mass factor $M \approx$ sec Z, is constant. Hence $p = n/M$ or

$$W \sim M^{-1/2} = (\cos Z)^{1/2}$$

where Z is the angle between the line of sight and the local vertical on Venus. At a phase angle i, we have typically $Z \approx i/2$, so that

$$W \sim [\cos(i/2)]^{1/2}$$

Such a variation is consistent with the observed phase effect for the stronger CO_2 bands (*12*). For example, the equivalent widths in the 8,689-Å and 10,488-Å CO_2 bands are about ⅓ as large near 165 deg phase as they are below 60 deg phase. We can also expect that the average gas temperature will vary by only ±3°K from zero phase to $i = 121$ deg (assuming a 5-km scale height and 4°K/km lapse rate), but that rotational temperatures observed near 165 deg phase will be some 20°K lower. This also agrees with observation (*12, 13*).

Finally, a similar argument explains the very weak center-to-limb effect. If we observe at small phase, we expect to find $W \sim (\cos Z)^{1/2}$, so that W is still 0.71 as large at $Z = 60$ deg (almost nine-tenths of the way from center to limb) as at the center of the disk. Halfway from the center to the limb, $Z = 30$ deg and W is 0.93 as large as at the center of the disk. These small effects are generally not measurable on Venus, because of its small angular size. However, such effects are observed on Jupiter, a similarly cloud-covered planet.

One last piece of evidence supporting a uniformly mixed aerosol may be mentioned. When Venus transits the sun, light is observed refracted through her upper atmosphere. The maximum refraction observed corresponds to pressure levels in the range from 3 to 6 mb (*14*). This pressure is an order of magnitude lower than the effective pressure of line formation for CO_2 and CO at 60 deg phase, where the effective air mass factor is $M \approx 9$ because of multiple scattering (*12*). The effective air mass factor for transmitted light at grazing incidence (*15*) is

$$M(90\text{ deg}) = (2\pi R/h)^{1/2}$$

which, for a planetary radius $R = 6100$ km and scale height $h = 5$ km, is about 88. Thus the increased air mass factor at grazing incidence compensates almost exactly for the lower pressure, and the total amount of gas in the line of sight is practically the same as at 60 deg phase. As both conditions correspond to an aerosol optical depth near unity, this equality is evidence for a constant aerosol mixing ratio over some 2.3 scale heights. It also supports the phase-invariance of the number of molecules in the line of sight.

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27 August 1973; revised 19 October 1973 ■

Suppression of Nitrogen Fixation by Blue-Green Algae in a Eutrophic Lake with Trace Additions of Copper

Abstract. *Nitrogen fixation by blue-green algae in highly eutrophic Clear Lake, California, was severely inhibited by trace amounts of copper. The chelation capacity of the lake is probably saturated by indigenous copper. Additions were only 1/200 of those normally used in algal control. Since nitrogen fixation provides half of the lake's annual nitrogen budget, economical eutrophication control appears possible.*

We report the specific effects of very low concentrations of added and indigenous Cu on phytoplanktonic N_2 fixation and photosynthesis in a lake where natural chelation should be high. In summer, eutrophic Clear Lake, California, contains large quantities of particulate and dissolved organic matter (*1, 2*). Both these classes of material have been demonstrated to chelate Cu (*3*).

Copper sulfate has long been used as an algicide in aquatic ecosystems but its use in more subtle ways was unknown hitherto. There have been several reports of inhibition of algal photosynthesis by Cu added at concentrations below those found for soluble Cu in the natural environment (*4*). These were studies of laboratory cultures of algae grown in the absence of chelating agents. These studies assumed that such low Cu concentrations had no effect in situ because of chelation with various substances. Certainly ethylenediaminetetraacetic acid (EDTA) will rapidly remove the toxic effects of Cu in natural phytoplanktonic populations (*5*). Thus, if indigenous Cu in a water body is chelated, variations in Cu concentrations should play no role in controlling algae. The effects of small additions of Cu (5 to 10 μg/liter) should again be small, especially where there is much organic material in the water, because of rapid chelation or precipitation of Cu (*5*). Our studies have been concentrated on these postulations.

The method used was an extension of the bioassay devised by Goldman (*6*) which involves simultaneously adding nutrients and $NaHCO_3$ labeled with ^{14}C to natural phytoplankton and measuring the changes in ^{14}C uptake produced, relative to a control. In this case, changes in N_2 fixation, chlorophyll a content, species biomass, and composition were also followed. There are three limitations in the use of this bioassay for periods of several days: bottle wall effects, respiration of photosynthetically fixed CO_2, and changes in the ratio O_2/CO_2 resulting from incubation in small impermeable bottles. In experiments in cool oligotrophic lakes these effects do not present serious problems since biomass and rates of activity are low. This is not the case with warm eutrophic lakes such as Clear Lake, where summer chlorophyll a concentrations range from 50 to as much as 80,000 μg/liter and water temperatures of 25°C are frequent. To overcome such problems we used large flasks and short-term incubation of subsamples with tracer, and allowed free gaseous exchange through cotton wool bungs (*7*). Copper was analyzed by atomic absorption spectrometry of concentrated, filtered water samples.

Samples of phytoplankton from the Upper Arm of Clear Lake were taken in September 1972, a period when *Anabaena* is the major N_2 fixing genus (*8*). Two-liter samples were incubated for 8 to 10 days in 5-liter conical flasks at 20°C in low, continuous light (approximately 1100 lu/m^2). Additions of $CuSO_4$-Cu in concentrations of 5, 10, and 50 μg/liter were made. Every 2 days subsamples were taken to assay nitrogenase activity, ^{14}C uptake, and chlorophyll a content. Nitrogen fixation was assayed by using an acetylene reduction technique (*8*), ^{14}C uptake by using the method of (*6*), and chlorophyll a content by extraction in hot methanol (*9*).

There are considerable variations in the concentration of soluble Cu in the waters of Clear Lake (*2*), but the averages obtained by simultaneous sampling at 32 stations in September 1969 and April 1970 were 2.7 and 3.7 μg/liter, respectively. Individual values ranged from undetectable to 33 μg/liter, and concentrations as high as 63 μg/liter have been reported (*5*). It seems entirely probable that blue-green algae, which form surface scums and move somewhat independently of the main water mass, could experience changes of ambient Cu concentration of the same magnitude as those we have used.

Figure 1A shows that the addition of Cu at 5 μg/liter reduced N_2 fixation by 76 percent in 2 days and 90 to 95 percent for the duration of the experiment. In contrast, photosynthesis was reduced by only 7 to 34 percent. The standing crop, measured as chlorophyll a, varied from minus 13 to 42 percent to plus 9 to 27 percent. The addition of Cu at 10 μg/liter caused a dramatic and permanent drop in N_2 fixation. This reached zero in 2 days (Fig. 1B).

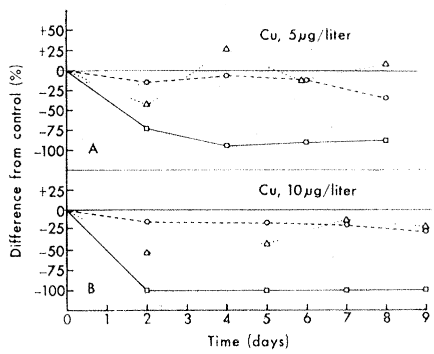

Fig. 1. Effect of low levels of Cu on (squares) N_2 fixation, (circles) photosynthesis, and (triangles) chlorophyll a concentration in an autumnal bloom of phytoplankton on Clear Lake, California, 1972. Copper was added at (A) 5 μg/liter and (B) 10 μg/liter.

Even at these higher Cu concentrations the effects on photosynthesis and chlorophyll were relatively small. At a Cu concentration of 50 μg/liter, N_2 fixation was rapidly reduced to zero and photosynthesis reduced by 86 percent in 1 day. A previous experiment (*5*) showed 83 to 100 percent inhibition of photosynthesis in a natural population of algae at Clear Lake with Cu concentrations of 31 to 46 μg/liter.

The sensitivity of "planktonic" blue-green algae to Cu concentrations of milligrams per liter has been reported (*10*) and has been attributed to enhanced Cu uptake by the Cyanophyceae (*11*). We have found these organisms to be very sensitive to Cu concentrations of micrograms per liter.

Table 1 indicates that with Cu concentrations of 5 to 10 μg/liter, only the N_2 fixing blue-green algae *Aphanizomenon* and *Anabaena* were adversely affected. Populations of the green alga *Oocystis* and the diatom *Melosira* remained similar to the control within experimental error. *Anabaena* growth was less affected by Cu than *Aphanizomenon* growth, especially at 5 μg/liter. A difference in sensitivity to Cu was not unexpected, because changes in the dominant blue-green algal type have been brought about by large additions of Cu to lakes (*12*).

Despite our laboratory results, we have not shown unequivocally that the low indigenous concentrations of Cu in Clear Lake inhibit either N_2 fixation or photosynthesis in situ. In the September 1969 synoptic survey there was no significant correlation at the 5 percent significance level between indigenous concentrations of Cu and N_2 fixation ($r = -.0614$; 12 degrees of freedom) or photosynthesis ($r = -.0376$; 29 degrees of freedom) (*2*). We thus conclude that blue-green algae detect a major difference between a few micrograms per liter of artificially added Cu and a similar increase in indigenous Cu which occurs during wind mixing. The natural Cu is presumably chelated and nontoxic. Inhibition by artificially added Cu occurs regardless of whether the initial lake concentrations are 2 to 3 (*2*) or 60 to 70 μg/liter (*5*). Studies with the physiologically distinct populations of *Aphanizomenon* show that the toxic effects of up to 70 μg/liter of Cu are removed if EDTA is mixed with the Cu a few minutes before addition to the lake water, but not when the EDTA is added simultaneously (*13*). Thus, there must be little excess chelation capacity in lake samples with wide ranges of Cu concentrations, at least within the time limits of our experiments. There should be ample chelation sites on the organic matter in the lake (*3*), but no significant chelation occurred during our experiments.

The original sources of the indigenous Cu in Clear Lake are not definitely known but its use as an algicide and orchard pesticide is known. In addition, the inflow from rivers may contain dissolved or sediment-adsorbed Cu from the friable soils of the metalliferous Coast Range which forms the lake's drainage basin. It is curious that the adjacent Eel River drainage has much lower Cu levels (*14*).

Any factor which affects N_2 fixation is important since it is a major contributor to the N budget of Clear Lake (*8*) and other lakes (*15*). It is likely that productive water bodies with high contents of indigenous Cu will still be favorable for the growth of nuisance blue-green algae. Inflow with a high ionic Cu content is at present a possible inhibitor of blue-green algae in Onondaga Lake, New York (*16*). Ironically, industrial pollution control for this lake could result in an increase in N_2 fixing blue-green algal scums.

Table 1. Effect of low Cu concentrations on major phytoplanktonic genera in an autumnal bloom in Clear Lake, California, 1972.

Cu added (μg/liter)	Time (days)	Algal volume (μm^3/ml)			
		Aphanizomenon	*Anabaena*	*Oocystis*	*Melosira*
0	0	1.34	0.96	1.5	0.15
5	9	0.5	1.8	5.8	16.6
0	9	2.1	3.2	4.0	13.4
0	0	1.0	0.45	3.9	0.015
10	8	0.0	0.2	6.7	18.9
0	8	2.3	3.4	7.1	8.4

Our results have a bearing on the reversal of eutrophication in lakes where N_2 fixation is a major supplier of algal N (*17*). We have shown that N_2 fixation is inhibited by freshly added Cu at concentrations as low as 1/200 of those normally used to kill blue-green algal blooms. We have also shown that low levels of Cu favor the more desirable algal groups such as diatoms, at least in laboratory incubations of lake water.

In the lake a predominance of algae other than blue-greens in early spring is unlikely because *Aphanizomenon* normally dominates both early and late spring blooms when algal growth is mainly on NO_3-N and N_2-N, respectively. The dominance of *Aphanizomenon* is due, apart from the N_2 fixation in late spring, to its ability to regulate its buoyancy and remain at a depth with favorable light and nutrients (*18*). This buoyancy also enables *Aphanizomenon* to dominate the muddy-water winter phytoplankton and provide a large "inoculum" for the spring bloom. Suppression of N_2 fixation will most probably alter the current ecological balance away from *Aphanizomenon* only between late spring, when the winter store of NO_3-N has been used up, and autumn. At present in late summer there are sometimes moderate phytoplankton crops dominated by N-limited algae other than blue-greens.

In Clear Lake, where an estimated 500 tons of N_2 is fixed annually by blue-green algae, the low Cu additions we propose could be used to reduce the total N budget of the lake by 40 to 50 percent. This could be accomplished at a fraction of the cost required to remove inflowing sewage N by advanced wastewater treatment. Both wastewater treatment and trace Cu addition are techniques which need to be used in the foreseeable future. Neither system provides a "once only" lake cleanser. A suitable tertiary sewage treatment would include a denitrification stage, with an added carbon energy source. Since sewage N represents only 10 percent of the annual N budget of the lake (*8*), suppression of N_2 fixation by trace levels of Cu is a cheaper and more effective way of reversing eutrophication in this lake. However, a successful method of controlling N_2 fixation, with no tertiary sewage treatment or change in river inflow, would decrease the absolute amount of N entering the lake, but increase the percentage contribution of sewage N and thus its importance. Both advanced wastewater treatment and some method of directly inhibiting N_2 fixation by blue-green algae would be needed to end the yearly occurrence of serious nuisance blooms.

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6 August 1973; revised 1 October 1973

Detection of Radon Emission at the Edges of Lunar Maria with the Apollo Alpha-Particle Spectrometer

Abstract. *The distribution of radioactive polonium-210, a decay product of radon-222, shows enhanced concentrations at the edges of lunar maria. Enhancements are seen at the edges of Mare Fecunditatis, Mare Crisium, Mare Smythii, Mare Tranquillitatis, Mare Nubium, Mare Cognitum, and Oceanus Procellarum. The observation is indicative of the transient emission of radon gas from the perimeters of lunar maria.*

The noble gas ^{222}Rn is produced in the natural decay chain of uranium. It decays with a half-life of 3.8 days by the emission of an alpha particle. Under certain conditions ^{222}Rn may diffuse through the lunar regolith and appear above the lunar surface before undergoing radioactive decay. Moreover, ^{222}Rn has a descendant, ^{210}Po, which is also an alpha-particle emitter but delayed by the 21-year half-life of ^{210}Pb. The orbiting alpha-particle detectors aboard the Apollo 15 and Apollo 16 spacecraft had spatial and energy resolution sufficient to identify and locate concentrations of either species.

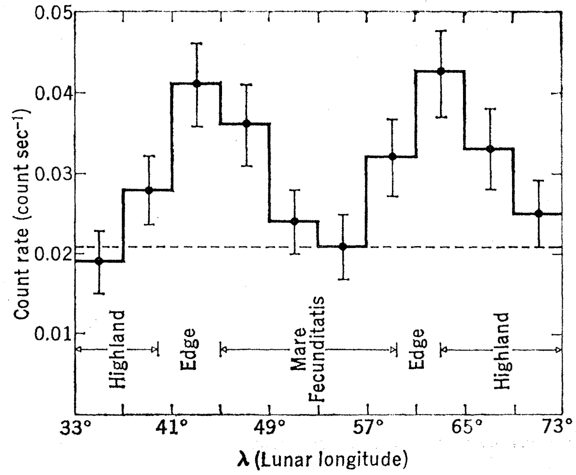

Fig. 1. Count rate of ^{210}Po across Mare Fecunditatis. The dashed line at 0.021 count sec^{-1} shows the background level.