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VOLVOCACEAN NATURE OF SOME PALAEOZOIC NON-RADIOSPHAERID CALCISPHERES AND PARATHURAMMINID "FORAMINIFERA"

Abstract. — A number of Devonian and Carboniferous microfossils generally referred to as non-radiosphaerid calcispheres or parathuramminid foraminifera are identified as poor preservations of the Devonian volvocacean alga *Eovolvox silesiensis*. The cell walls are decomposed and embedded in a calcareous matrix of combined early and late diagenetic origin. The main stages of the complex preservational history of the Devonian volvocaceans are discussed and each results in the formation of microfossils known so far as *Vicinesphaera* Antropov, *Polyderma* Dervillé, *Palaeocancellus* Dervillé, *Pachysphaerina* Conil & Lys, and *Archaesphaera* Suleimanov. These microfossils have a world-wide distribution and are particularly common in certain Upper Devonian and Lower Carboniferous limestones. They are often associated with radiosphaerid calcispheres and in the Devonian sometime with *Amphipora*. The presence of autochthonous and abundant volvocacean algae in sediments, up till now interpreted as marine or restricted marine deposits, probably indicates brackish (oligohaline) or fresh-water depositional environments similar to modern strongly eutrophized lakes. Volvocacean calcispheres appear to be a very sensitive paleoenvironmental indicator.

INTRODUCTION

The first unquestionable fossil colonial Volvocales (Chlorophyta) have been recently discovered by the author (Kaźmierczak, 1975) in thin sections of Upper Devonian (Frasnian) *Amphipora*-calcisphere limestone of southern Poland (Upper Silesia). Except for unusually well preserved volvocacean coenobia many colonies have been observed with more or less obliterated cell walls. Such forms are usually identified as the enigmatic microfossils long known as calcispheres or parathuramminid foraminifera. They are very common in certain Upper Devonian — Lower Carboniferous shallow water carbonates of Eurasia and North America.

The purpose of this paper is to show the main stages of the complex preservational history of volvocacean coenobia leading to the formation of structures often completely dissimilar to the initial organisms. Since the ecological status of all extant volvocacean algae is rather limited (eutrophized lakes and ponds) the possibility of deciphering the presence of such algae in ancient sediments appears to be very attractive for paleoenvironmental studies.

This paper has been prepared at the Palaeozoological Institute (abbreviated as ZPAL) of the Polish Academy of Sciences in Warsaw where the illustrated specimens (thin sections) are housed.

SYNOPSIS OF PALAEOZOIC CALCISPHERES

The term "*Calcisphaera*" was introduced by Williamson (1880) for microscopic (average diameter 80—170 μm) spherical hollow calcareous bodies of unknown affinity common in certain Lower Carboniferous rocks of Wales (UK) and Middle Devonian limestones of Ohio (USA). Since that time different calcispheric structures have been reported especially from the Devonian and Carboniferous carbonate deposits (for review see: Reitlinger, 1957; Stanton, 1967; Flügel & Hötzl, 1971).

Well preserved Palaeozoic calcispheres can be generally divided into radiosphaerid calcispheres (after typical forms known as *Radiosphaera* Reitlinger) armoured with more or less prominent, radially distributed external spines (pl. XIX, figs 1-3; pl. XX, fig. 4) and non-radiosphaerid calcispheres with generally a smooth external surface. In both groups the inside of the wall is always smooth and commonly circular in cross-section. The wall of radiosphaerid calcispheres is built by coarse calcite prisms usually radially arranged whereas that of non-radiosphaerid calcispheres and forms assigned sometimes to parathuramminid foraminifera is micritic or finely crystalline. The wall frequently contains an admixture of (?) organic substance making it opaque in transmitted light. In some non-radiosphaerid calcispheres (*Polyderma*) a multilayered structure of the walls has been noted (Dervillé, 1941). The layers in such calcispheres can be recognized by organic rich layers and varying crystal size. The possible genesis of such forms is given further in the text.

The central chamber of both groups of calcispheres is filled with two calcite cements (see also Stanton, 1963): (1) rims of radially arranged fibrous crystals extending inward with an average thickness of 10—15 μm, and (2) coarse, euhedral calcite filling the remainder of the cavity.

Different opinions have been expressed on the systematic position of Palaeozoic calcispheres excluding those which are charophyte oogonia and umbellas. They have been classified as foraminiferan (mostly parathuramminid) and radiolarian protozoans (e.g. Cayeux, 1929; Bykova, 1955; Conil & Lys, 1964; Chuvashov, 1965) or algal (mostly chlorophycean) reproductive cysts (e.g. Cayeux, 1929; Dervillé, 1931, 1941; Rupp, 1966). An inorganic origin for calcispheres has been postulated by Pia (1937).

Although it is possible to recognize most non-radiosphaerid calcispheres as permineralized remnants of volvocacean algae other calcispheres remain an enigma. I agree with Konishi (1958) that they probably belong to different groups of organisms. Various globular microfossils from Mesozoic and Tertiary strata described as calcispheres or calcispherulid structures (for review: Villain, 1975) are hardly comparable with the Palaeozoic forms mentioned above and were probably formed by different kinds of organisms.

STAGES OF PRESERVATIONAL HISTORY OF THE DEVONIAN VOLVOCACEAN ALGAE AND RESULTING CALCISPHERES

Four main stages in the complex preservational history of the Devonian volvocacean algae *Eovolvox silesiensis* Kaźmierczak can be recognized, each results in the formation of structures which can be identified with microfossils known so far as non-radiosphaerid calcispheres or parathuramminids. The colonies may be buried at any time during the stages of the preservational process.

Stage 1

Early postmortum lysis (hydrolysis, bacteriolysis, acetolysis etc.) of the cells and surrounding mucus stopped by eogenetic permineralization of colonies during shallow burial (text-fig. 1 A, D, G).

Discussion. — The circular outline of *Eovolvox* colonies shows evidence of very early diagenetic permineralization of colonies which protected them against compaction and further decay. Well preserved cell walls (pl. XXI, fig. 1; pl. XXII, fig. 4) indicate only slight postmortum decomposition which was limited to the mucous surrounding the coenobia. The main factors retarding decomposition of the cellulose cell walls in *Eovolvox* are thought to be similar to the present day processes which retard first of all bacteriolysis. High alkalinity and more or less anaerobic conditions near the bottom are the most effective antidecompositional factors (e.g. White, 1933; Krause, 1959; Degens & Mopper, 1975). Such conditions are characteristic for the bottom zone of eutrophic waters occupied very often by extant volvocacean algae. It can be assumed from experimental studies on carbonate precipitation evoked by bacterial breakdown of organic matter (e.g. Oppenheimer, 1961; Berner, 1968; McCunn, 1972; Krumbein, 1974) that rapid permineralization with $CaCO_3$ of volvocacean colonies was connected with strongly increased pH around the decaying algae. This was accompanied by a high concentration of Ca^+ ions in the water. Simultaneously reducing conditions at the water/sediment interface (dissolved H_2S) enabled the formation of iron sulphides within some mineralized colonies.

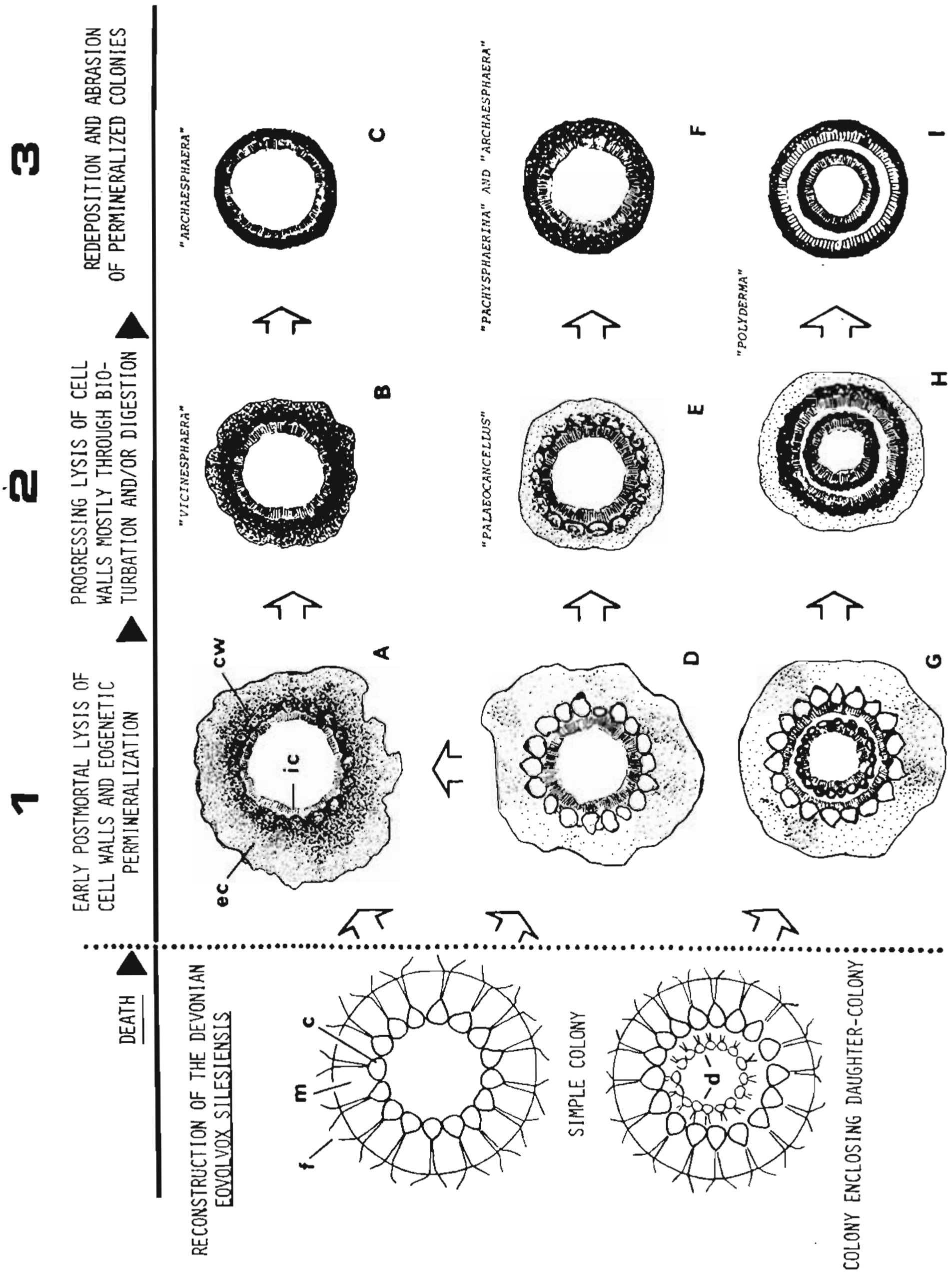

Fig. 1. Diagram showing the main stages of preservational history of the Devonian volvocacean alga *Eovolvox silesiensis* Kaźmierczak and resulting microfossils. *c* — cells, *cw* — cell walls, *d* — daughter-colony, *ec* — external calcareous coating, *f* — flagella, *ic* — internal calcareous coating (rim), *m* — mucus.

Resulting microfossils. — Buried at this stage permineralized volvocaceans show well preserved outlines of the cells. The colonies are embedded in thick, irregularly circular, calcitic coatings either finely-crystalline (text-fig. 1D; pl. XXI, fig. 1) or micritic (text-fig. 1A; pl. XXI, fig. 2). The internal chamber was lined at this stage by thin rim of fibrous calcite which in case of micritization of the external coating remains always clearly fibrous. These microfossils are easy identifiable as volvocacean algae (here *Eovolvox silesiensis*) represented by simple colonies (pl. XXI, fig. 1) or colonies enclosing daughter-colonies (pl. XXII, fig. 4). However even at this stage some colonies embedded in micritic calcite (pl. XX, fig. 1; pl. XXI, fig. 2) display a great similarity to microfossils known as *Vicinesphaera* Antropov which is frequently described from the Devonian and Carboniferous limestones particularly of the Soviet Union (e.g. Bykova, 1955; Chuvashov, 1965). It should be noted, that permineralized volvocacean colonies with well preserved cell walls are rarities among fairly common and widely distributed poorer states of preservation.

Stage 2

Progressing decomposition (lysis) of cell walls mainly through bioerosion (bioturbation and/or digestion) of partially or completely permineralized colonies results in the forms shown in text-fig. 1 B, E and H.

Discussion. — In indistinctly laminated bituminous micrite containing colonies with well preserved cell walls (pl. XIX, fig. 1) I have observed patchy accumulations of sediment with colonies in which the cell walls are almost completely obliterated. The calcareous coatings on such colonies are usually slightly thinner and their external outlines are much more circular than those of colonies with well preserved cells. The cell walls in these partially obliterated colonies are, as a rule, degraded in their external part. The patchy sediment is clearly more sparitic than the surrounding laminated micrite. It is concluded from the above that the primary organic rich volvocacean-bearing sediment has been in many places bioturbated and the presence of faecal pellets (pl. XIX, fig. 2) suggests digestion by burrowing deposit feeders. Through bioturbation the coatings of partially or completely permineralized colonies have been to some extent eroded and the cell walls underwent further degradation through oxidation and acidic reaction during digestive processes (pl. XX, figs 2-3; pl. XXI, fig. 3; pl. XXII, figs 2-3 and 5-6). The very strongly bioturbated character of some volvocacean-bearing sediments indicates that bioerosion may have played considerable role in the preservational history of these algae.

Resulting microfossils. — Most volvocacean colonies at this stage of their preservational history have lost almost all of their characteristic features and represent a sort of shadow-fossils. The majority of Devonian and Carboniferous non-radiosphaerid calcispheres and a few forms described as parathuramminid foraminifera represent this type of volvocacean preservation.

The effective obliteration of cell walls in volvocacean colonies embedded in dark, micritic calcareous substance (text-fig. 1B; pl. XX, figs 2-3; pl. XXI, fig. 3) results in structures originally described as *Vicinesphaera* Antropov or species of *Parathurammina* Suleimanov. They are often cited from Devonian and Carboniferous limestones of the Soviet Union (e.g. Bykova, 1955, pl. 3, fig. 2; Chuvashov, 1965, pl. 1, figs 11, 13-14; Brazhnikova & Vdovyenko, 1971, pl. 11, figs 8-10; Menner & Reitlinger, 1971, pl. 4, fig. 4a). *Vicinesphaera* has been also described from the Givetian of Germany (Flügel & Hötzl, 1971, fig. 2; 7) and from the Dinantian of Belgium (Conil & Lys, 1964, pl. 4, figs 17-18).

When the obliteration of cell walls is more advanced in the external zone of a colony and the deeper parts remain preserved, structures occur which are very similar to microfossils described usually as *Palaeocancellus* Dervillé (text-fig. 1E, pl. XXII, figs 1-3). In this case calcareous coatings are not so dark in transmitted light and are clearly more crystalline than in the *Vicinesphaera* type. Good examples of such structures are described as *Calcisphaera cancellata* by Williamson (1880, pl. 20, fig. 79) and Ozonkowa (1962, pl. 37, fig. 5), as *Palaeocancellus cancellatus* by Dervillé (1950, pl. 24, fig. 5) and Conil & Lys (1964, pl. 6, fig. 69). *Calcisphaera fimbriata* described by Williamson (1880, pl. 20, fig. 67) from the Welsh Carboniferous Limestone and calcispheroid structures reported by Baxter (1960, pl. 144, figs 4 and 9) from the Mississipian of Illinois and by Flügel and Hötzl (1971, fig. 3: 3, 4 and 8) from the Givetian of western Germany seem to represent very similar forms with slightly poorer preservation. It should be noted that not all forms actually assigned to *Palaeocancellus* represent volvocacean remnants. For instance structures described by Conil and Lys (1964) as *P. canaliculatus* (Derv.), *P. robustus* (Derv.) and *Palaeocancellus* sp. belong clearly to other organisms.

Bioeroded volvocacean colonies enclosing daughter-colonies can be easily identify with calcispheres described as *Polyderma* Dervillé. The main phases of origin of *Polyderma*-like structure from permineralized colony of the Devonian *Eovolvox silesiensis* containing a daughter-colony is shown on text-fig. 1G-I and pl. XXII, figs 4-6. Typical *Polyderma* have been illustrated by Dervillé (1941, pl. 7, fig. 5; 1950, pl. 14, figs 1, 4-5) and they come from the Carboniferous Limestone of northern France. Very similar forms have been described as *Polyderma chovanensis* Reitlinger by Brazhnikova and Vdovyenko (1971, pl. 1, fig. 27) from the Tournaisian of the Donets Basin. Forms described as *Eovolutina elementa* Antropov and *E. tulmasensis* Lipina (Lipina, 1955, pl. 2, figs. 5-7) from the Tournaisian of the Volgo-Uralian province seem to represent also remnants of volvocacean colonies enclosing daughter-colonies. Very interesting forms of *Polyderma* are those composed of three more or less concentrically arranged spheres (e.g. *Polyderma polyderma* — see Dervillé, 1941, pl. 7, fig. 5, and *P. incertum* — see Dervillé, 1950, pl. 14, fig. 5). Such forms undoubtedly represent colonies of volvocacean algae in which a daughter-colony is producing another daughter-colony before liberation from the parent colony. Such phenomenon is well known in some extant volvocaceans (e.g. *Volvox africanus*) in which up to four generations can be formed in the parent-colony (Chapman, 1964, p. 31). Multispherical *Polyderma* can be very easily detected in thin sections even when the cell walls are completely obliterated (pl. XXII, fig. 6).

Stage 3

Redeposition and abrasion of permineralized colonies (text-fig. 1 C, F and I).

Discussion. — There is good evidence that the permineralized volvocacean colonies were commonly redeposited in a new sedimentary environment with a completely different biota (pl. XIX, fig. 3). During this redeposition they underwent abrasion which considerably diminished the thickness of their calcareous coatings. This abrasion may even remove the zone in which the cells are distributed. However, the degree of abrasion observed in the same thin section may vary suggesting origins different for particular colonies (pl. XX, fig. 3). The redeposition results in oxidation of cell walls and any other organic matter still present in the calcareous matrix of coatings. The main destructive factor is thought to be the high redox potential of the turbulent environment of redeposition. As a result no traces of the primary volvocacean structure (cell walls) can be detected in colonies which passed through this stage. Usually only dark, micritic thin-walled spheres remain from abraded and finally decomposed colonies (pl. XXI, fig. 4).

Resulting microfossils. — Abraded permineralized colonies of the Devonian *Eovolvox silesiensis* display a great similarity to globular microfossils usually termed *Archaesphaera* Suleimanov or *Pachysphaerina* Conil & Lys (text-fig. 1C and F; pl. XXI, fig. 4). They are widely distributed in some Devonian and Carboniferous shallow water carbonates and are classified as parathuramminid foraminifera or as calcispheres (for review, Flügel & Hötzl, 1971). It is not easy to determine in uniformly reworked well-sorted sediment if all such forms represent abraded volvocacean colonies. Very similar structures could have been formed as a result of abrasion of radiosphaerid calcispheres which are very often associated with volvocaceans. They can be however distinguished from the latter by the clearly crystalline, coarse granular structure of their walls. Examples of spherical microfossils of *Archaesphaera-Pachysphaerina* type of either volvocacean (dark micritic walls) or radiosphaerid (granular crystalline walls) origin can be seen in Baxter (1960, pl. 144, figs 2-3, 12 and 14), Conil & Lys (1964, pl. 4, figs 36-40; pl. 6, figs 59-68), and Brazhnikova & Vdovyenko (1971, pl. 4, figs 13-15, 19-20). A common feature of all these microfossils is their distribution in high-energy sediments, mostly sparry calcarenites.

Stage 4

Final burial of permineralized colonies and late diagenetical processes.

Discussion. — After final burial which often took place in a quite diferent environment than the eogenetic permineralization, the remaining hollow chambers of colonies have been filled by blocky calcite. It is apparently later than the fibrous internal rims and has been most probably introduced to the colonies during late diagenesis. The blocky calcite cement is present in all colonies regardless of the stage of their preservational history when they were finally buried.

PALAEOENVIRONMENTAL SIGNIFICANCE OF VOLVOCACEAN CALCISPHERES

The detection of the volvocacean nature of some non-radiosphaerid calcispheres and forms assigned so far to parathuramminid foraminifera is thought to be of great importance for palaeoenvironmental interpretation. This is because modern members of the volvocacean algae are exclusively inhabitants of fresh water and it is highly probable that the Devonian volvocaceans represented by the excellently preserved *Eovolvox silesiensis* had the same or very similar ecological requirements. Most extant volvocaceans are limited to very shallow and strongly eutrophized (i.e. enriched in dissolved organic substances) lakes and ponds (e.g. Pringsheim & Pringsheim, 1959). Such environments are characterized by high alkalinity and high content of Ca^{+} (Elster, 1958). It is commonly known that such conditions are very favourable for calcium carbonate precipitation. The formation of eogenetic calcareous coatings on the Devonian volvocacean algae and the presence of internal rims indicate very similar environmental conditions. Summarizing, I suggest that in the case of *in situ* deposited volvocacean calcispheres the sediment enclosing them was most probably of lacustrine or very brackish (oligohaline) origin. Such a sedimentary environment has been postulated (Kaźmierczak, 1975) for the Frasnian black bituminous *Amphipora*-calcisphere limestone from southern Poland with abundant *Eovolvox silesiensis*. Associated with volvocaceans in these sediments are abundant radiosphaerid calcispheres, problematical foraminifera *Parathurammina* and *Irregularina*, and occasionally the enigmatic alga *Uraloporella*. Sediments of this type have so far been interpreted as products of marine or restricted marine environment (back-reef or lagoonal facies — e.g. Klovan, 1964; Stanton, 1967; Reid, 1973).

Sediments containing volvocacean calcispheres *in situ* are extremely rare. Normally the algae after permineralization have been redeposited and mixed with what is described as a marine biota; commonly with different stromatoporoids and tabulate corals, and to a lesser degree with tetracorals, calcareous foraminifera, brachiopods and crinoids. As allochems volvocacean calcispheres are therefore indicative of a close proximity of areas with very low, most probably lacustrine salinity within more or less normal marine conditions.

The abundance of volvocacean calcispheres in many Devonian and Carboniferous shallow-water limestones suggests that the areas occupied by these organisms were extensive and characterized by very high phytoplankton production. The lack of terrigenous material in *in situ* deposited volvocacean-bearing sediments indicates the off-shore position of these environments. Such a conclusion is supported by the known palaeogeographic position of these sediments. It is suggested that in very shallow epeiric seas during the Devonian and Carboniferous broad areas of shoals and blue-green algal marshes (the latter producing the so called laminites) existed which during prolonged periods of humid climate and heavy precipitation produced salinities low enough to encourage the colonization of a fresh-water algal biota. Today such extensive off-shore lacustrine or highly brackish areas with carbonate sedimentation are unknown. A small scale modern analogue of the close coexistance of marine and fresh-water environments with carbonate sedimentation induced by algal activity is Andros Island (Monty, 1972). However, the low salinity of large parts of ancient epeiric seas documented by the presence of abundant volvocacean algae in the Devonian-Carboniferous carbonate sequences appears to be a non-actualistic phenomenon. This very intriguing problem needs further special studies.

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TOCZKOWCOWE POCHODZENIE NIEKTÓRYCH PALEOZOICZNYCH KALCYSFER I PARATURAMINIDOWYCH „OTWORNIC"

Streszczenie

Szereg dewońskich i karbońskich problematycznych mikroskamieniałości odnoszonych najczęściej do kalcysfer lub paraturaminidowych otwornic reprezentuje różne typy fosylizacji kolonii toczkowców identycznych lub zbliżonych do unikalnie zachowanych *Eovolvox silesiensis* Kaźmierczak opisanych z wapieni górnego dewonu (franu) Górnego Śląska. Zrekonstruowane zostały główne etapy złożonego procesu fosylizacji dewońskich toczkowców, w rezultacie którego doszło do powstania struktur biosedymentacyjno-diagenetycznych znanych w literaturze mikropaleontologicznej jako *Vicinesphaera* Antropov, *Polyderma* Dervillé, *Palaeocancellus* Dervillé, *Pachysphaerina* Conil & Lys i *Archaesphaera* Suleimanov. Struktury te charakteryzują się światowym rozprzestrzenieniem i są szczególnie częste w niektórych typach wapieni górnego dewonu i dolnego karbonu. W osadach *in situ* są one zwykle stowarzyszone z kalcysferami radiosferowymi, a w dewonie także czasami z *Amphipora*. Obecność licznych, autochtonicznych kolonijnych toczkowców w osadach uważanych dotychczas za morskie wydaje się raczej wskazywać na brakiczne (oligohalinowe) lub słodkowodne środowisko sedymentacji tych osadów, zbliżone do dzisiejszych silnie zeutrofizowanych jezior. Toczkowcowe kalcysfery mogą zatem stanowić nowy, bardzo czuły wskaźnik gradientów zasolenia niektórych peryferycznych obszarów dawnych zbiorników epikontynentalnych.

ЮЗЕФ КАЗЬМЕРЧАК

ВОЛЬВОКСОВОЕ ПРОИСХОЖДЕНИЕ НЕКОТОРЫХ ПАЛЕОЗОЙСКИХ КАЛЬЦИСФЕР И ПАРАТУРАМИНИДНЫХ „ФОРАМИНИФЕР”

Резюме

Ряд девонских и каменноугольных проблематических микроокаменелостей, чаще всего относимых к кальцисферам или паратураминидным фораминиферам, представляет разные виды фоссилизации колоний сильно напоминающих уникальные *Eovolvox silesiensis* Kaźmierczak, распространенные в верхнедевонских (франских) известняках Верхней Силезии. Производится реконструкция основных этапов сложного процесса фоссилизации девонских Volvocales в итоге которого образовались биоседиментационно-диагенетические структуры, известные в микропалеонтологической литературе под названиями *Vicinesphaera* Antropov, *Polyderma* Dervillé, *Palaeocancellus* Dervillé, *Pachysphaerina* Conil & Lys и *Archaeosphaera* Suleimanov. Эти структуры характеризуются глобальным распространением и особенно часто встречаются в некоторых типах известняков верхнего девона и нижнего карбона. В непереотложенных осадках они обычно сопровождают радиосфорические кальцисферы, а в девоне иногда и амфипоры. Наличие многочисленных колониальных автохтонных Volvocales в осадках, которые до сих пор считались морскими отложениями, свидетельствуют, вероятнее всего, об опресненной (олигогалинной) или пресноводной среде осадконакопления, напоминающей современные сильно эутрофные озера. Из сказан-

ного следует, что описанные формы могут представлять новый, весьма чувствительный показатель степени солености некоторых периферических зон древних эпиконтинентальных бассейнов.

EXPLANATION OF PLATES

Plate XIX

Fig. 1. Volvocacean (V) and radiosphaerid (R) calcispheres in *in situ* deposited bituminous limestone. ZPAL Al. III/1; Upper Devonian (Frasnian) of Upper Silesia (Sosnowiec IG-1 borehole, depth 2385—2395 m), southern Poland.

Fig. 2. Volvocacean (V) and radiosphaerid (R) calcispheres in bioturbated and digested volvocacean bearing sediment with abundant faecal pellets (P) and lumpy intraclasts (I). ZPAL Al. III/40d; Upper Devonian (Frasnian) of Upper Silesia (Sosnowiec IG-1 borehole, depth 2385—2395 m), southern Poland.

Fig. 3. Abraded volvocacean (V) and radiosphaerid (R) calcispheres in high-energy intrabiosparite with irregular intraclasts (I). ZPAL Al. III/B8; Upper Devonian (Frasnian) of the western Holy Cross Mts., Poland.

Bar scale for all 0.5 mm

Plate XX

Fig. 1. Two permineralized volvocacean (*Eovolvox silesiensis* Kaźm.) colonies with differently decomposed cell walls. The upper colony resembles "*Vicinesphaera*" stage of preservation. ZPAL Al. III/2, stage coordinates: 60.2/9.0.

Fig. 2. Two volvocacean (*Eovolvox silesiensis* Kaźm.) colonies with almost completely decomposed cell walls and micritized calcareous coatings ("*Vicinesphaera*" stage of preservation). ZPAL Al. III/50b, stage coordinates: 56.5/13.3.

Fig. 3. Two volvocacean (*Eovolvox silesiensis* Kaźm.) colonies with differently abraded calcereous coatings. The less abraded colony represents "*Vicinesphaera*" stage of preservation, the more abraded is near "*Archaesphaera-Pachysphaerina*" stage. ZPAL Al. III/50e, stage coordinates: 52.9/13.3.

Fig. 4. Poorly preserved volvocacean (*Eovolvox silesiensis* Kaźm.) calcisphere (upper half of the photograph) with decomposed cell walls and micritized calcareous coating ("*Vicinesphaera*" stage of preservation) compared with a typical radiosphaerid calcisphere (below). ZPAL Al. III/112A, stage coordinates: 45.5/14.3.

Upper Devonian (Frasnian) of Upper Silesia (Sosnowiec IG-1 borehole, depth 2385—2395 m), southern Poland; bar scale for all 50 μm.

Plate XXI

Figs 1-4. Main stages of preservational history of volvocacean (*Eovolvox silesiensis* Kaźm.) colonies showing: fig. 1 — well preserved colony embedded in crystalline calcareous coating, fig. 2 — a colony with partially decomposed cell walls and micritized coating (*Vicinesphaera*-like stage), fig. 3 — a colony with wholly decomposed cell walls and heavily micritized calcareous coating (typical "*Vicinesphaera*" stage), fig. 4 — strongly abraded colony ("*Archaesphaera-Pachysphaerina*" stage). fig. 1 — ZPAL Al. III/4, stage coordinates: 52.3/21.2; fig. 2 — ZPAL Al. III/50b, stage coordinates: 57.2/14.5; fig. 3 — ZPAL Al. III/50b, stage coordinates: 55.3/13.7; fig. 4 — ZPAL Al. III/50e, stage coordinates: 54.9/9.7;

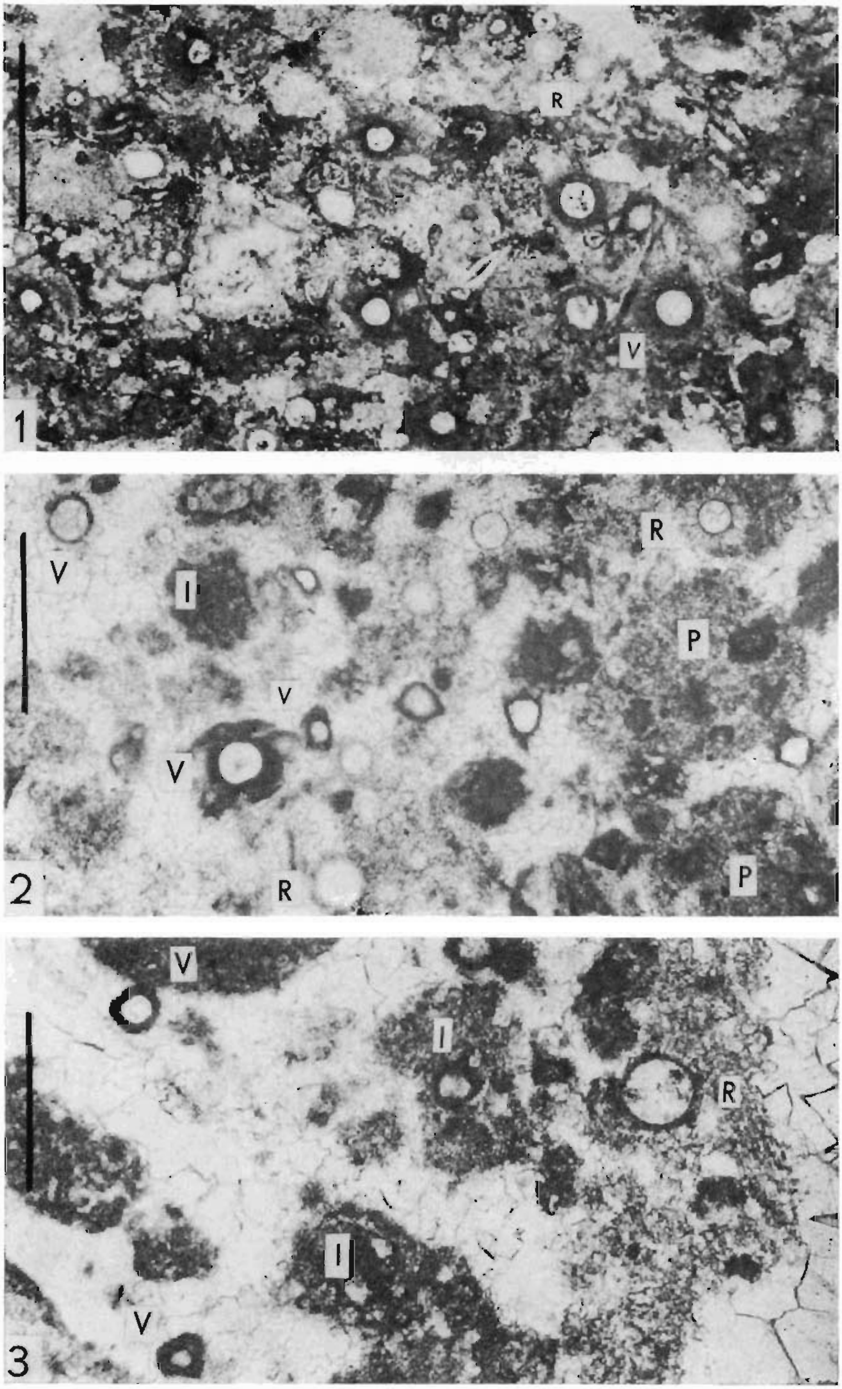
Upper Devonian (Frasnian) of Upper Silesia (Sosnowiec IG-1 borehole, depth 2385—2395 m), southern Poland; bar scale for all 30 μm.

Plate XXII

Figs 1-3. Three permineralized volvocacean (*Eovolvox silesiensis* Kaźm.) with partially decomposed cell walls. Forms illustrated on figs 1 and 2 represent typical "*Palaeocancellus*" stage of volvocacean preservation. fig. 1 — ZPAL Al. III/14, stage coordinates: 57.5/18.4; fig. 2 — ZPAL Al. III/60d, stage coordinates: 41.4/20.0; fig. 3 — ZPAL Al. III/60m, stage coordinates: 49.8/14.4.

Figs 4-6. Three permineralized volvocacean (*Eovolvox silesiensis* Kaźm.) colonies containing daughter-colonies. The colony on fig. 4 is preserved with cell walls, those on figs 5 and 6 with decomposed cell walls represent "*Polyderma*" stage of volvocacean preservation. fig. 4 — ZPAL Al. III/60m, stage coordinates: 48.7/16.2; fig. 5 — ZPAL Al. III/80a, stage coordinates: 49.5/14.5; fig. 6 — ZPAL Al. III/50e, stage coordinates: 60.5/19.1;

Upper Devonian (Frasnian) of Upper Silesia (Sosnowiec IG-1 borehole, depth 2385—2395 m), southern Poland; bar scale for all 30 μm.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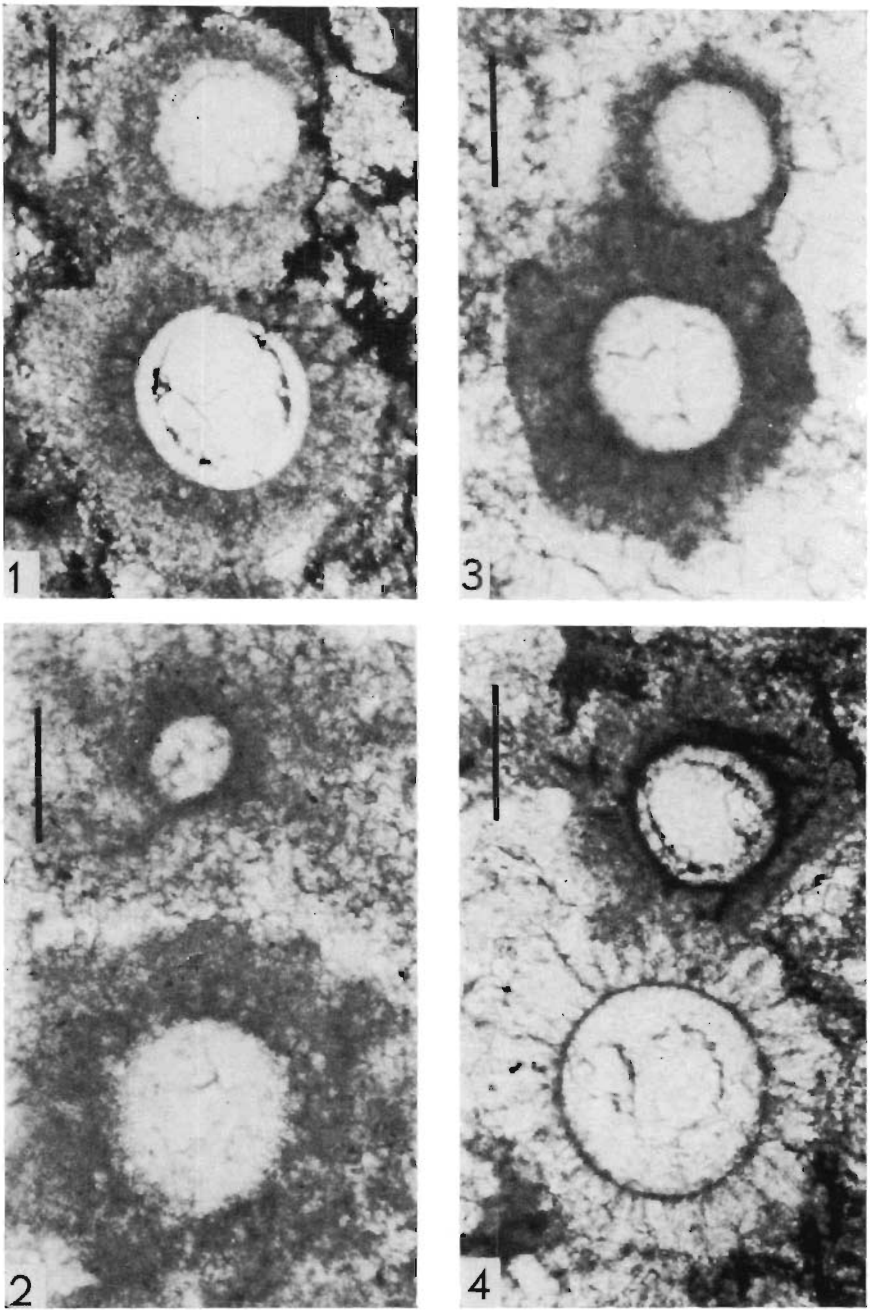
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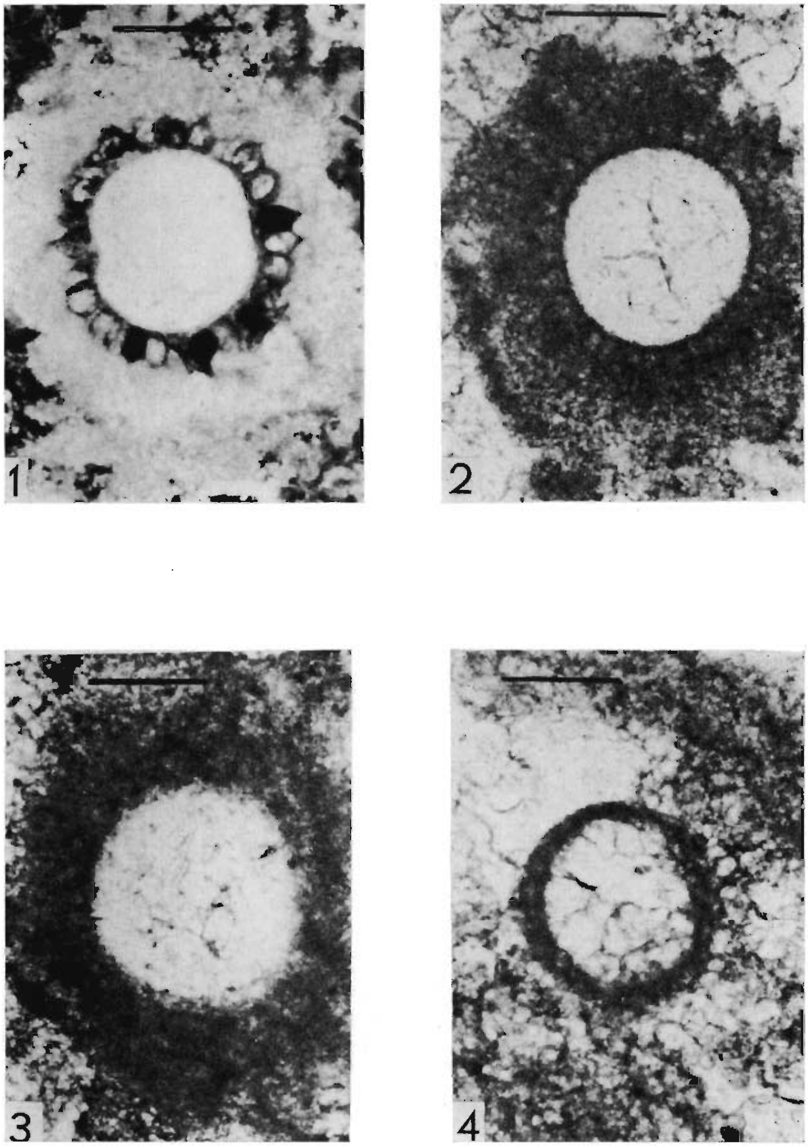
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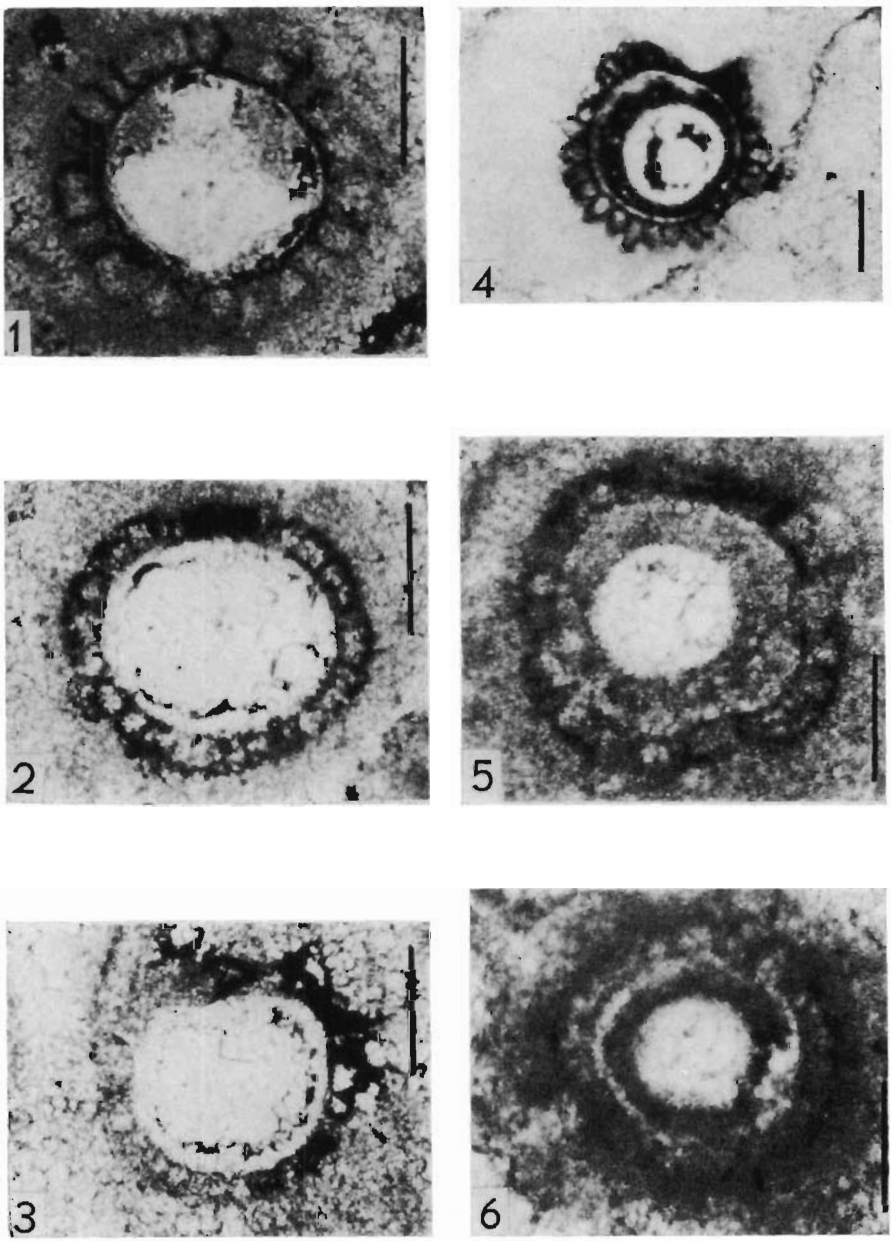
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