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CHLORITE AND CHLORITE-HEMATITE ONCOIDS FROM THE JURASSIC LIMESTONES OF THE WESTERN CARPATHIANS, SLOVAKIA

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Abstract: Pelagic chlorite and chlorite-hematite oncoids occur in red nodular limestones of the Toarcian and Oxfordian age, thought to represent intervals of condensed sedimentation. At a single locality, they were also found in an intraformational limestone breccia with fragments of a calcrete. Intraclasts, fragments of hardgrounds and belemnite rostra form oncoid nuclei. Wrinkled laminae and pseudocolumnar structures characterize their cortices. Encrusting foraminifers are important builders of the studied oncoids. Rare synsedimentary cracking of oncoids is indicated by the presence of neptunic microdykes. Sets of chlorite and hematite concentric laminae responded differently during compaction and tectonic processes. A peculiar phenomenon is the recrystallization (aggrading neomorphism) of the micrite admixture in hematite and chlorite oncoids; new-formed larger calcite grains contain the hematite pigment arranged in dendritic patterns. The hematite pigment also formed characteristic "teeth" in the early diagenetic calcite veinlets. The oncoids are formed by Fe-chlorite, polytype IIb. The origin of the chlorite was connected neither with volcanic activity nor with the initial metamorphism. The condensed sedimentation with mineralized oncoids was associated either with local conditions or with the sea level high stand.

Key words: Western Carpathians, Jurassic limestones, chlorite oncoids, hematite oncoids, encrusting foraminifers.

Introduction

Calcite oncoids are concentric structures formed mainly by cyanophytes and green algae. Their concentric laminae originate by the adhesion of fine grains of sediment on the mucilagineous surface of the algal mats and also by the precipitation of the calcium carbonate in response to the withdrawal of the carbon dioxide by algae during photosynthesis.

Oncoids can also consist of other minerals — e.g. hematite, manganese oxides, phosphatic minerals, chlorite. Such "mineralized" oncoids are of bacterial origin (other groups than Cyanobacteria). Meanwhile calcite oncoids are restricted to the shallow euphotic zone, bacterial (non-calcite) oncoids lack such a dependence. For instance, manganese oncoids ("nodules", "concretions") are formed on the deep ocean bottom. Non-calcite oncoids usually contain a certain portion of microcrystalline calcite; the replacement of micritic laminae e.g. by hematite is frequent. "Mineralized" oncoids are typical in zones of condensed sedimentation, which are represented mostly by red nodular limestones and associated hardgrounds.

Chlorite oncoids are a very rare variety and are thus described here in detail. Our chlorite oncoids are unique because encrusting foraminifers significantly contributed to their growth. We found only two mentions about the chlorite "concretions" in the literature, both indicated as chamosite concretions: Athanasov (1961) from the Jurassic strata of Bulgaria and Birkenmajer (1977, p. 48) from the Middle Jurassic Flaki Formation in the Pieniny Klippen Belt of Poland. Through the courtesy of M. Krobicki we had the opportunity to study some samples from the last mentioned locality for comparative purposes. These oncoids are very similar to ours by the abundance of encrusting foraminifers, they are also formed by Fe-chlorite, polytype IIb.

Geological setting

Chlorite and chlorite-hematite oncoids were found at two stratigraphic levels of the red nodular limestone facies of Late Liassic (Toarcian) and Late Jurassic (Oxfordian) age.

Localities in the Toarcian limestones of the Krížna Nappe, Veľká Fatra Mts.

Information about the chlorite and hematite oncoids was first published under the term chlorite-hematite concretions (Mišík 1964, p. 71). Five localities are known in the following valleys: Bystrická, Gaderská, Suchá, Horná Turecká and Terlenská dolina (Fig. 1). The horizon with the chlorite and hematite oncoids occurs in the uppermost part of the red nodular limestones (Adneth Limestone) which overlain by grey siliceous spotty marls. The Adneth Limestone (red nodular) in this area is of Pliensbachian-Toarcian age. The age of its upper part is indicated by a Toarcian ammonite (Rakús 1964). The profile of the Liassic sequence in the Bystrická Valley (Fig. 2) may serve as a representative section. An additional profile in the Horná Turecká Valley was published in the previous paper (Mišík 1964, Annexe 4).

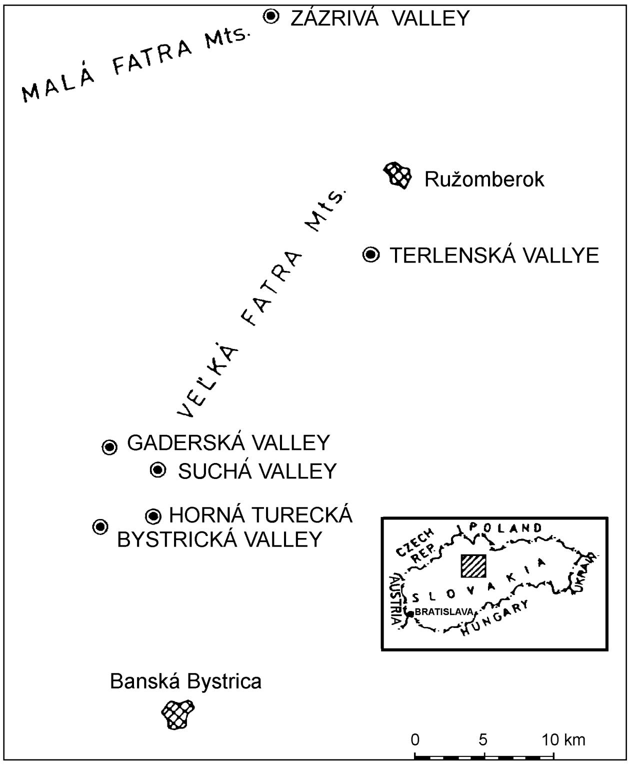


Fig. 1. Localities with the chlorite and hematite oncoids in the Jurassic red nodular limestones.

Localities in the Oxfordian limestones of the Tatric Unit, Malá Fatra Mts.

Chlorite and hematite oncoids occur in the Zázrivá Valley at three neighbouring localities (Fig. 1): 1 — The lowest part of the Bralo quarry; 2 — About 200 m to the east of it; 3 — In the core of a borehole for the planned Párnica dam.

The host rock is red indistinctly nodular limestone. In the Bralo quarry, an intraformational breccia is also present. On the basis of the occurrence of the first "*Cadosinidae*" and the absence of *Saccocoma* and *Tintinnidae* an Oxfordian age is indicated (Borza 1984). The overlying grey micritic limestones of Kimmeridgian to Barremian age were described from the same quarry under the name of Lučivná Limestone by Polák & Bujnovský (1979) and Michalík et al. (1986). Both papers fail to mention the red limestones with oncoids.

Microscopical study of Liassic oncoids from the Veľká Fatra Mts.

The Adneth Limestone from the five previously mentioned localities contains chlorite, hematite and combined chlorite-hematite oncoids with a considerable admixture of micrite (Pl. I: Fig. A). They possess ovoid shapes flattened by compaction, with diameters up to 5 cm and wrinkled concentric laminae.

The host rock is a biomicrite-wackestone. Spicules of silicisponges (monaxone and rhaxa) that have been dissolved and filled by calcite predominate among the biodetritus. Other

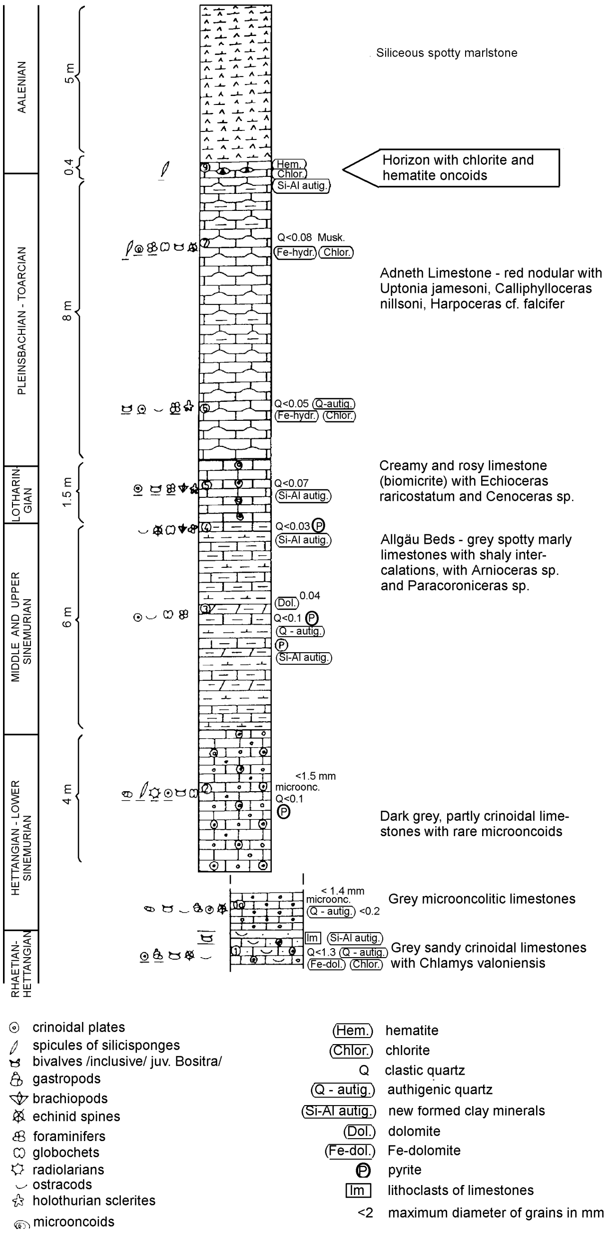
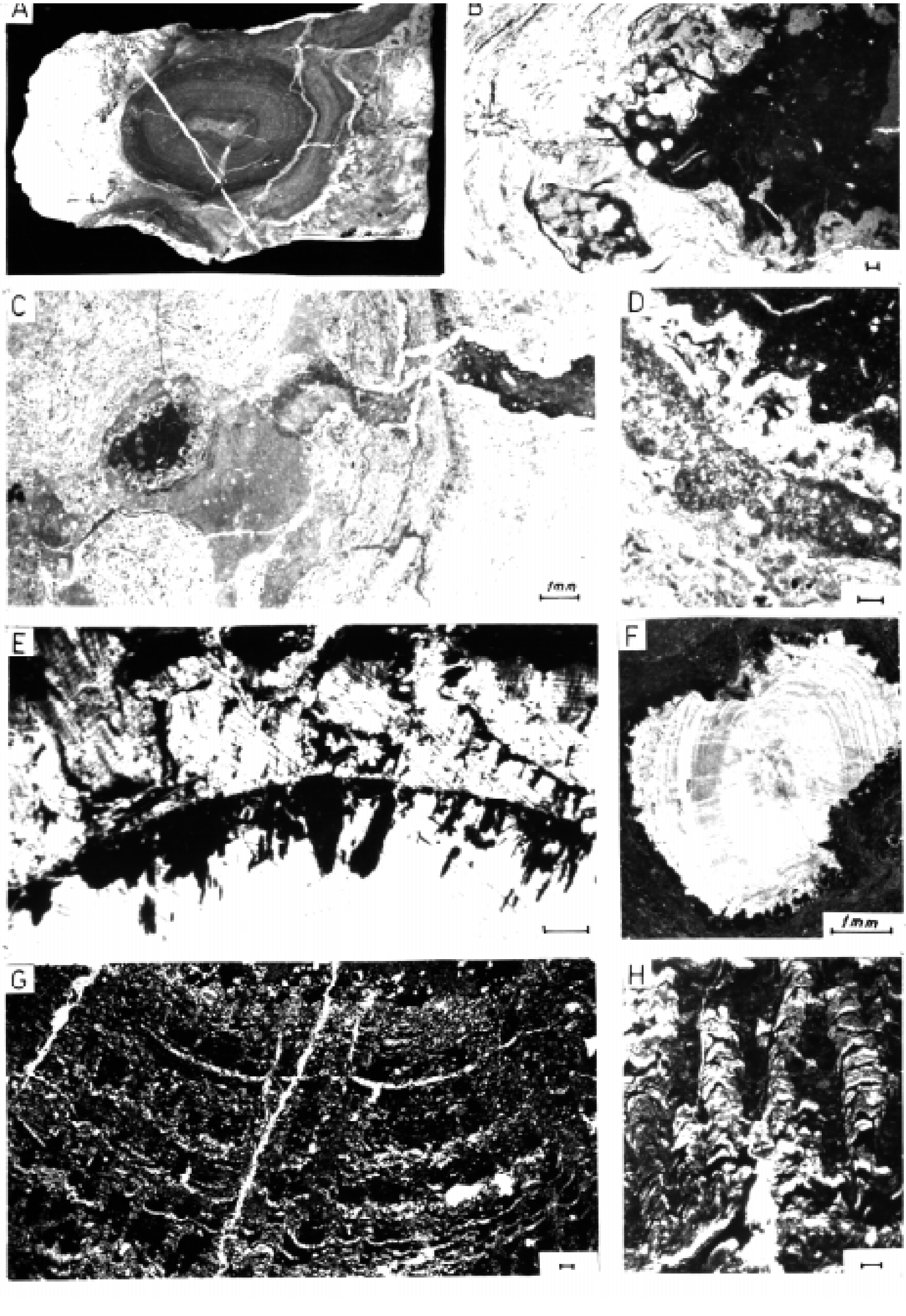


Fig. 2. Profile of the Liassic strata (Krížna Nappe) in the Bystrická Valley, Veľká Fatra Mts.

Plate I: Fig. A. Chlorite-hematite oncoid in the red nodular Adneth Limestone. Upper Liassic (Toarcian) of the Krížna Nappe, upper part of the Gaderská Valley. Polished slab, natural size. **Fig. B.** Intraclast perforated by boring organisms served as the core for the chlorite oncoid. Oxfordian, Tatric Unit, in front of the Bralo quarry, Zázrivá Valley. Thin section. **Fig. C.** Chlorite oncoid penetrated by a microdyke, with endostromatolites along the core margin. Toarcian, Horná Turecká Valley. **Fig. D.** Close-up from the previous. The voids after the boring organisms were filled by endostromatolites. **Fig. E.** Syntaxial rim overgrew the belemnite rostrum corroded by boring organisms; core of the hematite oncoid, Toarcian, Gaderská Valley. **Fig. F.** Chlorite oncoid on the corroded belemnite rostrum, Toarcian, Horná Turecká Valley. **Fig. G.** Chlorite-hematite oncoid with wrinkled laminae, Toarcian, Bystrická Valley. **Fig. H.** Pseudocolumnar structure in the oncoid; chlorite and hematite laminae partly replaced by calcite, Toarcian, Gaderská Valley. Scale bars = 0.1 mm, if no other indication.

PLATE I



constituents are short "filaments" (juvenile shells of *Bositra*), rare echinoderm plates, foraminifers (mainly *Lenticulina* sp.), juvenile ammonites and ostracods. The bioturbation is extensive. Silt size grains of clastic quartz are very rare. Authigenic idiomorphe plagioclases occur in one sample.

The nuclei of the oncoids are represented mostly by intraclasts which may contain fragments of older oncoids. The microfacies of the intraclasts are usually not identical to those of the host rock, consisting mostly of a wackestone depleted in biodetritus with a predominance of other bioclasts, e.g. echinoderm plates; spicules predominating in the host rock. The occurrence of little "hooks" sometimes with forked ends (Pl. IV: Figs. C, E) are typical for them in the thin sections. They might represent tiny juvenile chambers of encrusting foraminifers-nubecularids. Their association with dark red portions of limestone might suggest a symbiosis with ferric bacteria. The nuclei usually bear traces of boring organisms along their rims. Larger borings were used by endostromatolites for inward growth in an opposite direction to the oncoid growth (Pl. I: Figs. C, D). Occasionally bored belemnite rostra formed the oncoid cores (Pl. I: Figs. F, G). Their margins are densely bored by algae and fungi; syntaxial overgrowths on the rostra margins formed at the expense of micrite were observed (Pl. I: Fig. E).

The cortices of the oncoids consist mostly of wrinkled laminae (Pl. IV: Figs. E, F). A pseudocolumnar structure (SH-stromatolite — Pl. I: Fig. H) is sometimes present forming the second order rhythms. In some cases the pseudocolumns are deformed away from the radial direction by compaction (Pl. II: Fig. A). The pseudocolumnar structure is never observed for the early stage of growth. Encrusting foraminifers preferentially occupied saddles between the columns where they were better protected. Their presence prevented the growth on saddles and thus accentuated the pseudocolumnar fabric. The enhanced growth of encrusting foraminifers between the pseudocolumns was also observed by Martin-Algarra & Vera (1994, Fig. 9E). The "anticlinal" part is usually more strongly stained by Fe-oxides.

Growth conditions changed very often, which resulted in the alternation of hematite, chlorite and calcite laminae and variable amounts of encrusting foraminifers. Carbonate mud was trapped in the hematite cortices. Visual recognition of calcite is enhanced by the recrystallization of micrite within the oncoid. Quartz grains of silt size and rare echinoderm plates occur within the cortices.

The micrite admixture in the hematite oncoids frequently recrystallized under the influence of Fe-oxides (Mišík 1968, p. 129–130, Figs. 1–3). By the aggrading neomorphism (Folk 1965) larger limpid, rarely yellowish calcite grains up to 0.5 mm long were formed. In the thin sections, they contain sometimes rosy triangular points of crystallographically arranged hematite pigment or fan-arrays of hematite inclusions (Pl. II: Figs. C, D). The grains of pseudosparite were sometimes corroded by Fe-oxide. A single calcite crystal may contain several rosy triangular patterns. Similar recrystallization was also observed in the hematite-calcite oncoids from the Adneth Limestone of the Silica Nappe (Pl. II: Figs. B, E).

Encrusting foraminifers contributed substantially to the formation of oncoids. They are sometimes so abundant that the term "mobile microreefs" can be applied. Nubecularids with microcrystalline test possess the plane basement and chambers bulging towards the oncoid periphery (centrifugal growth — Pl. II: Figs. F, G). Occasionally larger tests are agglutinated from tiny quartz grains (*Tolypamminidae, Miniacina* sp.). Thin-walled tests are rarely replaced by chlorite, and are almost isotropic in the polarized light. The chambers are infilled either by limpid calcite or by opaque Fe-oxide and rarely by chlorite, showing that they were empty at the beginning of the diagenesis. Hayes (1970) described infilling of the encrusting foraminifers by chlorite (polytype Ib) in a Pennsylvanian limestone. Our samples contain not only infilling, but also perfect replacement of tests by chlorite IIb. The replacement of foraminifers *Involutina liassica* by chlorite was recognized long ago (Mišík 1961).

From other genera *Planiinvoluta* sp., trochospiral types with large umbillicus (Pl. III: Fig. B), a test with planispiral coiling of juvenile stage and other forms were found (Pl. III: Figs. D–F). Some tiny unilocular sections occur; they are comparable to those "hooks" (supposed juvenile non-encrusted nubecularids — Pl. IV: Figs. C–E) found mainly in the cores or in immediate vicinity of oncoids. The smallest size of the encrusted unilocular tests is only 0.038 mm, while the dimensions of the mentioned objects scarcely attain 0.022 mm. It should be stressed that encrusting foraminifers were not found in the surrounding Adneth Limestone.

Neptunic microdykes occurred several times within the oncoids. They represent 1–2 mm thick synsedimentary cracks filled by micrite, mostly sterile or with the tiny bioclasts of indeterminable detritus (Pl. I: Fig. C, Pl. IV: Figs: F, G). In only one case a microdyke filled by red micrite contained foraminifers and sponge rhaxa filled by radial-fibrous calcite (Pl. IV: Fig. G). Microdykes penetrating up to the core were rarely observed. The undulating very thin microdykes approximately vertical to the layering originated during the compaction.

Concentric veinlets parallel to the lamination and filled by fibrous to thin-prismatic calcite occur in almost all oncoids. They can be interpreted as retractional cracks; their thickness was increased by recrystallization of the neighboring oncoid matter. The calcite infilling often contains hematite pigment arranged in aggregates displaying triangular patterns in thin

Plate II: Fig. A. Chlorite-hematite oncoid with the pseudocolumnar structure, in its lower part replaced by calcite; an early diagenetic transversal veinlet contains teeth-like arranged hematite pigment within the calcite grains. Adneth Limestone, Toarcian, Gaderská Valley. **Fig. B.** Recrystallized calcite grains with zonal arrangment of the hematite pigment in an originally hematite-micrite oncoid. In the upper part of the photo the host rock-biomicrite with short "filaments" is visible. Adneth Limestone, Liassic, Silica Nappe, under the Kornalip saddle near Drnava. **Fig. C.** Recrystallized calcite grain with the arborescent arrangement of the hematite pigment in an oncoid, Toarcian, Gaderská Valley. **Fig. D.** The same, Toarcian, Veľká Turecká Valley. **Fig. E.** Hematite-micrite oncoid with the recrystallized calcite grains disturbing fine concentric laminae; locality as B. **Fig. F.** Encrusting nubecularid foraminifers in the hematite oncoids; locality as C. **Fig. G.** Encrusting foraminifers as the substancial component of the oncoid. The same locality. All scale bars = 0.1 mm.

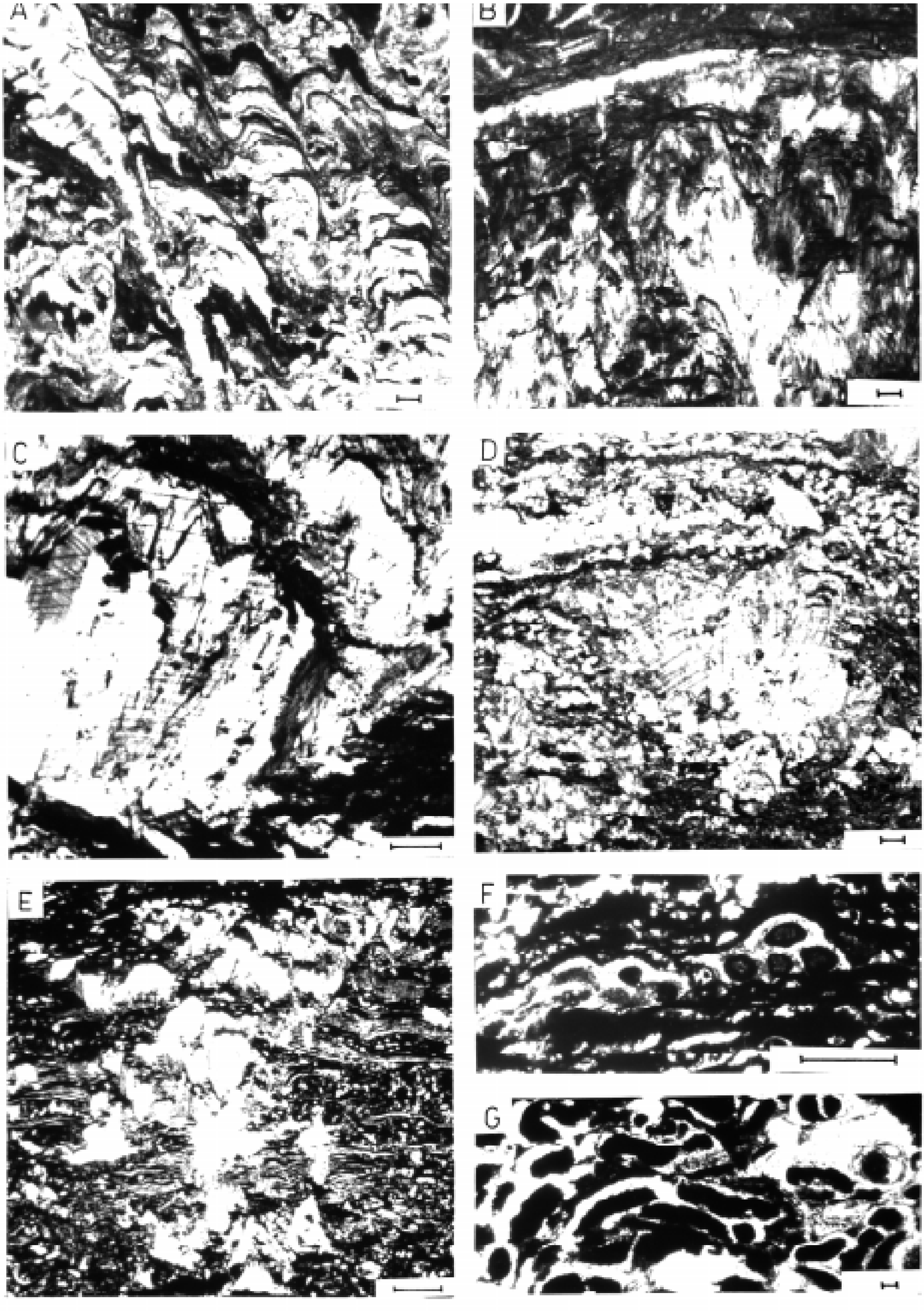

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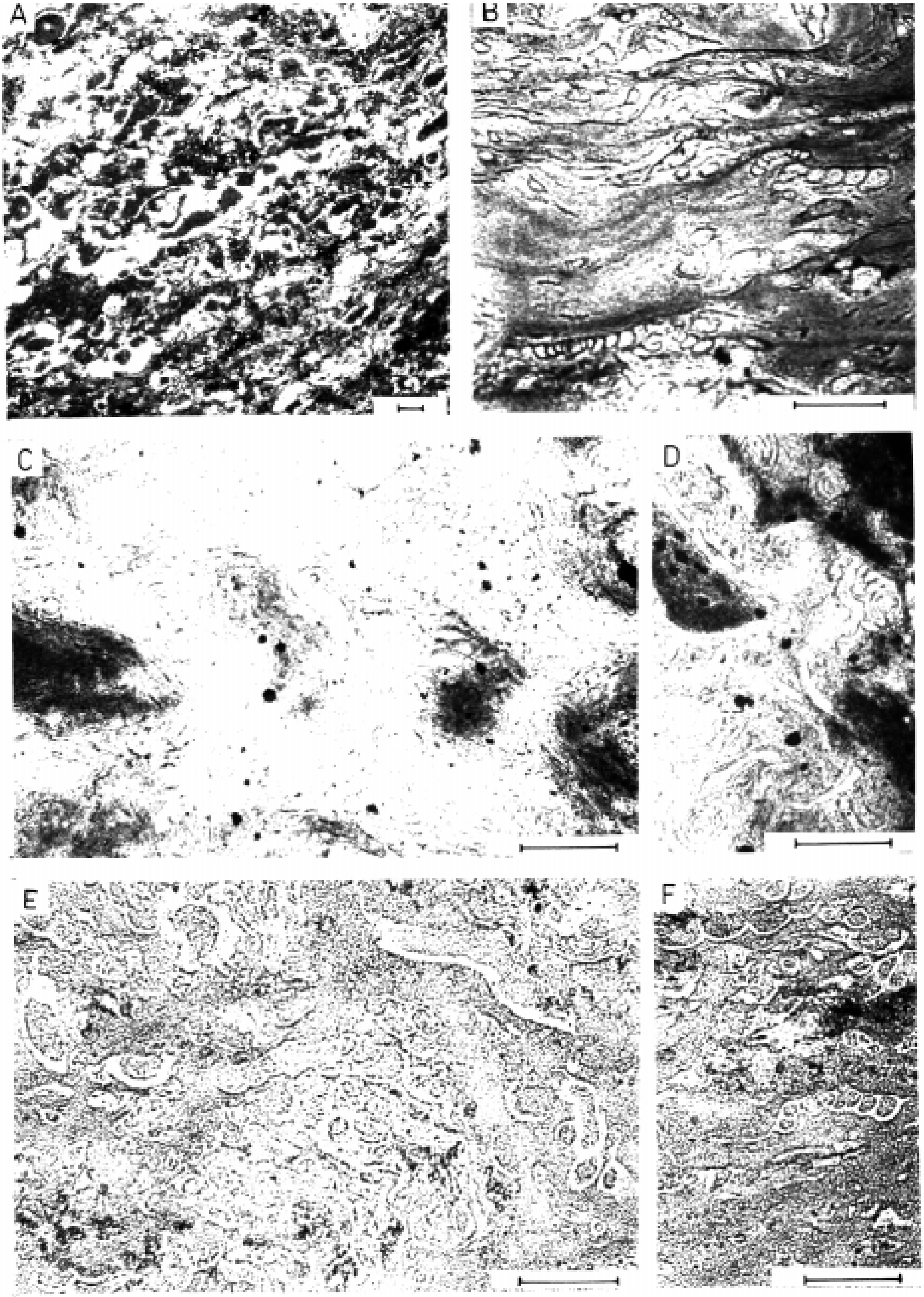
PLATE III



sections (Pl. V: Fig. C). Their terminations tend always toward the centre of the veinlet. Several oblique veinlets cutting the lamination also possess an early diagenetic infilling which grew synchronously from both sides (Pl. V: Fig. A). Mobility of the Fe-oxides was possible only in the very early phase of diagenesis, we never found them in any epigenetic (tectonic) calcite veinlet within the red nodular limestones. The younger extensional veinlets in the oncoids originated by tectonic processes due to differences in the plasticity of the host rock and the oncoid. They cut the oncoids approximately perpendicular to the bedding. Their infilling is of clear asbestos-like aggregate with S-bended calcite fibres. They wedge out after entering from the hematite set of laminae into the more plastic chlorite set and are reestablished in the next more rigid hematite set. The youngest epigenetic veinlets are filled by clear aggregate of the isometric calcite grains.

The mineral composition determined by optical microscopy (thin section — Pl. V: Figs. B, E; electron micrograph of replica - Pl. V: Fig. D) shows that the chlorite in the oncoids forms sheaf-like and fan-like aggregates (Pl. V: Fig. E). The occurrence of the anatas pigment in chlorite was observed (Pl. V: Figs. F, G). The calcite and quartz admixture are variable. The fine-clastic quartz is included in agglutinated tests of encrusting foraminifers. Tiny pyrite grains are rare. Hematite represents another variety of oncoids or occurs in combined chlorite-hematite oncoids. More detailed mineralogical characterization of the chlorite and hematite (X-ray diffraction study) is given below. As an example of the chemical composition a bulk analysis of the chlorite oncoid from the Liassic limestones, Bystrická dolina Valley, is included (data in wt. %):

SiO_2 = 43.31 %, TiO_2 = 0.42 %, Al_2O_3 = 13.20 %, Fe_2O_3 = 6.07 %, FeO = 9.79 %, MnO = 0.13 %, P_2O_5 = 0.16 %, CaO = 12.19 %, MgO = 5.05 %, K_2O = 0.28 %, Na_2O = 0.50 %, Loss of ignition = 9.44 %. The analysis indicates that the calcite admixture in the oncoids was about 20 %.

Oxfordian chlorite oncoids from the Malá Fatra Mts.

Oncoids from Zázrivá Valley display many similarities with the Liassic chlorite oncoids described above. Their diameter attains up to 7 cm (Pl. VI: Fig. A). The cores are also biomicritic intraclasts, often bored by lithophags (Pl. I: Fig. B) containing some ostracods, "filaments" (juvenile bivalvian shells), echinoderm plates, globochaets, sponge spicules and juvenile ammonites.

The host limestone is a rosy biomicrite with small nodules, and radiolarian or *Globuligerina* microfacies. The nodules containing both microfacies were observed together in the same thin section indicating the partial redeposition. Other remains are represented by globochaets, bivalvian fragments, rhaxa (voids after rhaxa and radiolarians are filled by calcite), *Cadosina parvula* Nagy, *Colomisphaera* sp., foraminifers (*Lagenidae*), rare ostracods, echinoderm plates, aptychi, fragments of ammonites, rhyncholites, belemnite rostra and phosphatized fish scales. The clastic quartz is very rare or totally absent in the sections. The occurrence of the first *"Cadosinidae"* namely *Cadosina parvula* indicates the Oxfordian age (Borza 1984). The Callovian age of some samples with *Globuligerina* ("protoglobigerina") microfacies without "*Cadosinidae"* cannot be ruled out.

The cortex is composed of finely wrinkled concentric laminae of chlorite displaying leafy aggregates under polarized light. Macroscopically, the chlorite oncoids are always green, in thin section green or light-brown, sometimes with an alternation of both colours. Some chlorite laminae contain abundant micritic inclusions, or are stained by hematite pigment. The admixture of microcrystalline calcite is well visualized in the case of the recrystallization (aggrading neomorphism). New formed roughly isometric calcite grains sometimes contain fan-like arranged hematite pigment. The oncoids rarely contain clastic quartz; exceptionally some rhaxa were attached to the growing oncoid. Tiny anatas inclusions in the chlorite are rare.

The Upper Jurassic oncoids were also substantially built by the encrusting foraminifers, such as *Miniacina* with tests agglutinated of the very fine-grained quartz (PI. III: Fig. A), nubecularids and other types. Several tests were replaced by chlorite.

Early diagenetic veinlets are filled by calcite aggregates containing hematite inclusions arranged in triangular patterns (Pl. IV: Fig. B, Pl: VI: Fig. I). Concentric retractional veinlets were broadened by recrystallization.

The locality Bralo-quarry differs from the other as only small chlorite oncoids (up to 0.7 cm) occur there, but thin chlorite and hematite crusts and planar chloritic stromatolites are frequent. The host rock — an intraformational limestone breccia with rosy, grey, white, red and green fragments is also different. Pale red and grey intraclasts contain marine biodetritus, white and red fragments originating from a disintegrated calcrete. Green clasts are hardground fragments, but the majority of the chlorite aggregates are part of the scarce matrix.

Rosy and grey intraclasts belong to the biomicrite-wackestone with radiolarian microfacies, rhaxa, globochaets, rare ostracods, echinoderm plates, foraminifers (including *Globuligerina* sp.), "filaments", *Colomisphaera* sp., belemnite rostra, rhyncholites and aptychi.

Fragments of calcrete. White and white-red clasts (up to 5 cm across) show patterns of a fine-grained breccia. Small white microsparite clasts bear traces of the synsedimentary cracking (Pl. VI: Fig. D); some cracks (microdykes) are unfossiliferous micrite with pyrite pigment. They contain pelletal grains and irregular micritic envelopes and spots within the microsparite (Pl. VI: Fig. E). Some of the small clasts were silicified, replaced by microquartz (Pl. VI: Fig. B), which initiated as usual the formation of tiny Fe-carbonate

Plate III: Fig. A. Chlorite oncoid full of encrusting foraminifers, Oxfordian, Tatric Unit, borehole S-1, 12.5 m, Párnica, Malá Fatra Mts. **Fig. B.** Encrusting foraminifers in the chlorite oncoid, Toarcian, Bystrická Valley. **Fig. C.** Encrusting foraminifers possessing juvenile stage with planispiral coiling in a chlorite oncoid, Toarcian, Horná Turecká Valley. **Fig. D.** The same. **Fig. E.** Encrusting foraminifers in the chlorite oncoid, Toarcian, Suchá Valley. **Fig. F.** The same. All scale bars = 0.1 mm.

PLATE IV

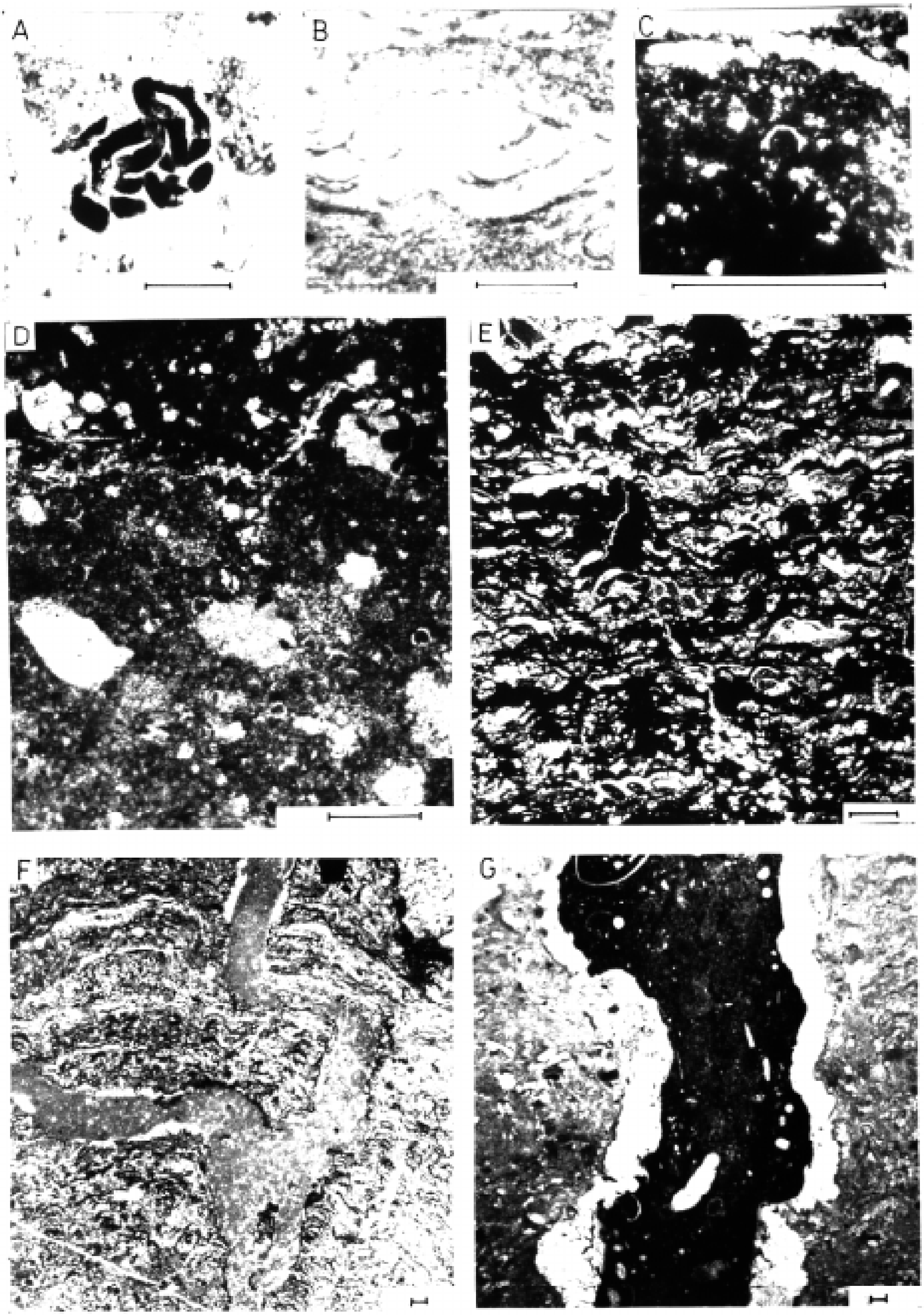
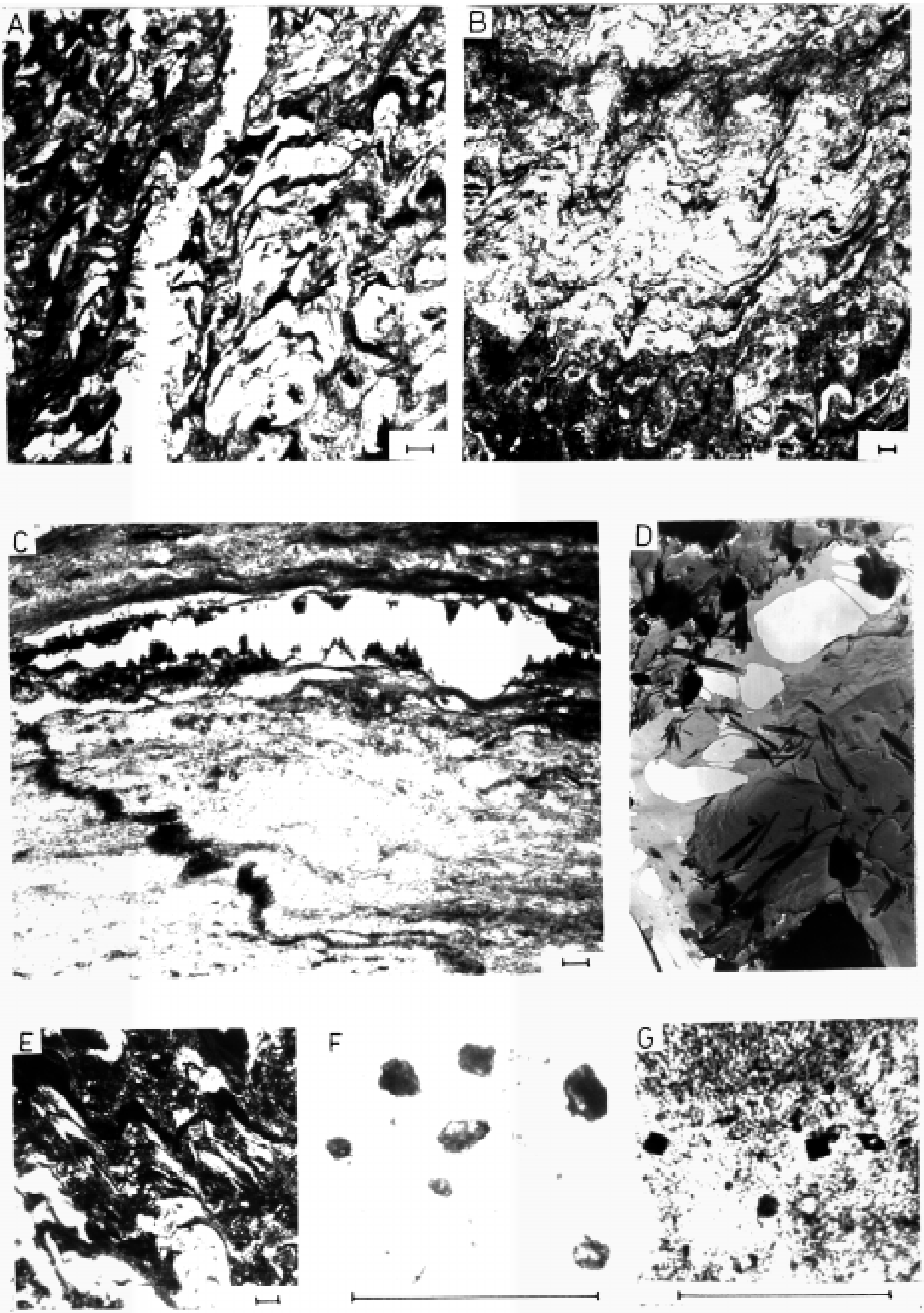
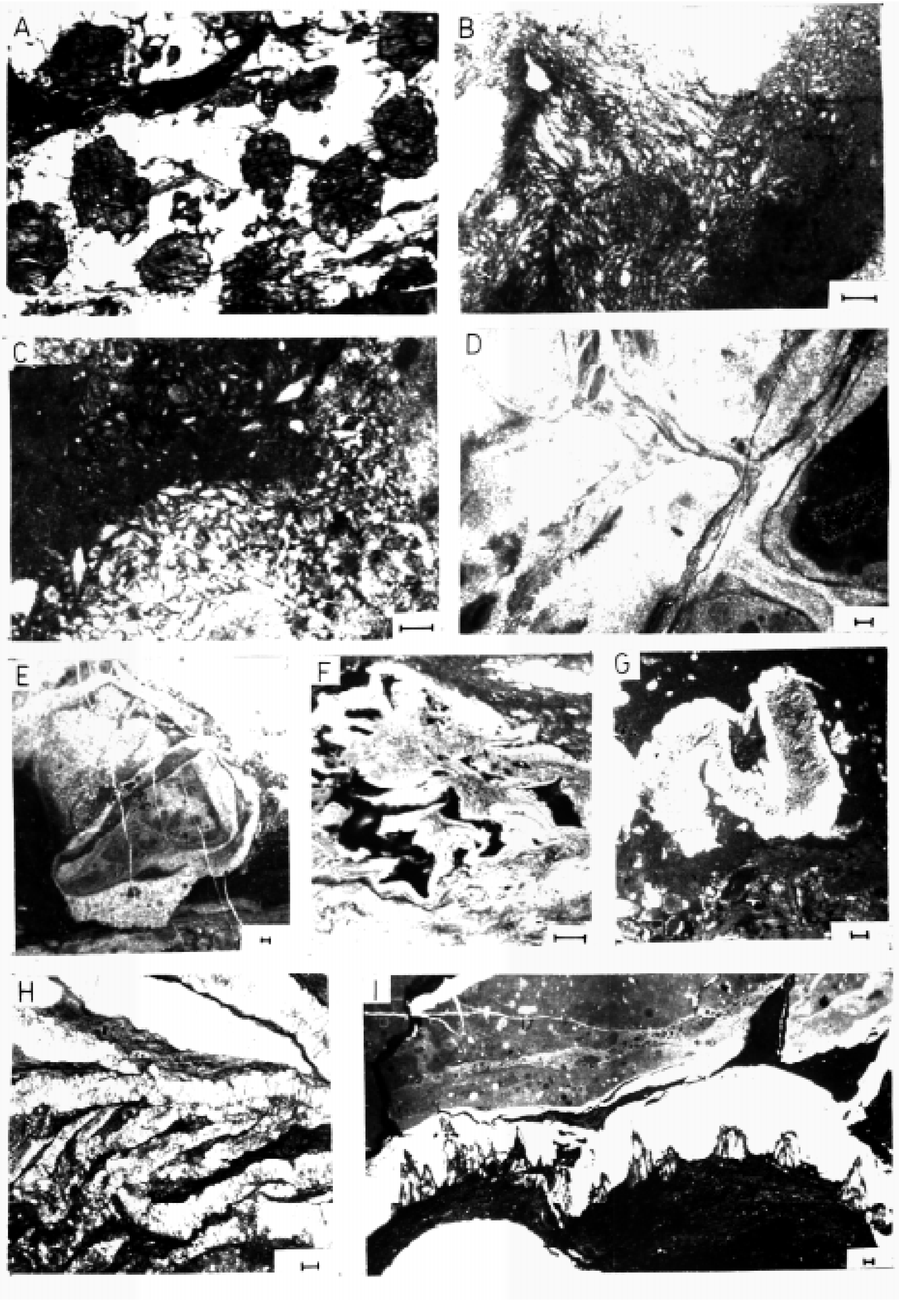


PLATE V

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rhombs (Mišík 1991). The isotopic composition of a white clast was $\delta^{13}C = +2.23$ ‰ PDB, $\delta^{18}O = -0.7$ 1‰ PDB which is characteristic for marine water. The matrix joining the white clasts of the second order is formed by an aggregate displaying fluid structure formed by tiny elongated calcite grains - imperfect miniature scalenohedra (Pl. VI: Figs. B, C); the fluidal aggregate used to be stained by limonite. Fossil remains are completely absent which contrasts strongly with their richness in the described Jurassic limestones. The parent rock did not originate in the marine environment; several of the described phenomena point to eroded calcrete. The isolated clasts of the marine Jurassic limestones in the calcrete could be considered as an ancient slope debris (Pl. VI: Fig. C). It is necessary to note that the traces of a temporary local emersion during the Jurassic were not documented in the Central Western Carpathians prior to the present study. The paucity of outcrops containing the Upper Jurassic strata of the Tatric Unit in the Malá Fatra Mts. prevented further observations.

Plate IV: Fig. A. Encrusting foraminifer in the chlorite oncoid, Toarcian, Krížna Nappe, Horná Turecká Valley. **Fig. B.** Encrusting foraminifer in the chlorite oncoid, Oxfordian, Tatric Unit in front of the Bralo quarry, Zázrivá Valley. **Fig. C.** Hook-like section (perhaps juvenile stage of an encrusting foraminifer) in the host rock close to the hematite oncoid, Toarcian, Gaderská Valley. **Fig. D.** Section in the form of tiny hooks and rings (perhaps unilocular juvenile stage of nubecularid foraminifer) in the core of a hematite oncoid; the same locality. **Fig. E.** Encrusting foraminifers and isolated "hooks" in the Fe-oncoid. Toarcian, Bystrická Valley. **Fig. F.** Synsedimentary crack in the hematite oncoid (neptunic microdyke) with micrite infilling, Toarcian, Gaderská Valley. **Fig. G.** Microdyke consisting of the biomicrite-wackestone with ostracods, lagenid foraminifers and rhaxa - evidence of the synsedimentary cracking of the chlorite oncoid. Firstly, the inicial calcite cement was precipitated on the crack walls, later the micrite penetrated into the residual space, Toarcian, Horná Turecká Valley. All scale bars = 0.1 mm.

Plate V: Fig. A. Early calcite veinlet in the Fe-oncoid containing rosy points, oriented hematite inclusions, Toarcian, Gaderská Valley. **Fig. B.** Chlorite oncoid, Toarcian, Suchá Valley. **Fig. C.** Calcite veinlet with the rosy points-oriented hematite pigment, perhaps a retractional crack concordant with the oncoid laminae; Oxfordian, in front of the Bralo quarry, Zázrivá Valley. **Fig. D.** Chlorite sheets separated from the oncoid, Toarcian, Gaderská Valley; suspension under the electrone microscope, magnification 9500×. **Fig. E.** Thin section of the same oncoid, polarized light. **Fig. F.** Anatas pigment in the chlorite oncoid, Toarcian, Horná Turecká Valley. **Fig. G.** The same. All scale bars (except of D) = 0.1 mm.

Plate VI: Fig. A. Chlorite oncoids on the weathered surface of the Oxfordian limestone (the diameter of the white circle is 24 mm); in front of the Bralo quarry, Zázrivá Valley, Malá Fatra Mts. **Fig. B.** Fragment of a calcrete with the fluidal patterns formed by tiny calcite crystals-imperfect scalenohedra and partial silicification (white parts); clast from the intraformational carbonate breccia containing chlorite oncoids. Oxfordian, Tatric Unit, Bralo quarry, Zázrivá Valley. **Fig. C.** The same. **Fig. D.** Another clast of the calcrete with desiccation cracks includes a limestone fragment with the crinoidal plate proceeding from the ancient scree. **Fig. E.** Clast of the calcrete with irregular concentric structure. **Fig. F.** Chlorite hardground with the marked compaction patterns. **Fig. G.** Crinoidal plate with recrystallized margins (white) within the chlorite hardground; the crystallization of chlorite caused the calcite recrystallization. **Fig. H.** Ptygmatic veinlets in the chlorite hardground (dehydratation accompanied by the compaction). **Fig. I.** Calcite veinlet with points pigmented by the hematite in a Fe-hardground within the intraformational breccia. Figs. B–I are from the same locality. All scale bars = 0.1 mm.

The scarce matrix of the Jurassic intraformational breccia consists of red biomicrite with echinoderm plates, foraminifers, "filaments", *Colomisphaera* etc. Rare angular clastic quartz attains up to 0.3 mm across. Several thin milimeter thick chlorite and hematite hardgrounds are part of the matrix.

Chlorite crusts mostly with stromatolite lamination occur sometimes immediatly between the fragments of the breccia; they were compacted to seams with a zigzag structure (Pl. VI: Fig. F). Ptygmatic calcite veinlets are also of compactional origin (Pl. VI: Fig. H). A part of the stromatolites contain encrusting foraminifers and quartz silt. Some chlorite crusts are homogeneous, without any internal structure and with pyrite grains. The chlorite aggregates sometimes possess calcite rims formed by the calcite cement growing into the retractional interspaces during the dehydratation of the aggregates (Mišík & Šucha 1994). The chlorite oncoids at this locality are small and rare. Their cores stained by limonite might represent fragments of hardground.

Besides chlorite, hematite hardgrounds also occur there. These hematite crusts without lamination originated by the staining and replacement of the underlying limestone. Their mechanical properties so differing from the host limestone caused an intensive cracking of the hematite crusts during the tectonic pressure; they are penetrated by a dense set of the thin vertical calcite veinlets.

Mineralogical characteristic of chlorite and hematite oncoids

Chlorite, calcite, hematite, quartz, pyrite and anatas were identified by their optical microscopy. Further mineralogical analyses were carried out by the following methods.

The material of the oncoids was ground to pass a 0.16 mm sieve and subsequently disintegrated by ultrasonic probe and treated by sodium acetate buffer at 80 °C to remove as much of the carbonate matter as possible. Then the clay fraction < 2 μm was separated by sedimentation. X-ray diffraction analysis (XRD) was conducted using a Philips diffractometer PW-1710 and a Siemens D-500, both equipped with Cu radiation. Oriented specimens prepared by sedimentation onto glass slides were analyzed in air dried state and after saturation with ethylene glycol (8 hours at 70 °C). Infrared spectra were obtained on a FTIR spectrometer Nicolet Magna 750 equipped with a DTGS detector. Each sample was recorded in the 4000–400 cm^{-1} spectral range in the transmission mode with a resolution of 4 cm^{-1}. The KBr pressed-disk technique (0.4 mg sample and 200 mg KBr) was used.

Four samples of chlorite oncoids from the following localities were analysed: N1, N3 (both Suchá Valley), N4 (Bystrická Valley) of Toarcian age; N2 (Zázrivá Valley) of Oxfordian age. The chlorite composition of both stratigraphical horizons is almost identical.

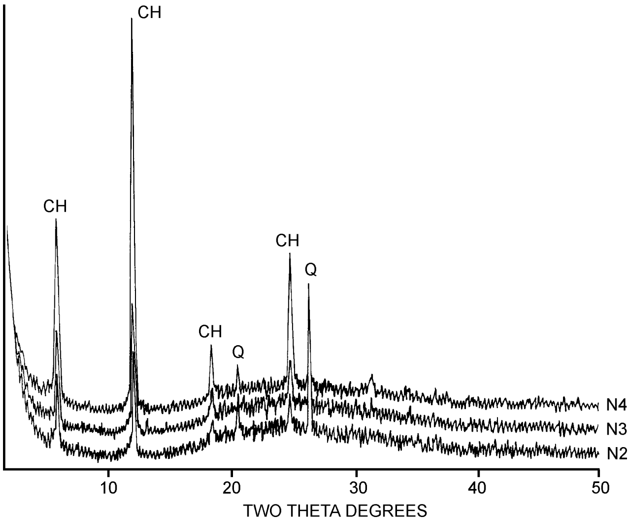

Fig. 3. X-ray diffraction patterns of air dried oriented specimens of the < 2 mm fraction. CH = chlorite, Q = quartz (samples N2, N3, N4; their localization is in the text).

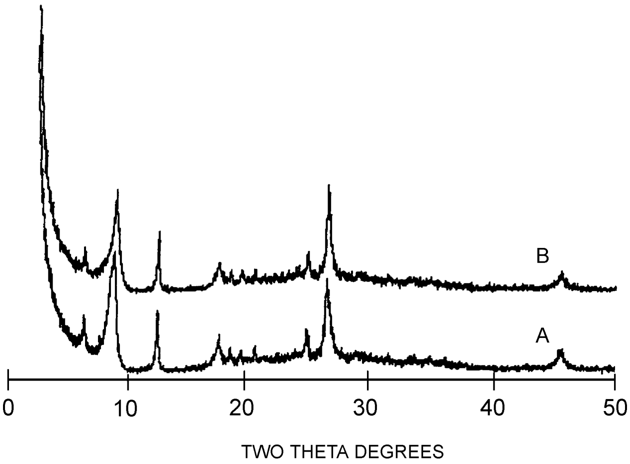

Fig. 4. X-ray diffraction patterns of air dried (A) and ethylene glycolated (B) specimens of the < 2 μm fraction of sample N1.

The presence of the main mineralogical components (chlorite and/or hematite) was also confirmed by XRD of randomly oriented bulk samples. For a more detailed analysis of the layer silicates a clay fraction < 2 μm of four samples was separated. In the clay fraction chlorite and quartz are the major phases (Fig. 3). In sample N1 a significant amount of illite was also present. Illite XRD reflections do not change their positions after ethylene glycol saturation (Fig. 4). Only some intensity changes of the 001 and 003 peaks were noticed. An intensity ratio I(001)/I(003) air dried vs. I(001)/I(003) glycolated representing the amount of expandable layers in the illite structure (Srodon 1984) shows a value higher than 1 (Ir = 1.30). This means that some expandable layers are still present in the illite. The illite crystallinity index (0.80° 2 theta) shows that illite crystals are either very thin or contain many stacking defects.

Chlorite mineralogy

Several aspects of the chlorite chemistry and structure were determined by XRD and IR spectroscopy on the < 2 mm fraction. The XRD patterns give sharp and symmetrical basal chlorite reflections with no changes after saturation by ethylene glycol for all samples. The intensity distribution is roughly the same for all the studied samples (Table 1). Higher intensities of 002 and 004 than 001 and 003 reflections indicate a high Fe content in octahedral sites of the chlorite structure. Two plots based on the basal peaks intensity were used for estimation of the iron content in the chlorite structure (Oinuma 1973; Weiss 1992). Both indicate a chemistry close to Fe-chlorite. This is also supported by IR spectroscopy (Fig. 5). Stretching bands at 3542 cm^{-1} (Si-O) together with the band at 652 cm^{-1} indicate high Fe content in the chlorite structure (Farmer 1984; Shirozu 1985). IR spectra also show a relatively high content of quartz in the clay fraction (bands at 1165, 1089, 799 and 780 cm^{-1}). The IR spectra of three chlorites from different localities show almost no differences.

XRD analyses of randomly oriented clay powder of 4 samples give a sharp 201 reflections characteristic for IIb polytype. The most intensive was a doublet of 202 at 0.259 nm and 201 at 0.255 nm.

The XRD analyses of the red oncoids gave results typical for hematite.

Table 1: Intensities of chlorite basal reflections recalculated to 100 % (data are in %).

Sample	I(001)	I(002)	I(003)	I(004)
N1	24	43	11	22
N2	26	46	10	18
N3	32	45	9	15
N4	24	53	7	16

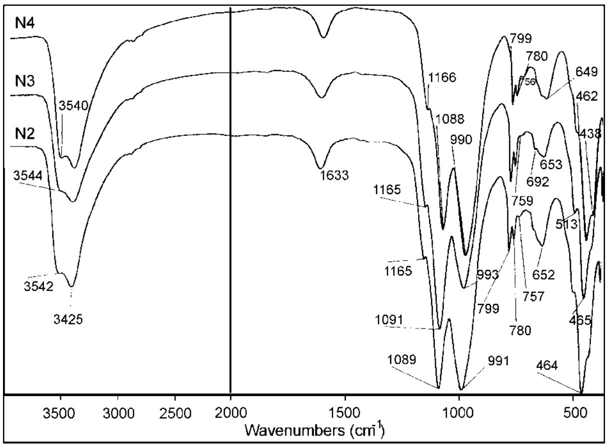

Fig. 5. Infrared spectra of samples N2, N3, N4.

Environmental interpretation and conclusions

The chlorite and hematite oncoids were associated with the condensed sedimentation of the red nodular limestones facies during the Toarcian and Oxfordian. According to the associated organic remains, they are pelagic oncoids formed below the wave erosional base, most probably at depths of 100-200 m. At a single locality Bralo chlorite oncoids occur in the intraformational limestone scarp breccia with fragments of a supposed calcrete what could demonstrate a nearby local emersion. Bored intraclasts from the disintegrated hardgrounds and belemnite rostra served as the cores for the oncoid growth. Long-distance transport of the oncoids by currents can be ruled out since the tests of encrusting foraminifers cut by erosion were never observed.

The hematite oncoids lithified rapidly as can be occasionally evidenced by their cracking and the micritic sediment infilling of these synsedimentary veinlets (neptunic microdykes). The lithification of the chlorite oncoids was much slower; its consequence was a considerable compactional deformation and flattening.

The aggradational recrystallization of the microcrystalline calcite included in oncoids under the influence of Fe-oxides is a frequent phenomenon. The recrystallized aggregates frequently display a fan-like arrangement of hematite pigment. The first generation of the early diagenetic calcite veinlets is also remarkable for the hematite pigment arranged in triangular patterns visible in thin sections.

The described chlorite oncoids are an unusual phenomenon. They belong to the authigenic iron-rich chlorite of polytype IIb, a product of the diagenesis. The chlorite composition is in accordance with the analysed rocks bearing not even the slighest traces of metamorphism, which in turn was also shown by the analysis of the illite in sample N1. They cannot be connected with any volcanism; no volcanic activity is known from the Toarcian or Oxfordian from the Western Carpathians (Mišík 1992). The nearest traces of the volcanic activity (mostly trachytic) occur in the Adneth Limestone of the Rumanian Eastern Carpathians (Patrulius 1960), in the Getic Nappe of the Southern Carpathians (Sandulescu et al. 1974), and in the Lessini Mts. of the Southern Alps and Western Sicily (Bernouilli & Peters 1970), then in the very remote areas.

The oncoids described prior to the present study from the Jurassic red nodular limestones (Ammonitico Rosso) always belonged to calcite, hematite or goethite oncoids (Massari 1983; Szulczewski 1963; Farinacci 1967, p. 441). Vera & Martin-Algarra (1994, p. 34) and Ballarini et al. (1994) observed Fe-Mn oncoids in the Middle and Upper Jurassic (Ammonitico Rosso facies). They were described by Zydorowicz & Wierzbowski (1986) from the same facies of the Oxfordian age (Czorsztyn Limestone). Hematite oncoids also occur at many other localities in Slovakia (e.g. Liassic of the Silica Unit).

Encrusting foraminifers substantially contributed to the growth of the described oncoids. They were mentioned firstly from the Mn-oncoids or nodules (Greenslate 1974; Wendt 1974). It is noteworthy that the higher concentration of the metallic compounds did nor prevent foraminiferal growth. On the contrary, one species of the nubecularids seems to prefer those parts of oncoids formed by the set of hematite laminae; a symbiotic relation to the ferric bacteria is possible. The abundance of encrusted foraminifers in chlorite, hematite and Mn-oncoids contrasts with their paucity in calcite oncoids. Perhaps it might be caused by some protective chemical compounds secreted by *Cyanophyceae*. Perfect replacement of the vitrocalcareous tests by chlorite was observed, but their replacement by hematite was not found. Neither fixed encrusting foraminifers nor redeposited ones occur in the host limestones. Similar associations of encrusting foraminifers grown on oncoids in rather deep water at remote localities ("oases") could lead to the opinion that these encrusting foraminifers produced a huge amount of juvenile planktonic individuals.

The episodes characterized by mineralized oncoids and hardgrounds could be connected either with the local conditions or with the eustatic movements. The formation of turbidites, the redeposition phenomena occur mainly during the periods of the lowest sea-level (minima on the eustatic curve); the condensed sedimentation with hardgrounds and mineralised oncoids should be typical for the eustatic high stands. It is in accordance with the fact that the horizon containing Toarcian chlorite oncoids in red nodular Adneth Limestone lies immediately under the grey spotty marls, generally considered as hemipelagic sediments.

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