

## **Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of the Barrandian (Kosov quarry)**

**Hydrodynamické poměry a bentózní společenstvo vápňitých břidlic svrchního wenlocku v z. části Barrandienu (lom Kosov) (Czech summary)**

*(4 text-figures, 10 plates)*

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The upper Wenlockian shales (Testograptus testis Zone) from the quarry on the western slope of Kosov Hill near Králův Dvůr (western part of the central Barrandian basin, south of the main volcanic centre) are rich in fossils. Besides the characteristic graptolite association and other planktonic and epiplanktonic organisms, they contain a remarkable benthic community and a large amount of current-oriented cephalopod shells. Whereas the environment within shales was lethal for all infaunas, a weak but rather persistent current trending WSW–ENE made possible the inhabitation of the basin bottom by sessile benthic community, little diversified in species but relatively rich in individuals. The community mainly involved brachiopods, crinoids and bivalves, which used empty nautiloid shells as substratum.

Whilst the fauna of the upper Wenlockian volcano-carbonate facies in the northern limb of the Barrandian, comprising rich associations of trilobites, brachiopods, etc. (comp. Bouček 1941, Horný - Prantl - Vaněk 1958, Havlíček et al. 1958, Horný 1960, 1962 et seq.) has been for a great part systematically elaborated, the upper Wenlockian shaly facies attracted little attention. According to deep-rooted ideas, the greyish-black calcareous shales of the Testograptus testis Zone, which occur mainly in the southern limb of the Barrandian synclinorium, do not differ essentially from the underlying graptolite shales and represent an originally strongly reducing environment, absolutely unsuitable for benthic organisms on account of the presence of hydrogen sulphide. However, the rather rich assemblages recently found S of the main volcanic centre in the western part of the central Barrandian basin, on Kosov hill near Králův Dvůr, and other unsystematic data from other parts of the Barrandian have shown that these concepts should be re-appraised.

One of the most instructive profiles of the upper Wenlockian and the Ludlovian

is provided by the active quarry on cement raw material on the western slope of the hill Kosov. When the area was mapped by Horný (1953–1958) (Horný 1954, 1955a, b, 1960) the quarry was not yet opened in this part the hill. The present quarry face with five levels (the space flooded with a lake not included) is 60–70 m high. Although in the middle levels and in the southern part of the quarry the tectonic situation is complicated, some selected sectors permit to follow the facies development from the upper Wenlockian and lower Ludlovian up to the Přidolian in the old quarry.

The recent investigation was directed at the low parts of the quarry face (the lowermost and the following levels), which are relatively little tectonically disturbed and dip only moderately towards the centre of the basin. In addition to sample collecting, the study was aimed at hydrodynamic conditions and the mode of orientation of empty cephalopod shells on the basis of other faunas, especially graptolites.

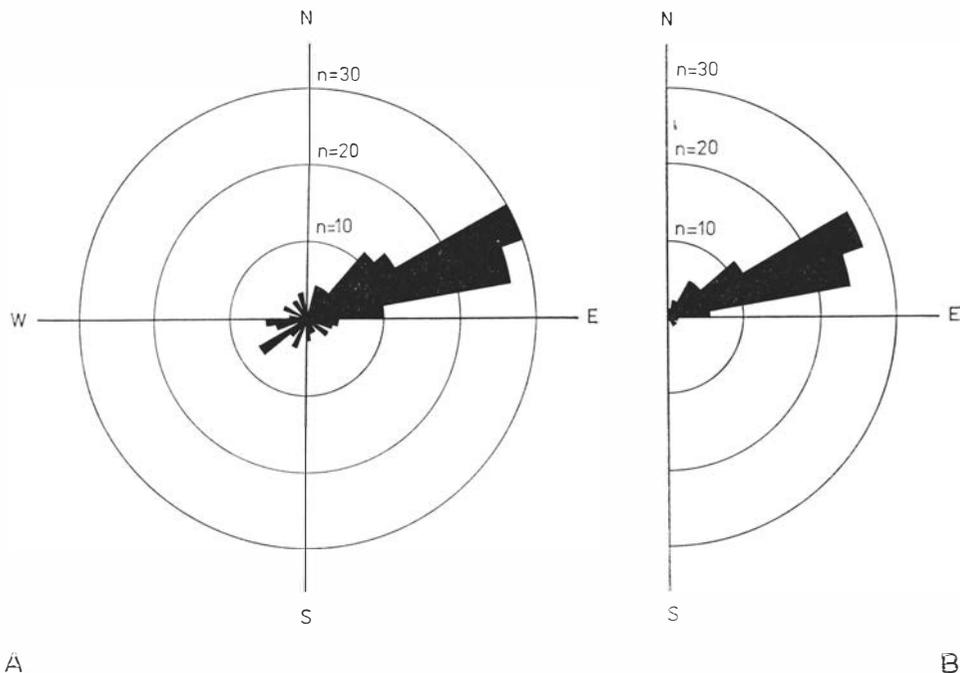
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#### **Current orientation of cephalopod shells and graptolite rhabdosomes**

The common occurrences of current-oriented graptolites and cephalopods make it possible to establish convincing proof of the mode of deposition of cephalopod orthoceracone shells in flowing water. The orientation of graptolite rhabdosomes in the Silurian shales of the Barrandian was already observed by Bouček (1932). The measurement of the orientation of cephalopod shells (Petránek - Komárková 1953) made at different stratigraphic levels of the Silurian to Lower Devonian revealed a more or less stable hydrodynamic regime. No concrete data, however, have so far been published on the Wenlockian and/or Llandoveryan of the Barrandian. The exposure studied permitted to complement the existing data, although the diversified sea floor (in result of intensive volcanic activity) and a lack of data from other parts of the Barrandian do not admit to generalize the new information for this time interval.

The measurement results obtained at four places on the lowermost and the following levels of the Kosov quarry (stratigraphically spaced max. 3–4 m) come from a surface of about 5 m<sup>2</sup>. On the whole 165 cephalopod shells longer than 2 cm were examined. In addition to cephalopods, the direction of straight graptolite rhabdosomes was determined without assessing the orientation of the proximal or distal part (88 rhabdosomes were measured). As the measurement results in different parts of the profile did not differ appreciably and the measurement points could not be strictly stratigraphically correlated, the measurements were summarized into two separate diagrams (fig. 1).

The following facts can be deduced from field observations and the measured values: a) During sedimentation the current regime was of constant direction but of varying intensity, which is reflected in the degree of orientation of cephalopod shells and graptolite rhabdosomes; b) weak currents along the floor made possible



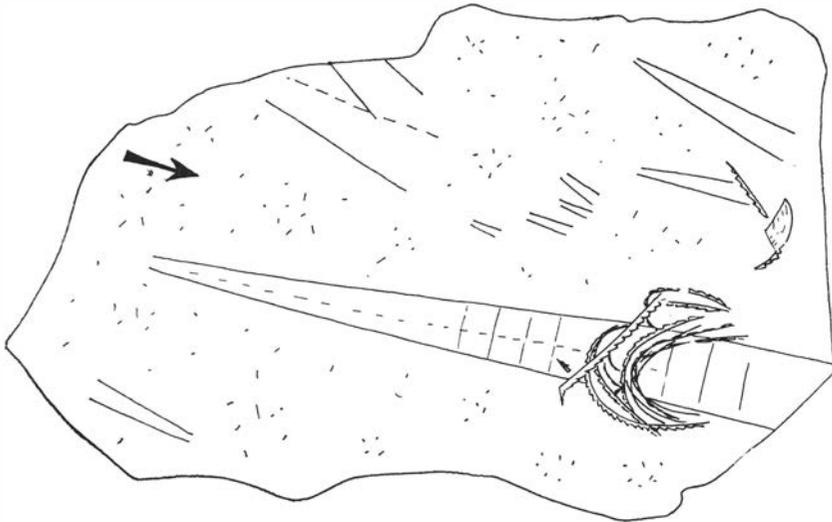
1. A — Circular histogram showing azimuthal orientation of 165 orthoceracone nautiloid shells. Apices of shells in the centre of the diagram. B — semicircular histogram showing orientation of 83 straight graptolite rhabdosomes. Measured as lineation, regardless of orientation of the proximal or distal part. Upper Wenlockian (T. testis Zone), Kosov quarry

the living of selected groups of benthic organisms; c) the apices of most orthoceracone shells point to WSW. The WSW—ENE trend is dominant in the deposition of straight graptolite rhabdosomes; d) the graptolite clusters caught and bent on orthoceracone shells of comet-like form are almost invariably oriented apically with their apices; e) the frequent asymmetry of crinoid holdfasts is probably also controlled by hydrodynamic conditions along the floor; f) the relatively rigid stems of crinoids on bedding surfaces are oriented aperturally but often also apically in relation to cephalopod shells to which these crinoids were attached.

The orientation of various invertebrate groups as controlled by current and wave action has attracted attention of a number of authors (see in Müller 1979, Boucot 1981). The external cephalopod shells provide to a certain degree a special problem. Reymont (1958) made a detailed analysis of buoyancy with respect to orthoceracone shells, which is the decisive factor controlling their deposition on the sea floor,

but the experiments do not permit to model satisfactorily all factors that may have influenced it. As little convincing evidence has so far been submitted for the mode of orientation of orthoceracone shells, which may also be influenced by the taxonomic composition of the cephalopod association, the present author has endeavoured to assemble unambiguous proofs by field investigations.

It is generally accepted that the shells are oriented at right angles to the current with their minimum cross-section (cf. Müller 1979). Nagle (1967) deduced from a number of experiments that the elongately conical shells are essentially oriented up or downstream with their apices, depending on the geometry and distribution of the shell mass. With this orientation of cephalopods with external shell, the size and shape of the area facing the current are not decisive (unless their orientation was reverted additionally in a very strong current), but the position of a shell dropping to the sea floor (Turek 1974) is the main factor. Cameral deposits secreted by most orthocerids, their development stronger in apical direction than in the last camerae (cf. e.g. Teichert *in* Moore 1964, Crick 1982, et.) caused the shell of a living individual to keep a subhorizontal position. The higher density of the body and mainly of the shell in the proximity of the aperture was balanced by the largest volume of last camerae. The centre of buoyancy of an empty shell but with phragmocone still filled with gas was not near the apex but in the adapertural part of phragmocone. This opinion is evidenced by the deposition of shells pointing downwards with their apices, as observed by Schmidt (1930). Šrámek provided another evidence based on his study of the position of nautiloid shells in concretions from the upper layers of the Liteň Formation at the Kosov locality. The shells not only lie horizontally but also occur stuck at different angles or even



2. Obliquely deposited nautiloid shell with attached graptolites, demonstrating the mode of orientation of cephalopod shells due to the action of a current. Full arrow indicates the direction of current. According to L 20566,  $\times 0,7$

in vertical position. The obliquely or vertically disposed shells are always oriented downwards with their apices. On the basis of these theoretical aspects and field observations the opinion on the deposition of orthocone cephalopod shells generally with their apices facing the current can be fully accepted.

Unambiguous evidence for this interpretation is provided by the confrontation with „bundles” of graptolite rhabdosomes intercepted by cephalopod shells. On 15 shale fragments bearing both graptolites and cephalopods, apices of 41 shells were directed against the current and seven reversely. A direct proof of the current direction has been obtained by measurements of two graptolite “comets” found in situ, oriented towards WSW and their correlation with the measurement results on cephalopod shells in the profile studied.

The measured values show that in the late Wenlockian the currents were flowing from WSW to ENE in this part of the Barrandian. Although Petránek and Komárková (1953) derived their conclusions on the general current direction in the Barrandian from other theoretical premises, they came to the same view as concerns the later Silurian.

### Ecological and taxonomic composition of the association

The association recovered comprises benthic (also symbiotic), planktonic, epiplanktonic, nektonic and necroplanktonic forms. With respect to the mode of preservation (compression in shales, partial or complete leaching of shell material) a precise taxonomic determination is in many cases impossible.

### Benthos

No infauna nor traces of boring and burrowing activity of organisms have been found, but epifauna is relatively rich. It seems to be represented exclusively by sessile forms and forms united otherwise with a solid substrate, such as empty shells of cephalopods and major bivalves, algae of the *Sargassum* type dropped to the sea floor (cf. Sheehan 1977), or living benthic organisms with which they may live even in closer relationship. Brachiopods and crinoids are the main members of these communities.

Brachiopods. It is a more or less monospecific community represented by the genus *Lissatrypa*. These brachiopods fixed by means of pedicle are currently found on shells of cephalopods and occasionally of bivalves, or in their vicinity. Individuals of the same growth stages usually occur on one and the same shell; they are predominantly adult brachiopods 7–9 mm in size. Juvenile stages of about 1.5 mm size, however, have also been found. Their position on shells does not show any marked preferred orientation. Brachiopods occur isolately, in small groups or large clusters, but never more than one generation appears on one shell. The find of minute, smooth atrypid brachiopods inside the body chamber of an orthocone nautiloid was exceptional; their apices were there oriented towards the shell wall.

**Crinoids.** The external surface of cephalopod shells often bear separate or groups of crinoid holdfasts, frequently jointly with brachiopods. They were sporadically found even on the internal surface (pls. V-5, VI-1). Columnals or larger parts of stems are also common. The absolutely exceptional find of a sole poorly preserved calyx (pl. IV-2) and its comparison with a similar find from the locality Praha-Dvorce (Prokop - Turek 1983) permit to assume the crinoid to belong to the group *Flexibilia* with free calyx plates. The discoidal type of holdfasts lends support to this opinion (cf. Brett 1981). The holdfasts are in general of two types. Besides star-like holdfasts with long points, usually with unbranched basal processes of axial channel (e.g. pl. V-1,3; pl. VI-2), there are also more massive holdfasts with rather richly branched axial channels (pl. V-2, 4). Although the holdfasts cannot fully express the diversity of species (cf. Brett 1981), the character of specimens suggests that only a small number of taxa is involved. The forms are generally minute, subtle, with stem diameter of 3 mm at most and the maximum length of 15 cm. The find of a part of stem 4 mm across was quite exceptional.

**Bivalvia.** Relatively frequent are the finds of *Cardiola agna* Kříž, (pl. VII-6), representative of the family *Cardiolidae*, for which epibenthic mode of life and association with cephalopod shells are presumed (cf. Kříž 1979). A close relationship to cephalopod shells can also be presupposed for the species *Slava* cf. *fibrosa* (Sowerby in Murchison) (pl. VII-1) representing the family *Slavidae*; a reclining mode of life combined with attachment by byssus seems to be most adequate for this species (cf. Kříž 1982). The recovered "Dualina" sp. characterized by valves inserted in one another had brachiopods attached to the inner surface (pl. VII-2). *Cardiolidae* occur in different growth stages, their shells attain a length of ca. 25 mm. One juvenile specimen with opened valves and several pairs of later growth stages have also been found. *Slava* cf. *fibrosa* attains a deformation length of up to 50 mm. The material also yielded one specimen with both, partly overlapping valves and two specimens with brachiopods set on the outer shell surface. In these cases it is not impossible that the brachiopod larvae attached themselves to living bivalves. The bivalved specimens provide evidence that also this community is more or less "in situ".

**Gastropods.** Minute, precisely undetermined representatives of the genus *Platyceras* (pl. VII-3) occur sporadically; they are supposed to lead a coprophagous mode of life in crowns of crinoids.

**Annelids.** The only representative is the euryhaline *Spirorbis*, of a wide stratigraphic and geographic distribution. Sporadic tubes of this worm were found on shells of cephalopods (pl. VII-4) and an indeterminable brachiopod.

**Bryozoans.** An only small encrusting zoarium was found on a coil of barrandocerid (of the genus *Peismoceras*) (pl. VIII-1, 2), characterized by dense ribbing and fine "longitudinal" sculpture. It is most likely indicative of the substrate selection by settling larvae (cf. Boucot 1981), although no further generalization can be drawn from an exceptional find. Small dimensions of the zoarium indicate

that the environment was inappropriate for this faunal group. The direction of zoarium growth shows that the shell became overgrown only after the death of the cephalopod.

### Plankton and epiplankton

This group of organisms is represented mainly by graptolites and algal remains; the finds of bivalves are sporadic.

**Graptolites.** The graptolite association is of a small specific variety, which corresponds to the overall character of the upper Wenlockian graptolite fauna (cf. Berry 1973). The index graptolite species *Testograptus testis* (Barrande) occurs abundantly on both the floor of the quarry and the first level on the southern side of the exposure. Rhabdosomes are exceptionally up to 28 cm long. In places *Cyrtograptus lundgreni* Tullberg is very frequent. With one exception, this significant species constitutes all graptolite clusters discovered on orthocone nautiloid shells and is the only very frequently found cyrtograptid. Besides *Monograptus flemingi* (Salter), which also occurs abundantly (rhabdosomes up to 35 cm long), *Pristograptus dubius* (Suess), *P. pseudodubius* (Bouček), *P. vulgaris* Wood, *P. aff. lodenicensis* Bouček, *Monoclimacis flumendosae* (Gortani) are also present. Of interest is the find of *Cyrtograptus trilleri* Eisel so far known from Praha-Malá Chuchle it occurs there in association with *C. lundgreni* but not with *T. testis* (see Bouček - Přibyl 1952), which indicates the lower layers of this zone. All new material comes from isolated blocks out of the profile.

In addition to rhabdosomes of the graptolites mentioned above, two rhabdosomes of a precisely unidentifiable pristiograptid have been recovered; they have a so-called "float" of elliptic outline, which is situated near the proximal part of rhabdosome, whose proximal end, however, remains free (pl. III-4, 5). The mode of preservation, i.e. dorsoventral compression of both rhabdosomes, and the comparison in *Monograptus pala* (cf. Bulman 1970) suggest that this structure was somewhat compressed in the cross section.

A striking feature of the faunal composition is the complete absence of retiolitids.

**Bivalves.** Epiplanktonic mode of life is attributed to the family *Butovicellidae*, represented by the species *Butovicella migrans* (Barrande) (pl. VII-5). They could use as a substrate stalks of algae (cf. Kříž 1969) or more rigid rhabdosomes of some graptolites, such as *Monograptus flemingi*, as demonstrated by one of the finds.

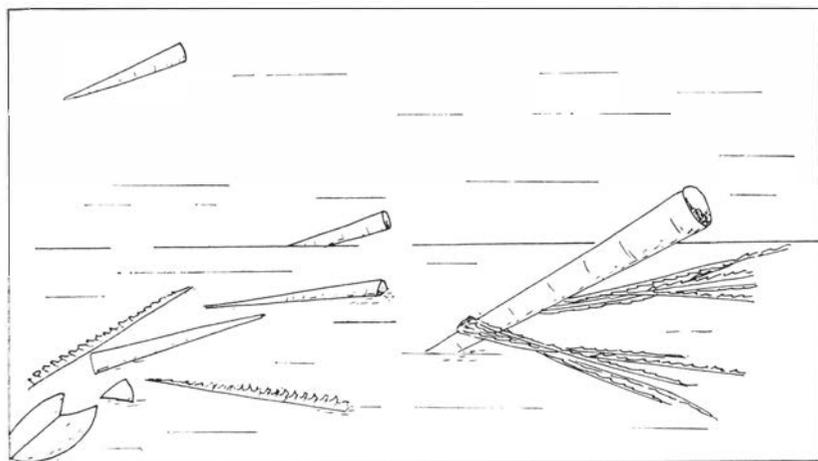
**Algae.** The finds of carbonized fragments of algal thalli, generally called *Prototaxites*, are rather scarce. Rare pachythecae occur either separately or together with the thalli. Three basic types are distinguishable according to the size, surface sculpture and mode of occurrence (pl. VIII-3—5): a) isolated pachythecae 1.5—2 mm in size, with finely reticulate surface, b) pairs of pachythecae about 0.8 mm large, whose surface consists of major irregular facets, c) pachythecae 0.8—1 mm in size, with reticulate surface, forming an aggregate (one find only).

## Nekton

*Ceratiocaris* sp. established sporadically.

## Necroplankton

In places there are very abundant longicone shells of orthocerids, more or less current-orientated. Smooth types, usually with preserved body chambers, which have not been identified precisely, predominate. The length of most more or less complete shells does not exceed 10–15 cm. In one case the shell fragment had the

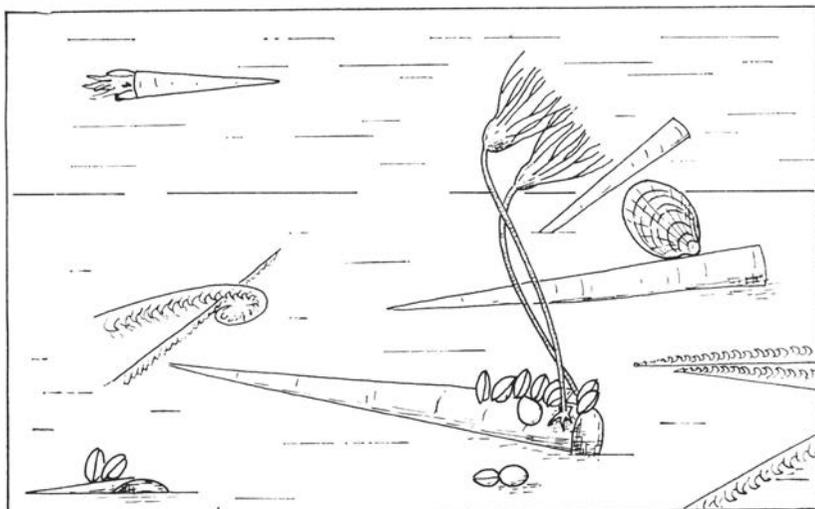


3. Diagrammatic reconstruction of the deposition of cephalopod shells and their orientation on the sea floor; development of graptolite "comets".  
Direction of current from left to right

cross-section of ca. 10 cm. Types with annulate sculpture and *Parakionoceras* and *Geisonoceras* are substantially scarcer. Finds of the genera *Rizosceras* and *Peismoceras* are exceptional. Of interest is the frequent occurrence of aptychopsids in some layers. Joined or partly disjoint lateral valves covered broadly one half of more than 200 specimens found. In four cases whole opercula have been recovered. From the comparison with other finds of aptychopsids in situ (Turek 1978, Holland - Stridsberg - Bergström 1978) they probably occur in association with their hosts. The existence of more than 25 complete opercula from the Barrandian devoid of any sign of shifting disproves the opinion that the odd subtriangular valve might represent the upper jaw and the pair of lateral valves the lower jaw of cephalopods (cf. Dzik 1981). The more frequent finds of joined lateral valves without the third odd valve can be due not only to a firmer conjunction but also to their greater mass.

### Epibenthic pioneer community

In the faunal association a so-called pioneer community of epibenthic organisms can be discriminated, which used the inhomogeneity of the sea floor caused by the accumulation of empty cephalopod shells and adapted itself to the extreme environmental conditions. The shells obviously constitute the only solid substrate which, with its number of individuals, complied with the needs of the numerous brachiopod and crinoid colonies. Some bivalves also attached themselves to the convex surface of cephalopod shells (cf. Kříž 1979). *Polychaeta* — the genus *Spirorbis* — are less frequent, an encrusting bryozoan has been found only in one



4. Diagrammatic reconstruction of the epibenthic community of brachiopods (*Glassia* sp.), crinoids (*Flexibilia*) and bivalves (*Cardo*!) on empty cephalopod shells. Direction of current from left to right

case. Coprophagous platyceratids lived in symbiosis with crinoids. A small specific diversity of the whole community given by a small number of taxa, some of which are relatively abundant, indicates the severity of conditions in which this community has survived (cf. Scott 1972).

Of no less interest is to observe the mode and preferred sites of settling on cephalopod shells. The early ontogenetic stages of brachiopods and the adult shells are usually of roughly the same size and suggest that the larval stages settled down prevalently all at once. With a few exceptions, both brachiopods and crinoids are settled on shells longer than ca. 10 cm, on their body chambers, usually close to the aperture. Bivalve shells with attached brachiopods are rarely found. The settling of the first larvae probably influenced the preferred attachment of other crinoid and brachiopod larvae. Although solitary individuals have also been attached to shells (in case of brachiopods, of course, some individuals may have fallen off after death), settling in groups predominates. On one bedding

surface there are shells densely settled beside shells quite devoid of sessile organisms, but a time factor, which might be decisive in many cases cannot be traced on any bedding plane. Settling of larval stages may have occurred even during their necroplanktonic stage or during the life of the cephalopod. There is, however, little reliable evidence for such cases. These stages developed into adult individuals doubtless only after empty shells had been deposited on the sea floor. This contention is based e.g. on the currently supposed short duration of the necroplanktonic stage of Lower Palaeozoic cephalopods, on the time interval needed for the development of brachiopods and crinoids into adult individuals, which could have lasted months to several years (cf. Rudwick 1965, Breimer 1978), and on the position of the settling sites of larvae. The attachment to body chambers and close to the aperture can be accounted for by the tendency to occupy a position as high above the sea floor as possible, in a better oxygenated environment than exists in the immediate proximity of the floor. Crinoids have been found not only on the outer but also on the inner surface of shell walls. Suitable conditions for settling of epizoans inside the body chambers of recent nautiloids are discussed, e.g. by Hamada (1964).

The present stage of knowledge does not make it possible to discriminate individual communities within the scope of an association of planktonic and epiplanktonic organisms.

#### **Extinction of colonies of sessile organisms**

Some finds indicate a premature extinction of brachiopod and crinoid colonies. As mentioned above, the brachiopods recovered represent forms attached to the substrate by their pedicles, i.e. by "soft" tissue, which decays within a certain time after the death of the organism. The question arises how, under the conditions of slow sedimentation of upper Wenlockian shales, brachiopods uncemented to the substrate or segments of crinoid stems could have been preserved on the convex surface of cephalopod shells. These finds can be explained in two ways: either that these organisms settled on shells buried for the most part by sediments or, in contrast, on shells not yet stabilized enough so that the epifauna disturbed their centre of gravity. A partial turning aside thus caused led to the disintegration of the brachiopod colony. The solitary brachiopods are very likely individuals fallen off the substrate after death.

The premature extinction of the organisms could also have been provoked by various external conditions which, being generally of minor importance, might represent a limiting factor for the organisms living in extreme conditions. We can take into account mainly the changes of water temperature due to submarine volcanism controlling the O<sub>2</sub> content, changes in current intensity, or more serious events such as contamination of water by hydrogen sulphide etc. (cf. Prokop - Turek 1983).

### Stratigraphic and sedimentological remarks

The total thickness of the *Testograptus testis* Zone cannot be as yet precisely established. Horný (1955a) gave values of some 80 m (including volcanites) from the Kosov area. In the parts accessible nowadays neither the lower boundary of this zone with the *Cyrtograptus radians* Zone nor the Wenlockian—Ludlovian boundary has been strictly established. The index graptolites species *T. testis* was found in abundance at several places in the quarry floor and in the southern part of the next higher level, at an interval of ca. 3–4 m. *C. trilleri* found in isolated blocks indicates the lower layers of this zone (cf. Bouček - Přibyl 1952). The upper boundary of the *T. testis* Zone runs probably inside the volcanic complex, approximately in the mid-height of the quarry wall, about 60 m high. The following two levels (thickness of ca. 25 m) belong demonstrably to the Ludlow stage (horizons with *Cromus beaumonti* and *Ananaspis fecunda*). It can be assumed with great probability that these beds are underlain by at least several metres thick stratal sequence also assigned to the Ludlovian (cf. Horný 1962). On the basis of the above data the author estimates the total thickness of the *T. testis* Zone in the profile studied at maximum 30 m, including volcanites, the thickness of the shale complex being about 20 m. The existence of stratigraphic hiatuses cannot be ruled out in the exposure, mainly in the boundary Wenlock/Ludlovian beds.

With regard to the most recent, even if widely differing, data on the duration of the Silurian (Spjeldnaes 1978, Ross et al. 1982) and to the number of graptolite zones generally discriminated, the average value of the duration of one graptolite zone will be ca. 0.75–1 million years. This value is confirmed by the recent radiometric age data on the upper Wenlockian and Ludlovian (Ross et al. 1982). If we accept the value of one million years as an approximate length of sedimentation period for the *T. testis* Zone, the 2 mm thickness of a diagenetically lithified sediments represents a time interval of 100 years, i.e. several times the sedimentation rate of upper Llandoveryian true graptolite shales (cf. Carter - Trexler - Churkin 1980). (For comparison, Lindström 1971 gives a value of 2.5–5.7 mm of lithified sediment in 100 years for upper Wenlockian *Cyrtograptus* shales in Skåne, see Laufeld — Bergström — Warren 1975.) Šrámek (1976) claims that the concretions in shales (Kosov quarry) were growing under conditions of very slow sedimentation (according to a decrease of carbonates outwards from the centre of concretion).

The greyish-black shales of the *T. testis* Zone contain about 15 mass per cent calcite (Šrámek 1976). Limestone concretions of different forms and size (from a few mm to about 75 cm) originated in the stage of early diagenesis are abundant in some layers and have recently been studied in detail (Šrámek 1974, 1976). Partly weathered shales are well cleavable and display a striking banding which reflects the alternation of finer- to coarser-grained layers of micritic calcite. From the measurement of lamination inside and outside the concretions a reduction of the thickness by 68 to 78% has been inferred (Šrámek 1976). The banding is very regular, not broken by bioturbations. Conclusive evidence of submarine

erosion (cf. pl. IX-1) accompanied by graded and diagonal bedding was found exceptionally by P. Čepěk in isolated blocks scattered in rock debris. The depth of erosion grooves does not exceed several cm. Their formation could have been closely connected with volcanic activity. Beds of tuffs are sporadic and their thickness is usually only a few centimetres.

### Bathymetric conditions

The graptolite facies in itself provides almost no information about the bathymetric conditions (cf. Bulman 1970). The data from the upper Wenlockian of the Barrandian are insufficient. The study of concretions in the profile discussed indicates that the Lower Silurian rocks belong to a relatively deep-sea facies (Šrámek 1976). The unusually regular lamination of shales points to sedimentation in a very quiescent environment, out of reach of surface wave action. With respect to its depth reach (esp. during powerful storms, recurring in 500–1000 years' periods) and on the basis of data on the present-day seas and oceans (cf. Kukul 1977), a depth of more than 100 m should be considered. The application of the correlation of graptolite association with benthic communities and thus with the bathymetric conditions in the late Llandoveryan (cf. Berry 1962, Ziegler 1965, Berry - Boucot 1972, 1975) to the late Wenlockian leads to analogous results. They are supported mainly by the occurrence of cyrtograptids and an absolute deficiency in retiolitids. The more or less monospecific community of small-shell brachiopods, the absence of larger forms and subtle crinoid skeletons with very thin stems also show a relatively deep-sea character. The common occurrences of nautiloids with aptychopsids and the mode of preservation permit to assume that they at least partly occur near the environment inhabited by living individuals. Their longicone shells are able to withstand a higher hydrostatic pressure than pressure corresponding to 200 m depth (cf. Westermann 1975). According to Boucot (1975), the lower limit for shelly benthos is ca. 165–200 m. However, the above data suggest that even greater depths existed in this area at the time of deposition of the upper Wenlockian shales.

*Translated by H. Zárubová*

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#### Hydrodynamické poměry a bentózní společenstvo vápnných břidlic svrchního wenlocku v z. části Barrandienu (lom Kosov)

Vápnité břidlice svrchního wenlocku (zóna *Testograptus testis*) sledované v lomu na z. svahu vrchu Kosov u Králova Dvora (z. část centrální barrandienské pánve) obsahují vedle charakteristické graptolitové asociace velké množství proudem usměrněných cefalopodových schránek, přednostně orientovaných vrcholem k ZJZ. Nalezené graptolitové shluky ve tvaru komety, zachycené o ortocerakonní schránky nautiloidů, podávají jednoznačný doklad, že k jejich uložení došlo v proudící vodě, kde se ukládaly přednostně vrcholem proti proudu. Vedle této asociace a dalších planktonních a epiplanktonních organismů (*Algae*, *Bivalvia* — *Butovicella*) obsahují břidlice pozoruhodné bentózní společenstvo. Zatímco prostředí uvnitř sedimentu bylo letální pro veškerou infaunu, což dokládá neporušená laminace břidlic a nepřítomnost jakýchkoliv stop lezení na dně, slabý směrově perzistentní proud s kolísající intenzitou umožnil osídlení dna druhově málo diverzifikovaným, ale co do počtu jedinců poměrně bohatým společenstvím brachiopodů, krinoidů a bivalvií. Tato fauna využívala jako podkladu prázdných schránek cefalopodů. Z dalších bentózních organismů byli zjištěni *Spirorbis* a koprofágní platyceři, žijící s největší pravděpodobností v symbiotických vztazích s krinoidy. Ojedinelý je nález povlékavého zoaria mechovky. Přednostně byly osídlovány větší schránky cefalopodů, a to jejich obývací komory, zpravidla při ústí. Vzácné jsou nálezy mlžů s přisedlými brachiopody. Byly zjištěny i případy, kdy k usazení došlo jak na vnějším, tak na vnitřním povrchu schránek.

Celková mocnost zóny T. testis včetně vulkanitů je na studovaném profilu odhadována na 30 m, což odpovídá rychlosti usazování zhruba 2 mm diageneticky zpevněného sedimentu za 100 let. Texturní znaky sedimentu, graptolitová a cefalopodová asociace i bentózní fauna, mají relativně hlubokovodní charakter a dovolují předpokládat, že k ukládání břidlic svrchního wenlocku zde došlo v hloubkách při hranici 200 m nebo pod ní.

#### Explanation of plates

All material comes from the upper layers of the Liteň Formation (upper Wenlockian T. testis Zone) — Kosov quarry near Králův Dvůr, western slope of Kosov hill. Material is deposited in the collections of the Palaeontological Dept. of the National Museum, Prague. Specimens figured on plates IV to VIII whitened with ammonium chloride. Pl. VIII, figs. 3, 5, Pl. IX and Pl. X photographed by K. Drábek, other photos taken by the author.

#### Plate I

Rhabdosomes of graptolites *Cyrtograptus lundgreni* (Tullberg) and *Monograptus flemingii* (Salter) intercepted successively on orthocerid shell; the find shows the general orientation of orthoceracone shells with respect to current direction. L 20512,  $\times 1.1$ .

#### Plate II

Graptolite cluster (a "comet") formed by interception of rhabdosomes of *Cyrtograptus lundgreni* (Tullberg) on an orthoceracone nautiloid shell, stuck obliquely into the substrate. L 20503,  $\times 1.2$ .

#### Plate III

1–2. *Cyrtograptus lundgreni* (Tullberg), unusual habit of rhabdosomes due to the mode of preservation. 1. L 20501,  $\times 1.6$ ; 2. L 20506,  $\times 1.8$ ; 3. *Cyrtograptus trilleri* Eisel. L. 20533,  $\times 1.7$ ; 4–5. *Pristiograptus* sp. Rhabdosomes compressed dorsoventrally with a so-called "float": 4. L 20498,  $\times 1.1$ ; 5. L 20570, (laterally deformed rhabdosome does not belong to the float)  $\times 1.5$ ; 6. *Testograptus testis* (Barrande), L 20531,  $\times 1$ .

#### Plate IV

1. Orthocerid shell with brachiopods settled on body chamber. L 20490,  $\times 2$ . 2. Orthoceracone shell having the surface of body chamber densely covered with brachiopods *Lissatrypa* sp. and crinoids. The crown of one crinoid preserved, L 20496,  $\times 2.3$ .

#### Plate V

1–5. Crinoid holdfasts on adapertural parts of orthocerid shells. 1. Asymmetric star-shaped holdfasts. L 20509,  $\times 1.6$ ; 3. the same specimen, detail.  $\times 2.7$ ; 2. branching of basal processes of the axial channel, and asymmetry caused by partial separation from the substrate. L 20493,  $\times 2.2$ ; 4. rick branching of basal processes of the axial channel, negative. L 20487,  $\times 4.1$ ; 5. settling on the outer and inner walls of the shell. L 20486,  $\times 2$ .

#### Plate VI

1. Adapertural part of orthoceracone shell with epifauna on both the outer and inner surfaces of shell walls. L 20504,  $\times 2.3$ ; 2. basal parts of crinoids with long-tipped holdfasts and xenomorphic stem. L 20535,  $\times 3$ ; 3. star-shaped holdfasts on the very margin of aperture. L 20502,  $\times 1.3$ ; 4. *Aptychopsis prima* Barrande, 1872. Complete operculum with slightly shifted odd valve, L 20508,  $\times 1.3$ ; 5. body chamber of orthocerid with sessile epifauna on the surface (*Crinoidea*, *Brachiopoda*). L 20511,  $\times 1.3$ ; 6. *Rizosceras* sp. L 20491  $\times 1.4$ ; 7. orthoceracone shell with preserved protoconch, bent after death. L 20497,  $\times 1$ ,

## Plate VII

1. *Slava* cf. *fibrosa* (Soverby in Murchison), left valve. L 20495,  $\times 1.2$ ; 2. ?*Dualina* sp. with brachiopods settled on inner surface of both valves. L 20494,  $\times 2$ ; 3. *Platyceras* sp. L 20489,  $\times 3.4$ ; 4. *Spirorbis* sp. on a fragment of cephalopod shell. L 20500,  $\times 8.5$ ; 5. *Butovicella migrans* (Barrande), right valve. L 20510,  $\times 5.8$ ; 6. *Cardiola agna* Kříž and orthoceracone shell with crinoid holdfasts at the opening. L 20499,  $\times 1.4$ .

## Plate VIII

1–2. *Peismoceras* sp. overgrown with bryozoan. L 20492. 1.  $\times 2$ , 2.  $\times 4$ ; 3–5. Morphological types of pachythecae. 3. L 20594,  $\times 32$ , 4. L 20507,  $\times 22$ , 5. L 20513,  $\times 28$ .

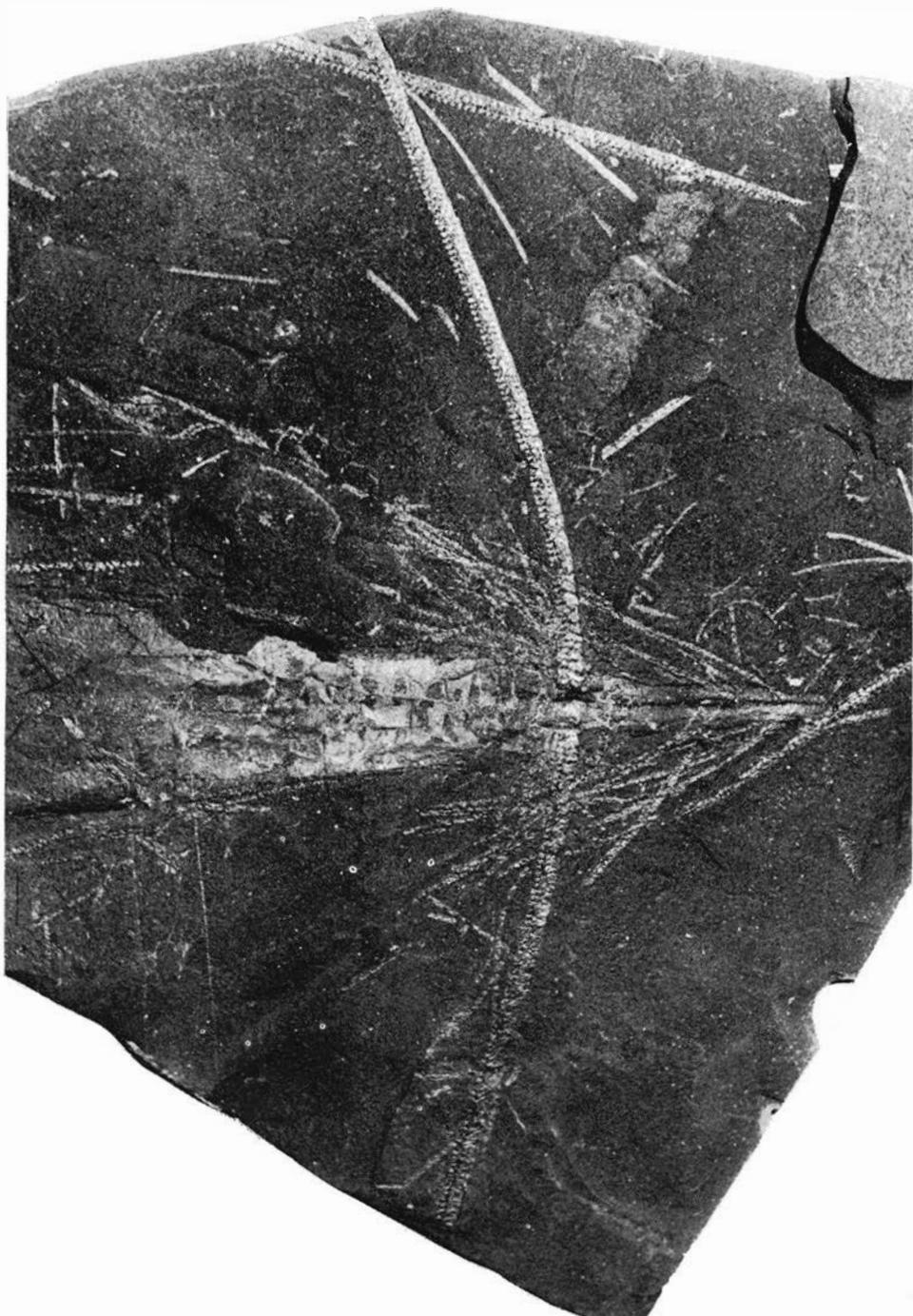
## Plate IX

1. Erosion groove inside the laminated Liteň Shales (T. testis Zone), filled with limestone with tuffaceous admixture, showing graded bedding. On the left, a slightly turned calcareous concretion.
2. Perfect lamination of the Liteň Shales (T. testis Zone), unaffected by bioturbations.

## Plate X

Kosov near Králův Dvůr. Quarry on cement corrective material, southern wall, tectonically strongly disrupted. Sampling sites denoted by arrows. Dashed line indicates the lower limit of the volcanic complex developed at the Wenlockian/Ludlovian boundary. Exposure in September 1982.

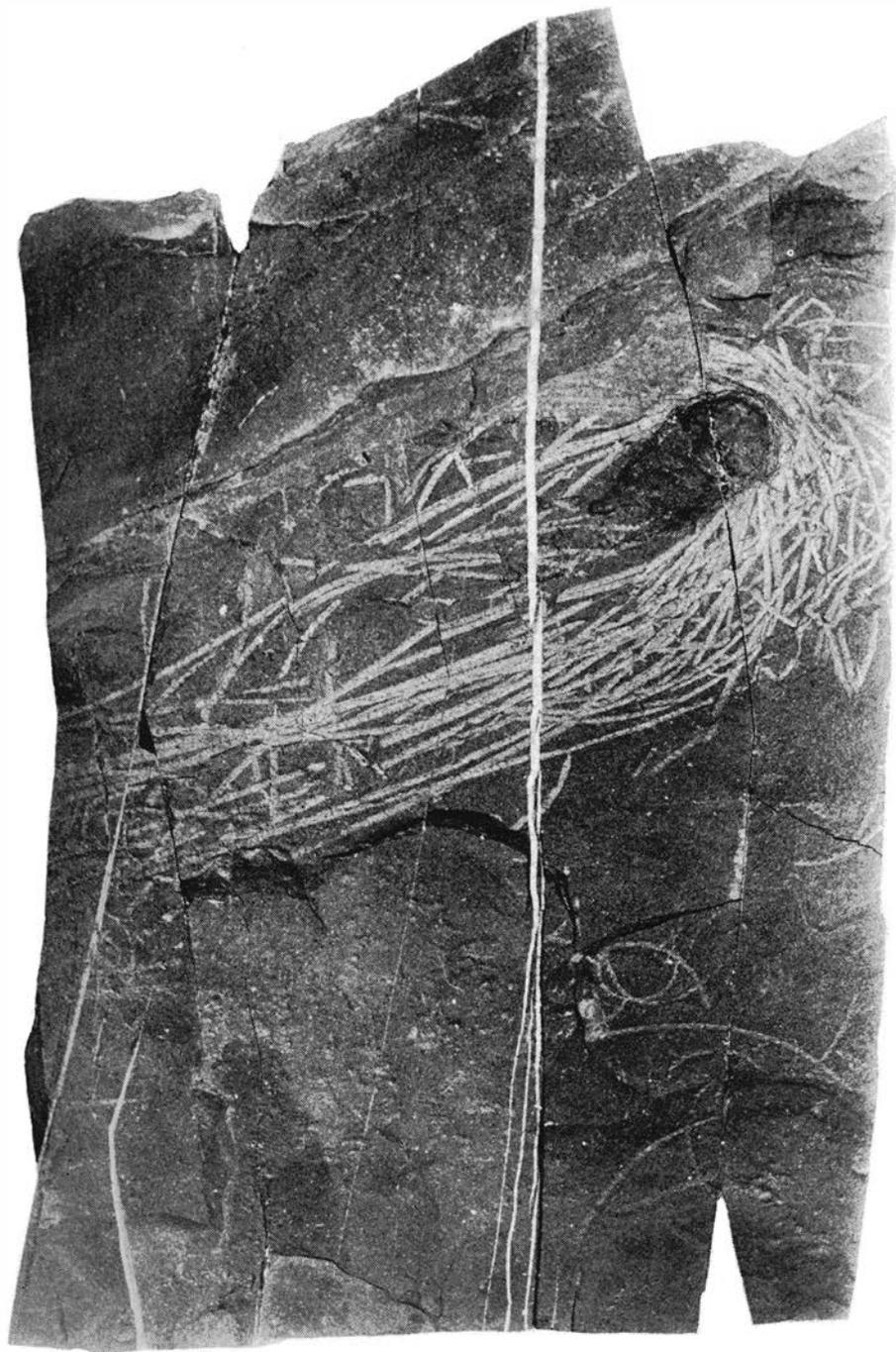
V Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the eastern part of the Barrandian (Pl. I)



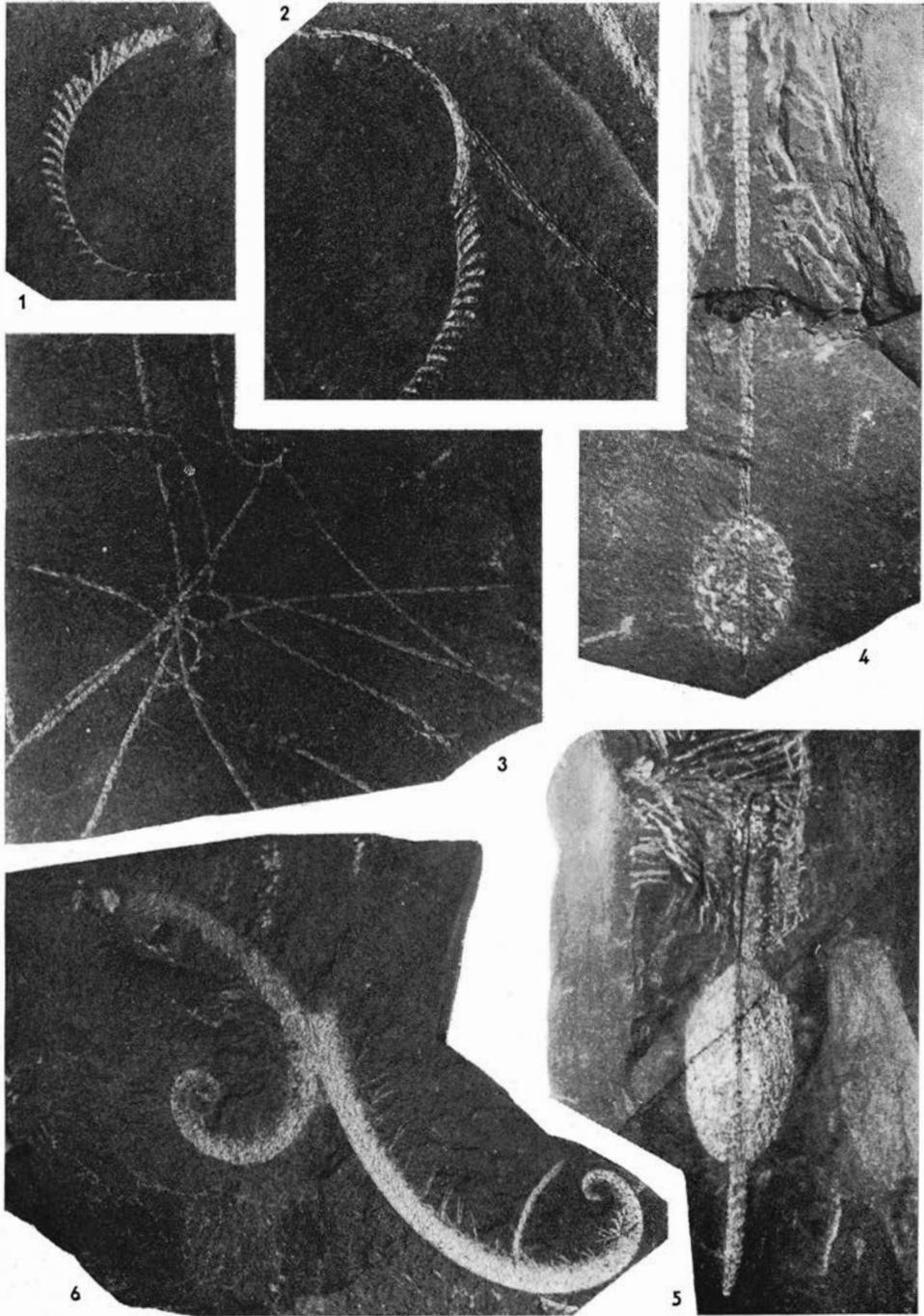
For explanation see p. 259

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V. Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of the Barrandian (Pl. II)



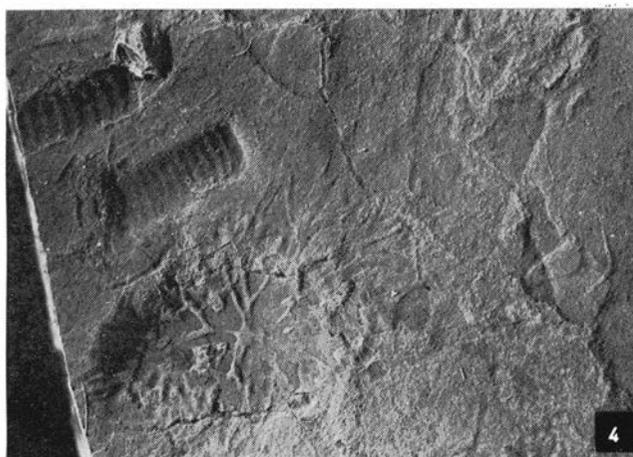
V. Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of Barrandian (Pl. III)



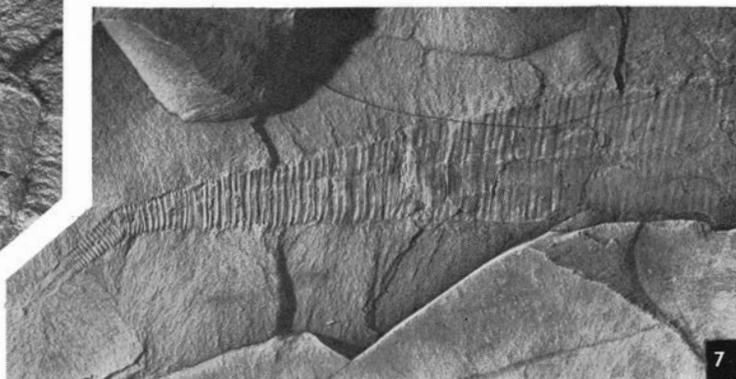
V. Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of the Barrandian (Pl. IV)



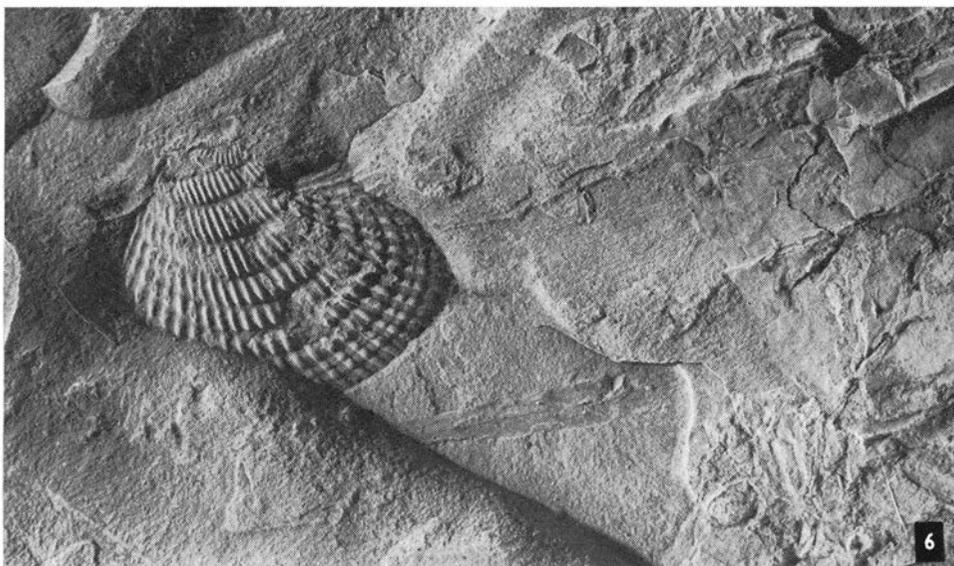
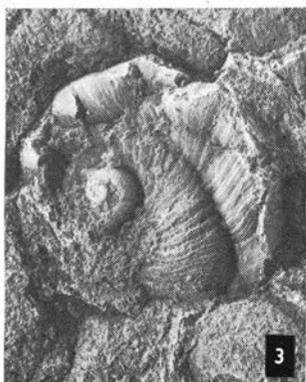
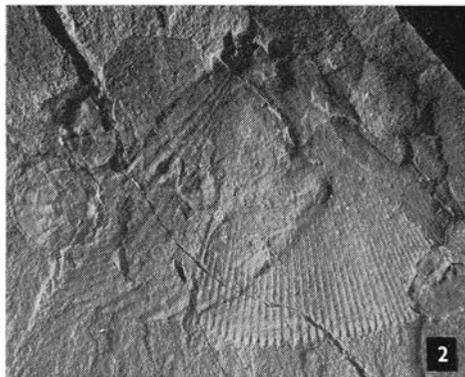
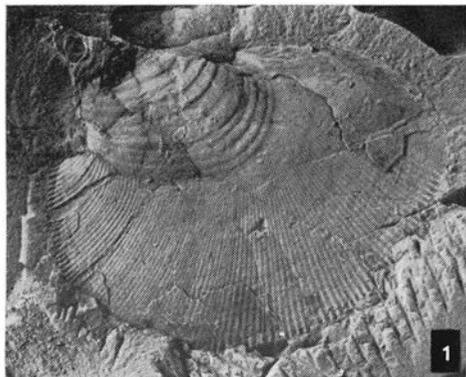
V. Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of the Barrandian (Pl. V)



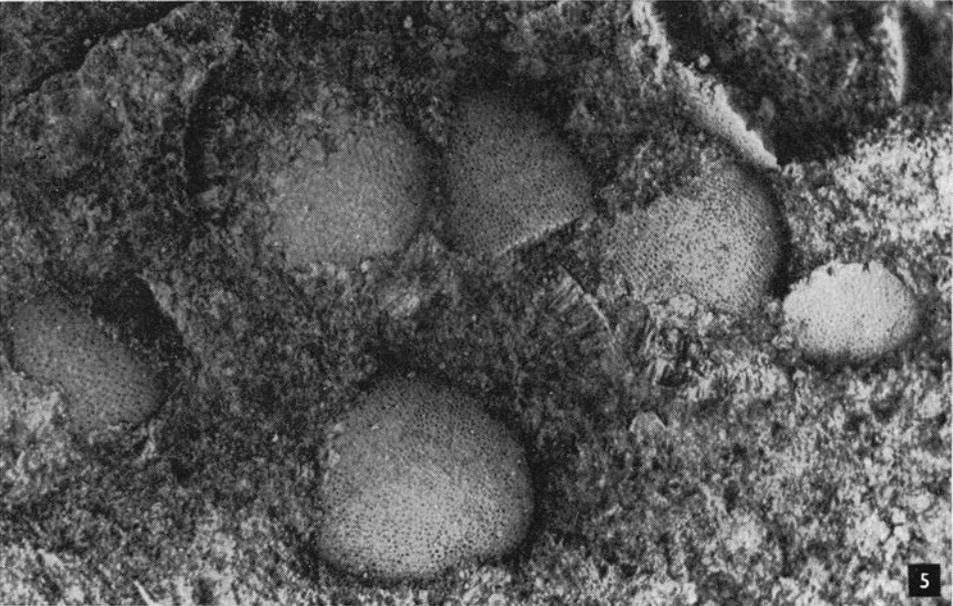
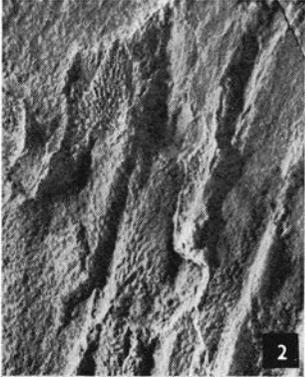
V. Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of the Barrandian (Pl. VI)



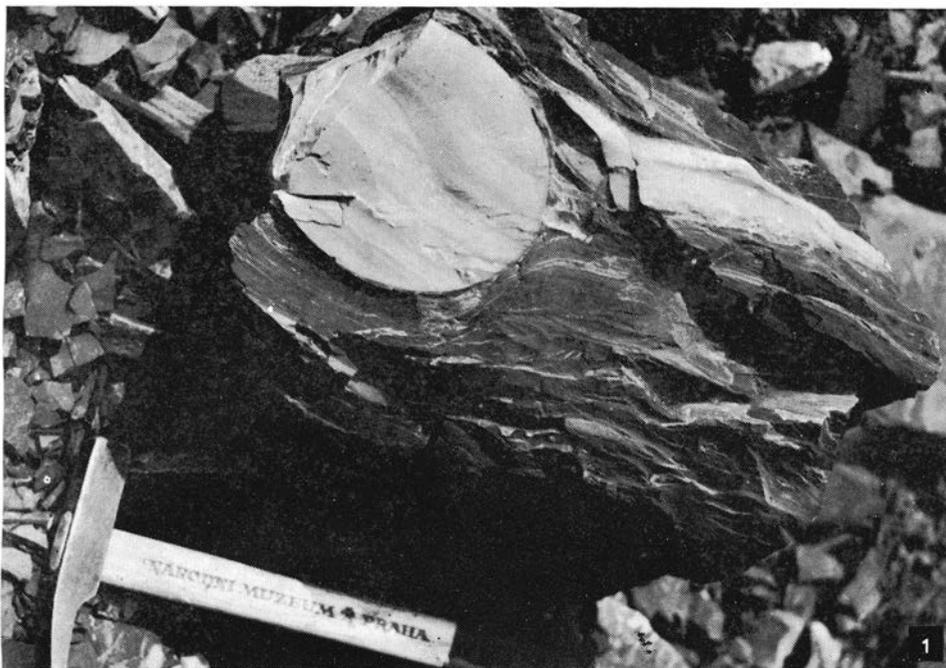
V. Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of the Barrandian (Pl. VII)



V. Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of the Barrandian (Pl. VIII)



V. Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of the Barrandian (Pl. IX)



V. Turek: Hydrodynamic conditions and the benthic community of upper Wenlockian calcareous shales in the western part of the Barrandian (Pl. X)

