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UGENE T. OBORN

HEMISTRY OF MANGANESE IN NATURAL WATER

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INTRACELLULAR AND EXTRACELLULAR CONCENTRATION OF MANGANESE AND OTHER ELEMENTS BY AQUATIC ORGANISMS

By EUGENE T. OBORN

ABSTRACT

Examinations of mineral concretions or deposits accumulated on the inside walls of plant-culture tanks used in a greenhouse study show that the amount of the mineral deposited is related to the aquatic-plant species growing in the tanks.

A bacterium tentatively identified as *Bacterium precipitatum* Kalin commonly grows symbiotically on sago pondweed. This bacterium is responsible for deposition of a mineral, mainly calcite, on the plant-body surface of the pondweed; this deposit may amount to more than 1.2 percent of the fresh weight of the plant.

Micrococci spp. bacteria were abundant in both manganese and phosphorite nodules taken from the ocean floor. Water-submersed lake-bottom soil had four times as much manganese as adjacent farm-land soil. The manganese concentration in aquatic plants may be more than 30 times that found in comparable parts of land plants.

Microscopic study of plant sections shows that mineral deposition patterns associated with the growth of pond scum, stonewort, and pondweed range widely. In addition to the inanimate phenomena of water-body area, depth, and evaporation, the growth processes of the different aquatic-organism species and species associates are significant in the determination of the amount and type of mineral accumulations.

INTRODUCTION

The expression "balance of nature" implies to those working in the natural sciences a state of equilibrium brought about by an existent order of influences. If the equilibrium is disturbed it may be rapidly reestablished or may remain out of balance for years. The return to equilibrium may involve either the animate or the inanimate factors of the natural system, or a combination of both, in varying degrees. The dissolved mineral matter in natural water is a factor in a complex system which can be strongly influenced by many forms of aquatic life.

Both water-rooted and soil-rooted species of aquatic plants absorb and accumulate mineral matter. Mineral deposition around and (or) in the commonly occurring aquatic plants is apparently related to the morphology and physiology of a plant species. In some plant species, intracellular deposits of mineral matter are predominant; in others the plants become encased in extracellular deposits.

Limnologists share the general concept that soil-rooted aquatic plants, although wholly submerged, obtain most of their mineral salts from the substratum and not from the surrounding water. On the other hand, floating or drifting water-rooted plants obtain their mineral salts directly from the surrounding water (Putcher, 1933).

The influence of the morphology of individual plants on the amount of mineral deposition became apparent in earlier work (Oborn, 1960). The degree to which the water surface was shaded from sunlight or other light sources affected both ecological associates and microbiological symbionts. The interrelation between water-surface shading, atmosphere-hydrosphere gas exchange, oxidation-reduction potential (Eh), and mineral content of water at the soil-water interface in greenhouse tanks has been reported from an earlier study (Oborn and Hem, 1962).

Microbiological symbiosis and water demineralization by aquatic plants are widespread in diverse aquatic mineral environments, and their study has become increasingly significant owing to their varying response to many local biological and environmental factors.

In recent years the significant removal of water-soluble radioactive elements from water bodies by plankton has been frequently noted (Klement and Schultz, 1962). The commonly held belief, however, is that such concentration by the organism is only temporary—after the death of the organism and the disintegration of its protoplasm, the mineral is assumed to be returned to aqueous solution.

Mineral removal is accomplished by the intracellular concentration of mineral matter by water organisms prevalent in nearly all natural water bodies. Such mineral absorption may be mostly from the water-submersed soil or directly from the water, depending on whether the species involved was soil- or water-rooted, respectively.

PURPOSE

The primary aim of the present study is to consider the manner in which plants and associated biota incorporate mineral matter into their structure and to obtain data on the composition of the mineral matter so deposited, especially with respect to manganese. The mineral accumulations studied formed in chemically diverse waters and in widely separated geographic areas. Such information should be a valuable aid to geologists and others workers in interpreting the dissolved-mineral content and content changes taking place in any natural water body.

MINERAL DEPOSITION ASSOCIATED WITH PLANT GROWTH

GREENHOUSE STUDY

Each species of aquatic plant investigated grew in 30-, 15-, and 5-gallon tanks made of stoneware. Each tank contained a 4-inch layer of bottom soil from the Denver Federal Center Lake bottom, and Denver tap water was used to fill the tanks and to replenish the water used each week of the year. After the termination of a 1-year study of the effects of aquatic plants on the iron content of water in the tanks (Oborn and Hem, 1962), deposits of solid material were observed in the tanks. The amount of mineral concretions or deposits which had accumulated around the inside periphery of the respective plant-culture tanks seemed to differ from one species series to another.

The mineral-microbe deposition mixtures obtained from the plant-culture tanks of the four species series are listed in table 1. In the table, initial and predominant plants grown in the tanks are listed in the order of decreasing mineral deposition.

TABLE 1.—*Mineral-microbe deposition mixtures identified and measured on greenhouse culture tanks after 1 year of plant growth in the tanks*

Initial and predominant vegetation-species series	Average water use (gallons per week per square foot of tank surface)	Microbe population, other than bacteria, mixed with mineral deposit	Grams of microbe-mineral deposit in species series per square foot of open tank surface
Eichhornia crassipes (Mart.) Solms (water-hyacinth).	2. 0	Blue-green algae *Microcystis* sp. *Nostoc* sp. *Phormidium* sp. Green algae: *Chlamydomonas* sp. Diatoms: *Eunotia* sp.	2. 42
Myriophyllum brasiliense Camb. (parrot-feather).	1. 0	Blue-green algae *Microcystis* sp. *Phormidium* sp. Green algae: *Chlamydomonas* sp. *Cladophora* sp. Diatoms: *Diatoma* sp. *Gomphonema* sp.	2. 26
Elodea nuttallii (Planch.) St. John (western water-weed).	. 9	Blue-green algae: *Phormidium* sp. Green algae: *Cladophora* sp.	. 63
Carex aquatilis Wahlenb. (water-sedge).	3. 0	Blue-green algae *Microcystis* sp. *Phormidium* sp. Green algae: *Pleurococcus* sp.	. 06

Table 1 shows that the amount of deposition was more closel related to the kind of emergent or submersed aquatic-plant specie growing in the tank than to the amount of water used. Blum (1956 wrote that one of the blue-green algal organisms (*Phormidium*) i able to convert an entire tuft or stratum of continuous tufts of alga growth into a mineral crust 4–5 millimeters thick.

Mineral fragments collected from the tanks were crushed an placed in water overnight. Microscopic examination the followin morning showed algal filaments beginning to grow from each of mos of the individual mineral fragments. The blue-green algae *Micro cystis* sp. and *Phormidium* sp. and an assortment of green algae an diatoms were identified in the solid material and evidently wer effective in absorbing and depositing minerals taken from the plant culture water.

If the mineral accumulation around the tank-top periphery wer directly related to transpiration and (or) evaporation, then the cultur tanks containing *Carex aquatilis* growth should have had the larges mineral accumulation. Compared with other aquatic plants thi species used large amounts of water during the test period; howeve mineral accumulation in tanks containing *Carex aquatilis* average only 0.06 gram per square foot of open tank surface.

Sections of the filaments of one of the green algae (fig. 1) shov abundant and irregular deposition of mineral around the older fila ments. This deposition may be related to the fact that aquati plants, by photosynthesis, exhaust the carbon dioxide in water, thu promoting the deposition of calcium carbonate (Whipple, 1927) The varying amount of mineral accumulation indicates that, i addition to the influence of water body area, depth, and evaporation the growth processes of the different species and their symbionts ar significant in mineral accumulations.

The cationic composition of the deposited material is shown i table 2, where the calcium content probably indicates that much o the material is calcium carbonate. Earlier studies (Oborn and Hem 1962) showed that *Cladophora* filaments contain iron, and the amoun of manganese in the filaments is shown in table 5 of this report.

IRRIGATION-WATER STUDY

Irrigation systems in the 17 Western States of the continental Unite States total more than 47,000 miles of canals that are infested wit submersed aquatic weeds and more than 20,000 miles of canals tha support thick growths of algae (Timmons, 1960). One of the mos common and abundant of the submersed aquatic plants is sago pond weed (*Potamogeton pectinatus* L.).

In 1961 an opportunity arose which permitted the measurement of extracellular mineral deposition by the single species sago pondweed. More than a ton of this water plant was harvested in pure form from an irrigation canal west of Phoenix, Ariz., in July 1961.

After harvesting, the plants were water washed, turned frequently, and allowed to dry in the sun for 30 days. An inconspicuous mineral incrustation that had formed on the submersed plants loosened and scaled off as the moisture content of the plants decreased from an original value of 90 percent to a final value of less than 10 percent. The mineral incrustation was about 90 percent calcite. Among the

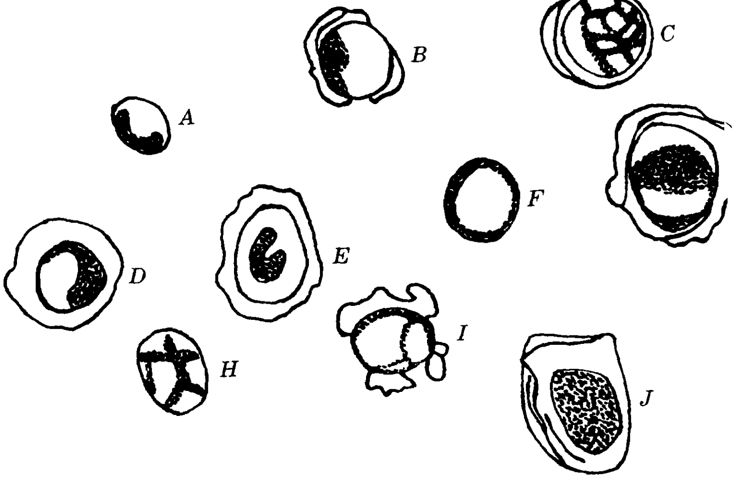

FIGURE 1.—Typical sections of *Cladophora* sp. filaments. Note that the younger filaments (*A, F, H*) consist of the algal protoplast alone and show little or no extracellular mineral deposition. The shape and amount of amorphous mineral deposited varies for other filaments. (Magnification 532 ×.)

common impurities in the calcite were manganese, iron, magnesium, cobalt, barium, and strontium, elements which may substitute for calcium in variable amounts. For a 200-pound sample of sun-dried pondweed containing less than 10 percent moisture, this extracellular mineral material amounted to about 12 percent of the total weight, or about 1.2 percent of the total weight of the fresh plants.

The same kind of mineral deposit involved here was illustrated earlier by Oborn and others (1954, fig. 13) from the leaves of the closely related leafy pondweed (*Potamogeton foliosus* Raf.). Ward and Whipple (1918, p. 185–187), after posing several hypothetical chemical explanations to account for the mineral deposition, concluded with

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certainty only that the mineral deposition is a consequence of processe in the plant.

Many bacteria were interspersed with the mineral deposit on th pondweed, but in other published discussions of similar deposits the were not mentioned. The bacteria can be readily separated from th rest of the deposit by using Gram's differential-staining procedur (Bryan and Bryan, 1942). The bacteria are Gram-negative and average 5 by 15 microns in size. They have been tentatively identifie as *Bacterium precipitatum* Kalin, a form which, together with iro bacteria, actively precipitates minerals in the Kara Sea (Kalinenko 1949).

Bacterium precipitatum Kalin has been consistently found by th writer in great abundance among the particles of mineral matte deposited on sago pondweed. This bacterium was on the precipitate material on plants growing in Denver tap water in the greenhous and on plants growing in brackish water at Timpie Big Spring, Utah (See following section on "Brackish-water study.")

Because of the persistent abundance of this bacterium in mineral precipitated at widely separated locations and from water of divers mineral compositions, this bacterium is probably a constant symbion that plays a major role in the precipitation of minerals on sago pondweed and, presumably, the other water macrophytes.

The composition of material precipitated by organisms from wate from three different sources is shown in table 2. The ash represent the residue remaining after heating at 575° C. Constituents of thi residue are reported as percentages of the residue dried at 62° C.

BRACKISH-WATER STUDY

Timpie Big Spring is about a quarter of a mile southeast of Timpie Utah, and just south of Great Salt Lake; the spring pool has a surfac area of about 2 acres. The main inlet from the ground-water bod is below the water surface at the extreme south end of the pool. A additional seep in the east side of the pool contributes a volume o water about two-thirds that from the main inlet. The water flow north, leaving the spring area through a culvert under U.S. Highwa 40–50, and eventually reaches Great Salt Lake.

In a salinity study of closed lakes, Langbein (1961) found that significant part of differences in salinity could be explained b differences in lake area, mean depth, rate of evaporation, tributar area, and volume between lake level and level of overflow. Thi study suggested also that biological factors may play a major rol in lake demineralization.

Analyses of water from Timpie Big Spring (table 3) showed tha the dissolved-solids content of the water was about 9,000 ppm (part

TABLE 2.—*Composition of material precipitated by organisms from tap, irrigation, and brackish waters*

[Percent composition (dry-weight basis)]

	Tap water (Denver, Colo.)	Irrigation water (Phoenix, Ariz.)	Brackish water (Timpie, Utah)
Ash in dry matter	77.8	87.5	95.7
Iron (Fe)	.18	.07	.00
Manganese (Mn)	.02	.04	.00
Calcium (Ca)	19.2	34.1	15.8
Magnesium (Mg)	.00	.05	.30
Sodium (Na)	1.74	1.82	10.5
Potassium (K)	5.70	2.48	.22

per million), most of which was sodium chloride. The analyses also showed a general decrease in dissolved solids between inlet and outlet. The spring was visited several times, and on each occasion the flora of the spring was examined. It was evident that mineral matter was being deposited on the vegetation in the Timpie Big Spring water.

Three of the most abundant and conspicuous submersed aquatic plants identified with mineral deposition in Timpie Big Spring were sago pondweed (*Potamogeton pectinatus* L.), pond scum (*Cladophora glomerata* [L.] Kütz.), and stonewort (*Chara fragilis* Desvaux and Loiseleur-Deslongchamps). Samples of all three in various stages of mineral encasement are illustrated in figure 2. Deposition of mineral

TABLE 3.—*Chemical analyses of water samples from inlet and outlet of Timpie Big Spring*

[Results in parts per million, except as indicated]

	Inlet (average of samples 21543 and 22014)	Outlet (average of samples 20012, 22521, 22520, 23262, and 23264)
Silica (SiO_2)	10	9.9
Iron (Fe), dissolved	.01	.01
Calcium (Ca)	156	141
Magnesium (Mg)	89	78
Sodium (Na)	3,090	2,820
Potassium (K)	109	101
Bicarbonate (HCO_3)	219	203
Carbonate (CO_3)	0	0
Sulfate (SO_4)	364	346
Chloride (Cl)	4,980	4,580
Nitrate (NO_3)	13	11
Boron (B)	1.1	.9
Dissolved solids (residue on evaporation at 180° C)	8,870	8,310
Specific conductance (micromhos per cm at 25° C)	14,800	13,800
pH	7.7	7.7
Temperature (° F)	55	56

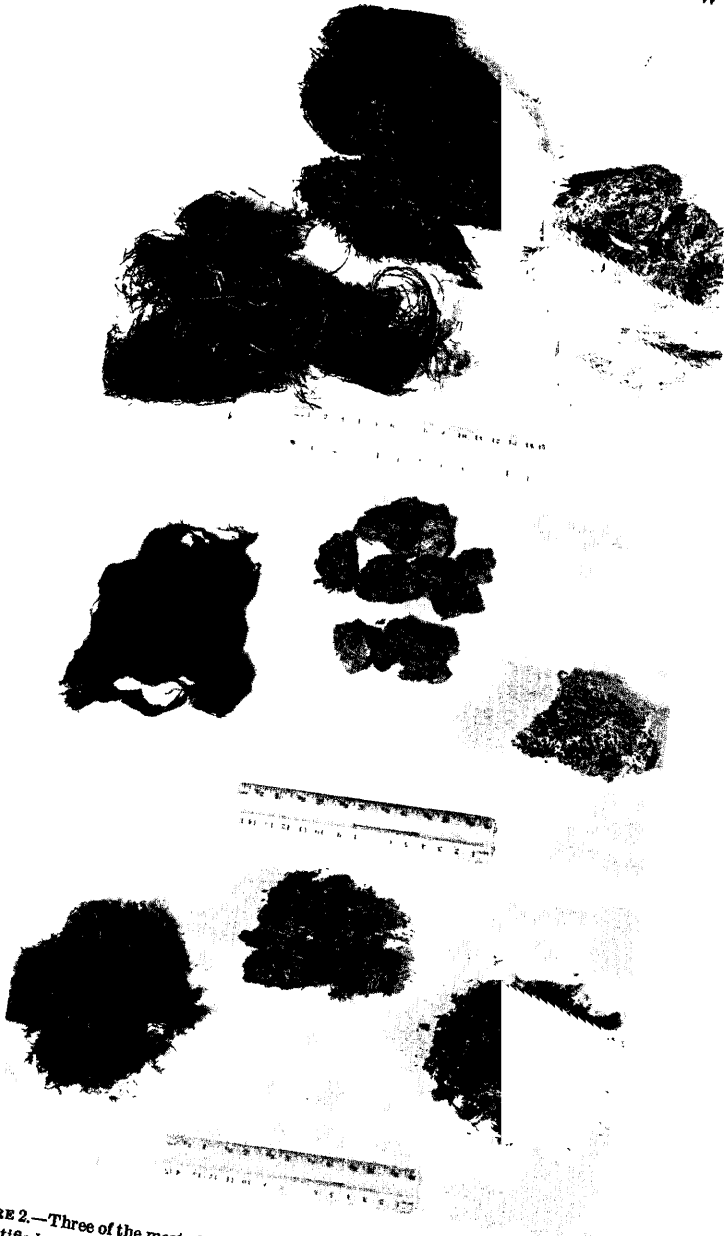

FIGURE 2.—Three of the most abundant and conspicuous submersed aquatic plants identified with demineralization in Timpie Big Spring. In each of the three sets of photographs, left, mineral deposition minimal; center, mineral deposition intermediate; right, mineral deposition heavy. Top, sago pondweed; center, pond scum; bottom, stonewort.

round the filaments of pond scum has already been illustrated in gure 1. It is significant here to mention that, of the pond scums, ıembers of the genus *Spirogyra* were not identified in mineral accumuıtions. Differences in the type of mineral deposition are thus due to he specific functions of the particular aquatic plants or associated ymbionts.

Examination of sections of pondweed, pond scum, and stonewort in arious stages of incrustation reveals significant differences in types of ıineral deposition. For pond scum, mineral deposition was entirely y encasement of the filament. Pondweed, in about half the sections xamined, had mineral deposition in the lacunae of the leaf cells, and nineral encasement of the plant parts originated from several foci. Aineral deposition in stonewort was both internal cell deposition and ell-wall impregnation; deposition by encasement did not take place. Because of these differences in the form of mineral deposition, stonevort should retain its external appearance during the incrustation ɔrocess better than the other two aquatic plants. Photomicrographs of typical sections of pond scum, sago pondweed, and stonewort are hown in figure 3. The deposited material appears black in these llustrations.

The principal aquatic plants growing in the spring pool at Timpie Big Spring, and their associated microflora, are listed in table 4.

ABLE 4.—*Microbe populations identified as symbiont associates of the more conspicuous submerged aquatic plants growing in Timpie Big Spring, Utah*

Conspicuous vegetation	*Microbe population mixed with mineral deposit on the plants*
Potamogeton pectinatus L. (sago pondweed).	Bacteria
	Bacterium precipitatum Kalin
	Desmids
	Closterium sp.
	Diatoms
	Melosira sp.
	Synedra sp.
Cladophora glomerata [L.] Kütz (pond scum).	Blue-green algae
	Microcystis sp.
	Phormidium sp.
	Green algae
	Chlorella sp.
	Diatoms
	Cyclotella sp.
	Diatoma sp.
	Melosira sp.
	Navicula sp.
	Nitzchia sp.
Chara fragilis (Desvaux and Loiseleur-Deslongchamps) (stonewort).	Green algae
	Botryococcus sp.
	Chlamydomonas sp.
	Chlorella sp.
	Diatoms
	Amphora sp.
	Navicula sp.
	Synedra sp.

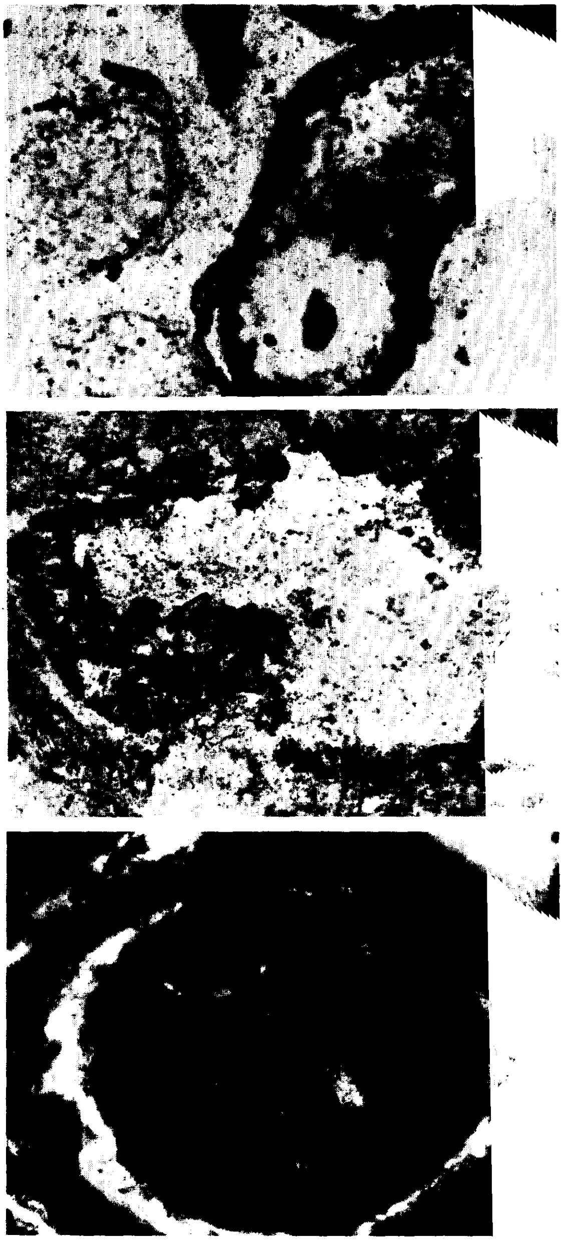

FIGURE 3.—Photomicrographs showing different types of mineral deposition in the three aquatic plants illustrated in figure 2. Note that in pond scum (top), mineral deposition is encasement. In sago pondweed (center), half of the lacunae examined have mineral deposits; encasement originates from several foci. In stonewort (bottom), cell-wall impregnation and internal cell deposition are dominant; actual encasement is minor. All magnifications 1,000 ×.

The bacterial mineral precipitant *Bacterium precipitatum* Kalin was abundant among the mineral particles deposted on sago pondweed. This association also was noted earlier for sago pondweed growing in the Denver greenhouse and in the irrigation canals at Phoenix, Ariz.

The nature of the deposit on plants growing in Timpie Big Spring was determined by chemical analysis (table 2). The deposited material is rather high in sodium, but manganese content was below detection.

The analyses for Timpie Big Spring showed that the outflowing water had a fairly constant composition, but data on the composition of inflow and outflow are not complete enough to allow computation of the rate at which mineral matter is being deposited on plants.

BIOLOGICAL EXAMINATION OF OCEAN NODULES

In the summer of 1962 one manganese nodule and one phosphorite nodule taken from the bottom of the Pacific Ocean were received by the writer for microbiological study. The manganese nodule was submitted by Robert W. Geehan, Regional Director, Region 3, U.S. Bureau of Mines, and was described as having been taken from very deep Pacific Ocean water in 1953. The phosphorite nodule was submitted by John L. Mero, Research Engineer, California Institute of Marine Resources, and was described as having been taken from the Forty Mile Bank deposit about 40 miles due west of San Diego, Calif.

Scrapings from both nodules were pulverized using mortar and pestle and then stained with Gram's differential stain (Bryan and Bryan, 1942). Gram-positive cocci, *Micrococcus* spp., were found in abundance in the pulverized scrapings from both the manganese nodule and the phosphorite nodule.

Mero (1960) discussed the physical and chemical factors possibly responsible for the formation of manganese and phosphorite nodules on the ocean floor. Krauskopf (1955) and ZoBell (1957) suggested microbioorganic processes which may play a major role in nodule formation.

INTRACELLULAR CONCENTRATION OF MANGANESE BY AQUATIC PLANTS

The chemistry of manganese is somewhat like that of iron, in that both elements are considered to be oxidation-reduction element regulators in protoplasm. Water near the bottom of a lake where oxygen is depleted and redox potential is low may be rich in manganese and even richer in dissolved iron. Bottom water of lakes having a high manganese content may have a pronounced opalescent turbidity and, sometimes, a rich brown color. When carried to the surface during seasonal turnover, manganese in Japanese lakes becam oxidized and insoluble and finally precipitated as a reddish-brow powder (Yoshimura, 1931).

Riddick (1958) successfully precipitated manganese in a reservo by artificial aeration. Much study has been given to methods c removing manganese from water because of the problem produce when brown or black precipitates form in water-supply system Riddick and others (1958) found that oxidation by chlorination wa an effective method of manganese removal.

In studying the Japanese lakes, Yoshimura (1931) did not believ that the inflowing water would account for the increase of manga nese during stagnation. More recently, Perkins and Novielli (1958 found that microbiota are active in leaching manganese from ore Hem (1963) investigated various aspects of chemical equilibria an rates of manganese oxidation.

An extensive literature has been built up on the utilization c manganese by plants. Levanidov (1957) found that when trees i a birch forest shed their leaves, approximately 2 pounds of manganes per acre is transferred to the ground surface, and that in 30 hours 43–53 percent of the manganese in the leaves is extracted by leaching Ljunggren (1951), working in Sweden, found that manganese i ash from spruce needles ranged between 1.3 and 7.6 percent, th higher values being found in the ash from needles of trees growin in old river channels. Gamelin (1937), in his study of the Pinale found the order of manganese concentration in any tree to be leave > bark > twigs > heartwood > fruits > sapwood.

Bertrand and Rosenblatt (1921), reporting on the general presenc of manganese in the vegetable kingdom, found 0.21–17 milligrams c manganese per 100 grams of dry plant parts, the largest amount being found in the roots. These investigators mentioned also tha fresh-water plants of the lower types (probably algae) contain 10–77 milligrams per 100 grams of dry plant material. Cannon (1960 reported 0.48 percent manganese in ash on the basis of published dat on all plant types.

A good indication of the optimum amount of manganese whic should be in water for plant extraction was reported by Ellis an Swaney (1947) in connection with commercial hydroponic growth c plants. They suggested that the ion concentration, in parts pe million, of manganese should range between 0.25 and 0.50, preferenc being given to the lower concentration.

Murata (1939) noted that exchangeable manganese in soil an sediment increased and insoluble oxides decreased as a result c reducing conditions brought about by the presence of organic matte Riquier (1954) observed that manganese was carried with humi natter by subterranean waters. Krauskopf (1957) observed that at any pH–Eh condition, manganese compounds are more soluble than are those of iron.

Proper evaluation of the effectiveness of aquatic plants in removing manganese from a lake's water or mud bottom required that an adequately diverse assortment of plants be collected, processed, analyzed, and categorized as to method of normal manganese extraction from the natural environment. The usual precautions for sample collection and preparation were followed, and duplicate samples were analyzed in accordance with methods of analysis designated by the Association of Official Agricultural Chemists (1955). Pertinent reports have been prepared on the natural occurrence of manganese and on precautions to be followed in its analysis (Rainwater and Thatcher, 1960, p. 205–209; Hem, 1959, p. 66–68). The contents of dry matter, ash, and manganese for each species tested are presented in table 5. In table 5 the plant growth classification is, of course, not exact. Nevertheless, such a breakdown into rock, land, water-emergent, water-submersed, soil- and water-rooted aquatic organisms adequately categorized groups according to both their manganese extraction method and the amount of manganese absorbed by the plants.

Earlier, studies of the iron content in the same species of plants (Oborn, 1960) showed a concentration pattern similar to the one here reported for manganese. However, the manganese content of most species studied tends to be lower than the iron content. This tendency is particularly notable in the crustose lichens which are very high in iron but, as a group, have only about twice as much manganese as land plants. Water-emergent leaf culms and the water-emergent, water-rooted duckweed were especially notable in having more manganese than iron. The highest manganese concentration was 5.41 milligrams per gram of dry matter in sago pondweed.

Table 6 contains averages of the analyses reported in table 5 for types of plant and plant parts tested. The content of manganese, in milligrams per gram of dry matter, in these plant types suggests the following conclusions:

1. Leafy culms of the hard-stem bullrush and both the narrow-leaved and broad-leaved cattail (all water-emergent soil-rooted plants) contain more manganese than comparable parts of American pondweed, a water-submersed soil-rooted species;
2. the leafy culms of these water-emergent soil-rooted species had four times as much manganese as the rhizome roots.

Summaries B, D, and E in table 6 show average manganese content of the whole plant. These data show that the water-submersed aquatic plants had the highest manganese content. Manganese

TABLE 5.—*Dry matter, ash, and manganese content of various types of plants*

Type of plant	Name of plant [1]	Plant part tested	Condition of growth and date of harvest	Percentage contents of plant constituents, in weight percent: Dry matter	Ash in dry matter	Manganese in ash	Milligrams of manganese per gram of dry matter
Rock	*Lecanora rubina* (Vill.) Ach. (Crustose lichen, gray)	Whole plant	7/16/57	92.2	20.2	0.04	0.07
	Candelariella spraguei (Tuck.) Zahlbr. (Crustose lichen, yellow).	do	7/16/57	93.2	14.4	.06	.08
	Gasparrinia elegans (Link) Stein apud Cohn (Crustose lichen, red).	do	7/16/57	88.7	13.1	.06	.08
Rock-soil	*Parmelia conspersa* (Ehrh.) Ach. (Foliose lichen, gray)	do	7/16/57	31.2	25.7	.04	.09
	Grimmia apocarpa Hedw. (Black moss)	do	Fruiting 7/16/57	17.6	26.2	.13	.34
Land	*Bassica oleracea* L. var. *broccoli* L. (Broccoli)	Leaves, stems, flower primordia.	Preflowering [2] 10/2/57	14.7	12.0	.01	.01
	Convolvulus arvensis L. (Bindweed)	Whole plant	Preflowering 10/2/57	20.4	10.6	.04	.04
	Cynodon dactylon (L.) Pers. (Bermuda grass)	do	Preflowering 10/2/57	27.6	9.71	.04	.04
	Malva rotundifolia L. (Round-leaved mallow)	do	Fruiting 10/2/57	16.0	15.4	.03	.05
	Medicago sativa L. (Alfalfa)	do [3]	Flowering and fruiting. 7/26/57	23.5	8.52	.01	.01
	Nephrolepsis exaltata L. Schott. var. *Bostoniensis* Davenport (Boston fern).	Leaf	Prefruiting 7/16/57	20.4	12.2	.17	.17
	Petroselinum crispum (Mill.) Mansf. (Parsley)	do	Preflowering [2] 10/2/57	13.4	17.6	.01	.01
	Spinacia oleracea L. (Spinach)	do	Preflowering [2] 10/2/57	11.6	18.3	.01	.01
	Taraxacum officinale Weber (Dandelion)	Whole plant	Postfruiting 10/2/57	12.5	14.9	.05	.07
	Tribulus terrestris L. (Puncture vine)	do	Flowering and fruiting. 10/2/57	22.6	16.1	.02	.04
Land water: Herbs	*Carex aquatilis* Wahlenb. (Water-sedge)	do	Postfruiting 10/2/57	32.4	7.99	.20	.16
	Elocharis palustris (L.) R. and S. (Marsh spike-rush)	do	Postfruiting 10/2/57	18.6	20.5	.18	.36
Shrubs-trees	*Populus deltoides* Marsh. (Cottonwood)	Leaf	Postfruiting 7/25/57	30.5	9.77	.07	.07
	Populus balsamifera L. (Balsam poplar)	Root (rotted)	Rotting 7/16/57	88.7	22.9	.05	.11
	Tamarix gallica L. (Salt cedar)	Leaf	Flowering	30.3	15.2	.10	.16

	...eed).		7/23/57				
	Eichhornia crassipes (Mart.) Solms. (Water-hyacinth)	do	Postfruiting 10/2/57	5.3	19.6	.55	1.07
	Myriophyllum brasiliense Camb. (Parrotfeather)	do	Preflowering 7/23/57	25.8	13.5	.77	1.02
	Masturtium officinale R. Br. (True water cress)	do	Preflowering 7/23/57	6.7	18.1	.65	1.18
	Scirpus acutus Muhl. (Hard-stem bulrush)	Culm	Fruiting 10/2/57	69.1	9.26	.85	.77
	Typha angustifolia L. (Narrow-leaved cattail)	Leaf	Postfruiting 7/26/57	23.1	9.56	.53	.50
		Rhizome-roots	Dormant 2/21/58	16.1	6.21	.61	.38
	Typha latifolia L. (Broad-leaved cattail)	Leaf	Postfruiting 7/26/57	27.8	8.08	2.50	2.03
		Rhizome-roots	Dormant 2/21/58	14.0	6.03	.24	.14
Submersed: **Water roots**	*Cladophora* sp. Kützing (Pond scum)	Whole plant	Vegetative 7/23/57	17.2	22.1	.71	1.59
	Spirogyra sp. Link (Pond scum)	do	Vegetative 7/23/57	14.4	20.7	.73	1.50
Soil roots	*Eleocharis acicularis* (L.) R. and S. (Needle spike-rush)	do	Fruiting 7/23/57	15.0	46.4	.07	.30
	Elodea densa (Planch.) Caspary (Dense waterweed)	do	Preflowering 7/23/57	12.2	15.2	.76	1.15
	Elodea nuttallii (Planch.) St. John (Western waterweed).	do	Preflowering 7/23/57	10.3	16.2	.40	.65
	Heteranthera dubia (Jacq.) MacM. (Water-stargrass)	do	Postflowering 7/23/57	7.2	15.6	.15	.24
	Potamogeton foliosus Raf. var. *macellus* Fern. (Meagre leafy pondweed).	do	Fruting 7/22/57	18.1	9.23	2.20	2.03
	Potamogeton nodosus Poir (American pondweed)	do	Fruting 7/22/57	14.0	9.67	.47	.46
		Leaf	Fruiting 7/22/57	16.8	10.0	.37	.37
	Potamogeton pectinatus L. (Sago pondweed)	Whole plant	Preflowering 7/23/57	9.9	19.0	2.85	5.41
	Potamogeton richardsonii (Ar. Benn.) Rydb. (Redhead pondweed).	Whole plant, mostly roots.	Preflowering [4] 10/2/57	8.7	17.6	.36	.64
		Whole plant, mostly tops.	Postfruiting 7/23/57	7.0	21.7	.35	.75
	Sagittaria subulata (L.) Buchenau (Dwarf arrowhead)	Whole plant	Preflowering [4] 7/23/57	5.8	22.9	1.28	2.94
	Zannichellia palustris L. (Horned pondweed)	do	Preflowering [4] 10/2/57	6.1	21.7	.90	1.95

[1] All lichen identifications by S. Shushan, University of Colorado; moss identification by R. A. Pursell, University of Colorado; remainder of identifications by the author.
[2] From store.
[3] Parts above the ground and 3 inches of the root.
[4] Rootstocks of this sample were planted and grown in greenhouse culture tanks. Although the harvest date was late, there had been no fruiting during growth; therefore, this harvest is classified as preflowering.

TABLE 6.—*Average analyses for types of plant and plant parts tested*

Summary	Type of plant	Plant part tested	Percentage contents of plant constituents, in weight percent			Mill grams man gane per g of matt
			Dry matter	Ash in dry matter	Manganese in ash	
A	Land	Leafy culms	15.1	16.1	0.06	[illegible]
	Land-water	do	30.4	12.5	.08	
	Water emergent:					
	Soil-roots	do	40.0	8.97	1.29	1
	do	Rhizome-roots	15.0	6.12	.42	
	Water submersed:					
	Soil-roots	Leafy culms	16.8	10.0	.37	
B	Rock	Whole plant	91.4	15.9	.05	
	Rock-soil	do	24.4	26.0	.08	
	Land	do	19.6	12.5	.03	
	Land-water	do	25.5	14.3	.19	
	Water emergent:					
	Water-roots	do	6.2	17.5	.80	1
	Soil-roots	do	14.8	14.6	.66	
	Water submersed:					
	Water-roots	do	15.8	21.4	.72	1
	Soil-roots	do	10.4	19.6	.89	1
C	Water emergent (including land-water type).	Leafy culms	36.2	10.4	.81	
	Water submersed	do	16.8	10.0	.37	
D	Water emergent (including land-water type).	Whole plant	16.6	14.9	.54	
	Water submersed	do	11.2	19.8	.86	1
E	Rock (including rock-soil type)	do	64.6	19.9	.07	
	Land	do	19.6	12.5	.03	
	Water (including land-water type)	do	13.1	18.1	.75	1

content of the water-emergent aquatic plants was lower than that the water-submersed group but much higher than that of the no aquatic plants. Rock-soil plants, including foliose lichen and bla moss, had nearly three times as much manganese as the rock plan represented by the crustose lichens. The results show clearly th aquatic plants in general contain much more manganese than land plants and that the aquatics plants are effective mangane accumulators.

The entry of manganese into cells of the living organism requir passage through a differentially permeable cell wall. The me presence of abundant manganese or any other mineral in nutrie solutions available to the organism does not necessarily mean unusual buildup or concentration of the particular mineral by th organism. Conversely, minerals in water or soils in small amoun may be concentrated in the living organisms inhabiting such medi

Since manganese content of aquatic plants, as compared to lar plants, is high, it seemed desirable to compare manganese content the soils on which these two classes of plants grow. Crested whea grass, a land plant, was growing at the Denver Federal Center topsoil which had 0.12 percent manganese in its nonvolatile (at 575° (residue. The comparable manganese value for Denver Feder Center Lake bottom soil on which a variety of aquatic plants we growing was 0.50 percent. The enrichment in manganese of tl ke-bottom soil is probably the result of accumulation of manganese aquatic plants and the continuing addition of dead plant material the debris on the lake bottom during the period of the lake's istence.

GENERAL CONCLUSIONS

All water organisms absorb mineral matter from water; some ecies, alone or in symbiotic combination, precipitate minerals such iron or manganese oxide or calcium carbonate. The organisms ually include both the microbiological and macrobiological species. bacterial symbiont tentatively identified as *Bacterium precipitatum* alin commonly occurs as a mineral precipitator in natural water areas where sago pondweed (presumably, other aquatic species so) grows. The bacterium was a symbiont associate of sago pondeed growing in the greenhouse in Denver, in the irrigation canals at hoenix, Ariz., and in the brackish water at Timpie Big Spring in tah.

Microscopic examination of pond scum, sago pondweed, and stoneort, all from Timpie Big Spring, shows different patterns or methods f mineral deposition around the plant organism.

The intracellular deposition of manganese in aquatic and marsh lants amounts to many times that deposited in comparable parts of nd plants.

Crustose lichens are not necessarily high in manganese content. 'oliose lichen and black moss may contain several times more mananese than the crustose lichens.

It is evident that biochemical factors play a major role in establishng the chemical composition of natural water.

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