Stratigraphy and facies of the Upper Marine Molasse (OMM) of southwesternmost Bavaria (Allgäu)

Dissertation zur Erlangung des naturwissenschaftlichen Doktorgrades an
der Fakultät für Geowissenschaften
der Ludwig-Maximilians-Universität München

vorgelegt von

Dipl.-Geol. Dorothea Frieling

München, den 16. September 2009

Eingereicht am: 16.09.2009

Mitglieder der Promotionskommission:
Prof. Dr. B. Reichenbacher
Prof. Dr. A. Schäfer, Univ. Bonn
PD Dr. R. Pentcheva
Prof. Dr. A. Altenbach
Prof. Dr. W. Altermann
Prof. Dr. M. Amler

Vorsitzender: PD Dr. R. Pentcheva
1. Gutachterin: Prof. Dr. B. Reichenbacher
2. Gutachter: Prof. Dr. Andreas Schäfer

Tag der Disputation: 16.12.2009

Doktorurkunde ausgehändigt am:

Contents

1. Introduction

The deposits of the OMM from the southeastern Bavarian part of the Molasse Basin were studied micropalaeontologically and, less extensively, sedimentologically by HAGN & HÖLZL (1952), KNIPSCHER (1952), HAGN (1959, 1961), PAULUS (1963), WENGER (1987a), PIPPÈRR (2004, 2005), PIPPÈRR et al. (2007) and PIPPÈRR & REICHENBACHER (2009). Additionally, in the eastern part of the basin (eastern Lower Bavaria) many new outcrops were mapped by the „Bayerisches Landesamt für Umwelt" (formerly „Bayerisches Geologisches Landesamt"; see PIPPÈRR et al. 2007a). Sedimentological or micropalaeontological data exist for eastern Lower Bavaria and western Upper Austria (SALVERMOSER 1999) and for core material from well Altdorf (PIPPÈRR 2004). The area along the northern part of Lake Constance (Überlinger See) has been investigated by HAGN (1961), SCHREINER (1966, 1984), WINDER (1983) and WENGER (1987b); and geological and biostratigraphical data (mainly collected on the outcrops in the "Flächenalb") for the northern margin of the Molasse basin were published by GALL (1975) and GEYER & GWINNER (1979).

To date, the development of the Upper Marine Molasse (with the abbreviation OMM according to the German term "Obere Meeresmolasse") especially in the southwestern German part of the Molasse Basin remains poorly understood. There have been few recent sedimentological investigations and no attempts have been made at a basin-wide parallelisation. Even though several well exposed sections exist for example in the Allgäu part of the Molasse Basin, only a little data has been published about the marine successions there (JÜRGES 1970, SCHOLZ 1989, SCHAAD et al. 1992).

The present study is devoted to the examination of the well exposed outcrops along the southwestern rim of the Molasse Basin. This area between Lake Constance and river Lech (Vorarlberg, Allgäu) occupies a key position for a parallelisation of the well-known southeastern Bavarian part and the Swiss part of the Molasse Basin. The main objectives of this study are to develop a model for the tidal-influenced deposition of the OMM, and to attempt a basin-wide parallelisation of the sediments.

To meet the latter aim, a detailed lithostratigraphical and chronostratigraphical subdivision of the OMM was necessary. This was based on detailed profiling in the study area, something which had hitherto never been satisfactorily completed. But it seemed worth trying because of some excellent outcrops in southwestern Bavaria. However, correlating the different sections and every kind of subdivision of the succession proved to be difficult and was impeded by a number of problems. Because of their marginal position related to the Molasse Basin the marine deposits exposed here show a strong freshwater influence which caused fluctuating salinities in time and space. Thus, even after making sedimentological or palaeontological observations in some sections it was difficult to distinguish freshwater from marine deposits. Moreover, in the areas of the proximal alluvial fan deltas it was sometimes not possible to define the boundaries exactly separating the marine deposits from freshwater sediments below and at the top of OMM. Additional problems were caused by strong facies changes, facies migration as well as massive thickness differences of the successions, which can be observed parallel as well as perpendicular to the southern rim of this sedimentary basin. Due to these differences of facies and thickness even prominent layers like conglomerates tend to wedge out within short distances, so that a lithological parallelisation of some sections may be difficult or even impossible, although they are nearby. Additionally a correlation with micropalaeontological methods turned out to be impossible due to the scarcity of microfossils and the nearly complete absence of key types in the most sections. Much time was devoted to the stratigraphic classification of different sections with magnetostratigraphic methods here. However, this attempt also failed, because of the weak and unclear magnetic signals, a fact, which seems to have been mostly caused by the scarcity of unweathered clayey or marly sediments in the OMM successions. So sequence stratigraphy remains a relatively promising method for the subdivision of the OMM in the study area. A facies and cycle model, based on relatively little biostratigraphic data is established here. On the basis of this quite plausible new model further more specific investigations appear to be more promising as a way of solving the long series of remaining questions. Hopefully, investigations into e.g. nannoplankton and Sr-isotopes could be helpful as a way of confirming some of the results and solving some of the remaining biostratigraphical and chronostratigraphical questions.

2. Geological setting

During the transition from the Eocene to the Oligocene a large sedimentary basin, the Molasse Basin, developed in front of the prograding Alpine nappes. As subsidence continued for ca. 30 Ma, thick wedge-shaped sequences of clastic sediments accumulated in this area both under terrestrial and marine conditions. These successions mainly contain debris of the growing Alps known as “Molasse” (LEMCKE 1988; SCHOLZ 2000).

The north-alpine Molasse basin is a typical asymmetric-shaped peripheral foreland basin. Its German part is bounded to the south by the Alpine nappes, to the north by the Danube River, to the northeast by the crystalline rocks of the Bohemian Massif and to the west by Lake Constance. Owing to tectonics and basin geometry, the OMM deposits only pinch out in a narrow and repeatedly interrupted belt parallel to the present-day rim of the basin (Fig. 1). Except in the south, this recent belt of the OMM is fairly concordant with the palaeo-extension of the Molasse Sea. A short summary of the geological situation in the Bavarian part of the Molasse Basin is given e.g. by LEMCKE (1988), SCHOLZ (1995), and FREUDENBERGER & SCHWERD (1996).

The Molasse Basin has been repeatedly invaded by a sea linking the Tethys with a northern seaway, the so-called Paratethys (ALLEN et al. 1985; TESSIER & GIGOT 1989). During Eggenburgian times, the sea again occupied a narrow but elongated area along the Alpine mountain front (BIEG et al. 2008). The subsequent transgression proceeded northwards during Ottnangian times and finally filled the entire southern German sector of the Molasse Basin (LEMCKE 1988, WENGER 1987a, b).

For Eggenburgian and Ottnangian times a continuous marine connection between the Rhône depression and the modern Caspian Sea, the Burdigalian Seaway, has been suggested (RÖGL & STEININGER 1983, RÖGL 1998), linking the Mediterranean realm in the southwest with the Paratethys realm in the northeast. The marine deposits of this time (between approximately 20 and 17 Ma) are called OMM in Bavaria, Württemberg and Switzerland. Alluvial fans and deltaic complexes were fed by Alpine debris from the south and prograded into the shallow marine environment of the basin.

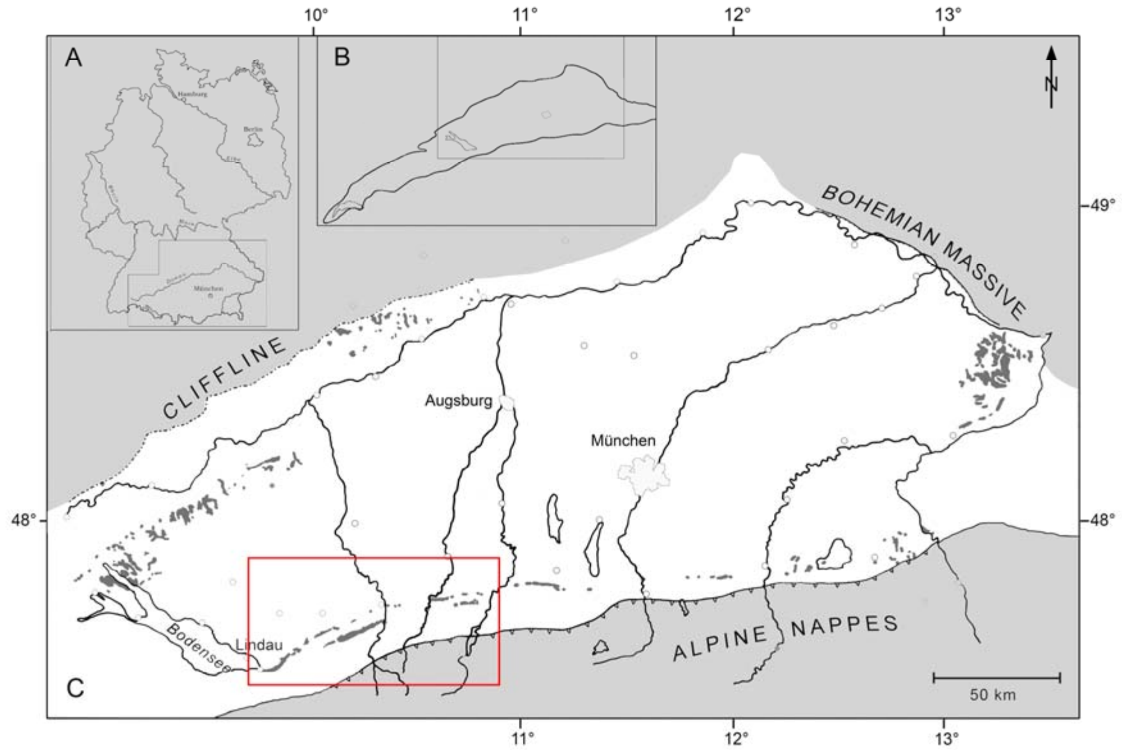


Fig. 1: Simplified maps of (A) Germany (frame indicating position of (C)); and (B) the Molasse Basin (frame indicating position of (C)). (C) German part of Molasse Basin (white colour) with study area (frame); areas with outcropping OMM are shown in grey colour. Cliffline sensu Lemcke (1988). Map source: Geological map of the South German Molasse 1:300000; Abele et al. (1955).

The OMM sea was a shallow epicontinental sea. Sedimentological data indicate a tidal influence in the Swiss and German parts of the basin, and corresponding features are known from outcrops in various marginal parts of the basin (eastern part: SALVERMOSER 1999; FAUPL & ROETZEL 1987, PIPPÈRR et al. 2007a, b; western part: KELLER 1989, 1990; southwestern part: SCHAAD et al. 1992, FRIELING et al. 2009, acc.; northwestern part: BIEG et al. 2007). A tidal influence in the central part of the basin is postulated by BIEG et al. (2008) based on a simulation of tidal flow and circulation patterns in the Burdigalian seaway. This is supported by field findings in the western part (WINDER 1983, BIEG et al. 2007, HEIMANN et al. 2009).

The stratigraphy of the Early Miocene (Eggenburgian and Ottnangian; c. 20-17 Ma) OMM sediments is based on benthic foraminifera from the southeastern German and Austrian parts of the basin (HAGN 1959, 1961, KNIPSCHER 1952,; WENGER 1987a, b, PIPPÈRR et al. 2007a, b; PIPPÈRR & REICHENBACHER 2009). The cyclicity of the OMM deposits was demonstrated by LEMCKE et al. (1953), LEMCKE (1988), PLÖCHINGER et al. (1958), GALL (1975), HERRMANN & SCHWERD (1983), WENGER (1987a), FREUDENBERGER & SCHWERD

(1996) and REICHENBACHER et al. (2005). It is generally accepted that the OMM in the central part of the basin was deposited in two predominantly eustatic-controlled cycles (e.g. LEMCKE et al. 1953, SCHREINER 1966, GALL 1975, WENGER 1987a, b, LEMCKE 1988, ZWEIGEL 1998, FRIELING et al. acc.). Because of different data about the beginning and the duration of these sequences in southern Germany and Switzerland, a correlation with the Swiss sequences (SCHLUNEGGER 1997a, b; KEMPF et al. 1999, REICHENBACHER et al. 2005) is problematic. One possibility to constrain the end of the first sequence in Switzerland are magnetostratigraphic correlations (KEMPF et al. 1999).

3. Materials and methods

Between Lake Constance in the west and the Auerberg in the east 25 sections (Fig. 2) were investigated, lithologically and sedimentologically. Thicknesses were measured with measuring-tape, compass and "Jakobsstab". Parts of selected sections were analysed magnetostratigraphically.

About 80 samples from marly and fine sandy layers were sampled in all sections for micropalaeontological analyses, biostratigraphical classification and to gather ecological information on the OMM sequence. Between 1-1.5 kg sediment of each sample were processed in hydrogen peroxide for several hours, wet-sieved into different size fractions (> 0.063, 0.2, 0.4, 0.63, 1 mm) and dried at 40°C. Microfossils where recovered from the samples with special focus on benthic foraminera. Microfossil determination and micropalaeontological analyses were kindly provided by Martina Pippèrr.

30 polished slabs and 110 thin sections of sandstone and conglomerate samples were examined for their mineralogical composition, fossil content and structural character. These data then allowed a detailed facies analysis (FRIELING 2007 – see appendix 3, FRIELING et al. 2009b – see appendix 2, FRIELING et al. acc. – see appendix 1).

Three sections were sampled for a pilot palaeomagnetic study; namely the Leckenbach and Kesselbach section (Pfänder area) and the Badwerk section (Auerberg area). Core plugs (15 to 25 cm length, 25 mm diameter) were recovered from the outcrop with a special hand-drill. Palaeomagnetic plug samples from all fine-grained horizons were taken in pairs in 0.5 to 2 m increments and restored into their correct relative orientations in the field. The two magnetic components were separated from each other by subjecting each plug sample to either an incremental thermal demagnetisation (TH; steps of 75 °C up to a maximum of 575°C) or, on a trial basis, to alternating field (AF; 2.5, 5 and 10 mT up to a maximum of 120 mT). Some of the plug pairs were subjected to both demagnetisation methods. During the studies it became clear that for the TH method the optimum temperature ranged from 200 and 400°C and demagnetisation was completed between 350 and 425 °C, and with the AF method between 50 and 100 mT. The palaeomagnetic studies were kindly supported by Valerian Bachtadse and Hayfaa Abdul-Aziz of the Institute for Geophysics at the University of Munich.

A cyclo-stratigraphic interpretation of the whole Molasse Basin was attempted based on a detailed sequence stratigraphic analysis of the Pfänder region in the western part of the study area (cf. FRIELING et al. acc. – appendix 1).

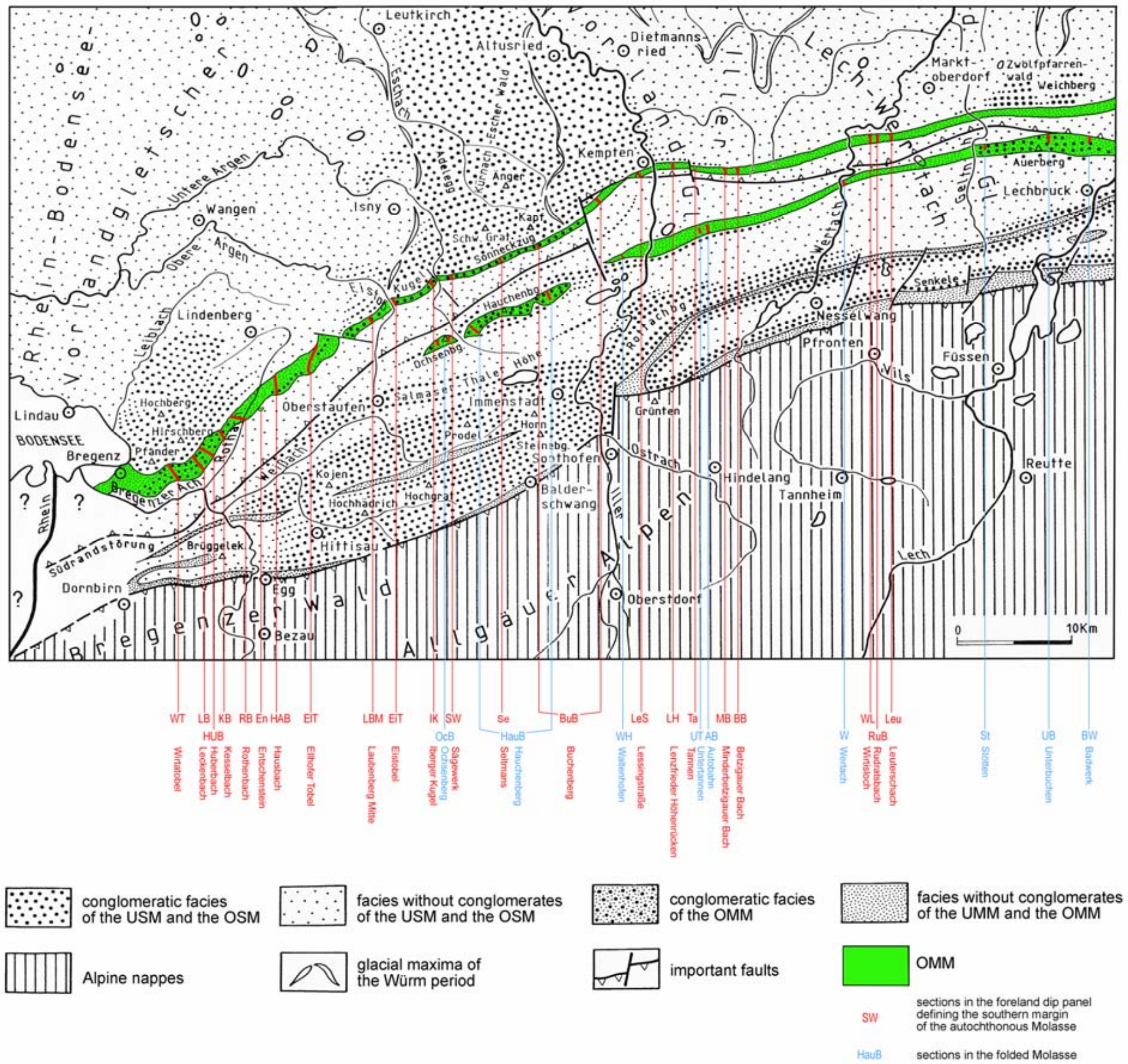


Fig. 2: Simplified geological map of southwestern Gemany (Allgäu) with the positions of the studied sections (modified after SCHOLZ 2000). OMM = Upper Marine Molasse, OSM = Upper Freshwater Molasse, UMM = Lower Marine Molasse, USM = Lower Freshwater Molasse

4. Results

4.1 References within the framework of this cumulative dissertation

A main part of the results gathered during the PhD work at Ludwig-Maximilians-Universität München correspond to manuscripts published in international and national journals (manuscripts 2-5) and accepted for publication in a national journal (manuscript 1). The references are listed below. A short summary of this work is presented above all in chapters 4.2.1, 4.2.2, 4.3.4, 5.1 and 5.2. Moreover, results which have not been published so long are presented in chapters 4.2.3 – 4.2.5, 4.3.2, 4.3.3, 5.3 – 5.5 and 7.

Manuscript 1

FRIELING, D., AEHNELT, M., SCHOLZ, H. & REICHENBACHER, B. (acc.): Sequence stratigraphy of an alluvial-fan delta in the OMM (Pfänder area, Late Burdigalian) – Z. dt. Ges. Geowiss.

see appendix 1

Manuscript 2

FRIELING, D., MAZUMDER, R. & REICHENBACHER, B. (2009b): Tidal sediments in the OMM (OMM) of the Allgäu area (Lower Miocene, Southwest Germany). – N. Jb. Geol. Paläont. Abh. 254: 151-163; Stuttgart.

see appendix 2

Manuscript 3

FRIELING, D. (2007): Rosselia socialis in the OMM of southwestern Germany. - Facies 53:479-492; Berlin, Heidelberg.

see appendix 3

Manuscript 4

SCHOLZ, H. & FRIELING, D. (2006): Wulstgefüge, Rutschfalten und Sandsteingänge in Molassesedimenten - Hinweise auf seismische Unruhe im Oligozän und Miozän des Alpenvorlandes. - N. Jb. Geol. Paläont. Abh. 241(3): 345-382; Stuttgart.

see appendix 4

Manuscript 5

FRIELING, D., PIPPÈRR, M., SCHNEIDER, S. & REICHENBACHER (2009a): Sedimentology and stratigraphy at the rocky coast of the upper Burdigalian Molasse Sea: a case study from Gurlarn near Passau (SE Germany). – Facies 55: 47–62; Berlin, Heidelberg.

see appendix 5

4.2 Succession from the southwestern rim of the basin (Allgäu/Vorarlberg)

Palaeogeographically the study area (Vorarlberg, Allgäu) is located in the southwestern part of the former marine basin near the Miocene coast which also is the recent southwestern margin of the basin (Fig. 1).

The OMM is exposed in numerous sections and crops out both in the foreland dip panel, which defines the southern margin of the autochthonous Molasse, and in the northern part of the folded Molasse (Figs. 2 and 3). The sediment successions consist of clastics, mostly sandstones with intercalations of marls. In proximal settings, in the alluvial fan deltas, the material shows a rather coarse grain size (e.g. conglomerates of the Pfänder, Hauchenberg, Sonneck ridge, Auerberg) whereas the sediments in the interfan areas are devoid of major coarse-grained intervals (e.g. sections near Weiler, Sulzbrunn, Leuterschach). Sedimentary structures are diverse and include among others even lamination, cross-stratification of various dimensions and shapes, massive structures and bioturbation.

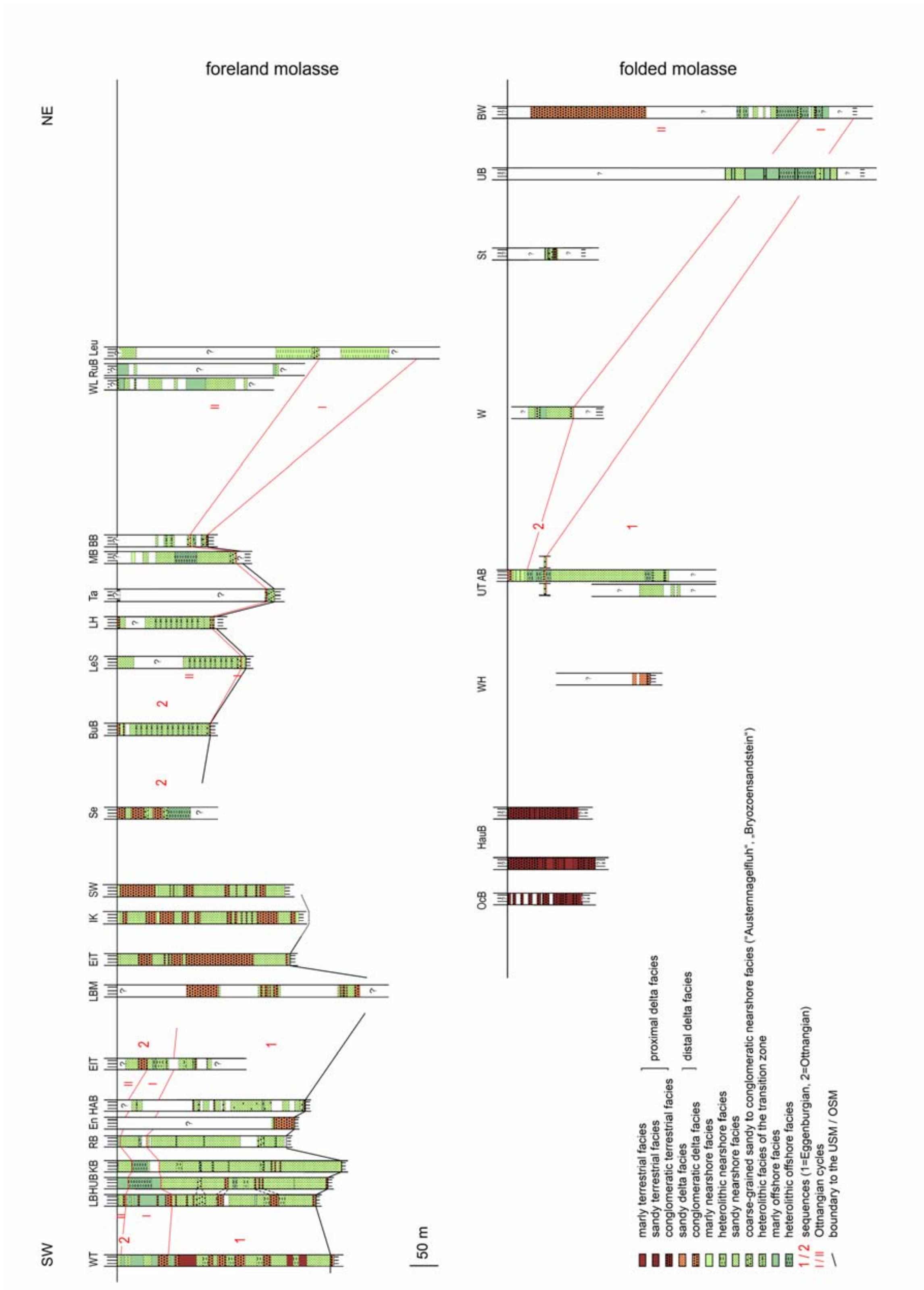


Fig. 3: Simplified schematic lithological logs in the study area (for the position of the sections see Fig. 2). WT(Wirtatobel) – after SCHAAD et al. (1992); LBM (Laubenberg Mitte), EiT (Eistobel) – after STROHMENGER (1991); IK (Iberger Kugel), SW (Sägewerk) – after DEGELMANN (1991); OcB (Ochsenberg) – after BÜHRING (1993); HauB (Hauchenberg) – after BEIL (1991); Se (Seltmans), BuB (Buchenberg), LeS (Lessingstraße), LH (Lenzfrieder Höhenrücken) – modified after SCHOLZ (1989); AB (Autobahn) – after SCHOLZ (1989).

According to UNGER (1996) and WENGER (1987a) the OMM is more than 1000 m thick in the central part of the basin. In the study area, however, the OMM succession is only about 200 m to 500 m thick (own observations), the greatest thickness is obtained with 400 m in front of the Pfänder Fan and with nearly 500 m in in front of the Auerberg Fan, which can be deduced from the detailed geological map of NEUBERT (1999). East of the Hochgrat Fan near Kempten, the thickness does not exceed 200 m (cf. HURST 1988, WEILAND 1988) whereas 300 m are assumed in the folded Molasse further to the south (SCHOLZ 1989). The far greater thickness shown on the geological map sheet Nesselwang West (GK 25 Nr. 8323, SCHWERD 1983) appears to be overestimated. A thickness of more than 500 m near Leuterschach which was estimated by WASSERRAB (1999) is based on very discontinuous outcrops of marine sediments and seems to be unrealistic, but 200 to 275 m can be confirmed in the region of Marktoberdorf.

4.2.1 Area of the Pfänder Fan (Vorarlberg/Westallgäu)

The Pfänder ridge east of Lake Constance (south-western Germany) comprises clastic sediments of the Upper Freshwater Molasse (OSM), the OMM and the Lower Freshwater Molasse (USM). The OMM succession in the area between Bregenz (Vorarlberg) and Weiler (Allgäu, Bavaria) reaches nearly 400 m and consists of deltaic deposits that formed during the Eggenburgian/Ottnangian transgression (Lower Miocene) in front of the alluvial Pfänder Fan. The marine succession was subdivided from base to top into four sedimentological units:

(1) a “basal” conglomerate;

(2) a monotonous “zone of glauconitic sandstones”;

(3) a heterogenous “zone of deltaic facies” with sandstones, thin marly layers, and various conglomerates;

(4) a “zone of marls and fine-grained sandstones” (FRIELING et al. acc. – appendix 1).

The pebble spectrum of the conglomerates in the Pfänder area is mainly dominated by Flysch components, additionally occur Austroalpine and a few Paleogene carbonates, which may also be of Austroalpine origin (UHLIG 1987, SCHOLZ 2000).

With increasing distance from the talus centre in the Wirtatobel region the studied sections display a successive change from a proximal shallow marine environment with strong deltaic influences in the southwest (Wirtatobel, Huberbach, Leckenbach section) to a distal, shallow marine environment with no or very little influence from the Pfänder Fan in the northeast (Rothenbach, Kesselbach section).

For more detailed information see FRIELING et al. (acc. – appendix 1). Additional study on a horizon with ichnofossils occurring in one of the sections was given by FRIELING (2007 – appendix 3). Moreover, SCHOLZ & FRIELING (2006 – appendix 4) described seismites occurring in the OMM of the Pfänder region.

4.2.2 Interfan region between Pfänder Fan and Hochgrat-Adelegg Fan (Westallgäu)

The Ellhofer Tobel section (FRIELING et al. 2009b – appendix 2) is the most intriguing among the sections representing the interfan area between the Pfänder Fan and the Hochgrat-Adelegg Fan (in the Weiler region). It is closer to the Pfänder Fan than to the Hochgrat-Adelegg Fan, although an influence of the Hochgrat-Adelegg Fan is indicated by the presence of crystalline pebbles in the conglomerates (SCHOLZ 2000) which are absent in deposits that solely derived from the Pfänder Fan (see chapter 4.2.1). The c. 140 m thick succession of the upper part of the OMM is overlain by terrestrial sediments of the OSM. The OMM sediments mainly consist of fine- to medium-grained sandstones, marls and minor conglomerates. Four major lithofacies types can be distinguished from base to top:

(1) a Glauconitic Sandstone Facies;

(2) a Heterolithic Facies of interbedded sandstones and marlstones;

(3) a Cross-Stratified Sandstone Facies with epsilon cross-stratification or foreset laminae;

(4) a Conglomeratic Facies (Frieling et al. 2009b – appendix 2).

These lithofacies represent different near coastal and shallow marine environments. A general northward current direction is indicated by subaquatic dune foresets and the orientation of ripple foresets.

For details see FRIELING et al. (2009b – appendix 2).

4.2.3 Area of the Hochgrat-Adelegg Fan (Westallgäu/Oberallgäu)

Deposits of the Hochgrat-Adelegg Fan clearly differ from those of the Pfänder Fan by the occurrence of crystalline pebbles in the coarse-grained layers; the Pfänder spectrum is devoid of such crystalline pebbles.

The Entschenstein conglomerate south of Weiler (see SCHOLZ 1993a, APPEL 1992) shows a Hochgrat spectrum with crystalline pebbles. It forms part of the foreland dip panel which defines the southern margin of the autochthonous Molasse and occurs in the interfan region mentioned above (cf. chapter 4.2.2; Fig. 2). The c. 30 m thick and coarse- to medium-grained conglomerate erosively overlies the USM marls and contains crystalline clasts along with fragments of oyster shells, polished quartz and chert pebbles. The abundance of oyster shells increases to the southwest. Moreover, the conglomerate is layered and characterised by the occurrence of orientated pebbles, sand layers and sand lenses. A large-scale cross-bedding can be observed, and the planar cross-bedding dips 18 to 20° to the southwest. The upper part of the conglomerate is concealed by vegetation although large boulders that have fallen from this part denote an interface between underlying foresets and overlying topsets in the conglomerate, which has an angle of about 20° (Plate IV, Fig. F). Glauconitic sandstones (facies type GS, see FRIELING et al. acc. – appendix 1) appear to form the hanging wall of the conglomerate (the transition is not exposed).

C. 10 km to the northeast the foreland dip panel becomes morphologically more distinct in the SW-NE striking mountain ridges “Kugel” and “Sonneck”. Several sections in this area show the coarse-grained deposits of the Hochgrat-Adelegg Fan.

A more than 400 m thick OMM succession of thick conglomeratic layers with intercalations of sandstones and marls is exposed in the Eistobel gorge (Fig. 2; JÜRGES 1970, DEGELMANN 1991, STROHMENGER 1991). The conglomerate pebbles display a Hochgrat-gravel spectrum (crystalline pebbles). The base is erosive in places. The thickest conglomerates occur in the lower part of the section and are large-scale cross-bedded with planar foresets dipping c. 30° NW (Plate IV, Fig. B). Those parts of the marine Eistobel succession which are dominated by sandstone dip with lower angles. Occasionally there are planar bedded or indistinctly cross-bedded parts dipping with very low angles (Plate III, Fig. E). These parts of the succession contain only few thin ripple-bedded and reddish fine-sandy to marly layers. In other parts occurs a sandy and marly heterolithic facies with double mud drapes (Plate I, Figs E, F), bioturbation and flute casts, the latter reflecting a southward current directions.

Other sections in the OMM deposits of the Hochgrat-Adelegg Fan are exposed further to the east, on the southern slopes of the Kugel and Sonneck mountains (DEGELMANN 1991, STROHMENGER 1991, this study; Fig. 2). In these places they comprise 250 to 480 m of interbedded sandstones and conglomerates, with marly intercalations in the basal parts of the sections (Fig. 4).

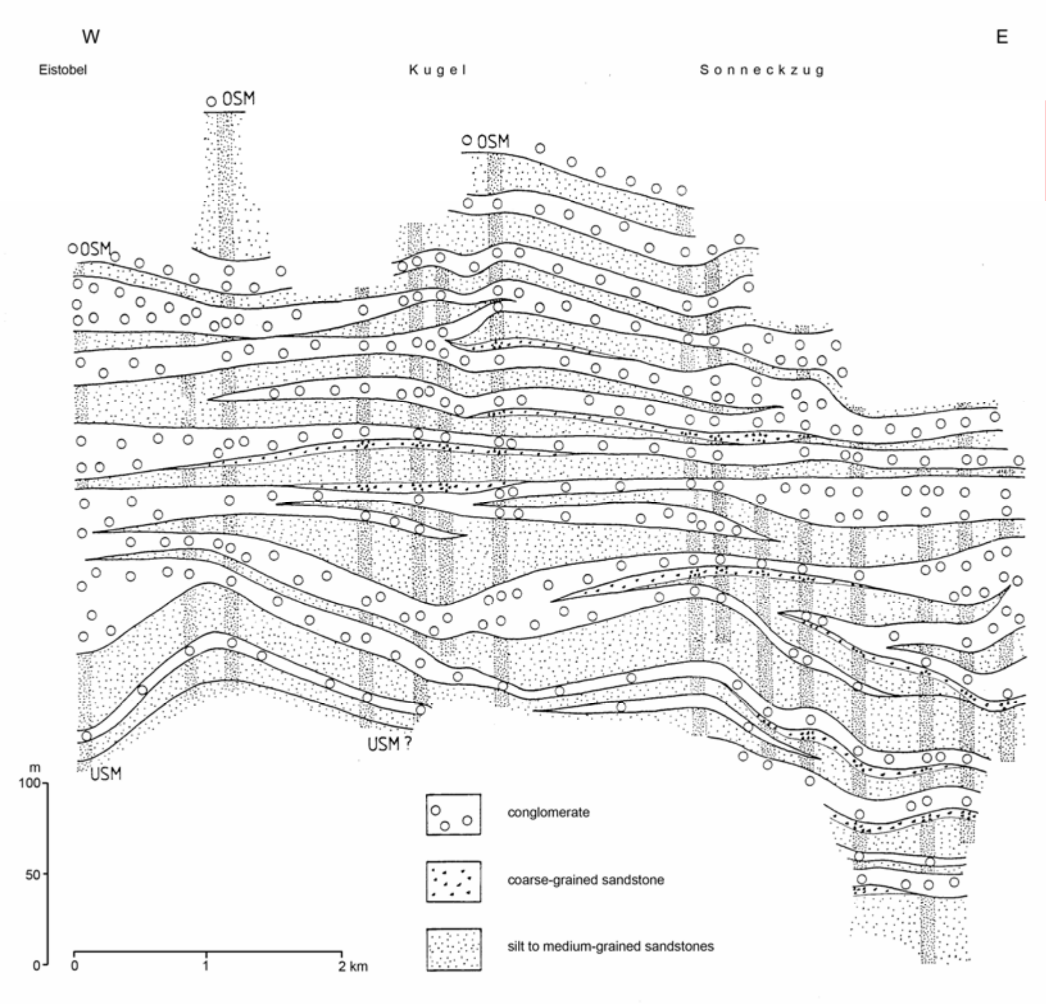


Fig. 4: Schematic diagram of the OMM succession of the Hochgrat-Adelegg delta in the region Eistobel-Kugel-Sonneck (after DEGELMANN 1991).

The basal marls are finely laminated to massive, with local wavy or lenticular bedding, isolated bioturbation and remains of *Pinna sp*. (DEGELMANN 1991). About half the succession consists of reddish conglomerates of mainly medium grain size (Plate IV, Fig. /C). The deposits are generally bedded indistinctly and unsorted, although poor sorting can locally be observed, and occasionally pebbles are poorly rounded. The conglomerates abundantly display a debris flow-like habitus (e.g. rock wall “Klettergarten Seltmans”; see also DEGELMANN 1991). According to EBERHARD (1987), 5 to 10 % of the pebbles are gneisses, while some of the more distinctly bedded horizons contain shells of marine invertebrates. Fine to coarse-grained sandstones make up c. 40 % of the succession. They are massive or cross-bedded, show ripple bedding, longitudinal cross-bedding, pebbly layers and local bioturbation. The main part of the sandstones contains glauconite, abundant plant remains, and intraclasts. Own observations confirm the logs given by DEGELMANN 1991, STROHMENGER 1991. Locally there are shells of marine molluscs (cf. DEGELMANN 1991, STROHMENGER 1991), although only the coarse-grained beds with pebbles are rich in fragments of oysters, balanids, pelecypodes, bryozoans and fish teeth. Thin marly or heterolithic intercalations in the conglomerate-sandstone-succession are multicoloured, locally fine laminated or wavy bedded, and contain plant remains and shell fragments of pelecypodes (see also DEGELMANN 1991, STROHMENGER 1991).

Further southward follow the prominent mountain ridges Hauchenberg and Ochsenberg (Fig. 2). They consist of deposits of the Hochgrat-Adelegg fan which are part of the folded Molasse (Hauchenberg syncline). The OMM succession in this area is predominated by coarse-grained clastics (Fig. 5), mainly in form of alluvial fan conglomerates with terrestrial habitus (Plate IV, Figs A, D). The sandy matrix of the conglomerates shows a pale red colour. The sole difference between these deposits and the overlying OSM conglomerates consists in the presence of oyster shells (Plate IV, Fig. E). These shells led previous authors (see LEMCKE 1988) to characterise the succession as marine deposits, however, this cannot be verified from a sedimentological point of view. The conglomerates are poorly sorted, extremely coarse-grained in places, and contain quartz and chert pebbles, which are never polished. Intercalated marls and sandstones show pale red to purple colours (Plate IV, Fig. A) and contain remains of limnic gastropods (*Bithynia* sp.) which are the only species.

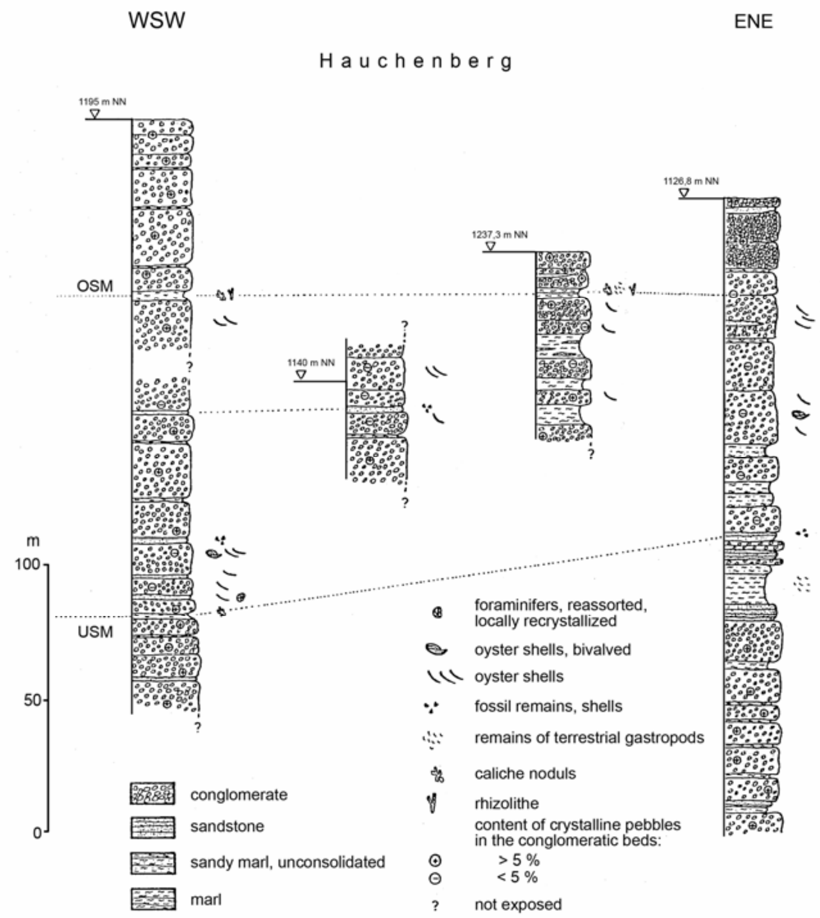


Fig. 5: Schematic logs of the Hauchenberg succession (after BEIL 1991 and own field studies).

4.2.4 Interfan region between Kempten and Leuterschach (Oberallgäu/Ostallgäu)

Between Hauchenberg and Sonneck mountains to the west and Auerberg mountain to the east, the OMM sediments do not form prominent hills. Near Kempten, the OMM succession is exposed in small ravines and small outcrops east of the town (LH, Th, MB, BB; Fig. 2). In addition, there exist relicts of former outcrops west of Kempten (cf. SCHOLZ 1989; OsH, BuB, LeS; Fig. 2) which represent deposits in the foreland dip panel. Further southward an OMM succession with a thickness of more than 250 m was temporarily exposed in the folded Molasse (northern part of the Hauchenberg-syncline) during the construction of the A7 Ulm-Füssen motorway (cf. SCHOLZ 1989; AB, Fig. 2). Further eastwards the OMM crops out in an undercut slope of the river Wertach (folded Molasse; W, see Fig. 2) and near Marktoberdorf east of this river (foreland dip panel; WL, RuB, Leu see Fig. 2).

The marine succession in the entire region contains only few coarse-grained intercalations (see Fig. 3), the most characteristic of which occurs in nearly all sections in a coarse-grained sandstone / conglomeratic facies, the so called "Bryozoensandstein" (GÜMBEL 1861, MILLER 1877, this study). In the region around Kempten it is placed in a relatively basal position (see Fig. 3). The "Bryozoensandstein" forms a steeply inclined ridge which, east of Kempten, appears as a hill chain, the "Lenzfrieder Höhenrücken" (LH, see Fig. 2). The

“Bryozoensandstein” consists of extremely poorly sorted coarse-grained sandstones and fine-grained conglomerates, which are rich in shell debris and pebbles of various composition (Plate V, Figs A, C-F). Characteristic components are polished quartz and chert pebbles. Abundant oyster shells, other molluscs, barnacles, bryozoans, pieces of echinoderms, shark’s teeth, and teeth of other fish and whales are typical as are, locally, large pieces of carbonaceous wood fragments (Plate VI, Figs C-F). In places the sediment is enriched by bioclasts to such a degree that it may be classified as lumachelle with sand grains and pebbles. Limestone pebbles (of Alpine origin) and wood pieces often show holes derived from boring mussels (Plate IX, Fig. E). Locally, the “Bryozoensandstein” has an erosive base. The sediments are generally well-bedded with medium to large scale, partly longitudinal cross-bedding (Plate VI, Figs A-C). Chaotic structures appear only occasionally. Ripple surfaces (oscillation and interference ripples) are common.

The “Bryozoensandstein” in the Kempten area can be subdivided into two parts, separated by intercalations of fine-grained sandstones or marls, of 1 to 20 m thickness (see Fig. 3).

A special type of the “Bryozoensandstein” is exposed in one outcrop in the centre of the study area, within the abandoned sandstone quarry of Tannen near Kempten (Ta, see Fig. 2). This type was also found in and described from a formerly exposed section in Kempten (SCHOLZ 1976). One layer in this special type of “Bryozoensandstein” is enriched with nodular growing bryozoans, which have diameters ranging from a few centimetres up to one decimetre (*Ceriopora simplex*, SCHOLZ 1989, 1992; Plate VI, Fig. D).

In addition, in the area around Kempten, another coarse-grained facies type has developed. The upper part of the succession here is built up from a very coarse-grained local conglomerate (Fig. 3). Its sandy matrix contains shell debris of molluscs.

The main part of the OMM-succession, however, is dominated here by thick, monotonous glauconitic fine-sandy deposits (Plate III, Fig. D). They are mostly parallel or indistinct cross-bedded and display different ripple marks (Plate VIII, Figs B-D). In some sections they may appear massive, probably as a result of destratification caused by intensive bioturbation. Different ichnofossils occur (e.g. FRIELING 2007 – appendix 3). Locally thin layers of coarse-grained sandstones with pebbles, mud pebbles or shell accumulations are intercalated.

Marly deposits in the Kempten area are rare. Varve-like laminated pelites form a thin segment in the upper part of the Minderbetzigauer Bach section (MB, Figs 2, 3, Plate I, Figs C, D). Thin marly layers are intercalated in the sandstones in the central part of this section, in the sandstones between both “Bryozoensandstein” facies in the Betzigauer Bach section (BB) as well as in the sandstones of the sections west of Kempten (Figs 2, 3). Marly layers are also intercalated in the lower and upper part of the A7 section (AB, SCHOLZ 1989; Figs 2, 3). Thicker marly horizons are part of the sections east of the river Wertach (Figs 2, 3). There pelites also occur in a thick heterolithic facies forming the lower part of the Leuterschach section (Leu, see Fig. 2, Plate II, Figs A, B). All these pelites are very poor in microfossils.

Based on sedimentary loggings on the map sheets Isny to Nesselwang West,a standard section of this so called basin facies of the OMM has been constructed by SCHOLZ (1989; foreland and folded Molasses; Fig. 6). This standard section consists of three lithostratigraphical series: 1) the basal „Bryozoensandstein“ together with other sandstones forming the transgression series (“Transgressionsserie“) and indicating a base level rise; 2) fine-sandstones and marls above form the sand-marl series („Sandmergelserie“) that marks a high base level; 3) finally coarse-grained and fossiliferous sandstones and conglomerates form the regression series (“Regressionsserie”) in response to a base level fall.

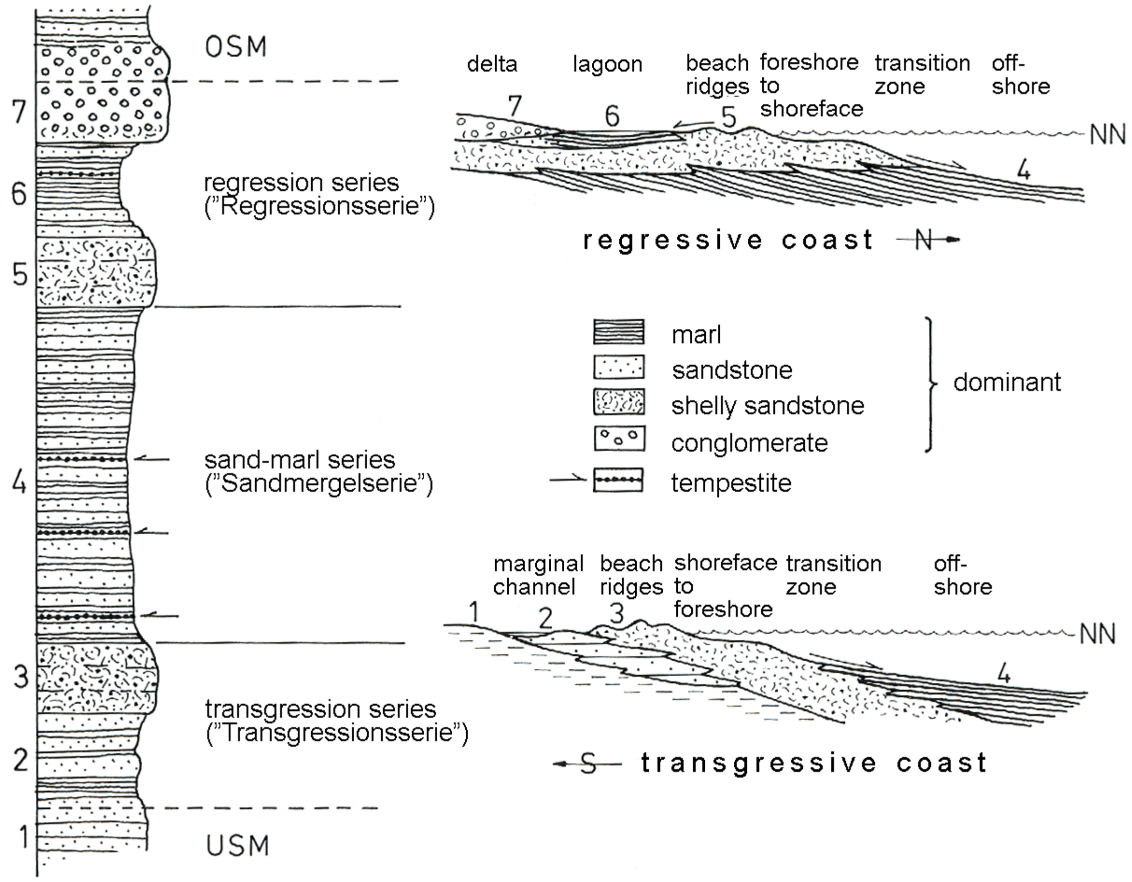


Fig. 6: Standard section of the Kempten area (re-drawn after SCHOLZ 1989). However, in contrast to SCHOLZ (1989), the upper “Bryozoensandstein” occurs only in the succession of the folded Molasse (AB section see Fig. 2), and the lower “Bryozoensandstein” in the Kempten area is subdivided into two parts, separated by intercalations of fine-grained sandstones or marls (see Fig. 3). Thus, opposing the original idea by SCHOLZ (1989), who viewed the Kempten succession as mono-cyclic, it consists of at least two cycles (see chapter 5.4).

4.2.5 Area of the Auerberg-Nesselburg Fan (Ostallgäu)

Auerberg mountain in the eastern Allgäu with a height of more than 1000 m is built up by a coarse-grained conglomeratic facies of the OMM which represent deposits of the Auerberg-Nesselburg fan (see Fig. 2). It is a part of the folded Molasse or, to be precise, of the northern flank of the Hauchenberg-Peißenberg syncline. North of and directly below the Auerberg, OMM deposits are exposed in two small ravines situated east of Stötten. Here only the basal part of the OMM succession crops out. In both sections the hanging layers are not exposed. However, it seems to consist of the OMM-conglomerates mentioned above.

In this region the OMM deposits are obviously part of two tectonic units lying upon each other. One of the sections (BW, Fig. 2) exposes the underlying wedge. Here the boundary with the underlying USM can be confined to a few decimetres, but the boundary with the hanging layer (OSM) is obscured by Quaternary deposits and is presumably also bounded in the north by a fault (see Fig. 2). The other section (UB, Fig. 2) exposes the overlying wedge, where the underlying as well as the overlying beds are preserved, as can be seen on the geological map by NEUBERT (1999). However, neither the boundary to the underlying nor to the hanging layer is exposed in this section. Nevertheless, according to detailed geological maps of the region (KUHNERT & ROHR 1975, NEUBERT 1999) the exposed succession belongs to the lower part of the OMM succession.

In contrast to all the other sections studied in the OMM of westernmost Bavaria mentioned above, the marine deposits north of the Auerberg are fine-sand and marl dominated (see Fig. 3, Plate II, Figs E, F, Plate IX, Fig. D). Sandy marls prevail, which contain some deposits of thin platy fine-grained sandstones and thin isolated pebbly intercalations. Coarse-grained deposits are lacking. The deposits of these two sections are the only sediments with a certain content of microfossils in the whole study area (see chapter 4.3.3).

4.3 Stratigraphy of the Allgäu area

4.3.1 Introduction

Since no absolute determination of the age of the OMM is yet available, the sediments are traditionally subdivided into the Eggenburgian and Ottnangian stages of the western Paratethys. Thus they probably span a period of 21 to 17 Ma (LEMCKE 1988, STRUNCK & MATTER 2002, BERGER et al. 2005, REICHENBACHER et al. 2005, DOPPLER et al. 2005, HARZHAUSER & PILLER 2007). The absolute time interval of these stages is not known exactly, but the limit between both stages is now thought to be about 18 Ma (e.g. STEININGER 1999, LATAL et al. 2006, HARZHAUSER & PILLER 2007): formerly it was estimated at 23 Ma (VASS & BAGDASARJAN in PAPP et al. 1973). The absolute age of the limit between the Ottnagian and the Karpatian is better known and has been fixed at 17.235 Ma (HARZHAUSER & PILLER 2007). Based on benthic foraminifera (WENGER 1987a, b) and secondary also on ostracods (WITT 1967) as well as mammals (KÄLIN 1997) a biostratigraphical subdivision of the sedimentary succession in Middle and Upper Eggenburgian as well as Lower and Middle Ottnangian respectively in the mammalian stages MN 3a/b and MN 4a/b is possible.

A stratigraphic classification and subdivision of the OMM succession has not existed until now in the Allgäu area with the exception of the Pfänder region (see FRIELING et al. acc. – appendix 1). However, as the geographic location of this part should be ideal for a lithostratigraphical comparison of the Swiss and German successions, their correlation is not possible without ideas about their stratigraphical subdivision. Attempts using bio- and magnetostratigraphical methods mostly failed because of the special sedimentary conditions there, i.e. the high sedimentation rates and the lack or scarcity of fine-clastic layers. Only one of the sections (BW) containing many marl layers was rather successfully investigated with both methods leading to quite useful results (see chapters 4.3.2, 4.3.3). Thus, the lithofacies and sedimentary environment were primarily investigated as the basis for a lithostratigraphical and sequence stratigraphical model. However, the biostratigraphical analysis of the Badwerk section is an important calibration point for the sequence stratigraphical division in the eastern part of the study area (see Fig. 9). Moreover, it plays the role of a key section for the study area as a whole.

4.3.2 Magnetostratigraphy

Three sections (two in the Pfänder region, one in the Auerberg region) were sampled for a pilot palaeomagnetic study. Sampling and measurements were supported by the Section of Geophysics in Munich. However, the magnetic signals obtained were weak and not clear, probably due to the lack of unweathered clayey or marly sediments in the sections. In the field the degree of weathering of the samples was often not visible. The palaeomagnetic results show that the natural remanent magnetisation (NRM) intensity is weak. As all samples displayed a strong superimposition of the modern earth's magnetic field, normal polarities were more clearly visibly than reversed, which were often only recognizable on the tendency of the graph. In these cases the data of declination and inclination are mostly contradictory (e.g. the last is positive, as the first shows southward).

The only section with relatively utilizable results was the Auerberg section.

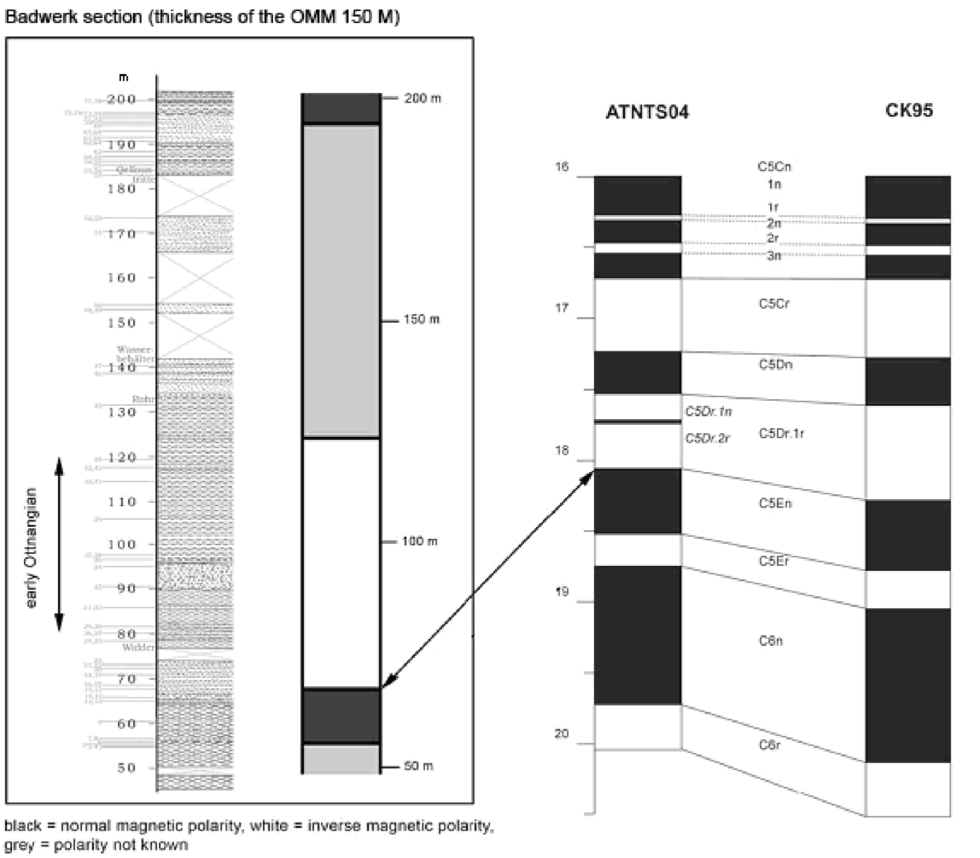


Fig. 7: Polarisations and correlation of the Auerberg section with the Astronomical Tuned Neogene Timescale (LOURENS et al. 2004) and the geomagnetic polarity timescale (CANDE & KENT 1995). The arrow shows the possible correlation of the normal/reversed change in this section with the upper border of C5En.

Biostratigraphic data (see below) resulted in a Lower Ottnangian age of the sediments between 80 and 120 metres. If this age is correct, then the normal interval at the base of the section should correspond to the Chron C5En, and the next normal interval at 200 m should correspond to the Chron C5Dr.1n (see Fig. 7). This results in a sedimentation rate of about 21 cm / 1000 a.

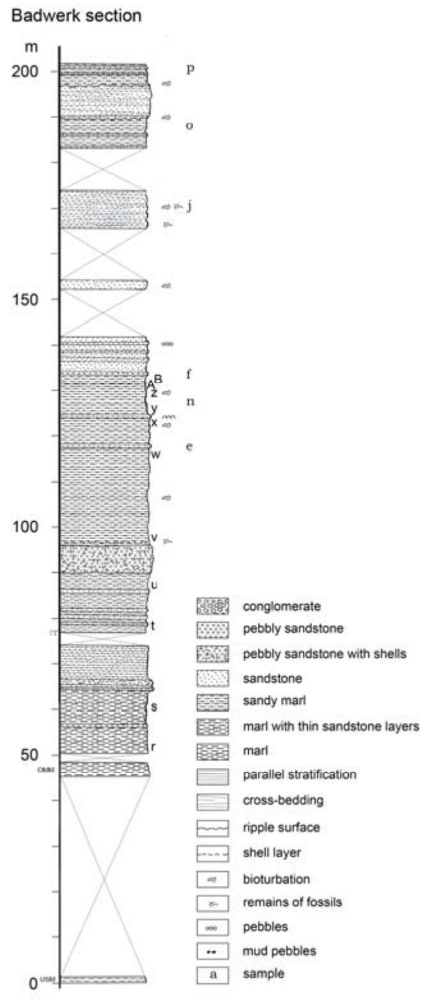
4.3.3 Biostratigraphy

About 80 marly samples from all studied sections in southwesternmost Bavaria (Allgäu) were taken for micropalaeontological analysis, but only the Badwerk section (Auerberg succession) yielded biostratigraphic results. In this section, samples were taken from fine-grained sediments deposited in the basin directly in front of the Auerberg-Nesselburg fan, and contained a higher concentration of microfossils compared with all other sections of the study area. The determination of benthic foraminifera as well as their stratigraphical and palaeoecological interpretation was kindly done by Martina Pippèrr, the same work concerning ostracods was kindly carried out by Dr. Wolfgang Witt.

<u>Stratigraphy:</u> Index fossils are absent, nevertheless a classification of the succession is possible.

Bolivina concinna (samples t, d, e) is typical for the „Helvétien“ (Early Ottnangian according to WENGER 1987 b: 164) of the Swabian and Swiss Lake Constance area (HAGN 1961: 301). In this area *Melonis pompilioides* (sample d) is confined to the „Sandschiefer”, which after HAGN (1961: 307) can be correlated with the Early Ottnangian “Neuhofener Schichten” of eastern Bavaria. WENGER (1987 b) described this species also from the Upper Eggenburgian, but more commonly from the Ottnangian. Altogether, in sample d the foraminiferal assemblage seems to reflect an Ottnangian date, but the discrimination to the Upper Eggenburgian here is not certain.

In the samples above (u, e, x, and B) *Spiroplectammina pectinata* may suggest an early Ottnangian age. In the South German part of the Molasse Basin the species is typical and abundant in the early Ottnangian; in Egerian, Eggenburgian, and middle Ottnangian deposits the taxon only rarely occurs (Wenger 1987 a, b). According to WENGER (S. 251) *Spiroplectammina pectinata* is typical for the deep neritic basin facies of the early Ottnangian Molasse Sea, i.e. the “Neuhofener Schichten” of eastern Bavaria. Moreover, in the Lake Constance area *Spiroplectammina pectinata* occurs in the Lower Ottnangian „Sandschiefer“ (HAGN 1961: Tab. 19 u. S. 307), just as *Textularia subangulata* (= *T. gramen*). The latter species occurs in sample e; it is common in the marginal facies of the “Neuhofener Schichten” in eastern Bavaria (WENGER 1987: 246). Taken as a whole, the foraminiferal assemblage of samples e and x, and also u and B is comparable with the marginal facies of the Neuhofen Beds and with the „Sandschiefer“.



A

Foraminifers:

k	a	l	h	s	m	i	t	d	u	v	w	e	x	n	B	o	p	samples
									.			/						*Textularia gramen* D' ORB.
									/			○	○		/			***Spiroplectammina pectinata*** **(REUSS)**
												.			.			*Spiroplectammina carinata* (D' ORB.)
							.	/										*Lagena* div. sp
							.		.									Polymorphinidae
								.				.	.	.				*Bulimina* sp.
												.						*Caucasina* sp.
							.	/				/						***Bolivina concinna*** **(KNIPSCHEER & MARTIN)**
												.						*Bolivina crenulata trunensis* HOFFMANN
														.		/		*Bolivina* sp.
													.					*Fissurina orbignyana* SEGUENZA
							.											*Stilostomella ? danuviensis* WENGER
												.						*Stilostomella ? scabra* (REUSS)
							.							.				*Stilostomella* sp.
		/		.				.										*Elphidium crispum* (LINNÉ)
								○	/									*Elphidium subtypicum* PAPP
								.							.			*Elphidium matzenense* PAPP
						.												*Elphidium ?angulatum* (EGGER)
								/										*Elphidium macellum* (FICHTEL & MOLL)
						.	●	○	○	.	/		.		/	.	/	*Elphidium glabratum* CUSHMAN
						.	●	○		.	○	/	.	.	●	.	/	*Elphidium* div. sp.
						○	.					/						*Elphidiella heteropora* (EGGER)
						/	/	/			/				/		/	*Elphidiella minuta* (REUSS)
								.					.					*Elphidiella semiincisa* WENGER
								/										*Porosononion granosum* (D' ORB.)
						○	.	/	/			○	○	.		.	/	*Nonion commune* (D' ORB.)
								.										*Protelphidium roemeri* (CUSHMAN)
								/			.							*Melonis pompilioides* (FICHTEL & MOLL)
						●	●	●	○	.	○	○	/	/	/	/	/	*Ammonia beccarii* (LINNÉ) s.l.
																		Rosalina obtusa D' ORB.
						.		.			.							*Discorbis* sp.
				.		/	●	●	/	/	●	○	○	/	/	○	/	Cibicididae
									●	/		/			.			*Heterolepa dutemplei* (D' ORB.)
											○	.	/		.		/	*Hanzawaia boueana* (D' ORB.)
							○	○			/	/	.	/		○	○	planktonic foraminifera

Ostracods:

c	i	d	e	samples
/				*Cytherella* sp.
/			/	*Cytheridea* cf. *hoerstgenensis* Bassiouni, 1962
/				*Carinovalva* aff. *neuhofenensis* Witt, 1967
.				*Hemicythere ? triangularis* Oertli, 1956
			.	*Pontocythere* sp., juv.

B

Fig. 8: (A) Schematic log of the Badwerk section (BW, see Fig. 2) with the position of the samples. (B) Distribution and abundances of foraminifers and ostracods. · = 1 Ex., / = 2-5 Ex., ○ = 6-20 Ex., ● = > 21 Ex.; for foraminifers: light grey = typical shallow-water taxa (*Ammonia* and keeled *Elphidium*: 0-50 m water depth; non-keeled *Elphidium*, *Elphidiella* and *Hanzawaia*: inner shelf (after MURRAY 1991); dark grey = characteristic of somewhat deeper water (*Lagena*: infralitoral to bathyal, preferred depth range from 20 m down; *Melonis pompilioides*: circalitoral to bathyal (after RÖGL & SPEZZAFERRI 2003); Cibicididae: *Cibicidoides lopjanicus* (MYATLYUK), *C. tenellus* (REUSS) / *Cibicides lobatulus* (WALKER & JACOB). Bold: taxa are typical for the Ottnangian, but rarely may occur also in the Eggenburgian.

Determination of benthic foraminifera as well as their stratigraphical and palaeoecological interpretation provided by Martina Pippèrr, data concerning ostracods provided by Dr. Wolfgang Witt.

Palaeoecology: The lowest samples containing foraminiferal tests are l and s, but they contain only *Elphidium crispum* and Cibicididae gen sp. indet. *Elphidium* favours environments with a water depth of 0 to 50 m (MURRAY 1991, 2006). The low abundance and diversity of foraminifers in these samples is characteristic of stressed or extreme environments (MURRAY 2006). The next sample containing foraminifera is i. An extremely shallow, marginal marine environment with a water-depth of less than 50 m is indicated here by the predominance of *Ammonia* and *Elphidium* (see RUPP & HAUNOLD-JENKE 2003: 243).

The high proportion of *Ammonia* possibly indicates a slight freshening of the sea. The more diverse benthic foraminiferal assemblages and the occurrence of planktonic foraminifera in samples t and d however, suggest a marine environment with euhaline salinity. Moreover, the benthic foraminiferal assemblage reflects a shallow marine environment below 50 m water-depth. The most abundant taxa in samples u, v, w are *Cibicidoides*/*Cibicides* and *Heterolepa*, the assemblage as a whole is also indicative of a marine environment. Above, the most clayey sample x probably represents the deepest deposits of the Auerberg succession, because of the abundance of *Spiroplectammina pectinata* and the relatively infrequent occurrence of *Elphidium* and *Ammonia*. In the overlying samples B and p however, *Elphidium* and *Ammonia* occur again in higher abundance and indicate a regressive tendency.

Ostracods confirm a marine environment and an Ottnangian date (samples c, e).

Another section from which biostratigraphic results were reported is the Wirtatobel section (Pfänder region), situated at the southwestern margin of the study area. Foraminifers, bivalves and nannoplankton of the OMM succession in this section were studied by some earlier authors (see a short conclusion in FRIELING et al. acc. – appendix 1), who ascertained that it consists of an Eggenburgian and an Ottnangian part.

The Wirtatobel section at the western margin of the study area and the Badwerk section at its eastern margin provide an important biostratigraphic frame for the sequence stratigraphic interpretation of the Allgäu as shown in Fig. 9.

4.3.4 Sequence stratigraphy

The south-western part of the study area, i.e. the Pfänder region with four well exposed sections, cutting through a thick marine succession, appeared to be most suitable for a sequence stratigraphical analysis. Here the OMM consists of two transgressive-regressive sequences. The lower one can be correlated with the Eggenburgian, the upper sequence is proposed to belong to the Ottnangian. The Ottnangian sequence can be subdivided into two subordinate cycles (FRIELING et al. acc. – appendix 1) that probably correspond with the two transgressive-regressive cycles of the Ottnangian known in the southwestern section of the Bavarian part of the Molasse Basin (sensu LEMCKE et al. 1953). Additionally, the sequences described here from the Pfänder region correlate well with the sequences from the Hörnli and Napf delta reported by KELLER (1989).

For detailed explanations see FRIELING et al. (acc. – appendix 1).

A sequence stratigraphical analysis is much more complicated for the, mostly rather incomplete, sections in the other parts of the study area. Additionally, a biostratigrahic correlation between these sections is not possible due to the lack of indicator fossils. Nevertheless an attempt for a sequence stratigraphical analysis and a correlation was made based on lithofacies and sedimentological data (see chapter 5, Fig. 9).

5. Interpretation of the Allgäu succession

The sedimentary rocks of the OMM in the regions of south-western most Bavaria (Allgäu) and western most Austria (Vorarlberg) represent siliciclastic coastal near-shore deposits of a high-energetic neritic province, characterized by a strong clastic input derived from the Alps to the south. Interlockings of the marine sediments with alluvial fan deposits are common, and the boundary to the OSM succession is often gradual. In Eggenburgian and Ottnangian times, the marginal marine environment was controlled by three large fans: the Pfänder fan in the west, the Adelegg-Hochgrat fan in the central part of the study area, and the Auerberg-Nesselburg fan in the east (e.g. KUHLEMANN & KEMPF 2002, BERGER et al. 2005, this study).

In the western part of the study area, the OMM succession consists of two sedimentary sequences (Eggenburgian and Ottnangian) with subordinate sedimentary cycles (FRIELING et al. acc.). In contrast, further to the east, the Eggenburgian part is missing in the succession (Badwerk section, see Fig. 9). Two subordinate Ottnangian cycles are detectable in the western and also in the eastern study region, but in the central part (the area around Kempten) locally only one cycle is traceable; and in the sections representing the Hochgrat-Adelegg delta a division in sequences and cycles seems not possible (see Fig. 9).

5.1 The area of the Pfänder fan (Vorarlberg/Westallgäu)

The OMM succession of the Pfänder fan consists of two transgressive-regressive sequences of third order. The lower sequence can be correlated with the Eggenburgian, and it's highstand system tract is represented by deltaic sediments. The younger sequence, for which an Ottnangian age has to be assumed, can be subdivided into two subordinate sequences, that probably correlate with the two known transgressive-regressive cycles of the Ottnangian, in the south-western part of the Bavarian Molasse Basin. The Wirtatobel coal seam, well-known from former mining activities, is the most important of several freshwater sediments deposited on the delta plain near the talus centre.

For more information see FRIELING et al. (acc. – appendix 1).

5.2 The interfan region between Pfänder fan and Hochgrat-Adelegg fan (Westallgäu)

A tidal influence on the interfan region between Pfänder and Hochgrat-Adelegg is indicated in the Ellhofer Tobel section by the presence of a heterolithic facies with associated epsilon cross-stratification and megaripples, i.e. subaquatic dunes.

In general, the Ellhofer Tobel succession displays a transgressive-regressive sequence. However, a lithostratigraphical correlation with the Pfänder succession allows for a more detailed sequence stratigraphic interpretation and also an interpretation of the biostratigraphy (Figs. 3, 9). Accordingly, the lower part of the succession is probably Eggenburgian in age, and the upper, Ottnangian part, can be subdivided into two sedimentary cycles (Figs 3, 9).

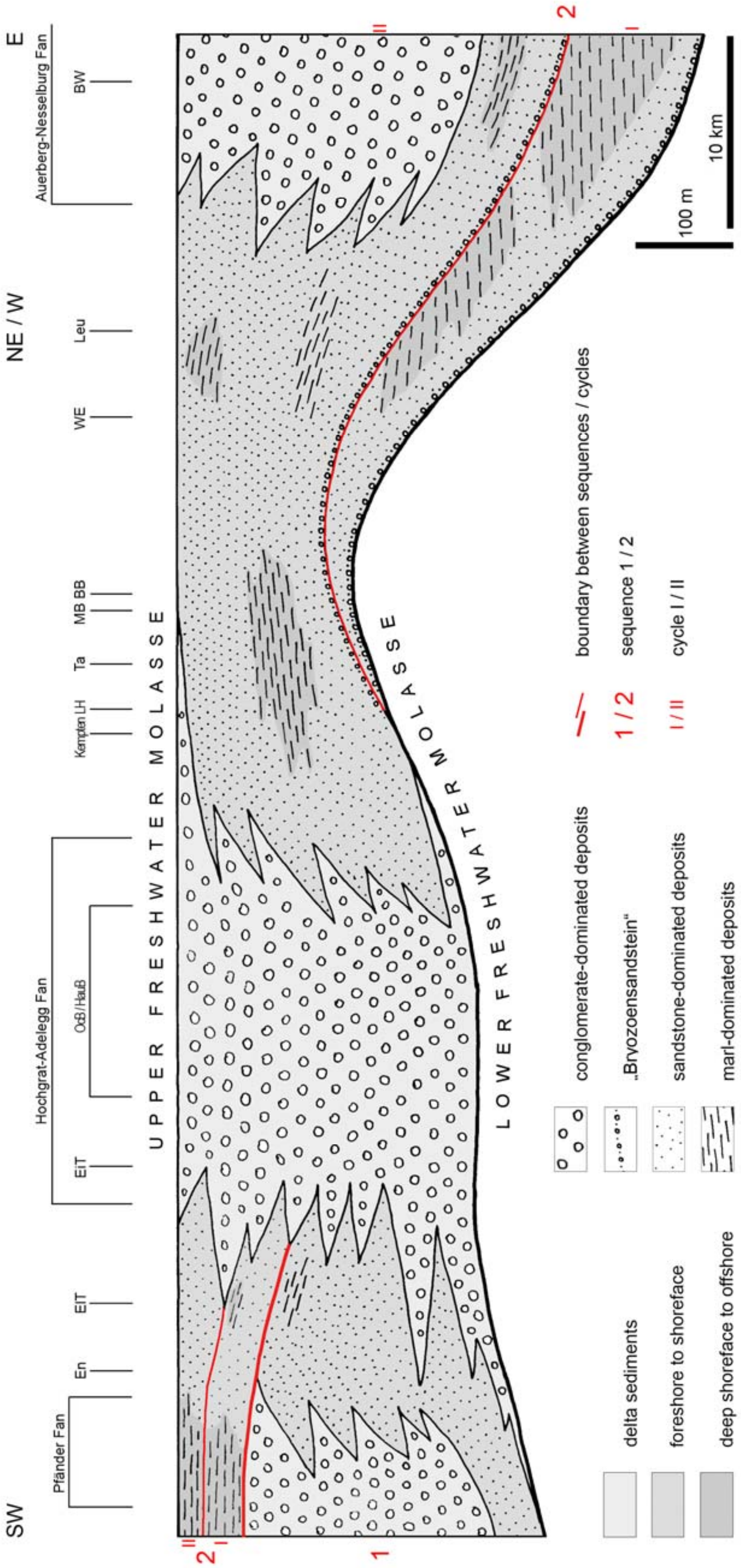


Fig. 9: Schematic diagram of the OMM succession in the study area (Allgäu/Vorarlberg) and sequence stratigraphic interpretation. See Figs 2, 3 for abbreviations of sections.

5.3 The area of the Hochgrat-Adelegg fan (Westallgäu/Oberallgäu)

As indicated by the common occurrences of oyster shells, the Entschenstein conglomerate near Weiler is obviously a marine deposit (KELLENBERGER 1930, SCHOLZ 1993a), and its interpretation as terrestrial deposits (USM) by VOLLMEYER & ZIEGLER (1976) is erroneous. The large scale cross-bedding of this conglomerate suggests a deltaic setup. The conglomeratic topsets of this small Gilbert-type delta are visible on giant rock slide boulders, below the conglomerate escarpment (SCHOLZ 1993a; Plate IV, Fig. F).

The OMM conglomerate at Entschenstein, at the very base of the marine succession, forms a rather small isolated conglomeratic occurrence in this area (VOLLMEYER & ZIEGLER 1976, this study), and passes into glauconitic OMM sandstones towards NE and SW. Thus, it was originally deposited in and restricted to a N-S to NE-SW-orientated channel like structure, cut into sandstones and marls of the underlying USM succession by erosion. As demonstrated by the orientation of the channel, as well as by the crystalline-rich pebble spectrum of the conglomerate (SCHOLZ 1993b), these deltaic deposits were fed by debris derived from the western part of the Hochgrat-Adelegg fan. This conglomeratic channel-fill apparently represents an erosive phase at the interface between USM and OMM that predates the initial flooding of the OMM. This interpretation fits well with the proposed explanation for the basal conglomerate within the Pfänder succession (FRIELING et al. acc. – appendix 1). Also the glauconitic sandstones above the Entschenstein conglomerate are comparable to the facies at the Pfänder succession, which is there of Eggenburgian age. Thus, at least the western margin of the Hochgrat delta seems to have a similar initial development as the Pfänder delta: an erosive surface on top of the USM with isolated conglomeratic channel-fills at the base, and the area-wide occurrence of glauconitic sandstones above it. The south-westward dipping deltaic foresets of the Entschenstein conglomerate display its rather distal position in the Hochgrat-Adeleg fan related to the talus centre. The Entschenstein conglomerate is clearly different from the Eistobel conglomerate (see below), which is located nearly in the centre of this fan and has, moreover, a higher stratigraphic position.

Petrographic analysis of conglomerate pebbles (STROHMENGER 1991) evidences that coarse-grained debris deriving from the Hochgrat-Adelegg fan temporarily attained even Vorarlberg (see also FRIELING et al. acc. – appendix 1). This westward transport of pebbles into the interfan region is also noticeable in the Ellhofer Tobel section, near Weiler (FRIELING et al. 2009b – appendix 2). Here, a more than 15 m thick shell-bearing marine conglomerate is intercalated in a sandy and marly interfan succession and contains a considerable portion of crystalline pebbles, which are typical of the Hochgrat spectrum. Such crystalline pebbles are missing in the Pfänder area (SCHOLZ 2000).

Further to the northeast, conglomerates are exposed in the Eistobel gorge and at the mountains of Kugel and Sonneck and represent proximal deposits of a large fan-delta complex in front of the Hochgrat-Adelegg fan to the south. These conglomerates mostly represent a coastal and supratidal environment with restricted marine influence. Very coarse-grained conglomerates dominate the succession, according to SCHOLZ (2000) they were deposited by rivers and redeposited by debris flow-like grain flows. At least two Gilbert-type deltas can be detected in the Eistobel gorge; the two thick, large scale cross-bedded conglomerates, which are separated by a succession of fine-grained sediments, are indicative for the foresets of a Gilbert type delta (Plate IV, Fig. B). The intercalated finer-grained, partly fossiliferous marine sediments (Plate III, Fig. E) were probably deposited in a subtidal environment, and thus indicate a relative subsidence of the depositional area and the flooding of the former delta plain. Altogether, this succession provides support for the assumption of some fluctuations in the relative sea level, resulting in repeated drowning and renewed progradation of the delta. In contrast to the Entschenstein conglomerate mentioned above, the north-westward dipping foresets of the Eistobel conglomerates display their almost central position in the fan lobe.

Detailed investigations by DEGELMANN (1991) and during this study of the Kugel-Sonneck successions have revealed that different facies types of the delta complex appear. Basal offshore mudstones are overlain by a thick conglomerate-sandstone succession. The very coarse-grained, unsorted and massive conglomerates (Plate IV, Fig. C) represent grain flow deposits and /or debris flow-like re-deposited fluvial gravel (see also VAN HOUTEN 1974, SCHOLZ 2000). They are very similar to conglomerates of the same area in the OSM, which have been mainly deposited as locally channelized subaeric grain flows. Other bedded and well-sorted conglomerates occurring within the marine succession, can be interpreted as fluvial channel fills of braided river systems on the delta plain, or as foresets of the delta front, similarly to the conglomerates of the Pfänder delta (see FRIELING et al. acc. – appendix 1). Sedimentary structures preserved within the sandstones indicate their deposition within fluvial channels of the delta plains, beaches and intertidal environments. Marly intercalations in the conglomerate-sandstone succession are lacking marine microfossils; they may be interpreted as sediments from brackish to freshwater environments, or as lagoonal and fluvial deposits of the delta plain.

The Hauchenberg-Ochsenberg succession represents a rather proximal delta facies of the Hochgrat-Adelegg fan and marks the southern Miocene coast line of the OMM sea. The very coarse-grained, unsorted and not bedded conglomerates (Plate IV, Figs A, D) were deposited most probably as marine grain flows during high-energetic events and consist of redeposited fluvial gravels derived from the proximal part of the fan (this study, see also SCHOLZ 1989, 2000). These southernmost and extremely coarse-grained deposits of the OMM in the study area have only a rather moderate thickness, when compared with the succession to the north (Kugel and Sonneck ridge). The differences may be explained by a bypass system within the Hauchenberg-Ochsenberg fan-delta depository: The coarse-grained detritus deriving from the talus centre to the south was generally deposited in proximal areas of the fan-delta; this is the Hauchenberg-Ochsenberg succession. During these periods, sandy equivalents of these grain flows were deposited in the distal parts of the delta (Kugel-Sonneck succession). However, in the case of extremely high-energy events, the coarse-grained material was not deposited in proximal areas of the fan-delta (Hauchenberg-Ochsenberg). In such cases the grain flows passed via erosive channel systems the proximal fan-delta and were deposited further to the north, in a more distal realm (Kugel-Sonneck). As a result, the equivalents of the Ochsenberg-Hauchenberg conglomerates (OcB, HauB) (i) are represented by sandy and marly intercalations in the Kugel-Sonneck to the north (LBM, EiT, IK und SW), and (ii) the conglomerates of the Kugel-

Sonneck do not have facies equivalents in the Ochsenberg-Hauchenberg succession. Decreasing energy caused a back-stepping of the deposition, i.e. renewed sedimentation of fine-clastic detritus in the Kugel-Sonneck area and conglomeratic sedimentation in the Ochsenberg-Hauchenberg area. An increasing subsidence towards the centre of the basin could have been an additional reason for the obviously greater thickness of the marine succession at Kugel and Sonneck ridge.

An alternative explanation for the reduced thickness of the marine succession at Hauchenberg and Ochsenberg is possible in the case that this succession represents only the Ottnangian time, and that the underlying Eggenburgian deposits (so-called “Hauchenbergschichten”) represent a terrestrial facies. Due to the occurrence of certain terrestrial gastropodes this partly conglomeratic sequence has been regarded as “Burdigalian“ and has therefore been termed “Landburdigal” (MÜLLER 1930, WENZ 1934). In contrast to LEMCKE (1988), the transgression of the Eggenburgian seaway must have used a depression situated originally just north of the Hauchenberg. No facies equivalents of the “Hauchenbergschichten” are known from the Kugel or Sonneck area and therefore it is possible that the higher thicknesses in that region results from a share of marine Eggenburgian at their base. However, due to the lack of microfossils this simple and plausible idea cannot be yet confirmed.

5.4 The inter-fan region between Kempten and Leuterschach (Oberallgäu/Ostallgäu)

The region around Kempten was a shallow marine nearshore area in the Early Miocene (for the description of the succession see chapter 4.2.4), situated between the Hochgrat-Adelegg fan to the west and the Auerberg fan to the east. It was hardly influenced by the coarse-grained input deriving from these fans.

The only prominent coarse-grained horizon in the OMM succession of this inter-fan region is the “Bryozoensandstein” occurring most notably in the Kempten area, in basal parts of the succession (Plate V, Figs A, C-F). The examination of different outcrops shows that these badly sorted, pebble-containing, coarse-grained and cross-bedded sandstones represent different marine depositional environments, e.g. transgressive or regressive beach ridge deposits, or deposits of rip channels in the foreshore or upper shore-face. A high-energetic shallow marine environment, probably above the low-tide level, and influenced by strong tidal currents can be assumed for the “Bryozoensandstein” with nodular-growing bryozoans (Plate VI, Fig. D) occurring in Tannen and in the Lessingstraße (LeS, Ta; see Fig. 2). According to NEBELSICK (1996), nodular colonies of bryozoans can occur in different genera and demonstrate an adaptation to special high energetic conditions, which, however, are poorly understood until to date.

The bedded and mostly fine-sandy sediments above the “Bryozoensandstein” were termed as "Sandmergelserie" in SCHOLZ (1989). They reflect a deposition on the deeper shoreface of a wave-dominated coast. Only occasionally, higher energetic events resulted in thin coarse-grained intercalations, and may be interpreted as storm layers. The lithofacies in the upper part of the Minderbetzigauer Bach and at the highway section (MB, AB sections, see Figs 2, 3) indicate that marly sediments were locally deposited in still-water areas, e.g. in restricted lagoons (Plate I, Figs C, D), possibly with an abnormally low salinity proven by the mass-occurrence of *Corbicula* (SCHOLZ 1989). This scenario could also offer an explanation for the low content of microfossils in these rocks. In other parts, there occur only thin, marly intercalations in the sandstone successions; e.g. in the middle part of the MB section; thick sandy parts in the sections west of Kempten, between the "Bryozoensandstein" within the BB section, as well as in the lower and upper parts of the AB section (see Figs 2, 3). They may be interpreted as sediments of the transition zone. In some sections, e.g. in the upper part of the sections of AB, W, WL, RuB, and Leu (see Figs 2, 3) additionally offshore marls can be observed. Contrasting heterolithic facies, representing sediments of a tidal flat, occurs as thick beds in the Leuterschach section (Plate II, Figs A, C).

SCHOLZ (1989) described the OMM succession in the here considered interfan area near Kempten as a succession that represents a single transgressive-regressive cycle (see Fig. 6). This is in conflict with the here assumed presence of two sequences (Eggenburgian and Ottnangian) with five subordinated cycles in the Eggenburgian-Ottnangian in the Pfänder fan area (see FRIELING et al. acc. – appendix 1) and two or three Ottnangian cycles in the central part of the basin (LEMCKE et al. 1953, GALL 1975).

However, in contrast to SCHOLZ (1989), the "Bryozoensandstein" in the Kempten area can be subdivided into two parts (see Figs 3, 9). These two separate "Bryozoensandstein" levels were found in several, partly excellently exposed sections during this study, therefore a tectonical doubling of the "Bryozoensandstein" is unlikely. Consequently, the younger level of the "Bryozoensandstein" above the fine-grained intercalation points to a second transgression. Thus, at least two cycles can be recognized also in the Kempten region; the lower cycle is rather thin to locally missing (see Fig. 9), but to the east, it is swelling again. Samples taken for micropalaeontological analysis lack biostratigraphical indicative microfossils, therefore it is very difficult to correlate these two cycles with cycles occurring in other regions. JERZ (1974) reported Eggenburgian and Ottnangian ages by referring to Otto Hölzl's unpublished study of a marine mollusc assemblage from a ditch in Waltenhofen (folded Molasse, south of Kempten). As the region probably was located in a channel-like trough ("Burdigalian seaway" sensu RÖGL & STEINIGER 1983) close to the southern margin of the basin, Eggenburgian sediments may in fact have been preserved (see also WENGER 1989b). However, to the north, in the area around Kempten, it is unlikely that the OMM-succession includes the complete Eggenburgian and Ottnangian periods because it seems to be not thick enough and also contains too few cycles. Perhaps the Kempten region belonged to an elevated area to the north of the "Burdigalian seaway" and therefore marine Eggenburgian sediments were not deposited (see also Fig. 9). Similar to the "Hauchenberg-Schichten" in the Hauchenberg region, the Eggenburgian may be represented here by terrestrial sediments ("Landburdigal" according to MÜLLER 1930, WENZ 1934, JERZ 1974).

SCHOLZ (1989), correlated his „Sandmergelserie" with the „Sandmergelserie" defined by LEMCKE et al. (1953), but biostratigraphic data to support this correlation are not available until to date. If the hypothesis that Eggenburgian deposits are not preserved in the Kempten area is correct (see above), both cycles in this region should be of Ottnangian age. As a result, the "Sandmergelserie" sensu SCHOLZ (1989) would be part of the younger Ottnangian cycle and would be younger than the "Sandmergelserie" sensu LEMCKE et al. (1953). In that case, also the correlation of the „Regressionsserie" with the „Baltringer Schichten" as proposed by SCHOLZ (1989) is unlikely.

5.5 The area of the Auerberg-Nesselburg fan (Ostallgäu)

The Auerberg conglomerates are coarse-grained sediments of an Alpine river system, which was active at least since the Early Miocene (SCHOLZ 1989). The prograding deltaic and alluvial deposits of the so-called Auerberg fan had an Oligocene predecessor, called Nesselburg fan (SCHOLZ 2000). The Oligocene Nesselburg fan and the Miocene Auerberg fan are sometimes summarized as a combined Auerberg-Nesselburg fan. However, the progradation of the Nesselburg fan was interrupted in the Late Oligocene and the earliest Miocene, because coarse-grained sediments from that time span are missing (SCHOLZ 1989).

The marl-dominated sediments (Plate II, Figs E, F, Plate IX, Fig. D), originally deposited just in front of the deltaic Auerberg-Nesselburg fan, represent a quiet and relatively deep marine depositional environment (see chapter 4.3.3). Prior to the middle Ottnangian (see chapter 4.3.3), this area was obviously not controlled by the prograding alluvial Auerberg-Nesselburg fan in the hinterland. There, the fan is represented by coarse-grained conglomerates, which form the younger part of the OMM succession at the top of the Auerberg mountain. Therefore it can be assumed that the progradation of the Auerberg-Nesselburg fan into the OMM basin happened later in comparison with the other fans further to the west (see chapter 5.3 and FRIELING et al. acc.).

6. The OMM in other parts of the Molasse Basin

6.1 Lithostratigraphy

The OMM succession in the central western German part of the Molasse basin, in the area between Lake Constance and river Lech, has been described by LEMCKE et al. (1953), WINDER (1983) and SCHREINER (1984, amongst others). It is composed of the following parts (bottom to top, see Fig. 10): Heidenlöcher Schichten, Sandmergelserie, Baltringer Horizont / Bodmansande, Feinsandserie / Deckschichten. According to microfossil findings the entire succession is of Ottnangian age (e.g. WENGER 1987b).

Special deposits are exposed at the northern marginal regions of this western part of the basin: the "Randengrobkalk", the "Grobsandzug", the "Erminger Turritellenplatte", and a fossil cliff cut into Jurassic limestones of the Alb (e.g. SCHREINER 1984, GEYER & GWINNER 1991, DOPPLER et al. 2005, BIEG et al. 2007).

The OMM succession in Upper and Lower Bavaria consists of Eggenburgian sediments (mainly in southern Upper Bavaria), above follow the Ottnangian Untersimbacher Schichten, Neuhofener Schichten, Blättermergel / Glaukonitsande (Fig. 10; HAGN 1959, 1961; KNIPSCHER 1952; WENGER 1987a, b; PIPPÈRR et al. 2007a, b; PIPPÈRR & REICHENBACHER 2009). Locally, unusual deposits were reported from the eastern margin of the basin and include a "Litoralfazies", deposits of a bryozoan "reef", and marls representing a shallow equivalent of the “Neuhofener Schichten” (see EDER 1954, SEITNER 1977, UNGER 1984, PIPPÈRR et al. 2007a, **Frieling et al. 2009a-appendix 5**).

6.2 Biostratigraphy

A biostratigraphic subdivision of the OMM for the Lower and Upper Bavarian part of the Molasse Basin is mainly based on benthic foraminifera and on ostracods, (see HAGN & HÖLZL 1952, KNIPSCHER 1952, HAGN 1959, 1961, PAULUS 1963, WENGER 1987a, PIPPÈRR 2004, 2005, PIPPÈRR et al. 2007a, b, PIPPÈRR & REICHENBACHER 2009, WITT 1967). The sedimentary succession is subdivided into Lower, Middle and Upper Eggenburgian as well as Lower and Middle Ottnangian (see Fig. 10).

6.3 Depositional sequences / cycles

First sequence stratigraphic ideas were presented by LEMCKE et al. (1953) on the subdivision of the OMM in the central South German part of the Molasse Basin. These authors recognized two transgressive-regressive cycles in the OMM, west of Munich, chiefly based on the analysis of drill cores. Modern sequence stratigraphical studies in the southern Bavarian part of the Molasse Basin followed mainly in the area east of Munich and were based on seismic lines and well logs (JIN 1995, ZWEIGEL 1998, PEÑA 2007). According to JIN (1995) and ZWEIGEL (1998), the succession of the OMM, i.e. the “Neuhofener Schichten” and the overlying Ottnangian strata, represent a part of a single second order sequence. ZWEIGEL (1998) and PEÑA (2007) identified four or rather five subordinated cycles in the OMM and interpreted the respective sequence boundaries as controlled mainly by Paratethys sea level falls.

On the base of benthic foraminifera, the transgressive-regressive cycle 1 sensu LEMCKE et al. (1953) is correlated with the Lower Ottnangian and cycle 2 with the Middle Ottnangian. A hiatus is most probably developed between cycle 1 and 2 as well as above cycle 2, west of Munich. In contrast, HEIMANN et al. (2009) assume the existence of only one cycle. However, because of the local boundedness of the only, even incomplete, studied section this assumption is doubtful. Indeed, the Ottnangian sedimentation seems to be continuous in the OMM succession east of Munich and in Upper Austria, with the exception of the Simssee sections (PIPPÈRR et al. 2007b) and the Ortenburg drillings (see Fig. 11). Moreover, the OMM succession in Lower Bavaria represents only a single transgressive-regressive cycle (see PIPPÈRR et al. 2007b, **FRIELING et al. 2009a – appendix 5**) that includes both, the Early and Middle Ottnangian.

Sequence stratigraphic analysis of the OMM in the Napf and Hörnli area in eastern Switzerland (KELLER 1989) show two transgressive-regressive sequences, the first in the Eggenburgian and the second in the Ottnangian, with 5 subordinated cycles, comparable to the Pfänder area (FRIELING et al. acc. – appendix 1).

		„Westmolasse"			„Ostmolasse"			
		Vorarlberg/ Westallgäu + eastern Switzerland SCHAAD et al. (1992), FRIELING et al. (acc.), KELLER (1990)	**Oberallgäu/ Ostallgäu** this study	**Iller-Lech-Isar** (central part) (northern margin) LEMCKE et al. (1953), DOPPLER et al. (2005)	**Munich-Landshut** logs of drillings provided by the Geological Survey and other sources (unpublished data)	**Oberbayern** WENGER (1987a), PIPPÈRR & REICHENBACHER (2009)	**Niederbayern**	**Oberösterreich** (central part) (northern part) FAUPL & ROETZEL (1987), SALVERMOSER (1999), RUPP & VAN HUSEN (2007)
Ottnang	oberes	OSM	OSM	Süßbrack-wassermolasse sensu LEMCKE et al. (1953)	Oncophora-Sch.	Oncophora-Sch.	Oncophora-Sch.	Oncophora-Schichten
	mittleres	St. Gallen Formation/ Sequence 2: subord. cycle 2	subord. cycle 2	Feinsandserie Baltringer Sch. development of the „cliffline"	Glaukonitsande u. Blättermergel	Glaukonitsande u. Blättermergel	Glaukonitsande u. Blättermergel	Glaukonit. Serie: Treubacher Sande Braunauer Schlier Mehrnbacher Sande Sande v. Reith / Rieder Schichten
	unteres	St. Gallen Formation/ Sequence 2: subord. cycle 1	subord. cycle 1	Sandmergelserie Heidenlöcher Schichten Erminger Turritellen-platte / Randen-grobkalk	Neuhofener Sch. Basisschichten	Neuhofener Sch. Untersimbacher Sch.	Neuhofener Sch. Untersimbacher Sch. (Phosphoritsande- / Grobsande)	Robulus-Schlier s.l.: Ottnanger Schlier Atzbacher Sande Vöcklaschichten Enzenkirch. Sande + Phosphoritsande / Fossilr. Grobsande
Eggenburg		Luzern-Formation/ Sequence 1	Hiatus / Sequence 1	Hiatus	Hiatus	*Lenticulina buergli*-Schichten	*Lenticulina buergli*-Schichten Ortenburger Meeressand	Haller Serie

Fig. 10: The Eggenburgian and Ottnangian marine succession in the Vorarlbergian, Bavarian, and Upper Austrian part of the Molasse Basin.

7. Relation between the Allgäu and the rest of the German part of the Molasse basin

7.1 Correlation of Eggenburgian deposits

A sequence stratigraphic subdivision of the OMM succession is practicable for the western study area (Vorarlberg, western Allgäu; see FRIELING et al. acc. – appendix 1). The correlation becomes, however, more and more problematic towards the east because of scarcity of biostratigraphic data. Most probably, the succession in the east is incomplete and presumably, in certain regions the Eggenburgian part (sequence 1) has not been deposited, and locally also the lower part of the Ottnangian (cycle I of sequence 2; see Fig. 9) is lacking. This assumption is supported by biostratigraphic data from the easternmost studied sections, i.e. the Badwerk section (see chapter 4.3.3). Here, the absence of Eggenburgian sediments may be caused by the palaeo-topography and a morphological high, respectively, during Eggenburgian times.

Generally, Eggenburgian deposits are restricted to the southern margin of the OMM basin (see WENGER 1987b) and to the “Ortenburger Senkungsfeld” in the easternmost part of the OMM basin (Wenger 1987a). The restricted distribution of the Eggenburgian is confirmed also by some drill cores from the OMM succession (see Figs 10, 11). The Eggenburgian part of the succession at Pfänder, Entschenstein section and south of Kempten (AB section) can be correlated with the Eggenburgian of Upper Bavaria, e.g. at Hohenpeißenberg (WENGER 1987b) and at Kaltenbach, Simssee, Prien and Traun (HÖLZL 1973, WENGER 1987a; Fig. 11).

	thickness					
drilling	Eggen-burg [m]	Basis-schichten [m]	Neuhofener Sch. [m]	Blätter-mergel [m]	Glaukonit-sande [m]	data provided by:
Unterhaching		4 (sand/gravel)	211	43	72	Geothermie Unterhaching GmbH & Co KG
Pullach			196	42	69	Fa. Erdwerk
Riem		2 (sand)	203	50-55	81	Fa. Erdwerk
Unterschleiß-heim		2 (sand)	120	51	74	Geothermie Unterschleißheim A.G.
Haimhausen			240			Gemeinde Haimhausen
Münchnerau		8 (sand/gravel)	42	18	44	Bayer. Geol. Landesamt
Salzdorf		2 coal	132	38	65	Bayer. Geol. Landesamt
Furth		10	27	71		Bayer. Geol. Landesamt
Wörth			33	61		Bayer. Geol. Landesamt
Inzenham	337 - 426		269 - 280	50 - 62		Geologisches Büro München
Bad Wörishofen		252				Bayer. Geol. Landesamt

Fig. 11: (B) Compilation of the unpublished drilling data, which are used in (A, next page).

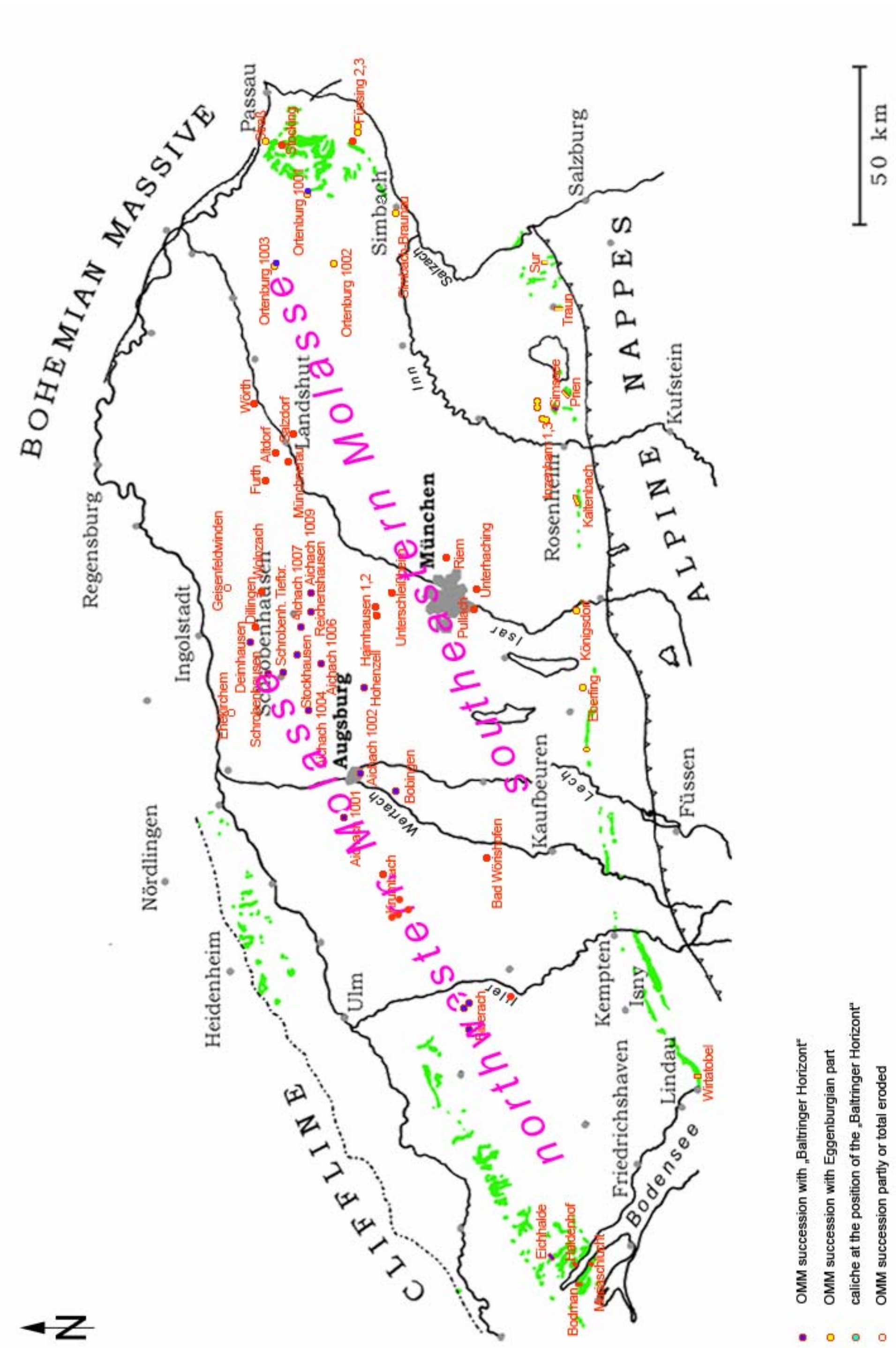


Fig. 11: (A) Simplified map of the German part of the Molasse Basin with the position of the interpreted drillings and sections (sections studied by WENGER 1987b, WINDER 1983, SCHREINER 1984, PIPPERR 2004). Drillings and logs of drillings after LEMCKE et al. (1953: Aichach, Hohenzell, Bobingen, Krumbach, Biberach), HAGN (1953: Ortenburg), PAULUS (1963: Eberfing, Königsdorf), RISCH (1993: Füssing), UNGER & RISCH (2001: Simbach), DOPPLER et al. (2002: Ehekirchen, Deimhausen, Dillingen, Geisenfeldwinden, Wolnzach, Reichertshausen, Stockhausen), DOPPLER & WIERER (2003: Schrobenhausen), PIPPÈRR (2005: Altdorf), PIPPÈRR & REICHENBACHER (2009: Straß) as well as unpublished data (provided by the Geological Survey / Hof and other sources; see B). Note that the here proposed northwestern and southeastern Molasse regions have a different geographic extension in comparison with the “Westmolasse” and “Ostmolasse” sensu DOPPLER et al. (2005).

Summary

The study area is situated at the southwestern margin of the Molasse basin, which was influenced by four big alluvial fans forming deltaic complexes. In this area, the Lower Miocene OMM succession consists of coastal to near-shore sediments deposited at the bottom of a shallow epicontinental sea. The older parts of the succession belong to the Eggenburgian, the younger to the Ottnangian.

Eggenburgian deposits occur in the Pfänder area and probably also in the area near Weiler. The Eggenburgian southern coastline of the Molasse sea lined the front of the big alluvial fans (Pfänder and Hochgrat-Adelegg). Thus, in contrast to LEMCKE (1988), the transgression of the Eggenburgian seaway must have used a depression situated originally just north of the Hauchenberg. East of the Pfänder-Hauchenberg region Eggenburgian deposits most probably are not present, and only the Ottnangian part of the succession has been deposited here.

The alluvial fans, which controlled the deposition of the OMM succession in this area, were active at different times. The Hochgrat-Adelegg fan began to prograde already in the Early Oligocene and transformed into a Miocene delta in the Eggenburgian. The Auerberg-Nesselburg fan also began to prograde in the Early Oligocene (Nesselburg fan). However, the sedimentary input faded and was interrupted in the Early Miocene. Not prior to the Middle Ottnangian, the fan was active again (Auerberg fan) and since then the delta prograded. An activity in the Pfänder fan cannot be proved to be older than Eggenburgian, when coarse-grained deltaic deposits prograded close to the modern Lake Constance. In Middle Ottnangian times, the progradation of the Pfänder fan became weaker. Only the Hochgrat-Adelegg fan, the largest of the fans in the study area, was active over the whole period under investigation.

The Molasse sea in this marginal area was clearly affected by tides, as postulated already by BIEG et al. (2008) and observed in the field during this study. In the Ellhofer Tobel section a tidal influence is indicated by the presence of a heterolithic facies which contains associated epsilon cross-stratification and megaripples (or subaquatic dunes). A general current direction from south to north is consistent documented by subaquatic dune foresets and the orientation of ripple foresets. If the coastal environment near the southern coast of the Molasse Sea had a rather simple tidal current regime this dominant northerly current direction could be interpreted as ebb currents.

Because of the general lack of biostratigraphic data in the study area, the correlation of the OMM succession from the Allgäu/Vorarlberg area to other parts of the basin is only practicable by means of sequence stratigraphic methods, i.e. an interpretation of base level cyclicity and sea level variations. In the western part of the study area, the OMM succession consists of two transgressive-regressive sequences with five subordinated cycles (Pfänder delta), which is well comparable with the succession in eastern Switzerland (KELLER 1989). The lower sequence is correlated with the Eggenburgian, its highstand systems tract is represented by deltaic sediments. The upper sequence, for which an Ottnangian age has been assumed, can be subdivided into two base-level cycles. They probably can be correlated with the two known transgressive-regressive cycles of the Ottnangian, which can

be proved in the central parts of the "Westmolasse" (LEMCKE et al. 1953). These two Ottnangian cycles are detectable also in the whole study area (see Fig. 9). However, in this marginal region locally one of the cycles potentially has been either never deposited or has been eroded.

In contrast to the "Westmolasse", the Ottnangian sedimentation seems to be mostly continuous in the OMM succession east of Munich and in Upper Austria. Moreover, the OMM succession in Lower Bavaria represents only a single transgressive-regressive cycle that includes both, the Early and Middle Ottnangian. An example is the Gurlarn section with an Ottnangian near-shore succession in direct contact with the crystalline basement of the Bohemian Massif representing a marginal-marine equivalent of the Neuhofen and Blättermergel Beds.

Acknowledgements

I would like to thank my supervisor Prof. Dr. Bettina Reichenbacher for mentoring this study. I'am indebted to Dr. Michaela Aehnelt (Liverpool) for her unremittingly interest in my work, many productive discussions with numerous incitations suggestions, her constant willingness to cast a critical eye over my text, her constant constructive criticism and frequent encouragement. I would like to thank Dr. Achim Wehrmann (Wilhelmshaven) sincerely for the invitation to „Senckenberg am Meer" in Wilhelmshaven where he patiently helped me to understand the depositional processes of tidal influenced marine sediments. Many thanks also due to all the people who have accompanied me and supported my fieldwork: Dr. Beat Keller (Zürich), Dr. Wladyslaw Altermann (Munich), Dr. Dieter Schmid (München), Dr. Hugo Ortner (Innsbruck), Martina Pippèrr (Munich). Martina Pippèrr and Manuela Aigelsdorfer (Munich) supported me during my work in the laboratories. Moreover Martina Pippèrr and Dr. Wolfgang Witt (Munich) identified the microfauna. Prof. Dr. Valerian Bachtadse (Munich), Hayfaa Abdul-Aziz (Utrecht), Dr. Hugo Ortner and Dr. Wolfgang Thöni (both Innsbruck) as well as Manuela Weiß (Niederlippbach) helped me in all aspects of my magnetostratigraphical investigations. Warm thanks to all these people. My colleagues Martina Pippèrr und Dr. Tanja Schulz-Mirbach (both Munich) deserve special thanks for all their interest in my research, for their patience during disussions and for the motivation they gave me. I am, in addition, grateful to Dr. Katharina Wien (Llandudno / Wales), Wladislaw Altermann (Munich), and Peter Barber (London) for improving the English of this report as well as to Cathleen Helbig (Munich) for the production of thin sections. I would like to thank the Fa. Erdwerk, Geothermie Unterhaching GmbH & Co KG, Geothermie Unterschleißheim A.G, Geologisches Büro München, the municipality Haimhausen as well as the Geological Survey of Bavaria for kindly providing the data of unpublished drillings. Last but not least I am grateful to my family: to my husband Herbert Scholz for all his support during the last few years, for many illuminating discussions about the OMM, and for his support in the field studies and in the care of our little son; and my parents for their patience.

References

ABELE, G., BESCHOREN, B., DEHM, R., ERB, L., FUCHS, B., GANSS, O., KIDERLEN, H., NATHAN, H., NEUMAIER, F., SCHMIDT-THOMÉ, P. & STEPHAN, W. (1955): Erläuterungen zur Geologischen Übersichtskarte der Süddeutschen Molasse 1 : 300 000. – 106 pp.; München (Bayer. Geol. L.-Amt).

ALLEN, P., MANGE-RAJETZKY, M., MATTER, A. & HOMEWOOD, P. (1985): Dynamic palaeogeography of open Burdigalian sea-way, Swiss Molasse Basin. – Eclog. geol. Helv. 79: 351-381.

APPEL, D. (1992): Erläuterungen zur geologischen Karte des Gebietes südlich von Weiler im Allgäu. – Unpublished Diploma Thesis, 71 pp., Lehrst. f. Geologie der TU München; Garching.

BEIHL, T. (1991): Die Geologie auf Blatt Isny im Allgäu/Süd, Teilblatt SE, mit benachbarten Randgebieten und Untersuchungen zur Genese mächtiger verwitterter Deckschichten auf jungen glazialen Ablagerungen im Westallgäu. – Unpublished Diploma Thesis, 133 pp., Lehrst. f. Geologie der TU München; Garching.

BERGER, J.-P., REICHENBACHER, B., BECKER, D., GRIMM, M., GRIMM, K., PICOT, L., STORNI, A., PIRKENSEER, C., DERER, C. & SCHAEFER, A. (2005): Paleogeography of the Upper Rhine Graben (URG) and the Swiss Molasse Basin (SMB) from Eocene to Pliocene. – Int. J. Earth Sci. (Geol. Rundsch.), 94: 697-710.

BIEG, U., NEBELSICK, J. H. & RASSER, M. (2007): North Alpine Foreland Basin (OMM) of southwest Germany: sedimentology, stratigraphy and palaeontology. – Geo. Alp 4: 149-158.

BIEG, U., SUESS, M. P. & KUHLEMANN, J. (2008): Simulation of tidal Xow and circulation pattern in the Burdigalian seaway (OMM, early Miocene). – Spec. Publ. Int. Assoc. Sedimentol. (2008) 40: 145–169.

BÜHRING, C. (1993): Erläuterung des Gebietes nördlich der Salmaser Höhe (Subalpine Molasse, Quartär) zwischen Oberstaufen und Missen (Allgäu).– Unpublished Diploma Thesis, 70 pp., Lehrst. f. Geologie der TU München; Garching.

CANDE, S. C. & KENT, D. V. (1995): Revised calibration of geomagnetic polarity timescale for the Late Cretaceous and Cenocoic. – Journal of Geophysical Research 100 (B 4): 6093-6095.

DEGELMANN, S. (1991): Geologie der Umgebung des Wengener Tals (Westallgäu) unter besonderer Berücksichtigung der Oberen Meeresmolasse zwischen dem Sonneckzug und dem Eistobel (Obere Argen). – Unpublished Diploma Thesis, 116 pp., Lehrst. f. Geologie der TU München; Garching.

DOPPLER, G. & WIERER, J. F. (2003): Kurzerläuterung zur Geologischen Karte 1:25000 7433 Schrobenhausen. – 40 pp.; München (Bayer. Geol. Landesamt).

DOPPLER, G., FIEBIG, M. & MEYER, R. K. F. (2002): Erläuterungen zur Geologischen Karte 1 : 100 000. – Geowiss. Landesaufnahme Planungsregion 10 Ingolstadt; München (Bayer.Geolog. Landesamt).

DOPPLER, G., HEISSIG, K. & REICHENBACHER, B. (2005): Die Gliederung des Tertiärs im süddeutschen Molassebecken. – Newsl. Stratigr. 41 (1-3): 359-375.

EBERHARD, M. (1987): Entwicklung von Sedimentation, Flora, Fauna, Klima und Relief vom Mittelmiozän bis Quartär zwischen Arlberg (Vorarlberg) und SAdelegg (Allgäu). – Mitteilungen aus dem Geol. Inst. Der ETH Zürich, N. F. 267: 242 pp.

EDER, M. (1954): Geologische und sedimentpetrographische Untersuchungen des Jungtertiärs im Raum von Passau. – Unpublished PhD Thesis, 85 pp., Univ. München; München.

FAUPL, P. & ROETZEL, R. (1987): Gezeitenbeeinflusste Ablagerungen der Innviertler Gruppe (Ottnangien) in der oberösterreichischen Molassezone. – Jahresbericht der Geologischen Bundesanstalt 130 (4): 415-447.

FREUDENBERGER W. & SCHWERD K. (1996): Erläuterungen zur Geologischen Karte von Bayern 1:50000 – 329 pp.; München (Bayer. Geol. Landesamt).

FRIELING, D. (2007): Rosselia socialis in the OMM of southwestern Germany. – Facies (2007) 53:479-492.

FRIELING, D., PIPPÈRR, M., SCHNEIDER, S. & REICHENBACHER (2009a): Sedimentology and stratigraphy at the rocky coast of the upper Burdigalian Molasse Sea: a case study from Gurlarn near Passau (SE Germany). – Facies 55: 47–62.

FRIELING, D., MAZUMDER, R. & REICHENBACHER, B. (2009b): Tidal sediments in the OMM (OMM) of the Allgäu area (Lower Miocene, Southwest Germany). – N. Jb. Geol. Paläont. Abh. 254: 151-163.

GALL, H. (1975): Der III. Zyklus der Oberen Meeresmolasse (Helvet) am Südrand der Schwäbisch-Fränkischen Alb. – Mitteilungen der Bayerischen Staatssammlung für Paläontologie u. historische Geologie 15: 179-205.

GEYER, O. F. & GWINNER , M. P. (1979): Die Schwäbische Alb und ihr Vorland. – Samml. geol. Führer 67, 271 pp.; Berlin & Stuttgart (Borntraeger).

GÜMBEL, C. W. v. (1861): Geognostischen Beschreibung des bayerischen Alpengebirges und seines Vorlandes – 20 + 950 pp.; Gotha (Perthes).

HAGN, H. (1953): Paläontologische Untersuchungen am Bohrgut der Bohrungen Ortenburg CF 1001, 1002 und 1003 in Niederbayern. – 324-359.

HAGN, H. (1959): Die Gliederung der bayerischen Miozän-Molasse mit Hilfe von Kleinforaminiferen. – Mitt. Geol. Gesell. 52: 133-141.

HAGN, H. (1961): Die Gliederung der Oberen Meeresmolasse nördlich vom Überlinger See (Bodensee) in mikropaläontologischer Sicht. – Jh. geol. Landesamt Baden-Württemberg 5, 293-321.

HAGN, H. & HÖLZL, O. (1952): Geologisch-paläontologische Untersuchungen in der subalpinen Molasse des östlichen Oberbayerns zwischen Prien und Sur mit Berücksichtigung des im Süden anschließenden Helvetikums. – Geologica Bvarica 10: 1-208.

HARDENBOL, J., THIERRY, J., FARLEY, M. B., JACQUIN, T., GRACIANSKY, P.-C. & VAIL, P. R. (1998): Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins. – In: GRACIANSKY, C.-P., HARDENBOL, J., JACQUIN, T. & VAIL, P.R. (Eds.): Mesozoic and Cenozoic Sequence Stratigraphy of European Basins: SEPM, Special Publications 60: 3–13, Tulsa.

HARZHAUSER, M. & PILLER, W. E. (2007): Benchmark data of a changing sea - Palaeogeography, Palaeobiogeography and events in the Central Paratethys during the Miocene. – Palaeogeography, Palaeoclimatology, Palaeoecology 253: 8–31.

HAUS, H. A. (1951): Zur paläogeographischen Entwicklung des Molassetrogs im Bodenseegebiet während des Mittleren Miozäns. – Mitt.-Bl. Bad. Geol. Landesanst. 1950: 48-66.

HEIMANN, F. U. M., SCHMID, D. U., PIPPÈRR, M. & REICHENBACHER, B. (2009): Re-interpreting the Baltringer Horizont as a subtidal channel facies: Implications for a new understanding of the OMM „Cycles“ (Early Miocene). – N. Jb. Geol. Paläont. Abh. 254: 135-149.

HERRMANN, P. & SCHWERD, K. (1983): Geologische Karte der Republik Österreich 1 : 25.000. – Erläuterungen zu Blatt 82 Bregenz: 28 pp.; Wien (Geol. B.-A.).

HÖLZL, O. (1973): Faziostratotypus: Kaltenbachgraben – In: RÖGL F., SCHULTZ O., HÖLZL O.: Beschreibung des Holostratotypus und der Faziostratotypen – In: PAPP, A., RÖGL, F., SENES, J. (Eds.): Chronostratigraphie und Neostratotypen, Miozän M2 Ottnangien. Slowakische Akademie der Wissenschaften, Bratislava, 297-355.

HURST, S. (1988): Geologische Kartierung des Gebietes östlich der Iller bei Kempten. – Unpublished Diploma Thesis, 61 pp., Lehrst. f. Geologie der TU München; Garching.

JERZ, H. (1974): Geologische Karte von Bayern 1 : 25.000 – Erläuterungen zum Blatt Nr. 8327 Buchenberg. – 181 pp.; München (Bayer. Geol. L.-Amt).

JIN, J. (1995): Dynamic stratigraphy analysis and modelling in the south-eastern German Molasse Basin. – Tübinger Geowiss. Arbeiten 24: 153 pp.

JÜRGES, R.-A. (1970): Zur Geologie des Eistobels / Allgäu. – Geologica Bavarica 63: 119-139.

KÄLIN, D. (1997): The mammal zonation of the OMM of Switzerland reconsidered – a local Biozonation ofMN 2-MN 5. – In: AGUILAR, J.P., LEGENDRE, S. & MICHAUX, J. (Eds.): Actes du congres BiochroM’97. M´em Trav EPHE Inst Montpellier 21:515– 535.

KELLENBERGER, M. (1930): Geologisches aus dem Westallgäu. – Sonderdruck aus den „Westallgäuer Heimatblättern“ 1929/3: 21-24 and 1930/4 (1): 19 pp.

KELLER, B. (1989): Fazies und Stratigraphie der Oberen Meeresmolasse (unteres Miozän) zwischen Napf und Bodensee. – Unpublished PhD Thesis, 302 pp., Phil.-naturwiss. Fakultät der Univ. Bern.

KELLER, B. (1990): Wirkung von Wellen und Gezeiten bei der Ablagerung der Oberen Meeresmolasse – Löwendenkmal und Gletschergarten – zwei anschauliche geologische Studienobjekte. – Mitteilungen der Naturforschenden Gesellschaft Luzern 31: 245-271.

KEMPF, O., MATTER, A., BURBANK, D. W. & MANGE, M. (1999): Depositional and structural evolution of a foreland basin margin in a magnetostratigraphic framework: the eastern Swiss Molasse Basin. – Int. Journ. Earth Sciences 88: 253–275.

KNIPSCHER, H. C. G. (1952): Die Gliederung der ungefalteten Molasse im östlichen Teil Bayerns auf Grund mikropaläontologischer Untersuchungen. – Geol. Bav. 14: 48-67.

KUHLEMANN, J. & KEMPF, O. (2002): Post-Eocene evolution of the North Alpine Foreland Basin and its response to Alpine tectonics. - Sedimentary Geology 152: 45-78.

KUHNERT, C. & ROHR, W.-M. (1975): Geologische Karte von Bayern 1 : 25.000 – Erläuterungen zum Blatt Nr. 8230 Lechbruck. – 99 pp.; München (Bayer. Geol. L.-Amt).

LATAL, C., PILLER, W.E. & HARZHAUSER, M. (2006): Shifts in oxygen and carbon isotope signals in marine molluscs from the Central Paratethys around the Lower/Middle Miocene transition. – Palaeogeography, Palaeoclimatology, Palaeoecology 231: 347–360.

LEMCKE, K. (1988) Geologie von Bayern I. Das bayerische Alpenvorland vor der Eiszeit. – 175 pp., Stuttgart (Schweizerbart).

LEMCKE, K., V. ENGELHARDT, W. & FÜCHTBAUER, H. (1953): Geologische und sedimentpetrographische Untersuchungen im Westteil der ungefalteten Molasse des süddeutschen Alpenvorlandes. – Beihefte zum Geologischen Jahrbuch 11: 1-182.

LOURENS, L., HILGEN, F., SHACKLETON, N.J., LASKAR, J. & WILSON, D. (2004): The Neogene Period. – In: GRADSTEIN, F., OGG, J.& SMITH, A. (Eds.): Geologic Time Scale 2004. Cambridge University Press.

MILLER, K. (1877): Das Molassemeer in der Bodenseegegend. – Schr. Ver. Geschichte d. Bodensees u.s. Umgebung 7: 1-80; Lindau.

MÜLLER, F. (1930): Acht Profile und ein paar Worte zur Kenntnis des geologischen Baues der Allgäuer Faltenmolasse. – Ber. Naturw. Ver. Schwaben und Neuburg, 48: 11-28; Augsburg.

MURRAY, J.W. (1991): Ecology and palaeoecology of benthic foraminifera. – 397 pp.; Harlow, Essex (Longman Scientific & Technical).

MURRAY, J.W. (2006): Ecology and Applications of Benthic Foraminifera. – 426 pp.; Cambridge (Cambridge University Press).

NEBELSICK, J. (1996): Encrustation of small substrates in Tertiary limestones and their importance for carbonate sedimentation. – In: REITNER, J., NEUWEILER, F. & GUNKEL, F. (Eds.): Global and regional controls on biogenic sediemntation. I. Reef evolution. Research Reports. – Göttinger Arb. Geol. Paläont. Sb2: 161-167.

NEUBERT, J. (1999): Erläuterungen zur geologischen Karte der Gemeinde von Stötten am Auerberg (Molasse/Quartär), mit einer speziellen Darstellung der hydrogeologischen Verhältnisse. – Unpublished Diploma Thesis, 147 pp., Lehrst. f. Geologie der TU München; Garching.

PAPP, A. & STEININGER, F. (1973): Die Stellung des Ottnangien zum Typusprofil des Helvetien. – In: PAPP, A., RÖGL, F. & SENES, J. (Eds.): Chronostratigraphie und Neostratotypen, Bd. 3, M2 Ottnangien: 29-31.

PAULUS, B. (1963): Zur Stratigraphie und Fazies der oligozänen und miozänen Molasse im südlichen Oberbayern. – Bulletin der Vereinigung Schweiz. Petroleum Geologen und Ingenieure 30 (78): 53-97.

PEÑA, F. A. C. (2007): The Early Miocene OMM of the German part of the Molasse Basin – a subsurface study. Sequence Stratigraphy, Depositional Environment and Architecture, 3D Basin Modelling – Unpubl. PhD thesis,119 pp., Eberhard-Karls-Universität Tübingen.

PIPPÈRR, M. (2004): Geologische Diplom-Kartierung / Blatt Nr. 8139 Stephanskirchen, Teilgebiet am Simssee. – Unpublished Diploma Thesis (geological map), 52 pp., Univ. München; München.

PIPPÈRR, M. (2005): Stratigraphie und Fazies der Oberen Meeresmolasse und Oberen Brackwassermolasse in Ostbayern (Forschungsbohrung Altdorf und Gebiet am Simssee). – Unpublished Diploma Thesis, 72 pp., Univ. München; München.

PIPPÈRR, M., FRIELING, D. & REICHENBACHER, B. (2007a): Vertiefte Untersuchungen der Schichtenfolge des Eggenburg und Ottnang in der Region 12 – Unpublished report, Bavarian Geological Survey, 151 pp., München

PIPPÈRR, M., REICHENBACHER, B., WITT, W. & ROCHOLL, A. (2007b): The Middle and Upper Ottnangian of the Simssee area (SE Germany): Micropalaeontology, biostratigraphy and chronostratigraphy. – N. Jb. Geol. Paläont. Abh. 245, 353-378.

PIPPÈRR, M. & REICHENBACHER, B. (2009): Biostratigraphy and paleoecology of benthic foraminifera from the Eggenburgian "Ortenburger Meeressande" of southeastern Germany (Early Miocene, Paratethys). – N. Jb. Geol. Paläont. Abh. 254: 41-61.

PLÖCHINGER, B., OBERHAUSER, R. & WOLETZ, G. (1958): Das Molasseprofil längs der Bregenzer Ach und des Wirtatobels. – Jb. Geol. B.-A. 101: 293-322.

REICHENBACHER, B., KÄLIN, D. & JOST, J. (2005): A fourth St. Gallen Formation cycle (?) in the Karpatian OMM of central Switzerland. – Facies 51: 160-172.

RISCH, H. (1993): Revision der mikrobiostratigraphischen Untergliederung der Bohrungen Füssing 2 und Füssing 3 (GUDDEN & ZIEGLER 1965). – Geologica Bavarica 97: 135-145.

RÖGL F. & STEININGER F. (1983): Vom Zerfall der Tethys zu Mediterran und Paratethys. – Ann. Naturhist. Mus. Wien Ser. A 85: 135-163.

RÖGL, F. (1998): Palaeogeographic considerations for Mediterranean and Paratethys seaways (Oligocene to Miocene). – Ann. Naturhist. Mus. Wien 99A: 279-310.

RÖGL, F. & STEININGER, F. (1983): Vom Zerfall der Tethys zu Mediterran und Paratethys. – Ann. Naturhist. Mus. Wien Ser. A85: 135-163.

RÖGL, F. & SPEZZAFERRi, S. (2003): Foraminiferal paleoecology and biostratigraphy of the Mühlbach section (Gaindorf Formation, Lower Badenian), Lower Austria. – Ann. Naturhist. Mus. Wien 104A: 23-75.

RUPP, C. & VAN HUSEN, D. (2007): Zur Geologie des Kartenblattes Ried im Innkreis. – In: EGGER, H. & RUPP, C. (2007): Beiträge zur Geologie Oberösterreichs, Arbeitstagung der Geologischen Bundesanstalt 2007.

RUPP, CH. & HAUNOLD-JENKE, Y. (2003): Untermiozäne Foraminiferenfaunen aus dem oberösterreichischen Zentralraum. – Jahrbuch der Geologischen Bundesanstalt 143 (2): 227-302.

SALVERMOSER, S. (1999): Zur Sedimentologie gezeitenbeeinflußter Sande in der Oberen Meeresmolasse und Süßbrackwassermolasse (Ottnangium) von Niederbayern und Oberösterreich. – Münchner Geol. Hefte A 26: 1-179.

SCHAAD, W., KELLER, B. & MATTER, A. (1992): Die Obere Meeresmolasse (OMM) am Pfänder: Beispiel eines Gilbert-Deltakomplexes. – Eclogae geolicae Helvetiae 85/1: 145-168.

SCHLUNEGGER, F., MATTER, A., BURBANK, D.W. & KLAPER, E. M. (1997a): Magnetostratigraphic constraints on relationships between evolution of the central Swiss Molasse basin and Alpine orogenic events. – GSA Bull 109:225–241.

SCHLUNEGGER, F., JORDAN, T.E., KLAPER, E. M. (1997b): Controls of erosional denudation in the orogen on foreland basin evolution: the Oligocene central Swiss Molasse Basin as an example. – Tectonics 16:823–840.

SCHOLZ, H. (1989): Die Obere Meeresmolasse (OMM) am Südrand des Molassebeckens im Allgäu. – Geologica Bavarica 94: 49-81.

SCHOLZ, H. (2000): Die tertiären Grobschüttungen am Südrande des Molassebeckens im Allgäu (Südwestbayern) – eine Synopsis. – N. Jb. Geol. Paläont. Abh. 218 (1/2): 61-84.

SCHOLZ, H. (1976): Ein neuer Aufschluß in der Oberen Meeresmolasse in Kempten. – Mitt. Naturwiss. Arbeitskr. Kempten 20 (2): 46-50.

SCHOLZ, H. (1993a): Der Grenzbereich zwischen Falten- und Vorlandmolasse im Gebiet zwischen Rhein- und Illergletscher im Westallgäu (Exkursion G am 16. April 1993). – Jber. Mitt. Oberrhein. Geol. Ver., N. F. 75: 155-176.

SCHOLZ, H. (1993b): Geologischer Bau und Landschaftsgeschichte des Landkreises Lindau. – Mitt. naturwiss. Ver. für Schwaben 79 (Sonderheft), 56 pp.

SCHOLZ, H. (1995): Bau und Werden der Allgäuer Landschaft. – 290 pp.; Stuttgart (Schweizerbart).

SCHOLZ, H. (2000): Die tertiären Grobsedimente am Südrande des Molassebeckens im Allgäu (Südwestbayern) – eine Synopsis.– N. Jb. Geol. Paläont. Abh. 218 (1/2): 61-84.

SCHOLZ, H. & FRIELING, D. (2006): Wulstgefüge, Rutschfalten und Sandsteingänge in Molassesedimenten - Hinweise auf seismische Unruhe im Oligozän und Miozän des Alpenvorlandes. – N. Jb. Geol. Paläont. Abh. 241(3): 345-382.

SCHREINER, A. (1966): Zur Stratigraphie der Oberen Meeresmolasse zwischen der Oberen Donau und dem Überlinger See (Baden-Württemberg). – Jber. Mitt. Oberrhein. Geol. Ver., N. F. 48: 91-104.

SCHREINER, A. (1984): Hegau und westlicher Bodensee. – Samml. geol. Führer 62: 93 pp., Berlin & Stuttgart (Borntraeger).

SCHWERD, K. (1983): Erläuterungen zur Geologischen Karte von Bayern 1 : 25 000, Blatt Nr. 8328 Nesselwang West. – 192 pp.; München.

SEITNER, L. (1977): Teil I: Geologische und sedimentpetrographische Untersuchungen der ostniederbayerischen Molasse im Gebiet zwischen Fürstenzell, Neukirchen a. Inn und Rittsteig b. Passau. Teil II: Sedimentpetrographische Untersuchungen der Oberen Meeresmolasse im Aufschluss Höch bei Fürstdobl. – Unpublished Diploma Thesis, part I: 136 pp., part II: 81 pp., Univ. München; München.

STEININGER, F.F. (1999): Chronostratigraphy, Geochronology and Biochronology of the "European Land Mammal Mega-Zones" (ELMMZ) and the Miocene "Mammal-Zones" (MN-Zones. – In: RÖSSNER, G.E. & HEISSIG, K. (Eds.): The Miocene Land Mammals of Europe: 9–24; München (Dr. Friedrich Pfeil).

STROHMENGER, M. (1991): Zur Geologie der Umgebung des Eistobels (Allgäu) unter besonderer Berücksichtigung mikrofazieller Untersuchungen an Konglomeraten der Oberen Meeresmolasse. – Unpublished Diploma Thesis, 177 pp; Lehrst. f. Geologie der TU München, Garching.

STRUNCK, P. & MATTER, A. (2002): Depositional evolution of the western Swiss Molasse. – Eclogae Geol Helv 95:197–222.

TESSIER, B. & GIGOT, P. (1989): A vertical record of different tidal cyclicities: an example from the Miocene Marine Molasse of Digne (Haute Province, France). – Sedimentology 36: 767-776.

UHLIG, S. (1987): Geröllanalytische Untersuchungen im Pfändergebiet. – Unpublished Diploma Thesis, 36 pp., Lehrst. f. Geologie der TU München; Garching.

UNGER, H. J. (1984): Geologische Karte von Bayern 1:50 000, Erläuterungen zum Blatt Nr. L7544 Griesbach i. Rottal. Bayer. – 245 pp; München (Bayer. Geol. L.-Amt).

UNGER, H. J. (1996): Östliche Vorlandmolasse und Braunkohlentertiär i.w.S. – In: FREUDENBERGER W. & SCHWERD K. (Eds.): Erläuterungen zur Geologischen Karte von Bayern 1:50000: 168-185; München (Bayer. Geol. L.-Amt).

UNGER, H. J. & RISCH, H. (2001): Die Bohrung Simbach-Braunau Thermal 1 – Geologie, Mikrofaunen, paläogeographische Einbindung. – Geologica Bavarica 106: 33-58.

VAN HOUTEN, F. B. (1974): Northern Alpine molasses and similar Cenozoic sequences of southern Europe. – In: Modern and Ancient Geosynclinal Sedimentation. Successor Basin Assemblages. – Soc. Econ. Paleontol. Mineral., Spec. Publ. 19: 260-273.

VOLLMAYR, Th. & ZIEGLER, J.H. (1976): Erläuterungen zur Geologischen Karte von Bayern 1 : 25 000, Blatt Nr. 8425 Weiler i. Allgäu.– 76 pp; München (Bayer. Geol. L.-Amt).

WASSERRAB, T. (1999): Zur Geologie der Umgebung von Wald im Ostallgäu. Sedimentpetrographische Untersuchungen an den Molassesandsteinen des Kartiergebietes. – Unpublished Diploma Thesis, 168 pp., Lehrst. f. Geologie der TU München; Garching.

WEILAND, I. (1988): Die Geologie südlich von Wildpoldsried (Allgäu). – Unpublished Diploma Thesis, 59 pp., Lehrst. f. Geologie der TU München; Garching..

WENGER, W.F. (1987a): Die Foraminiferen des Miozäns der bayerischen Molasse und ihre stratigraphische sowie paläogeographische Auswertung. – Zitteliana 16: 173-340.

WENGER, W.F. (1987b): Die Basis der Oberen Meeresmolasse im westlichen Oberbayern, am Überlinger See, in Vorarlberg und St. Gallen. – Mitteilungen der Bayerischen Staatssammlung für Paläontologie und historische Geologie 27: 159-174.

WENZ, W. (1934): Eine neue Triptychia aus süddeutschem Burdigal. – Arch. Molluskenk. 66/1: 54-56.

WINDER, H. (1983): Untersuchungen zur Facies der Oberen Meeresmolasse nördlich des Überlinger Sees (Bodensee). - Unpublished Diploma Thesis, 71 pp., Geowissenschaftliche Fakultät der Universität Tübingen, Tübingen.

WITT, W. (1967): Ostracoden der bayerischen Molasse (unter besonderer Berücksichtigung der Cytherinae, Leptocytherinae, Trachyleberidine, Hemicytherinae und Cytherettinae). – Geologica Bavarica 57: 1-120.

ZWEIGEL, J. (1998): Eustatic versus tectonic control on foreland basin fill - Sequence stratigraphy, subsidence analysis, stratigraphic modelling, and reservoir modelling applied to the German Molasse basin. – Contributions to Sedimentary Geology 20: 1-140.

List of publications

Publications in peer-reviewed journals:

FRIELING, D., AEHNELT, M., SCHOLZ, H. & REICHENBACHER, B. (2009c): Sequencestratigraphy of an alluvial fan-delta in the Upper Marine Molasse (Pfänder area, Late Burdigalian, Miocene) – Z. dt. Ges. Geowiss. 160/4: 333-357; Stuttgart.

FRIELING, D., MAZUMDER, R. & REICHENBACHER, B. (2009b): Tidal sediments in the Upper Marine Molasse (OMM) of the Allgäu area (Lower Miocene, Southwest-Germany). – N. Jb. Geol. Paläont. Abh. 254/1-2: 151-163; Stuttgart.

FRIELING, D., PIPPÈRR, M., SCHNEIDER, S. & REICHENBACHER (2009): Sedimentology and stratigraphy at the rocky coast of the upper Burdigalian Molasse Sea: a case study from Gurlarn near Passau (SE Germany). – Facies 55: 47–62; Berlin, Heidelberg.

FRIELING, D. (2007): Rosselia socialis in the Upper Marine Molasse of southwestern Germany. - Facies 53:479-492; Berlin, Heidelberg.

FRIELING, D. & MRAZEK, J. (2007): Sind Manganknollen Tiefwasser-Onkoide? – Senckenbergiana maritima, 37 (2): 93-128; Frankfurt a.M.

SCHOLZ, H. & **FRIELING**, D. (2006): Wulstgefüge, Rutschfalten und Sandsteingänge in Molassesedimenten - Hinweise auf seismische Unruhe im Oligozän und Miozän des Alpenvorlandes. - N. Jb. Geol. Paläont. Abh. 241(3): 345-382; Stuttgart.

FRIELING, D. & MRAZEK, J. (2005): Geochemische und strukturelle Untersuchungen an Fe-Mn-Knollen vom Fisher-Rücken / Costa Rica. – Greifswalder Geowissenschaftliche Beiträge, 13: 163-175; Greifswald.

FRIELING, D. & DIETRICH, H. (1999): Untersuchungen zum Diagenesegrad von Sandsteinen aus dem Alpinen Buntsandstein der Nördlichen Kalkalpen bei St. Johann in Tirol. – Geol. Paläont. Mitt. Innsbruck, 24: 17-21; Innsbruck.

Unpublished research report:

PIPPÈRR, M., **FRIELING**, D. & REICHENBACHER, B. (2007): Vertiefte Untersuchungen der Schichtenfolge des Eggenburg und Ottnang in der Region 12. – Forschungsbericht für den Geologischen Dienst am Landesamt für Umwelt im Rahmen des Ziel-2-Programms Bayern 2000-2006; München.

Conference abstracts:

FRIELING, D. (in prep.): Zur zyklischen Gliederung der Oberen Meeresmolasse am Beispiel des Allgäu. – Molasse Group Meeting, Munich, 21.-23.5.2010. – *Talk – Talk*

FRIELING, D. & REICHENBACHER, B. (2007): The Lower Miocene Pfänder-Delta on the Southern Coast of the Molasse Basin - Geo.Alp, vol. 4, p. 45. – *Poster*

PIPPÈRR, M., JUNG, D., WENGER, W., **FRIELING**, F. & REICHENBACHER, B. (2006): Die Bohrung Straß bei Passau - Foraminiferen-Vergesellschaftung und Stratigraphie. - Tagung der Paläontologischen Gesellschaft, Kiel, 28.-31.8.2006. – *Poster*

FRIELING, D. (2006): Evidence of tide and storm sedimentation from the Upper Marine Molasse (Lower Miocene), Southwest Germany. – In: Eynatten, H. v., Dunkl, I., Fischer, C. Karius, V. & Ruppert, H. [Eds.]: Sediment 2006: 21th Meeting of Sedimentologists / 4th Meeting og SEPM Central European Section. - Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften 45: 74-75. - *Poster*

REICHENBACHER, B., PIPPÈRR, M., ROCHOLL, A., ABDUL-AZIZ, H., **FRIELING**, D., BACHTADSE, V. & BÖHME, M. (2006): Stratigraphy of the Ottnangian - an interdisciplinary study. - Molasse-Meeting, Natural Museum Geneva, 5.-6.5.2006. – *Talk*

FRIELING, D. (2006): Die Obere Meeresmolasse in Südwestdeutschland. - Molasse-Meeting, Natural Museum Geneva, 5.-6.5.2006. – *Talk*

FRIELING, D. & REICHENBACHER, B. (2005): Faziestypen in der Oberen Meeresmolasse (Unter-Miozän) im Allgäu. - Berichte des Institutes für Erdwissenschaften, Karl-Franzens-Universität Graz, 10: 14-17. – *Poster*

REICHENBACHER, B., PIPPERR, M., **FRIELING**, D., BACHTADSE, V., ROCHOLL, A., BÖHME, M., SCHOLZ, H., HEISSIG, K. & KÄLIN, D. (2005): Stratigraphy and palaeoecology of the Upper Marine Molasse (Lower Miocene) in the northalpine foreland basin - an interdisciplinary study. - Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften, 39: 302-303. – *Talk*

REICHENBACHER, B., PIPPERR, M., **FRIELING**, D., BACHTADSE, V., ROCHOLL, A., BÖHME, M., SCHOLZ, H., HEISSIG, K. & KÄLIN, D. (2005): Stratigraphy and palaeoecology of the Upper Marine Molasse (Lower Miocene) in the northalpine foreland basin - an interdisciplinary study. - 12th Congrss R.C.M.N.S., p. 189-190; Vienna. – *Talk*

FRIELING, D. (2005): Die OMM im deutschen Alpenvorland – Stratigraphie und Faziesanalyse. – Molasse-Workshop 1.-2.4.2005, München. – *Talk*

Curriculum vitae

Dr. Dorothea Frieling
Zeisigweg 8 Department für Geo- und Umweltwissenschaften, Sektion Paläontologie
82140 Olching Ludwig-Maximilians-Universität (LMU)
08142/442485 Richard-Wagner-Str. 10
80333 München
089/2180-6618
d.frieling@lrz.uni-muenchen.de

Persönliche Informationen	Familienstand: verheiratet Nationalität: deutsch Geburtsdatum: 19.07.1971 Geburtsort: Borna Eltern: Dörte & Hans-Rudolf Frieling
Ausbildung	1978-1990 Polytechnische und Erweiterte Oberschule Greifswald **Abitur** 1990-1992 Hochschule für Musik Schwerin Vordiplom/Querflöte 1993-2000 Ernst-Moritz-Arndt-Universität Greifswald Leopold-Franzens-Universität Innsbruck **Diplom//Geologie** 2004-2009 Ludwig-Maximilians-Universität München Promotionsstudium
Berufliche Tätigkeit	Quellkartierung für die Tunnelverbindung Außerfern/Tirol im Auftrag des Ingenieurbüros IIF in Innsbruck Hydrogeologische Kartierungsarbeiten und Untersuchungen im Allgäu im Auftrag des Ingenieurbüros GUT in Marktoberdorf Trassenuntersuchungen Augsburg/Hainhofen für das Ingenieurbüro Georadar Solutions in München Text- und Bildrecherche für 2 Lehr-DVDs des FWU (Institut für Film und Bild in Wissenschaft und Unterricht, München): „Erdgeschichte CD-ROM“ und „Unruhiger Planet CD-ROM“ Geologische Textentwürfe und Graphiken im Auftrag eines Ingenieurbüros für die Bergschau „Oberstdorf und Fellhorn“ Texte zum geologischen Lehrpfad „Aggenstein“ (Allgäuer Alpen) im Auftrag der Gemeinde Pfronten und der Breitenberg-Bahn Textentwürfe und Graphiken für die Neugestaltung eines Raumes zur Geologie der Vilser Alpen im Heimatmuseum Vils (Tirol) im Auftrag des Museumsvereins Neugestaltung einer geologischen Ausstellung mit Textentwürfen, Graphiken und Modellen im Rahmen des „Knappendorfes“ am Grünten, im Auftrag der Gemeinde Burgberg im Allgäu Anstellung am Bayerischen Geologischen Landesamt in München vom 17.09.2001-31.12.2003: Mitarbeit am Projekt „Hydrogeologische Landesaufnahme Bayerns“ Anstellung am Institut für Paläontologie 01.07.2004-30.06.2006: wissenschaftliche Angestellte an der Ludwig-Maximilians-Universität München mit dem Ziel einer Promotion Erstellung einer redaktionsreifen geologischen Karte 1:25 000 (GK 25) des TK25-Kartenblattes Nr. 8228 Wildpoldsried sowie Erstellung der textlichen Erläuterungen LfU-Projekt 0413 seit 01.02.2009

Appendix

Appendix 1: FRIELING, D., AEHNELT, M., SCHOLZ, H. & REICHENBACHER, B. (2009c): Sequencestratigraphy of an alluvial fan-delta in the Upper Marine Molasse (Pfänder area, Late Burdigalian, Miocene) – Z. dt. Ges. Geowiss. 160/4: 333-357; Stuttgart.

Appendix 2: FRIELING, D., MAZUMDER, R. & REICHENBACHER, B. (2009b): Tidal sediments in the Upper Marine Molasse (OMM) of the Allgäu area (Lower Miocene, Southwest-Germany). – N. Jb. Geol. Paläont. Abh. 254/1-2: 151-163; Stuttgart.

Appendix 3: FRIELING, D. (2007): Rosselia socialis in the OMM of southwestern Germany. – Facies 53:479-492; Berlin, Heidelberg.

Appendix 4: SCHOLZ, H. & FRIELING, D. (2006): Wulstgefüge, Rutschfalten und Sandsteingänge in Molassesedimenten - Hinweise auf seismische Unruhe im Oligozän und Miozän des Alpenvorlandes. – N. Jb. Geol. Paläont. Abh. 241(3): 345-382; Stuttgart.

Appendix 5: FRIELING, D., PIPPÈRR, M., SCHNEIDER, S. & REICHENBACHER (2009a): Sedimentology and stratigraphy at the rocky coast of the upper Burdigalian Molasse Sea: a case study from Gurlarn near Passau (SE Germany). – Facies 55: 47–62; Berlin, Heidelberg.

Appendix 6: Plates

Appendix 6

Plates

Plate I

Fine-grained sediments

(marls and heterolithic facies)

Fig. A: Slightly bedded offshore marls in the Leckenbach section, dipping towards NW.

Fig. B: Layered offshore marls in the Leckenbach section, slightly dipping to the right (NW), with an intercalated sandy tempestite bed (arrows). Scale bar: 30 cm.

Figs C, D: Fine-laminated marls in the upper part of the Minderbetzigauer Bach section, with horizontal layering (C) and dipping towards NW (D). These sediments were interpreted as lagoonal deposits.

Figs E, F: Tidal bedding with wavy bedding in the Eistobel section. The reddish colour in Fig. F is probably a result of diagenesis.

Plate I

Fine-grained sediments
(marls and heterolithic facies)

A

B

C

D

E

F

Plate II

Fine-grained sediments

(marls and heterolithic facies)

Fig. A: Tidal bedding with wavy bedding in the Leuterschach section. Locally double mud drapes are recognizable (arrows).

Fig. B: Tidal bedding with lenticular bedding in the Leuterschach section.

Figs C, D: Tidal bedding with wavy to lenticular bedding in the Leckenbach section. The reddish colour (D) is probably a result of diagenesis.

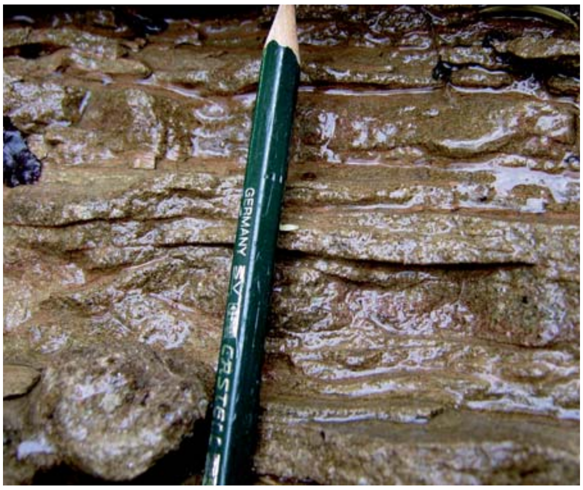
Figs E, F: Heterolithic facies of the transition zone in the Auerberg succession (A = Unterbuchen section, B = Badwerk section).

Plate II

Fine-grained sediments
(marls and heterolithic facies)

A

B



C

D

E

F

Plate III

Sandstones

Fig. A: Monotonous glauconitic sandstones of the shoreface in the lower part of the Betzigauer Bach section, parallel-laminated to low-angle cross-laminated.

Fig. B: Indistinctly ripple-bedded sandstones in the Minderbetzigauer Bach section.

Figs C, D: Monotonous glauconitic sandstones representing the shoreface in the lower (A) and upper part (B) of the Kesselbach section: thin platy, slightly cross-bedded at low angles (< 3°), and even bedding planes (B).

Fig. E: Sandstone intercalation between thick conglomerates in the Eistobel section representing deposits of a sand flat. Sandstones are parallel layered, with even bedding planes and locally fine-lamination. Only few thin and red mud drapes are intercalated.

Fig. F: Thin section of a glauconitic sandstone (polarized light) from the Betzigauer Bach section. Glauconite grains occur mainly as peloids here.

Plate III
Sandstones

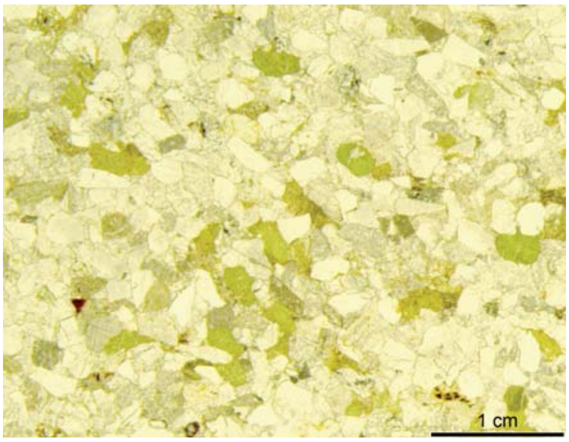
A

B

C

D

E



F

Plate IV

Conglomerates

Fig. A: Proximal deltaic sediments from the Hauchenberg section. Reddish grain flow conglomerates dominate the succession containing red sandstone-marl intercalations (centre of the outcrop). They indicate a terrestrial habitus and contain remains of terrestrial gastropods.

Fig. B: Conglomerates of the “Hohe Wand” in the Eistobel section (the outcrop is about 45 m high). Conglomerates dip with 30 to 40° towards NW (which is clearly steeper than the dipping of the sandstones above and below) and represent large-scale cross-bedding and foresets of a Gilbert type delta, respectively.

Fig. C: Hardly sorted pale red conglomerates of the Sonneck ridge succession. Pebbles are oriented, the conglomerate show a grain flow habitus.

Fig. D: Red-coloured and poorly sorted alluvial fan conglomerates of the Hauchenberg succession. Their interpretation as deltaic deposits is only supported by the presence of oyster shells.

Fig. E: Accumulation of oyster shells (arrows) in alluvial fan conglomerates of the Hauchenberg succession.

Fig. F: Giant rock fall boulder of the Entschenstein conglomerate, lying upside down. An unconformity is recognizable (indicated with arrow) between steeper inclined foresets and more flat lying topsets.

Plate IV

Conglomerates

A

B

C

D

E

F

Plate V

„Bryozoensandstein“/

„Austernnagelfluh“

Fig. A: “Bryozoensandstein” in the Betzigauer Bach section, a poorly sorted coarse-grained sandstone with shell debris and pebbles of various composition.

Fig. B: „Austernnagelfluh“ in the Rothenbach section: pebbly coarse-grained sandstone with many fragments of shells (oyster shell in the centre).

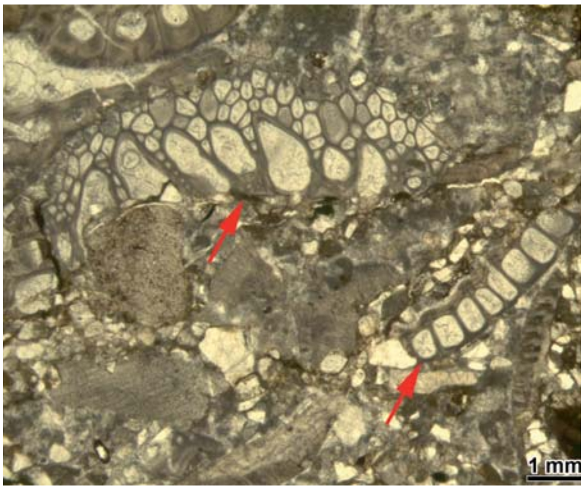
Figs C, D, E: Thin sections (polarized light) from the “Bryozoensandstein” in the Lenzfrieder Höhenrücken section. C: remains of barnackles (indicated with arrows); D: recrystallized shells of mussels besides pebbles and a barnackle fragment (arrow); E: Bryozoan skeleton (arrow) and a barnackle shell.

Fig. F: Thin section (polarized light) from the upper part of the “Bryozoensandstein” in the folded Molasse south of Kempten, showing a mussel shell and remains of dendroid bryozoan skeletons (indicated with arrows).

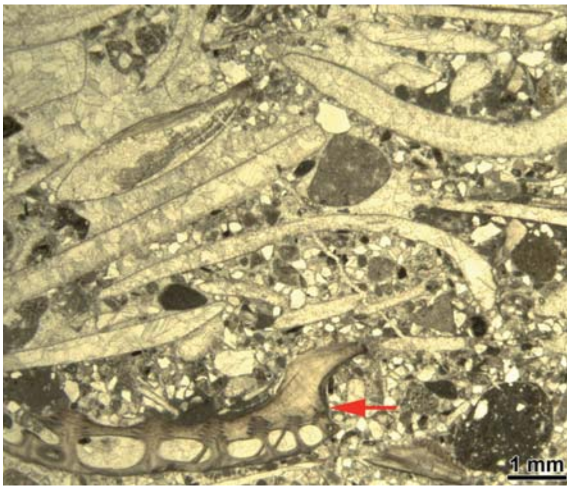
Plate V
„Bryozoensandstein“/
„Austernnagelfluh“

A

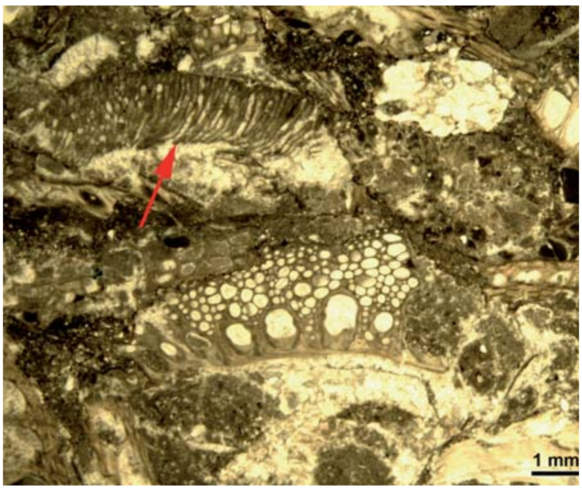
B



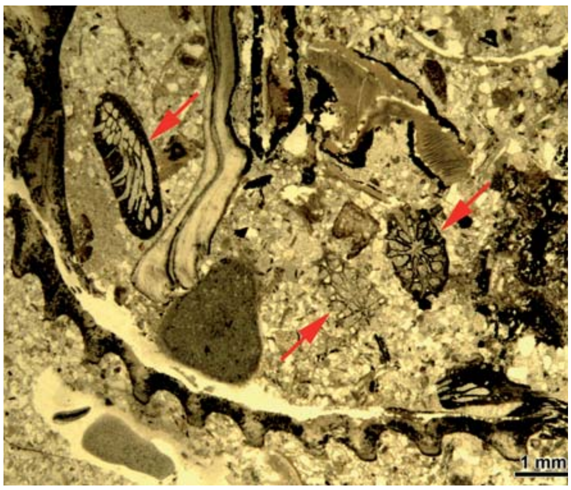
C



D



E



F

Plate VI

„Bryozoensandstein“/ sedimentary structures

Figs A, B, C: The main part of the “Bryozoensandstein” in the Betzigauer Bach section shows epsilon cross-stratification. These structures indicate tidal creeks and channels in a shallow marine environment.

Fig. D: Thin section (polarized light) of a nodular bryozoan skeleton (*Ceriopora simplex*) from the “Bryozoensandstein” in the Tannen section. The skeleton shows two boreholes drilled by mussles.

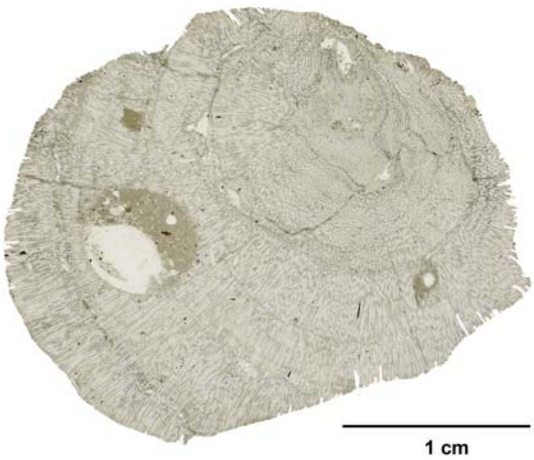
Figs E, F: Epsilon cross-stratification in the Pfänder succession (E = Rothenbach section, scale bar: 10 cm, F = Kesselbach section) representing a channel fill in deltaic sediments.

Plate VI
„Bryozoensandstein"/
sedimentary structures

A

B

C



D

E

F

Plate VII

Sedimentary structures

Figs A, B: Fine-laminated sandstones in the Waltenhofen section (A) and in deltaic sediments of the Kesselbach section (B) reflecting high energetic currents.

Fig. C: Load casts at the lower boundary of a conglomeratic layer in the Eistobel succession.

Fig. D: Small load casts in glauconitic sandstones in the Betzigauer Bach section.

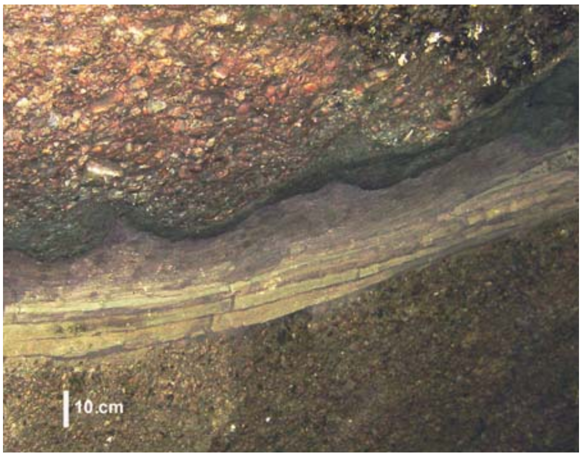
Fig. E: Intraclasts in glauconitic sandstones in the Kesselbach section (E) and the Betzigauer Bach section (F).

Plate VII

Sedimentary structures

A

B



C

D

E

F

Plate VIII

Sedimentary structures

Fig. A: Small-scale lingoid ripples in deltaic sediments of the Kesselbach section.

Figs B, C: Small-scale current ripples in glauconitic sandstones in the Betzigauer Bach section.

Fig. D: Small-scale oscillation ripples in glauconitic sandstones in the Betzigauer Bach section.

Plate VIII
Sedimentary structures

A

B

C

D

Plate IX

Sedimentary structures

(ichnofossils)

Fig. A: Thin section (polarized light) with isolated burrows in fine-sandy / marly sediments in the Minderbetzigauer Bach section.

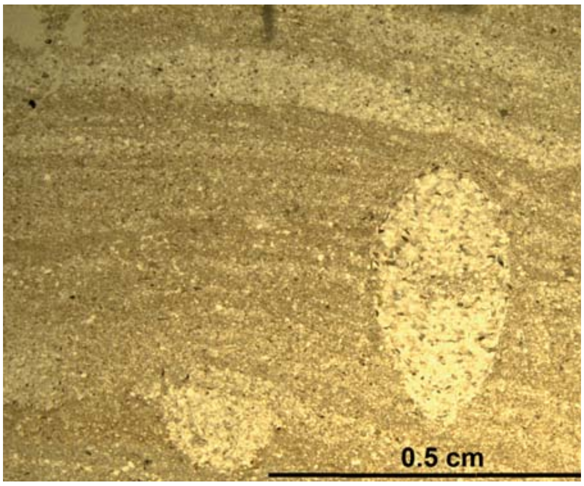
Fig. B: Strongly bioturbated sandstones in the Kesselbach section with clearly visible individual burrows.

Fig. C: Isolated burrow (arrow) visible in strongly bioturbated marls in the Leckenbach section.

Fig. D: Strongly bioturbated marls in the Badwerk section, with clearly visible individual burrows.

Fig. E: Limestone pebble with mussel-boreholes from a pebbly sandstone at the erosive base of the Buchenberg section.

Plate IX
Sedimentary structures
(ichnofossils)



A

B

C

D

E