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The Upper Jurassic of Gräfenberg (Southern Germany): Implications for Microfacies Development and Relative Sea-Level Change

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Abstract: The studied sequence of microfacies types allows an interpretation of the marine depositional environment from the Oxfordian to the Kimmeridgian of Gräfenberg (Middle Franconian Alb). The Malm alpha starts with a lithoclastic wackestone and continues with microbial affected mud- to wackestones, indicating a swell situation within deep neritic conditions consistent until Malm beta. The onset of Malm gamma, characterised by the *platynota* marl above the Oxfordian/Kimmeridgian transition, reveals a *Saccocoma* facies, which indicates transgressive spreading of the Tethys onto the continental platform of Southern Germany. The glauconitic *platynota* marl exhibits the highest percentage of pelagic organisms and therefore is believed to represent a condensation horizon which developed during a high sea level. Both the gradual increase of the amount and grain-size of the particles during the subsequent Malm gamma and the development of demosponge rich microbialites (bindstones) of the Malm delta are interpreted as a consequence of a gradually dropping sea-level.

Zusammenfassung: Die untersuchte Abfolge von Mikrofaziestypen in den oberjurassischen Karbonaten Gräfenbergs (Mittlere Frankenalb) ermöglicht eine Interpretation der marinen Ablagerungsbedingungen vom Oxfordium bis zum Kimmeridgium, beginnend mit einem lithoklastischen Wackestone an der Basis. Dieser entwickelt sich zunächst in feinbioklastische Mud- bis Wackestones mit zwischengeschalteten mikrobiell beeinflussten Untertypen, welche auf einer Schwelle innerhalb einer übergeordneten, mäßig tiefen Schelfsituation abgelagert wurden. Etwa mit Beginn des Kimmeridgium setzt sukkzessive eine *Saccocoma*-Fazies ein, welche als transgressives Übergreifen der pelagischen, tethyalen Bedingungen auf die epikontinentale Plattform Süddeutschlands interpretiert wird. Der glaukonitische *platynota*-Mergel weist den höchsten Anteil von Pelagizität anzeigender Organismen auf und wird als das Resultat einer anhaltenden Kondensation während eines hohen Meeresspiegels interpretiert. Der weitere Faziesverlauf im Malm gamma indiziert eine übergeordneten Verflachung, angezeigt durch eine generelle Zunahme des Anteils und der Grösse der Komponenten. Darüber folgen von demospongiden Schwämmen dominierte Bindstones (Mikrobialithe), welche ebenfalls als Produkt einer Verflachung des Ablagerungsraumes angesehen werden.

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Introduction

Due to the insufficient processing of the Upper Jurassic limestone microfacies in Franconia (southeastern Germany) this study was conceived to gain new insights into the submarine environmental system and the coupled microfacial development of the sediment. The aim is to document both the Upper Jurassic microfacies and the inferred sea-level from the Oxfordian to the Kimmeridgian summarizing the results of a diploma thesis (Biskaborn 2008). Former studies concerning and illustrating the microfacies of the Upper Jurassic in a related regional setting was made by Brachert (1986), Brugger (1990), Flügel (1978, 2004), Herrmann (1996), Hornung (2001, 2002), Keupp et al. (1993), Knoblauch (2004), Lang (1989), Matyszkiewicz (1997), Michalik et al. (1993), Pomoni-Papaioannou et al. (1989) and Schmid (1996).

Geological setting

The studied Malm succession is located in two quarries in Gräfenberg (Deuerlein and Endress, Fig. 1) which are situated in the Süddeutsche Schichtstufenland (Bavaria, Southern Germany). The study area belongs to the Middle Franconian Alb, which is, in contrast to the Northern and Southern Franconian Alb characterised by a lower percentage of marl (Zeiss 1968). The stratigraphic succession from Oxfordian to Kimmeridgian is usually subdivided into lithostratigraphic units labeled with Greek letters according to Quenstedt (1858). Exact biostratigraphic boundaries can vary in their relation to the lithological formation. An idealized stratigraphical comparison between biostratigraphy, international lithostratigraphical standards and the traditional subdivision based on Quenstedt (1858) is given in Fig. 2.

During the Late Jurassic period Southern Germany was covered by an extension of the Tethys. The marine depositional environment was situated at the northern edge of the Tethys and is reconstructed as a 180 km broad shallow-water platform (Meyer 1996) with an average water depth of 50-200 m (Flügel 2004, Schmid et al. 2005). Keupp et al. (1990) also suggest a gently north-south inclined carbonate ramp situation with almost horizontal platform areas. After diagenesis the deposited carbonates and clays are building the present succession of limestone-beds and marls, famous for its high abundance of macrofossils. Especially ammonites are demanded as index fossils and collectables. The studied rocks represent a nearly horizontal and undisturbed Upper Jurassic marl-limestone alternation. The entire profile covers 60 m of thin-bedded marl-rich to thick-bedded limestone-rich sequences which taper off into thick and bulky spongiolites towards the top (Figs. 5-6).

Material and methods

To gain information on the microfacies development nine vertical sections in the Gräfenberg quarries were measured, correlated and sampled to prepare thin sections for microscope analyses. The sections could be combined to one comprehensive profile by bed-to-bed correlation. The stratigraphy was derived as far as possible by using ammonites and lithostratigraphic marker horizons (e.g. *platynota* marl). Samples were taken in intervals of approximately 1 m perpendicular to the bedding. Within the *platynota* marl sequence each limestone bank was sampled with an average distance of 0.2 m (Fig. 6). For the preparation of the thin sections (100 mm by 50 mm slides, polished to 30-50 μm) in the laboratory of Freie Universität Berlin the method of Wissing & Herrig (1999) was adopted. The so-called ultrafacies has been analysed through investigations of the matrix (groundmass) using a scanning electron microscope (Cambridge Stereoscan 360). The microfacies of the limestones has been analysed and classified according to the methods of Dunham (1962) and Embry & Klovan (1971) as well as Folk (1959) and Strohmenger & Wirsing (1991). To refine the significance of the relation between matrix and components the wackestones are subdivided according to the amount of components into (i) sparse wackestones (< 30 %), (ii) normal wackestones (30-50 %) and (iii) packed wackestones (>50 %). Quantitative analyses were made following the method of line counting based on Flügel (2004).

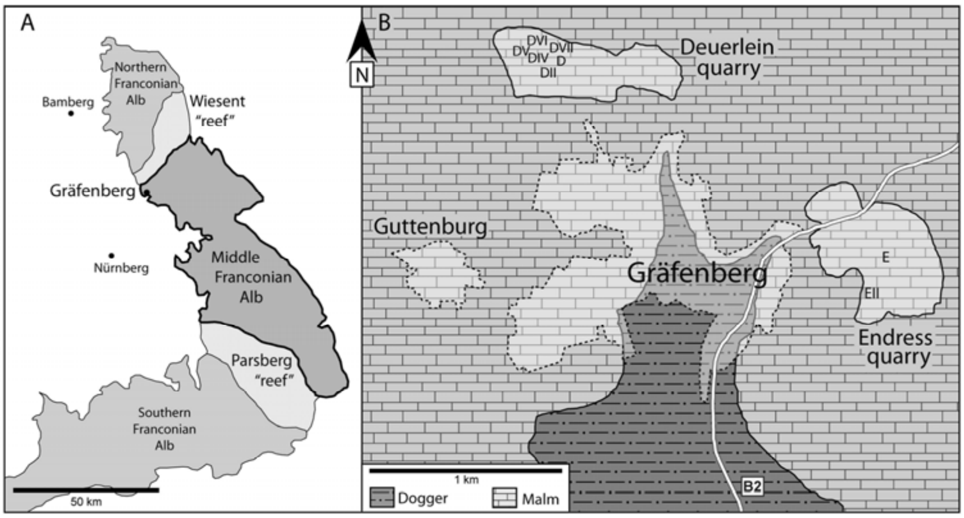

Fig. 1: A) The position of Gräfenberg within the Middle Franconian Alb, based on Zeiss (1968); B) Geological outline map of the Gräfenberg area based on Biskaborn (2008). Sections are marked with the first letters of the quarry and numbered with Roman numerals. Dotted lines indicate urban region.

Kimmeridgian	Upper	*beckeri*	Rögling Fm	Malm epsilon
			Torleite Fm	
		pseudomutabilis	Treuchtlingen Fm	Malm delta
		mutabilis		
	Lower	*divisum*	Arzberg Fm	Malm gamma
		hypselocyclum		
		platynota		
		planula	Dietfurt Fm	Malm beta
Oxfordian	Upper	*bimammatum*		Malm alpha
	Middle	*bifurcatus*		
		transversarium		
	Lower	*cordatum*	Glaukonitsandmergel Mb	uppermost Dogger
		mariae	Sengenthal Fm	

Fig. 2: Stratigraphic range of the Oxfordian and the Kimmeridgian in the Franconian Alb as an idealized comparison between biostratigraphy, international lithostratigraphical formation names and the traditional subdivision based on Quenstedt (1858) (data from various authors).

Microfacies types

As shortly summarized below, seven microfacies types (MFT) could be distinguished. The analysis according to Folk (1959) and Strohmenger & Wirsing (1991) is listed after the classification based on Dunham (1962) and Embry & Klovan (1971).

MFT 1: Wackestones with partial packstone-areas dominated by lithoclasts and peloids; intrapelmicrite (Fig. 7A). The biogenes are dominated by benthic foraminifera. Most of the peloids and lithoclasts are characterised by an enrichment of fine spread pyrite. Glauconite occurs as rounded green grains of 0.2 to 0.3 mm size.

MFT 2: Bioclastic mudstones and sparse wackstones rich in benthic foraminifera (approx. with the same rates of agglutinated and calcareous taxa), echinoderm fragments and radiolarians. Intraclasts, cortoids and peloids occur relating to bioturbation. Glauconite is rare.

MFT 2a includes bioclastic mudstones and very fine-grained sparse wackestones; micrite and biomicrite (Fig. 7B). The primary sediment textures are often distinct alterated by micritisation and recrystallization processes.

MFT 2b contains highly bioturbate packed wackestones; intrabiopelmicrite. Bio-retexturing leads to an in situ enrichment in lithoclasts, peloids and coated grains.

MFT 3: Sparse to packed wackestones often rich in allochthonous components, e.g. reworked oncoids and fossils as *Tubiphytes*, *Terebella* and tuberoids (Fig. 7F); oncobiopelmicrite. This MFT is characterised by a frequent occurrence of foraminiferal oncoids, lithoclasts with microborings and also bioturbation. Many cores of the oncoids represent partly micritizated hexactinellid tuberoids. Glauconite, if occurring, is restricted to an intraparticle green stain.

MFT 4: Glauconite-bearing (Fig. 7E) mud- to normal wackestones dominated by echinoderm fragments and filaments, especially rich in *Saccocoma* (antler-like fragments of planktonic crinoids); biomicrite (Fig. 7D,G). Glauconite is abundant. Bioturbation can occur.

MFT 4a includes condensed packstone areas. Fine bioclastic components as saccocoms, sponge spicules, filaments and fossils of planktonic microorganisms are common.

MFT 4b bears sponges and increased rates of clasts and coated grains accompanied by a slightly less frequent occurrence of fine bioclastic components.

MFT 5: Normal wacke- to packstones dominated by frequent filaments and sponge spicules; biomicrite (Fig. 7H). Besides echinoderm fragments and foraminifera, tubiphytes and glauconite can occur.

MFT 5a represents bioclastic normal and packed wackestones dominated by filaments and sponge spicules. Benthic foraminifera are represented by same rates of both agglutinated and calcareous specimens. Intrabiopelmicritic areas represent local enrichment of microbial in situ formations.

MFT 5b includes glauconite-bearing bioclastic packed wackestones and diagenetic packstone-areas with high abundance of radiolarians and calcispheres beside filaments and also saccocoms.

MFT 6: Microbialite characterised by various microbial crusts with frequently occurring *Tubiphytes*, sponges, annelid tube worms (mainly *Terebella*) and other encrusting organisms (Fig. 7M). The in situ bindstone facies dominates compared to semi-autochthonous detritus. Grain size can exceed 2 mm leading to floatstone areas. Rare grainstone textures occur associated with dominating crusts and shelter porosity. The rates of sparite increase towards the top of Malm delta related to diagenetic texture alteration indicated by microstylolites. Dolomitisation occurs most frequently in association with bindstone facies.

MFT 6a represents tuberoid-bearing bindstones dominated by *Tubiphytes* (Fig. 7L); biolithite. The thin sections show streaky trombolitic and stromatolitic (laminated) microbial crusts composed of fine peloidal automicrite. The components are mostly encrusted and hence building coated grains in a partly dolomitised matrix compound of fine bioclastics.

MFT 6b includes semi-autochthonous floatstones (Fig. 7J) rich in microbial crusts and tuberoids with a packed wackestone/packstone-matrix dominated by filaments, spicules and coated grains; intrabio-pelmicrudite. Grains exceeding 2 mm are represented by sponges and filled ammonite or brachiopod shells which are often shattered due to transportation (clasts) and/or encrusted (oncoids). The bimodal texture exhibits a fine packed wackestone composed of spicules, filaments, *Tubiphytes*, *Terebella* and coated grains building the groundmass of the characterizing floatstones.

MFT 7: Semi-autochthonous and allochthonous packed wackestones and packstones rich in microbial crusts; intrabiopelmicrite (Fig. 7I,K). MFT 7 represents a dense packed variation of the fine-grained fraction of MFT 6b with glauconite and pyrite as intraparticle mineral enrichments.

Matrix and minerals

The ultrafacies of the matrix within the Malm beta succession mainly reveals allomicrite indicated by disintegrated skeletal material with an average size of approximately 2-3 µm. Pseudomicrite occurs as areas of recrystallization and grain diminution indicating enhanced diagenetic alteration. Analyses of one sample from the *platynota* zone reveal areas of uniform small-scale carbonate beads, indicating microbial precipitated micrite. Microcrystalline, drusy and granular sparite occurs as (i) a filling of intraparticle-, shelter- and interparticle primary porosity and (ii) a filling of secondary fracture porosity. Glauconite occurs from Malm alpha to lower Malm delta as (i) distinctly defined small grains (< 0.5 mm), (ii) a diffuse intra-particular green stain, (iii) a coating of fossils especially in the *platynota* marl. Transitions between these different states of glauconitization occur as glauconite grains with micritic centres. The dolomitisation is mainly related to sponge-rich microbialites of the Malm delta. The thin sections of those bindstones reveal dolomite as clustered idiomorphic rhombs with an average size of 0.15 mm and a crystal fabric reaching from hypidiotopic to porphyrotopic.

Interpretation and discussion of the results

The genesis of the Upper Jurassic micrite is believed to be controlled by coccal cyanobacteria, coccolithophorids and dinoflagellates as the main organisms supplying fine-grained sediment material (Meyer 1979). According to a personal communication with H. Keupp, who analysed the ultrafacial carbonate genesis of the Upper Malm (Keupp 1977), a primary increase in pH-value induced by bacterial depletion of nitrate can become important for the precipitation of carbonate.

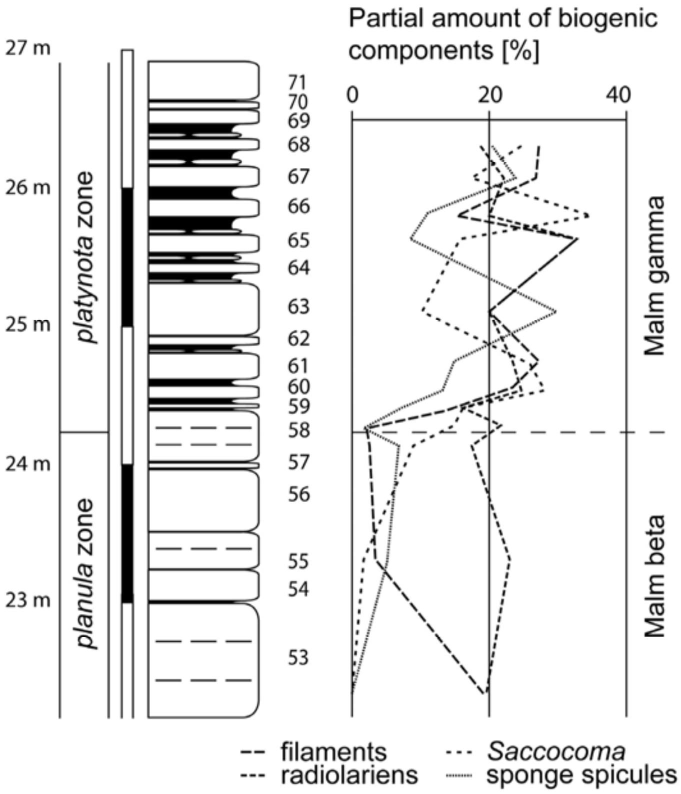

Fig. 3: The percentage amounts of filaments, radiolarians, *Saccocoma* and sponge spicules, related to the total amount of biogenic components, increase at the onset of the *platynota* zone indicating a high sea-level.

The basis of the marl-limestone alternation (Fig. 5, bed 1) is characterized by a strong condensation indicated by MFT 1. This data agrees with the regression owing to a climate-cooling during Lower Oxfordian (Dromart et al. 2003). The alternation of monotone micrite and limestones with aggregate grains, peloids and coated grains (MFT 2 and MFT 3) in Malm alpha possibly reflects a deep neritic deposition area with proximity to microbial influenced spongiolites. Following Flügel (1978, 2004) those microbial affected components occur in shallow water conditions.

Due to the significance of saccocoms (Figs. 7D, G) associated with an increase in planktonic organisms (Fig. 3), which are indicators of pelagic conditions (Keupp & Matyszіewicz 1997), MFT 4 is believed to indicate a transgressive system which starts in the uppermost Malm beta (according to Schmid et al. (2005)) and reaches a maximum in the *platynota* zone. Brachert (1992) interprets the *platynota* zone as a highstand sediment marked by a transgressive condensation of pelagic fossils and the forming of glauconite as well.

Above the *platynota* marl the establishing filaments and spicules (MFT 5) show low water energy which indicates maintaining deeper neritic conditions. Considering the relation between compacted marl-layers and MFT 5b the occurrence of this facies type can be interpreted as a diagenetic enrichment of components. As already mentioned in Koch et al. (2003) the increasing grain-size and grain/matrix ratio indicates a successively shallowing from the Malm gamma 2 to Malm delta following the "Energy-Index" of Plumley (1962). The distinct predominance of demosponges compared with hexactinellids in the Malm delta could be interpreted as an adaption to the biological demands of shallow water conditions following the functional morphology of siliceous sponges after Leinfelder et al. (1996) (Fig. 4).

The observed regressive tendency of the Late Jurassic sedimentation patterns contradicting the global sea-level rise (represented by the eustatic sea-level curve according to Haq et al. 1988) can be explained by the "bucket principle" (Kendall & Schlager 1981, Keupp et al. 1990) in which the biogenic growth-rates of the spongiolites exceed the eustatic sea-level rise. Considering these facts the alternation of MFT 6 and MFT 7 reflects sufficient (bindstones) or insufficient (wacke-, pack- and floatstones) microbial fixation and stabilization of the spongiolites, although there are fluent passages between this facies types.

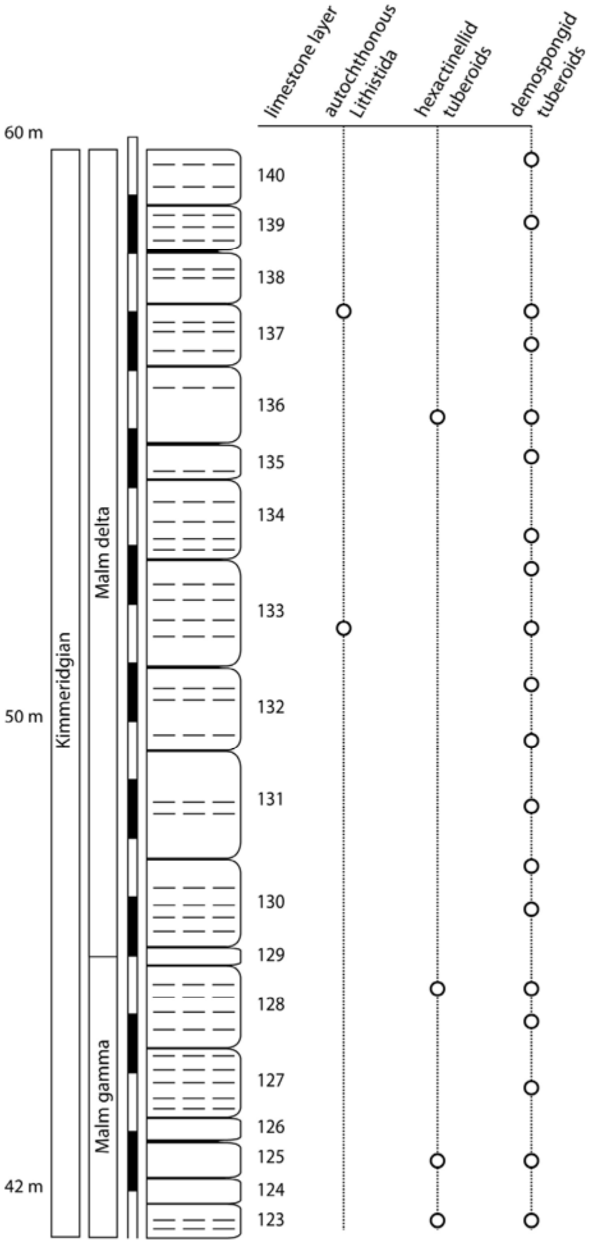

Fig. 4: The vertical distribution of sponges and tuberoids within Malm delta shows that demosponge structures are predominant throughout the succession, while hexactinellid sponge structures are losing importance towards the upper Malm delta. Considering the biological demands of demosponges (shallow water) and hexactinellids (deeper water) (Leinfelder et al. 1996) this could represent an adaption to a dropping sea-level.

The occurrence of glauconite grains with micritic centres indicates an authigenic formation of concretions near the sediment surface within a rather reducing milieu during sedimentary condensation. Hornung (2001) considers the glauconitic coating of the ammonite stony casts to be a result of decaying organic material („pellicula“) at the inner wall of the phragmocones inducing a reducing micromilieu. Following Koch (2000) the main dolomitisation of the Malm limestones occurred during the shallow subsidence-related diagenesis and proceeded as a result of fluid migration through fine fracture systems, strained grain boundaries and microporosity. Enhanced fabric density (diagenetic packstones) and nodules associated with marly layers (Fig. 7F) indicate differential compaction resulting from horizontally separated zones of both disolution and precipitation of carbonate (Ricken 1986). Due to the diagenetic character of the bedding the primary control factors of the genesis of the marl-limestone sequence (e.g. bio-productivity of carbonate precipitating organisms) can not be directly correlated to the bedding sequence and consequently no short-term cyclicity can be derived.

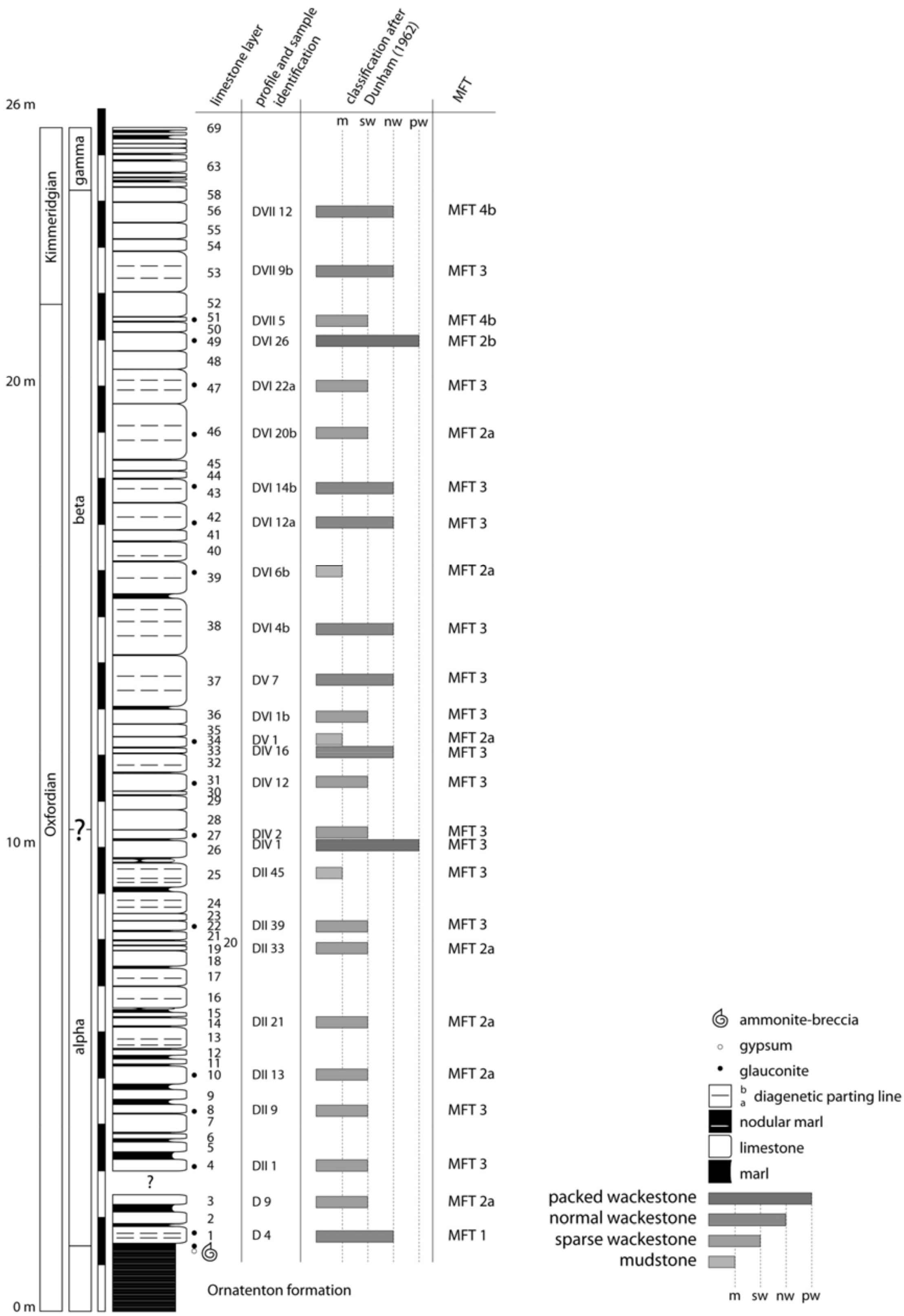

Fig. 5: Lithological and facial profile of the Oxfordian and lowest Kimmeridgian of Gräfenberg (Deuerlein quarry).

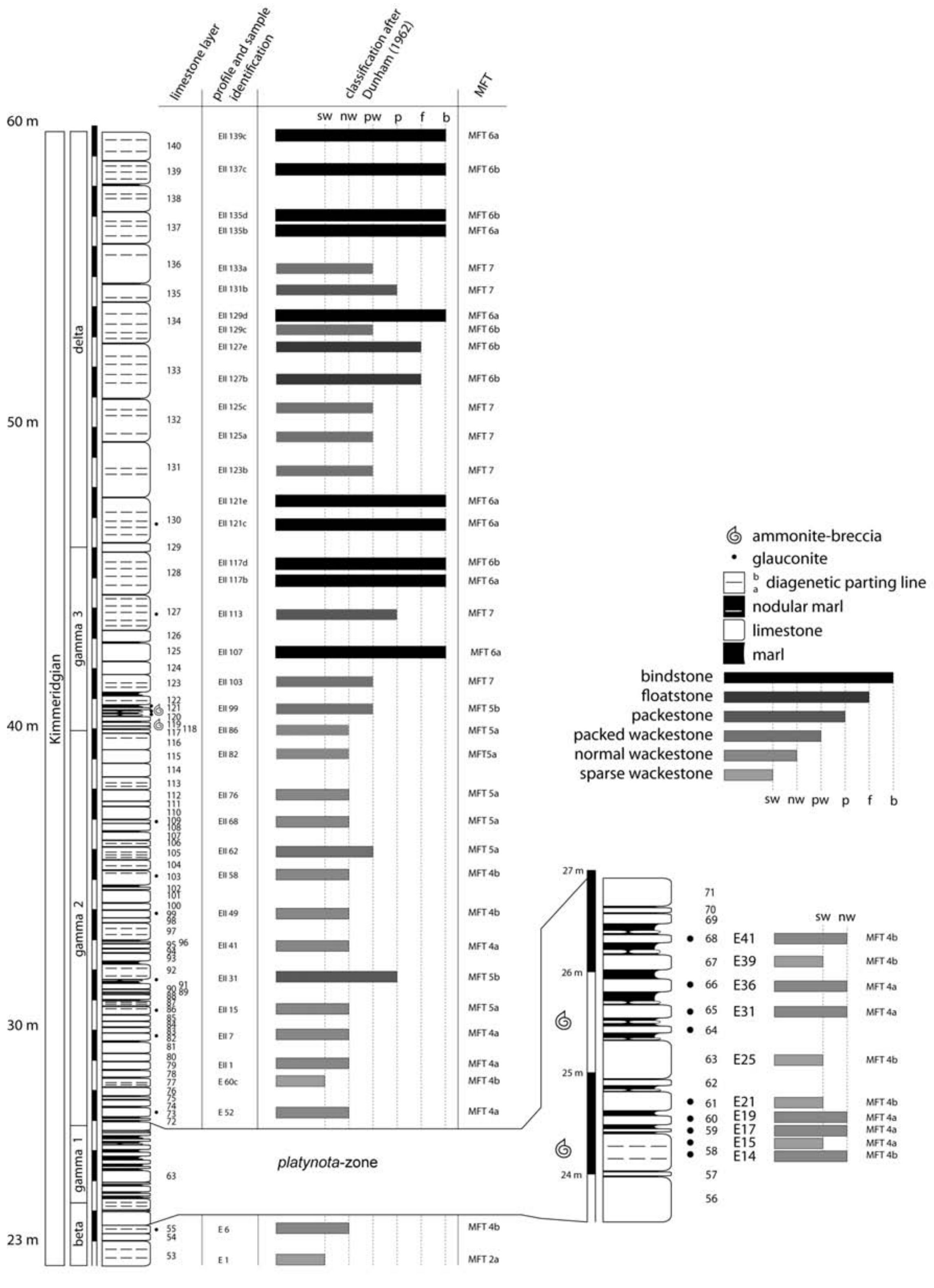

Fig. 6: Lithological and facial profile of the Kimmeridgian of Gräfenberg (Endress quarry) with a close-up view of the *platynota* zone.

Conclusions

The Upper Jurassic microfacies of Gräfenberg and its application for reconstructing the environmental conditions, especially the sea-level during accumulation, has been outlined. A relative development of the sea-level could be assessed using facies-indicating microfossils and sedimentary structures derived from thin sections. This work contributes to a better understanding of the ammonite-rich *platynota* marl formation (lower Malm gamma). Additionally an assessment of the genesis of the so-called Massenkalkfazies (Malm delta) at Gräfenberg is included.

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Fig. 7: (next page)

A) Densely packed intraclasts and peloids beside fine spread glauconite grains and one single foraminifera (*Lenticulina*). The interstice is secondary filled with pyrite (and partly sparite). Bed 1, normal wackestone, MFT 1.

B) Fine bioclastic micrite with a planktonic protoglobigerinid foraminifera (down left), a benthic *Lenticulina* (middle left) and a juvenile gastropod (right). Bed 19, sparse wackestone, MFT 2a.

C) Globigerinid planktonic foraminifera. Bed 59, normal wackestone, MFT 4a.

D) Arm element (brachialia) of *Saccocoma*; *platynota* zone, lower Kimmeridgian. Bed 65, normal wackestone, MFT 4a.

E) Glauconite grain with a micritic centre. Bed 59, normal wackestone, MFT 4a.

F) Dark and streaky horizontal enrichment of clay minerals indicates advanced compaction. The clasts are represented mostly by tuberoids and *Tubiphytes*. Layer 26/27 (marl), packed wackestone, MFT 3.

G) Fine spread bioclasts with abundant *Saccocoma* arm elements, sponge spicules and radiolarians beside glauconite grains. Bed 65, normal wackestone, MFT 4a

H) Slightly horizontally layered filaments and mostly monaxon sponge spicules as the main components in the upper "Mergelkalk" of Malm gamma. Bed 105, packed wackestone, MFT 5a.

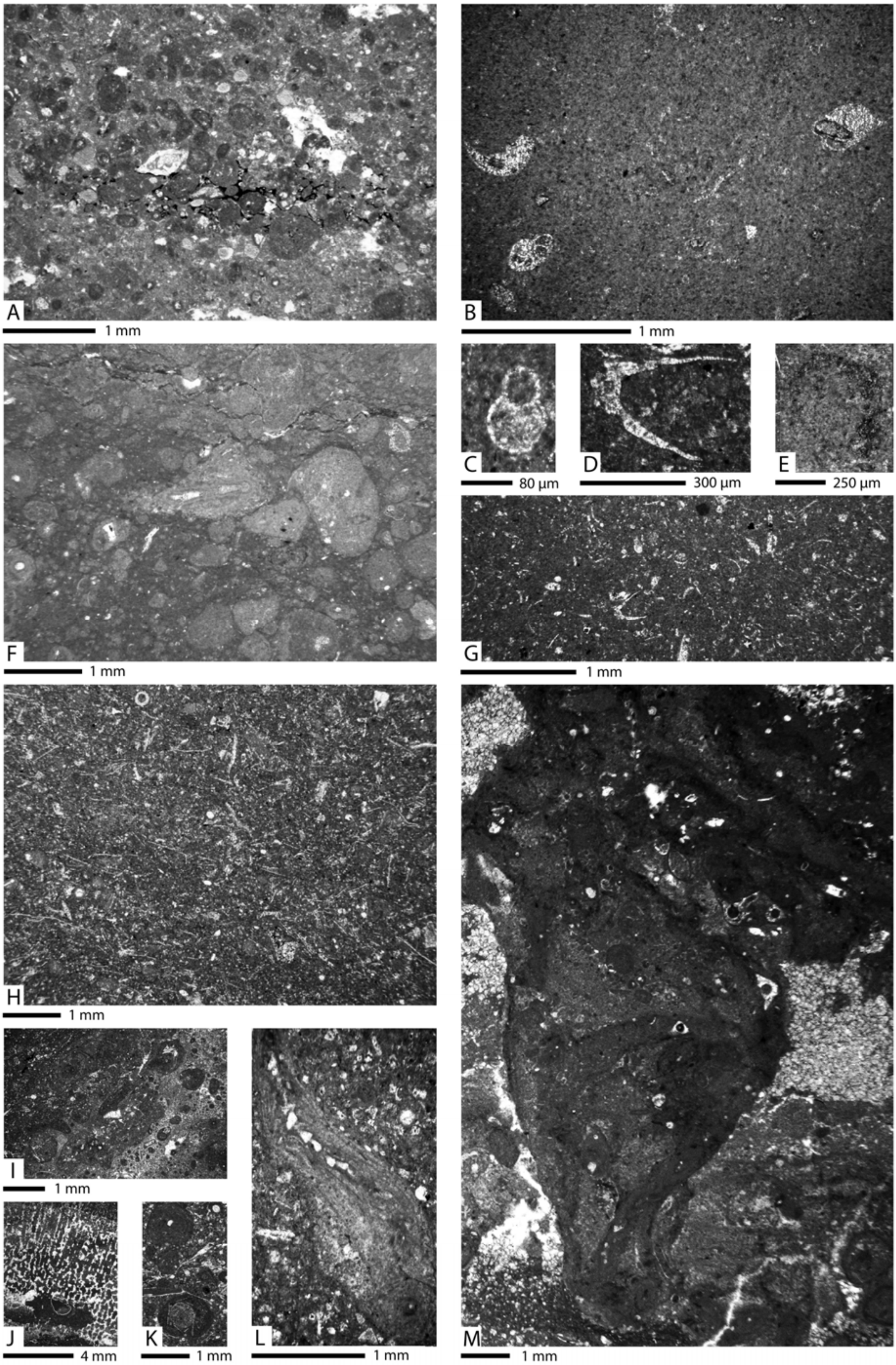
I) Hexactinellid relic structure of a tuberoid embedded in a groundmass dominated by intraclasts, cortoids and peloids. The mostly automicritic matrix also reveals partially sparite. To the upper left microborings mark the transition zone to the dominant bioclastic packed wackestone fabric. Bed 123, packed wackestone, MFT 7.

J) Parautochthonous lithistid demosponge with a fibrous crown consisting of monaxon spicules sprawling into a fine-peloidal matrix (upper right). An articulate brachiopod is situated within a micritic filled borehole. Bed 133, floatstone, MFT 6b.

K) *Terebella* (Polychaeta) with agglutinated filaments situated below *Tubiphytes morronensis* as an instance of the typical *Tubiphytes*-*Terebella*-association towards the upper Malm gamma and Malm delta. Bed 132, packed wackestone, MFT 7.

L) *Tubiphytes morronensis*. Bed 128, Bindstone, MFT 6a.

M) Streaky microbial crusts binding together the secondary dolomitised sediment. Incrusting organisms are (besides bacterial community) *Tubiphytes*, other foraminifera and serpulid tube worms. The association of organisms indicates trombolites, but also stromatolitic (laminated) structures are present. The dolomitisation is enriched in clusters. Bed 125, bindstone, MFT 6a.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