissolved following the standard preparation procedures.

Fig. 8 displays ~~the~~ differences in the ~~quantitative~~ composition of ~~the~~ foraminiferal assemblage between samples from firm marly limestone and samples from softer marls. No trends pointing towards a significant diagenetic ~~impact~~ on the foraminiferal community are recorded in those parts of a sedimentary cycle.

A slight shift towards compact biserial microfossils could be ~~taken into account~~ in one sample (07/38). In general, heterohelicids are more frequently recorded in higher numbers in samples from firmer carbonates than in samples from marls – in the three limestone-marl couplets examined here, the numbers of biserial planktonic taxa exceed the average abundance of heterohelicids ~~assessed~~ in all other samples of this section, as well as the average number of heterohelicids calculated for these three couplets.

However, most abundance data recorded from limestones give results within the standard deviations calculated for each taxonomic group (i.e.: globotruncanids, globigerinelloids, heterohelicids, hedbergellids and benthic ~~F~~oraminifera) in marls. Furthermore, no difference in species diversity was observed.

Nevertheless, the fact that rhythmic limestone marl alternations are likely to represent orbital influence on climate should not be overlooked (e.g., Bernet et al., 1998, Sageman et al., 1998, Westphal et al., 2004). Thus, significant changes in the abundance and frequency of groups of microfossils do not necessarily need to be explained by ~~the diagenetic impact~~ but may reflect changing environmental conditions during orbital cycles as does the changing lithology. Precession cycles result from changes in insolation, which have a considerable ecological impact. In this study we compare few examples from the “margins” of orbital cycles and believe that subtle changes in foraminiferal assemblages could also be ~~inflicted~~ by changes in ~~the~~ ecological conditions. For instance, the fact that all samples from firm carbonates record higher ~~values in~~ heterohelicid abundance could ~~be interpreted as~~ changes in the extent of the oxygen minimum zone at the end (or the beginning) of a precession cycle due to changes in detrital input and plankton productivity (similar patterns were observed in planktonic foraminifera assemblages in sapropel-cycles from the Mediterranean: e.g., Sierro et al., 1997).

~~W~~e ~~furthermore~~ ~~assume that according to the~~ results from ~~the~~ comparison of ~~the~~ abundance data from marls and marly limestones~~,~~ ~~we suppose~~ that ~~in both lithologies~~ dissolution effects on microfossils were either the same or absent.

6. Conclusion

The evaluation of planktonic foraminiferal communities (>63 µm) from the late Campanian *R. calcarata* Taxon Range Zone, recorded in rhythmic limestone–marl alternations at Postalm section (Northern Calcareous Alps, Austria), gives detailed information on the behaviour of planktonic communities within a well~~-~~defined time frame.

~~Even~~ though microfossils exhibit a moderate to poor state of preservation, the main characteristics of foraminiferal communities could be tracked. ~~T~~he prominent zonal marker fossil, *R. calcarata* is considered a reliable marker in Late Cretaceous biostratigraphy, despite its rare ~~appearance.~~

Morphotypes and ecological groups in planktonic foraminifera were recorded, permitting speculations on the depositional environment and palaeoecology. Postalm section displays a hemipelagic to pelagic ~~foraminiferal assemblage~~, dominat~~ed~~ by r-selected opportunistic taxa, predominantly represented by “*Heterohelix*” and *Hedbergella.* K-selected specialist taxa represent approximately 10~~ percent~~ of the assemblage. The same applies to “r/K intermediate” taxa (such as macroglobigerinelloids). The planktonic foraminiferal community from Postalm displays a typical mid-latitude distribution of taxonomic groups.

Minor fluctuations in the distributional pattern of foraminiferal genera have been recorded. However, no distinct trends or ~~incisive~~ events ~~were recognised. N~~o significant difference between the general assemblage structure in marls and marly limestones could be recognised. Therefore, diagenesis had a minor influence, and lithological cycles are interpreted as ~~being~~ triggered mainly by insolation-induced climate cycles.

All major foraminiferal taxonomic groups and a broad spectrum of ecological strategies were recognised from the Late Cretaceous foraminiferal assemblages at Postalm. Therefore, we assume an unrestricted environment for the Campanian Penninic Ocean, ~~maintaining~~ open connections to the Tethy~~s~~.

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Appendix 1 – distribution and depth ranges of benthic foraminifera

Distribution of benthic foraminiferal taxa at Postalm section (also see Wolfgring et al., 2015):

	POST_07/33	POST_07/34	POST_07/35	POST_07/36	POST_07/37	POST_07/38	POST_07/39	POST_07/40	POST_07/41	POST_07/42	POST_07/43	POST_07/44	POST_08/01	POST_08/02	POST_08/03	POST_08/04	POST_08/05b	POST_08/05a	POST_08/06	POST_08/07	POST_08/08	POST_08/09	POST_08/10	POST_08/11	POST_08/12
Allomorphina cretacea																				**1**					
Ammodiscus cretaceus												**1**													
Ammosphaeroidina pseudopauciloculata		**1**				**1**	**1**						**1**			**1**									
Anomalinoides larseni																				**1**					
Bathysiphon sp.	**1**					**1**														**1**		**1**			
Bolivinoides clavatus	**1**			**1**						**1**															
Bulimina obtusa		**1**									**1**								**1**		**1**		**1**		
Caudammina excelsa									**1**		**1**				**1**				**1**					**1**	
tubular agglutinates *(cf Ammobaculites)*				**1**	**1**	**1**					**1**													**1**	
Clavulina amorpha		**1**							**1**				**1**			**1**		**1**			**1**				
Clavulina trilatera			**1**	**1**	**1**	**1**	**1**	**1**			**1**														
Conglophragmium irregularis					**1**																				
Conorboides sp.						**1**											**1**				**1**				
Cribrostomoides spp.	**1**	**1**		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**		**1**	**1**	**1**				**1**	**1**		
Dentalina annulata	**1**			**1**																		**1**			

Dentalina catenula			1												1			1		1				1	
Dentalina sp (*solvata*?)	1																								
Dentalina sp.		1		1	1	1	1			1	1			1					1		1				
Dentalina sp.1 (thick wall)							1									1									
Dentalina sp.2 (pustules)							1	1							1										
Dentalina sp.3 (aculeate term. chmb.)																1									
Dentalina sp.4 (aculeate term. chamber)			1																						
Dorothia conula				1			1	1	1		1			1							1	1	1	1	
Dorothia pupoides													1									1			
Dorothia sp.						1	1						1												
Eponides beisseli	1	1	1	1		1	1	1	1	1		1	1	1	1	1	1	1		1	1	1	1	1	
Eponides sp.1																								1	
Gaudryina laevigata													1									1		1	1
Gaudryina pyramidata	1	1	1		1			1			1	1	1	1	1	1	1			1	1	1			
Gaudryina rugosa							1		1											1	1				
Gaudryina sp.	1	1		1	1		1							1		1		1		1			1		
Gaudryina sp.2	1	1							1											1	1	1			
Globorotalites multiseptus			1	1	1	1		1	1	1	1													1	1
Guttulina																					1				

communis																									
Guttulina sp.		1				1	1				1				1						1				
Gyroidin~~ew~~s nitidus					1							1					1		1	1	1		1		
Gyroidinoides lenticulus																	1		1						
Hyperammina sp.												1				1				1		1			1
Lagena apiculata		1	1				1		1		1	1											1		
Lagena emaciata																						1	1	1	
Lagena sp.		1				1	1		1		1														
Lenticulina sp.			1	1	1		1			1					1									1	
Lenticulina sp.1											1				1										
Lenticulina subangulata																						1	1		1
Lenticulina velascoensis	1	1			1																				
Lenticulinites rotulata			1	1									1	1		1									
Marginullina sp	1	1											1			1				1	1				
Marssonella oxycona					1		1			1	1											1		1	
Marssonella sp.					1	1								1	1				1		1				
Marssonella trochus																									1
Nodogeneria pseudoscripta									1																
Nodosaria paupereule							1																		
Nodosaria sp.			1			1					1	1	1												
Nothia excelsa											1			1	1		1			1					

Osangularia cordieriana																				**1**	**1**	**1**	**1**		**1**
Osangularia sp.																									**1**
Paratrochamminoides deflexiformis													**1**							**1**			**1**		
Placentammina placenta			**1**							**1**				**1**					**1**						
Pleurostomella sp.	**1**		**1**			**1**							**1**			**1**								**1**	**1**
Pleurostomella wadow				**1**	**1**	**1**	**1**						**1**		**1**	**1**	**1**			**1**	**1**	**1**			
Praebulimina sp.	**1**			**1**								**1**													
Pullenia sp.										**1**										**1**					
Ramulina sp.						**1**																**1**			
Ramulina wrightyi					**1**																				
Reussella sp. 1			**1**	**1**		**1**	**1**	**1**	**1**	**1**		**1**	**1**	**1**		**1**	**1**	**1**	**1**						**1**
Reussella szajnochae		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**			**1**		**1**				**1**	**1**	**1**				
Spiroplectammina praelonga	**1**																								
Spiroplectinella dentata			**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**		**1**	**1**	**1**	**1**								**1**	**1**
Spiroplectinella sp.1								**1**	**1**	**1**	**1**												**1**	**1**	
Stensioina pommerana		**1**	**1**	**1**			**1**						**1**									**1**			
Stilostomella alexanderi											**1**														
Stilostomella sp.				**1**						**1**														**1**	
Textularia sp.	**1**			**1**																					

Thalmannammina sp.								**1**																	
Tritaxia sp.1 *(tripleura ?)*		**1**		**1**					**1**		**1**		**1**	**1**		**1**		**1**						**1**	**1**
Tritaxia sp.																									
Tritaxia eggeri									**1**								**1**	**1**	**1**		**1**	**1**	**1**	**1**	**1**
Trochammina boehmi																								**1**	
Trochammina sp.						**1**								**1**						**1**					
Trochamminoides proteus								**1**							**1**										
Verneulina muensteri												**1**													
Verneulina sp.			**1**							**1**						**1**									

Estimated depth ranges of benthic foraminiferal taxa in metres:

	min	*max*
Allomorphina cretacea	*500*	*3500*
Ammobaculites agglutinans	*150*	*3500*
Ammodiscus cretaceus	*100*	*3000*
Ammodiscus sp.	*100*	*4000*
Ammosphaeroidina pseudopauciloculata	*150*	*4000*
Anomalinoides larseni	*1500*	*4000*
Astacolus sp.	*10*	*2000*
Bathysiphon sp.	*500*	*2000*

Bolivinoides clavatus	500	3000
Bulimina obtusa	600	2000
Caudammina excelsa	500	3125
*tubular agglutinates (*cf *Ammobaculites)*	150	4000
Cibicidoides pseudoacutus	150	1500
Cibicidoides voltzianus	500	3000
Clavulina amorpha	200	2500
Clavulina trilatera	200	2000
Conglophragmium irregularis	200	4000
Conorboides sp.	1	4000
Cribrostomoides spp.	400	3000
Dentalina annulata	50	2500
Dentalina catenula	50	2500
Dentalina filiformis	50	2500
Dentalina marcki	50	2500
Dentalina oligostegia	50	2500
Dentalinasp (solvata?)	50	2500
Dentalina sp.	50	2500
Dentalina sp.1 *(thick wall)*	50	2500
Dentalina sp.2 *pustulae (?)*	50	2500
Dentalina sp.3 *(aculeate term. chmb.)*	50	2500
Dentalina sp.4 *(aculeate term. chamber)*	50	2500
Dorothia conula	200	4000

Dorothia pupoides	*200*	*4000*
Dorothia sp.	*200*	*4000*
Ellipsodimorphia hrubieszowiensis	*1000*	*2500*
Entosolenia/Fissurina orbignyana	*1000*	*2500*
Eponides beisseli	*150*	*2700*
Eponides sp.1	*150*	*2700*
Globorotalites multiseptus	*150*	*2700*
Frondicularia canaliculata	*100*	*2000*
Gaudryina laevigata	*200*	*2000*
Gaudryina pyramidata	*200*	*2000*
Gaudryina rugosa	*200*	*2000*
Gaudryina sp.	*200*	*2000*
Gaudryina sp.2	*200*	*2000*
Gavellinopsis involuta	*500*	*1500*
Glandulina pygmaea	*125*	*3700*
Guttulina communis	*200*	*1600*
Guttulina sp.	*200*	*1600*
Guttulina trigonula	*200*	*1600*
Gyroidinews nitidus	*200*	*2700*
Gyroidinoides bandyi	*200*	*2700*
Gyroidinoides girarianus	*200*	*2700*
Gyroidinoides lenticulus	*200*	*2700*
Gyroidinoides sp.	*200*	*2700*

Gyroidinoudes umbilicatus	*200*	*2700*
Hyperammina sp.	*4000*	
Laevidentalina sp.	*100*	*3500*
Lagena apiculata	*100*	*4000*
Lagena emaciata	*100*	*4000*
Lagena laevis	*100*	*4000*
Lagena sp.	*100*	*4000*
Lenticulina (Robulus) subalatus	*50*	*3500*
Lenticulina marcki	*50*	*3500*
Lenticulina sp.	*50*	*3500*
Lenticulina sp.1	*50*	*3500*
Lenticulina subangulata	*50*	*3500*
Lenticulina trachyomphalus	*50*	*3500*
Lenticulina velascoensis	*50*	*3500*
~~l~~enticulinites rotulata	*50*	*3500*
Marginulina sp.2	*50*	*4000*
Marginullina sp.	*50*	*4000*
Marssonella oxycona	*200*	*4000*
Marssonella~~sp~~.	*200*	*4000*
Marssonella trochus	*200*	*4000*
Neoflabellina sp.	*50*	*1500*
Nodogeneria pseudoscripta	*50*	*2000*
Nodosaria aspera	*50*	*4000*

Nodosaria limbata	*50*	*4000*
Nodosaria monile	*50*	*4000*
Nodosaria paupereule	*50*	*4000*
Nodosaria sp.	*50*	*4000*
Nothia excelsa	*300*	*4000*
Nothia-? sp. 1	*300*	*4000*
Osangularia cordieriana	*600*	*4000*
Osangularia sp.	*600*	*4000*
Paratrochamminoides deflexiformis	*200*	*4000*
Placentammina placenta	*200*	*2000*
Pleurostomella sp.	*500*	*2500*
Pleurostomella spinosa	*500*	*2500*
Pleurostomella wadow	*500*	*2500*
Praebulimina sp.	*500*	*1500*
Pullenia sp.	*200*	*4000*
Ramulina sp.	*200*	*1500*
Ramulina wrightyi	*200*	*1500*
Reophax globosus	*150*	*4000*
Reopphax sp.	*150*	*4000*
Reussella sp. 1	*200*	*3000*
Reussella szajnochae	*200*	*3000*
Rzehakia lata	*200*	*3000*
Saracenaria triangularis	*500*	*3000*

Spiroplectammina praelonga	*400*	*2500*
Spiroplectinella dentata	*400*	*2500*
Spiroplectinella sp.1	*400*	*4000*
Stensioina pommerana	*200*	*1500*
Stilostomella alexanderi	*500*	*2000*
Stilostomella sp.	*500*	*2000*
Subreophax sp.	*100*	*2500*
Textularia sp.	*1500*	*3500*
Thalmannammina sp.	*200*	*3000*
Tritaxiasp.1(tripleura ?)	*500*	*3000*
Tritaxia sp.	*500*	*3000*
Tritaxia eggeri	*500*	*2700*
Trochammina boehmi	*1600*	*4000*
Trochammina sp.	*1600*	*4000*
Trochammina sp.1	*1600*	*4000*
Trochamminoides proteus	*1600*	*4000*
Verneulina muensteri	*500*	*1500*
Verneulina sp.	*500*	*1500*

Figure 1(on next page)

Geological sketch map of the Austrian Alps

The Postalm section is situated some kilometres south of the city of Salzburg.

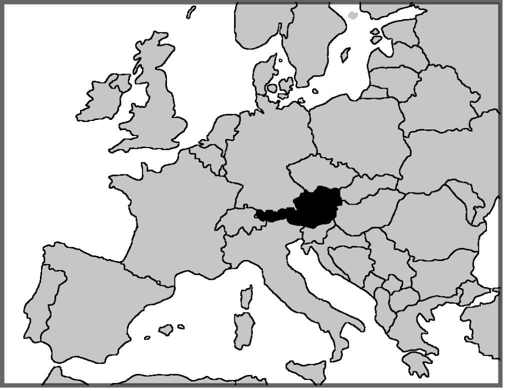

Figure 2(on next page)

Palaeogeographic reconstruction of the Penninic realm (after Schettino and Turco, 2011).

The Postalm section is located in the Northern Calcareous Alps on the southern active margin of the Penninic Ocean (1).

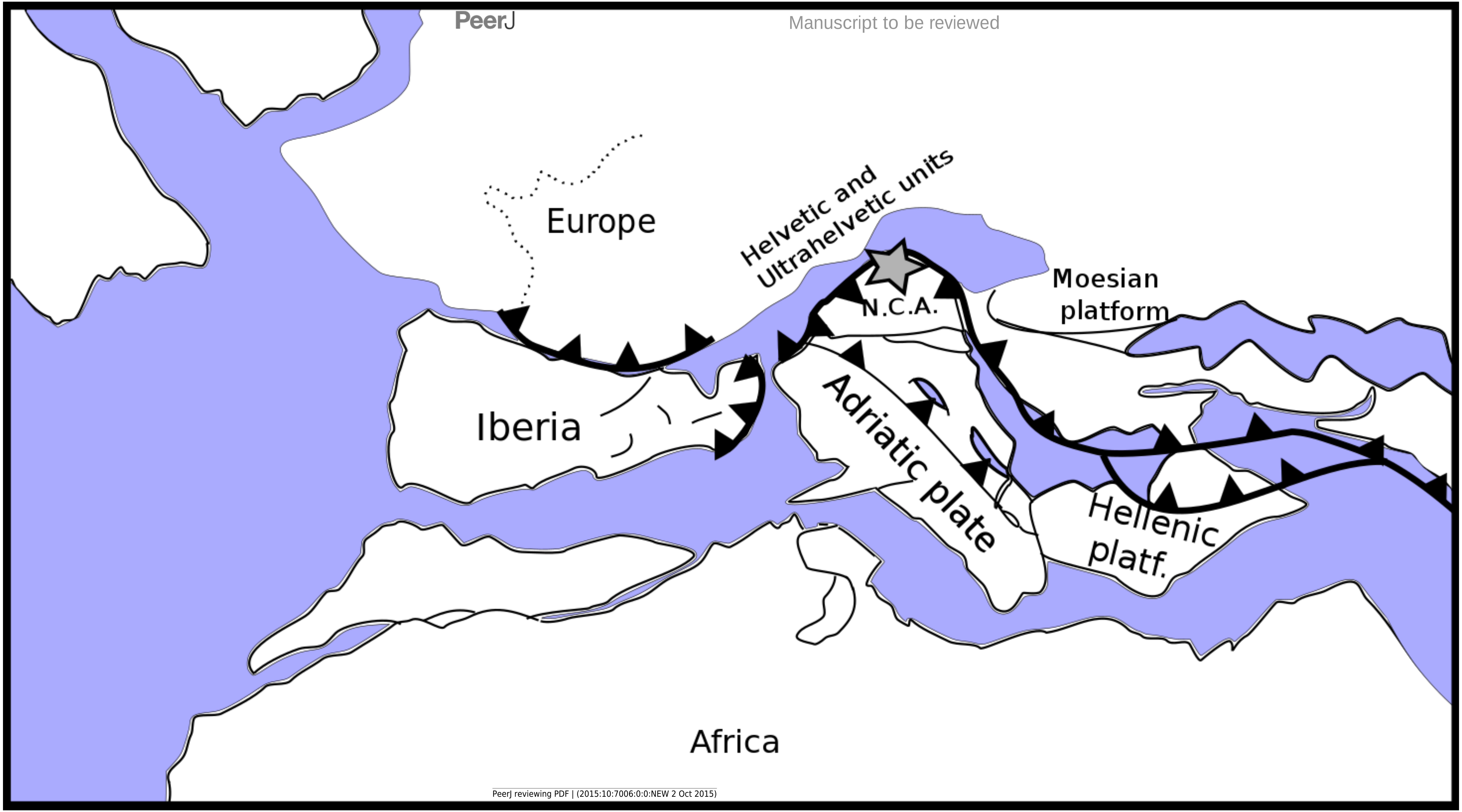
Europe
Helvetic and
Ultrahelvetic units
N.C.A.
Moesian
platform
Iberia
Adriatic plate
Hellenic
platf.
Africa

Figure 3(on next page)

Detail of cyclic marl-marly limestone alternations at Postalm depicting the older part of the R. calcarata interval.

The deposits at Postalm cab be defined as CORBS (Cretaceous Oceanic Redbeds).

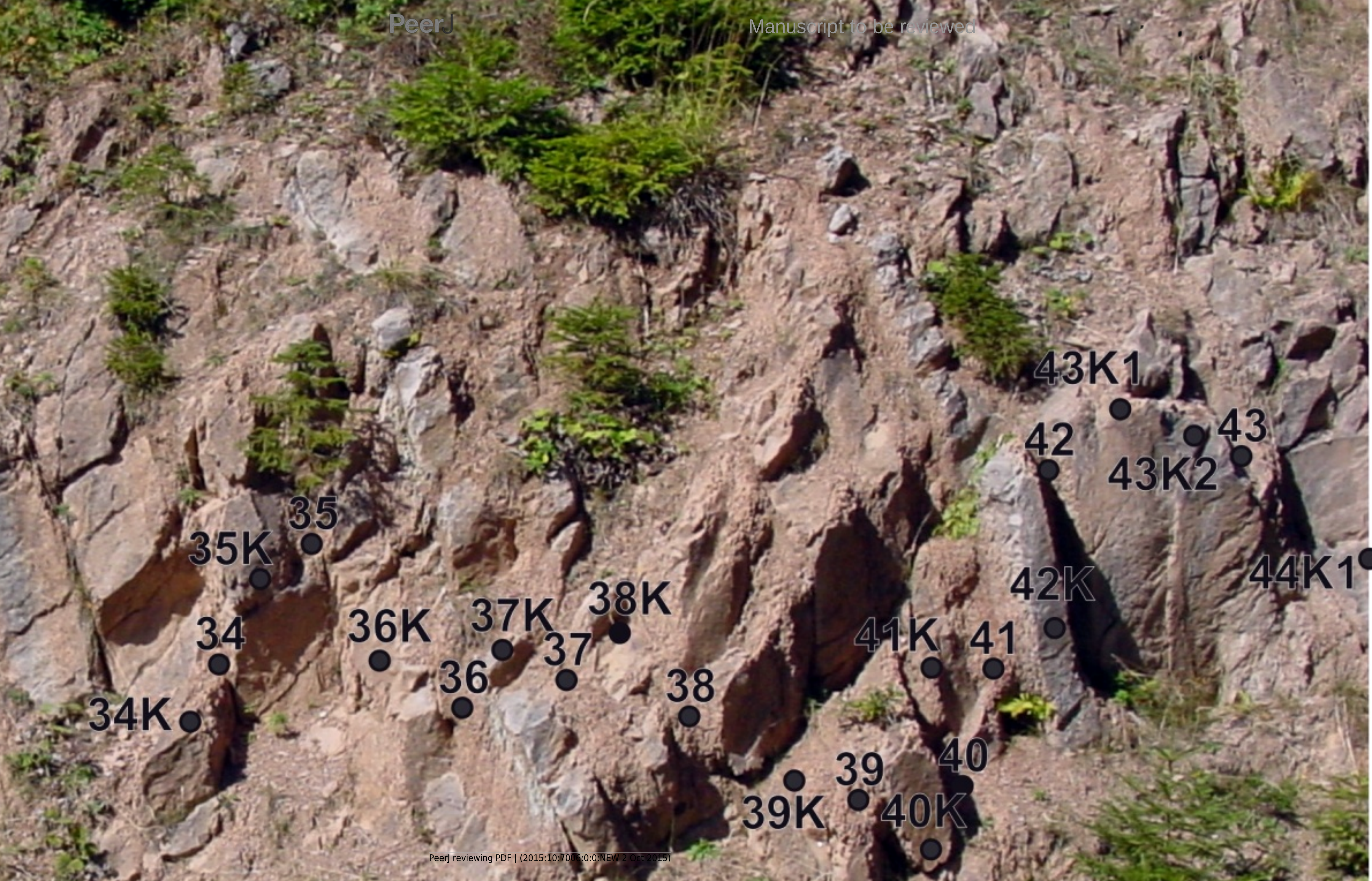
43K1
42
43
43K2
35
35K
44K1
42K
38K
37K
36K
34
37
41K
41
36
38
34K
40
39
39K
40K

Figure 4(on next page)

Overview on the geological setting at Postalm section and the R. calcarata interval in detail. Sample points are flagged with stars.

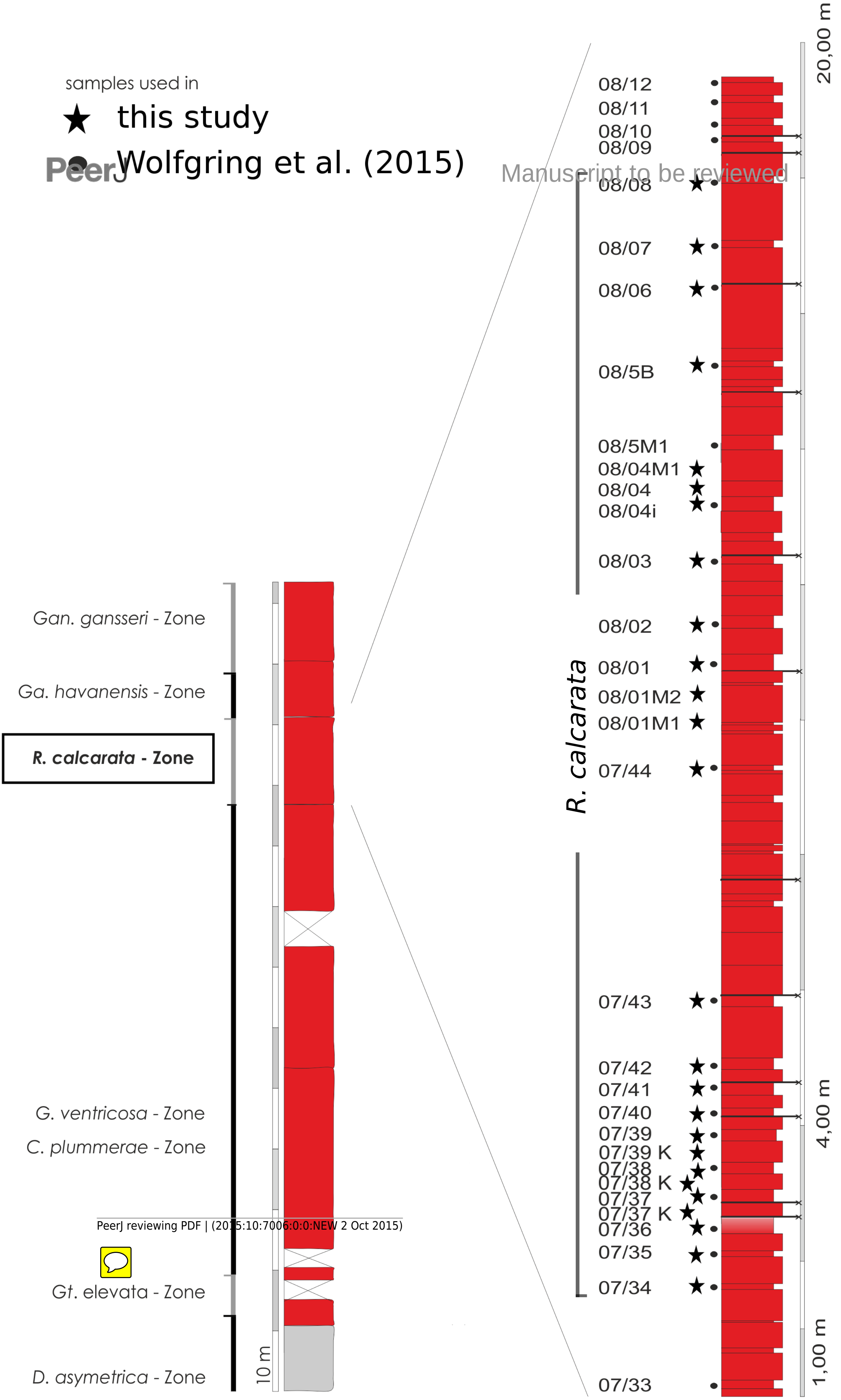
samples used in
★ this study
● Wolfgring et al. (2015)
Gan. gansseri - Zone
Ga. havanensis - Zone
R. calcarata - Zone
G. ventricosa - Zone
C. plummerae - Zone
Gt. elevata - Zone
D. asymetrica - Zone
10 m
R. calcarata
20,00 m
4,00 m
1,00 m
08/12
08/11
08/10
08/09
08/08
08/07
08/06
08/5B
08/5M1
08/04M1
08/04
08/04i
08/03
08/02
08/01
08/01M2
08/01M1
07/44
07/43
07/42
07/41
07/40
07/39
07/39 K
07/38
07/38 K
07/37
07/37 K
07/36
07/35
07/34
07/33

Figure 5(on next page)

Relative abundance of foraminiferal species in the R. calcarata interval at Postalm section (>63 µm).

Species marked with an asterisk are necessarily displayed at a different scale. Species are in order of their stratigraphical appearance.

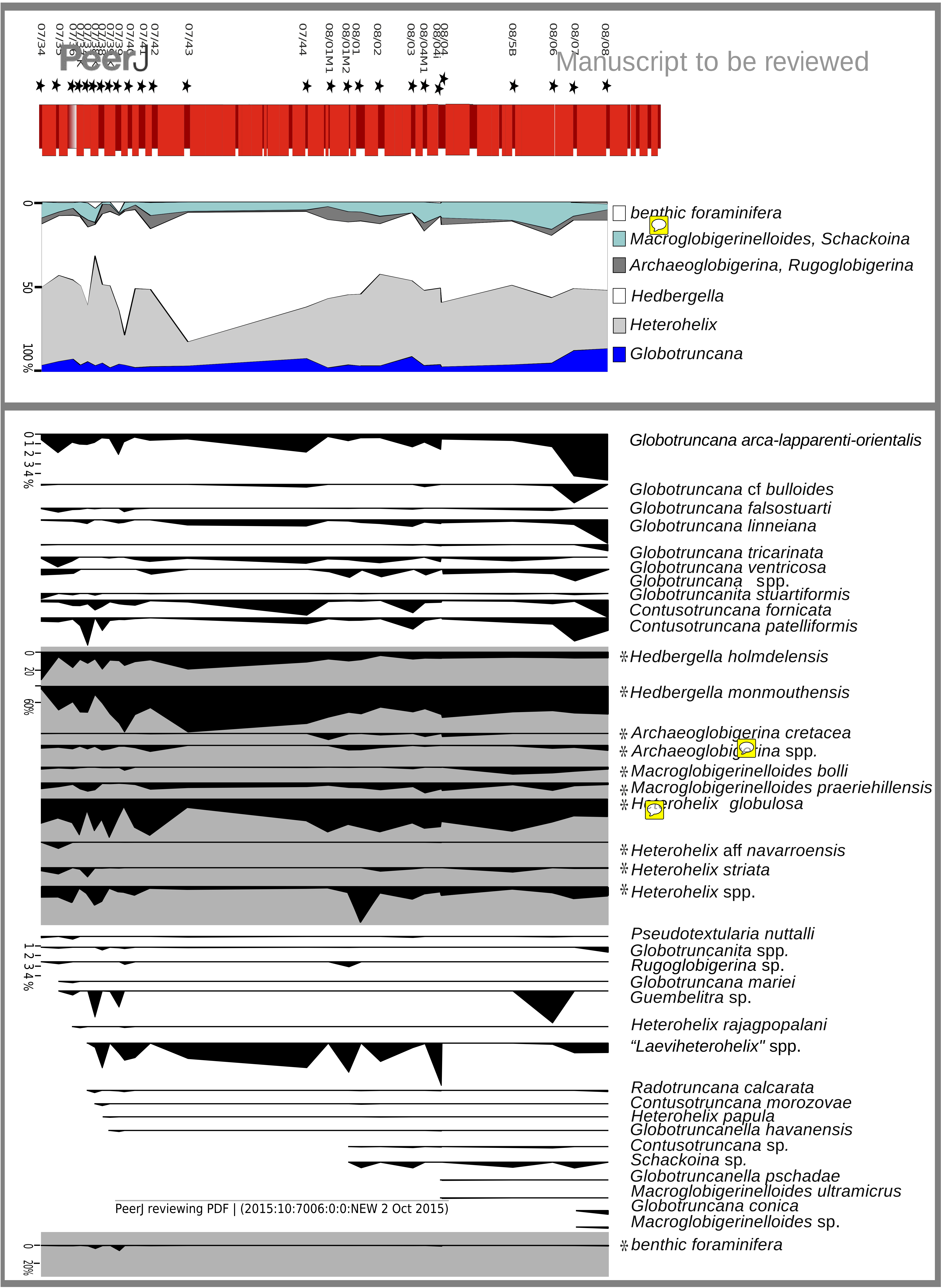
07/34
07/40
07/41
07/42
07/43
07/44
08/01M1
08/01M2
08/01
08/02
08/03
08/04M1
08/04i
08/5B
08/06
08/07
08/08
0
50
100 %
☐ benthic foraminifera
▨ Macroglobigerinelloides, Schackoina
■ Archaeoglobigerina, Rugoglobigerina
☐ Hedbergella
▨ Heterohelix
■ Globotruncana
0 1 2 3 4 %
Globotruncana arca-lapparenti-orientalis
Globotruncana cf bulloides
Globotruncana falsostuarti
Globotruncana linneiana
Globotruncana tricarinata
Globotruncana ventricosa
Globotruncana spp.
Globotruncanita stuartiformis
Contusotruncana fornicata
Contusotruncana patelliformis
0
20
60%
*Hedbergella holmdelensis
*Hedbergella monmouthensis
*Archaeoglobigerina cretacea
*Archaeoglobigerina spp.
*Macroglobigerinelloides bolli
*Macroglobigerinelloides praeriehillensis
*Heterohelix globulosa
*Heterohelix aff navarroensis
*Heterohelix striata
*Heterohelix spp.
1 2 3 4 %
Pseudotextularia nuttalli
Globotruncanita spp.
Rugoglobigerina sp.
Globotruncana mariei
Guembelitra sp.
Heterohelix rajagpopalani
“Laeviheterohelix" spp.
Radotruncana calcarata
Contusotruncana morozovae
Heterohelix papula
Globotruncanella havanensis
Contusotruncana sp.
Schackoina sp.
Globotruncanella pschadae
Macroglobigerinelloides ultramicrus
Globotruncana conica
Macroglobigerinelloides sp.
0
20%
*benthic foraminifera

Figure 6(on next page)

Frequency of foraminifera ~~in~~ respect to their ecological characteristics

The vast majority of individuals in the > 63µm fraction assign to opportunistic r-selected taxa (grey), r/K intermediates (light blue) and K-selected taxa (dark blue) are represented by 10 percent each.

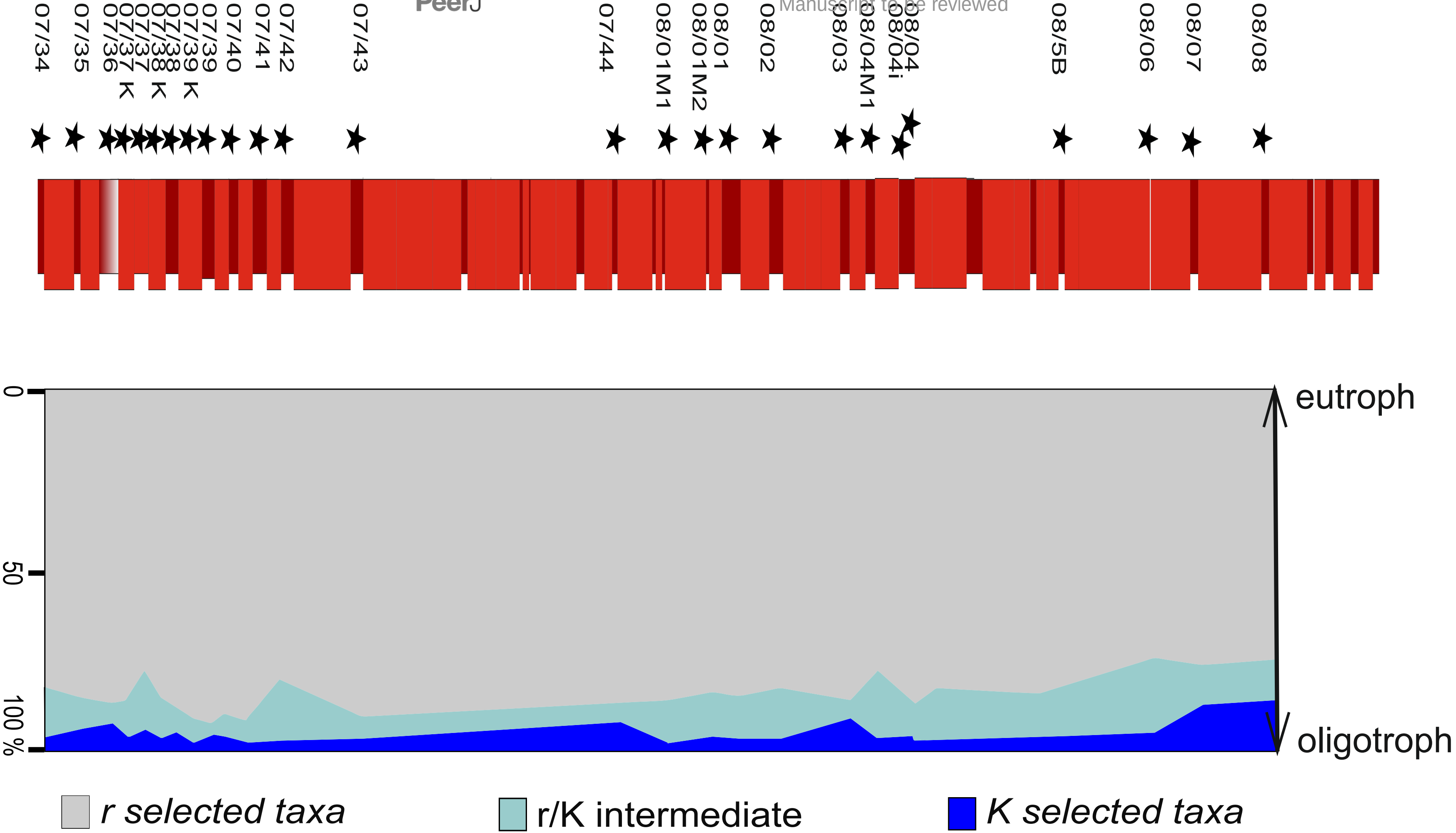
07/34
07/35
07/36
07/37 K
07/37
07/38 K
07/38
07/39 K
07/39
07/40
07/41
07/42
07/43
07/44
08/01M1
08/01M2
08/01
08/02
08/03
08/04M1
08/04i
08/04
08/5B
08/06
08/07
08/08
0
50
100 %
eutroph
oligotroph
r selected taxa
r/K intermediate
K selected taxa

Figure 7(on next page)

An average palaeo-waterdepth was calculated applying the methods of Hohenegger (2005) and Van der Zwaan et al. (1990).

Quantitative data assessed in this study was applied to calculate palaeo waterdepths after Van der Zwaan (1990). The benthic foraminiferal presence-absence dataset assessed in Wolfgring et al. (2015) was applied to calculate palaeo-waterdepths after the method of Hohenegger (2005).

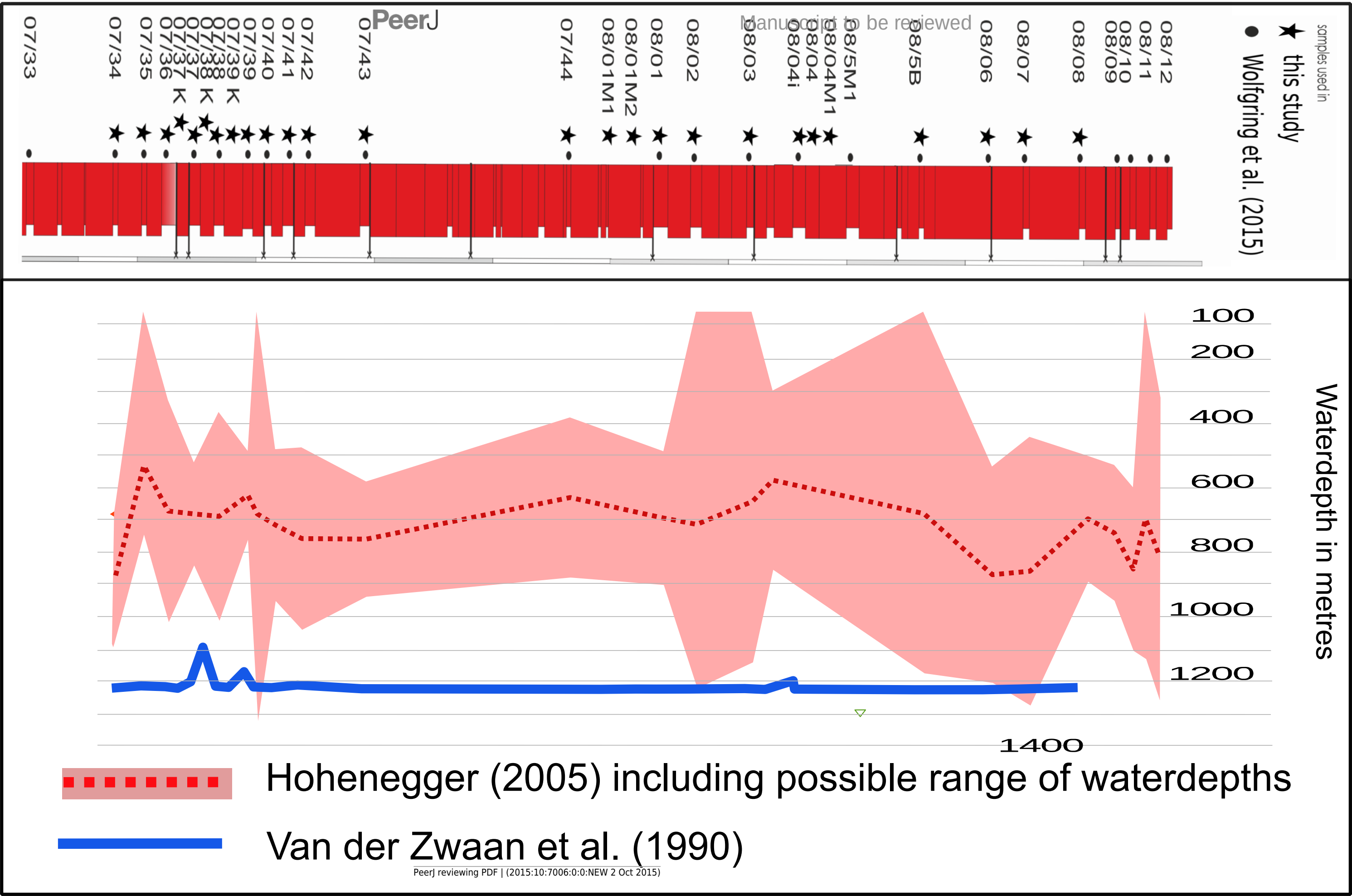
07/33
07/34
07/35
07/36
07/37 K
07/37
07/38 K
07/38
07/39 K
07/39
07/40
07/41
07/42
07/43
07/44
08/01M1
08/01M2
08/01
08/02
08/03
08/04i
08/04
08/04M1
08/5M1
08/5B
08/06
08/07
08/08
08/09
08/10
08/11
08/12
samples used in
★ this study
● Wolfgring et al. (2015)
100
200
400
600
800
1000
1200
1400
Waterdepth in metres
Hohenegger (2005) including possible range of waterdepths
Van der Zwaan et al. (1990)

Figure 8(on next page)

Differences in the composition of foraminiferal assmblages in marls and marly limestones.

Frequencies of globotruncanids, heterohelicids, hedbergellids, archaeoglobigerinids, ~~macro~~globigerinellids and benthic foraminifera from limestone- marl couplets. Biserial planktonic taxa are more abundant in the firmer limestone samples.

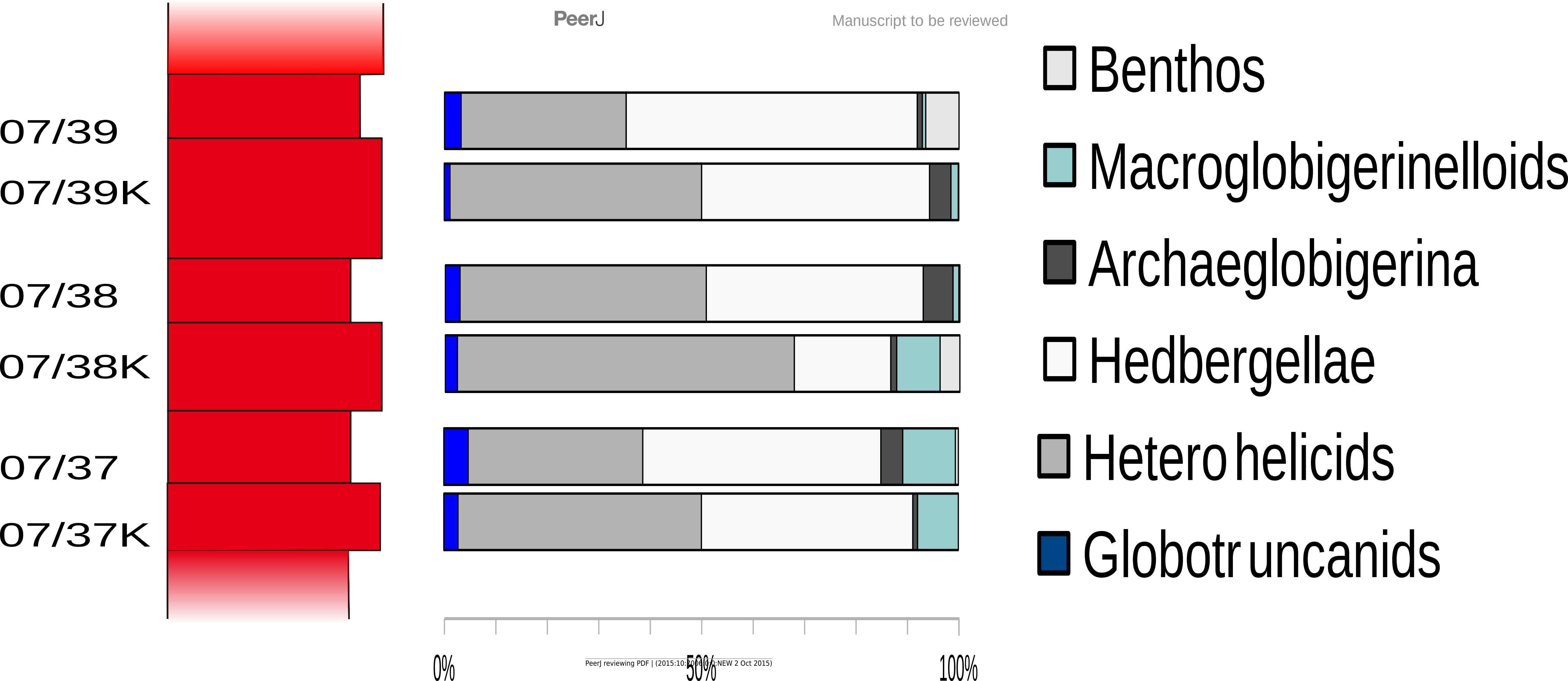
07/39
07/39K
07/38
07/38K
07/37
07/37K
0%
50%
100%
Benthos
Macroglobigerinelloids
Archaeglobigerina
Hedbergellae
Hetero helicids
Globotr uncanids

Table 1(on next page)

Proportional frequencies of foraminiferal taxa per sample at Postalm section.

Species	07/34	07/35	07/36	07/37K	07/37	07/38K	07/38	07/39K	07/39	07/40	07/41	07/42K	07/43	07/44	08/1M1	08/1M2	08/01	08/02	08/03	08/4M1	08/4i	08/04	08/5b	08/06	08/07	08/08
Archaeoglobigerina blowi	x	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. cretacea	0.2	-	-	-	-	-	-	-	-	-	-	0.4	-	-	7.7	0.5	-	1.8	-	3.8	-	3.9	-	-	-	-
Archaeoglobigerina spp.	3.4	2.3	4.2	0.9	4.2	1.1	5.8	4.2	1.0	0.9	2.7	7.5	-	-	0.2	5.7	5.4	2.8	0.1	1.1	0.1	0.1	0.5	3.6	2.4	6.3
Contusotruncana fornicata	0.2	0.2	0.6	0.6	0.4	1.0	0.7	0.2	0.4	0.4	0.5	0.1	0.2	1.6	0.1	0.1	0.1	0.0	1.3	0.3	0.2	0.1	0.1	0.4	0.1	1.8
C. morozovae	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	0.0	-	-	-	-	-	-	-	-	-
C. patelliformis	0.4	0.4	0.1	0.8	2.9	-	1.3	0.3	0.2	0.2	0.1	-	0.1	0.6	0.1	0.3	0.2	0.1	1.2	0.3	-	0.1	0.5	0.7	2.4	1.3
C. plummerae	x	-	-	-	-	-	x	-	-	-	-	-	x	-	-	-	-	x	-	-	-	-	x	-	x	x
Contusotruncana sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	-	0.1	-	0.0	-	0.1	0.1	-	-
Globotruncana arca-lapparenti.-orientalis.	0.5	1.9	0.8	1.0	1.1	0.9	0.4	0.4	2.1	0.8	0.3	0.6	0.5	1.9	0.2	0.7	0.4	0.4	1.3	0.8	1.6	0.5	0.7	1.3	4.4	4.8
G. aff. *conica*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
G. atlantica	-	-	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G. bulloides	0.1	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	0.2	-	-	-	0.1	1.9	-
G. falsostuarti	0.0	0.4	0.1	0.1	-	0.1	-	-	-	0.4	0.1	-	-	-	0.0	0.0	-	-	0.1	-	-	-	0.1	0.2	-	-
G. linneiana	0.0	0.1	0.1	0.2	0.4	-	-	0.1	0.3	0.3	-	-	0.5	0.6	0.1	0.1	0.3	0.4	0.7	0.2	0.4	0.3	0.1	0.3	0.5	2.5
G. stuartiformis	0.5	-	0.1	-	-	0.2	-	-	-	-	-	0.0	-	-	0.0	-	0.0	-	-	-	-	-	0.1	-	0.1	-
G. tricarinata	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	-	0.1	0.1	-	-	-	0.7
G. ventricosa	0.1	1.0	0.4	-	-	-	-	0.1	-	-	0.2	0.4	0.1	0.6	0.2	0.3	0.4	0.6	0.2	-	0.5	0.1	0.4	0.2	-	-
G. mariei	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Globotruncana sp.	0.6	0.5	0.4	-	-	-	-	-	-	-	-	0.5	-	-	0.3	0.8	0.1	0.8	-	0.6	-	0.5	0.3	0.5	1.2	-
Globotruncanella havanensis	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	0.0	-	-	-	-	-
Ga. pschadae/sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	-	-	-	-
Globotruncanita sp.	-	0.1	-	-	-	-	0.3	-	0.1	0.1	-	-	0.0	-	0.0	0.0	-	-	-	-	-	-	-	-	-	0.5
Gta. elevata	x	-	x	-	-	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-
Gta. subspinosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-
Guembelitra sp.	-	-	0.4	-	-	2.8	-	0.0	1.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.4	-	-
Hedbergella holmdelensis	34.6	6.0	19.3	9.0	13.9	8.4	21.3	9.9	10.5	16.6	11.8	9.5	21.2	12.3	8.5	10.9	9.3	4.0	8.6	7.4	7.7	7.4	6.4	6.7	7.3	7.0
H. monmouthensis	3.2	29.6	19.3	32.1	32.4	10.3	20.9	34.4	46.1	57.3	35.3	26.6	57.2	46.6	38.6	32.4	34.4	26.0	31.9	28.0	35.2	39.0	31.9	30.4	33.4	34.8
"*Heterohelix*" *globulosa*	30.4	23.7	29.5	45.0	14.7	39.8	25.6	48.3	23.4	9.6	35.3	45.5	10.4	27.1	41.2	31.7	-	41.1	29.9	36.5	34.6	28.1	40.3	28.8	21.0	21.9
H. navarroensis	-	7.8	0.1	-	-	-	-	-	-	0.0	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-
H. pupa	-	-	-	-	-	-	-	0.0	-	-	-	-	-	-	-	-	-	0.0	-	-	-	-	-	-	-	-
H. rajagopalani	-	-	-	0.1	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H. striata	3.8	7.8	-	1.8	11.6	0.5	0.6	0.1	0.4	0.0	-	-	0.0	-	0.0	-	0.0	4.3	1.4	-	0.0	-	5.4	0.0	0.8	0.8
"*Heterohelix*" spp.	12.3	12.1	20.1	0.3	7.7	21.9	18.5	0.4	5.4	6.0	10.0	0.7	2.1	0.6	0.1	6.5	42.7	7.0	15.5	8.2	5.4	10.3	1.7	6.7	14.1	10.9
"Leaviheterohelix" spp.	-	-	-	-	-	0.5	3.1	-	1.3	2.1	1.8	-	1.9	3.1	-	3.7	-	2.3	0.6	0.1	5.4	-	-	0.1	1.2	1.2
Macroglobigerinelloides bolli	2.4	0.9	1.7	0.6	-	-	0.6	0.6	0.3	3.8	-	-	-	0.3	-	0.2	-	-	1.8	-	0.2	-	8.7	7.1	5.0	2.3
M. prairiehillensis	7.1	4.6	1.7	7.3	10.2	8.4	0.6	0.8	0.3	0.7	1.8	7.7	5.6	4.4	2.8	5.5	5.9	8.5	4.5	12.4	7.5	9.4	2.2	9.2	3.4	2.0

M. ultramicrus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-
Macroglobigerinelloides sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1
Pseudotextularia nutalli	0.1	-	0.3	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	0.1	-	-	-	-	0.0	-	-
Radotruncana calcarata	-	-	-	-	-	0.2	-	-	0.1	0.1	-	-	-	-	-	-	0.0	-	-	-	0.0	-	-	-	-	0.1
Rugoglobigerina sp.	-	0.2	-	-	-	-	-	-	-	0.3	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-
Shackoina sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	-	0.6	-	-	-	0.5	-	0.6	-
benthic foraminifera	-	0.4	0.4	-	0.6	3.8	0.2	0.1	6.5	0.2	0.1	0.3	-	-	0.0	0.1	0.0	0.0	0.1	0.0	0.8	0.1	0.0	0.0	0.1	0.7

Table 2(on next page)

Life strategies of planktonic foraminifera at Postalm section (after Premoli Silva and Sliter, 1999, Petrizzo, 2002).

Table 2

K-selected:
Contusotruncana aff. *morozovae*
C. patelliformis
C. plummerae
Contusotruncana fornicata
Contusotruncana sp.
Globotruncana arca-lapparenti-orientalis
G. aff. conica
G. atlantica
G. bulloides
G. falsostuarti
G. linneiana
G. mariei
G. stuartiformis
G. tricarinata
G. ventricosa
Globotruncana sp.
Globotruncanita sp.
Gta. elevata
Gta. subspinosa

r/K – intermediates:
Archaeoglobigerina spp.
A. cretacea
Archaeoglobigerina blowi
Globotruncanella havanensis
Ga. pschadae/sp
Macroglobigerinelloides bolli
M. prairiehillensis
M. ultramicrus
Macroglobigerinelloides sp.
Pseudotextularia nutalli

r- selected:
Guembelitra sp.
"Heterohelix" globulosa
H. navarroensis
H. punctulata
H. rajagopalani
H. striata
"Heterohelix" spp.
Hedbergella holmdelensis
H. monmouthensis
„Laeviheterohelix" spp.
Radotruncana calcarata
Rugoglobigerina sp.

Table 2: Life strategies of planktonic foraminifera at Postalm section (after

Premoli Silva and Sliter, 1999, Petrizzo, 2002).