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Carnian (Late Triassic) charophyte flora of the *Paleorhinus* biochron at Krasiejów (SW Poland)

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with 1 table, 6 figures and 1 plate

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Keywords: Charophyta, Triassic, Carnian, *Paleorhinus*, Germanic Basin, Poland.

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Abstract

Sediments from around the bone-bearing horizon of Late Carnian age at Krasiejów, south-western Poland, include an abundant charophyte flora preserved as calcitized oospores (gyrogonites). The assemblage consists of four organ-species: *Stellatochara germanica* KOZUR & REINHARDT, *Stomochara starozhilovae* (KISIELEVSKY), *Porochara triassica* (SAIDAKOVSKY) and variable morphologically *Stenochara kisielevkyi* BILAN. The most abundant assemblage lived during sedimentation of the bone-bearing bed. Higher in the succession, charophyte numbers dropped drastically due to environmental change to more saline or more turbulent conditions. The preliminary geochemical analysis has shown that an increase in salinity might have been the main limiting factor of charophyte growth.

Zusammenfassung

Sedimente im Bereich eines vertebratenführenden Niveaus im Oberkarn bei Krasiejów, SW Polen, enthalten eine reiche Charophyten-Flora in Form calcifizierter Oogonien (Gyrogonite). Die Vergesellschaftung besteht aus vier Arten: *Stellatochara germanica* KOZUR & REINHARDT, *Stomochara starozhilovae* (KISIELEVSKY), *Porochara triassica* (SAIDAKOVSKY) und (morphologisch variable) *Stenochara kisielevkyi* BILAN. Die reichste Flora tritt zur Zeit der Ablagerung des Vertebratenhorizonts auf. In jüngeren Profilabschnitten geht die Zahl der Charophyten aufgrund der Zunahme von Salinität und Turbulenz drastisch zurück. Erste geochemische Analysen belegen, dass die Zunahme der Salintät den entscheidenden limitierenden Faktor darstellte.

1 Introduction

The *Paleorhinus* biochron was introduced by HUNT & LUCAS (1991) for the Upper Triassic deposits containing characteristic phytosaurs of the genus *Paleorhinus*. The *Paleorhinus* assemblage (sensu LUCAS, 1998), together with additional vertebrates (e.g. metoposaurids, aetosaurids) is distinctive and thus of great biochronological significance throughout Pangea (HUNT & LUCAS, 1991).
Recently, the ninth site with Late Triassic *Paleorhinus* assemblage was identified in south-western Poland (DZIK et al., 2000; DZIK, 2001). Apart from a rich vertebrate fauna, the deposits are extremely fossiliferous in charophyte gyrogonites. Although Tertiary and Quaternary gyrogonites have been studied extensively (e.g. SOULIÉ-MÄRSCHE, 1998; BHATIA et al., 1998; BERGER, 1999; HAAS, 1999; ZHAMANGARA & LUCAS, 1999), no important data concerning Late Triassic specimens arose since 1988 (BILAN, 1988; BREUER, 1988). The abundant charophyte flora from Krasiejów allows an examination of their diversity, as well as of the Late Triassic habitat during the sedimentation of vertebrate-rich bed.

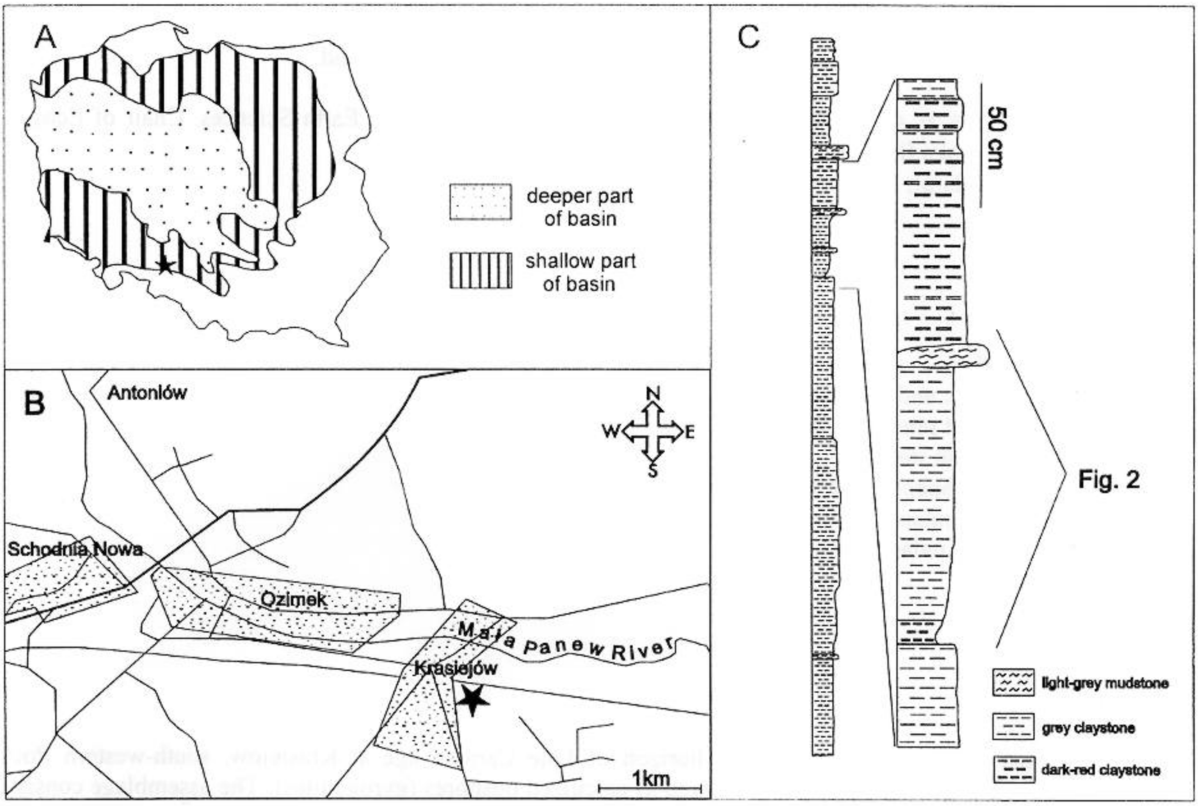

Fig. 1: Map of Poland with investigated site of eastern part of the Late Triassic Germanic Basin (after DZIK et al., 2000); B - detailed localization of investigated site; C - general section outcroped at Krasiejów (after DZIK et al., 2000) with the studied portion.

2 Stratigraphic and lithologic setting of charophyte-rich deposits

The investigated site is located at Krasiejów village, in the Opole Silesia region of south-western Poland (fig. 1a & b). The abandoned quarry consists of Keuper (Upper Triassic) dark-red and grey, alternating claystones and mudstones (fig. 1c). The sampled portion of the sequence at Krasiejów comprises four beds (fig. 2). The lowermost layer consists of dark-red claystone, which is overlain by grey claystone with numerous remains of Triassic land-tetrapodes: the main bone-bearing bed (DZIK et al., 2000). Above, a dark-red bed occurs with calcareous concretions, which may also include bone fragments. At the top of this bed, accumulations of bivalve moulds of the genus *Unionites* appear. The final studied bed consists of light-grey mudstone. Above these beds, the sequence continues in a characteristic colour-cyclic pattern.
The bone-bearing level corresponds to the Drawno Beds and is probably coeval with the Lehrberg Beds in the western part of the Germanic Basin (SULEJ, 2002). This level lies above the Reed Sandstone - the equivalent of

German Schilfsandstein Formation - which contains similar vertebrate assemblage. Radiometric dating of the Schilfsandstein (KÖPPEN & CARTER, 2000) indicates a Middle Carnian age. Therefore, DZIK et al. (2000) proposed a Late Carnian age for the bone-bed at Krasiejów. This is also supported by findings of *Paleorhinus* in marine deposits of Late Carnian age in Austria (LUCAS, 1998).

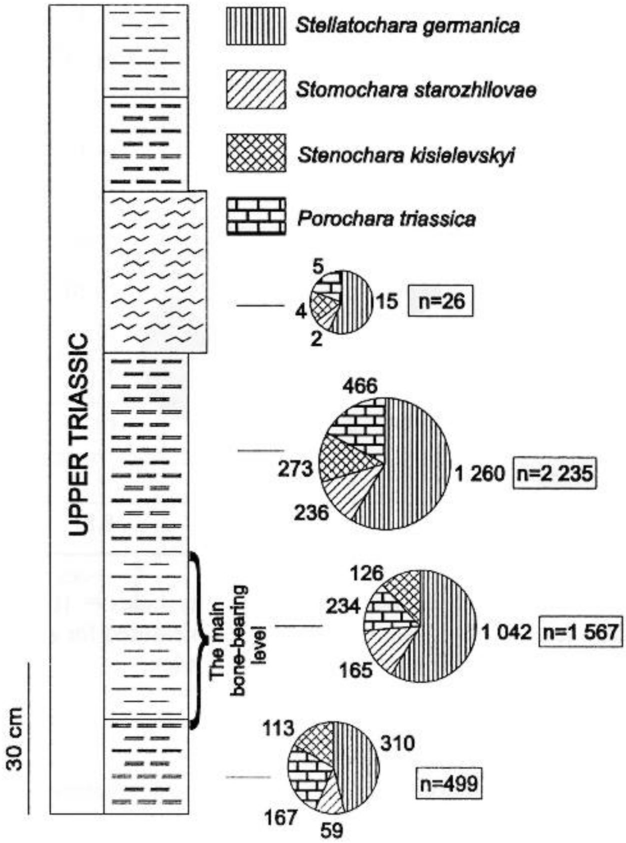

Fig. 2: Sampled succession around the *Paleorhinus* horizon (compare fig. 1) and composition and frequency of charophyte associations (number of gyrogonites per sample).

2 Material and preservation

Four samples of 1 kg in weight were taken from around the bone-bearing bed in the investigated section (fig. 2). The samples were disintegrated in a solution of glauber salt. The samples were washed using 0.03, 0.25 and 0.315 mm sieves. After drying the fractions at 80 °C, oospores, associated ostracodes, and vertebrate teeth were picked under a binocular. The number of oospores per kilogram of sediment varies from several to more than three thousand specimens. The total number of each organ-species (fig. 2) is presented to show the absolute abundance of charophyte flora in each sample. The authors' collection is housed at the Department of Earth Sciences of Silesian University, Sosnowiec (abreviated GIUS 7-2315-2318 Kras 1- 4).

The preservation of gyrogonites is mostly good to very good. However, the ornamentation of some specimens is not visible due to recrystalization. Some specimens are covered by dark organic matter (pl. 1, fig. 12). The colour of the gyrogonites is light-brown and amber-coloured. Very few specimens are black what may be caused by diagenetic processes (see BILAN, 1988).

4 Biometry and statistics

Determination of oospores has been carried out using morphological observations and biometric analyses based on BILAN (1974, 1988) and SOULIÉ-MÄRSCHE (1998). The standard measurable parameters as length (L), width (W) and isopolarity index (ISI) of all morphotypes has been statistically tested using *test d* (ELLIOTT, 1977). This test operates on variations and mean values of all variables, and requires the samples of $n > 50$. When $d > 1,96$ therefore the differences between the mean values are statistically significant at 5 % ($p = 0,05$); $d > 2,58$, the differences are statistically significant at 1 % ($p = 0,01$); $d > 3,29$ the differences are statistically significant at 0,1 % ($p = 0,001$). The difference between the mean values of all morphotypes is statistically significant at 5 % ($p = 0,05$), 1 % ($p = 0,01$) and even at 0,1 % ($p = 0,001$), thus all morphotypes differ significantly enough to be separate species. Taking into account the high variability among charophyte gyrogonites, we also decided to test subfossil oospores described in the literature to see if they also statistically differ. We chose two populations of *Lamprothamnium papulosum* from the Early Holocene of Mauritania, because of the many visible morphotypes of this species (SOULIÉ-MÄRSCHE, 1998). In this case *test d* also showed significant differences between these populations at 1 % (length) and 0,1 % (width and ISI). It is now clear that all morphotypes differ significantly. Therefore, we grouped all morphotypes from Krasiejów into four species, on the basis of non-measurable features, especially the character of the apical pole, which is different in these species. Standard biometrical and statistical data of the gyrogonites are shown in table 1. Correlation diagrams (figs. 3-6) have been produced using PAST (Palaeontological Statistics, ver. 0. 98) shareware program (HAMMER et al., 2001).

Species	Parameters	N	Min	Max	Mean	S	S²	V (%)
Stellatochara germanica	Length	211	270	510	427	48.32	2335	11.31
	Width	211	220	460	340	48.01	2304	14.12
	ISI	211	102	158	125	12.04	144	9.6
Stomochara starozhilovae	Length	162	290	530	411	58.04	3368	14.12
	Width	162	200	362	295	37.10	1376	12.57
	ISI	162	111	180	138	10.85	117	7.86
Stenochara kisielevskyi	Length	118	293	550	413,5	42.18	1779	10.20
	Width	118	206	375	297,1	32.54	1059	10.95
	ISI	118	123	162	139,5	8.48	71,9	6.07
Porochara triassica	Length	196	255	500	398,2	42,2	1780	10.59
	Width	196	188	413	299,5	38,6	1493	12.88
	ISI	196	102	177	134,1	11,9	141,8	8.87

Tab. 1: Biometrical data of gyrogonites. Measurements in microns. Symbols: ISI - Isopolarity Index = 100 × length/width; N - number of measurements; Min - lowest value, Max - highest value measured for each parameter; Mean - mean value; s^2 - variance; s - standard deviation; V (%) - variation index.

5 Concept of species in Late Triassic Charophytes

As BERGER (1999) stated on the basis of Tertiary charophytes, the concept of fossil species is problematic and subject to intense debate. Like most fossil charophytes, Late Triassic ones are only known from the calcareous part of fructification, called gyrogonites. It is questionable whether these morphotypes are the real biological species, because classification of modern charophytes is based to a large extent upon thallus morphology (e.g. HORN AF RANTZIEN, 1959), which is very rarely fossilized. The authors material, comprising a few thousands of gyrogonites from the bone-bearing bed, consists of many morphotypes with distinct transitional forms (figs. 3-6). In older articles concerned with this problem (e.g. KISIELEVSKY, 1969; SAIDAKOVSKY, 1962, 1971; BILAN, 1969, 1974, 1988), the authors described many species, most of them occur in one of our samples. Because of transitional morphotype occurrences it seems very plausible that many previously recognized species are in fact morphotypes of the same biological species. Many morphotypes of similar shape were distinguished in previous literature as separate species, on the basis of just one feature (e.g. spirals or slightly narrower apical neck).

6 Systematic palaeontology

Division Charophyta MIGULA, 1890
Class Charophyceae G.M. SMITH, 1938
Order Charales LINDLEY, 1836
Family Porocharaceae GRAMBAST, 1962
Subfamily Stellatocharoideae GRAMBAST, 1962
Genus *Stellatochara* HORN AF RANTZIEN, 1954

Stellatochara germanica KOZUR & REINHARDT, 1969
fig. 3; pl. 1, figs. 1-4

1969 *Stellatochara germanica* KOZUR & REINHARDT, 1969, p. 374-376, pl. 1, figs. 1, 2a-c.

1988 *Stellatochara germanica*; BREUER, pl. 2, figs. d-f.
1988 *Stellatochara germanica*; BILAN, p. 85-86, pl. 1, fig. 7.
1988 *Stellatochara silesiana* BILAN, p. 88-91, pl. 3, figs 5-7, pl. 12, fig. 2.

Material: More than 2500 well preserved gyrogonites.

Description: Gyrogonites prolate, through ovoidal to nearly spheroidal. At the summit, spirals form the apical neck having a pentagonal or irregular apical opening. From 8 to 10 concave spirals are visible in lateral view, with the biggest width in the middle part of a gyrogonite. Interspiral ridges low. Basal pole rounded with small, pentagonal opening. L = 270-510 μm, W = 220-460 μm, ISI = 102-158.

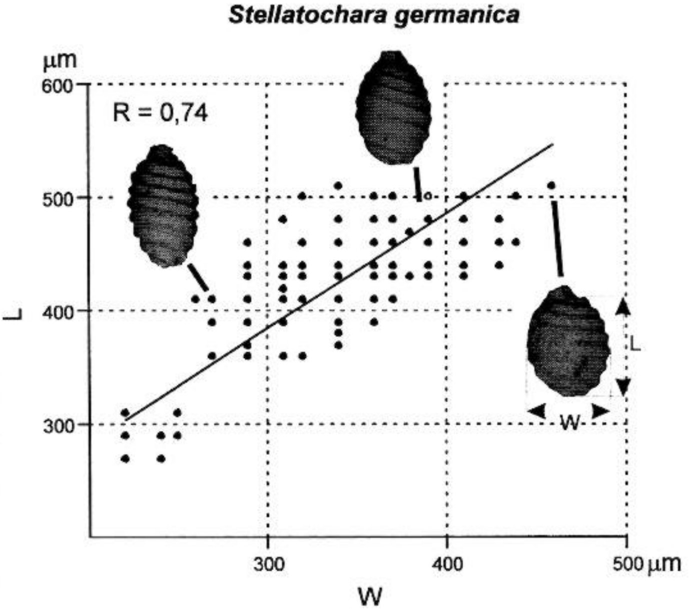

Fig. 3: Correlation diagram for length and width as measured on 211 gyrogonites of *Stellatochara germanica* illustrated by its morphotypes (comp. tab. 1).

Remarks: BILAN (1988) described the new species *Stellatochara silesiana*, to which the investigated material is identical. He also determined in his collection the species *Stellatochara germanica* KOZUR & REINHARDT which, in our opinion, differs only in its narrower apical neck. In the same year, BREUER (1988) revised the charophytes from the Keuper (Late Triassic) of Germany. She presented a figure of *Stellatochara germanica* KOZUR & REINHARDT, which does not differ from *Stellatochara silesiana* BILAN neither in overall shape, nor in shape of the neck. The spirals in German specimens were strongly concave, although KOZUR & REINHARDT (1969) determined the spirals as slightly convex, and BILAN (1988) as flat. In our material, the population display the transitional spiral morphology from almost flat to concave. Therefore we account these specimens to one species. The gyrogonites vary in shape, and three main morphotypes can be distinguished (fig. 3) from prolate to more spheroidal ones.

Occurrence: Upper Carnian of Krasiejów (the bone-bearing as well as the under- and overlying layers). Uppermost Anisian and Ladinian of Germany (KOZUR & REINHARDT, 1969), Anisian of the East European Platform (SAIDAKOVSKY & KISIELEVSKY, 1985), Röt to Lower Rhaetian of the Polish Lowland (BILAN, 1988).

Genus *Stomochara* GRAMBAST, 1961

Stomochara starozhilovae (KISIELEVSKY, 1967)
fig. 4; pl. 1, figs. 5-8

1967 *Auerbachichara starozhilovae* KISIELEVSKY, 1967, p. 40, pl. 1, figs. 6-7.
1974 *Auerbachichara polonica* BILAN, 1974, p. 487-488, text-fig. 4a-c, pl. 1, fig. 4 a-c.
1988 *Auerbachichara baskuntschakiensis*; BILAN, p. 112, pl. 11, figs 4 -5.
1988 *Auerbachichara polonica*; BILAN, p.113, pl. 11, fig. 1.
1988 *Auerbachichara starozhilovae*; BILAN, p. 112, pl. 9, figs 2-3, pl. 10, fig. 1.

Material: More than 450 well preserved gyrogonites.

Description: Gyrogonites ovoidal to prolate in shape. At the summit, ends of the spirals form five denticles. Apical opening in the shape of a star. From 7 to 10 generally concave or, in a lesser manner, flat spirals. The

1988 *Stellatochara germanica*; BREUER, pl. 2, figs. d-f.
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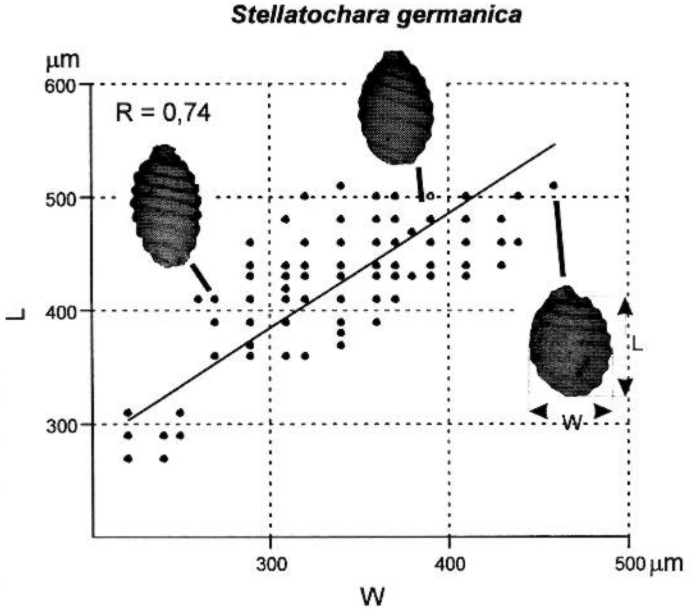

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Occurrence: Upper Carnian of Krasiejów (the bone-bearing as well as the under- and overlying layers). Uppermost Anisian and Ladinian of Germany (KOZUR & REINHARDT, 1969), Anisian of the East European Platform (SAIDAKOVSKY & KISIELEVSKY, 1985), Röt to Lower Rhaetian of the Polish Lowland (BILAN, 1988).

Genus *Stomochara* GRAMBAST, 1961

Stomochara starozhilovae (KISIELEVSKY, 1967)
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1967 *Auerbachichara starozhilovae* KISIELEVSKY, 1967, p. 40, pl. 1, figs. 6-7.
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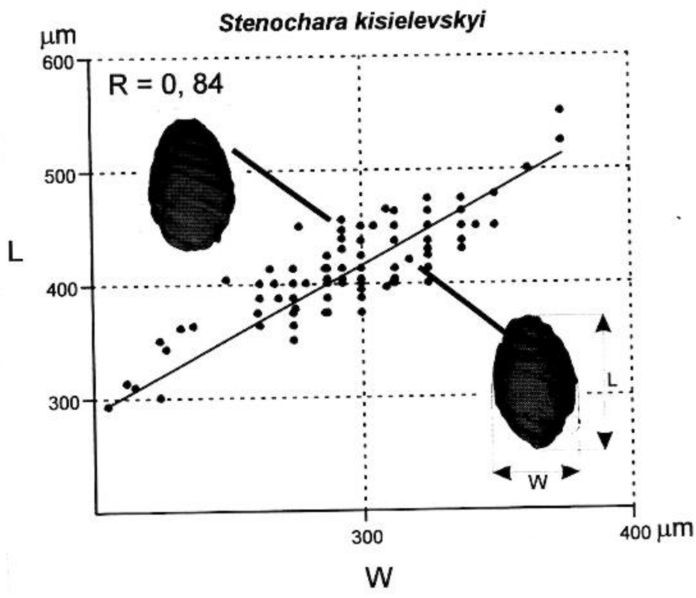
1988 *Auerbachichara polonica*; BILAN, p.113, pl. 11, fig. 1.
1988 *Auerbachichara starozhilovae*; BILAN, p. 112, pl. 9, figs 2-3, pl. 10, fig. 1.

Material: More than 450 well preserved gyrogonites.

Description: Gyrogonites ovoidal to prolate in shape. At the summit, ends of the spirals form five denticles. Apical opening in the shape of a star. From 7 to 10 generally concave or, in a lesser manner, flat spirals. The



BILAN. This species also possesses the same number of lateral spirals. In BILAN's (1988) opinion, the only differences between these species are a summit morphology and a smaller diameter of apical opening.

Fig. 5: Correlation diagram for length and width as measured on 118 gyrogonites of *Stenochara kisielevskyi* illustrated by its morphotypes (comp. tab. 1).

Occurrence: Upper Carnian of Krasiejów in all investigated layers. Middle Buntsandstein to Lower Rhaetian in the Polish part of the Germanic Basin.

Subfamily Porocharoideae GRAMBAST, 1961

Genus *Porochara* (MÄDLER, 1955) emend. SCHUDACK, 1986

Porochara triassica (SAIDAKOVSKY) GRAMBAST, 1961
fig. 6; pl. 1, figs. 12-14

1961 *Porochara triassica* (SAIDAKOVSKY) GRAMBAST, 1961: 201.
1969 *Porochara sphaerica* KISIELEVSKY, 1969, p. 29-30, pl. 1, figs. 8-9.
1969 *Porochara triassica* (SAIDAKOVSKY); BILAN, p. 445-446, fig. 8a-c.
1988 *Porochara triassica* (SAIDAKOVSKY); BILAN, p. 101, pl. 7, fig. 1.
1988 *Porochara sphaerica* KISIELEVSKY; BILAN, p. 104-105, pl. 6, fig. 4.

Material: About 850 well preserved gyrogonites.

Description: Gyrogonites spheroidal to prolate spheroidal. The apical pole is rounded with pentagonal opening. The basal pole is also rounded with a smaller pentagonal or oval opening. From 7 to 10 spirals with the maximum width in the middle part of the gyrogonite. Interspiral ridges distinct and sharp, less commonly blunted. L = 255-500 µm, W = 188-413 µm, ISI = 102-177 µm.

Remarks: Our material comprises of specimens similar to both *Porochara triassica* (SAIDAKOVSKY) and *Porochara sphaerica* KISIELEVSKY. The overall shape of these species is practically the same. A difference may occur in basal morphology of some specimens. The "*sphaerica*"-like gyrogonites have more rounded poles, while the specimens similar to *Porochara triassica* SAIDAKOVSKY may possess only slightly sharp poles. But, looking at the whole and numerous population, transitional varieties occur. Thus, it is hard to put a distinct boundary between our specimens. We interpret that as variability within the population rather than two (or even more) different species.

Occurrence: Upper Carnian of Krasiejów (all investigated layers). Lower and Middle Triassic of the East European Platform (KISIELEVSKY, 1969) and of Kazakhstan as well as Olenekian of Germany (KOZUR, 1974). In the Polish part of the Germanic Basin they occur in the Middle Buntsandstein to Lower Rhaetian interval (BILAN, 1988).

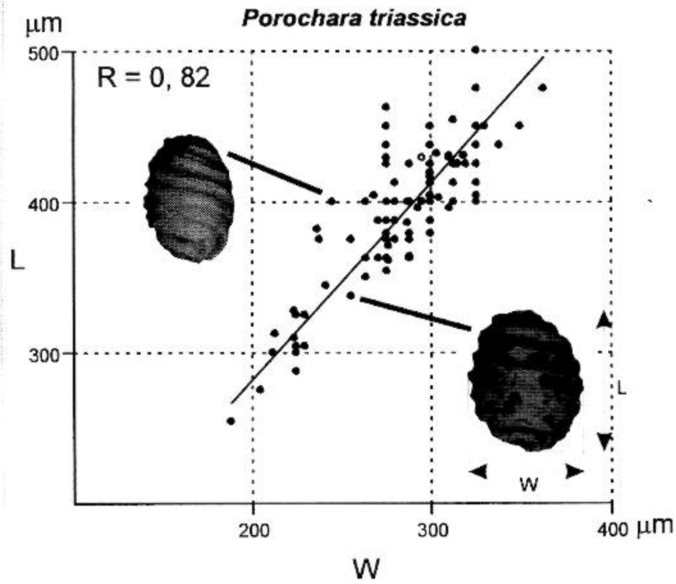


Fig. 6. Correlation diagram for length and width as measured on 196 gyrogonites of *Porochara triassica* illustrated by its morphotypes (comp. tab. 1).

7 Remarks on palaeoenvironment

The Krasiejów area in Late Carnian times was situated in the eastern part of the Germanic Basin within the subtropical climate zone, and under a great influence by monsoon circulation (REINHARDT & RICKEN, 2000). Such a climate in this part of Pangea had a great impact on alternating humid and arid seasons, reflected in the colours of the sediments, i.e. grey and dark-red.

The investigated charophytes belong to the extinct family Porocharaceae and have no modern counterparts. Actualistic data can be useful in general determination of the environment, but, like in case of many other fossil charophytes (see RACKI, 1982), the strict parameters, especially salinity, should be interpreted with caution. The depth of Late Triassic basin could has been up to 15 m. This estimation is based on the fact that this is an upper limit of mean depth for charophyte vegetation (BHATIA et al., 1998). Estimation whether the environment characterised of fresh- or bracish waters is also problematic. Even the co-occuring ostracodes (*Darwinula*, *Suchonella*) have quite broad ecological tolerance from freshwater to mesohaline (SCHUDACK et al., 1998), DZIK et al. (2000) interpreted the environment as mostly freshwater, because of the presence of *Unionites* bivalves (see also RICKEN et al., 2003).

The biotope of charophytes and vertebrates was probably a shallow, freshwater lake. Although some vertebrate remains could have been drifted into the lake by rivers (see DZIK et al., 2000), the abundant and well preserved gyrogonites attest an *in situ* fossilization (BHATIA et al., 1998). During the sedimentation of the bone-bearing level the conditions must have been optimal, because charophytes reached their peak abundance. The diversity of charophytes was not great, with only four species: *Stellatochara germanica* KOZUR & REINHARDT, *Stomochara starozhilovae* (KISIELEVSKY), *Porochara triassica* (SAIDAKOVSKY) and *Stenochara kisielevskyi* BILAN, but these algae must have formed huge meadows. There were also numerous associated ostracodes of the genera *Darwinula* and *Suchonella*.

In the overlying grey mudstone the number of gyrogonites drastically drops to only 26 specimens per kilogram of sediment, while ostracodes abundance remains almost the same. The change in fraction of the sediment toward more coarse, and the rapid drop in charophyte abundance must have been caused by a change in environment to more saline, or more turbulent conditions. The *Darwinula* ostracodes are known from more saline waters (SCHUDACK et al., 1998), as well as from high energy environments (SCHWALB et al., 2002). The preliminary geochemical analysis of this interval has shown an increase of sodium content from 1047.7718 ppm (bone-bearing layer) through 1075.4372 ppm (above the main bone-bearing level) to 2862.1363 ppm (grey mudstone). This proxy may indicate the encroachment of more saline conditions (VEIZER et al., 1977, 1978; BRAND, 1987; ZWOLSMAN & VAN ECK, 1999), which could have influenced the charophyte growth, but more geochemical as well as sedimentological data are needed.

Acknowledgments

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Plate 1

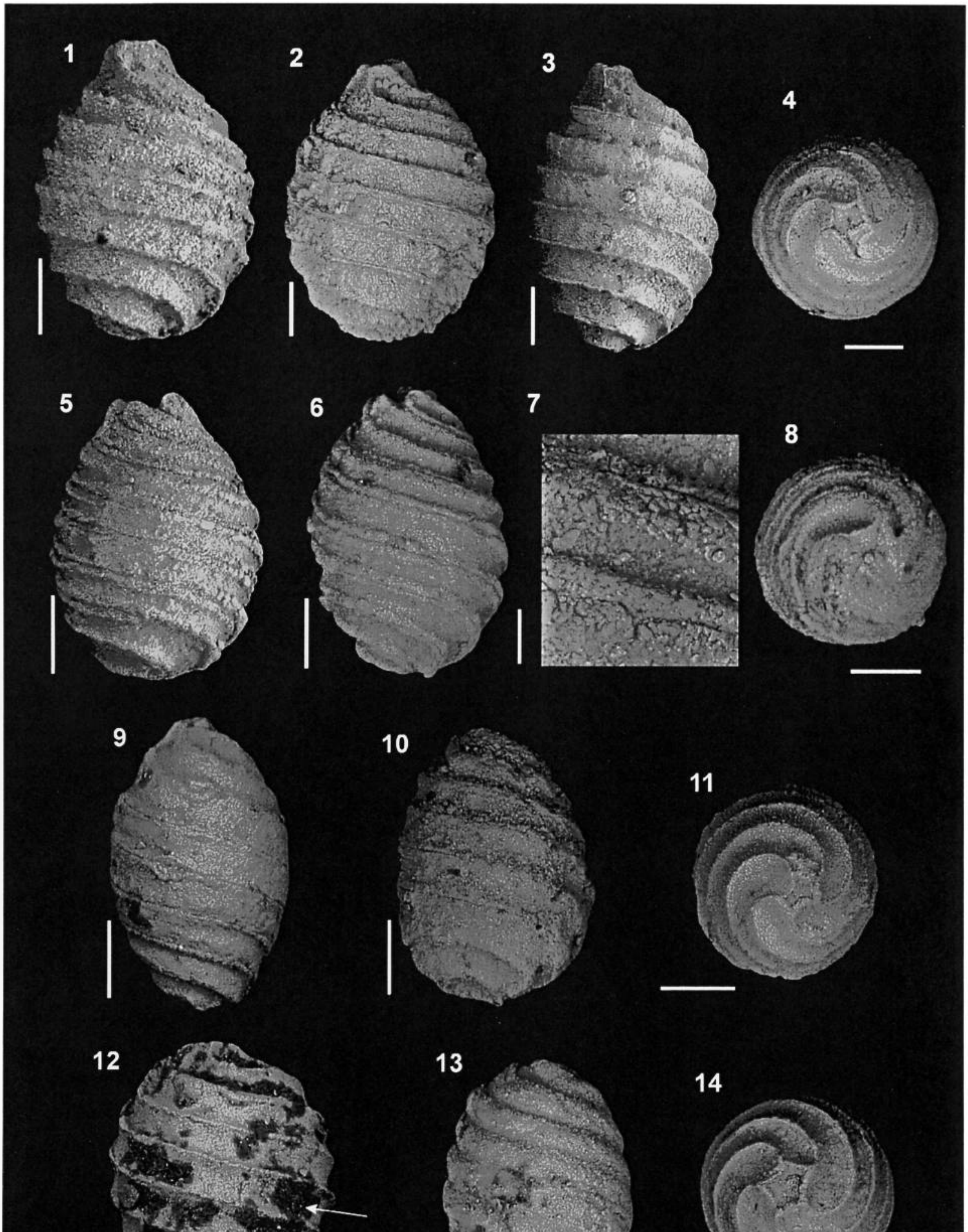
Scale bars indicate 100 μm.

Fig. 1-4: *Stellatochara germanica* KOZUR & REINHARDT; 1, 2, 3 - lateral views; 4 - view on apical opening.

Fig. 5-8: *Stomochara starozhilovae* (KISIELEVSKY); 5, 6 - lateral views; 7 - view on distinct double suture; 8 - view on apical opening.

Fig. 9-11: *Stenochara kisielevskyi* BILAN; 9, 10 - lateral views; 11 - view on apical opening.

Fig. 12-14: *Porochara triassica* (SAIDAKOVSKY) GRAMBAST; 12, 13 - lateral views; 14 - view on apical opening; arrow: organic matter.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