

# A morphotype-rich assemblage of chrysophycean stomatocysts in mountain lakes in the Cameroon Highlands, Africa

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**Abstract** – Based on samples collected from two mountain lakes named as Lacs Paponoun located in the Cameroon Highlands (Africa), an assemblage of chrysophycean stomatocysts was investigated using scanning electron microscopy. Twenty stomatocysts are reported and described following the guidelines of the International Statospore Working Group (ISWG). Eleven cysts are described as new morphotypes. The present study documents the largest assemblage of chrysophycean stomatocysts from the recent sediments in tropical Africa detected so far. Additionally, it provides new data on global diversity of chrysophycean stomatocysts.

**Africa / Cameroon / lakes / recent sediments / chrysophycean stomatocysts / new morphotypes**

## INTRODUCTION

Chrysophytes are organisms, which are widely distributed throughout the world. They are best studied and known in Europe and North America, but much less is known about the diversity of chrysophytes in the tropics. All chrysophyte species are characterized by the ability to produce resting stage forms, i.e. stomatocysts, which are variously shaped and sized hollow siliceous structures, with one pore and a single collar or complex collars which may surround the pore. Sometimes the collar is absent. Stomatocysts may have a smooth or ornamented surface (Duff *et al.*, 1995, Wilkinson *et al.*, 2001).

Similar to the knowledge of living chrysophytes, Europe and North America are best known for the presence of stomatocysts (e.g., Cronberg, 1986; Zeeb & Smol, 1993; Zeeb *et al.*, 1994; Duff *et al.*, 1995; Facher & Schmidt, 1996a; Hansen, 2001; Kamenik *et al.*, 2001; Pla, 2001; Wilkinson *et al.*, 2001; Cabała, 2002, 2005a; Cabała & Piątek, 2004; Pla & Anderson, 2005; Pla & Catalan, 2005; Piątek, 2006, 2007). However, much less is known about stomatocysts from subtropical and tropical ecosystems in Africa, Asia, South America and Australia. To date, research has mostly focused on living chrysophytes (Rich, 1932; Compère, 1973, 1974, 1975; Wujek & Asmund, 1979; Cronberg & Hickel, 1985; Cronberg, 1988, 1989, 1996; Hansen & Kristiansen, 1995; Hansen, 1996; Wujek *et al.*, 2003-2004, 2008, 2010, 2011; Nemcová *et al.*, 2011, Piątek & Mossebo, 2008; Piątek, 2015; Piątek & Łukaszek, 2016) while little information regarding stomatocysts is available.

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In Africa, stomatocysts were recently investigated in subtropical Egypt for the first time where chrysophycean stomatocysts were found in a unique habitat – a thermal, highly mineralized spring. The assemblage of stomatocysts consisted of seven morphotypes, four of which represented morphotypes new to science, including one morphotype characterized by a new type of ornamentation not previously identified in any known stomatocyst group (Piątek *et al.*, 2009). The next report of African stomatocysts was related to encysted specimens of *Dinobryon sertularia* Ehrenb. which were observed in the material collected from a small man-made pond in tropical Cameroon. The stomatocyst produced by this chrysophyte species was described as a new morphotype. This was the first discovery of an encysted chrysophyte in Africa and the first connection of *Dinobryon sertularia* with its stomatocyst evidenced by both LM and SEM observations (Piątek *et al.*, 2012). A chrysophycean stomatocyst was also elaborated from a small lake in the Guineo-Congolian rainforest in eastern Cameroon. Only one morphotype was noted in the bottom sediments of the lake: stomatocyst 49 Piątek J., which was described as new to science (Piątek & Piątek, 2014). However, the diversity and richness of African stomatocysts are probably much greater as indicated by other, unpublished results of studies investigating the materials from several countries in West Africa. Australia is the only continent on which stomatocysts have not been observed. Like other continents, stomatocysts in Australian waters and sediments are most probably present but have never been examined.

This study aims to investigate an assemblage of chrysophycean stomatocysts from the recent sediments of two mountain lakes in the Cameroon Highlands in tropical Africa, including illustrative descriptions of all the morphotypes found and to provide new data regarding the global diversity of chrysophycean stomatocysts.

## MATERIAL & METHODS

The material was collected on 6 March 2007, at the end of dry season, from two twin lakes of different size named as Lacs Paponoun (= Lacs Petponoun), located in the Department of Noun, at about 30 km NE of the centre of Bafoussam, the capital of the West Region of Cameroon (Fig. 1). The Lacs Paponoun are shallow, volcanic lakes with a weakly developed crater rim (Kling, 1988), located in the Cameroon Highlands, which belong to the Afromontane archipelago-like regional centre of endemism (White, 1983), within the Guinean savanna vegetation, and the two lakes are 400 m apart. The lakes differ in size. The smaller lake (05°38'10"N, 10°37'52"E, elev. ca 1128 m) was fully exposed to the sun, sparsely overgrown by *Nymphaea nouchali* Burm. plants and surrounded by a well-developed marsh vegetation (Figs 2-3). The larger lake (05°37'53"N, 10°38'16"E, elev. ca 1138 m) was fully exposed to the sun, sparsely overgrown by *Nymphaea nouchali* plants and surrounded by marsh vegetation though less developed than in the former lake (Fig. 4).

The material was taken by syringe suction and included surface sediment samples from the bottom of the lakes and water squeezed from water plants. Each sample, containing about 5 ml of sediment and 5 ml of water, was placed into 15 ml plastic container and fixed with Lugol's solution. The chemical and physical parameters of the water were not measured. In the laboratory, each sample was divided into two parts. One part fixed with Lugol's solution was preserved without

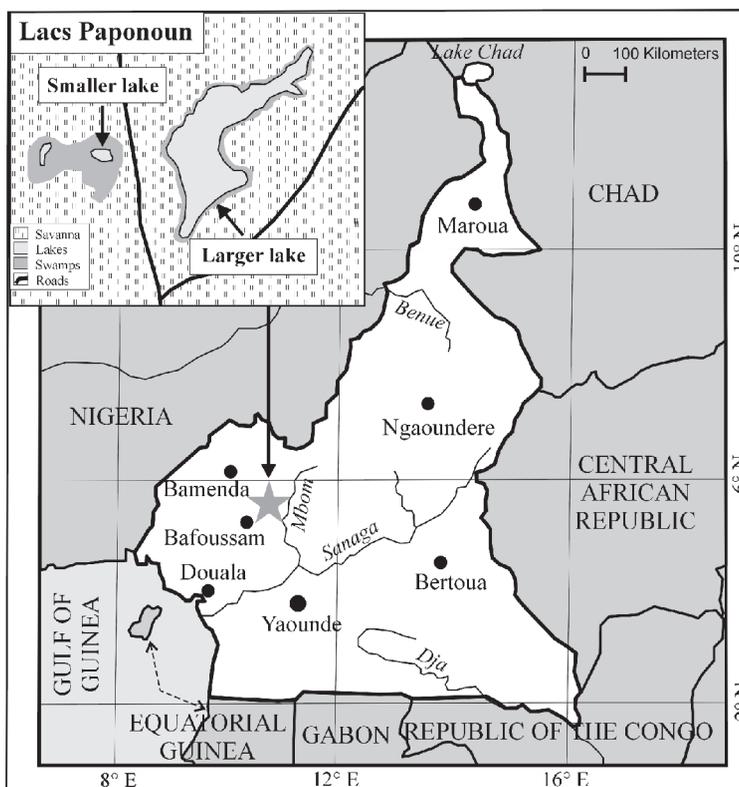


Fig. 1. Location of the study area in Cameroon and map of the smaller and larger lakes of the Lacs Paponoun.

changes, and the other part was prepared for scanning electron microscope (SEM) according to the following procedure. Each sample was placed in a glass scintillation vial, covered with 10% HCl (to remove carbonates) and allowed to stand for 24 h, boiled for 15 min, and rinsed several times with distilled water. The samples were covered with 30% H<sub>2</sub>O<sub>2</sub> and allowed to stand for 24 h, then boiled for 30 min with a small amount of C<sub>1</sub>O<sub>3</sub>, and rinsed several times with distilled water, with a settling time of 24 h between each aspiration. Finally, the samples were slurried in glass vials and covered with 95% alcohol.

The samples were examined using scanning electron microscope (SEM, Hitachi S-4700). For scanning electron microscope (SEM) analysis, a few droplets of the prepared samples were pipetted onto clean glass, air-dried, and affixed to an aluminium stub with double-sided transparent tape. The stubs were sputter-coated with carbon using a Cressington sputter-coater and viewed with SEM. The stomatocysts were measured and described from SEM micrographs and described according to International Statospore Working Group (ISWG) guidelines (Cronberg & Sandgren, 1986). New stomatocysts were assigned numbers from Piątek J., beginning with stomatocyst #50, Piątek J., and are cited as described in 'this paper'. Following Duff *et al.* (1995), the new morphotypes are usually described based on at least two SEM specimens observed. In a few cases, however, the description of new morphotypes is based on only one SEM specimen observed. In those cases the cysts were highly unique in terms of pore and collar morphology and/or ornamentation. Wet samples (fixed with Lugol's solution and preserved with 95% alcohol after

boiling with chemicals) and SEM holders are available in the Department of Phycology, W. Szafer Institute of Botany, Polish Academy of Sciences, Lubicz 46, PL-31-512 Kraków, Poland.

2



3



4



Figs 2-4. **2-3.** The general view of smaller Lacs Paponoun. **4.** The general view of larger Lacs Paponoun (phot. M. Piątek).

## RESULTS

The SEM study of six holders, three from the larger lake and three from the smaller lake, revealed 324 specimens of stomatocysts, of which 129 specimens were unidentifiable because the most important diagnostic features (collar, pore) were not visible. The remaining 195 specimens were used in morphological observations and measurements, and were consequently assigned to 20 different morphotypes of chrysophycean stomatocysts. Amongst 20 recorded stomatocysts, 10 were unornamented and 10 were ornamented with conula, ridges and with compound ornamentation. In the group of ornamented morphotypes, stomatocysts with ridges (6 stomatocysts) dominated in the lakes. Interestingly, five of them are new morphotypes (stomatocysts: #56, #57, #58, #59 and #60 Piątek J.).

Altogether, 11 stomatocysts are described here as new to science, representing almost 55% of the stomatocysts recorded, and only 9 stomatocysts were previously recorded from other parts of the world, mostly from outside Africa. Only one morphotype: stomatocyst 42 Duff & Smol 1989, has already been reported from this continent. It was previously found in Egypt in recent sediments of a thermomineral spring in Ain Sukhna (Piątek *et al.*, 2009). In total, 19 stomatocysts recorded in the Lacs Paponoun are reported from the African continent for the first time.

The largest number of morphotypes (six morphotypes) was represented by one specimen (stomatocysts cf. 6, 24, #52, #58, #59 and #60). Four of them are newly described morphotypes. However, all the important diagnostic features (pore, collar, ornamentation) were well visible in each case and their accurate identification was possible. Additionally, four of them have the characteristic ornamentation of the cyst body. Other morphotypes were represented by two specimens (stomatocysts 9, 19, 39 and #51), three specimens (stomatocyst cf. 171), four specimens (stomatocysts #56, #57), five specimens (stomatocysts cf. 27, #54), seven specimens (stomatocyst 127), eight specimens (stomatocyst 42), nine specimens (stomatocyst #55) and thirteen specimens (stomatocyst #50). One morphotype: stomatocyst #53, dominated in the Lacs Paponoun. As many as 28 specimens of this morphotype were recorded and it additionally occurred in both lakes.

The number of stomatocysts differed between the two lakes. The stomatocyst assemblage was more diverse in the smaller lake than in the larger lake, consisting of 17 and 6 morphotypes respectively. Only three stomatocysts (cf. 27, 127 and #53) occurred in both lakes.

All the stomatocysts identified are described, illustrated and discussed below. The stomatocysts are presented in groups based on their shared morphological characters, following Duff *et al.* (1995) and Wilkinson *et al.* (2001).

### UNORNAMENTED STOMATOCYSTS

#### *Spherical stomatocysts lacking a collar*

**Stomatocyst 9**, Duff & Smol 1988 *emend.* Zeeb & Smol 1993

**Fig. 5**

*Picture-file number* — Piątek J., Camer7-55.

*Number of specimens* — 2.

*Biological affinity* — According to Duff *et al.* (1995) this cyst is probably produced by several chrysophyte species, including *Chrysolepidomonas dendrolepidota* Peters & Andersen.

*Locality* — Cameroon – Lacs Paponoun (smaller lake).

*Description* — This stomatocyst is spherical, 7.4-8.3  $\mu\text{m}$  in diameter. The pore is regular, 0.4-0.6  $\mu\text{m}$  in diameter. The cyst body surface is smooth. Some (pseudo-)ornamentation of cyst body resembling scabrae and psilae is caused by glued sediment remnants.

*Distribution* — This is widely distributed stomatocyst, reported from various habitats in North America, Greenland and Europe (Duff *et al.*, 1995; Facher & Schmidt, 1996a, b; Kamenik *et al.*, 2001; Pla, 2001; Betts-Piper *et al.*, 2004; Cabała & Piątek, 2004; Wołowski *et al.*, 2004; Cabała, 2005a, b; Pla & Andersen, 2005; Piątek, 2006). It is reported for the first time from Africa.

**Stomatocyst 19**, Duff & Smol 1988

**Fig. 6**

*Picture-file number* — Piątek J., Camer7-84.

*Number of specimens* — 2.

*Biological affinity* — According to Duff *et al.* (1995) this stomatocyst is similar to cysts produced by several *Epipyxis* species, including *E. tubulosa* (Mack) Hilliard & Asmund.

*Locality* — Cameroon – Lacs Paponoun (smaller lake).

*Description* — This stomatocyst is oval, 7.3-8.7  $\mu\text{m}$  long and 6.7-8.3  $\mu\text{m}$  wide. The pore is usually concave, inner diameter 0.5-0.6  $\mu\text{m}$ , outer diameter 1.1-1.3  $\mu\text{m}$ . The cyst body surface is smooth.

*Distribution* — This is widely distributed stomatocyst, reported from various habitats in North America and Europe (Duff *et al.*, 1995; Facher & Schmidt, 1996a; Cabała, 2002; Betts-Piper *et al.*, 2004; Cabała, 2005a; Piątek & Piątek, 2005), and South America (Coradeghini & Vigna 2001). Here, it is reported for the first time from Africa.

**Stomatocyst 42**, Duff & Smol 1989

**Fig. 7**

*Picture-file number* — Piątek J., Camer7-46.

*Number of specimens* — 8.

*Biological affinity* — According to Duff *et al.* (1995) this stomatocyst is probably produced by several species, including *Synura petersenii* Korshikov and *Chrysosphaerella longispina* Lauterborn *emend.* Korshikov.

*Locality* — Cameroon – Lacs Paponoun (smaller lake).

*Description* — This stomatocyst is spherical, (8.1-)9.1-13.7  $\mu\text{m}$  in diameter. The pore is concave, inner diameter 0.6-0.9  $\mu\text{m}$ , outer diameter 1.1-2.3  $\mu\text{m}$ . The cyst body surface is smooth.

*Distribution* — This is widespread morphotype, previously reported from various places in North America and Europe (Rybak, 1987; Duff *et al.*, 1995; Pla, 2001; Betts-Piper *et al.*, 2004; Wołowski *et al.*, 2004; Buczkó & Wojtal, 2005; Pla & Anderson, 2005; Piątek & Piątek, 2005; Piątek, 2007; Wołowski *et al.*, 2011), Africa (Piątek *et al.*, 2009), and also known from sub-Antarctic region of South Georgia (van de Vijver & Beyens, 1997b).

**Stomatocyst 39**, Coradeghini & Vigna 2008

**Fig. 8**

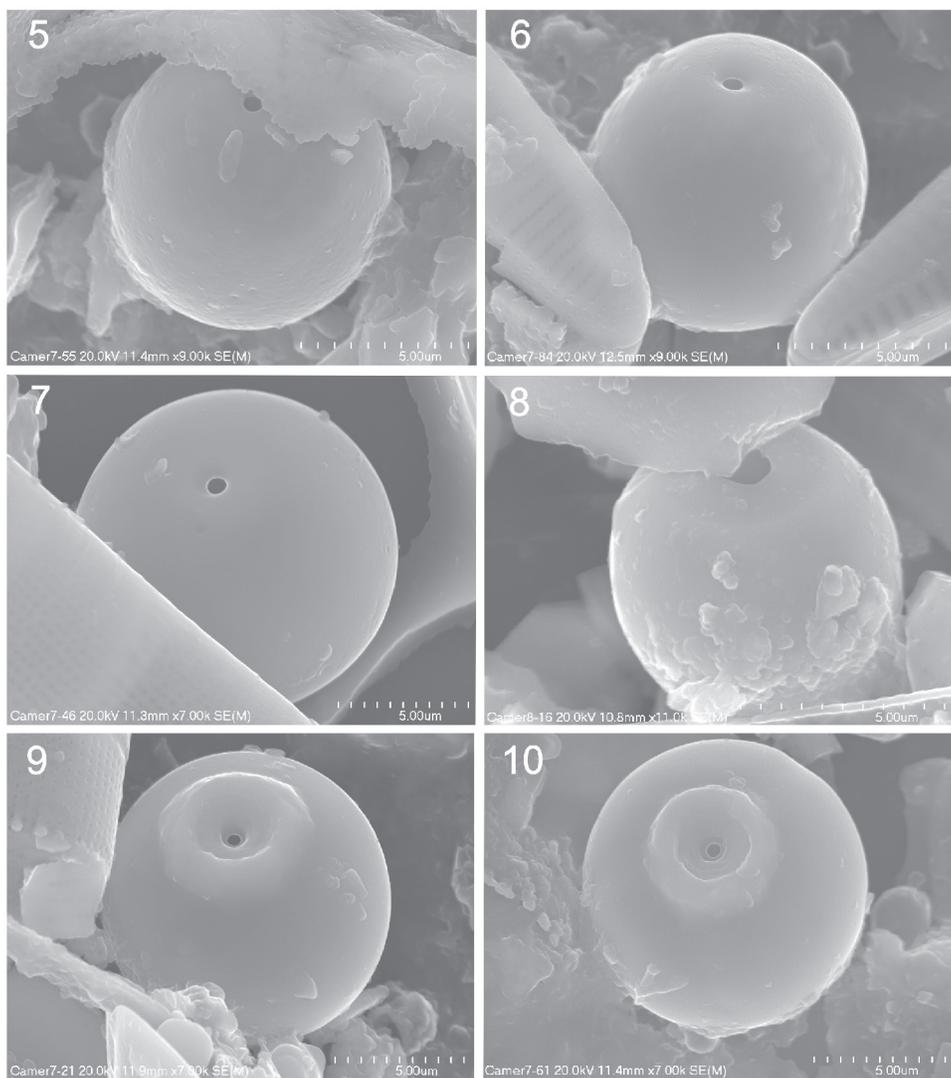
*Picture-file number* — Piątek J., Camer8-16.

*Number of specimens* — 2.

*Biological affinity* — Unknown.

*Locality* — Cameroon – Lacs Paponoun (larger lake).

*Description* — This stomatocyst is spherical, but sometimes slightly irregular, 7.2-9.1  $\mu\text{m}$  in diameter. The pore is relatively large and regular, 1.0-1.4  $\mu\text{m}$  in diameter, sometimes surrounded by slightly depressed area (diameter 4.6  $\mu\text{m}$ ), without collar. The cyst body surface is smooth and unornamented.



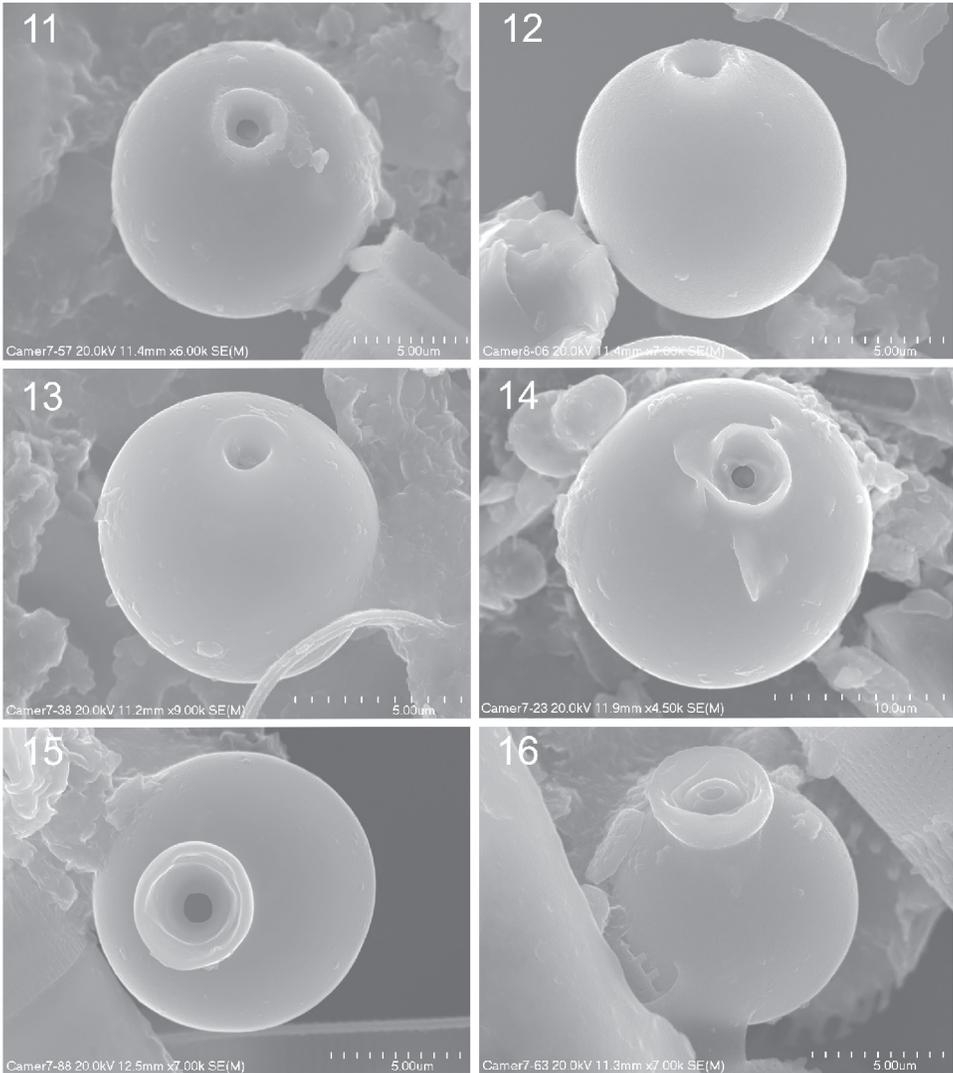
Figs 5-10 (SEM). 5. Stomatocyst 9, Duff & Smol 1988 *emend.* Zeeb & Smol 1993. 6. Stomatocyst 19, Duff & Smol 1988. 7. Stomatocyst 42, Duff & Smol 1989. 8. Stomatocyst 39, Coradeghini & Vigna 2008. 9-10. Stomatocyst #50, Piątek J., this paper.

*Distribution* — Stomatocyst 39 has been previously recorded only from Primavera Station in Antarctica (Coradeghini & Vigna, 2008). Here, it is reported for the first time in Africa on its second station in the world.

*Comments* — Stomatocyst 39 is similar to stomatocysts 1 Vigna 1995 and 3 Coradeghini & Vigna 2001, both described from recent sediments in Argentina. However, stomatocyst 1 has larger cyst body (9.5-10.0 µm in diameter) and pore diameter (2 µm). Stomatocyst 3 is different from stomatocyst 39 in having deep conical pore.

*With conical collar***Stomatocyst #50**, Piątek J., this paper**Figs 9-10***Picture-file number* — Piątek J., picture-file Camer7-21, Fig. 9.*Number of specimens* — 13.*Biological affinity* — Unknown.*Locality* — Cameroon – Lacs Paponoun (smaller lake).*Description* — This stomatocyst is spherical to slightly oval, sometimes oblate, (9.2-) 10.0-11.9  $\mu\text{m}$  in diameter. The pore, (0.1-)0.5-0.6  $\mu\text{m}$  in diameter, is surrounded by swollen pseudoannulus or planar pseudoannulus. The collar is wide and conical, 2.6-3.9  $\mu\text{m}$  in diameter at the apex, (3.3-)4.5-6.1  $\mu\text{m}$  in diameter at the base, and 1.0-1.5  $\mu\text{m}$  high. The cyst body surface is smooth and unornamented.*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.*Comments* — This morphotype has not been previously observed, and is therefore described as new for science. A characteristic feature of stomatocyst #50 is a quite unique morphology of the collar. This cyst is partly similar to several previously described stomatocysts: 156 Zeeb & Smol 1993, 15 Facher & Schmidt 1996a, 49 van de Vijver B. & Beyens L. 1997b, 23 Hansen 2001, 181 Brown & Smol in Brown *et al.* 1994 *emend.* Taylor & Smol (according to Wilkinson *et al.*, 2001), 256 Zeeb & Smol in Zeeb *et al.* 1996 and stomatocyst 33 Pang & Wang 2014. However, stomatocyst 156 has different morphology of collar. Stomatocyst 15 is larger (11.0-14.0  $\mu\text{m}$  in diameter) and has collar with different morphology. Stomatocyst 49 has regular pore, different collar morphology and partly ornamented cyst body surface (by some broad blunt spines located mainly in the posterior hemisphere). Stomatocyst 23 is smaller (8.1-9.0  $\mu\text{m}$  in diameter) and has larger pore (0.7-0.8  $\mu\text{m}$  in diameter). Stomatocysts 181 and 256 have smaller collar diameter (apical diameter 0.7-2.7  $\mu\text{m}$  and basal diameter 2.1-2.7  $\mu\text{m}$ ; apical diameter 2.2-2.4  $\mu\text{m}$  and basal diameter 3.2-3.4  $\mu\text{m}$ , respectively). Both of them have also regular pore, but not with swollen pseudoannulus or planar pseudoannulus as stomatocyst #50. Stomatocyst 33 Pang & Wang 2014 has smaller (1.2-2.7  $\mu\text{m}$  in diameter, height 0.6-1.9  $\mu\text{m}$ ) and cylindrical collar (not conical) (Pang & Wang, 2014).*With cylindrical collar***Stomatocyst 127**, Duff & Smol in Duff *et al.* 1992**Figs 11-13***Picture-file number* — Piątek J., picture-file Camer7-57.*Number of specimens* — 7.*Biological affinity* — Unknown.*Locality* — Cameroon – Lacs Paponoun (both smaller and larger lakes).*Description* — This stomatocyst is usually spherical, sometimes slightly oval, (8.3-) 10.4-12.7  $\mu\text{m}$  in diameter. The regular pore, 0.5-1.1  $\mu\text{m}$  in diameter, is surrounded by flat planar annulus. The collar is cylindrical, sometimes slightly conical, 2.0-3.8  $\mu\text{m}$  in diameter and 0.3-1.1  $\mu\text{m}$  high. The collar diameter to cyst body diameter ratio is 0.27-0.30. The cyst body surface is smooth.*Distribution* — This stomatocyst has been previously recorded from Canada and USA (Duff *et al.*, 1995), from central Europe (Facher & Schmidt; 1996a, Cabała, 2005a), from the Spanish part of Pyrenees (Pla, 2001) and from China (Pang & Wang, 2014). Here, it is reported for the first time from Africa.

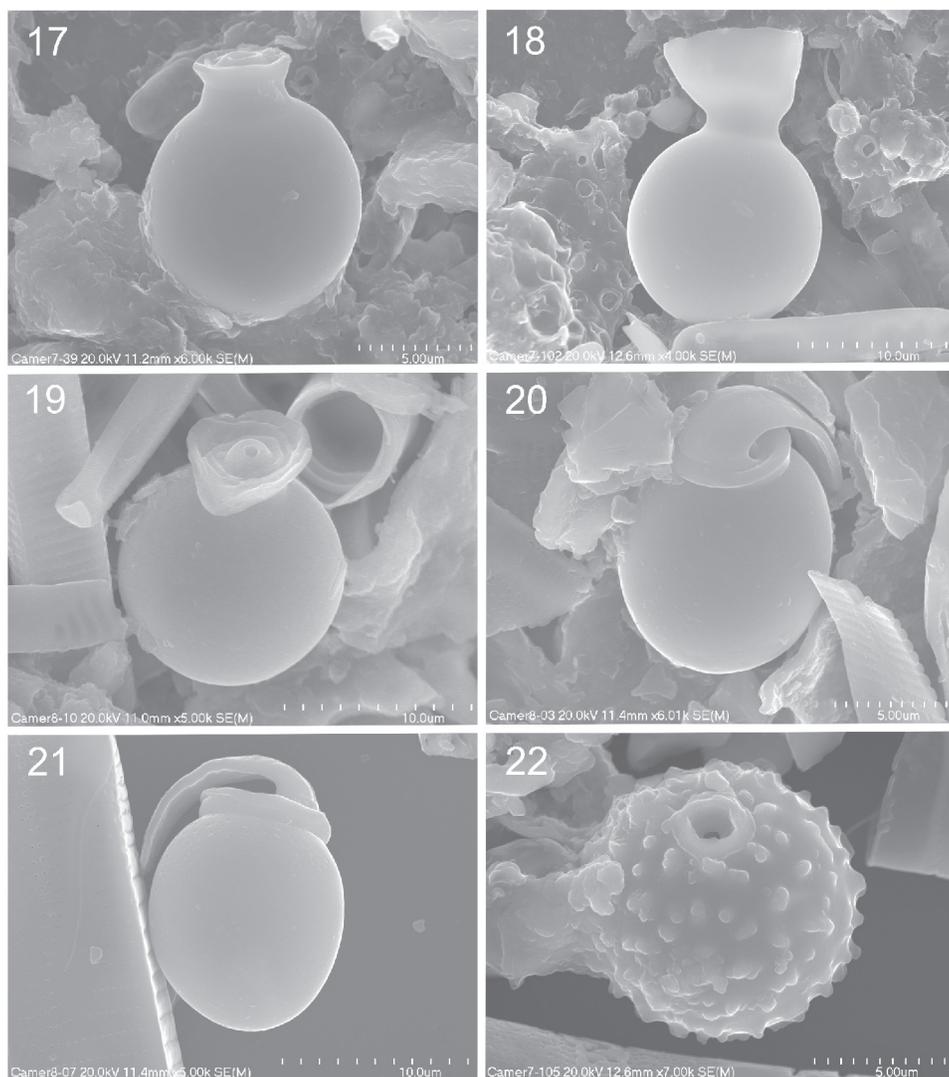
*With obconical collar***Stomatocyst #51**, Piątek J., this paper**Fig. 14***Picture-file number* — Piątek J., picture-file Camer7-23, Fig. 14.*Number of specimens* — 2.*Biological affinity* — Unknown.*Locality* — Cameroon – Lacs Paponoun (smaller lake).*Description* — This stomatocyst is spherical, 17.0-18.2  $\mu\text{m}$  in diameter. The regular pore, 1.4  $\mu\text{m}$  in diameter, is surrounded by planar pseudoannulus. The collar is cylindrical, 5.0-5.8  $\mu\text{m}$  in diameter and 1.0  $\mu\text{m}$  high; three thin, helicoidal ridges extending from the collar were observed in one specimen. The collar diameter to cyst body diameter ratio is 0.27-0.34. The cyst body surface is smooth and unornamented.*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.*Comments* — This morphotype has not been previously observed, and is therefore described as new for science. Stomatocyst #51 is similar to three previously described stomatocysts: 127 Duff & Smol in Duff *et al.* 1992, 308 Brown & Smol in Brown *et al.* 1997 and 132 Kamenik C. & Schmidt R. in Kamenik *et al.* 2001. However, stomatocyst 127 has smaller cyst body diameter (10.2-15.0  $\mu\text{m}$ ) with cylindrical to conical, smaller collar (2.2-3.2  $\mu\text{m}$  in diameter, 0.3-0.9  $\mu\text{m}$  high). Stomatocyst 308 is smaller (4.5-10.5  $\mu\text{m}$  in diameter) and has conical, smaller collar (diameter 1.3-3.1  $\mu\text{m}$ ). Stomatocyst 132 is also smaller (diameter 9.1-12.6  $\mu\text{m}$ ) and has conical pore.**Stomatocyst #52**, Piątek J., this paper**Fig. 15***Picture-file number* — Piątek J., picture-file Camer7-88, Fig. 15.*Number of specimens* — 1.*Biological affinity* — Unknown.*Locality* — Cameroon – Lacs Paponoun (smaller lake).*Description* — This stomatocyst is spherical, 10.8  $\mu\text{m}$  in diameter. The regular pore, 1.1  $\mu\text{m}$  in diameter, is surrounded by planar pseudoannulus. The collar is widely obconical, with apical diameter 4.6  $\mu\text{m}$ . The inner collar margin is ornamented with one concentric siliceous ring. The cyst body surface is smooth and unornamented.*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.*Comments* — This morphotype has not been previously observed. It is described as new for science. Stomatocyst #52 is similar to two previously described stomatocysts: 132 Duff & Smol in Duff *et al.* 1992, and 146 Zeeb & Smol in Pienitz *et al.* 1992 (= 11 Sandgren & Carney, 1983). However, stomatocyst 132 is two times smaller (diameter 5.5-5.7  $\mu\text{m}$ ), with smaller collar (2.9-3.3  $\mu\text{m}$ ). Stomatocyst 146 is smaller (5.6-8.6  $\mu\text{m}$  in diameter) and has smaller collar diameter (2.2-2.7  $\mu\text{m}$ ).*With a true or false complex collar***Stomatocyst #53**, Piątek J., this paper**Figs 16-19***Picture-file number* — Piątek J., picture-file Camer7-63 (Forma A), Fig. 16; Camer8-10 (Forma B), Fig. 19.*Number of specimens* — 28 (Forma A – 11 specimens, Forma B – 17 specimens).*Biological affinity* — Unknown.



Figs 11-16 (SEM). **11-13.** Stomatocyst 127, Duff & Smol in Duff *et al.* 1992. **14.** Stomatocyst #51, Piątek J., this paper. **15.** Stomatocyst #52, Piątek J., this paper. **16.** Stomatocyst #53, Forma A, Piątek J., this paper.

*Locality* — Cameroon – Lacs Paponoun (both smaller and larger lakes).

*Description* — This stomatocyst is usually spherical, sometimes ovate or slightly obovate, (8.5-)-9.0-14.7 µm in diameter. The pore is regular, 0.7-1.5 µm in diameter. The collar is complex. The primary collar is conical, 2.1-2.7 µm in diameter at the base, 1.2-2.2 µm in diameter at the apex, and 0.5-1.6 µm high. The secondary collar is wide and abruptly obconical, 3.5-5.8 µm in diameter at the base, (2.9-)-4.1-9.3 µm in diameter at the apex, and 1.3-6.8 µm high. The inner wall of the secondary collar is ornamented with spiralling rings. Sometimes part of the apex of the secondary collar is revolute towards the cyst surface. The cyst body surface is smooth.



Figs 17-22 (SEM). **17.** Stomatocyst #53, Forma A, Piątek J., this paper. **18-19.** Stomatocyst #53, Forma B, Piątek J., this paper. **20-21.** Stomatocyst #54, Piątek J., this paper. **22.** Stomatocyst #55, Piątek J., this paper.

This morphotype could be divided into two different *formae*: A and B that may be distinguished by the size of the cyst body and the size of the secondary collar:

1. Forma A – The diameter of cyst body is always  $< 12.0 \mu\text{m}$  [(8.5)-9.3-11.5  $\mu\text{m}$ ]. The diameter at the base of the secondary collar is always  $< 4.0 \mu\text{m}$  (3.5-3.9  $\mu\text{m}$ ), the diameter at the apex is always  $< 5.0 \mu\text{m}$  [(2.9)-4.1-4.9  $\mu\text{m}$ ].
2. Forma B – The diameter of cyst body is always  $\geq 12.0 \mu\text{m}$  (12.0-14.7  $\mu\text{m}$ ). The diameter at the base of the secondary collar is  $\geq 4.0 \mu\text{m}$  (4.2-5.2  $\mu\text{m}$ ) and the diameter at the apex is always  $\geq 5.0 \mu\text{m}$  (5.0-9.3  $\mu\text{m}$ ).

*Distribution* — This stomatocyst is currently known only from one locality (though from two neighbouring twin lakes) in Cameroon.

*Comments* — This morphotype has not been previously observed and is therefore described as new for science. This stomatocyst is similar to stomatocyst 39 Hansen, 2001, which is different in having smaller size of cyst body (6.8-7.0  $\mu\text{m}$ ), smaller primary collar (1.3  $\mu\text{m}$  in diameter) and smaller secondary collar (3.9  $\mu\text{m}$  in diameter and 1.2  $\mu\text{m}$  high).

**Stomatocyst #54**, Piątek J., this paper

**Figs 20-21**

*Picture-file number* — Piątek J., picture-file Camer8-07, Fig. 21.

*Number of specimens* — 5.

*Biological affinity* — Unknown.

*Locality* — Cameroon – Lacs Paponoun (larger lake).

*Description* — This stomatocyst is usually oval or sometimes slightly obovate, 9.2-11.3  $\mu\text{m}$  long and 8.6-10.4  $\mu\text{m}$  wide. The pore is regular, 0.6  $\mu\text{m}$  in diameter. The collar complex is composed with two collars. The primary collar is conical, 1.6  $\mu\text{m}$  wide and 0.4  $\mu\text{m}$  high. The secondary collar is obconical or sometimes somewhat cylindrical, 3.1-7.3  $\mu\text{m}$  wide and 0.4-1.0  $\mu\text{m}$  high. Close to the primary collar is located hooked projection, up to 12.7  $\mu\text{m}$  long and 3.5-3.8  $\mu\text{m}$  wide. The cyst body surface is usually smooth but sometimes ornamented with psilae.

*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.

*Comments* — Stomatocyst #54 is similar to stomatocysts: 135 Duff & Smol in Duff *et al.*, 1992 and 46 Hansen, 2001, but these two cysts differ in having three collars and hooked projection extending from the secondary collar.

## ORNAMENTED STOMATOCYSTS

### *With conula*

**Stomatocyst #55**, Piątek J., this paper

**Fig. 22**

*Picture-file number* — Piątek J., picture-file Camer7-105, Fig. 22.

*Number of specimens* — 9.

*Biological affinity* — Unknown.

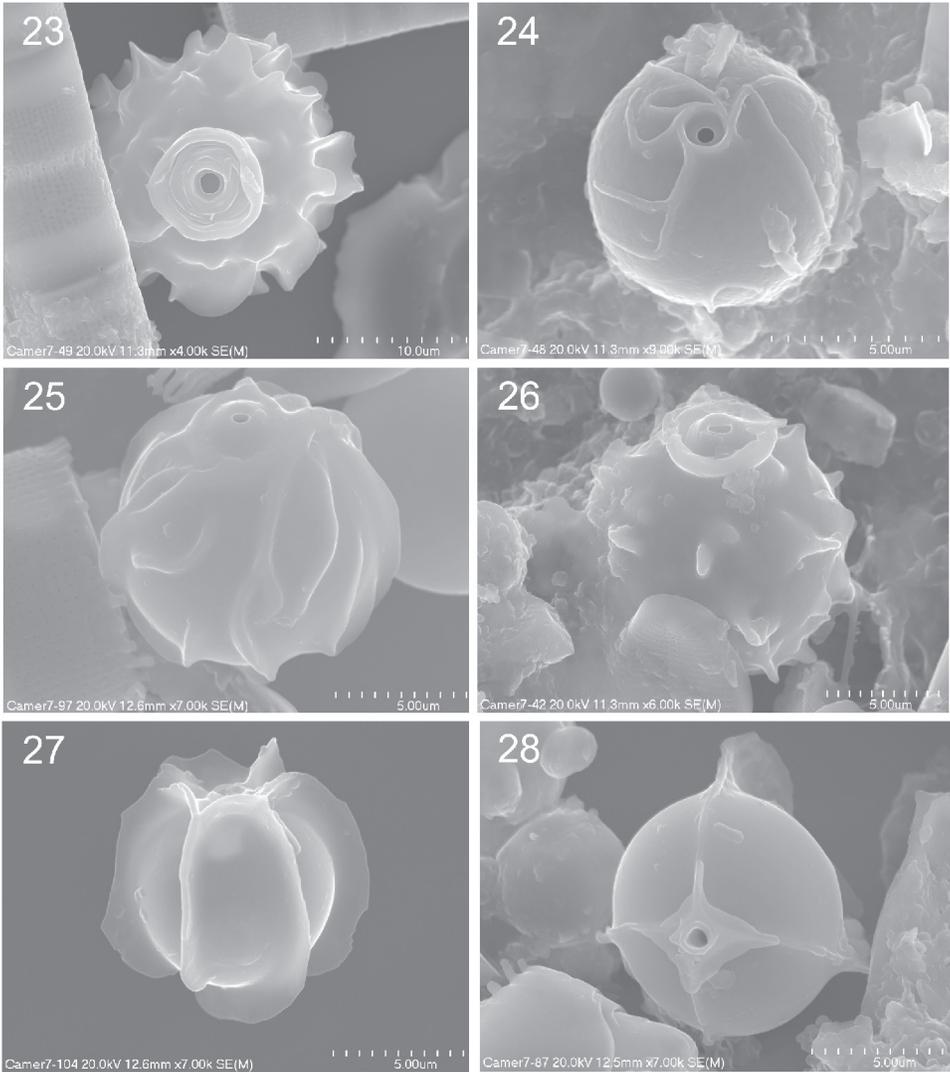
*Locality* — Cameroon – Lacs Paponoun (smaller lake).

*Description* — This stomatocyst is spherical, 9.0-10.2  $\mu\text{m}$  in diameter. The pore is concave, 0.6  $\mu\text{m}$  in diameter. The collar is 2.6-3.3  $\mu\text{m}$  in diameter and 0.5-0.9  $\mu\text{m}$  high. The cyst body surface is ornamented with conula and verrucae, 0.3-0.6  $\mu\text{m}$  wide and 0.4-0.6  $\mu\text{m}$  high.

*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.

*Comments* — This morphotype has not been previously observed, and is therefore described as new for science. Stomatocyst #55 is similar to stomatocyst 314 Brown & Smol in Brown *et al.* 1997, which is different in having smaller size of cyst body (6.6  $\mu\text{m}$  in diameter), regular pore and other collar morphology.

*With ridges***Stomatocyst 24**, van de Vijver B. & Beyens L. 1997a**Fig. 23***Picture-file number* — Piątek J., Camer7-49.*Number of specimens* — 1.*Biological affinity* — Unknown.*Locality* — Cameroon – Lacs Paponoun (smaller lake).*Description* — This stomatocyst is spherical, 15.4  $\mu\text{m}$  in diameter. The regular pore, 1.4  $\mu\text{m}$  in diameter, is surrounded by planar pseudoannulus. The collar is obconical and composed with concentric ridges. The collar is 5.7  $\mu\text{m}$  in diameter at the apex, 7.7  $\mu\text{m}$  in diameter at the base, and 1.8  $\mu\text{m}$  high. The cyst body surface is ornamented with ridges, 0.2-0.3  $\mu\text{m}$  wide, and up to 2.7  $\mu\text{m}$  high.*Distribution* — This morphotype has been previously reported only from one locality in the sub-Antarctic region of Kerguelen Islands (van de Vijver & Beyens, 1997a). Here, it is reported for the first time in Africa from its second world locality.*Comments* — Stomatocyst 24 has been originally described based on two specimens (van de Vijver & Beyens, 1997a), and only one specimen of this cyst has been observed in the present study. Despite different ecological conditions in the Kerguelen Islands and Cameroon, the cyst specimens from these two localities are inseparable morphologically. The cyst body diameter is 14.6-15.5  $\mu\text{m}$  in specimens from Kerguelen Islands and 15.4  $\mu\text{m}$  in specimen from Cameroon, the pore is regular in all specimens and is 1.2-1.3  $\mu\text{m}$  in diameter in specimens from Kerguelen Islands and 1.4  $\mu\text{m}$  in specimen from Cameroon. Therefore, specimen from Cameroon is assigned to stomatocyst 24.**Stomatocyst #56**, Piątek J., this paper**Fig. 24***Picture-file number* — Piątek J., picture-file Camer7-48, Fig. 24.*Number of specimen* — 4.*Biological affinity* — Unknown.*Locality* — Cameroon – Lacs Paponoun (smaller lake).*Description* — This stomatocyst is spherical, 7.5-8.8  $\mu\text{m}$  in diameter. The pore is regular, 0.5-0.6  $\mu\text{m}$  in diameter, with planar pseudoannulus. The collar is cylindrical, 1.4-1.7  $\mu\text{m}$  in diameter, and 0.2-0.5  $\mu\text{m}$  high. Two to five ridges extend directly from the outer collar margin that are subsequently randomly oriented and branched, with different length, 0.1-0.2  $\mu\text{m}$  wide and 0.2-0.6  $\mu\text{m}$  high.*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.*Comments* — This morphotype has not been previously observed and is described as new for science. There is no comparable stomatocyst described so far.**Stomatocyst #57**, Piątek J., this paper**Fig. 25***Picture-file number* — Piątek J., picture-file Camer7-97, Fig. 25.*Number of specimens* — 4.*Biological affinity* — Unknown.*Locality* — Cameroon – Lacs Paponoun (smaller lake).*Description* — This stomatocyst is spherical, 9.6-10.0  $\mu\text{m}$  in diameter. The pore is regular, 0.6  $\mu\text{m}$  in diameter. The primary collar is conical, 1.2  $\mu\text{m}$  in diameter at the apex, 2.0  $\mu\text{m}$  in diameter at the base, and 0.8  $\mu\text{m}$  high. The secondary collar is 3.6  $\mu\text{m}$  in diameter and 0.4  $\mu\text{m}$  high. The cyst body surface is ornamented with low



Figs 23-28 (SEM). **23.** Stomatocyst 24, van de Vijver B. & Beyens L. 1997a. **24.** Stomatocyst #56, Piątek J., this paper. **25.** Stomatocyst #57, Piątek J., this paper. **26.** Stomatocyst #58, Piątek J., this paper. **27.** Stomatocyst #59, Piątek J., this paper. **28.** Stomatocyst #60, Piątek J., this paper.

ridges extending directly from the secondary collar margin, the ridges are of different length, 0.2-0.3  $\mu\text{m}$  wide and up to 1.0  $\mu\text{m}$  high.

*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.

*Comments* — This morphotype has not been previously observed, and is described as new for science. It is similar to stomatocyst 133 Duff & Smol in Duff *et al.* 1992 *emend.* Zeeb *et al.* *subm. emend.* Duff & Smol 1994. Nevertheless, stomatocyst from Lacs Paponoun has collar complex with different size and morphology.

**Stomatocyst #58**, Piątek J., this paper**Fig. 26**

*Picture-file number* — Piątek J., picture-file Camer7-42, Fig. 26.

*Number of specimens* — 1.

*Biological affinity* — Unknown.

*Locality* — Cameroon – Lacs Paponoun (smaller lake).

*Description* — This stomatocyst is spherical, 10.9  $\mu\text{m}$  in diameter. The pore is regular, 1.1  $\mu\text{m}$  in diameter. The primary collar is conical, 2.2  $\mu\text{m}$  in diameter and 1.1  $\mu\text{m}$  high. The secondary collar, 5.0  $\mu\text{m}$  in diameter and 0.6  $\mu\text{m}$  high, is curled down towards the cyst body surface. The cyst body surface is ornamented with morphologically variable ridges, 0.9-1.2  $\mu\text{m}$  high.

*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.

*Comments* — This morphotype has not been previously observed, and is described as new for science. Stomatocyst #58 is similar to stomatocyst 186 Brown & Smol in Brown *et al.* 1994, but differs in having other morphology of the secondary collar. Other than morphological difference, stomatocyst 186 seems to have different ecological requirements as it was recorded from cold environments in Canada (Duff *et al.*, 1995) and Svalbard (Betts-Piper *et al.*, 2004). The algal specimens identified as *Trachelomonas yberiensis* var. *membranosa* Frenguelli in Argentina and *Outesia yberensis* var. *reticulato-spinosa* Conrad in the USA that resemble and could represent stomatocyst 186 (Duff *et al.*, 1995) are also from areas environmentally different than habitat of stomatocyst #58.

**Stomatocyst #59**, Piątek J., this paper**Fig. 27**

*Picture-file number* — Piątek J., picture-file Camer7-104, Fig. 27.

*Number of specimens* — 1.

*Biological affinity* — Unknown.

*Locality* — Cameroon – Lacs Paponoun (smaller lake).

*Description* — This stomatocyst is spherical, 7.4  $\mu\text{m}$  in diameter. The pore is not visible. The low, slightly conical collar is 1.5  $\mu\text{m}$  in diameter and 0.2  $\mu\text{m}$  high. Six evenly-spaced ridges, 1.3-1.5  $\mu\text{m}$  high and 0.2  $\mu\text{m}$  wide, extend longitudinally from the collar. The cyst body surface between the ridges is smooth.

*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.

*Comments* — This morphotype has not been previously observed. It is described as new for science. There is no comparable stomatocyst described so far.

**Stomatocyst #60**, Piątek J., this paper**Fig. 28**

*Picture-file number* — Piątek J., picture-file Camer7-87, Fig. 28.

*Number of specimens* — 1.

*Biological affinity* — Unknown.

*Locality* — Cameroon – Lacs Paponoun (smaller lake).

*Description* — This stomatocyst is spherical, 8.8  $\mu\text{m}$  in diameter. The pore is regular, 0.6  $\mu\text{m}$  in diameter. The collar is slightly conical, 1.3  $\mu\text{m}$  in diameter and 0.5  $\mu\text{m}$  high. Four equidistantly placed ridges, which could be also interpreted as two circuli, extend longitudinally from the outer collar margin and run down to the posterior hemisphere. Ridge height range from 0.2  $\mu\text{m}$  on the anterior pole to 2.2  $\mu\text{m}$  on the posterior pole, ridge width is 0.2  $\mu\text{m}$ . The cyst body surface between the ridges is smooth.

*Distribution* — This stomatocyst is currently known only from one locality in Cameroon.

*Comments* — This morphotype has not been previously observed. It is described as new for science. It is similar to stomatocyst 176 Zeeb & Smol 1993, which is different in having smaller size of cyst body, somewhat different morphology of ridges in the collar area, and very low irregular patches with circular lacunae on the cyst body surface between the ridges.

*With compound ornamentation*

**Stomatocyst cf. 171**, Zeeb & Smol 1993

**Fig. 29**

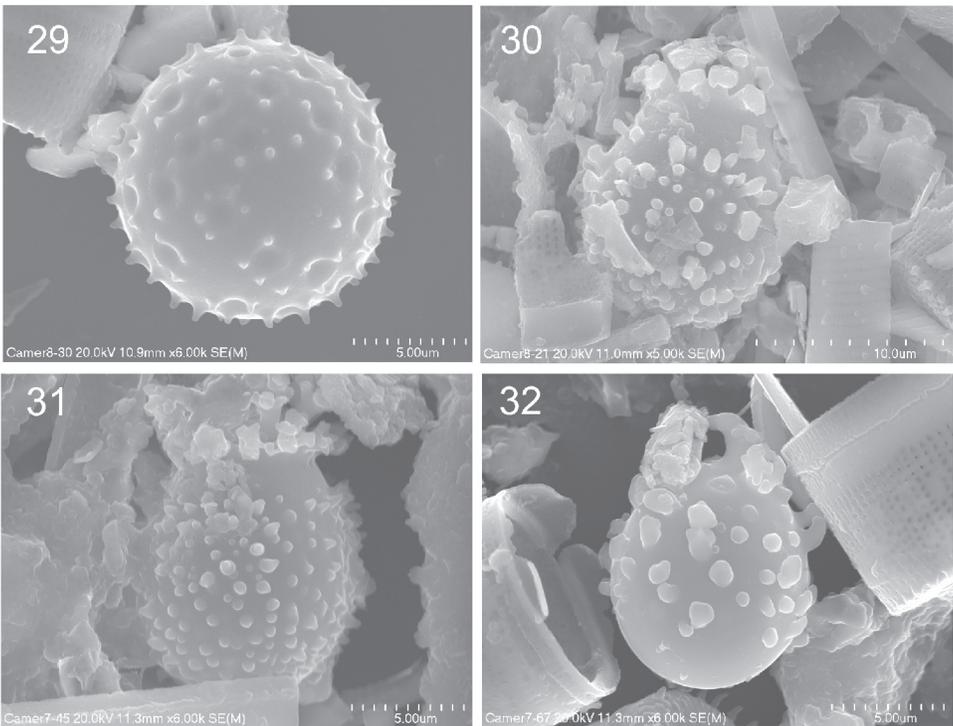
*Picture-file number* — Piątek J., Camer8-30.

*Number of specimens* — 3.

*Biological affinity* — Unknown.

*Locality* — Cameroon – Lacs Paponoun (larger lake).

*Description* — This stomatocyst is spherical, 12.1-12.4  $\mu\text{m}$  in diameter. The pore is not visible. The collar is slightly obconical, 1.4  $\mu\text{m}$  in diameter at the base, 1.1  $\mu\text{m}$  in diameter at the apex and 0.3  $\mu\text{m}$  high. The cyst body surface is ornamented with circular depressions (1.4-1.5  $\mu\text{m}$  in diameter), conula and echinate spines (0.4-0.5  $\mu\text{m}$  wide and 0.6-0.7  $\mu\text{m}$  high).



Figs 29-32 (SEM). **29.** Stomatocyst cf. 171, Zeeb & Smol 1993. **30-31.** Stomatocyst cf. 27, van de Vijver B. & Beyens L. 1997a. **32.** Stomatocyst cf. 6, Coradeghini & Vigna 2001.

*Distribution* — This stomatocyst has been previously reported from North America (Duff *et al.*, 1995) and Europe (Duff *et al.*, 1995; Pla, 2001; Piątek, 2007). Here, it is reported for the first time in Africa.

*Comments* — Since the pore is not visible and for this reason this cyst is identified to cf.

**Stomatocyst cf. 27**, van de Vijver B. & Beyens L. 1997a

**Figs 30-31**

*Picture-file number* — Piątek J., Camer8-21 and Camer7-45.

*Number of specimens* — 5.

*Biological affinity* — Unknown.

*Locality* — Cameroon – Lacs Paponoun (both smaller and larger lakes).

*Description* — This stomatocyst is ovate or oval, 7.5-11.8  $\mu\text{m}$  long and 7.9-10.2  $\mu\text{m}$  wide. The pore is not visible. The collar is complex. The primary collar consists of several unequal projections with irregular shape, 1.8-3.6  $\mu\text{m}$  high. The secondary collar is broad and obconical, 5.7-7.8  $\mu\text{m}$  in diameter and 2.4-3.6  $\mu\text{m}$  high, with the apex consisting several irregularly shaped projections. The cyst body surface is ornamented with different kinds of projections including verrucae, conula and short baculate spines (0.3-0.9  $\mu\text{m}$  in diameter and 0.4-1.5  $\mu\text{m}$  high).

*Distribution* — Morphologically similar morphotype has been previously described from the sub-Antarctic region of Kerguelen Islands (van de Vijver & Beyens, 1997a) and reported from China (Pang & Wang, 2016). Here, this stomatocyst is reported for the first time in Africa.

*Comments* — This morphotype is most similar to stomatocyst 27 van de Vijver B. & Beyens L. 1997a, but since the pore was not visible and the projections emerging from primary collar were higher the material from Cameroon is only provisionally assigned to stomatocyst 27. Van de Vijver & Beyens (1997a) described primary collar with 9 unequal projections having maximal height of 1.3  $\mu\text{m}$ , but they observed only one specimen of stomatocyst 27 that may not cover whole variability of this stomatocyst. Stomatocyst 27 van de Vijver B. & Beyens L. 1997a may represent immature specimen of cyst morphotype that was later described as stomatocyst 12 Coradeghini & Vigna 2001.

**Stomatocyst cf. 6**, Coradeghini & Vigna 2001

**Fig. 32**

*Picture-file number* — Piątek J., Camer7-67.

*Number of specimens* — 1.

*Locality* — Cameroon – Lacs Paponoun (smaller lake).

*Description* — This stomatocyst is ovate, 9.8  $\mu\text{m}$  long and 8.6  $\mu\text{m}$  wide. The pore is not visible due to inwardly hooked projection (1.2  $\mu\text{m}$  in diameter and 2.3  $\mu\text{m}$  high) located near the pore. The cyst body surface is mostly ornamented with baculate spines and conula (0.4-0.9  $\mu\text{m}$  in diameter and 0.4-1.5  $\mu\text{m}$  high), only the posterior pole lacks ornamentation.

*Distribution* — Morphologically similar morphotype has been previously described from Argentina (Coradeghini & Vigna, 2001). Here, this stomatocyst is reported for the first time in Africa on its second locality in the world.

*Comments* — This morphotype is very similar to stomatocyst 6 Coradeghini & Vigna 2001, but since the pore and collar were not visible the material from Cameroon is only provisionally assigned to stomatocyst 6.

## DISCUSSION

This study documents the largest assemblage of chrysophycean stomatocysts in the recent sediments in tropical Africa detected so far. Additionally, it provides new data on global diversity of chrysophycean stomatocysts. Twenty morphotypes of chrysophycean stomatocysts were identified in two neighbouring mountain lakes named as Lacs Paponoun located in the Cameroon Highlands. Seventeen different stomatocysts were observed in the smaller lake (Fig. 1) and only six stomatocysts in the larger lake. A reversed situation was observed in two tropical, high-mountain lakes in Central Mexico (Vilaclara *et al.*, 2005), where stomatocysts from two lakes in close proximity were also studied. One of them was larger (El Sol) and the second was smaller (La Luna). In contrast to the material from Cameroon, greater richness was reported in the bigger lake, with as many as 27 different morphotype stomatocysts, while only four morphotypes were present in the smaller lake and ones that also were present in the bigger El Sol (Vilaclara *et al.*, 2005). According to the study, the lakes also differed by other physical and chemical properties of the water (e.g. pH,  $Z_{\max}$ ,  $K_{25}$ ), which probably determined the diversity of the morphology of the stomatocysts. Unfortunately, it was not possible to conduct physico-chemical studies of water in the Cameroonian lakes and it is difficult to identify specific reasons for the large difference in the number and the abundance of stomatocysts in these closely located lakes.

Three among the cysts identified: stomatocysts 9, 19 and 42, have a cosmopolitan distribution. They have been reported from different parts of the world and different climatic zones, from habitats with extremely different physical and chemical conditions, ranging from slightly acidic to alkaline lakes and ponds, to the sulfuric saline water, and thermo-mineral springs. An additional argument in favour of the cosmopolitan nature is the fact that they are most probably produced by more than one species. Stomatocyst 19 has mainly been found in several arctic and alpine lakes and ponds, across a wide range of pH values and it is suggested that it is produced by a cold-tolerant taxon (Duff *et al.*, 1995). Additionally, stomatocyst 19 has also been noted at other sites in the world, in South America (Coradeghini & Vigna, 2001) and here it is reported from Africa. This may indicate that it is produced by a 'widely distributed' taxon. According to Kristiansen (2000), a taxon is 'widely distributed' if it occurs on four or five out of the six continents.

Stomatocysts 127, cf. 171 and cf. 27 are cysts of unknown biological affinities. They have been reported from different parts of the world. They are probably produced by a widely distributed freshwater chrysophytes. Rybak *et al.* (1987) suggested that stomatocyst 171 may be produced by a eutrophic taxon. Moreover, it was commonly found in slightly acidic to circumneutral water and classified as pH-indifferent (Duff *et al.*, 1995). This data may suggest that this is a widely distributed stomatocyst in the world. Similar case may represent stomatocyst 127, which was associated with shallow, alkaline lakes and peat bog, but its ecological optima and tolerance are still unclear (Duff *et al.*, 1995). Stomatocyst 27 has been described from the subfossil materials (age  $1320 \pm 70$  BP) from the Kerguelen Islands (van de Vijver & Beyens, 1997a) and recently reported from the cattail marsh and meadow marsh in China (Pang & Wang, 2016). Its ecological requirements are still weakly known.

Stomatocysts 39 and 24 are cysts of unknown biological affinities and have so far been reported only from their respective *locus classicus*: stomatocyst 39 from Antarctica (Coradeghini & Vigna, 2008) and stomatocyst 24 from the Kerguelen Islands (van de Vijver & Beyens, 1997a). Both morphotypes were described from

the materials originating from the zone of the circumpolar climate. It is difficult to say which factors determine the occurrence of these stomatocysts in such different environments and ecoregions as tropical (in Cameroon) and circumpolar zones (in Antarctica and Kerguelen Islands). This may be due to their potentially wider ecological tolerance. Further studies of the material worldwide are necessary to confirm or deny these assumptions.

The most numerous group consists of eleven newly described stomatocysts: #50-#60, Piątek J. The biological affinities of these stomatocysts are not known and their autecological requirements are not yet available, except the fact that they are associated with mountain lake(s) in tropical Africa. Future research in other African lakes and habitats should reveal whether these stomatocysts are more widely distributed or represent morphotypes restricted to small area in the Cameroon Highlands.

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