ALGAL DIVERSITY IN, AND THE DESCRIPTION OF THREE NEW DIATOM (BACILLARIOPHYTA) SPECIES FROM, LAKE OF THE CLOUDS, PORCUPINE MOUNTAINS WILDERNESS STATE PARK, MICHIGAN USA

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ABSTRACT

The Lake of the Clouds, located inside the Porcupine Mountains and two miles away from Lake Superior, is a famous vista site within the Porcupine Mountains Wilderness State Park, Michigan. Even though several fishery surveys of the lake were released by the Michigan Department of Natural Resources in the 1940s, no known algal studies have been conducted. The Porcupine Mountains Wilderness State Park has experienced a relatively low level of anthropogenic disturbance compared to other regions of the Great Lakes, which makes it an appealing site for algal studies. This paper reports the exploratory research done by professors and students at the University of Michigan Biological Station on the algal diversity of the Lake of the Clouds. Water chemistry shows this lake to be slightly acidic and with low nutrients and low conductivity. In this study, fresh samples of algae and cleaned diatom samples were investigated. From the living algal samples, 7 algal divisions were observed. The inventory showed that, based on the number of genera recorded, the Chlorophyta is more diverse than other algal divisions. A total of 78 genera (excluding diatoms) and 29 species of algae were identified from the living samples. Nearly 150 species in 58 genera of diatoms (Bacillariophyta) were also recorded from the cleaned samples. Among the diatoms, three species new to science were identified and are described here. These are **Brachysira ontonageniana** Kociolek & Lowe, **B. gatesii** Kociolek & Lowe, and **Gomphonema porcupiniana** Kociolek & Lowe. This rich list of algal taxa is only the first step in exploring the algal diversity, microhabitats, and ecosystem of the Lake of the Clouds. The diversity of algal taxa found in this study suggests that further algal research on the Lake of the Clouds is warranted.

KEY WORDS: Algal diversity, Lake of the Clouds, new diatom species, *Brachsira*, *Gomphonema*

INTRODUCTION

Although there are large-scale surveys of the algal flora of Michigan (e.g., Prescott 1962), and individual groups of algae have been documented from specific sites or habitats (Ackley 1929, 1932), there are few surveys of the entire algal flora from individual sites. In particular, we know of no previous work on

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the algal flora of lotic (flowing water) or lentic (still water) ecosystems in the Porcupine Mountains, which is located in the northwestern part of the Michigan's Upper Peninsula.

The Porcupine Mountains contain one of North America's largest stands of northern hardwoods, stretching over 31,000 acres of old growth forest (Davis 1993). The Porcupine Mountain range is on the southern edge of the Canadian Shield, a vast region of common geologic origin (Larson and Schaetzl 2001; Derouin et al. 2007). The bedrock in and around the Porcupine Mountains is primarily Precambrian, making it over 3.5 billion years old (Ojakangas and Matsch 1982).

Porcupine Mountains Wilderness State Park was established in 1945 and has experienced relatively little human disturbance. The first European contact resulted from the fur trade in the 1700-1800s, although this attracted settlers in only small numbers compared to subsequent waves of miners. Between 1845 and 1910, 45 copper mines operated on present day parkland. Most mines went bankrupt or closed before the mid 1900s. The area is still extremely rich in copper ore, in part because the copper particles are particularly fine and difficult to mine. White pines along the shore of Lake Superior were targeted by loggers for their ease of harvest and drew contact to the area in the early 1900s (Davis 1993).

The Lake of the Clouds, one of the four lakes in the Porcupine Mountains Wilderness State Park, is located in Section 22 of Township 51 North, Range 43 West in Ontonagon County of Michigan's Upper Peninsula (Taube 1949) and is a part of the Carp River Valley. The lake, which is approximately 330 meters above sea level and is overlooked by an escarpment rising an additional 120 meters overhead (Taube 1949), has a surface area of 133 acres and a maximum depth of 4 meters (Moffett 1940). Lake of the Clouds drains into Lake Superior to the north. The lake has sufficient levels of dissolved oxygen to support fish life at all depths, a circumneutral acidity, and a soft water composition at approximately 25 ppm dissolved salts (Moffett 1940). Around two dozen species of vascular aquatic plants occupy the littoral zone, of which three-way sedge (*Dulichium arundinaceum*), spike rush (*Eleocharis* sp.), yellow water lily (*Nuphar* sp.), and a pond weed (*Potamogeton angustifolius*) are the most prevalent macroflora species. Perch, smallmouth bass, and brook trout are the most common species of fish in the lake (Moffett 1940).

No previous effort to catalog the algal diversity of Lake of the Clouds is known. Due to the lake's unknown algal flora and its relatively short history of human interaction, Lake of the Clouds presents an ideal environment for conducting a survey of algal diversity.

MATERIALS AND METHODS

On July 9, 2012, a survey of the algal diversity in the Lake of the Clouds was conducted. Five different microhabitats were sampled to include epiphytic, epipelic, epilithic, deep benthic, and planktonic algae.

Collection Sites

Five collection sites were chosen for this study. Four of them were located nearly equidistantly across an approximately1290 meter transect along the southern shore of Lake of the Clouds. Sites 1-

4 were located at ca. 300 m, 600 m, 900 m and 1290 m from the outflow. Site 1 was a sheltered cove with emergent aquatic vegetation; Site 2 was an exposed site with obvious benthic algal production; Site 3 had a gravel bottom with epilithic algae evident; and Site 4 was at a small spit at which evident wave action was present. The fifth site was located at the bridge over the outflow of the lake (Carp River Outflow), and thus had flowing water. The five sites were chosen to include a diversity in vegetative density, amount of current flow, sunlight intensity, substrate availability, and similar factors. Spacing out the collection sites was necessary for gaining a fair representation of the entire lake.

Sampling Processes Algae

Epiphytic algae were collected by squeezing liquid and associated algae out of aquatic plants into 100 mL Whirlpaks®. A small sample of each plant was also collected. Epipelic algae were sampled from the upper few millimeters of the sediment with a turkey baster. Planktonic algae were collected with a size 25 plankton net with 64-µm mesh openings.

Each sample of epilithic algae (algae attached to rock), epidendric algae (algae attached to wood) and deep benthic algae (algae living in the sediment surface of the lake) was collected from sites 2 - 3 meters below lake surface. For sampling the epilithic algae and epidendric algae, a pocketknife was used for scraping algal specimens from the substrate. A snorkel, diving goggles, and a turkey baster were used for diving into the lake and collecting all samples from these three algal habitats. Each sample was placed into a 100 mL resealable Whirlpaks. A total of 25 samples were brought back to the lab on ice for analysis and stored in a refrigerator to slow down the biological processes of the organisms and prevent their degradation.

Sampling Process for Water Temperature, pH and Water Chemistry

At each site, temperature and pH were measured and recorded. A Fisher Scientific Accumet® portable meter was used to measure both pH and the temperature. A water sample was taken in a 1 L plastic Nalgene bottle, kept on ice, and returned to the University of Michigan Biological Station for analysis by standard methods with an autoanalyzer. The following environmental variables were measured: Total phosphorus, total nitrogen, silica, chloride, conductivity, alkalinity, dissolved organic carbon and turbidity.

Samples Analysis—Living Algae

Samples were examined microscopically using microscope slides, pipettes, cover glasses, American Optical Spencer light microscopes and an Olympus BX-51 light microscope. Genera and species were documented by site number and habitat, and photomicrographs were taken to document taxa. Soft algae (non-diatom) were identified at 400X magnification. Identification of the algal taxa was based on Canter-Lund and Lund 1995; Croasdale et al. 1983; Dillard 1989a, 1989b, 1990, 1991a, 1991b, 1993, 1999; Komarek and Anagnostidis 1999, 2005 Prescott, 1962, 1978; Prescott *et al.* 1972, 1975, 1977, 1981, 1982; Wehr & Sheath 2003; West and West 1904, 1905, 1908, 1912; and West *et al.* 1912.

Identified genera and species were recorded on a master list. Photomicrographs of specimens were taken with the cellSens® entry program and the Olympus microscope. Approximately 5 mL of several rich samples were preserved with glutaraldehyde so that the soft algae could be further analyzed over time.

Additional subsamples were allocated for cleaning of diatoms.

Sample Analysis—Cleaned Diatoms

Subsamples of the living algae were cleaned by the method of van der Werff (1955). After cleaning, the diatom valves were mounted in Naphrax®, and specimens were observed using an Olympus BX51 light microscope. Diatoms were viewed at 1000x, and light micrographs of the specimens were captured with an Olympus DP71 camera. Cleaned specimens were mounted onto coverslips, coated with gold-palladium, and prepared for observations with scanning electron microscopy (SEM). Electron micrographs were obtained by using a JEOL 7401F field emission scanning electron microscope and the microscope JEOL software. Stria densities were measured at the valve margin at the valve center across a full length of 10 microns. Cleaned diatoms and permanent slides have been deposited in the Kociolek Collection at the University of Colorado Herbarium (COLO).

RESULTS

Living Algae Samples

Samples containing living algae from Lake of the Clouds contained a wide variety of taxa. A total of 7 divisions and 88 genera from the 5 collection sites were identified. The division with the most genera was Chlorophyta, with 48 genera. Eighteen genera of Cyanophyta and 11 genera of Bacillariophyta were identified prior to cleaning. In addition, 4 genera of Euglenophyta, 4 genera of Pyrrophyta, 3 genera of Chrysophyta and 2 genera of Xanthophyta were identified. The complete list of taxa from these samples is presented in Table 1.

Four genera, *Microcystis, Staurastrum, Mougeotia, and Desmidium*, were found in all five collection sites. Of these, *Microcystis* and *Mougeotia* were found in several different microhabitats among the sites. Eleven genera were found in 4 of the 5 collection sites; these included the diatoms *Fragilaria and Tabellaria,* the chlorophytes *Bulbochaete, Closterium, Cosmarium, Hyalotheca, Pediastrum, Pleurotaeniu and, Zygnema,* and the cyanophytes *Gloeotrichia,* and *Oscillatoria*. Of those found in four sites, *Fragilaria, Tabellaria, Closterium, Cosmarium, Hyalotheca, Pediastrum*, and *Zygnema* were found in several different microhabitats among the sites.

Microhabitats

Community richness was also analyzed as a function of the various algal microhabitats—epiphytic, epipelic, epilithic, epidendric, deep benthic, metaphytic and planktonic. The largest number of genera, 68, was found in epiphytic microhabitats. In addition, 38 genera were found in metaphytic microhabitats, 22 genera in deep benthic microhabitats, 21 genera in epipelic microhabitats, 18 genera in planktonic microhabitats, and 15 genera in epidendric habitats. The genera found in epilithic microhabitats were mainly diatoms.

Cleaned Diatoms

A total of 147 diatom taxa from 58 different genera were identified from the cleaned material. Three species new to science are included in this list. Formal descriptions are presented later in this article. Genera with the most taxa represented in this survey included *Navicula* (10), *Gomphonema* (9), *Eunotia* (9), *Neidium* (8), and *Stauroneis* (8). Several monoraphid genera were also well represented (e.g., *Psammothidium*, *Planothidium*). Although there were some planktonic species present in our samples (e.g., *Fragilaria crotonensis*, *Stephanodiscus superiorensis*), the vast majority of the species were from benthic microhabitats. The cumulative list of diatoms encountered from the 5 sites is presented in Table 2.

TABLE 1. List of algal taxa from live samples collected from Lake of the Clouds. For each taxon, the habitat or habitats in which it was collected at each site is indicated by the following letters: E=epiphyton, M-metaphyton, PL=plankton, B=benthic, PE=epipelon and D-epidendron.

Taxa Sites	1	2	3	4	5
CHLOROPHYTA					
Chaetophorales					
Aphanochaete sp.	M				
Chaetophora sp.		E		E, D	
Chlamydomonales					
Eudorina sp.	M				
Chlorellales					
Zoochlorella sp.					PE
Chlorococcales					
Characium sp.	E				
Coelastrum sp.					PE
Dictyosphaerium sp.	E, M				
Dictyosphaerium pulchellum Wood	E				
Nephrocytium sp.					
Radiofilum flavescens G.S. West	E				
Coleochaetales					
Chaetosphaeridium sp.	E				
Coleochaete sp.	E				
Desmidiales					
Bambusina sp.	E, M				E, PE
Closterium sp.	E	B	B		E, PE
Closterium kutzingii Brébisson	E				
Cosmarium sp.	E, M	PL		E, D	PE
Cosmocladium sp.	M				
Desmidium sp.	E, PE	B	E, PE	E	E
Desmidium grevillii (Kützing) De Bary				E, D	E
Euastrum sp.	E, M				E
Euastrum dubium Nägeli	E				E
Gonatozygon sp.	E				
Hyalotheca sp.	E	PL		E, M, PL	E, PE
Hyalotheca mucosa (Dillwyn) Ehrenberg	E	PL		E, M, PL	
Micrasterias sp.	E, M	E			E
Micrasterias laticeps Nordstedt	E				
Micrasterias radiata Hassall	E				
Onychonema sp.	E				
Pleurotaenium sp.	E	B	E, B	E	E
Pleurotaenium ehrenbergii (Brébisson) De Bary	E				
Pleurotaenium trabecula (Ehrenberg) Nägeli		B			
Sphaerozosma sp.	E, M	E		E, D	
Sphaerozosma vertebratum (Brébisson) Ralfs		E		E, D	
Spondylosium sp.	E, M		E		PE
Spondylosium aubertianum var. archerii (Gutwinski) W. & G.S. West				E, M, PL	
Staurastrum sp.	E, M, PL	B	E, PL	E, M, PL	E, PE
Triploceras sp.	PE				
Xanthidium sp.	E, M	B			E
Xanthidium brebissonii Ralfs	M	B			

TABLE 1. (Continued).

Taxa Sites	1	2	3	4	5
CHLOROPHYTA (Continued)					
Glaucocystales					
Glaucocystis nostochinearum (Itzigsohn) Rabenhorst	E, M				
Microsporales					
Microspora sp.	M				
Oedogoniales					
Bulbochaete sp.	E	E	E	E, D	
Oedogonium sp.		E			
Sphaeropleales					
Ankistrodesmus sp.	E, M				PE
Gloeocystis sp.		M		PL	
Kirchneriella lunaris (Kirchner) Möbius	E				
Pediastrum sp.	E, PL	B	E, PL		E, PE
Pediastrum boryanum (Turpin) Meneghini		B			
Pediastrum duplex Meyen	E, M				
Quadrigula sp.	E				
Scenedesmus sp.	E, M, PE		E, B		E, PE
Scenedesmus quadricauda (Turpin) Brébisson in Brébisson et Godey	E				
Sorastrum americanum (Bohlin) Schmidle	E				
Tetraedron sp.	E				
Tetraedron minimumm (A. Braun) Hansgirg	E				
Ulotrichales					
Ulothrix sp.		PL		M, PL	
Ulothrix variabilis Kützing		PL			
Volvocales					
Pandorina sp.	E, M				
Volvox sp.			PL		
Zygnematales					
Cylindrocystis sp.	E				
Mougeotia sp.	E, M, PL	E, B	E, D	E, M, PL	E
Netrium sp.	E		E, D		E
Spirogyra sp.	E, M	B		E	PE
Zygnema sp.	E,M	B		E	PE
CYANOPHYTA					
Chroococales					
Aphanothece sp.	E, M			E	PE
Chroococcus sp.	E, M			E	
Dactylococcopsis fascicularis Lemmermann	E			PE	
Microcystis sp.	E, M, PL	B, PL	B, PL	M, PL	E
Nostocales					
Amphithrix sp.			E, D		
Anabaena sp.	E, M	B, PL	D, PE, PL		
Dolichospermum spiroides (Kleb.) Wacklin, L.Hoffm. & Komárek		B			
Calothrix sp.	E		E, D	E	

TABLE 1. (Continued).

Taxa Sites	1	2	3	4	5
CYANOPHYTA (Continued)					
Hapalosiphon sp.	E				
Nostoc sp.	E	E			
Stigonema sp.	E				E
Tolypothrix sp.	E				
Oscillatoriales					
Lyngbya sp.	E			E	
Oscillatoria sp.		B	B	E, B	E
Pseudanabaenales					
Spirulina sp.	M				
Synechococcales					
Aphanocapsa	E, M	E			
Coelosphaerium sp.	E				
Coelosphaerium kutzingianum Nägeli	E				
Merismopedia sp.	E, M		E		
CHRYSOPHYTA					
Chromulinales					
Chrysosphaerella sp.	M				
Dinobryon sp.	M		PL		
Hibberdiales					
Derepyxis sp.	E				
EUGLENOPHYTA					
Euglenales					
Euglena sp.	E, PE, PL				PE
Euglena acus Ehrenberg	E				
Lepocinclis acuta Prescott in Prescott et al.		PE			
Phacus sp.		PL		E	
Trachelomonas sp.	E				
PYRROPHYTA					
Gonyaulacales					
Ceratium sp.		B, PL	PL	E	
Ceratium hirudinella (O.F. Müller) Dujardin		B, PL		E	
Peridiniales					
Peridinium sp.	E				
Phytodinales					
Cystodinium sp.	E				
Stylodinium sp.	E				
XANTHOPHYTA					
Mischococcales					
Ophiocytium sp.	E, M				
Ophiocytium bicuspidatum (Borge) Lemmermann	E				
Trebouxiales					
Botryococcus braunii Kützing	E	E			

TABLE 2. Inventory of the Diatom Taxa Identified from Lake of the Clouds, All Sites Combined.

Achnanthidium exiguum (Grunow) Czarnecki
Achnanthidium exiguum var. *heterovalvum* (Krasske) Czarnecki
Achnanthidium minutissimum (Kützing) Czarnecki
Amphipleura pellucida (Kützing) Kützing
Amphora pediculus (Kützing) Grunow
Asterionella formosa Hassall
Aulacoseira italica (Ehrenberg) Simonsen
Brachysira gatesii Kociolek et Lowe, sp. nov.
Brachysira ontonageniana Kociolek et Lowe, sp. nov.
Brachysira serians (Brébisson) Round et Mann
Brachysira vitrea (Grunow) Ross
Brachysira zellensis (Grunow) Round & Mann
Caloneis bacillum (Grunow) Cleve
Caloneis lewisii Patrick
Caloneis silicula (Ehrenberg) Cleve
Caloneis tenuis (Gregory) Krammer
Cavinula cocconeiformis (Gregory ex Greville) Mann et Stickle
Cavinula jaernefeltii (Hustedt) Mann et Stickle
Cavinula pseudoscutiformis (Hustedt) Mann et Stickle
Chamaepinnularia mediocris (Krasske) Lange-Bertalot
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow
Cocconeis pseudothumensis Reichardt
Craticula cuspidata (Kützing) Mann
Cyclotella comensis Grunow
Cymbella aspera (Ehrenberg) Cleve
Cymbella ehrenbergii Kützing
Cymbella lanceolata (Agardh) Agardh
Cymbopleura hybrida (Grunow) Krammer
Decussata placenta (Ehrenberg) Lange-Bertalot
Diploneis elliptica (Kützing) Cleve
Diploneis marginestriata Hustedt
Discostella stelligera (Cleve et Grunow) Houk et Klee
Encyonema elginense (Krammer) Mann
Encyonema hebridicum Grunow ex Cleve
Encyonema lunatum (Smith) Van Heurck
Encyonema minutum (Hilse) Mann
Encyonopsis microcephala (Grunow) Krammer
Entomoneis alata (Ehrenberg) Ehrenberg
Eolimna minima (Grunow) Lange-Bertalot
Eucocconeis alpestris (Brun) Lange-Bertalot
Eunotia didyma Grunow in Moller
Eunotia formica Ehrenberg
Eunotia implicata Nörpel, Alles et Lange-Bertalot
Eunotia incisa Smith ex Gregory
Eunotia monodon Ehrenberg
Eunotia naegelii Migula
Eunotia pectinalis var. *undulata* (Ralfs) Rabenhorst
Eunotia praerupta Ehrenberg
Eunotia tetraodon Ehrenberg
Fragilaria crotonensis Kitton
Fragilaria vaucheriae (Kützing) Petersen
Fragilariforma constricta (Ehrenberg) Williams et Round
Frustulia krammeri Lange-Bertalot et Metzeltin
Frustulia saxonica Rabenhorst
Frustulia vulgaris (Thwaites) De Toni
Frustulia weinholdii Hustedt

TABLE 2. Continued.

Geissleria paludosa (Hustedt) Lange-Bertalot et Metzeltin
Gomphonema acuminatum Ehrenberg
Gomphonema affine Kützing
Gomphonema augur Ehrenberg
Gomphonema brebissonii Kützing
Gomphonema intricatum Kützing
Gomphonema parvulum (Kützing) Kützing
Gomphonema patricki Kociolek et Stoermer
Gomphonema porcupiniana Kociolek et Lowe, sp. nov.
Gomphonema truncatum Ehrenberg
Gomphosphenia grovei (M. Schmidt) Lange-Bertalot
Gyrosigma sp.
Handmannia radiosa (Grunow) Kociolek & Khursevich
Hantzschia amphioxys (Ehrenberg) Grunow
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin et Witkowski
Karayevia clevei (Grunow) Bukhtiyarova
Karayevia laterostrata (Hustedt) Bukhtiyarova
Karayevia suchlandtii (Hustedt) Bukhtiyarova
Meridion circulare (Greville) Agardh
Navicula aboensis (Cleve) Cleve-Euler
Navicula angusta Grunow
Navicula constans Hustedt
Navicula laterostrata Hustedt
Navicula pseudoventralis Hustedt
Navicula radiosa Kützing
Navicula rhynchocephala Kützing
Navicula schadei Krasske
Navicula tridentula Krasske
Navicula viridula (Kützing) Kützing
Neidiopsis levanderi (Hustedt) Lange-Bertalot et Metzeltin
Neidium affine (Ehrenberg) Pfitzer
Neidium affine var. *humerus* Reimer
Neidium amphigomphus (Ehrenberg) Pfitzer
Neidium apiculatum Reimer
Neidium bisulcatum (Lagerstedt) Cleve
Neidium firma (Kützing) Pfitzer
Neidium hitchcockii (Ehrenberg) Cleve
Neidium productum (Smith) Cleve
Nitzschia dissipata (Kützing) Grunow
Nitzschia recta Hantzsch ex Rabenhorst
Nupela impexiformis (Lange-Bertalot) Lange-Bertalot
Nupela sp.
Opephora olsenii Møller
Pinnularia biceps Gregory
Pinnularia microstauron (Ehrenberg) Cleve
Pinnularia nodosa (Ehrenberg) Smith
Pinnularia viridis (Nitzsch) Ehrenberg
Placoneis clementis (Grunow) Cox
Placoneis gastrum (Ehrenberg) Mereschkowsky
Planothidium apiculatum (Patrick) Lange-Bertalot
Planothidium dubium (Grunow) Round et Bukhtiyarova
Planothidium joursacense (Héribaud) Lange-Bertalot
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot
Planothidium peragalli (Brun et Héribaud) Round et Bukhtiyarova
Planothidium pseudotanense (Cleve-Euler) Lange-Bertalot
Psammothidium bioretii (Germain) Bukhtiyarova et Round

TABLE 2. Continued.

Psammothidium chlidanos (Hohn et Hellerman) Lange-Bertalot
Psammothidium didymum (Hustedt) Bukhtiyarova et Round
Psammothidium rossii (Hustedt) Bukhtiyarova et Round
Psammothidium subatomoides (Hustedt) Bukhtiyarova et Round
Psammothidium ventralis (Krasske) Bukhtiyarova et Round
Pseudostaurosira brevistriata (Grunow) Williams et Round
Pseudostaurosira elliptica (Schumann) Edlund, Morales et Spaulding
Reimeria sinuata (Gregory) Kociolek et Stoermer
Rhopalodia gibba (Ehrenberg) Müller
Rossithidium pusillum (Grunow) Round et Bukhtiyarova
Sellaphora americana (Ehrenberg) Mann
Sellaphora laevissima (Kützing) Mann
Sellaphora pupula (Kützing) Meresckowsky
Stauroneis anceps fo. *gracilis* Rabenhorst
Stauroneis anceps var. *americana* Reimer
Stauroneis kriegeri Patrick
Stauroneis livingstonii Reimer
Stauroneis phoenicenteron (Nitzsch) Ehrenberg
Stauroneis smithii Grunow
Stauroneis stodderi Greenleaf
Staurosira construens Ehrenberg
Staurosirella pinnata (Ehrenberg) Williams et Round
Stenopterobia anceps (Lewis) Brébisson ex Van Heurck
Stenopterobia curvula (Smith) Krammer
Stenopterobia delicatissima (Lewis) Van Heurck
Stephanodiscus superiorensis Stoermer & Theriot in Theriot & Stoermer
Surirella angusta Kützing
Surirella brebissonii Krammer et Lange-Bertalot
Surirella minuta Brébisson
Surirella tenera var. *nervosa* Schmidt
Tabellaria fenestrata (Lyngbye) Kützing
Tabellaria flocculosa (Roth) Kützing
Tryblionella victoriae Grunow
Ulnaria delicatissima (W. Smith) Aboal et Silva

Water Chemistry

At the time of collection, the water temperature was 23°C, and the pH ranged from 6.92 to 7.70. Nutrients were relatively low, with total P measured at 8.7 µg/L and total N at 0.157 mg/L. Soluble SiO_2 was 2 mg/L and chloride was 0.3 mg/L. Alkalinity (measured as mg $CaCO_3$/L) was 24.2 and conductivity was 42.6 µS at 25°C), indicating rather dilute water. Dissolved organic carbon was 10.4 mg/L, and turbidity, as measured in Jackson units, was 20, which together indicate the water was relatively clear.

DISCUSSION

Lake of the Clouds Water Profile

Circumneutral pH often coincides with high algal diversity. According to the research results, Lake of the Clouds satisfied this correlation. Its moderate temperature is also a probable cause of the wide range of genera of Chlorophyta that were observed (Denicola 1996).

Lake of the Clouds Algal Flora

Based on the number of genera observed, diatoms were by far the dominant algal group in Lake of the Clouds. This is typical of alkaline to circumneutral bodies of water in North America (Stevenson et al. 1996). The discovery of three species new to science leads us to believe that there may be more undescribed diatoms that our initial survey did not detect.

Desmidiales was the most abundant order among the Chlorophyta found in Lake of the Clouds. Desmids can indicate good water quality, because they do not prefer anthropogenically disturbed or extremely eutrophic bodies of water (Ngearnpat and Peerapornpisal 2007). Most of the samples collected were from the eulittoral zone, the relatively shallow portions of the lake. This study suggests that Lake of the Clouds has a soft water quality because an abundance of desmids in the eulittoral zone can indicate a calcium poor water body (Stevenson et al. 1996). The lake's geology is a potential cause of its lack of calcium. The lake's bedrock is part of the Canadian Shield, which contributes monovalent cations instead of divalent cations to water bodies. A higher divalent cation concentration would lead to harder water, reduce the occurrence of desmids, and increase the prevalence of cyanobacteria (Molot and Dillon 2008).

Based on the number of genera, Chlorophyta was the most diverse non-diatom algal division in the samples. The abundance of Chlorophyta is typical for the soft water chemistry of the lake, since soft water lakes often have algal distributions characterized by *Mougeotia* and other filamentous genera as well as *Cosmarium*, and *Staurastrum* (Stevenson et al. 1996).

Based on the number of genera, Cyanophyta was the second most diverse non-diatom algal division. A few genera of Cyanophyta, such as *Microcystis* and *Anabaena*, produce toxic metabolites that can be hazardous to the ecosystem (Burgess 2001). These two genera were observed only in relatively small numbers. Other indicator taxa, such as desmids (which prefer soft water and a lower calcium level) and members of the Zygnemataceae (which also dominate the littoral zone of soft water lakes), were more common than Cyanophyta (Stevenson et al. 1996).

Comparison of Algal Taxa Between Lake of the Clouds and Other Lakes in the Midwest

Comparison of our results with other published records for the state of Michigan or the Midwest region is difficult, since there are few studies of all algal groups from specific ecosystems, especially where taxa are treated to the level of species. Unlike in Lake of the Clouds, *Bambusina* and *Desmidium* were not observed in great numbers in other Michigan lakes such as Wycamp Lake, Lark's Lake, Paradise Lake, Monro Lake, Lancaster Lake, Walloon Lake, Burt Lake, Long Lake, and Douglas Lake (unpublished, Warren 1995). *Scenedesmus, Oscillatoria*, and *Anabaena*, which were reported to be abundant in Douglas Lake

(Gulley and Kennedy 1987), were not found in Lake of the Clouds in large numbers. Similarly, *Anabaena*, *Oscillatoria,* and *Schizothrix*, which were abundant in Northern Lower Michigan groundwater springs and seeps (Smith 1995) were not common in Lake of the Clouds.

The description of three new species of diatoms from this lake in the midwestern United States, one of the more intensively studied regions of the country, suggests that this oligotrophic lake may harbor other new species of algae. Unlike other algal groups (e.g., Prescott 1962), the diatoms of Michigan, especially the Upper Peninsula, are not well known. Further study of the algal flora of the region is warranted and may result in the description of other new taxa.

Sources of Error and Possible Future Study

A few possible error sources should be addressed and considered for future investigations. A more comprehensive floral survey could have incorporated more diversity in collection sites. For instance, the northern shoreline of the lake and the inflow have not yet been investigated for algal flora. Considering that the inflow is a transition point from a river to lake ecosystem, algae may be present due to changes in both biotic and abiotic conditions. Additionally, it may be interesting to compare inflow taxa data with the outflow data. Collecting near the landslide on the northern shoreline could show what impact this particular disturbance has on the flora, and the area could be a unique habitat for algae.

The abundance and distribution of algal species will vary seasonally in the lake. This is partly due to the availability of various nutrients, such as nitrogen and phosphorus, which are necessary in different quantities for different taxa. The abundance of a nutrient might benefit one alga more than another, conferring a competitive advantage. For example, an aquatic system low in nitrogen greatly limits the ability of green algae (Chlorophyta) to photosynthesize and thus to grow and reproduce, but does not affect some blue-green algae (Cyanophyta), since they have the ability to fix their own nitrogen through use of a heterocyte (Canter-Lund and Lund 1995). Sampling at various times throughout the season would increase the likelihood of finding more taxa of algae, leading to a more complete floral record and understanding of the algal ecology in the lake.

CONCLUSION

Since no previous algal floristic studies have been conducted in Lake of the Clouds, the location was suitable for a biodiversity survey. In this research, the diatoms were the most abundant and diverse in genera. However, the presence of several taxa of Chlorophyta indicated that Lake of the Clouds has a soft water body and relatively low levels of pollutants. The results showed that the lake is a clean water body with a relatively rich algal community. Our records of the rich algal taxa is consistent with the history of relatively few anthropogenic activities in the Porcupine Mountains Wilderness State Park. Because this study is not exhaustive, we recommend further algal diversity research on Lake of the Clouds.

TAXONOMIC TREATMENT

Brachysira ontonageniana Kociolek et Lowe, sp. nov.

Description: Valves lanceolate-clavate, apices not protracted, rounded at the headpole and footpole. Length 16–40 µm, breadth 4.5–5.5 µm. Axial area narrow, straight, forming a small, indistinct, narrowly lanceolate central area. An elongated areola may be positioned on one side of the central area. Raphe filiform, straight, with external proximal raphe ends dilated, round. Striae distinctly punctate, areolae within a stria appear slightly offset from neighboring striae. Striae radiate the entire length of the valve. Striae number 28-31/10 µm.

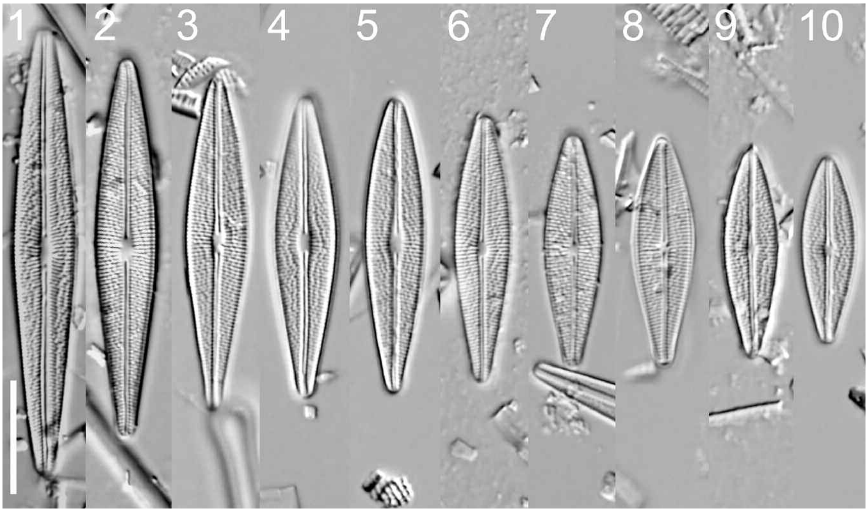
Holotype: JPK Collection, slide number 273055, University of Colorado (COLO)

Etymology: This species is named for the Michigan county in which it is found.

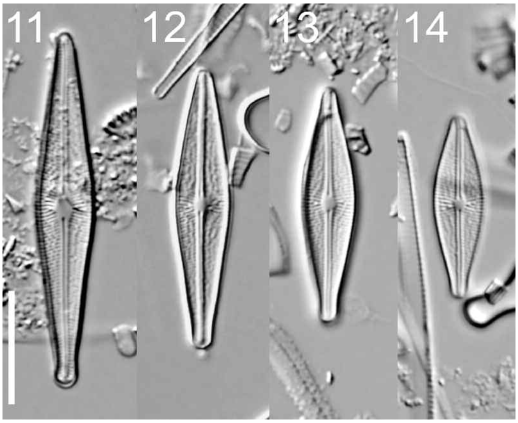
Figures 1–10, 15, 16; Figure 1 is of the holotype.

Brachysira gatesii Kociolek et Lowe, sp. nov.

Description: Valves lanceolate, barely clavate, with headpole rounded and footpole protracted, broadly rounded. Length 16–32 µm, breadth 4-5 µm. Axial area narrow, straight, forming a small but distinct, rounded central area, bordered on both sides by shortened striae the shortest being in the middle. Raphe fili-



FIGURES 1–10. LM, *Brachysira ontonageniana*, sp. nov. Valve view, size diminution series. Scale bar = 10 µm. Figure 1 is of the holotype.



FIGURES 11–14. LM. *Brachysira gatesii*, sp. nov. Valve view, size diminution series. Scale bar = 10 µm. Figure 11 is of the holoytpe.

form, external proximal raphe ends not rounded. Striae distinctly punctate, areolae within a stria slightly offset from those in neighboring striae giving the impression of longitudinal undulations. Striae radiate throughout the length of the valve, numbering 29-32/10 µm.

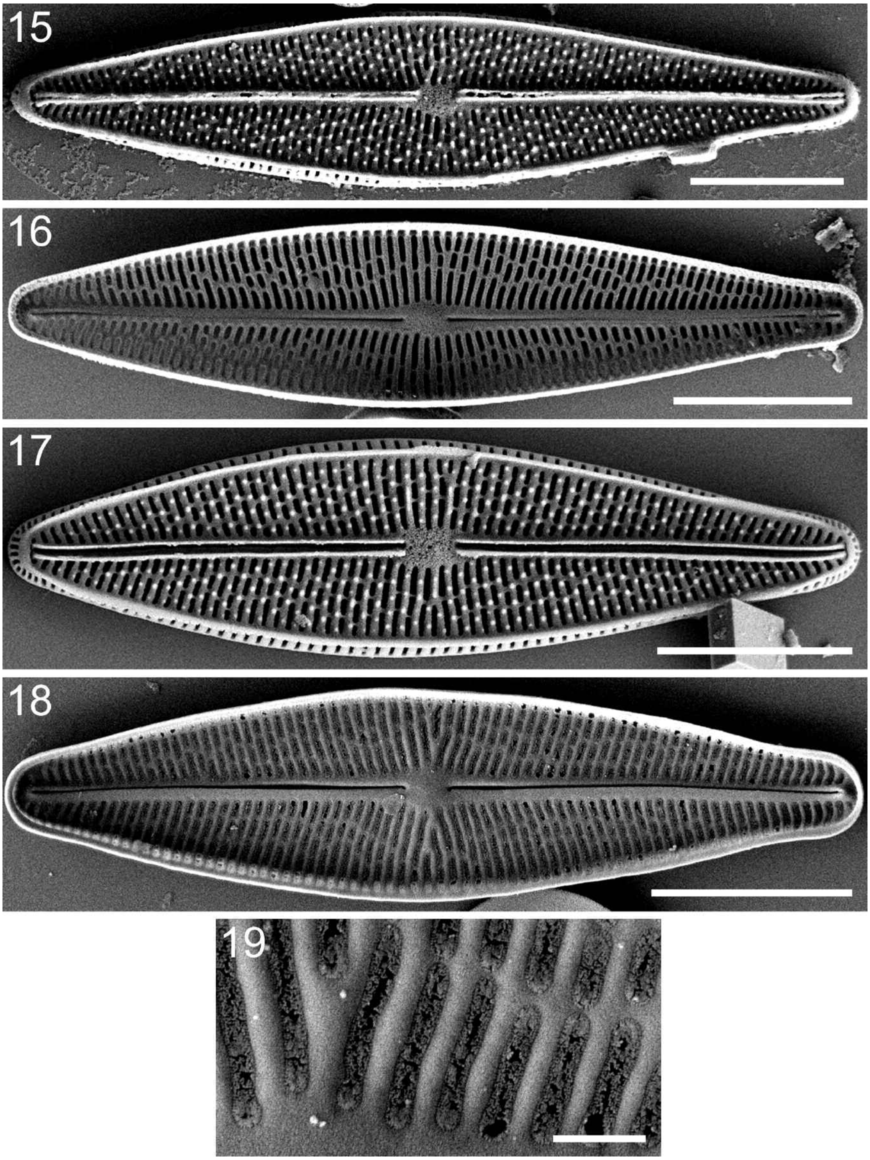
Holotype: JPK Collection, slide number 273056, University of Colorado (COLO)

Etymology: The species is named for former UMBS director, Dr. David Gates.

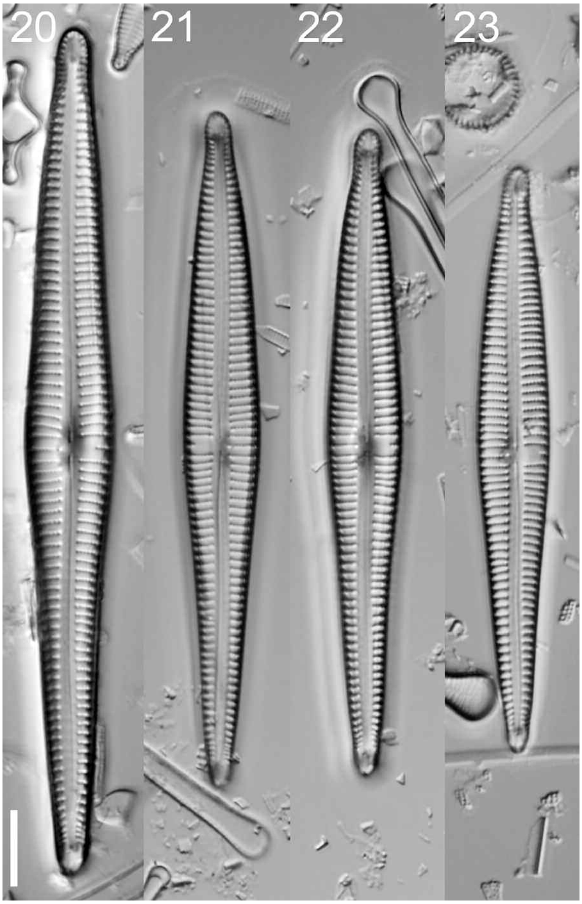
In the SEM, both *Brachysira ontonageniana* (Figures 15, 16) and *B. gatesii* (Figures 17, 18) have valve exteriors with a thick marginal ridge along each side of the valve with the raphe bordered on both sides by longitudinal ribs. The valve face has elongated to ellipsoidal areolae that are covered internally by hymens (Figure 19). Siliceous nodules ("warts" of Round et al. 1990, p. 540) are found scattered along the interstriae. Elongated areolae occur on the mantle of the valve. The elongated areolae are evident internally. The central nodule is small and barely elevated internally. At the poles are indistinct helictoglossae.

Brachysira gatesii differs from *B. ontonageniana* in the shape of the valve, striae of the central area, and undifferentiated external proximal raphe ends.

These two species possess the features typical for the genus *Brachysira* (Round et al. 1990). In addition, they are slightly asymmetrical to the transapical axis, and this feature has been documented for other *Brachysira* species. Lange-Bertalot and Moser (1994) illustrate several species of the genus with this asymmetry, including species from New Caledonia (e.g. *B. microclava* Lange-Bertalot & Moser, *B. archibaldi* Coste & Ricard among others), the Philippines (e.g. *B. irawanae* (Podzorski & Håkansson) Lange-Bertalot & Moser), and Australia (*B. archibaldii* var. *crassistriata* Lange-Bertalot). A similar asymmetry is not well known in the northern hemisphere. Lange-Bertalot and Moser (1994) illustrate unnamed species from the Rocky Mountains (see plate 31, figs. 20, 21



FIGURES 15–19. SEM. Figs 15, 16. *Brachysira ontonageniana*, sp. nov. Figure 15, External valve view. Note thickened siliceous rib bordering the raphe and scattered nodules oriented along the striae. Scale bar = 5 µm. Figure 16. Internal valve view. Scale bar = 5 µm. Figures 17–19, *B. gatesii*. Figure 17. External valve view. Note thickened siliceous rib bordering the raphe and scattered nodules oriented along the striae Striae on the mantle are elongated areolae. Scale bar = 5 µm. Figure 18. Internal valve view. Note that the areolae are occluded by hymenate coverings. Scale bar = 5 µm. Fig. 19. Close up of areolae showing the fine hymenate occlusions. Scale bar = 0.5 µm



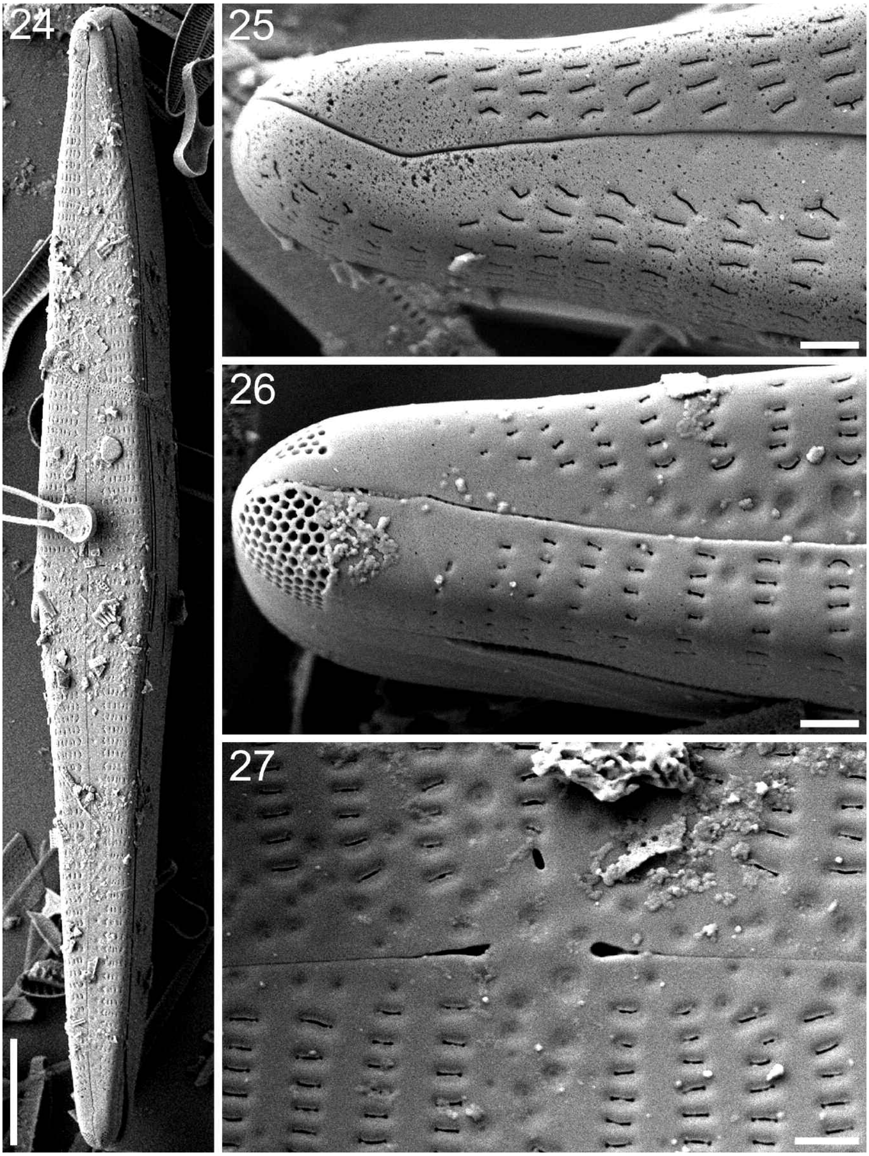
FIGURES 20–23. LM. *Gomphonema porcupiniana*, sp. nov. Valve view, size diminution series. Scale bar = 10 µm. Figure 20 is of the holotype.

and plate 46, fig. 26 therein) that resemble these species from Lake of the Clouds.

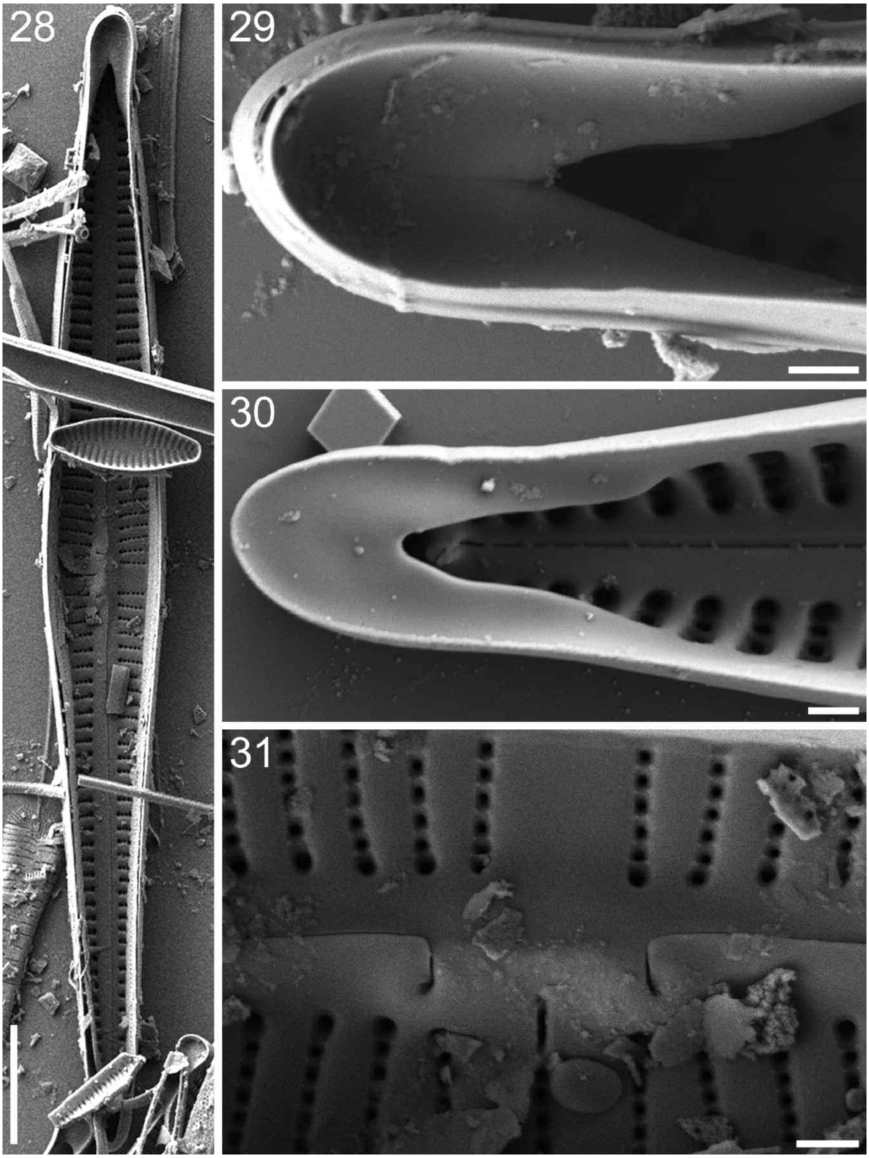
Figures 11–14, 17–19; Figure 11 is of the holotype.

Gomphonema porcupiniana Kociolek et Lowe, sp. nov.

Description: Valves large, length 77–110 µm, breadth 9–12 µm. Valves linear-clavate with headpole protracted, sometimes bent to one side and rounded, footpole. Axial area straight, forming a unilaterally expanded central area bordered by 2–4 shortened striae. On the other side of the central area is a small, rounded stigma positioned at the end of the central stria. The central nodule is large and prominent. Raphe distinctly lateral, slightly undulate, with external distal raphe ends deflected towards the same side of the valve, opposite the stigma. Striae are distinctly punctate, radiate about the center becoming strongly radiate near the poles. Striae continue around the headpole. Striae number 7–8/10 µm in the mid-



FIGURES 24–27. SEM. *Gomphonema porcupiniana*. External views. Figure 24. Valve view showing outline of the valve. Scale bar =10 μm. Figure 25. Headpole, with deflected distal raphe end. Areolae are narrow slits. Scale bar = 1 μm. Figure 26. Footpole with porelli of the apical pore field physically separate and morphological distinct from the areolae. Distal raphe end bisects the pore field. Scale bar = 1 μm. Figure 27. Central area with dilated external proximal raphe ends. Stigmal opening is elliptical. Striae are narrow slits. Scale bar = 1 μm.



FIGURES 28–31. SEM. *Gomphonema porcupiniana*. Internal views. Figure 28. Valve view showing outline of the valve. Scale bar = 10 µm. Figure 29. Large septum present at the headpole. Scale bar = 1 µm. Figure 30. Footpole, with large pseudoseptum and below it a helictoglossa offset from the raphe branch. Scale bar = 1 µm. Figure 31. Central nodule, with recurved proximal raphe ends and slit-like stigma opening. Scale bar = 1 µm.

dle of the valve, 11–13/10 μm at the apices. A distinct, bilobed apical pore field is positioned at the footpole on the valve face. Septa and pseudosepta are present at both poles.

Holotype: JPK Collection, slide number 273054, University of Colorado (COLO)

Etymology: This species is named for the Porcupine Mountains of Michigan, where it is found.

In the SEM, the valve exterior is covered with narrow, slit-like areolae that may be bifurcated (Figures 24–27). The headpole shows the distal raphe ends to be deflected on the mantle (Figure 25). At the footpole (Figure 26), the apical pore fields are comprised of round porelli, that are physically separate and differentiated from the slit-like areolae. The pore field extends from the valve face to the mantle, and appears to be asymmetrical, with one side being more extensive than the other. Small depressions are evident in the central area of the valve (Figure 27). The proximal raphe ends are dilated and tear-drop shaped, and the stigma opening is elongated, quite different as compared to the slit-like areolae. The slit-like appearance of the areolae is unlike most "typical" *Gomphonema* species that typically have "c"-shaped openings (Kociolek and Kingston 1999; Round *et al.* 1990; Reichardt 1999, 2001). The slit-like areolae in *G. porcupinensis* appear to differ from the lineolate striae seen in *G. reimeri* Kociolek & Kingston (Kociolek & Kingston 1999).

Internally, there is a large septum associated with the girdle band (Figures 28-30), especially at the headpole. The central nodule is elongate and bears recurved proximal raphe ends and at the base of the central nodule an elongate stigma opening (Figure 31). Striae have fine siliceous struts oriented perpendicular to the striae (Figure 31).

This species resembles *G. sagitta* Schumann in overall shape, but is much larger. Patrick & Reimer (1975) report the length of *G. sagitta* (as *G. subtile* Ehrenberg var. *sagitta* (Schumann) Cleve) to be 40-51 μm; a similar size range is given by Krammer and Lange-Bertalot (1986), though they lump *G. sagitta* with *G. subtile*. Krammer and Lange-Bertalot (1986) suggest tropical forms may be up to 70 μm in length, but these are still smaller than this Lake of the Clouds endemic.

Figures 20–31; Figure 20 is of the holotype.

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