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STRATIGRAPHY AND CORRELATION OF THE GRUND FORMATION IN THE MOLASSE BASIN, NORTHEASTERN AUSTRIA (MIDDLE MIOCENE, LOWER BADENIAN)

STJEPAN ĆORIĆ[1], MATHIAS HARZHAUSER[2], JOHANN HOHENEGGER[1], OLEG MANDIC[1], PETER PERVESLER[1], REINHARD ROETZEL[3], FRED RÖGL[2], ROBERT SCHOLGER[4], SILVIA SPEZZAFERRI[5], KARL STINGL[4], LILIAN ŠVÁBENICKÁ[6], IRENE ZORN[3] and MARTIN ZUSCHIN[1]

[1]Department of Paleontology, University of Vienna, Althanstrasse 14, A-1090 Wien, Austria; stjepan.coric@univie.ac.at; johann.hohenegger@univie.ac.at
[2]Museum of Natural History Vienna, Burgring 7, A-1014 Wien, Austria; mathias.harzhauser@nhm-wien.ac.at; fred.roegl@nhm-wien.ac.at
[3]Geological Survey of Austria, Rasumofskygasse 23, A-1030 Wien, Austria; roerei@cc.geolba.ac.at; zorire@cc.geolba.ac.at
[4]Institute of Geophysics, Montanuniversität Leoben, Peter Tunner Strasse 27, A-8700 Leoben; robert.scholger@unileoben.ac.at
[5]Universitè Fribourg, Suisse; silvia.spezzaferri@unifr.ch
[6]Czech Geological Survey, Klárov 131/3, P.B. 85, 118 21 Praha, Czech Republic; svab@cgu.cz

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Abstract: Mollusc bearing Neogene strata were collectively designated as "Grund Beds" in the 19th century. The different lithostratigraphic formations of these Grund Beds were studied in the Austrian Molasse Basin north of the Danube (Alpine-Carpathian Foredeep). Biostratigraphic methods and paleomagnetic measurements revealed that the entire Karpatian Laa Formation spans nannoplankton Zone NN4. It is transgressive on the Lower Miocene, Ottnangian marine sequences. The upper part of the Laa Formation correlates with the first occurrence of *Globigerinoides bisphericus* and is correlated in the type locality with the reverse Chron C5Cr and the normal chron C5Cn.2n. A distinct unconformity separates the Karpatian and Badenian sequences. The first Badenian transgression of the Molasse Basin resulted in a clastic sequence which, for the time being, has no lithostratigraphic designation. The lower part belongs to nannoplankton Zone NN4, with the first occurrence of *Praeorbulina glomerosa glomerosa* (Middle Miocene, Zone M5). The upper part of this basal clastic sequence belongs to nannoplankton Zone NN5. A coarse conglomerate, overlying a further unconformity, is interpreted as the transgression horizon of the fine clastic, more than 250 m thick Grund Formation. It spans nannoplankton Zone NN5 and contains *Praeorbulina glomerosa circularis.* Higher up in the sections, this species occurs together with *Orbulina suturalis* (plankton Zone M6). Ostracods and molluscs from the Grund Formation is distinctly different from the Karpatian, and indicate an unambiguously Badenian age. The normal paleomagnetic polarity measured in the type locality of the Grund Formation is interpreted as Chron C5Bn.2n. The Gaindorf Formation is coeval with the Grund Formation, developed along the western coast of the Molasse Basin. The more eastern development of the Mailberg Formation stratigraphically corresponds to the upper part of the Grund Formation with the co-occurrence of *Po. glomerosa circularis* and *O. suturalis*. In the Mailberg Formation a reverse magnetization is interpreted as correlating with Chron C5Bn.r.

Key words: Miocene, Karpatian, Badenian, Austria, Alpine-Carpathian Foredeep, Grund Formation, stratigraphy.

Introduction

The Austrian part of the Molasse Basin or Alpine-Carpathian Foredeep north of the Danube (Fig. 1) belongs to the Central Paratethys, with a corresponding regional stratigraphic stage system. Marine sedimentation started in the Egerian (Upper Oligocene to Lower Miocene). Fossiliferous Eggenburgian (Lower Miocene) shallow-water sediments are widely spread on top of the Bohemian Massif. At the surface, basin sediments are exposed as the Ottnangian Zellerndorf Formation, the shallow-water "*Rzehakia* Beds", and the transgressive Karpatian Laa Formation. The overlying transgressive Badenian (Middle Miocene) sediments represent several formations. Only restricted areas are covered by Sarmatian (Middle Miocene) and Lower Pannonian (Upper Miocene) deposits. The fluvial gravels of the Pannonian Hollabrunn-Mistelbach Formation are of regional extent (comp. Roetzel et al. 1999).

Recent debates about the stratigraphic position and range of the Grund Formation (e.g. Švábenická & Čtyroká 1998; Cicha 1999a) gave rise to intensified research. This investigation was facilitated by excavations of the Institute of Paleontology of the University of Vienna at the type locality of Grund in 1998 and 1999 (Roetzel et al. 1999; Roetzel & Pervesler 2004). The Grund excavations have been studied in detail for sedimentology, trace fossils, and molluscan assemblages. In the deep drill site Roggendorf-1, the base of the Grund Formation and the transgression of the Badenian on Karpatian sediments were observed (Ćorić & Rögl 2004). Additionally, the discovery of vertebrate remains in the localities of Grund and Mühlbach enabled the correlation of marine and terrestrial biota (Daxner-Höck 2003). New stratigraphic results have been achieved by studying calcareous nannoplankton, foraminifers, molluscs, and by paleomagnetic measurements.

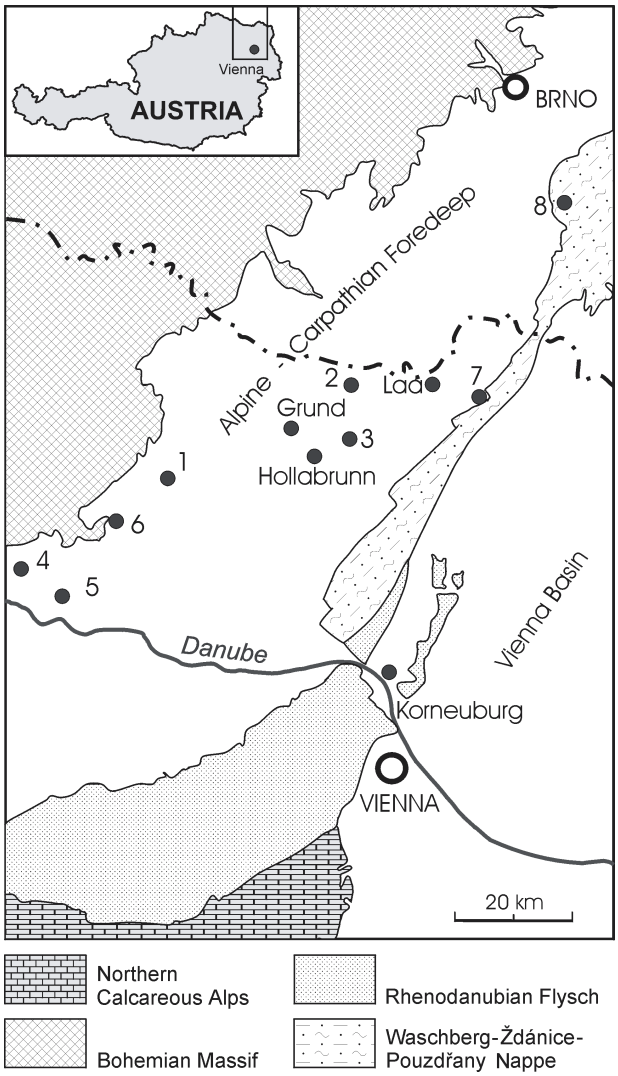

Fig. 1. Geological sketch of the Alpine-Carpathian Foredeep in northeastern Austria and southern Moravia (acc. Rögl & Spezzaferri 2003). Location map of important outcrops and type localities mentioned in the text: 1 — Gaindorf, 2 — Buchberg near Mailberg, 3 — deep drilling Roggendorf-1, 4 — exploration well NÖ-06 Gneixendorf, 5 — exploration well NÖ-07 Diendorf near Hadersdorf am Kamp, 6 — Mühlbach, 7 — Kautendorf near Staatz, 8 — Pouzdřany.

The problem of the Grund Beds

The Grund Beds or "Grunder Schichten" (Rolle 1859) have been of great paleontological interest since the 19th century. At that time, excavations for new wine cellars in the village of Grund exposed a very rich molluscan fauna, dominated by large specimens (e.g. Hoernes M. 1851–1856; Hoernes M. & Reuss 1862–1870; Hoernes R. & Auinger 1879–1882; Sieber 1949; Schultz 2001). These faunas were used by Mayer (= Mayer-Eymar 1868) for a subdivison of his Helvetian Stage. Originally, Mayer (1858) included in the Helvetian the marine Molasse from the region of Berne (Switzerland) to Upper Bavaria. Later, in 1865, Mayer subdivided the Helvetian into the *Couches de Vienne* and the *Couche de Steinabrunn*. Both regions are in the Vienna Basin and the deposits belong to the Middle Miocene (Badenian). To add to the confusion, Mayer-Eymar (1868) published a three-fold subdivision of the Helvetian: I. *Couches de Grund*, II. *Couches de Serravalle*, III. *Couches de St. Gall*. Due to the inclusion of such different stratigraphic levels, Rutsch (1958) solved the Helvetian problem by defining a stratotype at the Imihubel near Berne, belonging to the Lower Miocene Belperg Beds.

Later, Rutsch (1971) cemented the erroneous intermingling by using the occurrence of *Megacardita jouanneti* at the Helvetian stratotype as a biomarker. This species is absent not only in the Eggenburgian (Early Burdigalian) beds of Lower Austria, but also in the Burdigalian stratotype in SW France. This appeared to be a biostratigraphically significant record because this large-sized bivalve species is a characteristic fossil in beds exposed throughout southern and central Europe, formerly erroneously correlated with the "Helvetian" (e.g. Turin Mountains in NW Italy, Salles in SW France, Grund in Lower Austria) and "Tortonian" (e.g. Gainfarn in Lower Austria) stages. However, the presence of *Megacardita jouanneti* at the stratotype in the Swiss Molasse was rejected by Pfister & Wegmüller (1994–2001). They re-investigated in detail the Swiss marine Miocene bivalve assemblages and found no evidence for that species. Moreover, they pointed out that the *Megacardita jouanneti* specimen of Rutsch (1928) represents an erroneous identification of their *Megacardita guenterti* n. sp., and correlates morphologically better with *Megacardita zelebori* (Hoernes) from the Eggenburgian of Lower Austria. Nevertheless, *Megacardita jouanneti* appears already in the Burdigalian (e.g. Baldissero in Northern Italy) and is a poor candidate for biostratigraphy at the Early/Middle Miocene boundary.

Rutsch & Salaj (1974), attempted to correlate the Helvetian and the Karpatian. In this poorly documented paper the authors also included the *Rzehakia* Beds (Upper Ottnangian) into the Lower Karpatian and correlated these beds with the Helvetian because of the occurrence of *"Uvigerina" bononiensis compressa* and *"U." bononiensis primiformis*. The species *Pappina compressa* was described by Cushman (1925) from the Badenian of the Vienna Basin and is synonymous with *P. parkeri* (Karrer). It belongs to the *bononiensis* group, but is not found in the Karpatian. Otherwise, *P. primiformis* occurs already in the Lower Eggenburgian of the Loibersdorf stratotype. The occurrence at Imihubel, the stratotype of the Helvetian, does not give a stratigraphic correlation tie-point. The determination of one specimen of *Globigerinoides bisphericus* from the Imihubel section may be questioned because it is not figured and no later record could be found.

Another stratigraphic subdivision for the Austrian Neogene was given by Th. Fuchs (1873) and consisted of the *1. Mediterranstufe* for the sediments around Horn and Eggenburg (Lower Miocene, Eggenburgian), and the *2. Mediterranstufe* for the "Badener Tegel", marine sands and "Leithakalk" in the Vienna Basin. At that time the term Vienna Basin also included the Molasse Basin (Alpine-Carpathian Foredeep) north of the Danube ("Ausseralpines Wiener Becken"). Based on these subdivisions, different sedimentological sequences were long included in the Grund Beds. Even in 1951, Schaffer & Grill correlated the Grund Beds with the "*Oncophora*" Beds as a

more marine Upper Helvetian equivalent, and also included the deposits of the Korneuburg Basin in the Grund Beds. A distinction between a lower (Helvetian) part and an upper part ("Tortonian" at that time) on the basis of molluscs was speculated, but not yet possible (Kautsky 1928; Sieber 1937, 1949). Otherwise, on the basis of orbulinas and cancellate globigerinas, Vašíček (1946) already subdivided the younger marine sediments of the Carpathian Foredeep into a Helvetian and "Tortonian" part. Similarly, later studies subdivided the Grund Beds using foraminifers (Weinhandl 1957; Grill 1958).

For the lower part of the Grund Beds a new formation name, the "Laaer Schichten", was introduced (Kapounek et al. 1960) and correlated with the new stage Karpatian of Cicha & Tejkal (1959). The Laa Formation transgresses discordantly over the Ottnangian Zellerndorf Formation. For the Karpatian deposits of the Korneuburg Basin, the term "Korneuburger Schichten" was introduced (Grill 1968). Recent investigations of ostracod and molluscan faunas from the Korneuburg Basin (Čtyroký 2002; Harzhauser 2002; Zorn 1998) demonstrated the position of the former Lower Grund Beds within the Karpatian. Similarly, research at the type locality of the Laa Formation, Laa an der Thaya, with so-called Grund Beds on top, made a correlation possible with the Karpatian (Late Burdigalian), *Globigerinoides bisphericus* level and nannoplankton Zone NN4 (Cicha 1997; Martini & Müller 1975; Rögl 1969; Rögl et al. 1997). The former Upper Grund Beds have been separated into the Grund Formation and the Gaindorf Formation (Cicha 1999b; Roetzel et al. 1999).

New biostratigraphic results on the Karpatian and Badenian

In recent years a new biostratigraphic and paleoecological subdivision of the Karpatian and Badenian successions in the Alpine-Carpathian Foredeep, with reference to the Grund Formation, was proposed (Cicha 1999a, 2001; Švábenická & Čtyroká 1998, 1999). This subdivision is based on calcareous nannoplankton and foraminifers, both benthic and planktonic. Those authors placed the lower part of the Grund Formation in the Karpatian. Generally, the subdivision of assemblages corresponds to our results on the paleoecological development of the Karpatian and Badenian in the Alpine-Carpathian Foredeep (Molasse Basin in Austria) and to the distribution of important species. The main difference pertains to the stratigraphic interpretation, which contrasts to the results by the newly recorded *Praeorbulina* in the Grund type locality (Rögl et al. 2002; Spezzaferri 2004).

Foraminifera

Strong differences in foraminiferal assemblages between the horizons of the former "Grunder Schichten" support the stratigraphic subdivision into the Laa and Korneuburg Formations (Karpatian), and the Grund, Gaindorf and Mailberg Formations (Lower Badenian). This is reflected not only in the increasing richness of the fauna but also in the species diversity in individual samples. In the basin facies of the Laa Formation, the highest diversity is 46 benthic and 19 planktonic species per sample. In the shallow environment of the Korneuburg Formation, a maximum of 25 benthic and 6 planktonic species were recorded in a single sample. The diversity in the lowermost Badenian clastic sequences is still rather low, between 20 to 40 benthic and 6 to 16 planktonic species. In the Grund and Gaindorf Formations the species number increases from 20 to >170 benthic and from 12 to >30 planktonic forms. A similar high diversity — 174 benthic and 16 planktonic species — was observed in marly layers of corallinacean limestones of the Mailberg Formation and also in the marly basin facies in the eastern part of the Molasse Basin (Kautendorf near Staatz).

No new results are available for dating the Karpatian. The planktonic assemblages of the Laa Formation are dominated by small globigerinas without stratigraphic significance. Only single specimens of *Globigerinoides bisphericus* have been recorded (Rögl 1969). In some counterflash drillings of OMV at the eastern border of the Molasse Basin and on top of the Waschberg Unit, the probably Upper Karpatian contains richer planktonic assemblages with *G. bisphericus* and first globorotalias (Rögl et al. 2002). Such assemblages are also reported from the Pouzdřany Unit at Kolby Hill (Southern Moravia) in claystones of the Laa Formation (Stráník & Brzobohatý 2000).

The lowermost Badenian transgressive sediments were recorded in deep drillings only, and are characterized by a basal unconformity, partly on top of the Karpatian Laa Formation. As documented in Roggendorf-1, 105 m of conglomerates and sandstones underlie the fine-clastic Grund Formation; they contain a scarce foraminiferal assemblage without stratigraphic significance (Ćorić & Rögl 2004). Marly intercalations in the basal conglomerate of prospection well NÖ-07 (Diendorf near Hadersdorf), at 260.4–281.2 m, contain a scarce fauna with species such as *Globigerinoides quadrilobatus, Globoquadrina* cf. *altispira*, and *Globorotalia bykovae*. The next horizon of grey silty and sandy marls (240.0–260.4 m) shows a distinct faunal increase, additionally with *Paragloborotalia mayeri, P. pseudocontinuosa*, and uvigerinids, *Pappina primiformis* and *Uvigerina macrocarinata.* Only in the level 237.0–237.1 m do the first *Praeorbulina glomerosa circularis* appear together with *Orbulina suturalis*, which correlates to higher parts of the Grund Formation. In the shallower prospection well NÖ-06 (Gneixendorf) the first microfauna appears on top of a clastic sequence, which transgressed on crystalline rocks of the Bohemian Massif at 126.8 m. The first fossiliferous sample (104.7–104.8 m) has a rich assemblage with *Praeorbulina glomerosa glomerosa, Globigerinoides quadrilobatus, G. trilobus, Globigerina* spp., *Globoquadrina* cf. *altispira, Paragloborotalia* cf. *mayeri, Globorotalia bykovae* (Rögl & Spezzaferri 2003).

Of stratigraphic importance for dating the Grund Formation is the appearance of *P. glomerosa circularis* together with *Uvigerina macrocarinata* in the type locality Grund (Rögl & Spezzaferri 2002; Spezzaferri 2004). The last appearance of *Uvigerina graciliformis* (the index species for the begin of the Karpatian) and of *Pappina breviformis* and *P. primiformis* is found in the higher part of the Grund Formation, at the co-occurrence level of *Praeorbulina glomerosa circularis* and *Orbulina suturalis* (comp. Švábenická & Čtyroká 1999). The

planktonic assemblage of the higher Grund Formation (e.g. Kalladorf, Maria Roggendorf, Obergrabern) is characterized by intergrading forms of *Praeorbulina* and *Orbulina suturalis*, together with species such as *Globigerinoides apertasuturalis, G. bisphericus*, *Paragloborotalia acrostoma, P. mayeri, Globorotalia bykovae,* and *G. transsylvanica*. Marly intercalations in the corallinacean limestone of the Mailberg Formation have a similar assemblage with *Praeorbulina glomerosa circularis, Orbulina suturalis*, and *Uvigerina macrocarinata*. The benthic assemblages in the deeper-water facies (Kautendorf) contain species such as *Lenticulina echinata, Planularia auris, P. cassis, P. dentata*, *Vaginulina legumen,* and uvigerinas: *Uvigerina macrocarinata, U. pygmoides, U. uniseriata*, and first *U. grilli*.

Calcareous nannoplankton

Karpatian: Spezzaferri & Ćorić (2001) studied the biostratigraphy and paleoecology of Laa Formation sediments from Hole BL 503 drilled outside the Wienerberger brickyard at Laa, based on foraminifers and calcareous nannoplankton. They contain: *Helicosphaera ampliaperta*, *H. carteri, Sphenolithus heteromorphus*, *Coccolithus pelagicus*, *C. miopelagicus*, *Calcidiscus leptoporus*, *Cyclicargolithus floridanus*, and are dated as nannoplankton Zone NN4 (comp. Martini & Müller 1975). The described nannofossil assemblages are generally identical to the interval 360–612 m in Roggendorf-1 (Ćorić & Rögl 2004).

The **Badenian** transgression is documented in different drill sites in the Austrian Molasse Basin. In Roggendorf-1 a clastic sequence (255–360 m) underlying the Grund Formation contains rather well-developed nannoplankton assemblages. Within this section the boundary between nannoplankton Zones NN4 and NN5 was based on the extinction of *H. ampliaperta* at 320 m. The lower part (NN4) is characterized by *Coccolithus pelagicus*, *C. floridanus*, *Coronocyclus nitescens*, *H. scissura, Syracosphaera pulchra.* The upper part of this clastic level (NN5) contains: *Helicosphaera waltrans, H. vedderi, H. walbersdorfensis*, and higher percentages of *Reticulofenestra minuta*. The deeper part of prospection well NÖ-07 (Diendorf near Hadersdorf) is attributed to nannoplankton Zone NN4 based on the co-occurrence of *Sphenolithus heteromorphus* and *Helicosphaera ampliaperta* in the samples 256.6–256.7 m and 264–267 m. The sediments, which are dominated by *C. pelagicus*, also contain: *Helicosphaera carteri*, *H. mediterranea*, *R. minuta*, *Sphenolithus moriformis*, *Syracosphaera pulchra,* and *Thoracosphaera* spp. In well NÖ-06 (Gneixendorf), NN4 was also recorded in the lower part of the Badenian. The sample 100.2–100.3 m contains scarce *H. ampliaperta* and *H. scissura*; *Sphenolithus heteromorphus* is absent. Zone NN5 was also recorded in both sections. Samples from marly sediments at 237.0–237.1 m of NÖ-07 contain the following species: *C. pelagicus*, *Coronocyclus nitescens*, *Geminilithella rotula*, *Helicosphaera carteri*, *H. vedderi*, *H. walbersdorfensis*, *Reticulofenestra minuta*, *Sphenolithus heteromorphus*, *Umbilicosphaera jafarii*. Only a few specimens of *Helicosphaera waltrans* have been recorded. In well NÖ-06, the sample 95–97 m yields a nannoplankton assemblage with *Helicosphaera vedderi* and *H. walbersdorfensis*, typical for Zone NN5.

The **Grund Formation** from the deep drilling Roggendorf-1 (2–255 m) contains very abundant nannoplankton assemblages, typical for nannoplankton Zone NN5 of Martini (1971), with the presence of: *Sphenolithus heteromorphus*, *Helicosphaera waltrans*, and *H. walbersdorfensis*. They are characterized by the dominance of *Reticulofenestra minuta* and relatively scarce *Coccolithus pelagicus*. In the type locality of the Grund Formation at Grund near Hollabrunn, a series of sections have been studied (Ćorić & Švábenická 2004). Nannofossil assemblages of NN5 are characterized by the following phenomena:

— presence of *Helicosphaera waltrans* (relatively common), irregular occurrence of *H. walbersdorfensis*, relative abundance of *H. carteri,* absence of *Sphenolithus heteromorphus,* scarce occurrence of reworked *H. ampliaperta*, rare occurrence of discoasters, *Umbilicosphaera, Calcidiscus,* and *Pontosphaera*.

Calcareous nannofossil assemblages from the outcrop Mühlbach, Gaindorf Formation (Ćorić 2003) are stratigraphically similar to the Grund Formation (NN5), characterized by the presence of: *Coccolithus pelagicus, Coronocyclus nitescens*, *Helicosphaera carteri*, *H. vedderi*, *H. waltrans*, *Reticulofenestra minuta, R. haqii, R. pseudoumbilica, Sphenolithus heteromorphus, S. moriformis, Syracosphaera histrica, S. pulchra, Thoracosphaera heimii.*

Ostracoda

Few investigations have been done on ostracods from the so-called Miocene “Grunder Schichten” or Grund Beds. Ostracods from the Karpatian Laa Formation are documented from the type locality Laa in the Molasse Basin. Rögl et al. (1997) mention 20 species. Most of these species are also represented in the more diverse ostracod fauna of the coeval Korneuburg Formation in the Korneuburg Basin. Zorn (1998) described 48 species, which reflect a shallow-water environment with temporary brackish water influence. The infraneritic facies of the Laa Formation is only indicated by the occurrence of *Pterygocythereis* and *Krithe*.

The ostracod assemblages of the Badenian Grund and Gaindorf Formations (Molasse Basin) show evident differences compared to the Laa and Korneuburg Formations. The ostracods from the Gaindorf Formation were recently investigated by Zorn (1999, 2003). Twenty-seven species, which represent elements of the lower infralittoral to the circalittoral, were distinguished. The ostracod fauna of the coeval Grund Formation consists of about 60 species (Zorn 2004). The Hemicytheridae are much more diverse in the Grund Formation, which is typical for shallow-water environments. Deep-water elements are *Krithe* and *Henryhowella.*

A high diversity of Ostracoda and especially of the Hemicytheridae is generally characteristic for the Badenian in the Central Paratethys. The occurrence of most of the Hemicytheridae species is valuable for the identification of the Badenian, but is very probably not applicable to subdivide the Badenian (see Brestenská & Jiříček 1978; Gross 2002). The presence of the following species, found in the Grund and

Gaindorf Formations is restricted to the Badenian: *Acanthocythereis hystrix, Aurila albicans, A. galeata, A. punctata, Cytheridea acuminata*, *Cnestocythere lamellicosta*, and *Olimfalunia spinulosa.* Also restricted to the Badenian are *Aurila angulata, A. haueri, A. opaca, A. trigonella, Costa reticulata, Urocythereis kostelensis, Semicytherura galea, Renicytherura textilis cornuta*, and *Tenedocythere sulcatopunctata*, which have been found in the Grund Formation only. *Acanthocythereis hystrix* is an index fossil for the Lower Badenian (Jiříček 1983). *Aurila albicans* and *Renicytherura textilis cornuta* are scarcely known in the Central Paratethys but also seem to be restricted to the Early Badenian.

The Karpatian formations in Austria can mainly be separated from the Badenian formations by the occurrence of *Loxoconcha vaisonna*. Furthermore, *Callistocythere karpatiensis, Cyamocytheridea gracilis, Heliocythere leobendorfensis*, and *Cytherura teiritzbergensis* only occur in the Korneuburg Formation. The species *Cytheridea paracuminata, Cyamocytheridea derii*, and *Senesia vadaszi* first occur in the Karpatian, but the first two have a stratigraphic range up to the Badenian and the last to the Sarmatian.

Mollusca

Lower Austria and Styria provide the best evidence for the late Early Miocene (Karpatian) and early Middle Miocene (Early Badenian) molluscan assemblages of the marine shelves of the western Central Paratethys. Clearly, two stratigraphically quite different faunas contributed to the so-called "Grund Fauna". The late Early Miocene age of the Laa and Korneuburg Formations and the Middle Miocene status of the fauna of the Grund and Gaindorf Formations were accepted by most workers on the basis of increased biostratigraphic data. Karpatian molluscs derive from the Korneuburg Formation in the Korneuburg Basin and the Laa Formation in the Molasse Basin. Recently, the Karpatian molluscan faunas have been revised by Binder (2002), Čtyroký (2002), Harzhauser (2002), and Mandic (2004). In total, 230 taxa of gastropods, bivalves, and scaphopods are documented.

The Grund Formation includes the species-rich faunas from such historic localities as Grund, Immendorf, Windpassing, Braunsdorf, and Guntersdorf. The extraordinarily rich coquinas consisting of densely packed, often abraded shells derive mainly from proximal and distal tempestitic shelly beds and reveal a sub-autochthonous character (Zuschin et al. 2001, 2004).

The separation between the Karpatian and the Early Badenian molluscan faunas in Lower Austria was long hampered by similarities in the composition of the assemblages due to coinciding facies and by the low percentage of genuine Karpatian species. Among the gastropods, only 9 species (about 7 %), such as *Agapilia pachii, Turritella bellardii*, and *Clavatula barbarae*, are documented until now solely from the Karpatian (Harzhauser 2002). An additional problem is that several "old-fashioned" typical Early Miocene species, such as *Melongena cornuta, Tudicla rusticula*, *Euthriofusus burdigalensis*, and *Ficus cingulata* display a unique acme in the Central Paratethys; this acme lasted from the Karpatian up to the Early Badenian, before the Middle Badenian decline. In contrast, the Badenian gastropod assemblages are usually easily recognized by their much higher diversity, yielding many species unknown from Karpatian strata. Among these, *Cerithium procrenatum, Cerithium bronni, Cassidaria cingulifera*, *Cypraecassis cypraeiformis*, *Bursa nodosa, Charonia apenninica, Charonia nodifera, Murex (Tubicauda) spinicosta*, and *Muricopsis cristatum* are typical. About 150 gastropod species of the Karpatian compare with more than 300 species of the Early Badenian. This "Badenian bloom" is traceable within most gastropod families, but is most conspicuous within the cypraeids, turrids, cancellariids, nassariids, or muricids.

A spectacular Middle Miocene bloom is also observed within the bivalve faunas. Only 140 species are recorded from the Karpatian deposits, whereas the Lower Badenian is characterized by more than 340 species (cf. Harzhauser et al. subm.). The so-called "Grund Horizon" (Grund Formation) alone contains about 270 species and has stratigraphical equivalents from eastern Austria through southern Poland to the Romanian Transylvanian Basin; its species diversity is almost two times higher than the Karpatian one. Thereafter, the species diversity underwent no further major changes during the Early Badenian, except for a slight drop. Hence, about 240 species have been recorded in the Upper Lagenidae Zone. Such a bloom within the "Grund Horizon" is a consequence of numerous first occurrences in the Central Paratethys. Hence the Middle Miocene position of the Grund Formation is well defined by the presence of taxa absent from the Karpatian sediments such as *Plicatula* (*Plicatula*) *mytilina*, *Hinnites cristatus*, *Pseudolepton bayeri*, *Lasaeina austriaca*, *Cardites partschi*, *Megacardita jouanneti*, *Donacilla cornea* and *Clausinella vindobonensis.* Additionally several taxa such as *Thyasira* (*Th.*) *michelottii* and *Arcopagia* (*A.*) *strohmayeri* seem to be restricted to the Lower Lagenidae Zone, whereas few Lower Miocene elements such as *Circomphalus haidingeri* or *Rzehakia dubiosa* become extinct in the Paratethys at the end of the Lower Lagenidae Zone. In contrast the Karpatian assemblage, differing principally by the absence of Badenian taxa and significantly lower diversity, is mainly constituted by species passing the Early/Middle Miocene boundary. Among the few exceptions becoming extinct at the end of the Karpatian is *Acanthocardia* (*A.*) *michelottiana* recorded by Čtyroký (2002) from the Korneuburg Basin.

New paleomagnetic investigations

In the locality Grund, anisotropy of low-field magnetic susceptibility documented a primary sedimentary origin of the magnetic fabric. Most of the specimens did not show a statistically significant anisotropy, and the remaining samples yielded susceptibility ellipsoids that indicated depositional fabrics: the maximum susceptibility axes (Kmax) were aligned in the horizontal plane, while the minimum susceptibility axes (Kmin) formed a cluster around the pole to the bedding plane. Magnetic lineation (Kmax/Kint) was typically below 1.01, with an average lineation of 1.001; the average magnetic foliation (Kint/Kmin) was 1.016. The results suggested the presence of a weak or moderate paleocurrent (NNW–SSE) during the time of deposition. The paleocurrent probably produced

the weak lineation by aligning the long axes of prolate grains parallel to the direction of flow.

Demagnetization yielded well-defined demagnetization paths with one or two components of NRM (natural remanent magnezation) and a good separation of the unblocking coercivity spectra. Typically, the samples were fully demagnetized at 100 mT alternating-field strengths. Characteristic remanent magnetization directions (ChRM) for single samples were determined by principle component analyses of the magnetization components observed during demagnetization. A well-grouped normal polarity component (Dec = 330°, Inc = 48°), which decayed towards the origin between 10 and 100 mT, could be isolated in 13 samples. This component could be regarded as the primary characteristic remanence direction vector.

Complementary results from sediments with the same stratigraphic age in other localities provided means for paleomagnetic significance tests (fold-test and reversals-test) in order to prove the primarity of the vector components. For instance, marls of Badenian age from the locality of Mailberg in the Molasse Basin yielded a reverse component (Dec = 145°, Inc = −47°), that is antipodal within the statistical confidence limits to the normal vector direction observed in Grund. A magnetostratigraphic section of 10 m thickness in the nearby locality Laa/Thaya showed a succession of magnetozones with a normal polarity zone covering the upper part of the section. The observed rotation values and paleo-inclinations are in accordance with previous paleomagnetic results from Karpatian deposits in Teiritzberg (Dec = 340°, Inc = 49°) and Obergänserndorf (Dec = 336°; Inc = 56°) in the Korneuburg Basin (Scholger 1998). A detailed description of the paleomagnetic results will be presented separately (Scholger 2004).

In addition to the locality Grund, complementary results of Karpatian–Badenian age (Table 1) were obtained from sites in Kuffern, Mailberg, and Laa/Thaya in the Austrian Molasse Basin. The normal part of the Laa brickyard section corresponds to the pyritized *Virgulinella* Horizon, which appears in the deep drilling Laa Thermal S-1 at a depth of 170–240 m. Other data comprise published results from sites in the Korneuburg Basin (Teiritzberg and Obergänserndorf) and new sites from the Northern Vienna Basin (Kleinhadersdorf) and the Southern Vienna Basin (Gainfarn). The easternmost part of the study area was covered by further sampling sites from the Hainburger Swell in Deutsch-Altenburg and from the Mattersburg Embayment in Rohrbach.

Discussion

During research at the Grund type locality and in the Karpatian and Badenian marine formations of the Alpine-Carpathian Foredeep, the debate on the stratigraphic position of the former Grund Beds was re-opened. The combined effort of different projects yielded new insights into the sedimentation around the Early/Middle Miocene boundary in this region (Fig. 2).

All the **Karpatian** sediments of the Laa Formation were deposited within the range of nannoplankton Zone NN4. Foraminifers do not give exact stratigraphic correlations. The Upper Karpatian can be approximated with the *Globigerinoides bisphericus* level, whereas for the regional correlation the first appearance of *Uvigerina graciliformis* defines the base of the Karpatian. The occurrence of *Loxoconcha vaisonna* in the ostracod assemblages is characteristic for the Karpatian, as is also the case with certain gastropod species such as *Agapilia pachii, Turritella bellardii*, and *Clavatula barbarae.*

The **Badenian** transgression follows after a gap and is recorded from deep wells only. Sediments consist mainly of clastic deposits attributed to nannoplankton Zone NN4. The top of NN4 is defined by the last appearance of *Helicosphaera ampliaperta*. In these wells a continuous sedimentation up into Zone NN5 is documented. The record of *Helicosphaera waltrans* is most important for the definition of nannoplankton Zone NN5 and the correlation with the Mediterranean Basin. In prospection well NÖ-06, in the Krems embayment, it was possible to document the appearance of the planktonic foraminifer *Praeorbulina glomerosa glomerosa* within NN4.

The fine clastic **Grund Formation** in Roggendorf-1 follows with a distinct discordance and is underlain by a coarse transgressive conglomerate. The Grund Formation in this well and in the type locality Grund is characterized by a rich nannoflora of NN5, with *H. waltrans*. A similar nannoflora is recorded from the Gaindorf Formation at Mühlbach. In the sections at Grund, very scarce *Praeorbulina glomerosa circularis* are present and give a good correlation with the nannoplankton stratigraphy. In higher parts of the Grund Formation, and in the Gaindorf and Mailberg Formations, highly evolved *Po. glomerosa circularis* and *Orbulina suturalis* occur together. This marks the base of planktonic foraminiferal Zone M6/Mt6. The benthic marker *Uvigerina macrocarinata* appears in the Lower Badenian together with the last occur-

Table 1: New magnetostratigraphic results from the Lower and Middle Miocene in Northern Austria.

Site	WGS84E	WGS8N	Tectonic Unit	Stratigraphy	Lithology	Polarity
Grund	16.059	48.639	Eastern Molasse Basin	Badenian	clay, silt	normal
Kuffern	15.653	48.317	Eastern Molasse Basin	Badenian	clay, sand	normal
Mailberg	16.157	48.671	Eastern Molasse Basin	Badenian	limy marl	reverse
Laa/Thaya, upper section	16.411	48.718	Eastern Molasse Basin	Karpatian	clay, silt	normal
Laa/Thaya, lower section	16.411	48.718	Eastern Molasse Basin	Karpatian	clay, silt	reverse
Kleinhadersdorf	16.594	48.661	Northern Vienna Basin	Badenian	silt	normal
Gainfarn	16.176	47.950	Southern Vienna Basin	Badenian	silt, clay	normal
Deutsch-Altenburg	16.884	48.129	Hainburg Swell	Badenian	limestone	normal
Rohrbach	16.435	47.719	Mattersburg Embayment	Badenian	clay	normal

rence of *U. graciliformis*. Toward the top of the Grund Formation a strong increase in species diversity and warm-water indicators of calcareous nannofossils and foraminifers can be observed.

Ostracods and molluscs have also been studied from outcrops in the Grund, Gaindorf, and Mailberg Formations. Here as well, the strong increase in faunal diversity compared to the Karpatian Laa and Korneuburg Formations is remarkable. A number of different Ostracoda are only known from these Badenian formations, together with the index fossil *Acanthocythereis hystrix*. From the molluscan assemblages, the first Badenian appearance of species such as *Cerithium procrenatum* and *Plicatula (Plicatula) mytilina* has to be mentioned.

Paleomagnetic results support the biostratigraphic results. A reverse and normal sequence was measured in a continuous section from the Karpatian Laa Formation in the Laa brickyard. Compared with the stratigraphic time scale of Berggren et al. (1995), the lower, reverse part is doubtfully interpreted, eventually it may correspond to Chron C5Cr, whereas the normal measurements are correlated to Chron C5Cn.2n (16.327–16.488 Ma). The normal chron also comprises the upper part of the Karpatian as measured in the Korneuburg Formation (Scholger 1998). These results compare well with paleomagnetic measurements in the Carpathian Foredeep, in the deep drilling Nosislav-3 (Kropáček & Malkovský 1992). A continuous section showed changes of reverse and normal magnetization for the Karpatian (66–280 m). The interpretation of chrons (Table 2) is adapted according to Kropáček & Malkovský (1992) and to the paleomagnetic measurements of the Ottnangian of the West Styrian Basin (Mauritsch & Scholger 1998).

The paleomagnetic measurements of Badenian sections can be correlated only based on the above-reported biostratigraphic investigations. In the Grund Formation *P. glomerosa circularis* occurs (locality Grund), followed slightly higher by *O.*

Table 2: Magnetostratigraphic results from well Nosislav-3, Carpathian Foredeep (Kropáček & Malkovský 1992), correlated with the Austrian Molasse Basin and the Styrian Basin. (Interpretation of chrons according to Berggren et al. 1995.)

Stage	Nosislav-3 drill depth	Polarity	Chron	Austrian localities
Karpatian (NN4)	66–70 m	reverse	C5Cn.2r	
	70–130 m	normal	C5Cn.3n	Korneuburg; Laa, upper part
	130–140 m	reverse	?	Laa, lower part ?
	140–240 m	normal	C5Cn.3n	
	240–280 m	reverse	C5Cr	
Ottnangian (NN3–4)	280–335 m	normal	C5Dn	West Styrian Basin (Oberdorf)

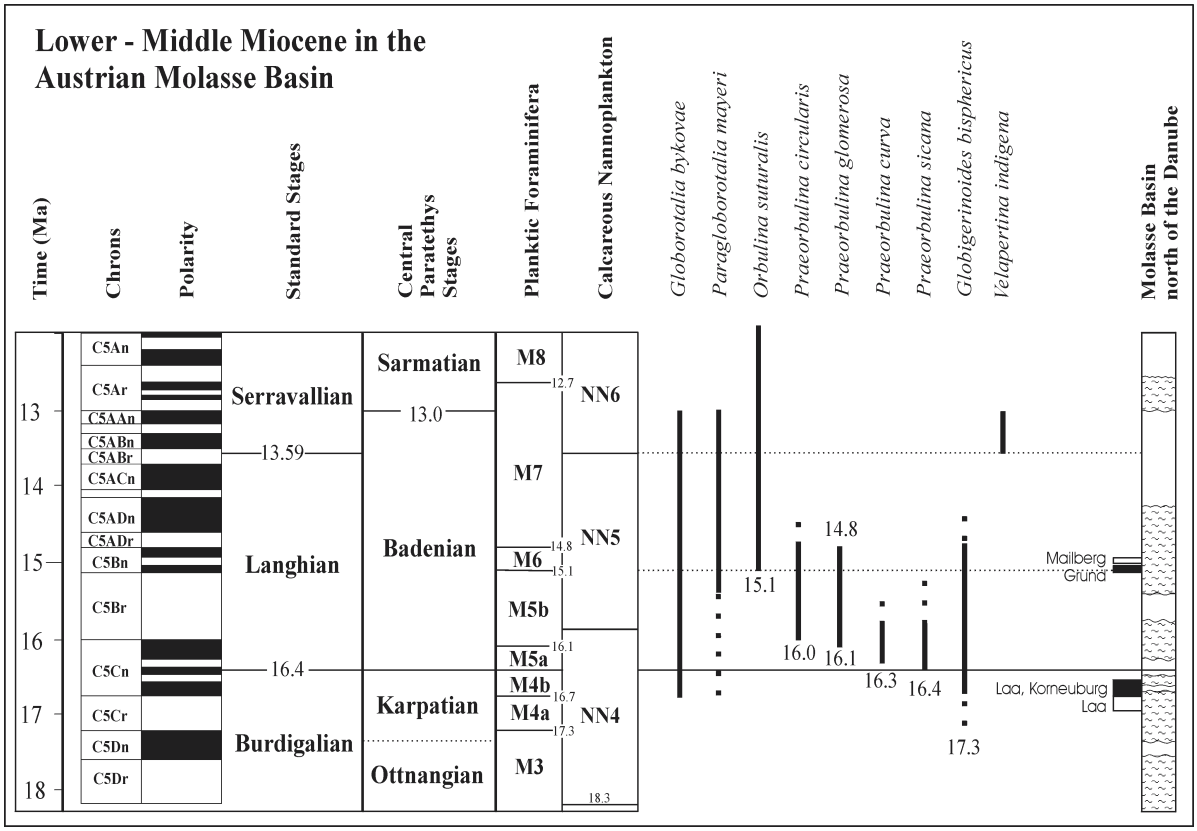

Fig. 2. Integrated stratigraphy of the late Lower and Middle Miocene in the Alpine-Carpathian Foredeep (Austrian Molasse Basin), and new magnetostratigraphic results. Chronostratigraphy, paleomagnetic polarity, planktonic foraminiferal zonation, and time span of planktonic index species according to Berggren et al. (1995), nannoplankton zonation according to Martini (1971) and Young (1998); position of Langhian-Serravallian boundary according to Sprovieri et al. (2002).

suturalis. The magnetic normal therefore corresponds to Chron C5Bn.2n (15.034–15.155 Ma). The reverse measurement in the Mailberg Formation is correlated by the occurrence of *O. suturalis* with Chron C5Bn.r. (comp. Berggren et al. 1995).

There was no continuous sedimentation between the Karpatian and the Lower Badenian Grund Formation in the Alpine-Carpathian Foredeep. The Grund Formation is, however, separated from the underlying Laa Formation not only by a long-lasting gap (more then 1 Ma), but also by a hitherto unknown first basal Badenian transgression event.

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