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26

4th International Symposium on Lithographic Limestone and Plattenkalk

Eichstätt/Solnhofen, Germany

September 12th-18th, 2005

- Abstracts and Field Trip Guides -

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Organised by

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Jura-Museum, Eichstätt

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– Abstracts and Field Trip Guides –

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Cover illustration: *Mesolimulus walchi* Desmarest; horse-shoe crab with its trail; Lower Tithonian, Solnhofen (BSPG AS I 944).

Umschlagbild: *Mesolimulus walchi* Desmarest; Pfeilschwanzkrebs mit Fährte; Lower Tithonian, Solnhofen (BSPG AS I 944).

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Field Trip B

East Bavarian Plattenkalk - Different Types of Upper Kimmeridgian to Lower Tithonian Plattenkalk Deposits and Facies

September 12th, 2005

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(English Translation: Martina Kölbl-Ebert)

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Introduction to the Plattenkalk and the Fossillagerstätten of Solnhofen

1. Solnhofen, a geological term

The importance of the early bird *Archaeopteryx* as proof and „missing link" for CHARLES DARWIN's theory of evolution following the years 1859 and the use of the rocks in the printing technique of lithography made Solnhofen into an important piece of terminology for the science of earth history. In this process lithography was so crucial that *Archaeopteryx lithographica* bears the invention of ALOIS SENEFELDER in its species name.

The term „Schiefer von Solnhofen" (shale of Solnhofen), which was used in the past, has been transferred to all areas of the Franconian Alb between Langenaltheim/Solnhofen in the west and Regensburg in the east across a distance of some 100 kilometres. Wherever stone-slabs of a similar quality appeared, quarrying started. In this region the roofs of the portly Jura-houses where tiled with Plattenkalk, transferring the structure of the landscape to human culture. Many of these houses today are protected.

The classic quarry areas are in the West near Langenaltheim, Solnhofen and Mörnsheim. Only here, in an area of a few square-kilometres, the true lithography stones are found. Further to the east follows the neighbouring vast quarry region of Eichstätt near Schernfeld, Wintershof and Workerszell. Further east follow the isolated Plattenkalk deposits of Pfalzpaint, Zandt, Jachenhausen, Painten and Kelheim. In all these regions, the quarry workers discovered an abundance of fossils. Small as Solnhofen may be as a village, so big is Solnhofen as location in earth history.

1.1 The Upper Jurassic Solnhofen archipelago

The first fossil to be figured from the Plattenkalk was depicted by MARIUS BESLER in the year 1616. JAKOB BAIER and EMANUEL WALCH followed; the latter giving his name to one of the most well-known Solnhofen fossils, the horseshoe-crab *Mesolimulus walchi*. During the last centuries rich collections of fossils originated which allow, together with geological studies, a differentiated view of the area of the Jurassic Solnhofen archipelago and the Solnhofen-type of Fossillagerstätte. Whichever model people may prefer, one thing seems to be certain: In the immediate vicinity of the Plattenkalk areas, there have been small islands and also bigger areas that rose above sea-level. The Solnhofen archipelago describes an image of a landscape with subtropical lagoons under a subtropical sun, islands, reefs and the more open areas of a carbonate platform with shallow water conditions. The shallow marine character of the region and the existence of at least a few islands can be viewed as proven today.

1.2 "Solnhofen" – a diversity of facies and fossils

Lithography and *Archaeopteryx* have promoted the trademark of Solnhofen internationally. This had consequences especially for the fossils. No matter, whether a fossil was found in the slabs near Solnhofen or in Kelheim, 80 km further east, it used to be labelled as fossil from the "lithographic shale of Solnhofen". "Schiefer" was the quarry workers' term for thin slabs. With „Plattenkalk" they addressed somewhat thicker slabs and „Bänke" were those with a thickness of up to 30 cm. The petrographically correct term of Plattenkalk remained. Because of the inclusive use of the Solnhofen trademark along its some 100 km wide distributional area with locally very

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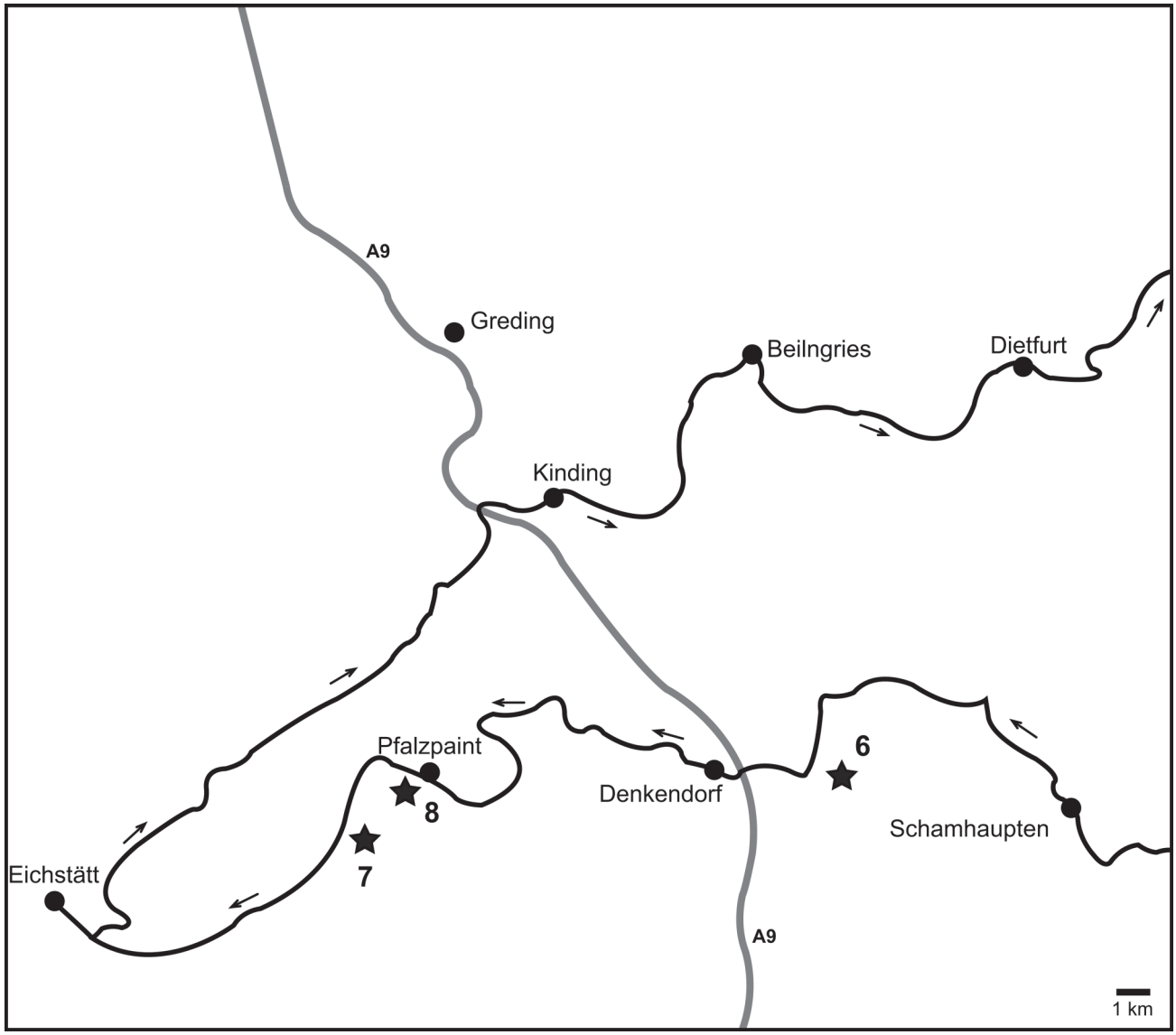

Figure 1: Location of the outcrops.

different fossils, a sort of 'stew' ("Eintopf"), i.e. a strongly simplified image of 'Solnhofen' fossils was created. This process of merging everything under one heading possibly reached its peak in KARL ALBERT FRICKHINGER's first book of 1994 about the fossils of Solnhofen. In principle, still a decade ago, all the fossils were interpreted as 'Solnhofen' fossils, whether they came from finely bedded or laminated sediments, from debris fans of the coral reefs or from the interbedded limestone banks of the Upper Jurassic of Bavaria, although the true lithographic stone s. str. was found only in a tiny area of a few square-kilometres in the Solnhofen area. Only the second volume (FRICKHINGER 1999) contains in the supplement the attempt of a more differentiated view of the single Plattenkalk basins and Fossillagerstätten.

This phenomenon, in principles recognized in 1904 by the Jena university professor JOHANNES WALTHER, allows for fascinating possibilities of detailed regional documentation of the different deposits between Solnhofen and Regensburg. Surrounded of massive limestone and carbonate-sands there are a wealth of smaller and larger sediment basins, of which the most important ones shall be characterized here:

- The basin of Solnhofen with the localities of Solnhofen, Mörnsheim, Mühlheim and Langenaltheim. They represent the central facies of the basin and the so-called 'Solnhofen Plattenkalk facies'. Near Haunsfeld a facies belonging to the basin rim is visible. Similar to other basins, this rim facies is characterised by a wealth of trace fossils.
- The basin of Eichstätt with the localities Schernfeld, Wegscheid, Birkhof, Wintershof and Workerszell. These deposits belong to the so-called 'Eichstätt Schieferfazies' (Eichstätt shale-facies).
- The unusual facies of Pfalzpaint with its marked influence of currents in the mouth of a channel connecting two Plattenkalk basins.
- The basin of Denkendorf-Böhmfeld with trace fossil- and burrow-bearing shales.
- The isolated basin of Schamhaupten-Zandt with three stratigraphically different Fossillagerstätten above each other: Schamhaupten, Breitenhill and Zandt.

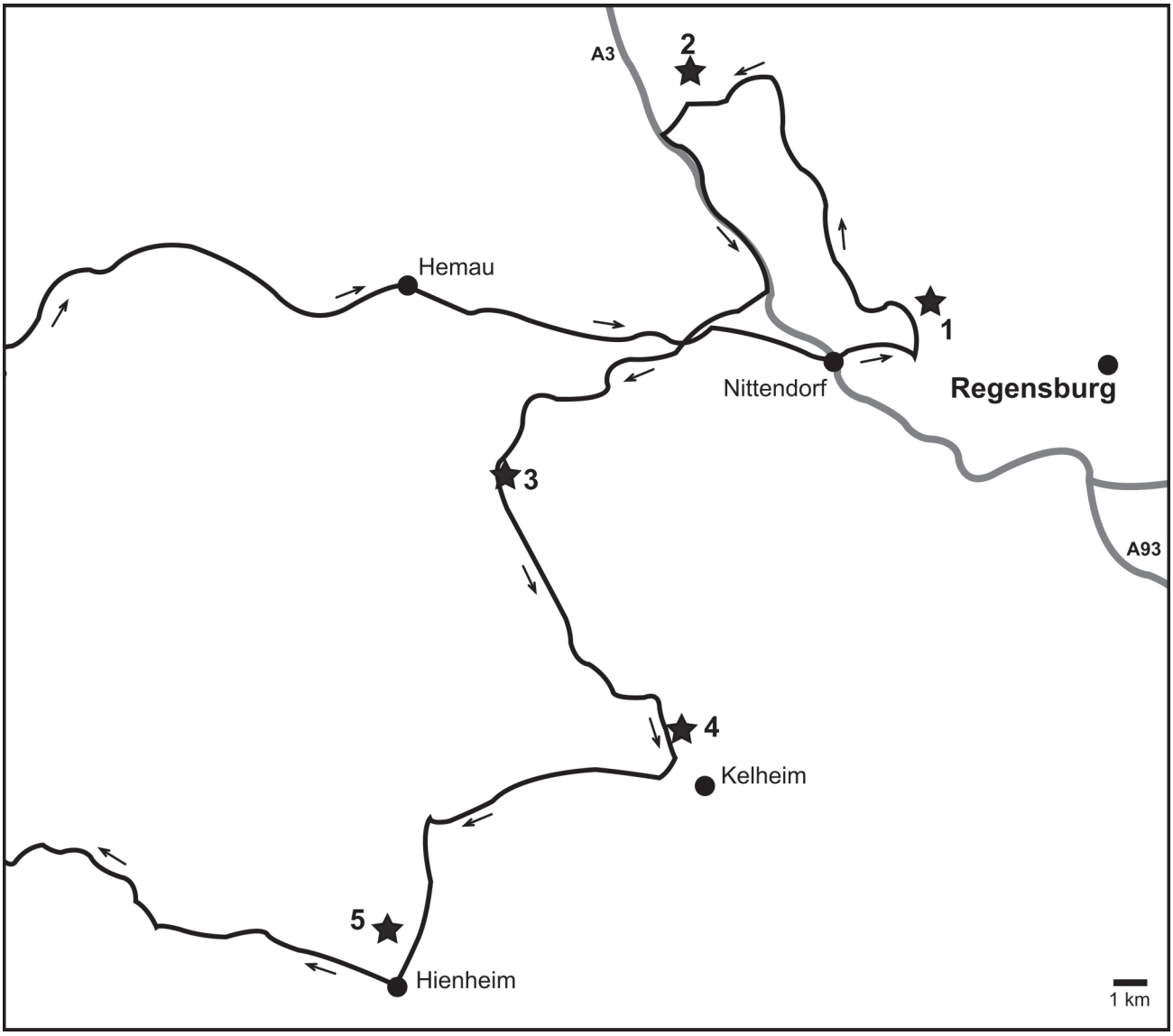

Figure 1 cont.

- The basin of Hartheim-Hepberg with bioturbated limestone banks.
- The basin of Hienheim-Kelheim with Lithographic Plattenkalk and the Fossillagerstätte Hienheim in the younger marly Plattenkalk.
- The basin of Painten with variable types of Plattenkalk and Fossillagerstätten near Jachenhausen and Painten.
- The basin of Pfraundorf-Heitzenhofen with the oldest Solnhofen-type Fossillagerstätte near Brunn.
- South of Brunn there are more Plattenkalk-basins in the region of Kelheim. Also in the west, i.e. south of Solnhofen, there is another much extended Plattenkalk-area with the youngest Solnhofen-type Fossillagerstätte near Daiting.

2. Plattenkalk types

Lithographic Plattenkalk

This Plattenkalk-type with the widest distribution consists of finest grained limestone slabs (Flinz) irregularly interbedded by marl layers (Fäule). The Flinz is the only type which is quarried to be used as flagstones. Therefore, the number of fossils found in these rocks is great. Stratigraphically, this rock-type is mainly restricted to the Lower Tithonian. It has its farthest distribution in the Solnhofen Formation, in the past also called the Solnhofen Beds in the Franconian Malm zeta 2. The main areas of distribution are around Solnhofen and Eichstätt. Further to the east follow Pfalzpaint, Zandt, Jachenhausen, Painten and Kelheim.

As far as the borders of these basins are known at all, most areas are bordered by carbonate sands or the dense limestone complexes of former sponges-microbial reefs. With the exception of the region around Jachenhausen and Kelheim an influence of reefs can nowhere be demonstrated. Mostly the Lithographic Plattenkalk represents the central parts of the lagoons in considerable distance to the active reefs. They are also more proximal to land as the following type. Typically for these lagoonal areas are the very changeable ecological conditions within the lagoons.

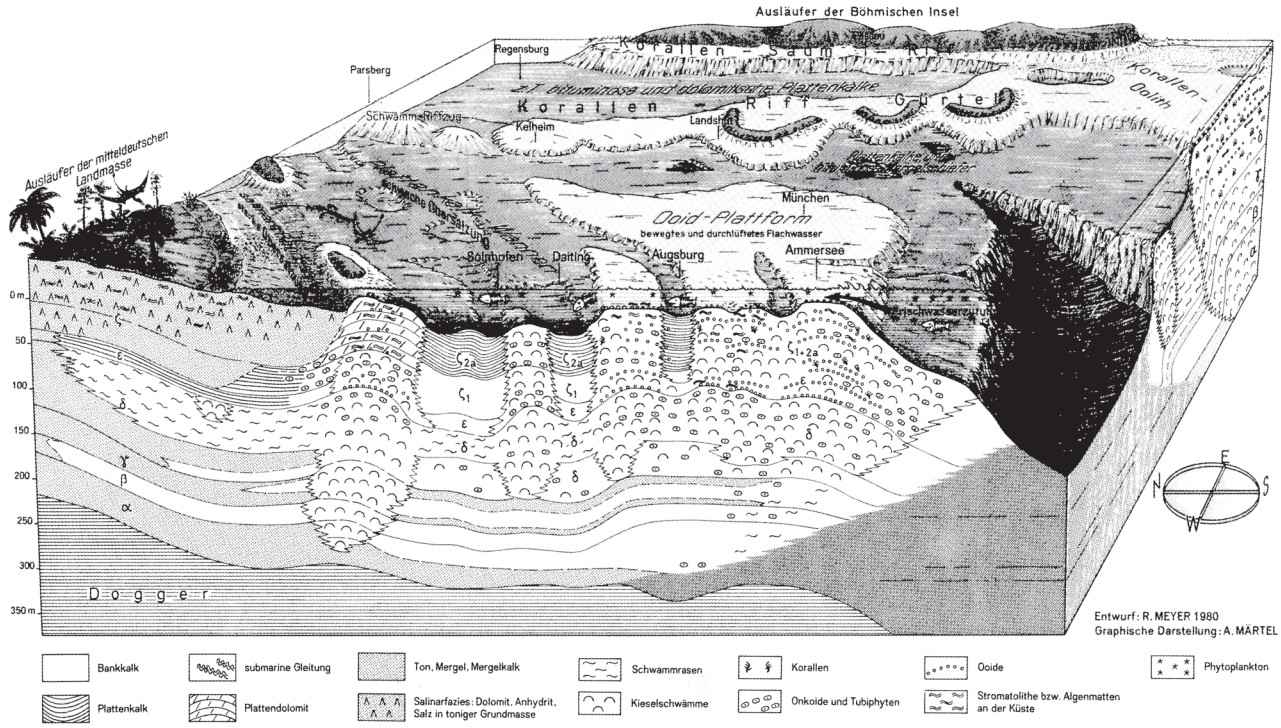

Figure 2: Upper Jurassic palaeogeography during the origin of the Lithographic Limestones of Solnhofen (Lower Tithonian, Malm zeta 2 b) (from MEYER & SCHMIDT-KALER 1991)

Silicified Plattenkalk

This term was derived from works by the Erlangen professor of geology BRUNO VON FREYBERG. He described so-called "Kieselplattenserien" (silicified slab series) from below as well as from above the Lithographic Plattenkalk, in which locally marls, fans of reef debris and limestone banks have been interbedded. Characteristic for these locally very fossil-rich beds of different stratigraphic age are the silicifications. In many outcrops, beds split only very badly. Locally many horizons are rich in trace fossils.

Within the Silicified Plattenkalk two big series can be distinguished. The first is older than the Solnhofen Plattenkalk s. str.. The exact stratigraphic age is still unknown. Currently, it is placed within the Upper Kimmeridgian; however there is first evidence of ammonites of the genus *Sutneria apora*, an argument for lowermost Lower Tithonian in these beds. Main area of distribution is the eastern part of the Solnhofen archipelago. The most famous of the Fossillagerstätten of this Plattenkalk type are near Schamhaupten and Painten. The second big series of Silicified Plattenkalk follows above the Solnhofen Plattenkalk s. str. and is called the Mörnsheim Formation. It is found in the western part of the southern Franconian Alb. Type-locality is the village of Mörnsheim near Solnhofen. Further south, already in the Swabian part of Bavaria is Daiting, the best known Fossillagerstätte in the Mörnsheim Formation. Lithostratigraphically, they belong to the Malm zeta 3. The two series of Silicified Plattenkalk have one thing in common: they represent the same type of facies; i.e., they originated in a similar palaeogeographic position and under comparable conditions. They show also considerable similarities in fossil content and biostratinomy. However, the guideline that the facies types of Plattenkalk move independently of their stratigraphic position through space and time, of course is also true for the Lithographic Plattenkalk.

Rhythmic Plattenkalk

Like the Marly Plattenkalk (see below), the Rhythmic Plattenkalk is restricted to the eastern part of the Solnhofen archipelago within the East-Bavarian reef girdle. Deposits are known from the locality Kapfelberg near Bad Abbach at the river Danube and along the Naab valley near Brunn, Duggendorf and Heitzenhofen. Characteristic for this type of Plattenkalk are "Papierschiefer" (paper-shales) in the truest sense of the word, in which Flinz layers and marls are interbedded rhythmically. The differences to the Solnhofen Plattenkalk s. str. are important. While the Upper Solnhofen Formation at Maxberg near Solnhofen has 60 metres of workable Lithographic Plattenkalk, Brunn has only eight thin stacks of layers with a thickness of up to 60 cm. These stacks consist of thousands of individual layers.

The Rhythmic Plattenkalk is known for its local richness in terrestrial plants. Beside Daiting in the west, Brunn is the most important palaeobotanical Fossillagerstätte within the Solnhofen archipelago.

Marly Plattenkalk

This facies type within the Solnhofen archipelago is con-

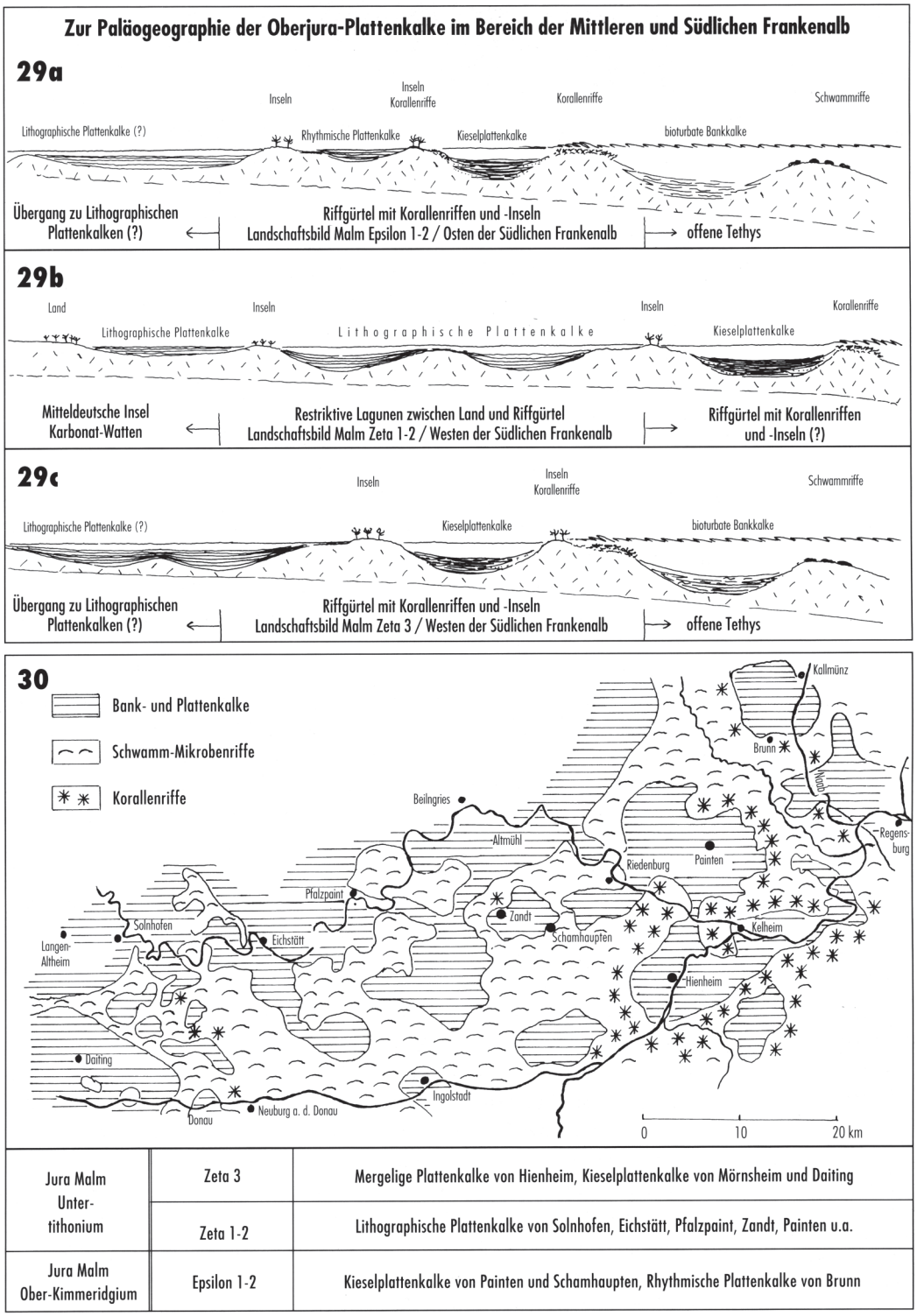

Figure 3: Distribution of reefs and sedimentary basins of the different plattenkalk types in the Southern Franconian Alb (strongly simplified). The age ranges from the Upper Kimmeridgian (Malm epsilon) to the Lower Tithonian (Malm zeta 1-3) (from Röper & Rothgaenger 1998).

centrated to one single basin and one Fossillagerstätte. This basin is situated near Hienheim and Kelheim, and is intersected by the Danube-valley. The Marly Plattenkalk belongs to the Hienheim Formation, a time equivalent of the Mörnsheim Formation with its Silicified Plattenkalk in the west. The sediments bear more resemblance to the echinoderm-bearing Dogger deposits near La Voulte sur Rhone in France than to the nearby Solnhofen Plattenkalk s. str.; evidence for the extreme variability of the Solnhofen-type Fossillagerstätten.

Similar to the other facies types, the Marly Plattenkalk consists of different sediment types. The so-called "Papierschiefer" (paper-shale) dominate; however, locally there are also debris

fans and limestone banks, especially in the upper part of the Hienheim Formation. Additionally, the proportion of bioturbated marls can increase so much that the Plattenkalk facies grades into a normal marine limestone bank facies. Hienheim is the only locality of the Solnhofen archipelago, which, from a terminological point of view, is situated in the midst between Plattenkalk and limestone banks.

Within the Hienheim Formation there are all possible transitions between a conservational and a burying Fossillagerstätte, similar as in the Lithographic Plattenkalk of Pfalzpaint or the Silicified Plattenkalk. At the locality Brunn conservational and benthos-bearing horizons can create a very variable sequence even within less than a millimetre.

Definition of Plattenkalk

All these described differences lead to the question, as to which character is common to all these deposits, which are summarized today under the term of Plattenkalk. As it has been noted already, this term originally was not coined by scientists but came from the quarrying of these rocks. Thin slabs were called "Schiefer" (shale), although this term is petrographically incorrect. Today, the term Schiefer is only used as a descriptive term to address very thin or finely laminated slabs.

In the past, very thick individual layers with up to 30 cm thickness have been called "Bänke" (banks). Today, however, the term of limestone banks refers to bioturbated marine sediments without conserving conditions. The term Plattenkalk, in the past restricted to workable slabs of intermediate thickness, has been transferred to all carbonate marine sediments, in which bioturbation – for whatever reason – partially or completely stopped and because of the relapse of bioturbation the primary lamination and fine stratification of the sediments was preserved. In contrast to publications in the past, taphonomy of the fossils is no longer a criterion in the definition. By this, we want to stress, that pure conserving and stagnant conditions, which lead to completely articulated organisms, are not imperative for the formation of Plattenkalk. i.e., in one single Plattenkalk section, both conserving as well as burying Fossillagerstätten can occur.

3. Flinz and Fäule – the two stone qualities of Plattenkalk

Traditionally two different rock qualities of the Solnhofen Plattenkalk are distinguished: the rhytmically, evenly-bedded limestone called 'Flinz', and the intercalated finely-laminated calcareous marl, called 'Fäule' ('foul rock'; the term refers to the fact that this material is useless for the quarry industry).

Flinz – the Flinz layers are finest micrites and consist of 95-98% Calcium carbonate independent of the thickness of the layer (measured form one to the next fine layering). The remaining 2 to 5 % are Mg-, SiO_2 and Fe-components as well as organic substance. At Solnhofen and Eichstätt several classes of layer-thickness are distinguished, however without nomenclature being obligatory:

- Papierflinz (i.e. paper-Flinz): 1-2 mm
- Blätterflinz (i.e. leave-Flinz): 2-9 mm
- Dünnflinz (i.e. thin-Flinz): 10-29 mm
- Dickflinz (i.e. thick-Flinz): 50-99 mm
- Bankflinz (i.e. bank-Flinz): > 100 mm

Laminae within the individual slabs, which cannot be split (latent fine-lamination) form **IIIrd order bedding planes** (smooth planes without surface relief; fossil-poorest bedding-plane type; very short interruption of sedimentation).

Difficult to split and with splitting surfaces of regular coarseness form **IInd order bedding planes** (without fractal phenomena of microbial mats; fossil poor type without fossil-rich horizons; short interruption of sedimentation, mostly with very well conserved fossils – the most famous fossil on such a surface: the Berlin specimen of *Archaeopteryx* from the Blumenberg).

Splitting planes with surface relief represents **Ist order bedding planes** (with fractal phenomena of microbial mats, clay coating, interruption of sedimentation of longer duration with fossil-rich horizons, especially with *Saccocoma*). The quarry workers split the Flinz-layers along the planes of major pauses of sedimentation (1st order). If these still contain 2nd order surfaces, the Flinz-layers must be 'skinned' individually (in the local slang: 'abhäuteln').

Laterally the different types of sediment-surfaces merge into one another. I.e., it is possible to have, e.g., a 'Dünn-Flinz' in one place which splits up into 'Papier- or Blätter-Flinz' elsewhere, which makes the correlation of individual layers very difficult. In the past, Mayr (1967) had described the fractal surface patterns as imprint of tiny rain-drops (cf. Röper 1992). Janicke (1969) interpreted these structures (tiny craters on the upper surface of the slabs) as the consequence of water escape from the compacting sediment, still in the submarine environment ('Synärese'). It was Röper et al. (1999), who using the marks of dragged woods succeeded in showing that the fractal surface relief of the major breaks in sedimentation where caused by microbial mats. This interpretation is in accordance with Seilacher (1999). The different types of sedimentation breaks are caused by a variable ecology of the depositional milieu (Röper et al. 1999, 2000). The variability of sediment surfaces, which was already described by Mayr (1967) and Keupp (1977), were in recent years investigated in greater detail by Röper (1991, 1992, 1997) and Röper et al. (1999, 2000). It was found that during longer breaks in sedimentation of calcium carbonate, while only a thin clay coating was produced as background sedimentation, the floors of the lagoons were covered by autochthonous microbial mats. Remarkably, in the area of Solnhofen/Eichstätt thin marl layers are missing between the individual Flinz layers which are so typical for the Plattenkalk in Brunn (simple rhythmites, Flinz-marl sequences). While in Brunn, we have sedimentation of marl

between two Flinz-events, we have only bio-mats and a thin clay coating in the Lithographic Plattenkalk.

Fäule – The Fäule-layers are clay-bearing Plattenkalk with 80-90 % calcium carbonate, i.e. the clay content varies between 10-20 % (Hückel 1974). The thickness of Fäule layers ranges between far less than 1 mm up to 3 mm. Without in-between laying Flinz-layers, several Fäule layers can form thicker Fäule-beds. Fäule-layers are more strongly compacted than Flinz-layers (cf. Meyer & Schmidt-Kaler 1994). In general, Fäule-layers are neither richer nor poorer in fossils than Flinz layers. However, fossil-rich horizons (e.g. *Saccocoma*-beds) usually occur more often in Flinz than in Fäule layers.

There is a whole continuum of rock-qualities from highest-quality Flinz to the lowest-quality Fäule.

Stop 1: Abandoned quarry of Ebenwies NE Etterzhausen Thin layers of Silicified Plattenkalk of the Lower Kimmeridgian

Geological map 1:25 000, sheet 6937 Laaber; R 4499800, H 5434000; old quarry 500 m south of the little village Ebenwies

Ref.: Meyer & Schmidt-Kaler (1983)

The first stop leads to an old, abandoned quarry face with a 15 m thick shallow water-limestone bank series of the Lower Kimmeridgian, in which two thin bands of Silicified Plattenkalk are interbedded. Apart from fishes, squids and ammonites were especially abundant. The locality Ebenwies is the oldest Plattenkalk occurrence within the Solnhofen archipelago. Like no other locality, this section shows a change in facies of short duration from normal marine limestone banks to Plattenkalk. The change in facies is interpreted as result of short-term cutting off of the Ebenwies basin from the open sea.

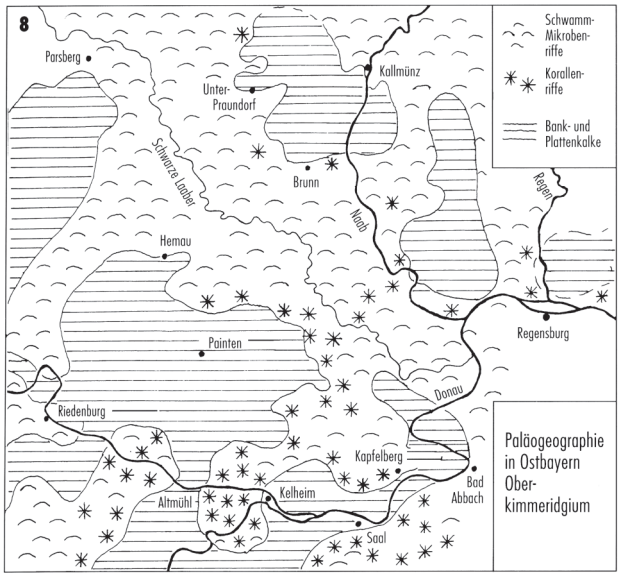

Figure 4: Distribution of reefs and plattenkalk basins in eastern Bavaria at the top of the Upper Kimmeridgian (from Röper & Rothgänger 1996).

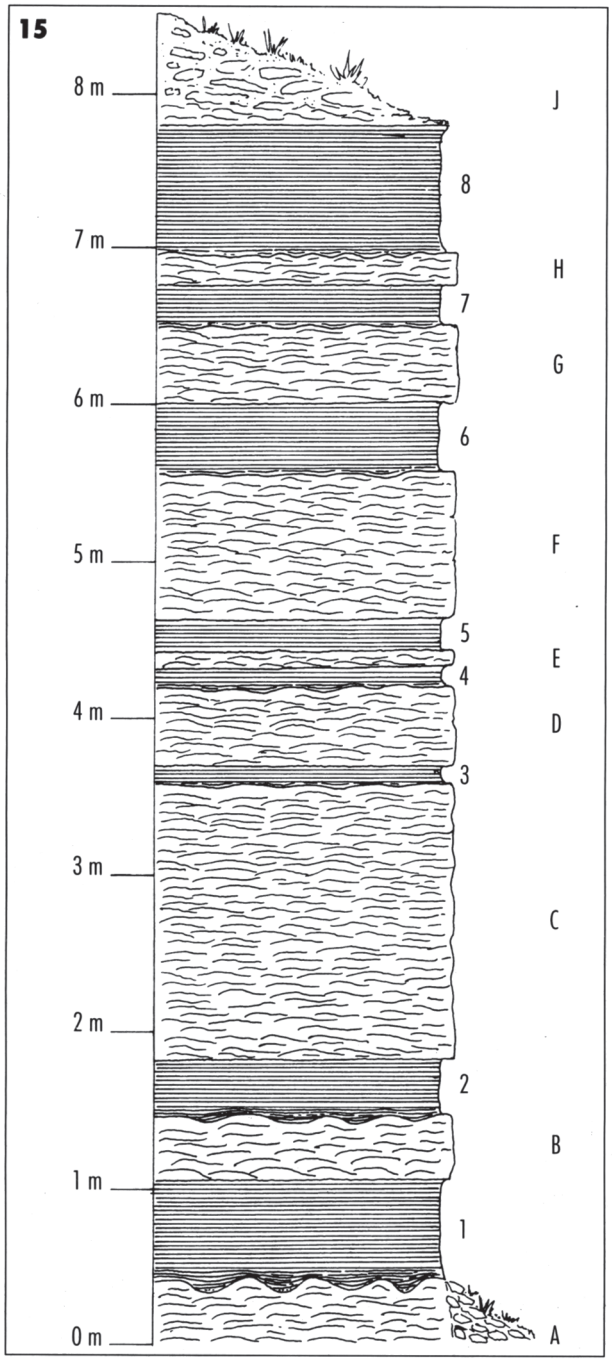

Figure 5: Lithological section of the Brunn quarry (composed from different parts of the Quarry) with alternating thick bedded limestones (A-J) and plattenkalks (1-8) (from Röper & Rothgänger 1996).

Stop 2: Rhythmic Plattenkalk and Fossillagerstätte Brunn of the Upper Kimmerdigian, a small Cerin in Bavaria

Geological map 1:25 000, sheet 6937 Laaber and sheet 6837 Kallmünz; protected small quarry within the forest between Brunn and Wischenhofen

Ref.: Röper & Rothgänger (1995, 1997)

Figs 4-6

The Rhythmic Plattenkalk of Brunn is of Upper Kimmeridgian age (Subeumela Subzone) and therefore, the stratigraphically oldest Fossillagerstätte of the Solnhofen type. It is even older than the Plattenkalk from Nusplingen in Baden-Württemberg. Palaeogeographically, it is part of the Plattenkalk deposits of the Pfraundorf-Heitzenhofen Basin.

The some 8 m thick section consists of only eight thin stacks of Plattenkalk with up to 60 cm thickness, interrupted by a layer with reworked Plattenkalk. The benthos- and clay-rich sediments in the lower part of the section are interpreted as deposits of a tidal to shallow lagoonal environment. They represent margins of the lagoon. The uppermost laminated carbonate-rich part of the section is without any benthos and represents deposits of a central part of the lagoon. For descriptive purposes, the Brunn Plattenkalk may be called

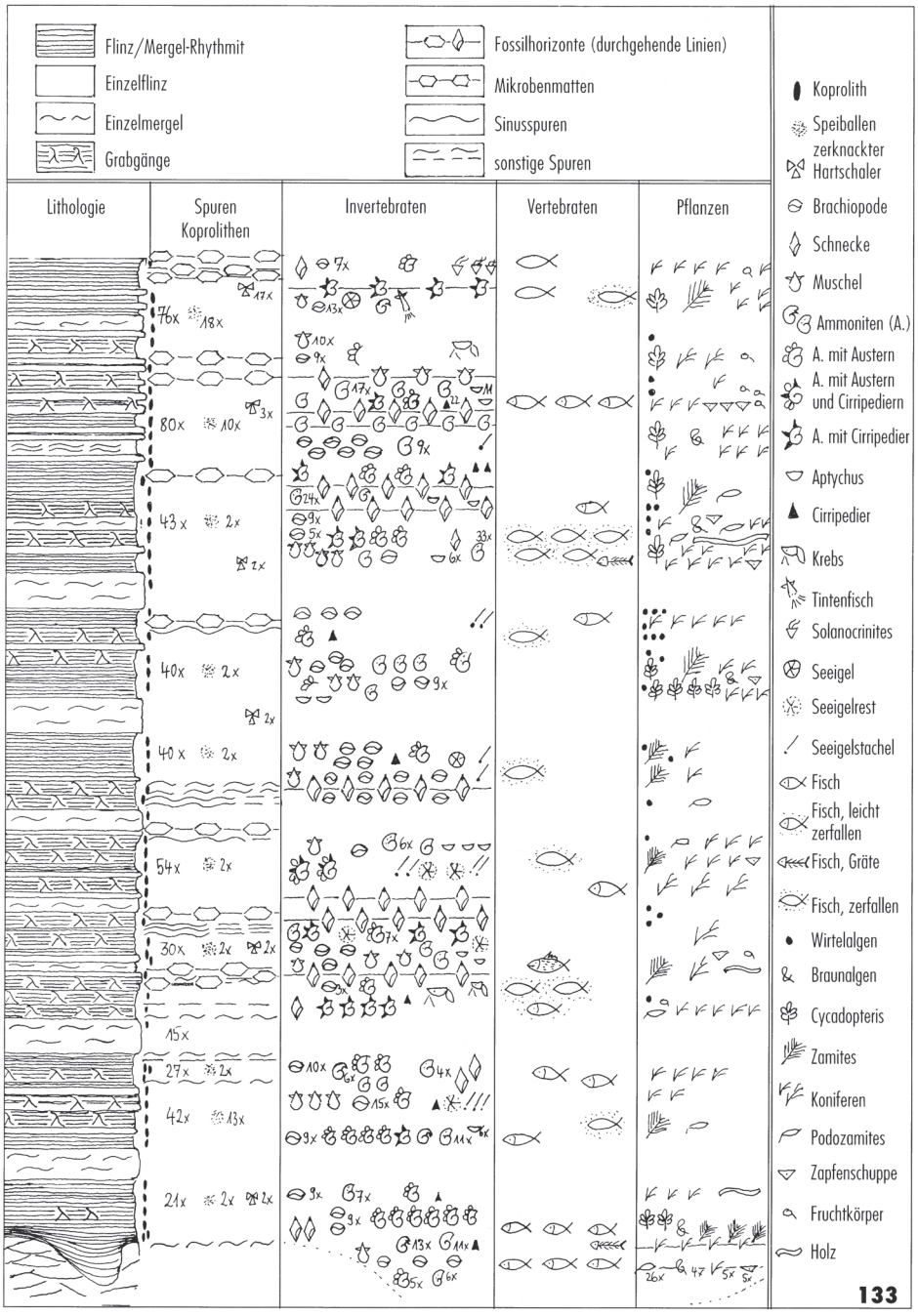

Figure 6: Palaeoecological section of the plattenkalk bed 1, strata 1/21-1/30 of the Brunn section. Height of section: 15 cm; at the base: thick bedded limestone A (cf. section, fig. 5) (from Röper & Rothgänger 1996).

'Papierplattenkalk' (i.e. paper-Plattenkalk).

Fauna and flora of this smallest of the Solnhofen-type Fossillagerstätte are completely different to the deposits of the type-locality Solnhofen itself. A similar flora and fauna is only known from the French Plattenkalk of Upper Kimmeridgian age near Cerin in the Department Ain. Especially to be noted is the richness in terrestrial plants, which have been swept in from nearby islands. Apart from conifers, we have seed-ferns, Bennettitales and more rarely Cycadales. One of the specialities of Brunn is the marine flora of dasycladacean algae, which, in a similar fashion, is only known from Cerin. Other specialities of the locality Brunn are trails of benthic life such as traces of snails and bivalves which sometimes cover whole sediment surfaces. There are also microbial mats.

The crustacean fauna is dominated by lobsters and cirripedians. Also, the Brunn fauna is rich in other marine invertebrates (e.g. brachiopods, echinoids). Vertebrates are rare (very few fish and reptile species). Some of them like the shark *Phorcynis* and the ganoid fish *"Eugnathus" praelongus* used to be only known from Cerin.

Stop 3: Quarry of the 'Kalkwerke Rygol' (lime factory Rygol)

Silicified Plattenkalk and Fossillagerstätte Painten 1; Lithographic Plattenkalk and Fossillagerstätte Painten 2; Upper Kimmeridgian to Lower Tithonian

Geological map 1:25 000, sheet 7036 Riedenburg;
R 4487300, H 5430200; quarry north of Painten on the road to Deuerling

Ref.: Meyer & Schmidt-Kaler (1983), Pförringer (2000)

The Painten Basin, north of Kelheim, is the biggest, continuous Plattenkalk area of the Solnhofen archipelago. The deposits start in the Upper Kimmeridgian and continue up to the Lower Tithonian. Painten is situated close to the eastern margin of the basin. Based on the development of facies, two distinct types of Fossillagerstätten have to be described. 'Painten 1' is within the Silicified Plattenkalk facies of the Upper Kimmeridgian, 'Painten 2' is within the Lithographic Plattenkalk of the Lower Tithonian.

Silicified Plattenkalk and Fossillagerstätte Painten 1

The lower, some 15 m thick part of the section of Painten, here called 'Painten 1', consists of a coarse debris facies of silicified Plattenkalk. Some horizons are strongly bituminous. The complete depositional environment is influenced by coral reefs in the vicinity. Repeatedly, we find their debris fans within the Plattenkalk beds.

Many land plants point to the existence of nearby islands. On the other hand, an exceptional abundance of squids suggests a direct connection of the Painten lagoon with the open sea. Thus, the laminites in this quarry contain a rich flora and fauna from very different ecosystems. Therefore, experts value the Painten Silicified Plattenkalk as a jewel among the Fossillagerstätten of the Solnhofen archipelago.

Among terrestrial plants conifers and seed-ferns dominate. Among the marine fauna, reef-dwelling sea-urchins have to be pointed out. Basically, however, Painten is famous for its wonderfully preserved diverse fish-fauna. Coloured naturally by brown to black minerals, the dark fossils on the white limestone are among the most beautiful of the 'Solnhofen' fossils. Meanwhile, the Silicified Plattenkalk of Painten is also praised for very rare reptiles. Apart from turtles and fragments of marine crocodiles, several new pterosaur species have been found recently.

Lithographic Plattenkalk and Fossillagerstätte Painten 2

The overlying 35 m thick series of Lithographic Plattenkalk shall be called here 'Painten 2'. During the Lower Tithonian (probably time equivalent to the Solnhofen Plattenkalk s. str.), the depositional environment of Painten was that of a restricted lagoon. The influence of the reefs had become less important, but was still present. It was partly influenced by currents and possibly shows also a tidal character.

Slabs from Painten 2 are known for their current indicators, ammonite roll marks (e.g. *Euaspidoceras* roll marks) as well as for well preserved microbial mats, which are divided by polygonal and ridge-like patterns. Flora and fauna are less rich than in the Silicified Plattenkalk within the lower part of the section. Generally, we find Perisphinctids, *Saccocoma* and small teleosts. Additionally, there are some coral fish (*Eomesodon*), bigger carnivorous fish and reptiles, a complete echinoid with its spines, and the imprint of a star-fish species, which is not known from elsewhere in the Plattenkalk of southern Germany. From here the only yet known tetrapod tracks of the 'Solnhofen' Plattenkalk are described (Pförringer 2000). They were probably made by a small dinosaur, possibly a *Compsognathus*, in the shallow lagoon near the coast of an island.

Despite its richness and diversity the fossil fauna and flora of the Painten quarry is by no means known or published.

Stop 4: Quarry Kelheim-Goldberg NE Kelheim. Marly Plattenkalk of the Lower Tithonian

Geological map 1:25 000, sheet 7037 Kelheim; R 4491800, H 5421250; protected quarry of the Forstdirektion Kelheim, ca. 600 m north of the hospital of Kelheim

Ref.: Röper & Schuster (2003)

Fig. 7

General view of the Marly Plattenkalk in the Hienheim and Kelheim area

The structure of the basin of Kelheim-Hienheim already developed in the Malm zeta 2. To the north, the Hienheim basin

was mostly separated from the Painten basin. Only the 'Essing Channel' formed a connection between these two large basins. The central part of the southern basin was near the village of Hienheim, which was connected to the Tethys-Sea in the south. To the north, the Hienheim basin graded into the shallower Kelheim bay. While the Hienheim region represents the central part of the basin, the Plattenkalk between Weltenburg and Kelheim must be regarded as a marginal facies of the basin.

Ammonites are rare; nearly all specimens belong to the species *Gravesiana gravesiana*. This guide fossil of the Malm zeta 3 sometimes carries colonies of cirripedians of the genus *Archaeolepas*. Apart from these, arthropods are rare. Only the benthic crustacean *Eryma* and the horseshoe-crab *Mesolimulus* are sometimes discovered. Upon closer inspection of sediment surfaces affected by frost, also marine worms can be discovered. Having so much evidence for benthic live within the marly slabs of the central facies, it is not astonishing that articulated fish and reptiles are rare.

The Lower Hienheim Beds near Weltenburg

Near Weltenburg, we have the marginal facies of the 'Hienheim sub-basin' with finest laminated, more carbonate-rich deposits of the 'Weltenburg Papierschiefer' (Weltenburg paper-shale). They show already many similarities to the deposits of the Kelheim bay. This marginal facies shows the influence of nearby hard-ground ecosystem. Trace fossils, burrows and bivalve horizons demonstrate an extended benthic fauna of a few specialists for the local environment. Generally, the marginal facies is 'relatively' rich in specimens, however poor in the number of species of small fossils, with ammonites being especially rare.

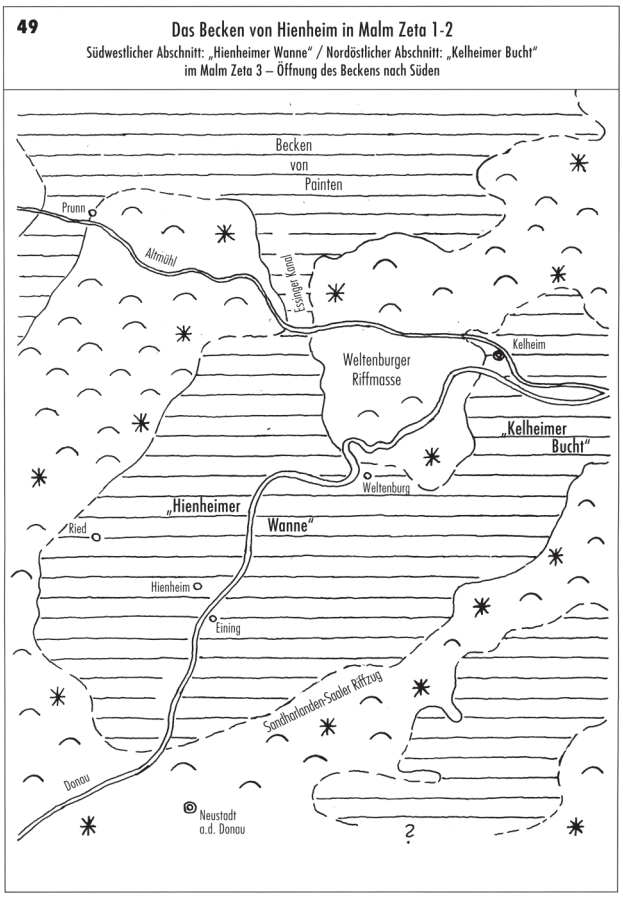

Figure 7: Palaeogeography of the Hienheim Basin in the Lower Tithonian (Malm zeta 1-2/3). Note the connection to the Painten Basin in the north ("Essinger Kanal", e.g., channel of Essing) and the Kelheim Bay in the north-east (from Röper & Rothgänger 1998, modified from Meyer et al. 1994).

The Goldberg section

The Goldberg is situated at the northern margin of the Kelheim bay, rather closed off from the central facies near Hienheim. The section of Kelheim-Goldberg is a good example of this palaeogeographic situation. Between some thick limestone banks are stacks of thin plattenkalk or paper-shale of the type 'Marly Plattenkalk'. From the lower to the higher part of the section the proportion of limestone banks increases. The limestone banks can be followed through the whole of the outcrop, while their actual thickness varies in the range of centimetres. Subaquatic slumping as it occurs in the Weltenburg area, have not been found at the Goldberg. Finest laminations and fine bedding, which has been partially destroyed by endobenthic organisms, seem to dominate. There is hardly any evidence for strong currents at the sea floor except of some accumulations of brachiopod shells which might be regarded as such.

The few Plattenkalk layers of the section are of the pure Flinz-type. Near the top and the bottom the Flinz layers grade into clay-rich Fäule-like material. Therefore the sediment surfaces consist of marl and only rarely of pure Flinz material with microbial mats. The marly slabs are yellowish to brownish in colour, near fissures, the colour changes to white.

Pure Fäule layers, as they are present in between the Flinz layers of the Lithographic Plattenkalk of Solnhofen are not very common in this section. Mostly, marls and limestone occur as simple rhythmites (marl-Flinz-alternation). This is an interesting parallel to the Plattenkalk of the locality Brunn, which is also a simple rhythmite.

Fossil content

Flora: one single find of a dasycladacean alga.

Marine fauna: A special feature of this site is the richness in horizons with mass occurrences of small terebratulid brachiopods. No other locality within the Plattenkalk, even within the Weltenburg area, has such quantities of brachiopod horizons. Similar to Brunn, more than 99 % of the brachiopods are Terebratulids. Rhynchonellids remain rare (e.g. one specimen of *Ornithella*). Together with the Terebratulids, small echinoids and the worm *Muensteria* can be found on the sediment surfaces. Additional rare elements are tiny snails and pectinid bivalves. Many of these finds point towards the existence of a nearby hard-ground ecosystem, from which many benthic organisms have been derived. These characteristics are in accordance to the Weltenburg area, with the single exception that the influence of the marginal ecosystem is much more pronounced in Kelheim. At the locality Kelheim-Goldberg, also one ophiuroid horizon consisting exclusively of specimens

of *Ophiopetra lithographicas* was found.

The few bivalve species and their traces on the sediment surface, which are present in the whole of the section point to a soft substrate during the time of colonisation. The high number of individuals and low number of species argue for a strongly restricted environment, suitable only for a few specialists. Borrowings of crustaceans demonstrate the adaptation of one or two crustacean species to this ecosystem. Traces of the horseshoe-crab *Mesolimulus walchi* are abundant and show that this species must have lived at least close by.

Influence of hard-ground ecosystems on the one hand and the existence of a soft ground community in the Plattenkalk area on the other hand prove that oxygen was present down to the seafloor in the Kelheim bay. The fossil record of the Kelheim-Goldberg clearly contains a remarkable percentage of autochthonous and parautochthonous benthic organisms. A hostile, permanently hypersalinar deep water and lethal zone, presumably also containing H_2S, as it sometimes still is assumed for the Eichstätt basin in the west, cannot be demonstrated for the depositional area of the Hienheim Beds.

Interesting are the cirripedians *Archaeolepas*, which have grown on ammonites of the genus *Gravesia*, similar to the Brunn cirripedians of the genus *Pollicipes* on ammonites (e.g. *Aspidoceras*). The Kelheim cirripedia are much rarer than those of Brunn. The reason might be that also ammonites at Kelheim-Goldberg are equally rarer than in Brunn.

The fossil record of benthic organisms at Kelheim-Goldberg is not as rich as that of the central basin facies near Hienheim. Obviously, the conditions have been more restricted in the Kelheim bay compared to the Hienheim sub-basin.

Apart from the benthic fauna the beds of the locality Kelheim-Goldberg regularly contain remains of vertebrate fossils (e.g. the small teleost *Leptolepides*, more rarely *Tharsis, Thrissops*, *Orthogonikleithrus*, and bone-bearing coprolites of probably carnivorous fishes). Similar to other localities of the Hienheim Beds, ganoid fishes are very rare (e.g., a small *Furo*-like fish, a carnivorous fish of 0.5 m length, pycnodotids of the genus *Proscinetes*, which is extremely rare in the Solnhofen Plattenkalk).

With its particular faunal content and facies the section of Kelheim-Goldberg cannot be compared with any of the hitherto taken sections of the Solnhofen-type Upper Jurassic Fossillagerstätten.

Stop 5: Quarry of the Stieberberg N Hienheim - Fossillagerstätte Hienheim; starfish-ecosystem at the margin of the Jurassic Sea

Geological map 1:25 000, sheet 7136 Neustadt a. d. Donau, R 4482250, H 5416000; quarry of city of Neustadt a. d. Donau; ca. 1,6 km north of the village of Hienheim.

Ref.: Röper & Rothgänger (1998), Kutscher & Röper (1995, 1998)

Fig. 8

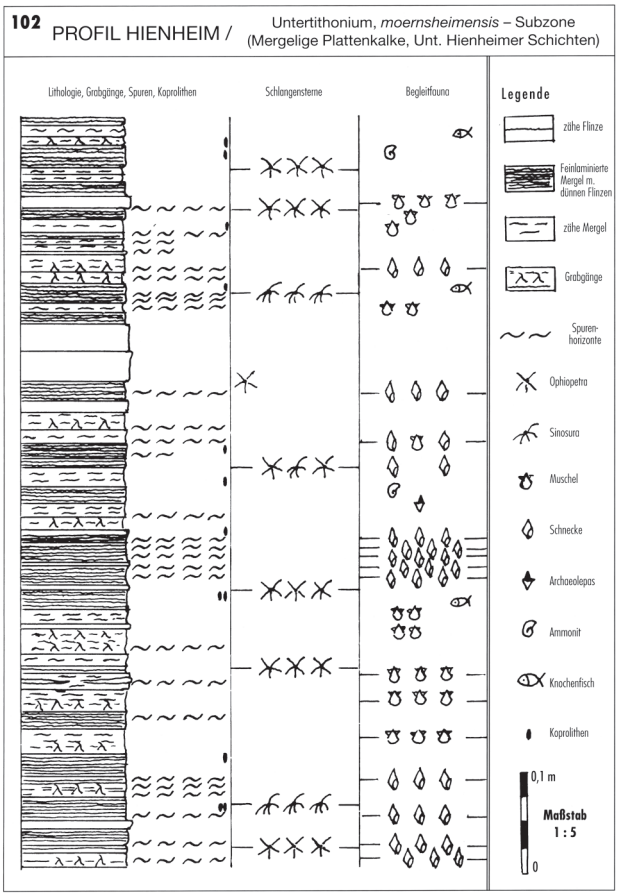

Figure 8: Detailed lithological-palaeoecological study of a part of the Hienheim section (Lower Hienheim Beds; Lower Tithonian, Malm zeta 3) (from Röper & Rothgänger 1998).

The Fossillagerstätte of Hienheim shows Marly Plattenkalk including the old 'Weltenburg Papierschiefer'. It is probably a little bit older than the facies of the Mörnsheim Formation in the west. The Hienheim Plattenkalk is well known because of its richness in horizons with remains of benthic organisms. No other Solnhofen-type Fossillagerstätte is as rich in trace fossils. This locality is of great importance because of its ophiuroids (Röper & Rothgänger 1998, Kutscher & Röper 1995). While earlier researchers thought that the ophiuroids had been washed from elevated reefs into a deeper, hostile basin, new investigations showed evidence to the contrary. The ophiuroids have apparently been buried in their native environment.

The mass occurrences are composed of two ophiuroid species. The more slender, delicate *Sinosura kelheimense* with only weak development of spines lived buried within the sediment. This species lived with up to 3000 individuals per square-metre. It was a filter-feeder using the organic material within the sediment. The robust, heavily spined, carnivorous *Ophiopetra lithographica* lived on the sea bottom. Apart from the ophiuorids, the starfish *Pentasteria tithonica* occurs in one horizon.

Stop 6: Quarry Reizer; Lithographic Plattenkalk and Fossillagerstätte Zandt in the centre of the Solnhofen archipelago, Lower Tithonian

Geological map 1:25 000, sheet 7035 Schamhaupten,
R 4464320, H 5420200; 1.5 km SE of the village of Zandt
Ref.: Bausch (1963), Meyer & Schmidt-Kaler (1983)

Palaeogeographically, the locality Zandt is situated close to the transition between the East-Bavarian areas and the Franconian deposits in the west. The Plattenkalk deposits reflect a very calm depositional environment. There is no evidence for a situation influenced by a nearby coast or tides similar to Painten.

In the quarry of Zandt a series of 25 m undisturbed, very thin-bedded Plattenkalk layers are exposed. The Flinz layers are separated by thin Fäule layers. The Zandt Plattenkalk follows stratigraphically above the Silicified Plattenkalk of Schamhaupten as well as above the Oechselberg Plattenkalk which occurs in outcrops about 2 km south of Zandt and belongs to the same Plattenkalk basin. We assume a similar age as for the Solnhofen Fossillagerstätte s. str. (Lower Tithonian, Malm zeta 2b). Comparing the Fossillagerstätten, it seems mandatory to view the very hard and brittle Zandt Plattenkalk and its marine fauna as independent type of Fossillagerstätte. Even the Fäule-layers are different from all other Fossillagerstätten of the Solnhofen archipelago. The Lithographic Plattenkalk of Zandt is characterized by the near complete lack of microbial mats on the sediment surfaces. Therefore only such beds can be split easily which are coated with clay.

There is hardly any evidence of a terrestrial flora. In Fäule-layers, sklerites of silica-sponges are prominent. This is a singular occurrence for the whole of the Plattenkalk area. However, a latent influence of reefs suggests that it might be suitable to view Zandt in connection with the East-Bavarian deposits of the Kelheim and Painten Basins.

The locality Zandt is famous for ophiuroid fossils (e.g., *Geocoma carinata*). The spectrum of the fish and reptile fauna is near identical to the East-Bavarian faunas. Some peculiarities should be stressed: there are no fossil horizons with small teleosts and free swimming crinoids (*Saccocoma*), i.e., there are no such lethal events, which are typical for restricted lagoons with strong oscillation in chemical and physical conditions of their waters such as represented by the Plattenkalk of Eichstätt and Solnhofen.

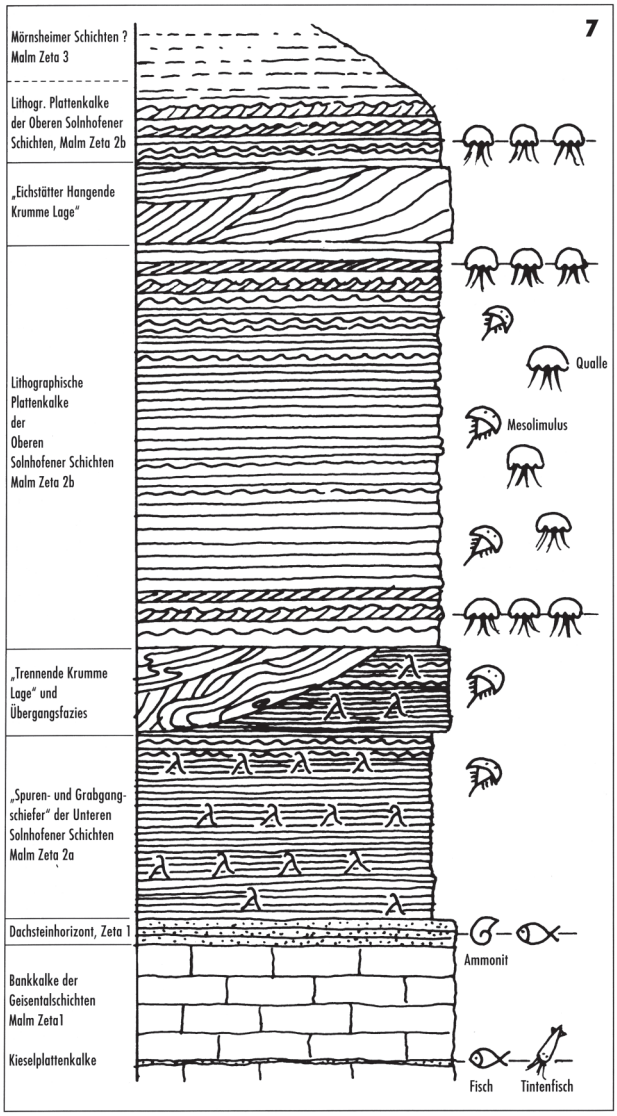

Figure 9: Idealised section of the Lower Tithonian series of the Pfalzpaint region showing the main stratigraphical distribution of the horseshoe crab *Mesolimulus* and the jelly-fish (from Röper et al. 1999).

Stop 7: Quarry Schrimmel of the company JUMA-Natursteinwerke. Thin Lithographic Plattenkalk with restricted benthos, Lower Solnhofen Formation, Lower Tithonian

Geological map 1:25 000, sheet 7033 Titting; R 4449600,
H 5419200; some 800 m SE of Walting
Ref.: Leich (1972), Meyer & Schmidt-Kaler (1983),
Röper et al. (1999)
Figs 9-10

The outcrops of Stop 7 and 8 lead to the marginal facies of the Lithographic Plattenkalk of Pfalzpaint. Palaeogeographically, the deposit lies exposed within a channel which connected the basins of Denkendorf-Böhmfeld and Eichstätt.

The 18 to 20 m thick section of the Schrimmel quarry consists of thin Blätterflinz, in some lower beds also of finely laminated paper shale. Repeatedly, thicker Flinz appears. In the upper part, very thin Flinz with 1 to 5 cm thickness dominates. In the past, also weakly developed slumping structures of a 'Krumme Lage' were visible. The Flinz mostly have a relatively high clay content and are separated by thin Fäule-layers. Today, the quarry is mostly filled up and hardly accessible.

Characteristic for the Schrimmel quarry near Walting is a diverse soft-sediment ecosystem, which is rather singular compared to the other outcrops of the region. Here traces of benthic life (trails of mussels, snails, *Mesolimulus* = *Kouphichnium lithographicum* Oppel; *Thalassinoides*) are more frequent

than at the IMBERG quarry (stop 8). There are also some *Saccocoma* horizons with oriented *Saccocoma*, analogous to similar features in the 'Spuren- und Grabgangschiefer' (traces and burrows shales) of the Lower Solnhofen Beds of the 'Eichstätt shale facies' near Eichstätt.

In 1998, for better documentation of the still accessible beds a small lithological-makropalaeontological section was taken in the SW-corner of the quarry. This demonstrated less diversity in the ichnofauna compared to the deeper lying very thin beds. Towards the top of the section, there is a change in facies, and also some thicker Flinz-layers appear. The ichnofauna of this part of the section consist near completely of a single type (the so-called 'Hörnergrabgänge', i.e. horned burrows, possibly caused by crustaceans), rarely also of the track-ways of molluscs. In the area of the excavation site, the beds dipped locally to the NE/E. There were also current indicators.

Faunal elements (e.g., RÖPER, LEICH & ROTHGÄNGER 1998):

Ammonites: *Glochiceras* sp., *Neochetoceras steraspis* (OPPEL), *Silicisphinctes irregulare* (OHMERT & ZEISS)
Bivalves: *Solemya* sp.
Crustaceans: *Eryma modestiforme* (SCHLOTHEIM)
Echinoderms: *Saccocoma tenella* (GOLDFUSS)
Pisces: *Leptolepides* cf. *sprattiformis* (BLAINVILLE), *Tharsis dubius* (BLAINVILLE), *Ascalabos voithi* MÜNSTER
Coprolites: *Lumbricaria*, phosphatic fish coprolites

Stop 8: Abandoned quarry of the company IMBERG-Natursteinwerke, Pfalzpaint, a classical outcrop within the Lithographic Plattenkalk, Upper Solnhofen Formation (Lower Tithonian)

Geological map 1:25 000, sheet 7033 Titting, R 4450760, H 5419680; 2.3 km south of Pfalzpaint

Ref.: RÖPER et al. (1998), JANICKE (1969)

Fig. 11

Within this infilled quarry the uppermost parts of the former existing section are now again exposed through to some excavation campaigns in the last years. These today visible horizons are the youngest parts of the Lithographic Plattenkalk of the Pfalzpaint area. Here, clearly visible the 'Upper Krumme Lage' described by JANICKE (1969) dips towards the SE. In the northern part of the eastern quarry face, it reaches the surface. In the western part, it has already been eroded. Here the oldest beds reach the surface. Thus, the 'Krumme Lage' of the IMBERG quarry lies in a higher stratigraphic level than in the previous outcrop near Walting.

This locality is famous for its richness in jelly-fish. For long time, there were reports of three jellyfish-horizons, of which one produced especially beautiful specimens of *Myogramma speciosum* MAAS. However, only such horizons where noticed, which produced 'beautiful jelly-fish' ('Teller' i.e. plates in the quarry-workers' slang). The excavations in the years 1998

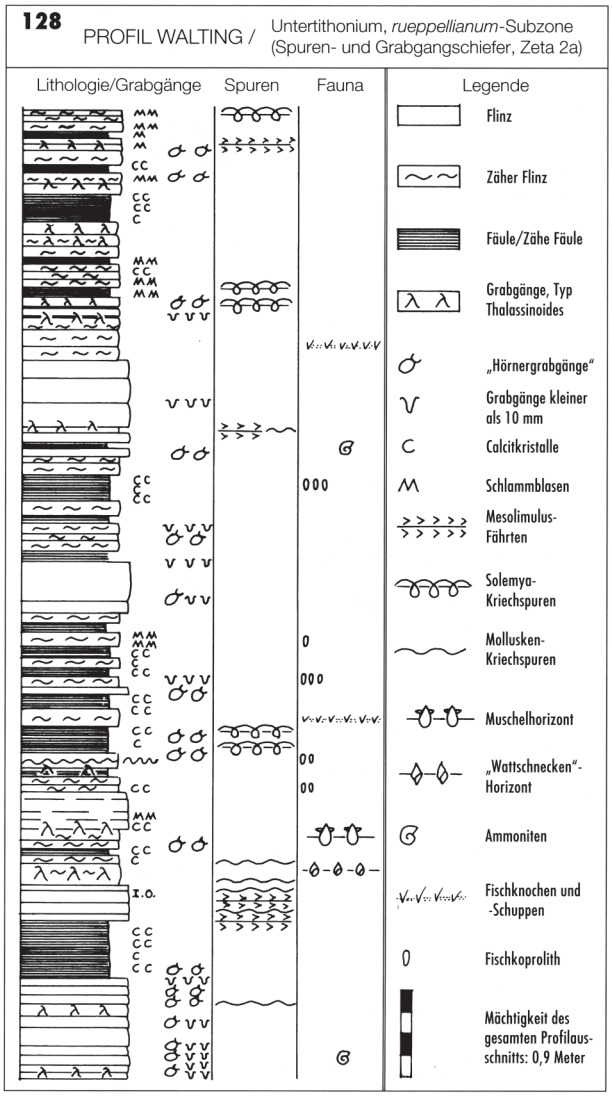

Figure 10: Detailed lithological-palaeoecological study of a part of the Walting section (Lower Tithonian, Malm zeta 2a) (from RÖPER et al. 1999).

to 2005 discovered several new horizons with *Rhizostomites admirandus* HAECKEL above the 'Eichstätt Upper Krumme Lage' in the eastern wall. This concentration of jelly-fish was unknown before, possibly because this area was never interesting for the quarrying of flagstones.

The jelly-fish are preserved in different positions: On the surface of the Flinz (covered by the thin layer of carbonate), oblique within the Flinz (sometimes several specimens stacked within each other) or at the base of a Flinz-layer. In general, the lower side of the jelly-fish is visible.

Horizons with current indicators, trace fossils of molluscs and 'Hörnergrabgänge' as well as an often disturbed bedding and additionally the occurrence of 'carbonate sands' on the bedding planes are characteristic for these newly found fossiliferous rock unit. The beds dip much more strongly to the SE.

Fauna and flora (from RÖPER et al. 1998):

Ammonites: *Lingulaticeras solenoides* (QUENSTEDT), *Neochetoceras steraspis* OPPEL
Jelly-fish: *Rhizostomites admirandus* HAECKEL, *Myogramma*

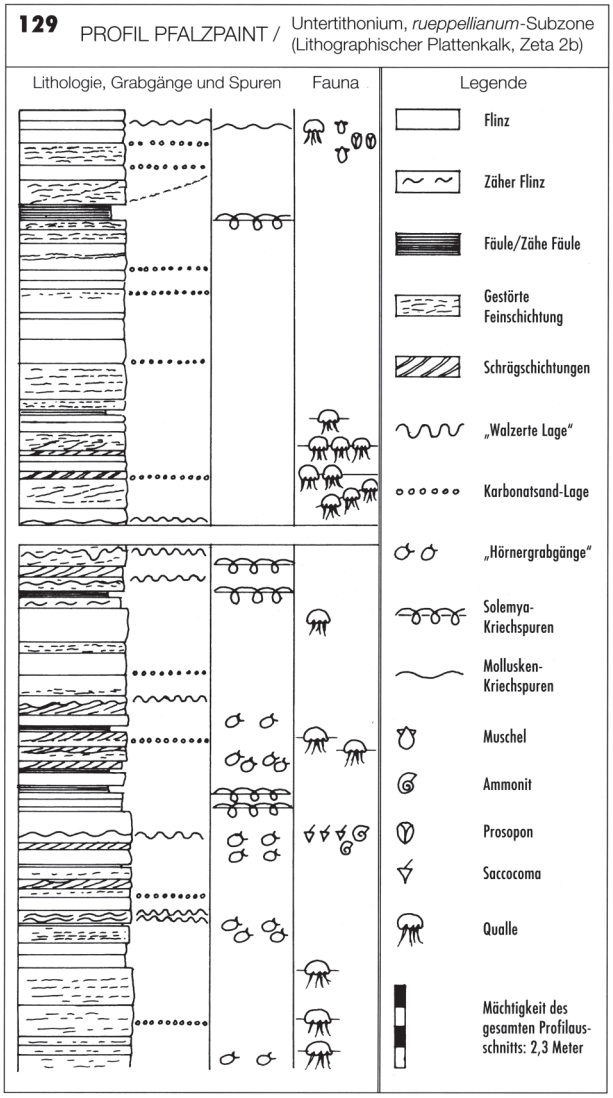

Figure 11: Detailed lithological-palaeoecological study of upper parts of the Pfalzpaint section above the „Eichstätter Upper Krumme Lage" (cf. fig. 9); IMBERG quarry, Lower Tithonian, Malm zeta 2b. Note the distribution of jelly-fish layers (from RÖPER et al. 1999).

speciosum MAAS, *Semaeostomites Zitteli* HAECKEL, *„Medusites" bicinctus* HAECKEL, *Hydrocraspedota mayri* KOLB (?Hydromedusa)

Porifera: *Ammonella quadrata* WALTHER

Gastropoda: *Rissoa* sp.

Bivalvia: *Solemya* sp., several undetermined bivalves and whole sediment surfaces covered by bivalves

Arthropoda: *Pithonoton* sp., the lobsters *Mecochirus brevimanus* MÜNSTER, *Eryma modestiforme* SCHLOTHEIM, *Magila* cf. *latimana* MÜNSTER; *Mesolimulus walchi* (DESMAREST)

Crinoidea: *Saccocoma tenella* (GOLDFUSS), rare *Millericrinus* sp.

Echinoidea: *Rhabdocidaris mayri* BANTZ, *Pedina lithographica* DAMES)

Pisces: *Tharsis dubius* (BLAINVILLE), *Ascalabos voithi* MÜNSTER)

Ichnofauna: *Kouphichnium lithographicum* OPPEL, *Solemya* traces, 'Hörnergrabgänge' (i.e. horned burrows)

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