Bryophytes Associated with Mineral Deposits and Solutions in Alaska

GEOLOGICAL SURVEY BULLETIN 1198-C

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By HANSFORD T. SHACKLETTE

CONTRIBUTIONS TO GEOCHEMICAL PROSPECTING FOR MINERALS

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BRYOPHYTES ASSOCIATED WITH MINERAL DEPOSITS AND SOLUTIONS IN ALASKA

By HANSFORD T. SHACKLETTE

ABSTRACT

Many bryophyte species are associated with concentrations of minerals, but in Alaska only two species seem to have an obligate relation to certain minerals; these species are *Gymnocolea acutiloba*, which grows on or near copper deposits, and *Grimmia maritima*, which grows on coastal rocks that are continually being coated with sodium chloride from sea spray. *Nardia scalaris* grows on soil containing 0.6 percent copper, and *Oligotrichum parallelum* and *O. hercynicum* grow on mineralized rock containing 0.26 percent nickel and 0.21 percent copper. *Rhacomitrium sudeticum* was found growing on copper ore that contains 30.45 percent copper. Soil containing 165–215 ppm (parts per million) copper in the A horizon supports many species. Only *Cephalozia bicuspidata* was found growing on an ore vein that contains 12.9 percent lead and 34.0 percent zinc, although several other bryophyte species grew on rock adjacent to the vein. Soil containing 1,300 ppm lead and 870 ppm zinc does not inhibit bryophyte growth. Luxuriant bryophyte mats overlie soil that contains 40 ppm mercury, 95 ppm antimony, and 900 ppm arsenic in the A horizon. *Blepharostoma trichophyllum, Cephalozia bicuspidata, Dicranella cerviculata, D. subulata,* and *Lophozia wenzelii* grow on gypsum evaporite and are incrusted with this mineral. Eleven species grow on tufa deposits, and some species are heavily incrusted. Only a few species grow on pyrite, but many species grow over pyrite bodies on the acid A horizon of soil that contains 200 ppm lead, 150 ppm zinc, and 400 ppm copper. Limonite precipitated from stream water is forming fossil casts of vascular plants and liverworts and, in places, has formed consolidated deposits of these. High iron content in water apparently does not inhibit the growth of bryophytes, and many species occur in this environment. Serpentinized rock weathers to form soil containing as much as 4,000 ppm nickel and 900 ppm chromium, yet these elements have no visible effect on the bryoflora; 21 species, both calcicole and silicole, were found growing on serpentinized rock. Six bryophyte species grow on substrates that are submerged in sea water at high tide, and 23 species were found at sites subjected to sea spray.

INTRODUCTION

During the summers of 1957, 1958, and 1960, while a member of a field party of the U.S. Geological Survey engaged in geochemical investigations, I studied plant-substrate relations in widely separated regions of Alaska and the Yukon Territory. Our itinerary and areas of intensive study were described by Persson (1963) in his account of some bryophyte species that I collected. Although my principal studies concerned vascular plants as indicators of mineral deposits I collected bryophytes in all regions that our party visited and noted the characteristics of the substrates on which the bryophytes grew. In identifying the rocks and minerals that supported bryophytes, I had the assistance of geologists Robert M. Chapman, Charles T. Prewitt, and Donald H. Shaw. Chemists Walter A. Bowles, Daniel B. Hawkins, and Christian F. Wyller, Jr., analyzed samples of substrates in the field, which facilitated the location of mineralized sites from which plant samples were collected.

After each field season, the University of Michigan Herbarium, Ann Arbor, Mich., the Biology Department of Georgetown College, Georgetown, Ky., and the U.S. Geological Survey laboratories in Denver, Colo., provided facilities with which to continue studies of the specimens and data. A most valuable asset was the generous assistance of Dr. Herman Persson, Riksmuseets Paleobotaniska Avdelning, Stockholm, Sweden, in examining and naming all my bryophyte specimens. I also thank Dr. Shoichiro Hayashi of the Geological Survey of Japan for translating a Japanese report.

BRYOPHYTE SPECIES, COMMUNITIES, AND HABITATS ASSOCIATED WITH MINERAL ENRICHMENT

Certain species of bryophytes are known to be either commonly or exclusively associated with mineral deposits. Most significant of these are the "copper mosses," which were discussed at length by Mårtensson and Berggren (1954), Schatz (1955), Persson (1948, 1956), and others. References to the association of bryophytes with metallic elements other than copper are sparse in botanical literature, but some of these references are given in the papers by the above-cited authors.

The original plant communities around most metalliferous deposits that were examined in Alaska had been disturbed during exploration or mining, but the vegetation at abandoned mines had reestablished itself. Mining operations often make available large exposures of mineralized rock to plant growth, and the widespread dispersal of dust and debris from mining may provide extensive areas of mineral-enriched substrates near the mines. Thus, man's disturbance of these areas generally has increased, rather than diminished, the opportunities for the influence of concentrated elements on plant growth.

Bryophytes that grow on ore are adapted to growing on rock surfaces or on fresh inorganic soils and have, in addition, a resistance to or a requirement for the metallic elements in the ore. Organic substrates may become greatly contaminated by metallic elements and may support species that characteristically grow on noncontaminated organic deposits rather than on rock surfaces; thus, a large number of species may be influenced by these elements. If a species that grows at a mineralized site is found also at a nonmineralized site, only the tolerance of or resistance to certain elements is indicated. If a species occurs only on mineral-rich substrates (which, I believe, rarely happens in Alaska), its requirement for a particular element is indicated but not proved; its restriction to these sites may be due to competition with species that are less tolerant of the element. Of course, the controlling factor in the occurrence of a species may be only the great acidity of the substrate produced by weathering of sulfide ores—not the particular metal of the ore, as was suggested by Persson (1948, p. 77–78).

The vegetation associated with mineral deposits that are not ore grade, and with minerals that are not commercially exploited in Alaska, was also studied. Plants on these deposits generally had not been greatly disturbed by man, and edaphic climax communities prevailed. Plant communities growing in concentrated solutions of calcite, iron, and salt (sea water) were investigated also.

It was not practical in this study to analyze chemically the bryophyte plants and thus relate them more closely to their mineral-bearing substrates, as was done extensively with vascular plants. Only the substrates were analyzed; the amounts of the elements absorbed by the bryophytes are unknown. Bryophytes generally grow in such intimate contact with their substrates that contamination of the plant surfaces may, in chemical analysis, mask the small amounts of metallic elements present in the plant tissue. If content of elements in bryophytes is to be determined, special cleaning procedures are first necessary to rid the plants of superficial contamination.

All bryophyte species found associated with mineral deposits and solutions in Alaska are listed in table 1. The species are further characterized as growing either on or near the minerals. The term "on" indicates that the plants were, at the time of study, actually in contact with the surface of the mineral or were incrusted with the mineral. The term "near" indicates that the plants grew on material derived directly from the mineral or that they were so located that solutions from the mineral deposit strongly influenced them. If the species were found to be submerged by tides or waves or were found growing on driftwood in the sea, they are reported as "in" sea water. If they were only very near the sea but were not periodically submerged, they are reported as being subjected to "spray." This latter category has rather indefinite limits; generally it is applied only to those species growing within 30 feet of the strand.

TABLE 1.—*Location of bryophytes in relation to mineral deposits*

[For explanation see text]

Bryophyte	Copper minerals	Lead and zinc minerals	Mercury, antimony, arsenic minerals	Gypsum	Calcite (tufa only)	Pyrite	Serpentine	Iron oxides	Salt (sea water)
HEPATICAE (Liverworts)									
Bazzania ambigua (Lindenb.) Trev									spray.
Blepharostoma trichophyllum (L.) Dum				on					
Calypogeia muelleriana (Schiffn.) K.M.						on			
Cephalozia bicuspidata (L.) Dum		on		on		on			
media Lindb	on								
Diplophyllum albicans (L.) Dum		on, near							spray.
Frullania nisqualensis Sull		on							spray.
Gymnocolea acutiloba (Kaal.) K. M	on, near								
inflata (Huds.) Dum					on				
Leiocolea heterocolpa (Thed.) Buch								on	
Lophozia latifolia Schust					on			on	
wenzelii (N.) St				on					
Marsupella emarginata (Ehrh.) Dum		near							
Nardia scalaris (Schrad.) Gray						on			
Orthocaulis quadrilobus (Lindb.) Buch					on				
Plectocolea rubra (Gott.) Evans							near		
Scapania undulata (L.) Dum	on	near				on		on	in, spray.
Tritomaria quinquedentata (Huds.) Buch	near								
SPHAGNALES (Sphagnum)									
Sphagnum cuspidatum Ehrh						near			
squarrosum Pers								on	
MUSCI (Mosses)									
Abietinella abietina (Hedw.) C.M					on		on		
Arctoa fulvella (Dicks.) Bruch & Schimp									in, spray.
Aulacomnium turgidum (Wg.) Schwaegr								on	
Barbula icmadophila Bruch & Schimp	near								
Bartramia ithyphylla Brid	near								
Brachythecium albicans (Hedw.) Bruch & Schimp	near								
nelsoni Grout	near								
turgidum (Hn.) Kindb					on			on	
Bryum argenteum Hedw									spray.
capillare (L.) Hedw									spray.
inclinatum (Brid.) Bruch & Schimp									in, spray.

Calliergon cordifolium (Hedw.) Kindb.			near						
sarmentosum (Wg.) Kindb.								on	
stramineum (Brid.) Kindb.								on	
Campylium stellatum (Hedw.) Lange & C. Jens.					on				spray.
Ceratodon purpureus (Hedw.) Brid.							on, near		spray.
Climacium dendroides (Hedw.) Web. & Mohr.			near						
Desmatodon latifolius (Hedw.) Brid.	near							on	
Dichodontium pellucidum (Hedw.) Schimp.						on			
Dicranella cerviculata (Hedw.) Schimp.				on					
subulata (Hedw.) Schimp.				on					
Dicranodontium asperulum Wils.									spray.
Dicranum elongatum Schleich.							on		
fuscescens Turn.							near		
muehlenbeckii Bruch & Schimp.	near								
undulatum (Ehrh.) Sturm.							near		
Distichium inclinatum (Hedw.) Bruch & Schimp.					on				
Drepanocladus revolvens (Sw.) Warnst.								on	
uncinatus (Hedw.) Warnst.						on		on	
Encalypta longicolla Bruch.							on		
procera Bruch.							on		
Eurhynchium praelongum (Hedw.) Hobk.		on							in, spray.
pulchellum (Hedw.) Dix.							near		
Grimmia maritima Turn.									in, spray.
tenuicaulis Williams.							on		
Gymnostomum calcareum Nees & Hornsch.					on				
Hedwigia ciliata (Hedw.) Bruch & Schimp.							on, near		
Hygrohypnum luridum (Hedw.) Dix.							on		
ochraceum (Turn.) Loeske.							on		
Hypnum circinale Hook.									spray.
Isopterygium elegans (Hook.) Lindb.		on							spray.
Kiaeria blyttii (Schimp.) Broth.						on			
Leptobryum pyriforme (Hedw.) Wils.								on	
Lyellia lescurii (James) Frye.	on								
Mnium glabrescens Kindb.		near							spray.
punctatum var. *elatum* Schimp.			near						
rugicum Laur.								on	
Myurella julacea (Hedw.) Bruch & Schimp.							on, near		
Oligotrichum aligerum Mitt.	near					on			
hercynicum (Hedw.) Lam. & DC.	on, near					on			
parallelum (Mitt.) Kindb.	near								
Orthothecium chryseum (Schwaegr.) Bruch & Schimp.					on				
intricatum (Hartm.) Bruch & Schimp.							on		
Plagiothecium laetum Bruch & Schimp.			near						
Pogonatum capillare (Mx.) Brid.									spray.
Pohlia drummondii (C. Muell.) Andrews.						on			
nutans (Hedw.) Lindb.		on, near							in, spray.
rothii (Corr.) Broth.	near								
wahlenbergii (Web. & Mohr) Andrews.					on				
Polytrichum piliferum Hedw.	near						near		

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TABLE 1.—*Location of bryophytes in relation to mineral deposits*—Continued

Bryophyte	Copper minerals	Lead and zinc minerals	Mercury, antimony, arsenic minerals	Gypsum	Calcite (tufa only)	Pyrite	Serpentine	Iron oxides
MUSCI (Mosses)—Continued								
Rhacomitrium canescens var. *ericoides* (Brid.) Bruch & Schimp.	near	on				near		
fasciculare (Hedw.) Brid.						on		
lanuginosum (Hedw.) Brid.							on	
sudeticum (Funck) Bruch & Schimp.	on							
Rhytidium rugosum (Hedw.) Kindb.							on, near	
Schistidium alpicola (Hedw.) Schimp.							on	
apocarpum (Hedw.) BSG							on	
strictum (Turn.) Loeske							on	
Scorpidium scorpioides (Hedw.) BSG								on
Tortula norvegica (Web. & Mohr) Wahlb.	near							
ruralis (Hedw.) Schwaegr.								
Ulota barclayi Mitt.								
obtusiuscula C. Muell. & Kindb.								
phyllantha Brid.								
Weisia viridula Hedw.							on, near	

INFLUENCE OF MINERAL DEPOSITS AND SOLUTIONS ON BRYOPHYTES

COPPER MINERALS

Copper deposits that our field party studied in Alaska contain chalcopyrite ($CuFeS_2$) and bornite (Cu_5FeS_4) as primary minerals and malachite ($CuCO_3 \cdot Cu(OH)_2$), azurite ($2CuCO_3 \cdot Cu(OH)_2$), and chrysocolla ($CuSiO_3 \cdot 2H_2O$) as secondary minerals. Some native copper was also found.

The largest area of copper-contaminated soil that we examined is near the Beatson mine on Latouche Island. Here, where the plant community is composed almost entirely of *Nardia scalaris* and the herb *Saxifraga ferruginea* Graham, the A_1 soil horizon contains more than 6,000 ppm (parts per million) (0.6 percent) copper, which is the greatest concentration of copper in soil that we found in Alaska (the amount of lead is also great—200 ppm). Fraser (1961) described the growth of the moss *Pohlia nutans* on even more highly concentrated syngenetic copper deposits in New Brunswick peat soil—these concentrations of copper (3–10 percent) killed the trees at this site. He said (p. 956), "The presence of *Pohlia nutans* in the swampy forest invariably indicates excessive surface copper content."

We frequently found the moss *Oligotrichum hercynicum* associated with copper deposits. This species was collected at seven mineralized sites in Alaska and at two sites where there was no apparent mineral enrichment. It is commonly associated with nickel-copper deposits on Yakobi Island, southeastern Alaska, and forms, with *O. parallelum*, the only plant growth on debris from an exploration pit into a mineralized body that was reported by Reed and Dorr (1942, p. 123) to average 0.26 percent nickel and 0.21 percent copper. I could not determine whether the metal content of this debris or its physical nature (coarse unweathered rock fragments and virtually no organic matter) had excluded other bryophytes from this site. Deposits at many others sites, however, had a similar physical nature but a lower metal content and were densely colonized by other species. Therefore, I believe that the chemical properties of the deposits at the Yakobi Island site exclude other species.

The liverwort *Gymnocolea acutiloba* was found only in association with copper minerals; this fact lends support to reports in the literature that this liverwort is probably an obligate cuprophile. I described its occurrence on Latouche Island (Shacklette, 1961), where the abundance and vigor of this species on a soil having high copper content are noteworthy.

At the K–M copper mine near Maclaren Glacier, Alaska Range, a vein of high-grade copper ore that contains as much as 30.45 percent copper (Chapman and Saunders, 1954, p. 5) was exposed by prospectors, and only *Rhacomitrium sudeticum* now grows directly on the ore. This species is not limited to substrates rich in copper, but it does have tolerance to high concentrations of this element. Immediately above this vein the virtually undisturbed mountain tundra soil bears the usual shrubs, forbs, and grasses. This soil contains 165–215 ppm copper in the A horizon and 350–375 ppm copper in the B–C horizon. The bryophytes on this soil are, among others, *Bartramia ithyphylla*, *Brachythecium albicans*, *Desmatodon latifolius*, *Polytrichum piliferum*, *Tortula norvegica*, and *Tritomaria quinquedentata*. The same species are found also on the nearby tundra soil, which has a low copper content.

Mårtensson (1956, p. 140), in reference to copper content of soils, stated, "* * * amounts higher than 100 ppm are certainly poisonous for vascular plants at least when the substratum is not strongly basic." My observations of Alaskan vascular plants, however, indicate that they tolerate considerably more than 100 ppm soil copper without being poisoned, even on an acid soil. I believe that, in general, bryophytes can tolerate even more copper than can vascular plants.

LEAD AND ZINC MINERALS

Plants associated with these two elements are discussed together because lead and zinc minerals occur together at the Mahoney Creek mine on Revillagigedo Island, southeastern Alaska—the only site which we examined that has lead and zinc deposits of ore grade (Twenhofel, 1953; Shacklette, 1960). Lead occurs here in galena (PbS) and zinc occurs in sphalerite (ZnS) in a vein deposit surrounded by black slate. The ore was uncovered by prospectors, and it and the adjacent black slate are now completely colonized by bryophytes. The liverwort *Cephalozia bicuspidata* covers the entire surface of the ore, to the exclusion of all other plant species (fig. 1). Ore taken from this exposed rock surface contains 12.9 percent lead, 34.0 percent zinc, 18.0 percent silicon dioxide, 7.5 percent iron, and trace amounts of copper, arsenic, and antimony (assay in 1958 by Ralph Pray, Assay Office, Territory of Alaska). Exposures of the surrounding black slate are occupied by *Diplophyllum albicans*, *Marsupella emarginata*, *Mnium glabrescens*, *Pohlia nutans*, and *Scapania undulata*.

The soil of this area is classified as Half-Bog and is composed of fine-textured brown peat having some mineral admixture. The soil over the ore vein contains an average of 1,300 ppm lead and 870 ppm zinc. Similar soil 30–40 feet from the vein averages 20 ppm lead and 30 ppm zinc. Bryophytes grow luxuriantly on both soils, the most abundant species being *Hylocomium splendens* var. *giganteum*, *Poly-*

FIGURE 1.—Bryophytes on and near a galena-sphalerite ore vein at Mahoney Creek, Revillagigedo Island, Alaska. The exposed ore vein at the 12-inch ruler and on the vertical surface to the right of center is exactly indicated by the dark-colored area of the liverwort *Cephalozia bicuspidata.* Other bryophyte species cover the black slate adjacent to the vein. Photographed June 15, 1958.

trichum formosum, and *Rhytidiadelphus loreus*, but many other species are also present; together they make a moss mat 4–6 inches thick over the soil. The very wet north-temperature climate here is especially favorable to the growth of bryophytes, and colonization by mosses on felled trees and newly exposed rock or soil surfaces is rather rapid.

MERCURY, ANTIMONY, AND ARSENIC MINERALS

Cinnabar (HgS) is currently mined at Red Devil on the Kuskokwim River, Lower Yukon River district. There, it occurs in vein deposits that also contain stibnite (Sb_2S_3), realgar (AsS), and orpiment (As_2S_3) (Cady and others, 1955, p. 105–106). Presumably, the soil in the vicinity of the mine, mill, and smelter has been contaminated as a result of several years' operation of these installations; however, both bryophytes and vascular plants appeared to be remarkably unaffected. Mosses common to the region grow in a cinnabar mill and smelter drainage stream in which metallic mercury could be seen, and plants on a mountain tundra slope immediately adjacent to and on a level with the mercury-smelter exhaust stacks appeared undamaged. No undisturbed outcrops of cinnabar that bryophytes could have colonized were found; but cinnabar was found in placer deposits and in rock used to surface a road, as well as around the mine shafts, and it did not appear to have had any effect on the mosses growing near it. We exposed some cinnabar outcrops by digging and found tree and shrub roots that were in contact with the mineral. Branches of the plants having root contact contained anomalous amounts of mercury (as much as 3.5 ppm in ash of the shrub *Ledum decumbens* ssp. *minor* (Ait.) Hult.), antimony (50 ppm in *Betula resinifera* Britton), and arsenic (6 ppm in *B. resinifera;* Lorraine Patten, analyst), yet the plants showed no toxicity symptoms.

Where undisturbed, the mineralized area is covered with a thick moss and shrub mat overlying a Half-Bog soil. The A_2 and B horizons of this soil contain as much as 40 ppm mercury, 95 ppm antimony, and 900 ppm arsenic (W. A. Bowles, analyst). Goldschmidt (1954, p. 278) reported the occurrence of drops of metallic mercury under the moss cover of the forest floor near mercury deposits in the Rhine Palatinate; however, I did not find any in or under the moss mats near the Red Devil mine.

All bryophyte species growing in the vicinity of the Red Devil mine probably are exposed to greater than usual concentrations of mercury, antimony, and arsenic in their substrates. The portal of the adit at the inactive Barometer cinnabar mine was very extensively vegetated with bryophytes, and although a quantitative determination of the concentration of these elements was impractical, the amounts doubtless are large. *Plagiothecium laetum* was growing abundantly on the rotting timbers at the portal, and *Calliergon cordifolium*, *Climacium dendroides*, *Drepanocladus uncinatus*, and *Mnium punctatum* var. *elatum* flourished in the small drain leading from the mine. Thus, these species apparently have a high degree of resistance to the three elements, but I do not imply that other species of bryophytes in the vicinity are not equally resistant.

GYPSUM

We found only two gypsum ($CaSO_4 \cdot 2H_2O$) deposits, each of small extent (about 0.50 sq m). At both, the gypsum occurs as evaporite from water seeps that issue from rock cliffs. On the deposit at Eldorado Creek, near Kantishna, Alaska Range, only the liverwort *Blepharostoma trichophyllum* grows, and it is heavily incrusted with gypsum. The other deposit, on the slate cliffs at the Beatson mine, Latouche Island, is occupied mostly by the moss *Dicranella cerviculata*, which is so heavily incrusted with gypsum that only the branch tips are green. Other bryophytes growing on this deposit are *D.*

subulata, *Cephalozia bicuspidata*, and *Lophozia wenzelii*. These plants at this site were discussed in an earlier paper (Shacklette, 1961, p. 9–10). The great tolerance of some mosses to gypsum was mentioned by Flowers (1933, p. 36); however, the Alaskan gypsum deposits are too small for use in testing the tolerance of the northern bryoflora.

PYRITE

A large near-surface outcrop of massive sulfides—chiefly pyrite (FeS_2), but containing some copper, lead, and zinc sulfides—occurs on Latouche Island. According to Stejer (1956, p. 114), "Pyrite is by far the most abundant mineral, and in many places the massive sulfide is essentially pure pyrite." Eight ore samples from one claim contained 10 percent or more iron (Stejer, 1956, p. 115). Natural surface outcrops of this ore are rare, but several are sparsely colonized by bryophytes, as described in an earlier paper (Shacklette, 1961, p. 10–11). I do not know whether the metal or the sulfur ions of these compounds exert the greater influence on the plant communities associated with them.

These sulfide bodies are mostly overlain by a Half-Bog soil that grades to Bog soil in depressions. A thick mat of mosses and other plants covers the highly organic A soil horizon, which contains as much as 200 ppm lead, 150 ppm zinc, and 400 ppm copper. The B–C soil horizon contains as much as 200 ppm lead and 200 ppm zinc, and it contains more than 4,000 ppm copper at certain sites. Iron-stained layers are common in the B–C horizon and contain as much as 21 percent iron. Thus, the rich bryoflora here is subjected to large amounts of these metals and to an abundance of water, which may facilitate element migration in the distinctly acid environment.

The sulfur content of the soil probably is very high also. No distinctive species or communities are present, however, that I can relate to the unusual chemical composition of this substrate. The only factor controlling species or community occurrence at the sample sites seemed to be the amount of water present.

CALCITE

Only the bryophytes that are related to tufaceous deposits of calcite ($CaCO_3$)—not the ordinary calcicolous species—are considered here. A small area (about 2 sq mi) of active tufa formation was observed in a stream flowing into Bergh Lake, Mount McKinley National Park, Alaska Range. Sediments in this stream contain 8.8 percent carbonates (CO_3); only bryophytes grow in and adjacent to this stream, and many of them are so heavily coated with calcite that only the tips of the plants are pliable. *Drepanocladus revolvens* and

Distichium inclinatum are the most abundant species in the stream and are being imbedded in a firm tufa deposit. Other, less abundant species, also somewhat incrusted are *Brachythecium turgidum*, *Campylium stellatum*, *Gymnocolea inflata*, *Lophozia latifolia*, *Orthocaulis quadrilobus*, *Orthothecium chryseum*, *Pohlia wahlenbergii*, and *Schistidium apocarpum*.

A small area of tufa formation was studied in another region of Alaska. This area is on the Taylor Highway near Eagle, Central Yukon River district, where a small intermittent stream flows over a limestone and calcite outcrop. Only one moss species, *Gymnostomum calcareum*, grows on the area of active tufa deposition, although many characteristic calcicolous bryophytes grow on other parts of the outcrop.

SERPENTINE

The term "serpentine" frequently is used in botanical literature to characterize the habitat of a species or a flora that grows on soil derived from serpentinized rock; it is also properly applied to both a mineral ($H_4Mg_3Si_2O_9$) and the rock that is composed largely of this mineral but contains various quantities of nickel, chromium, and other metallic elements. Serpentinized rock reportedly weathers to form a soil that is unfavorable to the growth of many plant species. This characteristic is attributed partly to the rock's low supply of nutrient elements, as well as to its toxic amounts of nickel and chromium (Walker, 1954).

Nagano and Noguchi (1960) published detailed studies of bryophyte communities on serpentine in Japan. They said, in summary (p. 106):

> About 76 species of bryophytes were found on serpentine, but most of them occur on another kind of substratum. In the bryophyte society on the same rock several silicole and calcicole mosses were often found. * * * The bryophyte societies on serpentine are represented by *Grimmia pilifera* communities, accompanying various mosses, but they seem to be replaced by *Hypnum plumaeforme–H. oldhamii* communities as time went on. * * * Certain alpine or subalpine mosses were found in the present serpentine area.

Our party studied the vegetation and soils in two areas of serpentinized rock in the Central Yukon River district. At a site near Livengood, soil derived from this rock contained 300–4,000 ppm nickel and 300–800 ppm chromium. Certain vascular plants growing in this soil contained highly anomalous amounts of nickel (as much as 1,100 ppm in ash). Shaded serpentinized rock is commonly vegetated with small polsters of *Schistidium strictum* (fig. 2) and may also support, in varying abundance, growths of *Abietinella abietina*, *Grimmia tenuicaulis*, *Hedwigia ciliata*, *Rhytidium rugosum*, and *Weisia viridula*. These species probably occur as successional stages in colonization of the rock.

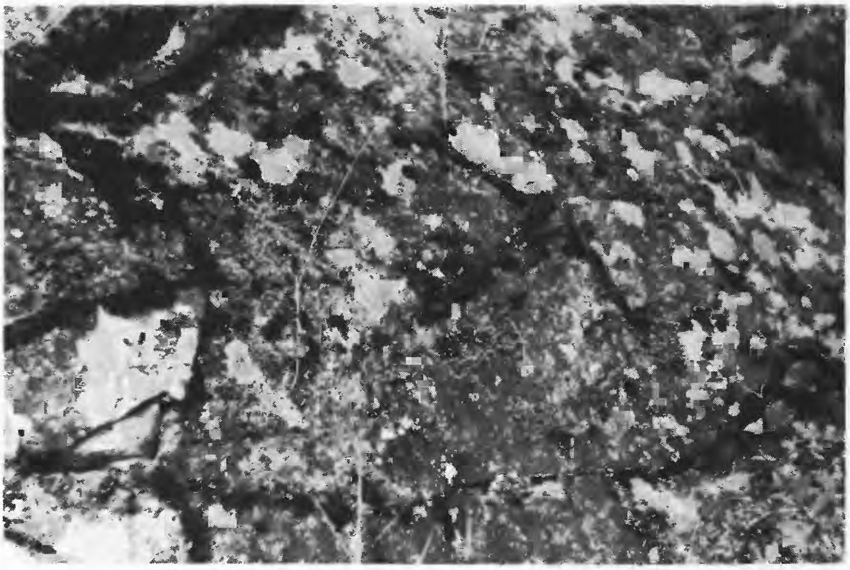

FIGURE 2.—Colonization by *Schistidium strictum* (black cushions in the center and along fissures), *Selaginella sibirica* (light tufts, left center), and crustose and foliose lichens on shaded outcrop of serpentinized bedrock near Livengood, Alaska. Photographed June 21, 1960.

Serpentinized rocks having full sun exposure commonly lack bryophytes or, in some localities, are colonized by large dense mats of *Rhacomitrium lanuginosum* (fig. 3), generally accompanied by *Selaginella sibirica* (Milde) Hieron. The moss plants shown in figure 3 have no rhizoidal attachment to the rocks or to the 1.5 inches of reddish-brown highly organic "soil" on the underlying rocks; the upper part of the moss stems is living, and the lower part is decomposing to form the "soil" beneath, which has a pH of 6.0. The apparent growth rate of the plants is 0.25 inch per year. Individual stems are about 9.5 inches long and have a calculated age of about 38 years. The length of time necessary to produce the underlying "soil" could not be estimated. At the base of serpentinized boulders, and on the soil nearby, are mosses that are common to the region, including *Ceratodon purpureus*, *Dicranum fuscescens*, *D. undulatum*, *D. elongatum*, *Eurhynchium pulchellum*, *Hedwigia ciliata*, *Polytrichum piliferum*, *Rhytidium rugosum*, and *Weisia viridula.* Liverworts are not common at these sites, probably because of excessive dryness of the substrates; *Plectocolea rubra* was the only species found.

At a site near Eagle, serpentinized rock crops out in a ravine through which a stream flows; the area is thus favorable for the more mesic and hydric bryophytes. *Hygrohypnum ochraceum* grows submersed and attached to the rock, and *H. luridum* and *Schistidium*

FIGURE 3.—Mat of *Rhacomitrium lanuginosum* extending over talus of serpentinized rock near Eagle, Alaska. The site has full sun exposure. Photographed June 28, 1960.

alpicola grow on moist serpentine at the stream margins. On the drier rocks *Encalypta procera* and *E. longicolla* grow intermixed.

In summary, my limited study of the bryoflora of serpentinized rock in Alaska points to the same conclusions as were reached by Nagano and Noguchi (1960)—that this rock does not support a distinctive flora. All species found on it were also found on other kinds of rock. Moreover, I found silicole and calcicole species growing intermixed; I also found indications of a succession similar to that reported on serpentine in Japan—that is, from acrocarpous (Grimmiaceae) to pleurocarpous (Hypnaceae) mosses. Alpine and subalpine species are also present on the Alaskan serpentine, but these species occur commonly on various substrates in this part of Alaska. I saw no evidence that the chemical nature of serpentine limits the bryophyte species that can grow on it. The common species of the region are sufficiently oligotropic and resistant to nickel and chromium to grow on serpentine rocks, or on soils derived therefrom, if the water supply and insolation meet the requirements of the particular species.

IRON OXIDES

Bryophytes were found at several Alaskan locations in water of streams and pools that contained sufficient iron compounds to color the water yellow to reddish yellow. The iron compounds were not identified; thus, they are here referred to as limonite, an inclusive term for unidentified hydrous iron oxides, or mixtures of them, which may be expressed as $FeO(OH) \cdot nH_2O$.

On Latouche Island I observed plant fossilization in progress in an iron-bearing stream that drains a mineral deposit. Bryophytes and vascular plants grow at the edges of the stream and are densely coated with precipitated limonite; only their new growth remains green. Farther back on the stream bank and beneath the vegetation mat, the limonite has formed firmly consolidated deposits, which when broken were found to contain fossil casts of the same plant species as are living above them and at the stream margins. Leaf casts of the shrub *Vaccinium vitis-idaea* ssp. *minus* (Lodd.) Hult. are especially well defined in the limonite, even the veins being distinct. Liverworts, particularly *Scapania undulata* that grows attached to graywacke in the stream, can also be recognized from casts in the limonite.

At Kantishna, Alaska Range, a small stream that is heavily charged with limonite issues as a spring and drains into Moose Creek. *Leptobryum pyriforme* and *Drepanocladus revolvens* grow in this stream and are coated with an iron precipitate, but consolidated limonite deposits are not being formed.

At Cape Krusenstern, Bering Strait district, I studied a series of pools containing sufficient floccules of limonite to distinctly color the water. These pools have originated as a result of beach-ridge formation, that was described by Moore and Giddings (1961), who stated that these ridges range in age from about 3000 B.C. to the present time. The pools and pool sites likewise range in age; however, evidence of the older pools remains only as a limonite zone 4–6 inches thick in the organic tundra soil at various distances from the surface. A sample of the fine-textured and very loosely structured reddish-yellow soil from this zone contains 33 percent iron (John McHugh, analyst). Similar deposits form a marginal zone around some of the beach pools, and bottoms of the shallow pools are covered with fine-textured limonite.

Oborn (1960) discussed the role of aquatic and terrestrial plants in the geochemical cycling of iron and pointed out that plants can promote the release of soluble iron from relatively insoluble compounds and then remove this soluble iron from the water by absorption into their tissues. The "iron bacterium" *Leptothrix* sp. was reported to contain 19.3 percent iron in its ash, or 135 milligrams per gram of the dried plant. He did not analyze bryophytes for iron content.

Iron-accumulating micro-organisms were found in the Cape Krusenstern beach pools; under microscopic examination these micro-organisms had the appearance of "iron bacteria." Bryophytes having a heavy limonite deposit on the lower part of their stems were abundant at the pool edges and borders. These bryophytes, however, are not preserved in the limonite soil zones that I believe originated as old pool beds; bryophytes apparently are too fragile to endure the chemical and physical processes that occur in the formation of this zone. In contrast, vascular plants are well represented by abundant stem and root fragments in the limonite soil zone.

The bryoflora of these pool margins includes the following species: *Aulacomnium turgidum*, *Brachythecium turgidum*, *Calliergon sarmentosum*, *C. stramineum*, *Desmatodon latifolius*, *Drepanocladus uncinatus*, *Leiocolea heterocolpa*, *Lophozia latifolia*, *Mnium rugicum*, *Scorpidium scorpioides*, and *Sphagnum squarrosum*. A more careful search at these sites would doubtless reveal other species, for the flora is characteristic of a wet tundra, and the high iron content of the soil at the pool margins does not seem unfavorable to any tundra species.

SALT

A very small salt (NaCl) deposit—the only one reported in Alaska—occurs near Kruzgamepa Hot Springs, Seward Peninsula. Waring (1917, p. 96) described the deposit as follows: "* * * several patches in the lowland near the creek below the springs are whitened by a saline efflorescence." Only two other Alaskan springs—Sitka Hot Springs near Sitka and Arctic Hot Springs near Nome—were said by Waring to have a noticeable salt content. These sites were not visited by our party, and I have found no reports of their vegetation.

The long coastline of Alaska provides abundant habitats for bryophytes that can withstand the concentration of salt in sea water (NaCl about 2.7 percent, according to Rankama and Sahama, 1955, p. 318) or sea spray. Most bryophytes are generally very intolerant of salt, although some species can endure relatively large amounts. Flowers (1933, p. 36) said, in discussing the salts in soils of the Great Salt Lake region, Utah, "Sodium chloride is the typical salt of this region and mosses will tolerate it up to about 0.5%."

In an earlier report (Shacklette, 1961, p. 11–13) I listed some bryophytes found on Latouche Island that are subjected to tidal inundations or sea spray, and I discussed their possible relationship to salt water in northern regions. The following additional species were found on sea cliffs at Revillagigedo and Yakobi Islands: *Bazzania ambigua*, *Bryum capillare*, *Campylium stellatum*, *Diplophyllum albicans*, *Frullania nisqualensis*, *Isopterygium elegans*, *Rhacomitrium fasciculare*, *Schistidium apocarpum*, *Ulota barclayi*, and *U. obtusiuscula*.

At Cape Krusenstern and Point Barrow, gravel in the beach ridges nearest the water (which at least receive sea spray, if not waves, during storms) supports a very limited bryoflora. *Tortula ruralis* is the most abundant species here, although *Bryum argenteum* and *Ceratodon purpureus* are also present; careful search would probably yield a few additional species. The common arctic bryophytes grow luxuriantly on beach ridges farther from the water and on low earth or rock cliffs on the seashore at both Arctic Ocean sites, and these plants have not been visibly affected by the sea spray that they probably receive from time to time.

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