Geo.Alp, Vol. 4, S. 149–158, 2007

NORTH ALPINE FORELAND BASIN (UPPER MARINE MOLASSE) OF SOUTHWEST GERMANY: SEDIMENTOLOGY, STRATIGRAPHY AND PALAEONTOLOGY

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Introduction

During the Early Miocene, the North Alpine Foreland Basin was flooded by a shallow marine sea. During its maximum extent (Ottnangian – ca. 17.8 Ma), the so called Burdigalian Seaway was established. This seaway linked the Mediterranean realm in the Southwest with the Paratethys realm in the Northeast. The field trip provides an overview of the marginal and basinal successions of the North Alpine Foreland Basin in south-western Germany in the environs of Lake Constance.

Geological setting and stratigraphic framework

The North Alpine foreland basin (also known as the Molasse Zone) is a typical asymmetric, peripheral foreland basin. The evolution started during the late Eocene and was triggered by the underthrusting of the European Plate underneath the Adriatic-African Plate during the Alpine orogeny. A deep-marine "Flysch-phase" was followed in the early Oligocene by the "Molasse phase" representing a shallower depositional environment. The depositional history of basin fill is complex and mainly controlled by tectonic subsidence, eustatic sea-level changes and variations in sediment supply. The Molasse stage is subdivided into two major transgressive-regressive cycles traditionally known as the Lower Marine Molasse/Lower Freshwater Molasse and the Upper Marine Molasse/Upper Freshwater Molasse.

This field guide focuses on shallow water siliciclastic and mixed siliciclastic/carbonate environments deposited in the North Alpine Foreland Basin during the Upper Marine Molasse ("Obere Meeresmolasse": OMM, Early Miocene). Results from new investigations concerning the complex stratigraphic successions, sedimentary structures and fossil content will be shown and discussed. The importance of both sedimentological and palaeontological data for the interpretation of these and similar sediments will be reviewed.

The field trip starts with OMM successions in the vicinity of the Lake Constance. Sub- to intertidal architectural elements show a first marine transgression with a tidal flat environment (the Heidenlöcher beds, at the Überlinger Stadtgraben, Stop 1). Moving towards the NE, the field trip will continue with Stops 2 and 3, which are part of the same stratigraphic unit, the so called "Grobsandzug" (the „coarse sand lineament"). This unit was first described by and designated as the "Grobsandzug Friedingen-Rengetsweiler". The "Grobsandzug" forms an elongate body, running 20-25 km parallel to the northern margin of the stratigraphically younger "Graupensand - rinne", an erosive structure cutting into sediments of the OMM succession. The "Grobsandzug" forms the northern border of the extended "Graupensadrinne". Deposits in Ursendorf (Stop 2) comprise a large tidal channel, some 100m in width and around 15 m in height, with cross-bedded lateral accretion elements filling up the cut-structures. In Rengetsweiler (Stop 3), deposits show a further foreshore environment with deep and wide tidal channels of a high tidal flat at the base. This is followed by several major erosional unconformities indicating a general rise in sea-level moving towards a low tidal flat environment.

On the second day we will move towards the northern coast of the OMM Sea in this area (Stops 4 and 5). In the vicinity of Tengen, the "Randengrobkalk" successions show a nearshore, mixed siliciclastic-carbonate environment. We will focus on the microfacies assemblages, sedimentary structures, depositional environments and the general stratigraphic succession of the area.

Description of stops

Day 1

Stop 1: Outcrop: "Grundgraben" in the city of Überlingen; Stratigraphy: Heidenlöcher beds; Main features: sub- to intertidal bedforms, tidal bundles, sandwaves, tidal channels

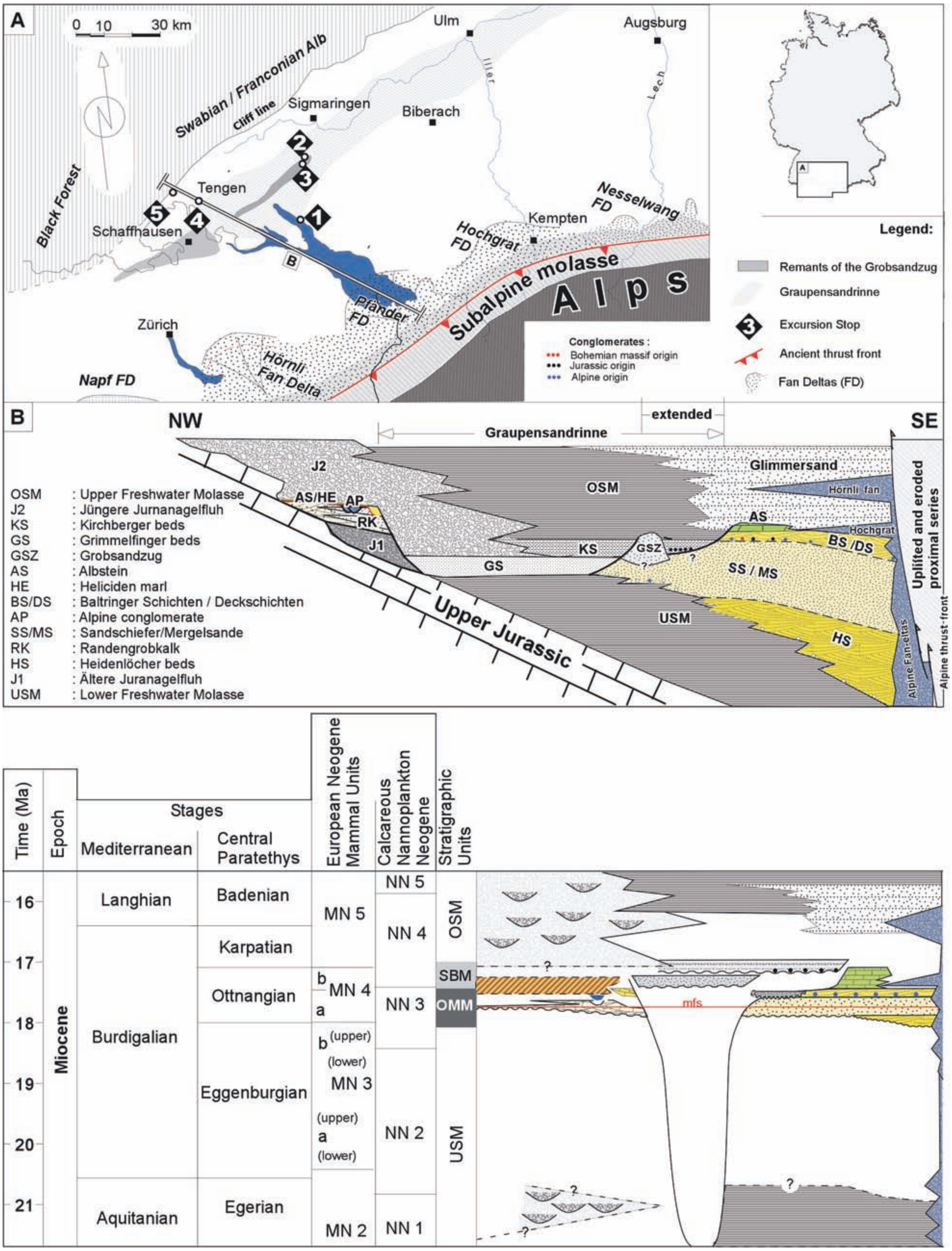

Fig. 1: Sketch map with excursion stops and a schematic stratigraphic NW-SE cross-section of the SW German part of the North Alpine Foreland Basin.

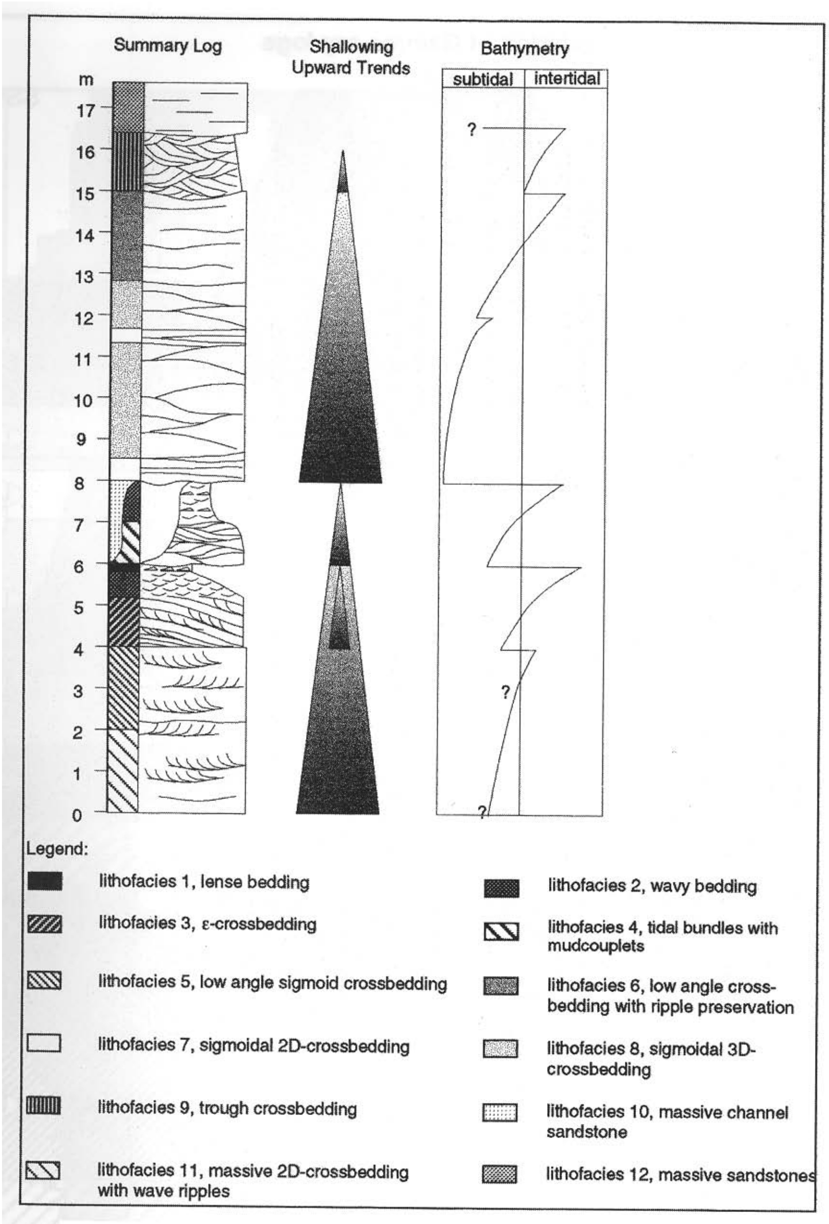

Fig. 2: OMM succession in the Überlingen "Stadtgraben" (Zweigel 1998).

The excellent outcrops in the "Stadtgraben" (the city moat) are described by Winder (1983) and Zweigel (1998). The succession is composed of sandy to shaley-sandy tidal deposits of mainly subtidal and a few of inter-tidal origin. Different types of sand flat and mixed mud-sandflat deposits can be distinguished as well as different kinds of tidal channels. Zweigel (1998) also recognized two 8 to 10m thick shallowing upward cycles separated by a distinct transgressive surface which can be traced across the entire outcrop. The lower sequence contains very well-preserved neap-spring tidal bundles with sigmoidal foreset laminae and double clay drapes (see e.g. Visser 1980).

Stop 2: Outcrop: Ursendorf; Stratigraphy: Grobsandzug; Main features: Large scale cut and fill structure of some 100 m in length and some 10 m height

The sandpit near Ursendorf shows four depositional units. The lowermost unit is characterized by silt and fine sand; no sedimentary structures are observed. Above an erosional unconformity, laterally aligned lenticular bedding shows a heterolithic facies composed of coarse sands forming current and wave ripples. Ripple troughs are filled with fine sand. This results in wavy and irregular bedding, suggesting frequent changes in current velocity aggrading

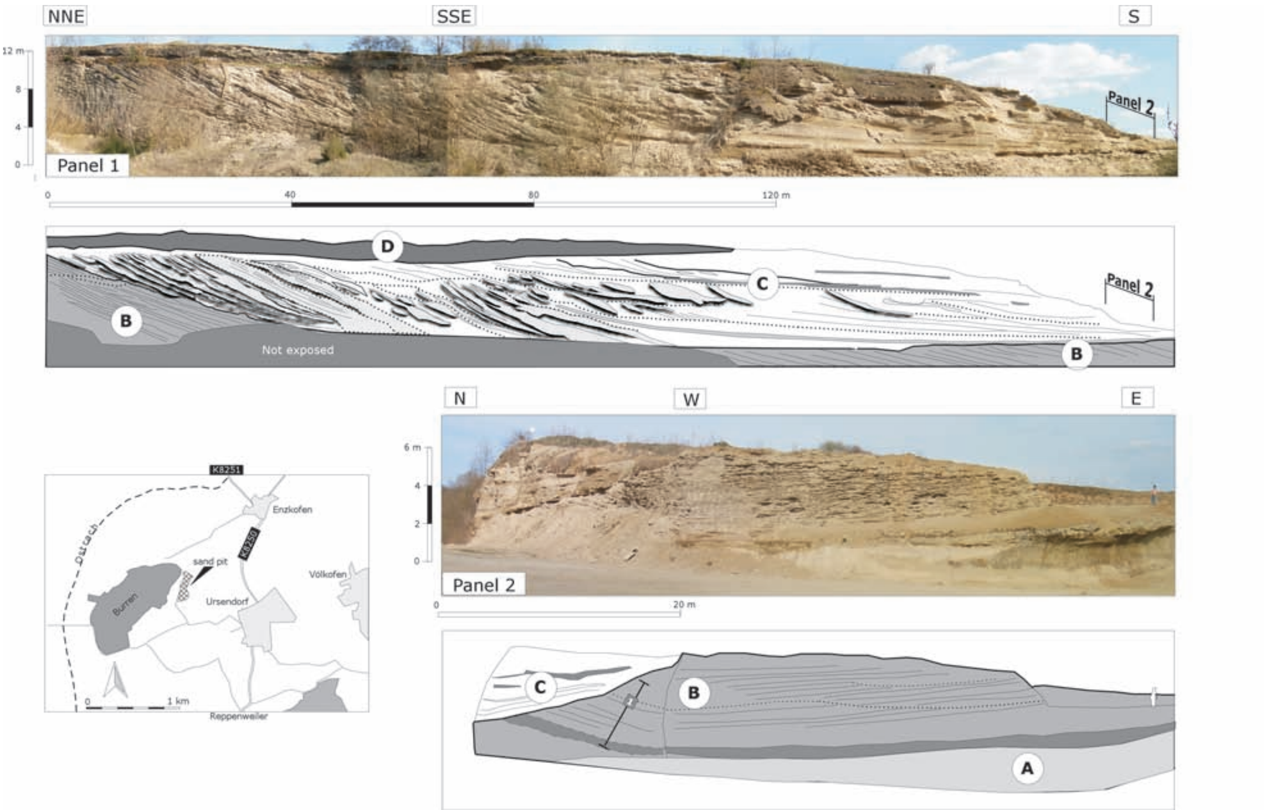

Fig. 3: Outcop panels showing different depositional units. Unit C shows prominent tangential foresets. Grain size decreases towards the S indicating a filling of the cut structure from the NNE in a multi storey fashion.

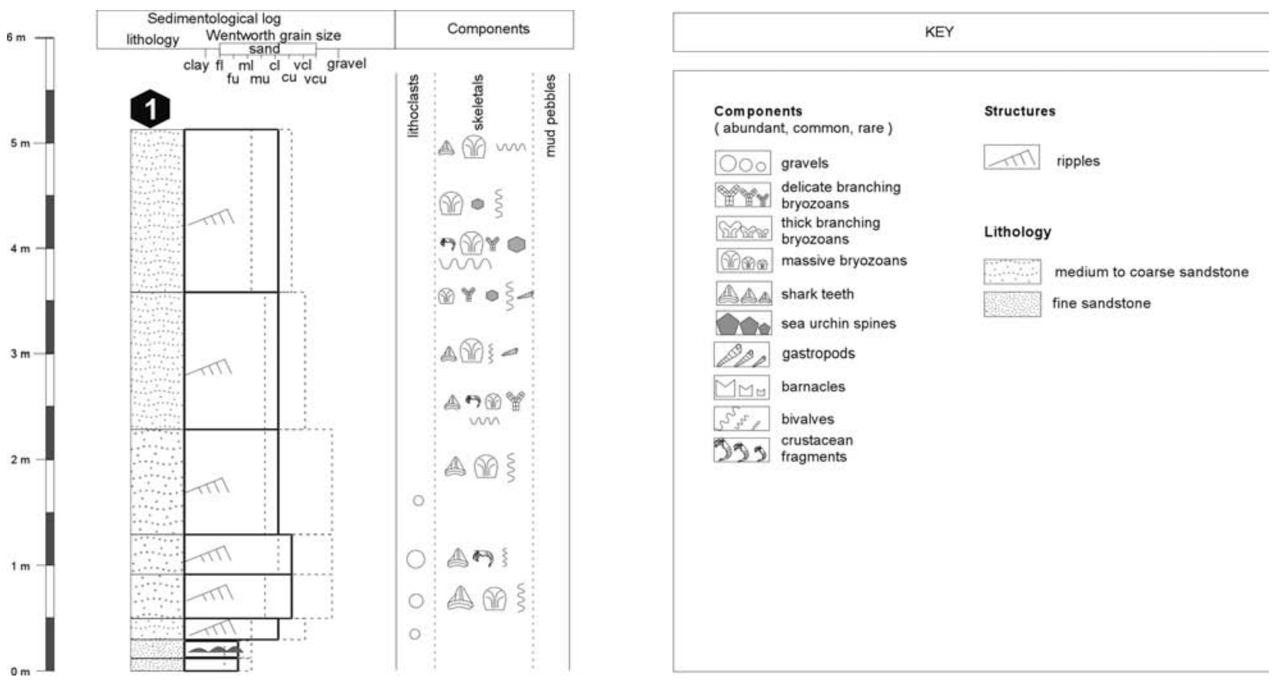

Fig: 4: Lithological column of Unit B.

Fig. 5: Lithological columns of the sandpit near Rengetsweiler.

in the veritcal. Current velocity, however, must always have been above the threshold for sand moving as a bedload component. Moreover, this unit is characterized by shallow troughs cutting into the ripple bed horizons. Post-depositional cementation with preferential fluid pathways in the coarse grained sand fraction cemented the ripple beds and show typical weathering in the medium sand interbeds. The ripple bedded succession shows a general decrease in ripple wavelength and amplitude towards the top of the succession indicating a gradual decrease in hydrodynamic energy and thus a rise in sea-level.

A prominent concave erosional discontinuity, which is traceable throughout the whole outcrop, separates the lower unit 2 from the unit above. This Unit 3 is characterized by sigmoidal to tangential foresets of coarse sand with intercalated fine sand troughs showing also internal cross bedding. The whole structure progrades towards the south and fills the undercut channel in a multi-storey fashion displayed by various reactivation and erosional surfaces.

The Ursendorf locality is historically well known for its bryozoan fauna, but also for its molluscs and shark teeths. Both Miller (1875, 1877) and Engel (1908) mentioned the Ursendorf locality which includes a rich bryozoan fauna as well as six echinoid species including a sea-urchin named after the locality (*Spatangus ursendorfensis*). These fossiliferous parts are, unfortunately, no longer accessible. Recently, Höltke (accepted) described 11 bivalve and 9 gastropod genera from museum collection material. The gastropods are only preserved as internal moulds. Interestingly, turritelline gastropods, which can be abundant at some localities in the OMM (e.g. *Turritella*: Ermingen and Northern Lake Constance area), are absent in Ursendorf. Recent investigations by the authors show that shark teeth dominate the fossil content together with massive, nodular bryozoans and bivalves. Among the bivalves, only calcitic shelled taxa, such as ostreids and pectinids, occur with their shells preserved. The basal, silty to fine-sandy sediments without structures lack macrofossils. The overlying unit reveals a general trend with shark-teeth becoming less abundant upsection, with a concurrent increase in the massive, nodular bryozoan colonies.

Stop 3: Outcrop: Rengetsweiler: Sandpit "Steidle GmbH"; Stratigraphy: Grobsandzug, unknown stratigraphic position; Main features: tidal laminates, tidal creek and tidal flats

The succession starts with a muddy tidal flat which is drained by most probably meandering tidal creeks. Tidal channels are floored with rip apart sandy lithoclasts up to 50 cm in size derived from the coast. Towards the top of the succession, the tidal flat deposits change several times from flaser bedded indicating high tidal flats to ripple bedded indicating lower tidal flats. These are each separated by major erosional unconformities designated by lag composed of quartz, pebbles and shark teeth overlying the basal unconformity.

The deposition of tidal rhythmites (tidal flat deposits) requires a morphological restricted environment and high concentrations of suspended sediment resulting from active wave-induced resuspension in an outer bay or offshore environment. A protected environment is necessary to limit erosional processes resulting from wave action or highly energetic tidal currents. The wide range of bedding types that express the tidal rhythmites are a reflection of highly variable hydrodynamic conditions. These vary from 1) weak energy with suspension load transport and settling which result in planar bedding to 2) more energetic dynamic conditions with bedload transport and erosional processes resulting in climbing ripple bedding and flaser- and wavy bedding.

The observed high turbidity can be related to offshore wave dynamics. High turbidity may also occur within fluvial-tidal settings such as an estuarine environment with high river discharge. The top of the succession is dominated by large-scale dunes prograding towards the Southwest. Within the foresets, the cyclic tidal current reversals have resulted in the generation of "tidal bundles" enclosed between planes characterized by erosion or non-erosion. Non-erosional surfaces represent the still-stand phase of dune migration during the subordinate tide. "Pause planes" may be draped by one or two thin mud laminae representing slack water conditions. Usually most of the slack water drape deposited on the ripple front directly after the dominant tide is eroded. Only a mud drape deposited after the subordinated tide is preserved. However, medium-scale dunes in the sand pit show "mud layer couplets" indicating low flood current velocity, which is not strong enough to erode the sediment.

During measuring and sampling of the sections by the authors, the outcrop was sieved for fossil material. The locality is well-known for its fossil shark teeth, which also dominated our samples. The largest specimens (up to 55 mm) and highest abundance of shark teeth was found within a rubble layer, which suggest hydrodynamically induced sorting within a lag deposit. Other fossils include crustacean fragments, massive and delicate branching bryozoans, fragile echinoid spines and other echinoid fragments as well as bivalves and a few gastropods. Pectinids and ostreids dominate among the bivalves. Generally, the abundance of fossils appear to decrease upsection. The large scale dunes at the top of the succession completely lack fossils.

Day 2

The Randengrobkalk and associated sediments in the Hegau region of southern Baden-Württemberg.

Marine, Lower Miocene coastal and near coastal sediments of the North Alpine Foreland Basin (NAFB) are found in Southern Germany near the border to the Swiss Canton of Schaffhausen in an area known as the Hegau. This area is bordered by Jurassic rocks of the Swabian Alb to the north and west, to the east by Lake Constance and to the south by the Rhine River with a landscape characterized by a number of exposed Neogene volcanic stumps. In general, sediments and rocks of the NAFB are poorly exposed with the exception of abandoned quarries which were worked in order to extract the 'Randengrobkalk' for building stone material. The Randengrobkalk and associated sediments are especially well exposed in the Tengen quarry section and other localities in the vicinity. Vertical wall faces allow for the analysis of the lateral and vertical development and lithostratigraphic units and facies variations.

The Randengrobkalk can generally be described as a mixed siliciclastic - carbonate environment. A number of different sedimentary and facies types are present characterized by different biotic composition and preservation, variations in the types of lithoclasts as well as by numerous sedimentary structures. The biota is dominated by gastropods, aragonitic bivalves, pectinid bivalves, oysters, bryozoans and balanid barnacles. Preservation ranges from well preserved to highly fragmented and rounded components. Lithoclasts are dominated by coarse angular quartz grains; rounded Jurassic components may also be present. Numerous sedimentary structures are observable including irregular to wavy planar bedding, massive to subhorizontal bedding, bidirectional foresets, and trough cross-bedding. These facies are found in different localites including Heilinbuck, Wiechs a.R. and the Tengen outcrops.

The Randengrobkalk shows an onshore – offshore gradient with a differentiated nearshore carbonate factory, offshore mixed carbonate-siliciclastic including high energy, subtidal environments with shoals and channels. The carbonates belong to the Bryomol type and can be compared to sediments now being formed in nutrient rich, warm temperate environments such as in the present Mediterranean Sea.

Stop 4: Outcrop: Tengen; Stratigraphy: "Randengrobkalk"; Main features: mixed carbonate/siliciclastic sediments with sedimentary structures, gastropod limestones, quartzose sandstones

A number of different sediment types can be found in the Tengen outcrop. These include:

1) Gastropod rudstones along with subordinate aragonitic and pectinid bivalves, oysters, bryozoans and balanids make up the typical Randengrobkalk which was quarried for building stone. It is found, for example, at the base of the Tengen outcrop (in the eastern part). Coarse and angular quartz grains also occur. The bedding is massive to subhorizontal; the top is sharp and sometimes erosive. This is interpreted as a higher energy, more offshore environment with permanent current action.

2) Quartz rich bivalve – barnacle packstones are found as massive, moderately sorted sands containing some m-scale undulating beds filled with trough, low- angle cross-bedding. The components are highly fragmented and in part rounded suggesting a transported assemblage.
   The environment of deposition is interpreted to be an offshore current swept substrate. This facies dominates for example in the Wiechs a.R. Section located a few km south of the Tengen Quarry.

3) Bioclastic sandstones containing very common quartz and rare abraded oyster fragments and isolated barnacles plates show bidirectional foresets and trough cross-bedding. Additionally, thin silty layer spread over the foresets. This is interpreted as subtidal channels with indications of slack water periods. These sandstones can be seen on the walls of the Tengen Quarry.

4) Finally, as also seen in the Tengen Quarry, there are quartzose sandstones with mega-scale planar sets with cross cutting troughs. Thinly-bedded mega-scale planar sets, inclined between 6°-10° are found with 0.5 to 2 cm thick laminae. Single troughs can be seen to cut the structure. 2D dunes with opposing inclination are present in the bottom set. This facies is interpreted as representing an ebb tidal delta.

Stop 5: Outcrop: Heilinbuck near Zollhaus; Stratigraphy: "Randengrobkalk"; Main features: transgression of Miocene carbonates over Jurassic limestones.

The Heilinbuck quarry near Zollhaus near the Swiss – German border shows the direct transgression of the Randengrobkalk over the Jurassic Limestones of the stable North European Platform. These Miocene carbonates here show different facies types than that found in the Tengen Quarry. The sediment consists of poorly sorted packstones and grainstones containing well preserved coralline algae, bryozoans, molluscs and peloids with subordinate, oysters, barnacles and small benthic foraminifera. Not surprisingly, rounded Jurassic limestone lithoclasts are also present in the limesontes. The sedimentary structures consist of irregular to wavy planar bedding, shallow troughs 2–4 m in length. These sediments are interpreted as belonging to a near-shore environment with moderate energy conditions.

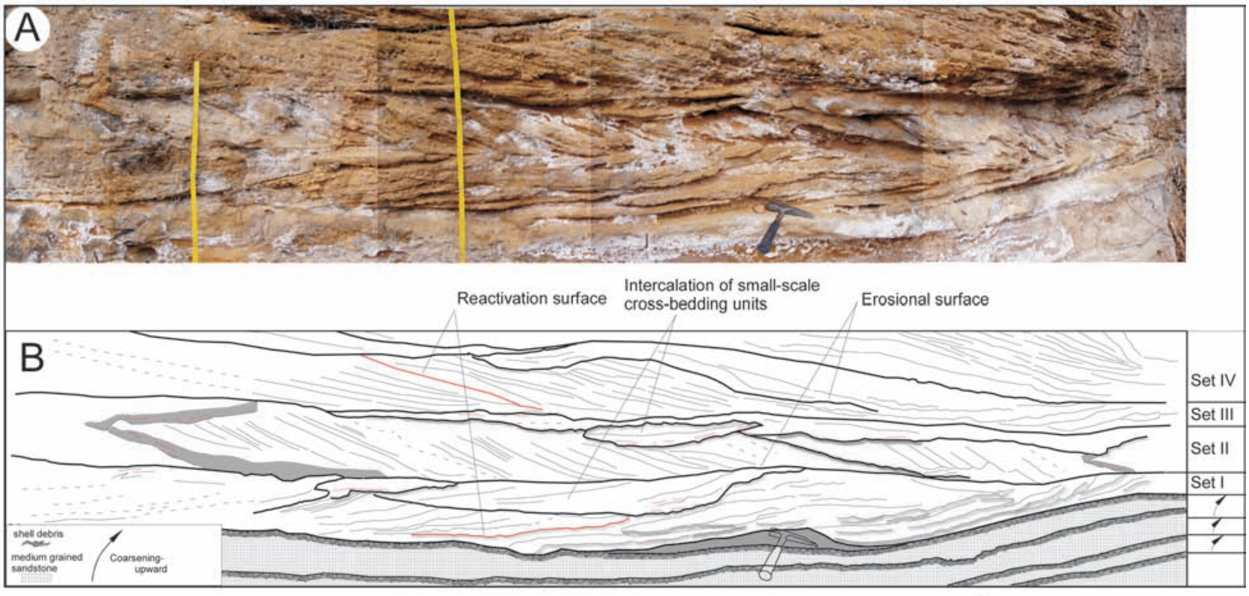

Fig. 6: Decimeter scale trough- to tabular cross-bedding. Foresets of coarse shelly debris are separated by silt interbeds typical for the slack water periods of a tidal cycle.

Fig. 7: Examples of different microfacies, components and diagenesis. Pore space is coloured blue.

A) Pack- to grainstone dominated by coralline algae (CA) and mollusc remains with gastropods (G) and oysters (Oy). Note the finer sediments within the body cavity of the gastropod seen here in cross section. Many fragments of former aragonitic mollusc shell remains bivalves are also present and characterized by micritized rims. Locality: Heilinbuck, TS HB-Basis, Scale bar = 2 mm.
B) Quartz rich, bivalve – barnacle packstone. A single large balanid barnacle plate (Ba) shows typical canals and tree-like structures in cross section. Locality: Tengen, TS: 2 Scale bar = 2 mm.
C) Grainstone with rounded oyster fragments (Oy) , aragonitic bivalve remains (AB) and subangular to subrounded quartz grains (Q). Locality: Tengen, TS: 7, Scale bar = 2 mm.
D) Bioclastic sandstones containing very common quartz and rare fragmented and abraded oyster fragments. Locality: Tengen, TS: 6, Scale bar = 2 mm.
E) A cross section through a gastropod surrounded and infilled by coarse angular to subrounded quartz grains (Q). A lithoclasts (L) is also present within the shell. The micritized gastropod shell (M) has been completely replaced by sparite. Locality: Tengen, TS: 5, Scale bar = 1 mm.
F) Detail showing rounded, fragmented oyster fragment and different types of pore space. A gastropod shows primary pore space within the shell (PP). The shell itself has been micritized (M), dissolved, and only partially replaced by blocky sparite cement (BC) , resulting in common secondary pore space (SP). Locality: Tengen, TS: 7, Scale bar = 1 mm.

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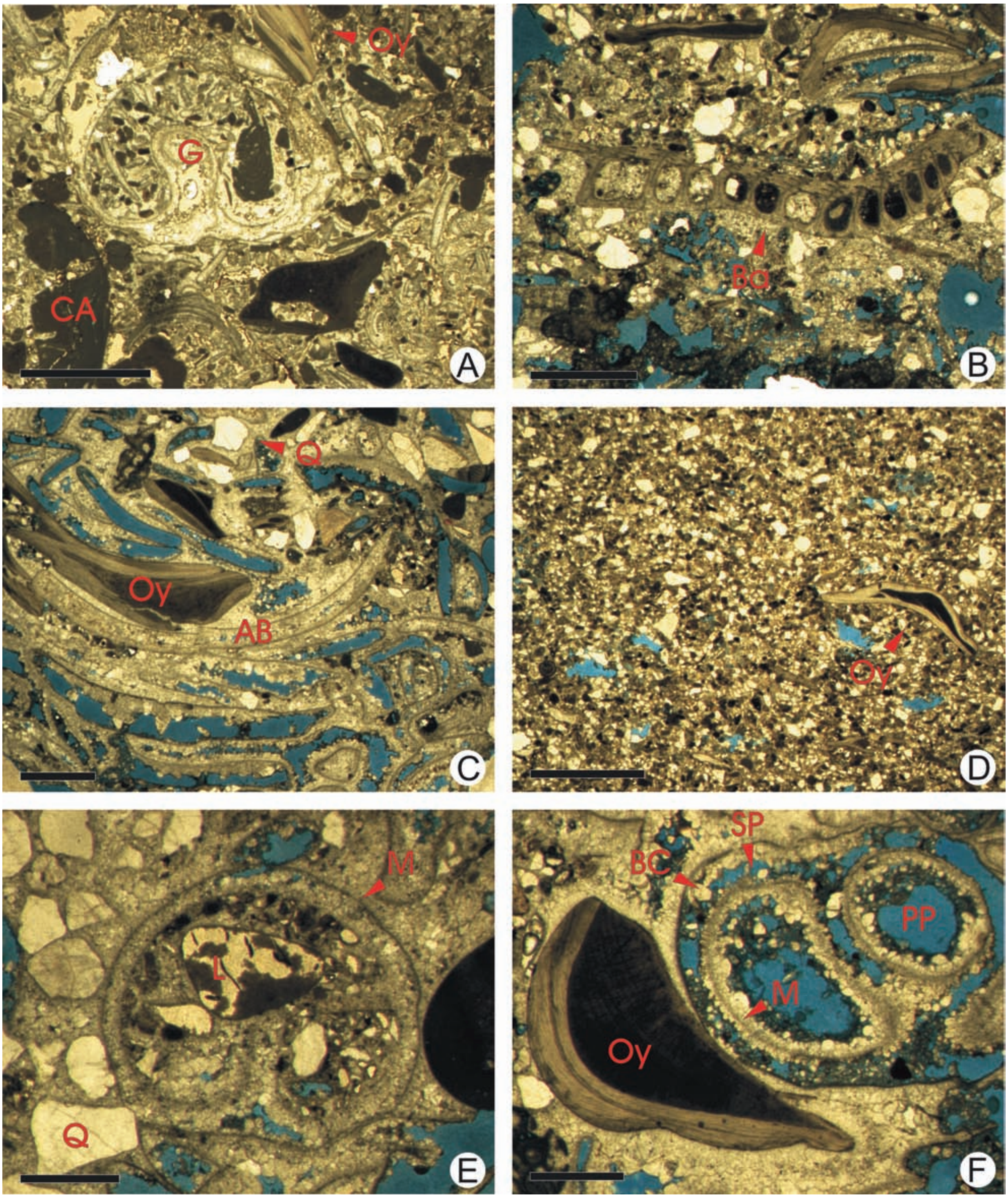
Fig. 7



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