How Green Lakes State Park Got Its Name: The optics and appearance of Fayetteville Green Lakes

Eric A. Schiff
Syracuse University

How Green Lakes State Park Got Its Name:
The optics and appearance of Fayetteville Green Lakes

Eric A. Schiff,[1] Department of Physics
Syracuse University, Syracuse, New York 13244-1130

The extraordinary and variable appearance of the Fayetteville Green Lakes in the spring, summer, and fall has been the subject of journalistic and scientific attention for more than 150 years. This article addresses the subject in two sections for differing readerships. The first section is a description of the essential science for a general readership. The second section is an abstract of the science for technically knowledgeable readers. The layout of the article is designed for a folded paper flier suitable for distribution to visitors to the lakes.

The article describes the three key properties of the lakes' waters that are responsible for the unusual optics. The first is the high concentration of dissolved calcium carbonate due to the limestone bed of the lakes. The second is the flourishing of a strain of cyanobacteria picoplankton in the lakes from the spring to the fall. The picoplankton absorb the red and blue components of sunlight to drive photosynthesis within the cells. The third is the precipitation of calcite nanocrystals in the water by the picoplankton, which causes seasonal "whiting" events. Rayleigh scattering by calcite aggregates then leads to the brilliant green and the opacity of the lakes when illuminated directly by sunlight.

[1] E-mail: easchiff@syr.edu

How Green Lakes State Park got its name

Eric A. Schiff
Syracuse University

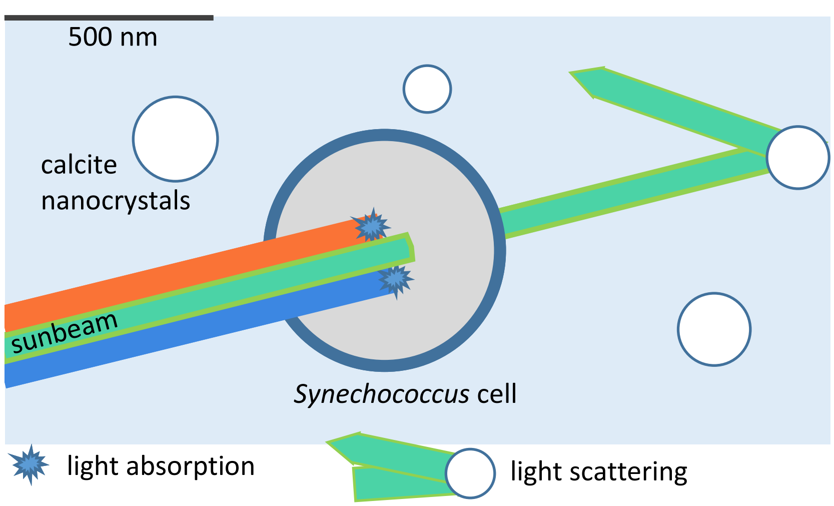
More than 160 years ago, Ledyard Lincklaen wrote about the Green Lakes of Onondaga: “The color of the water is, as we have said, very remarkable. Where it reflects the open sky, it approaches a pale, ultramarine blue; but in the shade of overhanging trees, it shows a peculiar transparent green.” As illustrated in the photos, the color is bright under the September sun, and the water is milky. By October the water is darker and more blue than in summer. The waters will remain dark blue through the winter until the following June.

The summer color is due to tiny living plankton cells called *Synechococcus*. They thrive in Green Lakes. Like the cells in tree leaves, the plankton are photosynthetic. They use sunlight to synthesize their own fuels. Not all the colors in sunlight are useful to the plankton cells. They mostly use up the red and blue parts. The remaining green light is what you see. It’s not very close to the color of tree leaves. *Synechococcus* and other similar planktons are called *Cyanophyta* after their characteristic cyan color.

Many bodies of water have this cyan color. What makes Green Lakes extraordinary is their brightness in the summer sun. The brightness is the result of tiny particles of the mineral calcite. These particles are suspended in the water alongside the plankton cells. The particles scatter light in all directions, which leads to the bright glow of the lake surface. The scattering effect is like that from sandblasted glass, which looks frosted instead of clear. With time, the calcite particles drift down and form the white powder you can see at the lake shore.

The plankton create these particles from the minerals already dissolved in the water. It occurs here because Green Lakes are saturated with mineral ions from the rocky beds in which the lakes sit. Other types of plankton actually build tiny calcite shells around themselves.

The plankton are particularly active in summer when sunlight is strongest and the waters are warmer. In the cold winter, with much less sunlight, there are fewer *Synechococcus* cells and they are less active. The waters of Green Lakes then become a more commonplace dark blue-green.



Technical information:

The quotation is from Ledyard Lincklaen's article "The Green Lakes of Onondaga," *Putnam's Magazine* **6**(36), pp. 618-623 (1855). Lincklaen's "ultramarine blue" is most likely the glow from the lakes under direct sunlight, and not literally the reflection of the blue sky by the lake's surface. The "peculiar transparent green" that Lincklaen observed when the water was shaded from direct sunlight is its color when exposed only to the indirect lighting of the blue sky.

The two photographs at the top of the article were taken at noon on days without significant cloud cover and with dewpoints less than 15 C. The photographs were taken with the same camera and have not been color-corrected. The color of the blue sky was very similar on the two days.

The main scientific sources for this note are:

(i) Bohren, Craig F. and Huffman, Donald R. (1983). *Absorption and Scattering of Light by Small Particles* (Wiley-VCH reprint, 2004), pp. 132-134.

(ii) Callieri, Cristiana (2007). "Picophytoplankton in freshwater ecosystems: the importance of small-sized phototrophs", *Freshwater Reviews* **1**, 1–28; doi: 10.1608/FRJ-1.1.1 .

(iii) Hilfinger IV, Martin F.; Mullins, Henry T. (1997). "Geology, limnology and paleoclimatology of Green Lakes State Park, New York" (PDF). In Rayne, Todd W.; Bailey, David G.; Tewksbury, Barbara J. *Field trip guide for the 69th Annual Meeting of the New York State Geological Association : September 26-28, 1997, Hamilton College, Clinton, NY*. New York State Geological Association, pp. 127–158. OCLC 926099919. Hilfinger and Mullins prepared a remarkably complete guide for a walking tour of the park.

(iv) McCormick, M. (2012). "Geomicrobiology of a Meromictic Lake, Green Lake, Fayetteville, NY" (PDF). In Rayne, Todd W., *Field Trip Guidebook for the 84th Annual Meeting of the New York State Geological Association*, New York State Geological Association, pp. B4-1 – B4-16. OCLC 859204684.

(v) Thompson, J. B., Schultze-Lam, S., Beveridge, T. J., Des Marais, D. J. (1997). "Whiting events: Biogenic origin due to the photosynthetic activity of cyanobacterial picoplankton," *Limnology and Oceanography* **42**(1), 133–141; doi: 10.4319/lo.1997.42.1.0133 Thompson and his co-workers were apparently the first to identify *Synechococcus* cells with the origin of the calcite suspended in the lake waters.

About Synechococcus: The tiny plankton cells that dominate the near-surface region of the lakes belong to the photosynthetic genus *Synechococcus* (Thompson, *et al.*, 1997). The density of the cells near the surface of the lakes is roughly 10^5 cm^{-3}. The main pigment of the cells is chlorophyll a, which absorbs sunlight at wavelengths shorter than 450 nm or longer than 630 nm. There is variation in the optical characteristics among *Synechococcus* strains due to the presence of other pigments in the cells besides chlorophyll a (Callieri, 2007). The absorption and other optical properties of the particular strains that flourish at Green Lakes State Park have apparently not been studied.

About the light scattering: Thompson, *et al.* (1997) did a comprehensive study of the *Synechococcus* cells and the calcite ($CaCO_3$) particles in the lake at different seasons. The light scattering was studied using a "Secchi disk". One lowers the disk into the water and records the depth below which the disk disappears from view. The corresponding length is of order 5-10 meters in summer. The mass density (mg/l) of the calcite suspended in the water is about 100 times the mass density of the *Synechococcus* cells, and the observed light scattering is consistent with rough calculations of scattering by the calcite crystals.

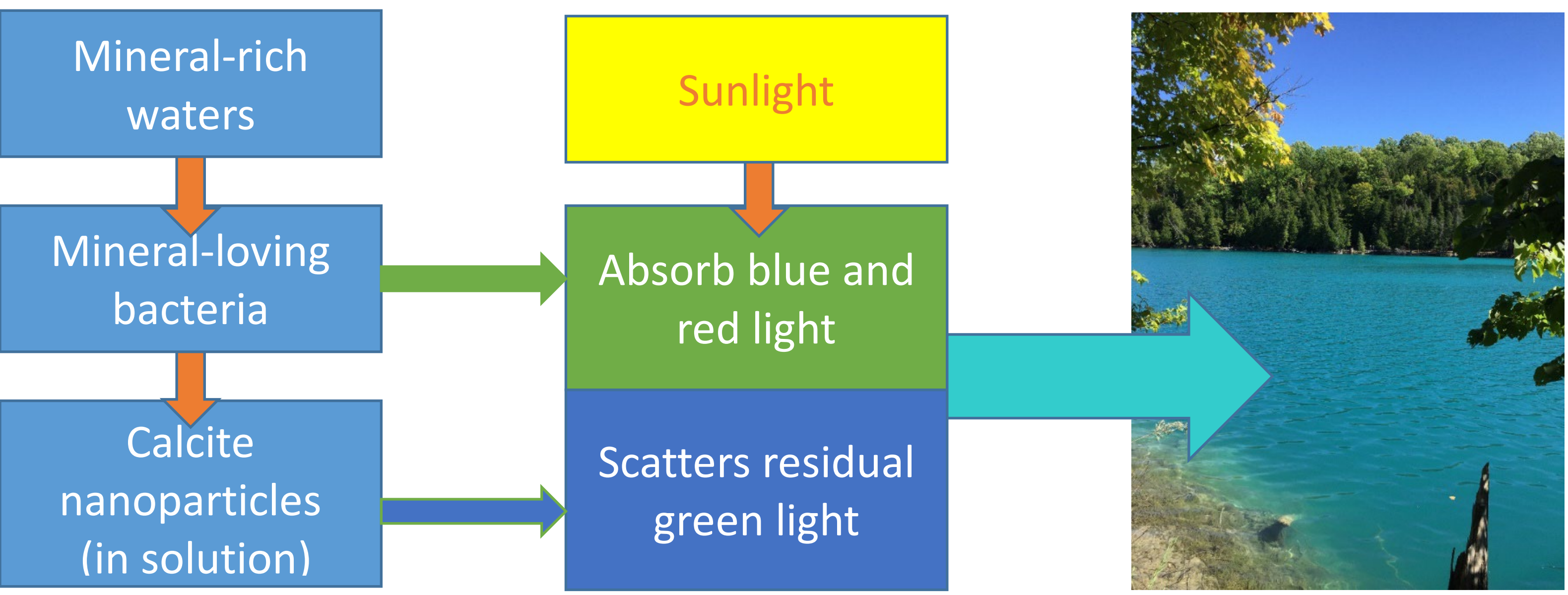
In summer, the calcite particles amount to about 1 mg/l of water near the surface, with particle diameters greater than 0.2 microns and less than 5 microns. The particle size distribution in the suspension wasn't measured. Assuming a particle diameter of 1 micron, the density of calcite particles is $N_{calcite} \approx 7 \times 10^5$ cm^{-3} and the projected area of a particle is about 10^{-8} cm^2. To calculate a scattering cross-section σ, the projected area needs to be reduced by a factor related to the ratio of the index of refraction of calcite (about 1.6) and of water (1.33). The factor is $(m^2 - 1)/(m^2 + 2)$, where m is the index ratio. The factor is then about 0.12, leading to $\sigma \approx 10^{-9}$ cm^2. The scattering length $l_{scatter} = 1/(N_{calcite}\sigma) \approx 14$ meters. The calculation agrees roughly with the Secchi disk measurements.

The *Synechococcus* cells themselves are not the origin of the milkiness. In September their density is about $N_{cell} \approx 10^5$ cm^{-3}. The cells are about 0.5 x 10^{-4} cm in diameter. The product projected area of the cells ($a \approx 3 \times 10^{-9}$ cm^2) and the refractive index factor yield $\sigma \approx 2 \times 10^{-10}$ cm^2. The scattering length of the suspension of cells is then $l_{scatter} = 1/(N_{cell}\sigma) \approx 500$ m, which is too long to explain the milkiness of the lake water.

New York Times article:

The answers begin with the chemical composition of the lake water, which is rich in saturated with minerals. The chart below illustrates the processes.

The lakes lie in a bed of shale rock, and the water has lots of calcium, bicarbonate, and other ions.



One consequence of the calcium carbonate is that a strain of photosynthetic *Synechococcus* bacteria thrives in the lakes' waters. The bacteria are about 300 – 500 nm in diameter. They precipitate nanocrystals of calcite (a form of $CaCO_3$) from the water. In the transmission electron micrograph below, the black arrows are pointing at the layer of 10 nm calcite crystallites at the surface of a *Synechococcus* cell.

In summer, there is a substantial density of these bacteria (as high as 3×10^5 cm^{-3}) near the surface of the lake. Their photosynthetic activities produce a dribble of calcite nanocrystals into the water.

Deadman's Point in May (credit: Wikipedia).

Transmission electron micrograph of a *Synechococcus* bacterium (credit: Thompson, *et al.* (1997)).