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ON STRATIGRAPHY AND LITHOLOGY OF CZORSZTYN LIMESTONE FORMATION IN THE CENTRAL WEST CARPATHIANS (JURASSIC, MALM)

(Figs. 13)

Abstract: The paper deals with position and detailed litho- and biostratigraphic classification of the significant Upper Jurassic lithostratigraphic unit of two characteristic West Carpathian regions: Manín succession of Mt. Butkov in the Strážovské vrchy Mts. and Vysoká succession of the Biele pohorie Mts. in the Malé Karpaty Mts. The authors give detailed analysis of microfacies, associations of microplanktonic remnants (tintinnids, colomisphaeres, cadosins, globochaetes) and survey of views on this lithofacies genesis.

Резюме: Статья занимается положением и детальной лито- и биостратиграфической классификацией значительной верхнеюрской литостратиграфической единицы двух характерных районов Западных Карпат: манинской последовательности г. Бутков в Стражевских горах и высоцкой последовательности Белых гор Малых Карпат. Авторы дают детальный анализ микрофаций, ассоциаций микропланктонных остатков (тинтинниды, коломисферы, кадосины, глобохеты) и обзор взглядов на генезис этой литофации.

Introduction

According to Birkenmajer (1977), Czorsztyn Limestone Formation is the Upper Jurassic complex of red nodular limestones with marly and hematite admixture comprising sporadic intercalations of fine-grained crinoidal limestone, coquinas of ammonites, aptychi, nucleatid and pygopid brachiopods and only rare nodules of cherts. The formation lies in the Klippen Belt on red crinoidal limestone of Krupianka Formation (Czorsztyn succession) or on radiolarites of Czajakowa Formation (Magura, Czertezik, Niedzica, Branisko and Haligovce successions), upwards it passes to Dursztyn limestone sequence or to pelagic complex of Pieniny Limestone Formation.

Mojsisovics (1867) was author of the term "Czorsztyn limestone". This lithofacies was distinguished already before him by several Carpathian geologists (Staszic, 1815; Pusch, 1824; Zejszner, 1846; etc.). Type locality of the sequence is represented by Czorsztyn castle klippe, typical sequence of strata is Czorsztyn succession of the Klippen Belt (Birkenmajer, 1953). It turned out that this term had to denote also facially identical developments in the Krížna Nappe in the Tatra (Lefeld et al., 1985), Malá and Veľká Fatra Mts. (Matějka—Andrusov, 1931; Andrusov, 1959), in the Strážovské vrchy Mts. (Borza, 1980), in the Malé Karpaty Mts. (Maheľ et al., 1962, 1967) and in Manín unit (Mišík, 1957; Rakús, 1962; etc.). Mišík (l. c.) distinguished the lower spongy and upper foraminifer-radiolarian micro-

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facies in the Dogger—Malm sequence of Manín narrow nodular limestones. According to this author (pers. comm.), parallelization of the Central Carpathian Upper Jurassic nodular limestones with the Czorsztyn Formation is problematic (sedimentary areas were perhaps not contiguous)and, therefore, the term from the Eastern Alps which are palaeotectonically closer should be rather applied (Klauskalk, Steinmühlkalk). Birkenmajer (1977) divided the Czorsztyn Formation into three informal parts: Callovian and Kimmeridgian — Middle Tithonian nodular limestones are separated by bed of Oxfordian siliceous limestones. "Lower" nodular limestones in Belá succession (Borza, 1980) of the Strážovské vrchy Mts. are of Bathonian to Oxfordian age, dividing interval of massive limestones is Kimmeridgian, "upper" nodular limestones are of the Tithonian to Lower Berriasian age.

Thus, it is evident that sequence of nodular limestones has different extent in different regions and it passes vertically to different lithofacies. Its position is expressively changing in lateral sense and interpretation requires detailed stratigraphic and lithological study in the sections documented by "strata by strata" method. In the past period, representation of the Czorsztyn Formation in Manín succession of Mt. Butkov in the Strážovské vrchy Mts. and in Vysoká succession of the Krížna Nappe in the Malé Karpaty Mts. was studied in such way (Fig. 1). Results are given in the following chapter.

Stratigraphy and lithology of the sections

A. Butkov sequence (Manín succession)

1. State of present information

Striking sequence of red nodular limestones is a lower member of the Upper Jurassic — Lower Cretaceous limestone sequence used for lime and cement production since the last century. Expressive complex of the Bathonian—Callovian Czajakowa Formation lies in its basement (mainly radiolarites with sporadic intercalations of radiolarian limestones), with silicified pinkish-grey grained cherty limestone intercalations in the uppermost part. Sequence of nodular limestones forms a distinct step on the slope accompanied with small rock exposures (Kališčo — Butkov — Tlstá hora — Ostré vŕšky hills). Classification of the sequence based on ammonite fauna was changed several times in the past. Telegdi—Roth (1915) relying on *Lytoceras* cf. *rubescens* (DUMORT.), *Stephanoceras longaevum* (VACEK), *Oppelia* cf. *subaspidoides* (VAC.), *Dumortieria* sp., *Phyloceras* sp., *Aptychus* sp. fauna findings placed it to the Lower Dogger. Andrusov (1945) supplemented the findings with *Oppelia aspidoides* (OPP.) and *Cadomites* ap. and he considered age of the sequence to be Bajocian—Bathonian. However, Rakús (1962) established the following forms by revision of this fauna: *Holcophylloceras* cf. *mediterraneum* (NEUMAYER), *Perisphinctes orbignyi* LORIOL, *P.* ex *gr. martelli* (OPPEL), *P.* sp., *Lytoceras polycyclum* NEUMAYER referring to the Oxfordian till Kimmeridgian age. Maheľ et al. (1962) affiliated pink, reddish to whitish nodular limestones to the Upper Dogger till Malm. Kullmanová (1961) placed red nodular limestones from Belušské Slatiny to the Malm, their uppermost part to the Kimmeridgian. The lower red-brown limestones were characterized by Globochaete-filamentous to

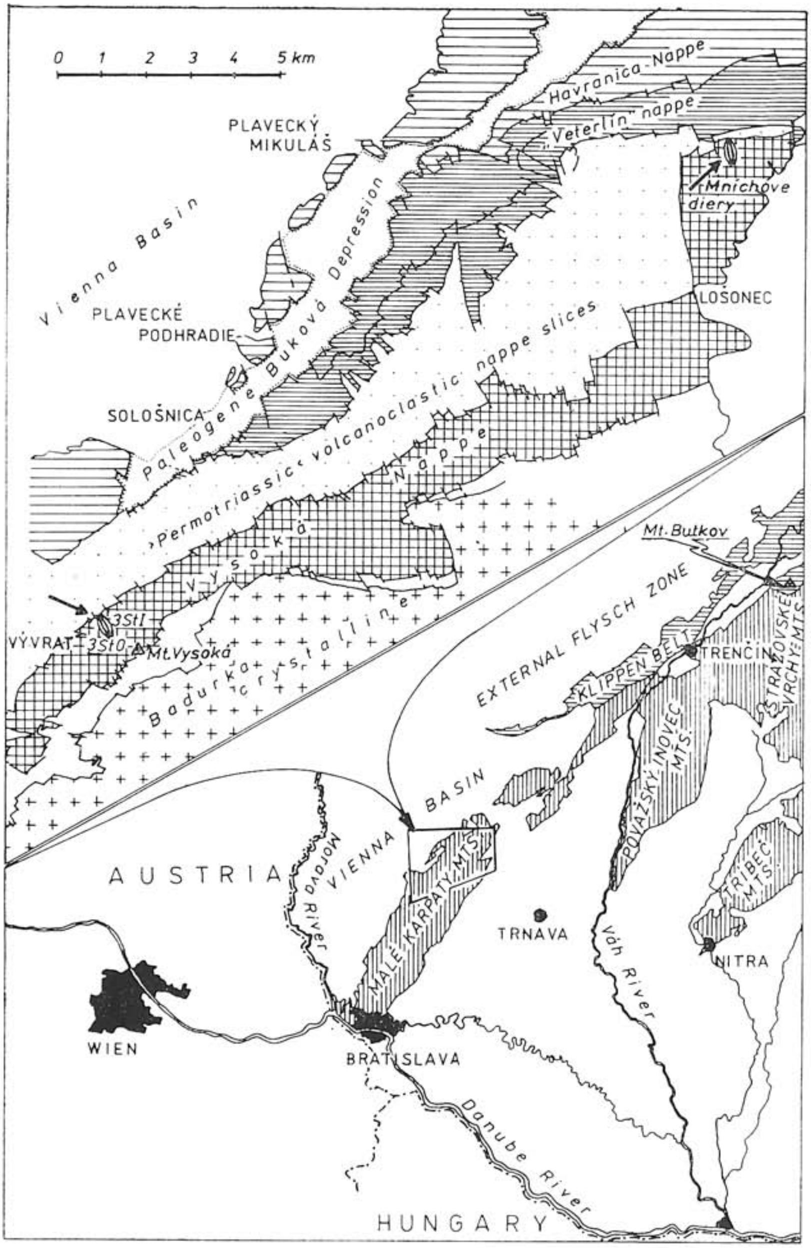


Fig. 1. Situation map of the studied localities in the western part of the Central West Carpathians (below). Above: situation geological sketch of the Biele vrchy hills in the Malé Karpaty Mts. with denotion of the studied sections (Tri Stodôlky: 3St-0, 3St-I, Mníchove diery, see arrows).

Globochaete-Saccocoma microfacies, whereby the upper pink part contained predominantly Saccocoma microfacies. F e d o r (1977) ranged red nodular limestones to the Malm till the Lower Tithonian. The more detailed classification of the sequence (B o r z a, 1969, 1980) has been lately worked out during work in the Butkov locality (B o r z a et al., 1983, 1986).

2. *Lithostratigraphy of the sequence*

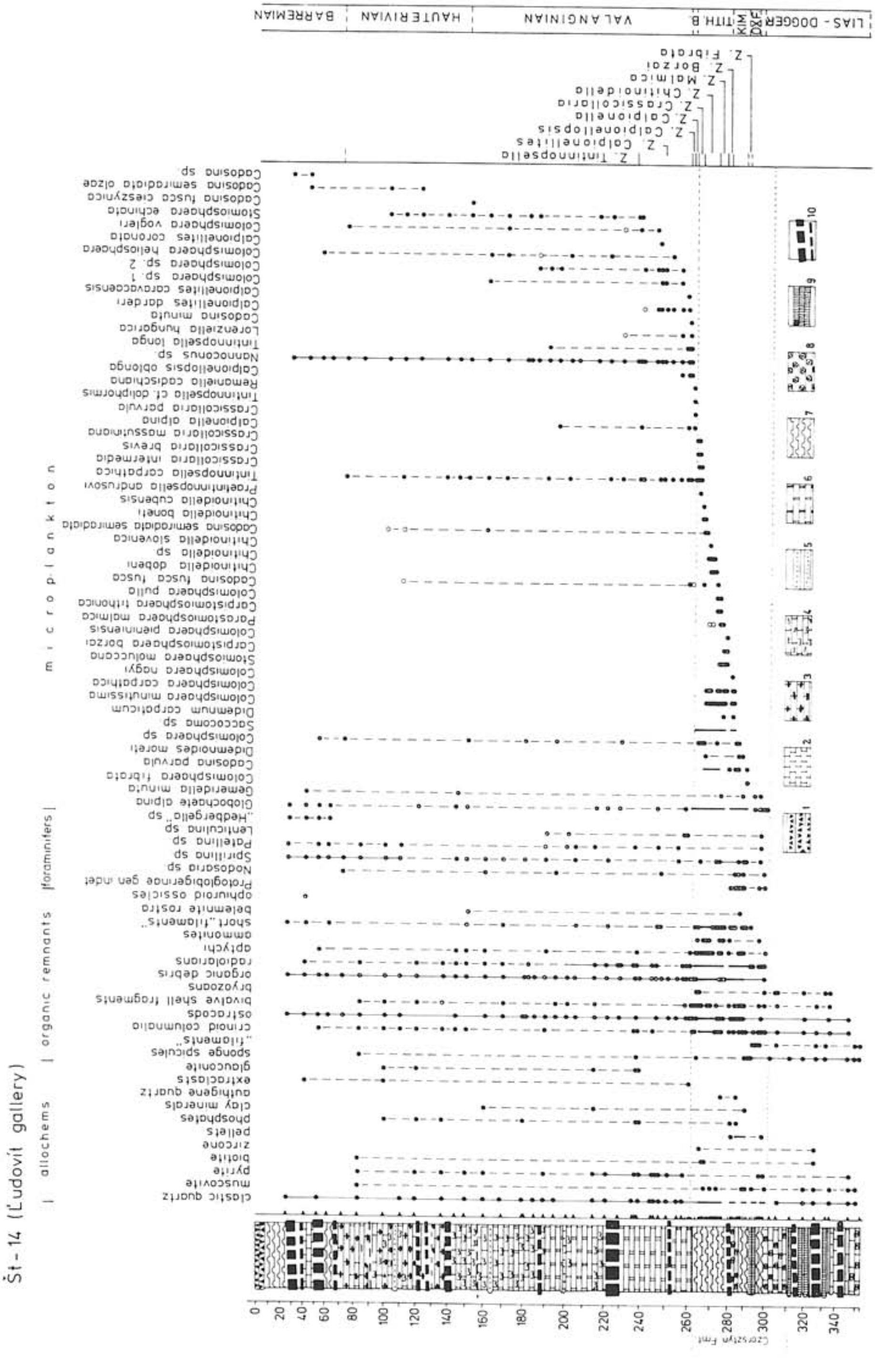
Though there are several exposures of nodular limestones on the studied territory on the northern slopes of Kališčo, Butkov, Tlstá hora and Ostré vŕšky hills, one of them allows to analyze complete sequence in detail. Nor exploitation work in quarry of the Považské cementárne cement works exposes anywhere section through this sequence. Therefore, in detailed lithostratigraphic study we were confined to prospection galleries (10, 11, 12, 13 and 14). Division of the sequence into three informal lithostratigraphic units which may be further divided on the basis of micropalaeontological study was confirmed (Fig. 2).

a) "L o w e r" n o d u l a r l i m e s t o n e. Red-brown, sometimes yellowish-brown to greenish nodular limestones (gal. 11: 188—196 m; gal. 12: 188 m) have breccia-like character on the base of the complex. Their matrix is of richer colour than nodules, it has a raised content of ferrous pigment, coarse-grained organogenic detritus and marly admixture. Biomicritic to biomicrosparitic limestone contains frequent "filaments", some beds contain radiolarian accumulations, the other ones-frequent globochaetes. Crinoidal ossicles, foraminifers (*Protoglobigerinae, Nodosaria* sp., *Lenticulina* sp., *Spirillina* sp.), fragments of bivalve shells, ostracods, aptychi, spines of sea urchins, bryozoans and gastropods are rare. The most frequent macrofaunal remnant is represented by belemnites and badly preserved ammonites. Pellets are rare, clastic quartz grains (to 0.2 mm), authigene guartz crystals and glauconite grains are sporadic. In the uppermost part, chlorite (?) and manganese coatings of nodules and indistinctly limited concretions of red-brown to meat-red cherty jaspers are observed. This member characterized by "filamentous microfacies" reaches thickness of 4—6 m.

b) Y e l l o w - b r o w n q u a r t z y ("b a n a n a") l i m e s t o n e s a n d r a d i o l a r i t e s. "Lower" nodular limestones pass without sharp border upwards, to micritic-microsparitic limestones with frequent radiolarians (filled up with microcrystalline quartz or chalcedon), less frequently with sponge spicules, filaments, crinoidal ossicles and aptychi. Quartz grains, mica leaves with expressive pleochroism and authigene carbonate rhombohedrons are rare. Lamination in the lower part of siliceous limestones (gal. 11: 188 m) caused by alteration of lighter beds rich in radiolarians with beds enriched with

Fig. 2. Lithological sequence, distribution of allochems, organic remnants and microbiostratigraphy of the succession exposed in gallery No. 14 (Ľudovít) in the cement works quarry in Butkov.

Legend to lithostratigraphic column: 1 — breccia; 2 — micritic limestones; 3 — cherty limestones; 4 — marly spotted limestones; 5 — turbiditic intercalations of organodetrital limestone; 6 — "sublithographic" limestones; 7 — nodular limestones; 8 — crinoidal limestone; 9 — radiolarites; 10 — faults and dislocation zones.


Št - 14 (Ľudovít gallery)
LIAS - DOGGER
OXF
KIM
TITH. B
VALANGINIAN
HAUTERIVIAN
BARREMIAN
Z. Fibrata
Z. Borzai
Z. Malmica
Z. Chitinoidella
Z. Crassicollaria
Z. Calpionella
Z. Calpionellopsis
Z. Calpionellites
Z. Tintinnopsella
allochems
organic remnants
foraminifers
microplankton
Cadosina sp.
Cadosina semiradiata olzae
Cadosina fusca cieszynica
Stomiosphaera echinata
Colomisphaera vogleri
Calpionellites coronata
Colomisphaera heliosphaera
Colomisphaera sp. 2
Colomisphaera sp. 1
Calpionellites caravacaensis
Calpionellites darderi
Cadosina minuta
Lorenziella hungarica
Tintinnopsella longa
Nannoconus sp.
Calpionellopsis oblonga
Remaniella cadischiana
Tintinnopsella cf. doliphormis
Crassicollaria parvula
Calpionella alpina
Crassicollaria massutiniana
Crassicollaria brevis
Crassicollaria intermedia
Tintinnopsella carpathica
Praetintinnopsella andrusovi
Chitinoidella cubensis
Chitinoidella boneti
Cadosina semiradiata semiradiata
Chitinoidella slovenica
Chitinoidella sp.
Chitinoidella dobeni
Cadosina fusca fusca
Colomisphaera pulla
Carpistomiosphaera tithonica
Parastomiosphaera malmica
Colomisphaera pieniniensis
Carpistomiosphaera borzai
Stomiosphaera moluccana
Colomisphaera nagyi
Colomisphaera carpathica
Colomisphaera minutissima
Didemnum carpaticum
Saccocoma sp.
Colomisphaera sp.
Didemnoides moreti
Cadosina parvula
Colomisphaera fibrata
Gemeridella minuta
Globochaete alpina
"Hedbergella" sp.
Lenticulina sp.
Patellina sp.
Spirillina sp.
Nodosaria sp.
Protoglobigerinae gen indet
ophiuroid ossicles
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short "filaments"
ammonites
aptychi
radiolarians
organic debris
bryozoans
bivalve shell fragments
ostracods
crinoid columnalia
"filaments"
sponge spicules
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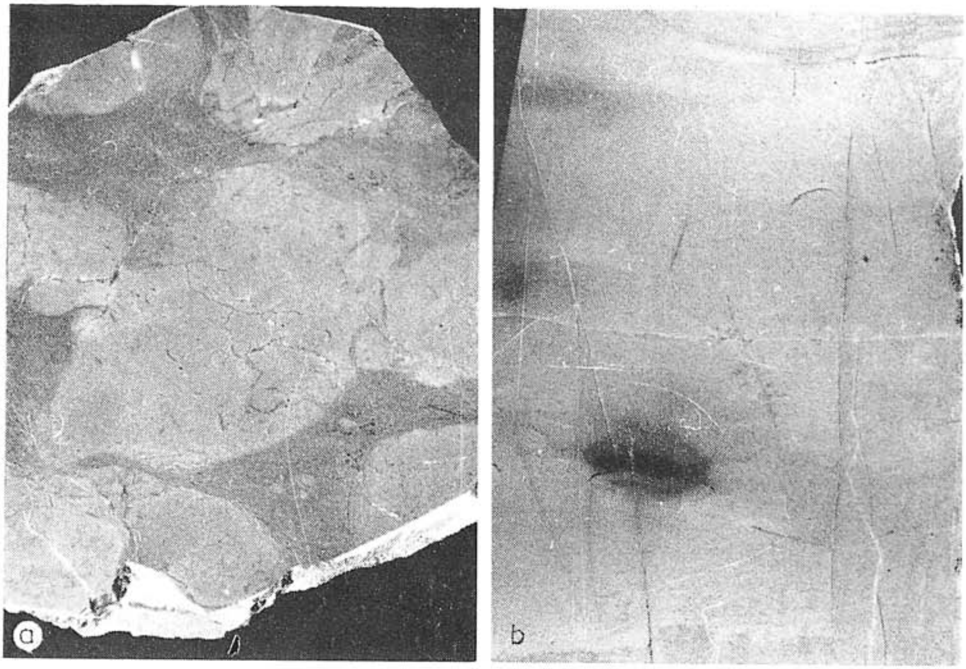


Fig. 3. Polished sections of important rock types from the sequence of the Upper Jurassic sediments in gallery No. 11 in Butkov.
a) "upper" nodular limestone from the Czorsztyn Formation, gall. 11, 175 m, sample 285 42; b) "banana radiolarite", gall. 11, 185 m, sample 285 79.
Photo: F. M a r t a n č í k.

filaments and iron oxides suggests an activity of slight bottom current. Radiolarites are formed by microcrystalline quartz with frequent light sections of radiolarians. Organic remnants are similar as in radiolarian limestones.

"Banana" radiolarites form relatively thin (2—4 m) intercalation in the sequence of nodular limestones indicating neighbourhood of "lower" nodular limestone formation environment with silicites sedimentary environment (Fig. 3).

c) "U p p e r" n o d u l a r l i m e s t o n e s. Oxfordian part of the sequence (gall. 11: 180 m; gall. 13: 258—272 m). Micritic, microsparitic, sometimes organogenic red and pink-brown nodular limestones contain very frequent *Globochaete alpina* LOMBARD. Calcified radiolarians are common, whereby protoglobigerinas, "filaments", ostracods, crinoidal ossicles, fragments of bivalve shells, *Colomisphaera* cf. *tenuis* (NAGY), *Cadosina parvula* NAGY occur rarely. Foraminifers (*Lenticulina* sp., *Spirillina* sp., *Patellina* sp.), *Didemnoides moreti* (DURAND DELGA), *Didemnum carpaticum* MIŠÍK et BORZA, *Colomisphaera* sp., aptychi, ammonites, gastropods, bryozoans, spines of sea urchins, fish teeth, fine organic debris occur sporadically similarly as grains of eolian (?) quartz and clay minerals. Microfacies of this interval form transitions

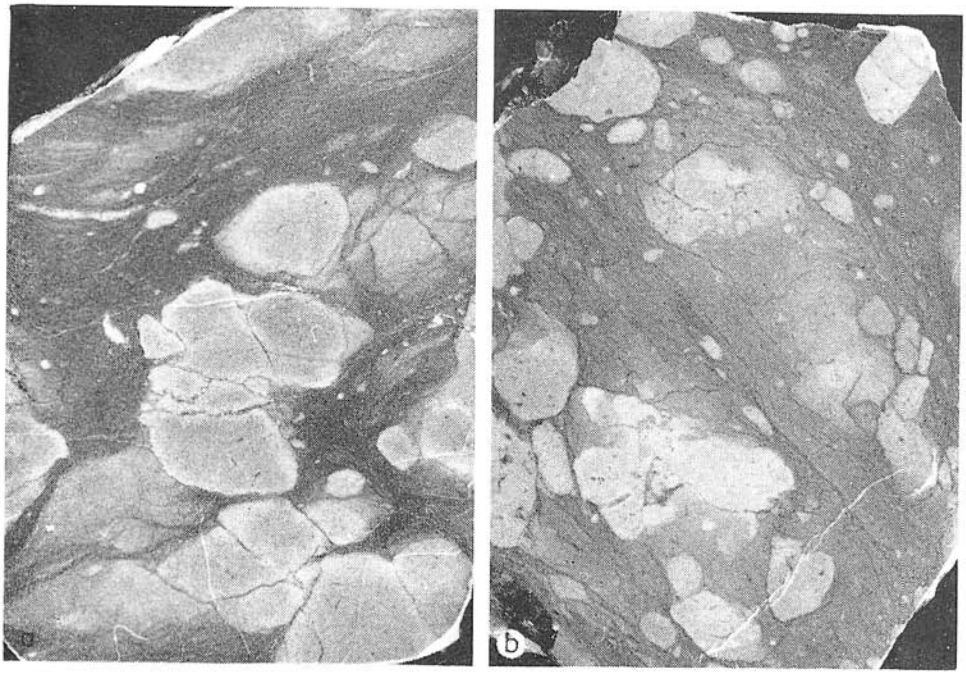


Fig. 4. Polished sections of Czorsztyn nodular limestone from gallery No. 11 in Butkov.
a) "lower" nodular limestone, gall. 11, 190 m, sample 285 43; b) "upper" nodular limestone, gall. 11, 165 m, sample 285 44.
Photo: F. Martančík.

between Globochaete-, Protoglobigerina-Globochaete-, sometimes Globochaete--filamentous microfacies (Cuvillier, 1951).

Microdykes filled up with microsparite with pellets and association of organic remnants similar to associations of wall rock occur in several places. These microdykes were formed probably during gliding of sediment and its repeated compaction. They occur also in the other regions (cf. Borza, 1980). Horizons of breccia limestones with indistinct limitation (Fig. 4) are local.

Thin (50 cm) bed of pinkish limestones with sporadic cherts occurs on the base of "upper" nodular limestones in Mojtín valley (Borza, 1980). It is formed by biopelmicrosparitic limestone with micritic, microsparitic and sparitic pellets, sporadic grains of clastic quartz. Radiolarians and *Colomisphaera fibrata* (NAGY) are frequent, *Cadosina parvula*, crinoidal ossicles, *Globochaete alpina* and "filaments" occur rarely.

Presence of *Colomisphaera fibrata* indicates the Oxfordian age of this part of the "upper" nodular limestones. Red-brown and pink-brown (7—9 m thick) limestones with Globochaete- and Globochaete-radiolarian microfacies are ranged to the Oxfordian too.

Kimmeridgian part of the sequence (gall. 11: 170—178 m; gall. 12: 184—185 m; gall. 13: 252—256 m) is represented by red-brown and pink-brown, the upper beds — by pink nodular Saccocoma limestones. They contain more often clay minerals, clastic quartz, pellets and coarse-grained organic debris. Biomicritic to biomicrosparitic limestones contain most frequently *Globochaete alpina* and *Saccocoma* sp. (mainly in the higher horizons). Radiolarians, juvenile ammonites, crinoidal ossicles, fragments of bivalve shells, *Colomisphaera carpatica* (BORZA), *C. minutissima* (COLOM), *Cadosina parvula*, "filaments", protoglobigerinas, *Didemnoides moreti* occur commonly. *Colomisphaera pieniniensis* (BORZA) occurs in the upper horizons of the Kimmeridgian part of the sequence, *Carpistomioshaera borzai* (NAGY) and *Stomiosphaera moluccana* (WANNER) in the uppermost part. Some beds are enriched with "filaments" (gall. 11: 176 m), the other ones (gall. 11: 178 m) contain crinoidal biosparite with fragments of bivalve shells, *Saccocoma* sp., aptychi, "filaments" and foraminifers (*Nodosaria* sp., *Lenticulina* sp.). Microstylolites affecting margins of crinoidal ossicles are frequent (cf. Borza, 1980). Rich spectrum of organic remnants, absence of radiolarite intercalations and vice versa, presence of unsorted crinoidal limestone intercalations prove gradual shallowing of sedimentary environment.

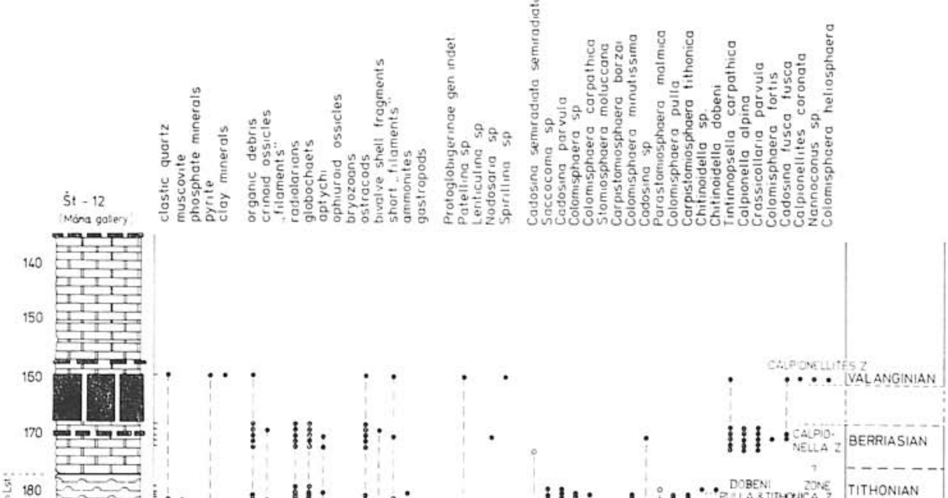


Fig. 5. Lithological sequence, distribution of allochems, organic remnants and microbiostratigraphy of the succession exposed in gallery No. 12 (Mária) in quarry of the Ladce cement works in Butkov. Legend as in Fig. 2.

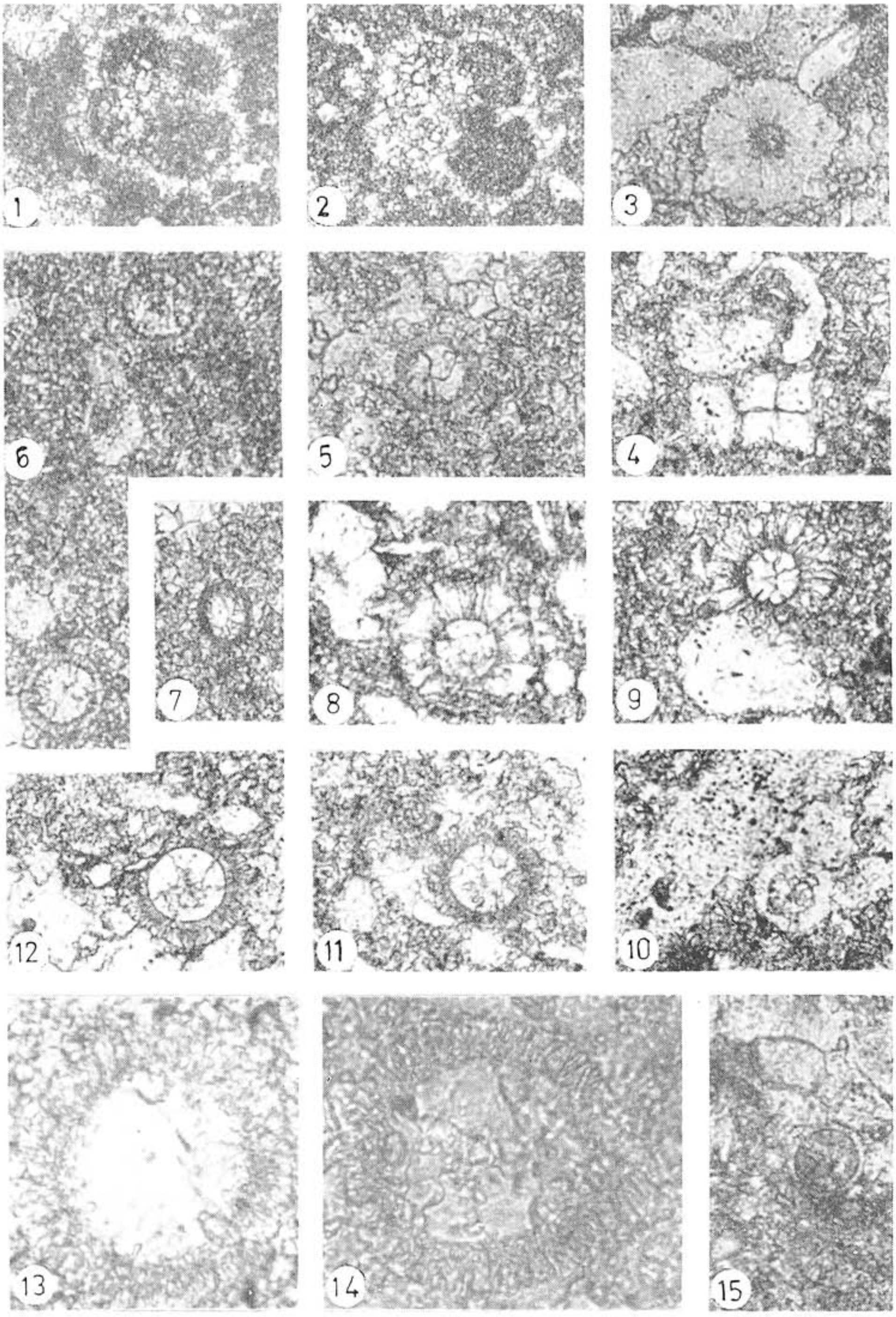
The Lower Tithonian part of the sequence is formed by indistinctly bedded pink to red-brown nodular biomicritic limestones, sporadically slightly recrystallized (gall. 11: 165—168 m; gall. 12: 182 m; gall. 13: 250 m) with frequent *Saccocoma* sp. and *Globochaete alpina*, less with *Carpistomio-*

sphaera tithonica NOWAK, *Colomisphaera pulla* (BORZA), radiolarians, *Cadosina parvula, Parastomiosphaera malmica* (BORZA) (Fig. 6). Crinoidal ossicles, fragments of bivalve shells, *Colomisphaera minutissima, Col. carpatica*, ostracods, short "filaments", aptychi, juvenile ammonites, *Cadosina* cf. *fusca fusca* WANNER, *Stomiosphaera moluccana, Didemnoides moreti*, gastropods, foraminifers (*Lenticulina* sp., *Spirillina* sp.) and organogenic detritus are less frequent. Pellets, clay minerals and clastic quartz of silty size occur sporadically. Also this part of the sequence bears the features of slight shallowing of the environment.

Middle Tithonian section has in fact identical lithological character as the lower parts of the sequence. Chitinoidella Zone with Dobeni Subzone (gall. 10: 112 m; gall. 11: 162—164 m; gall. 12: 180 m; gall. 13: 244—248 m) and Boneti Subzone (gall. 11: 160 m; gall. 13: 241—242 m) may distinguished. Limestones of Dobeni Subzone are biomicritic, they contain frequently *Saccocoma* sp., *Globochaete alpina*, radiolarians, rarely *Chitinoidella dobeni* BORZA, *Ch. slovenica* BORZA, *Ch.* sp., *Colomisphaera carpatica, Col. minutissima, Parastomiosphaera malmica, Cadosina parvula, Cad.* sp., *Didemnum carpaticum*, crinoidal ossicles, fragments of

Fig. 6. Typical Oxfordian till Middle Tithonian microfossils of the Czorsztyn Limestone Formation, Butkov, quarry of the cement works Ladce.
Explanations: 1 — *Protoglobigerina* sp., Butkov, gall. 14; 284 m, spec. 878-2, magn. x 217; 2 — *Protoglobigerina* sp., Butkov, gall. 14; 290.5 m, No. 8807, magn. x 217; 3 — *Didemnoides moreti* D. — DELGA, Butkov, gall. 14; 272 m, No. 876-24, magn. x 265; 4 — *Didemnum carpathicum* MIŠ. et BO., gall. 14; 269.5 m, No. 873-18, magn. x 265; 5 — *Colomisphaera fibrata* (NAGY), gall. 14; 290.5 m, No. 880-1, magn. x 265; 6 — *C. fibrata*, gall. 14; 290.5 m, No. 880-8, magn. x 265; 7 — *Cadosina parvula* NAGY, gall. 13; 262 m, No. 849-16, magn. x 265; 8 — *Colomisphaera carpatica* (BORZA), gall. 14; 268 m, No. 872-8, magn. x 265; 9 — *C. carpatica*, gall. 14; 268 m, No. 872-14, magn. x 265; 10 — *Stomiosphaera* cf. *moluccana* WANNER, gall. 14; 271 m, No. 872-29, magn. x 265; 11 — *Carpistomiosphaera tithonica* NOWAK, gall. 14; 271 m, No. 874-10, magn. x 265; 12 — *Colomisphaera pulla* (BORZA), gall. 14; 271 m, No. 874-10 ,magn. x 265; 13 — *C. pulla*, gall. 14; 271 m, No. 874-20, magn. x 530; 14 — *C. pulla*, gall. 14; 271.5 m, No. 875-14, magn. x 530; 15 — *Parastomiosphaera malmica* (BORZA), gall. 14; 272 m, No. 876-2, magn. 265. All photographs: H. Brodnianska.

Fig. 7. Middle till Upper Tithonian microfossils of the Czorsztyn Limestone Formation, quarry of the cement works Ladce in Butkov.
Explanations: 1 — *Stomiosphaera moluccana* WANNER, gall. 13; 250 m, No. 845-6, magn. x 265; 2 — *Parastomiosphaera malmica* (BORZA), gall. 14; 273 m, No. 877-18, magn. x 110; 3 — *Chitinoidella dobeni* BORZA, gall. 13; 244 m, No. 843-7, magn. x 530; 4 — *Ch. dobeni*, gall. 13; 244 m, No. 843-10; magn. x 530; 5 — *Ch. sp.*, gall. 14; 269.5 m, No. 873-20, magn. x 530; 6 — *Ch. boneti* DOBEN, gall. 13; 241 m, No. 842-29, magn. x 265; 7 — *Praetintinnopsella andrusovi* BORZA, gall. 13; 240 m, No. 841-32, magn. x 265; 8 — *Semichitinoidella* sp., gall. 13; 241 m, No. 842-30, magn. x 265; 9 — *Aeolisaccus* sp., gall. 13; 258 m, No. 847-3, magn. x 265; 10 — *Crassicollaria intermedia* (D.-DELGA), gall. 13; 240 m, No. 842-6, magn. x 265; 11 — *Crassicollaria parvula* REM., gall. 13; 238 m, No. 841-23, magn. x 265; 12 — *Tintinnopsella carpathica* (M.-FILIP.), gall. 13; 238 m, No. 841-29, magn. x 265; 13 — *Colomisphaera nagyi* BORZA, gall. 13; 258 m, No. 847-6, magn. x 265; 14 — *Cadosina* cf. *semiradiata* WANN., gall. 14; 270.5 m, No. 873-33, magn. x 265; 15 — *Praecalpionellopsis gemeriensis* BORZA, gall. 14; 269 m, No. 873-3, magn. x 265. All photographs: H. Brodnianska.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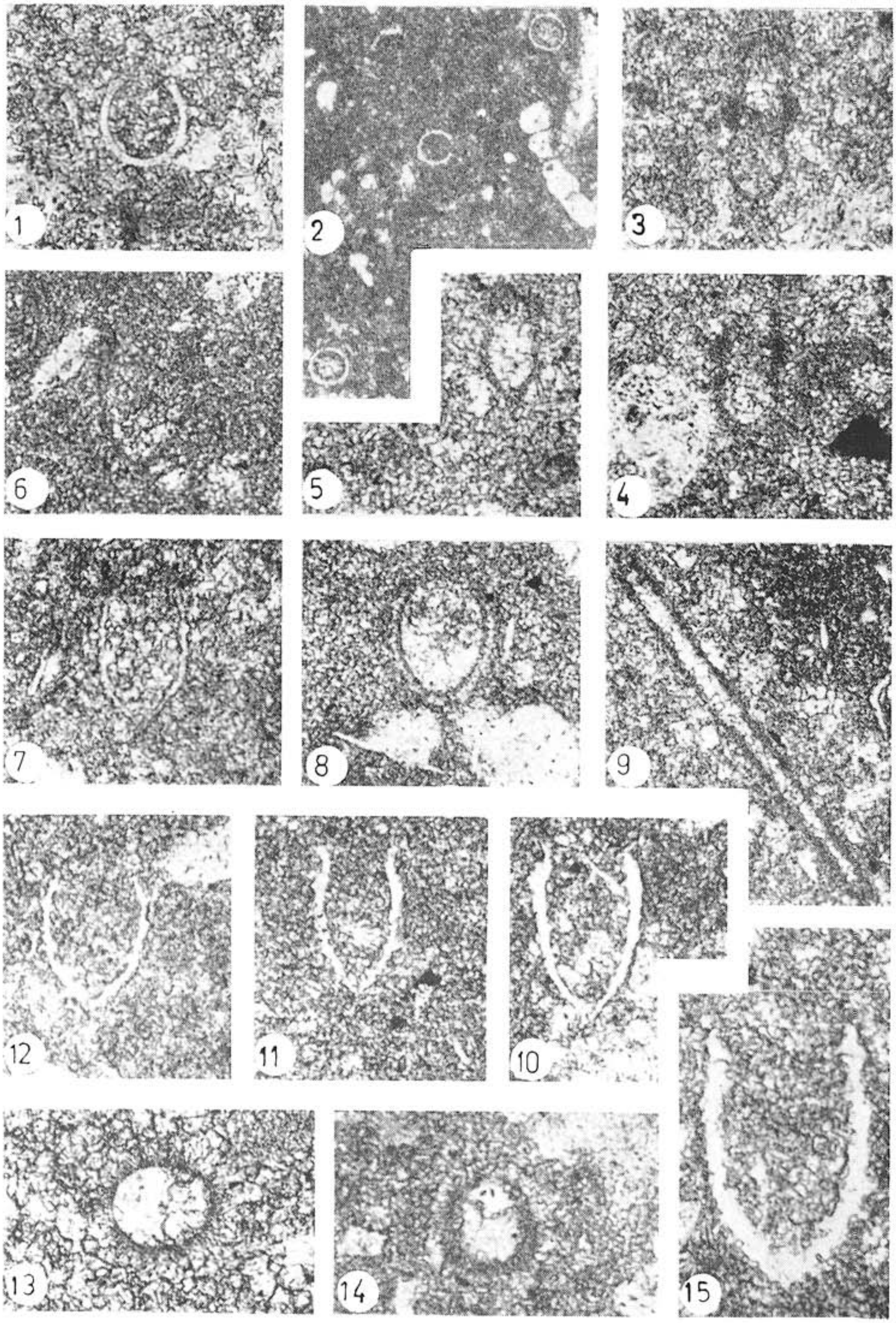
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bivalve shells, ostracods, short "filaments", aptychi, juvenile ammonites and organogenic detritus occur rarely. Quartz grains and leaves of clay minerals represent second-rate component. The lower part of the subzone is characterized by Saccocoma-Globochaete microfacies (similarly as in Belá succession, cf. Borza, 1980, p. 42).

While macroscopic character of limestones is not changing upwards, changes take place in association of organic remnants. After temporary regression of small chitinoidels (*Ch. dobeni* and *Ch. slovenica*) the species characterizing the Boneti Subzone occur: *Ch. boneti* DOBEN, *Ch. cubensis* (FURRAZOLA BERMUDEZ) together with *Saccocoma* sp., *Globochaete alpina*, crinoidal ossicles, fragments of bivalve shells, *Colomisphaera carpatica*, *Col. minutissima*, *Cadosina parvula*, ostracods, short "filaments", *Patellina* sp., *Spirillina* sp., aptychi, ammonites and organogenic detritus. Silty grains of clastic quartz with "eolian habitus" are sporadic (Fedor, 1977).

Association of organic remnants is again changing on the Middle Tithonian and Upper Tithonian boundary (Praetintinnopsella Zone, gall. 11: 159 m; gall. 13: 240.5 m, Fig. 7). Micritic limestones contain frequently *Globochaete alpina*, less radiolarians and *Saccocoma sp.*, *Praetintinnopsella andrusovi* BORZA, *Semichitinoidella* sp., *Colomisphaera minutissima*, *Didemnum carpaticum*, *Patellina* sp., *Spirillina* sp., ostracods, short "filaments", quartz grains of silty size, organic detritus. Clay minerals are sporadic, biotite leaves occur only rarely.

The Upper Tithonian Crassicollaria Zone is represented by red-brown and yellow-brown nodular to breccia-like limestones (gall. 11: 154—158.7 m; gall. 13: 240 m). Micritic limestones contain frequently *Globochaete alpina* and radiolarians, rare *Saccocoma* sp. and sporadically *Semichitinoidella* sp. in the lower part. *Crassicollaria intermedia* (DURAND DELGA), *Crass. brevis* REMANE, *Crass. massutiniana* (COLOM), *Calpionella alpina* LORENZ, *Tintinnopsella carpathica* (MURGEANU et FILIPESCU) and *Tint. remanei* BORZA accompanied with ostracods, short "filaments", *Cadosina fusca fusca*, *Colomisphaera minutissima*, *Col. carpatica*, *Cadosina* sp., *Didemnoides moreti*, *Didemnum carpaticum*, *Gemeridella minuta* BORZA et MIŠÍK, crinoidal ossicles, fragments of bivalve shells, aptychi and bryozoans appear in the upper part.

Breccia-like texture, fragmental character of organic remnants and arrangement of clasts prove intensification of submarine gliding. This fact, together with colour change from red shades of oxidation environment to yellowish and greenish colours and with loss of nodular texture in the uppermost part of the sequence prove gradual deepening of sedimentary environment during the Upper Tithonian. Subsidence was accompanied with lowering of morphological differences of individual bottom parts and perhaps with change of flow regime in the area. Intense development of plankton in the beginning of the Berriasian was manifested by raised content of organic remnants (especially nannocones) in sediment composition and by total acceleration of sedimentation rate. Simultaneous palaeotectonic changes of sedimentary basin structure may be supported by frequent gaps in the Berriasian and Lower Valanginian sequence, by abundance of breccia composed of clasts from the underlying Middle-, Upper Tithonian and Berriasian horizons and by sudden, irreversible change of sedimentation character during the Late Kimmerian movements.

Fragment of decomposed volcanite from breccia bed in the upper part of nodular limestones in gall. 14 (267.5 m) proves hithero unknown manifestations of tectonic activity connected with slight volcanism.

B. Vysoká succession of the Malé Karpaty Mts.

1. State of present information

In spite of certain doubts, sequences of Vysoká unit were ranged to the Krížna Nappe by Andrusov (1936), later he (1959) considered their Tatric origin. He distinguished the Kimmeridgian pink limestones with "lombardians" and globochaetes, and the Tithonian light micritic calpionelid limestones above the Doggerian cherty limestones. Mahel' (1959, 1961) characterized the Vysoká Nappe as a unit with the Upper Triassic sequence of typical Krížna type, but with the Jurassic sequence of cordillera development. Mahel' et al. (1967) characterized the Kimmeridgian sequence as pseudonodular to nodular limestones with radiolarite intercalations (Saccocoma are frequent in the lower beds, globochaetes, foraminifers, ostracods, spicules of sponges and crinoids in the higher ones). Platy limestones of biancône type with calpionels and chert nodules were ranged to the Tithonian by the above authors. Kullmanová (1957, 1965) used the similar classification. During the field work carried out in 1984—1985 we succeeded to divide the Malm sequence of the Vysoká unit in more detail.

2. Lithostratigraphy of the sequence

In the Upper Jurassic to the Lower Cretaceous complexes of the Vysoká unit in the Malé Karpaty Mts., thirteen sections documented in detail were laid out (Fig. 8). Sequence of nodular limestones equivalent to the Czorsztyn Formation is represented in eight of the sections (Tri Stodôlky 0 and I, Červená skalka, Veľká Biela Skala, Úžina pod Horným lesom, Horný les, Hlboč and Mníchove diery). Brief lithological, microfacial and biostratigraphic characteristics of the lithostratigraphic horizons of this sequence is given below:

a) Lower nodular limestone. Pinkish, pink and pink-brown micritic limestones with cherts and nodularity implications occur in silicite overlying strata. Biomicrosparites, pelmicrosparites and pelsparites are prevailing in the limestones. Upwards they pass to red-brown and pink nodular limestones with cherts and bed of red radiolarites. Stylolites occur in them, cracks are filled up with calcite or bituminous matter. Some beds frequently contain pellets, especially in the lower part. Limestones have a character of pelmicrosparites, pelsparites, microsparites to micrites, they are relatively poor in organic remnants. Beds of "packestones" character filled over with organic debris occur only in the easternmost part of the region (Mníchove diery section). *Colomisphaera fibrata* together with frequent *Globochaete alpina, Cadosina parvula, Colomisphaera* sp., "filaments" and short filaments occur in the lower beds of the sequence (Fig. 9). Calcified radiolarians and organic debris represent constant component, ostracods, protoglobigerinas, crinoidal ossicles, aptychi (in the higher part of the section) occur rarely, *Didemnoides moreti* and *Gemeridella minuta* are sporadic. From clastic admixture, quartz grains of max. 0.5 mm size and clay minerals occur sporadically. Authigene quartz crystals were formed in the rock. Microfossil association indicates the Oxfordian age of this part of the sequence.

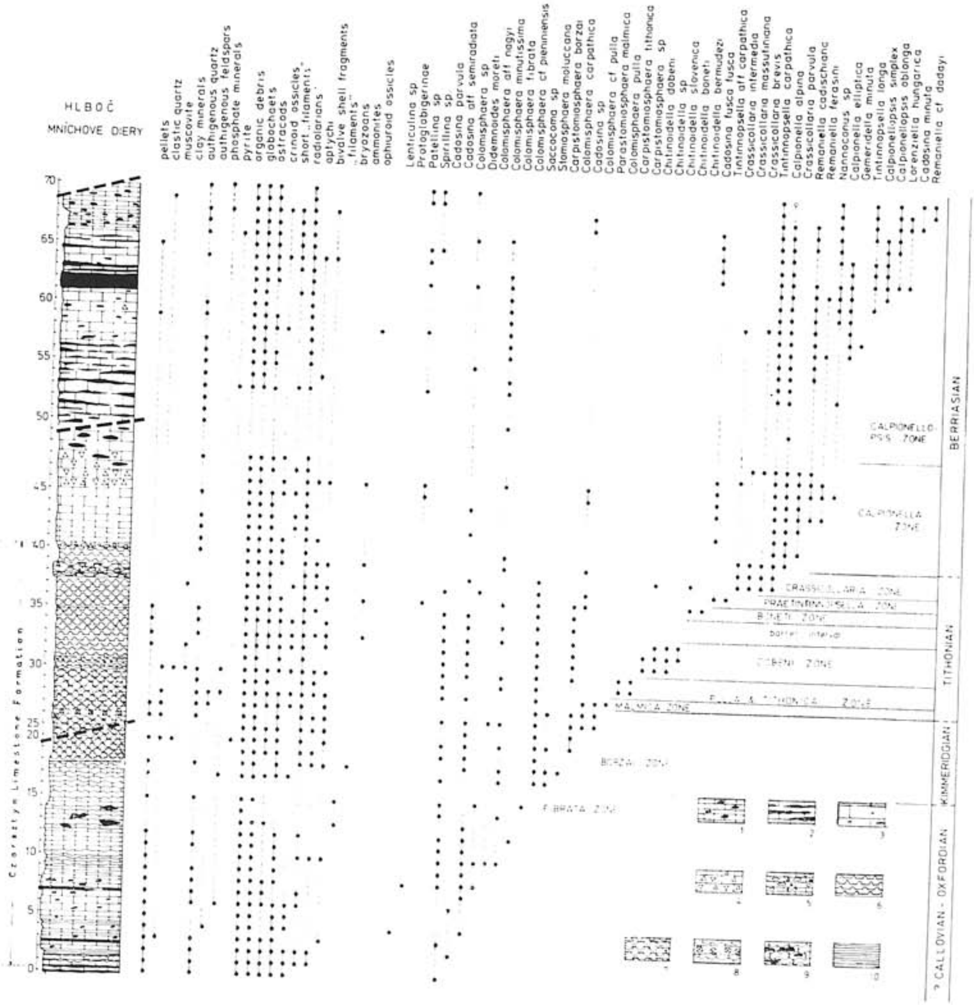


Fig. 8. Lithological composition, lithostratigraphy, distribution of allochems, organic remnants and microbiostratigraphy of the Mníchove diery section in Hlboč valley near Smolenice, Malé Karpaty Mts.

Legend: 1 — platy cherty limestones; 2 — thin-bedded limestones with stratiform cherts; 3 — massive to coarse-bedded micritic limestones with cherts; 4 — breccia-like limestones; 5 — thin-platy limestones with lime pebbles and clasts; 6 — pink indistinctly nodular limestone; 7 — red-brown distinctly nodular limestone; 8 — intercalations of crinoidal limestone; 9 — indistinctly nodular limestone with cherts; 10 — intercalations of marlstone and marl. Empty circles denote problematic occurrence.

b) "Upper" nodular limestones are represented by the Kimmeridgian and Tithonian sediments (well exposed in the region of Tri Stodôlky on the western slope of Vysoká hill and in Hlboč valley near Smolenice).

Kimmeridgian part of the sequence may be divided into four members. Basal pink to violet-grey marly crinoidal limestone differs from the basement by lack of cherts. It is crinoidal biosparite to biorudite. Crinoidal ossicles are mostly recrystallized, often twin-lamellated, they grow up congruently. Lamellae of fine-grained sediment contain *Saccocoma* sp. and sporadic foraminifers (*Lenticulina* sp., *Protoglobigerina* sp.).

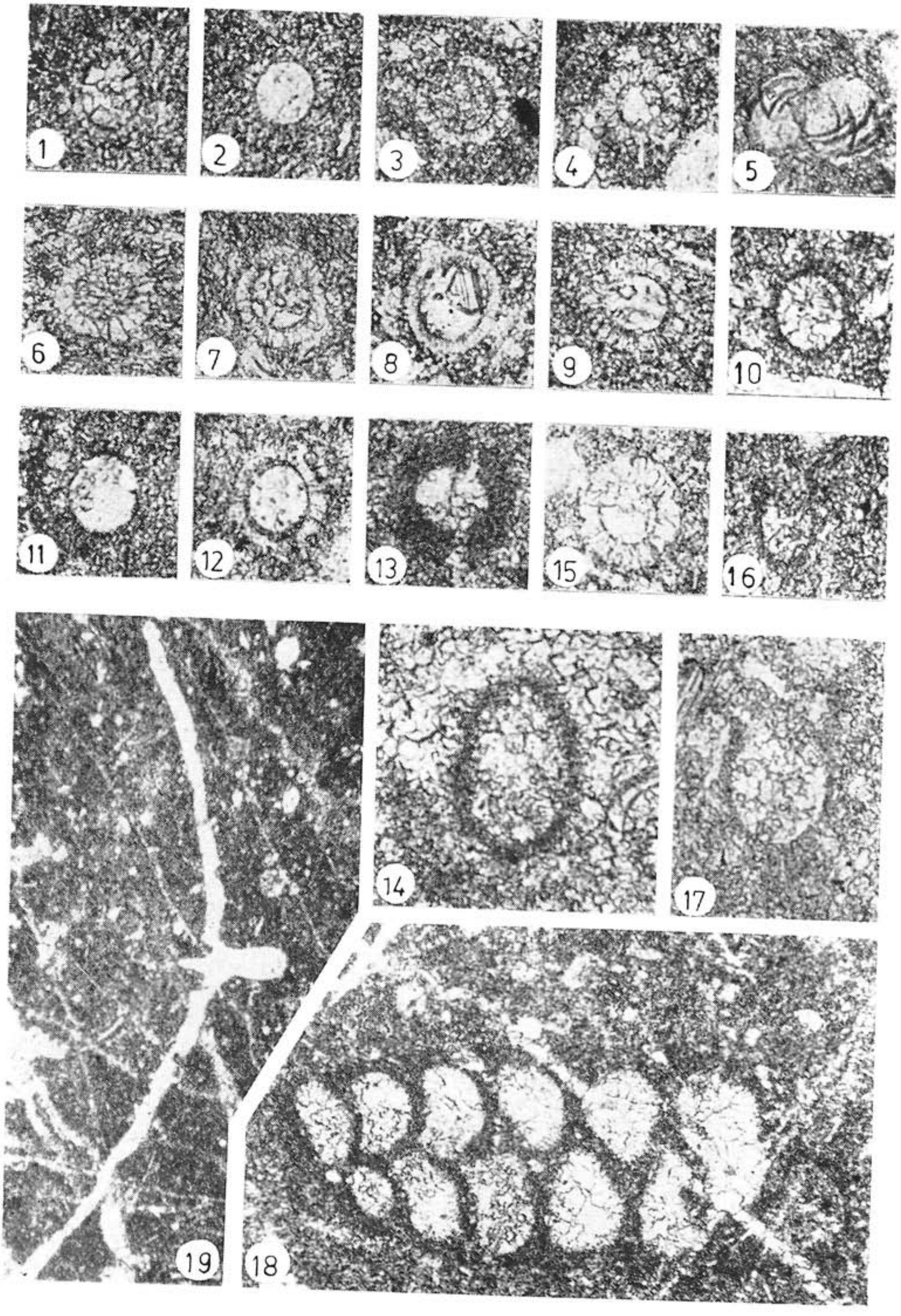
Pink nodular limestone with laminae of violetish marl with gradually growing admixture of clastic quartz, muscovite and zircon occurs in the higher beds. Aptychi and pellets appear in them, filaments and protoglobigerinas dissappear. Red-brown indistinctly nodular limestone of micritic to microsparitic character appears upwards. It frequently contains *Saccocoma* sp., *Globochaete alpina*, *Colomisphaera minutissima*, radiolarians, crinoidal ossicles, aptychi, juvenile ammonites and organogenic detritus. *Cadosina parvula*, *Colomisphaera carpatica*, ostracods, fragments of bivalve shells, short filaments and uniserial bryozoans are rare. Authigene quartz crystals, lamellae of clay minerals and sporadic grains of phosphate minerals occur in the rock.

Fig. 9. Oxfordian till Middle Tithonian microfossils of the Czorsztyn Limestone Formation, section 3St-0, Tri Stodôlky on the western slope of Vysoká hill, Malé Karpaty Mts. (Vysoká unit).

Explanations: 1 — 4, 6 — 10: *Colomisphaera* sp.: 1-bed No. 2, No. 1045-31; 2-3St0 2, No. 1045-32; 3-3St0 3, No. 1045-33; 4-3St0 3, No. 1045-34; 6-3St0 4, No. 1045-37; 7-3St0 4. No. 1045-38; 8-3St0 5, No. 1046-3; 9-3St0 5, No. 1046-4; 10-3St0 7, No. 1046-9, magn. x 456. 5 — *Globochaete alpina* LOMB., 3St0 4, No. 1045-36, magn. x 456; 11 — false "*Parastomiosphaera*", 3St0 5, No. 1046 6, magn. x 456; 12 — *Parastomiosphaera malmica* (BORZA), 3St0 6, No. 1046-7, magn. x 456; 13 — *Cadosina* sp., 3St0 4, No. 1045-35, magn. x 456; 14 — *Cadosina* sp., 3St0 13-1, No. 1046-27, magn. x 740; 15 — *Colomisphaera* cf. *carpatica* (BORZA), 3St0 4, No. 1046-1, magn. x 456; 16 — *Chitinoidella* sp., 3St0 1, No. 1046-5, magn. x 456; 17 — *Chitinoidella borzai* NAGY, 3St0 1, No. 1045 30, magn. x 740; 18 — *Foraminifera gen indet.*, 3St0 4, No. 1046 2, magn. x 16.92; 19 — *Saccocoma* sp., 3St0 1, No. 1045 29, magn. x 16.92. All photographs: H. Brodnianska.

Fig. 10. Oxfordian till Lower Tithonian microfossils of the Czorsztyn Limestone Formation, section 3St0, Tri Stodôlky on the western slope of Vysoká hill, Vysoká unit of the Malé Karpaty Mts.

Explanations: 1 — 4 — *Colomisphaera* sp., 3St0 13-1: 1a — No. 1046 21, magn. x 456, 1b — No. 1046 22, magn. x 740; 2 — No. 1046 23, magn. x 456; 3a — No. 1046 24, magn. x 456, 3b — No. 1046 26, magn. x 740; 4a — No. 1046 28, magn. x 456, 4b — No. 1046 29, magn. x 740; 5 — No. 1046 30, magn. x 456; 6 — 7 — *Colomisphaera* sp., 3St0 12: 6 — No. 1046 16, magn. x 456, 7 — No. 1046 17, magn. x 456; 8 — 9 — *Colomisphaera carpatica* (BORZA), 3St0 12: 8 — No. 1046 15, 9 — No. 1046 18, magn. x 456; 10 — *C.* cf. *pieniniensis* BORZA, 3St0 13-1: a — No. 1046 19, magn. x 456; b — No. 1046 20, magn. x 740; 11 — *Globochaete* sp. and authigene quartz, 3St0 14, No. 1046 14, magn. x 456; 12 — *Cadosina parvula* NAGY, 3St0 11, No. 1046 13, magn. x 265; 13 — *Cadosina* sp., 3St0 9, No. 1046 12, magn. x 256; 14 — 15 — *Parastomiosphaera malmica* (BORZA), 3St0 7.5 (Fig. 14) or 3St0 7 (Fig. 15), No. 1046 11 and 8, magn. x 456. All photographs: H. Brodnianska.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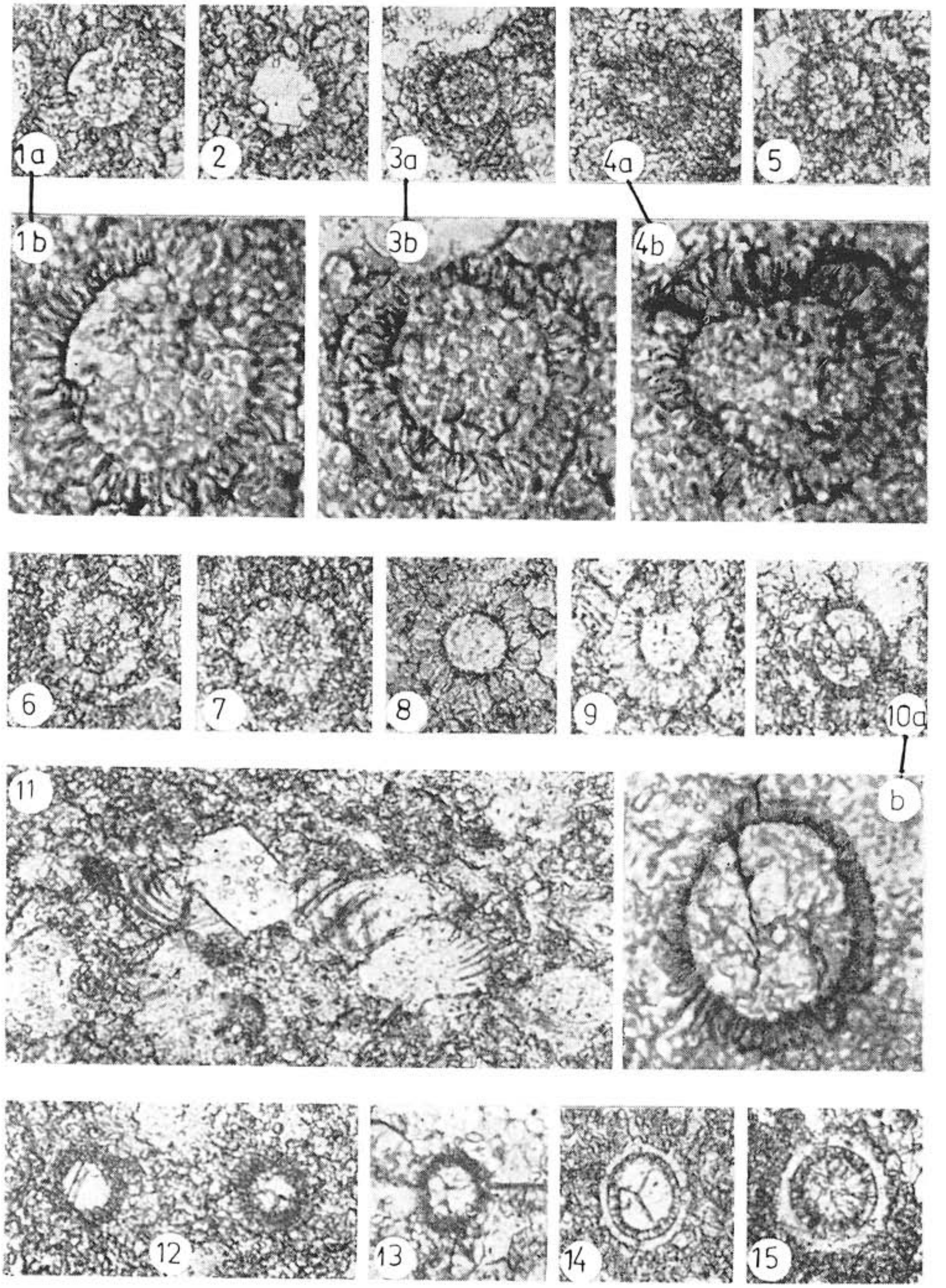
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Higher beds are formed by pink stylolitized limestone with *Stomiosphaera moluccana, Carpistomiosphaera borzai* and *Didemnoides moreti.*

The uppermost part of nodular limestones belongs to the Tithonian. The Lower Tithonian (T i t h o n i c a - P u l l a Z o n e) is represented by pinkish-grey and pinkish to brown indistinctly nodular limestones (beds 7c-11 in section 3St-I, 28—30 in section of Mníchove diery). Limestones are micritic to microsparitic, often stylolitized and tectonized. Association of organic remnants is formed by frequent *Saccocoma* sp., *Globochaete alpina* and radiolarians, sporadically also by abundant crinoidal columnals. *Parastomiosphaera malmica* occurs in the lower part of the section, *Colomisphaera pulla* and *Carpistomiosphaera tithonica* in the higher one. Other organic remnants are rare or sporadic: *Stomiosphaera* cf. *moluccana, Colomisphaera minutissima, C. carpatica. C.* sp., *Cadosina parvula, Lenticulina* sp., *Patellina* sp., fragments of bivalve shells, aptychi, juvenile ammonites, ostracods and spines of sea urchins. Grains of clastic quartz are of silty size, clay minerals are often accompanied with microstylolites. Limestone sporadically contains phosphate minerals or authigene quartz and feldspar crystals often accompanied with secondary calcite veinlets (Fig. 10).

B a s a l L o w e r T i t h o n i a n D o b e n i S u b z o n e is represented by pink nodular limestones of micritic and microsparitic character. Beds pigmented in black by bitumen occur sporadically. Microfossil association is not substantially changing in comparison with the underlying horizons: only *Parastom. malmica. Colom. pulla* and *Carpist. tithonica* are replaced by chitinoidelid association (*Ch. dobeni, Ch. slovenica* BORZA and *Carpistomiosphaera* sp.).

About 1—2 m thick bed of red-brown nodular limestone without chitinoidels or other characteristic Tithonian microfossils occurs in the overlying strata of D o b e n i S u b z o n e (3St-I/5a, Mníchove diery 34—35). In such way, association is acquiring "a Kimmeridgian character" (Fig. 11).

In the limestones of B o n e t i S u b z o n e, association with chitinoidels appears again, but their small forms are replaced by bigger species: *Ch. boneti, Ch. cubensis* (FURRAZOLA BERMUDEZ), *Ch. bermudezi* (FURR. BERM.), *Ch.* sp.

Micritic to microsparitic pinkish to reddish nodular limestones with frequent stylolites on transition of the Middle and Upper Tithonian sections are relatively poor in organic remnants. They contain *Saccocoma*, globochaetes, radiolarians, ostracods, short filaments, fragments of bivalve shells, *Cadosina parvula. C. fusca* WANNER, *C.* sp., *Didemnoides moreti, Praetintinnopsella andrusovi* and ancient forms of *Tintinnopsella carpathica.* There are schliers of clay minerals among nodules, sporadically fine organic debris. Limestones belong to the older Upper Tithonian P r a e t i n t i n n o p s e l l a Z o n e.

A special attention should be paid to grey nodular to breccia-like limestone from sample No. 38 — Mníchove diery section (Fig. 8). It contains minute clasts bordered with stylolites and composed of five limestone types. The oldest fragments belong to D o b e n i S u b z o n e. Fragments with quantitatively rich association of microfossils (*Ch. Boneti, Saccocoma* sp., *Glob. alpina*, radiolarians, ostracods, *Colomiella* sp., aptychi, etc.) and fragments with poor association (*Ch. boneti, Saccocoma* sp., globochaetes, radiolarians, ostracods and *Cadosina semiradiata*) may be distinguished among the limestone fragments from B o n e t i S u b z o n e. The fourth type is represented by limestones with ancient forms of *Tintinnopsella carpathica* which have still dark collar in some cases. In addition, they contain ostracods and *Colomiella* sp. The last distinguished type is represented by limestones with *Crassicollaria intermedia*, *C. brevis*, *C. massutiniana*, *Tintinnopsella carpathica*, *Globoch. alpina*, radiolarians, ostracods and other remnants of microorganisms. Thus, breccia containing clasts of the Middle to Upper Tithonian horizons is concerned.

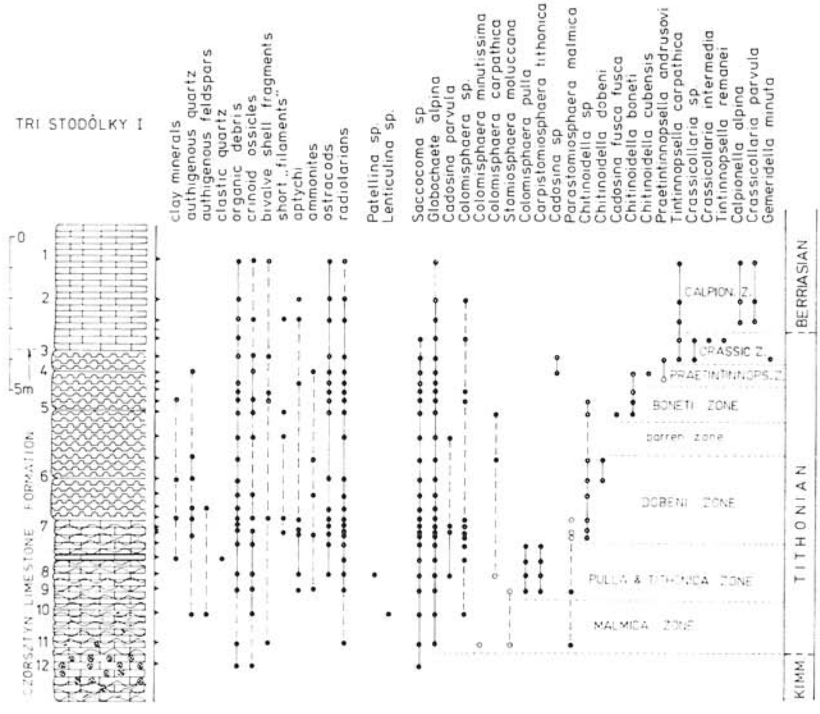

Fig. 11. Lithostratigraphy, lithology and microbiostratigraphy of section 3St-I. Tri Stodôlky on the western slope of Vysoká hill, Vysoká unit of the Malé Karpaty Mts. Legend as in Fig. 8.

The Upper Tithonian Crassicollaria Zone is represented by bedded pinkish, grey nodular limestones. Edges of nodules are often intensified by stylolitization. Micritic to microsparitic limestone contains *Crassicollaria intermedia*, *C. massutiniana*, *C. brevis*, *C.* sp., *Saccocoma* sp., *Globochaete alpina*, *Tintinnopsella carpathica*, *Colomiella* cf. *minutissima*, *Cadosina* sp., radiolarians, ostracods, fragments of bivalve and ammonite shells, crinoidal columnals, aptychi, etc. Expressive complex of massive cherty limestones lies in the overlying strata.

From the studied sections of the Vysoká succession, almost one half has incompletely preserved sequence of the Middle and Upper Tithonian sediments.

Detailed study of sequences in the sections shows that this fact is affected by tectonization of the sequence only in few cases. When compared with Manín succession of Mt. Butkov, sequences of the Jurassic—Cretaceous boundary are much more expressively affected by submarine erosion. Clasts in breccia bed come from the Upper Tithonian Crassicollaria and Praetintinnopsella Zones, erosion affected even the sediments of both subzones of the Middle Tithonian Chitinoidella Zone. Bathymetric contrast between environment of Czorsztyn limestone and its Berriasian overlying strata sediments formation is much greater in the Vysoká succession than in Butkov.

Discussion on genesis of the sequence

Red nodular limestones called "Calcare Ammonitico rosso", "calcaires noduleux", "Knollenkalken", "wapienie bulaste", etc. represent often discussed lithofacies (Kukal, 1975; Wieczorek, 1983, etc.). Though they form an important part of the Palaeozoic and Mesozoic pelagic carbonate sequences, in the Cenozoic sequences and recent sediments they are represented only by insignificant and often questionable specimens (Müller et Fabricius, 1974; Mullins et al., 1980, etc.). Nodular limestones are most often described from the Palaeozoic and Mesozoic orogenic regions of Eurasia and America. They are more represented in the Silurian—Devonian sequences (Montagne Noire, Rheingebirge, Kärnten and Bohemian Massif), in the Middle Triassic and Upper Triassic Tethyan sequences (Schreyeralm, Hanbulog, Hallstatt limestones). Limestones from the Alpine Jurassic sequences are the best studied (Adnet and Czorsztyn limestones of the Alps and Carpathians, Ammonitico Rosso of the Southern Alps and Apennines, etc., cf. Aubouin, 1964; Dritenbass, 1979; Jenkyns, 1974; Massari, 1983; etc.).

Limestones of "Ammonitico Rosso" type are characterized by nodular texture and red colour. Diameter of limestones nodules reaches several cm. They are of ovoid, ellipsoidal and lenticular form. Nodules are formed by micrite or biomicrite, internodular mass is more marly, it contains more organogenic detritus and hematite supporting oxidation conditions of sedimentation (Hallam, 1967). Border between nodules may be of various intensity owing to various degree of diagenesis up to stylolitization. Intensity of nodular texture depends on different degree of nodules differentiation. Nodules occur most frequently "in situ", in other cases transitions to types close to intraformational breccia may be observed. Therefore, significant features of red nodular limestones are represented by traces of oxidation environment connecting them with shallow-water sediments and strong condensation of the sequence. In the direction of shallower-water zones they often pass to "surfaces of solid bottom" where sedimentation was totally stopped by the current. On the Bahamas, a similar transition was observed at depths of 375—400 m. This phenomenon is connected with fauna accumulation, crusts, stromatolitic strata and nodules often described from the fossil "Ammonitico Rosso". Benthic shallow-water fauna is missing in this facies, in other cases it is represented only in some horizons (crinoids, brachiopods, rarely solitary corals). Ammonites, belemnites and pelagic bivalves are prevailing in the spectrum of preserved faunal remnants (Fig. 13). Microfossils are quite frequent: Saccocoma, radiolarians, tintinnids, spicules of sponges. Apparent lack of nannoplankton is a typical feature. On the other hand, ichnofossils (*Zoophycos, Teichichnus, Planolites, Chondrites*, cf. W i e c z o r e k, 1983) commonly occurring indicate relatively great depth of environment. These features together with observed transitions to radiolarites are used by several authors in order to support an assertion that at least the lower sedimentation border of nodular limestones might lie at depth of about 2000 m.

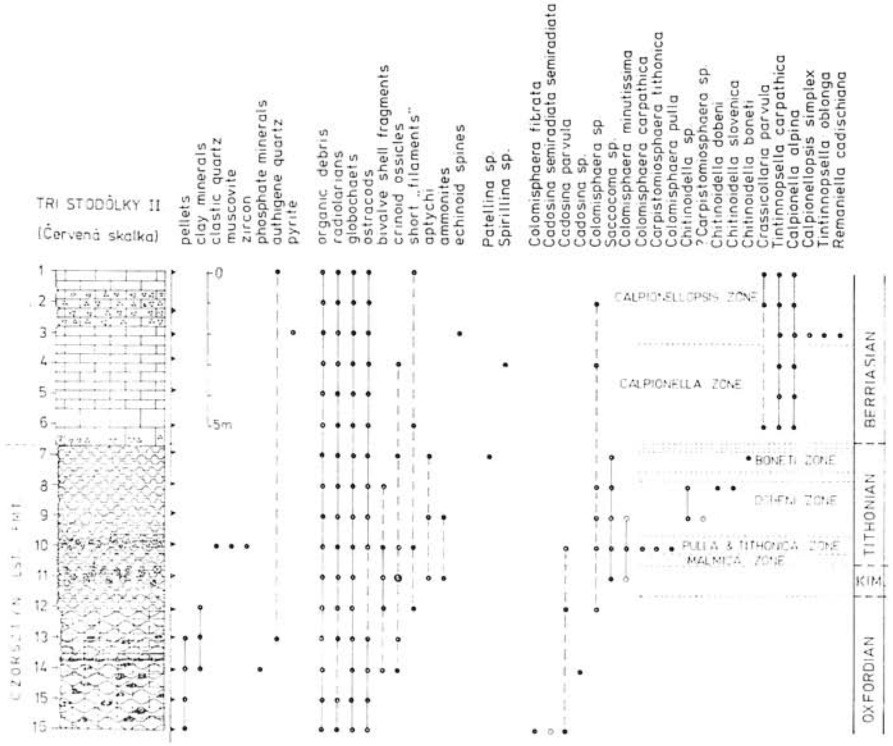

Fig. 12. Lithostratigraphy, lithology and microbiostratigraphy of section 3St-II (Červená skalka), Tri Stodôlky on the western slope of Vysoká hill, Vysoká unit of the Malé Karpaty Mts. Legend as in Fig. 3.

Problem of "Ammonitico Rosso" carbonate type formation has not yet been cleared up univocally. Several hypotheses have been worked out in order to interpret their genesis:

1. Concretional or diagenetic model (J e n k y n s, 1974) presupposes early diagenetic segregation of calcium carbonate comming from dissolved aragonite shells and intensification of existing clusters of resistant calcite material from which nodules are gradually formed.

2. Subsolution hypothesis (hypothesis of intrastratal dissolution) explains parallel effect of sedimentary and solution processes on basin bottom: marly matrix should represent a remnant after dissolution of carbonate (Hollmann, 1964). Similarly, Lefeld (1981) interpreted formation of the Carpathian nodular limestones, according to his theory the Callovian—Oxfordian radiolarites should represent a residuum after dissolution of the Dogger carbonate sequence. However, current textures in radiolarites (Kwiatkowski, 1981) make doubts of this interpretation.

3. Activity of infaunal organisms (Fürsich, 1973) played an important role in formation of some shallow-water types of nodular limestones, but it could give rise to growth of calcitic clusters which were finally formed into nodules by early phase of diagenesis.

4. Mechanical crushing of partly lithified sediment by current, glides or submarine slides did not play a significant role in formation of typical nodular limestones as a whole, but it might give rise to several breccia-like horizons in their sequence.

5. Finally, several authors were inclined to interpret this problem in tectonic terms as a product of boudinage of limestone beds in the sequences formed by regularly alternating limestone lamellae and marl intercalations. However, excluding exceptions, presumption of intense tectonization of typical red nodular limestones is contradicted by preservation of fossils.

At present, majority of authors upholds either concretional-diagenetic or subsolution conception or various combinations of the both. At the same time, it is generally accepted that also other factors may co-act in this process. It may be stated that almost all hypotheses presuppose early diagenetic origin of nodularity. Several processes in consideration do not exclude each other and they may co-act in formation of nodular texture (Wieczorek, 1984).

Conclusions on depth of sedimentary environment of nodular limestones are quite contradictory in various authors (Wieczorek, op. cit.): from several tens of metres to several hundreds and thousands of metres. However, majority of authors supports a same view that sedimentary environment represented elevations in pelagic environment separated from clastic material supply where marine currents impeded accumulation of pelagic sediments (similarly as e. g. Carnegie Ridge, the Pacific Ocean). Typical "Ammonitico rosso calcaire" (Aubouin, 1964) was formed on the surface of elevations at depths of 400—800 m. On the other hand, "Ammonitico rosso marneux" characterized by greater thickness, more frequent breccia-like beds and higher content of marly component was formed on slopes of elevations at depths of 1500—2000 m.

Fig. 13. Polished section of Czorsztyn nodular limestone from the cut of forest road in Stará Bebrava valley opposite Hrádok nad Čiernou Lehotou (Belá unit of the Krížna Nappe). Contact of the bed of compact micritic limestone with the overlying nodular limestone. Surface of limestone is uneven, forming frequent "tufts". Nodules are formed by coagulation of calcitic material around ammonite shells (a), intraclasts (i) or further undefinable clusters of sediment (n). "Lamination" perpendicular to denoted orientation of stratification is probably a secondary phenomenon caused perhaps by migration of colloidal Fe compounds in the sediment. Photo: C. Michaliková.


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Therefore, red nodular limestones represent shelf sediment of the regions remote from the coast and affected by pelagic current.* Appearance of such shelves in the West Carpathian basins at the end of the Callovian, their partial submersion in the Middle Oxfordian and erosion at the end of the Tithonian and Berriasian are especially significant indicators of palaeotectonic movements. Observation of nodular limestones facies distribution helps to clear up palaeotectonic and palaeogeographic features of development of the region in the period studied.

Translated by O. Mišániová

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* *Note of reviewer:* Generalization of red nodular limestones as shelf sediment does not fully hold in some cases (Triassic Hallstatt limestones, etc.).

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