6th International Triassic Field Workshop

(Pan-European Correlation of the Triassic)

Triassic of Southwest Germany

175th Anniversary of the Foundation of the Triassic System by

FRIEDRICH VON ALBERTI

September 7 – 11, 2009, Tübingen and Ingelfingen

Field Guide

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with contributions of

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International Triassic Field Workshops

The annual International Triassic Field Workshops will provide an informal forum for earth scientists who are interested in the Triassic system. The Workshops give the opportunity to visit the different settings of the European Triassic and thus encourage researchers to start cooperation by bringing together their research ideas and outputs. The workshops intend to support area and basin based studies of the European Triassic using a multidisciplinary approach.

So far the following International Triassic Workshops were held or are planned:

2004 England (organized by M Hounslow)

2005 Central Germany (organized by G. H. Bachmann, G. Beutler)

2006 Eastern France (organized by S. Bourquin, M. Durand)

2007 Western Poland (organized by A. Szulc, A. Becker)

2008 Hungary (organized by T. Budai, J. Haas, G. Konrad, H. Kozur, K. Sebe)

2009 Southern Germany (organized by H. Hagdorn, T. Simon, E. Nitsch, T. Aigner)

2010 Dolomites (organized by P. Gianolla, M. Avanzini, E. Kustatscher, N. Preto, G. Roghi)

2011 Provence: Var and Alpes-maritimes (organized by M. Durand, J.-P. Caron & H. Hagdorn)

2012 Lombardian Alps (A. Tintori, F. Jadoul, M. Felber, M. Gaetani, F. Rettori, C. Lombardo, A. Nicora, A. Cecconi, S. Frisia, F. Berra, M.T. Galli, G. Muttoni, M. Rigo, S. Cirilli)

2013 Eastern Iberian Ranges (J. Lopez-Gomez, R. de la Horra, A. Arche, J.F. Barrenechea, M.J. Escudero-Mozo, B. Galán-Abellán & J. Martín-Chivelet)

2014 Southern Israel (D. Korngren, O. Bialik, Ch. Bejamini & R. Rabinovich)

Field guides can be downloaded at: http://www.stratigraphie.de/perm-trias/trias_workshops.html

Programme

Monday, September 7, 2009

Institut für Geowissenschaften der Universität Tübingen, Sigwartstr. 11

18.00 h	Welcome by Prof. Dr. RALPH WATZEL, Regierungspräsidium Baden-Württemberg, Landesamt für Geologie, Rohstoffe und Bergbau
18.15 h	Prof. Dr. GERHARD H. BACHMANN, Halle (Saale): Introduction to the classic Germanic Triassic of the Southwest German type area
19.00 h	Prof. Dr.THOMAS AIGNER: 3D sequence stratigraphy – An example from the Muschelkalk
20.00 h	Reception at the Museum. Württembergian wines and pretzel snacks

Field Trips

Guides: T. AIGNER, A. ETZOLD, H. HAGDORN, E. NITSCH, T. SIMON

Tuesday, September 8, 2009

Buntsandstein and Muschelkalk (Early – Middle Triassic) **in Central Württemberg**

Stop 1	Lower and Middle Buntsandstein; Induan – Olenekian: cliffs and road cuts along forest trail around Reutiner Berg near Alpirsbach
Stop 2	Buntsandstein/Muschelkalk boundary (Röt and Freudenstadt formations); early Anisian: abandoned quarry near Freudenstadt-Glatten
Stop 3	Lower Muschelkalk (Freudenstadt Formation / Wellendolomit); Anisian: abandoned clay pit near Freudenstadt-Dietersweiler
Stop 4	Upper Muschelkalk (Rottweil formation), Lower Keuper (Erfurt Formation); late Anisian – early Ladinian: Frommenhausen quarry
20.00 h	Dr. ROBERT WEEMS, USGS, Reston VA: Correlations among the Newark Supergroup and the Germanic Basin

Wednesday, September 9, 2009

Keuper (Late Triassic) **in Central Württemberg**

Stop 5	Middle Keuper (Grabfeld Formation / Gipskeuper); latest Ladinian: gypsum pit Entringen
Stop 6	Middle Keuper (Stuttgart Formation / Schilfsandstein); Carnian: abandoned sandstone quarries near Wendelsheim
Stop 7	Middle Keuper (Weser Formation / Bunte Mergel), Löwenstein Formation ~ Stubensandstein); Norian: abandoned quarries near Kayh
Stop 8	Upper Keuper and Triassic-Jurassic boundary; Rhaetian: active sandstone quarry near Tübingen-Pfrondorf

Transfer to Ingelfingen (approximately 135 km, approx. 2 h).

20.00 h	Muschelkalkmuseum Hagdorn Stadt Ingelfingen. Reception by Mayor MICHAEL BAUER

Thursday, September 10, 2009

Buntsandstein and Muschelkalk (Middle Triassic) **in Northern Württemberg**

Stop 9	Upper Muschelkalk (Trochitenkalk and Meißner formations); Anisian, Ladinian: abandoned quarry at Künzelsau-Garnberg
Stop 10	Upper Muschelkalk (Quaderkalk Formation); early Ladinian: quarry near Krensheim
Stop 11	Lower and Middle Muschelkalk (Jena, Karlstadt, Heilbronn, and Diemel formations); Anisian: quarry near Werbach on River Tauber
Stop 12	Upper Buntsandstein (Plattensandstein and Rötton formations); earliest Anisian: vineyard road cutting near Homburg on River Main

20.00 h	Kulturforum Schwarzer Hof, Ingelfingen Dr. WOLFGANG HANSCH, Naturhistorisches Museum Heilbronn FRIEDRICH VON ALBERTI – his life and work

Friday, September 11, 2009

Muschelkalk and Keuper (Middle Triassic) **in Northern Württemberg**

Stop 13	Lower Keuper (Erfurt Formation); Ladinian: quarry with vertebrate lagerstaetten near Vellberg-Eschenau
Stop 14	Lower Keuper (Erfurt Formation); Ladinian: abandoned sandstone quarry near Crailsheim-Fallteich
Stop 15	Upper Muschelkalk (Trochitenkalk and Meißner formations); Anisian, Ladinian: quarry near Satteldorf-Neidenfels

14.00 h	Restaurant Wacker (Bölgentaler Straße 6, 74589 Satteldorf – Gröningen, Tel. 07955/13 19) Lunch and Final Discussion.

Transfer to Crailsheim Railway Station

Additional optional Programme

Saturday, September 12

Visit to exhibits and collections of the Muschelkalkmuseum.

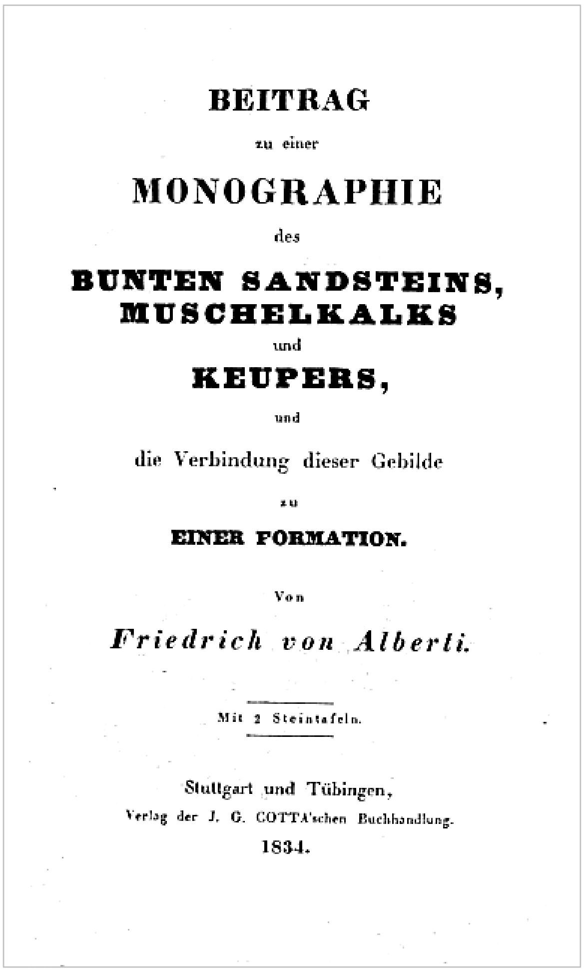
Saturday, September 12 – Sunday, September 13, 2009

Field Trip to Upper Permian/Lower Triassic Buntsandstein (cyclicity and conchostracan biostratigraphy) near Halle on River Saale (approx. 450 km NE). (Guides: H. W. KOZUR, G. H. BACHMANN).

The Germanic Triassic in its Southwest German type area

H. HAGDORN & E. NITSCH

In 1834, the Württembergian Mining Director FRIEDRICH VON ALBERTI united the rock units known as Buntsandstein, Muschelkalk and Keuper, that contain some common fossils strictly different from those of the Permian and Jurassic, and called it *Triasformation* (ALBERTI 1834, HAGDORN & NITSCH 1999; Fig. 1). His interest originally centred on the rock salt of the Muschelkalk, which was exploited in salt mines since the beginning of the 19th century, but soon expanded to the grey fossiliferous limestones and variegated clastics symmetrically arranged below and above the salt deposit. Within short time, the name "*Trias*" was internationally accepted as a term for the period of earth´s history that initiated the Mesozoic Era. Thus, southwest Germany became the type area of the Triassic System. Moreover, in Europe and even in Asia, Triassic deposits in alternating terrestrial and marine facies are called *Triassic in Germanic facies*. In German language, the term *Trias* is still used as a noun, as originally coined, while the English terms *Triassic* and the French *Triasique* are independent adjectives of the omitted nouns *Period* or *System*. The same is true for *Bunter* (the German word for *variegated*) that is adjective to *Sandstein* (*sandstone*).


BEITRAG
zu einer
MONOGRAPHIE
des
BUNTEN SANDSTEINS,
MUSCHELKALKS
und
KEUPERS,
und
die Verbindung dieser Gebilde
zu
EINER FORMATION.
Von
Friedrich von Alberti.
Mit 2 Steintafeln.
Stuttgart und Tübingen,
Verlag der J. G. COTTA'schen Buchhandlung.
1834.

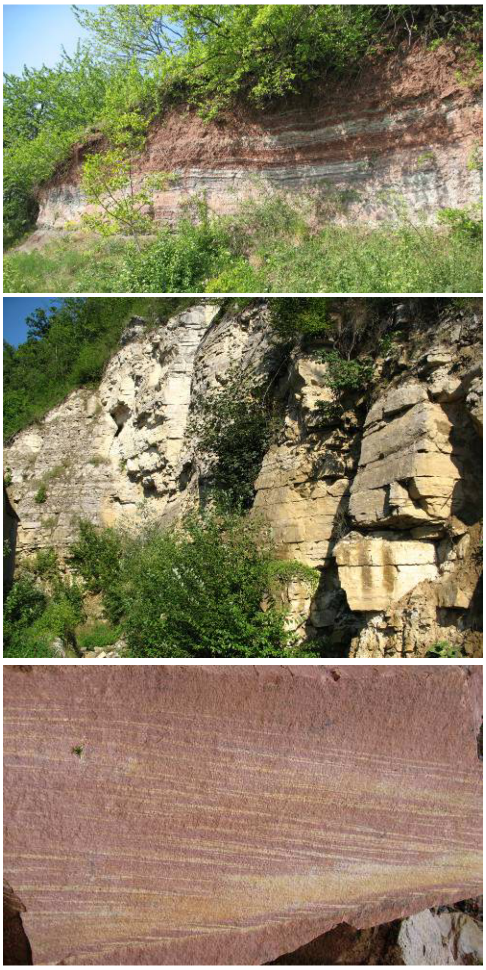


Fig. 1 Title of Friedrich von ALBERTI´s 1834 monograph with the foundation of the Triassic System. The monograph has been reprinted by the Alberti Foundation of the Hohenlohe Quarry Companies. On the right side some typical outcrop views of Buntsandstein, Muschelkalk and Keuper rocks from different parts of Baden-Württemberg (Photos: NITSCH).

Today, Triassic rocks in Germanic facies comprise the Germanic Triassic supergroup of Central Europe. Their outcrop area dominates the North and the West of the Southwest-German cuesta landscape and thus large parts of Baden-Württemberg (Fig. 2). They form three escarpments of about one hundred meters each (Fig. 3), bordering the paleozoic basement of the Black Forest and Odenwald mountains and dipping gently to the Southeast below the Jurassic rocks of the Swabian Alb. Regionally they are further subdivided into several smaller cuestas. In total, the Germanic Triassic reaches a thickness of 1000 to 1100 m in northern Baden-Württemberg, decreasing towards the South to approximately 400 m at the upper runs of Rivers Danube and Rhine. Triassic rocks are present in the subsurface of the Upper Rhine Graben, the Swabian Alb, and the subalpine Molasse Basin, where Muschelkalk and Keuper onlap the Early Triassic basin margin. Further to the southwest, the thickness is decreasing to less than 200 m in the subsurface of Lake Constance and the Allgäu region. The Germanic Triassic is also present in similar facies in neighbouring France (Alsace, Lorraine, parts of the Paris Basin and Burgundy Trough), and Switzerland, as well as in all federal states of Germany (Bundesländer, sometimes in the subsurface only), including the much thicker Triassic deposits of the so-called Southern Permian Basin of Northern Germany and neighbouring regions. For the Triassic, this Central European Basin System is also known as the "Germanic Basin".

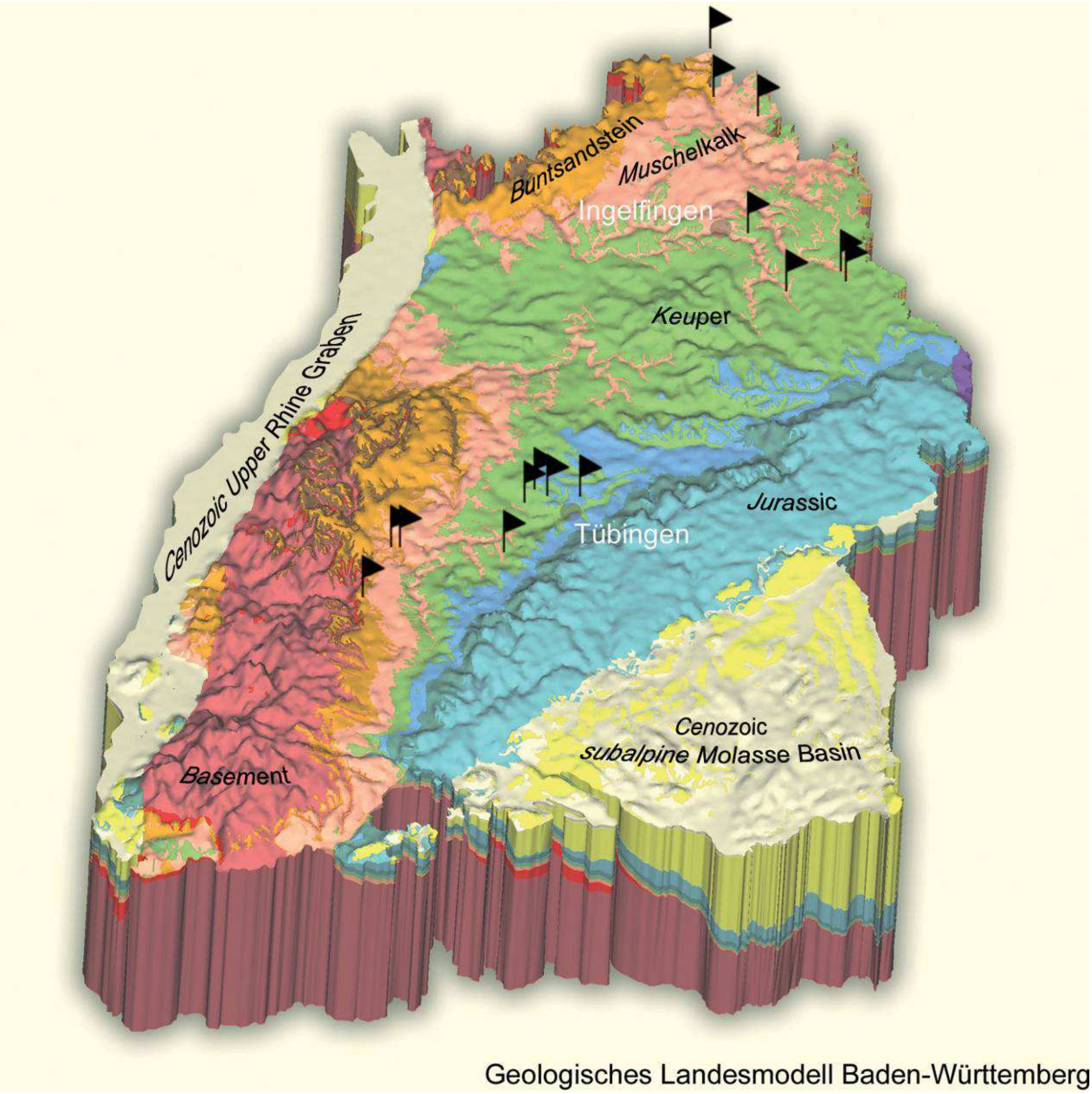


Fig. 2 Geological perspective block diagram of Baden-Württemberg (from RUPF & NITSCH 2008) and position of the stops of the field trip.

Geological setting

During Triassic times, the depositional area of the Central European Basin was expanding intermittently over former erosional areas. In Late Permian times, the Zechstein sea only shortly impinged northern Baden-Württemberg, as documented by up to ca. 50 m of fossiliferous marine dolomites and mudstones. Most of the Zechstein Group in Baden-Württemberg, however, has been deposited in terrestrial facies fringing the southern basin margin with a clastic rim 100 to 300 km wide. The Late Permian white and red fluvial sandstones ("Tigersandstein", for its black mottles) and red-brown playa mudstones ("Bröckelschiefer", for their crumbly disintegration behaviour) indeed have initially been interpreted as basal part of the Triassic by ALBERTI (1834) and QUENSTEDT (1843). Their equivalents still are assigned to the Buntsandstein Group in France, but have been formally integrated into the Zechstein Group in Germany (LEPPER 1993).

Fig. 3 The Keuper cuesta (Keuper-Schichtstufe in German) of the Schönbuch hills between Tübingen and Herrenberg. The forested hills are build of sandstones of the Löwenstein Formation, capped by some Rhaetian to Early Jurassic rocks on the plateau. The lower terrain to the left is the outcrop area of mainly claystones and evaporites of the lower parts of the Keuper and grades downward to the cuesta plateau of the Muschelkalk cuesta (Photo: NITSCH).

The southern basin margin of the Lower Buntsandstein was situated close to its Late Permian position near the transition from the Central to the Southern Black Forest, where the highland ridge of the Southern Black Forest Swell, a paleotectonically positive area from Carboniferous to Jurassic time, acted as a source area for basement pebbles. From here the 0-m-isopach bends to the northeast, to cross the boundary to Bavaria a few kilometres north of the Neogene impact structure of the Nördlingen Ries. Middle to Upper Buntsandstein deposits show increasing south-easterly onlap onto the paleorelief of the Southern Black Forest Swell. So the basin margin has been shifted to the northern Lake Constance area at the Buntsandstein-Muschelkalk boundary, and farther towards the Southeast to the Allgäu Pre-Alps by the end of the Lower Muschelkalk deposition. Further onlap of the Upper Muschelkalk and Middle Keuper deposits onto the former Vindelician Highland shifted the basin margin finally to Upper Bavaria and the Oberpfalz region at the end of the Triassic.

Thickness maps show differentiated subsidence patterns within the basin area (Figs. 6, 8, and 14). Some Late Carboniferous basement uplifts, generally striking to the Northeast, still represent swells of restrained subsidence, accompanied since Late Permian times by NNE striking swells and depressions crossing them (RUPF & NITSCH 2008). These swells and depressions partly control the dispersal of clastic sediments within the depositional area and the patterns of facies distribution during most of Triassic (and Jurassic) times, e.g., the area and thickness of Muschelkalk salt (Fig. 8) deposition and the western boundary of some Keuper sandstones (Fig. 14). In Buntsandstein paleogeography, the Odenwald–Spessart Swell in the North partly separated the depositional area of Baden-Württemberg, which is devoid of eolian sediments, from Lorraine, Palatinate and South Hesse, where fluvial sediments alternate with eolian facies.

The Buntsandstein unconformities known from Northern Germany are not clearly documented from Southern Germany. Synsedimentary tectonic movements are indicated by debris flows in the Muschelkalk and are thought to be triggered by earthquakes. Unconformities, ommitting tens of meters of sediments, are present within the Keuper, well documented on top of the Northern Black Forest Swell (LUTZ & ETZOLD 2003, DSK 2005) and on the Spaichingen Swell. On the latter one, the Upper Keuper deposits known from the paleotectonic depressions locally are partly or completely eroded beneath the base of the Lower Jurassic.

During the Early Triassic, fluvial sands were generally transported from Southwest to Northeast in south-western Germany, as indicated by grain size and paleocurrent patterns. Most of the Buntsandstein clastics are commonly presumed to have their provenance area in the French Massif Central, although little diagnostic features are preserved within the quartz sandstones. Local sources from the Southern Black Forest Swell also were of importance in the lowermost Buntsandstein, and input from the Vindelician Highland in the Southeast increasingly gets important to the East of Baden-Württemberg. In Anisian times, the Röt and Muschelkalk seas were transgressing from the Polish

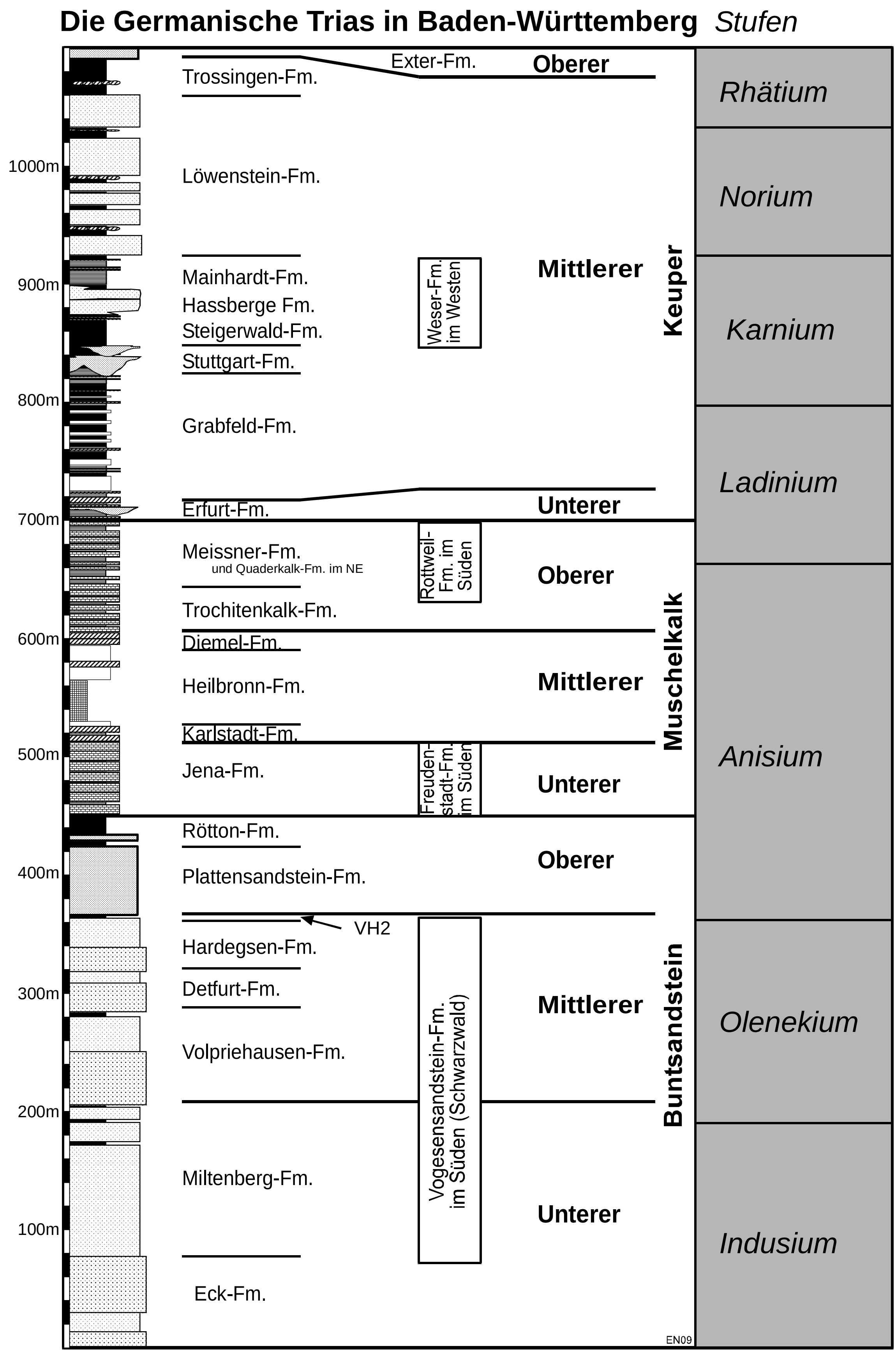


Fig. 4 Simplified lithostratigraphic summary section of the Germanic Triassic in Baden-Württemberg. Thicknesses are drawn according to the depocenters in the North (Kraichgau – Hohenlohe and Odenwald regions). Due to facies changes in more marginal areas of the sedimentary basin, the first part of the field trip will show some different formations developed in southern to central Baden-Württtemberg (diagram: LGRB/NITSCH).

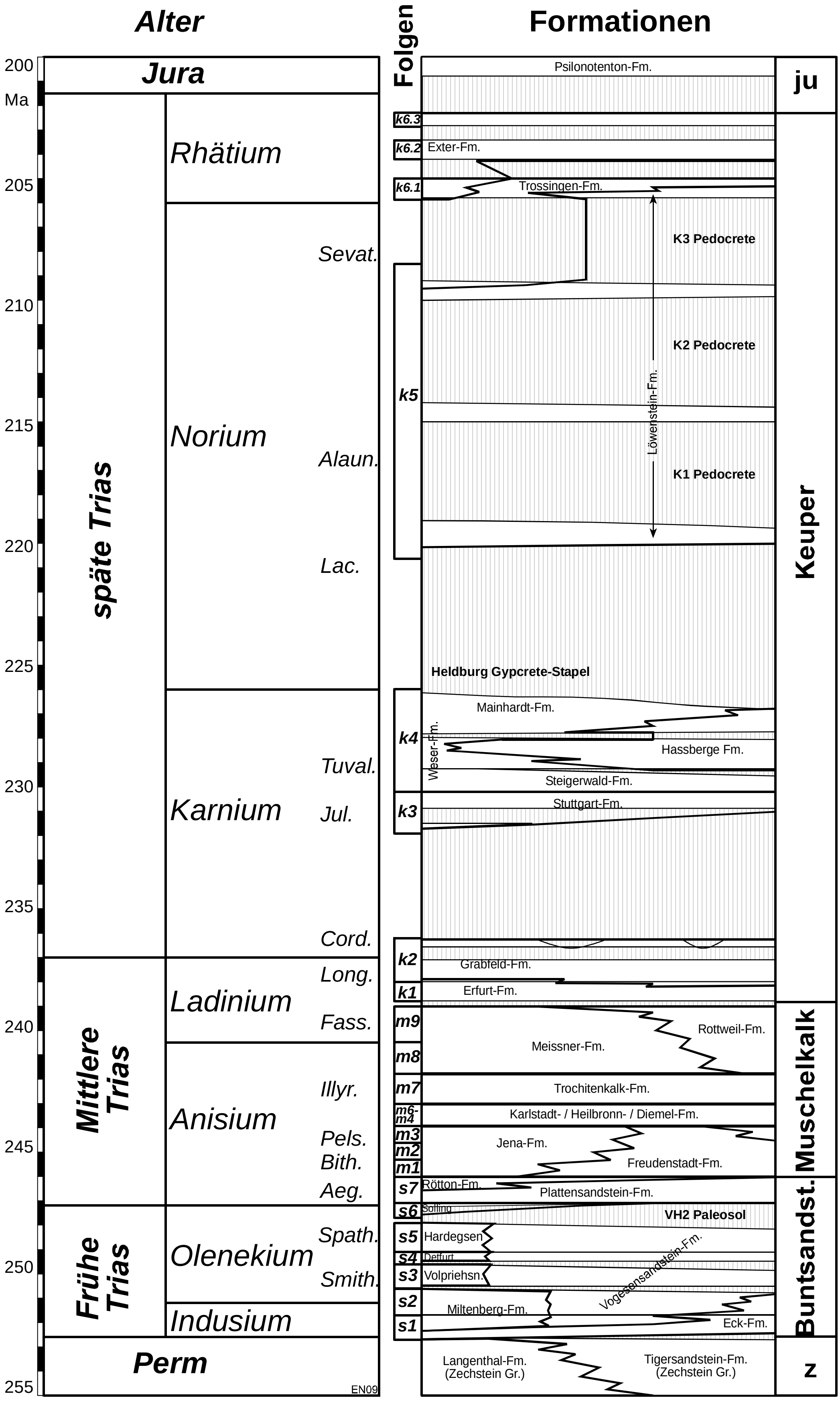


Fig. 5 Simplified chronostratigraphic summary of the Germanic Triassic in Baden-Württemberg (diargram LGRB/NITSCH, based on STD 2002, NITSCH et al. 2005a, KOZUR & BACHMANN 2008). Thin lines denote time-equivalent slices of sediments (Folgen s1 to k6), thick lines are formation boundaries (main facies boundaries).

Lowlands via Thuringia and Lower Franconia into south-western Germany and eastern France. While the Upper Buntsandstein of Baden-Württemberg is partly correlated with the northeast German marine Myophoria Beds and the Lower Gogolin Formation in Poland, the Lower Muschelkalk sea expanded to the Upper Rhine and Alpine foreland areas. In the Vosges mountains and their surroundings, siliciclastic marine Muschelkalk (Udelfangen Formation) overlays the nonmarine Grès á *Voltzia* and is followed by marine carbonates correlated with the middle part of the Jena Formation. Below the subalpine Molasse Basin, Lower Muschelkalk coastal to shallow marine sandstones (Eschenbach Formation) transgress onto the basement rocks and Rotliegend Basins of the Vindelician Highland. During a temporary sea level fall in Early Illyrian (ealy Late Anisian) times the Middle Muschelkalk evaporites were deposited. From late Illyrian to Fassanian (early Ladinian) times, Southwest Germany was dominated by marine conditions of the Upper Muschelkalk. By the Late Ladinian (Longobardian), marine ingressions were reduced to some short-lived incursions, alternating with increasing periods of nonmarine deposition. The Lower Keuper epeiric delta complex (Erfurt Formation) is characterized by rapid but regular facies changes between freshwater and estuarine to deltaic channel and pond deposition, short-lived brackish marine incursions, evaporite precipitation, and terrestrial soil formation – the latter including some of the worlds first peat deposits post-dating the end-Permian extinction, the "Lettenkohle" beds of muddy brown coal. In Late Longobardian times, the environments became mostly evaporitic. The latest Ladinian to Carnian "Gipskeuper" facies of the Grabfeld and Weser Formations largely consists of anhydrite (/ gypsum) deposits alternating with claystone vertisols, bedded mudstones containing some brackish to freshwater fossils, and some more marine ingression deposits.

The fine grained sands of the Lower Keuper where shed from the North and have a Scandinavian provenance, proven by Caledonian ages of detrital mica (PAUL et al. 2008). Otherwise, most of the sands present in the Late Ladinian to Early Rhaetian Middle Keuper, with exception of the also "nordic" Schilfsandstein deposits of the Stuttgart Formation, do have a Vindelician source area and were shed from the Southeast. These Vindelician sandstones are most widely distributed in the northern part of Baden-Württemberg. The reason for this is a paleotectonic depression (the Central Swabian Depression), now situated in the subsurface of the Swabian Alb, that was trapping the fluvial transport systems and directed most of them towards the Franconian Depession in the North. Input of fluvial sandstones increased sharply in Norian times, possibly initiated by tectonic uplift of the Vindelician hinterland, but certainly accompanied by a change to less arid climates. Evaporites ceased to precipitate at this time, and paleosols, clay mineralogy and oxygen isotopes of the Löwenstein and Trossingen Formation show a shift to semiarid conditions (REINHARDT 2002, NITSCH 2005b). In early Rhaetian times, nonmarine environments continued with deposition of the uppermost Löwenstein and Trossingen Formations (KOZUR & BACHMANN 2008), but the "Middle Rhaetian" transgression of the Contorta Sea also transgressed the western and northern part of Baden-Württemberg. Marine mudstones with some thin sandstone beds ("Contortaton") were deposited west of the Spaichingen Swell, but age-equivalent shallow marine to coastal sandstones can be found on this Swell and to the East of it. Latest Rhaetian freshwater sediments of the Triletes Beds are only preserved in paleotectonic depressions, but have been eroded by the transgressing Jurassic sea on top of the swells.

Subdivision

For two centuries, the Triassic has been subdivided in different ways. Due to the federal organisation of Germany, dozens of homonyms and synonyms for regional stratigraphic units have been introduced and caused a terminological thicket that is hard to manage even by stratigraphers. Only in the second half of the 20th century, proposals for basin wide correlation and standardisation of the nomenclature were made, especially for the Buntsandstein (BOIGK 1959, EISSELE 1966, RICHTER-BERNBURG 1974) und the Keuper (GWINNER 1980, BRENNER & VILLINGER 1981, DUCHROW 1984). Since Germany´s re-unification, the Subcommission of Permian and Triassic Stratigraphy (SPTK) of the Deutsche Stratigraphische Kommission (DSK) is elaborating a standardised system of terms and names for the Germanic Triassic in Germany according to the international stratigraphical classification and terminology (Fig. 4).

The biostratigraphic subdivision of the Germanic Triassic has for a long time been restricted to the marine Muschelkalk. Generations of paleontologists have been searching for fossils that occur both in the Alpine and the Germanic Triassic and could be used for correlation of the Tethyan and the Germanic Triassic. Due to the endemic lineage of the Upper Muschelkalk ceratite chronokline, correlations of the zonal schemes remained problematic, until valuable data could be added by systematic research on microfossils, especially conodonts (KOZUR 1974a, 1974b, 1975, 1998). In the second half of the 20th century, the position of the Triassic stage boundaries could be fixed within

Buntsandstein, Muschelkalk, and Keuper. As a result, the Upper Buntsandstein already belongs to the Anisian stage, and the Lower Keuper and lower part of the Middle Keuper still have a Ladinian age (KOZUR 1974a, 1974b, 1975, 1998, STD 2002, KOZUR & BACHMANN 2004, 2008; Fig. 5).
Because high resolution biostratigraphy is not possible for Buntsandstein and Keuper, an allostratigraphic scheme based on marker beds, unconformities and other discontinuities has been established (THÜRACH 1888/89, WAGNER 1913). Facies-independent correlation of such markers (e.g. ecologically overimprinted shell beds, unconformities, or transgressive surfaces), especially in Muschelkalk and Keuper, led to a detailed subdivision of quasi-isochronous units that are called *Folgen* (LUTZ et al. 2005). To be clearly distinguished from formations and other lithostratigraphic units, the Folgen of the Germanic Triassic do not bear names but combinations of the small letters (s for Buntsandstein, m for Muschelkalk, and k for Keuper) and numbers (e.g. s1, m9, k3).

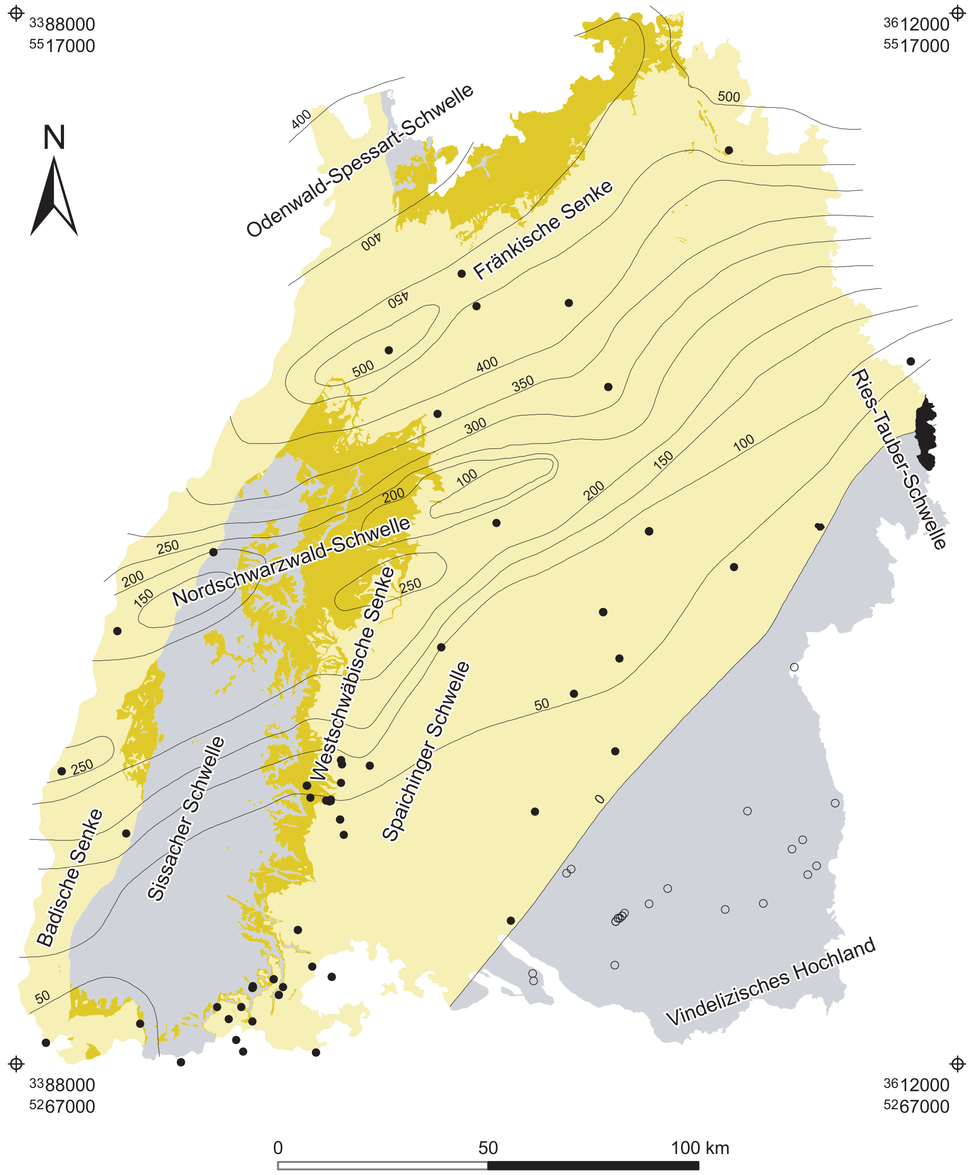


Fig. 6 Thickness map for the Buntsandstein Group in Baden-Württemberg, isopach lines at 50 m distance (from RUPF & NITSCH 2008). Filled dots point to borehole data, open circles to borehole evidence that the unit is missing.

Buntsandstein

The Buntsandstein of Baden-Württemberg represents the southern marginal facies belt of the basin. A maximum thickness of nearly 500 m has been drilled in the Kraichgau area of north eastern Baden-Württemberg, but in the outcrop areas of the Black Forest mountains thicknesses are commonly less than 400 m (Fig. 6). Most of the Buntsandstein here is of red to red-brown colour, so the term “bunt” (variegated) does not strictly apply to the Black Forest Buntsandstein as well as it does for the Thuringian type area, where this Group has been named originally. The Lower and Middle Buntsandstein, more than 400 m thick at the local depocentre of northern Baden-Württemberg, consist of fluvial to alluvial coarse grained sandstones, pebbly sandstones and conglomerates that still resist a clear subdivision on the maps, although single outcrop sections can be correlated in some detail with the Folgen units of the more distal facies in Northern Germany. It is only in the Odenwald mountains, where the Lower and Middle Buntsandstein change to a more distal facies and the formations of the more northerly basin areas (i. e., north of river Main) can be traced on a map with some confidence (Fig. 7). The Upper Buntsandstein is represented by up to 70 m of medium to fine-grained fluvial and sheetflood sandstones and a topmost layer of playa mudstones only a few meters thick.
Fossils are rare in the Buntsandstein of south-western Germany, and most of them have been found in the Upper Buntsandstein. Yet, vertebrate remains have been collected from Lower and Middle Buntsandstein rocks, mostly of labyrinthodonts, but also including the oldest lungfish remnant of the genus *Ceratodus* (*C. priscus* FRAAS). Conchostracans have been reported from clay lenses several times, but not yet examined in detail. There are only few paleosols, some bearing root traces. A sparse, but comparatively more diverse fauna and flora is present in the Upper Buntsandstein. The plant remains include conifers (*Voltzia*), horsetails (*Equisetites*), ferns (*Anomopteris*), and the well-known *Pleuromeia*. Labyrinthodonts, rauisuchians (and their track *Chirotherium*) and an early species of *Tanystropheus* have also been found, as well as different species of fishes, decapods, and conchostracans. The flora and fauna found in Baden-Württemberg does not allow clues about biostratigraphy – the conchostracan finds have not been investigated yet –, so all age information is deduced from lithostratigraphic correlation with dated deposits in more distal parts of the basin.
The **Lower to Middle Buntsandstein** of the Black Forest has been termed “Vogesensandstein” by ALBERTI (1834), correlating it to the Grès vosgien of L. ELIE DE BEAUMONT on the opposite side of river Rhine. This unit has first been subdivided by H. ECK (1892) into a lower conglomerate, pebble free sandstones in the middle part, and an upper conglomerate on top. In honour of his work, the “lower conglomerate”, a series of coarse channel sandstones with variable pebble content and some minor mudstone lenses, has been called **Eck Formation**. It represents the lower part of Folge s1 in the northern Black Forest and further to the North, but includes increasingly younger deposits towards South in the Central Black Forest. These younger deposits, representing the upper Folge s1 and Folge s2, grade northwards to pebble-free sandstones of the **Badischer Bausandstein Member** of what today again is called **Vogesensandstein Formation**. These sandstones have long been used as ashlar sandstones (Bausandstein), and for tens of years they have been mapped as a separate “Bausandstein-Formation”, distinguished from the Middle Buntsandstein “Geröllsandstein-Formation” above. Yet, this distinction has been made only in outcrop sections, but could not be mapped satisfactory, because some of these “Geröllsandstein” pebbly sandstones are quite poor in pebbles and the facies boundary to the pebble-free sandstones below therefore apparently may shift by several tens of meters within one kilometre, depending on the position of more or less pebbly channel fills. Thus both units, Badischer Bausandstein and Geröllsandstein, have recently been included as members into one formation. In some outcrop sections of the northern Black Forest, the **Geröllsandstein Member** can be subdivided into three depositional cycles from more conglomeratic to more sandy deposits (Unterer, Mittlerer, Oberer Geröllsandstein; EISSELE 1966). These cycles are thought to represent a southern equivalent of the Middle Buntsandstein cycles of BOIGK (1959) and thus the Folgen s3 to s5. However, lateral variations in pebble content and the effects of local channel incision make it difficult to access the accuracy of straightforward correlations, and impossible to trace these cycle boundaries on a map. The Vogesensandstein Formation closes on top with the **Kristallsandstein Member**, formerly also taken as a separate formation. The boundary between Geröllsandstein and Kristallsandstein Members locally is marked by a purple paleosol (Violetter Horizont VH1; ORTLAM 1967), but commonly just a facies change to coarse sandstones poor in or devoid of pebbles. The sandstones are typically silicified, and the name “Kristallsandstein” is derived from tiny reflecting quartz crystal surfaces commonly seen in the pore space. On top of the Kristallsandstein Member a paleosol is developed and present in most sections, called Violetter Horizont VH2 (EISSELE 1966, ORTLAM 1967). Folge s6 seems to be missing in the Black Forest, but possibly some of the pedogenetically altered sediments of VH2 can be interpreted as its time equivalent.

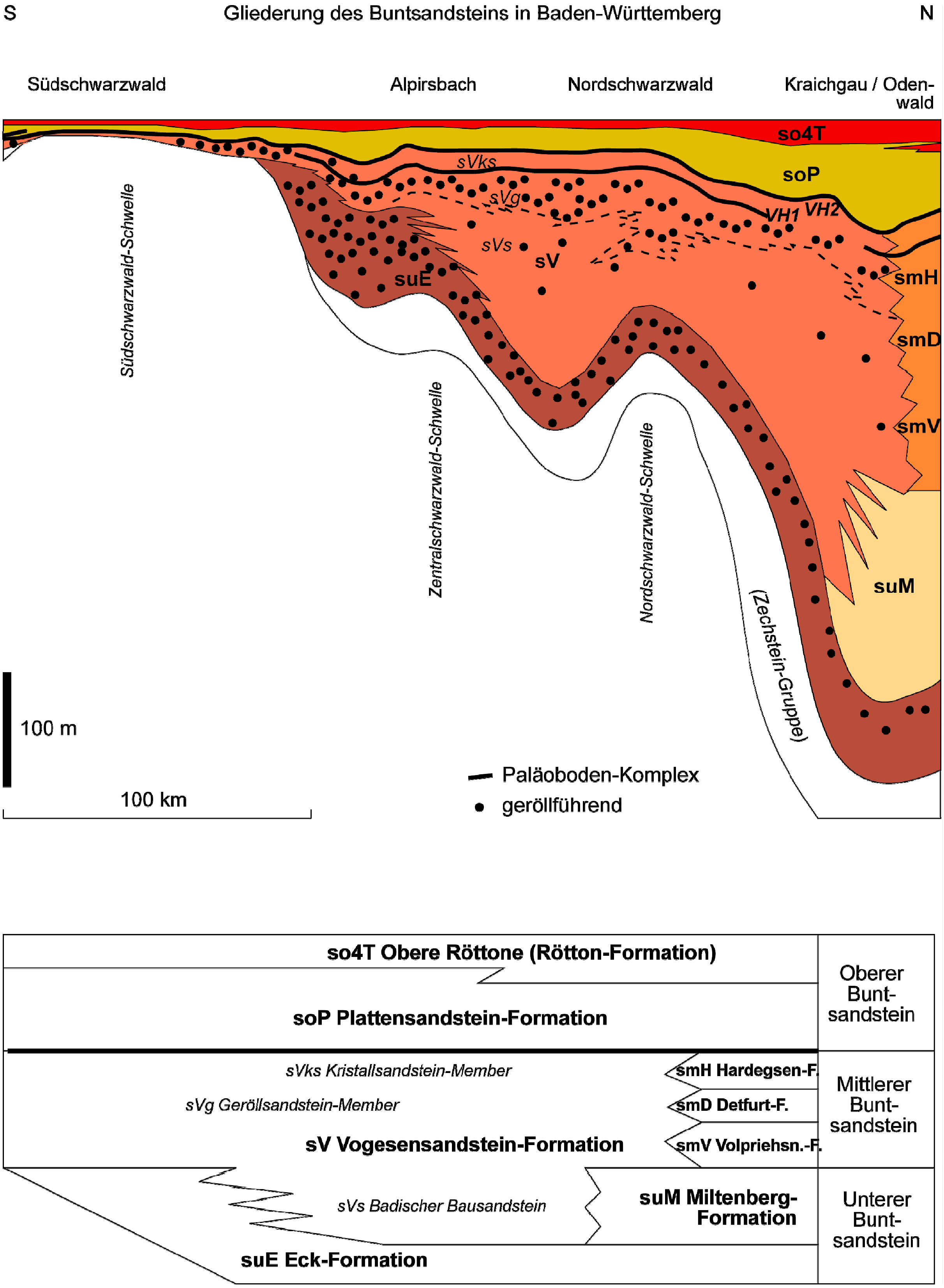


Fig. 7 Generalized facies section of the Buntsandstein Group in Baden-Württemberg (above; modified after GEYER & GWINNER 1991) and lithostratigraphic nomenclature.

The **Upper Buntsandstein** mainly consists of medium to fine grained micaceous sandstones of the **Plattensandstein Formation**. They mostly are thin-bedded sheetflood and crevasse splay sandstones locally interbedded with thicker channel sandstone bodies. Early diagenetic silification and carbonate pedocretes as well as “purple soil horizons” (Violette Horizonte VH3 to VH5: ORTLAM 1967) occur at different stratigraphic levels, but correlation over more than a few kilometres remains controversial. Thickness is about 50 m in the northern Black Forest and decreases to less than 30 m in the southern Black Forest, where locally this formation is the first Buntsandstein deposit on top of some paleotopographic highs of the Southern Black Forest Swell basement rocks. The uppermost 3 to 8 m of the Upper Buntsandstein are developed in playa mudstone facies in most of the Black Forest. This **Rötton Formation** consists of red-brown silty claystones, typically altered to massive vertisols. Towards northern Baden-Württemberg the facies change from fluvial Plattensandstein facies to the muddy facies of the Rötton Formation occurs earlier, and in parts of Hohenlohe and in the Main river area a Lower Rötton is developed as an equivalent of parts of the Black Forest Plattensandstein. Gypsum nodules and some minor halite content in the pore space (preserved in the subsurface only: ALBERTI 1834, FELS et al. 2003) can be attributed to aridisol pedogenesis shortly after deposition. The top of the Rötton Formation often is marked by an irregular bleached band of green claystone immediately below the first marine deposit of the Muschelkalk.

Muschelkalk

Lithologically the Muschelkalk Group is subdivided in the Lower, the Middle, and the Upper Muschelkalk subgroups. Its maximum thickness is in the Franconian Depression North of Heilbronn and exceeds 240 m (Fig. 8). Towards the Vindelician Massif, it decreases to less than 30 m below the Swabian Alb. Due to its position near the Western and Eastern margins of the basin, the Southwest German Muschelkalk is developed in facies belts that generally follow the basin margins. These facies belts are congruent with the formations that may have regional or basin wide extension (HAGDORN & SIMON 2005; Fig. 9). Additionally, the marker beds, e.g. seismite debris flows or tempestite shell beds that may be ecologically overimprinted, allow a high resolution bed-by-bed allostratigraphy (WAGNER 1913, GWINNER 1970, HAGDORN & SIMON 1993 a). The Muschelkalk Folgen m1–m9 represent a basin wide chronological scheme that is more or less facies independent (HAGDORN & SIMON 2005 b). A high resolution biostratigraphic control of 14 ceratite biozones and 6 conodont biozones is correlated with the marker beds. Additional zonal schemes have been established by means of palynomorphs and invertebrate fossils (echinoderms, brachiopods, bivalves, ostracods) and by marine reptiles. Cyclostratigraphic and sequence stratigraphic analyses (AIGNER 1985, AIGNER & BACHMANN 1993) and geophysical data from drillholes (BRUNNER & SIMON 1985) provide further stratigraphical tools. However, all these methods do not allow sufficient stratigraphic correlation towards the clastic marginal facies devoid of fossils and with much reduced thickness.

Due to its position near the marine straits to the Tethys, the Muschelkalk of Southwest Germany is faunistically diverse and even yields episodical immigrants from the open Tethys. The earliest immigration via the East Carpathian Gate in early Anisian times reached Southwest Germany considerably later. In Pelsonian times the mayor immigration followed the Silesian-Moravian Gate. However, radiolarians, corals, Tethyan brachiopods and ammonoids give evidence for a periodic second marine connection via the Western Gate (BRAUN 1983, GISLER et al. 2007, SIMON et al. 2009). During Folge m4 to m6 (Middle Muschelkalk) the sea level dropped and caused a restriction of water exchange with the Tethys and subsequent evaporite deposition (anhydrite and halite). In late Illyrian times (basal Upper Muschelkalk) water exchange via the Burgundy Gate improved again and stenohaline faunas including echinoderms and ceratites immigrated from the Austroalpine faunal province (KOZUR 1974). From the late Folge 7b onward, the fauna of the Germanic Basin is more closely related to the West Mediterranean faunal province. Generally, the Upper Muschelkalk is most diverse in south-west Germany (URLICHS & MUNDLOS 1985, HAGDORN 1985, HAGDORN & SIMON 1993 a, URLICHS & KURZWEIL 1997).

Slower subsidence of southern Baden-Württemberg was responsible for increased bed thickness and dolomitic and bioclastic or clastic facies, while the faster subsiding Frankonian depression in northern Baden-Württemberg unit is in typical basin facies (AIGNER 1985, HAGDORN & OCKERT 1993). Along the margins of the Muschelkalk sea, accretions of marine clastics (Muschelsandstein) form a belt that reached parts of Baden-Württemberg. The Bithynian and Pelsonian Udelfangen Formation with clastics derived from Massif Central reached River Rhine with only one peak at the base of the Lower Muschelkalk, while the Eschenbach and Grafenwöhr Formations forming a belt along the Vindelician-Bohemian Massif are dominating the subsurface Muschelkalk in the East of the state. During Middle Muschelkalk, thin layers of eolian red dust from the Rhenish Massif can be traced over large parts of the area. Basinward, the clastic belts are followed by the dolomitic facies of the Lower Muschelkalk

Freudenstadt Formation and the Upper Muschelkalk Rottweil Formation (Figs. 10, 13). Above regional swells in more central positions of the South German part of the basin, the thickly bedded bioclastic and oolitic shoal sediments of the Crailsheim Member (Trochitenkalk Formation) and the Quaderkalk Formation were deposited. Towards the Kraichgau Depression, they grade into normal basinal facies of the Meißner Formation. Fully marine conditions were lasting until the end of the Muschelkalk time along the basin axis. However, during Upper Muschelkalk, it shifted from the Swabian Strait (in the Western Swabian paleotectonic depression) farther to the West into the Lotharingian Strait.
The Muschelkalk of the area has been interpreted in terms of cyclostratigraphy and sequence stratigraphy (e.g. AIGNER & BACHMANN 1993). The smallest units are transgressive/regressive minor cycles (parasequences) that are correlated with 100 ka orbital cycles. According to their number, the age of the Muschelkalk was estimated 6.4 Ma (MENNING et al. 2005) and 7.2 Ma respectively (KOZUR & BACHMANN 2008). In the view of AIGNER & BACHMANN (1993), the Muschelkalk comprises two systems tracts, with the base of the first situated at a "Rötquarzit Unconformity" as a Lowstand Systems Tract (LST), and the Maximum Flooding Surface (MFS) in the Terebratelbank Member of the Lower Muschelkalk (Folge m2b). The second systems tract commences in the Middle Muschelkalk salinar as LST (Heilbronn Formation, Folge m5) with the MFS enclosed between Tonhorizont 1 (alpha) and 3 (gamma) of the Meißner Formation (Folge m8) and the HST lasting until the end of the Muschelkalk (sequence boundary at Muschelkalk/Keuper boundary bonebed).

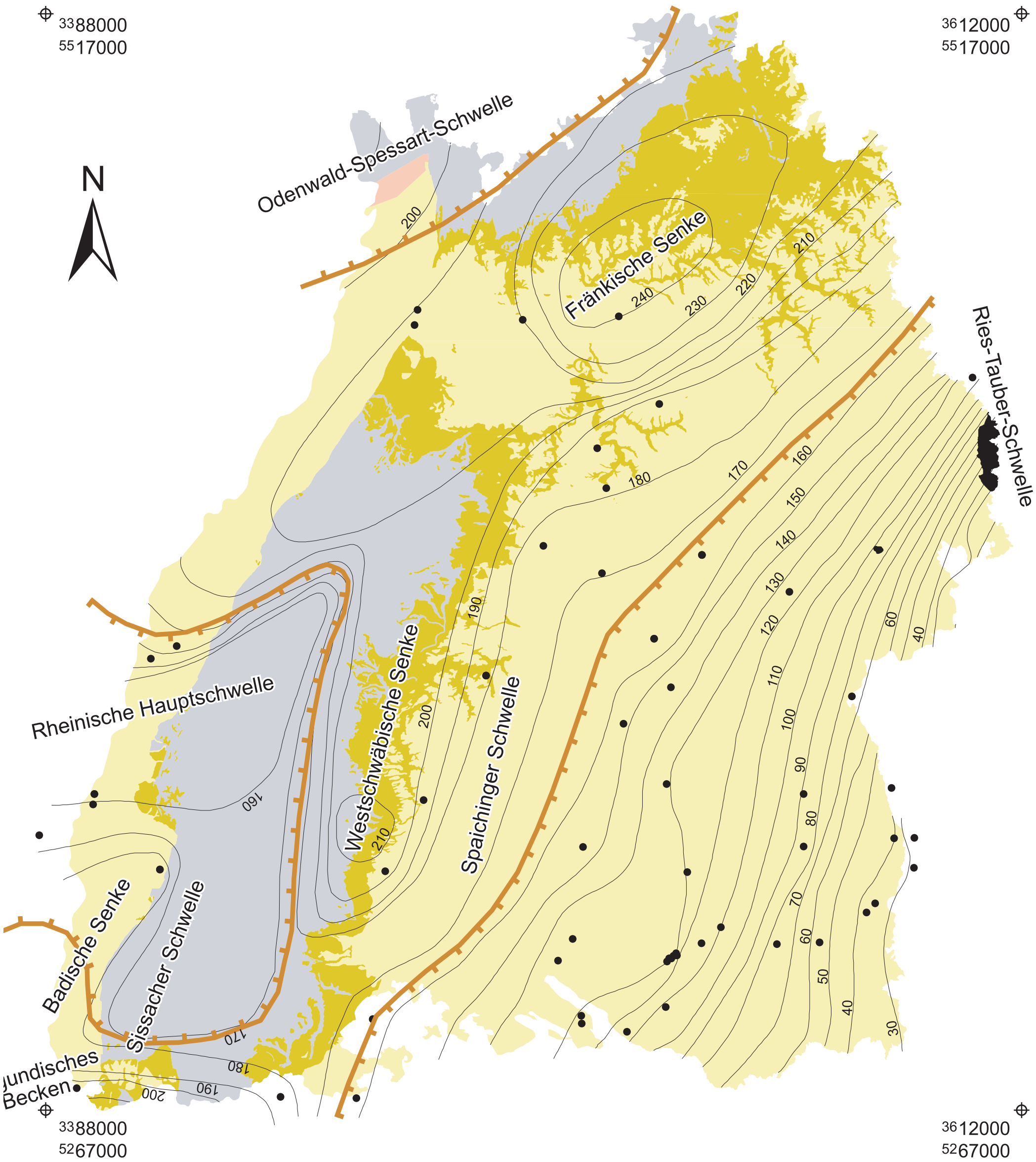


Fig. 8 Thickness map for the Muschelkalk Group in Baden-Württemberg, isopach lines at 10 m distance (from RUPF & NITSCH 2008).

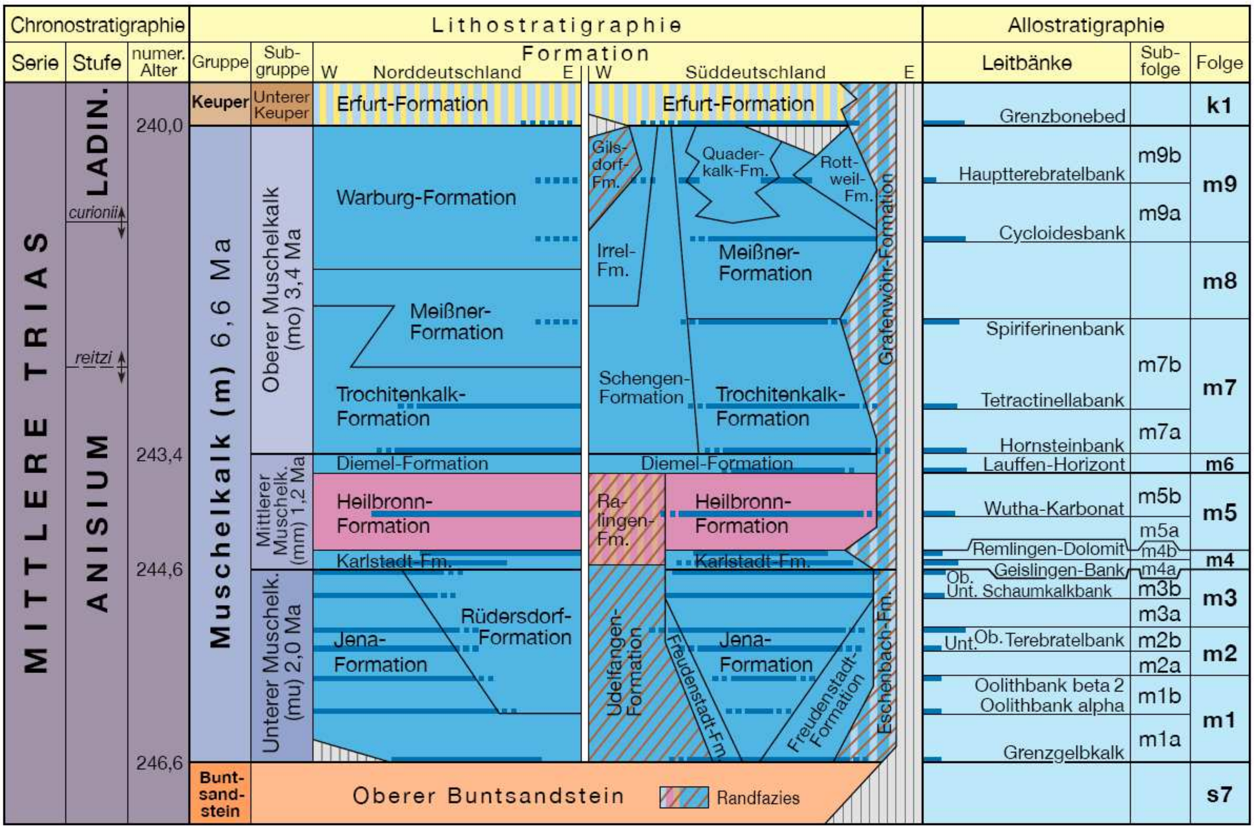


Fig. 9   Stratigraphic correlation chart of the Muschelkalk in Germany. From HAGDORN & SIMON 2005

The **Lower Muschelkalk** (mu) is up to 90 m thick in the North of Baden-Württemberg (Figs. 11) and wedges out in the clastic marginal facies that was drilled in the very Southeast (Allgäu). In the North, the Wellenkalk ("wavy limestone") facies of the Jena Formation covers the entire Lower Muschelkalk. Towards the South, its lower part is replaced by the dolomitic Freudenstadt Formation (Fig. 10). The **Jena Formation** is characterized by minor cycles of Wellenkalk with asymmetrical channels, slumping, debris flows, firmgrounds, hardgrounds, and tempestite shell beds, some of which are ecostratigraphic markers. The oolitic and/or shelly marker beds of the Schaumkalkbänke, the Terebratelbänke, and the Oolithbänke that can be traced almost over the entire basin make up the allostratigraphic frame of the Lower Muschelkalk. However, within Baden-Württemberg they are wedging out towards the South. Terebratelbänke and Schaumkalkbänke reach as far south as Freudenstadt. Typical soft ground faunal elements are the bivalves *Plagiostoma lineatum* with different epizoans, myophoriids, bakevelliids, small gastropods (*Omphaloptycha*), and trace fossils; hard and shelly ground fauna comprises encrinid and holocrinid crinoids, echinoids, the bivalve *Placunopsis* and the boring trace *Trypanites*. Among cephalopods, only *Beneckeia* and *Germanonautilus* are common, while the biostratigraphically important Tethyan *Noetlingites*, *Serpianites*, and *Discoptychites* are extremely rare. Vertebrates (mixosaurs, nothosaurs, actinopterygian fish) are also comparatively rare.
The **Freudenstadt Formation**, which is approx. 45 m thick in its type region, is dominated by brownish grey secondarily dolomitized marls with thin tempestitic shell beds (Stop 3). Its upper boundary is the transition to the limestones of the Jena Formation. In the Lower Muschelkalk column, this boundary is shifting upsection towards the South and covers the entire Lower Muschelkalk from the Northern Black Forest to the upper run of River Danube. Farther to the South, towards the Upper Rhine, it is shifting downsection and is overlain by Jena Formation again. The fauna is similar to that of the Jena Formation, however, single horizons with corals, Tethyan cephalopods and brachiopods and radiolarians give evidence for a periodic marine connection to the Neotethys via the western Alps (Alpenrhein Gate). Nowadays, the Freudenstadt Formation is poorly exposed since its marls are no longer used for brick production.
The lower boundary of the evaporite-dominated **Middle Muschelkalk** (mm) is at the top of the Upper Schaumkalkbank (Fig. 11). Its maximum thickness with original halite deposition is up to 100 m in the Western Swabian Depression and the Kraichgau. Towards the East, halite is grading into anhydrite and then into marlstones and dolomites, and finally into clastics (Fig. 10). In areas with complete

subsurface dissolution of salt and anhydrite, the overall thickness decreases to approx. 40 m. Widespread marker beds are the Geislingen Bed, the Zwischendolomit, and the Hornstein Bed (chert bed) at the top of the Subgroup. Sedimentary cycles indicate a duration of 1.2 Ma (MENNING et al. 2005), that would require a considerably higher subsidence rate (>80 m/Ma) compared to ca. 40 m/Ma for the Lower Muschelkalk or ca. 25 m/Ma for the Upper Muschelkalk. The 7-15 m thick **Karlstadt Formation** (former Orbicularismergel + Lower Dolomites) commences with Wellenkalk facies at its base that grade into evenly bedded, slightly bituminous limestones and dolomitic marls with shell pavements of the myophoriid bivalve *Neoschizodus orbicularis* and pachypleurosaurid marine reptiles. In the dolomitic facies of the Geislingen Bed, stromatolitic buildups (LLH) or laminar bacterial mats commonly occur. The **Heilbronn Formation** comprises the Middle Muschelkalk evaporite sequence sensu stricto (HANSCH & SIMON 2003), with cyclical precipitation of sulphate and up to 40 m of halite and finally again with sulphate. The economically important Muschelkalk rock salt is still mined today in Haigerloch-Stetten and in Heilbronn. The **Diemel Formation** comprises dolomitic marls deposited in huge marine sabkhas that covered wide areas of the Central European Basin. Oolitic beds in the uppermost part of the formation yielded well preserved and diverse invertebrate faunas and dasycladacean algae (HOHENSTEIN 1913).

The **Upper Muschelkalk** (mo) is developed in a carbonate-dominated facies in south-western Germany. The thickness reaches almost 100 m thickness in the Kraichgau Depression (Fig. 12), but generally decreases towards the Southeast, where the interbedded micrites, marlstones and thick bedded skeletal (oolitic, crinoidal, and shelly) limestones grade into dolomites and finally into siliciclastics. A subdivision of the Upper Muschelkalk based on marker beds was initiated by WAGNER (1913) and achieved its highest resolution in Southwest Germany (Fig. 9, 12). By recent work, many of the marker beds could be traced as far as Central Germany and Eastern France. These marker beds are characterized lithologically (e.g. Wellenkalke, Tonhorizonte) or by ecological marker fossils that indicate periodical immigration of Tethyan invertebrates, e.g., Tetractinellabank, Spiriferinabank, Reticulatabank, Holocrinusbank, Cycloidesbank, Hauptterebratelbank (HAGDORN & SIMON 1993a). Most of the Folgen-boundaries are fixed at these ecostratigraphical marker beds. Because 35 minor cycles have been identified, the duration of the Upper Muschelkalk is estimated to be 3.5 Ma. The Anisian/Ladinian boundary is situated close above the Cycloidesbank, and thus slightly above the maximum flooding surface. The **Trochitenkalk Formation**, up to 44 m thick, bears its name from the

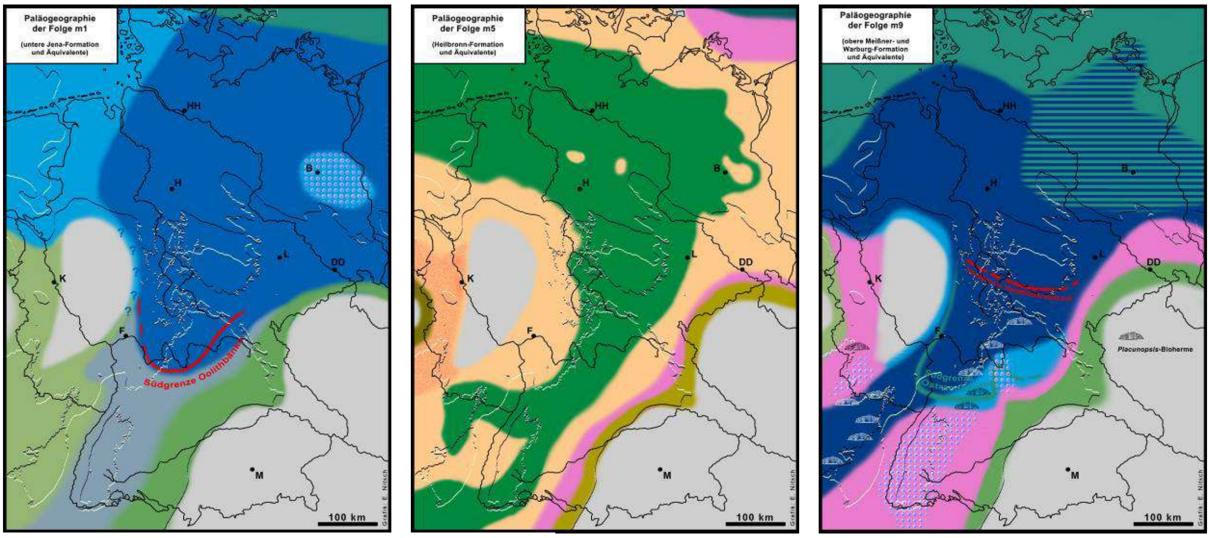


Fig. 10 Facies distribution maps for the Muschelkalk deposits of certain time intervals (HAGDORN et al., in prep.; all rights reserved).
Folge m1: Dark blue: Jena Fm., grey: Freudenstadt Fm., light green: Udelfangen Fm., dark green: Eschenbach Fm.
Folge m5: Green + light brown + pink: Heilbronn Fm., olive brown: Grafenwöhr Fm.
Folge m8. Dark blue: Meißner Fm. (light blue: Künzelsau Member), pink: Rottweil Fm., dotted: Oolite shoals with Quaderkalk Fm., dark green: Warburg Fm.

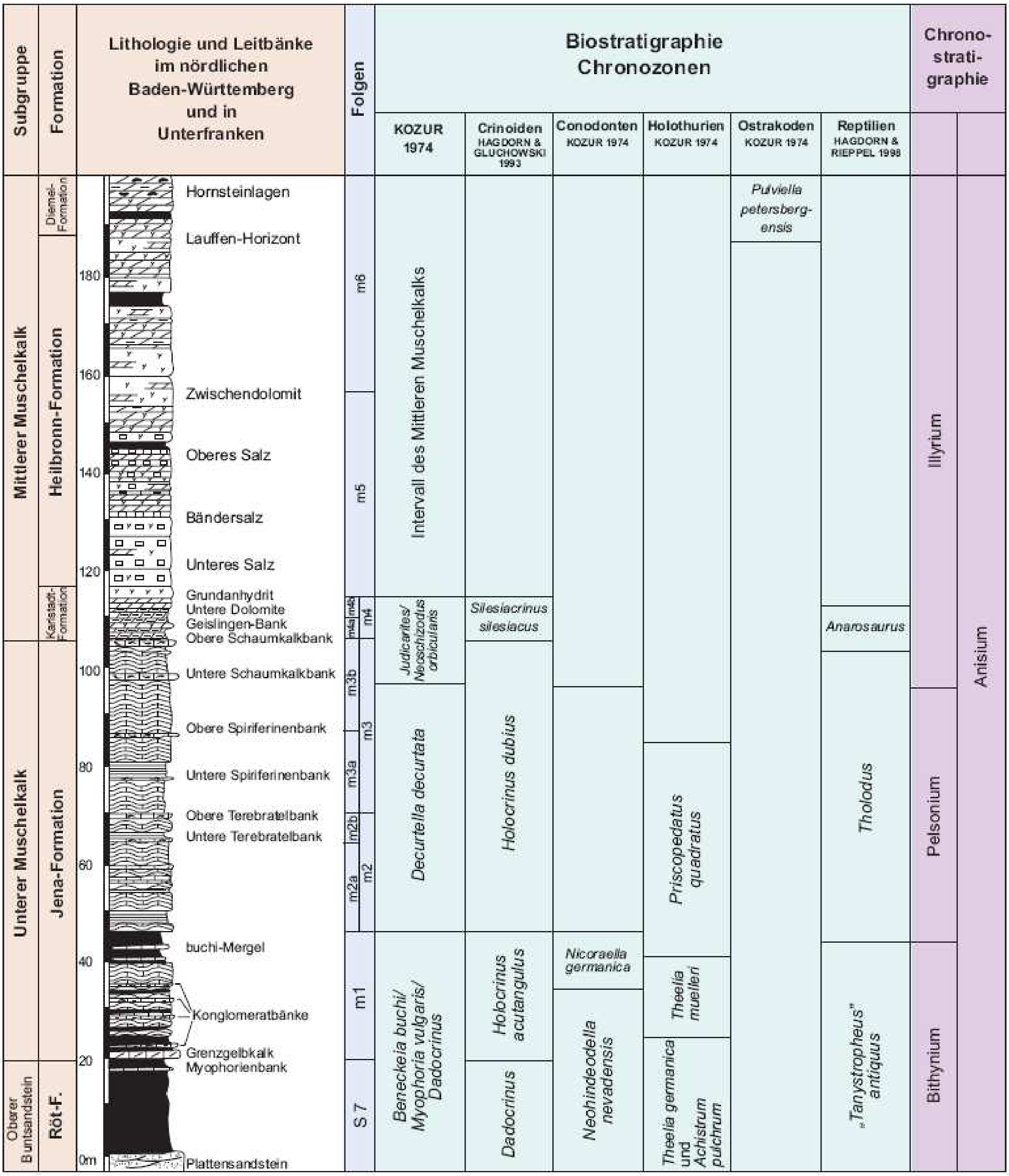


Fig. 11 Stratigraphic correlation chart and standard log of the Lower and Middle Muschelkalk in Southwest Germany. From HAGDORN 2004

cylindrical columnals of *Encrinus liliiformis*. It is characterized by thick bedded crinoidal limestones that may reach 16 m thickness in the Crailsheim Member (Stop 15). In the upper and the more basinal members, crinoidal limestone beds, the Trochitenbänke, are interbedded with micritic and skeletal limestones. Lensoid crinoid-terquemiid bioherms with in-situ clusters of crinoid holdfasts incrusting oyster-like terquemiid bivalves occur in the Crailheim and more basinal Hassmersheim Members (HAGDORN 1978, HAGDORN & OCKERT 1993). In the upsection Neckarwestheim and Bauland Members, soft bottom paleocommunities are dominating. At the top of the latter member the Spiriferinabank, named after the Tethyan immigrant *Punctospirella* (former *Spiriferina*) *fragilis*, holds the last occurrence of *Encrinus liliiformis.* In Southwest Baden-Württemberg, thick oolite bodies within the Trochitenkalk Formation represent further regional members.

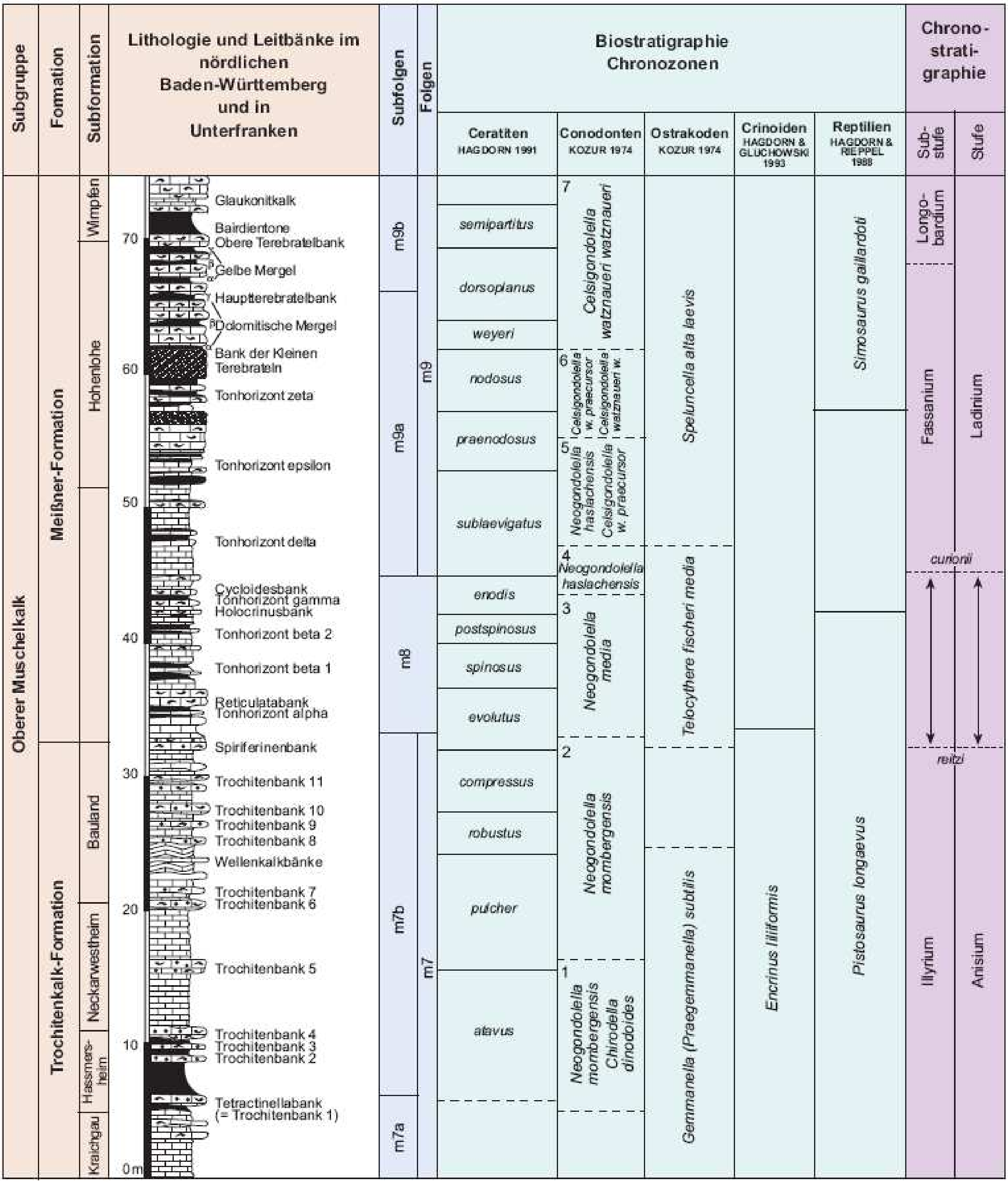


Fig. 12 Stratigraphic correlation chart of the Upper Muschelkalk. Now the Anisian/Ladinian boundary is fixed at the base of the *curionii* Biozone. From HAGDORN 2004

The up to 55 m thick **Meißner Formation** is defined by thinly bedded marlstone-limestone-tempestite intercalations (Tonplatten facies) that contain shell pavements with abundant soft bottom paleo-assemblages and cephalopods. In South-West Germany, shallowing upward cycles dominate the facies architecture of the Meißner Formation (Stop 9). Towards the North (Franconia) the clay content is increasing and deepening-up cycles become dominant. Important marker beds are the Tonhorizonte 1–6 (formerly alpha to zeta), the Holocrinusbank, the Cycloidesbank, the Hauptterebratelbank and the Upper Terebratelbank. In Northeast Baden-Württemberg bed thickness increases above Tonhorizont 4 (delta; Künzelsau Member), indicating gradual transition into the Quaderkalk Formation.

Towards the South and Southeast, the upper part of the formation is grading into the dolomites of the **Rottweil Formation** (traditionally called Trigonodusdolomit, named after the bivalve *Trigonodus sandbergeri*). The light grey to yellowish brown (if weathered), often cavernous dolomite and dolomitic limestone beds are interbedded with thin marl layers of constant thickness in 2–2.5 m thick minor cycles. Oolites, algal laminites, mudcracks and tepees indicate lagoonal and intertidal depositional

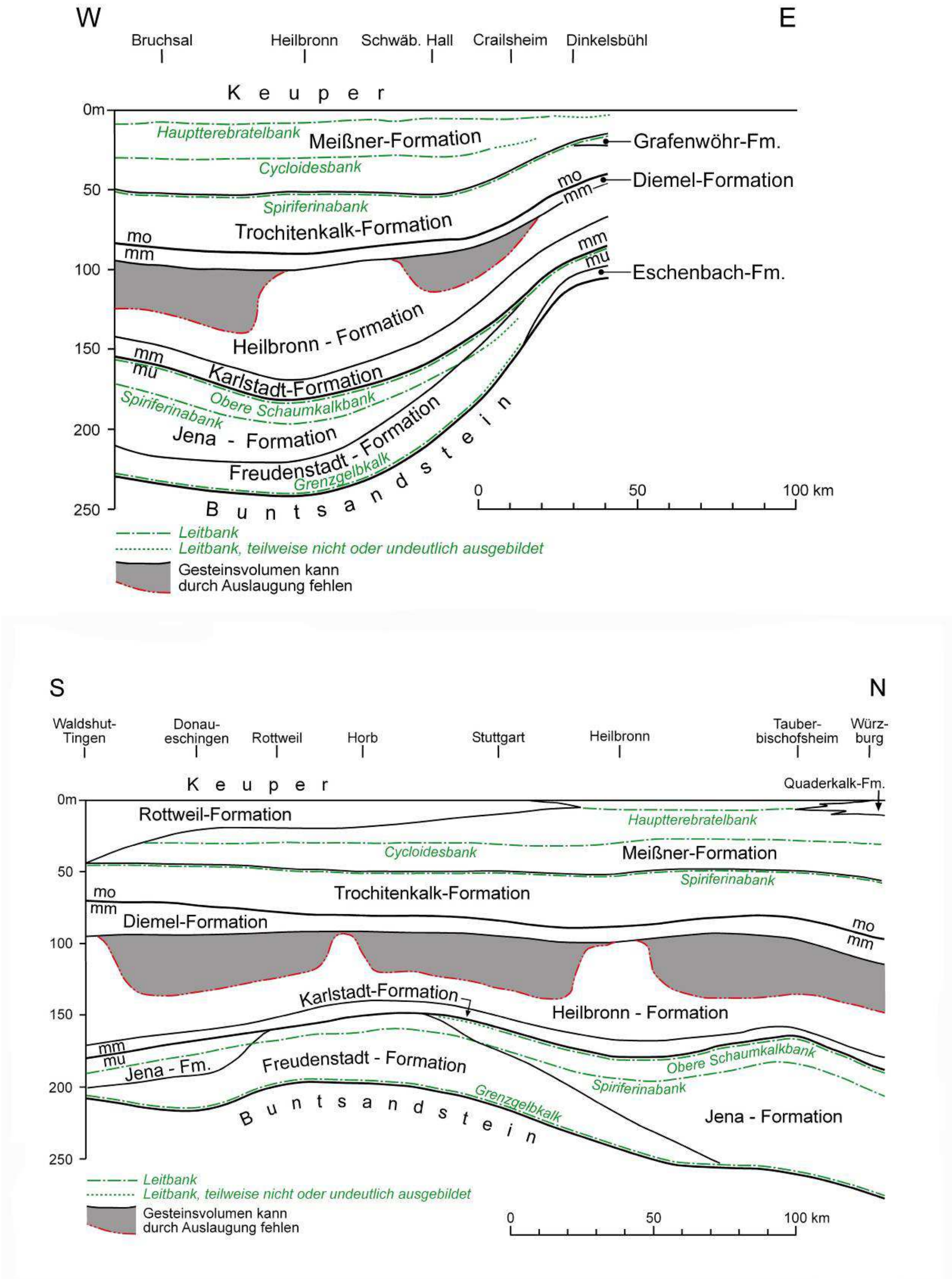


Fig. 13 Lithostratigraphic sections of the Muschelkalk in Baden-Württemberg (diagram: LGRB/Simon). Note the marker beds that may be facies independent and are used for stratigraphic correlation

environments (Stop 4). Towards the South, the lower boundary of the Rottweil Formation is shifting downsection (ALESI 1984). Thus, the Rottweil Formation reaches up to 50 m at the German-Swiss border. To the East, in the subsurface of the Swabian Alb and Molasse Basin, siliciclastics of the Grafenwöhr Formation indicate the nearby basin margin. Typical fossils are the euryhaline myophoriid *Costatoria goldfussi*, *Trigonodus sandbergeri*, and the gastropod *Promathildia ornata*. In Northern Baden-Württemberg and Lower Franconia (Bavaria), the thick bedded, cross stratified skeletal and oolitic limestones of the **Quaderkalk-Formation** were deposited as regional shallow water shoal sediments (BRAUN 2003, HAGDORN & AIGNER 2005). The paleogeographic position of this shoal was tied to the Ries-Tauber Swell (also called Gammesfeld Swell), a paleotectonic high present since Carboniferous times and still visible in structural maps today (RUPF & NITSCH 2008). The Quaderkalk shoal was an approximately 60 km long and 30 km wide shallow-water region expanding from eastern Hohenlohe towards the River Main, with the shoal centre shifting northwards upsection (Fig. 10, Stop 10). The maximum thickness of 20 m is between Ochsenfurt and Rothenburg ob der Tauber (GEISLER 1939, BRAUN 2003). Some of the Quaderkalk beds are interfingering southward into the Künzelsau Member of the Meißner Formation, e. g., the Künzelsau Kornstein. The Haupterebratelbank and the Obere Terebratelbank can be followed as marker beds well into the centre of the Quaderkalk shoal. These up to 2 m thick beds are cut and polished by several companies around Kirchheim (Franconia) and distributed worldwide. The skeletal beds have considerable potential reservoir qualitiy and their size and shape can be compared to actual hydrocarbon reservoirs in the Middle East (BRAUN 2003). The up to 4 m thick Wimpfen Member (former Fränkische Grenzschichten) at the top of the Meißner Formation is expanding over the Quaderkalk Formation. A rich ostracod fauna and a lack of stenohaline faunal elements indicate progradation of the brackish Muschelkalk facies of the Warburg Formation from the North. As shown in the facies maps (Fig. 10) and the N-S and W-E sections of the Southwest German Muschelkalk (Fig. 13), the facies belts of the Muschelkalk sea generally followed the basin margins.

Keuper

The Keuper Group has a maximum thickness of 400 to 420 m in the Frankonian depression of northern Baden-Württemberg. Towards the South and Southwest, the thickness diminishes to less than 100 m in the Allgäu area (Fig. 14). Most of the total thickness is taken up by the variegated and mainly nonmarine deposits of the Middle Keuper. The thickness of the Lower Keuper, made up of predominantly grey sediments of mixed marine to nonmarine facies, hardly exceeds 30 m in the north, and less than 2 m in the Hochrhein region east of Basel. The also predominantly grey to green Upper Keuper locally reaches a thickness of 16 to 20 m, but commonly is less than 10 m thick. In many places it is missing beneath an unconformity at the base of the Jurassic.
The term “Keuper” is derived from the Frankonian dialect, a word denoting the crumbling debris into which the red and green dolomitic Keuper claystones typically disintegrate (NITSCH 2005c). These claystones make up about 50 to 60 percent of the Keuper Group (in northern Germany even more) and are interbedded with sandstones, evaporites, and thin beds of dolomite or, more rarely, limestone (Fig. 15). Evaporites mainly are represented by anhydrite (diagenetically altered primary gypsum), recrystallized to secondary gypsum near the present surface. Halite is common in the pore space of the sulphate rocks, and even a local thin layer of halite has been exploited in the Kraichgau area in the 19th Century. Thick deposits of rock salt are present in the north German and Polish depocentres of the Basin as well as in the Burgundy trough to the Southwest and in the Paris basin to the West of Southern Germany. Subordinate amounts of coal, especially in the late Ladinian Lower Keuper (“Gruppe der Lettenkohle”: ALBERTI 1834), were some of the first documents of peat-forming ecosystems after the world-wide “coal gap” following the end-Permian mass extinction (KELBER & NITSCH 2005).
The environments of deposition were as variable as the petrographic composition and the colours of this group (BEUTLER et al. 1999, DSK 2005; Fig. 16, 17). There still were some marine incursions in southern Germany in Late Ladinian to Carnian times, and they left metre-scale grey horizons made up of thin-bedded claystones and decimetre-thick dolomite beds, traceable for hundreds of kilometres across the basin. Some gypsum beds associated with those “ingression-layers” can be attributed to a marginal marine environmental setting. But even within these “ingression-layers”, most of the fossils found are indicative of restricted marine to brackish-water environments. Yet, bedding planes with nonmarine fossils also occur, and locally paleosols developed. These “ingression-layers” alternate up-section with nonmarine redbeds and evaporites and finally cease to interrupt their succession during the Norian. Nonmarine environments changed significantly, however, between saline lake and freshwater settings, including thin-bedded saline lake sediments, playa mudstones with strong pedogenic alteration, brackish to freshwater mudstones and dolomites, containing anthracosiid and

early unionid bivalves, sheetflood and channelized alluvial to fluvial sandstones with associated overbank fines, muddy coals, and hardpan pedocretes. As these deposits crop out in one of the most densely populated regions of Europe, the Keuper Group became famous since early in the 19th Century for its sparse but impressive fossils of early dinosaurs (e.g., dozens of complete *Plateosaurus* skeletons), other huge reptiles, the worlds oldest known turtles, the largest amphibian of earth history (*Mastodonsaurus giganteum*), and some of the earliest known mammals – highlights that put into shadow other interesting fossils, like the giant horsetails of *Equisetites arenaceus*, some of the earliest unionid bivalves, and other specialities of primarily scientific interest (DSK 2005).

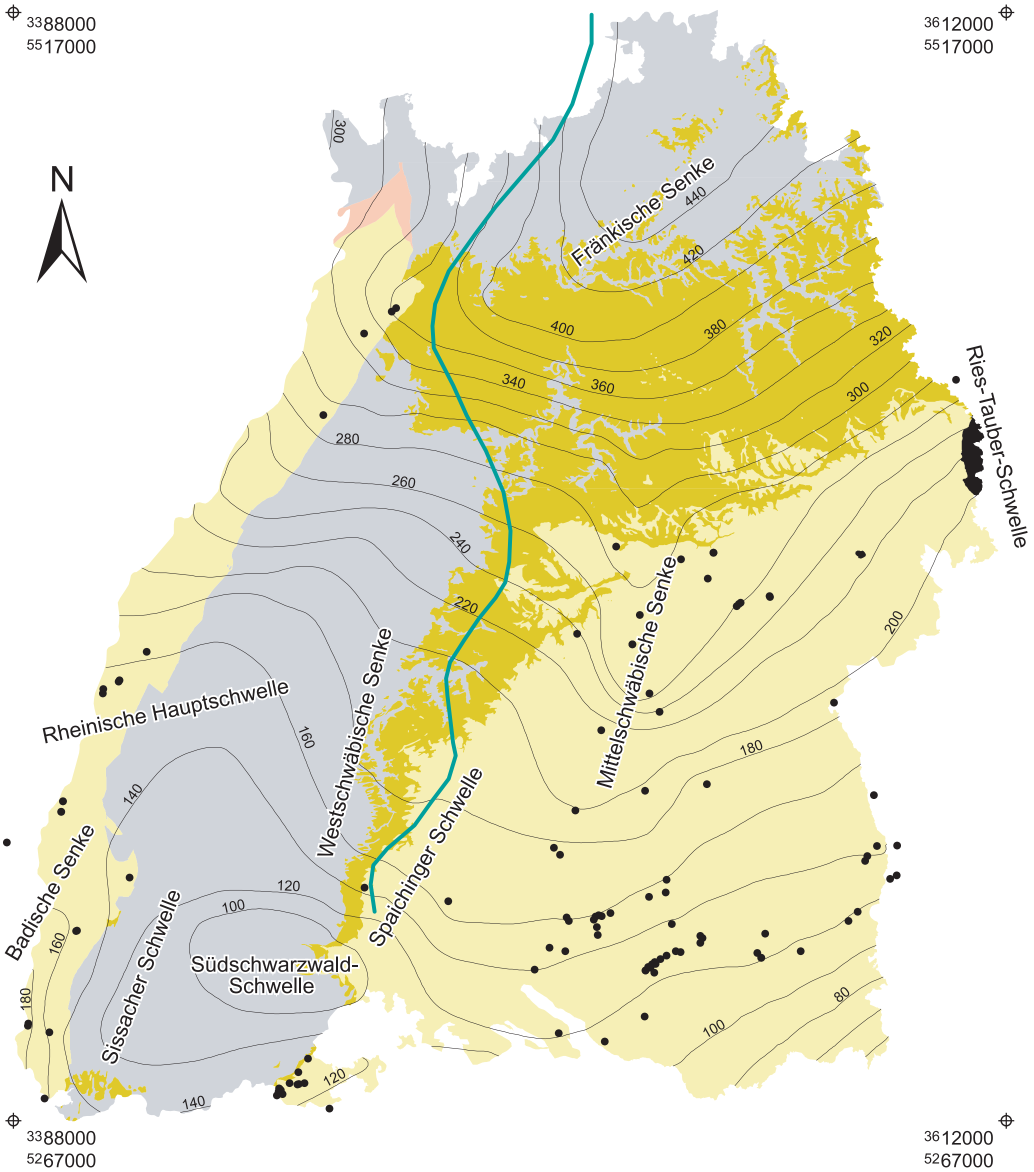


Fig. 14 Thickness map for the Keuper Group in Baden-Württemberg, isopach lines at 20 m distance (from RUPF & NITSCH 2008). The coloured line is the western limit of Kieselsandstein deposition (Hassberge Formation), an alluvial deposit shed from the Southeast.

There is some marked cyclicity in the sequence of facies throughout the Keuper, developed at different scales from depositional auto- and allocycles a few decimetres or even centimetres thick to significant stacking patterns of repetitive facies changes at a frequency of a few tens of metres. The latter has repeatedly been interpreted to reflect some climatic control, and attributed to almost any of the 50 ka to 400 ka Milankovich frequency bands in the literature (see DSK 2005 for discussion and references). Since biostratigraphic control still is quite poor and there are, at present, no radiometric or paleomagnetic data to use, none of these assumptions had so far any chance to be proved. Anyway,

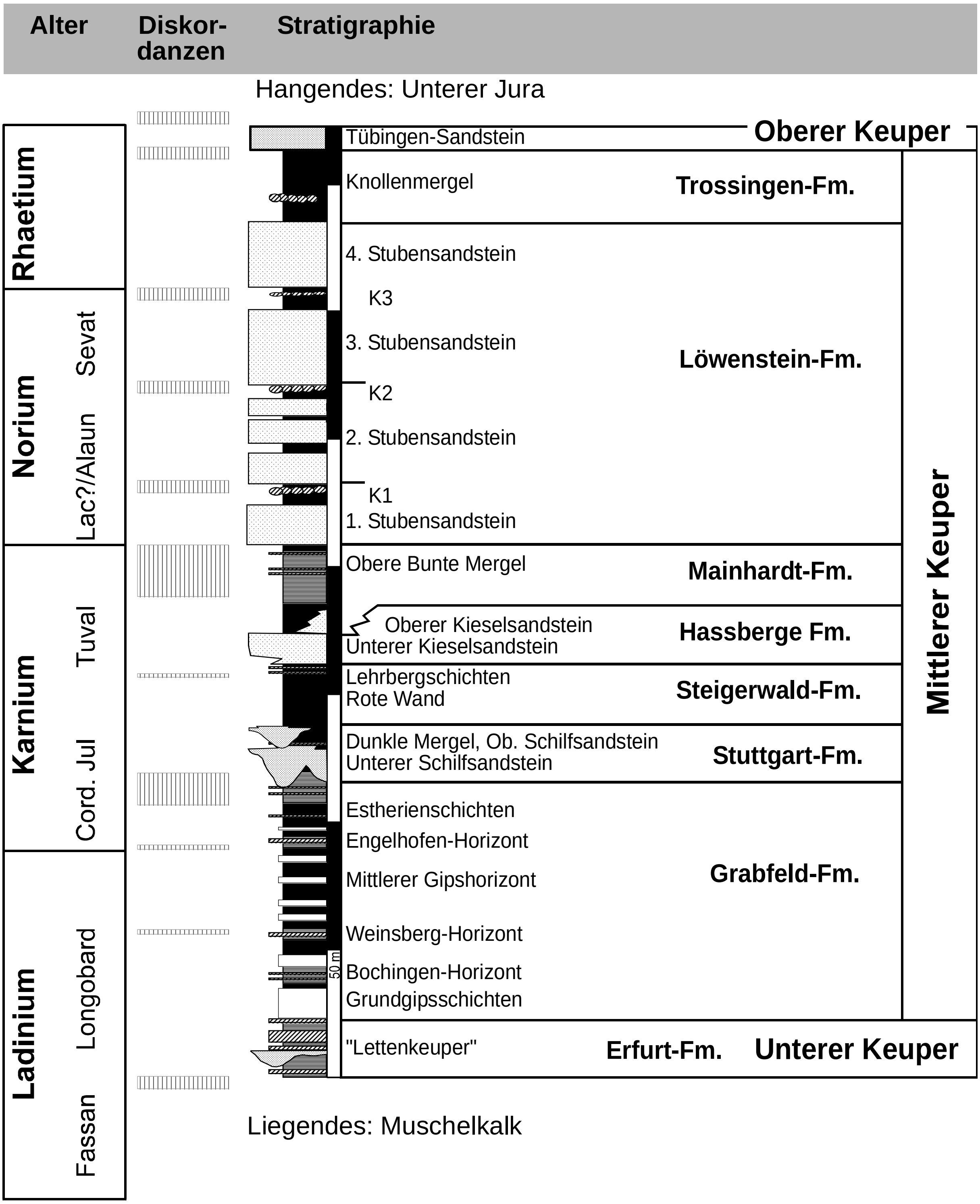


Fig. 15 Generalized sketch of the Keuper Group in Baden-Württemberg. Thicknesses refer to the northern part of the outcrop area (modified from NITSCH 2005b).

they can be used to obtain some maximum values for the time spans documented by sedimentary deposits. Such estimates, although slightly different in detail, strongly indicate that only about half of the time of the Late Triassic is represented by the sediments of the Keuper section – glimpses of rock record scattered over late Triassic time (NITSCH et al. 2005a). The hiatuses can be identified within the sections with some basin-wide unconformities (mainly developed upon paleotectonic swells; BEUTLER in DSK 2005) and by highly mature paleosol horizons (NITSCH 2005b, NITSCH et al. 2005). Typically there are significant biostratigraphic boundaries found between the deposits below and above these hiatuses, i. e., within them (KOZUR 1998, KOZUR & BACHMANN 2008; Figs. 15 and 5).

The **Lower Keuper** has a thickness of about 18 to 20 m in the Tübingen area and 26 to 30 m in the region of Ingelfingen and Crailsheim. Most of this subgroup is represented by only one formation, the **Erfurt Formation**, including the central facies zone of the basin. This formation is made up of eight to ten cyclothems of fluvial to deltaic, locally estuarine fine to medium grained sandstones, siltstones, and mudstones, grading up to freshwater and brackish-water claystones and brackish to marine “ingression layers”. Within the fluviodeltaic part of these cyclothems, or at the transition to the open-water deposits, local peat formation left to centimetre to decimetre thick muddy coals or coaly mudstones, the “Lettenkohle”, after which ALBERTI (1834) originally named this succession (NITSCH 2005c). Ingressions came from the Southwest, through the Burgundy Gate already of importance for Muschelkalk deposition, but clastic input predominantly came from the north. A Scandinavian provenance has been proposed for most of the sand, based on paleocurrent information and dating of detrital mica and zircon grains (PAUL et al. 2008). In south-western Germany, open-water mudstones and brackish-marine dolomite “ingression layers” predominate the section, but deltaic to prodeltaic sandstone deposits are present at seven levels in northern Baden-Württemberg. Two of them are still detectable near Tübingen, but all wedge out to the South, so none of them crosses the Rhine river to encounter Switzerland. Evaporites are present as gypcrete nodules developed in the dolomite beds. They grow increasingly important towards the top of the Erfurt Formation, especially in southern Baden-Württemberg, where also bedded sulphate rocks were deposited at different stratigraphic levels within this formation.
The **Middle Keuper** has a thickness of about 200 m near Tübingen, but more than 300 m in parts of northern Baden-Württemberg. This subgroup shows the most complex facies patterns of the Germanic Triassic and is divided into ten formations, eight of which are present in south-western Germany (Figs. 15, 16). The lowermost of these is the **Grabfeld Formation**, also known as “Gipskeuper” in south-western Germany (or as “Unterer Gipskeuper” in eastern and northern Germany). Its Lower and Middle Members have been dated to be late Ladinian in age, but its Upper Member already bears some Early Carnian fossils (DSK 2005, KOZUR & BACHMANN 2008). Up to 45 percent of sulphate rocks make this formation the most important resource for gypsum (and anhydrite) in southern Germany. The sulphate rocks accumulated in different primary gypsum facies, visible as pseudomorphs even in the anhydrite and secondary gypsum diagenetic products. They range from bedded selenite deposits to rippled gypsarenites, gypsum clast breccias and pedogenic gypcrete nodules. The sedimentary environment was partly marginal marine in the Lower Member – as evidenced from intercalated peritidal dolomite beds with some restricted marine fauna in the Grundgips, Bochingen, and

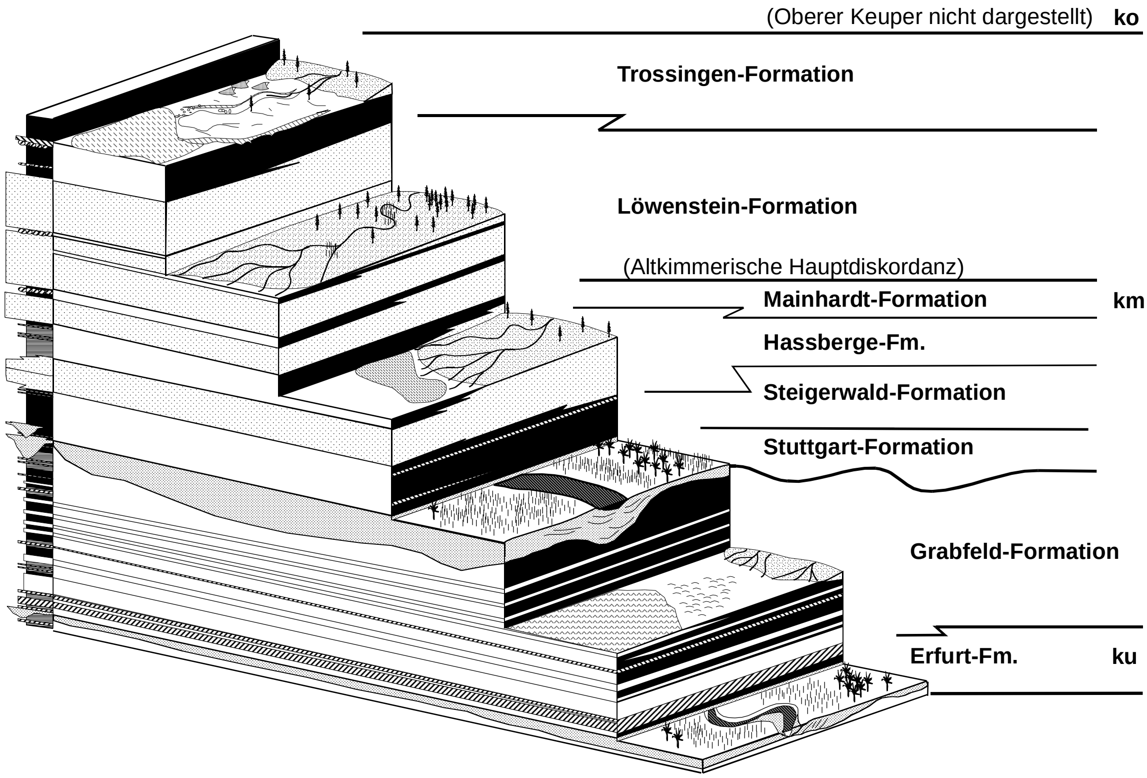


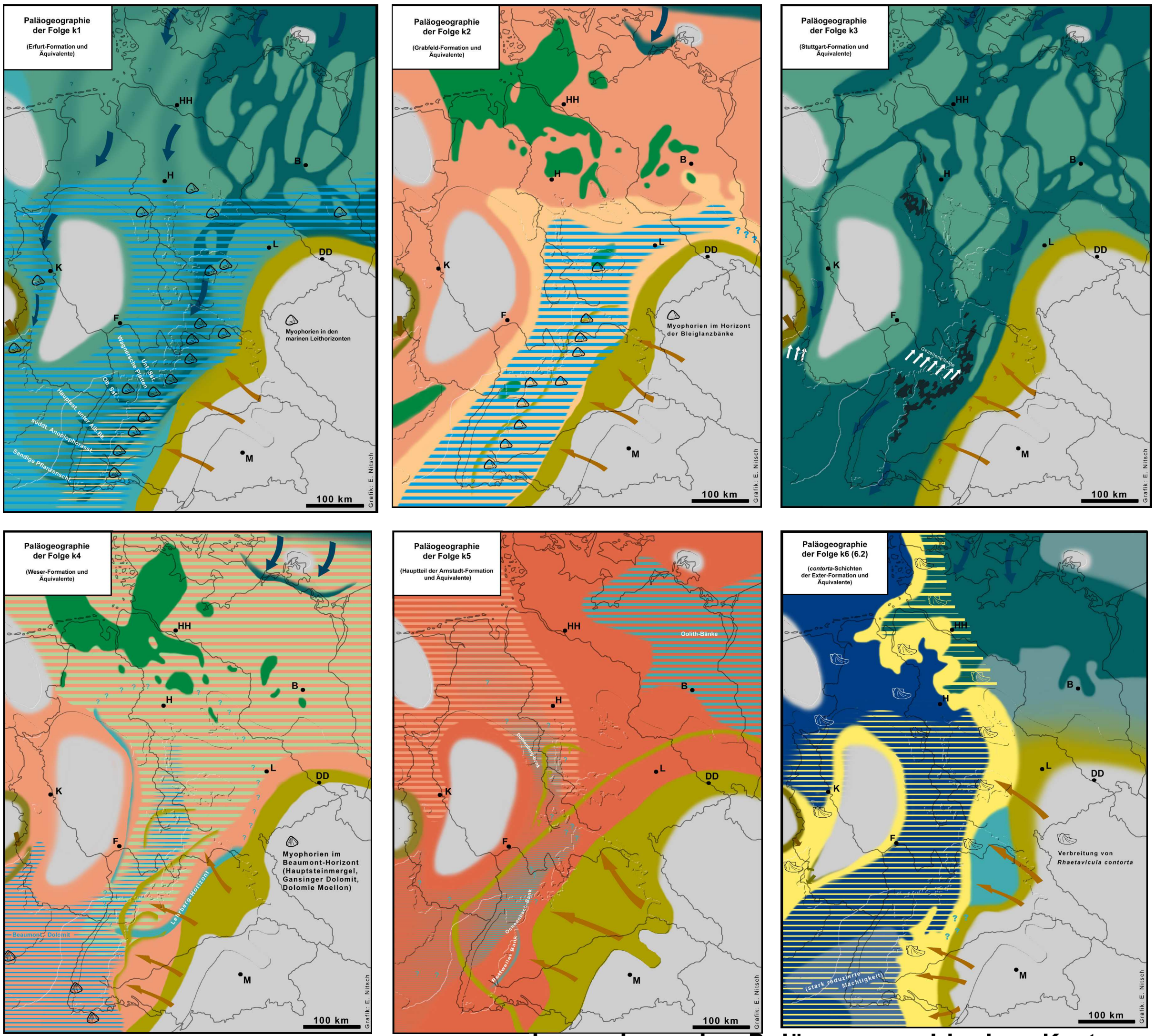
Fig. 16 Sketch diagram of environmental evolution and facies distribution of the Keuper Group in southern Germany (from Kelber & Nitsch 2005).

Weinsberg Horizons –, but mainly nonmarine during deposition of the Middle and Upper Member of the Grabfeld Formation, where they represent the gypsum zone of a “bulls eye” facies pattern, the halite zone being restricted to the intrabasinal depocentres (Lorraine, Kraichgau, Thuringia, several places in northern Germany and Poland; Fig. 17).

The Grabfeld Formation shows some distinct cyclicity in its facies succession that is most clearly visible in its mudstone facies (NITSCH et al 2005b, DSK 2005). Grey thin-bedded dolomitic claystones in the lower part of the cycles typically are associated with marine peritidal, brackish-water or nonmarine fossiliferous dolomite beds and bedded sulphate rocks. Upsection they are replaced by pedogenetically altered claystones or marls (gypsiferous vertisols), associated with enterolithic and nodular sulphate rocks and typically, aside some rare and local conchostrakan finds, prone of fossils. These cycles are normally 5 to 15 m thick and have been attributed to climate cycles of possibly 100 or 400 ka duration, depending on the author of the estimate (DSK 2005). Possibly, however, they do not reflect single Milankovich frequency band, but were controlled by a more irregular pattern of climate change caused by the superposition of several frequencies, being thus of different durations within a similar time range.

The **Stuttgart Formation**, named after the capital of Baden-Württemberg, has been dated into the Julian substage of the Carnian stage (DSK 2005, KOZUR & BACHMANN 2008). The formation almost completely consists of mudstones and sandstones, the latter renown as “Schilfsandstein” (reed sandstone), since early in the 19th Century the common fossil shoots of horsetails (*Equisetites arenaceus*) have been mistaken for reed (NITSCH 2008). The provenance area of the sandstones, that petrographically closely resemble those of the Erfurt Formation, has also been detected to be Scandinavia by caledonian radiometric ages of detrital mica (PAUL et al. 2008). The lithostratigraphic subdivision of this formation is tripartite, referring to a threefold repetition of erosion-accumulation-cycles. The lowermost of these cycles is known as Osterhagen Horizon or “Thürachs Übergangsschichten”, a thin succession of muddy sediment with only thin sandstone sheets, resting on a seemingly flat but erosive unconformity on top of the Grabfeld Formation. It is best developed in northern Germany and parts of Poland, where there seem to be some marine influences (KOZUR, pers. comm.), but is also locally present in southern Germany. In most sections of south Germany, however, this lower unit has been removed where the erosive phase of the second cycle created a paleorelief of incised valleys that have been cut down 5 to 30 m into the sediments of the upper Grabfeld Formation (DITTRICH 1989). After incision, these valleys have been filled up with the Lower Schilfsandstein Member. Named “Sandstein-Stränge” or “Flutfazies” in the older literature, this member consists of fluvial channel sands, levee deposits, crevasse splays and overbank fines, locally associated with minor seams of muddy coal. In places pond and lake sediments are present, containing freshwater bivalves (*Unio equisetitis*), proving a nonmarine depositional system. Yet, some of the channel sediments show regular changes in current velocity that have been attributed to tidal influence (GEHRMANN & AIGNER 2002), hundreds of kilometres upstream of the mouth of river system that is indicated by middle Carnian „Lettenkeuper“ facies deposits near Lyon in southern France. The fluvial deposits grade upward into lacustrine mudstones and dolomite beds of the Gaildorf Horizon. The Upper Schilfsandstein Member again is made up of fluvial and fluviolacustrine sandstones and mudstones. Its basal erosive unconformity has less relief, however, than that of the Lower Schilfsandstein, and rarely removed the Gaildorf Horizon completely. towards its top, it grades into dark purple to reddish sandy mudstones named “Dunkle Mergel”, superseded by the marine “ingression layer” of the Beaumont Horizon at the base of the Steigerwald or Weser Formation, respectively.

The Late Carnian is represented by different formations in south-western Germany, reflecting the facies changes from a completely muddy to evaporitic playa facies in the more central parts of the basin – the **Weser Formation** – to an alluvial sandstone facies in more marginal settings – the **Hassberge Formation**. Both facies belts interfinger with each other in a transitional facies belt about 100 km wide. To avoid repetition of one formation name along a single section below and above the Hassberge Formation, the equivalents of the lower Weser Formation within the transition belt were formally named **Steigerwald Formation**, those of the Upper Weser Formation are called **Mainhardt Formation** (BACHMANN et al. 1999, DSK 2005). The basal unit common of the Steigerwald and Lower Weser Formations is a marine “ingression layer”, named Beaumont Horizon after L. ELIE DE BEAUMONT, who was the first to recognize it in NW France early in the 1830´s. This horizon consists of marine fossiliferous dolomite beds in northern Switzerland, the northernmost fossils found near Freiburg i. Br. and in the western Vosges mountains. Towards the Northeast and North, these carbonate deposits are more and more replaced by bedded and nodular sulphate rocks and dark mudstones. The rest of the Lower Weser and Steigerwald Formations is made of massive to very poorly bedded brick-red mudstones of the Rote Wand Member (formerly constituting a “red wall” above the Schilfsandstein quarries). This member comprises a playa facies of stacked vertisols widespread throughout the basin. In the northern part of southern Germany and parts of northern



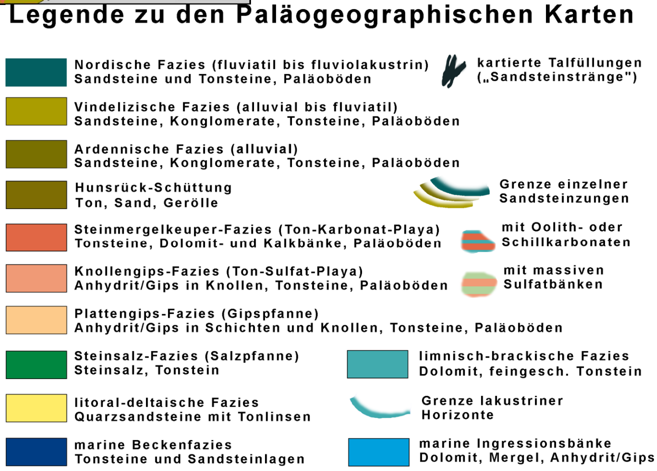


Fig. 17 Facies distribution maps for the Keuper deposits of certain time intervals (from DSK 2005).

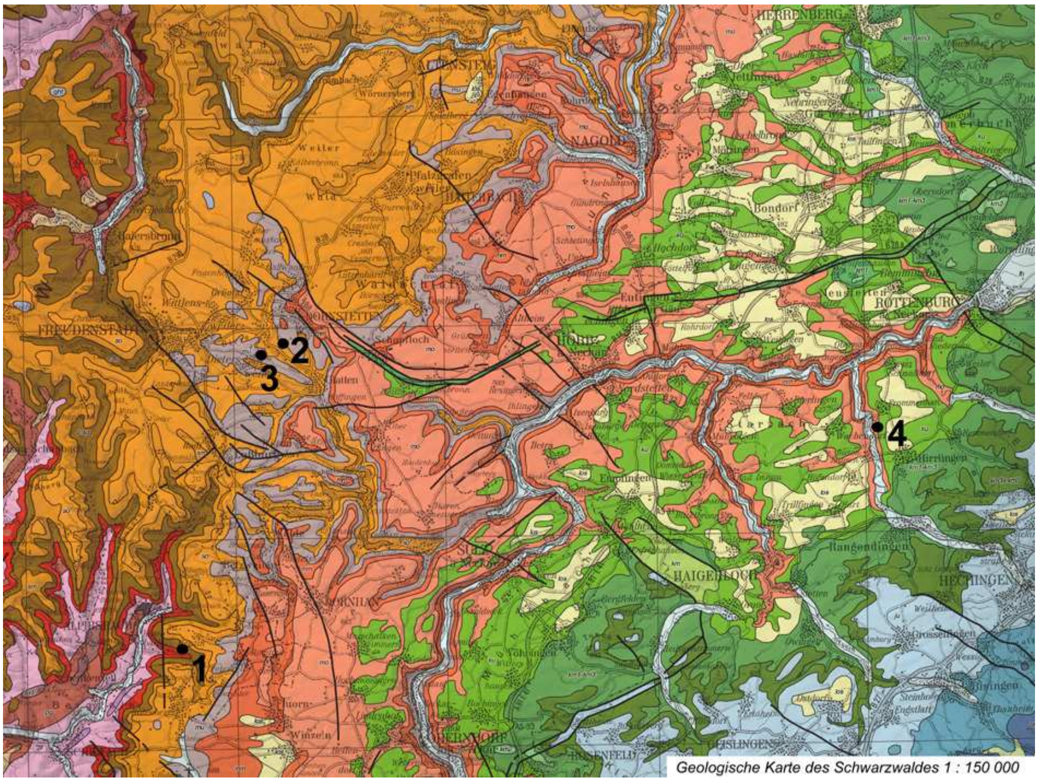
Germany, the Rote Wand is topped by three lacustrine dolomite beds, called the Lehrberg Beds or the Lehrberg Horizon, that wedge out south of Stuttgart. From southeast to northwest, prograding alluvial sandstones of the Hassberge Formation supersede this lacustrine horizon. Their distribution, however, is mainly restricted to the regions east of river Neckar. Their upper portion shows retrograding architecture, being successively replaced by playa mudstones and lacustrine to pedogenic carbonates of the Mainhardt Formation. Evaporites are most important in the more distal parts of the playa system, represented by the Upper Weser Formation beyond the reaches of the Hassberge Formation sandstones, but present as gypcrete nodules even in some levels of the Mainhardt type locality in northern Baden-Württemberg. On paleotectonic swells, Weser and Mainhardt Formations have been truncated below the Early Kimmerian Unconformity. In places near the Swiss border, less than 5 m of Steigerwald Formation is left below this most important Late Triassic unconformity and the Norian sediments above.

These Norian sediments are alluvial to fluvial sandstones cyclically alternating with fluvial to playa mudstones, attributed to the **Löwenstein Formation**. According to KOZUR & BACHMANN (2008) the uppermost of the sandstone-mudstone cycles, called 4. Stubensandstein, is already of early Rhaetian age. The term Stubensandstein ("room sandstone") is derived from using the sand of the more friable sandstones to support the broom in sweeping wooden floors. Firmly cemented sandstones, however, have long been used as ashlar sandstone and have also been known early in the 19th Century as "Löwensteiner Sandstein" after a town 30 km north of Stuttgart. The sandstones of this formation are mainly of coarse grain size and locally bear some small pebbles. They represent stacked braided to meandering channel fills up to ten meters thick and sometimes more than 100 m wide (HORNUNG 1999). Tree logs, local root traces, and a fauna of dinosaurs, phytosaurs, pseudosuchians, turtles, freshwater fish and unionid bivalves confirm a strictly nonmarine origin of these beds. They have a south-easterly provenance in the Vindelician Highland, now hidden below the Cenozoic subalpine Molasse Basin, and were shed into the basin to a distance of more than 200 km well into northern Alsace (France) and Thuringia (DSK 2005). For at least seven times, these coarse sandstones cyclically grade upward into red sandy mudstones with only minor sandstone intercalations, but mostly also filling small channels. HORNUNG (1999) interpreted these cycles as climatically induced changes between bed load and suspended load dominated river systems, more distally grading into playa mudstones with carbonate beds and pedocretes. These cycles, however, seemingly do not represent a continuous stack of facies fluctuations. Highly mature pedocretes at the cycle boundaries, commonly of complex architecture due to repeated reworking and re-cementation, are evidence of hiatuses between the individual cycles of at least several hundrets of thousands, possibly several millions of years (NITSCH et al. 2005a).

The topmost unit of the Middle Keuper is the **Trossingen Formation**, notorious for the slippery behaviour of its smectitic claystones when growing wet, giving rise to expensive landslide hazards. These red-brown to purple claystones, traditionally named Knollenmergel in Baden-Württemberg and Feuerletten in Bavaria, are an up to 30 m, locally up to 50 m thick poorly bedded stack of playa facies vertisols. Some layering is visible due to dolocrete and calcrete nodules or local massive hardpan calcrete. More rarely, thin layers of sand or purple mudstone still outline depositional surfaces, indicating as variable land surfaces in the depositional area as playa flats, small muddy channels, and possibly some gilgai relief. Some of these layers preserved from the intense peloturbation of the rest of the formation even delivered some fossils of quite diverse scales – millimetre-scale darwinulid ostracods as well as herds of 12-m-dinosaurs. Near the town of Trossingen, about 60 km SE of Tübingen and the most famous fossil excavation site within this formation, 55 skeletons of *Plateosaurus engelhardti* have been recovered, associated by some turtles. The Trossingen Formation has long been attributed to the latest Norian, but more recently an early Rhaetian age has been proposed based on its vertebrate fauna (KOZUR & BACHMANN 2008).

The **Upper Keuper** is not preserved everywhere in south-western Germany due to an erosive unconformity at the base of the Jurassic system. In Baden-Württemberg, as in most of Germany, the rocks that are preserved belong to only one formation, called **Exter Formation** after a river in northern Germany where it is exposed in a more complete section. The brackish north German lower part ("Postera Beds") of this formation probably is represented by the topmost parts of the nonmarine Löwenstein and Trossingen Formations in south-western Germany as its time-equivalent, but its marine middle part, called Contorta Beds, is already present in various places. The Contorta Claystone, black marine mudstones with thin sandstone layers, predominates in the more distal western part, but massive coastal marine sandstones of the Tübingen Sandstone Member are developed upon the Spaichingen paleotectonic swell (as in the Tübingen area) and east of it. Locally they contain a diverse marine mollusc fauna including *Rhaetavicula contorta*. This bivalve allowed biostratigraphic correlation of this unit to the alpine Rhaetian already in the 1850´s, soon after this stage has been established. The sandstones are sometimes topped by a bonebed layer, from which Triassic mammals have been recovered for the first time in 1847. In paleotectonic depressions, some deposits of the upper Exter Formation are preserved. These Triletes Beds consist of green freshwater claystones, to the East accompanied by micaceous sandstones. In the western and northern part of Baden-Württemberg, they commonly have been mapped together with the black Contorta Claystone below as "Rhätton", highlighting the youngest but earliest-known biostratigraphic date of the Keuper Group in its name.

Tuesday, 8. Sept. 2009



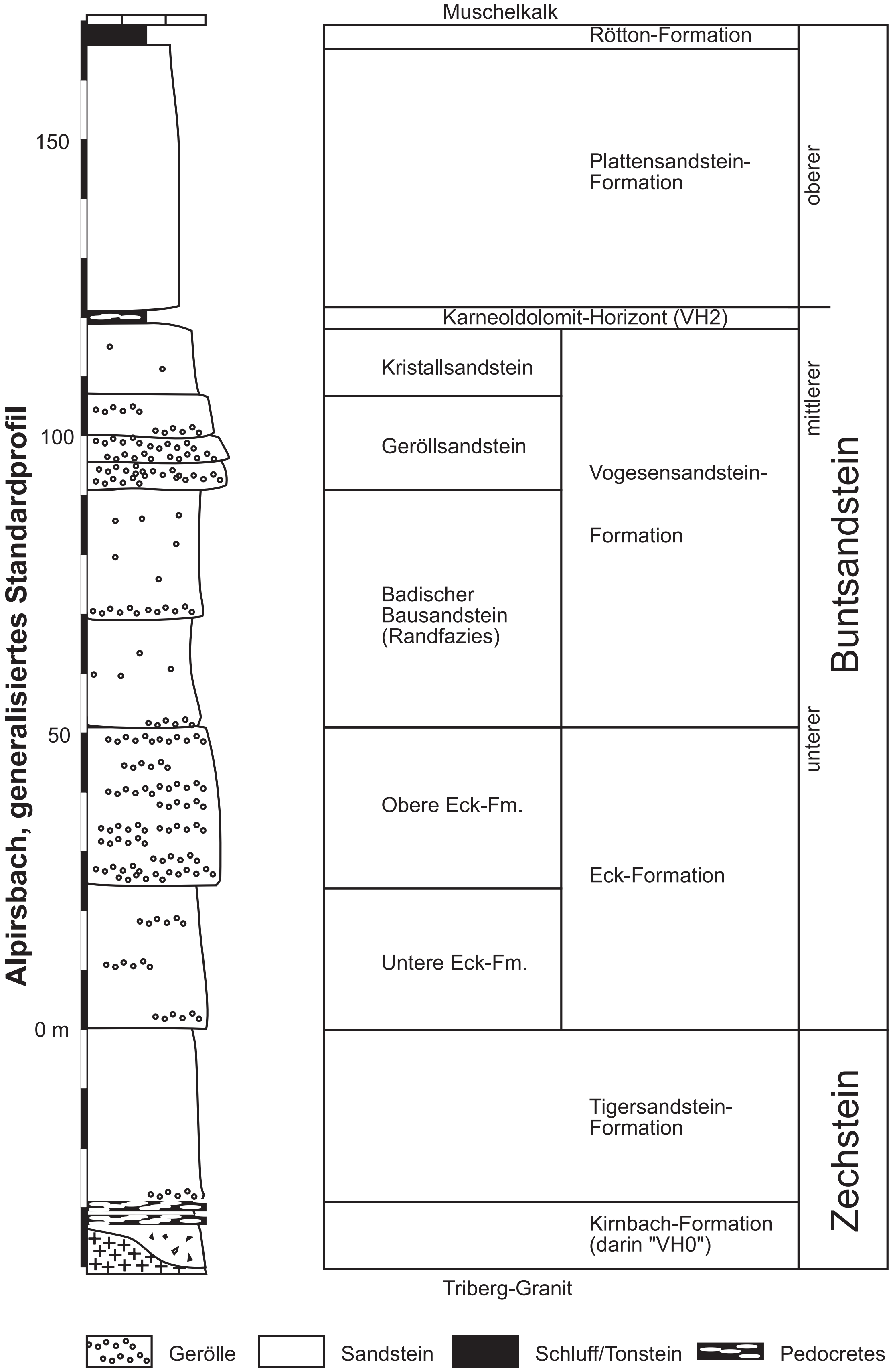
(map is reproduced smaller than in original scale; grid distance is 10 km)

Stop 1 Lower and Middle Buntsandstein; Induan – Olenekian: cliffs and road cuts along forest trail around Reutiner Berg near Alpirsbach

Stop 2 Buntsandstein/Muschelkalk boundary (Röt and Freudenstadt formations); early Anisian: abandoned quarry near Freudenstadt-Glatten

Stop 3 Lower Muschelkalk (Freudenstadt Formation / Wellendolomit); Anisian: abandoned clay pit near Freudenstadt-Dietersweiler

Stop 4 Upper Muschelkalk (Rottweil formation), Lower Keuper (Erfurt Formation); late Anisian – early Ladinian: Frommenhausen quarry



Schematic sketch of the Buntsandstein section near Alpirsbach. Redrawn after M. WERZ, unpubl. Diplomarbeit at Geological Institute, Univ. Freiburg i. Br., and data at LGRB, Freiburg.

Stop 1 **Alpirsbach-Rötenbach, natural cliff at the southern slope of Reutiner Berg. Lower Buntsandstein (Eck Formation, Vogesensandstein Formation)**

GK 25: 7616 Alpirsbach, R 34 57 270, H 53 54 950

Alberti 1834, § 28–42 „Der Vogesen-Sandstein Elie de Beaumonts“

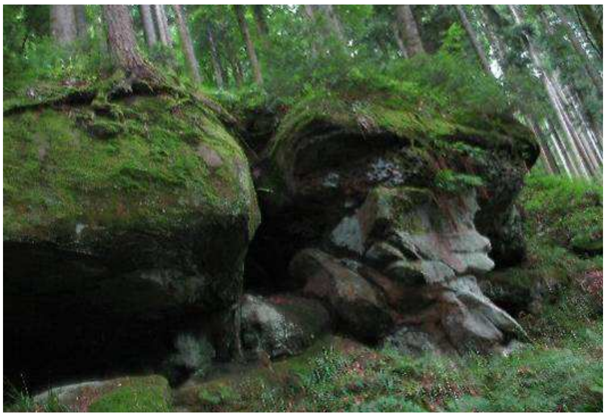
We leave the cars at Max Eyth-Strasse to walk about 400 m along a forest trail to our first outcrop – to meet an outcrop situation typical for the Black Forest. The outcrop, about 40 m uphill from the trail, shows cross bedded alluvial to fluvial sandstones of the Lower Buntsandstein at the transition from the pebbly coarse sandstones of the Eck Formation (formerly „Eck´sches Konglomerat“, first recognized by H. Eck 1892) to coarse to medium-grained sandstones poor or devoid of pebbles, known as Badischer Bausandstein of the Vogesensandstein-Formation.

- **Kirnbach Formation and Tigersandstein Formation of the Zechstein Group (Late Permian)**. Tiny vegetated outcrops at the forest trail hide (rather than exhibit) the marginal facies of the Late Permian Zechstein Group, including arkoses and pedogenic dolocretes of the Kirnbach Formation (formerly thought to be „Upper Rotliegend“) and alluvial sandstones of the Tigersandstein Formation (formerly thought to be „Lower Buntsandstein“).

- **Eck Formation of Lower Buntsandstein**. At this site, the formation is almost completely covered by forest soil and coarse blocks of slope rubble that crept downhill from the Middle Buntsandstein. Yet, some weathered blocks of the formation and single pebbles of Quartz and basement rocks, including wind-faceted specimens, can be found on the slope. The alluvial conglomerates and pebbly sandstones of the Eck Formation comprise the lowermost Triassic (Early Induan) unit in the most proximal part of the Basin. Only the uppermost beds of pebbly coarse-grained sandstones are exposed, grading into the Badischer Bausandstein above.

Windkanter, Reutiner Berg. Photo NITSCH.

- **Badischer Bausandstein**. Most of the cliff wall consists of cross-bedded medium-grained sandstones still containing some small to medium-grained quartz pebbles. Early diagenetic carbonate concretions are enriched in a certain level and cause „honeycomb-like“ weathering surfaces – „Kugelhorizonte“ (rock ball horizons) like this repeatedly were described as stratigraphic markers, but also repeatedly frustrated stratigraphers in being no key bed at all after closer examination. The pebble-bearing sandstones of this outcrop are a proximal facies (less than 50 km from the contemporaneous basin margin) of the pebble-free Bausandstein proper found farther to the north. Further to the south, however, these Lower Buntsandstein beds grade into pebbly sandstones as well, hardly discernable from those of the Middle Buntsandstein Geröllsandstein beds, formerly separated from the Bausandstein as a different formation.



Badischer Bausandstein, Reutiner Berg. Photo NITSCH.

Points of discussion

- Facies boundaries, formations and time units near the basin margins
- Nonmarine early diagenesis, pedogenesis and groundwater influence and their use for stratigraphy

References

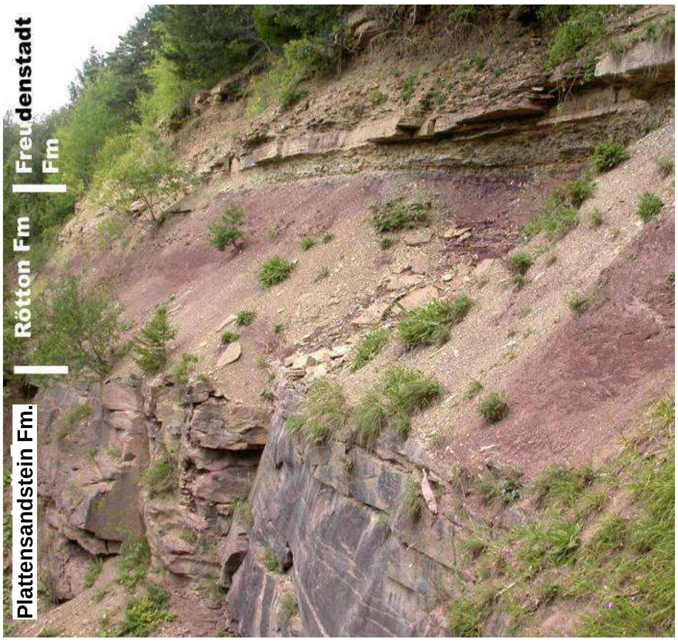
BRÄUHÄUSER & SAUER 1911, EISSELE 1957, 1966

Stop 2 Glatten, abandoned sandstone quarry N´ Hammerschmiede. Upper Buntsandstein (Plattensandstein Formation, Rötton Formation) and Lower Muschelkalk (Freudenstadt Formation)

GK 25: 7516 Freudenstadt, R 34 62 200, H 53 67 800

Alberti 1834, § 43–56 „Der bunte Sandstein Elie de Beaumonts“, § 57–58, 62–71 „Der Wellenkalk am Schwarzwalde“

Like many other Plattensandstein quarries in this region, this working stone quarry was abandoned after the 1960s. The Buntsandstein/Muschelkalk boundary is still well exposed. The section shows the following units:



Upper Buntsandstein and Lower Muschelkalk, Glatten quarry. Photo HAGDORN.

- **Plattensandstein Formation of Upper Buntsandstein**. Uppermost 5 – 7 m of the approx. 40 m thick reddish, finely grained, evenly bedded sandstone with mica on bedding planes. The exposed sandstone beds of up to 60 cm thickness are wedging out within the outcrop and are interbedded with reddish claystone lenses that yielded the conchostracan *Euestheria albertii* and the horsetail *Equisetites*. Unidentified vertebrate remains are preserved in violet or whiteish vivianite.
- **Rötton Formation**. 3 – 4 m of dark red, sandy claystone, with a set of greenish grey or ochre coloured, thinly bedded, sandy dolomite beds in the mid of the unit.
- **Liegende Dolomite of Freudenstadt Formation**. Approx. 3 m of yellowish to greyish evenly bedded dolomites and dolomitic marls that yielded marine vertebrate bones (nothosaurs, placodonts) and *Lingularia*. The thickest of these beds at the base of the unit is correlated with the Grenzgelbkalk. The upper part of the Liegende Dolomite, which is not exposed in this outcrop, has yielded a rich marine fauna in a nearby outcrop, including corals, the articulate brachiopod *Punctospirella*, and abundant columnals of an *Encrinus.* The Grenzgelbkalk as the first carbonate bed indicates the marine Muschelkalk transgression over Buntsandstein playas. It can be traced independent of facies over large parts of the basin (cf. Stop 12) and correlates with the Cellular Limestone at the base of the Upper Gogolin Formation in Upper Silesia (Poland); there, the lithostratigraphic base of the Muschelkalk is some 20 m deeper. In the Western part of the basin, e.g. the area of this field trip, this allostratigraphic boundary of the Folgen s7 and m1 is identical with the lithostratigraphic base of the Muschelkalk Group. Geochemical investigations along the Buntsandstein/Muschelkalk boundary give additional evidence for a facies migration towards the basin margin.

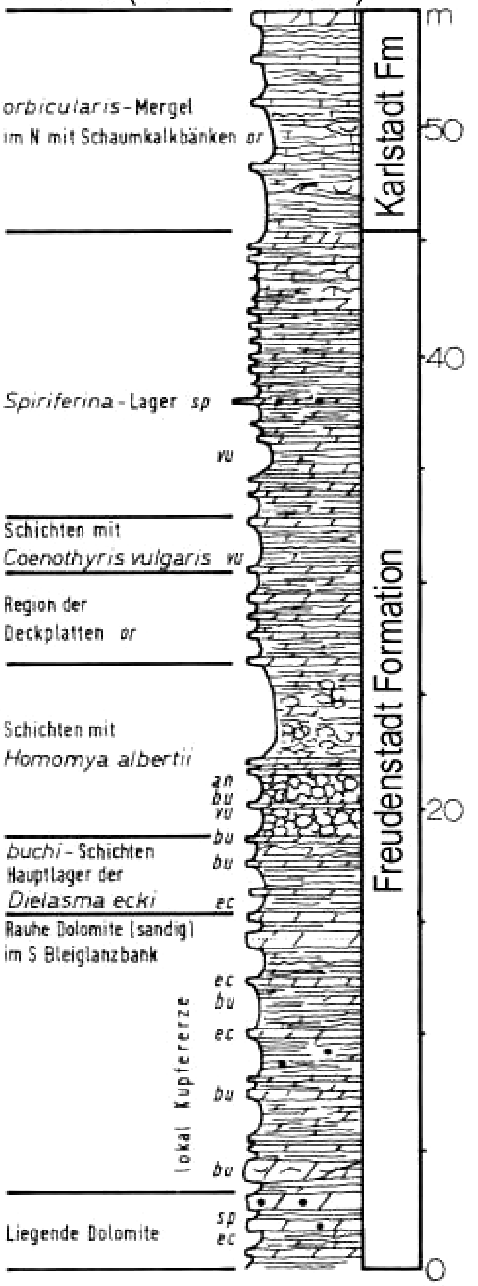
Points of discussion

- Lithostratigraphic versus allostratigraphic (marker bed) base of the Muschelkalk
- Geochemical distribution of heavy metals as a lithostratigraphical tool

References

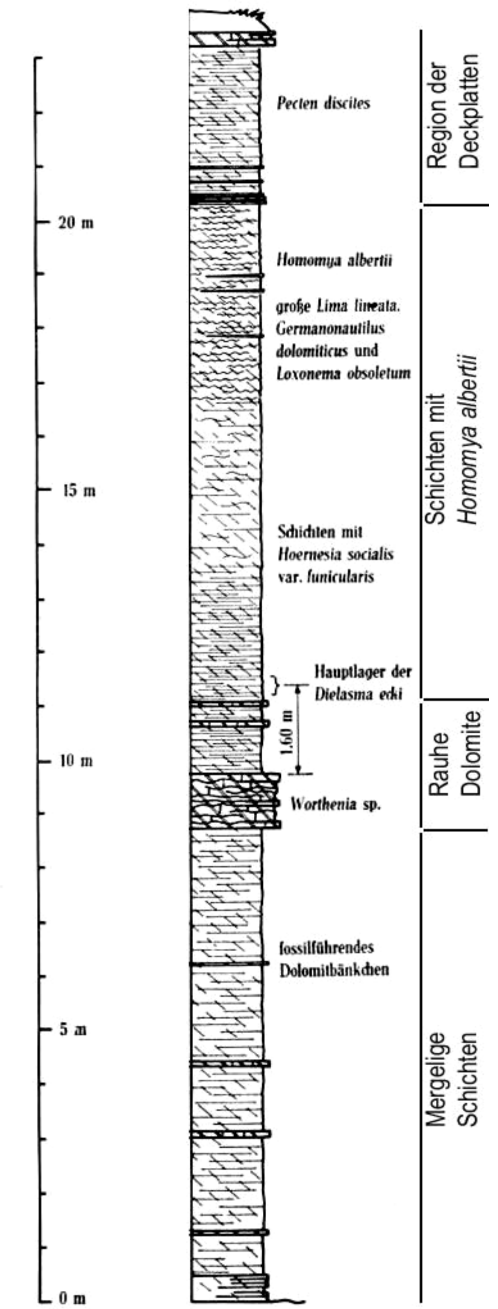
SCHMIDT 1907, SCHMIDT & RAU 1910, VOLLRATH 1923, SIMON 1999

Lower and basal Middle Muschelkalk in E Black Forest (Freudenstadt)



Generalized column of the Freudenstadt Formation. After GEYER & GWINNER 1991.

Abandoned clay pit Haas Dietersweiler



Lithostratigraphic log of the Dietersweiler clay pit. After MUNDLOS 1966.

Stop 3 Freudenstadt-Dietersweiler, abandoned clay pit Haas at Benzinger Berg N´ Dietersweiler. Lower Muschelkalk (Freudenstadt Formation)

GK 25: 7516 Freudenstadt. R 34 61 050, H 53 68 800

Alberti 1834, § 62–71 „Der Wellenkalk am Schwarzwalde“

The clay pit of the former Ziegelei Haas, now Naturschutzgebiet (natural preserve) is type locality of the Freudenstadt Formation. The exposed section comprises ca. 23 m of the middle part of the formation. However, due to rockfall, the lower part of the outcrop is presently not to be observed.

The section exposes the following members:

- **Mergelige Schichten**. Greyish to ochre coloured dolomitic marls with a few thin dolomite beds, some of which with pavements of bivalve shells on top (*Septihoernesia funicularis, Neoschizodus cardissoides, Arcomya fassaensis*). In the nearby abandoned clay pit Bacher large specimens of *Beneckeia buchi* and *Noetlingites strombecki* have been found in the lower part of this member.
- **Rauhe Dolomite**. Greyish to ochre coloured, wavy to nodular dolomites with poorly preserved, rare trace fossils (*Rhizocorallium*), bivalve and gastropod fossils.
- **Schichten mit *Homomya albertii***. Greyish to ochre coloured dolomitic marls with a few thin dolomite beds, some of which with pavements of bivalve shells on top, load casts with ball and pillow structures. The fossiliferous unit yielded double valved specimens of *Plagiostoma lineatum* with epizoic *Placunopsis matercula, P. plana*, *Umbrostrea difformis*, and *Microconchus valvatus*. Clusters of the articulate brachiopod *Dielasma ecki* occur at the base of the member, while pyritized nuclei of the otherwise common cephalopod *Beneckeia buchi* have not yet been found in this outcrop. The upper part of this unit yielded abundant double valved steinkerns of a soft bottom fauna: *Neoschizodus cradissoides, Homomya albertii, Arcomya fassaensis, Septihoernesia funicularis, Plagiostoma lineatum* with epizoans, *Loxonema obsoletum* and rare *Germanonautilus dolomiticus*. A well preserved specimen of *Serpianites antecedens* indicates Pelsonian age of this unit.
- **Region der Deckplatten**. Thinly bedded brownish dolomitic marls with several coarsely crystalline dolomite beds that may contain moulds of unidentified bivalves and scaphopods.

Points of discussion

- age of dolomitsation
- exotic Tethyan faunal elements and existence of a marine connection to the Neotethys via the Western Alps (Alpenrhein-Pforte, Western Gate) in Bithynian / Pelsonian times

References

SCHMIDT 1907, SCHMIDT & RAU 1910, VOLLRATH 1923, SEILACHER 1954, MUNDLOS 1963

Lower Muschelkalk, Freudenstadt Formation, Dietersweiler. Photo HAGDORN.

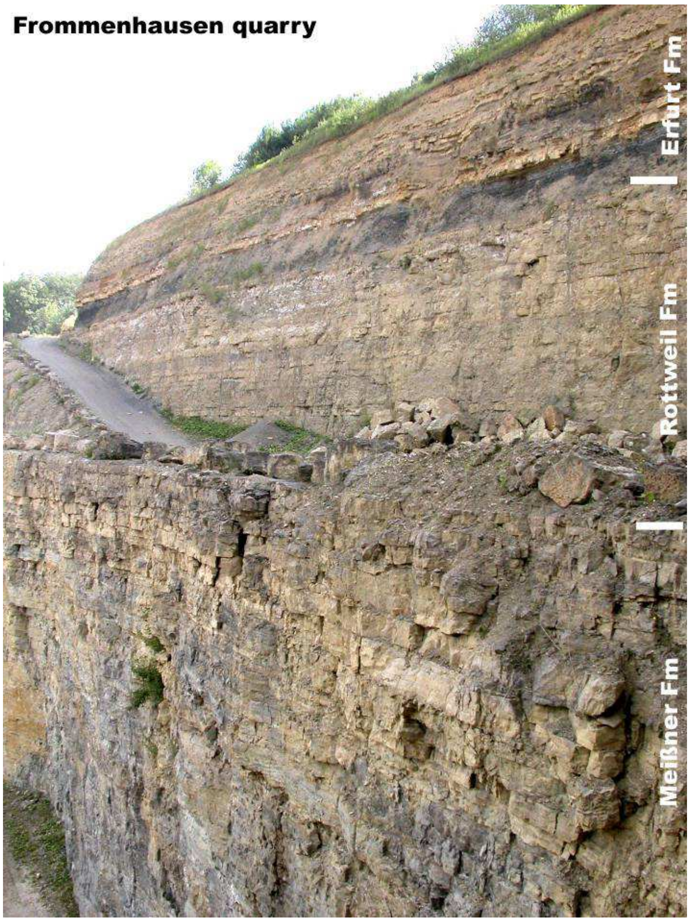
Stop 4 Frommenhausen, Schotterwerke Heinz GmbH & Co. KG, 1 km SSW´ Frommenhausen. Upper Muschelkalk (Rottweil Formation), Lower Keuper (Erfurt Formation)

GK 25: 7519 Rottenburg, R 34 90 240, H 53 64 960

Alberti 1834, § 119–126 „Kalkstein von Friedrichshall von Dolomiten überlagert", § 135–155 „Die Gruppe der Lettenkohle"

The quarry exposes almost the entire Upper Muschelkalk and Lower Keuper. However, the focus of the field trip is on Rottweil and Erfurt formations in the uppermost part of the section.

- **Rottweil Formation (former Trigonodusdolomit)**. Upper Muschelkalk in dolomitic backshoal facies. 20 m of light greyish, vertically jointed medium to thickly bedded dolomites; the uppermost 60 cm are interpreted as Hangenddolomit Member. The easily accessible and well weathered section allows detailed study of stratinomy with tempestites and a spectrum of dolomitic peritidal deposits ranging from oolithic grainstones (interpreted as shoal deposits and/or spillover lobes) to laminated mudstones with tepee horizons and flat pebble conglomerates (interpreted as inter to supratidal facies. Facies sequence shows a stacking pattern of various cycle types: peritidal facies form meter-scale fining up cycles. Upward changes of facies succession. Basic cycles are stacked in an overall regressive (shallowing) trend. The reservoir quality is varying within a meter-scale cycle and within overall sequence. In this locality, the Rottweil Formation is almost unfossiliferous; only at the very top internal moulds of *Costatoria goldfussi* are to be found. A 0,7 m thick algal laminate ("Bänderdolomit") approx. 1 m below the Muschelkalk top is easily identified, even in fragments.



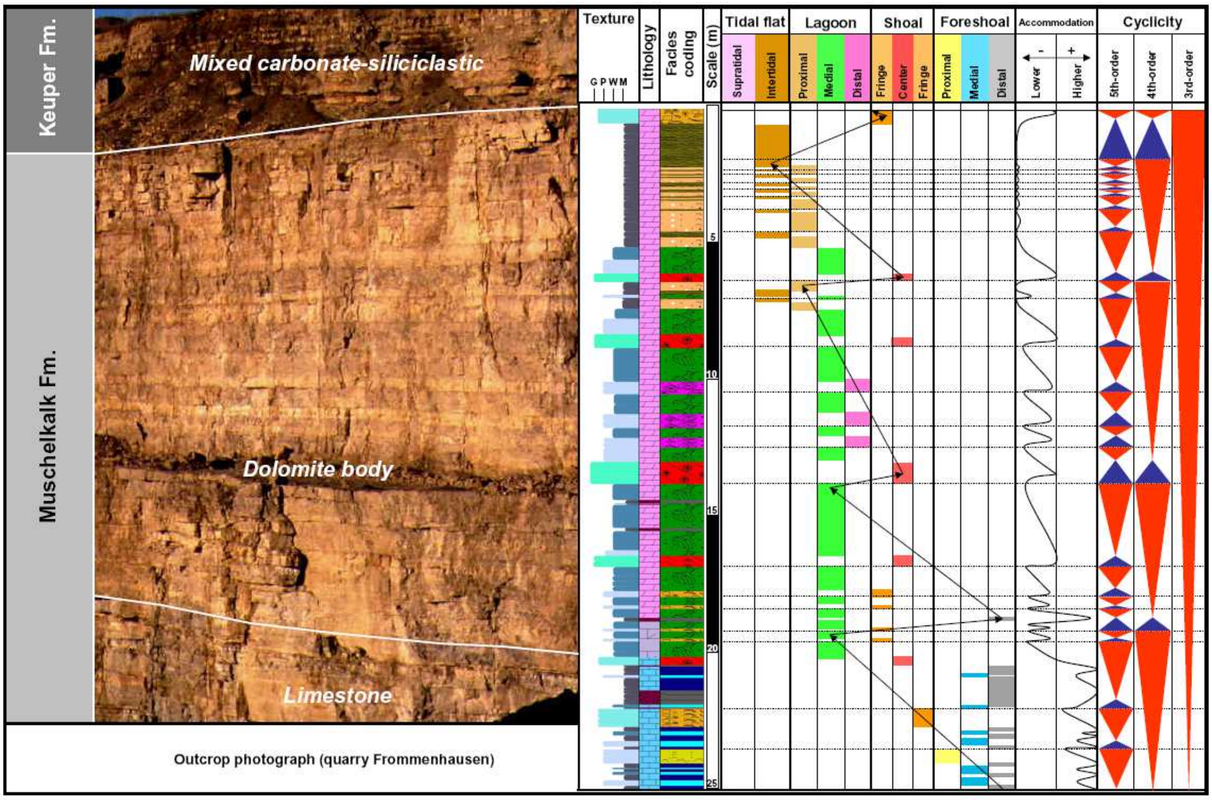
Rottweil and Erfurt Formations in the Frommenhausen quarry. Photo HAGDORN.

- **Erfurt Formation**. The outcrop exposes 12 m from the Boundary Bonebed to the Linguladolomit; the uppermost 4 – 5 m of the formation (Grüne Mergel and Grenzdolomit) is presently not exposed. Vitriolschiefer and Blaubank are extremely thin and the Hauptsandstein is untypical. Upsection of the Albertibank, the section corresponds with the Lower Keuper standard profile. This outcrop is well known for abundant *Placunopsis* bioherms at the base of the Anthrakonitbank. These reefs with stromatilithic (LLH) growth of the small bivalve shells are wide spread in the Upper Muschelkalk (m9b, Hauptterebratelbank). Their occurrence in the Erfurt Formation is restricted to the Southern part of Baden-Württemberg. However, the Lower Keuper bioherms are not thicker than 40 cm. The marls at the base of the – in this outcrop – unfossiliferous Anthrakonitbank have yielded poorly preserved moulds of *Hoernesia socialis* and *Bakevellia*.

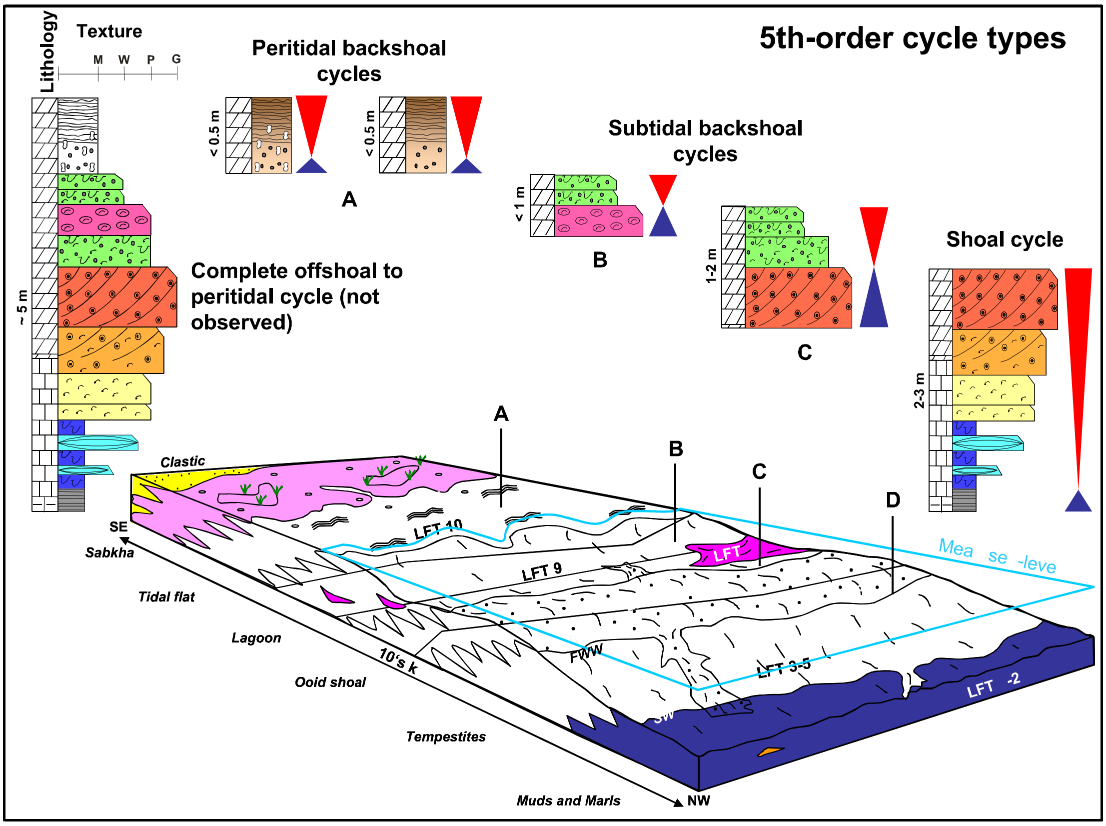
- **Points of discussion**
  - dolomitsation mechanisms
  - reservoir control by primary depositional facies vs. diagenetic alterations
  - N/G and porosity, flow barriers
  - Numerical geocellular reservoir model

References

ESSIGMANN 1979, ALESI 1984, SCHAUER & AIGNER 1997, PÖPPELREITER 1999, AIGNER & ETZOLD 1999, KÖHRER et al. in press

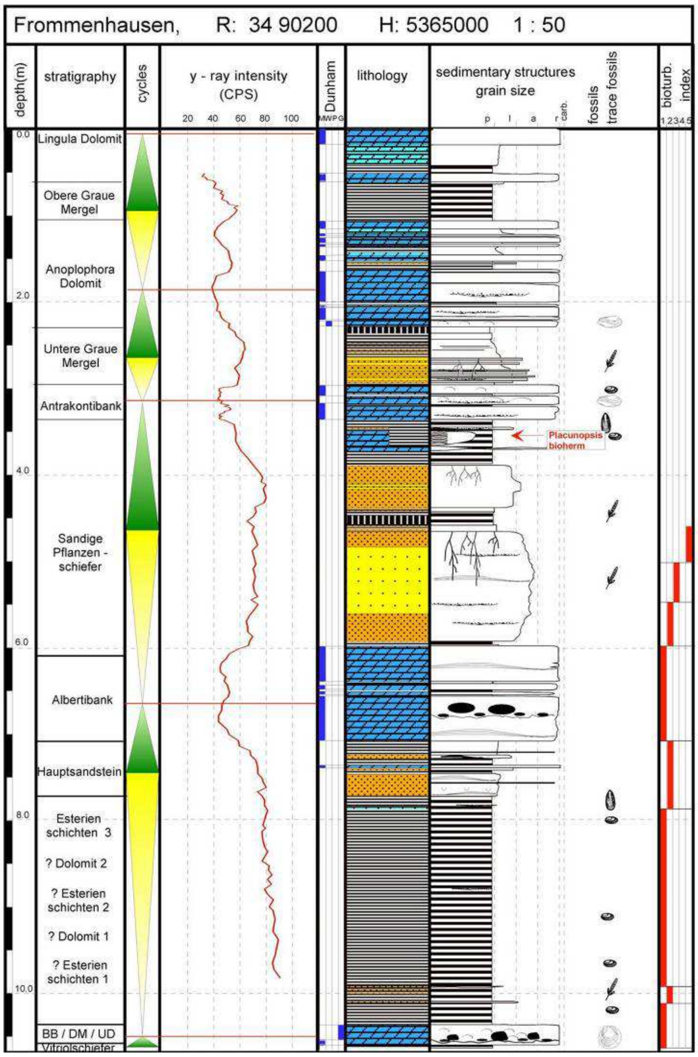


Stacking pattern. After KÖHRER (2007).



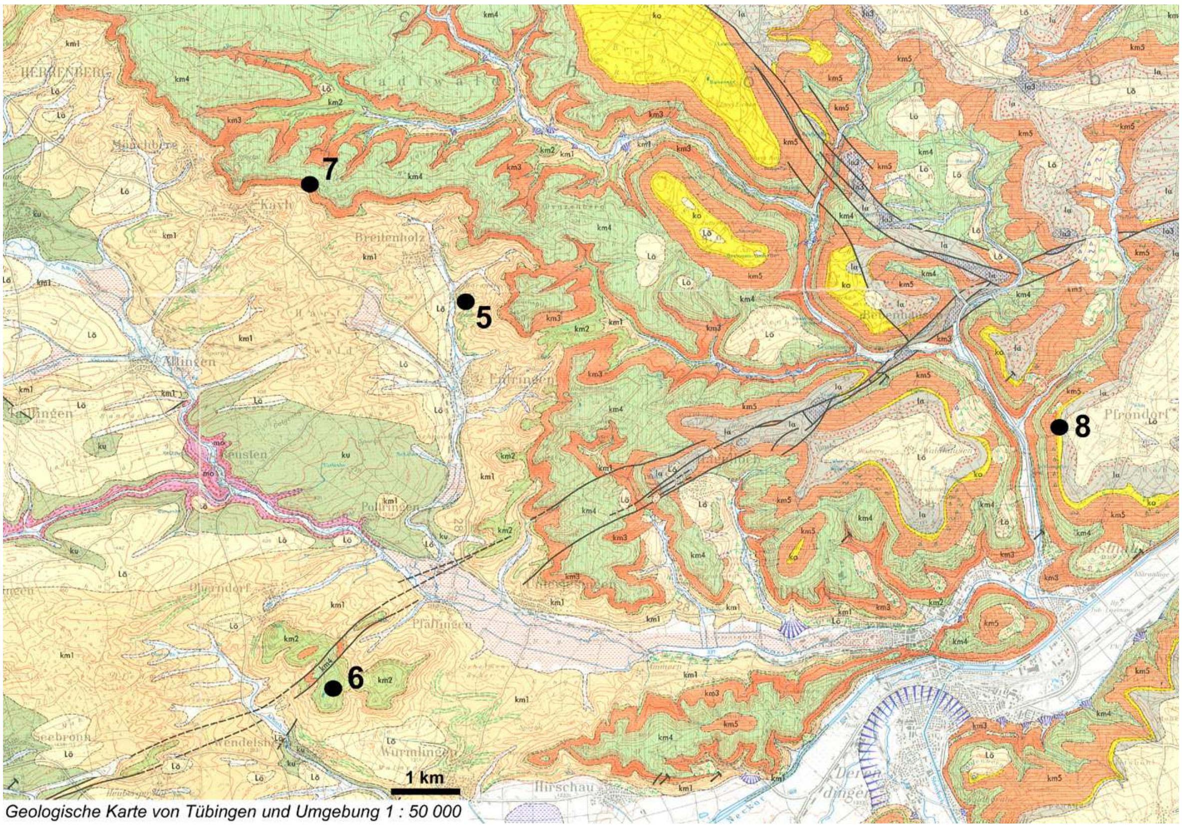
Facies model and cycle types of the Rottweil Formation. After KÖHRER (2007).

Erfurt Formation in the Frommenhausen quarry. "P" is a *Placunopsis* bioherm. Photo HAGDORN.



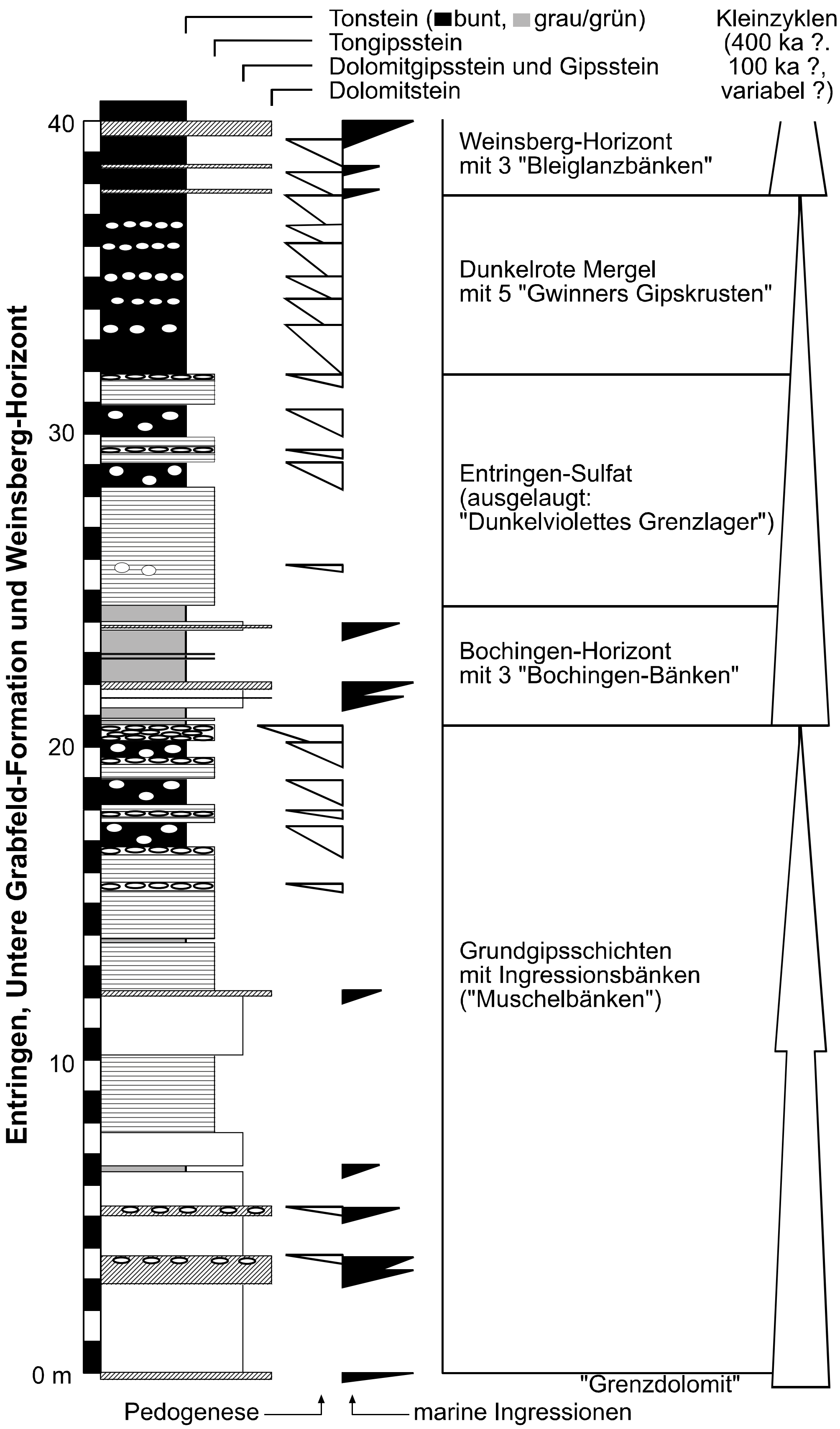
Log of the Erfurt Formation in the Frommenhausen quarry. From PÖPPELREITER (1999).

Wednesday, 9. Sept. 2009



Geologische Karte von Tübingen und Umgebung 1 : 50 000

Stop 5	Middle Keuper (Grabfeld Formation / Gipskeuper); latest Ladinian: gypsum pit Entringen
Stop 6	Middle Keuper (Stuttgart Formation / Schilfsandstein); Carnian: abandoned sandstone quarries near Wendelsheim
Stop 7	Middle Keuper (Weser Formation / Bunte Mergel), Löwenstein Formation ~ Stubensandstein); Norian: abandoned quarries near Kayh
Stop 8	Upper Keuper and Triassic-Jurassic boundary; Rhaetian: active sandstone quarry near Tübingen-Pfrondorf



Measured section of the Entringen quarry (NITSCH 1996).
Tonstein – claystone; bunt – variegated; grau/grün – grey, green; Tongipsstein – claystone-gypsite alternations; Dolomitgipsstein – dolomitic gypsite; Gipsstein – gypsite; Dolomitstein – dolomite.

Stop 5 Ammerbuch-Entringen, former gypsum pit north of Entringen. “Gipskeuper” facies of the Middle Keuper (Grabfeld Formation)

GK 25: 7419 Herrenberg, R 34 97 650, H 53 80 600

Alberti 1834, § 159–191 „Die Gruppe der Bunten Mergel mit Gyps“

The former gypsum pit has partly been filled, but most of the section still is accessible:

- **Grabfeld Formation**. In the lowest portion of the pit, about 20 m thick Grundgipsschichten consist in their lower 12 m of massive, slightly dolomitic sulphate deposits, now secondary gypsum rocks („Felsengips“), with some intercalated dolomite beds of a few centimetres in thickness. Towards the top of the Grundgipsschichten, thin varicoloured claystone layers become increasingly common to produce centimetre-scale intercalations of sulphate and claystone beds („Plattengips“). The uppermost ca. 4 m of the Grundgipsschichten show three massive claystone beds, each several decimeters in thickness, that bear pedogenic slickensides and gypsum nodules (gypsiferous paleo-vertisols) alternating with enterolithic to nodular gypsum layers (gypcretes).
  On top of the uppermost enterolite, an about 4 m thick bed of laminated grey claystones with some thin gypsum and three dolomite beds represent the Bochingen Horizon, an excellent marker horizon for regional correlation. On top of this, 7 m of gypsum-claystone intercalations („Plattengips“) with two thicker claystone-vertisols have been named Entringen Sulphate. They also can be correlated over large distances and have been identified all the way from the Swiss border to the Baltic Sea. The Upper part of the section its dominated by red and green massive claystones, called the Dunkelrote Mergel (ca. 6 m). Some kind of tiering is created by five levels bearing gypsum nodules. Pedogenic slickensides and gypcrete nodules indicate an stacked pedogenic origin for these massive claystone unit.

„Bleiglanzbank“, Weinsberg Horizon, Entringen

- To the east, the **Weinsberg Horizon** of the Middle Grabfeld Formation represent the uppermost unit visible. The unit consists of red, green and grey claystones and shows three of the famous „Bleiglanzbank“ beds – none bearing galena in this region and two of them only measuring less than 2 cm in thickness! (correlation shows that these beds are several dm in thickness in other places). The third bed, however, is about 20 cm thick and shows intensive bioturbation at its base and a *Pseudocorbula* lumachelle bed in its upper portion, indicating some restricted marine to brackish environment.

Points of discussion

- Cyclic stratigraphy and lateral variations in cycle counts
- The role of ingressions vs. freshwater evaporation for generating Keuper evaporites

References

WEIGELIN 1913, NITSCH 1996, NITSCH ET AL. 2005, DSK 2005

Grundgipsschichten, Bochingen Horizon, Dunkelrote Mergel, Entringen. Photos NITSCH.

Stop 6 **Rottenburg-Wendelsheim, abandoned sandstone quarry on top of the Pfaffenberg, known as "Märchensee". "Schilfsandstein" of the Middle Keuper (Stuttgart Formation)**

GK 25: 7419 Herrenberg, R 34 95 560, H 53 75 200

Alberti 1834, § 192–197 „Der feinkörnige Sandstein (Schilfsandstein Jäger´s)"

The Stuttgart Formation can be subdivided into three members. The lowermost of these, the Osterhagen beds, are not preserved in most of southern Germany. The Wendelsheim quarry shows the middle (Lower Schilfsandstein) and upper units (Upper Schilfsandstein):

- **Stuttgart Formation**. The quarry exploited fine to medium grained fluvial sandstones of the lower Stuttgart Formation. They have been extensively used as ashlar stones in the region and can be studied at many buildings, e. g. in Tübingen. The quarry probably followed a small SSW oriented string of massive channel sandstones. Those rocks left in the quarry, now visible in the quarry walls, mainly represent thin-bedded levee deposits with intercalated silt and clay drapes, showing low-angle cross bedding and some dish structures. Small-scale cut-and-fill channels cross-cut the otherwise horizontally bedded sediments. To the west, these levee deposits interfinger with muddy floodplain fines, altered to vertisols, and wedge out to thin crevasse splay beds at short distance. Near the hill slope, gypsum dissolution in the subsurface has bend down some clayey sandstones of the Upper Schilfsandstein.

Fluvial levee sandstones, Stuttgart Formation, Wendelsheim

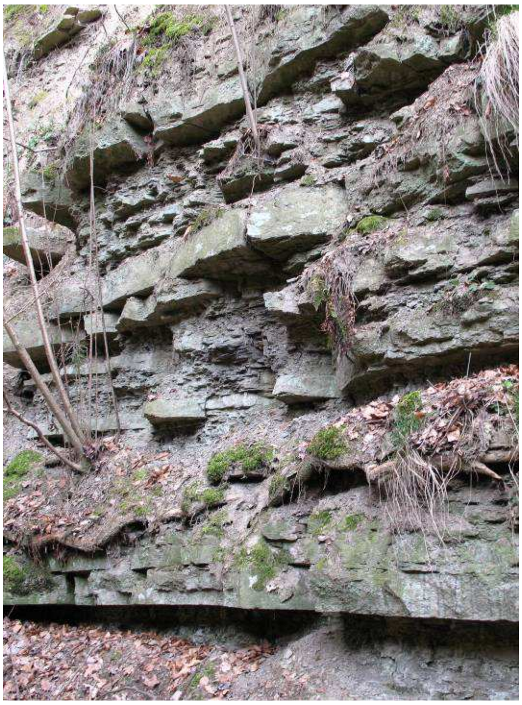
Points of discussion

- stratigraphic subdivision of the Stuttgart Formation
- lateral interfingering of different facies

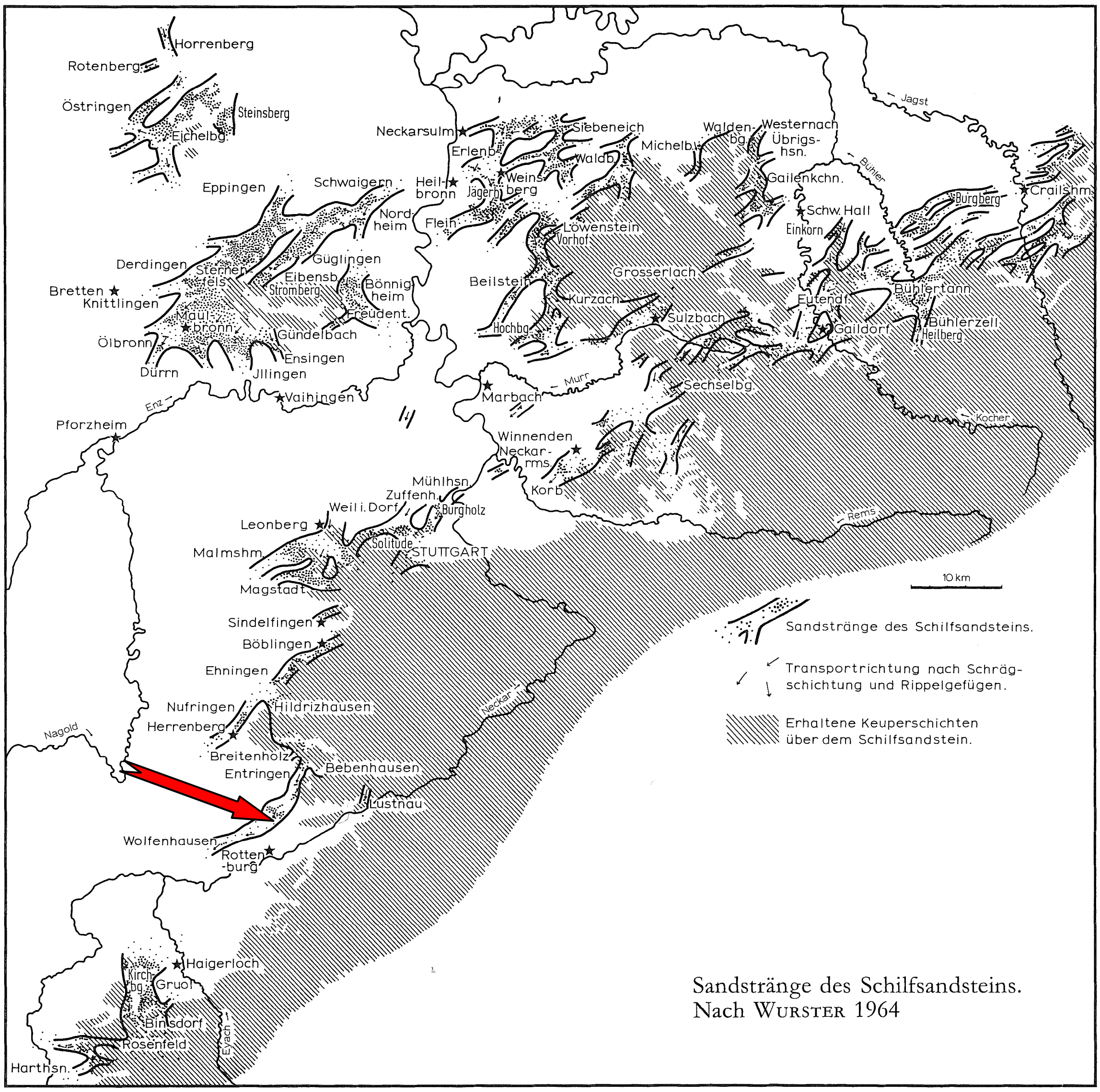
References

WURSTER 1964, RICKEN et al. 1998, AIGNER & ETZOLD 1999, DSK 2005

Crevasse channel cutting through the levee deposits



Crevasse splays interbedded with floodplain fines, Wendelsheim quarry. Photos NITSCH.



Schilfsandstein fluvial valley fills of the Stuttgart Formation (after WURSTER, from GEYER & GWINNER 1991). The red arrow points to the Wendelsheim quarry. The valleys have cut down 5 to 30 m into the sediments of the upper Grabfeld Formation and are filled with fluvial channel sands, levee deposits, crevasse splays and overbank fines. In places pond and lake sediments are present, containing freshwater bivalves (*Unio equisetitis*). Yet, some of the channel sediments show regular changes in current velocities that have been attributed to tidal influence.

Stop 7 Herrenberg-Kayh, roadside outcrop and abandoned quarry near the local sports field. “Bunte Mergel” (Weser Formation), “Stubensandstein” (Löwenstein Formation)

GK 25: 7419 Herrenberg, R 34 95 500, H 53 82 530

Alberti 1834, § 198–203 „Der kieselige Sandstein“, „Der grobkörnige Sandstein“

Between Herrenberg and Tübingen, the cuesta of the Schönbuch area is caused by the alluvial sandstones of the Löwenstein Formation of the upper Middle Keuper. At the slope of this cuesta, playa mudstones crop out between Stuttgart and Löwenstein Formations that belong to different formations in Tübingen than they do in Herrenberg (and Kayh) not because of different facies, but because the sandstones of the Hassberge Formation within this succession pinch out to the west. Where they are present, as in Tübingen and Bebenhausen, they divide the playa facies into Steigerwald Formation below and Mainhardt Formation above (formerly Untere Bunte Mergel, Kieselsandstein, Obere Bunte Mergel). At Kayh, no sandstones are present, and the continuos playa facies (formerly Bunte Mergel) is summarized as Weser Formation, formally.

- **Weser Formation.** The outcrop at the roadside exhibits most of the Formation. The gabions at the base of the outcrop hide the Beaumont Horizon (exposed before WW I). About 9 m of Rote Wand facies (equivalent of the Steigerwald Formation, partly hidden) represent the lower Weser Formation here. Since the Lehrberg Beds are missing south of Stuttgart, this “Rote Wand” is immediately followed by 18 m of claystones and carbonate beds of the “Steinmergelletten” (playa facies equivalent of alluvial facies Hassberge Formation). Most of the carbonates have been deposited in small ephemeral ponds or lakes, all of them have been overprinted, some even generated, by aridisol pedogenesis as caliche carbonates, showing internal breccias and tepee structures. At the very top of this lower outcrop, the first sandstone bed of the Löwenstein Formation can be found. Most of the Heldburg member is missing at the Early Cimmerian Unconformity.
- **Löwenstein Formation**. Two old abandoned quarries at the cuesta edge show alluvial sandstones and mudstones of the Middle Löwenstein Formation (s2.1 to s2.2 sandstone cycle). A well developed pedocrete shows small-scale variations in thickness (K2.1 Pedocrete).

2. Stubensandstein, Löwenstein Formation, Kayh

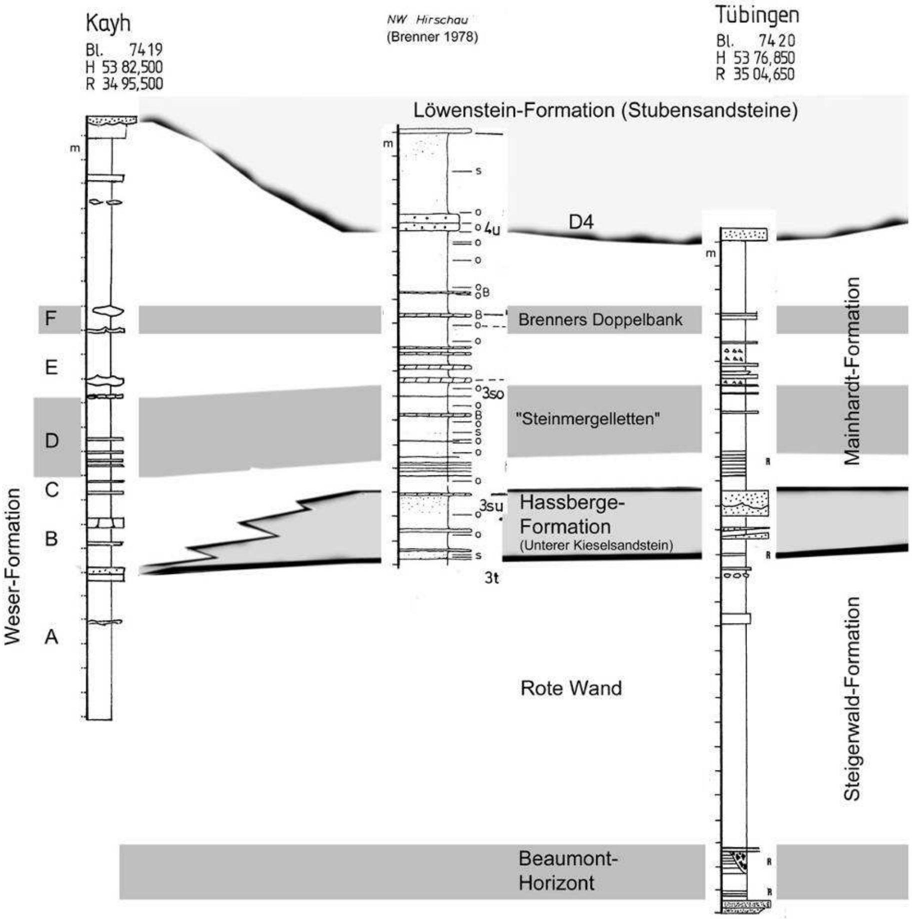
Steinmergelletten, Weser Formation (equ. Mainhardt Fm.), Kayh. Photos NITSCH.

Points of discussion

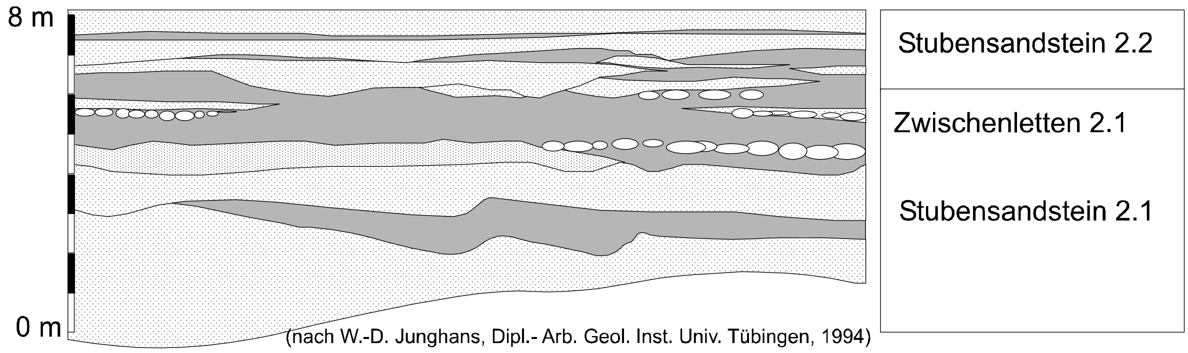
- Stratigraphic nomenclature in interfingering facies geometries
- Pedocretes as stratigraphic marker beds

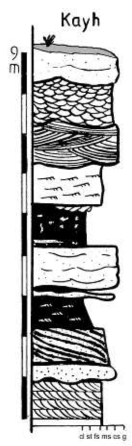
References

BRENNER 1978, AIGNER & ETZOLD 1999, DSK 2005



Correlation of the Weser / Mainhardt Formations of Kayh and Tübingen (after NITSCH & ETZOLD, unpubl. excursion guide of the DSK Keuper Group, 2003). Note D4 unconformity and missing Heldburg Member in this area.





Measured sections of the Kayh Stubensandstein quarry: outcrop wall map (redrawn after W.-D. JUNGHANS, unpubl., above) and vertical log in the western (left) part of the quarry (to the left, from DSK Keuper Group excursion guide 2003). The succession is dominated by channel sandstones of alternating type (meandering and braided) and floodplain fines partly altered to calcrete paleosols with some vertic features.

Stop 8 **Tübingen-Pfrondorf, active sandstone quarry Nagel, north of Pfrondorf. Contorta beds of the Upper Keuper (Tübingen Sandstone, Exter Formation) and Triassic-Jurassic boundary.**

GK 25: 7420 Tübingen, R 35 06 075, H 53 79 100

Alberti 1834, § 204–205 „Der versteinerungsreiche Sandstein“

The quarry exposes Upper Keuper Sandstones used for masonry and pavement stones, for stone troughs and other purposes. The section includes the latest Triassic as well as the earliest Jurassic rocks of the region, divided from each other by a significant hiatus.

- **Exter Formation, Tübingen Sandstone of Rhaetian age**. The well sorted medium-grained quartz sandstones (“Orthoquartzites”), about 9 to 10 m in thickness, are marine beach deposits of the Upper Keuper Exter Formation (Tübingen Sandstein). They show wave and current ripples, gently dipping (5°) upper plane bed laminations with current linea tions and swash fringes of mud pebbles and plant debris. Rare moulds of *Rhaetavicula contorta* confirm a marine environment and their stratigraphic position in the Contorta Beds. Triletes Beds are missing. As shown by AEPLER (1974), even the depositional system of the Contorta beach ridge has been truncated before the lower Jurassic sediments were deposited. The top surface of the sand body is patchily covered with sandy bonebed material, especially filling up shallow scours and furrows (“Grenzbonebed”). Reworking probably occurred over prolonged time, since Erika v. Huene (1933) even found in the bonebed ammonite protoconchs that seemed to be of Jurassic age, mixed up with Triassic vertebrate debris.

Oscillation ripples and current lineations in the Tübingen Sandstone, Pfrondorf

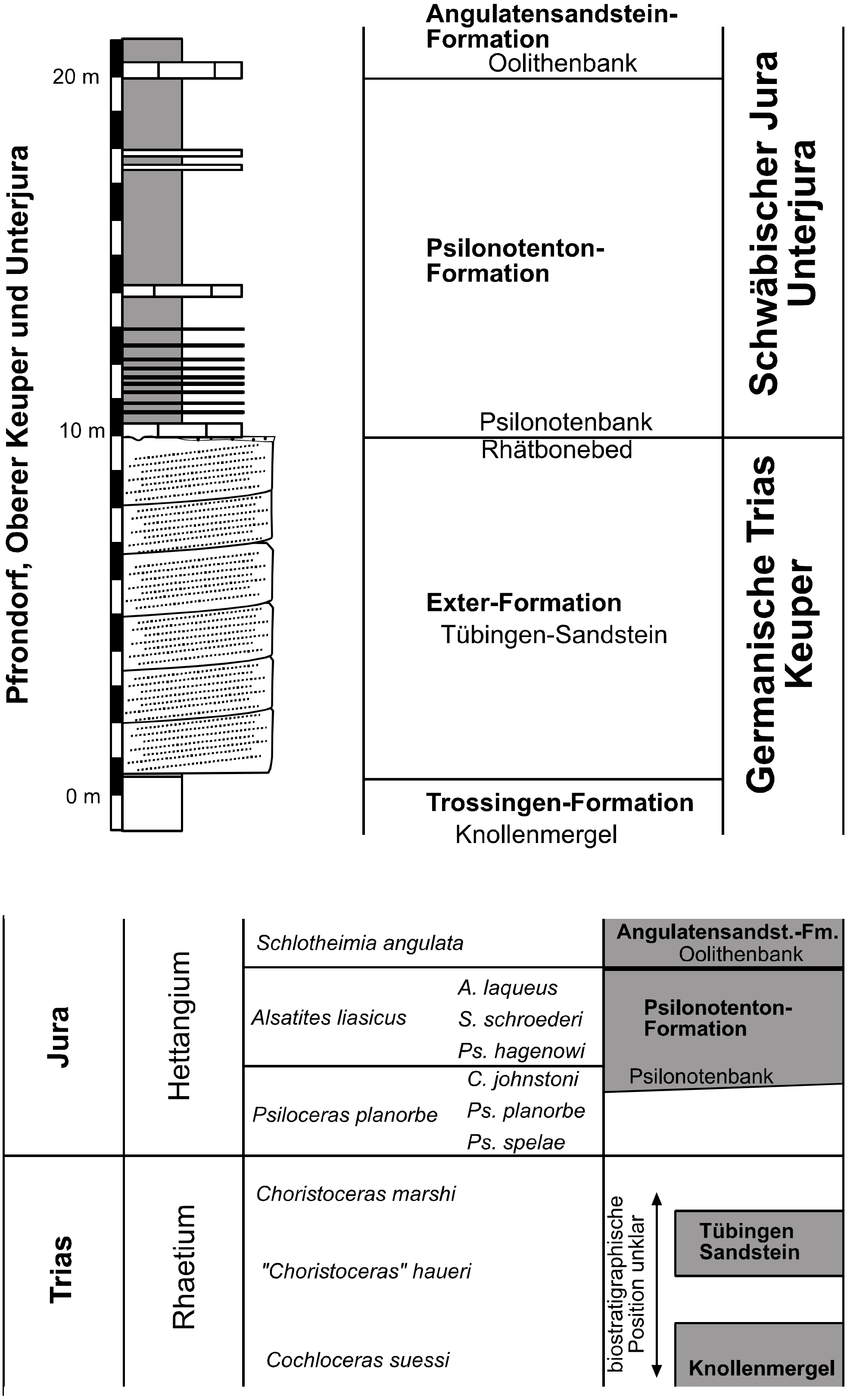
Rhaetian beach deposits and late Early to Late Hettangian shallow marine mudstones and calcareous tempestites, Pfrondorf quarry. Both photos: NITSCH.

- **Psilonotenton Formation of Hettangian age**. The sandstones are unconformably overlain by an early Hettangian marine limestone bed, with *Psiloceras (Caloceras) johnstoni* and a varied bivalve fauna, and about 10 m of Lower Hettangian marly claystones. An oolithic limestone bed near the top of the outcrop marks the base of the Upper Hettangian (Oolithenbank, *Schlotheimia angulata* Zone).

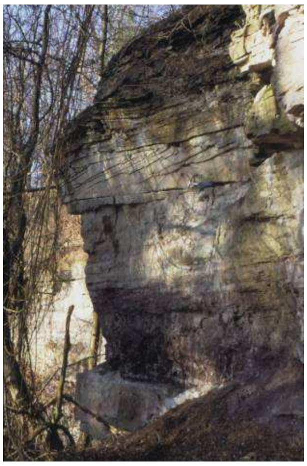
- **Points of discussion**
  - Age constraints of the Upper Keuper and its hiatuses
  - paleogeography and the source of the “Contorta sands”

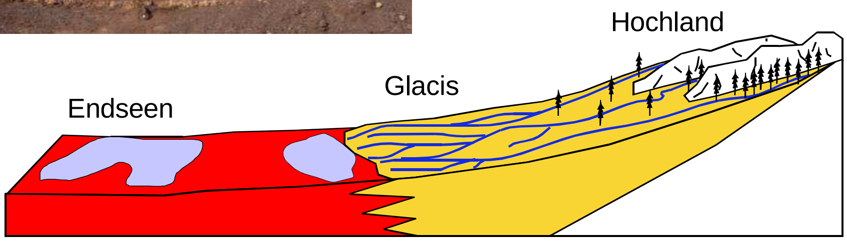
References

HUENE 1933, AEPLER 1974, AIGNER & ETZOLD 1999, DSK 2005.

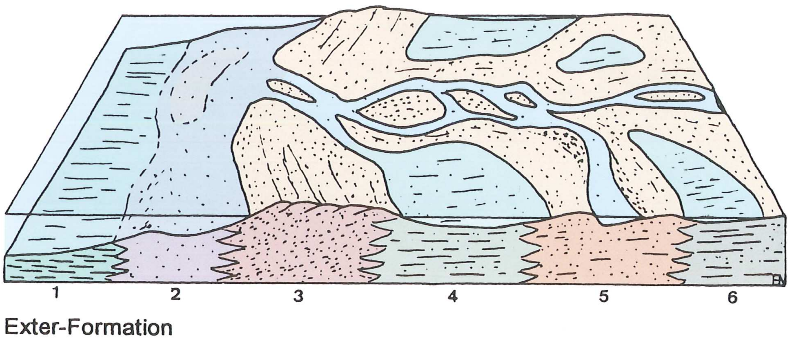


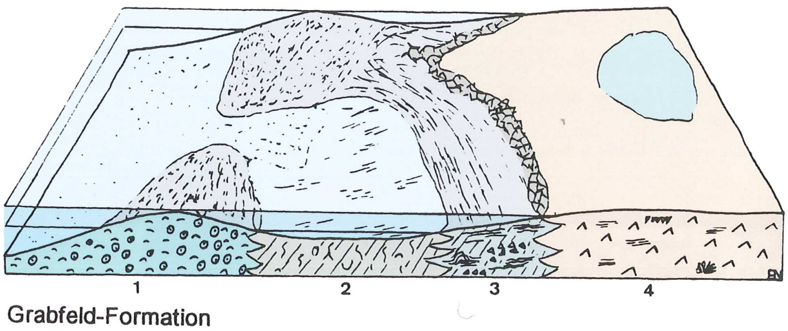
Measured section and biostratigraphic position of the Rhaetian to Hettangian deposits of the Pfrondorf quarry. The biostratigraphic position of the Rhaetian deposits is not clear in detail and shown tentatively.





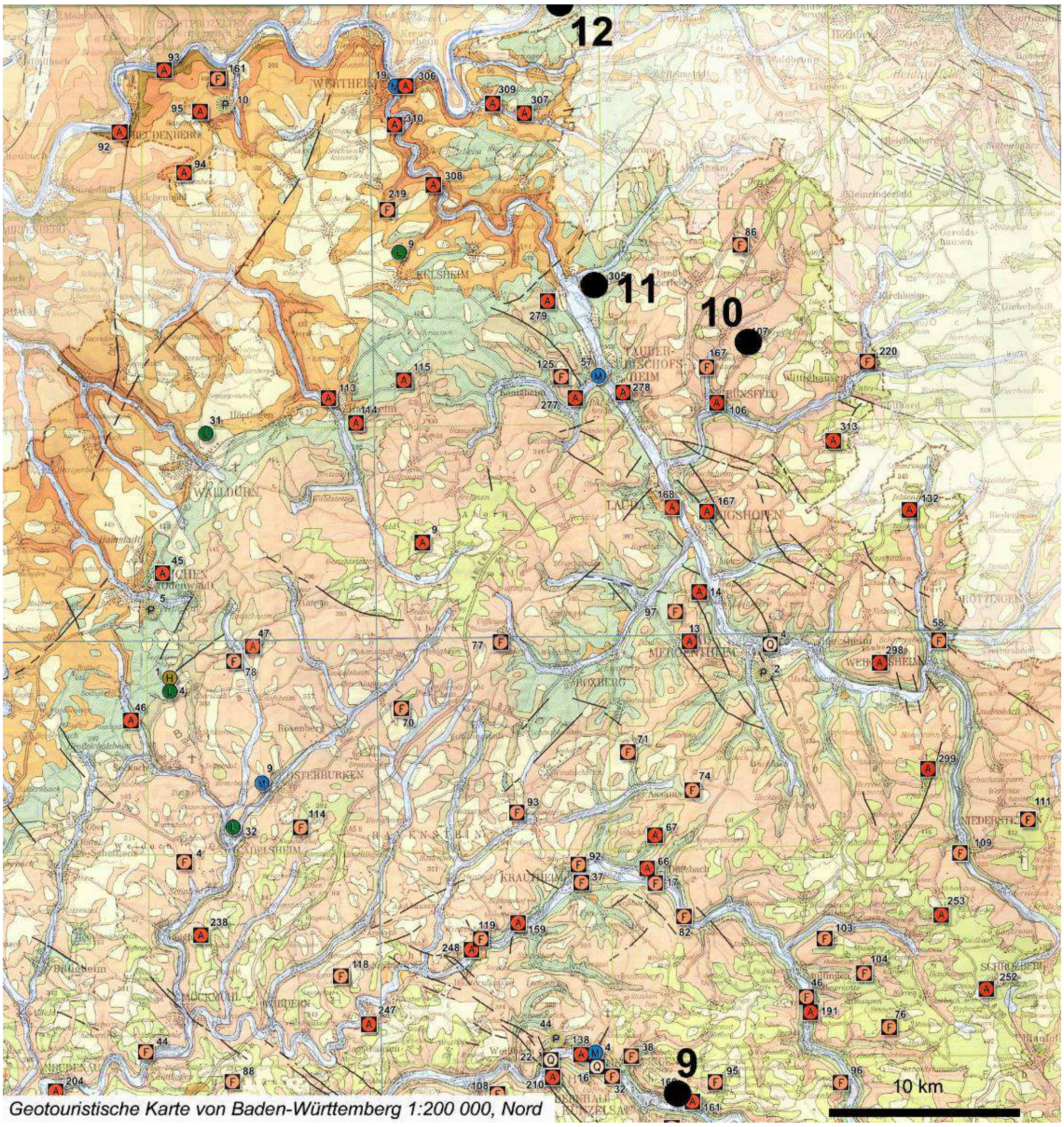
Schematic facies diagram of the braidplain to playa depositional system of the Middle Keuper (modified from NITSCH 2006). In the basin centre, playa or saline lake sediments represent hydrologically closed or semi-closed lake systems ("Endseen" in German). Alluvial river systems from the highlands ("Hochland") build up a sedimentary ramp of sand and mud ("Glacis"), at times more than 100 km wide, as a marginal facies belt of the basin.





Schematic facies diagram of coastal marine depositional systems of the Grabfeld Formation (below) and of the Exter Formation (above; from BEUTLER et al. 1999). The Late Ladinian carbonate-evaporite coasts, documented by oolite bars, lagoonal and peritidal dolomites (including fenestrate microbial mat and intraclast deposits), were closely related to evaporitic environments and sabkha facies early diagenesis (gypcrete formation, dolomitization; NITSCH 1996). These environments strongly differ from the Rhaetian deltaic and beach deposits found in the Upper Keuper (the numbers refer to distinct lithofacies; the facies seen in Pfrondorf is no. 3 in the upper diagram – see BEUTLER et al. 1999 for further reference).

Thursday, 10. Sept. 2009



Geotouristische Karte von Baden-Württemberg 1:200 000, Nord

Stop 9 Upper Muschelkalk (Trochitenkalk and Meißner formations); Anisian, Ladinian: abandoned quarry at Künzelsau-Garnberg

Stop 10 Upper Muschelkalk (Quaderkalk Formation); early Ladinian: quarry near Krensheim

Stop 11 Lower and Middle Muschelkalk (Jena, Karlstadt, Heilbronn, and Diemel formations); Anisian: quarry near Werbach on River Tauber

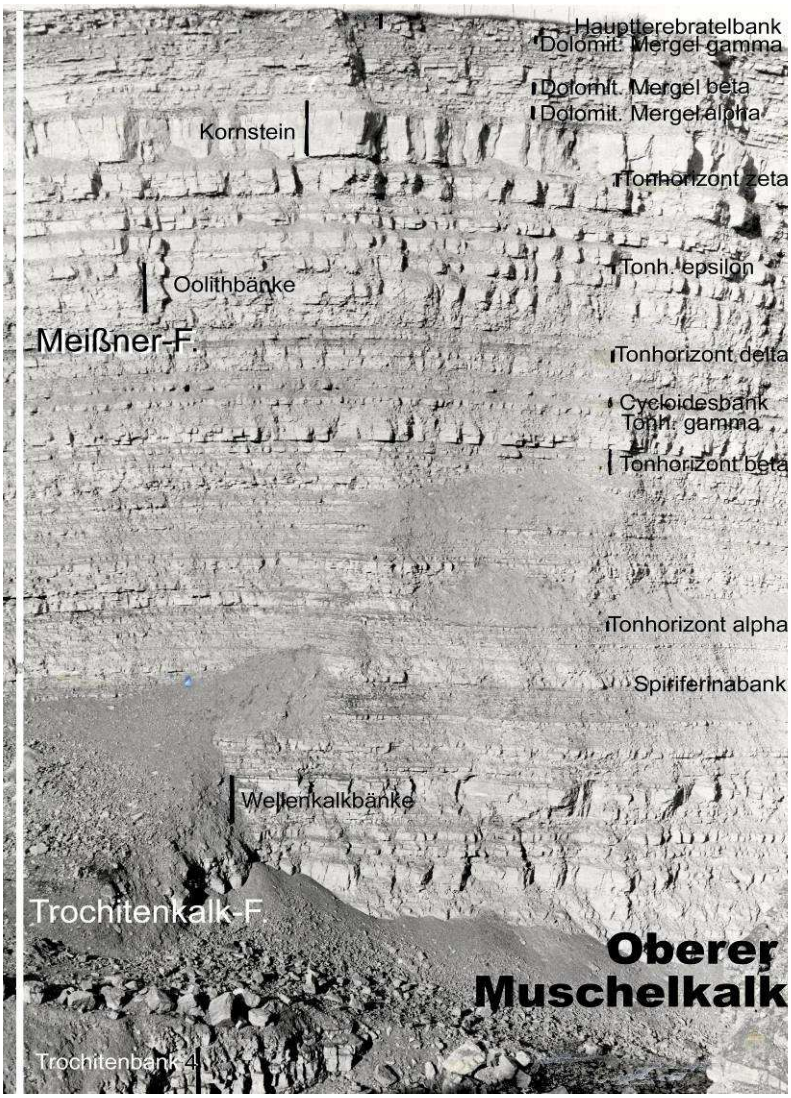
Stop 12 Upper Buntsandstein (Plattensandstein and Rötton formations); earliest Anisian: vineyard road cutting near Homburg on River Main

Stop 9 **Künzelsau-Garnberg, abandoned quarry of Hohenloher Schotterwerke GmbH & Co. KG, 600 m SE´ Künzelsau. Upper Muschelkalk (Trochitenkalk Formation, Meißner Formation)**

GK 25: 6322 Künzelsau, R 35 51 500, H 54 60 800

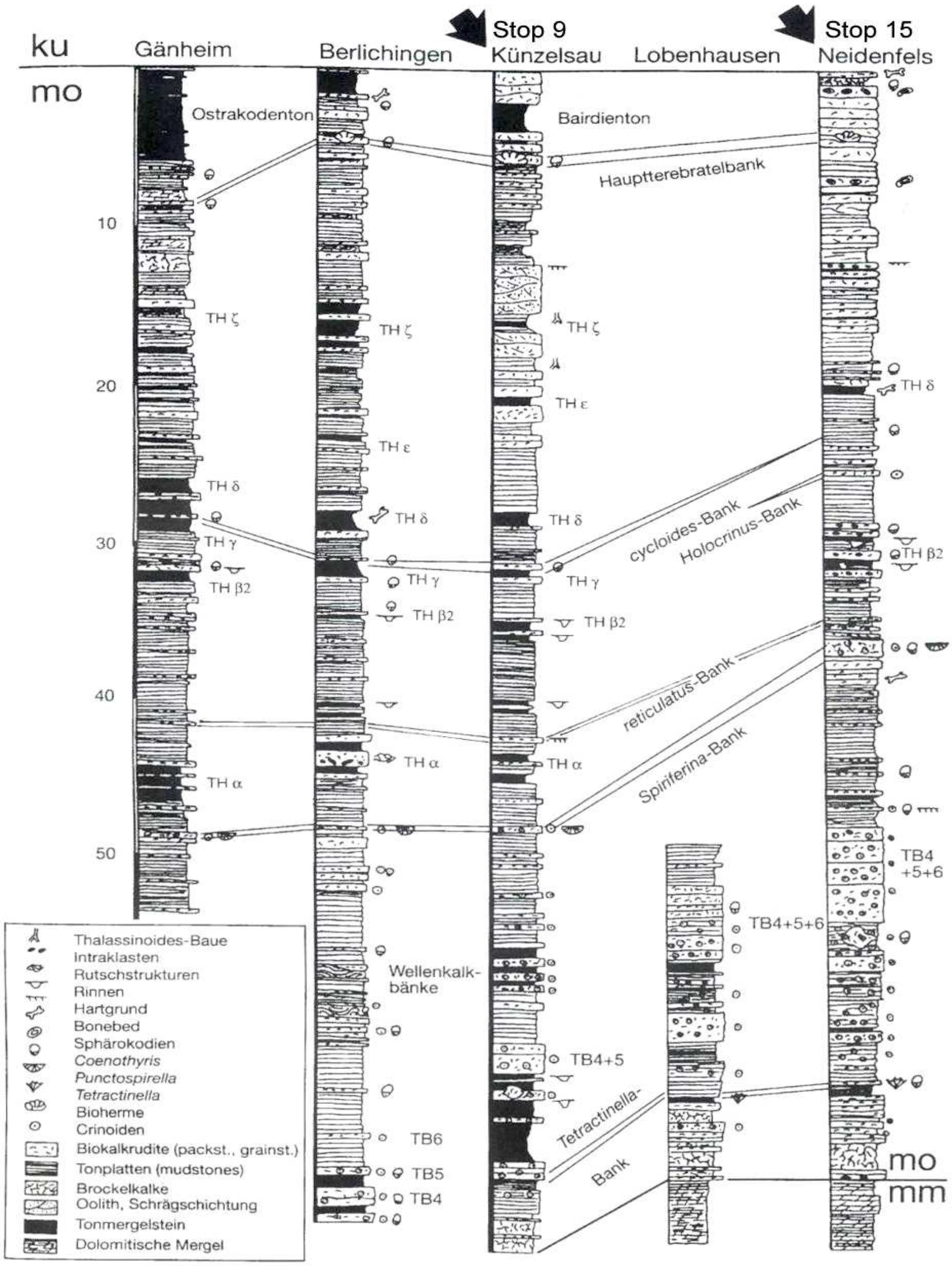
Alberti 1834, § 91–131 „Der Kalkstein von Friedrichshall"

While active, the quarry exposed almost the entire 75 m thick Upper Muschelkalk. However, due to rockfall, its lower part is not any longer accessible. Due to subrosion of the Middle Muschelkalk evaporites next to the edges of river Kocher valley, large Upper Muschelkalk blocks have moved towards the valley and caused deep joints that were infilled by talus deposits during Pleistocene. Palaeogeographically, the quarry, which belongs to the Kochendorf Facies, is in a transitional position of the deep to the shallow Upper Muschelkalk carbonate ramp with interfingering shallow water skeletal and oolitic limestones and deeper water marlstones. This results in a high resolution marker bed allostratigraphy (more than 40 marker beds). Thus, the section can be easily subdivided in Folgen and Subfolgen. Its wealth of ceratites allowed the correlation of the marker beds with the biostratigraphic zonal scheme. The outcrop is one of the best to demonstrate cyclicity.



Upper Muschelkalk at Künzelsau-Garnberg. The thinly bedded limestone-marlstone section around Tonhorizont beta represent the maximum flooding surface. Upsection meter-scale cycles with increasingly shallowing trend. Photo HAGDORN.

- **Trochitenkalk Formation**. Of the 29 m thick formation, presently only its upper member (Bauland Member) can be observed, characterized by cyclically alternating crinoidal limestone beds and soft bottom dominated "Tonplatten" facies (thinly bedded micrites and distal tempestites alternating with marls). The Spiriferinabank at the top of the member is the latest mass occurrence of *Encrinus liliiformis*.
- **Meißner Formation**. The lower part of the 46 m thick formation is developed in typical Tonplatten facies devoid of crinoidal remains. Upsection of Tonhorizont delta, bed thickness is increasing (Künzelsau Member). The ecostratigraphical markers of the Cycloidesbank and the Hauptterebratelbank are well developed.
- **Main features to be observed**. Individual beds: Proximal to distal tempestites with erosional bases, shelly lags, low angle (hummocky) stratification and wave ripple tops. Gutter casts. Amalgameted shelly/oolitic limestones. Shell pavements with soft bottom and shellyground fossil assemblages. Lateral facies change of the "Bank der kleinen Terebrateln", a southward extension of the Quaderkalk facies. Ecostratigraphical marker beds.



Lithological logs of Upper Muschelkalk in the Hohenlohe area with major marker beds. From HAGDORN et al. 1991

Facies sequences and stacking pattern: meter-scale cyclicity. Dominance of asymmetrical, shallowing-upward cycles. Transgressive/regressive stacking of meter-scale cycles. Maximum flooding surface at Tonhorizont beta2. Paleoecology: Large *Placunopsis* bioherms. Different fossil assemblages indicating different substrates. Spongeliomorph (thalassinoid) burrows with body fossils of the lobster *Pemphix sueuri*.

Points of discussion

- Cycle diversity caused by regional subsidence patterns
- Marlstone origin
- Position of maximum flooding surface

References

WAGNER 1913, HAGDORN 1982, HAGDORN & MUNDLOS 1982, AIGNER 1985, BACHMANN & BRUNNER 1988, BRUNNER 1988, HAGDORN & SIMON 1993, AIGNER et al. 1990, HAGDORN et al. 1991, 1998

Stop 10 Krensheim, quarry of E. Seubert GmbH Kleinrinderfeld, 900 m WSW´ Krensheim. Upper Muschelkalk (Quaderkalk Formation, Meißner Formation), Lower Keuper (Erfurt Formation)

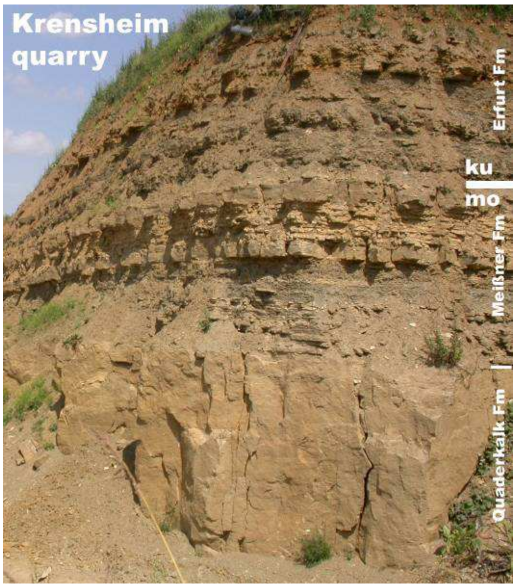
GK 25: 6324 Tauberbischofsheim-Ost, R 35 55 650, H 55 00 200

Alberti 1834, § 91–131 „Der Kalkstein von Friedrichshall"

In the Krensheim Quaderkalk area the Quaderkalk Formation is approx. 10 m thick, however, only the upper 5 m of the Upper Hauptquader Member are quarried. Due to jointing, the beds are broken in large blocks, the so called Quader, which makes quarrying much easier. Rocks of the upsection Meißner and Erfurt formations are removed und deposited on the dump.

- In the **Quaderkalk Formation**, up to 2 m thick skeletal grainstones with micritic seams of the arenitic to ruditic components and oolitic and peloid grainstones are dominating. The microfacies indicates a high energy depositional environment under shallow water with continuous bioclast reworking. Sedimentary structures are oblique bedding, megaripples, hummocky cross stratification, tempestites, and bipolar structures that are interpreted as tidal influence. Different types of minor cycles indicate changing water depths in a transgressive / regressive regime. The separate Quaderkalk layers form a set of pancake like bodies which were laterally shifting over the Northwestern extension of the Gammesfeld Swell.

- The overlying **Meißner Formation** commences with the 1.2 m thick Upper Terebratelbank, interbedded dm-thick brachiopod and bivalve shell beds and marlstones. Laterally the bed may reach up to 2 m. Gutter and pot casts contain a well preserved fossil assemblage (*Coenothyris vulgaris/Promysidilla eduliformis*-palaeocommunity) of epibenthic filter feeders, that were anchoring on large *Placunopsis* bioherms. Steinkerns of the zonal index *C. (Discoceratites) semipartitus* indicate the latest of the ceratite biozones. In the upsection Wimpfen-Subformation (Fränkische Grenzschichten), stenohaline faunal elements are replaced by abundant ostracods (1.5 m thick *Bairdia*-Ton), which is interpreted as the southernmost incursion of the dolomite and marlstone dominated Warburg-Formation of the Southern Permian Basin. The approx. 1,4 m thick Glaukonitkalk is characterized by septarian nodules, convolute bedding, and tepee-like folded and broken beds („Gekrösekalk").



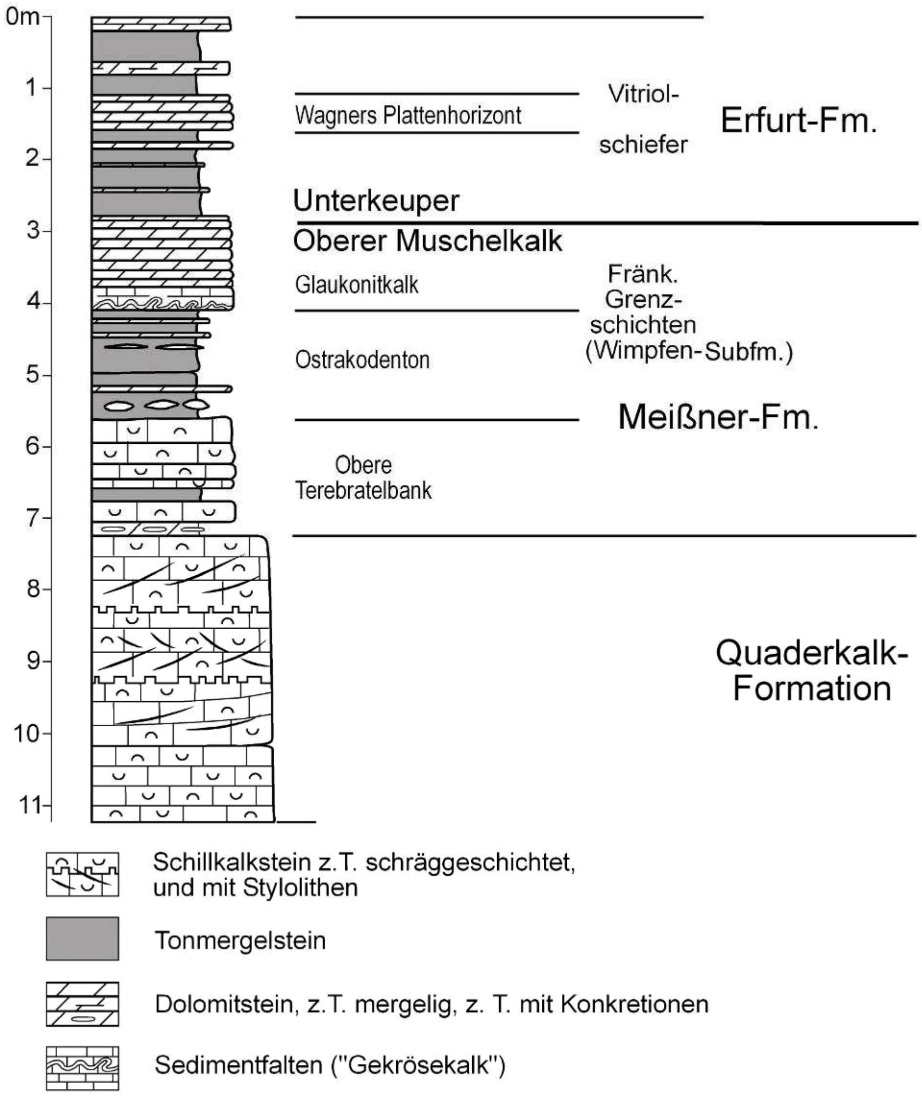
The Seubert quarry. Photo HAGDORN.

Points of discussion

- Gekrösekalk origin

References

WAGNER 1913, BACHMANN 1979, AIGNER et al. 1990, BRAUN 2003, GEYER 2002, KOSTIC & AIGNER 2004



Log of the Seubert quarry. From HAGDORN et al., in prep.

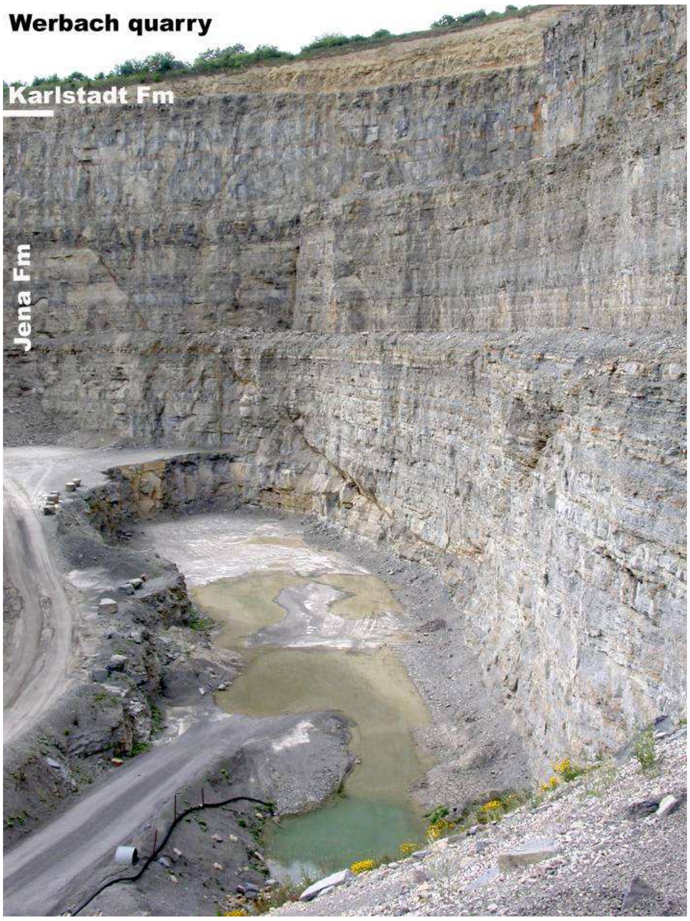
Stop 11 Werbach, quarry of Schotterwerke Hohenlohe-Bauland GmbH & Co KG Osterburken, 1.7 km ESE´ Werbach. Lower Muschelkalk (Jena Formation), Middle Muschelkalk (Karlstadt, Heilbronn, Diemel formations)

TK 25: 6323 Tauberbischofsheim-West, R 35 47 900, H 53 03 400

Alberti 1834, § 58–60 „Der Wellenkalk“, § 72–90 „Gruppe des Anhydrits“

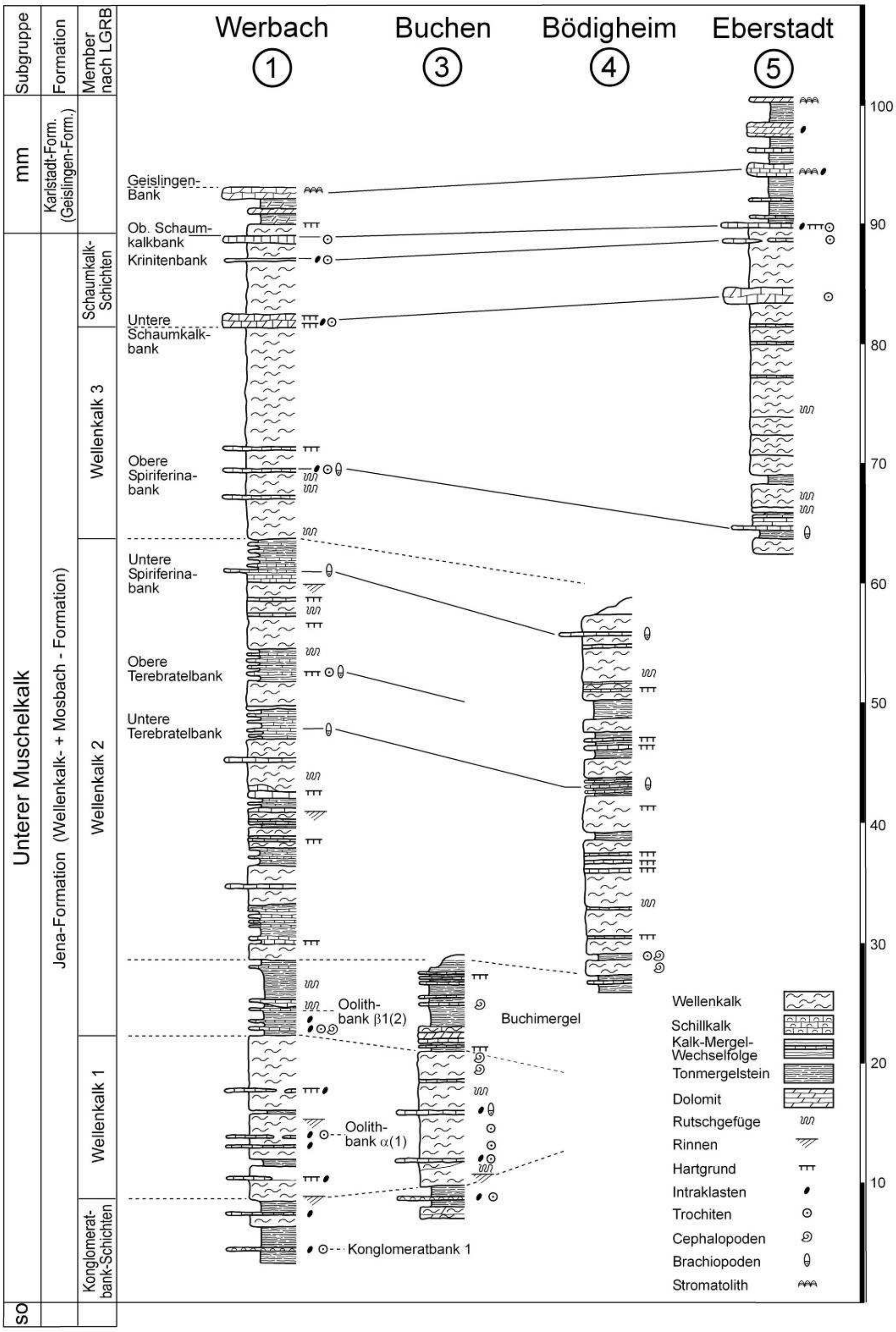
Depending on the quarrying situation, almost the entire Lower and Middle Muschelkalk are exposed. The basal 2 m of the Jena Formation were temporarily opened in a drill hole. The outcrop is situated in the transitional area of the marlstone dominated Mosbach facies and the typical Wellenkalk facies of the Jena Formation. At Werbach, the Lower Muschelkalk is attributed completely to the Jena Formation.

- The Konglomeratbank and Wellenkalk 1 members of the **Jena Formation** are characterized by Wellenkalk facies interbedded with the biointrasparitic Konglomeratbänke. The upsection 6.2 m thick Buchi Marls at the base of Wellenkalk 2 Member have higher clay content that is still increasing towards the South. The Buchi Marls can be correlated with the marker bed of Oolithbank β1 in areas farther to the North and with the basal *Homomya albertii* Beds of the Freudenstadt Formation (cf. Stop 3). Shell pavements may contain pyritized nuclei of the hedenstroemiid cephalopod *Beneckeia buchi* and bivalves. Within the upsection 18 m of marly, bioturbated Wellenkalks with hard grounds, channels, and seismically induced debris flows are the marker beds of the Lower and the Upper *Terebratula* Bed with the Schwarze Schiefertone inbetween. However, at Werbach they are thin distal tempestites or hard grounds with rare specimens of *Coenothyris vulgaris*. Farther to the North (Homburg-Lengfurt), they grade into dm-thick terebratulid coquinas, and finally (Central Germany) into m-thick skelatel and oolite beds.



The Werbach quarry. Photo HAGDORN.

Farther to the South, the Schwarze Schiefertone thickness increases. This horizon represents the MFS of the Lower Muschelkalk Sequence. Additional marker beds are the 2 upsection *Spiriferina* Beds with diverse epibenthic fauna, e.g. the Tethyan articulate brachiopods *Punctospirella fragilis* (former „*Spiriferina*“) and – restricted to the Upper *Spiriferina* Bed – *Hirsutella hirsuta*. The latter bed is already within Wellenkalk 3 Member with much less clay content and thinly flaser and platy bedded typical Wellenkalks that keep on to the top of the Lower Muschelkalk. In the Schaumkalkbank Member, the 2 up to 1 m thick, reddish skeletal and shelly Schaumkalk Beds can be indentified from distance. Along the steep and dry valleys, they form prominent ledges. Internally, the cross stratified marker beds have hard grounds that may laterally wedge out, layers with imbricating black pebbles, and a relatively diverse fauna including stenohaline echinoderms. The dm-thin tempestite of the Krinitenbank with abundant *Holocrinus dubius* and encrinid columnals can be traced through Lower



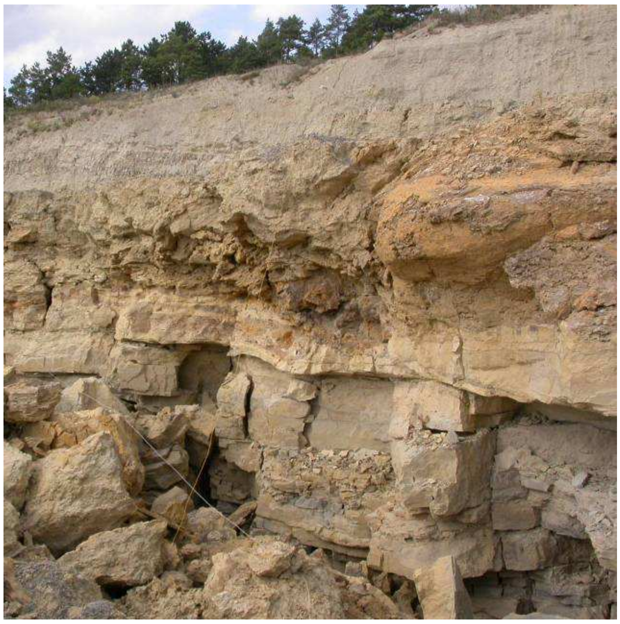
Lithostratigraphic logs of the Lower Muschelkalk at Werbach and nearby outcrops. From HAGDORN & SIMON 2005.

Franconia and North Badenia. The top of Folge m3 is at the surface of the Upper Schaumkalkbank that can be traced over hundreds of kilometres to the North and Northeast.

- The **Karlstadt Formation** of the Middle Muschelkalk commences with 1.5 m of Wellenkalks that grade into evenly bedded, slightly bituminous marlstones interbedded with thin limestones with abundant *Neoschizodus orbicularis* (myophoriid bivalve) that gave this unit its former name Orbicularisschichten. The Geislingen-Bank that bipartites the formation is a micritic and locally shelly limestone with lensoid stromatolite bioherms (LLH type) on its top. The upper 5.8

m of the Karlstadt Formation with the Stetten Conglomerate Bed are dolomitic marls with abundant *N. orbicularis* and stromatolitic limestones.

- The evaporites of the salinar **Heilbronn Formation** have been almost completely dissolved. Due to the quarrying situation, patchily distributed gypsum remains may be found. The formation commences with 7.5 m residual rock, upsection 1.5 m brecciated dolomites that may be laminated. cm-thin layers of reddish eolian sediments are derived from Massif Central. Towards the Western border of the Germanic Basin, they grade into the red dolomitic marls of the Ralingen Formation. Upsection follows the Zwischendolomit, a 7 m thick set of dolomitic marls and micritic limestones that may be stromatolitic, and then 15 m of residual rock.
- In the quarry, up to 4 m of the 15 m thick dolomitic, often laminated limestones of the **Diemel-Formation** were observed.



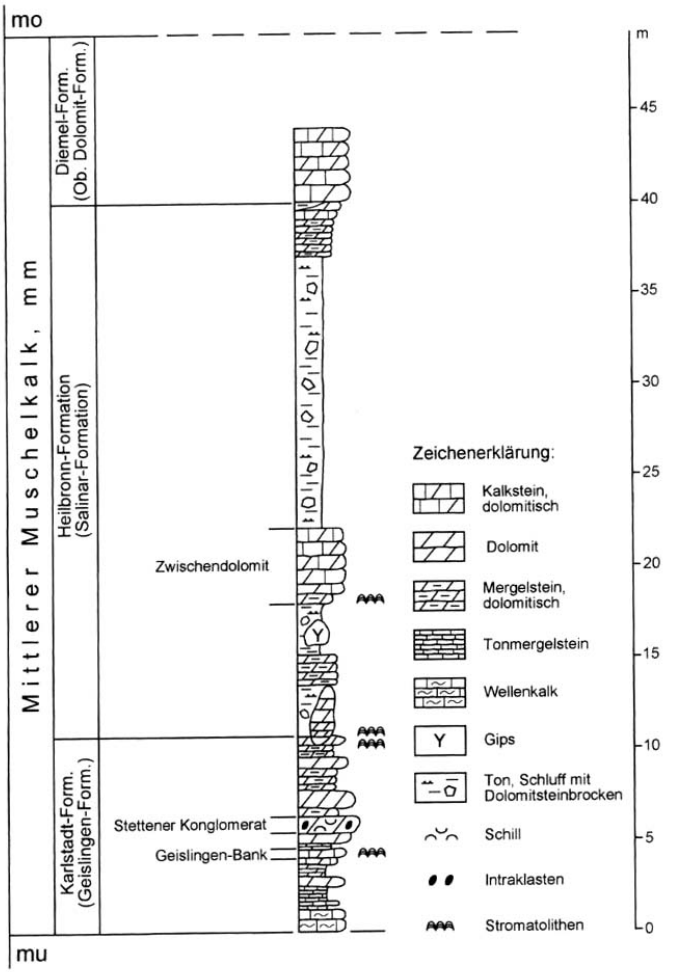
Stromatolite bioherm on top of the Geislingen Bed. Photo HAGDORN.

Points of discussion

- Lower/Middle Muschelkak boundary
- Depositional environment of stromatolites

References

VOLLRATH 1923, SCHWARZ 1970, SIMON 1982, 1991, 2003,
HAGDORN & HAGDORN & al. 1991,
SIMON 2005



Lithostratigraphic log of the Middle Muschelkalk in the Werbach quarry. Formation names of Geological Survey in brackets. From HAGDORN & SIMON 2005.

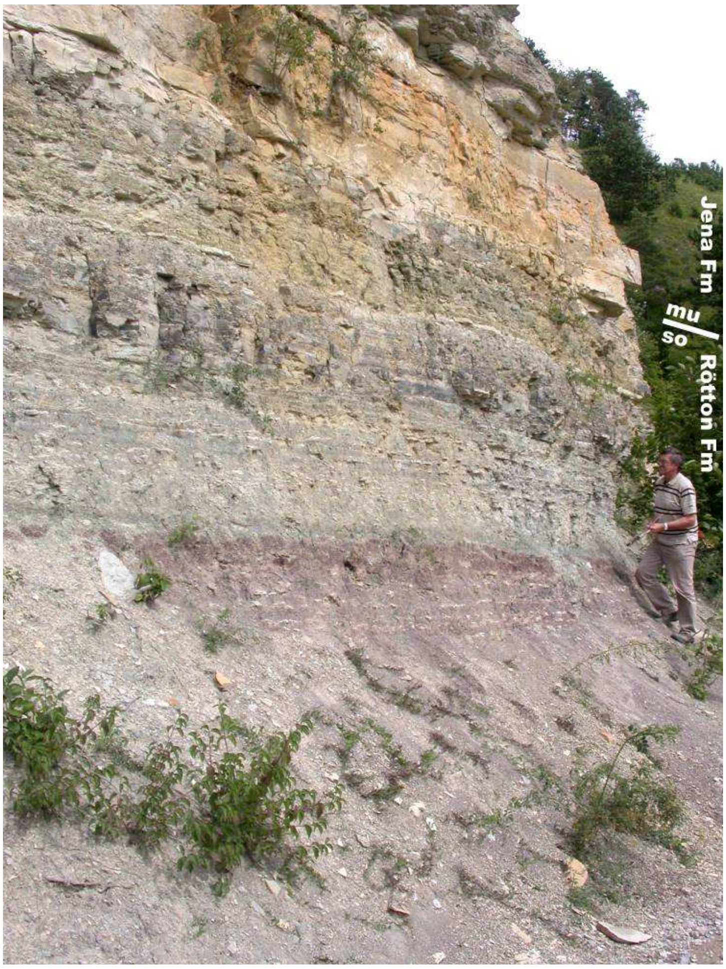
Stop 12 **Homburg on River Main, road cut along Oberer Weinbergweg (Upper vineyard road) in Naturschutzgebiet Kallmuth (natural preserve), 700 m N´ Homburg. Upper Buntsandstein (Rötton Formation), Lower Muschelkalk (Jena Formation)**

GK 25: 6123 Marktheidenfeld, R 35 45 290, H 55 18 600

Alberti 1834, § 43–56 „Der bunte Sandstein Elie de Beaumont´s“,
§ 58–59 „Der Wellenkalk“

The road exposes the Buntsandstein/Muschelkalk boundary and the lower part of the Lower Wellenkalk Member.

- Along the vineyard road, reddish, greyish and greenish sandy claystones of the 30 – 35 m thick Upper Rötton Member with the *Myophoria* Beds of the **Rötton Formation** are exposed. The downsection 5 – 8 m thick Rötquarzit (Fränkischer Chirotheriensandstein) is not exposed. Residual sediments give evidence for thin gypsum layers and nodules that have been dissolved; upsection, the carbonate content is increasing. The depositional environment was a playa plain that was occasionally flooded. Other outcrops have yielded conchostracans, *Myophoria vulgaris* and other bivalves, and small vertebrate remains. The uppermost layers are the yellowish, carbonatic Strohgelbe Kalke that have yielded insect remains (Coleoptera, Blattodea, Homoptera, Heteroptera, Planipennia) in nearby outcrops. *Myophoria vulgaris* indicates Anisian age.



The Buntsandstein/Muschelkalk boundary in the Kallmuth road cut. Photo HAGDORN.

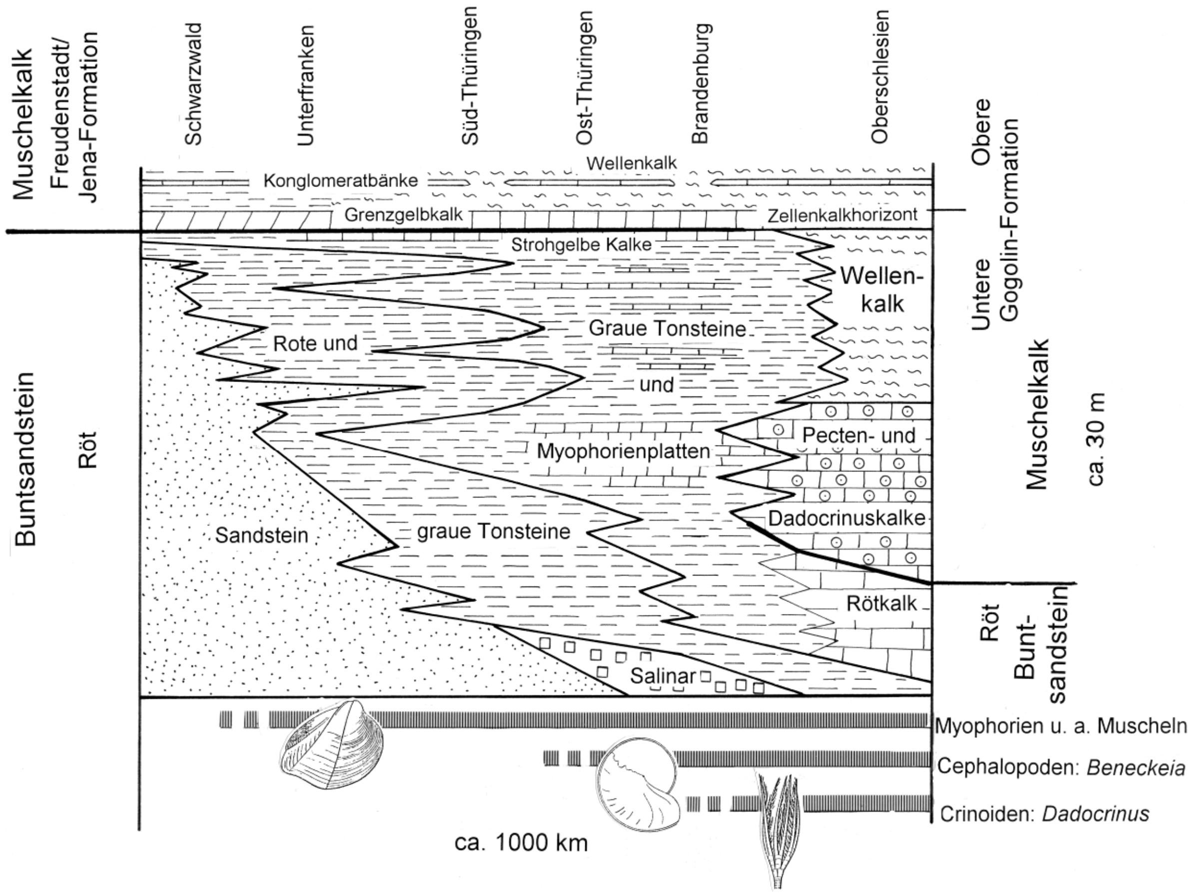
- The basal bed of the Lower Muschelkalk **Jena Formation** is the Grenzgelbkalk (Cellular Limestone in Poland) that can be traced as a marker bed (base of Folge m1) over large distances into the facies of the Freudenstadt and the even into the fully marine Gogolin Formation of Upper Silesia. It is a yellowish dolomitic marlstone that is mostly dedolomitized. In the Kallmuth outcrop it is overlain by a skeletal bed with crinoid ossicles and black pebbles. This is the first of the Konglomeratbänke, tempestite beds with reworked hard grounds. Their regional correlation is problematic because they disappear and reappear within larger outcrops. The Konglomeratbänke are interbedded with evenly bedded marlstones and Wellenkalk.

Points of discussion

- Lithostratigraphic versus allostratigraphic Muschelkalk base (cf. Stop 2)

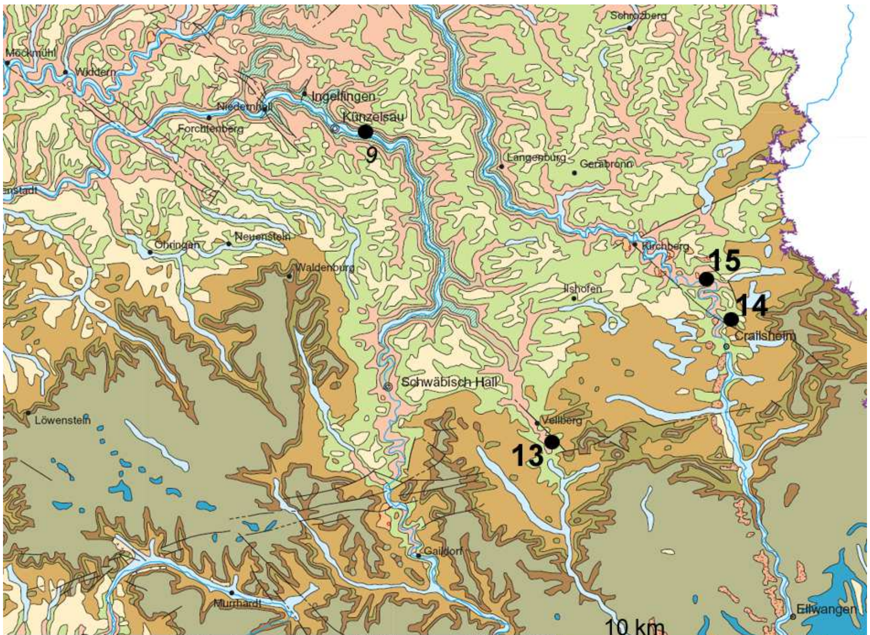
References

SCHUSTER 1936, FREUDENBERGER 1990, GEYER 2002



Schematic W-E section along the Buntsandstein/Muschelkalk boundary between Black Forest and South Poland. Due to the E-W transgression of the Muschelkalk sea, the lithostatigraphic Muschelkalk base is shifting upsection towards the West. Marine faunal elements gradually disappear towards the West. From HAGDORN & SIMON 2005.

Friday, 11. Sept. 2009



Geologische Übersichtskarte von Baden-Württemberg 1:300 000

Stop 13	Lower Keuper (Erfurt Formation); Ladinian: quarry with vertebrate lagerstaetten near Vellberg-Eschenau
Stop 14	Lower Keuper (Erfurt Formation); Ladinian: abandoned sandstone quarry near Crailsheim-Fallteich
Stop 15	Upper Muschelkalk (Trochitenkalk and Meißner formations); Anisian, Ladinian: quarry near Satteldorf-Neidenfels

Stop 13 **Vellberg-Eschenau, Quarry of F. Schumann GmbH Gründelhardt, 500 m SSE´ Eschenau. Upper Muschelkalk, Lower Keuper (Erfurt Formation)**

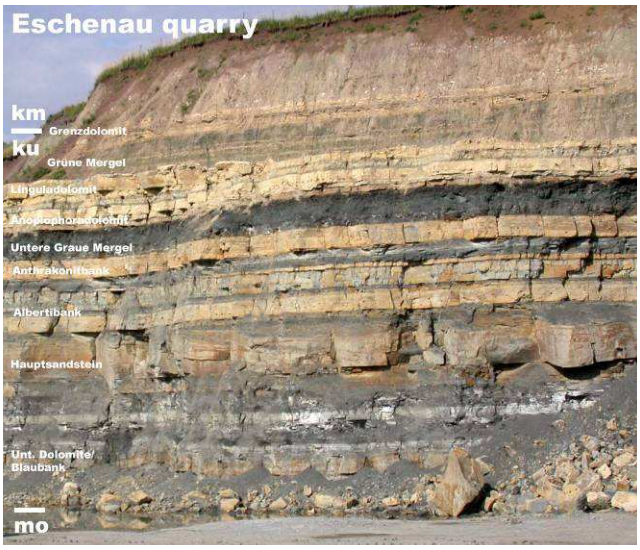
GK 25: 6925 Obersontheim, R 35 65 500, H 54 38 350

Alberti 1834, § 135–158 „Die Gruppe der Lettenkohle“

The quarry exposes almost the entire Upper Muschelkalk, the Lower Keuper, and the base of the Middle Keuper Grabfeld Formation. However, the focus of the field trip is on the Erfurt Formation. During the last 30 years, this quarry has become one of the most important Middle Triassic vertebrate localities. A plethora of labyrinthodont and reptile specimens collected by Werner Kugler from Crailsheim are exhibited in the Muschelkalkmuseum in Ingelfingen. The Vellberg Fault with Hercynian strike and up to 50 m displacement is touched within the quarry.

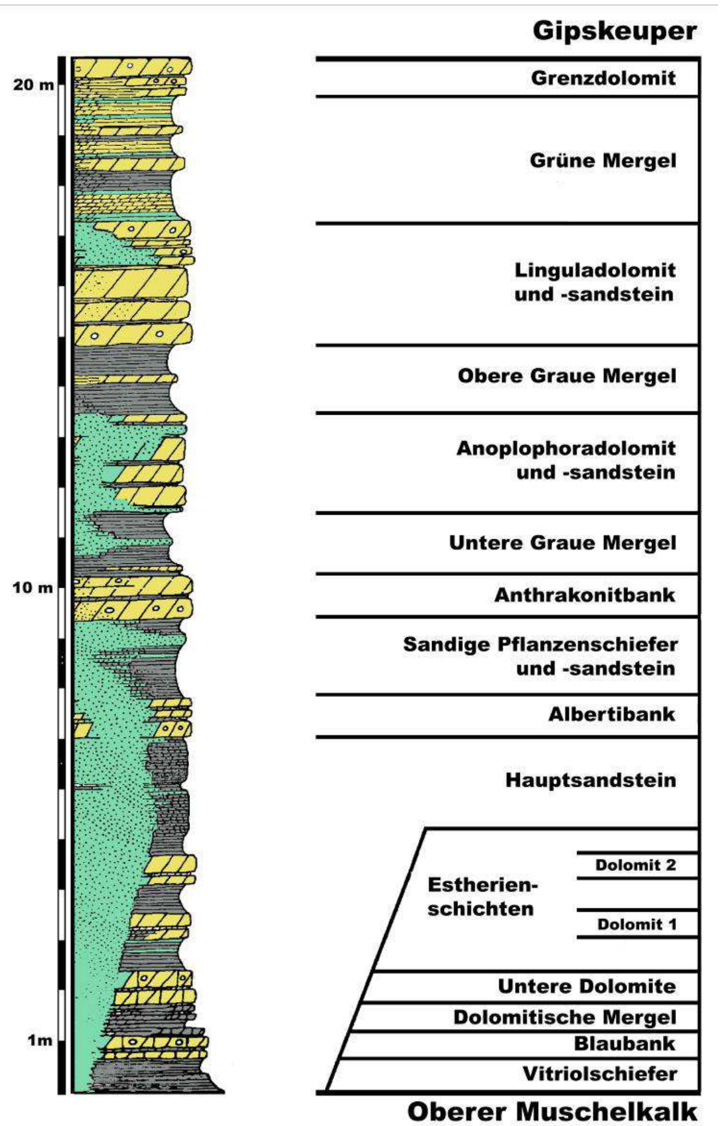
Upper Muschelkalk and Lower Keuper with Middle Keuper base – ca. 10 m of gypsum have been dissolved – in the Schumann quarry. Photo HAGDORN.

- The 26 m thick **Erfurt Formation** is developed in its typical North Baden-Württemberg facies. All members are easily accessible and can be studied in detail. The Muschelkalk-Keuper boundary bonebeds shows the microtectonic Querplattung structure, that is probably caused by seismic shock. Upsection of the ca. 0.8 m thick Vitriolschiefer, the Blaubank and the Lower Dolomites form a carbonate member with restricted marine invertebrate and vertebrate fauna, e.g. thin bone beds. Two dolomitic marlstone beds within the otherwise clay dominated Estherienschichten are rich in conchostracans and lingulid brachiopods, and have yielded a few fish and marine reptile skeletons (*Nothosaurus*). The upsection following Hauptsandstein is a greenish grey, finely grained, clay bound sandstone that was transported from Scandinavia in a braided river system. Within the outcrop, the lateral facies change of the sandstone can be observed: a channel of thick bedded sandstones with a basal bone bed and wood fragments has incised as deep as the Lower Dolomites (building stone facies); laterally it grades into thinly bedded, mica-rich sandstones and sandy claystones. Upsection, the carbonatic Albertibank deposited in a brackish or limnic environment contains poorly preserved bivalves. At the base of the restricted marine Anthrakonitbank, a bonebed has yielded a very diverse fish, amphibian, and reptile fauna (including the placodont *Psephosaurus*), however, only isolated bones, scales, and teeth. The most important vertebrate lagerstätte is within the Lower Grey Marls and the base of the Anoplophoradolomit. Continuous excavations have yielded many skulls and dentaries and postcranial elements of the huge *Mastodonsaurus*, the smaller stereospondyls *Kupferzellia, Trematolestes, Callistomordax,* and three plagiosaur genera, the rauisuchian crocodile *Batrachotomus*, basal archosauromorphs, chroniosuchians, and choristoderes. However, herbivores and faunal elements from the dry hinterland are still lacking.



Lower Keuper in the Schumann quarry. Photo HAGDORN.

The yellowish dolomitic marls farther upsection have yielded euryhaline invertebrates like conchostracans and lingulids. Only in the marine Grenzdolomit more diverse bivalve and gastropods (dominated by *Costatoria goldfussi*) occur. In nearby outcrops cephalopod *Germanonautilus* has been found.



Lower Keuper standard log for Northeast Baden-Württemberg. According to BRUNNER (1973).

Points of discussion

- lithostratigraphic correlation with the standard scheme
- small scale Lower Keuper facies patterns and environments
- dominance of large carnivore tetrapods

References

BRUNNER 1973, 1977, 1995, AIGNER et al. 1990, PÖPPELREITER, 1999, SCHOCH 2002

Stop 14 **Crailsheim-Fallteich, abandoned sandstone quarry of Schön + Hippelein GmbH & Co KG Satteldorf, 2 km NNW´ Crailsheim. Lower Keuper (Hauptsandstein Member of Erfurt Formation)**

GK 25: 6826 Crailsheim, R 35 78 800, H 54 46 800

Alberti 1834, § 135–158 „Die Gruppe der Lettenkohle"

The quarry still exposes up to 6 m of the up to 10 m thick Hauptsandstein in building stone facies. Traditional quarrying buildings and techniques can still be observed.

- The base of the **Hauptsandstein** is not exposed, upsection it is overlain by the Albertibank. The thick bedded sandstones are oblique and cross stratified and were transported at an angle of 230 – 245^{o} (NE – SW). The outcrop shows several holes from removed elliptical, sandy carbonate concretions in a layer in the middle of the Hauptsandstein. Obviously, the occurrence of these early diagenetic concretions that originated from a carbonate concentration gradient are restricted to the more marginal areas of the Lower Keuper basin. In Lower Franconia they are correlated with a nodule horizon at the top of the Estherienschichten in the inter-channel stillwater facies. These so called *Krotten* (toads) caused a lot of trouble for the quarry workers.

The Fallteich sandstone quarry. Photo HAGDORN.

Points of discussion

- concretion origin

References

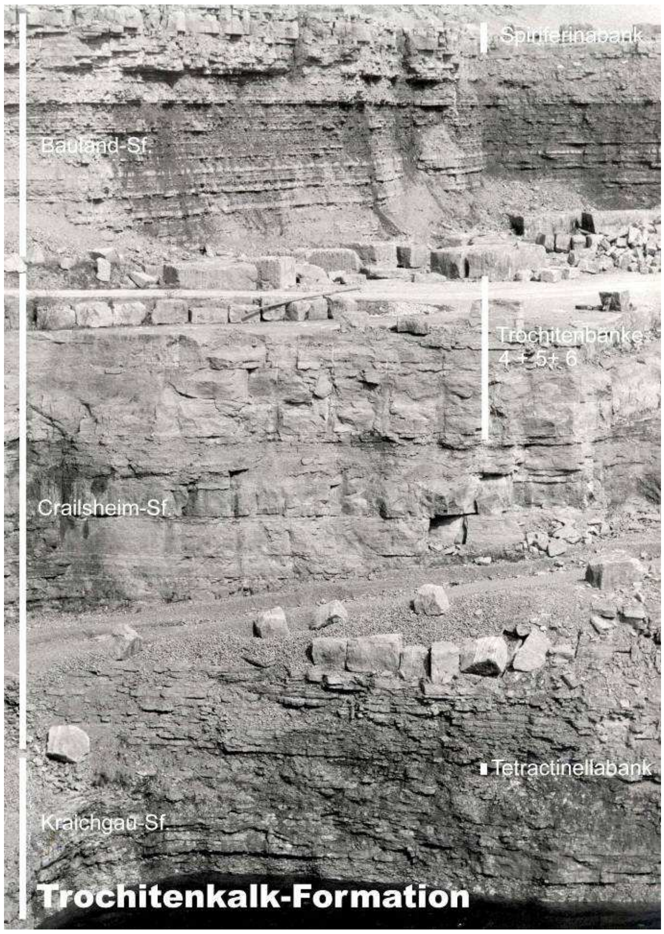
BRUNNER 1972, BRUNNER & HAGDORN 1985, ETZOLD & SCHWEIZER 2005

Stop 15 Satteldorf-Neidenfels, Quarry of Schön + Hippelein GmbH & Co KG Satteldorf, 700 m W´ Neidenfels. Upper Muschelkalk (Trochitenkalk Formation, Meißner Formation), Lower Keuper (Erfurt Formation)

GK 25: 6826 Crailsheim, R 35 77 000, H 54 49 350

Alberti 1834, § 91 –131 „ Der Kalkstein von Friedrichshall“, §135–158 „Die Gruppe der Lettenkohle“

The quarry exposes almost the entire Upper Muschelkalk and Lower Keuper. However, the focus of the field trip is on Trochitenkalk and lower part of Meißner formations. During the last 30 years, the well exposed and fossiliferous Crailsheim Muschelkalk has stimulated cyclostratigraphical and sequence stratigraphical (AIGNER (1985) and palaeoecological work (HAGDORN & SEILACHER 1993). Northwest of Crailsheim, River Jagst has incised into the morphologically resistant Upper Muschelkalk and formed a narrow valley devoid of roads with steep flanks and meanders. Downstream of Neidenfels the river has reached the thickly bedded crinoidal limestones of the Crailsheim Member (Trochitenkalk Formation), which are quarried as building stones since many centuries. Nowadays this working stone is cut and polished by the Schön & Hippelein Company. The Olympia Stadium in Berlin, the Kunsthalle Würth in Schwäbisch Hall, or the German Embassy in Tokyo are examples of buildings with Crailsheim Muschelkalk facades. At Neidenfels, the Upper Muschelkalk is 69 m thick; the lower 34 m belong to the Trochitenkalk Formation, the upper 35 m to the Meißner Formation (Fig. 9 –2). Presently, the 20 m thick Lower Keuper (Erfurt Formation) is well exposed. Many of the 100-ka-thickening-and-coarsening-upward-cycles can be recognized, as well as 4 superimposed sets of stacking 100-ka-cycles, and the general transgressive-regressive cycle covering the upper part of the Middle Muschelkalk and the entire Upper Muschelkalk. Each of the ecostratigraphical marker beds have been identified in the quarry, however, due to the relatively marginal position of the outcrop, they are untypical and hard to find.



Section of the Trochitenkalk Formation in the Schön + Hippelein Quarry (ca. 1988). Above the Middle Muschelkalk (water level), micritic limestones of the Kraichgau-Member, upsection thickly bedded crinoidal limestones of the Crailsheim Member, then thinly bedded limestone/marlstone facies of the Bauland-Member with the Spiriferinabank at the top. From: HAGDORN & OCKERT (1993).

- In the Southwest German **Trochitenkalk** carbonate ramp, the 16 m thick **Crailsheim Member** of thick bedded crinoidal limestones were deposited on a shallow ramp developed upon the Ries-Tauber Swell. Bed by bed correlation allows the stratigraphic connection with the 6 minor cycles of Trochitenbank 1 to 6 of the more basinal facies of the Frankonian depression (Hassmersheim and the Neckarwestheim members). During this time, the Crailsheim shoal that covered a few hundreds of km^2 was situated approx. 50 km Northwest of the coastline (HAGDORN& OCKERT 1993). On the carbonate ramp, different palaeocommunities, dominated by endobenthic bivalves, brachiopods, and crinoids are following from the deeper to the more shallow water. The crinoid *Encrinus liliiformis* preferred the shallow ramp and its offshore slope between wave base and storm wave base in a hydrodynamic regime that provided the filter feeders constantly with plankton and swept away muddy sediments. Farther towards the deeper water, small bioherms with a frame of terquemiid bivalves and crusts of crinoid-holdfasts occur every 100 m^2 (HAGDORN 1978, HAGDORN & OCKERT 1993). The crinoids were the most important producers of biomass and dominate the bioclasts in the sediment. *Encrinus* was living in clusters concentrated in the bioherms that acted as solid shell islands protruding a few decimetres over the otherwise muddy seafloor. While brachiopods and bivalves were filtering in the lowest tier close to the seafloor, *Encrinus* reached higher tiers up to 1.5 m, depending on its individual size. Frequent storm events in this depositional environment between wave base and storm wave base occasionally smothered the filter feeding benthic community and resulted in obrutional conservation lagerstätten, that yielded not only complete crinoids but also articulated echinoids, asteroids and ophiuroids. The top of Trochitenbank 4/5 is a hardground with a limonite veneer covered by irregular, dm-thick crusts of the cemented bivalve *Placunopsis ostracina* indicating a period of low sedimentation. These *Placunopsis* crusts cover more than a hundred km^2, in some areas concentrated on the crests of megaripples (HAGDORN & MUNDLOS 1982). The *Placunopsis* crusts were extensively bored by phoronoids; their mm-thick borings are filled with light-grey micritic limestone. Geometry of the Crailsheim Member carbonate body, its diagenetic history and reservoir potential has been studied by PALERMO (2007). Upsection, a facies change to thinly bedded limestones with tempestites, intercalating with marls (Bauland Subformation) indicates deeper water and soft-grounds with palaeocommunities dominated by endobenthic bivalves, *Rhizocorallium*, *Planolites*/*Palaeophycus* and *Thalassinoides,* and frequent ceratites of the *robustus* and *compressus* Biozones. The top of this set of stacked minor cycles is the 1.5 m thick Spiriferinabank, which is an oobiosparitic crinoidal grainstone in the Crailsheim area, however devoid of the brachiopod *Punctospirella fragilis*. During deposition of the Spiriferinabank, the Crailsheim area was situated on the re-established shallow ramp.

- The **Meißner Formation** commences with thinly bedded limestones intercalating with marlstone beds; some of the thicker beds are proximal tempestites with black pebbles. Compared to the more basinal facies, Folge m8 has reduced thickness. The Holocrinusbank, a 15 cm thick tempestite bed with an eroded firmground base, contains ossicles of the crinoid *Holocrinus doreckae,* a Tethyan immigrant. Due to the marginal position of Crailsheim, the Cycloidesbank is not typically developed at Neidenfels. Upsection, the marlstone intercalations become thinner in a general coarsening and thickening trend (Künzelsau Member). A m-thick grainstone contains *Girvanella*-Onkoids (*Sphaerocodium kokeni*). In the Crailsheim area, the Upper Muschelkalk ends in a low angle unconformity above the Upper Terebratelbank which is directly overlain by the Muschelkalk/Keuper boundary bonebed. The Wimpfen Member (Fränkische Grenzschichten), a minor cycle of up to 4 m thickness, has wedged out between Künzelsau and Crailsheim (WAGNER 1913, REIF 1974). The Upper Terebratelbank has yielded a diverse invertebrate fauna dominated by the brachiopod *Coenothyris vulgaris*. The Crailsheim area was famous for its well preserved specimens with reddish radial colour bands.

- With up to 30 cm, the boundary bonebed at the base of the **Erfurt Formation**, is the thickest and most widespread bonebed of the entire Germanic Triassic. Its base is considered a sequence boundary. At Neidenfels, the bonebed has a carbonatic base with intraclasts and rare reworked brachiopods and ceratite fragments. This layer is overlain by 2 – 5 cm of dolomitized and sandy marls that yielded well preserved vertebrate fossils. Upsection follows the typical bonebed, a dark grey, rusty-brownish weathering vertebrate sand with densely packed, reworked teeth, scales, bone fragments and coprolites. 30 species of actinopterygian, sarcopterygian, and elasmobranchian fish, amphibians, and reptiles have been identified in the Crailsheim boundary bonebed (HAGDORN & REIF 1988). Its fauna is dominated by marine elements, however, brackish tetrapods (*Plagiosternum, Mastodonsaurus*) also occur.

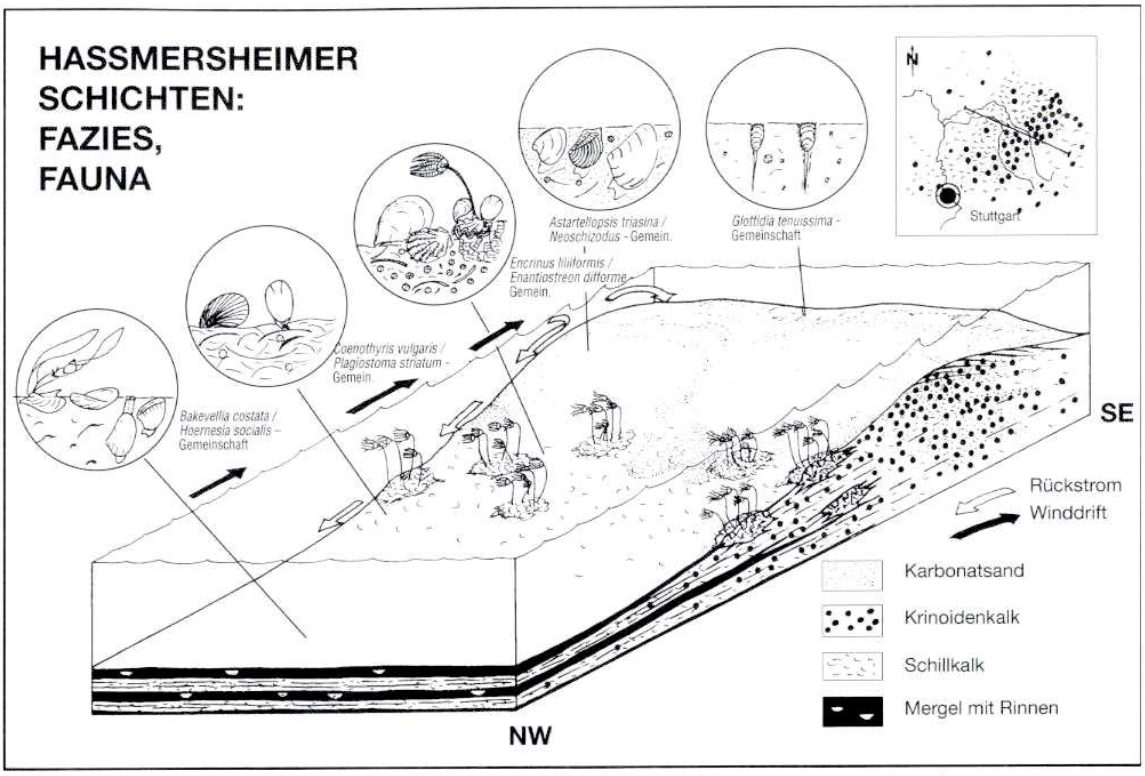
Points of discussion

- bonebed formation
- isochrony of marker beds
- disappearance of stenohaline faunal elements above MFS

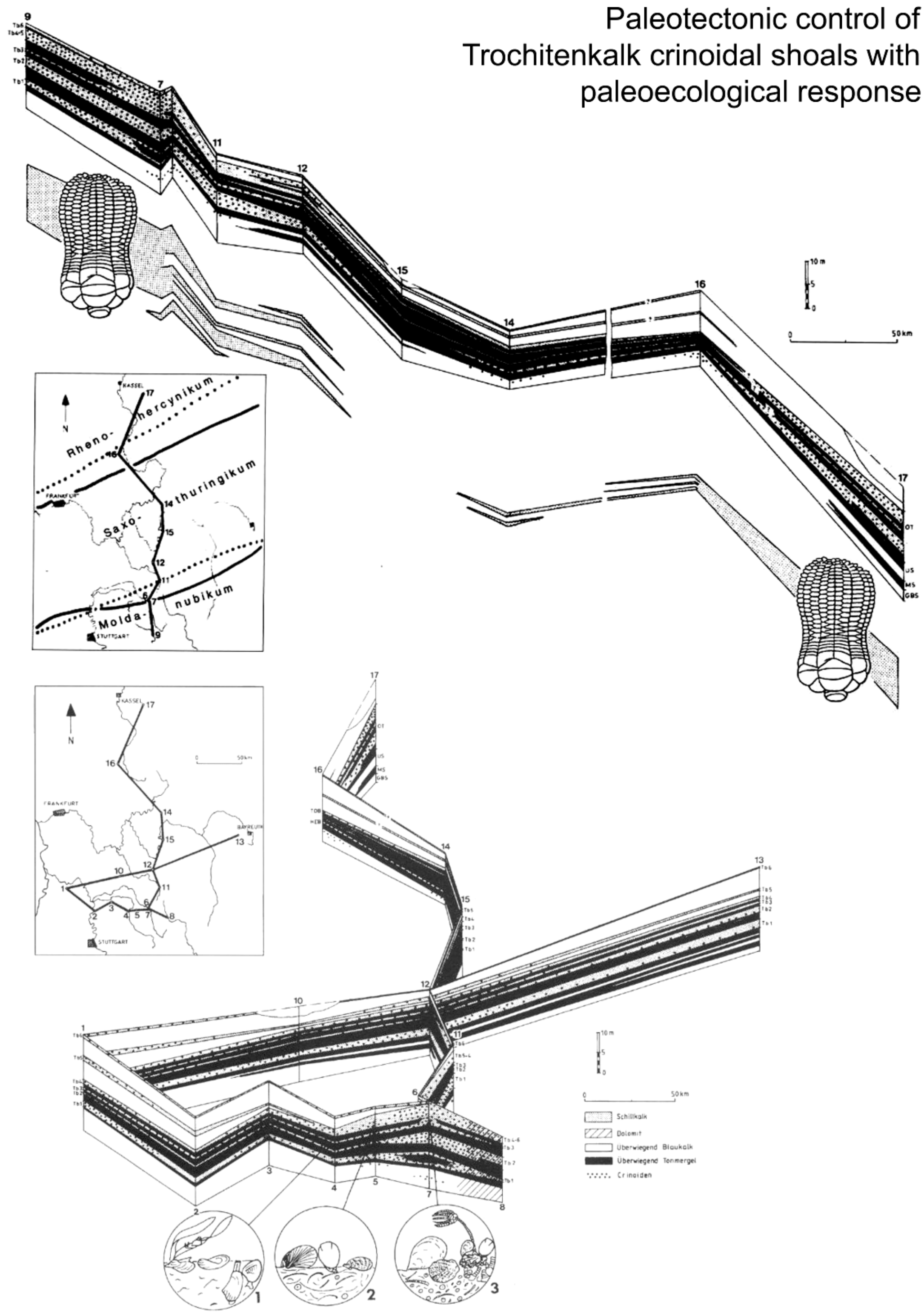
References

HAGDORN 1978, 1991, HAGDORN & MUNDLOS 1982, AIGNER 1985, HAGDORN & REIF 1988, HAGDORN & OCKERT 1993, PALERMO 2007

Schön + Hippelein quarry, actual situation 2009. Photo HAGDORN.



Southwest German Trochitenkalk carbonate ramp and zonation of palaeocommunities. From HAGDORN (1991).



Sections of the lower part of the Trochitenkalk Formation showing facies change due to paleotectonic positions. From HAGDORN (1991).

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