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LITHOLOGICAL, BIOFACIAL AND GEOCHEMICAL CHARACTERIZATION OF THE LOWER CRETACEOUS PELAGIC CARBONATE SEQUENCE OF MT. BUTKOV (MANÍN UNIT, WESTERN CARPATHIANS)

(Figs. 13)

Abstract: The paper presents results of lithostratigraphical, biostratigraphical, lithological, biofacial and geochemical study of the Lower Cretaceous pelagic limestones on Mt. Butkov. In the apparently monotonous sequence, four well-characterizable series have been distinguished, which can be correlated well with their equivalents in other paleogeographic and tectonic units. These series (classified as new formal lithostratigraphic units — the Ladce, Mráznica, Kališčo and Lúčkovská Formations) were the products of pelagic sedimentation on a morphologically gradually more pronounced carbonate ramp. The complex of pelagic limestones was during Aptian covered by detritic slope sediments of a prograding shallow-sea carbonate platform.

Резюме: Статья дает результаты литостратиграфического, биостратиграфического, литологического и геохимического изучений нижнемеловой последовательности пелагических известняков на г. Бутков. В кажущейся монотонной свите пластов были различены четыре хорошо характеризовательны формации которые можно хорошо коррелировать с эквивалентами в других палеогеографических и тектонических единицах. Эти формации (ладецкая, мразницкая, калиштянская и лучковская формации) были продуктами пелагической седиментации на морфологически постепенно более выразительной карбонатовой рампе. Комплекс пелагический известняков был в течении аптского яруса был прикрыт детритовыми отложениями склона развивающейся карбонатовой платформы.

Introduction

Andrusov (1945, p. 71), while describing the sequences exposed in the quarries on the northern slope of Mt. Butkov, considered the light-coloured limestones and marls overlying red nodular limestone (Czorsztyn Formation cf. Borza—Michalík, 1986) to represent probably Lower Malm and their upper part with *Calpionella alpina* LORENZ to belong to Tithonian to Berriasian. Kullmanová (1961) has also mentioned that nodular limestones change gradually into greyish-brown bedded limestones with *Calpionella* microfacies. In the lower layers of this series she found the microfauna *Calpionella alpina* LORENZ, *C. elliptica* CADISCH, *Globochaete alpina* LOMBARD. Further up-

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wards should have followed typical "Neocomian" light-grey, thin-bedded limestones with nodules of black cherts poor in microfossils: on the base they should have contained *Tintinnopsella carpathica* (MURGEANU et FILIPESCU) and *T. cadischiana* COLOM, higher up globochaetes, radiolarians, small foraminifers and, finally, rich nannocone microfacies.

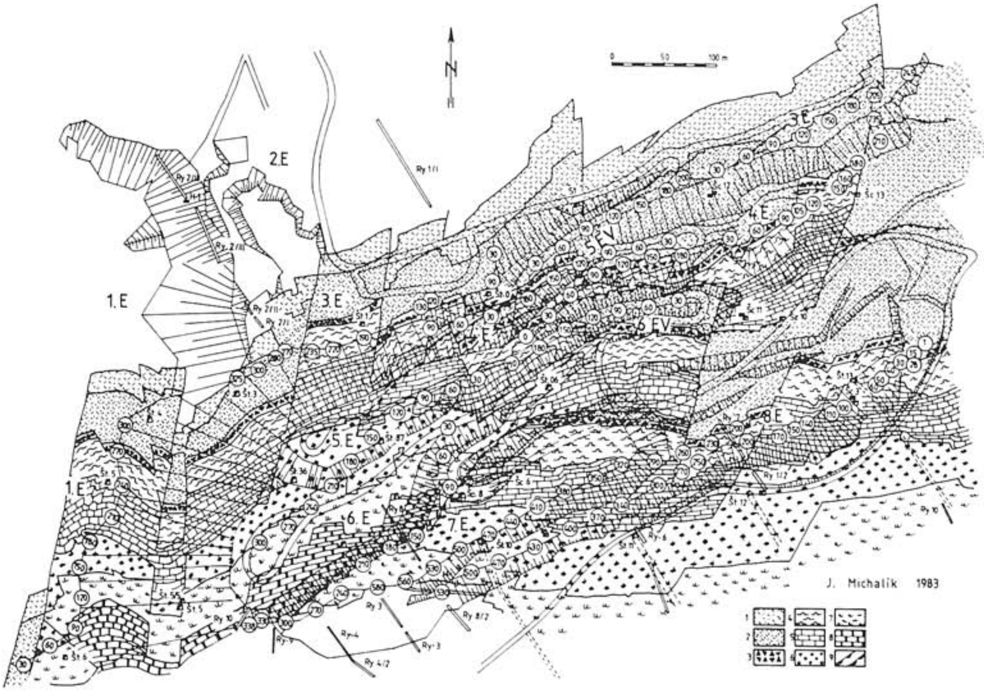

Fig. 1. A simplified geological map of the quarry of Považské Cement Works — Butkov with marked locations of surface samples (numbers in circles) on individual levels (1—8E).
Explanations: 1 — "Urgonian" organogenic limestones; 2 — Podhorie Formation; 3 — basal breccia of the Podhorie Formation; 4 — Lúčkovská Formation; 5 — micritic limestones of the Kališčo Formation; 6 — cherty limestones of the Kališčo Formation; 7 — Mráznica Formation; 8 — Ladce Formation; 9 — slip-faults.

From these considerations followed also the traditional division of the Mt. Butkov deposit complex into "pale stone" (assumed to be a representative of Malm limestones), "black stone" (identified as Neocomian) and "white stone" (representing Urgonian facies). This division has been reconsidered only by Mišík and Zelman (in Michel et al., 1966). In spite of their calpionellid study on the basis of which they divided the formations into more detailed units, the distinguishing characteristics for practicians remained the content of cherts. It was believed further on that the "Calpionella limestones of Tithonian" do not contain cherts, while in the overlying "Neocomian" limestones cherts are abundant.

In the past years (cf. B o r z a et al., 1983, 1986; M i c h a l í k et al., 1986) we have pursued a more detailed litho- and biostratigraphic division of this sequence. It turned out that the hithero used criteria are not sufficient even for a rough generalization of the actual situation. On the basis of profiles in mine workings as well as on superficial exposures documented in great detail we have succeeded in detailed age determination of the majority of the rock horizons. The results of this study are presented in the following text.

Results of stratigraphical study

1. L a d c e L i m e s t o n e F o r m a t i o n (n e w t e r m)

In the overlying strata of the Czorsztyn Formation — a complex of red nodular limestones of Upper Jurassic age (which have been characterized in detail in the work of B o r z a—M i c h a l í k, 1986) — "sublithographic" massive, slightly marly limestones are situated forming the lower part of pelagic "Neocomian" limestones. The Ladce Formation is exposed mostly only in prospecting galleries on the edge of the quarry. It is possible to divide it into a lower, clastic and upper, pelagic units; together they reach a thickness of about 30—35 meters.

The lower brecciated unit is variously thick. It consists of lime clasts of beige complexion-coloured limestones ("pale stone") with sizes of 5—6 mm, cemented by marly-carbonate matter roughly of the same character (Gallery 11: 152.3—153 m; Gal.—12: 170 m; Gal.—13: 238 m etc.). Micritic limestones contain abundantly *Calpionella alpina* LORENZ, *Globochaete alpina* LOMB., *Crassicollaria parvula* REM., scarcely appears *Tintinnopsella carpathica* (MURG. et FILIP.), *T. doliphormis* (COLOM), *Remaniella cadischiana* (COLOM), radiolarians, sporadically occur *Colomisphaera fortis* ŘEHÁNEK, fragments of bivalve shells, crinoid ossicles, *Patellina* sp., aptychi, ostracods, organodetritus, short "fibres" and *Cadosina* sp.. The majority of clasts (and apparently also the material of the cement) originates from the *Calpionella* Zone (Lower Berriasian) (Fig. 2).

In the upper part, light-brownish to ochre, slightly marly limestones can be found. In some layers it is possible to notice traces of the original brecciated structure: sometimes it is nevertheless difficult to distinguish clasts from the almost identical micritic "cementing" matrix. The limestone itself, in which the clasts occur, contains *Calpionella alpina* LOR., *C. elliptica* CADISCH, *Tint. carpathica*, *Remaniella cadischiana*, *Calpionellopsis simplex* (COLOM), *C. oblonga* (CADISCH), *Cadosina fusca fusca* WANNER, *Globochaete alpina*, *Patellina* sp., ostracods, short "fibres", radiolarians, *Colomisphaera minutissima* (COLOM), crinoid ossicles, fragments of ammonites and aptychi On the other hand, *Calpionella alpina* is predominant, in the clasts more scarce is *Tintinnopsella carpathica*, *Crassicollaria parvula*, *Globochaete alpina*, radiolarians and ostracods. Another type of limestone clasts contains less fossils (*Calpionella alpina* and larger forms of *Tintinnopsella carpathica*). Both limestone types originate most probably from the Lower Berriasian *Calpionella* Zone. On some locations (Gal. 13: 236 m) breccia of yellowish-brown micritic limestones occurs with abundant *Crassicollaria intermedia* (DURAND DELGA), more rarely with *Cr. brevis*

REMANE, *Tintinnopsella carpathica*, *Saccocoma* sp., *Globochaete alpina*, *Cadosina* sp., *Colomisphaera minutissima* (COLOM), radiolarians, ostracods, short "fibres" and organodetritus. The frequence of microfossils in individual clasts

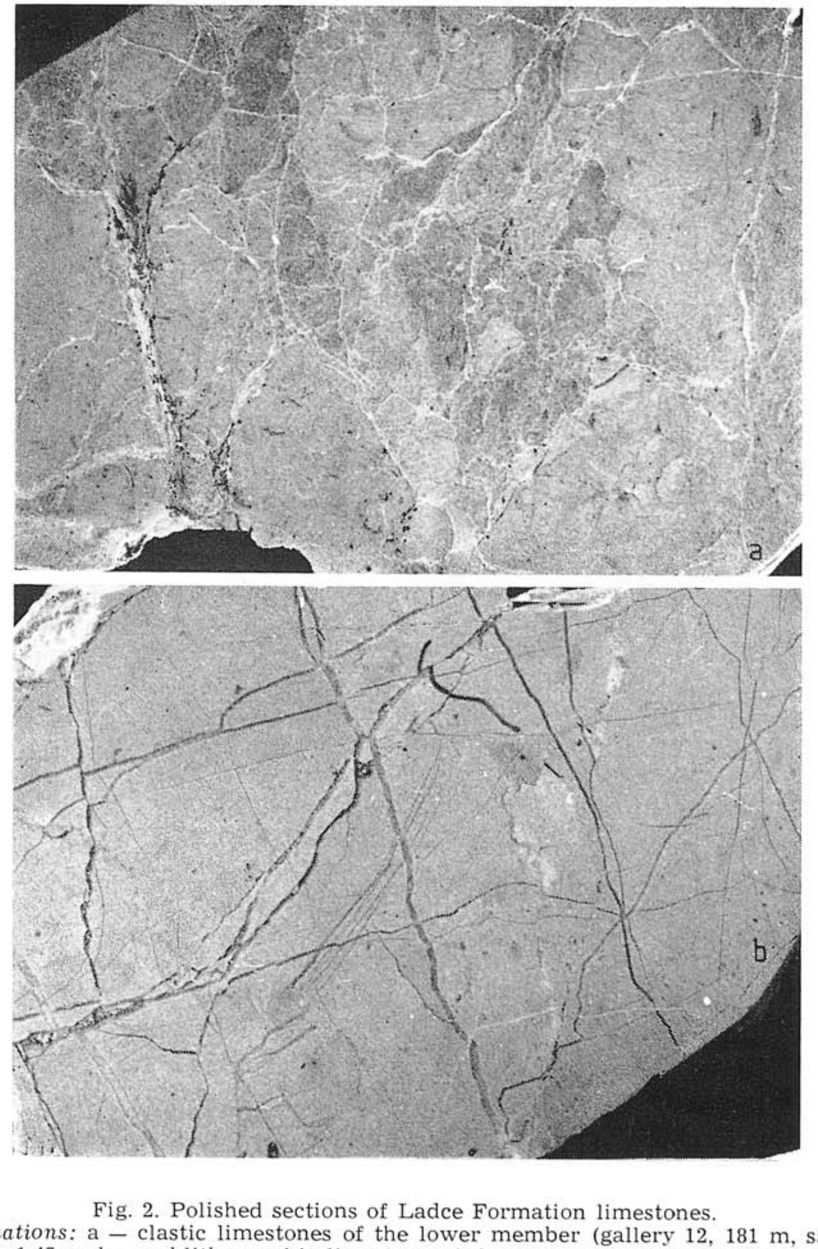

Fig. 2. Polished sections of Ladce Formation limestones.
Explanations: a — clastic limestones of the lower member (gallery 12, 181 m, sample 285 78), 1.45 x; b — sublithographic limestone of the upper member (gallery 13, 237 m, sample 285 08), 1.33x. (Photo F. M a r t a n č í k).

varies to a great extent. All fragments originate from the Upper Tithonian *Crassicollaria* Zone. It is necessary to note that both boundary zones of Tithonian and Berriasian (*Crassicollaria* and *Calpionella*, even *Calpionellopsis*) are frequently preserved only rudimentarily. Only a little more complete development was presented by B o r z a (1980) from the neighbouring Mojtín valley above Belušské Slatiny.

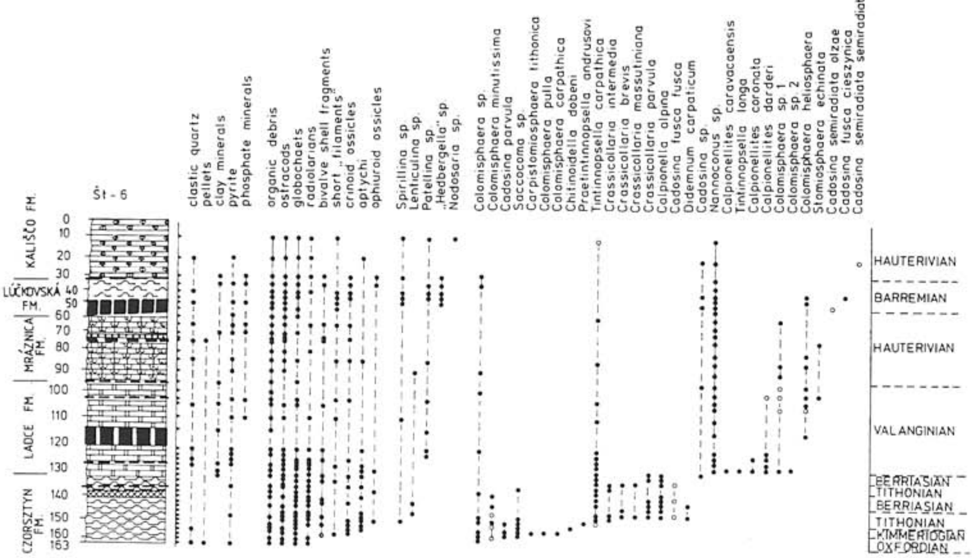

Fig. 3. Occurences of microfacial elements and microplanktic remnants in a lithostratigraphic section through the gallery Št-9 in the quarry Mt. Butkov.

The uppermost part of the Ladce Formation (1E: 110—125 m; 6EZ: 310—340 m; 8E: 510—590 m; Gal. 2: 120—180 m; Gal. 7: 210—242 m; Gal 10: 35—110 m; Gal. 12: 65, 158 m; Gal. 13: 111—234 m; Gal. 14: 238—250 m) (Fig. 3) is represented by complexion-coloured brownish to yellowish-grey slightly marly limestone with brownish limonite spots. The limestones are biomicritic, they contain abundant nannocones and organodetritus. Abundant tintinnids *Calpionella* cf. *alpina*, *Tintinnopsella carpathica*, *T. longa* (COLOM), *Calpionellites darderi* (COLOM), *C. caravacaensis* ALLEMANN, *C. coronata* TREJO, *Remaniella* cf. *cadischiana* (COLOM), *Lorenziella hungarica* KNAUER et NAGY indicate the *Calpionellites* Zone. Towars the overlying strata this community changes rapidly. Except the species *T. carpathica calpionellids* die out. Microfossils are represented by *Globochaete alpina*, radiolarians, ostracods, short "fibres", sponge spicules, foraminifers *Patellina* sp., *Spirillina* sp., *Nodosaria* sp., *Lenticulina* sp., *Heterohelix* sp. and *Frondicularia* sp., *Didemnum carpaticum* MIŠÍK et BORZA, *Didemnoides moreti* (DURAND DELGA), *Cadosina fusca fusca* WANNER, *Cadosina semiradiata olzae* NOWAK, *Stomiosphaera wanneri* BORZA, *S. echinata* NOWAK, *Colomisphaera heliosphaera* VOGLER, *C.* cf. *vogleri* BORZA, *C.* sp., *Gemeridella minuta* BORZA et MIŠÍK, aptychi, crinoid segments, fragments of bivalve shells, ophiuroid ossicles and sea-urchin spines. Limonitized pyrite is frequent, glauconite and phosphate minerals, clastic quartz grains of silt size and clay minerals occur scarcely. From groves hollowed out in this part of the formation we have acquired macrofauna of aptychi *Lamellaptychus aplanatus aplanatus* (GILL.), *L. aplanatus retroflexus* TRAUTH, *L. seranonis seranonis* (COQUAND) as well as ammonites *Olcostephanus* sp., *Kilianella* sp. and ? *Ptychophylloceras* sp., which, similarly as fauna mentioned by Telegdi Roth (1915), indicate most probably late Lower Valanginian age of the sediments.

Sporadic clastic layers of calciturbidite character occur in the uppermost part of the Ladce Formation (6E: 335 m; 7E: 555 m; 8E: 570 m; Gal. 11: 116 m etc.). The grey, grained organodetritic limestones forming beds 15—80 cm thick, have gradational structure; they are formed by, above all, crinoid ossicles more rare are fragments of bivalve shells, foraminifers and very rare are fragments of bryozoans and *Colomisphaera* sp. On the base of the strata, micrite limestone clasts are more frequent and sparite limestone clasts more rare. Pyrite and glauconite are scarce. The composition of these clastic "basal horizons" of individual turbiditic strata varies considerably (and it appears that it does also laterally within each of them). We have distinguished three types differing in roundness, size as well as composition of the clasts. Biomicrite limestone fragments in "fine-grained conglomerate" on the base of the calciturbidite 8E: 570 m are oval, with a size of 0.4—2 cm. The cement between the fragments originated probably by their abrasion: the boundaries of clasts with cement are frequently not clear. Individual clasts contain varying amount of microfossils (*Saccocoma* sp., *Crassicollaria intermedia* (DURAND DELGA), *Cr. brevis* REMANE, *Cr. massutiniana* (COLOM), *Praetintinnopsella* sp., *Tintinnopsella carpathica*, *T. remanei* BORZA, *Globochaete alpina*, radiolarians, juvenile ammonites, aptychi and biodetritus), which indicate Upper Tithonian age (*Crassicollaria* Zone) of the formation by the erosion of which the breccia horizon was formed. The second type (116 m in the gallery 11) of the brecciated base consists of brownish, slightly marly limestone clasts with a size of 1—3 cm. The assemblage of microfossils corresponds to Lower Berriasian *Calpionella* Zone (*C. alpina*, *Crass. parvula* REM., *Tintinn, carpathica)*. The third type usually forms the thickest strata of breccia (7E: 555 m). The size of the yellowish-brown slightly marly limestone fragments reaches up to 6 cm, their roundness decreases with increasing size. Micrite limestone in the clasts differs by its organic debris content. Nannocone content is high, crinoid columnalia, bivalve shell fragments, foraminifers, ostracods, *T. carpathica*, *Stomiosphaera echinata* NOWAK, *Glob. alpina*, radiolarians, sponge spicules are relatively frequent. This association indicates Late Valanginian, i. e. an age almost simultaneous with the sedimentation of the surrounding pelagic limestones. This conclusion is confirmed also by the finding of calciturbidite-biosparite clasts with pellets and extraclasts of micritic limestone (some with *Calp. alpina*) containing bivalves, ostracods, limonitized pyrite, glauconite and silt quartz grains up to 2 mm in size.

The Ladce Formation was formed during a time span between Upper Berriasian and Upper Valanginian. Its typical region of occurrence is the Mt.

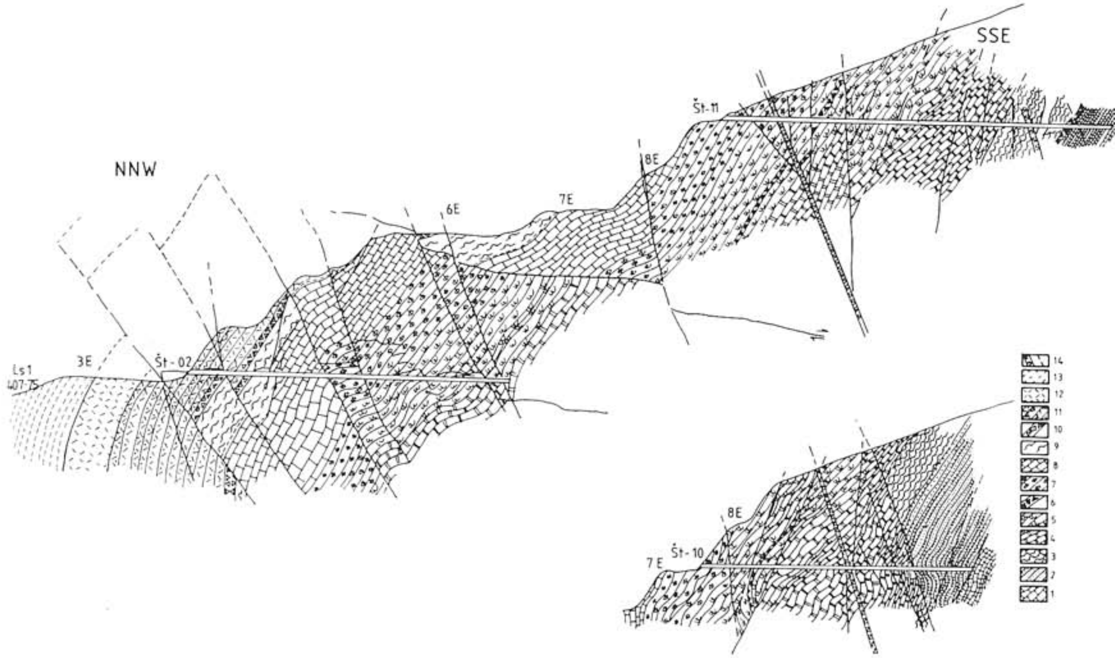

Fig. 4. Geological sections of the northern slope of Mt. Butkov in the line of exploration galleries Št-02, Št-10, Št-11.
Explanations: Tunežice crinoid al Limestone (Lias); 2 — Dogger siliceous limestones nad silicites; 3 — Czorsztyn Formation; 4 — Ladce Formation; 5 — Mráznica Formation; 6 — sediments of gravitational currents and calciturbidites; 7 — lower member of the Kališčo Formation; 8 — upper member of the Kališčo Formation; 9 — Lúčkovská Formation; 10 — basal breccia of the Podhorie Formation; 11 — Podhorie Formation; 12 — "Urgonian" organogenic limestones; 13 — Butkov Marlstone Formation; 14 — dislocation zones and faults.

Butkov section of the Manín unit. The formation is a partial time equivalent of the biancône facies and the Pieniny Limestone Formation of other regions.

2. Mráznica Limestone Formation (new term)

The Ladce Formation contains in the upper part thin interbeds of gray, inconspiciously spotted limestones with disseminated tiny cherts. The number of spotted interbeds increases upwards until they become the predominant lithotype. The boundary between the Ladce and Mráznica Formations is therefore in many places unclear, blurred. Earlier authors united both formations under the type of "pale limestones" (or Calpionella-nannocone limestones, cf. Andrusov, 1945; 1959; Kullmanová, 1961; Michel et al., 1966; Fedor, 1977) attributing them a substantially wide time-span (Tithonian-Berriasian to Barremian). These limestones should have belonged to the "deepest facies of the Carpathian geosyncline".

The Mráznica Formation (1E: 110—142 m; 5EZ: 87—105 m, 200—300 m; 6EZ: 60—120 m, 185—265 m; 7E: 295—535 m; 8E: 390—500 m, etc., cf. Figs. 1, 4) consists of grey bioturbated marly limestones with interbeds of marls or shaly marlstones. The colour of the carbonate depends on the contents of clayey ferric and organic admixture in the sediment: it varies from brownish-gray to violet-dark-gray. Besides rock-forming nannocones, these nannocone biomicrites contain a great amount of organic debris. Better identifiable microfossils are more rare: especially foraminifers (*Heterohelix*, *Patellina*, *Spirillina*, *Lenticulina*, in the upper part sporadic *Hedbergella*), fragments of bivalves, crinoid columnalia, ostracods, short fibres, radiolarians, globochaetes, sponge spicules, aptychi, ophiuroid ossicles and echinoid spines. From microplanktic remnants, *Cadosina fusca fusca* WANNER, *C. fusca cieszynica* NOWAK, *C. semiradiata semiradiata* WANNER, *C. semiradiata olzae* NOWAK, *Colomisphaera heliosphaera* VOGLER, *Col. vogleri* BORZA, *Col.* sp., *Stomiosphaera echinata*

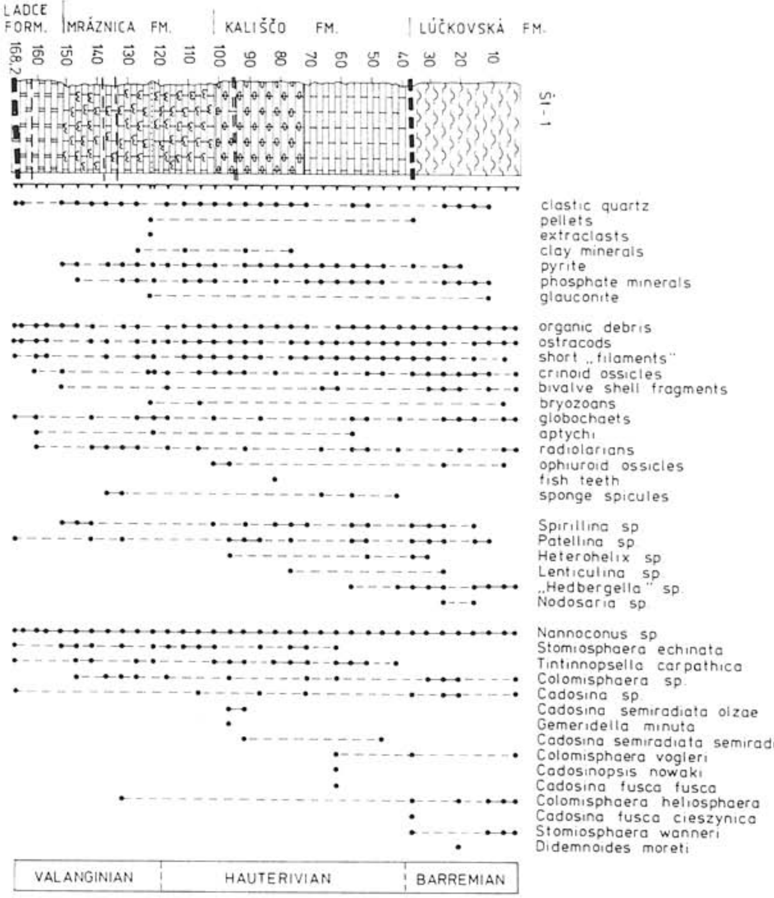

Fig. 5. Occurences of microfacial elements and microplanktic remnants in a lithostratigraphic section through the gallery Št-1 in the quarry Mt. Butkov.

NOWAK, *S. wanneri* BORZA, *Didemnoides moreti*, *Didemnum carpaticum*, *Tintinnopsella carpathica* are frequent. Radiolarians which form local accumulations are usually calcified, in the proximity of cherts they are filled with microcrystalline quartz or chalcedony. Except radiolarians, sponge spicules are some-

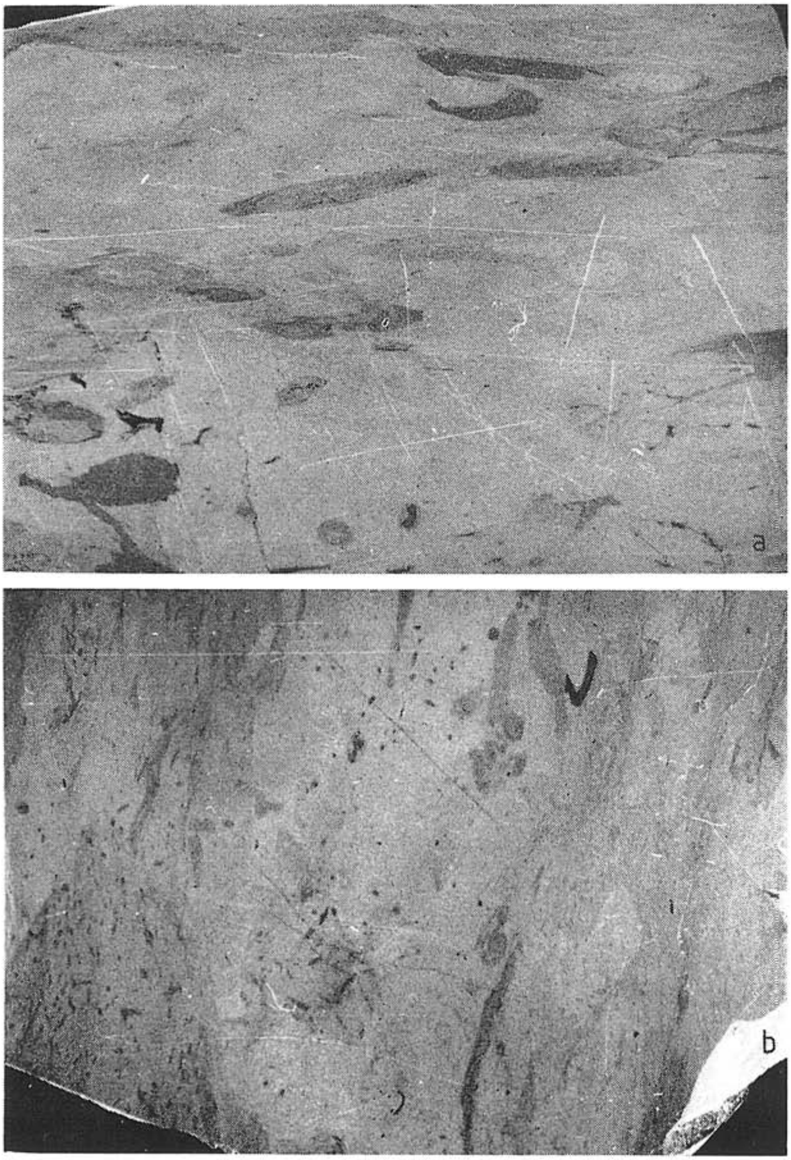

Fig. 6. Polished sections of spotted limestones of the Mráznica Formation, Mt. Butkov. *Explanations:* a — gallery Št-12. 92 m, sample 285 04, 1.35x; b — level 5E, 200 m, sample 28503, 1.26x. (Photo F. M a r t a n č í k).

times also present and the rock acquires then the character of radiolarian--spongolite microfacies (6EV: 20 m). The limestones contain frequently limonitized pyrite, more rarely phosphates, silt quartz grains and clay minerals. Muscovite plates and small dolomite rhombohedrons are rare.

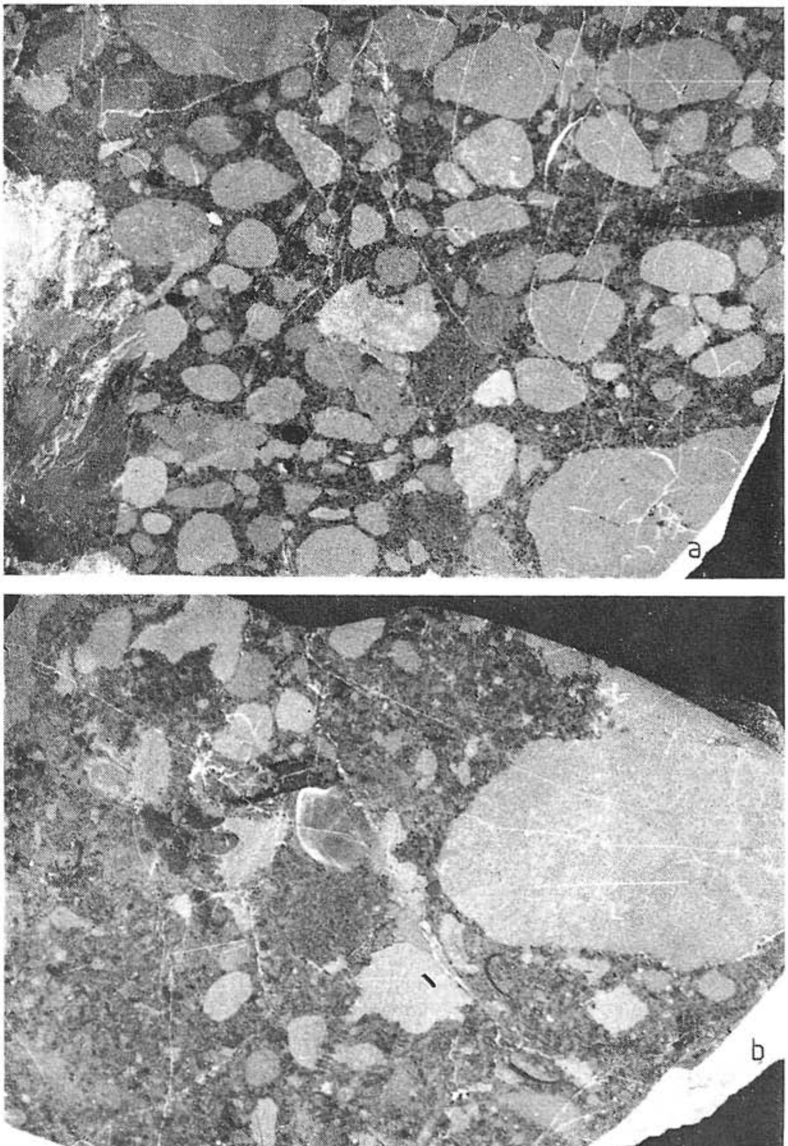

Fig. 7. Polished sections of turbiditic limestones of the Mráznica Formation. *Explanations:* a — gallery Št-13 (132 m), sample 285 88, 1.33x, quarry PC-Ladce on Mt. Butkov; b — level 6E (82 m), sample 479 03, 1.71x. (Photo F. M a r t a n č í k).

Turbidite layers of coarse-grained organodetrital limestones occur above all in the lower part of the Mráznica Formation. They consist of recrystallized crinoid columnalia fragments and pellets of limestones. The base of the turbidite interbeds has sometimes even the character of a fine-grained conglomerate (6E: 90 m) which clasts are up to 15 mm in size (Fig. 7). The most frequent limestone fragments consist of micrite nannocone limestones with *Stomiosphaera echinata*, biomicrite nannocone limestones with radiolarians and biomicrite limestones with *Calpionella alpina*, *Tintinnopsella carpathica*, globochaetes and radiolarians. Thus, erosion in this time did not affect the Tithonian Czorsztyn limestones any more. Main part of the turbidite layers consists of biosparite limestones with crinoid segments, fragments of bivalves, ostracods, foraminifers, bryozoans, *Colomisphaera* sp., muscovite plates, phosphate and glauconite grains. The grain-size of the rock decreases rapidly upwards until it changes into fine-grained laminite. The distribution of abundant cherts is usually bound to lithologic boundaries of turbidite intercalations. A more or less conspicious rhytmical structure is after all characteristic for the whole Mráznica Formation. Nevertheless, this feature looses its prominence upwards: the conspicious spottednes gradually also dissapears, the colour gets lighter, a whitish weathering colour appears as well as nodules of contour cherts. The boundary with the overlying Kališčo Formation is therefore not sharp.

Except rock-forming nannocones and a number of skeletons of other microplanktic organisms, sponge spicules and echinoderms, the formation contains a relatively abundant but often deformed macrofauna of ammonites, belemnites, and aptychi (*Duvalia dilatata* (BLAINVILLE), *Pseudobelus brevis* PAQUIER, *Neocomites* (TESCHENITES) *neocomiensiformis neocomiensiformis* (UHLIG), *N. (T.)* cf. *jordariensis* (DOUVILLÉ), *N. (T.)* cf. *pachydicranus* THIEULOY, *Eleniceras tchechitevi* BRESK and others, cf. Vašíček et Michalík, 1986). This fauna indicates Uppermost Valanginian to Lower Hauterivian age (on other localities the formation nevertheless includes whole Hauterivian to Barremian strata). It represents a typical development not only in the Manín unit, but also in the frontal parts of the Krížna Nappe in the Strážovské Mts., Malá and Veľká Fatra Mts. as well as in Vysoké Tatry Mts. Laterally it changes into marly limestones to marlstones (in the Vysoká unit of the Malé Karpaty Mts. it is represented by shaly cherty limestone).

3. Kališčo Limestone Formation (new term)

A marked feature like the appearance of cherts in the pelagic limestone sequence has attracted the attention of authors studying lithostratigraphy of the deposit. They considered them to be the representatives of whole "Lower Neocomian", i. e. they should have represented the sediments of Berriasian, Valanginian and according to some authors also Hauterivian age (Andrusov, 1945; Michel et al., 1966; Fedor, 1977; Rakús, 1977). The quantity of stratigraphically valuable fauna which we have succeeded to obtain from the formation in the last time enables it to make these data more precise in many aspects. Good exposure of the formation in the quarry makes it possible to characterize two strata members.

The lower (informal) member consists of greenish light grey limestones with contour cherts. Only in the upper parts of the quarry a marked turbiditic layer lays on its base limiting it clearly towards the underlying Mráznica Formation. The brecciated turbidite horizon has chertified traces of fluid cast type on its base. Typical rock of the formation is biomicrite with abundant nannocones, sponge spicules, ostracods and fine fragments of organic skeletons. Terrigene clastic quartz grains of silt size are rare, more frequent are idiomorphic grains of authigenic quartz. In more intensively silicified parts of the rock it is possible to observe various stages of silicification of fossils and micritic matrix as well as various grain developments dependent on the silicificiation conditions (cf. Fedor, 1977).

A typical feature of the formation are nodules of "contour" cherts with a diameter of 5—30 cm (Fig. 8). The 4 to 26 mm thick "crustal" layer consists of greenish-grey to brownish-grey chert, while the core, frequently containing well-preserved fossils, is almost unaffected by silicification. The three-dimensional preservation of fossils in the core of the cherts contrasts with the compression affecting organic remnants in the surrounding sediments. Nodular appearance of the bedding planes is obviously a late diagenetic feature caused by irregular, uneven compaction of differently silicified parts of sediment (the surroundings of chert nodules, shell clusters, infaunal burrows filling and silicified clusters were during diagenesis deformed less than the fine-grained marly sediment surrounding them). The 8—15 cm thick beds of limestone contain sometimes aptychi *Lamellaptychus angulicostatus longus* TRAUTH, *L. angulicostatus angulicostatus* (PICT. et LORIOL), ammonites *Lytoceras subfimbriatum* (D'ORB.), *Crioceratites* (CR.) *duvali* (D'ORB.), *Euphylloceras* sp., *Plesiospitidicus* sp., *Ptychoceras* sp., *Partschiceras infundibulum* (D'ORB.), belemnites *Duvalia* sp., *Hibolites* sp., *Pseudobelus brevis* PAQUIER, crinoid cups, brachiopods and ichnofossils *Chondrites* and *Zoophycos*. From microfossils foraminifers *Spirillina* sp., *Patellina* sp., as well as microproblematics *Tintinnopsella carpathica*, *Colomisphaera vogleri*, *C. heliosphaera*, *Stomiosphaera echinata*, *Globochaete alpina* and nannocones (cf. Borza et al., 1983, 1986) are frequent.

According to the mentioned fossils the stratigraphic range of this member corresponds to upper Lower to Upper Hauterivian (its thickness is 42—46 m).

The 20 to 25 m thick upper lithostratigraphic member consists of brownish-grey slightly marly, sometimes spotted nannocone biomicrites with fine biodetritus. They contain crinoid ossicles, fragments of bivalves, ostracods, sea-urchin spines, foraminifers (*Patellina* sp., *Spirillina* sp., *Heterohelix* sp.) and microplankton remnants *Tintinnopsella carpathica, Cadosina fusca cieszynica* NOW., *Colomisphaera heliosphaera, Didemnum carpathicum, Globochaete alpina* etc, (cf. Borza et al., 1983). In upper parts of the formation hedenbergellid foraminifers become abundant. From macrofossils, aptychi (*Lamellaptychus angulicostatus* (PICT. et LORIOL) appear sporadically as well as remnants of belemnite rostra *Pseudobelus brevis*. Large crioceratitid ammonites and shells of lingulid brachiopods occur rarely. Limonitized pyrite is frequent, rare are silt quartz grains and phosphate minerals. Tiny (2—5 cm) blackish-grey chert clusters with diffuse contours occur in the lower part of the member. The limestone is mostly thickly bedded, having conchoidal fracture and characteristic chipped disintegration mode. The content of marly component increases upwards and limestone changes into a bedded to thinly bedded one.

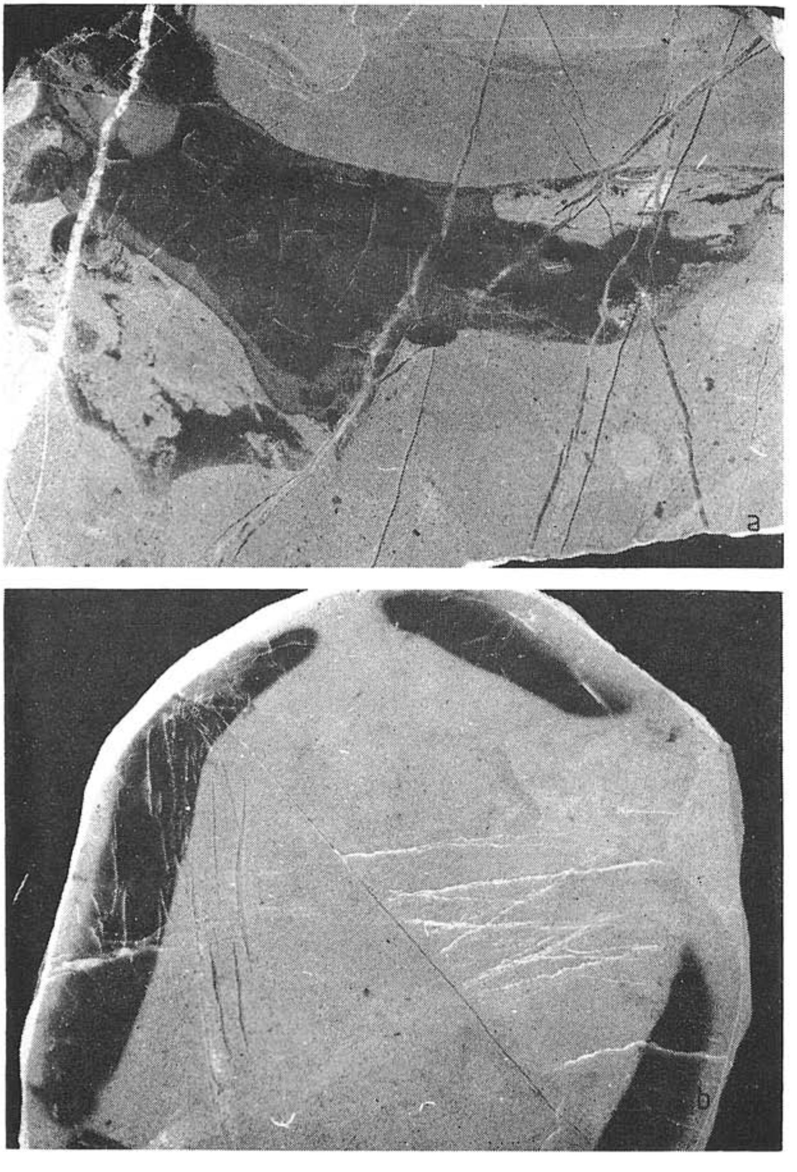

Fig. 8. Polished sections of limestones of the Mráznica and Kališčo Formations from the Mt. Butkov quarry.
Explanations: a – turbidite limestone of the Mráznica Formation, level 7E (555 m), sample 285 94, 1.5x; b – contour chert of the Kališčo Formation, level 7E (530 m), sample 285 93, 1.43x. (Photo F. M a r t a n č í k).

The stratigraphic range of the lithostratigraphic member is late Lower to Upper Hauterivian: the uppermost horizons can be already of Lower Barremian age. Direct evidence for their age determination is missing: it appears that the characteristic association of the "Pseudothurmannia horizon", indicating the base of Barremian in many other West Carpathian profiles, does not occur in the Lower Cretaceous sequence of Mt. Butkov.

4. Lúčkovská Limestone Formation (new term)

It can be divided into lower, strongly marly part (often affected by tectonics or insufficiently exposed) and upper member consisting of bedded grey micritic limestones which turns yellow by weathering.

The lower lithostratigraphic member has unclear boundaries with the underlying Kališčo Formation (progressively thicker marlstone interbeds occur in its uppermost part). It has a thickness of 4—5 m. The black to blackish-grey marls contain frequent interbeds of grey, not very conspiciously spotted (Fig. 9) marly biomicrite limestones with abundant nannocones, crinoid segments, sea-urchin spines, radiolarians, with less foraminifers (*Patellina* sp., *Spirillina* sp., *Lenticulina* sp., *Heterohelix* sp., "*Hedbergella*" sp.), ostracods, cadosinas, stomiosphaeras and globochaetes. Silt quartz grains, hydromicas, biotite and pyrite occur sporadically. From macrofauna occur here well-preserved sponges, skeleton elements of echinoderms (mainly long sea-urchin spines) and sporadic belemnites. Ammonite shells of the *Barremites* genus locally form coquina layers. In the upper part of the formation, interbeds of micritic carbonates appear and marls gradually change their colour into yellowish-grey, ochre-yellow to orange-light brown. Such marl strata contain abundartly belemnite rostra (*Hibolites longior* SCHWETZOFF, *H. jaculoides* SWINNERTON, *Vaunagites pistilliformis* (BLAINVILLE), *Duvalia binervia* (RASPAIL), *D. dilatata dilatata* (BLAINVILLE), *Mesohibolites platyurus* (DUVAL—JOUVE), etc., cf. Borza et al., 1983). On the basis of macro- as well as microfauna elements the described member can be classed with the upper part of Lower Barremian.

The upper lithostratigraphic member ("belemnite limestones") consists of markedly heavy-bedded (30—150 cm) grey, compact limestones, turning yellow by weathering, with intercalations of yellowish marl and with dark cherts. (Fig. 10). The bedding surfaces are uneven, often nodular, in many cases with traces of gravitational mud movement up to thin horizons of intraformational breccias. The breccias contain pelets, limestone extraclasts, rounded brachiopod shells and belemnite rostra. The surface of other beds is marked by slight current erosion, sometimes it is covered by great quantities of belemnite rostra ("battle fields" in Borza et al., 1983): *Duvalia grasiana* (DUV.—JOUVE), *Mesohibolites varians* (SCHWETZ.), *M. minaret* (RASP.), *M. gladiiformis* (UHLIG), *M. garshini* STOYAN—VERG., *Hibolites mirificus* STOYAN—VERG., etc., ammonite shells *Barremites* (B.) sp., *Abrytusites* sp., *Partschiceras infundibulum* (D'ORB.), except these, numerous brachiopods, sea-urchins, gastropods, corals, cups of isocrinid crinoids, and teeth of fish of the family *Hexacanthidae*. Biomicritic limestones contain abundant nannocones and fine organogenic debris, as well as frequent hedbergellid foraminifers. Other foraminifers (*Patellina* sp., *Spirillina* sp., *Heterohelix* sp., *Lenticulina* sp.) are more rare. The spectrum of microplanktic remnants is rich: *Colomisphaera heliosphaera* VOGLER, *Cadosina semiradiata semiradiata* WANNER, *Stomiosphaera*

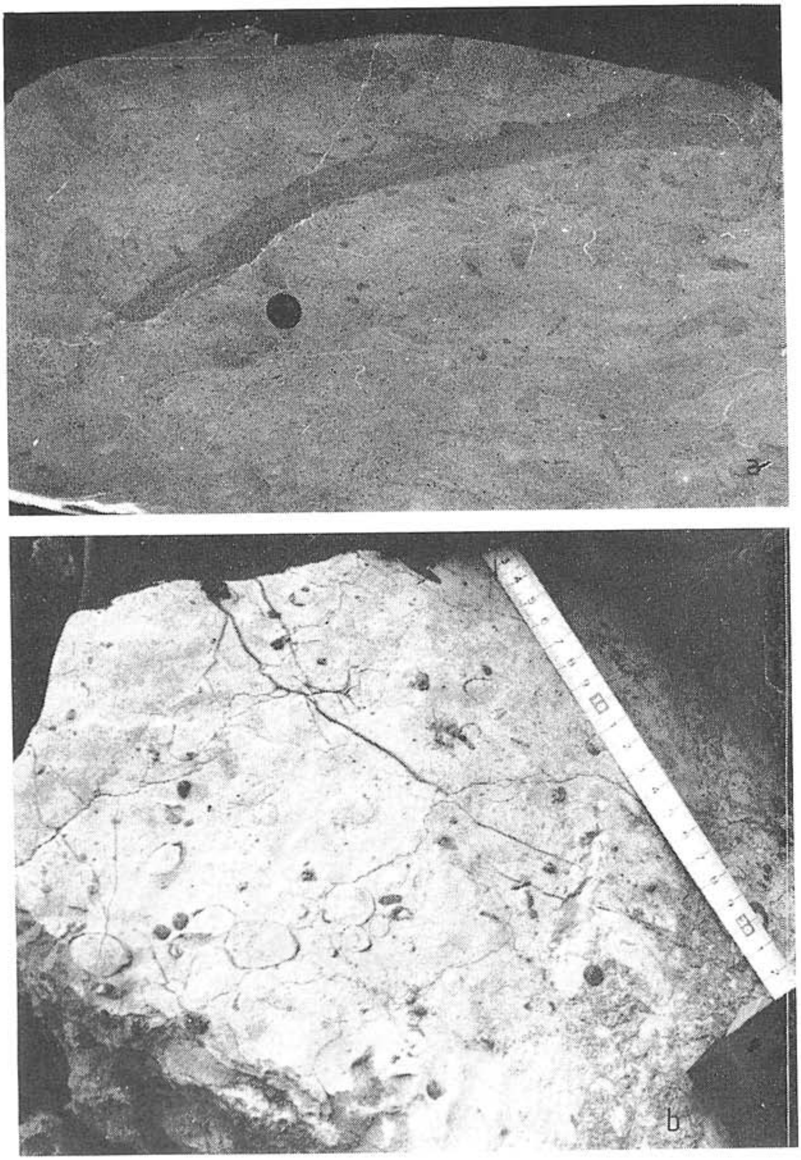

Fig. 9. Polished sections of Lúčkovská Formation Limestones, quarry Mt. Butkov. *Explanations:* a – "Barremites" spotted limestones, level 4EZ (60 m), sample 285 02, 1.46x; b – "belemnites" limestones, weathered surface, entrance of the gallery Št-12. (Photo F. Martančík).

Fig. 10. Exposure of a formation of yellowish-grey "belemnite" limestones of the Lúčkovská Formation, road to the fifth level (5EV, 60 m) of the PC Ladce quarry on Mt. Butkov. (Photo J. Michalík).

echinata NOWAK, *S. wanneri* BORZA, *Globochaete alpina*, *Didemnoides moreti* and *Didemnum carpaticum*. The organodetritus consists of solenoporid fragments, holothurian sclerites, radiolarians, sea-urchin spines, ostracods, short fibres, ophiuroid ossicles, limonitized pyrite, silt quartz grains, glauconite, phosphates and clay minerals are rare. The occurence of *Tintinnopsella carpathica* in the clasts of breccia layers indicates synsedimentary simultaneous erosion of underlying limestone horizons.

Dark-grey cherts form big loaf-like nodules (frequently with indented central part) occuring sometimes in stratiform layers inside thicker limestone beds. The cherts are evidently missing in more marly parts of the rock. Even though predominant part of the original chalcedony mass of the cherts is obviously dehydrated and recrystallized, the quartz formations have primarily spherical structure (Fedor, 1977). Sharp contours of the chert nodules are the result of substitution of the clay component of the rock by quartz matter during silicification. Dark colour of the chert is caused not only by organic admixture, but also by higher light transparency and lower reflectivity of quartz in comparison with the surrounding rock. In the uppermost part of the formation (Fig. 11), the direction of cherty horizons is clearly deformed into large tuft-like structures. Such a deformation indicates a sliding on submarine slopes after loading of the formation by overlying clastic slope sediments (Borza et al., 1983).

Fig. 11. Slide structure in a bed of cherty limestones of the Lúčkovská Formation on the first level of the PC Ladce quarry (270 m). (Photo J. Michalík).

Belemnite and sporadic ammonite fauna permits to range this member of the Lúčkovská Formation with Lower to Upper Barremian, (up to Lowermost Aptian). Its thickness reaches 35 to 40 meters.

5. Podhorie Limestone Formation (new term)

The formation begins with a 4—5 m thick brecciated member formed by markedly gradational strata rhytms. Clasts consist of organodetritic as well as of micritic limestones, cherts, rarely of fragments of basic extrusives and tuffs (Fig .12). The clasts are of Barremian to Middle Aptian age. The upper member, bedded bituminous organodetritic limestones with blackish grey cherts, is locally silicified. They form a substantial part of the formation; they change upwards into organodetritic limestones of "Urgonian" carbonate platform of Aptian to Lower Albian age. The lower boundary of the Podhorie Formation with the Lúčkovská Formation is markedly erosive; it is characteristic by a progradation of slope sediments of the originating carbonate platform through pelagic carbonate "ramp". The formation reaches a thickness of 65 to 75 meters. Most frequent are fragments of lamellibranch shells and crinoid ossicles, foraminiferid tests of *Hedbergella* type, *Sabaudia minuta* (HOFKER), miliolids and orbitolinas *Palorbitolina lenticularis* (BLUMENBACH), *Mesorbitolina parva* DOUGLAS, and *Orbitolinopsis simplex* (HENSON).

Geochemical characteristics and genesis of the formations

Results of chemical analyses

Except microscopical observation of thin-sections, we have based the evaluation of the composition of lithologic horizons also on a set of 317 chemical analyses. We correlated the changes of chemical composition with the changes of lithofacies in a lithostratigraphical column (Fig. 13) which enables us to gain a good idea of the changes in chemical composition of the sedimentation area in space and time. The investigated chemical components can be divided into three distinctly different groups: the first one consist of elements bound to clastic components (Si, Ti), the second one are elements connected with clay admixtures (Al, Fe, K, Mg). The third group consits of calciphilous elements like Ca, Na, SO_3.

a) Insoluble residue

The quantity of rock insoluble in monochlorine acetic acid is inversely proportional to calcinity (CaO, but also the contents of Na_2O and SO_3, cf. Fig. 13). On the other hand, it correlates positively with contents of SiO_2, TiO_2, Fe_2O_3, Al_2O_3, MgO and partly K_2O, which is an evidence of siliceous and clayey character of the greater part of the insoluble residue, while authigenic and clastic quartz and feldspars form its minor part. The correlation with Fe and Mg indicates the presence of limonite and glauconite (F e d o r, 1977). Minimum content (1 %) of insoluble residue is connected with carbonates of the Podhorie Formation, maximum (up to 30 %) with cherty parts of turbiditic rhythms of the Mráznica Formation.

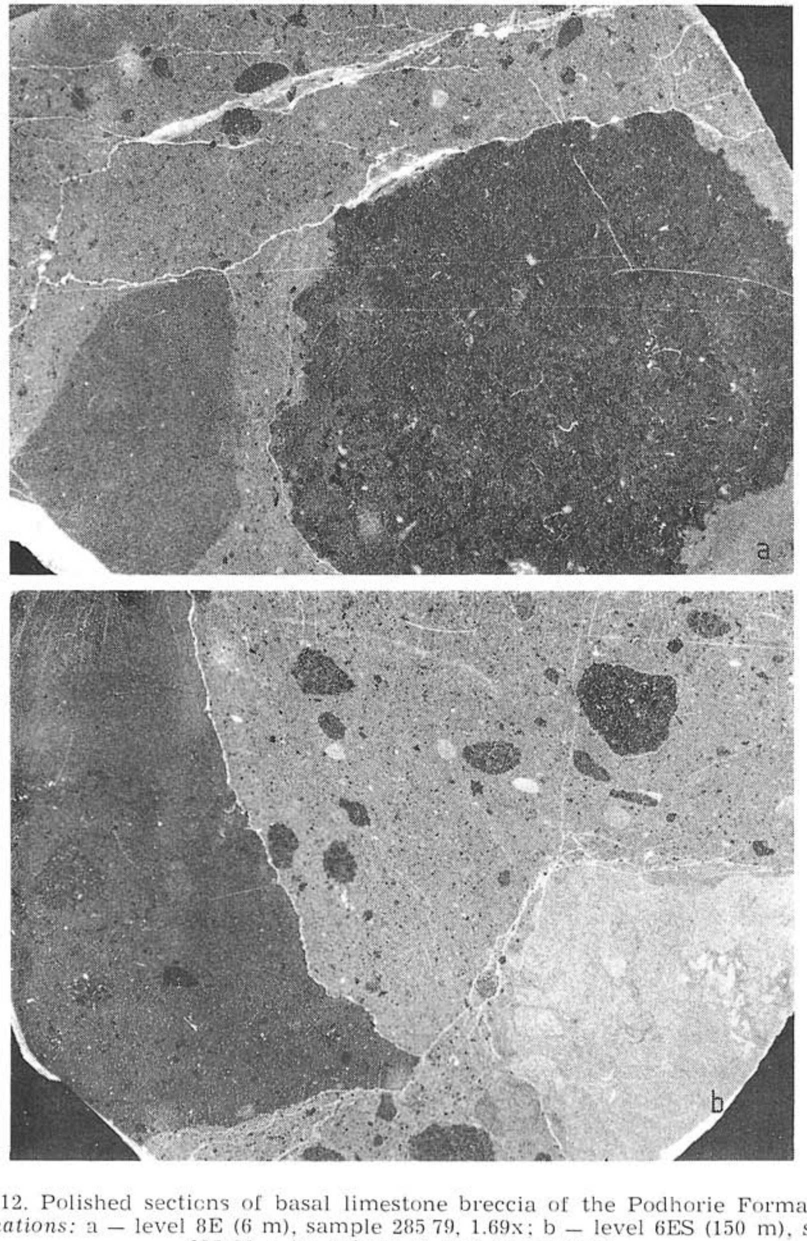

Fig. 12. Polished sections of basal limestone breccia of the Podhorie Formation. *Explanations:* a — level 8E (6 m), sample 285 79, 1.69x; b — level 6ES (150 m), sample 285 80, 1.6x. (Photo F. M a r t a n č í k).

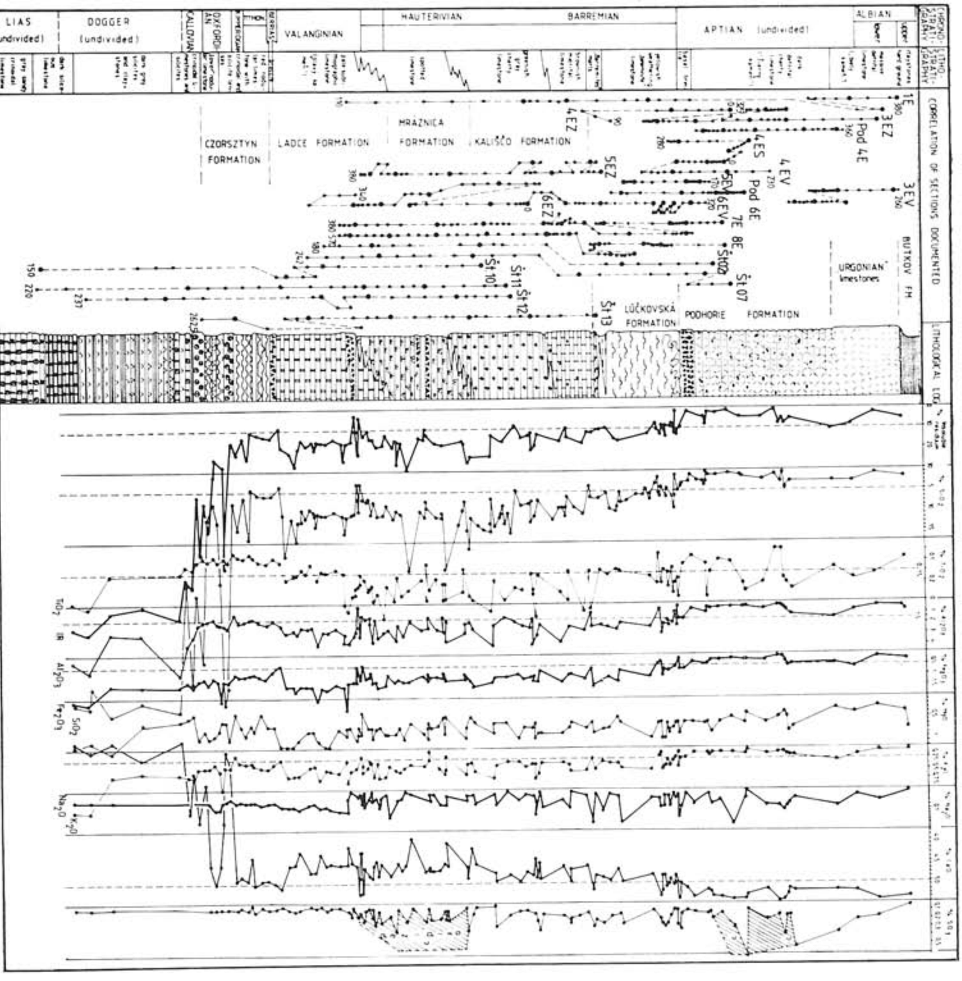

Fig. 13. Correlation of lithostratigraphy and chemical composition of limestones of Upper Jurassic and Lower Cretaceous formations exposed by the quarry of Považské Cement Works on the northern slope of Mt. Butkov.

b) SiO_2 content

Quartz modifications are after calcite the most frequent minerals of the samples of Lower Cretaceous limestones of Mt. Butkov (Fedor, 1977). Terrigene clastic grains are rare, they reach only silt size, more frequent are authigenic, sometimes partly idiomorphic crystals and aggregates. The main source of the SiO_2 component is, except clay minerals, the group of minerals of the recrystallization sequence chalcedony — quartzine — quartz.

The limestone sequence has three parts with varying SiO_2 contents (average is 7.29 %): while the content of this component in pelagic "Neocomian" micritic limestones reaches from 3—5 up to 15—30 %, it never exceeds 5 % in the limestones of the "Urgonian" organodetritic complex (cf. Fig. 13). Especially large anomalies ae accompanying turbidite horizons and cherty horizons in the Mráznica and Lúčkovská Formations. (The chert content in the rocks of the sequence was studied by Michalík et al., 1986).

c) TiO_2 content

The contents of this component in the horizons of the deposit are very variable (mean value is 0.22, limiting values 0.04 and 0.37 %). "Neocomian" formations contain as a rule more than 0.15 % TiO_2, while its content in the "Urgonian" complex is more variable and as a rule lower than 0.25 %. Deviations of the values are best correlable with the curve of SiO_2 contents, permittig us to assume the presence of Ti in the grains of clastic admixture. A part of TiO_2 could nevertheless be absorbed in clay component.

d) Al_2O_3 and Fe_2O_3 contents

The two mutually well correlable components are bound to the clay minerals content (the content of limonite is principially higher in marly limestones). Average Al_2O_3 content is 1.9 %, Fe_2O_3 content 0.89 %. Both elements occur in higher concentrations in the "Neocomian" part of the sequence, while in the "Urgonian" formations their contents are incomparably lower.

e) K_2O content

We can observe a division into two units in the distribution of this component (0.1 to 0.75 %, in average 0.35 %): the content in the "Neocomian" formations reaches 0.25 to 0.75 %, while in the "Urgonian" formations it usually falls bellow 0.25 %. The variation in K_2O contents which we can correlate with changes in Al and Fe contents suggests a binding of K on clay minerals, more rarely on newly formed feldspars.

f) MgO content

Deviations of the relatively constant MgO content (about 0.73 %, with deviations of 0.5 to 1 %) can be correlated with changes of clay admixture content; they are higher with glauconite occurrence. MgO content exceeds 1 % in the uppermost part of the "Urgonian" massive, light-coloured limestones (Fedor, 1977, mentioned up to 70 % of glauconite in the insoluble residue from these rocks).

g) Na_2O content

It is possible to limit the significantly varying content of this component by the values 0.01 % to 0.2 %, average content is 0.58 %. Anomalous concentration correlate best with CaO and SO_3 contents.

h) SO_3 content

SO_3 contents of the rocks is variable, it reaches values from 0.05 to 0.65 %, in average 0.17 %. On the basis of its contents it is also possible to distinguish pelagic limestones and the limestones of a carbonate platform, where it reaches surprisingly high values (Fig. 13). Because SO_3 correlates best with CaO and Na_2O and poorly with Fe_2O_3, we can assume that SO_3 is not so much a product of pyrite decomposition as a product of compounds formed after its decomposition, bitumens and other organic matter preserved in the rock.

i) CaO content

The Ladce and Mráznica Formations usually contain hardly 47 % CaO, in the Kališčo and Lúčkovská Limestones its content grows to 50 %, in the Podhorie Formation over 52 % (in the uppermost "Urgonian" part is its content even higher). This trend is the result of progressively increasing content of calcareous skeletons of plankton and nannoplankton, higher on as well of aragonite and calcite skeleton fragments of benthic organisms in the sediment. To obtain a more complete idea it would be suitable to supplement the analyses in the future by further elements which are considered to be facial indicators (P, B, Sr, Ba, Pb, V, Cu etc.).

Discussion to the genesis of the formations

a) Micrite nannocone limestones of the Ladce Formation originated from eupelagic calciferous lime muds similar to recent types of globigerine mud — pteropod and coccolith oozes, which sediment on submarine plains of tropical Atlantic Ocean and Mediterranean Sea at a speed of 20 to 100 mm in thousand years. These sediments characterize regions which are not directly influenced by the transport of material from continental slope. Separation of the region (either by primary distance or by natural barriers) is at the same time a far more important factor than the absolute depth of sedimentation environment (Kukal, 1964). Lime content of the sediment increases with water temperature (in higher geographic latitudes increases the occurences with siliceous skeletons). Lime oozes appear sporadically also in depths under 7000 m, where they are washed to by turbidity currents (calcitic particles are nevertheless affected by corrosion and the content of insoluble residue in the sediment thus increases). The majority of organic remnants is of planktic origin (coccoliths can form more than 60 % of the total mass of the sediment). A further, frequently predominant component of the sediment — fine-grained carbonate ooze — is formed by the decomposition of organic tests. Its quantity depends on iife activity of decomposing organism, transportation velocity and sedimentation rate. The section of currents affected especially the surface of bottom elevations.

Sedimentation rate of the Ladce Formation calculated from its thickness, assumed grade of diagenetic reduction and stratigraphic age determination of the horizons is approximately 20—30 mm in thousand years. Preservation of fossils indicates an oxidation environment with uniform sedimentation. The environment was in several aspects similar to the sedimentation model of the Czorsztyn Formation (B o r z a—M i c h a l í k, 1986).

The most important difference was an increase of sedimentation rate of planktic skeleton remnants. The increasing sediment masses and a more active tectonic pulse of the territory at the end of the sedimentation period of this formation have mostly smoothed the depressions isollating the sedimentary environment from turbidity currents. It is probable that this process was accompanied by a slight regression, so that at the end of Valanginian eupelagic sedimentation was substituted by hemipelagic one.

b) Spotted limestones of the Mráznica Formation, like Lias "Fleckenkalk" of the Allgäu Formation, belong to the equivalents of recent "blue mud" of hemipelagic regions of ocean bottom (M i š í k, 1958; K u k a l, 1964). These most typical hemipelagic sediments usually change with depth into the equivalents of globigerine mud. Decomposition of a quantity of organic matter in the sediment causes the characteristic oxygen insufficiency: a few mm thick oxidation layer originates sometimes only on the surface of blue mud. Although infaunal organisms bring oxygen under the surface of sediments, it is there usually soon exhausted and bituminous matter ("gyttja") accumulates in the infaunals burrows, what causes characteristic spotting of the sediment. The thickness of oxidation halmyrolitic layer depends on the porosity of the sediment (content of clay components) and sedimentation rate. After being covered, the reddish-brown colour of oxidated sediment can change into bluish-grey. W i e c z o r e k (1984) assumed on the basis of ichnofaunal analysis that Jurassic spotted limestones of the Tatra Mts. correspond to the *Zoophycos* ichnofacies of upper bathyal (depth of 200 to 2000 m). F a b r i c i u s (1960) explained the origin of anaerobic sedimentation conditions by sedimentation rate (a quantity of burried organic remnants did not moulder), while J a c o b s h a g e n (1965) attributed more importance to the shortage of currents in a partly isolated basin.

The last assumption is nevertheless contradicted by frequent occurence of turbiditic interbeds in the Mráznica Formation as well as in quoted facially equivalent formations. In accordance with W i e c z o r e k (l. c.) we assume that spotted limestone facies is characteristic for passive continental slopes of Tethys. It is not a case of deep-sea, but only hemipelagic facies.

c) Basic characteristics of the rocks of the Kališčo Formation are similar to those of the underlying Mráznica Formation. Both are products of a hemipelagic environment where the activity of turbidity currents gradually diminished. For the Kališčo Formation is nevertheless typical the origination of chert nodules which usually ended in its beginning stage. Silicic acid gel concetrations originated in fresh porous sediments: chalcedony coagulated gradually (sometimes clearly rhytmically) around tests of organisms. Radiolarian tests and sponge spicules are abundant in the silicified parts of the rock. It is possible that they were dissolved in the rest of the rock and that it was just this material that was the source SiO_2 concentrations. The assumption of "domestic" origin of SiO_2 is confirmed by the fact that total content of this component is in average not higher than in the underlying limestone types with no cherts.

The amount of benthic fauna in the assemblage of fossil remnants increases in the Kališčo Formation for the first time. A more even sedimentation rate

(20—25 mm in comparison with 30—50 mm in thousand years in the Mráznica Formation) gave rise to a stable bottom rendering a suitable substrate for benthic organisms (sponges, crinoids, brachiopods, etc.). The Kališčo Formation (especially limestones of the basal part) contains an abundant association of ichnofossils with up to 120 cm wide spirals of *Zoophycos Massalongo*. This association is, according to Seilacher (1964) characteristic for upper bathyal (depths of 200 to 2000 m).

d) "Barremite" (similarly as "belemnite") marls of the Lúčkovská Formation are products of a period of slowed-down $CaCO_3$ sedimentation in the complex of pelagic limestones (10 mm in thousand years). Except a quantity of dispersed organic matter and iron sulphide, the sediment contains a quantity of barremitid ammonite shells which predominate over other macrofossils (cf. Vašíček—Michalík, 1981). This change in sedimentation regime as well as in the association of macrofossils can be interpreted as an effect of upwelling of cold deep-oceanic waters. Preserved structures in limestone interbeds are most similar to those of the Mráznica Formation.

Similarly, limestones of the Lúčkovská Formation themselves sedimented very slowly (15—25 mm in thousand years). The slow sedimentation, sings of nodular structure as well as the division of lime and marly components make them similar to nodular limestones which sedimented as well in oxidation environment without an addition of terrigene material. Both formations are characterized by local small gaps and wash-outs, as well as by thin interbeds of intraformational breccias. The depth of sedimentation environment of the Lúčkovská Formation was nevertheless apparently smaller what is evidenced by the diversity of benthic fauna (probably near under the photic zone boundary). Noteworthy is the formation of loaf-like cherty nodules preserved in unconnected bands inside thicker limestone beds. Deformation of these bands by submarine slides is an evidence of early diagenetic origin of the cherts. Orientation of belemnite rostra indicates the presence of a bottom current.

e) Rapid growth of carbonate platform manifested in the Manín region during Barremian influenced the Aptian development of Mt. Butkov area. Boulder breccias of the foot of an advancing detritic slope gradually covered the surface of the carbonate ramp and caused the deformation of its sediments (Borza et al., 1986). Above the breccia bed followed the proper material of the detritic platform slope (Podhorie Formation), consisting of rounded skeletal fragments of shallow-water benthic organisms (solenoporaceans, bryozoans, orbitolinae, corals etc.). It is difficult to estimate the sedimentation rate (50—60 mm in thousand years) more reliably in the view of imprecise age determination of the formation base and mobile character of the substrate. In any case this sedimentation rate was sufficient to smooth the relief and fill the basin up to photic zone level to Early Albian. A more prominent formation of organodetritic material and carbonate platform was frequent in this period in many places of Tethyan as well as Subtethyan regions of Europe (Vocontian Trough, Northern Alps, Central Hungarian Mts. ..., cf. Ferry, 1984; Arnaud—Vanneau et al., 1979; Fülöp, 1964, etc.).

The sedimentation of carbonates stopped suddenly at the end of Lower Albian. An area of hard-ground originated on the whole surface of the carbonate platform, bearing the signs of biogenic as well as chemogene erosion of already consolidated carbonatic sediments. Low diversity of endolithic benthos remnants, missing of remnants of autotrophic organisms and sessil infauna on the hard-ground surface (only in the Slatinská valley region a thin stromatolithic coating was found covering endobiontic burrows) are the evidence of the formation of the hard-ground bellow photic zone level. Missing of epifauna as well as of sedimentation can be explained by assumed upwelling of cold waters from depth (Seňkovskij, 1978) the effects of which showed already in Early Barremian. The rapidly lithifying carbonate platform subsided into the zone of cold currents not favourable for the formation of calcareous skeletons. Exposed surface of the carbonate body became a target of bioerosive destruction. After further subsidence it got bellow the region exposed to currents until it was covered by deep-sea clay sediments of the Albian—Cenomanian Butkov Formation.

Translated by K. Janáková

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