



Fig. 16: Coal seams within the Karolinavölgy Sandstone, Lampas-völgy.

Komló cores 176 and 137

The Komló core 76 was drilled in 1972 as part of the exploration program of the Hungarian coal-mining industry and is a reference section of the geology of the Komló area. The core was palynologically studied by J. Bóna (cf. Bóna 1995) and here first, Bóna's palynological slides were compared with the slides of this study. Second, both materials were analysed with special respect to the definition of the Triassic/Jurassic boundary (see below). A documentation of the location and numbers of all drilled cores in the Komló mining area is published in Bóna (1995). Unfortunately, most of the cores are not stored anymore; reports of the core documentations and Bóna's palynological slides are kept in the Natural History Museum of Komló. Sedimentology of the Komló core 176 was documented by Gy. Hönig (internal report 1972, in Hungarian), who described a sedimentary series of fine-grained sandstones and siltstones in the basal part of the well section. Thin coal layers occur for the first time in the middle part of the succession, becoming more frequent upsection. Within the Triassic/Jurassic boundary interval five coal seams are developed with an average thickness of 0.5 m (Fig. 17).

In addition, the Komló core 137 has been sampled for palynological studies. A schematic sketch of the sediments is given in Fig. 18.

Komló K-176

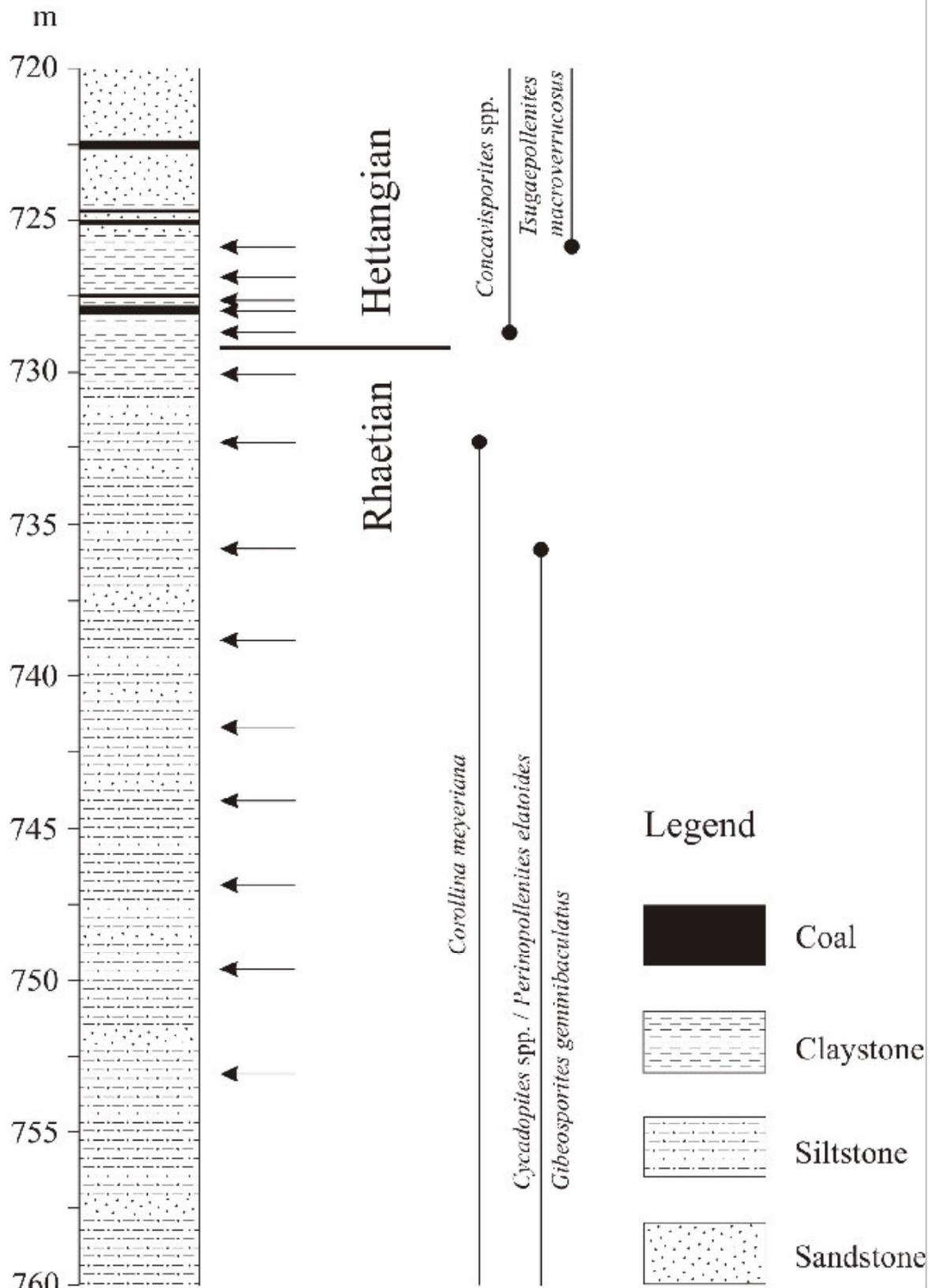


Fig. 17: Schematic sketch of the sediments of the Triassic/Jurassic boundary interval , Komló core 176 (after Hönig 1972; internal report in Hungarian).

Komló K-137

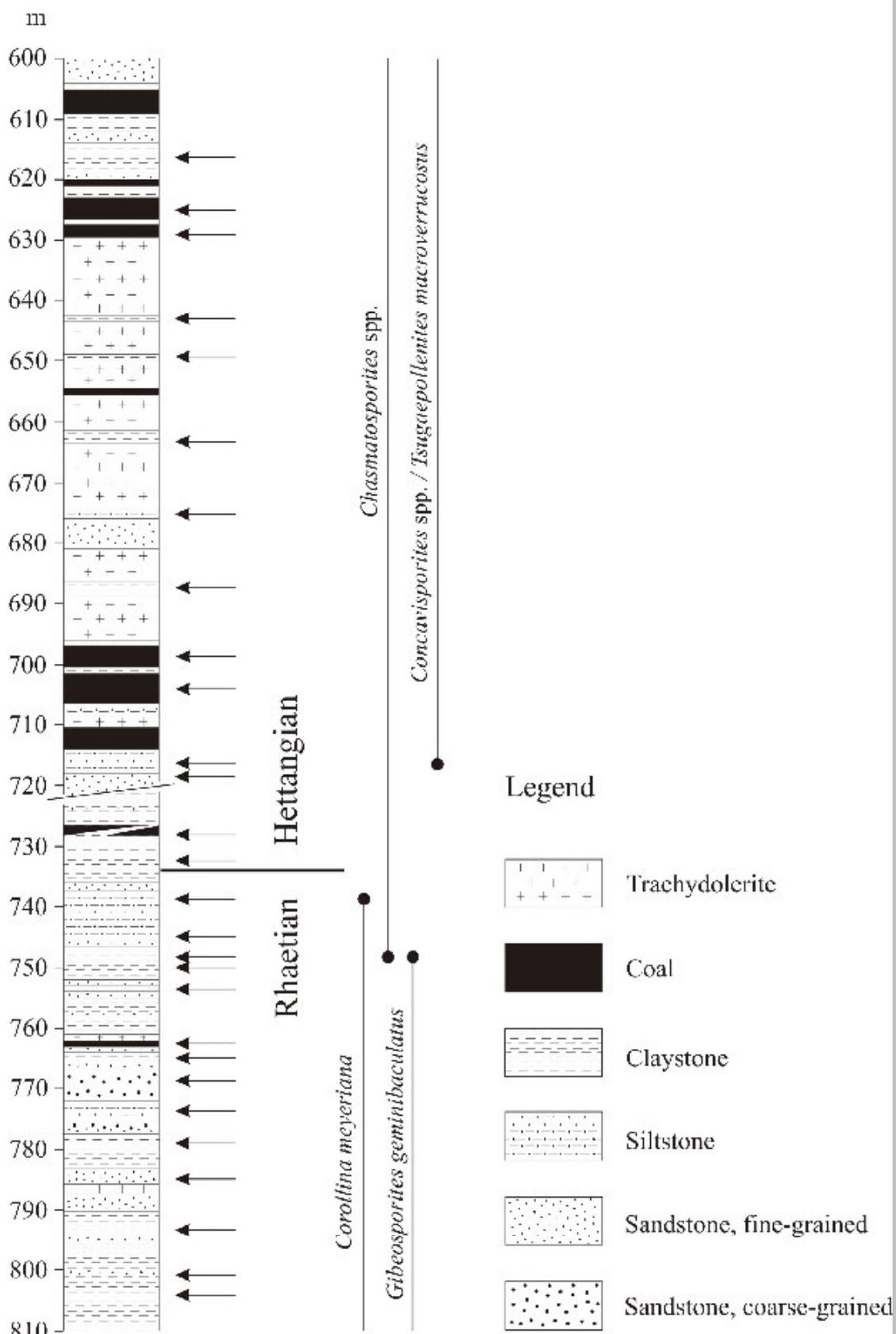


Fig. 18: Schematic sketch of the sediments of the Triassic/Jurassic boundary interval , Komló core 137.

4 Palynofacies

4.1 Principles of palynofacies analysis

The term palynofacies has been introduced to literature by Combaz (1964). In contrast to classical palynological investigations, palynofacies analysis deals with all components building the sedimentary organic matter, including marine and terrestrial palynomorphs as well as phytoclasts, resin, fungal filaments and amorphous organic matter. The term facies is used in sedimentology to describe a spatially segregated and broadly coeval body of sediment deposited within a specific depositional environment (or a specific depositional mechanism) (Tyson 1995). The main geological applications of the palynofacies technique are:

1. Determining the magnitude and location of terrigenous input (i.e., proximal-distal relationships with respect to sediment source)
2. Determining depositional polarity (i.e., onshore-offshore axes)
3. Identifying relative shallowing-deepening and regressive-transgressive trends in stratigraphic sequences (and thus depositional sequence boundaries)
4. Discriminating between open marine, 'restricted' marine (dysoxic-anoxic), brackish and freshwater depositional environments
5. Characterizing and subdividing sedimentologically 'uniform' facies, especially shales or other fine grained sediments
6. Deriving correlations either at levels below biostratigraphic resolution, or in absence of diagnostic biostratigraphic data
7. Determining hydrocarbon source rock potential, and qualifying bulk rock geochemical parameters (Tyson 1995).

The palynofacies assemblages can be subdivided into a terrestrial and a marine fraction (Steffen & Gorin 1993). A further subdivision leads to several groups and sub-groups that are used to define palynofacies ratios and parameters. The palynofacies analysis of this study focuses on the discrimination of the depositional environment, the subdivision of sedimentologically uniform facies and the correlation of different palaeoenvironments.

4.2 Palynofacies Components

4.2.1 Phytoclasts (plant and wood remains)

The lingo-cellulosic tissues of terrestrial macrophytes are the origin of the majority of fossil phytoclasts (Tyson 1995). The colour of these particles variegates from light brown to black. The lighter a phytoclast, the more translucent it is. Black phytoclasts are opaque and

completely oxidized. Opaque charcoal is produced by natural pyrolysis of terrestrial macrophyte material, i.e. the action of high temperature under conditions of oxygen starvation (Cope 1980, 1981). The main importance of charcoalification is the fact that it occurs in a wide range of terrestrial environments, including those where the burial and anaerobic preservation of plant material is generally unlikely (Tyson 1995). The most distinctive characterization of charcoal is the usually well-preserved botanical structure. Many dark phytoclasts are more irregularly shaped and do not show good structural preservation. It is apparently formed during desiccation, oxidation, and fungal mouldering of woody material exposed to atmospheric oxygen at or near to the surface of soils and peats (Styan & Bustin 1983). The origin of translucent phytoclasts is often non-woody, non-epidermal tissues of land plants and cuticles that represent epidermal tissues. Most cuticule fragments are derived from leaves. Thick cuticles are not restricted to hot climates, therefore they are typical of mid to high latitude floras (Thomas 1982).

4.2.2 Amorphous Organic Matter (AOM)

The Amorphous Organic Matter Group is build up by all organic particles that appear structureless at the scale of light microscopy. Constituent elements are phytoplankton- or bacterially-derived amorphous organic matter, higher plant resins, and amorphous products of the diagenesis of macrophyte tissues. The amorphous material commonly acts as a matrix for a variety of structured or “pseudoamorphous” inclusions (Tyson 1984). One of the most common sources of AOM in modern marine systems is non living “organic aggregates” (Riley 1970). A high amount of organic aggregate material is sedimented from the euphotic zone following or during the decline of phytoplankton blooms (Tyson 1993). The chemical composition of organic aggregates differs, fresh material has evidently a similarity to phytoplankton (Eppley et al. 1977). Another potential source of AOM are faecal pellets of zooplankton. The character of organic matter within faecal pellets is variable, but often consists primarily of amorphous matter (Honjo & Roman 1978). Cyanobacteria and Thiobacteria are important producers of oil-prone amorphous organic matter. Primary intra- and extracellular amorphous material is often produced by the biodegradation of terrestrial plant remains. Resin and amber are classified within the Amorphous Group because they are inherently structureless. They should not be referred to as AOM, because this term is traditionally reserved for material of phytoplankton or bacterial origin (Tyson 1995).

4.2.3 Degraded Organic Matter (DOM)

Organic particles that don't show clear defined structures are called Degraded Organic Matter. This term was introduced into literature by Götz (1996). Sensu Götz & Feist-Burkhardt (2000) the origin of DOM are primarily pollen grains and spores that are mechanically or chemically affected during transport and sedimentation.

4.2.4 Palynomorphs

4.2.4.1 Phytoplankton Subgroup

Acritarchs

The term acritarch was introduced in literature 1963 by Evitt as an informing holding category for all palynomorphs that do not belong to the sporomorph group and are not classified as dinoflagellate cysts. The name acritarch means 'of uncertain origin' (*akritos* = uncertain, mixed, and *arche* = origin, beginning) and up to now, a lot of palynomorphs with uncertain affinities are incorporated within acritarchs, waiting for a reclassification. Most acritarchs belong to the marine phytoplankton group and the organisms that produced this palynomorphs are extinct or unknown. It is supposed, that most acritarchs are organic-walled cysts of unicellular protists. The morphology of acritarchs is diverse, presumedly reflecting their heterogenous origins. Most individuals consist of a single hollow vesicle or theca that may be ornamented with processes and sculpturing elements (Strother 1996). Many acritarchs display encystment structures, which underlines the idea that they are algae cysts. The first acritarchs appeared in the late Precambrian. During the lower Palaeozoic they had their acme with respect to diversity and commonness. In Mesozoic and Cenozoic strata, acritarchs generally play a minor role in microplankton assemblages and show very low diversity. Due to the fact that acritarchs have an unknown affinity, it's not possible to state, if they are still existing in recent marine environments. Some acanthomorphs appear in modern sediments, but some scientists presume that these are dinoflagellates (Strother 1996).

Prasinophytes

The systematic classification of the Chlorophyta, including the prasinophycean algae, is not concluded definitely, yet. At present, it is expected that the prasinophycean algae are the most primitive form of green algae, but there is no satisfactory diagnostic definition of them (Fensome et al. 1996). Recent living prasinophycean algae are characterized by having two

distinct phases in their life history – a motile phase and a non-motile phase (Fig. 19). The quadriflagellate cell of the motile phase may reproduce itself by simple longitudinal fission, while the phycoma or cyst like non-motile phase develops directly from the motile one (Guy-Ohlson 1996). All organic-walled microfossils, that are classified as prasinophytes are in fact only the outer walls of phycomatas of prasinophycean green algae. The motile phase is typically not preserved in ancient sediments after utilizing a standard palynological preparation treatment.

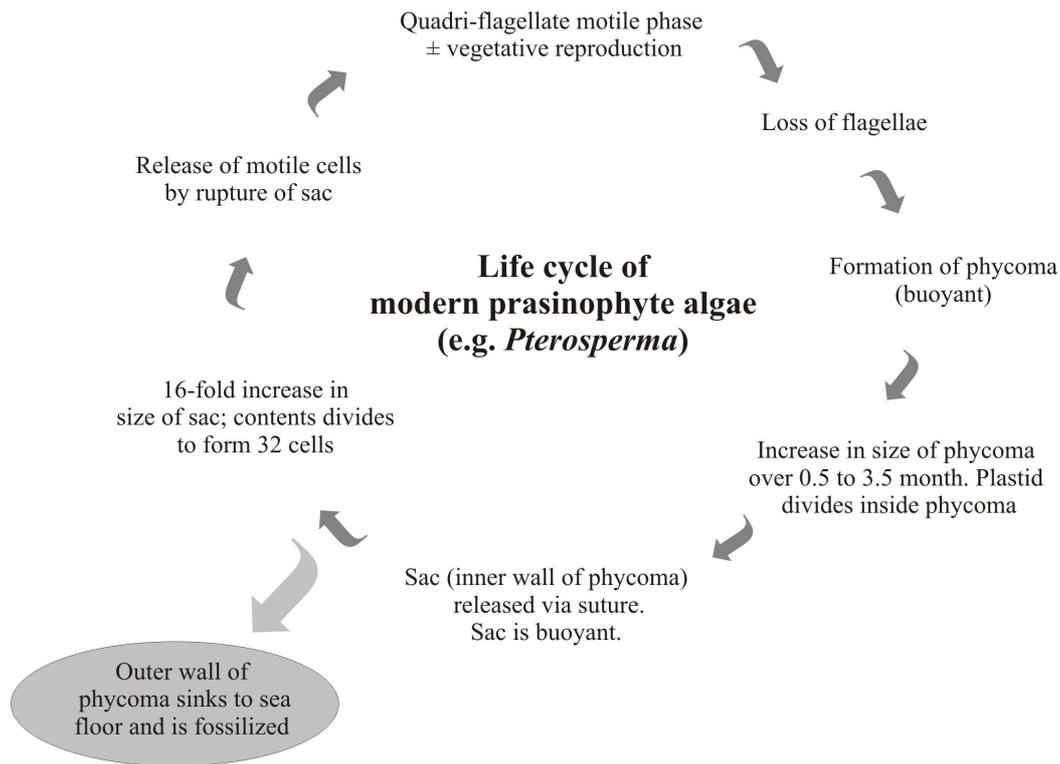


Fig. 19: Schematic representation of the life cycle of modern prasinophyte algae (modified after Tyson 1995).

Dinoflagellate cysts

The term dinoflagellata was introduced into literature by Bütschli (1885). He combined the Greek word *dinos*, “whirling rotation” and the Latin word *flagellum*, “small whip” to describe whirling, whip-bearing organisms. Dinoflagellates are primarily single-celled protists that occur typically as motile cells with two flagella (Fensome et al. 1996). Fossil dinoflagellates occur primarily in sediments of late Triassic to Recent age and are mostly of marine origin. Most fossil dinoflagellates appear to represent resting cysts or hypnozygotes, therefore the term dinoflagellate cyst is used in this study. Cysts are produced inside the dinoflagellate theca. It is supposed that the cyst shape may approximate that of the motile cell (Fig. 20). Cysts with processes are called chorate or proximochorate cysts, depending on the relation of

the size of the central body and the processes. Cysts without processes are called proximate. One important feature of dinoflagellate cysts is paratabulation, a reflection of the tabulation of the theca.

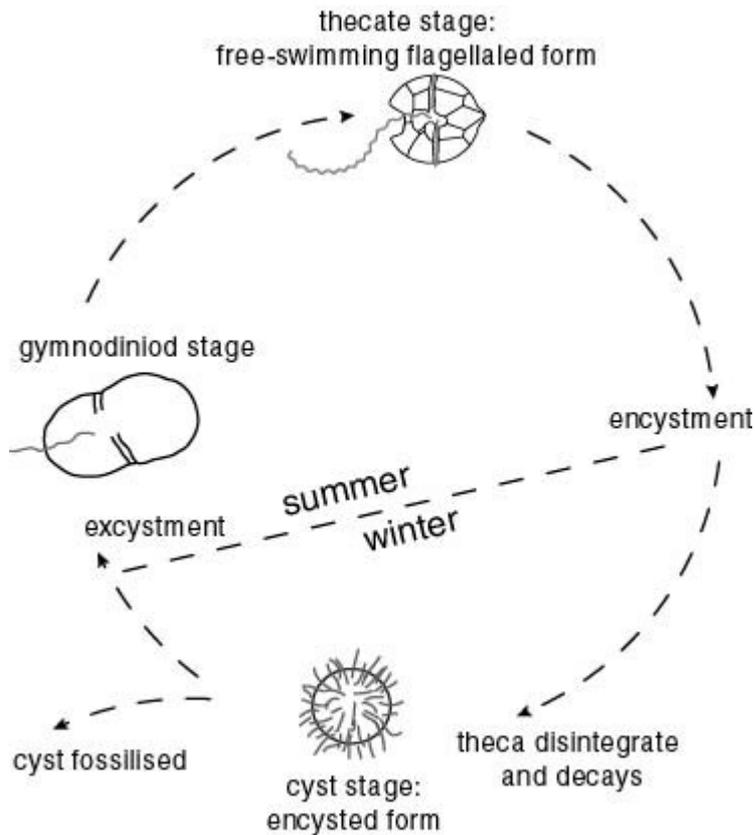


Fig. 20: Schematic representation of the life cycle of modern dinoflagellate cysts (Source: GEUS).

4.2.4.2 Zoomorph Subgroup

Foraminiferal test linings

The tectin linings of foraminifera are often elements of marine palynofacies assemblages. The linings of planispiral foraminifera are generally predominant (Traverse & Ginsburg 1966), but all morphotypes are found. Fossilizable linings appear to be produced entirely by benthic foraminifera (De Vernal et al. 1992).

Scolocodonts

Scolocodonts are the part-calcified chitinous jaw elements of benthic polychaete annelid worms. They occur almost entirely in marine sediments. Scolocodonts are known from a

quarter of all modern polychaete families (Brenchley 1979) and have a geological range from early Ordovician to Recent.

4.2.4.3 Sporomorph Subgroup

Pollen

The word pollen is a Latin derivative meaning fine flour or dust, descriptive of the powdery nature in mass. Linnaeus introduced the Latin version of the term 1751 into literature (Jarzen & Nichols 1996). Pollen has the function of male gametophytes and play an important role in the life cycle of all seed-producing plants (Fig. 21). Seed plants are divided into gymnosperms and angiosperms. Due to the fact that angiosperms appear first during Cretaceous times, this study focuses on the life cycle of gymnosperm plants. The pollen grains and the ovum represent the haploid or $1n$ gametophyte generation. The pollen grain consists of several cells, among which the most important are the generative cells which produce two sperm cells or nuclei, and a vegetative tube cell which directs the growth and progress of the pollen tube. The fertilized seed and all other stages in the life cycle are the diploid or $2n$ sporophyte generation (Jarzen & Nichols 1996). Pollen of several gymnosperm genera is saccate, which means, that a pollen grain is composed of the central body and one, two or three air sacs that are used for wind-controlled transport.

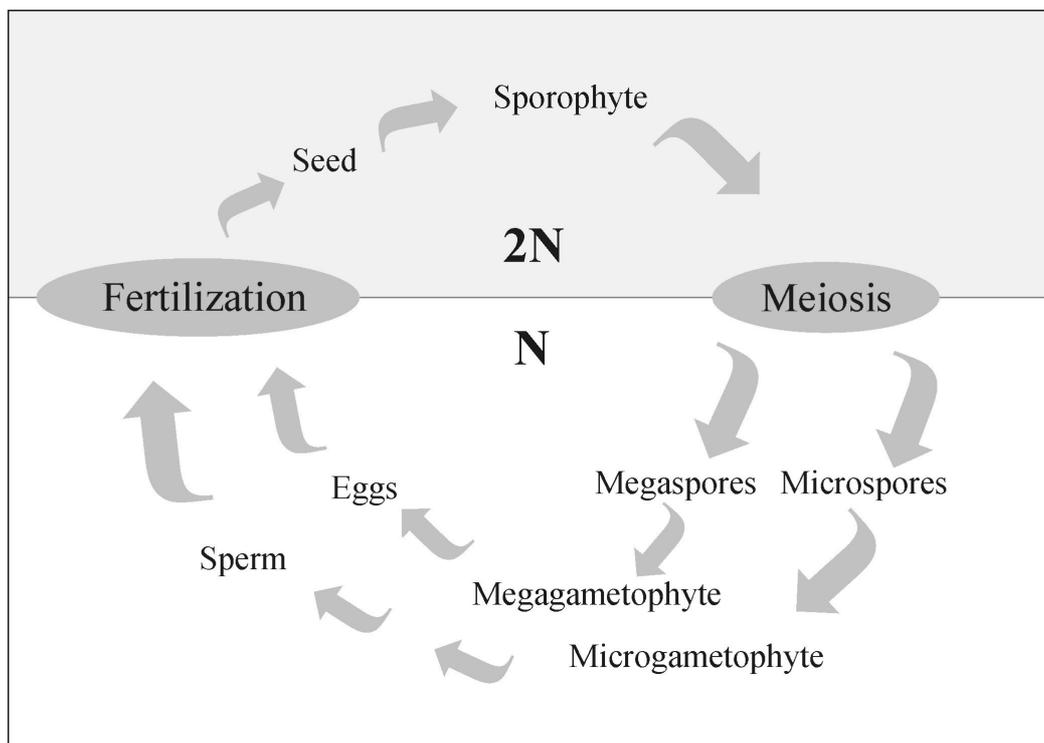


Fig. 21: Life cycle of a typical gymnosperm plant (modified after Traverse 1988).

Gymnosperm pollen share typically basic features, including aperture structure and surface ornamentation, but are very variable in size, shape and habitus. Whether a palynomorph is a pollen grain or a spore, or if it's a pollen grain of an angiosperm plant or a gymnosperm plant is a botanical issue and it's not necessarily expressed in its morphology (Jarzen & Nichols 1996).

Spores

Spores form part of the life cycles of many plants like fungi, mosses and ferns. Differences in their life cycles divide them into Bryophyta and Pteridophyta. The Bryophyta comprise the mosses and liverworts. They are non-vascular green plants, apparently related to the green algae and to the vascular green plants. The typical moss is a small, haploid plant with no true roots or vascular system (Fig. 22). This plant has female and male sex organs, which produce eggs and spermatozoids. The fertilized egg (zygote) develops into a small, diploid plantlet. It's only function is to produce a sporangium in which tetrads of spores are differentiated through meiosis. The spores are haploid and are isospores (Traverse 1988).

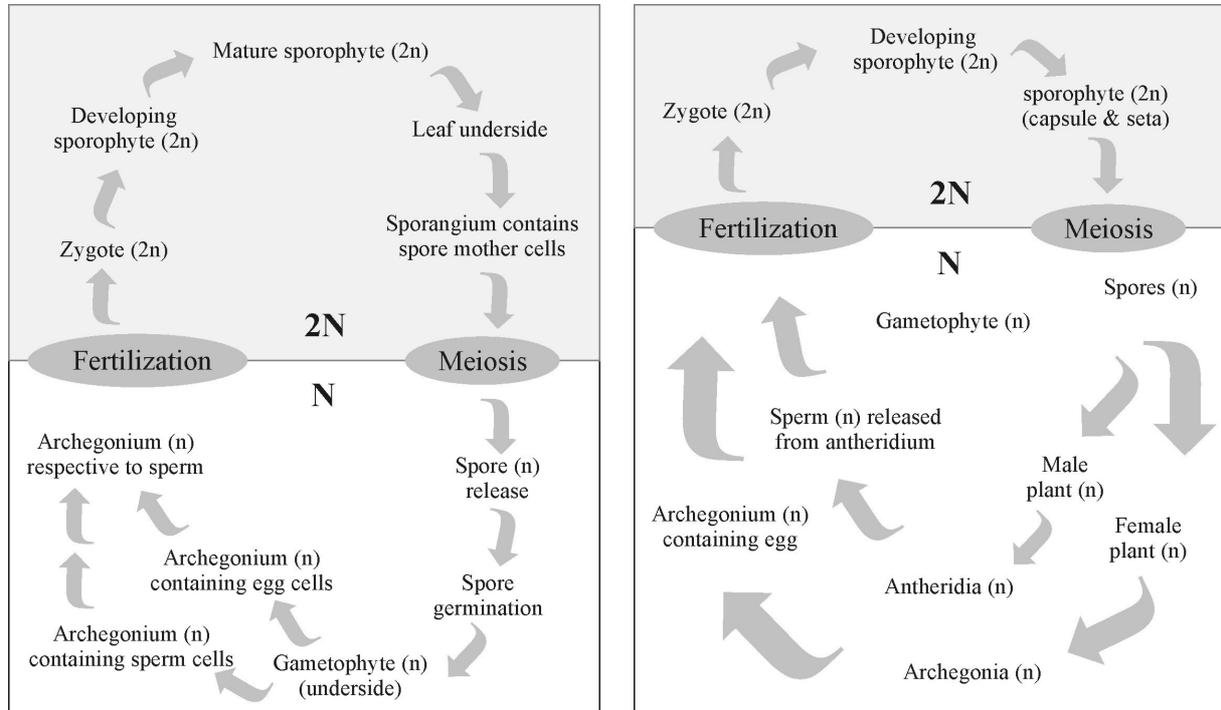


Fig 22: Pteridophyte (left) and Bryophyte (right) life cycle (modified after Traverse 1988).

4.3 Percentages and Ratios

Percentages are probably the most used kind of data. In this study, no absolute quantitative counting (number per gram) has been carried out. Therefore, all presented data including the percentage data are relative to a counted number of particles. The most informative percentages used in the present work are (1) percentage of phytoclasts of total palynofacies assemblage (2) percentage of palynomorphs of total palynofacies assemblage (3) percentage of spores of terrestrial palynomorphs and (4) percentage of bisaccate pollen of the terrestrial palynomorphs.

Ratios of different palynofacies components are often far more effective tools of illustrating stratigraphic trends than the crude percentage data (Tyson 1995). One of the major advantages is that they are unaffected by data closure effects, and the often significant proportion of unidentified counts that may result in uncertainties within the percentage data. The ratios used here are (1) ratio of terrestrial to marine components, (2) ratio of opaque and translucent phytoclasts, (3) ratio of equidimensional to blade-shaped particles. For climatic reconstruction (4) the ratio of spores and pollen is a striking feature. Additionally, this ratio yields information on the transport of distinct deposits.

4.5 Palynofacies data

4.5.1 Tatra Mountains

Furkaska section

Palynofacies of the Furkaska section is dominated by terrestrial particles (Pl. 1). The marine fraction is very small and mainly composed of the dinoflagellate cyst species *Dapcodinium priscum* (Pl. 2) and *Rhaetogonyaulax rhaetica* (Pl. 3). Degraded organic matter build up to 50 % of the palynofacies assemblage.

The palynofacies distribution pattern points to very shallow marine conditions. Due to the extremely small amount of marine components, the ratio of terrestrial to marine particles is not very meaningful with respect to sea-level changes within this interval. The relatively high amount of degraded organic matter points to a high-energy depositional system. Figure 19 shows the distribution of sporomorphs within the boundary interval. In the lower part of the Furkaska section, which belongs to the Rhaetian Fatra Formation, the ratio of pollen grains and spores is well balanced. A striking spore shift in bed number 408 displaces this proportion

to a spore dominated sporomorph assemblage during the lowermost Hettangian time interval. The sporomorph dominance within the palynomorph assemblage is pointing to a close proximity to fluvio-deltaic sources (cf. Tyson 1995, p. 448).

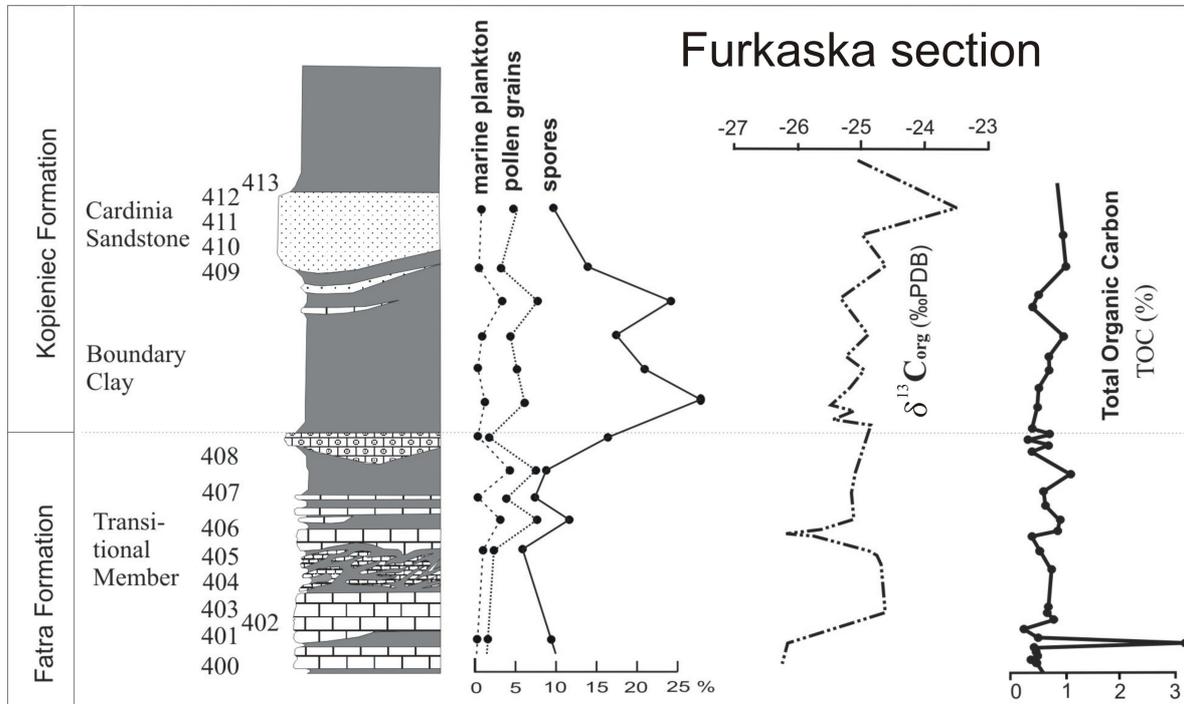


Fig. 23: Relative abundance of palynomorphs (marine plankton, pollen grains, spores) of total sedimentary organic matter (palynomorphs, phytoclasts, degraded organic matter), $\delta^{13}\text{C}$ signature and TOC distribution; Furkaska section (from Michalík et al., submitted). The turnover in bed 408 marks the palaeoenvironmental change within this interval.

Hybe section

Palynomorphs of the Hybe section are poorly preserved. Marine particles were not identified, which is interpreted as an effect of the preservation. Due to the findings of marine invertebrates, it is quite evident that marine plankton played an important role within this marine environment. Within the terrestrial sporomorph assemblage, a significant increase in the abundance of trilete spores is observed upsection (Fig. 24). The identification and subdivision of genera and species was in the majority of cases not possible. Only palynomorphs with a very significant habitus such as *Ricciisporites* spp., *Ovalipollis* spp., *Deltoispora* spp. and *Concavisporites* spp. could be identified and point to a characteristic Upper Rhaetian microfloral assemblage, similar to the well preserved material from the Fatra Formation of the Furkaska section. Due to the poor preservation of palynomorphs, the Hybe samples are only used for comparison.

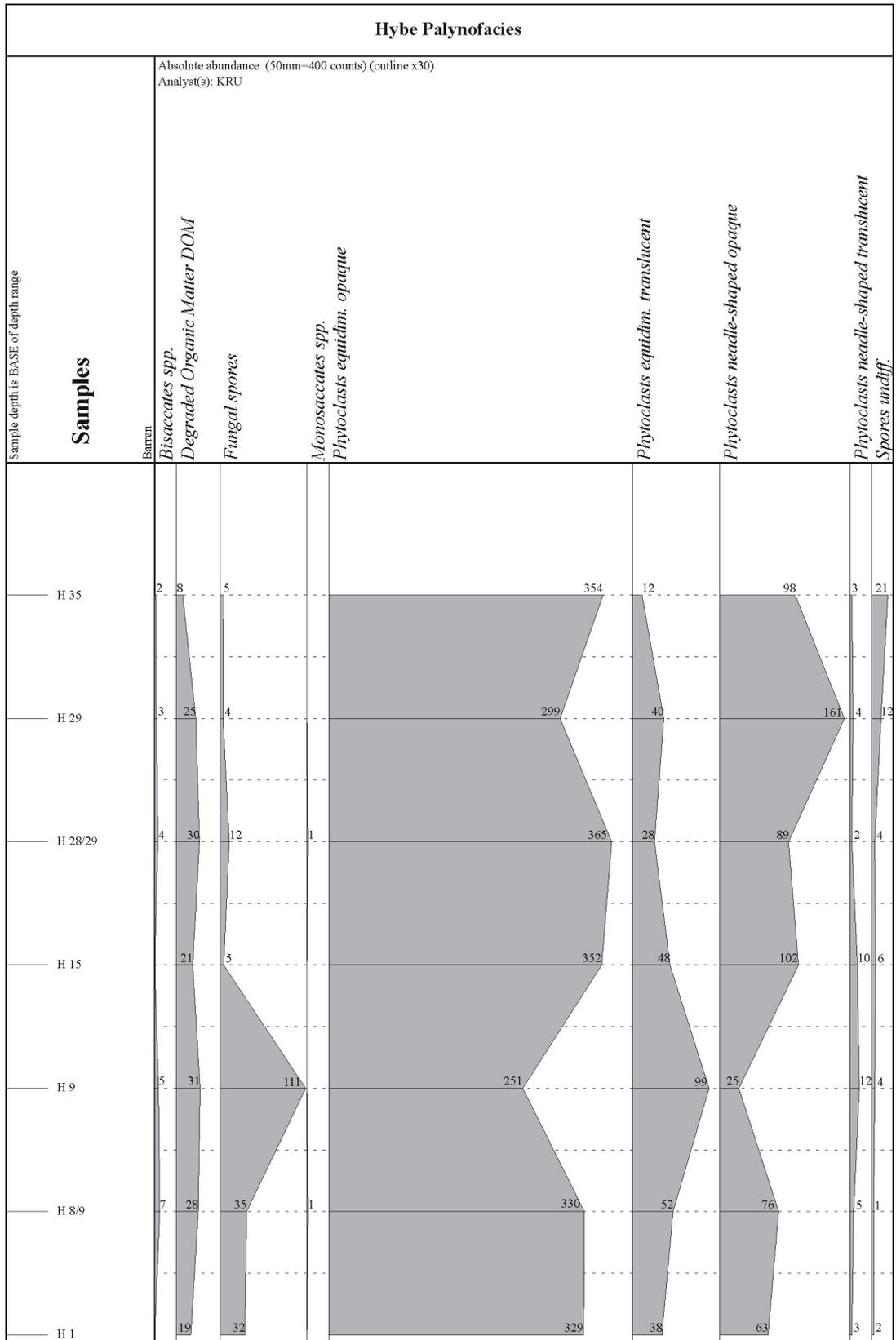


Fig 24: Palynofacies of the uppermost Rhaetian of the Hybe section (Tatra Mountains). A continuous increase of spores is observed during the complete interval.
Kardolína Section

Palynomorphs of the Kardolína section are poorly preserved. Marine particles were not identified, which is interpreted as an effect of the preservation. Due to the findings of marine invertebrates, it is quite evident that marine plankton played an important role within this marine environment. The fraction of terrestrial palynomorphs is mainly composed of trilete spores showing a gradual increase upsection (Fig. 25).

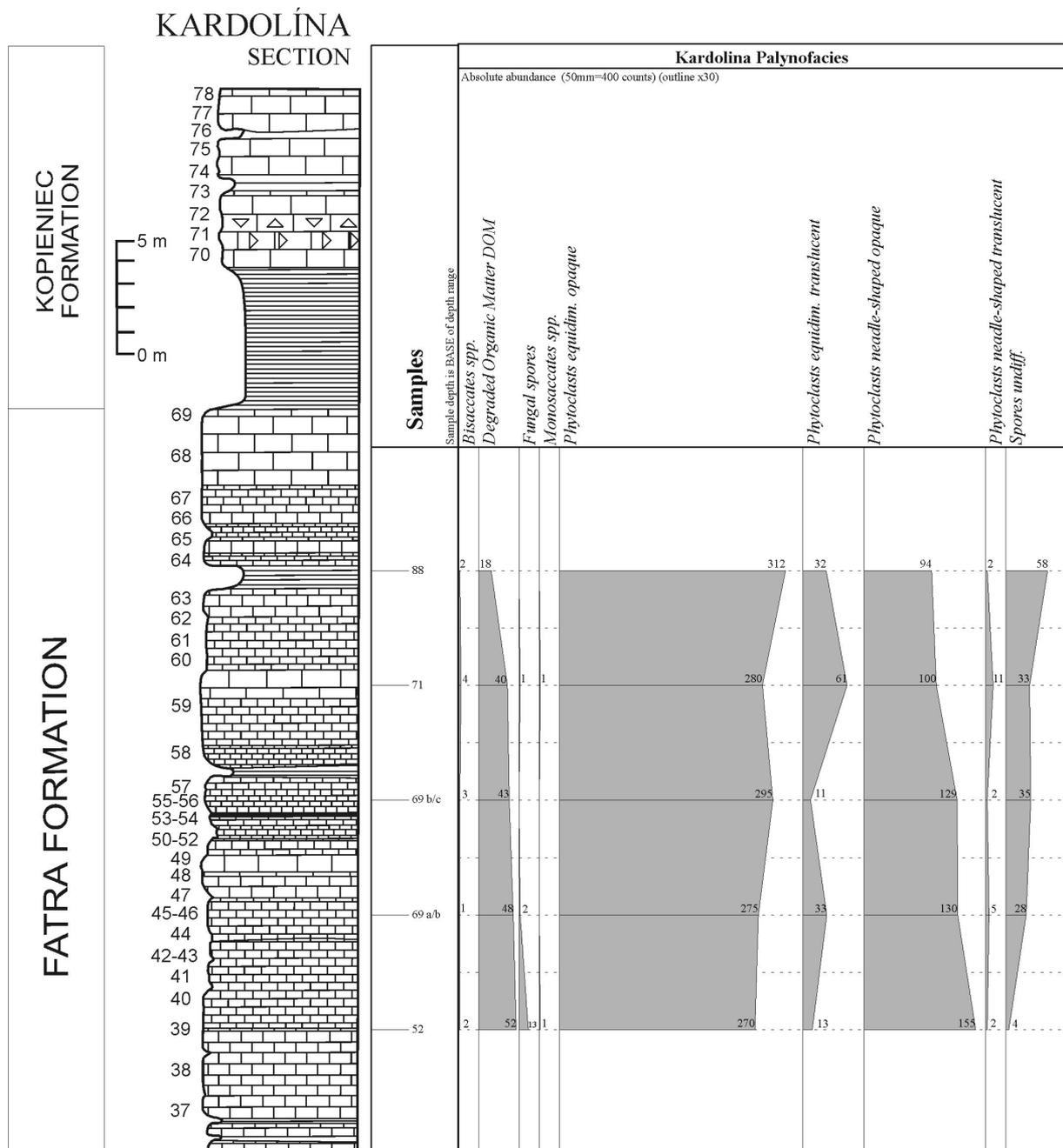


Fig. 25: Palynofacies within the Triassic/Jurassic boundary interval of the Kardolína section (Tatra Moutains).

Due to the poor preservation, the identification of genera and species was only in exceptional cases possible. Individuals of the following genera have been identified: *Ricciisporites*, *Ovalipollis*, *Deltoispora*, *Concavisporites*, *Trachysporites*, and *Corollina*. A decrease of the opaque needle-shaped phytoclasts is detected in the upper part of the section.

4.5.2 N Hungary

Csővár section

The studied samples of the lower part of the Vár-hegy section yield a typical Upper Rhaetian palynomorph assemblage, characterised by a high amount of Circumpolles (*Corollina*), *Rhaetipollis germanicus*, *Ovalipollis pseudoalatus* and numerous trilete spores such as *Acanthotriletes* spp., *Concavisporites* spp., *Deltoidospora* spp. The marine fraction is marked by foraminiferal test linings and prasinophytes of the genera *Tasmanites*, *Cymatiosphaera* and *Pterospermella*. A sudden increase in the abundance of prasinophytes (22 %) is recognized in Bed 47 (Fig. 4), corresponding to a peak abundance of trilete spores (35 %). Prasinophytes of the genus *Tasmanites* constitute the peak in Bed 47. The spore spike is documented by peak abundance of *Concavisporites* spp. and *Deltoidospora* spp. Acritarchs (*Micrhystridium* spp.) are very rare throughout the section and dinoflagellate cysts are absent.

Palynofacies of the sedimentary series exposed in the Vár-hegy section is dominated by terrestrial components. Numerous needle-shaped opaque particles, as well as a high amount of large translucent plant fragments (Fig.26) within the phytoclast group are a characteristic feature of the Rhaetian part of the section (Beds 21 to 49).

Palynofacies of the carbonates exposed in the upper part of the Vár-hegy section, dated as Early Hettangian based on radiolarians and ammonoids (Pálffy et al., 2007), is dominated by degraded organic matter, small equidimensional phytoclasts and foraminiferal test linings, pointing to a distal basinal setting (Beds 61 to 86).

The general dominance of terrestrial components throughout the section reflects a persistent high supply from the hinterland. The various preservation stages of terrestrial phytoclasts,

displayed in different sizes and shapes of plant debris as well as translucent to opaque particles, may point to the transport mechanism of sedimentary organic matter within the slope-to-basin setting, strongly related to the occurrence and frequency of turbidites along the slope. Fresh sedimentary organic material is transported into the basin by frequently occurring turbidity currents. The relative high amount of *Corollina* spp. points to semi-arid conditions of the hinterland, probably an island. The described microplankton assemblage, dominated by prasinophytes is characteristic of a permanently stratified deeper basin (cf. Tyson 1995).

The most striking feature of the entire succession is represented by synchronous peak abundances of spores and prasinophytes corresponding to the $\delta^{13}\text{C}$ negative excursion described by Pálffy et al. (2001, 2007). The sudden increase in the abundance of prasinophytes, known as „disaster species“ (Tappan, 1980; Van de Schootbrugge et al., 2007), may point to short-term changes of the ocean chemistry. The lack of dinoflagellate cysts and the very low abundance of acritarchs in the studied interval precludes the comparison of the reaction of these plankton groups with the observed prasinophyte signal. Significantly, the detected prasinophyte bloom correlates with the peak abundance of trilete spores (Fig. 27). Both signals, the marine and terrestrial, are recorded together in the Csóvár section which has not been reported from other marine Triassic/Jurassic boundary sections yet.

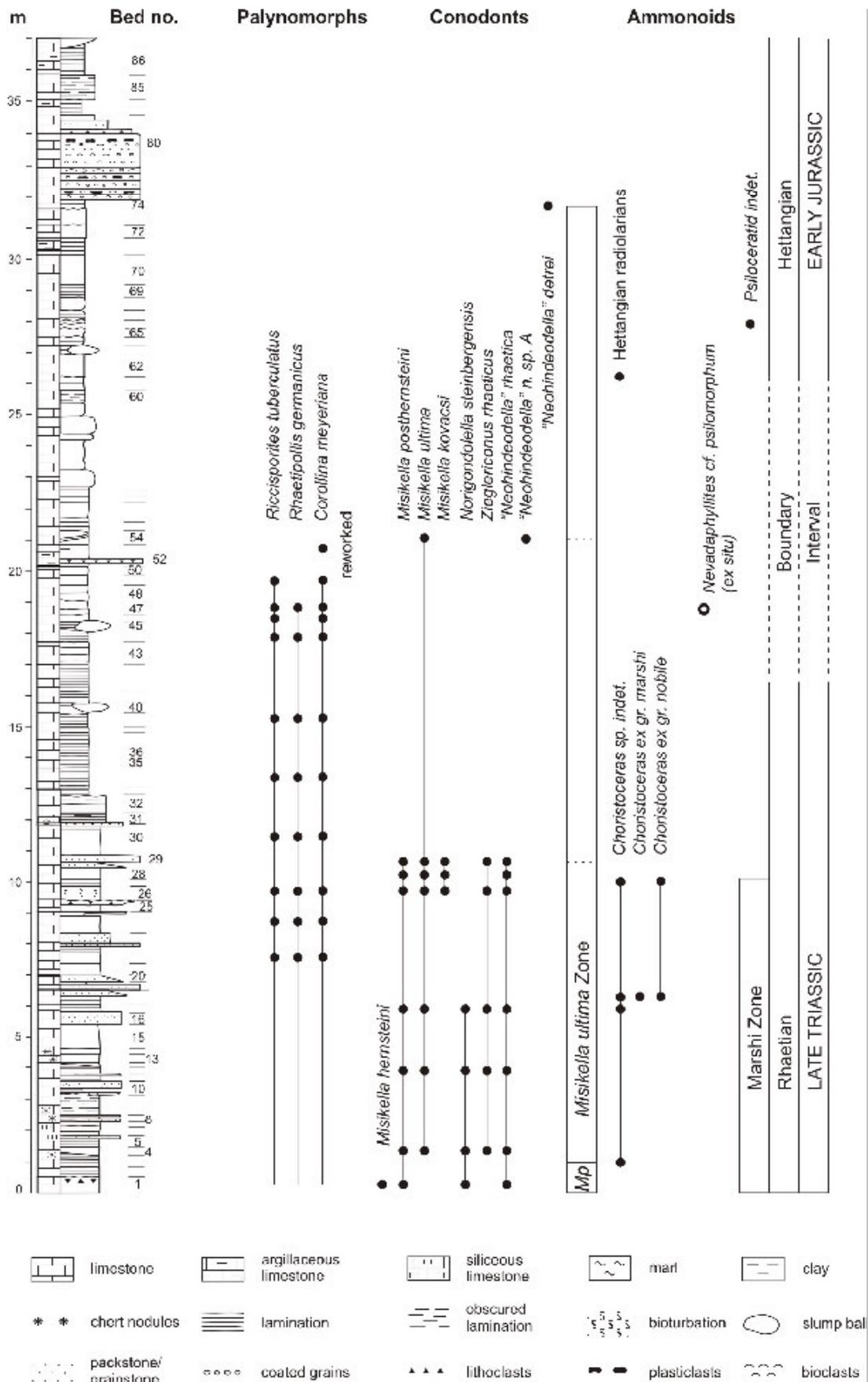


Fig. 26: Biostratigraphical data of the Csóvár section (after Pálfi et al. 2007).

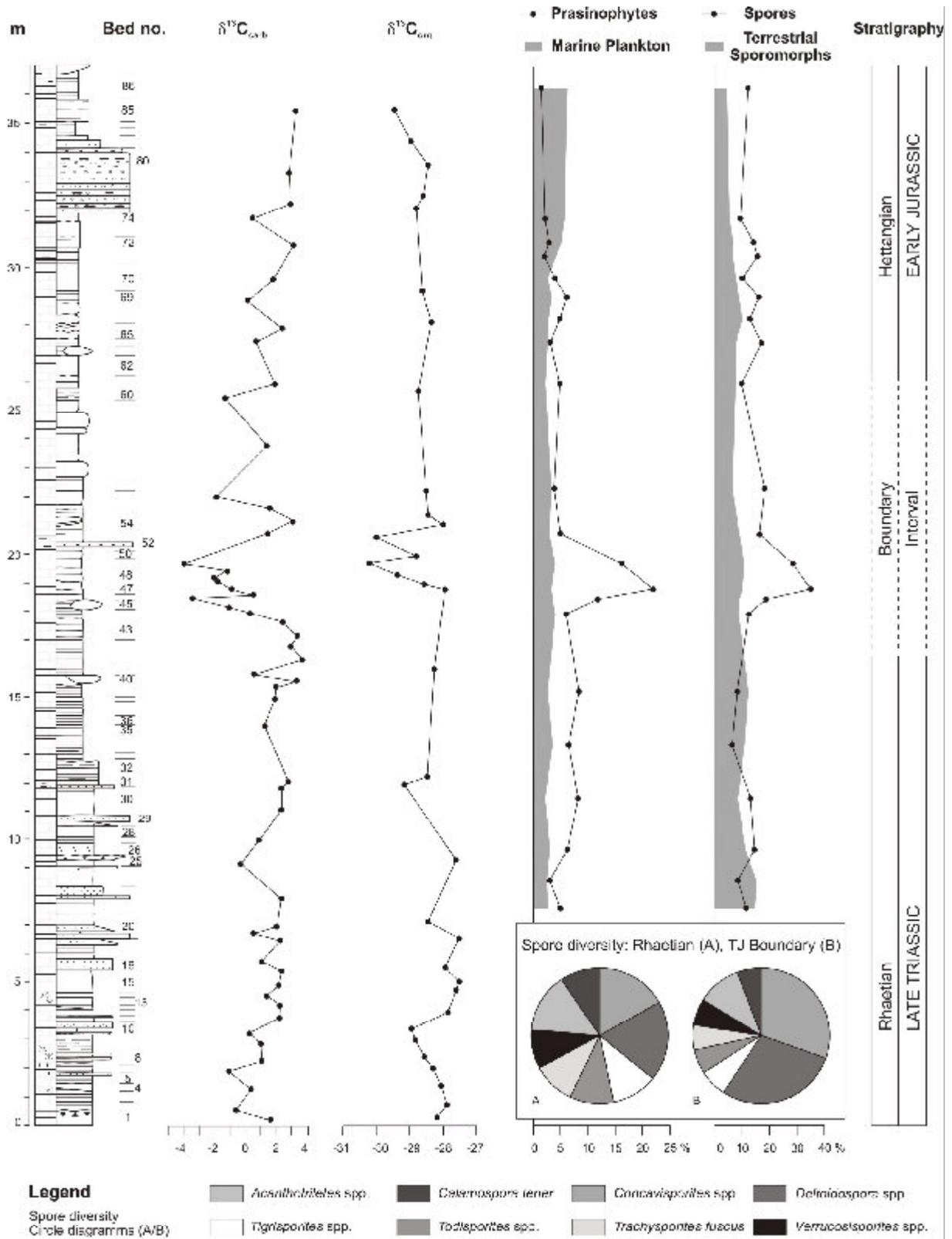


Fig. 27: $\delta^{13}\text{C}$ isotope data (after Pálffy et al. 2007) and palynofacies data of the Csóvár section. A simultaneous spore and prasinophyte spike occurs in the same interval as a negative isotope excursion.

4.5.2 S Hungary

Mecsek Mountains

Palynofacies analysis was carried out in marine series only, where terrestrial and marine fractions are present. The terrestrial series of the Mecsek Mountains have been studied with respect to environmental changes within the Triassic/Jurassic boundary interval by analysing the terrestrial sporomorph assemblages and sporomorph ecogroups, resp. (see chapter 7.3, 8.2).

5 Systematic Palynology

5.1 Palynology definition

The term palynology was introduced to literature by Hyde & Williams (1944). The word derived from the Greek *πάλυνω* (“I sprinkle”), suggestive of “fine meal”, which is cognate with the Latin *pollen* (“fine flour”, “dust”). Palaeopalynology is defined as the study of acid resistant organic microfossils that are found in sedimentary rocks (Traverse 1988).

5.2 Systematic Classification of palynomorphs

Recent palynological studies in the NW Tethyan realm focussed on the classical marine series of the Upper Triassic and basal Jurassic of the Northern Calcareous Alps (Holstein 2004, Kuerschner et al. 2007) and S England (van de Schootbrugge et al. 2007). Here, palynological data of Triassic/Jurassic boundary sections of the Tatra Mountains and the Transdanubian Range are presented for the first time.

Palynological studies of the Mecsek coal area have been carried out very detailed in the 60ies and 70ies of the last century with respect to economic mining. Unfortunately, the terminology used by J. Bóna is for many genera and species not related to published descriptions. Some of the genera and species have never been described officially. However, for comparison of the material of this study and the material analysed by Bóna, the nomenclature used by Bóna is applied. In that cases where a reliable classification is possible, the official botanical name is also mentioned below.

5.2.1 Terrestrial Palynomorphs

Laevigate trilete spores

Genus: *Aulisporites* LESCHIK 1954

Aulisporites astigosus (LESCHIK 1956a) KLAUS 1960

1956 *Calamospora astigmosa* sp. nov. – LESCHIK, p. 22, Plate 2 Fig. 17

1960 *Aulisporites astigosus* (Leschik) nov. Comb. – KLAUS, p. 119 - 120, Plate 28, fig. 2.

Genus: *Calamospora* SCHOPF, WILSON & BENTALL 1944

Calamospora tener (LESCHIK 1955) DE JERSEY 1962

1955 *Laevigatisporites tener* sp. nov. – LESCHIK, p. 13, Plate 1., Fig. 20.

1955 *Punctatisporites flavus* – LESCHIK, p. 31, Plate 4, Fig. 2.

1958 *Calamospora mesozoicus* – COUPER, p. 132, Plate 15/3+4.

1960 *Calamospora nathorstii* – KLAUS, p. 116, Plate 28, Fig. 1.

1962 *Calamospora tener* (LESCHIK) n. comb. - de Jersey, p. 3-4, Plate 1, fig 9 –10.

1964 *Calamospora tener* (LESCHIK 1955) n. comb. – MÄDLER (a), p. 92, Plate 8, Fig. 2.

Genus: *Cingulizonates* DYBOVA & JACHOWICS 1957

Cingulizonates rhaeticus (RHEINHARDT) SCHULZ 1967

1962 *Cingulizonates rhaeticus* sp. nov. – RHEINHARDT, p. 702, PLATE 2 FIG. 3

1964 *Anulatisporites drawehni* MAEDLER, p. 177, PLATE 2, FIGS. 1 – 2

1966 *Cingulizonates delicatus* ORLOWSKA – ZWOLINSKAP 1014, PLATE 7 FIGS 36 - 38

1967 *Cingulizonates rhaeticus* – SCHULZ P. 584, PLATE.13, FIG. 6- 7

Genus: *Concavisporites* THOMSON & PFLUG 1953

p. 49, Plate 1, Fig. 19

1953 *Concavisporites* gen. nov. – THOMSON & PFLUG, p. 49.

1959 *Toroisporites* gen. nov. – KRUTZSCH., p. 90.

Concavisporites crassexinius NILSSON 1958

p.35, Plate 1, Fig. d

1958 *Concavisporites crassexinius* sp. nov. – NILSSON, p. 35, Plate 1, Fig. 11.

Concavisporites mesozoicus sensu BÓNA

Comment: Sporomorphs described by Bóna as *C. mesozoicus* are comparable to *Concavisporites variverrucatus* described by COUPER 1958.

Concavisporites parvulus sensu BONA

The spores, described by Bóna as *C. parvulus* with a diameter of 20-24 µm are smaller as the other species of this genus.