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Arsenic biogeochemistry affected by eutrophication in Lake Biwa, Japan

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Aquatic organisms metabolize arsenic, forming non-toxic arsenic-containing ribofuranosides and arsenobetaine from arsenate. The metabolism results in the occurrence of thermodynamically unstable arsenite and methylarsenicals in natural waters. We studied the seasonal variations of arsenical species in the mesotrophic northern and eutrophic southern basins of Lake Biwa in Japan. The total arsenic concentration in the euphotic zones remained constant in the northern basin, while it was increased by 2-4 times in the southern basin in summer. Despite the larger biomass, the percentage of methylarsenicals was lower in the southern basin. These results indicate that the eutrophication may alter the concentration and speciation of trace elements in the hydrosphere.

Keywords: Arsenate / Arsenite / Methylarsenicals / Ferromanganese oxides / Aquatic organisms

Lake Biwa is the largest lake in Japan and located in the center of Honshu (Fig. 1). The lake is a source of water supply for the fourteen million people living in the Kansai area and supports many kinds of aquatic organisms including more than 50 endemic species. The northern basin is located in a rural area and has a surface area of 616 km² and an average depth of 44 m. The southern basin is located in urban area and has a surface area of 58 km² and an average depth of 3.5 m. The waters in the northern basin flow into the southern basin and flow out through the Seta River. The residence time of water is estimated to be 5.5 y for the northern basin and 0.04 y for the southern basin. Nowadays the northern and southern basins are estimated as mesotrophic and eutrophic, respectively, because of human activity. The lake is an intriguing environment, since one can observe a difference in the progression of eutrophication in the two originally identical basins.

Our observation was carried out from June, 1992 to February, 1995 mainly at stations N1 in the northern basin and S3 in the southern basin (1). We determined the concentrations of arsenate [As(V)], arsenite [As(III)], monomethylarsonic acid [MMAA(V)], monomethylarsonous acid [MMAA(III)], dimethylarsinic acid [DMAA(V)] and dimethylarsinous acid [DMAA(III)] in lake water (2). The concentrations of MMAA(III) and DMAA(III) were low (less than 0.3 nM), and therefore methylarsenicals were treated as MMAA(V+III) and DMAA(V+III). The total arsenic concentration was determined after the organoarsenicals were converted into As(V) by alkaline persulfate oxidation in a Teflon digestion bomb. This value agreed closely with As, the sum of concentrations of As(V), As(III), DMAA(V+III) and MMAA(V+III). Therefore, these species comprise more than 95% of dissolved arsenicals in Lake Biwa.
While the phosphate was reductively depleted in the hypolimnion in summer, Arsenicals were adsorbed onto ferro-manganese oxides formed at the oxic surface of the sediment, some of them is supplied to the lake water. The supply was large in 1994, when local anoxic conditions were extensively developed in the surface sediments.

The change in speciation of arsenicals mainly occurred in the euphotic zone. As(V) was distributed uniformly through the water column in winter and its concentration decreased in the epilimnion in summer. As(III) increased during spring and fall blooms, while DMAA(V+III) became dominant in summer. The seasonal variation is probably a common feature of lakes and seas in the temperate zone. The speciation change is a result of the arsenic metabolism of phytoplankton and other aquatic organisms. The biomass in the southern basin is much larger than that in the northern basin as indicated by the concentration of chlorophyll a and transparency. It was reported that in 1993 the mean density of phytoplankton was 950 and 2500 cells/ml at the centers of the northern and southern basin, respectively. The southern basin contained more kinds of plankton species in addition to almost all dominant species observed in the northern basin. Although higher productivity is expected in the southern basin, the concentrations of As(III) and methylarsonicals produced through the arsenic metabolism were comparable to those in the northern basin. The percentage of methylarsonicals was low in the southern basin (Fig. 2). A culture experiment has revealed that uptake of As(V) by marine algae is inhibited competitively by phosphate at concentrations on the order of μM. While the phosphate was nearly depleted in the epilimnion in both the basins, the total budget of phosphorus was larger in the southern basin. The large load of phosphorus may have decreased the arsenic metabolism efficiency of phytoplankton in the southern basin. Another possibility is that degradation of organoarsenicals by bacteria may have been rapid in the southern basin because of its large population.

The eutrophication changed the concentration and speciation of the trace element in the water, and the change may further affect the ecosystem in the lake.

References