Stratigraphic correlation of the Late Eocene to Early Miocene of the Waschberg Unit (Lower Austria) with the Zdanice and Pouzdrany Units (South Moravia)

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Abstract: The Waschberg Unit is positioned at the front of the Alpine-Carpathian nappe system and is related to the Outer West Carpathian thrust sheets of the Zdanice and Pouzdrany Units. Based on facies and microfossil content a stratigraphic correlation is presented. The facies development was influenced, besides the influence of the tectonic movements, by changing paleoenvironment of the Paratethys sea during Oligocene and Miocene. From open marine conditions in the Late Eocene (NP 19/20–NP 21), restricted circulations in the Early Oligocene changed the sedimentation from *Globigerina* marls to laminated and banded marls and clays (NP 22) with increasing dysaerobic bottom conditions. In the laminated marls a pteropod horizon (*"Spiratella"* = *Limacina* horizon) correlates throughout the Central Paratethys. A maximum of restricted circulation is reached during the deposition of diatomite ooze and coccolith ooze composed of nearly monospecific palaeoassemblages of calcareous nannofossils (NP 23). Strong run-off from the continent caused a stratification of the water column and brackish surface conditions, connected with deposition of brackish diatoms. Nannofossil carbonates which originated as coccolith ooze represent a marker horizon which can be traced as the Dynow Marlstone from the Austrian Molasse Basin to the Carpathians, and additionally yields a level with endemic bivalves (*"Cardium lipoldi"*-fauna) and ostracods (Cyprididae), correlatable to the Eastern Paratethys.

Discordantly follows clastic sedimentation of dark variegated shales. Slumps and pebble deposits in the basal part are connected to the sea-level fall at the base of the TA 4.5 eustatic cycle ("Sitborice Event"). The sedimentation change started in the uppermost NP 23 and ended in the Pouzdrany Unit in the Late Egerian (NP 25/NN 1?), in the Waschberg Unit in the Early Egerian (lower NP 25), whereas in the Zdanice Unit a change to flysch sedimentation (Krosno facies) occurred already during NP 24/25.

In the Early Miocene (nannoplankton zones NN 1–2) a similar marly sedimentation in all three units is caused by sea-level rises during TB 1.4 and TB 1.5 eustatic cycles. Only in the Late Eggenburgian to Ottnangian stronger differences are observed. The flysch sedimentation of the Krosno facies shifted from the Zdanice Unit westward to the Pouzdrany Unit. In the Waschberg Unit, the facies of the "Schieferige Tonmergel" lithostratigraphic unit differs in the eastern part where marly, fossiliferous deposits are developed, and in the more western region where flysch

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deposits occur. The Late Ottnangian ended in the entire area with a horizon of alternating non-calcareous shales and limonitic siltstones, probably sedimented under reduced salinity conditions. These sediments are present also in the Roseldorf subunit of the westernmost Waschberg Unit. In the Roseldorf subunit these shales top a sandy and clayey marine sedimentation (NN 3–4), which was compared formerly with the brackish "*Oncophora*" Beds of the Molasse Basin.

Piggy-back basins developed in the Zdanice Unit already in Eggenburgian, and on top of the Waschberg Unit beginning with the Karpatian Laa Formation, which is also present in the Pouzdrany and Zdanice Units. Younger sediments were deposited during times of connection between the Vienna Basin and the Molasse Basin or Carpathian Foredeep. From the paleoenvironmental point of view the sedimentary development and biofacies of the Waschberg Unit represents a transition between those of the Zdanice and the Pouzdrany Units.

Zusammenfassung: An der Außenseite der alpin-karpatischen Front liegen die Decken der Waschberg, Zdanice und Pouzdrany Einheiten, mit engen Beziehungen zu der Westkarpaten. In den tektonisch stark gestörten Einheiten wurde versucht eine Korrelation der oligozänen und untermiozänen Ablagerungen basierend auf Fazies und Mikrofossilinhalt durchzuführen. Die Faziesentwicklung ist von den paläogeographischen Veränderungen innerhalb der Paratethys stark beeinflußt. Im jüngsten Eozän (NP 20–NP 21) herrschte im Untersuchungsgebiet eine Sedimentation von hochmarinen Globigerinenmergeln. Abschnürungen der Paratethys von den offenen Ozeanen im unteren Oligozän führten zu starken Veränderungen, verbunden mit einer Stratifizierung der Wassersäule und eingeschränkter Bodenzirkulation. Zunächst wurden marine, laminierte und dünngebankte Mergel und Tone abgelagert (NP 22). In ihnen tritt ein Pteropoden-Horizont ("*Spiratella*" = *Limacina* Horizont) auf, der eine Korrelation innerhalb der Zentralen Paratethys ermöglicht. Starker Süßwasserzufluß verursachte eine Trennschicht mit brackischem Oberflächenwasser, Reduktion der Zirkulation und sauerstoffarme Bodenbedingungen. Über marinen Diatomiten wurden brackische Diatomite und dann pelagische Mergel mit fast monospezifischem Nannoplankton (NP 23) abgelagert. In diesem Mergelpaket des "Dynow Marlstone" liegt ein endemischer Ostracoden- und Bivalvenhorizont mit der sogenannten "*Cardium lipoldi*" Fauna, der einen Korrelationshorizont bis in die Östliche Paratethys darstellt.

Mit einer Schichtlücke folgt ein Umschwung in der Sedimentation zu fein-pelitischen Ablagerungen. Im basalen Teil der Schichtfolge auftretende Rutschmassen und Gerölle werden mit der Regression an der Basis der Meeresspiegelschwankung TA 4.5 korreliert ("Sitborice Event"). Der neue pelitische Sedimentationszyklus beginnt in der oberen Nannoplanktonzone NP 23 und endet in den verschiedenen Einheiten unterschiedlich. In der Pouzdrany Einheit reichen diese Ablagerungen bis ins Untermiozän (jüngeres Egerium), während sie in der Waschberg Einheit nur bis zur unteren NP 25 reichen. Am frühesten kommt es in der Zdanice Einheit zu einem Fazieswechsel. Es folgen ab dem Übergang NP 24/25 Flyschablagerungen, die mit der karpatischen Krosno-Fazies verglichen werden.

Im Untermiozän (Nannoplanktonzone NN 1–2) breitete sich eine ziemlich einheitliche Sedimentation mit kalkigen Tonen und Mergeln aus, die mit den Transgressionen während der eustatischen Zyklen TB 1.4 und TB 1.5 in Verbindung stehen. Darüber folgen unterschiedliche lithologische Einheiten. Die Flyschsedimentation verlagerte sich im Eggenburgium von der Zdanice Einheit nach Westen in die Pouzdrany Einheit. In der Waschberg Einheit beinhalten die "Schieferigen Tonmergel" des Eggenburgium und Ottnangium verschiedene lithologische Untereinheiten, mit mikrofossilführenden Mergeln im Osten und flyschoiden Ablagerungen im Westen. Im oberen Ottnangium bildet sich in der Zdanice und Pouzdrany Einheit ein einheitlicher Horizont mit bunten, dunklen, kalkfreien Tonen und dazwischen eingeschalteten limonitischen Siltlagen aus. Dieser Horizont tritt auch in der Waschberg Einheit in der Roseldorf Untereinheit auf, deren Ablagerungen früher mit den brackischen "*Oncophora*" Schichten der Molasse verglichen wurden. Es konnten aber marine Foraminiferen und Nannoplankton der Zone NN 3–4 nachgewiesen werden. Die Roseldorf Untereinheit stellt den westlichsten Teil der Waschberg Einheit dar.

Auf den überschobenen Decken der untersuchten Einheiten finden sich ab dem Untermiozän Ablagerungen in einer piggy-back Position, die eine Verbindung zwischen dem Wiener Becken und der Molassezone und der Karpatenvortiefe darstellen. Zuerst wurden im Eggenburgium auf der Zdanice Einheit marine Mergel abgelagert, dann ab dem Karpatium auch auf der Waschberg und Pouzdrany Einheit. Die Waschberg Einheit nimmt vom Gesichtspunkt der paläoökologischen und sedimentologischen Entwicklung eine Zwischenstellung im Ablagerungsraum zwischen Zdanice und Pouzdrany Einheit ein.

Keywords: Waschberg Unit, Zdanice Unit, Pouzdrany Unit, Paratethys, Late Eocene, Oligocene, Miocene

Contents

1. INTRODUCTION

Along the front of the Alpine-Carpathian nappe system, the Waschberg Unit in Lower Austria continues towards northeast in southern Moravia in the Zdanice Unit, which is overthrust on the Pouzdrany Unit. The Waschberg Unit originally has been named as "Äussere Klippenzone", and was renamed by GRILL (1953) as Waschbergzone, according to the "Waschberg-Nikolsburger Zone" of TERCIER (1936). It was considered to be part of the Molasse Basin, with Oligocene sediments as the matrix of imbricated tectonic klippen of stratigraphically older rocks (e.g., STUR, 1894; KOHN, 1911; GLAESSNER, 1931; SCHAFFER, 1951). The embedding sediments (clays, shales, marls, and sandstones) have been correlated with the "Auspitzer Mergel", the Hustopece Marls in southern Moravia. GRILL (1953) doubted the Oligocene age, and was the opinion that Early Miocene may

be included, which was confirmed as Burdigalian (GRILL, 1962, 1968; BRIX & GÖTZINGER, 1964).

The Waschberg Unit is considered by many Austrian geologists as continuation of the allochthonous Molasse or imbricated Molasse in front of the Alps (comp. STEININGER et al., 1986). But it is continuous in the Zdanice Unit in southern Moravia, which is there an outer Flysch nappe, lithologically advancing in the Subsilesian Flysch of the West Carpathians (comp. ROTH, 1974; ELIAS et al., 1990). Therefore already BRIX & GÖTZINGER (1964) discussed the term "Subkarpatische Molasse". South of the Danube, extending along the Alpine front to the west, a belt of allochthonous, imbricated Molasse is thrust northward upon the autochthonous Molasse (KRÖLL & WESSELY, 1967; WAGNER et al., 1986). The main difference to the Waschberg Unit is that the Mesozoic imbrications, scrapped off from the Molasse basement, primarily the Upper Jurassic limestones are missing in the allochthonous Molasse (BRIX et al., 1977).

In a comparison with the South Moravian Pouzdrany and Zdanice units similarities and differences of the Waschberg and Molasse units are demonstrated in this paper.

2. GEOLOGICAL SETTING AND LITHOSTRATIGRAPHIC SUBDIVISION

The Waschberg Unit represents a distinct tectonic unit between the autochthonous Molasse Basin and the thrustbelt of the Eastern Alps and Western Carpathians (Fig. 1). It is thrust northwestwards over Lower Miocene (Karpatian) Molasse sediments, and deeps down to the southeast under the Rhenodanubian Flysch. In a sequence of Neogene and partly Oligocene marine deep-water sediments different tectonical wedges of older rocks from Late Jurassic to Oligocene are imbricated. The strongly imbricated, folded and thrust-faulted unit extends from the Waschberg near Stockerau to the Austrian border near Mikulov, outcropping for about 50 km length and with a strongly varying width of 4 to 12 km. In the southern part exists a subdivision in two distinct subunits. The outer unit (Roseldorf Zone, WESSELY, 1998) is thrust onto the Molasse Basin along the Senning thrust, and consists of the youngest sediments of Late Ottnangian age. The inner unit, overthrust to the northwest along the Leitzersdorf thrust consists of Late Egerian to Ottnangian sediments which are imbricated with Mesozoic and older Paleogene rocks. Extensive hydrocarbon exploration threw light upon the internal tectonics of the unit, which deeps down to the southeast under the flysch nappes, down faulted in the area of the Vienna Basin (KAPOUNEK et al., 1965; WESSELY, 1993).

To the northeast the Waschberg Unit has its continuation in the Zdanice Unit in southern Moravia. This is a higher nappe of the Outer West Carpathians, overthrust to the northwest onto the Pouzdrany Unit. This later unit is interpreted as a marginal thrust sheet, thrust itself on the autochthonous sediments of the Carpathian Foredeep. The tectonic position of these units is demonstrated by a series of cross-sections by KREJCI & STRANIK (1992).

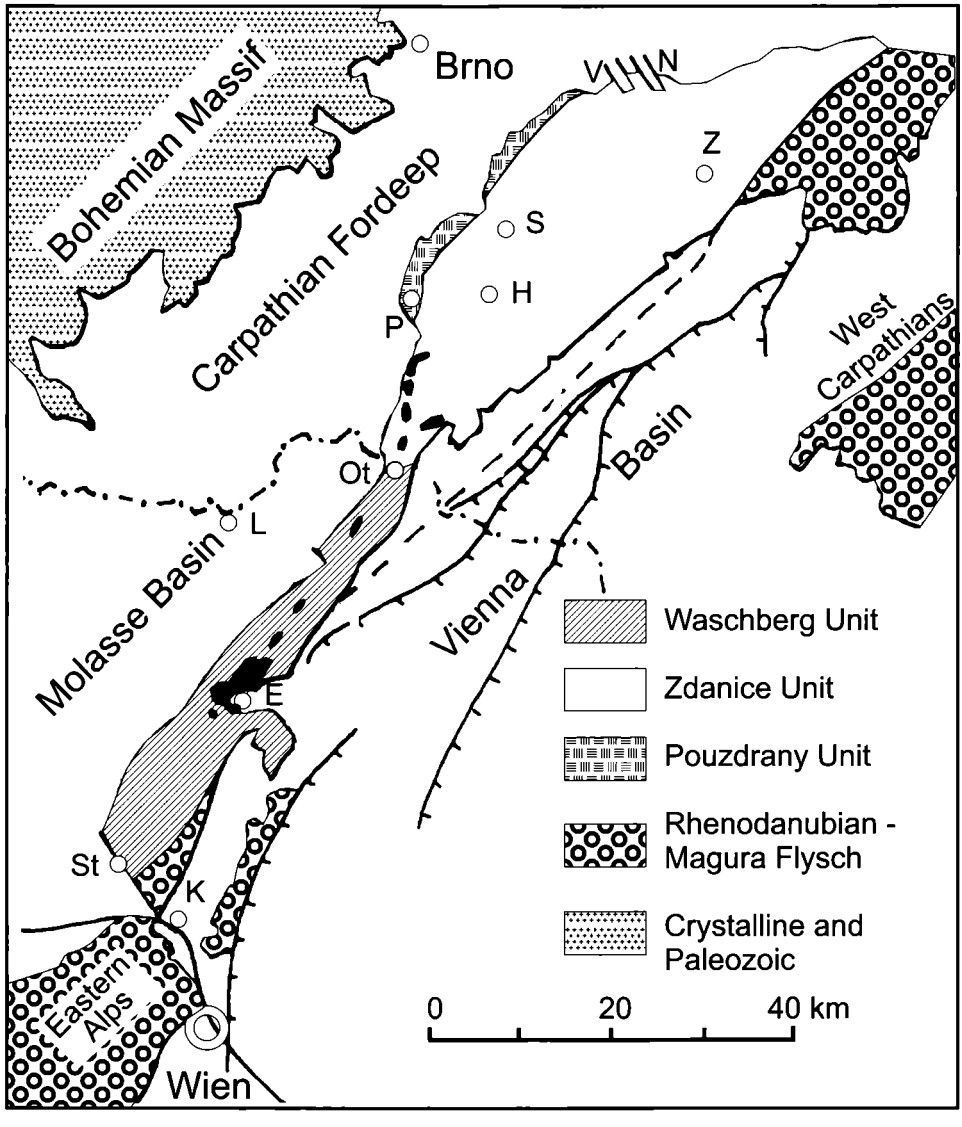

Fig. 1: Geological sketch with the position of Waschberg, Zdanice and Pouzdrany Units at the front of the Alpine-Carpathian system, overthrust onto the Molasse Basin and the Carpathian Foredeep. The Vienna Basin is a pull-apart basin down-faulted in the Alpine-Carpathian nappe system (acc. to HAMILTON et al., 1990).
Explanations: black spots = Mesozoic klippen; abbreviations: E = Ernstbrunn, H = Hustopece, K = Korneuburg, L = Laa, N = Nesvacilka Graben, P = Pouzdrany, S = Sitborice, St = Stockerau, V = Vranovice Graben, Z = Zdanice.

2.1. Waschberg Unit

In the Waschberg Unit the Mesozoic and Paleogene lithostratigraphic units are discontinuous and truncated in the imbricated tectonical wedges, whereas the younger deposits are represented by a nearly complete sequence of the Upper Egerian to the Ottnangian (GRILL, 1968; BRIX et al., 1977; SEIFERT, 1993). The present discussion of the correlation of the Waschberg Unit is restricted to the Late Eocene/Early Oligocene to Early Miocene formations, beginning with the first stage of Paratethys development (RÖGL, 1998).

2.1.1. Reingrub Formation

Late Eocene rocks are found isolated in a few places, mostly in the southern part of the Waschberg Unit. The most important is the "Reingrub series" with sandstones and sands at the Reingruberhöhe, the type locality of nannoplankton zone NP 19 (MARTINI, 1971). Near the village Niederhollabrunn the tectonic klippen of the Pfaffenholz Beds and the Hollingstein Limestone are present. The Pfaffenholz Beds are known also as limestone with *Mytilus levesquei*. In a brown sandy shale layer of these beds *Discocyclina* sp. and rhodoliths have been found. Both units are dated as Late Eocene according to molluscs (BACHMAYER, 1961; CTYROKY, 1966). A continuous sedimentary record of the Eocene to the Oligocene is missing. Southwest of Simonsfeld, Eocene brown-grey to green-grey calcareous shales with intercalated nummulitic sandstones (probably "Reingrub series") are reported by STRANIK (1997). He considers a continuation of the sedimentation into the Early Oligocene with brownish marls including layers of green clay. This sequence, encompassing also the Middle Eocene "Haidhof Beds" was correlated by STRANIK (1997) with the Nemcice Formation ("Niemtschitzer Schichten"). To classify the Upper Eocene sedimentation of the Waschberg Unit a formal lithostratigraphic definition of the "Reingruber Serie" is proposed here:

Reingrub Formation

Type area: Waschberg Unit (Fig. 1).

Type section: old quarry at Reingruberhöhe (Raingrubenhöhe) N Bruderndorf (ÖK 50/ sheet 40 Stockerau).

Coordinates: 48°29'33" N, 16°18'33" E, 322 m.

Synonymy: Reingruber Serie (GRILL, 1953, p.89), Sande und Sandsteine der Reingruberhöhe (GRILL, 1962, p.21), Nemtschitzer Schichtenfolge (STRANIK, 1997, p.291).

Lithology: According to Rzehak (1891) and GRILL (1962) the Late Eocene sediments of the type section consist from bottom to top of glauconitic sand, *Discocyclina* limestone, and "Hauptsandstein", main sandstone (orbitoid limestone and bryozoan bed in RZEHAK). The lithologic variation of the formation includes also yellowish fine sands at Haselbach (GRILL, 1957, 1962), and brown-green and greenish-grey calcareous shales with interbedded layers of light brown calcareous sandstone containing *Nummulites* and *Discocyclina* (STRANIK, 1997), in the area SW of Simonsfeld (ÖK 50/sheet 23 Hadres).

Chronostratigraphic age: Late Eocene, Priabonian.

Biostratigraphy: Reingruberhöhe is the type locality of calcareous nannoplankton zone NP 19 (MARTINI, 1971, p.759), with a rich coccolith assemblage (STRADNER, 1962; PERCH-NIELSEN et al.,

1985). Stratigraphically important is the first occurrence of *Istmolithus recurvus*; newly described from here are, e.g., *Orthozygus aureus, Lanternithus minutus*, and *Trochoaster conglobatus*. Other common species are *Cribrocentrum reticulatum, Dictyococcites bisectus, Reticulofenestra umbilicus, Pontosphaera multipora, Blackites spinosus, Markalius inversus*, and *Braarudosphaera bigelowii*. Discoasters are extremly rare. The foraminiferal fauna, mainly smaller benthics from the glauconitic sands were described by GOHRBANDT (1962). Planktic foraminifera from these sands (*Subbotina linaperta, S. yeguaensis, Globigerinatheka index, Turborotalia cerroazulensis*) indicate zone P 16. Larger foraminifera, as *Nummulites* (PAPP, 1958), discocyclinas, and actinocyclinas are found in the sandstones. A rich mollusc fauna from the glauconitic sands was investigated by SIEBER (1953).

Thickness: not recognized because of tectonic position, at the quarry some 10–15 m.

Base unit: clayey sand (tegeliger Sand of RZEHAK, 1891); according to the preserved material in the Museum of Natural History Vienna it is a rusty, clayey coarse sand with some reworking of Late Cretaceous (type sample of *Pseudotextularia elegans*); according to GOHRBANDT (1962, p.60) the sediment is Late Paleocene in age. These sediments belong to the Zaya Formation of SEIFERT et al. (1978).

Superimposed unit: Melettamergel (RZEHAK, 1891); Auspitzer Mergel (GRILL, 1962); "Schieferige Tonmergel" (this paper). Grey to blue-grey calcareous silty shales with some fish scales and a scarce foraminiferal fauna, considered by RZEHAK (1888) as possibly reworked.

Remarks: The isolated Late Eocene klippen of the Pfaffenholz Beds and the Hollingstein Limestone are considered as distinct lithologic units of the Reingrub Formation. The definition as lithostratigraphic members needs further investigations.

2.1.2. Ottenthal Formation

In the area of the Waschberg Unit some tectonical wedges of Oligocene sediments are imbricated, originally considered to be of Late Eocene age. The first record was given by JÜTTNER (1938, 1940) for the region of Ottenthal, and sediments have been compared with the "Pausramer Schiefer" in southern Moravia. These sediments, recorded also from the area of Ernstbrunn, Loosdorf, Staatz, Altruppersdorf, and in deep well Ameis 1 (1225–1230 m), including *Globigerina* marls, diatomites, and menilites were then correlated to the "Niemtschitzer Schichten", according to the sequences at Velke Nemcice, and dated as Late Eocene to earliest Oligocene (GRILL, 1953, 1968; STRADNER, 1962). For the complete sequence SEIFERT (1980, 1982) introduced the formation "Ottenthaler Schichten". As type section the carriage road to Klein-Schweinbarth E of Ottenthal, at the "Untere Leithen" was selected. From this section calcareous nannoplankton (STRADNER & SEIFERT, 1980), Archaeomonadacea (BRAUNSTEIN, 1985) and some microfossil associations were described (PERCH-NIELSEN et al., 1985). In a thesis the sedimentology and biostratigraphy of the "Ottenthaler Schichten" was investigated (HERLICSKA, 1989). The interesting occurrence of the "*Cardium lipoldi* fauna" conducted the correlation of the section with sequences in northern Hungary (SEIFERT et al., 1991). The original definition was revised by RÖGL et al. (1997) and restricted to the stratigraphically lower part, corresponding to nannoplankton zones NP 21–23. In a recent study the Ottenthal-Formation is subdivided into different members (RÖGL et al., this volume).

Stratigraphic range: (Late Eocene? to) Oligocene, (Late Priabonian? to) Early Kiscellian, NP 21–lower NP 23.

Ottenthal Member (SEIFERT, 1982): The lower part of the member consists of massive, light grey to brownish marls (*Globigerina* marl) with rich calcareous nannoplankton and planktic foraminifera assemblages. The upper part consists of layers of yellowish and dark brown laminated marls, partially with interbedded dark brown to black bituminous non-calcareous clay. Thin brown or rusty limonitic laminae of fine sand and silt are common. Pteropods (*"Spiratella"* = *Limacina*) occur in a distinct horizon. Nannoplankton and foraminifera show a reduction in species number and blooms of single species, caused by ecological stress.

A distinct Eocene age in the *Globigerina* marl facies is not yet proved, as *Hantkenina* or *Turborotalia cerroazulensis/cunialensis* are missing, and nannoplankton zone NP 21 spans the Eocene/Oligocene boundary. In the lowermost part the occurrence of *Coccolithus formosus, Clausiococcus subdistichus,* and *Istmolithus recurvus* enable a determination of NP 21. Planktic foraminiferal assemblages consist of large species with common subbotinas, catapsydracids, and globigerinas (e.g., *Subbotina cryptomphala, S. gortanii, S. prasaepis, Globigerina? ampliapertura, Catapsydrax unicavus*) and stratigraphically important species (*Pseudohastigerina praemicra, Chiloguembelina* cf. *cubensis, Cassigerinella chipolensis*). In the upper part, nannoplankton zone NP 22 is reported with blooms of *Cyclicargolithus floridanus* and *Dictyococcites hesslandii*. Planktic foraminiferal assemblages show mass occurrences of small specimens of *Globigerina officinalis, G. ouachitaensis, G. praebulloides,* and *Tenuitella? danvillensis*.

Stratigraphic range: Late Eocene? to Early Oligocene, latest Priabonian? to Early Kiscellian, nannoplankton zone NP 21–22.

Galgenberg Member (RÖGL et al., this volume): Instead of the terms "diatomites", "Menilit Schichten" or "Chert member" a new lithostratigraphic name is introduced.

At the base of the Galgenberg Member a horizon of non-calcareous shales with a few thin calcareous laminae occurs (and may be correlated with such a layer in the Zdanice and Pouzdrany Units). With the top of the Ottenthal Member the base of the member is dated as upper NP 22, planktic foraminifera zone P 18/19. The contact with diatomites and cherts is tectonized in all outcrops. The siliceous deposits begin with marine diatomites and are followed by brackish diatomites with a dominance of *Aulacoseira praeislandica*. Abundant Archaeomonadacea are reported by BRAUNSTEIN (1985). In a shale bed below the marine diatomites abundant radiolarians (nasselariids) were found. The top of this member at the known outcrops is likewise tectonised so that an exact boundary or transition to the following nannofossil chalks of Dynow Marlstone cannot be studied.

Stratigraphic range: Oligocene, Early Kiscellian, upper NP 22–lower NP 23, P 18/19.

Dynow Marlstone: This lithologic unit was first described from the Polish Carpathians (KOTLARCZYK, 1979). In the middle to lower bathyal sedimetary areas, as are those in the Polish Carpathians, these deposits are developed as a whitish to light grey, layered marlstone, sometimes brown and silicified. The marlstones originate from coccoliths

(nannofossil-chalk), commonly heavily recrystallised. The assemblages of the calcareous nannofossils are of low diversity, the rock forming species is *Dictyococcites ornatus*, characteristic species are *Transversopontis fibula* and *T. latus.* At Ottenthal locality the nannofossil chalks contain commonly diatoms, and in some places silicified layers which originated from diagenetically mobilised biogenic silica. Some smooth-shelled ostracods (Cyprididae) and a small bivalve fauna, endemic to the Paratethys, with *Cardium (Loxocardium?) lipoldi, Janschinella melitopolitana,* and *Janschinella* sp., can be found. The blooms of *Dictyococcites ornatus* with ostracods and brackish bivalves present an extraordinary good bioevent which enables correlation throughout the entire Central and Eastern Paratethys (Seifert et al., 1991; Popov et al., 1993).

Stratigraphic range: Oligocene, Middle Kiscellian, NP 23.

2.1.3. Thomasl Formation

The type section of the Thomasl Formation is positioned in core 3 (1760–1765 m) of the deep drilling Thomasl 1 (Papp et al., 1978). A revision of this formation is given by Fuchs et al. (this volume). The thickness of the formation in Thomasl 1 is nearly 130 m. The lithology consists of dark, variegated brownish to greenish-grey, calcareous and non-calcareous, commonly sandy shales and some sandstone layers. Cretaceous to Eocene reworking was observed. In the surface outcrops (e.g., Ottenthal sections) gypsum occurs commonly, and along cleavages yellowish veins of the iron sulfate Jarosite. The most interesting feature in this formation is the "Sitborice Event" (Krhovsky & Djurasinovic, 1993), represented by slump bodies of shales, gravels and sand, including Dynow Marlstone pebbles. This episode of submarine erosion was for the first time documented from the basal part of the Sitborice Member in the Zdanice Unit.

The autochthonous microfauna has some similarities with the Puchkirchen Formation of the Molasse Basin and with the Kiscell Clay in Hungary. Stratigraphically important amongst planktic species are *Paragloborotalia opima opima, Globigerina ciperoensis, G. wagneri, Tenuitella gemma, T. munda,* and *Beella rohiensis*; characteristic benthics are e.g., *Psammosiphonella cylindrica, Haplophragmoides carinatus, Reticulophragmium amplectens, Marginulina behmi, Bolivina beyrichi carinata, Uvigerina hantkeni, U. moravia, U. oligocaenica, U. steyri, Bulimina alsatica,* and *Virgulinella chalkophila.* Nannoplankton blooms of *Cyclicargolithus abisectus, C. floridanus,* and *Reticulofenestra lockerii* occur in laminated parts. Stratigraphically important are *Transversopontis pygmaeus, Dictyococcites bisectus, Helicosphaera recta,* and *Sphenolithus distentus.* Fish remnants are frequent. A deep water environment with partly oxygen depleted bottom conditions is interpreted from sediments and microfossils.

Stratigraphic range: Oligocene, Late Kiscellian to Early Egerian, upper NP 23 to lower NP 25, P 20 to lower P 22.

2.1.4. Michelstetten Formation

This formation has been described as "Michelstettener Schichten" by Grill (1952; 1968). A series of light grey to greenish silty marls, with a knobby weathering extends

along the outer rim of the Leiser Berge, best outcropping NW of Michelstetten. Originally considered as Early Oligocene, the stratigraphic range was corrected to Chattian-Aquitanian. Recent investigations of calcareous nannoplankton in surface outcrops point to a still younger age. The marls have a rich and characteristic microfauna, dominated by large benthic species (PAPP, 1960). The foraminiferal fauna compares with that of the Late Egerian in Hungary, but also with the Early Eggenburgian in the Pouzdrany Unit and in the Transylvanian Basin. In deep drillings of the Roseldorf subunit beds with quartz sands, sandstones and gravels were ascertained. The microfauna of these beds is comparable to that of the Michelstetten Formation. In these drill sites nannoplankton zone NP 25 has been recorded (R. Braunstein, pers. comm.). The beds are in a tectonic position, without known sedimentary contact to the underlying Thomasl Formation. The thickness of the formation is approximately between 100 and 150 m (FUCHS et al., 1980).

Some samples have been studied in the type area northwest of Michelstetten, N Steinmandl (at the northern carriage road to Phyra). Calcareous nannofossils were studied of light grey silty marls from the fields near the pathway (coll. KRHOVSKY, 1996). Sample 1: *Helicosphaera euphratis, H. scissura, H. mediterranea, Pontosphaera multipora, Reticulofenestra pseudoumbilicus, R. excavata, Pyrocyclus hermosus, Sphenolithus capricornutus, Triquetrorhabdulus carinatus*; NN 1; sample 2 (100 m W of sample 1): *Helicosphaera* cf. *ampliaperta*; NN 1–2; sample 3 (200 m W of sample 1): *Helicosphaera ampliaperta, H. kamptneri, H. mediterranea, Cyclicargolithus abisectus*; NN 2. At the pathway to Phyra, in the light grey silty marls from the fields, calcareous nannoplankton assemblages with *Helicosphaera ampliaperta, H. scissura, H. mediterranea,* and *Reticulofenestra excavata* were ascertained, indicating NN 2–3.

Foraminiferal assemblages from light grey and brownish silty to sandy clay at Michelstetten, N Steinmandl yield plankton with *Globigerina praebulloides, G. ottnangiensis, G. ouachitaensis, G. connecta, G. dubia, Globigerinoides cf. trilobus, Catapsydrax* sp., *Tenuitella minutissima, T. pseudoedita, Cassigerinella boudecensis*, and rich benthic faunas with *Uvigerina popescui* (abundant), *U. parviformis, Fontbotia wuellerstorfi*. The occurrence of *U. popescui* correlates with the Chechis Clay in the Transylvanian Basin (Eggenburgian).

Stratigraphic range: Late Oligocene to Early Miocene, Egerian to Eggenburgian, NP 25 to NN2.

2.1.5. Schieferige Tonmergel

The most extended formation in the Waschberg Unit are layered and well bedded, grey to greenish grey and light brown silty shales, with micaceous bedding planes. Sands and turbiditic sandstone layers with trace fossils are intercalated. Diatomaceous shales and menilites occur locally. This formation was called "Auspitzer Mergel", and "Schieferige Tone und Tonmergel" (GRILL, 1962, 1968), and BRIX & GÖTZINGER (1964) proposed the term "Ernstbrunner Tonmergelserie". It is not possible to use the term Ernstbrunn Formation, as this name is pre-occupied by "Ernstbrunner Schichten" for the Late Jurassic "Upper Carbonate Series", including the Ernstbrunn Limestone (BRIX et al., 1977; ELIAS & WESSELY, 1990). At the moment the informal term "Schieferige Tonmergel" is kept, as an extensive investigation is necessary to clarify the lithostratigraphy.

The clastic beds are poor in fossils, beside of some fish remains, and in whitish diatomaceous shales assemblages of diatoms, silicoflagellates, and radiolarians. Only in the imbrications of the eastern part of the Waschberg Unit calcareous clays and silty marls with well developed siliceous and calcareous microfossil assemblages are more common. These assemblages are well recorded in the old Ernstbrunn brickyard from where silicoflagellates are described by BACHMANN (1971). Planktic foraminifera are *Globigerina praebulloides, G. ottnangiensis, G. dubia, Globoquadrina langhiana,* and *Cassigerinella boudecensis.* Calcareous nannoplankton investigation in the brickyard sediments showed an assemblage of *Reticulofenestra excavata, R. pseudoumbilicus, Cyclicargolithus floridanus, Helicosphaera ampliaperta, H. scissura, Triquetrorhabdulus carinatus?,* and rare *Helicosphaera kamptneri* and *Sphenolithus* cf. *abies;* calcareous nannoplankton zone NN 2. In Ernstbrunn, building site Gartengasse 22, light grey silty marls with a scarce agglutinated foraminifera fauna were outcropping, dated by calcareous nannoplankton as NN 2–3.

Similar calcareous clays are exposed at Haidhof W of Ernstbrunn, waste depository at the road to Simonsfeld. Calcareous nannoplankton: *Helicosphaera scissura, H. kamptneri, Reticulofenestra pseudoumbilicus, R. excavata, Triquetrorhabdulus carinatus.* Benthic foraminifera: *Cribrostomoides subglobosus, Textularia, Karreriella bradyi, Dorothia, Martinotiella, Sigmoilopsis, Sigmoilinita tenuis, Lenticulina, Planularia moravica, Hemirobulina hantkeni, Marginulina behmi, Dentalina contorta, Laevidentalina communis, Nodosaria hispida, Pseudonodosaria, Stilostomella, Bolivina, Praeglobobulimina pupoides, Chilostomella ovoidea, Hidina variabilae, Pleurostomella, Globocassidulina, Gyroidinoides, Hansenisca, Melonis, Nonionella, Oridorsalis umbonatus, Hoeglundina elegans, Valvulineria complanata, Hanzawaia boueana, Escornebovina, Cibicidoides filicosta, C. pachyderma, C. ungerianus*; planktic foraminifera: *Globigerina lentiana, G. ottnangiensis, Tenuitellinata angustiumbilicata, Globorotaloides suteri, Cassigerinella boudecensis, C. globulosa.* (Eggenburgian).

At the top of the quarry on Hollingstein near Niederhollabrunn grey silty diatomaceous shales were exposed, covering the NW side of the Hollingstein Limestone. Siliceous fossils (kindly determined by A. BACHMANN): diatoms: *Triceratium favus, Actinoptychus senarius, Coscinodiscus marginatus, C. lineatus, Actinocyclus flos, Stephanogonia actinoptychus, Hyalodiscus subtilis, Stephanopyxis turris*; silicoflagellates: *Dictyocha ausonia, D. crux* f. *parva, Mesocena elliptica*; ebridiids: *Pseudoammodichium robustum*; some radiolarians and sponge spicules.

In the formation of "Schieferige Tonmergel" some lithologically different members are included. At the thrust planes of some imbrications extensive boulder beds are present, the "Blockschichten" (comp. HOLZER & KÜPPER, 1953). They consist of exotic boulders and pebbles in a sandy-clayey matrix; boulder size of granite up to 10 m length. The material are granites, gneiss, amphibolite, pegmatite, cherty limestones, cherts, and flysch sandstones. A typical outcrop is accessible at the top of the Hollingstein. Other members are the coarse sands of Altmanns, near Altmanns at the Zaya river, and in the deep drilling Ameis 1 the 200 m thick horizon of the Ameis Sands (GRILL, 1968).

Stratigraphic range: Early Miocene, Eggenburgien to Ottnangian, NN 2–3.

2.1.6. "Eisenschüssige Tone und Sande"

In the Roseldorf subunit (WESSELY, 1998) a series of variegated limonitic clays and yellowish sands crops out. In the upper part occur dark micaceous, well bedded clays alternating with partly endurated limonitic claystones. The sediments are generally barren, beside of some plant remains. The sequence is called "Eisenschüssige Tone und Sande" and is correlated with the Late Ottnangian "*Oncophora*" Beds (GRILL, 1962). Therefore in lithostratigraphic descriptions of deep drillings the name "*Oncophora*" Beds is used for this formation although the bivalve *Rzehakia* ("*Oncophora*") is not recorded. For this sequence a new lithologic description and denomination is necessary.

Outcrops in this formation are rare, mostly construction sites. The only better outcrops exist in Maisbirbaum with an alternation of grey to yellowish silty clays, claystones, sands, and sandstones (STRANIK, 1997; NOVAK & STRANIK, 1998). Along the road from Maisbirbaum to Bruderndorf, about 1 km south of Maisbirbaum at the wayside crucifix and in the field east of the road well bedded variegated, dark greenish-grey and dark brown, non-calcareous clays and limonitic claystones are outcropping. Another area of outcrops is around the village Roseldorf. The hillside east of the village consists of non-fossiliferous greenish to brownish clays and yellowish sands and sandstone. Passing the war memorial, about 150 m west of the village a ditch was opend near a barn. The outcropping variegated grey to brown clays and yellowish silts contain a small microfauna and some nannofossils: *Helicosphaera ampliaperta, Sphenolithus* cf. *heteromorphus*. Foraminifera: *Valvulineria complanata* (common), *Praeglobobulimina pupoides* (common), *Orthomorphina* sp., *Stilostomella* spp., *Allomorphina trigona, Melonis pompilioides, Uvigerina* cf. *acuminata; Globigerina ottnangiensis, Globorotalia scitula*. No exact age assignement is possible, but the foraminifera assemblage is similar to that of the Late Ottnangian (Braunau Schlier) of the Molasse Basin.

Stratigraphic range: Early Miocene, Ottnangian, NN 3–4?.

During the Karpatian the tectonic imbrication of the Waschberg Unit finalized, and only short distance thrusting to the northwest on the Molasse is observed. Basinal pelitic sediments ("Schlier") of the Karpatian Laa Formation are deposited already in a piggy-back basin position on top of the nappes. Erosional relics of Early Badenian deep water pelites of "Baden Tegel", Middle Badenian fluvial and deltaic sediments, and pelites of the Sarmatian Ziersdorf Formation are preserved in structural depressions. On top of the Waschberg Unit, along the Zaya Graben Pannonian fluvial gravels of a pre-Danube river are deposited as the Hollabrunn-Mistelbach Formation (BRIX et al., 1977; JIRICEK & SEIFERT, 1990; KREUTZER, 1993; ROETZEL et al., 1999).

2.2. Pouzdrany Unit

The Pouzdrany Unit (CICHA et al., 1965) represents a system of tectonic wedges built up of upper to middle bathyal, mainly pelitic, non-flysch deposits of Late Eocene to Early Miocene age. Towards the SE the Pouzdrany Unit submerges beneath the Zdanice nappe. Originally, the sedimentary sequences of the Pouzdrany Unit were deposited in the front of the deep Vranovice and Nesvacilka submarine valleys which originated as canyons eroded by rivers on

the SE margin of the Bohemian Massif along regional NW – SE faults during the Late Cretaceous, before the Late Campanian (Hamrsmid et al., 1990). The Maastrichtian, Paleogene and Lower Miocene fill of the troughs, up to 2000 m thick, is preserved in autochthonous position under the Zdanice nappe. During Karpatian time, the Late Eocene to Early Miocene part of these sequences were detached by the moving Zdanice nappe. They were originally deposited SE of the canyons and form now the Pouzdrany Unit. The older sedimentary filling of canyons is still in autochtonous position and has been found in boreholes under the Zdanice nappe during the oil prospection. The hypothesis that the Pouzdrany Unit correlates to the upper part of the fill of the canyons, detached by a frontal part of the overthrusted Zdanice nappe, is corroborated by the strong resemblance of the latest Eocene foraminiferal assemblages of the Pouzdrany Formation to those of the autochthonous fill of the Vranovice canyon (borehole Vranovice-1).

In the Pouzdrany Unit the Pouzdrany, Uhercice, Boudky, and Krepice Formations have been distinguished.

2.2.1. Pouzdrany Formation

Synonyms are "die braunen Pausramer Mergel", Untere Pouzdrany-Schichten, the Pouzdrany Marl (Rzehak, 1895; Pokorny, 1960; Cicha et al., 1965; Cicha, 1975; Stranik, 1983). The formation consists of dark brown-grey, highly calcareous silty shales and marls. Relatively high contents of organic material (1.5% on an average; Adamova, 1988), secondary gypsum, and the character of the benthic foraminiferal assemblages give evidence for a deposition under oxygen-depleted conditions. This coincides with the interpretation that the sequences of the Pouzdrany Unit deposited in Vranovice and Nesvacilka canyons are characteristic for such paleoenvironments of deep submarine valleys.

The lower part of the Pouzdrany Formation (calcareous nannoplankton zone NP 21) yields diverse assemblages of benthic and planktic foraminifera and calcareous nannofossils. Warm water calcareous nannoplankton (*Discoaster tanii, Helicosphaera* spp.) is still present. Among planktic foraminifera large subbotinas and catapsydracids dominate (*Subbotina pseudoeocaena, S. cryptomphala, S. angiporoides, S. gortanii, Catapsydrax unicavus*), but a distinct zonal determination is not possible due to the absence of characteristic index fossils.

In the upper part of the Pouzdrany Formation calcareous nannoplankton of the NP 22 biozone has been ascertained. Occurrences of *Tenuitella munda* in the uppermost part point to planktic foraminifera zone P 19. The gradual disappearance of the calcareous nannofossils *Cyclicargolithus floridanus, Sphenolithus predistentus, S. moriformis, Transversopontis pulcher,* and *Pontosphaera crucifera* through the Pouzdrany Formation upwards can be considered as effect of cooling.

Temporal changes in benthic foraminifera assemblages reflect a gradual decrease in bottom oxygenation caused by restriced communication with the open sea in the system of silled basins of the Paratethys. A succession of benthic foraminifera assemblages has been recognised in the NP 21 to NP 22 interval which clearly reflects a gradual oxygen depletion during the deposition of the Pouzdrany Formation (Krhovsky & Kucera 1995).

Towards the top of the formation diatoms become more frequent. In layers of silty calcareous bioturbated claystones, the taphocenoses of diatoms are strongly influenced

by dissolution. Fragments of heavy silicified diatoms (littoral planktic *Melosira sulcata, Actinoptychus undulatus, Pseudopodosira westii,* littoral benthic *Grammatophora, Isthmia, Diploneis, Plagiogramma, Mastogloia, Triceratium)* strongly dominate; neritic and neritic-oceanic planktic diatoms are rare (*Stephanopyxis, Coscinodiscus, Rhizosolenia, Pyxilla, Chaetoceros).* In this part of the Pouzdrany Formation a pteropod (*"Spiratella" = Limacina*) horizon is present. The increase of biogenic silica in the uppermost Pouzdrany Formation parallels the increase in arctotertiary palynofloral elements and also suggests a cooling (KONZALOVA & KRHOVSKY, 1996; REHAKOVA & KRHOVSKY, 1996).

At the top of the Pouzdrany Formation layers of laminated, calcareous clayey diatomites occur, which yield diatoms of the deeper neritic zone (*Hemiaulus polycistinorum, Pyxilla reticulata, Rhizosolenia hebetata* group, *Chaetoceros, Stephanopyxis turris, S. corona, Coscinodiscus apiculatus, C. bulliens, Brightwelia hyperborea, Rouxia obesa, Liradiscus asperulus,* spores of *Pterotheca*). Littoral meroplankton is less frequent (*Melosira architecturalis, Actinoptychus undulatus, Hyalodiscus scoticus, Trochosira trochlea, Cestodiscus pulchellus, Coscinodiscus rothii, Pseudopodosira westii, Melosira sulcata),* benthic diatoms are very rare, silicoflagellates are common (REHAKOVA & KRHOVSKY, 1996). Planktic foraminifera assemblages were influenced by the increased productivity of diatoms and cooling conditions. Only small species like *Tenuitella? danvillensis* and *Globigerina officinalis* are present in the diatomaceous shales. In the upper part of the Pouzdrany Formation cool water and/or near-shore calcareous nannoplankton became relatively more frequent as well as species which tolerate salinity fluctuations (*Reticulofenestra danica, R. ornata*).

Stratigraphic range: Late Eocene to Early Oligocene; Late Priabonian to Early Kiscellian, planktic foraminifera zones, up to P 19; calcareous nannoplankton zones NP 21–22.

2.2.2. Uhercice Formation

Synonym of the Uhercice Formation are "die Oberen Pouzdrany Schichten" of CICHA (1975). The formation comprises three members in the lower part: the non-calcareous marine diatomites, the non-calcareous claystones with laminae of brackish diatomites, and the diatomaceous nannofossil chalks. Autochthonous foraminifera are absent in these members.

The first member has a horizon of non-calcareous dark grey claystones with sand laminae at its base. Occurrence of freshwater organic walled microfossil *Pediastrum* (together with the absence of marine calcareous nanno- and microfossils) shows a strong run-off during a wet climatic period. The layers of marine diatomites (3.5 m thick in total) were deposited above the claystone horizon during a period of dry climate. In the marine diatomites assemblages of neritic planktic diatoms are dominant (*Stephanopyxis turris, S. turris* var. *intermedia, S. grunowii, Pterotheca reticulata, Coscinodiscus* spp., *Hemiaulus polycystinorum, Rhizosolenia hebetata* group, *Trinacria subcapitata, Brightwelia hyperborea, Pyxilla reticulata, Chaetoceros, Liradiscus, Dicladia capreolus, Goniothecium*). Pelagic species occur also, e.g. some species of *Chaetoceros, Coscinodiscus* and *Rhizosolenia*. Littoral plankton is less frequent (*Melosira architecturalis, M. sulcata* var. *crenulata, Actinoptychus undulatus, Coscinodiscus argus, C. rothii, Actinocyclus ehrenbergii, Trochosira coronata, T. spinosa, T. trochlea*). Silicoflagellata, ebridiids, and

siliceous cysts of archaeomonads occur, and the presence of *Cladogramma conicum* var. *campanulatum* is important for biostratigraphic correlations.

The claystones with laminae of brackish diatomites yield low diversity euryhaline freshwater assemblages, characterised by mass occurrences of planktic *Aulacoseira praegranulata* and *A. predistans*. Further fresh water epiphytic diatoms (*Achnanthes, Diatoma, Eunotia, Cymbella, Gomphonema, Gomphopleura*), cysts of archaeomonads, and spines of siliceous sponges occur.

Blooms of the calcareous nannofossil *Dictyococcites ornatus* characterise the diatomaceous nannofossil chalk (NP 23 biochron). Typical is the occurrence of calcareous nannoplankton species *Transversopontis fibula*. The co-occurring assemblages of diatoms are dominated by *Aulacoseira* (Rehakova, 1986) and resemble those of the previous member. Ostracods of the family Cyprididae point to decreased salinity (Pokorny, 1960). This member corresponds to the ostracod horizon (Polbinian Horizon) of the Eastern Paratethys.

The unit of variegated clays lies above the diatomaceous nannofossil chalks and represents the middle and upper part of the Uhercice Formation. It is, except for some layers, poor in calcareous microfossils. Decreased salinity in the upper part of the water column, stratification, and oxygen depletion near the bottom are supposed to be responsible. In the middle part of the member, foraminifera assemblages with *Paraglo-borotalia opima opima* exist. In the upper part *Cassigerinella boudecensis* and *Globigerinoides primordius* were reported (Cicha et al., 1965). Glauconitic sands of sublittoral origin (*Squalus* Sand) were transported into the bathyal variegated clays probably during the Late Egerian sea-level lowstand.

In the uppermost part of the Uhercice Formation non-calcareous layers predominate which are more or less barren. Thin calcareous layers with relatively rich foraminifera fauna and calcareous nannofossils occur only sporadically. The benthic foraminiferal fauna shows frequent bolivinas; in the planktic fauna *Globigerina ottnangiensis* is common, and less frequent are *G. angustiumbilicata, G. praebulloides, G. lentiana, G. ciperoensis, G. anguliofficinalis, Catapsydrax unicavus,* and *Tenuitella brevispira*, rare *Globigerinoides primordius* also occur.

The calcareous nannoplankton is of low diversity with abundant *Coccolithus pelagicus, Cyclicargolithus floridanus, Pontosphaera multipora* and small Prinsiaceae, accompanied by rare *Coccolithus miopelagicus, Cyclicargolithus abisectus, Pyrocyclus hermosus, Triquetrorhabdulus carinatus?, Sphenolithus* sp., and *Pontosphaera latelliptica.* These nannofossil assemblages represent occasional nannoplankton blooms during short-time periods of favourable living conditions. The biostratigraphic resolution is characteristic for the whole Egerian (Late Oligocene – Early Miocene). Samples from a thin laminated calcareous intercalation with abundant *Bolivina plicatella* contain blooms of *Reticulofenestra* sp.

Stratigraphic range: Early Kiscellian – Late Egerian, upper NP 23 and younger (NN 1?).

2.2.3. Boudky Formation

The Boudky Formation, synonym with "die grauen Pausramer Mergel" and the Boudky Marl (Rzehak, 1895; Pokorny, 1960; Cicha, et al., 1964, 1965; Cicha, 1975; Stranik,

1983), comprises grey, indistinctly stratified, highly calcareous marine shales and marls. The Boudky Formation on the Kolby Hill section was selected by CICHA (1975) as facies parastratotype of the Late Egerian. The sequence at Kolby Hill is about 40 m thick. Based on the presence of calcareous nannoplankton zone NN 2, KRHOVSKY et al. (1995) correlated the Boudky Formation with the Eggenburgian (*Helicospaera ampliaperta, H. scissura, H. kamptnerii, H. mediterranea, Sphenolithus conicus, S.* cf. *dissimilis*). Foraminifera assemblages are of Early Miocene age with abundant *Globigerina praebulloides,* frequent *G. angulifficinalis, G. lentiana, G. ottnangiensis, Tenuitella brevispira, T. pseudoedita, Cassigerinella boudecensis, C. globulosa,* sporadic *Globigerinoides trilobus,* and *G. immaturus*. Benthic assemblages with floods of *Uvigerina popescui* in the upper part of the Kolby Hill section corroborate an Eggenburgian age. Sphaeric spumellarias (*Actinomma, Stylosphaera, Hexalonche*) dominante over other genera (*Porodiscus, Heliodiscus, Lithocarpium?, Eucyrtidium, Conarachnium?*) in radiolarian assemblages. Sponge spicules are well preserved and variable in the Boudky Formation.

Frequent foraminifera, radiolarians, diatoms, and calcareous nannofossils, point to a restored communication with the open sea. The paleoenvironmental change reflects both, subsidence of the foreland in front of the thrusted nappes and eustatic sea-level rise. Late TB 1.4 and TB 1.5 eustatic cycles of HAQ et al. (1988) were inferred by KRHOVSKY et al. (1995).

Stratigraphic range: uppermost Egerian? to Early Eggenburgian, calcareous nannoplankton zone NN 2.

2.2.4. Krepice Formation

An erosive disconformity separates the Krepice Formation from the underlying Boudky Formation (STRANIK et al., 1981). That can be considered as sequence boundary correlatable with the intra-Eggenburgian sea-level fall between the TB 1.5 and TB 2.1 eustatic cycles (HAQ et al., 1988). The flysch deposits of the lower Krepice Formation are characterised by an alternation of grey shales and highly micaceous sandstones (Krosno lithofacies in the Carpathians) and can be considered to represent a lowstand and a transgressive system tract. The claystones and siltstones of the upper Krepice Formation with several 3 to 5 cm thick, Fe-rich layers in the uppermost part probably were deposited in the Ottnangian during the high-stand of the TB 2.1 eustatic cycle. In claystones of the turbiditic lower part of the Krepice Formation rare small agglutinated foraminifera "*Rhizammina*" sp. and "*Saccammina*" sp. occur, calcareous microfossils are very rare (*Ammonia beccarii, Elphidium macellum* in CICHA et al., 1965), redeposited probably from the marginal part of the sea but coeval with the Krepice Formation.

The Fe-rich layers (thin rusty, limonitic coloured intercalations of siltstones) in the uppermost part of the Krepice Formation are interpreted as deposits of short humid episods. Thin laminae of diatomites ascertained among the Fe-rich layers originated probably during short dry climatic episods (KRHOVSKY et al., 1995).

Stratigraphic range: Late Eggenburgian to Ottnangian.

2.2.5. Laa Formation

Alternating greenish-grey silty to sandy calcareous shales, and yellowish sands and gravels are preserved as erosional relics on the Pouzdrany Unit (STRANIK & BRZOBOHATY, 2000). The shales contain a rich foraminifera fauna comparable to the Karpatian Laa-Formation, with *Uvigerina graciliformis*. The sequence contains up-section assemblages similar to those of the lower part of the Grund Formation in the Molasse Basin. This is interpreted by STRANIK & BRZOBOHATY (2000) that during the deposition of the Laa Formation the Pouzdrany Unit was folded and integrated in the flysch belt, and together with these sediments was thrusted over the lower part of the Laa Formation in the foredeep.

2.3. Zdanice Unit

The Zdanice Unit is considered as the northern continuation of the Waschberg Unit in Austria. The middle to lower bathyal depositional area of the Zdanice Unit was located SE of the Pouzdrany depositional area. The deepest part of the continental slope and its foot, where the Cejc-Zajeci facies was deposited, is connected to the abyssal Magura Flysch Basin to the SE. In the Cenozoic of the Zdanice Unit, the Nemcice, Menilitic, Zdanice – Hustopece, Sakvice, Pavlovice, and Laa Formations have been distinguished.

2.3.1. Nemcice Formation

In the Upper Eocene part of the Nemcice Formation or "Submenilitic formation" (Late Cretaceous to Early Oligocene) the "Green Clays" are developed which were deposited during the Terminal Eocene Event when the CCD has risen in the oceans. Agglutinated foraminifera are the major microfossil group in the non-calcareous clay. Rare calcareous intercalations comprise planktic foraminifera and calcareous nannofossils of the NP 19/20 biozone. An assemblage of planktic foraminifera from an outcrop at Nikolcice (crossroad Kyjov – Sitborice) consists mainly of large subbotinids and catapsydracids (*Subbotina linaperta, S. pseudoeocaena, S. utilisindex, Catapsydrax pera, C. unicavus*), but also of *Turborotalia pseudoampliapertura* and rare specimens of *Truncorotaloides medizzai*. This species has an occurrence in planktic foraminifera zones P 12–P 15. The upper member of the Nemcice Formation is the Sheshory Marl (*Globigerina* Marl) with a total thickness of some 30 m. In the lower part of the member (latest Eocene, NP 19/20) greenish-grey calcareous claystones and marlstones alternate with ochreous weathering marlstones and marly limestones. The alternation of these lithologies is interpreted as reflecting productivity changes of the calcareous nannoplankton connected to orbital cyclicity. The growing content of pelagic carbonates corresponds to the paleoproductivity increase due to global cooling around the Eocene-Oligocene boundary (KRHOVSKY et al., 1993). Large species of planktic foraminifera are abundant, e.g., samples from Nikolcice along the road to Kurdejov (*Subbotina angiporoides, S. cryptomphala, S. prasaepis, S. pseudoeocaena, S. utilisindex, Catpsydrax* spp., *Turborotalia pseudoampliapertura, Pseudohastigerina micra*). The assemblage is characteristic for the Late Eocene to earliest Oligocene. Agglutinated benthic foraminifera are still frequent especially in the greenish grey, less calcareous layers. The upper part of the

member (earliest Oligocene, NP 21) consists of the brownish grey marlstones. Irregularly distributed laminae of fine-grained sands, rusty coloured by iron hydroxides indicate storm deposits (KONZALOVA et al., 1994). An increase in small planktic foraminifera (*Globigerina officinalis, Tenuitella liverovskae, Pseudohastigerina micra, Chiloguembelina gracillima*) was observed, agglutinated foraminifers are rare. Warm water calcareous nannoplankton species (discoasters, *Coccolithus formosus*) gradually disappear. Species occurring more frequently in near-shore waters, which require increased nutrient contents and tolerate greater variations in ecologic conditions, became more frequent (*Pontosphaera multipora, Transversopontis pulcheroides, Zygrhablithus bijugatus*).

Stratigraphic range: Late Eocene to earliest Oligocene, planktic foraminifera zone P 15–P 18, calcareous nannoplankton zone NP 19–21.

2.3.2. "Menilitic formation"

The "Menilitic formation" is divided into "Subchert member", "Chert member", Dynow Marlstone, and Sitborice Member.

In the "Subchert member" brown low-calcareous silty shales alternate with light coloured calcareous claystones to marlstones. The alternation of lithologies reflects the cyclic changes of the terrigenous input due to run-off fluctuations. The lower boundary of the member is placed at the first occurrence of cinamon-coloured laminated marlstone. Several thin layers of these laminites occur through the "Subchert member". Those in the middle part of the member contain frequent disarticulated fish remains. The lamination and scarcity or absence of benthic fossils suggest low oxygen or sometimes even anoxic bottom conditions during the "Subchert member" deposition. The differences between the Sheshory Marl and the "Subchert member" are interpreted as the result of incipient restriction of communication with the open ocean. Horizons with abundant pteropods (*Spiratella, Limacina* or *Planorbella* in Carpathian literature) on the bedding planes of marlstones are found in the middle part of the member. Small planktic foraminifera are more or less abundant in the marly layers. Assemblages of benthic foraminifera are rather poor due to oxygen depletion, small calcareous tests predominate, redeposited from the outer littoral zone (e.g., *Bolivina, Trifarina, Reussella, Cibicidoides, Biapertorbis, Asterigerinata, Fissurina, Favulina, Cibicides, Globocassidulina, Melonis*). Silty claystones have low carbonate content and are generally poor in foraminifera. The top of the member is laminated and slightly silicified in some sections (e.g., Velke Nemcice). In analogy with the Pouzdrany Unit diatoms and sponge spicules are thought to be responsible for the origin of silica.

The "Chert member" begins with a horizon of non-calcareous, dark brown-grey claystones (0.5–0.7 m thick). An equivalent horizon of non-calcareous claystones also occurs at the base of the Uhercice Formation. It was even recognised in the NW Fore-Caucasus (in the upper part of the Pshekha Beds, Khadum Formation). The horizon is interpreted as heavy run-off event in the Central and Eastern Paratethys. The non-calcareous claystone layer is overlain by cherts, barren of calcareous fossils. At the equivalent level in the Pouzdrany Unit marine diatomites occur. The cherts are diagenetically altered diatomites. This substitution of diatomites in the upper

bathyal Pouzdrany Unit by cherts in the middle and lower bathyal Zdanice Unit suggests, that the intensity of silica re-mobilisation during early diagenesis was depth dependant.

In the upper part of the "Chert member" brown-grey or brown silicified and non-silicified claystones with jarosite are developed, barren of calcareous fossils. In the Pouzdrany Unit laminae of brackish diatoms occur at this stratigraphic level.

The Dynow Marlstone was deposited in zone NP 23 and is typically developed as silicified marlstones. The carbonates are pelagic in origin and consist of blooms of the calcareous nannofossil *Dictyococcites ornatus*; and typical but rare *Transversopontis fibula*. This low diversity assemblage shows reduced salinity. The member is barren of foraminifera. Cylindrical cavities found in the silicified marlstones provide evidence for the original presence of fibrous colonies of centric diatoms. *Korobkovella* and other bivalves of the *Cardium lipoldi* fauna have been found on one bedding plane of the marlstones (probably redeposited from littoral zone during a storm event).

Blooms of *Dictyococcites ornatus* are found at Krepice. They are preserved as thin coccolith laminae (leached and preserved as casts only) alternating with chert laminae (originally horizons with diatoms – probably *Aulacoseira* which dominates at the equivalent level in the Pouzdrany Unit). This alternation has been interpreted as manifestations of seasonal variations in the predominant phytoplankton assemblages (Krhovsky et al., 1993).

The Sitborice Member forms the upper part of the "Menilitic formation". Pebbly mudstones and xenoclasts of the older deposits were described by Stranik (1981) from the base of the Sitborice Member. They are indications of submarine erosion connected with the sea-level fall at the base of the TA 4.5 eustatic cycle.These reflections of the sea-level fall were called the "Sitborice Event" by Krhovsky & Durasinovic (1993).

In the brown grey and greenish grey shales of the lower part of the Sitborice Member foraminifera and calcareous nannofossils occur only in several thin horizons. Fish remnants are common, and agglutinated foraminifera are rare (*Glomospira* sp., *Subtillina ?* sp.). In the nannofossil chalk laminae planktic foraminifera are common (e.g., *Globigerina praebulloides, Paragloborotalia opima opima*), benthic foraminifera are rare. Calcareous nannofossil assemblages contain *Zygrhablithus bijugatus, Coccolithus pelagicus, Helicosphaera compacta, H. recta, Pontosphaera multipora, Transversopontis pygmaeus, Cyclicargolithus floridanus, Reticulofenestra lockerii,* small Noelaerhabdaceae, and *Sphenolithus moriformis.*

In the middle part of the member three thin layers of dolomitized pelagic limestones occur, 10 and 8 m from each other. A diagenetic origin from nannofossil chalks is supposed. Krhovsky & Djurasinovic (1993) correlated them with the Tylawa Limestones of the Polish Carpathians.

In the uppermost part of the member three horizons of calcareous claystones and marlstones are correlated with the nannofossil chalks of the Jaslo Limestones s.l. of the Polish Carpathians, deposited during a sea-level highstand. Nannoplankton assemblages are diverse, and also the foraminiferal fauna of the upper Sitborice Member (Jurasova, 1987).

In the semi-isolated Paratethys the main paleoenvironmental control was the positive water balance and the estuarine circulation during sea-level lowstands, that led to salinity decrease and oxygen depletion. The observed semi-regularly distributed thin

layers of sideritic dolomitized carbonates connected with blooms of calcareous nannofossils are supposed to have occurred during short dry phases of the orbitally driven climatic cycles (long eccentricity cycles; comp. KRHOVSKY & DJURASINOVIC, 1993). During the deposition of the calcareous upper part of the member, influx of open marine surface waters from the oceans can be supposed at time of a sea-level high stand.

Stratigraphic range: Oligocene, Early Kiscellian, planktic zone P 18–P 21, calcareous nannoplankton zone NP 22–24 (NP 25?).

2.3.3. Zdanice-Hustopece Formation

In the Zdanice Unit, the Zdanice-Hustopece Formation represents an onset of the Krosno lithofacies deposition. This most extensive and thickest formation (up to 1250 m) of the Zdanice tectonic unit was deposited during the Egerian (STRANIK, 1983; STRANIK et al., 1991). The Zdanice-Hustopece Formation is poor in fossils. There are only scarce fossiliferous layers which contain biostratigraphically insignificant Egerian foraminifera assemblages (CICHA et al., 1964; CICHA, 1975). Except for the upper part, the assemblages of calcareous nannofossils are also poor. The influence of a brackish environment is frequently manifested.

Thick accumulations of sands and conglomerates, found in some places at the base of the formation, may evidence a sequence boundary associated with the sea-level fall between the TA 4.5 and TB 1.1 eustatic cycles, which was named the "Zdanice-Hustopece Event" (KRHOVSKY & DJURASINOVIC, 1993). The flysch deposits of the Zdanice-Hustopece Formation represent a lowstand and transgressive system tracks of the TB 1.1 to TB 1.4 eustatic cycles. The detrital material was supplied, at least partly, from the elevated front of the embryonal Magura Nappe (STRANIK, 1983). During highstands a deposition of calcareous shales (Hustopece Marls) was characteristic, the thick layers of sandstones and conglomerates (Zdanice Sandstone) point to lowstands.

Biostratigraphic evidence of the stratigraphic range is not unambiguous, according to different authors the formation extends from NP 24/25 biozone (CICHA et al., 1971) or from the upper part of the NP 25 to the NN 2 biozone (MOLCIKOVA & STRANIK, 1988).

Stratigraphic range: Egerian (to Eggenburgian in places), calcareous nannoplankton zone NP24/25 to NN 2.

2.3.4. Sakvice Formation

A communication with the open sea was renewed in Eggenburgian during the TB 1.5 eustatic cycle. The Sakvice Formation, rich in foraminifera and calcareous nannofossils, was deposited in a piggy-back basin position on the part of the Zdanice Nappe. Calcareous nannofossil assemblages with *Helicosphaera ampliaperta* indicate nannoplankton zone NN 2. The planktic foraminiferal fauna was dominated by *Globigerina praebulloides*, frequent are also *Cassigerinella globulosa, Globigerina ottnangiensis, G. lentiana,* and *Tenuitellinata angustiumbilicata.* In the upper part, the rare occurrence of *Paragloborotalia? mayeri, Globigerinoides* sp., and *Globoquadrina langhiana* indicate BLOW's zone N 5. The number of benthic species is usually below 20. Foraminiferal

assemblages of the Sakvice and Boudky Formations are similar, the benthic foraminifera indicate, however, that the Sakvice Formation was deposited in shallower environment which is corroborated also by lower diversity of siliceous microfossils in the Sakvice Marl than in the Boudky Formation (KRHOVSKY et al., 1995). Of stratigraphic interest is the occurrence of the pteropod *Clio triplicata*, which apppears at the base of the Hall Schlier (Eggenburgian) in the Molasse Basin (CTYROKY, 1991; ZORN, 1999).

Stratigraphic range: Upper Egerian – Eggenburgian, planktic foraminifera zone N 5 (M 2 in BERGGREN et al., 1995), calcareous nannofossil zone NN 2.

2.3.5. Pavlovice Fm. and Laa Formation

The non-calcareous claystones of the Pavlovice Formation (Late Eggenburgian to Ottnangian) and highly fossiliferous calcareous clays of the Laa Formation (Karpatian) are present only in a narrow transverse depression zone, that connected the Vienna Basin and the Carpathian Foredeep (STRANIK, 1983). The Pavlovice Formation was deposited in an anoxic environment unfavorable for benthic organisms. Only diatoms are present in the uppermost part, which are indicative of decreased salinity. In the upper part of the Pavlovice Formation (below the diatomites) several Fe-rich siltstone layers occur, which are comparable with those of the uppermost Krepice Formation.

The Laa Formation is developed as grey to green-grey, variably arenaceous, mostly highly micaceous, stratified calcareous claystones with micaceous bedding planes ("Schlier"). The rich fossil content in the Laa Formation is the evidence of a good communication with an open sea (STRANIK, 1983). Deposition during the TB 2.2 eustatic cycle can be supposed. Calcareous nannofossils (*Coccolithus pelagicus, Helicosphaera ampliaperta, Syracosphaera* sp., *Reticulofenestra pseudoumbilica, Sphenolithus heteromorphus*) indicate NN 4 Biozone.

3. STRATIGRAPHIC CORRELATION

The Oligocene to Early Miocene sedimentary history of the Waschberg, Zdanice, and Pouzdrany units is strongly related (see also STRANIK, 1997), and reflects the palaeogeographic and tectonic history of the West Carpathian flysch belt. Depending on the original geomorphology, bathymetry and tectonic history of the particular sedimentary areas, some differences in facies development are observed. During the Oligocene the palaeoenvironment of these sedimentary areas was strongly influenced by the restriction of the Paratethys from open oceanic circulations. In contrast, the Molasse Basin has stronger marine influences from the west, at least in some periods.

The subdivision of sedimentary sequences in formations and members is different in all three units (Fig. 2). The Late Eocene sedimentation in the Waschberg Unit with the Reingrub Formation includes nummulitic sandstones, partly intercalated in pelagic marls and calcareous shales, but is not continuously exposed. It is correlated with the Nemcice Formation of the Zdanice Unit by STRANIK (1997). The lithostratigraphic position of the Pfaffenholz Beds and the Hollingstein Limestone is not solved. In the lowermost part of the Ottenthal Formation of the Waschberg Unit few discontinuous tectonical wedges of

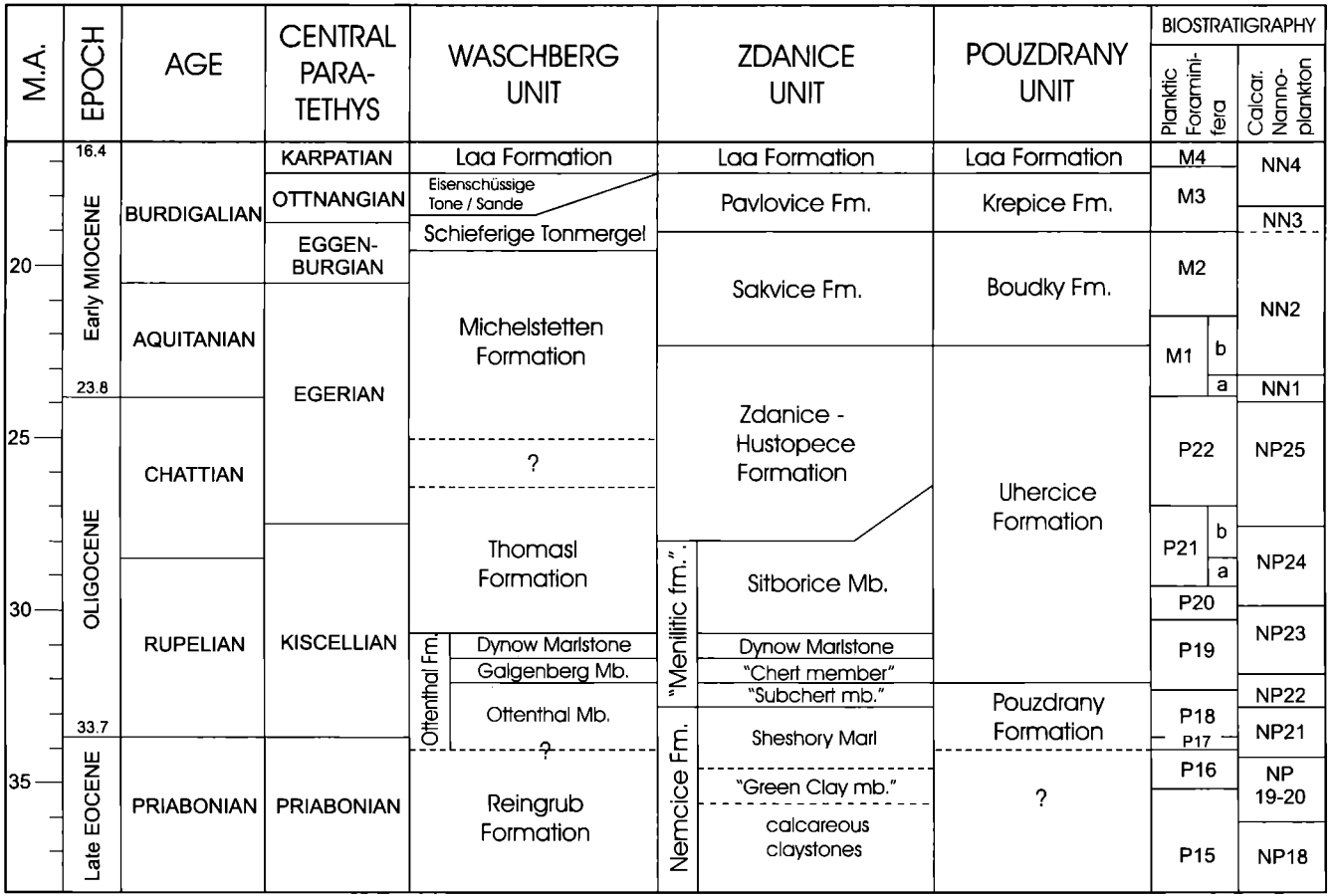

Fig. 2: Correlation scheme between the Waschberg, Zdanice and Pouzdrany Units, based on the biozonation of BERGGREN et al., 1995.

Globigerina Marl (lower Ottenthal Member) have been found, dated as nannoplankton zone NP 21 and deposited around the Eocene/Oligocene boundary. This lower part of the member correlates with the lower Pouzdrany Formation. The foraminifera assemblage of the Sheshory Marl shows a distinct deeper (upper to middle bathyal) deposition depth. The sedimentation of laminated and banded brown marls and clays of NP 22 is similar in all units, and also a horizon with pteropods ("*Spiratella*" = *Limacina* horizon) appears throughout the region. This pteropod horizon is a marker horizon in the Central Paratethys (Carpathians, Northern Hungary, Transylvanian Basin). In the upper Ottenthal Member these sediments comprise nearly all of nannoplankton zone NP 22. In the Zdanice Unit this sequence belongs to the lower "Menilitic formation", the "Subchert member", but the top of the member is silicified by diagenetically altered diatoms. Similarly also in the upper Pouzdrany Formation exists an increase of diatoms in silty claystones, and diatomaceous clay forms the top of the formation.

A distinct horizon of non-calcareous shale or claystone immediatelly precedes the widespread diatomite sedimentation in the Galgenberg Member of the Waschberg Unit, the "Chert member" in the Zdanice Unit, and the base of the Uhercice Formation in the Pouzdrany Unit. A shale horizon above the cherts in the Zdanice Unit and above the non-calcareous marine diatomites in the Pouzdrany Unit has not been recorded in the Ottenthal Formation. In the Uhercice- and "Menilitic" formations diatomaceous nannofossil chalks and silicified Dynow Marlstone, respectively, follow without break, whereas in the Ottenthal Formation only a tectonised contact has been observed. The Dynow Marlstone (NP 23) is silicified in the Zdanice Unit, and in few layers in the Waschberg Unit where, however, morphologically preserved diatoms predominate as in the Uhercice Formation. A horizon with small endemic bivalves, the so-called "*Cardium lipoldi*"-fauna, and smooth-shelled ostracods represent a far reaching correlation level in the Central and Eastern Paratethys. This level (Polbinian horizon, ostracod beds, beds with *Urbnisia*) is recorded as far east as the North Ustyurt Basin or in the Mangyshlak (Popov et al., 1993). The Dynow Marlstone ("Heller Mergelkalk") is the only horizon lithologically correlatable with the Upper Austrian Molasse Basin (Wagner, 1996, 1998).

In a comparison, this facies and microfossil content of marls, diatomites and nannofossil chalk give the impression, that the members of the Ottenthal Formation in the Waschberg Unit have originated in a similar depth as the upper bathyal Pouzdrany Unit. Origin in the similar depth is manifested also by preservation of diatom frustules in both units while in the middle to lower bathyal Zdanice Unit only cherts or silicified marlstones occur. It is significant for the silicification of diatomites and nannofossil chalks that early diagenesis and mobilisation of silica increase with increasing water depth. In the Waschberg sedimentary area the paleoenvironment of the pelagic zone was, however, more open marine than in the Pouzdrany Unit, more comparable to that of the Zdanice Unit.

In the uppermost NP 23 zone, the change to pelitic sedimentation of variegated dark shales is accompanied by a sedimentation of slumps and pebbles, caused by the sea-level fall at eustatic cycle TA 4.5, the "Sitborice Event". In the Pouzdrany Unit an erosional gap has been interpreted at the Pouzdrany – above the mill locality. In the Zdanice Unit these shales are included in the Sitborice Member of the "Menilitic formation", whereas in the Waschberg Unit this sequence is separated as the Thomasl Formation (upper NP 23 to lower NP 25). In the Pouzdrany Unit variegated shales form the upper part of

the Uhercice Formation. In the upper part of the variegated clays of the Uhercice Formation redeposited sublittoral glauconitic "*Squalus*" – Sands" can be found in places. The shale facies continues up into the Late Egerian (to NN 1?).

In the Zdanice Unit deposition of the thick flysch Zdanice-Hustopece Formation began already in the upper NP 24 zone or lower NP 25 zone. By a great variability with alternating micaceous sandstones, conglomerates, sands, shales, and calcareous claystones the Zdanice-Hustopece facies corresponds to the Krosno facies in the Polish Carpathians. Microfossils are poor, but an age of NP 24/25 to partly NN2 (Eggenburgian) is indicated. The following calcareous claystones and marls of the Sakvice Formation were deposited during a sea-level rise in the Eggenburgian (NN 2). In the Pouzdrany Unit marls and calcareous shales of the Boudky Formation (NN 2, uppermost Egerian? to Eggenburgian) were deposited, and were followed in the Late Eggenburgian to Ottnangian by the flysch deposits of Krepice Formation, very poor in fossils. In the Waschberg Unit, the Michelstetten-Formation is in a tectonic position, without known sedimentary contact to the Thomasl Formation. The surface outcrops of the Michelstetten Formation (NN1–NN 2) contain the same foraminiferal fauna as the Boudky Formation, also with local mass occurrences of *Uvigerina popescui* (corresponding to *U. gallowayi* in PAPP et al., 1978). Siliceous fossils in contrast are rare, only few sponge spicules occur. In deep drillings the foraminiferal assemblages are similar.

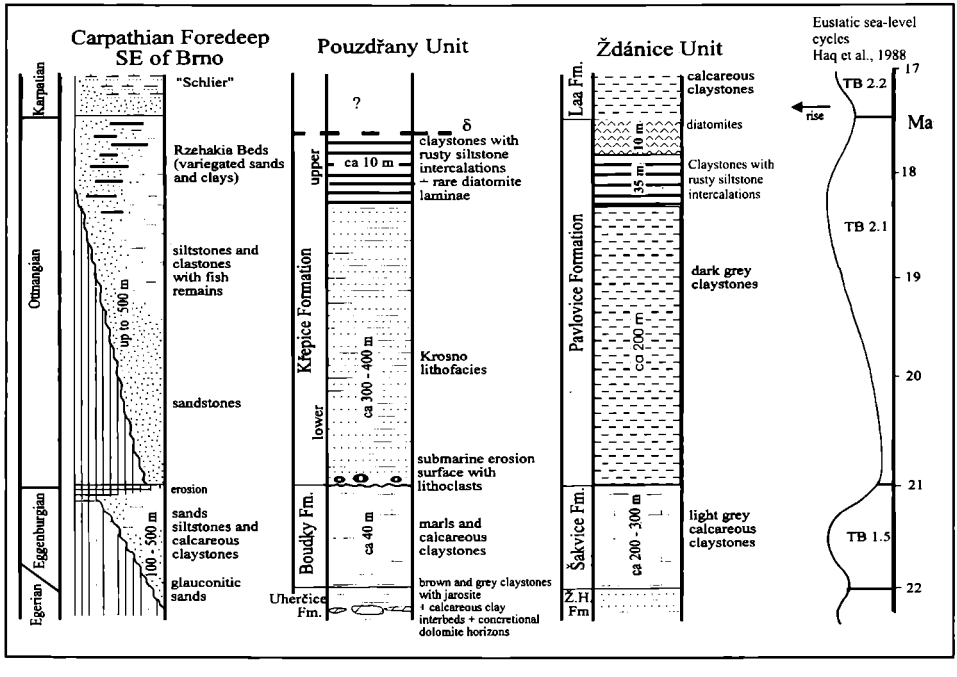

Fig. 3: Lithostratigraphic correlation of the Early Miocene in South Moravia (acc. KRHOVSKY et al., 1995).

Some problems arise also in the correlation of the "Schieferige Tonmergel" in the Waschberg Unit. The Zdanice Hustopece-Formation ("Auspitzer Mergel") has a similarly great variety of lithologies with sands, sandstones and pelitic facies, and a flyschlike alternation of sandstones and claystones (Egerian to Eggenburgian in places). The sedimentation in the Waschberg Unit, east of the Leitzersdorf thrust lithologically is similar, but considered to be younger in age (Eggenburgian to Ottnangian). Another formation of similar lithology as the "Schieferige Tonmergel" with alternating claystones and flyschoid sandstones is the Krepice Formation in the Pouzdrany Unit, with an Ottnangian age. The Boudky Formation (NN 2, Late Egerian ?, Eggenburgian) in the Pouzdrany Unit is a sequence of light grey to greenish grey, calcareous marls, with a rich microfossil community including siliceous fossils. Concerning the high content of siliceous fossils, this formation compares well with sediments in the Ernstbrunn brickyard (NN 2). Of same Eggenburgian age is the Sakvice Formation in the Zdanice Unit, mainly light grey to whitish marls, but without regularly interbedded sandstone layers. It has similarities with some deposits of light grey marls around Ernstbrunn. No one of these formations in southern Moravia corresponds by their lithofacies to all variable lithofacies of "Schieferige Tonmergel". It is not excluded that observation of better sections will enable in the future to differentiate this variable lithostratigraphic unit into at least two facially distinct formations. There are similarities to the Boudky and Sakvice Formations of the lower part of the "Schieferige Tonmergel" in the Ernstbrunn region. The marly Sakvice Formation is shallower, poor in siliceous fossils, and similar to the Michelstetten Formation. But in the marls of Ernstbrunn and especially in the Boudky Formation silicous fossils with radiolarians, indicators of a deep basin, are abundant. The younger part of "Schieferige Tonmergel" with flyschoid sedimentation may be compared to the lowstand sedimentary tract of the lower Krepice Formation deposited during the Early Ottnangian sea-level fall. A lithostratigraphic and chronostratigraphic correlation scheme of the South Moravian Early Miocene is presented in Fig. 3.

In the Zdanice Unit the claystones of the Pavlovice Formation (Late Eggenburgian to Ottnangian) were deposited only in a small depression in a piggy-back basin, similarly to the underlying Sakvice Formation.

The so-called "Eisenschüssige Tone und Sande" or "Oncophora Beds" in the Roseldorf subunit of the Waschberg Unit are still part of the thrust sheets. The uppermost member with alternating dark greenish non-calcareous claystones and limonitic claystones and siltstones corresponds to the same facies in the upper Pavlovice and upper Krepice Formations. These limonitic intercalations are not present in the Molasse Basin, and also not in the brackish "*Oncophora*" Beds, and point to a relation of the Waschberg Unit with the Zdanice and Pouzdrany Units. Nannoplankton of Ottnangian age (NN 3/4) and a small foraminiferal assemblage indicate marine environments for the underlying clays and sands of the "Eisenschüssige Tone und Sande".

Sedimentation in a piggy-back basin position occurred in the Waschberg Unit only with the begin of the Karpatian Laa Formation which sedimented also on the Pouzdrany and Zdanice Units. On top of the thrust sheets, younger sediments (Badenian to Pannonian) were deposited during times of short connections between the Vienna Basin and the Carpathian Foredeep or the Molasse Basin.

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