



***Staurophora caljonii* spec. nov. (Bacillariophyceae, Anomoeoneidaceae), a new halophilic diatom species from sub-recent lake deposits in Kenya**

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Received 21 October 2002; in revised form 17 August 2003; accepted 31 August 2003

Key words: diatoms, *Staurophora*, *Staurophora caljonii*, *Stauroneis*, Naivasha, Oloidien, Sonachi, salt lakes

Abstract

Fossil diatom analyses of lake-sediment cores representing the last ~250 years of Lakes Oloidien and Sonachi in the Eastern (Gregory) Rift Valley of central Kenya yielded a new diatom species, described here as *Staurophora caljonii* spec. nov. (Bacillariophyceae, Anomoeoneidaceae) on the basis of light and electron microscopic investigations of its frustule morphology. This presumably benthic halophilic species is known only from saline phases in the recent history of two sodium-bicarbonate (soda) lakes, when diatom-inferred conductivity was around 10 000 $\mu\text{S cm}^{-1}$. It has not been found in the modern diatom flora from saline Rift Valley lakes in Kenya (Sonachi, Nakuru, Elementeita) or Ethiopia (Abiyata, Langano), nor in Lake Oloidien, which is a freshwater lake nowadays. Its fossil distribution suggests that semi-permanent saline wetlands are its natural habitat. The closest modern relative of *Staurophora caljonii* appears to be *Stauroneis legleri* Hustedt, a taxon known only from a salt lake in Austria. Additional, a light microscopic description of the frustule of *S. legleri* is given as well as some scanning electron microscopic characteristics.

Introduction

The diatom flora of saline–alkaline lakes in the dry East African Rift Valley of Kenya, Ethiopia and Tanzania has been the subject of intensive taxonomic and ecological investigations (e.g. Hecky & Kilham, 1973; Gasse et al., 1983, 1995; Gasse, 1986) making it one of the better-known diatom floras of the world. Discovery of a new diatom species in these environments is therefore unexpected. Besides the cosmopolitan taxa (e.g. *Anomoeoneis sphaerophora* (Kütz.) Pfitzer, *Rhopalodia gibberula* (Ehr.) O. Müller) a number of the alkaline-saline diatom species known from East African has a distribution restricted to Africa (e.g. *Thalassiosira faurei* (Gasse) Hasle, *T. rudolfi* (Bachmann) Hasle, *Craticula elkab* (O. Müller) D.G. Mann).

Fossil diatom analysis of sediment cores collected in lakes Oloidien and Sonachi, two satellite basins of Lake Naivasha in Kenya's central Rift Valley, yielded

a previously unknown diatom species of the family Anomoeoneidaceae. In Lake Oloidien (5.1 km², 6 m deep), which during the past two centuries has undergone a succession of fresh and saline episodes (Verschuren et al., 1999b), this species was recovered only from sediments representing a late-18th to early-19th century desiccation phase when the lake floor was only seasonally flooded and diatom-inferred conductivity (Gasse et al., 1995) reached 10 000 $\mu\text{S cm}^{-1}$ (Fig. 1). In Lake Sonachi (0.14 km², 5 m deep), a small saline-alkaline crater lake maintained against the local water-balance deficit by groundwater flow from Lake Naivasha (Gaudet & Melack, 1982 in Verschuren, 1996), morphologically identical frustules were common in sediments of the same desiccation episode 200 years ago, but were also found in sediments covering much of the last 175 years of recent lake history, albeit not continuously and always in low abundance (Fig. 2). This lake has over the past 180 years experienced a succession of meromictic and holomictic epis-

odes (Verschuren, 1999b) and diatom-inferred conductivity variation between 1400 and 17 000 $\mu\text{S cm}^{-1}$ (Verschuren et al. 1999b); historical measurements of surface-water conductivity ($n = 39$; 1929–1991) range between 3000 and 11 550 $\mu\text{S cm}^{-1}$ (Verschuren 1996).

The present paper deals with the description of these sub-recent diatom frustules as belonging to a new species in the genus *Staurophora* Mereschowsky, evaluate its taxonomic relationships, and discuss its probable ecological affinities as inferred from the two known fossil occurrences. Sampling of the modern pelagic and littoral epiphytic and benthic diatom flora in Lake Sonachi in April 1999, and analysis of recently deposited diatom assemblages preserved at the top of a frozen sediment profile collected in August 1993, both failed to yield fresh material of this taxon. It has also not been found in modern pelagic and littoral phytoplankton samples of lakes Nakuru, Elementeita, and Bogoria, the three major saline lakes of the Kenya Rift Valley, nor in lakes Abiyata and Langanu in the Rift valley of Ethiopia.

A comparison with the most related species, *Stauroneis legleri* Hust., is made based on light and scanning electron microscopic characteristics.

Materials and methods

Material from Lake Oloidien was extracted from the stiff, low-organic clays between 88 and 90 cm of sediment core NO91.1-S, dated by lead-210 and carbon-14 to the late-18th and early-19th century (Verschuren, 1999a). Material from Lake Sonachi was extracted from 50 depth intervals of core NS93.2-F, representing the last two centuries of lake history (Verschuren, 1999a; Verschuren et al., 1999a). The sediment samples were processed for light-microscopic examination (LM) of fossil diatom frustules by oxidation with hydrogen peroxide and acetic acid (Schrader, 1974). Aliquots of the diluted suspension were mounted on microscope slides, permanently embedded in Naphrax, and studied at 1000 \times with a Leitz Diaplan microscope equipped with differential interference contrast. Scanning-electron microscope (SEM) investigation was done with a JEOL 840 operating at 15 KV.

Study material of the closely related species *Stauroneis legleri* (Hustedt 1959, II p. 793, Fig. 1138; Simonsen, 1987) includes the type specimen from Lake Alber (Burgenland, between Illmitz and

Neusiedler See) in Austria, collected on 8 November 1958 (slide E9771 of the Hustedt Collection at Bremerhaven, Germany), as well as additional material of the type collection available for SEM analysis.

Results

Staurophora caljonii was common in the diatom flora of Lake Oloidien during the late 18th and early 19th century (Fig. 1) and reached a maximum relative abundance of 12% of the total diatom composition. It was observed on three other occasions in the mid-19th century, the 1940s and the 1950s but it always remained rare (relative abundance 0.2, 0.2, 0.3%, respectively) and appears to have disappeared thereafter (Fig. 1).

In Lake Sonachi, *Staurophora caljonii* was also most common (1.9–3.8% relative abundance) during the late-18th and early-19th century (Fig. 2).

Description of Staurophora caljonii spec. nov.

Light microscopy (Figs 3–11)

Valves linear to linear lanceolate with slightly protracted rounded apices; valves weakly twisted. Length 17.5–39.4 μm , width 4.4–7.5 μm , 16–21 striae in 10 μm . No punctuation of the striae visible at 1000 \times . Striae straight to slightly radiate becoming parallel near the apices. Central area small, reaching the margin, sometimes 1–2 (exceptionally 3) shortened striae present (Fig. 6). Axial area small, becoming somewhat enlarged before the central nodulus. Raphe almost straight. Terminal raphe endings curved towards the same direction. Middle part of the frustules constricted in girdle view; width in girdle view: 3.5–5.5 μm , 3–5 μm in the constricted part; 20–24 striae in 10 μm . *Scanning electron microscopy* (Figs 12–27): External valve face flat. Central raphe fissures somewhat enlarged and slightly bent in the opposite direction of the terminal raphe endings (Fig. 12). Areolae laterally enlarged, 65–70 in 10 μm (Figs 15–16). Sometimes rimmed siliceous particles present around the areolae near one pole. Internal valve: helictoglossum present near the terminal raphe fissure on each pole (Fig. 27). Internal valve face with areolae occluded by a hymen (Fig. 26). Central raphe fissures laterally hooked (Fig. 25). The valve mantle of the epivalve overlaps the valve mantle of the hypovalve (Figs 20–24). Girdle bands not very distinct, except near the apices where 4 bands are observed (Figs 17–18, 20–23). One broad

Lake Oloidien

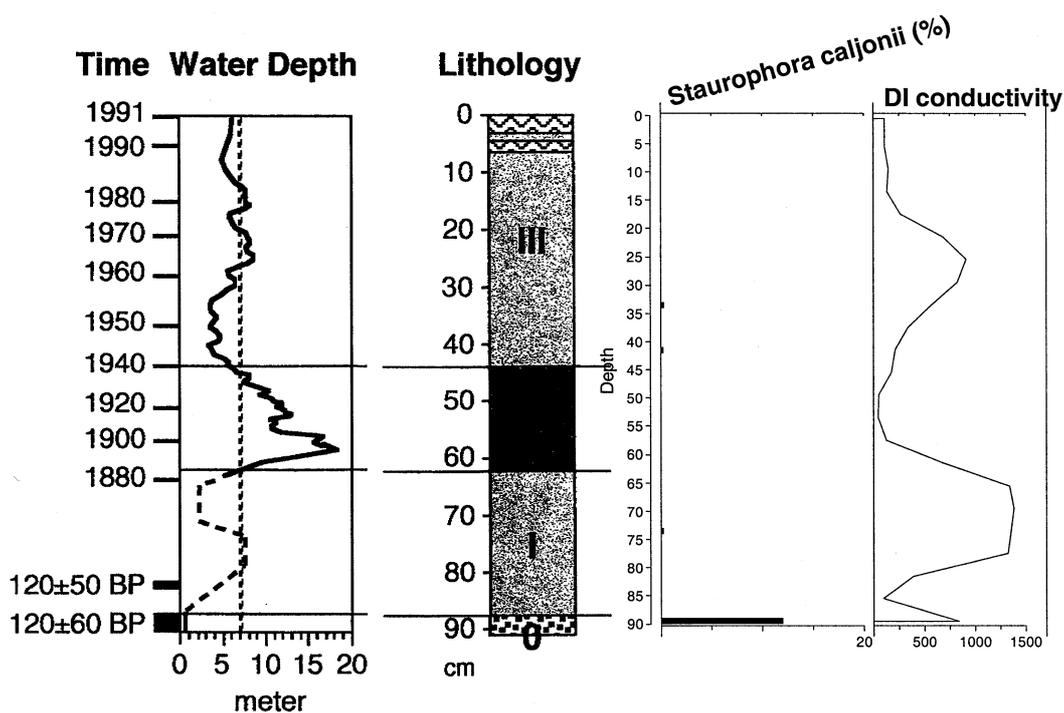


Figure 1. Fossil distribution of *Staurophora caljonii* (relative abundance) in the sediment record of Lake Oloidien (Kenya), in relation to core lithology, historical and reconstructed lake-level fluctuations and diatom-inferred conductivity variation (DI conductivity) during the past 200 years. Modified from Verschuren et al. (1999a).

Lake Sonachi

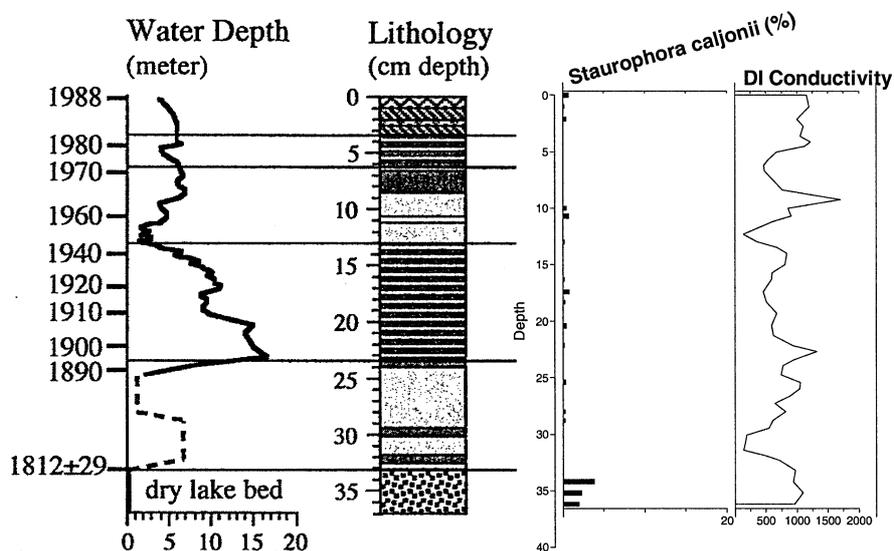


Figure 2. Fossil distribution of *Staurophora caljonii* (relative abundance) in the sediment record of Lake Sonachi (Kenya), in relation to core lithology, historical and reconstructed lake-level fluctuations and diatom-inferred conductivity variation (DI conductivity) during the past 200 years. Modified from Verschuren et al. (1999a).

band is present around the whole valve contour, sometimes bearing silica ridges (Figs 20–21). A second band is interrupted near the poles. The third band is only developed near the poles and bears sometimes a well-developed silica ridge. The fourth, broad band is interrupted near the apices and is overlapped by the third band near the apices. Two rows of tiny, elongated poroids are present on the girdle bands (Fig. 17).

Distribution: Kenya: Lake Oloidien and Lake Sonachi, Eastern (Gregory) Rift Valley, Kenya, 19th and 20th century sediments but not found in the modern flora.

Ecology: As inferred from its fossil distribution, *Staurophora caljonii* is a halophilic diatom from shallow and fluctuating, climate-sensitive tropical lakes, with a conductivity optimum probably around $10\,000\ \mu\text{S cm}^{-1}$. It is probably benthic or epiphytic, as are the other species belonging to the genus *Staurophora* (Round et al. 1990, Cox 1999).

Etymology: The specific epithet is *caljonii*, after A. Caljon, the late husband of the author who during the 1980s undertook algological studies in East Africa.

Diagnosis

Valvae lineares ad lanceolatas, apicibus protractis rotundatis leviter; valvae tortae leniter; $17.5\text{--}39.4\ \mu\text{m}$ longae, $4.4\text{--}7.5\ \mu\text{m}$ latae. Punctae striarum invisibiles in $1000\times$. Striae transapicales rectae vel radiatae leviter, parallelae ad polos, $16\text{--}21$ in $10\ \mu\text{m}$. Area centralis parva, ad marginem attingens, striae abbreviatae $1\text{--}2$ (3 raras) aliquandae. Area axialis angusta, prope nodulos centrales aucta aliquantum. Raphe recta fere. Extremi raphis curvi in directione eodem. Frustuli constricti in medio parte aspectu cingulari; $3.5\text{--}5.5\ \mu\text{m}$ latae, $3\text{--}5\ \mu\text{m}$ in parte constricto, $20\text{--}24$ striae in $10\ \mu\text{m}$.

Holotypus: preparatio BM 101035, The Natural History Museum, Department of Botany, London (UK).

Isotypus: preparatio Zu5/54, Friedrich Hustedt-Arbeitsplatz für Diatomeenkunde, Bremerhaven (Germany); preparatio NS93-2-F/47 bis, Department of Biology, Section Protistology and Aquatic Ecology, Ghent University (Belgium).

Iconotypus: figurae nostrae, figurae 3, 4, 12–19.

Statio: Lacus Sonachi, Kenya, sedimento.

Discussion

Allocation of the new diatom species to the genus *Staurophora* of the family Anomoeoneidaceae is based on frustule morphology structure. The striae

on the valves are uniseriate and composed of small round poroids (areolae), closed internally by finely perforated plates; the internal central raphe endings are laterally hooked as described for the genus *Staurophora* (Round et al., 1990). Species belonging to the closely related genus *Stauroneis* have often areolae slightly elongated in the direction of the striae and closed internally by finely perforated, confluent plates (Cox, 1999). The internal central raphe endings are fine, unexpanded but very slightly deflected in the genus *Stauroneis*. The girdle bands have a single row of simple pores in *Stauroneis*, two rows of tiny poroids in *Staurophora*.

The position and number of the plastids, an important characteristic distinguishing the genera *Staurophora* and *Stauroneis*, could not be studied because of the present lack of live material. *Staurophora* species have a single H-shaped chloroplast, which laps around the cell periphery with a lenticular pyrenoid at the centre, positioned against one girdle side (Round et al., 1990; Cox, 1999). In contrast, *Stauroneis sensu stricto* have two plate-like chloroplasts that each lie along one side of the girdle, with one or many lenticular pyrenoids per chloroplast (Round et al., 1990; Cox, 1999).

Under both LM and SEM, frustule morphology of the new taxon closely resembles that of *Stauroneis legleri* (Hustedt, 1959, Figs 11–14) a similarly halophilic diatom species known only from its type locality in Austria. As this taxon was described in German, I add here an English description and additional notes on scanning electron microscopic characteristics.

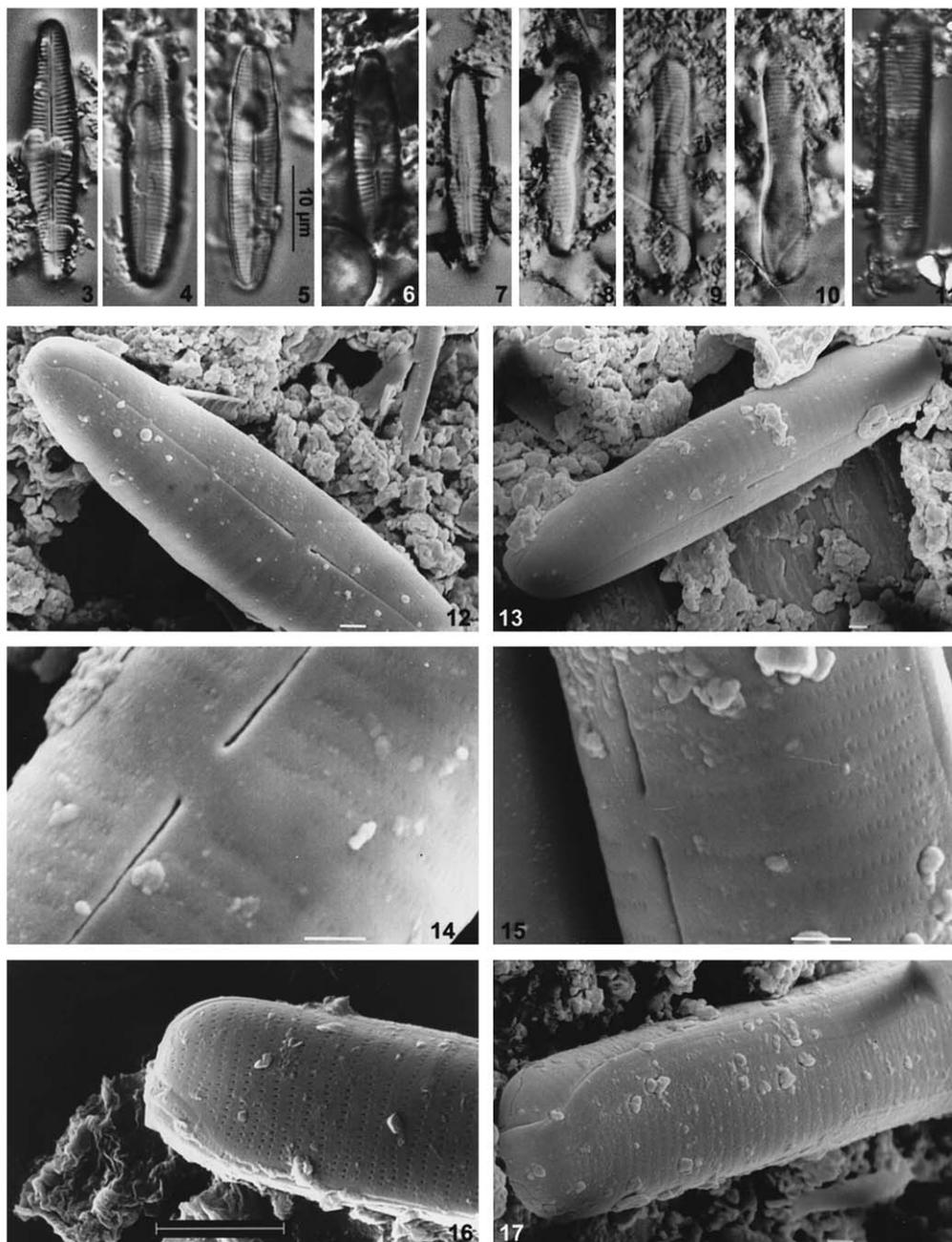
Description of *Stauroneis legleri*

Light microscopy (after Hustedt, 1959 and Figs 33–36)

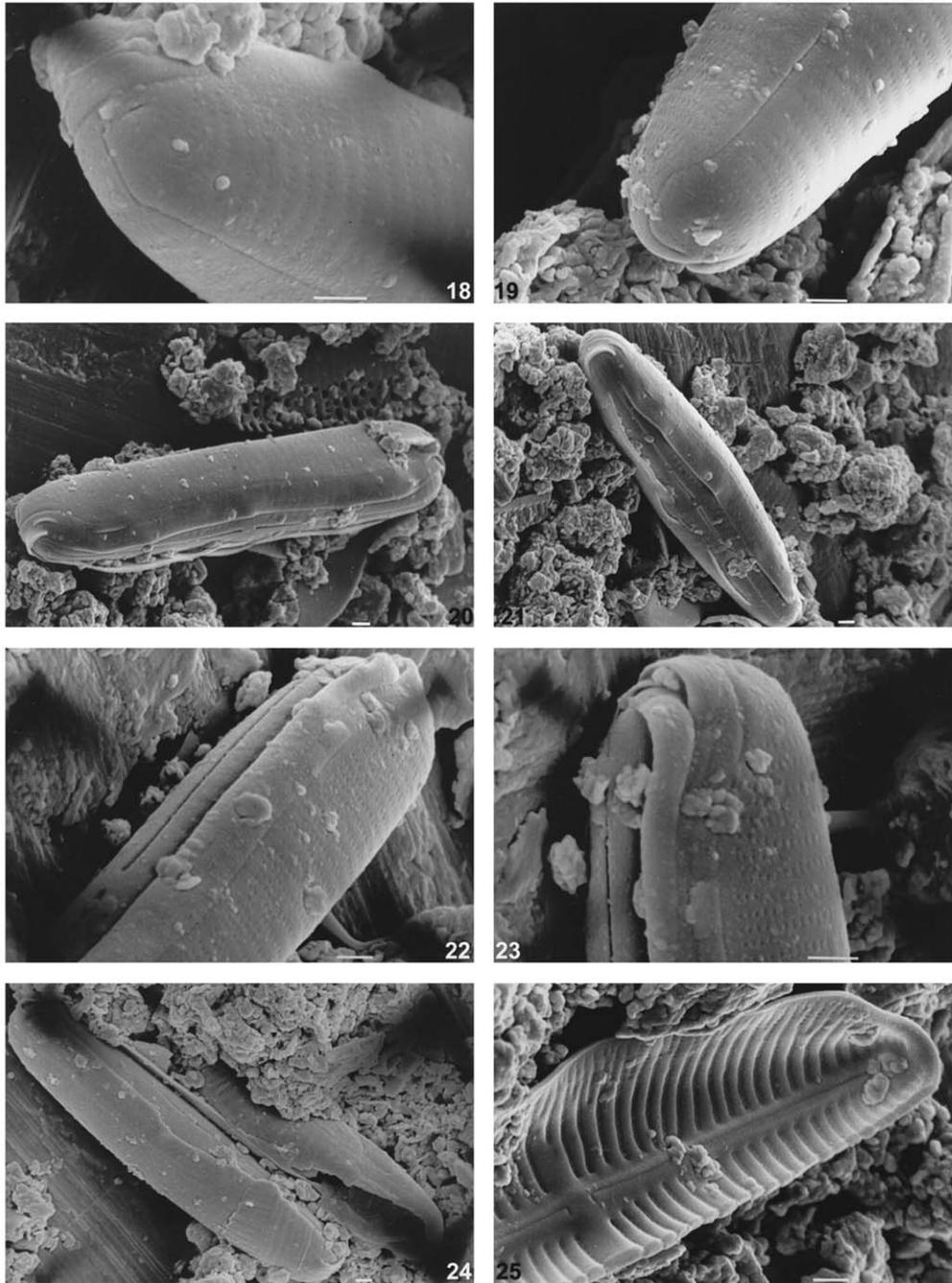
Valves somewhat twisted along the transapical axis. Length: $20\text{--}36\ \mu\text{m}$, width: $5\text{--}7\ \mu\text{m}$. Raphe straight, thread shaped, rather long terminal raphe endings; axial area: very small, linear; central area a small stauros reaching the valve margins with mostly $1\text{--}2$ short transapical striae near the edge. The striae are slightly radiate, irregular, 16 in $10\ \mu\text{m}$ in the centre, up to 20 in $10\ \mu\text{m}$ near the poles; very finely punctated. The striae may become parallel or even convergent near the poles.

Scanning electron microscopy (Figs 28–32)

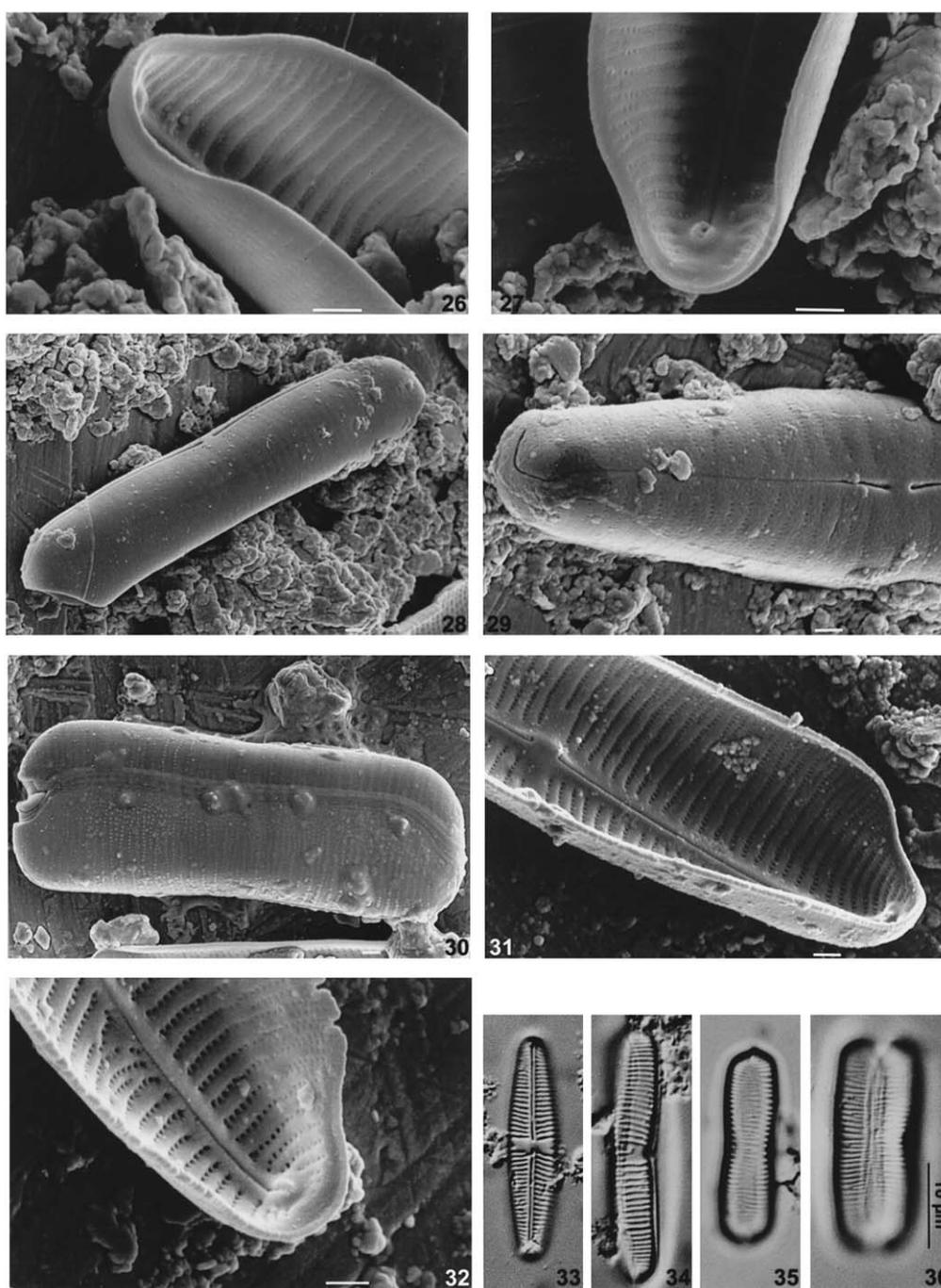
External valve face flat. Central raphe fissures enlarged and bent in the opposite direction of the ter-



Figures 3–17. *Staurophora caljonii*. Figs 3–11: LM, Figs 3–7 valvar view; Figs 8–9: view of the valves from the mantle side, Figs 10–11: girdle view; Figs 12–17: *Staurophora caljonii* SEM, external valve view. Scale bars SEM = 1 μ m, LM = 10 μ m.



Figures 18–25. *Staurophora caljonii* SEM. Figs 18–24: external views; Fig. 25. internal valve view. Scale bar = 1 μm .



Figures 26–27. *Staurophora calzonii* SEM, internal view. Fig. 27: terminal raphe fissure with helictoglossum. Figs 28–36: *Stauroneis legleri*. Figs 28–32: SEM, Figs 28–30: external view with somewhat enlarged central raphe fissures, Figs 31–32: internal view with the hooked central raphe fissures and the terminal raphe fissure with helictoglossum. Figs 33–36: LM from type slide number E9771 of the Hustedt Collection at Bremerhaven, Fig. 33: valvar view, Fig. 34: view of the valve from the mantle side, Figs 35–36: girdle view. Scale bars SEM = 1 μm , LM = 10 μm .

Table 1. Major characteristics of *Staurophora caljonii* and *Stauroneis legleri*. In bold the characteristics that are different in the two species.

	<i>Staurophora caljonii</i>	<i>Stauroneis legleri</i>
Valve length	17.5–39.4 μm	20–36 μm
Valve width	4.4–7.5 μm	5–7 μm
Valves	slightly protracted near the poles slender appearance twisted transapically difficult to bring the entire valve in focus in LM	not protracted near the poles less twisted transapically
Central area	small, reaching the valve margins sometimes 1–2 (3) shortened striae	small, reaching the valve margins mostly 1–2 shortened striae
Axial area	enlarged near the central nodulus	very small, linear less enlarged near the central nodulus
Striae	16–21 in 10 μm straight to slightly radiate straight near the poles	16–20 in 10 μm slightly radiate clearly convergent near the poles
Raphe	straight, thread shaped central fissures somewhat enlarged, bent in the opposite direction of the terminal fissures central fissures laterally hooked	straight, thread shaped central fissures enlarged, bent in the opposite direction of the terminal fissures central fissures laterally hooked
Areolae	65–70 in 10 μm laterally enlarged	50–60 in 10 μm laterally enlarged
Helictoglossum	present near the terminal raphe fissures	present near the terminal raphe fissures

terminal raphe endings (Fig. 29). Areolae laterally enlarged, 50–60 in 10 μm (Fig. 29). Internal valve: helictoglossum present near the terminal raphe fissure on each pole (Fig. 32); central raphe fissures laterally hooked (Fig. 31). Girdle bands very distinct (Fig. 30).

However, *Staurophora caljonii* differs from *Stauroneis legleri* in at least five aspects: valve shape, position of the striae, enlargement of the axial area and shortened striae in the central area and number of areolae (Table 1).

Stauroneis legleri has not previously been the subject of detailed taxonomic study. New understanding of generic concepts (e.g. Round et al., 1990), together with the SEM investigation undertaken here, suggest that *S. legleri* should be placed in the genus *Staurophora*. Further investigation, however, including the chloroplast structure is needed. There is the opinion that *Stauroneis legleri* is synonymous with *Navicula soodensis* Krasske (Krammer & Lange-Bertalot, 1997) but the publication don't provide any argumentation.

In Lake Oloidien *Staurophora caljonii* was common during the late-18th and early-19th century (Fig. 1), during a pronounced arid period when the lake floor desiccated completely for part of the year but was flooded at least for some time during the main wet season (Verschuren, 1999a). The diatom flora was at that moment dominated by halophilic community (e.g. *Craticula elkab* and *Thalassiosira rudolfi*), yielding a diatom-inferred conductivity of 10 000 $\mu\text{S cm}^{-1}$ (Verschuren et al. 1999b). However, contemporaneous presence of freshwater taxa, i.e. *Aulacoseira granulata*, *A. italica* and *Nitzschia palea* indicates that Lake Oloidien experienced large seasonal salinity variations (Verschuren, 1999a). These are characteristic for semi-permanent closed-basin wetlands (Gasse et al., 1990). During the past ~180 years since this most recent desiccation, Lake Oloidien has been a permanent water body. But the lake has undergone lake-depth fluctuations between ~4 and 19 m (Verschuren, 1999a) and a succession of fresh and saline episodes. The presence of fresh and saline periods depends on its degree of isolation from Lake Naivasha (Verschuren

et al., 2000, Fig. 35). These environmental changes do not appear to have included conditions very suitable for development of *Stauraphora caljonii*. It seems that Lake Oloidien was colonized by *Stauraphora caljonii* during at least three occasions in saline episode in the mid-19th century, the 1940s and the 1950s, but it always remained rare (relative abundance 0.2, 0.2, 0.3%, respectively) and appears to have disappeared thereafter.

In Lake Sonachi *Stauraphora caljonii* was also most common (1.9–3.8% relative abundance) in the late-18th and early-19th century (Fig. 2), when the lake floor was only seasonally flooded (Verschuren et al., 1999a). The local diatom flora at that time was characterised by meso- and polysaline halophilic diatoms, such as *Anomoeoneis sphaerophora*, *Craticula elkab*, *Nitzschia* cf. *latens*, *N. pura* and *Rhopalodia gibberula*, translated in diatom-inferred conductivity estimates of 10 000–11 000 $\mu\text{S cm}^{-1}$ (Verschuren et al., 1999a). Like Lake Oloidien, Lake Sonachi has been a permanent water body during the ~ 180 years since this desiccation phase, but it experienced considerable environmental changes including lake-depth fluctuations between ~ 3 and 18 m. Diatom-inferred conductivity varies between 1400 and 17 000 $\mu\text{S cm}^{-1}$ (Verschuren et al. 1999a). The intermittent occurrence of *Stauraphora caljonii* during this period suggests that the species may be present in the modern diatom flora of Lake Sonachi.

Probably, populations occasionally develop in littoral areas during seasonal lake-level rises, which are akin to the flooding of a semi-permanent saline wetland. Restriction to seasonally desiccating saline wetlands may explain why *Stauraphora caljonii* was not found in modern (2000) live samples, planktonic as well as benthic, from the most important saline lakes in Kenya and Ethiopia, Nakuru (43 200 $\mu\text{S cm}^{-1}$, D. Verschuren, Ghent University, pers. comm.), Elementeita (29 100 $\mu\text{S cm}^{-1}$), Bogoria (68 400 $\mu\text{S cm}^{-1}$), Abiyata (15 120 $\mu\text{S cm}^{-1}$) (Tudorancea et al., 1999), and Lake Langano (1643–1728 $\mu\text{S cm}^{-1}$, Tudorancea et al., 1999). In this case, a high percent abundance of *Stauraphora caljonii* in fossil diatom assemblages from hydrologically closed lake basins in East Africa may be a valuable bio-indicator of past episodes of pronounced aridity.

Acknowledgements

Thanks are due to Dr R.M. Crawford for providing type material of *Stauroneis legeri* Hustedt from the Hustedt Collection (Bremerhaven, Germany), to Dr D. Verschuren for the many instructive discussions on Lakes Naivasha, Olodien and Sonachi, to Mrs. R. Vandriessche for technical support, and to Dr C.N. Roberts and Dr J. Tibby for critical reading of the manuscript.

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