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LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT OF LOWER–MIDDLE JURASSIC CRINOIDAL LIMESTONE FORMATIONS OF THE VYSOKÁ NAPPE UNIT (MALÉ KARPATY MTS., WESTERN CARPATHIANS)

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Abstract: The Lower–Middle Jurassic sequence of the Vysoká Unit in the Malé Karpaty Mts. (Western Carpathians, Slovakia) comprises a complex of crinoidal limestones. The paper suggests newly dividing this unit into four formations: Trlenská Fm., Vývrat Fm., Prístodolok Fm. and Vils Fm., all of which are described in detail. Two of them, the Vývrat and the Prístodolok Fms., are defined as new formal lithostratigraphic units.
A connection is supposed between rhythmical facies changes in these sediments and relative sea level fluctuation. Two significant regressions are recognisable in a generally shallowing upward sequence with an uncertain number of cycles of lower order between them. The influence of eustatic and regional tectonic activity control on relative sea level changes has been not distinguished. The curve of sea level changes suggested by sequence stratigraphic analysis is comparable to the curve published by Haq et al. (1988). Lateral facies changes have been studied across the Vysoká Nappe Unit. The Lower–Middle Jurassic crinoidal complex is a part of a slope apron rimming the toe-of-slope of a carbonate plateau which probably originated due to tectonic collapse of the large Triassic carbonate platform during the Early Jurassic. Its proximal development (near to apex) was recognized at the SW and the distal development at the NE edge of the Vysoká Unit. Sedimentation of the crinoidal limestones was terminated by an abrupt rise of the relative sea level and followed by deposition of nodular limestone formations.

Key words: Lower Jurassic, Western Carpathians, carbonate sedimentology, lithostratigraphy, sequence stratigraphy, sea level change, slope apron, crinoidal limestone.

Introduction

During the early 60's, several papers discussing the lithology and stratigraphy of the Lower–Middle Jurassic crinoidal limestones of the Vysoká Nape in the Malé Karpaty Mts. were prepared, as a result of substantial research by the team of Maheľ and co-workers. The lithofacies characteristics of these sediments have been described in more detail by Kullmanová (1965), Szalontay (in Maheľ 1966) & Pevný (1964). However, no lateral and/or vertical facies relationships of the sedimentary bodies of different development, their geometry and position in the lithostratigraphic framework have been suggested by these authors. Nevertheless, the research provided a great amount of biostratigraphic data.

There are three main areas where the Lower–Middle Jurassic crinoidal limestones occur: Vývrat-Prístodolok, Buková hora and Smolenice (sea below, Fig. 1). Fortunately, the outcrops are distributed across the whole body of the Vysoká Nappe Unit (the study area). For exact localization of the outcrops, profiles and type localities see Koša (1997).

On the basis of the work mentioned above and after very detailed field research the author proposes in the present paper to divide the crinoidal complex into four formations: Trlenská Fm., Vývrat Fm., Prístodolok Fm. and Vils Fm.; two of them are suggested as new formal lithostratigraphic units. Within these formations, some lateral lithological changes are evident across the Vysoká Unit, supporting the idea of the paleodistributary system with its proximal deposits preserved at the SW and the distal ones at the NE margin of the Vysoká Unit (see

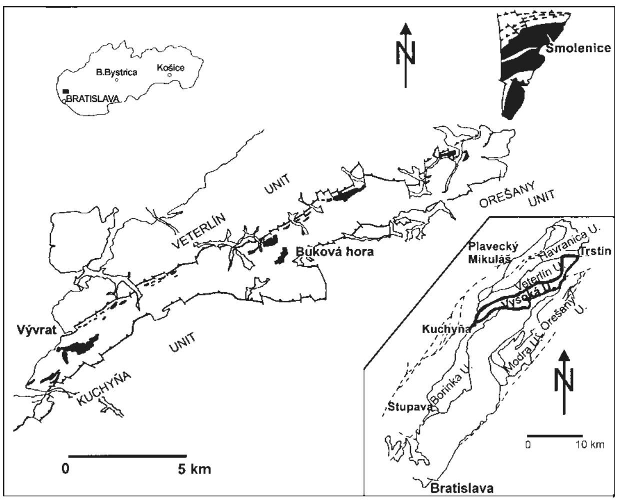


Fig. 1. Geological sketch of the Vysoká Nappe Unit showing distribution of the Lower–Middle Jurassic crinoidal limestones (black areas) and location of the most important localities (modified after Borza & Michalík 1987; Michalík 1997).

below). For this reason there are two descriptions given in some of the definitions of the formations: one for the development of the sediments studied at the type locality, and another one for their lateral equivalents.

Trlenská Formation

The Trlenská Fm. was defined by Bujnovský et al. (1979) in the Trlenská Valley in the Veľká Fatra Mts. (S of Ružomberok) in the Liassic sequence of the Šiprúň Group. In spite of the fact that it was originally defined as a unit belonging to the Tatric Superunit, this term has been also applied to the basal part of the crinoidal complex of the Vysoká Unit in the Malé Karpaty Mts. (Michalík in Plašienka et al. 1991).

In the study area this formation crops out at the E foot of the crest part of the Prístodolok Hill, in the massif of Mesačná and in a wider area NW from Smolenice. Its thickness is about 20 m at Prístodolok and 40–60 m in the vicinity of Smolenice (profile Smolenice, Fig. 2).

At the Prístodolok Hill the Trlenská Fm. is represented by bedded (10–20 cm in thickness) sandy crinoidal limestones, fresh fracture surfaces are dark grey to blue-black, with irregular nodules and longitudinal lenses of brown and grey silicites. Weathered surfaces are brown to brown-grey in colour, with abundant quartz grains and silicified bioclasts (unbroken, completely preserved shells of brachiopods, also bivalves and belemnites are common) are clearly visible (Pl. I: Fig. a). Microscopically, they are packstones composed mainly of crinoidal detritus, coarse biodetritus, with clastic sand-size quartz grains (5–10 %) and some foraminifers. In this development, lithoclasts of grey biomicritic limestones (see below) are common.

In the NE part of the study area the lateral equivalents of these limestones crop out at several localities near Smolenice (Hlboč Valley, Prielohy, Driny, see Koša 1997). These are sandy crinoidal packstones to grainstones without biomicritic lithoclasts, indistinctly bedded to massive and grey on the weathered surface.

The base of the formation is not exposed in outcrops. In the saddle between the Prístodolok and the Vysoká Hills, however, the geomorphology as well as the outcrops of the underlying Kopienec Fm. and the Trlenská Fm. in close proximity allow us to localize their boundary. However, this boundary documents a significant (and probably quite sharp) change in sedimentation style from the marl and clay dominated sediments of the Kopienec Fm. to crinoidal limestones which is interpreted as a major regression H/S (Fig. 10) in this area.

The chronostratigraphical range is Sinemurian–?Lotaringian (Maheľ et al. 1966; Pevný 1964; Michalík 1997, personal communication).

Vývrat Formation (newly suggested name)

The name of the Vývrat Fm. is after the locality of Vývrat (road crossing, hunting cottage, Fig. 1) situated at the SW edge of the study area.

The type profile of 55 m of stratigraphic thickness is found in an little old quarry situated beside the former forest railway at the S slope of the Prístodolok Hill (profile Vývrat 2). The lower part of the natural exposure of the little klippe at the left bank of the Vývrat creek ca. 150 m S (profile Vývrat 1) can serve as a reference profile for this formation. It is reasonable to study both, the relatively fresh, weakly weathered former, and the natural latter outcrop, for recognition of the diagnostic lithological features of the Vývrat Fm. Further larger outcrops of this formation are located on the S, SE and W slopes of the Buková hora Hill (profile Buková hora), on the S slopes of the Parná Valley and typically for the development of the NE part of the study area in the Vrtichov Quarry in the Hlboč Valley (NW of Smolenice) (profile Smolenice, Fig. 1, also see Koša 1997). The thickness of the formation is about 100 m.

The limestones are thick bedded to platy (10–100 cm, mostly 15–25 cm). Their typical textures are fine- to medium-grained crinoidal packstones. The rocks are strongly silicified, dark grey, grey to brown-grey on fresh fracture surfaces (occasionally also red!, see Koša 1997), grey or brownish grey on weathered surfaces. Typically a great amount (40–90 %) of large irregular lenses and stratiform layers of grey and brown cherts occurs. The bedding planes (which are not necessarily conformable with the primary bedding planes!, Fig. 5) are characteristically wavy, probably due to compaction of a selectively silicified sediment (Pl. I: Fig. b).

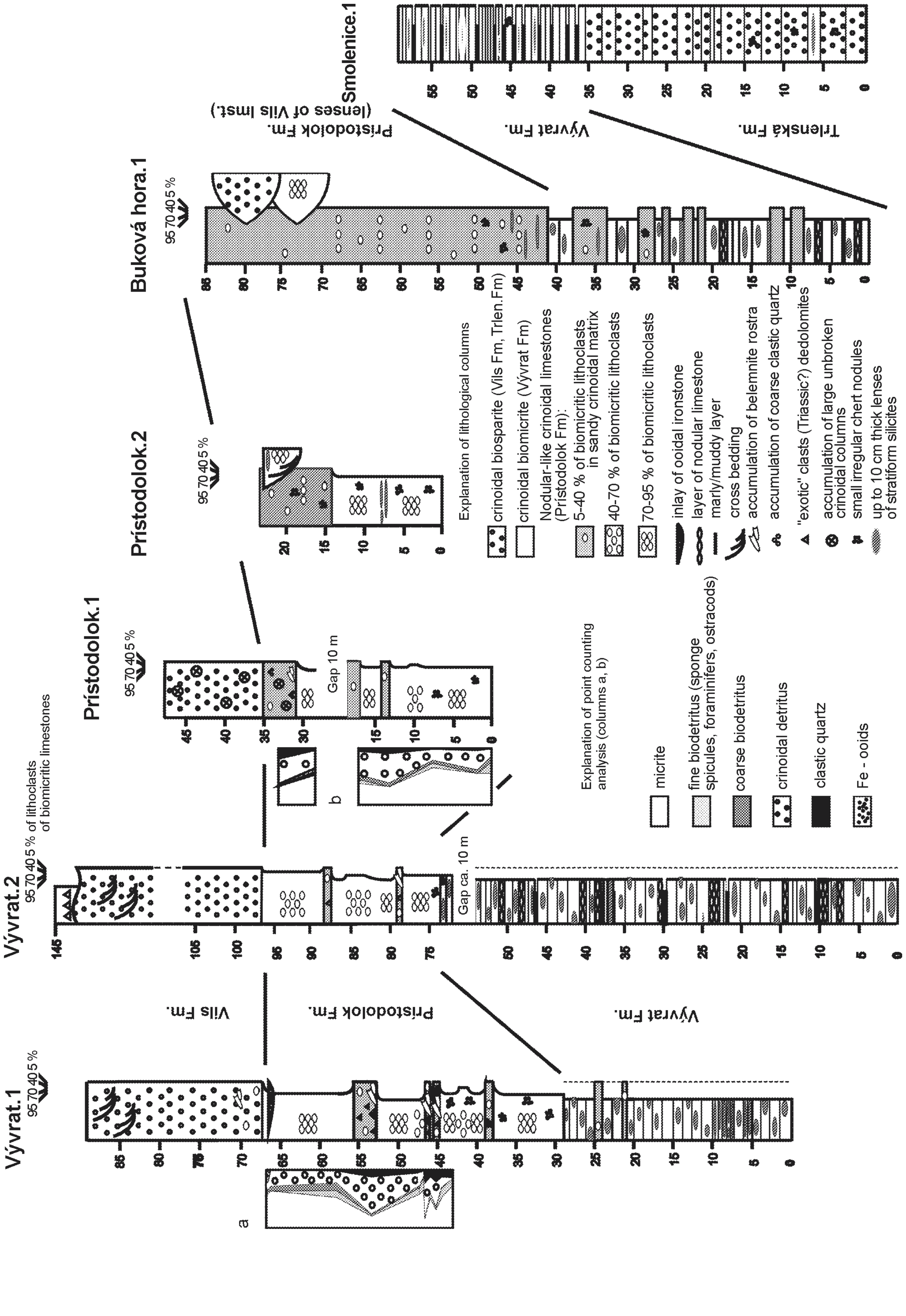
Thinning-upward cycles with occurrence of 0.5–3 cm thick marly and about 5 cm thick nodular limestone intercalations are visible in this formation. In the upper part of it, also layers of biodetrital, occasionally reddish to purple coloured limestones occur, showing features of the overlying formation (Fig. 2).

On the weathered surface, lithoclasts (in some cases also thin lenses and/or layers) of grey fine-grained biomicrites are visible in a coarser grained crinoidal biomicritic matrix. They are typical for the development exposed at the localities Vývrat-Prístodolok and Buková hora. They are not present in the development of the NE part of the study area.

The lateral equivalent of this formation in the NE part of the study area is an alodapic complex of bedded (5 to 30 cm) crinoidal packstones intercalated by 1 to 10 cm thick layers of marls, limy shales to bituminous shales which enclose thin (0.1 to 3 cm) lenses and intercalations of the crinoidal limestones identical with the neighbouring ones (Pl. I: Fig. e). The limestones are grey to greyish brown on fresh fracture surfaces, rusty brown on weathered surfaces. The silicification is more considerable in the upper part of the formation. Nevertheless, there are some small chert nodules and lenses occurring throughout the formation. These sediments represent a more distal, relatively deeper facies of the Vývrat Fm.

The base of the Vývrat Fm. is very obvious in the NE part of the study area, where the grey thick bedded to massive

Fig. 2. Simplified lithological collumns of selected profiles and lithostratigraphic scheme of the Lower–Middle Jurassic crinoidal complex.



Vývrat.1
Vývrat.2
Prístodolok.1
Prístodolok.2
Buková hora.1
Smolenice.1
95 70 40 5 %
95 70 40 5 % of lithoclasts of biomicritic limestones
Vils Fm.
Prístodolok Fm.
Vývrat Fm.
Prístodolok Fm. (lenses of Vils lmst.)
Trlenská Fm.
Gap ca. 10 m
Gap 10 m
a
b
Explanation of point counting analysis (columns a, b)
micrite
fine biodetritus (sponge spicules, foraminifers, ostracods)
coarse biodetritus
crinoidal detritus
clastic quartz
Fe - ooids
Explanation of lithological columns
crinoidal biosparite (Vils Fm, Trlen.Fm)
crinoidal biomicrite (Vývrat Fm)
Nodular-like crinoidal limestones (Prístodolok Fm):
5-40 % of biomicritic lithoclasts in sandy crinoidal matrix
40-70 % of biomicritic lithoclasts
70-95 % of biomicritic lithoclasts
inlay of ooidal ironstone
layer of nodular limestone
marly/muddy layer
cross bedding
accumulation of belemnite rostra
accumulation of coarse clastic quartz
"exotic" clasts (Triassic?) dedolomites
accumulation of large unbroken crinoidal columns
small irregular chert nodules
up to 10 cm thick lenses of stratiform silicites

sandy crinoidal grainstones of the Trlenská Fm. are overlain by the complex of rhythmically alternating crinoidal limestones and marlstones of the Vývrat Fm. The upper boundary is not evident. Conventionally it is based on the rate of silicification; in the uppermost parts of the Vývrat Fm. the lithological features are practically identical with those of the overlying formation, however they are interlayered with thick layers of stratiform cherts.

Chronostratigrafically this formation belongs to the Pliensbachian (Mahel' et al. 1966; Pevný 1964; Michalík 1997, personal communication). In the NE part of the study area where, the overlying layers belong predominantely to the Vývrat Fm., it is assumed that the stratigraphic range is broader (Pliensbachian–Bajocian–?Bathonian), however, it has not been proved on a profile.

Prístodolok Formation (newly suggested name)

The name is after the Prístodolok Hill at the SW edge of the study area (Fig. 1).

The type profile is at a little klippe rising on the left bank of the Vývrat Creek, about 300 m SE from the former hunting cottage Vývrat, where a continuous outcrop of this formation is known and parts of the under- and overlaying formations are also exposed (profile Vývrat 1). Very good profiles exposing up to 25 m stratigraphic thickness are found on the rocky crest of the Prístodolok Hill (profile Prístodolok 1, 2) as well as on the series of SW-NE oriented rocky ridges SE from the Buková hora Hill (profile Buková hora). In the NE part of the study area this formation is replaced by the Vývrat Fm. Its thickness is about 35 m at the locality of Vývrat-Prístodolok. At Buková hora the thickness of this formation together with the overlying one (see below) is about 100 m.

It is made up of grey, greyish pink, pink to purple red, indistinctly bedded to massive crinoidal nodular-like limestones. The seemingly nodular character of these limestones is partially due to the high content (0–95 %) of lithoclasts ("nodules, intraclasts") of pink and grey fine-grained biomicritic limestones. The lithoclasts are enclosed in a coarser sandy crinoidal matrix. Their amount varies rapidly vertically and laterally.

Vertically the decrease of micritic lithoclast content appears as an interlayer of a coarse grained, at Vývrat and Prístodolok typically dark red sandy crinoidal biosparite which may contain deformed white "nodules". A considerable concentration of coarse biodetritus including fragments as well as complete belemnite rostra is very characteristic. The presence of small (0.5–15 mm) beige extraclasts i.e. "exotic" lithoclasts (?Triassic dedolomites—Mišík 1997, personal communication, Pl. I: Fig. c) is typical. The preferential tectonic deformation can cause a shaly character of these layers.

The lenses and layers of purely detrital limestones in a sequences of limestones rich in biomicritic lithoclasts are always found in the outcrops of this formation. Their thickness and number vary rapidly both laterally and vertically.

The basal part of this formation is rich in small irregular nodules and lenses to stratiform layers of orange and/or grey silicites. Their abundance and size decrease upwards. In the upper parts of the formation the silicites are rather rare and their occurrence bears upon the zones of inhomogenities such as, for example paleodistributary channels fills (Fig. 7, see Koša 1997).

The succession from the Prístodolok Fm. to the overlying Vils Fm. with sharp contact between them outcrops at the locality Vývrat-Prístodolok. At Buková hora the transition is fairly continuous, indicating the lateral substitution of the two lithofacies up to the base of the formation overlying the Vils Fm. (Fig. 2).

Stratigrafically we assign the Prístodolok Fm. to the Toarcian. However, locally its stratigrafical range can be broader (Pliensbachian–Aalenian–(?Bathonian at Buková hora), Mahel' et al. 1966; Pevný 1964; Michalík 1997, personal communication).

Vils Formation

Defined by Hauer (1853) as a complex of crinoidal limestones with a huge amount of brachiopods. The name is after the village of Vils in Tyrol (Austria). In the Carpathians it was described by Hauer & Richthofen (1859) at the localities Stará Kremnica and Dolhoja. Štúr (1860) applied this term to the Jurassic crinoidal limestones of the Klippen Belt at the locality of Dolná Súča (now called the Krupianka and Smolegowce Limestones).

In a complete profile with a stratigraphic thickness of 44 m with transitions to the under- and overlying formations the Vils Fm. crops out along the former forest railway on the S slope of Prístodolok Hill (profile Vývrat 2). Laterally this outcrop can be followed almost continually toward the little klippe at the left bank of the Vývrat Creek to the W (profile Vývrat 1) and toward the W brink of the crest of Prístodolok Hill to the E (profile Prístodolok 1). Lensoid bodies of typically developed limestones of the Vils Fm. also crop out on the small ridge SSE of Buková hora Hill (profile Buková hora, Figs. 1, 2, see above, also see Koša 1997).

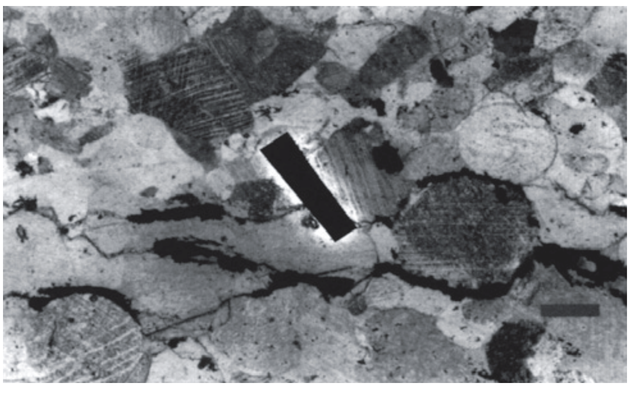


Fig. 3. Typical microfacies of crinoidal grainstones of the Vils Fm. Vývrat. 2–135 m, X, scale bar = 1 mm.

These are pink, greyish rose to grey, massive to indistinctly bedded crinoidal grainstones (Fig. 3), predominantly coarse grained, containing ca. 10 % of coarse sandy, or even coarser clastic quartz grains. On weathered surfaces they are grey and rough due to the quartz grains. Large (2–10 mm in diameter) completely preserved crinoidal columns prepared by weathering are also visible. The crinoidal ossicles are also conspicuous on fresh fracture surfaces.

The upper boundary of the Vils Fm. is sharp, erosive at the locality Vývrat-Prístodolok (Figs. 2, 9), with a layer of brecciated biomicritic limestone at the base of the overlying formation of the "true" nodular limestones with rare occurrence or lack of crinoidal detritus (lower nodular limestones after Borza & Michalík 1987). In the range of Buková hora it has a continuous transition to the same facies.

Stratigraphically the Vils Fm. is placed to the interval of Aalenian–Bathonian (Maheľ et al. 1966; Pevný 1964; Michalík 1997, personal communication).

For lists of identified fossils as well as for discussion of further problems related to determination of the lithostratigraphic relevance of the sediments described above (such as the possible influence of their subaerial exposure, intensity and type of weathering, variability in colour, relation between the primary and secondary — tectonically conditioned "bedding", problems of irregular distribution of silicites and biomicritic lithoclasts etc.) see Koša 1997.

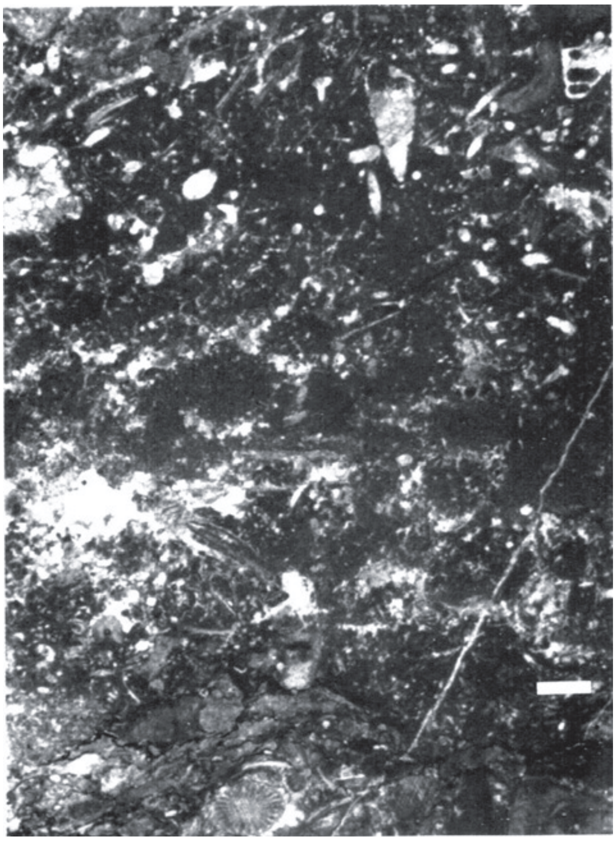


Fig. 4. Thin section showing contact of coarser grained crinoidal matrix and fine-grained biomicritic lithoclasts containing calcified sponge spicules, ostracodes and small gastropodes. Prístodolok Fm. Vývrat.1–47 m, X, scale bar = 1 mm.

Problem of "nodularity" and "nodular character" of limestone of the Prístodolok Fm.

Mišík (1964, p. 66) in the chapter discussing the problem of the "nodularity" of the Lower Liassic "untypical Adneth limestones" wrote: "The nodularity of the untypical Adneth limestones (with transitions to weakly crinoidal limestones) is always due to their clastic structure. The "nodules" are in reality clasts of micritic limestones often containing calcified sponge spicules, with no crinoidal detritus." This description corresponds very well to that of the character of the "nodularity" of the limestones of the Prístodolok Fm. (even if their composition: biomicritic lithoclasts in crinoidal matrix is typical for both of the underlying formations of the crinoidal complex as well).

In the lithoclasts of the biomicritic limestones, a relatively high percentage (10–20 %) of calcified sponge spicules is very typical. They also contain (often unbroken, complete) ostracodes, foraminifers and thin shelled bivalves (Fig. 4). Crinoidal fragments and silt-size quartzs are relatively rare. Microscopically they represent a characteristic spiculite microfacies in all of the Trlenská, Vývrat and Vils formations in their typical development in the SW part of the study area. The material of the lithoclasts may have been deposited in a relatively deeper environment and, after erosion, been transported in semiplastic condition and redeposited together with their obviously coarser sandy crinoidal matrix formed under relatively shallower conditions (Fig. 4, Pl. I: Fig. d). The matrix is composed of coarse crinoidal detritus, sand- and silt-size clastic quartz, brachiopodal, bivalval and bryozoan biodetritus, with rare foraminifers but no sponge spicules and

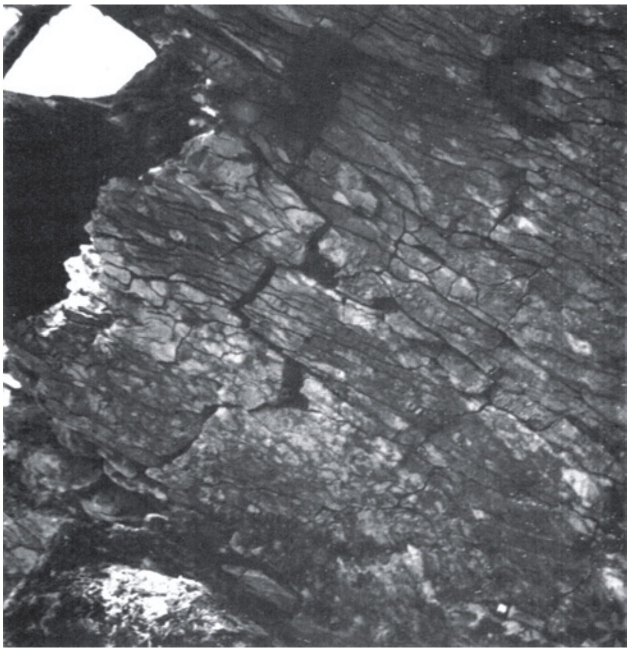


Fig. 5. "Bedding planes" of limestones of the Prístodolok Fm. are not parallel to stratification. The limestone is primarily enriched in biomicritic lithoclasts (light). Nodules and lenses of silicites are distributed symmetrically in these layers. Prístodolok Hill.

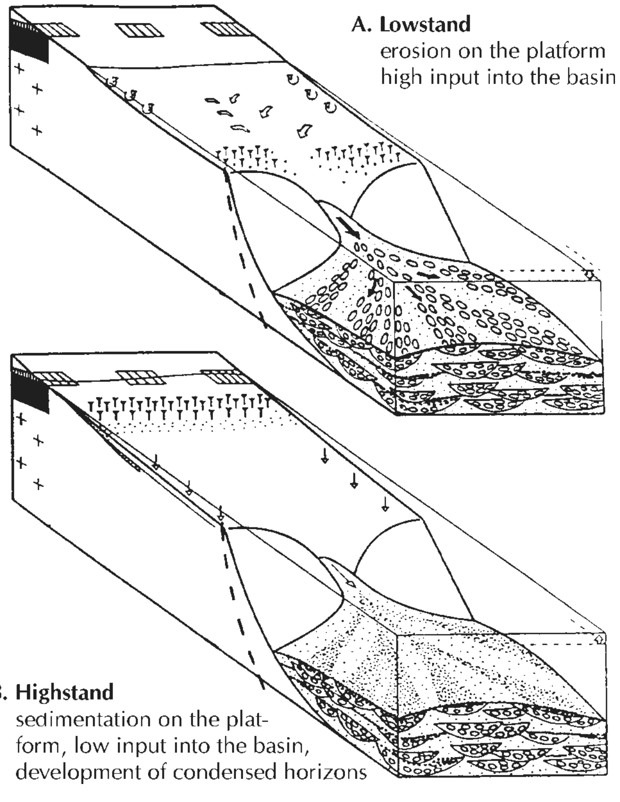


Fig. 6. Sedimentary model of origin of the facies found in the proximal development of the crinoidal complex (see profiles Vývrat. 1, 2, Prístodolok. 1, 2) showing how relative sea level changes influenced sedimentation. (No scale. For more explanation see text).

ostracodes. For the most part it is red stained by Fe-colloids. Especially within the detrital interlayers the colloids clearly mark out the internal structure of the strongly corroded crinoidal ossicles (Pl. I: Fig. f). The percentage of micrite varies in the range of 0–50 %.

The obvious heterogeneity of the "nodules" and the crinoidal matrix (i.e. the differences in granulometry of the quartz and biodetrital grains, differences in association and proportion of the allochems, as well as the plastic deformation of the lithoclasts and their reworking by erosion and transport) indicate that the "nodules" are actually clasts (plasticlasts) forming by redeposition of partially lithified and completely unlithified sediments (Figs. 6, 7).

Macroscopically, the matrix is characterized by coarser rough structure and relatively darker colours: pink to red on the weathered surfaces, whereas the biomicritic lithoclasts are generally pale grey to white and smooth (Fig. 5).

The amount of the biomicritic lithoclasts in the sandy crinoidal matrix varies in a range of 5–95 % (Fig. 2). Depending on the ratio between the two components the sediment shows features of the "true nodular limestones" of various types. It is probable that the pressure solution at the contacts of the prelithified and relatively solution resistent biomicritic lithoclasts played some role during the deep burial diagenesis of the sediments. However, evaluating the significance of these features and the primary heterogeneous character of the sediments, intraformational breccia formation seems to be plausible.

Fig. 7. Detail of margin of distributary channel filled by mixture of biomicritic lithoclasts (light, plastically deformed) and sandy and crinoidal detritus. There are no or only rare lithoclasts found outside the channel infill. Prístodolok Hill. Prístodolok Fm. Prístodolok 2–20 m.

Discussion of indicators of sedimentary processes and their importance for paleoenvironmental reconstruction

An analysis of the controling factors of both the lateral and vertical facies changes in the sedimentary processes is the subject of this chapter, on a small scale and also on a regional scale.

Considering our knowledge of the investigated sedimentary complex we cannot apply the approach of sequence stratigraphy all-embracingly. Use of the terms and categories of sequence stratigraphy in this paper is limited by various limiting factors, such as:

—insufficient precise (micro)biostratigraphical data;

—imperfect, rather uncontinuous exposure;

—different numbers of depositional cycles in the studied profiles due to relatively rapid alternation of sedimentation and erosion under conditions of changing energy;

—problems of correct distinction of allocyclic and autocyclic processes;

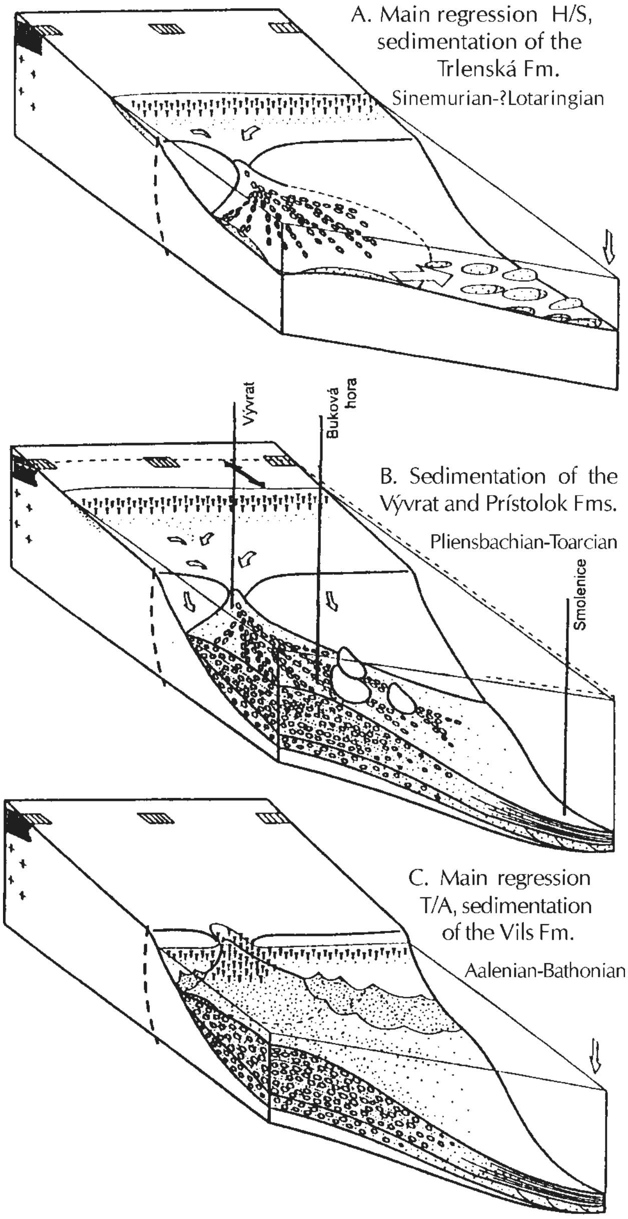


Fig. 8. Blockdiagram showing facies zonation and development of the crinoidal complex. (No scale. For more explanation see text).

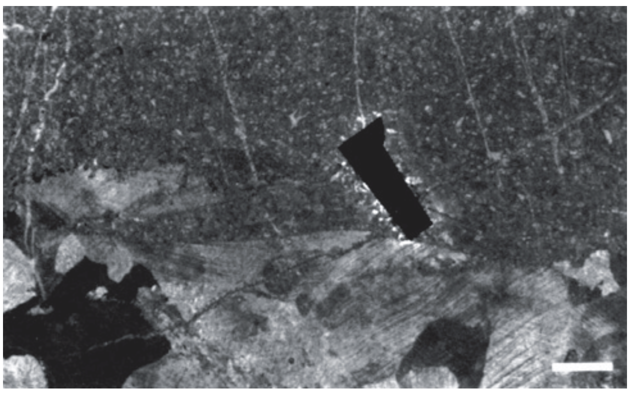


Fig. 9. Obviously erosional contact between crinoidal grainstone of the Vils Fm. and the overlying micritic limestone. Vývrat 2–145 m, X, scale bar = 1 mm.

—insufficient (or better lack) of correlative data on the relative sea-level changes in the related areas.

Discussion of the possible relation of the facies changes to relative sea-level changes

There are several indicators of the relative sea-level changes, such as (Fig. 10):

1) thinning upward of sequences (beds thicknesses) with intercalations of marly and nodular limestones occurring in the uppermost part of the Vývrat Fm. (see above);

2) periodical changes in the proportion of biomicritic limestones and the crinoidal matrix;

3) periodically occurring layers of red coarse detrital crinoidal limestones enriched in belemnite rostra;

4) periodical occurrence of "exotic" lithoclasts (up to 2 cm large) of beige coloured microcrystalline limestones containing less than 1 % of silt-size clastic quartz (?Triassic dedolomites, Mišík, personal communication) exclusively fixed upon those layers;

5) an oolitic ironstone layer with ferruginous crusts and banded ?microbialites, considerably enriched in amonites just below the base of the Vils Fm.;

6) sharp errosional contact between the Vils Fm. and the overlying nodular limestone formation with a basal breccia layer at the locality Vývrat-Prístodolok.

A model for the sedimentary processes and their relation with the relative sea level changes, as will be explained hereafter, is illustrated in Fig. 6.

Soták & Plašienka (1996) described the same facies from the northern part of the Veporic Superunit as a toe-of-slope accumulation. As we do not have enough data on the paleotectonic setting of the study area, the author´s suggestion is to regard the sedimentary paleoenvironment as a slope and toe-of-slope s.l., with an area producing platform carbonate material behind its upper margin, that is landwards.

Parts A) and B) of Fig. 6 show the facies zonation of the sedimentary environment. A flat coast served as the source area of lithologically well sorted (more than 99 % of quartz grains) material. Kullmanová (1965) considering the elongation coefficient of the quartz grains (1.4–1.8) supposed its origin in acid magmatites and metamorphites. Practically no feldspars and very few small muscovites are present, as well as rutile, zircon and epidote as accesoric constituents. The absence of kaolinite also indicates secondary origin of the siliciclasts, which may have been redeposited from previously sorted source rocks (e.g. Triassic terrigenous clastics). As for the clay minerals, the X-ray difractography analysis only showed the presence of illite.

The crinoidal meadows may have produced a large amount of crinoidal detritus covering large areas of a relatively shallow submarine plateau (carbonate ramp), and trapped the greater part of the terrigenous siliciclastics (mostly quartz). The sediments consisting of 60–80 % of lime mud (micrite) were deposited on its more distal parts. During the regression and lowstand systems tract (Fig. 6a) a considerable part of the unlithified to weakly lithified sediment was eroded and transported outside the ramp, partially down the slope and

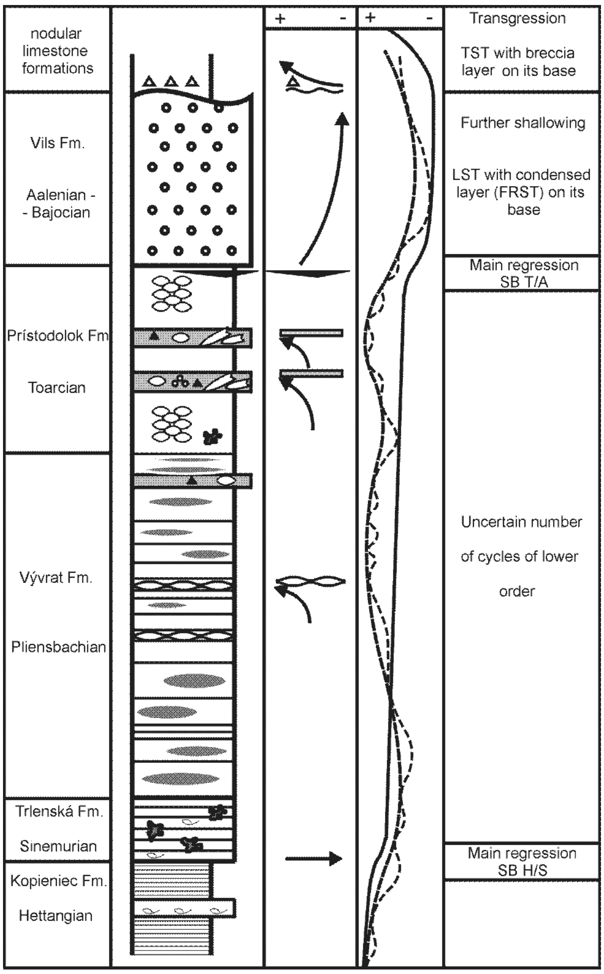


Fig. 10. Lithostratigrafic scheme of the crinoidal complex also displaying supposed trends of the relative sea level changes (full curve) and information useful for sequence stratigraphy. The broken curve after Haq et al. (1988). SB = sequence boundary, LST = lowstand systems tract, TST = transgresive systems tract, FRST = forced regression systems tract.

partially through a system of incised submarine valleys (canyons). From the canyons mouths the material derived both from the crinoidal biotops and the more distal parts of the ramp was further transported by a system of distributary channels (Fig. 7). Consequently, it was deposited (partially in form of intraformational breccias) forming huge canyon fed slope aprons at the toe-of-slope. Sediments consist of a mixture of redeposited lithoclasts of biomicritic platform carbonates and coarser grained biodetrital (mainly crinoidal) material representing the main feeding channel fill. Less differentiated sediments consisting mainly of crinoidal detritus and lime mud were deposited in the interchannel area.

After the relative sea level rise, the erosion stopped and sedimentation was resumed on the ramp causing starvation of the area behind its margin. A small amount of well washed clastic material was supplied to this area through a system of distribuary channels keeping its function henceforth. The material was deposited in the channels and on the slopes of the aprons creating thin condensed layers of detrital, strongly porous, typically red coloured limestones (Pl. I: Fig. g). The bioclasts have been strongly corroded and impregnated by Fe-colloids during the slow transport. A great number of belemnite rostra is typical for these layers. As the sea level rose, the shoreline may have reached outcrops of the source of the beige microcrystalline carbonate extraclasts, which are very characteristic of these layers (see above).

Subsequent fall of the relative sea level caused recurrance of the "normal" sedimentation behind the plateau margin.

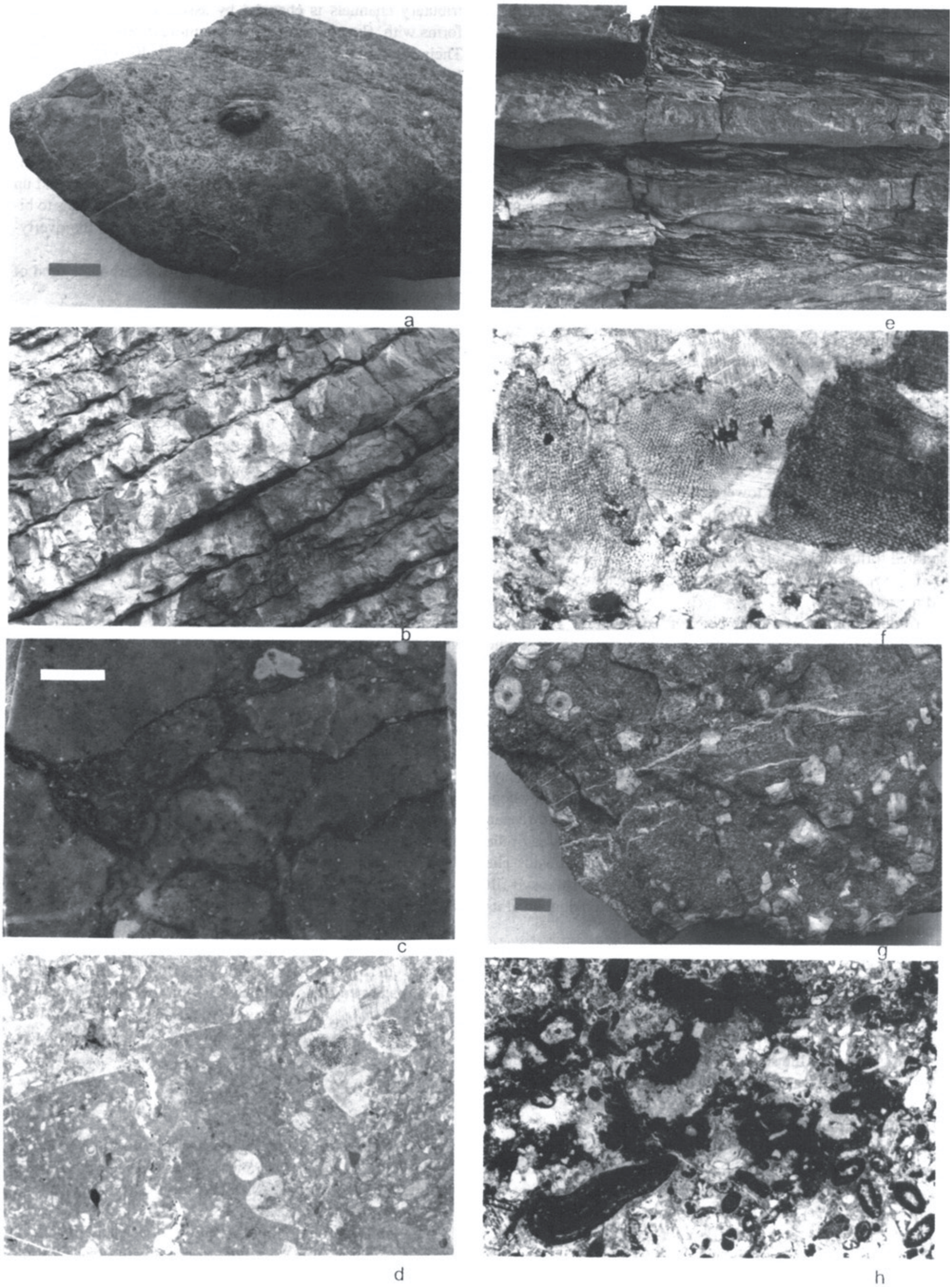
A very significant indicator of the influence of the relative sea-level change on sedimentation is the occurrence of a thin strongly ferruginous ooidal ironstone layer (lens) and related banded ferrugenous ?microbialites (Burkhalter 1995; now limonitic crusts, irregular coats and large Fe-pisolites) considerably enriched in amonites fauna just below the base of the Vils Fm. (Pl. I: Fig. h) representing a sedimentary record of the main regression T/A (Fig. 10, forced regression systems tract, e.g. Hunt et al. 1992; Plint & Nummendal, in press; also see Burkhalter 1995). At the end of the regression period, the sedimentary area of the well washed crinoidal biosparites closely connected to the crinoid meadows was moved to or below the plateau margin (Fig. 8c). The crinoidal grainstones of the Vils Fm. overlie downdip the top part of the apron sediments as it is visible in sections Vývrat 1, 2 and Prístodolok 1, 2.

Sedimentation of crinoidal grainstones of the Vils Fm. come to on end due to a significant fall in sea-level resulting in erosion.

Reconstruction of the paleoenvironment and development of the crinoidal complex

The Lower–Middle Jurassic complex of the crinoidal limestones of the Vysoká Unit is part of a large submarine slope

Plate I: Fig. a. Clast of the Trlenská lmst. in its proximal development. Silicified bioclasts (mainly brachiopods), quartz grains and biomicritic lithoclasts can be seen on its weathered surface. Scale bar = 1 cm. **Fig. b.** Thick bedded, strongly silicified limestones of the Vývrat Fm. Wavy, irregularly deformed bedding planes are typical. Vývrat. 2, ca. 20 m. The shoe is 30 cm long. **Fig. c.** Bazal part of a detrital layer within the Prístodolok Fm. Note its considerably brecciated shape and the beige microcrystalline "exotic" lithoclasts (at the lower and upper margin of image). Polished section, Vývrat.1–45 m, scale bar = 0.5 mm. **Fig. d.** Marks of erosion on the periphery of biomicritic lithoclasts. Its right margin is marked by an almost completely dissolved bivalve shell, the lower margin shows obvious marks of erosion disclosing its clastic origin. Prístodolok Fm. Vývrat. 1, II, 10×. (Figure is turned left of 90°). **Fig. e.** Intercalating alodapic crinoidal limestones and marls, marly shales to bitumenous shales represent the distal facies of the apron-related sediments. Vývrat Fm. Vrtichov quarry, Smolenice. **Fig. f.** Typical view of sandy crinoidal matrix in thin section. Intense corrosion of bioclasts is characteristic. Prístodolok Fm. Vývrat.1–55 m, X, 25×. **Fig. g.** Weathered surface of limestones of the Prístodolok Fm. in detrital development. Large clastic quartz grains and concentration of coarsest biodetritus characterize the condensed sediments filling the main feeding channels in the proximal part of apron. Prístodolok 1.32 m. **Fig. h.** Condensed oolitic ironstone layer representing record of forced regression. Strongly corroded echinodermal fragments (echinoid spines mainly) serve as cores of ferrugenous ooides and pisolites.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apron. It was created on the toe-of-slope of a submarine plateau (foot of the shelf slope, compare with Soták & Plašienka 1996) by redeposition of nonlithified or partially lithified material derived from the plateau (see above). Relatively shallow water conditions are supposed for this sedimentary system, i.e. tens to a few hundreds of metres. The top part of the sedimentary body is represented by the series cropping out at the locality of Vývrat-Prístodolok. Its distal development is represented by the succession at the locality of Smolenice.

Indicators suggesting the architecture of this sedimentary body are:

1) the most frequent character of the sediments — an intraformational breccia, a heterogeneous mixture of the lithoclasts of biomicritic limestones (formed in a relatively deeper environment) and sandy crinoidal matrix (formed in a relatively shallower environment);

2) transport of the sediment by a system of distributary channels (Fig. 7);

3) considerable lateral gradation of the grain size of the material transported (depending on the position in relation to the main feeding channels, Pl. I: Fig. g);

4) a trend of change of the character of sediments — from the relatively shallower towards the relatively deeper environment — in the direction Vývrat-Smolenice (Fig. 1), lateral changes towards the relatively deeper facies within the individual formations in this direction;

5) a trend of change in the formation thicknesses in the same direction;

6) development of a huge body of the crinoidal grainstones of the Vils Fm. at the locality of Vývrat-Prístodolok, while they are rare or absent in the more distant localities.

The beginning of sedimentation of the crinoidal complex at the Hettangian-Sinemurian boundary was connected with a considerable shallowing (main regression H/S, Fig. 10) of the sedimentary area and represented an essential change of the character of sedimentation: marlstones, siltstones and claystones of the underlying Kopienec Fm. were followed by deposition of sediments of the Trlenská Fm. It stands to reason that the shallowing was due to tectonic uplift in the area of the simultaneously initiated opening of the Zliechov Basin. The crinoidal complex described could thus represent the syn-rift sediments deposited in an elevated and dissected domain at its northern margin.

The formation of the system of canyons and channels transporting material from an elevated nearshore plateau may have been predisposed by the tectono-sedimentary conditions preceding the beginning of the Early Jurassic sedimentation cycle. The lateral facies zonation of the Trlenská Fm. reflects the depth gradient of the sedimentary area (Fig. 8a). The shallowest facies which was formed in the close vicinity of the canyon mouth is composed, in adition to the crinoidal and particularly abundant brachiopod detritus, also of lithoclasts of biomicritic limestones (see above). Some part of the sediment was transported further by currents. Subsequently, it was deposited in more distal areas, forming bodies of well washed biodetrital limestones (large-scale crinoidal dunes, Jenkyns 1971). The facies change is accompanied by change of the faunal association: prevalence of the rhynchonellid brachiopods indicating a high energy living environment and vicinity of the main distributary channels is changed by association of thin walled forms with flat commissures in the more distal development. Their colonies are preserved in situ (Michalík 1997, personal communication).

Sedimentation of the Vývrat Fm. was accompanied by deepening of the NE part of the Vysoká Unit. The formation of thick bedded, strongly silicified grey crinoidal limestones passes laterally into a sequence of alodapic irregularly intercalating grey crinoidal limestone layers (5–10 cm thick) and up to 10 cm thick intercalations of marlstones, marly shales to bituminous shales. This sequence also supplements the overlying Prístodolok Fm. in the distal development.

The slope apron also received unlithified carbonate mud of platform margin origin (Fig. 8b).

A considerable sea-level fall led to a basinward shift of the shoreline as far as the plateau margin or even beyond it (main regression T/A, Fig. 10) ending the sedimentation of the proximal development of the Prístodolok Fm. Subsequently, it was overlain by an up to 55 m thick body of the well washed and sorted crinoidal grainstones of the Vils Fm. (Fig. 8c).

The eroded top surface of the Vils Fm. at the locality of Vývrat is overlapped by a few metres thick layer of pink to yellowish-brown micritic limestones containing rare crinoidal detritus and a breccia layer at its base. Upwards it passes into the red "true" nodular limestones containing few or no crinoidal columns (lower crinoidal limestones sensu Borza & Michalík 1987).

In the slope area, the sea-level fall displaced by sedimentation of lensoid bodies of the Vils grainstones, irregularly, finger-like intercalating with the limestones of the Prístodolok Fm. After the subsequent sea level rise sedimentation of the "true" nodular limestones began on the surface of the slope and the more distal sediments, with gradual transition or, partially, with a breccia layer at the base.

The system of the distributary channels also kept its function during sedimentation of the Vils Fm. and the (re)deposition of brecciated micritic limestones of the following transgressive systems tract (Fig. 10) which underlies the laterally uniform formations of the nodular limestones of Upper Jurassic age.

Soták & Plašienka (1996) described a very similar sequence of Upper Triassic–Lower Jurassic sediments of the Lučatín Unit (transition element between the Veporic Unit and the Krížna Nappe Unit, analogous to the Veľký Bok Succession) in the Northern Veporic Superunit giving a more detailed paleogeografical reconstruction of the sedimentary system. They related its position to the shelf slope at the transition from the Veporic margin into the Zliechov Basin.

Conclusions

The results of the facies analysis of the Lower-Middle Jurassic complex of the crinoidal limestones of the Vysoká Unit in the Malé Karpaty Mts. (Western Carpathians, Slovakia) are:

a) its subdivision into four formations: Trlenská Fm., Vývrat Fm., Prístodolok Fm., Vils Fm.; two of them are newly defined as formal lithostratigraphic units;

b) interpretation of the sedimentary environment as part of a slope apron with a proximal development on the SW and a distal development on the NE margin of the Vysoká Unit;

c) the sedimentary model created on the basis of this analysis also explains the question of the origin of the facies in which lithoclasts of biomicritic limestones originating from a relatively deeper environment are mixed with the crinoidal calcarenites formed in a relatively shallower environment. This facies is not only typical of the Vysoká Unit (see Mišík 1964; Soták & Plašienka 1996);

d) on the basis of various indicators, the possible influence of the relative sea level fluctuation on sedimentation has been evaluated and a curve of the relative sea level changes is suggested, even if there are not enough data available for a detailed and comprehensive application of the sequence stratigraphy approach to the sedimentary unit studied.

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