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Three novel species of Bacillariophyta (Diatoms) in the genera *Surirella* and *Thalassiosira* from Pleistocene Paleolake Lorenyang (~2 - 1.6 Ma) Turkana Basin, Kenya

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Abstract

Three novel species of Bacillariophyta (diatom) are described from the sediments of Paleolake Lorenyang, a large lake that existed in the Turkana Basin, Kenya during the Gelasian age of the Pleistocene Epoch. Sediment cores extracted as part of the Hominin Sites and Paleolakes Drilling Project (HSPDP) were sampled to provide a diatom-based paleoecological record of Paleolake Lorenyang. Preliminary results of the paleoecological analysis unearthed three novel species of diatoms belonging to *Surirella* and *Thalassiosira* in the Natoo Member of the Nachukui Formation. Comparisons of *Surirella* from Paleolake Lorenyang are made to previous reports of *Surirella* from modern lakes in East Africa and comparisons of *Thalassiosira* species from the paleolake are made to modern and fossil species reported from East Africa. This is a first report of diatoms in the Natoo Member, which has previously been described as a floodplain deposit, and thus provides evidence of the last occurrence of Paleolake Lorenyang within the Turkana Basin. Herein we describe a new species of *Surirella* and two *Thalassiosira* with remarks on morphology and evolution of East African *Surirella* and *Thalassiosira.*

Introduction

The Hominin Sites and Paleolakes Drilling Project is an international, interdisciplinary collaborative that collected sediment cores from paleolake basins across Kenya and Ethiopia (Cohen *et al*. 2009). This project integrates paleoenvironment and paleoclimate records to better constrain the conditions in which hominins evolved. To this end, HSPDP targeted paleolake records representing critical junctures in hominin evolution (Cohen *et al.* 2016; Campisano *et al*. 2017). The Turkana Basin in northwestern Kenya, Figure 1, preserves a robust sedimentological and paleoanthropological record from the Miocene to present, including nine different species of hominins (Wood & Leakey 2011). Of particular interest are early examples of the genus *Homo* around 2 Ma, and finds such as the Nariokotome Boy (KNM-WT 15000) from the site NK3 within the Natoo Member of the Nachukui Formation (Brown *et al*. 1985; Harris *et al*. 1988; Feibel & Brown 1993). The HSPDP core in the Turkana Basin targeted the Kaitio Member of the Nachukui Formation from the west side of Lake Turkana.

The target interval is Paleolake Lorenyang, a deep lacustrine facies characterized by fine-grained sediments near the border fault of an asymmetrical half graben (Figure 2) (Feibel 2011). The drilling campaign recovered most of the Kaitio Member and subsequent Natoo Member, providing a unique opportunity to directly tie the core to outcrops of paleontological significance (Feibel *et al*. 2014; Cohen *et al*. 2016).

The silica skeletons of diatoms are generally well preserved in sediment deposits. These sediment fossil records are often utilized to provide paleoecological information for the interpretation of paleoenvironmental variation via environmental-ecological relationships. Well-preserved diatom presence in the HSPDP West Turkana Kaitio (WTK) core occurred primarily within the Natoo Member deposits (~1.38–1.48 Ma). Prior to 1.48 Ma, fossil diatom preservation typically ranged from poorly preserved specimens to complete diatom dissolution. Diatomites have been reported to reside in two other members of the Nachuku Formation, including the Lonyumun Member and the Kataboi Member (Harris *et al*. 1988). Research of these diatomites is not well documented. However, Harris *et al.* (1988) mentioned that diatoms were well preserved in the Kataboi Member diatomites.

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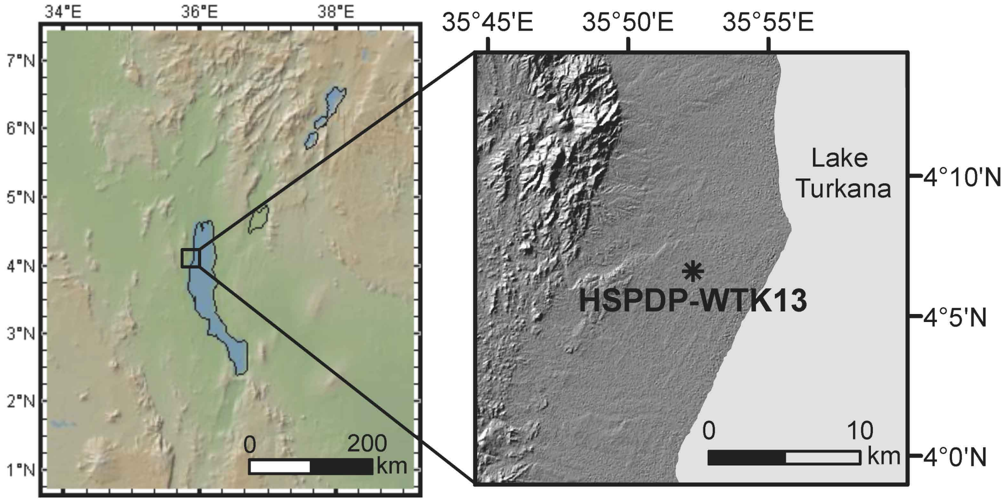

FIGURE 1. Location map of the coring site and modern Lake Turkana with surrounding topography.

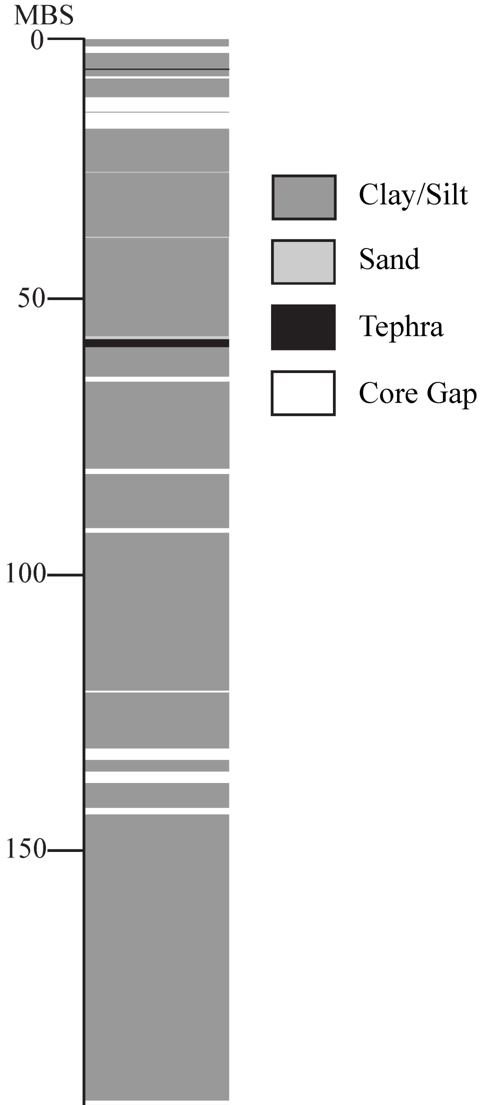

FIGURE 2. Simplified stratigraphic column of the WTK13-1A core.

In general, establishment of fossil diatom species furthers the understanding of diatom evolutionary history and ecological relationships for paleoecological studies. Diatom speciation has been shown to occur in as few as 4000 years (Theriot 1992) and is partly attributed to their extremely rapid reproductive rates. Consistent taxonomy is required to assure biostratigraphic integrity within and between lakes. This is especially true for paleoecological studies (Flower *et al*. 2013), where differences in skeletal features over longer timeframes may provide clues regarding changes in environmental parameters.

During our investigation of the Paleolake Lorenyang sediments, we observed two undescribed species of *Thalassiosira* Cleve (1873: 7) and one undescribed species of *Surirella* Turpin (1828: 363). A taxonomic treatment of these three novel species is provided herein. Gasse (1986) presents flora from modern lakes in the East African Rift Region; Gasse (1986) reported 535 taxa from 98 different locations, one of which closely resembles *Thalassiosira gasseae* (described herein). Gasse (1986) also reports an undescribed *Surirella* species, similar to *Surirella lorenyangensis* (described herein), from the modern Lake Turkana, which was later described as *Surirella turkanensis* Reichardt, E. (1994: 129).

Materials and Methods

Site description:—The HSPDP WTK coring site consisted of a single borehole 300 m from the Kaitio Laga (dry river bed) that exposed the type section of the Kaitio Member and outcrops of the overlying Natoo Member (Cohen *et al*. 2016; Campisano *et al*. 2017). Fine-grained lacustrine clays and silts that are frequently laminated to thinly bedded, dominate the Kaitio Member. The unit includes other aquatic markers such as concentrated ostracod sands and fish fossils. Continuing up section, the Natoo Member is comprised primarily of silts and tuffaceous silts with intervened sand beds (Brown *et al*. 1985). The coring site was selected to leverage existing outcrop stratigraphy and paleoanthropological research (Brown *et al*. 1985; Harris *et al*. 1988). The modern landscape is harsh, with limited vegetation and mean annual precipitation on the order of 200 mm or less (Butzer 1971). The WTK site is located < 4.5 km from the shore of modern Lake Turkana, a moderately saline, alkaline closed basin system (Yuretich 1979) with maximum dimensions of 257 km long, 29 km across, with an average depth of 33 m (Yuretich & Cerling 1983). During the Plio-Pleistocene, the depositional environment of the basin oscillated between open lacustrine and through-flowing fluvial systems resulting from the combined forces of climate and tectonics (Brown & Feibel 1988; Feibel 2011). Paleolake Lorenyang formed in the Turkana Basin beginning around 2 Ma, and persisted until 1.48 Ma (Brown & Feibel 1991; Lepre *et al*. 2007).

Field sampling and summary descriptions:—One core was collected from the WTK site (WTK13-1A, 4.109722° N, 35.871781° E) using a truck-mounted standard wireline diamond coring drill rig in July 2013. Below ~60 m the sedimentology of the core is characterized by greenish-gray fine-grained lithologies including laminated mudstones to paleosols. Above this level, the core contains slightly more sand and is reddish brown in color. These lithologic differences correspond to a first order facies transition from a lacustrine system at the bottom of the core to a fluvial deltaic one at the top. However, both these facies evidence repeated episodes of pedogenesis (frequently very weak), indicating that this margin was fluctuating dynamically on sub-Milankovitch time-scales.

Laboratory Methods:—Diatom sub-samples (~0.1 g) were dried and weighed. Extraction preparation was performed by adding 20 mL of 30% H2O2 as per Battarbee (1986). Subsamples were rinsed three times to remove supernatant fluids. A known concentration of microspheres was added to each sample for comparing diatom concentrations between samples. Diatom extracts were air dried onto coverslips and SEM stub mounts; evaporation was accelerated with a slide warmer. Coverslips were affixed to slides using p-naphrax™ 200T optical adhesive from Phyco Tech, Inc. St. Joseph, MI. Mounted SEM stubs were sputter-coated with gold.

Light microscopy observation, photography, and measurement was performed using a DM2500 light microscope, DFC450 affixed digital camera, and Leica Application Suite from Leica Microsystems, Wetzlar, Germany and the literature used for diatom identification included Gasse (1986), Reichardt (1994), Gasse (1980), Houk *et al*. (2010), and Houk *et al*. (2014). The *Surirella* species valves were observed and photographed at 400x magnification due to the large size and the *Thalassiosira* species valves were observed and photographed at 1000x magnification for light microscopy. Initial Scanning electron microscopy was performed at the University of Arizona's Laserchron Center on a 3400N SEM from © Hitachi, Ltd. Further imaging was conducted at Indiana University Purdue University Indianapolis' Integrated Nanosystems Development Institute on a 7800F SEM from JEOL USA, Inc. Peabody, MA.

Results

Class: **Bacillariophyceae**
Order ***Surirelales***
Family ***Surirellaceae***
Surirella

Surirella lorenyangensis Brindle, Mohan & Stone ***spec. nov.*** **(Figs 3 & 4)**

Valves are heteropolar, ovate, being symmetrical about the apical axis. Foot pole is subrostrate and slightly protracted, whereas the head pole is cuneate to rounded. Valve length ranges between 92–175 µm, widths are 31–43 µm. Distal ends of the median line and alar wings are arched toward the cingulum (base of the apical plane)(Fig. 4, A). Valve face convex, raised along the median line and covered in granules (Fig. 4, E & G). Small poroids are sparse. Raphe positioned in a slightly raised keel along the external margin of the alar wing (Fig. 4, F).

Type:—West Turkana Kaitio, northwestern Kenya, (4.109722° N, 35.871781° E) Pleistocene lake sediment core of the Natoo Member of the Nachukui Formation sediment core (HSPDP-WTK13-1A) material, sediment depth ~ 60 meters below surface, collected by *Feibel, C., Cohen, A., & Beck, C., July 2013*, **holotype, designated here**; deposited in ANSP! GC17191 (Circled specimen on slide WTK 173, illustrated herein as Fig. 3, C).

Etymology:—*Surirella lorenyangensis* is named as pertaining to Paleolake Lorenyang, the lake that existed in the Turkana Basin from 2.0 - 1.5 Ma (Brown & Feibel 1991; Lepre *et al*. 2007).

Remarks:—*Surirella lorenyangensis* resembles *S. turkanensis* Reichardt (1994: 129) by having similar size range and happens to reside in the modern Lake Turkana whereas Paleolake Lorenyang was present in the same basin. *S. lorenyangensis* differs from *S. turkanensis* by being heteropolar, exhibiting a distinct headpole and footpole. Terminal raphe ends and alar wings of *S. lorenyangensis* are also much more down-turned than in *S. turkanensis.*

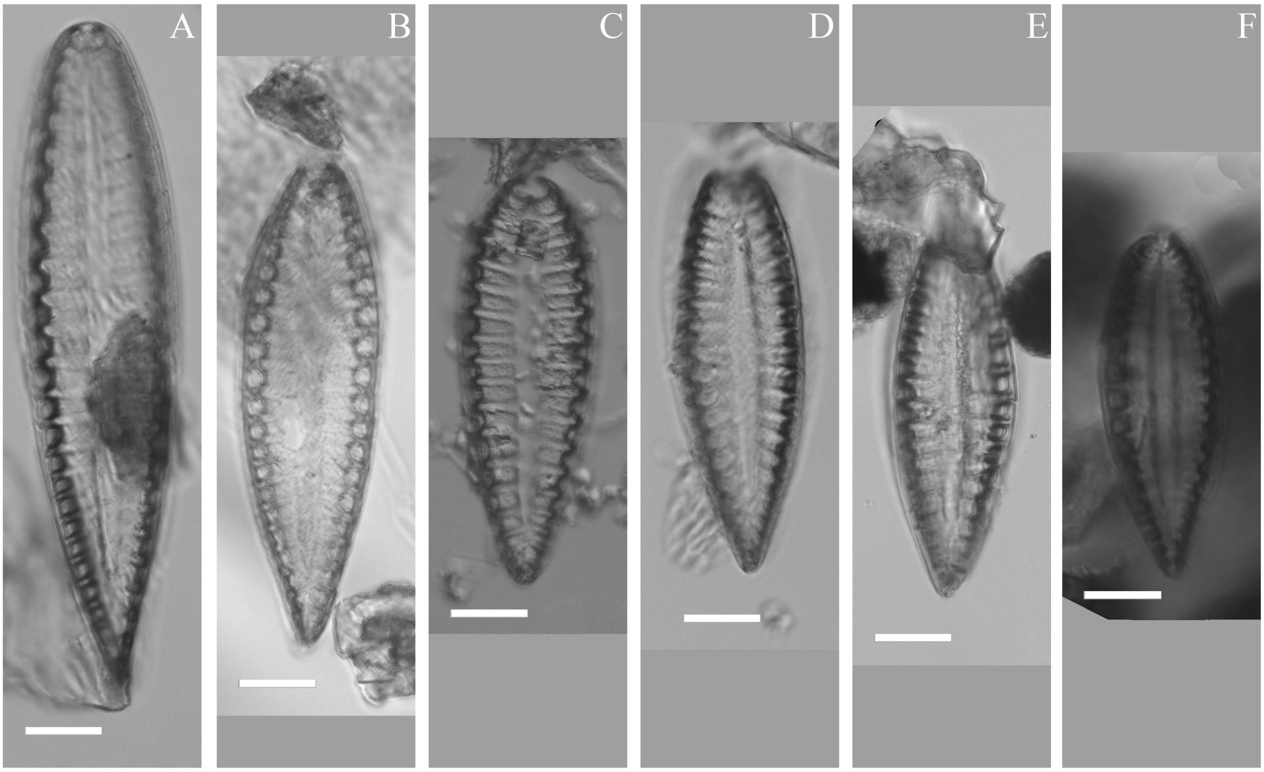

FIGURE 3. LM *Surirella lorenyangensis.* Size diminution series of *Surirella lorenyangensis* Images taken at x400. Scale bar is 30 µm. C is the holotype.

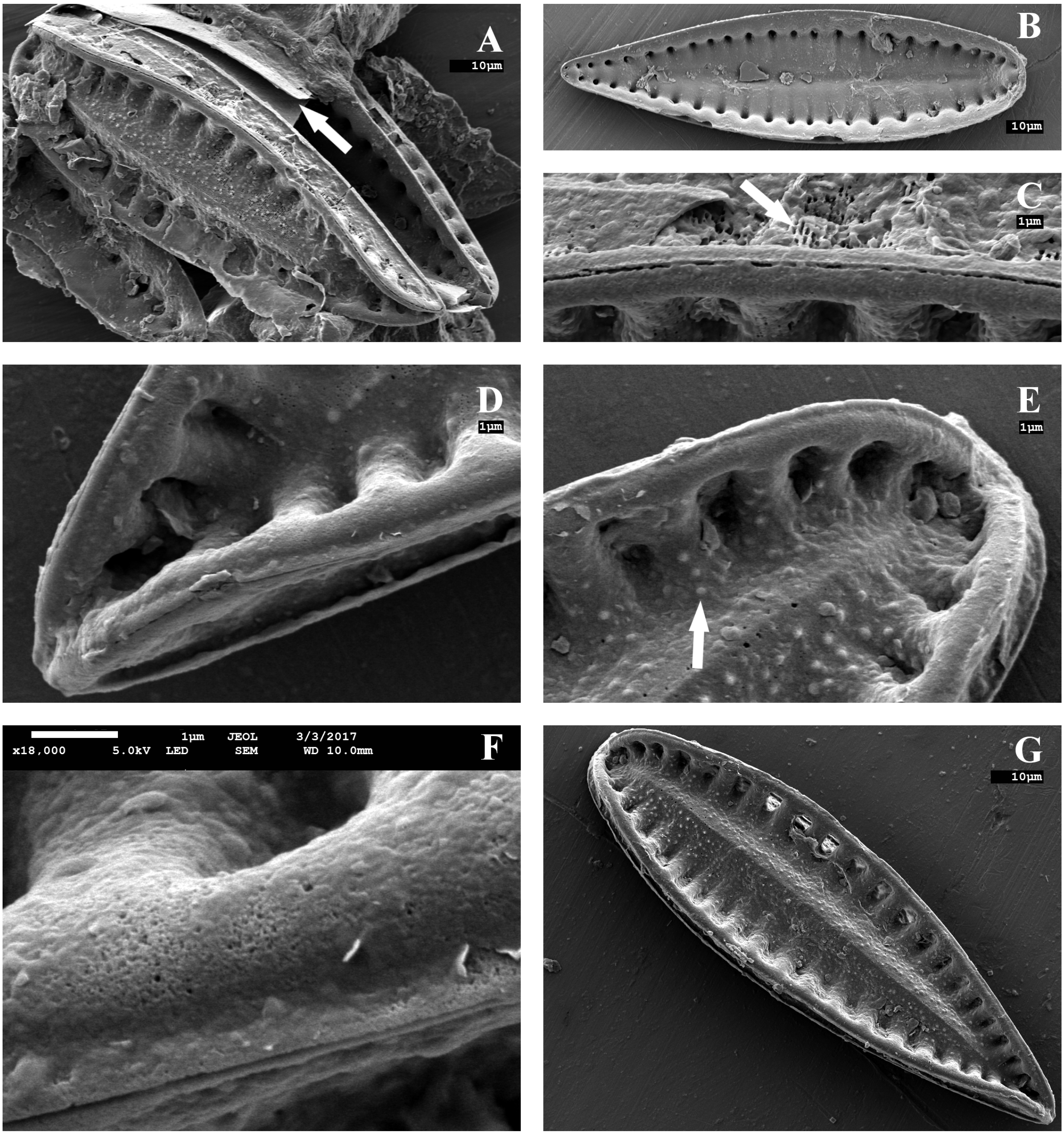

FIGURE 4. SEM *Surirella lorenyangensis.* Scanning electron micrographs of *Surirella lorenyangensis*. A nearly complete frustule (A) with both valves and an attached yet broken girdle band (arrowed). Internal structures are smooth (B) exhibiting hollow fibulae. The internal structure of the fibulae are marked by a lattice structure arrowed in (C). The footpole is rostrate (D), while the headpole is more rounded (E). The ala is downturned towards the girdle at both poles (D & E). The raphe is more towards the exterior sides of the ala in the middle of the valve (C & F) and moves to the top of the ala at the poles (D & E). The raphe is contained within a raised channel along the alar wings (F), ala are supported by the fibulae with unobstructed windows between fibulae (F & G). The exterior valve surface is covered in granules arranged weakly in rows, indicated by arrow in (E), also shown in (A & G).

Class: **Mediophyceae**
Order ***Thalassiosirales***
Family ***Thalassiosiraceae***
Thalassiosira

Thalassiosira feibelii Brindle & Mohan ***spec. nov*** **(Figs. 5 & 6)**

Valves are discoid, flat with a short down-turned mantle, diameter 12– 34 µm. Areolae on valve face are consistent in size and weakly arranged in curved rows. Areolae on the mantle are consistent in size and smaller than areolae on the valve face (Fig. 6, A). Foramen are located on the external wall of loculate areolae, elliptic velum is located on the internal wall (Fig. 6, F & G). A single row of compactly spaced fultoportulae encompasses the valve at the junction of the valve face and margin. Internal structure of the fultoportulae are raised and exhibit small struts that extend into four satellite pores. Externally the fultoportulae are raised ~1 µm from valve face and are covered in granules (Fig. 6, B & D). A single rimoportula is associated with fultoportulae that are slightly displaced toward valve center (Fig. 6, C).

Type:—West Turkana Kaitio, northwestern Kenya, (4.109722° N, 35.871781° E) Pleistocene lake sediment core of the Natoo Member of the Nachukui Formation sediment core (HSPDP-WTK13-1A) material, sediment depth ~ 60 meters below surface, collected by *Feibel, C., Cohen, A., & Beck, C., July 2013*, **holotype, designated here**; deposited in ANSP! (Circled specimen on slide WTK 179, illustrated herein as Fig. 5, B).

Etymology:—*Thalassiosira feibelii* is named in honor of Dr. Craig Feibel for his outstanding contributions to understand early hominin-environmental relationships in the Tukana Basin, Kenya.

Remarks:—*Thalassiosira feibelii* is remarkably similar to *T. faurii* (Gasse) Hasle (1978: 282), the most notable difference is that *T. feibelii* does not exhibit central fultoportulae while *T. faurii* is characterized as having three central fultoportulae separated by °120, being midway from valve center to valve margin.

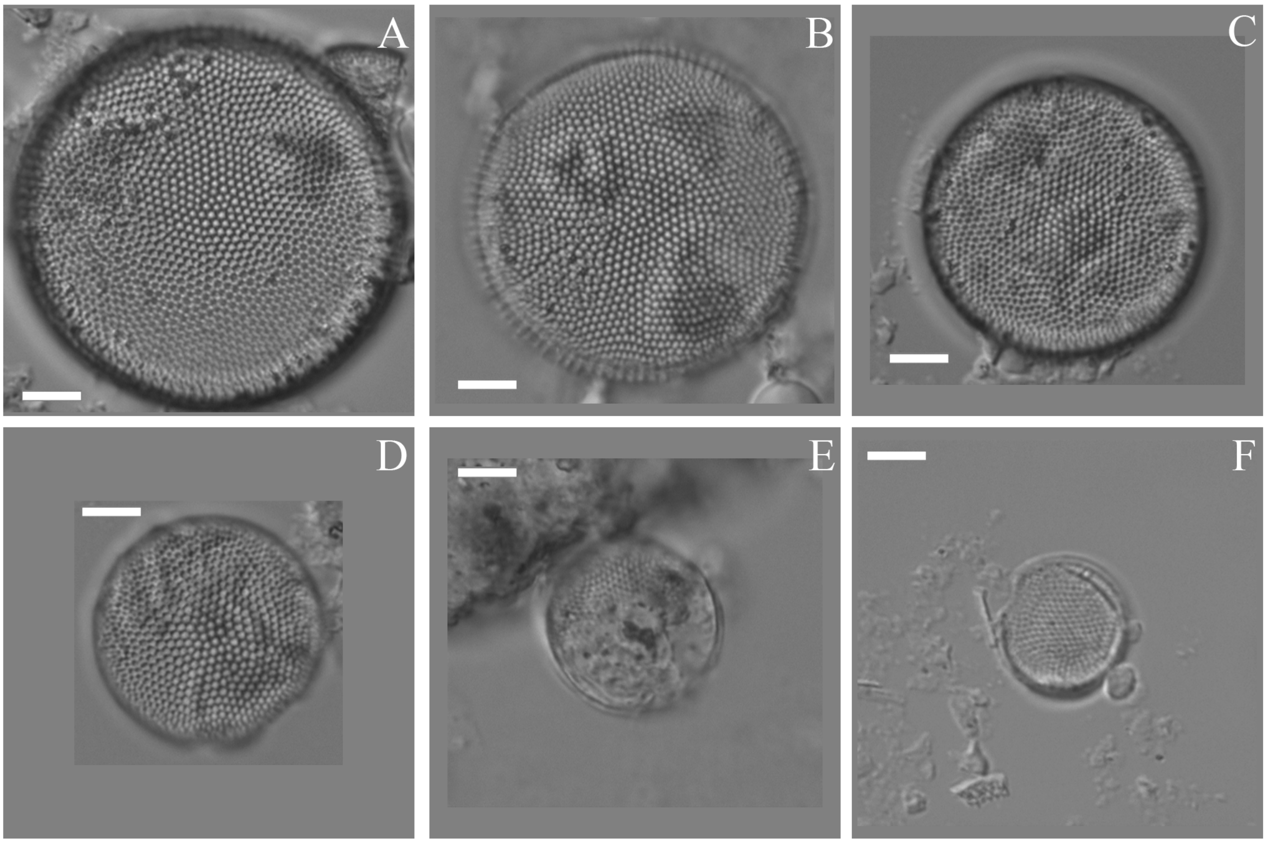

FIGURE 5. LM *Thalassiosira feibelii.* Size diminution series of *Thalassiosira feibelii* Images taken at x1000. Scale bar is 5 µm. B is the holotype.

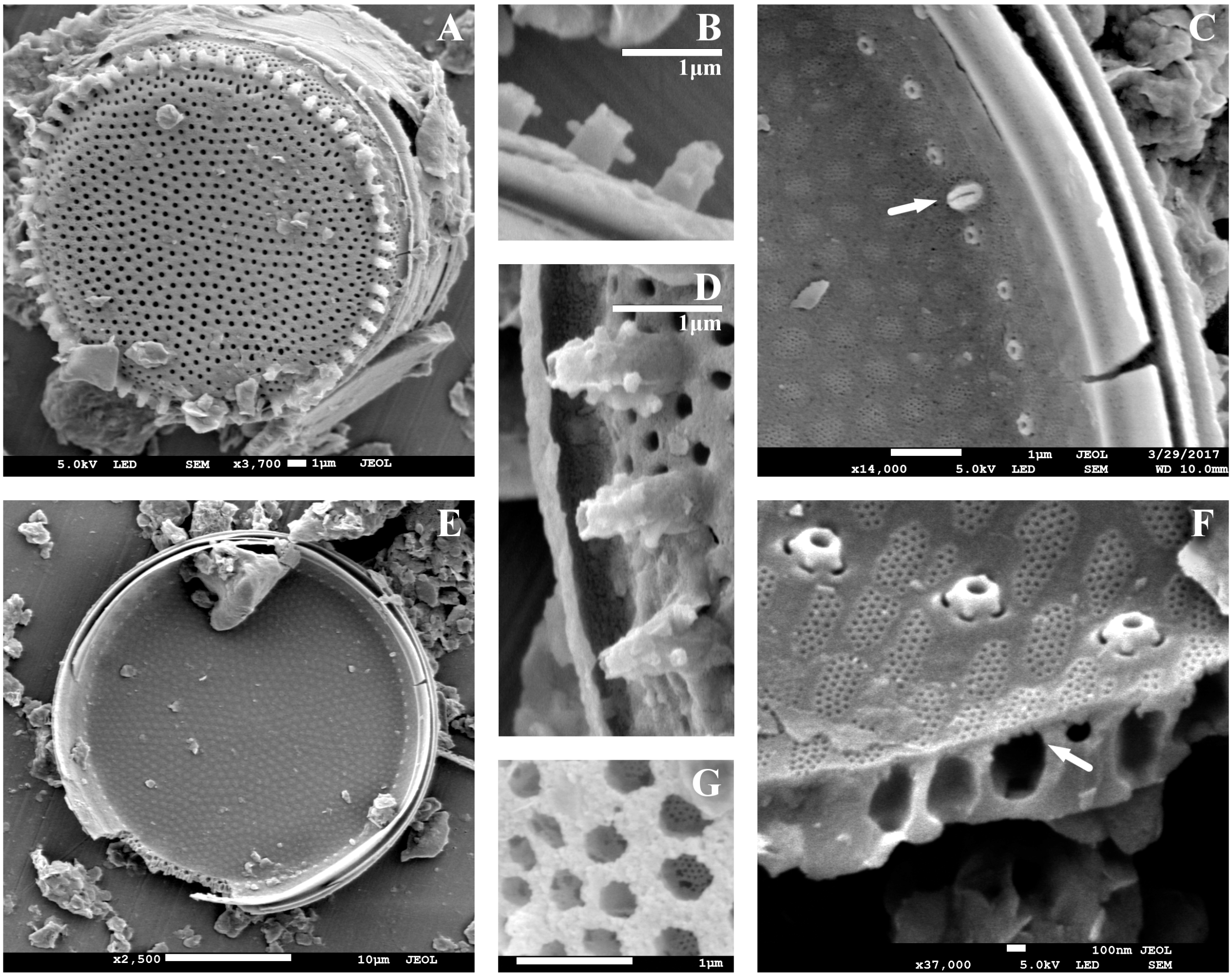

FIGURE 6. SEM *Thalassiosira feibelii.* Scanning electron micrographs of *Thalassiosira feibelii.* A complete frustule with intact girdle band (A) note the single ring of marginal fultoportulae. The exterior expression of the fultoportulae are marked by granules (B & D). An internal view of *T feibelii* (E) with exposed areolae in the lower-left portion. Internally, fultoportulae are raised with four satellite pores (F). Internally a simple rimoportula is located in line with the row fultoportulae and is expressed with slightly raised lips and aperture, arrowed in (C). Areolae are loculate, arrowed in (F), velum lies flat with the interior valve wall and foramen is on the exterior wall (G & F).

Thalassiosira gasseae Brindle & Mohan ***spec. nov.*** **(Figs. 7 & 8)**

Valves are discoid, valve face is flat, with diameter 5–10 μm. Areola are arranged in parallel to weakly curved rows across the valve face. Areolae are loculate with circular velum located on the internal wall (Fig. 8, C). Externally the areolae exhibit flat foramen. Fultoportulae are sparsely distributed around the valve margin. Externally the fultoportulae are simple, internally they are raised, circular, and exhibit four satellite pores. A single rimoportula is present between two fultoportulae (Fig. 8, B & D). Externally the rimoportula is simple and much larger than fultoportula (Fig. 8, A). Internally the rimoportula is simple and raised more near the center of the process (Fig. 8, D).

Type:—West Turkana Kaitio, northwestern Kenya, (4.109722° N, 35.871781° E) Pleistocene lake sediment core of the Natoo Member of the Nachukui Formation sediment core (HSPDP-WTK13-1A) material, sediment depth ~ 60 meters below surface, collected by *Feibel, C., Cohen, A., & Beck, C., July 2013*, **holotype, designated here**; deposited in ANSP! (Circled specimen on slide WTK 203, illustrated herein as Fig. 7, A).

Etymology:—*Thalassiosira gasseae* is named in honor of the original discoverer of this species. Françoise Gasse has contributed greatly to the understanding of modern and fossil diatoms with exceptional regards to the East African Rift Valley.

Remarks:—Gasse (1986) (Pl. 4, Figs. 11–15) reported this species from the Geradila Salt Marsh in the Gadeb Plains of Ethiopia but did not designate a species name. *Thalassiosira gasseae* has a similar size range to *T. minima* Gaarder (1951: 31) however, *T. minima* exhibits central fultoportulae while *T. gasseae* lacks central fultoportulae.

FIGURE 7. LM *Thalassiosira gassaea.* Size diminution series of *Thalassiosira gassaea*. Images taken at x1000. Scale bar is 2 µm. A is the holotype.

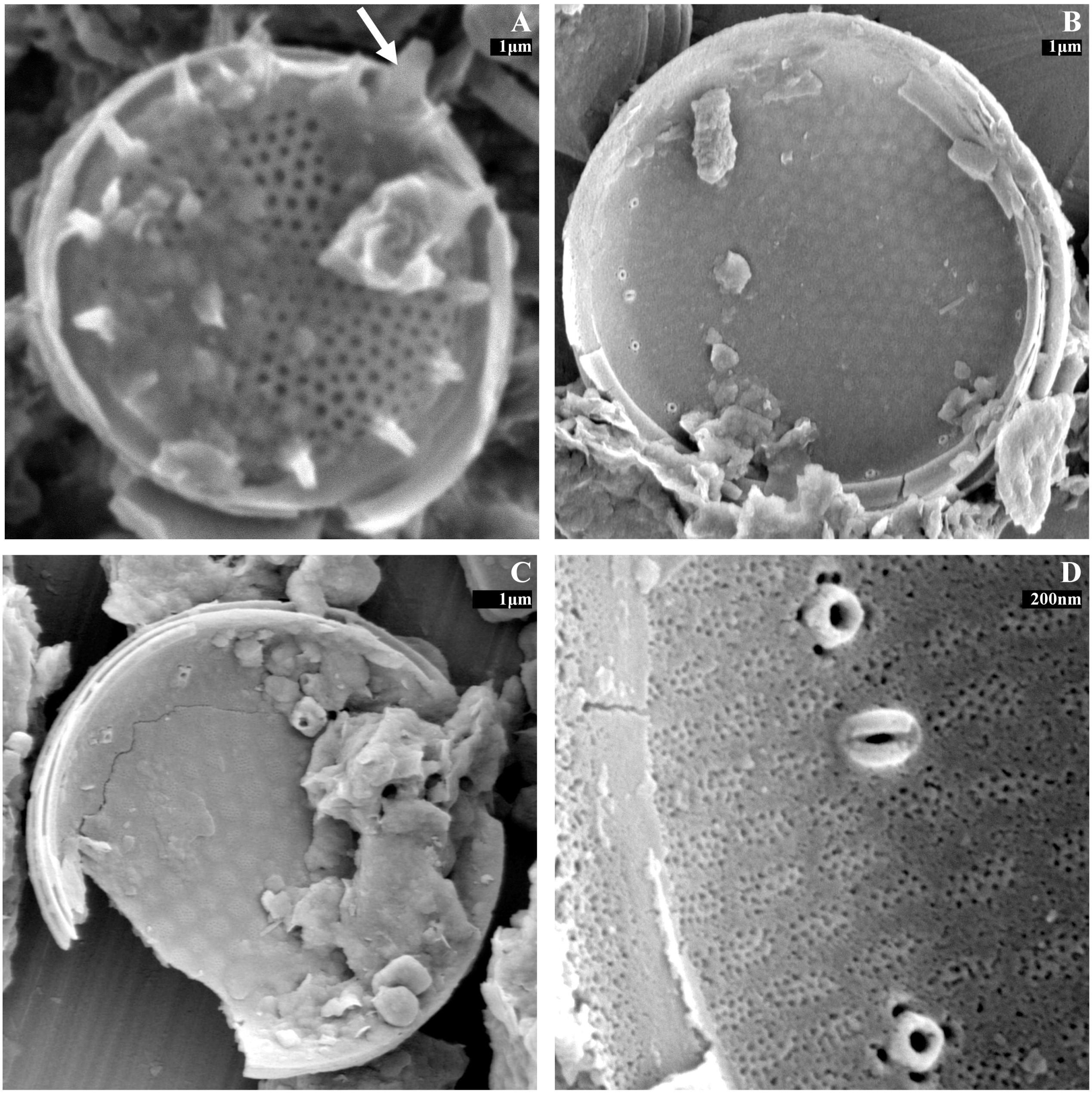

FIGURE 8. SEM *Thalassiosira gassaea.* Scanning electron micrographs of *Thalassiosira gassaea.* The exterior of the valve (A) is marked by sparse marginal fultoportulae and a single large rimoportula (arrowed). The interior of the valve exhibits a simple rimoportula with raised lips near the middle of the aperture and reduced near the outside ends of the aperture (D). The fultoportulae are slightly raised with four satellite pores, the areolae are marked with elliptical velum that are slightly depressed into interior valve surface. Internal views of the valve (B & C) show overall valve structure, rimoportula is closely associated with one fultoportula (B & D).

Discussion

The characterization and establishment of these newly discovered species are necessary for inferences regarding diatom community distribution related responses of these species to paleoenvironmental changes. Additionally, it is necessary to compare these extinct fossil species to similar extant species in order to infer paleoenvironmental or paleoclimatological changes recorded in the WTK core from the diatom community distributions via observable ecological responses of the extant species to environmental or climatological changes. Future work will compare other environmental and climatological data derived from the WTK core and other sources to the findings from the diatom community distributions from this core in order to validate the extant ecological comparisons.

Taxonomic precision is paramount to making any inferences regarding ecological, environmental, or climatological information using biological records. It leads to understanding evolutionary relationships of diatoms that can give insight to paleoecological parameters in the future via observation of related extant species. Furthermore, this precision is required for the application of statistical methods to diatom community distributions of species with known, unknown, or inferred ecology.

Most *Surirella* species are benthic and typically dwell on muddy or sandy substrates. The raphe system, which surrounds the margin of the valve, usually affords them greater motility among sediments (Spaulding & Edlund 2010). *S. lorenyangensis* and *S. turkanensis* are very similar in morphology, differing primarily in overall valve shape. These two species are located in the same basin separated only by time (~1–1.5 million years) in a basin exhibiting environmental variation. These details suggest that *S. lorenyangensis* may be an evolutionary predecessor to *S. turkanensis*.

Thalassiosira feibelii and *T. faurii* are exceptionally similar, differing only in that *T. feibelii* lacks central fultoportulae, suggesting an ancestor-decedent relationship. It is worth noting that Hasle (1978) reported remarkable similarity between *T. faurii* and *T. rudolfii* (Bachmann) Hasle (1978: 279). Even going so far as to suggest that the two species may represent one highly variable species and that the characteristics use to distinguish the two are “somewhat dubious” referring to areolae and cell diameter. These species also exist in a wide variety of salinity and ecological parameters (Hasle 1978). This indicates that *T. feibelii* may be the ancestor of this species complex.

Thalassiosira is a large planktonic genus containing fresh water, brackish, and salt-water species. DNA sequencing of *Thalassiosiriroid* has identified multiple colonizations from oceans to fresh water and *vice versa* (Alverson *et al.* 2007). The *Thalassiosira* species described herein may not be indicative of a specific water chemistry at this time, but most commonly they are found as plankton in alkaline and at least mildly brackish conditions, even in non-marine environments. However, through other better understood taxa, we can identify the type of paleoenvironment to expect when identifying the two species described herein.

Both novel *Thalassiosira* species observed from the Paleolake Lorenyang sediments can be distinguished from other similar taxa by the absence of central fultoportulae. Fultoportulae are usually associated with the secretion of β-chitin, and when positioned on the valve face, in *Thalassiosira*, typically allows for the formation of colonial chains attached by a chitinous thread (Round, Crawford, & Mann 1990). The absence of central fultoportulae in these species suggests that they do not form colonies and probably always live as isolated cells. While the genus *Thalassiosira* usually is defined by the presence of one or more central fultoportulae, there are other reported examples of other species of *Thalassiosira* without central fultoportulae observed in non-marine systems (Lowe & Busch 1975).

This represents a first report of diatoms from the Natoo Member of the Nachukui Formation. Occurrence of *Surirella* and *Thalassiosira* indicates that Paleolake Lorenyang shallowly covered the Turkana Basin, at this site, during deposition of the Natoo Member. The presence of *T. gasseae* which is also found in salt marsh conditions (Gasse, 1986) suggests a marsh or floodplain environment which corresponds with previous research and forthcoming facies models for the WTK core. Further research related to the paleoenvironmental and paleoclimatological relationships to the diatom community distributions in the WTK core will provide support to ongoing HSPDP investigations of hominin evolution in the African rift region.

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