The Biogeochemistry and Occurrence of Unusual Plant Species Inhabiting Acidic, Metal-Rich Water, Red Mountain, Bonnifield District, Alaska Range

By Larry P. Gough, Robert G. Eppinger, and Paul H. Briggs

Chapter J of

Recent U.S. Geological Survey Studies in the Tintina Gold Province, Alaska, United States, and Yukon, Canada—Results of a 5-Year Project

Edited by Larry P. Gough and Warren C. Day

Scientific Investigations Report 2007–5289–J

U.S. Department of the Interior
U.S. Geological Survey

Contents

Figures

Tables

The Biogeochemistry and Occurrence of Unusual Plant Species Inhabiting Acidic, Metal-Rich Water, Red Mountain, Bonnifield District, Alaska Range

By Larry P. Gough,[1] Robert G. Eppinger,[1] and Paul H. Briggs[1]

Abstract

This report presents results on the occurrence and biogeochemistry of unusual plant species, and of their supporting sediment, in an undisturbed volcanogenic massive sulfide deposit in the Tintina Gold Province (see fig. 1 of Editors' Preface and Overview). The extraordinary plant assemblage found growing in the acidic metal-rich waters that drain the area is composed predominantly of bryophytes (liverworts and mosses). Ferricrete-cemented silty alluvial sediments within seeps and streams are covered with the liverwort *Gymnocolea inflata*, whereas the mosses *Polytrichum commune* and *P. juniperinum* inhabit the area adjacent to the water and within the splash zone. Both the liverwort-encrusted sediment and *Polytrichum* thalli have high concentrations of major- and trace-metal cations (for example, Al, As, Cu, Fe, Hg, La, Mn, Pb, and Zn). Soils in the area do not reflect the geochemical signature of the mineral deposit, and we suspect that they are most influenced by the chemistry of airborne dust (aeolian material) derived from outside the area.

Introduction

In June 2004, we began investigating the occurrence, general ecology, and biogeochemistry of plants growing in association with acidic metal-rich water associated with the Red Mountain volcanogenic massive sulfide (VMS) deposit (Gough and others, 2006; Dusel-Bacon and others, this volume, chap. B; Eppinger and others, this volume, chap. I, Hubbard and others, this volume, chap. E). These unusual plant assemblages included liverworts and mosses (bryophytes) as well as forbs, grasses and shrubs, especially willow (*Salix*).

Many terrestrial and aquatic bryophytes are known to accumulate large amounts of metals through direct ion exchange at the leaf surface and have been used in both mineral exploration studies and as biomonitors of airborne metal deposition. Some bryophytes are found most commonly on substrates that are high in particular bioavailable metals (for example copper or lead) and may actually be restricted to this type of substrate (Shacklette, 1967; Shaw, 1987). Field studies of these occurrences are important for understanding the habitat requirements of rare or unusual species and for a full appreciation of the ecology of mineralized areas.

Geological and Ecological Setting

The Bonnifield mining district, and the Red Mountain VMS deposit, are part of the Tintina Gold Province (TGP). Red Mountain (fig. J1) has been the target of past mineral exploration activity. A detailed discussion of the geology and mineral potential of the Bonnifield mining district is given

Figure J1. U.S. Geological Survey scientist examining alteration zone rocks of Red Mountain. Photograph by R.G. Eppinger.

[1]U.S. Geological Survey.

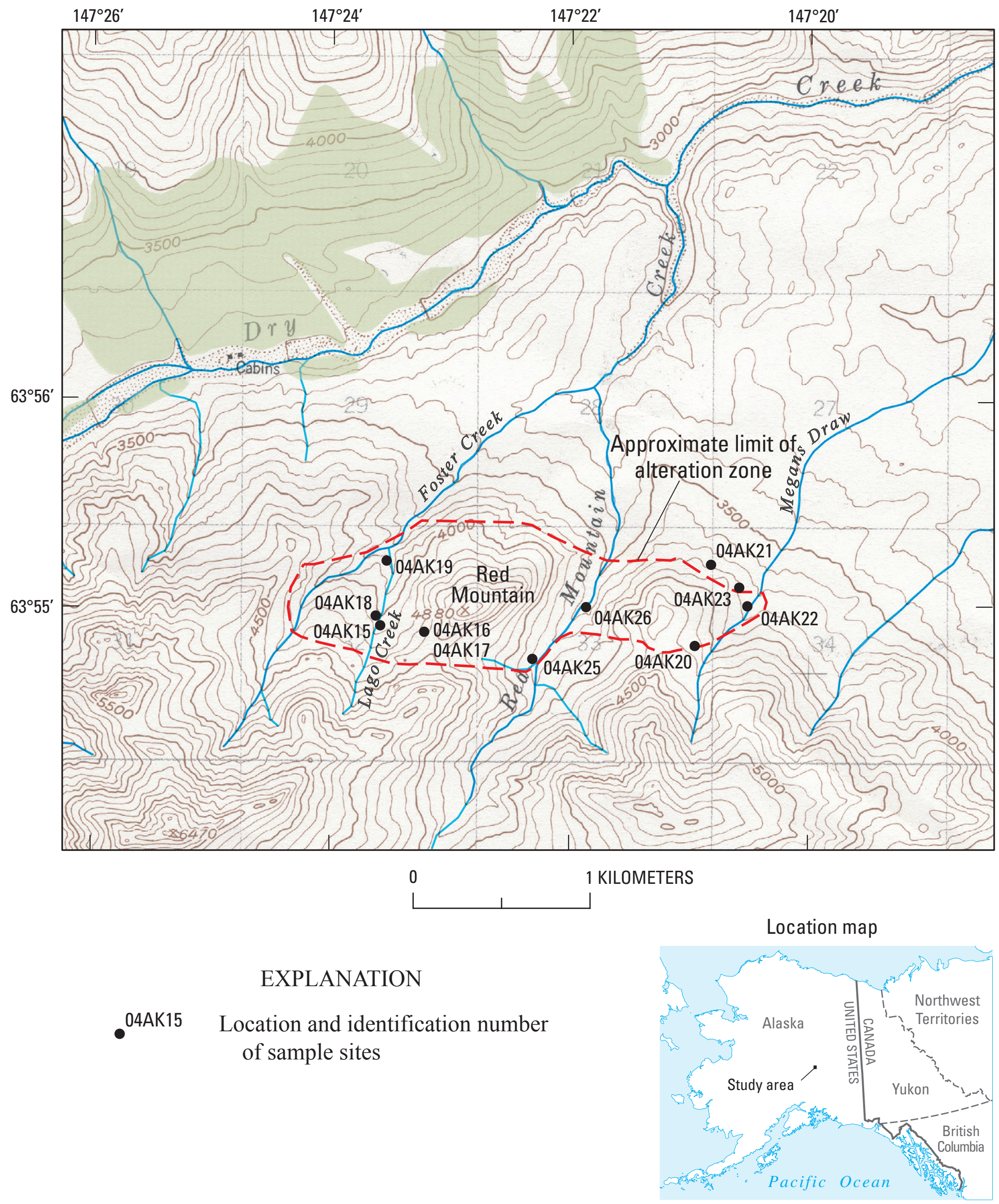

Figure J2. Map showing locations and identification numbers of sampling site locations within and near the Red Mountain volcanogenic massive sulfide deposit alteration zone. Red Mountain, Lago Creek, Foster Creek, and Megans Draw are all local names. Base map from U.S. Geological Survey Healy D–1 quadrangle, scale 1:63,360; contour interval 100 ft (30.48 m).

by Eppinger and others (2004), Dusel-Bacon and others (this volume, chap. B); and Eppinger and others (this volume, chap. I). In brief, Red Mountain is a pyrite-rich VMS deposit containing sphalerite, galena, chalcopyrite, and, locally, precious metals as outcropping and concealed massive to semimassive sulfides. A primary quartz-sericite-pyrite alteration zone (QSPAZ) is extensive, and pyrite oxidation is prevalent (fig. J2; see also fig. I1 in Eppinger and others, this volume, chap. I).

Red Mountain lies on the north slope of the Alaska Range foothills. The altitude of most of the Red Mountain study area (800 meters (m) to 1,800 m) is above the tree limit, and alpine tundra shrubs, grasses, sedges, and forbs dominate the vegetation. Many of the steep slopes are covered with scree and rubble whose stability is decreased by the rapid physical and chemical weathering of the extensive sulfidic alteration zone. Both permanent and intermittent streams, seeps, and springs permeate the slopes and ravines. In the mineralized areas, the submerged and emergent aquatic vegetation is dominated by bryophytes. Forbs and shrubs such as Labrador tea, spirea, cassiope, crowberry, and blueberry dominate the drier areas between the seeps, where there is a layer of soil. Willow, grasses, and sedges are common in the riparian zone immediately within and beside the several permanent streams that drain both the mineralized and nonmineralized areas.

Methods

We did not attempt to sample and analyze individual liverwort thalli (plant body), as they are very small (commonly

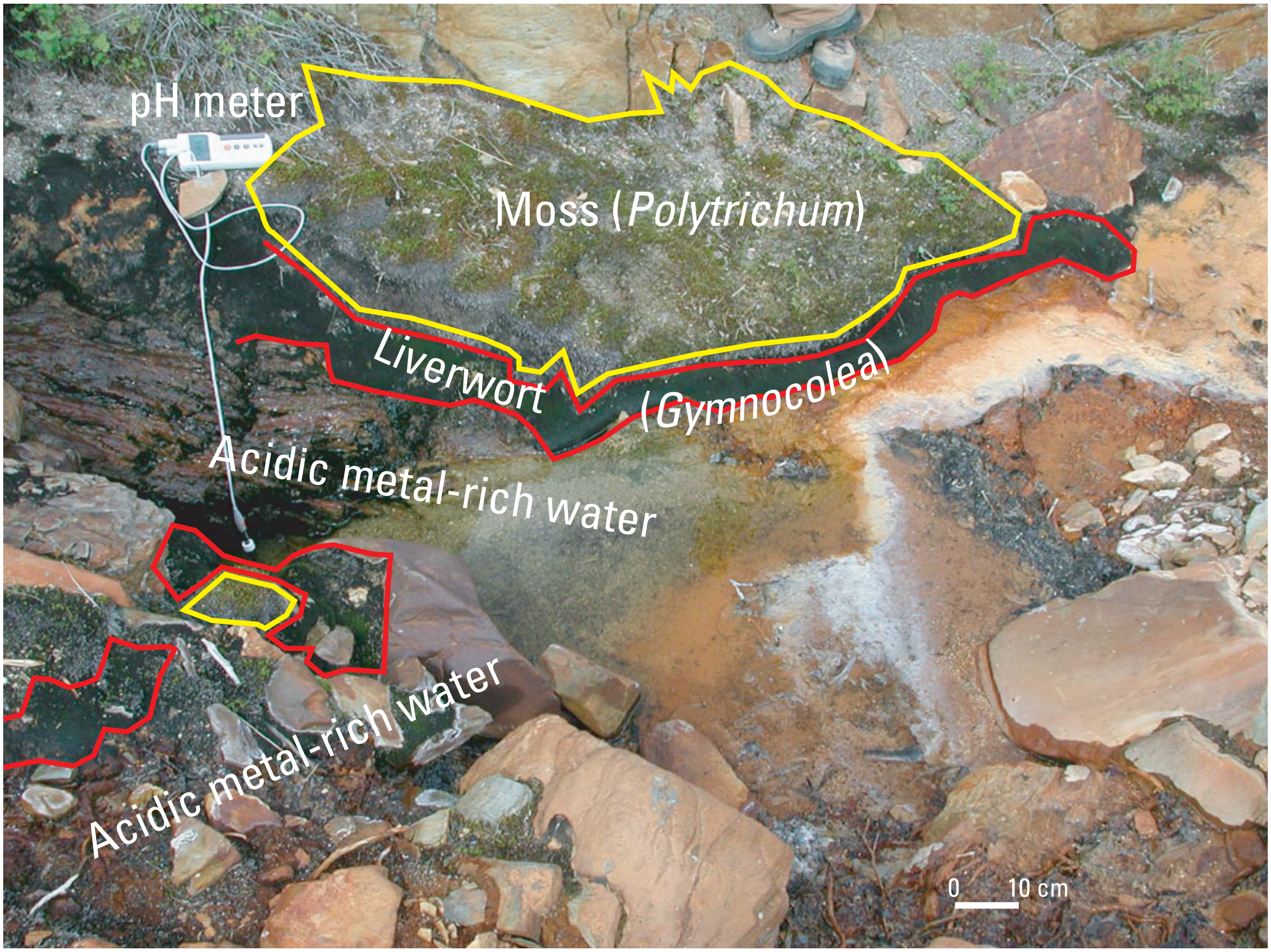

Figure J3. Liverwort and moss species growing in areas influenced by acidic waters. *Gymnocolea inflata*, *Pohlia obtusifolia* (not shown), and *Polytrichum juniperinum* mixed with *P. commune*. Photograph by R.G. Eppinger.

less than 1 millimeter, mm), compact, and grow in intimate association with the silty iron-rich sediments of the seeps and streams. We did, however, sample the composite iron- and organic-rich liverwort sediment substrate.

Samples of the mosses *Polytrichum commune* and *P. juniperinum*, nearby soils, and diamondleaf willow (*Salix pulchra*) leaves were collected for chemical analysis. The soils are poorly developed Gelisols that are dominated by silty colluvium. All geochemical data for this report can be found in Giles and others (2007).

Results and Discussion

Bryophyte Assemblage

The reader is referred to Gough and others (2006) for complete scientific referencing and more detailed results of our investigations. Figure J3 shows a typical bryophyte association found in or near acidic seeps and springs in the QSPAZ (fig. J2). From a distance, the stream or seep bryophyte-inhabited areas appeared black because of the visual dominance of the liverwort *Gymnocolea inflata*. At Red Mountain the liverwort occurred both in very damp sites and in areas with flowing water.

It is frequently observed that certain moss genera and a few liverworts are most common on, if not completely restricted to, substrates enriched with bioavailable heavy metals (Shaw, 1987). It is unclear, however, whether the bryophytes in this assemblage are simply acidophilic or actually require an abundance of a particular heavy metal such as copper. Also found in association with *G. inflata*, but much less common, was the moss *Pohlia obtusifolia*; we could find no mention in the literature of its association with acidic waters.

Of particular interest was the appearance of a mix of the haircap mosses *Polytrichum commune* and *P. juniperinum* within the splash zone of the seeps and small streams (fig. J3). At Red Mountain the acidic, metal-rich waters are an important component of the *Polytrichum* habitat. When ice free, the water is introduced both through capillary upward movement and aerial spray deposition. The moss grows in polsters (small mounds) that are 10 to 20 centimeters (cm) high (fig. J3) and occurs in luxuriant mixed populations when present near the seeps. We found no mention in the literature of *Polytrichum* being associated with highly acidic mineralized substrates or waters.

Bryophyte Substrate Geochemistry

Eppinger and others (this volume, chap. I) characterize the waters within the quartz-sericite-pyrite alteration zone (QSPAZ) as sulfate dominant with high concentrations of Al, Cd, Co, Cu, Fe, Mn, Ni, Pb, Y, Zn, and the rare-earth elements; and to a lesser extent F^- and Si. Upstream of the alteration zone they found that all streams had pH values of 6.5 or greater and conductivities from 370 to 830 microsiemens per centimeter (µS/cm), whereas within the QSPAZ, pH values below 3.5 (as low as 2.4) and conductivities above 2,500 µS/cm (up to 3,400) were common. Within the portion of the QSPAZ where this bryophyte association was observed, the pH of the water in 2003 varied from 2.7 to 3.3 (with conductivities of 1,270 to 3,410 µS/cm) and in 2004 varied from 2.6 to 4.5 (with conductivities of 1,350 to 4,800 µS/cm).

The water within and immediately below the QSPAZ had extremely high concentrations of trace elements; for example, Zn (mean, 41,000 micrograms per liter (µg/L); median, 13,000 µg/L), Mn (mean, 8,500 µg/L; median, 4,200 µg/L), and the rare-earth elements (mean, 6,100 µg/L, median 3,200 µg/L). Other metals having high concentrations and associated high means include Al, Fe, Cd, and Cu, and to a lesser extent Co, Ni, and Pb.

Compared to both the Red Mountain soils and surficial materials throughout Alaska, the Red Mountain iron-rich sediment samples showed notably higher concentrations of As, Cu, Fe, Hg, La, Pb, S, and Sb (Gough and others, 1988, 2006). Concentrations of other elements in sediment associated with VMS deposits (Co, Cr, Mn, Ni, and Zn) either differed little from amounts found in Red Mountain soils and Alaska surficial materials or contained somewhat less. This is due to the predominance of aeolian dust, from outside the area, that is incorporated into these soils (Gough and others, 2001, 2005).

Element Concentrations of Moss

Concentrations of elements in the dry material of a *Polytrichum commune* and *P. juniperinum* mix are reported in table J1. Also listed for comparison are data for another terrestrial moss, *Hylocomium splendens*, collected in an unmineralized area of the Kenai Peninsula of Alaska (Severson and others, 1990). Although these two species have different growth habits, both are often found together in high latitude alpine and subalpine areas. We do not know how similar their inorganic chemistries would be if collected contiguously, but the concentration of some of the major elements in these two populations is quite similar (Mg, K, and P). The trace element and metal cation levels in *Polytrichum* from Red Mountain are considerably higher than the levels in *Hylocomium* (As, Cu, Fe, Hg, Mn, Pb, Zn, and the rare-earth elements La, Ce, as well as Y). We assume that

Table J1. Comparison of the average concentration of selected elements in haircap mosses (Red Mountain, volcanogenic massive sulfide deposit) and in feather moss from a nonmineralized area in Alaska (Severson and others, 1990).

[Concentrations are in parts per million, dry weight basis, except as noted; n.d., not determined.]

Element	Haircap mosses[1] mean (n=4)	Feather moss[2] geometric mean (n=21)
Ash yield[3]	7.5	7.5
Aluminum (Al)	7,870	3,740
Antimony (Sb)	0.4	n.d.
Arsenic (As)	2.3	0.14
Barium (Ba)	93	69
Cadmium (Cd)	2.2	n.d.
Calcium (Ca)	2,200	6,830
Cerium (Ce)	210	1.3
Chromium (Cr)	2.4	3.4
Cobalt (Co)	2.1	1.1
Copper (Cu)	290	4.6
Galium (Ga)	2.6	0.9
Iron (Fe)	6,170	1,740
Lanthanum (La)	75	1.2
Lead (Pb)	120	2.1
Magnesium (Mg)	1,590	1,620
Manganese (Mn)	130	450
Mercury (Hg)	0.25	0.09
Nickel (Ni)	2.9	2.0
Phosphorus (P)	920	1,200
Sodium (Na)	320	1,320
Selenium (Se)	0.26	0.06
Strontium (Sr)	8.6	44
Sulfur (S)	n.d.[4]	720
Titanium (Ti)	120	170
Vanadium (V)	6.2	5.3
Yttrium (Y)	20	0.94
Zinc (Zn)	570	34

[1] *Polytrichum commune* and *P. juniperinum* mix

[2] *Hylocomium splendens*

[3] percent

this difference is the direct result of element uptake from the large dissolved metal load in the water that bathes the moss and of the bioavailable forms of these metals in the sediment.

Conclusions

The Red Mountain quartz-sericite-pyrite alteration zone (QSPAZ), and the VMS deposit that it is part of, are characterized as having acidic (as low as pH 2.4) metal-rich, high sulfate waters, active ferricrete formation in the silty alluvial sediments, and an abundance of primary (pyrite) and secondary (sulfate) acid-generating minerals. Areas such as Red Mountain are an important ecological niche because they support the presence of rare or unusual species. The seep, spring, and stream habitats contain an extraordinary bryophyte community dominated by the liverwort *Gymnocolia inflata* in the areas with standing or flowing water and the mosses *Polytrichum commune* and *P. juniperinum* adjacent to, but elevated above, the water. Both the sediment upon which the liverwort grows and the *Polytrichum* thalli that receive acidic metal-laden spray have high concentrations of some major and trace metals, especially As, Cd, Cu, Fe, Hg, Pb, and Zn. We were unable to determine whether *G. inflata* requires an acidic environment or, alternatively, high concentrations of a specific dissolved metal, such as copper. The moss assemblage of *P. commune* and *P. juniperinum* that dominates the vegetation of the splash zone near the acidic metal-rich waters is truly unusual and we could find no report in the literature of similar observations.

The shallow Gelisol soils that are found throughout the QSPAZ alteration zone are, in general, similar in their major and trace element chemistry to soils found throughout Alaska due to the influx of airborne dust.

Acknowledgments

Dr. JoAnn W. Flock, University of Colorado, and Dr. Won S. Hong, University of Great Falls, aided in the identification of the mosses and liverworts. Chemical analyses were preformed by Monique Adams, Zoe Ann Brown, and Cathy Ager.

References Cited

Eppinger, R.G., Briggs, P.H., and Dusel-Bacon, Cynthia, 2004, Environmental geochemistry of an undisturbed volcanogenic massive sulfide deposit, Red Mountain, Bonnifield mining district, east-central Alaska, *in* Wanty, R.B., and Seal, R.R. II, eds., Water-Rock Interaction, Proceedings of the Eleventh International Symposium on Water-Rock Interaction, Saratoga Springs, N.Y., June 27–July 2, 2004: London, Taylor and Francis Group Publishers, p. 1483–1487.

Giles, S.A., Eppinger, R.G., Granitto, Matthew, Zelenak, P.P., Adams, M.G., Anthony, M.W., Briggs, P.H., Gough, L.P., Hageman, P.L., Hammarstrom J.M., Horton, J.D., Sutley, S.J., Theodorakos, P.M., and Wolf, R.E., 2007, Geochemical data for stream-sediment, surface-water, rock, and vegetation samples from Red Mountain (Dry Creek), an unmined volcanogenic massive sulfide deposit in the Bonnifield district, Alaska Range, east-central Alaska: U.S. Geological Survey Data Series DS–204, 64 p., CD-ROM. (Also available online at *http://pubs.usgs.gov/ds/2006/204/*.)

Gough, L.P., Crock, J.G., Day, W.C., and Vohden, Jim, 2001, Biogeochemistry of arsenic and cadmium, Fortymile River watershed, east-central Alaska, *in* Gough, L.P., and Wilson, F.H., eds., Geological studies in Alaska by the U.S. Geological Survey: U.S. Geological Survey Professional Paper 1633, p. 109–126. (Also available online at *http://pubs.usgs.gov/pp/p1633/*.)

Gough, L.P., Day, W.C., Crock, J.G., Gamble, B.M., Henning, M.W., Ager, C.M., Meier, A.L., Briggs, P.H., Brown, Z.A., and Adams, M., 2005, Regional geochemical results from the analyses of rock, soil, and vegetation samples—Big Delta B–2 quadrangle, Alaska: U.S. Geological Survey Open-File Report 2005–1431, available only online at *http://pubs.usgs.gov/of/2005/1431/*. (Accessed August 13, 2007.)

Gough, L.P., Eppinger, R.G., Briggs, P.H., and Giles, S., 2006, Biogeochemical characterization of an undisturbed highly acidic, metal-rich bryophyte habitat, east-central Alaska, U.S.A.: Arctic, Antarctic, and Alpine Research, v. 38, no. 4, p. 522–529.

Gough, L.P., Severson, R.C., and Shacklette, H.T., 1988, Element concentrations in soils and other surficial materials of Alaska: U.S. Geological Survey Professional Paper 1458, 53 p. (Also available online at *http://geopubs.wr.usgs.gov/prof-paper/pp1458/*.)

Severson, R.C., Crock, J.G., and Gough, L.P., 1990, An assessment of the geochemical variability for plants and soils and an evaluation of industrial emissions near the Kenai National Wildlife Refuge, Alaska: U.S. Geological Survey Open-File Report 90–306, 90 p. (Also available online at *http://pubs.er.usgs.gov/usgspubs/ofr/ofr90306*.)

Shacklette, H.T., 1967, Copper mosses as indicators of metal concentrations: U.S. Geological Survey Bulletin 1198–G, 18 p. (Also available online at *http://pubs.er.usgs.gov/usgspubs/b/b1198G/*.)

Shaw, J., 1987, Evolution of heavy metal tolerance in bryophytes II; An ecological and experimental investigation of the "copper moss," *Scopelophila cataractae* (Pottaceae): American Journal of Botany, v. 74, no. 6, p. 813–821.