Airborne Chemical Elements in Spanish Moss

GEOLOGICAL SURVEY PROFESSIONAL PAPER 574-E

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By HANSFORD T. SHACKLETTE *and* JON J. CONNOR

STATISTICAL STUDIES IN FIELD GEOCHEMISTRY

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A study of local and regional variation
in airborne materials as indicated by
chemical analysis of an epiphyte

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STATISTICAL STUDIES IN FIELD GEOCHEMISTRY

AIRBORNE CHEMICAL ELEMENTS IN SPANISH MOSS

By HANSFORD T. SHACKLETTE and JON J. CONNOR

ABSTRACT

Spanish moss (*Tillandsia usneoides* L.), collected from its geographic range in Southern United States, was analyzed for 38 chemical elements in 123 samples. Although Spanish moss is an epiphyte and must obtain all of its element load from the atmosphere, most elements in samples of this plant occur in concentrations similar to those of ordinary soil-rooted plants. Analyses of Spanish moss samples collected at rural, residential, highway, and industrial locations reflected significant differences in concentrations of metals. Samples from industrial and highway locations are characterized as containing greater-than-average amounts of arsenic, cadmium, chromium, cobalt, copper, lead, nickel, and vanadium. The high levels of lead found in some samples from highway locations are especially noteworthy. Many samples from sites near the seashore contained greater-than-average amounts of sodium that is thought to have been derived from ocean spray. Samples from rural locations commonly contain low concentrations of the metals usually associated with industrial or urban activity but may contain large amounts of the elements that are ordinary constituents of soil dust. Four of six samples containing detectable amounts of tin were collected within 50 miles of the only tin smelter in the United States; this result suggests that elemental analyses of Spanish moss samples can provide an economical and rapid method of estimating the kind and relative degree of local atmospheric metal pollution.

INTRODUCTION

The importance of airborne materials in affecting the quality of the environment for organisms has prompted many investigators to search for materials and methods most suitable for measuring the concentrations and distribution of these materials. Commonly, the methods consist of various procedures for collecting the airborne materials by filtration and then chemically analyzing the materials, or for continuous instrumental monitoring of gaseous elements or compounds in the air. Recently, however, the degree and extent of airborne contamination have been evaluated by means of observation or chemical analysis of plants that either respond in some visible way to the airborne materials or have the ability to collect airborne materials by their physical structures, physiological functions, or both.

The use of suitable plants for measuring concentrations of airborne materials provides the advantages of (1) an integration of the periodic fluctuations in amounts of these materials that occur over relatively long periods of time, and (2) economy in sampling. A disadvantage of using plants, as opposed to filtration or direct monitoring, for this purpose is that analyses of the plants can give estimates only of the relative amounts of airborne materials at different locations, rather than the amounts in a known volume of air.

This study reports the use of Spanish moss (*Tillandsia usneoides* L.), an epiphyte (commonly called an "air plant") that is common in the Atlantic and Gulf Coastal Plains, for evaluating local and regional variation in airborne materials. Specimens were collected from industrial areas and near major highways, where man-related contaminants were expected to be abundant, as well as from rural areas, where more natural atmospheric burdens were believed to occur.

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RESPONSES OF PLANTS TO AIRBORNE CHEMICAL ELEMENTS

The effects of excessive concentrations of certain airborne materials on many types of organisms may be either deleterious or beneficial. The responses of plants to airborne toxic substances have been reported many times as evidence of aerial pollution, and the effects of this pollution were reviewed by the European Congress on the Influence of Air Pollution on Plants and Animals (1969).

Some plants, particularly lichens and mosses, are very sensitive to sulfur dioxide (and perhaps other gaseous compounds) in the air. More than a century ago Nylander (1866, p. 365) reported [translated], "lichens provide, through their behavior, a measure of the healthfulness of air, and are (one may say) very sensitive 'hygiometers.'" The sensitivity of both mosses and lichens to air pollution was discussed by LeBlanc (1969). The extent and physiological condition of lichen populations were used to map the degree of pollution in urban and industrial areas by Sloover and LeBlanc (1968).

Many plant species are sensitive to concentrations of airborne fluorine. Symptoms of fluorine poisoning in plants were discussed by Brewer (1966, p. 180–196), and the "normal" fluorine contents of many species were given by Garber (1968, p. 42–48) for use in evaluating the extent of fluorine pollution from industrial emissions.

Although additions of extraneous materials to the air generally are considered to be undesirable, increased atmospheric concentrations of certain elements may be beneficial to plants. Ingham (1950) discussed the importance of the mineral content of air and rain to agriculture. Egnér (1965) reviewed the importance to soil fertility of sulfur compounds that are supplied by atmospheric precipitation, and Riehm (1965) described the role of this source in supplying the biologically essential elements calcium, chlorine, boron, potassium, magnesium, nitrogen, and sodium to soils in Europe.

The absorption of atmospheric ammonia by soils in New Jersey was measured by Malo and Purvis (1964). They found that 8.2 pounds of ammoniacal nitrogen per acre was deposited from precipitation in a year, and they believed that nitrogen from this source was a factor in the high yields of maize that was grown without the addition of nitrogen fertilizers from 1958 to 1960. The direct absorption of atmospheric ammonia by plant leaves was demonstrated by Hutchinson, Millington, and Peters (1972), who stated,

> We believe that our data have broad implications in regard to both plant nutrition and air pollution and water pollution control. Calculations [based on their data] indicate that the annual NH_3 absorption by plant canopies could be about 20 kg per hectare. This rate of NH_3 supply is large enough to contribute significantly to the nitrogen budget of a growing plant community and could exert a prodigious influence on the long-term behavior of an ecosystem.

Shacklette and Cuthbert (1967, p. 42) calculated that the total iodine content of certain soil-rooted plants could be obtained from the exchanges of atmospheric gases that accompany the process of photosynthesis. The total amount of atmospheric iodine added to the soil each year in England was estimated to slightly exceed the amount of iodine removed from the soil in a crop of kale (Chilean Iodine Educ. Bur., 1956).

The "normal" concentration of carbon dioxide in air is generally considered to be about 300 ppm (parts per million), and amounts much greater than this may be considered undesirable for animals. Yet experiments have shown that above-normal concentrations of this gas in the atmosphere increase the growth rate of plants. Holley (1965) found that increasing the carbon dioxide content of the air in greenhouses to as much as 1,000 ppm was economically feasible, and at present the use of carbon dioxide generators is a common practice in the production of some greenhouse crops.

Many other reports have pointed out the importance to land plants of nutrient elements that are obtained directly or indirectly from the atmosphere. However, reports apparently lack conclusive experiments on the relative amounts of certain chemical elements absorbed by land plants from the soil solution, as opposed to amounts of these elements absorbed directly from the atmosphere (Shacklette and Cuthbert, 1967, p. 41). The problem of element source does not arise in discussing Spanish moss because this plant obtains all nutrients from atmospheric gases, precipitation, and airborne particulate matter.

Most kinds of airborne materials cause no apparent damage to plants that are subjected to them. However, the plants may respond by accumulating large amounts of certain of these materials either within the tissues, in deposits on the surfaces of the plants, or both. Ordinary terrestrial plants may incorporate airborne materials into their tissues directly through leaves or indirectly by root absorption of fallout material that accumulates in soils. Wöhlbier (1968, p. 142) noted [translated], "Plants take fluorine from the soil by means of their roots, and from the air through the stomates of the leaves." Garber, Guderian, and Stratmann (1968, p. 41) concluded [translated],

> The variation in fluorine enrichment in plants from experi-

> mental soil that has not been polluted is insignificant in comparison with the possible enrichment through fluorine-containing air pollution. Therefore, analyses of the fluorine content of plants can be of consequence as an important adjunct in diagnosing the effects of fluorine in areas of airborne industrial emissions.

The mechanisms of element absorption by, or fixation on, leaves and stems of plants are not fully understood; doubtless, the mechanisms vary greatly, depending on elements and plant species. Generally, the amounts of airborne substances absorbed and incorporated in the plant tissue cannot be distinguished from the amounts held only on the surfaces of leaves and stems. Washing the samples with water or other solvents may remove some of the surficial deposits that are not firmly bound to the plant surfaces. Goodman and Roberts (1971, p. 298) reported,

> Earlier experiments clearly showed that it was not possible to wash any significant amounts of metals either from moss samples or grass material when it was obtained outside the moss desert [an area so heavily polluted from atmospheric fallout that mosses could not grow in it]. Grass samples taken inside the desert, however, bore significant quantities of washable metals. * * * as much as 45% of analysed metals could be removed by washing.

MacIntire, Hardin, and Hester (1952, p. 1368) found analyses of Spanish moss useful in measuring relative degrees of atmospheric fluorine at different locations, but they did not determine whether the increases in fluorine content in the experimental plants were due to metabolic functions of the plants or to chemical or physical fixation on the plant. In a study of air pollution as measured by analysis of the moss *Hypnum cupressiforme*, Goodman and Roberts (1971, p. 291) stated,

> Further information is, however, required about the relative bonding energies of the metals on the exchange surfaces of *Hypnum* and the modifying influences of rainfall pH. It is also important to know the relative contribution to uptake made by dry deposition (sedimentation and diffusion of various particle sizes) and wash-out processes by rainfall.

Practical applications of the pronounced ability of mosses and lichens to accumulate airborne contaminants have been made recently in Europe. By analyzing specimens of the mosses *Hylocomium splendens, Pleurozium schreberi,* and *Hypnum cupressiforme* that were preserved in the Botanical Museum in Lund, Sweden, and that had been collected at intervals from 1860 to 1968 from the same locations, Rühling and Tyler (1968) were able to record the effect of human activity on the concentration of atmospheric lead. They wrote (1968, p. 321), "From values of c. 20 ppm [dry weight basis] in the years 1860–1875 the concentration of lead was more than doubled between 1875 and 1900. During the first half of the 20th century no measurable changes were observed, but after about 1950 there was a new strong increase to a present average of c. 80–90 ppm." Rühling and Tyler (1968, 1969, 1971) and Rühling (1969, 1971) conducted studies of regional distribution of other airborne heavy metals by analyzing samples of mosses and other plants, and they found this method effective in evaluating aerial pollution.

Jaakkola, Takahashi, and Miettinen (1971) analyzed specimens of a lichen (*Cladonia alpestris*) to measure the airborne cadmium that was released by a recently constructed zinc refinery in Finland. Goodman and Roberts (1971) used samples of the moss *Hypnum cupressiforme* to measure the airborne heavy metals in some industrial areas in Wales. They concluded (1971, p. 291), "Our methods are much more rapid, inexpensive, and probably more meaningful than spot-sampling of air by filtration, for which prohibitive resources are needed for a few months' operation."

MORPHOLOGY AND ECOLOGY OF SPANISH MOSS

Certain morphological features of plants enhance their ability to accumulate airborne materials; therefore, as the physical structures among different species vary, so do responses to airborne materials. Osburn (1963) found moss and lichen mats to be effective filters of radioactive fallout in snow melt water in the Rocky Mountains. In a study of radionuclide fallout from the atmosphere, Watson, Hanson, Davis, and Rickard (1966) stated, "Direct foliar interception by plants is regarded as one of the principal sources of contamination from fallout materials. * * * Foliar surface area and plant density are therefore important factors requiring consideration in evaluating fallout accumulation." In the same study the writers pointed out (p. 1176) that greater accumulations of atmospheric fallout occur in plants (1) with persistent above-ground parts (perennial plants), (2) capable of obtaining water and nutrients from the atmosphere, and (3) having great absorptive characteristics. Mosses, lichens, Spanish moss, and certain other plants have all these attributes; moreover, Spanish moss has the advantage, for use in evaluating the kind and amount of airborne materials, of having no roots or rootlike organs and hence of having no direct contact with the soil.

Results of chemical element analyses of plant samples are expressed, on the basis of weight, as the proportion of the element of concern in relation to the total sample. Therefore, plants with a great foliar surface in proportion to their weight tend to accumulate greater concentrations of elements from the air than do other plants because their large surface area favors increased absorption and surface deposition of the airborne materials. Thin, small, numerous, and finely divided stems and leaves (or stemlike and leaflike organs, as occur in lichens) are morphological expressions of great surface area relative to the weight of the plant.

Spanish moss is classed as an epiphyte because it most commonly grows on trees. It is not parasitic because it gets all essential elements and water from the air and produces its own food by photosynthesis. It is in the pineapple family (Bromeliaceae), and most species in this family are epiphytes with highly specialized morphological adaptations that assist in obtaining water and other materials from the air. The morphology of this plant was outlined by Garth (1964), who also gave the major references in the literature.

The plant body consists of a sinuous pendant stem that bears curved filiform leaves at nodes on the stem (fig. 1*A*). The entire plant body, except the flowers and seed capsules, is closely invested with overlapping translucent scales (fig. 1*H*), each scale being attached to the stem or leaf at a central point (fig. 1*G*). These abundant scales greatly increase the surface of the plant that is exposed to the air. Aso (1909), on the basis of experiments he conducted on lithium nitrate absorption, concluded that salts could pass through the scales into the plant. The ability of the scales to entrap airborne particulate matter is obvious. The scales also assist in water absorption by the body of the plant and contribute to the ability of the plant to withstand drying even when placed in a strong dessicant (Billings, 1904).

Small yellow flowers (fig. 1*B*) borne terminally on short branches that arise from leaf axils (fig. 1*A*) appear usually in March and April and probably are self-pollinated. The seed capsules (fig. 1*A* and *C*) begin to form in June but do not mature until the following December and January (Garth, 1964). The capsules then open (dehisce), and each releases 10 to 20 seeds (fig. 1*D*). Each seed bears a plume of long epidermal hairs (fig. 1*E*) that add buoyancy to the seed and enable it to become airborne. If the seed falls on a suitable substrate, such as the rough bark of a tree or a mass of Spanish moss plants, the small barbs at the joints of the hairs (fig. 1*F*) assist the seed in adhering to the substrate (Billings, 1904, p. 107). After germination of the seed, rootlike organs (rhizoids) attach the plant to the substrate (fig. 1*I*) but do not function as absorbing organs (Garth, 1964). These anchoring organs soon degenerate, and the plant is supported only by its densely intertwined stems and leaves.

The factors responsible for the occurrence of Spanish moss at particular locations, and for its regional distribution, are imperfectly understood, although the ecology of the plant has been investigated extensively. In many large areas Spanish moss is extremely abundant and grows on almost any kind of support, whereas in others it occurs at discontinuous locations or is found only closely associated with ponds and streams. It grows on both living and dead trees and in full sun exposure or in shade (fig. 2). Masses of the plants are torn from the supporting trees by winds, and if dropped at suitable locations, they continue growth and establish new colonies. Garth (1964) suggested that the distribution of Spanish moss in the United States is related to major storm paths which arise in Mexico and move laterally over the coastal plains.

The northern limit of the distribution of Spanish moss (fig. 3) is controlled in some manner by seasonal temperatures, although the plant will endure short periods of freezing weather and snowfall. Transplant experiments have proved that it will survive and reproduce at favorable locations as much as 75 miles north of its natural range (Garth, 1964). Its western limit, in east-central Texas, probably is controlled by the frequency of rainfall. Garth (1964) demonstrated that the plant could survive only about 3 to 4 months if deprived of rain, even if natural high humidity was maintained around the plant.

METHODS OF STUDY

SAMPLING PLAN

The collection of samples for this study was begun in 1965 and was continued through 1970 as opportunities arose while we were engaged in other field studies. The general plan was to obtain samples from as many areas as possible at sites spaced about 50 miles apart throughout the range of Spanish moss. In order to obtain samples from some areas that we could not visit, County Agricultural Extension Agents in selected counties were requested to collect and submit samples, and 22 agents responded. In addition, single samples were contributed by several other persons.

Samples were obtained from a wide variety of habitats, including roadsides, industrial and urban areas, remote locations in forests and swamps, ocean beaches, and agricultural areas. Special efforts were made to procure some specimens from sites at the western and northern limits of the plant's range. The samples were pulled from trees or other supports, and visible extraneous matter was removed from the samples before they were placed in cardboard boxes and shipped to the U.S. Geological Survey laboratories in Denver.

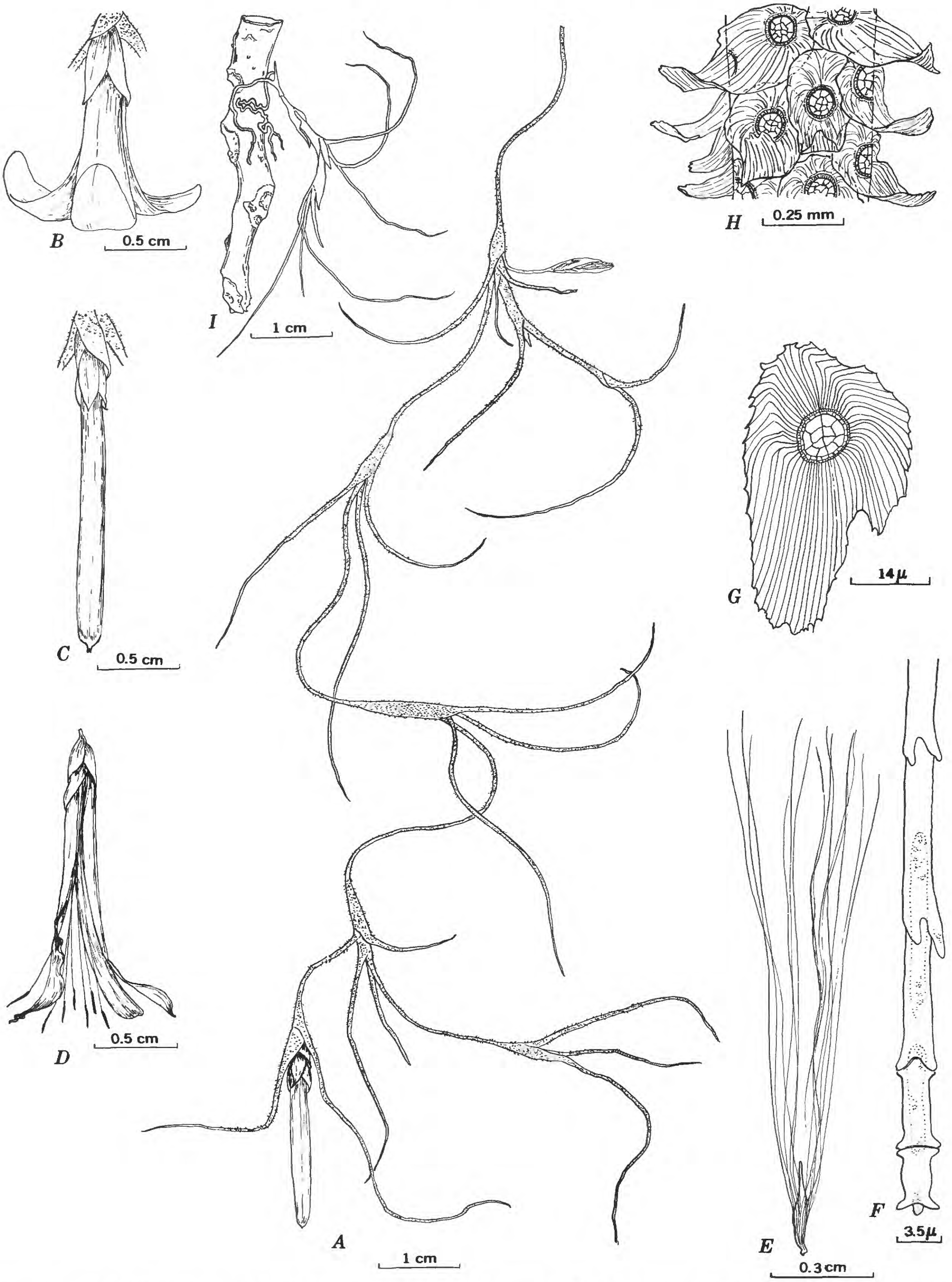


FIGURE 1. — Growth habit and morphological features of Spanish moss (*Tillandsia usneoides* L.). *A*, mature plant bearing a seed capsule; *B*, flower; *C*, immature seed capsule; *D*, dehiscence of the mature capsule, which releases the seed; *E*, airborne seed, with plume of epidermal hairs; *F*, distal portion of a single epidermal hair; *G*, a peltate epidermal scale; *H*, portion of stem, showing imbricated translucent scales; *I*, young seedling attached to a branch by means of rhizoids.

FIGURE 2. — Growth of Spanish moss on the tops of pond cypress (*Taxodium ascendens* Brongn.) and on the more shaded lower branches. Okefenokee Swamp, Charlton County, Ga. Photographed July 23, 1963.

The sampling sites are plotted in figure 3 and described in table 1. All samples were analyzed in the winter of 1970–71. Although the gain or loss of elements during storage of the samples could not be precisely evaluated, we noted no correlation between storage time and concentrations of the more volatile elements.

ANALYTICAL METHODS

In order to minimize the effects of analytical drift, the samples were arranged in a randomized order before being submitted to the laboratories, and they were analyzed in the same sequence. The unwashed samples were ovendried and then pulverized in a blender. A wet-digestion method was used to prepare the samples for determining their arsenic, mercury, and selenium concentrations. For determining the concentrations of other elements in the samples, portions of the pulverized plants were transferred to ceramic crucibles, weighed, and burned to ash in an electric muffle in which the heat was increased 50°C per hour to a temperature of 550°C and held at this temperature for about 24 hours. The ash was then weighed to determine the ash yield of the dry plant sample. A colorimetric method was used to analyze the ash for phosphorus content, and an atomic absorption method was used for determining cadmium, calcium, lithium, potassium, sodium, and zinc. Concentrations of the remaining elements in ash were determined by a semiquantitative emission spectrographic method (Myers and others, 1961).

The values obtained by spectrography were reported in geometric brackets having boundaries, in percent, of 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, and so forth; the brackets are identified by their respective geometric midpoints, 1.0, 0.7, 0.5, 0.3, 0.2, 0.15, and so forth. Thus, a reported value of 0.3 percent, for example, identifies the bracket from 0.26 to 0.38 percent as the analyst's best estimate of the concentration present. The precision of a reported value is approximately plus or minus one bracket at the 68-percent level of confidence and plus or minus two brackets at the 95-percent level.

The approximate limits of detection of the analytical methods that were used are given in table 2. Some combinations of elements in a sample, however, affect these limits. For example, concentrations somewhat lower than these values may be detected in unusually favorable materials, whereas these limits of detection may not be attained in unfavorable materials.

DATA PRESENTATION

The concentration of each element in each sample (or its ash) and the location of the corresponding sample site expressed as degrees and minutes of latitude and longitude were entered on automatic-data-processing cards. The analytical values were transformed to logarithms through a computer program which also determined the minimum and maximum values and the basic statistics. In addition, the program reported all occurrences of missing data, indicated the concentrations that were beyond the limits of detection of the analytical methods, and printed both a histogram of the analytical values and an accompanying table of frequencies and cumulative frequencies for each class designation on the histogram.

The table of frequencies could be used to divide the range of reported values into five classes so that as far as possible about 20 percent of the values fell into each class. For some elements the limited ranges in values prohibited use of more than two or three classes to represent the total distribution. Class-in-

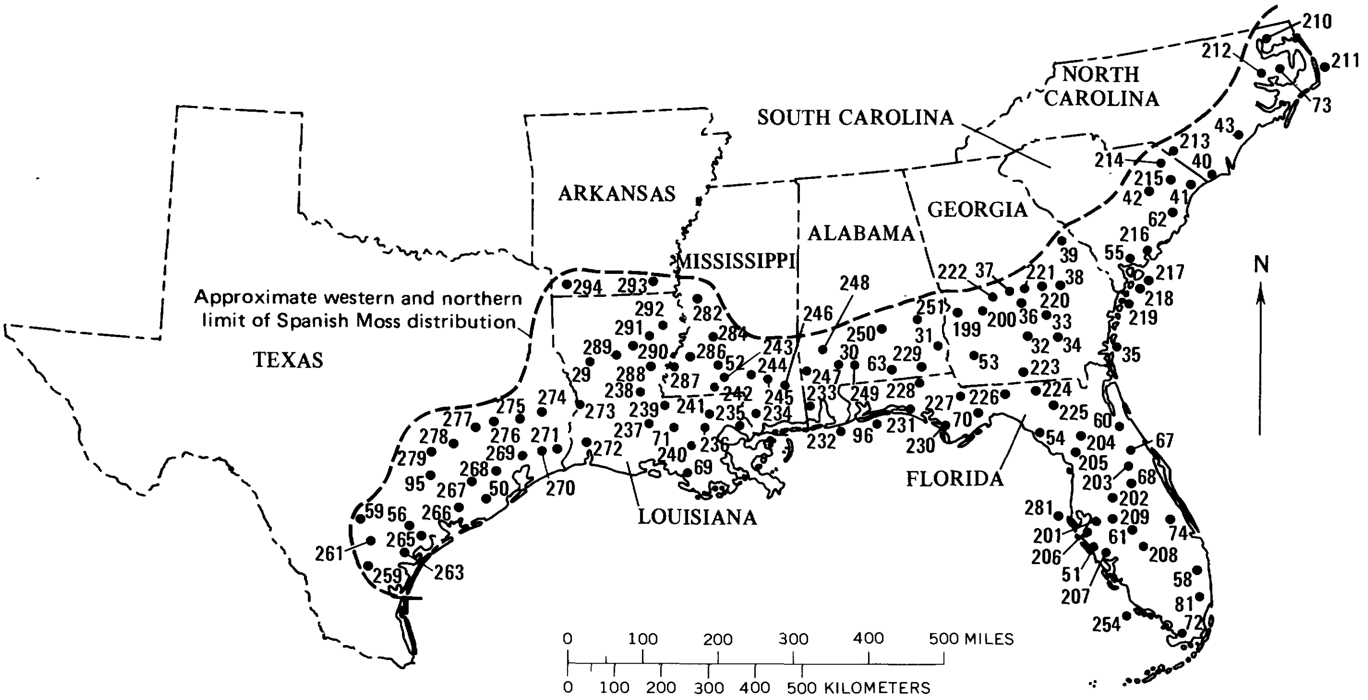


FIGURE 3. — Spanish moss sample localities (described in table 1). Seashore sites are plotted offshore.

TABLE 1. — *Spanish moss sample localities and sampling dates*

Locality (fig. 3)	Laboratory No. (D414–)	Sampling date	Locality: State	Locality: County or parish	Locality: Area
29	376	June 1965	Louisiana	Natchitoches	2 miles E. of Clarence.
30	330	do	Alabama	Monroe	U.S. Route 84, at Perdue Hill on Alabama River.
31	337	do	do	Henry	State Route 10, 2 miles E. of Shorterville.
32	299	do	Georgia	Irwin	State Route 32, 10 miles E. of Ocilla.
33	413	do	do	Jeff Davis	U.S. Route 23, 5 miles NW. of Hazelhurst.
34	349	do	do	Bacon	U.S. Route 1, 4 miles S. of Alma.
35	397	July 1965	do	Glynn	St. Simons Island, near Fort Fredrica.
36	324	do	do	Dodge	State Route 117, at Rhine.
37	384	do	do	Bleckley	State Route 87, 12 miles N. of Cochran.
38	336	do	do	Emanuel	State Route 192, 3.5 miles W. of Stillmore.
39	321	do	do	Burke	U.S. Route 25, 10 miles N. of Waynesboro.
40	409	do	North Carolina	Brunswick	State Route 211, 3 miles W. of Supply.
41	303	do	South Carolina	Horry	U.S. Route 17, at Little River.
42	333	do	do	Florence	State Route 378, 2 miles W. of Lake City.
43	329	do	North Carolina	Onslow	State Route 17, 1 mile S. of Verona.
50	411	September 1965	Texas	Brazoria	5 miles NW. of Angleton, Farm Road 521, at Oyster Creek.
51	301	do	Florida	Sarasota	On Wilkinson Road.
52	348	do	Mississippi	Lawrence	6 miles S. of Monticello, near Pearl River.
53	312	do	Georgia	Baker	Mixed pine-hardwood forest.
54	414	do	Florida	Dixie	In city park, Cross City.
55	346	do	South Carolina	Charleston	Edisto Island.
56	308	do	Texas	Victoria	Bank of Guadalupe River, near Victoria.
58	368	do	Florida	Palm Beach	Junction of Pike and Belvedere Road, West Palm Beach.
59	404	do	Texas	Karnes	Bank of San Antonio River.
60	361	do	Florida	St. Johns	In St. Augustine.
61	311	do	do	Highlands	In Sebring.
62	320	do	South Carolina	Georgetown	In Georgetown.
63	372	do	Alabama	Covington	7 miles SW. of Opp.
67	339	do	Florida	Volusia	In DeLand.
68	355	do	do	Orange	At 2350 E. Michigan Ave., Orlando.
69	357	do	Louisiana	Terrebonne	In Gibson.
70	332	October 1965	Florida	Wakulla	3.5 miles W. of Crawfordville.
71	314	September 1965	Louisiana	East Baton Rouge	R. 1 E., T. 8 S.
72	383	do	Florida	Dade	Paradise Key, Everglades National Park.
73	326	do	North Carolina	Tyrrell	Near Albemarle Sound shore, 0.5 miles N. of Columbia.
74	418	do	Florida	Indian River	At Vero Beach.
81	309	October 1965	Florida	Broward	On Prospect Road, Fort Lauderdale.
95	405	March 1966	Texas	Colorado	At rest stop, State Route 71, 8 miles NW. of Columbus.
96	338	do	Florida	Okaloosa	On Fort Walton Beach.
199	408	January 1969	Georgia	Chattahoochee	U.S. Route 280, 8 miles E. of Cusetta.
200	399	do	do	Sumter	State Route 49, 3 miles S. of Andersonville.
201	334	December 1968	Florida	Hillsboro	State Route 60, in Limona, about 5 miles E. of Tampa.
202	325	do	do	Polk	State Route 33, at Eva.
203	373	do	do	Seminole	U.S. Route 17–92, at margin of Lake Jessup.
204	360	do	do	Alachula	U.S. Route 441, 1 mile S. of Micanopy.
205	356	do	do	Levy	U.S. Route 41, 2 miles S. of Morriston.

TABLE 1. — *Spanish moss sample localities and sampling dates* — Continued

Locality (fig. 3)	Laboratory No. (D414–)	Sampling date	Locality		
			State	County or parish	Area
206	310	do	do	Manatee	U.S. Route 41, undisturbed lot at N. edge of Bradenton.
207	375	do	do	Charlotte	U.S. Route 41, 5 miles W. of Murdock.
208	379	do	do	Highlands	U.S. Route 27, 5 miles S. of Sebring.
209	343	do	do	Polk	State Route 60, at edge of Bartow.
210	370	January 1970	North Carolina	Pasquotank	U.S. Route 158, 10 miles E. of Sunbury.
211	318	do	do	Dare	U.S. Route 158, 3 miles N. of Kitty Hawk.
212	340	do	do	Washington	State Route 64, 8 miles E. of Rober.
213	300	do	do	Robeson	Interstate Highway 95, at Lumber River, 3 miles S. of Lumberton.
214	317	do	South Carolina	Dillon	U.S. Route 301, 1 mile N. of Latta.
215	351	do	do	Marion	State Route 501, at Little Pee Dee River.
216	353	do	do	Charleston	U.S. Route 17, at W. city limits of Charleston.
217	366	do	do	Beauford	Hunting Island State Park.
218	387	do	do	do	Folly Field, 200 yards from the beach, Hilton Head Island.
219	393	do	Georgia	Chatham	Savannah Beach, near the lighthouse, Tybee Island.
220	313	do	do	Emanuel	U.S. Route 80, 2 miles E. of Adrian.
221	364	do	do	Laurens	U.S. Route 80, at Ford Branch, 3 miles W. of Dublin.
222	342	do	do	Houston	Interstate Highway 75, 2 miles S. of Perry.
223	398	do	do	Lowndes	Interstate Highway 75, 2 miles N. of Valdosta.
224	319	do	Florida	Hamilton	Interstate Highway 75, at Jasper-Madison exit.
225	335	do	do	Suwanee	U.S. Route 90, at Wellborn.
226	362	do	do	Jefferson	U.S. Route 90, 1 mile W. of Monticello.
227	407	do	do	Gadsden	U.S. Route 90, 5 miles W. of Gretna.
228	378	do	do	Holmes	State Route 79, 3 miles N. of Bonifay.
229	385	do	Alabama	Geneva	County road, 5 miles NE. of Hartford.
230	315	do	Florida	Bay	U.S. Route 98, W. side of Panama City.
231	298	do	do	Walton	U.S. Route 98, bridge at Philips Inlet, 2 miles W. of Sunnyside.
232	305	do	Alabama	Baldwin	On the beach at Josephine.
233	402	do	do	Mobile	Interstate Highway 10, 5 miles W. of Mobile.
234	371	do	Mississippi	Hancock	In Bay St. Louis.
235	396	do	Louisiana	St. Tammany	Junction of U.S. Routes 90 and 190, 4 miles W. of Perlington.
236	410	do	do	Tangipahoa	U.S. Route 190, at Robert.
237	420	do	do	St. Landry	At Krotz Springs.
238	363	do	do	Avoyelles	State Route 1, at Maureville.
239	412	do	do	Pointe Coupee	State Route 1, 2 miles S. of Batchelor.
240	306	do	do	Ascension	U.S. Route 61, at Sorrento.
241	304	do	do	St. Tammany	State Route 25, at Folsom.
242	417	do	Mississippi	Walthall	State Route 5, at Mississippi-Louisiana State line.
243	419	February 1970	do	Marion	U.S. Route 98, at Columbia.
244	377	do	do	Forest	U.S. Route 11, on bank of Leaf River, at Hattiesburg.
245	307	do	do	Perry	State Route 15, on bank of Leaf River, at Beaumont.
246	322	do	do	Greene	State Route 63, on bank of Chickasawhay River, at Leakesville.
247	345	do	Alabama	Washington	State Route 56, 7 miles W. of Chatom.
248	367	do	do	Clarke	U.S. Route 84, 1 mile W. of Whatley.
249	350	do	do	Conecuh	U.S. Route 84, 2 miles E. of Belleville.
250	406	do	do	Lowndes	Interstate Highway 65, 3 miles S. of Letohatchee exit.
251	344	do	do	Elmore	U.S. Route 231, at the Tallapoosa River.
254	400	April 1970	Florida	Collier	Coximba area, Marco Island.
259	323	May 1970	Texas	San Patricio	Bank of Nueces River, near Sandia.
261	394	do	do	Live Oak	State Route 59, at the Nueces River.
263	386	do	do	Aransas	State Route 35, 1 mile N. of Aransas Pass.
265	395	do	do	Calhoun	State Route 35, near the Guadelupe River.
266	328	do	do	Matagorda	State Route 35, 2 miles E. of Blessing.
267	416	do	do	Fort Bend	In Sugar Land.
268	331	do	do	Harris	Interstate Highway 10, 5 miles E. of junction with Interstate Highway 610.
269	390	do	do	Chambers	Interstate Highway 10, at E. side of Trinity River, Wallisville.
270	341	do	do	Jefferson	Interstate Highway 10, at W. city limits of Beaumont.
271	359	do	do	Orange	Interstate Highway 10, at W. side of Orange.
272	347	do	Louisiana	Calcasieu	U.S. Route 171, 4 miles N. of Lake Charles.
273	365	do	do	Vernon	State Route 8, at the Sabine River bridge.
274	374	do	Texas	Jasper	U.S. Route 190, 1 mile E. of Neches River.
275	302	do	do	Tyler	U.S. Route 190, 1 mile E. of Polk County line.
276	316	do	do	Polk	U.S. Route 190, 1 mile E. of San Jacinto.
277	358	do	do	Walker	State Route 30, 10 miles W. of Huntsville.
278	380	do	do	Grimes	State Route 90, 1 mile S. of Navasota.
279	392	do	do	Washington	U.S. Route 290, 5 miles W. of Brenham.
281	381	April 1970	Florida	Pinellas	At Crystal Beach.
282	403	June 1970	Mississippi	Yazoo	U.S. Route 49W, 6 miles W. of Yazoo.
284	391	do	do	Hinds	Interstate Highway 55, at Pearl River, 2 miles S. of Jackson.
286	327	do	do	Jefferson	State Route 28, 18 miles W. of Union Church.
287	401	do	do	Adams	U.S. Route 61, 4 miles W. of Natchez.
288	388	do	Louisiana	Concordia	U.S. Route 84, 2 miles W. of Wildsvilie.
289	369	do	do	La Salle	U.S. Route 165, 5 miles NE. of Tullos.
290	415	do	do	Caldwell	U.S. Route 165, at Columbia.
291	389	do	do	Franklin	State Route 4, 1 mile NE. of Winnsboro.
292	354	do	do	Richland	State Route 17, 4 miles N. of Delhi.
293	382	do	Arkansas	Ashley	State Route 8, 1 mile W. of Parkdale, on Cutoff Creek.
294	352	do	do	Lafayette	U.S. Route 82, 2 miles E. of Red River.

terval code numbers were assigned to each analytical value; these numbers were entered on base maps by an automatic plotter at the proper geographical location of the corresponding sample and then replaced with symbols as shown in figures 5 to 35.

The geometric means and geometric deviations given in figures 5 to 35 are antilogs of the arithmetic means and standard deviations, respectively, of the logarithms of the analytical values. Where some of the concentrations for an element were determined to be less than the sensitivity of the analytical method (table 2), the means and standard deviations of the logarithms were estimated by means of a censored-distribution technique devised by Cohen (1961). Means estimated by the use of this technique may be lower than the limits of detection for certain elements, as is illustrated by the mean arsenic content of 0.79 ppm in Spanish moss (fig. 7), whereas the limit of detection for arsenic is 1 ppm (table 2). Further discussions of the treatment of censored frequency distributions of geochemical data and of the use of geometric means and geometric deviations were given by Miesch (1967) and Shacklette, Sauer, and Miesch (1970).

All data analysis in this study is based on logarithms of reported concentrations because minor elements commonly tend to exhibit positively skewed frequency distributions. The geometric mean is the best measure of central tendency in log normally distributed data and, as such, is an estimate of the typical or most common concentration for the element. The range from the geometric mean multiplied by the geometric deviation to the geometric mean divided by the geometric deviation generally includes about two-thirds of the analytical values. About 95 percent of the values occur in the range from the geometric mean multiplied by the square of the geometric deviation to the geometric mean divided by the square of the geometric deviation. For example, the geometric mean cadmium content of ash of Spanish moss is 7.9 ppm, and the geometric deviation is 1.65 (fig. 10). Thus, probably about two-thirds of a large group of randomly selected samples will have cadmium contents in the range $7.9 \div 1.65 = 4.8$ ppm to $7.9 \times 1.65 = 13.0$ ppm, and about 95 percent will have cadmium contents in the range $7.9 \div 1.65^2 = 2.9$ ppm to $7.9 \times 1.65^2 = 21.5$ ppm.

TABLE 2. — *Analytical limits of detection*

[Analyses made by semiquantitative spectrographic method, except as indicated. Dry plant material was used for arsenic, mercury, and selenium analyses; plant ash was used for analyses of all other elements. Data reported in parts per million]

Element	Lower limit of detection	Element	Lower limit of detection
Aluminum	20	Mercury	[1]0.5
Arsenic	[1]1	Molybdenum	7
Barium	3	Neodymium	150
Beryllium	2	Nickel	10
Boron	50	Niobium	20
Cadmium	[2].5	Phosphorus	[1]2
Calcium	[2]150	Potassium	[2]50
Cerium	300	Scandium	10
Chromium	2	Selenium	[1]1
Cobalt	7	Silver	1
Copper	2	Sodium	[2]100
Gallium	10	Strontium	10
Germanium	15	Tin	20
Iron	20	Titanium	5
Lanthanum	70	Vanadium	15
Lead	20	Ytterbium	2
Lithium	[2]4	Yttrium	20
Magnesium	50	Zinc	[2]25
Manganese	2	Zirconium	20

[1] Analyzed by colorimetric method.

[2] Analyzed by atomic absorption method.

ELEMENTAL COMPOSITION OF SPANISH MOSS

Chemical analyses of Spanish moss were performed first by Wherry and Buchanan (1926) and later by Wherry and Capen (1928); the analyses indicated that the plant obtains a wide range of chemical elements from the atmosphere. MacIntire, Hardin, and Hester (1952) transplanted specimens of Spanish moss that contained about 27 ppm fluorine in ash when growing in Florida to sites in Tennessee at different distances from factories that emitted fluorine from their stacks. After 3 months the fluorine content of the transplanted specimens ranged from 100 ppm to as much as 2,418 ppm on a dry-weight basis, the amount in the specimen being inversely proportional to the distance of the sample from the factory. Shacklette and Cuthbert (1967, p. 43) reported that the iodine content of five Spanish moss specimens averaged 5 ppm in dry matter and ranged from 4 to 7 ppm.

Martinez, Nathany, and Dharmarajan (1971) reported lead analyses of eight Spanish moss samples from Baton Rouge, La., from sites near heavily traveled highways and from sites more distant from heavy traffic. They found that the lead concentration was greatest in the samples from sites near highways, with a maximum of 0.085 percent (850 ppm) in the dry samples, whereas samples from sites more distant from highways contained as little as 0.0051 percent (51 ppm). The percentages of ash obtained by burning the samples were not given; if the ash yield of these samples was similar to the mean ash content of samples analyzed in the present study (4.5 percent of dry weight), their maximum lead concentration would convert to about 18,700 ppm in ash, and their minimum lead concentrations would convert to about 1,122 ppm in ash. These values are well within the range (70 to 50,000 ppm lead in ash) given in figure 17 of the present report.

Benzing and Renfrow (1971) analyzed samples of *Tillandsia circinata* Schlecht., a small epiphyte closely related to Spanish moss. They reported concentrations of the nutritive elements calcium, magnesium, nitrogen, phosphorus, potassium, and sodium in samples of prefruiting, fruiting, and postfruiting plants from six sites in southern Florida. Although considerable variation was found in the concentrations of these elements among sites and growth stages, plants in the prefruiting stage generally contained more potassium, magnesium, and phosphorus than plants in other growth stages. Trends in growth-stage concentrations of the other elements were not pronounced, although the postfruiting stage at one sampling site contained the largest amounts of magnesium, calcium, and sodium.

Shacklette (1972) reported that the cadmium concentrations in the Spanish moss samples discussed in the present report ranged from 2.2 to 27 ppm in ash. The concentrations were thought to be related to the degree and kind of aerial pollution at the locations where the samples grew.

The ash yield and the concentrations of selected elements in the samples of Spanish moss collected in this study are presented in figures 5 to 35. Sample localities indicated by symbols in these figures are referred to by locality numbers in figure 3 and are described in table 1.

Concentrations of all elements but arsenic, mercury, and selenium (figs. 4–35) are given as parts per million in ash. The percentages of ash obtained by burning the dry samples are given in figure 5. The parts per million of an element in ash can be converted to approximate parts per million in the dry material by means of the following equation:

$$\text{Element (ppm) in dry plant} = \text{element (ppm) in ash} \times \frac{\text{ash content (percent)}}{100}$$

The elements beryllium, cerium, germanium, mercury, neodymium, niobium, selenium, and tin were not commonly detected in the samples. The localities where samples containing these elements were collected and the concentrations of the elements in the samples are shown in figure 4.

Some elements were looked for in all samples but were not found. These elements, analyzed by the semiquantitative emission spectrographic method, and their lower detection limits, in parts per million,

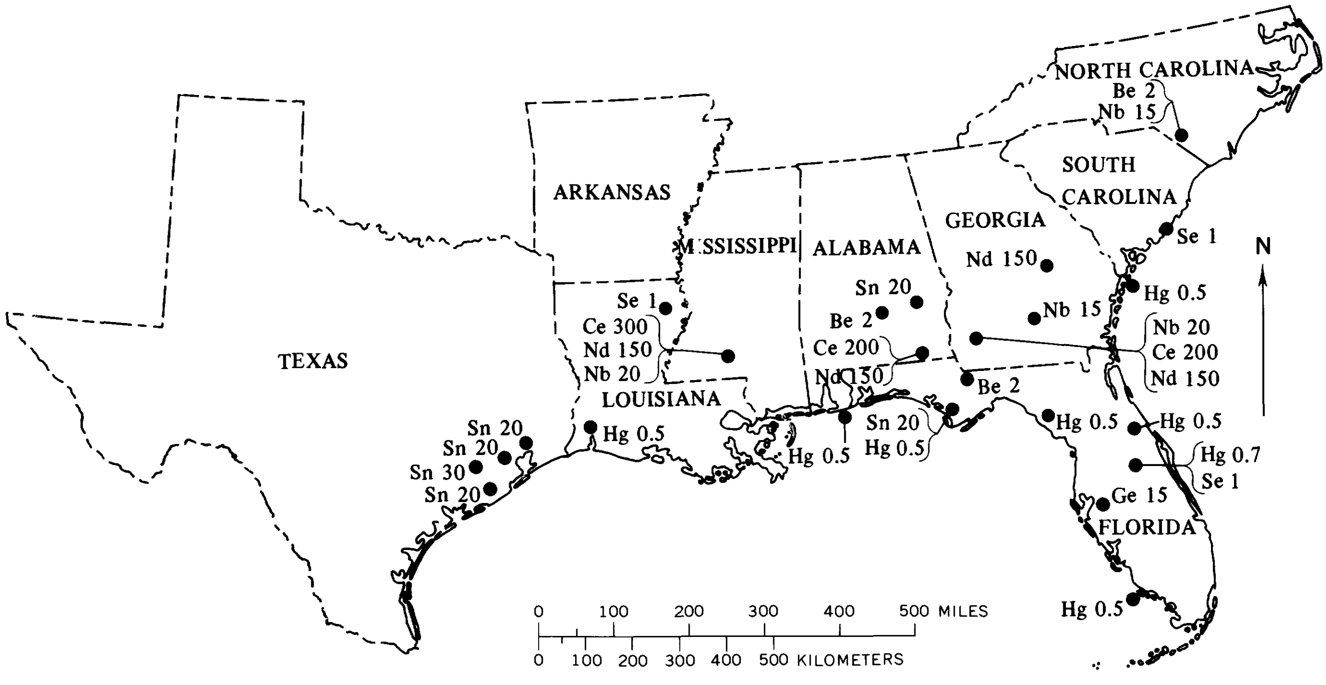
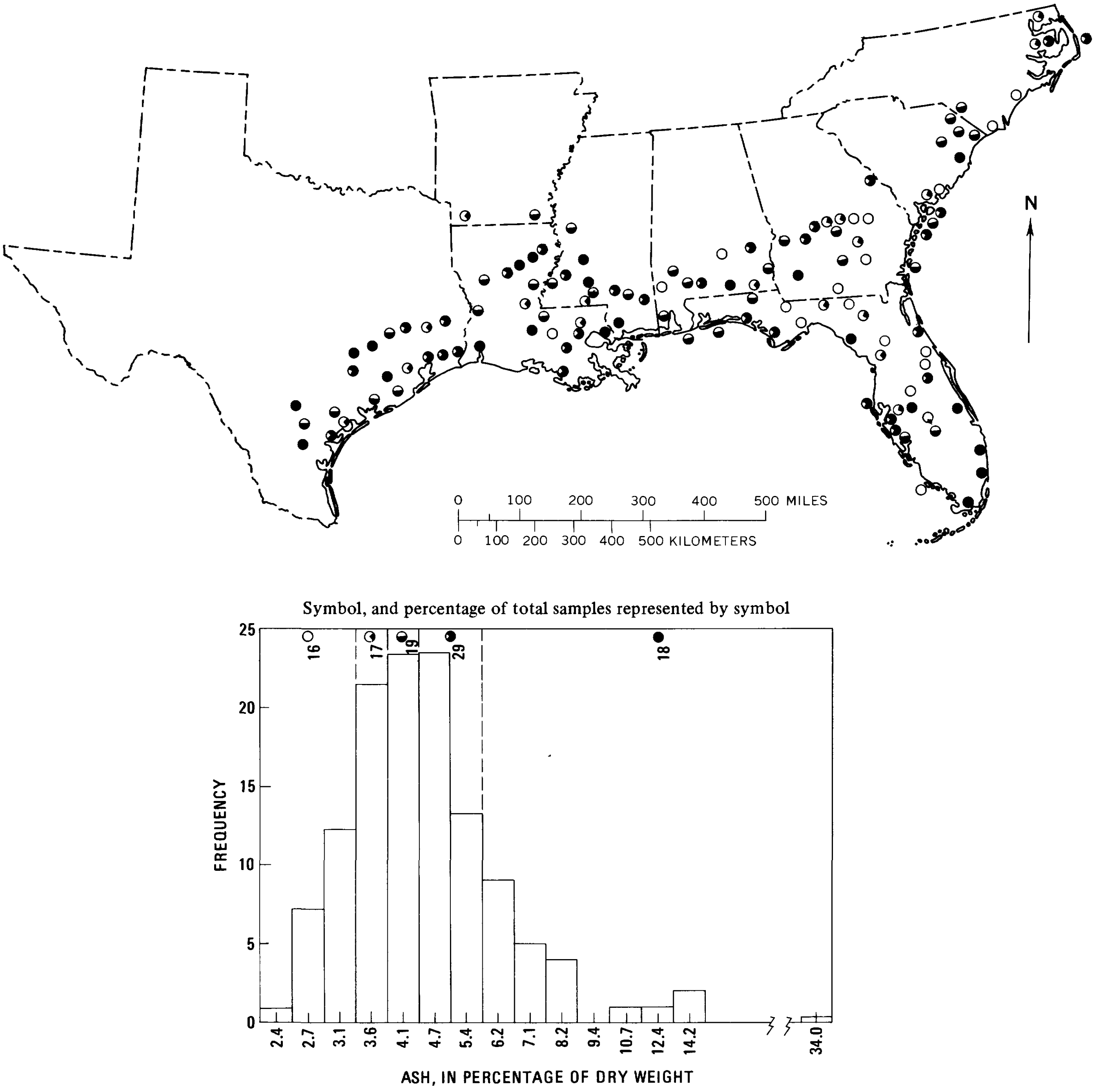


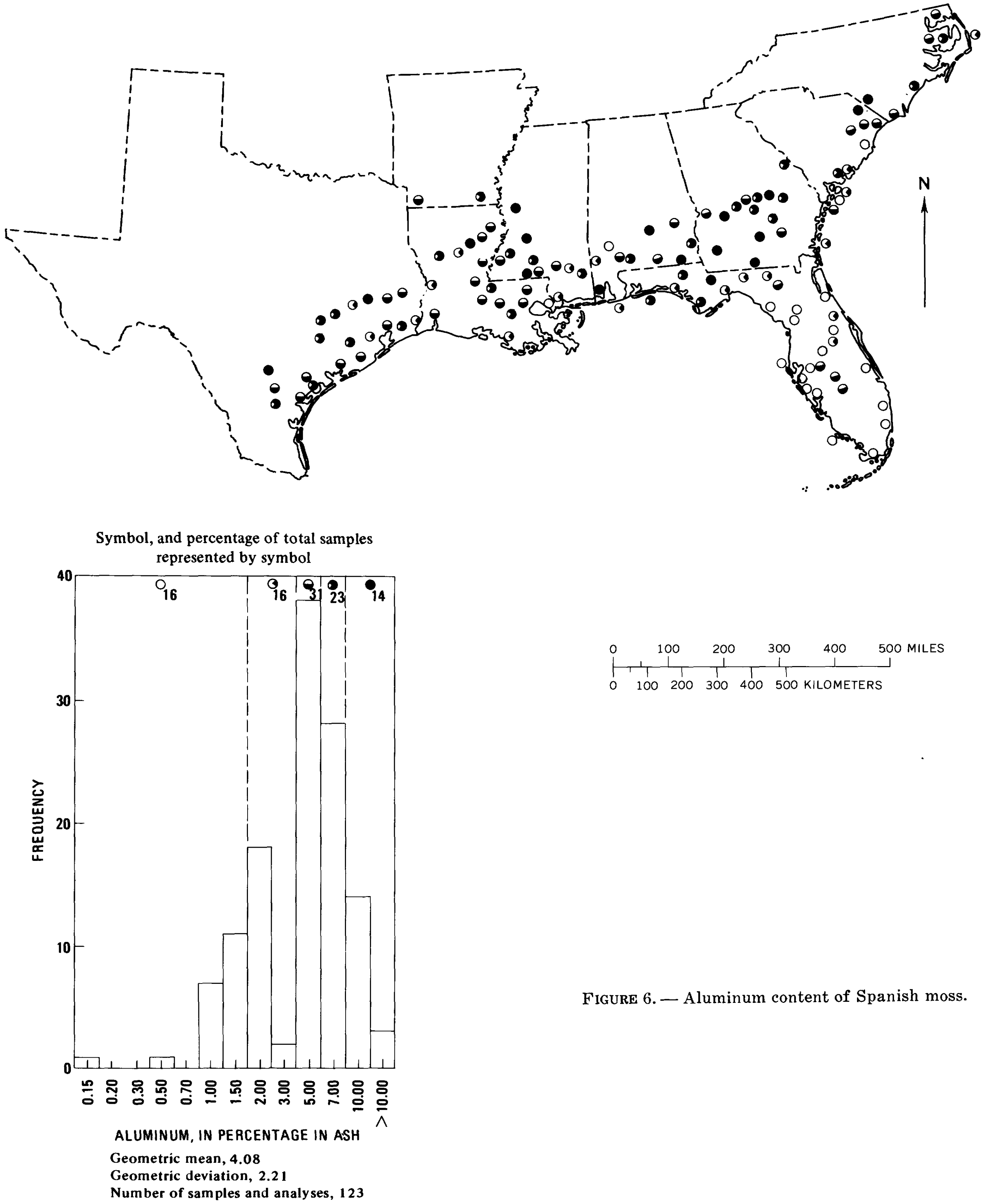
FIGURE 4. — Localities of Spanish moss samples containing elements not commonly detected and the concentrations of the elements. Mercury (Hg) and selenium (Se) values are expressed as parts per million in dry plant material; beryllium (Be), cerium (Ce), germanium (Ge), neodymium (Nd), niobium (Nb), and tin (Sn) values are expressed as parts per million in ash.

are as follows: Gold, 40; hafnium, 200; indium, 20; platinum, 60; palladium, 2; rhenium, 60; tantalum, 400; tellurium, 4,000; thallium, 100; thorium, 400; and uranium, 1,000. If lanthanum or cerium was found in a sample, the following elements, with their stated lower detection limits, were specifically looked for in the same sample: Dysprosium, 100; erbium, 100; gadolinium, 100; holmium, 40; lutetium, 60; terbium, 600; and thulium, 40. Though looked for, none of these elements was found.



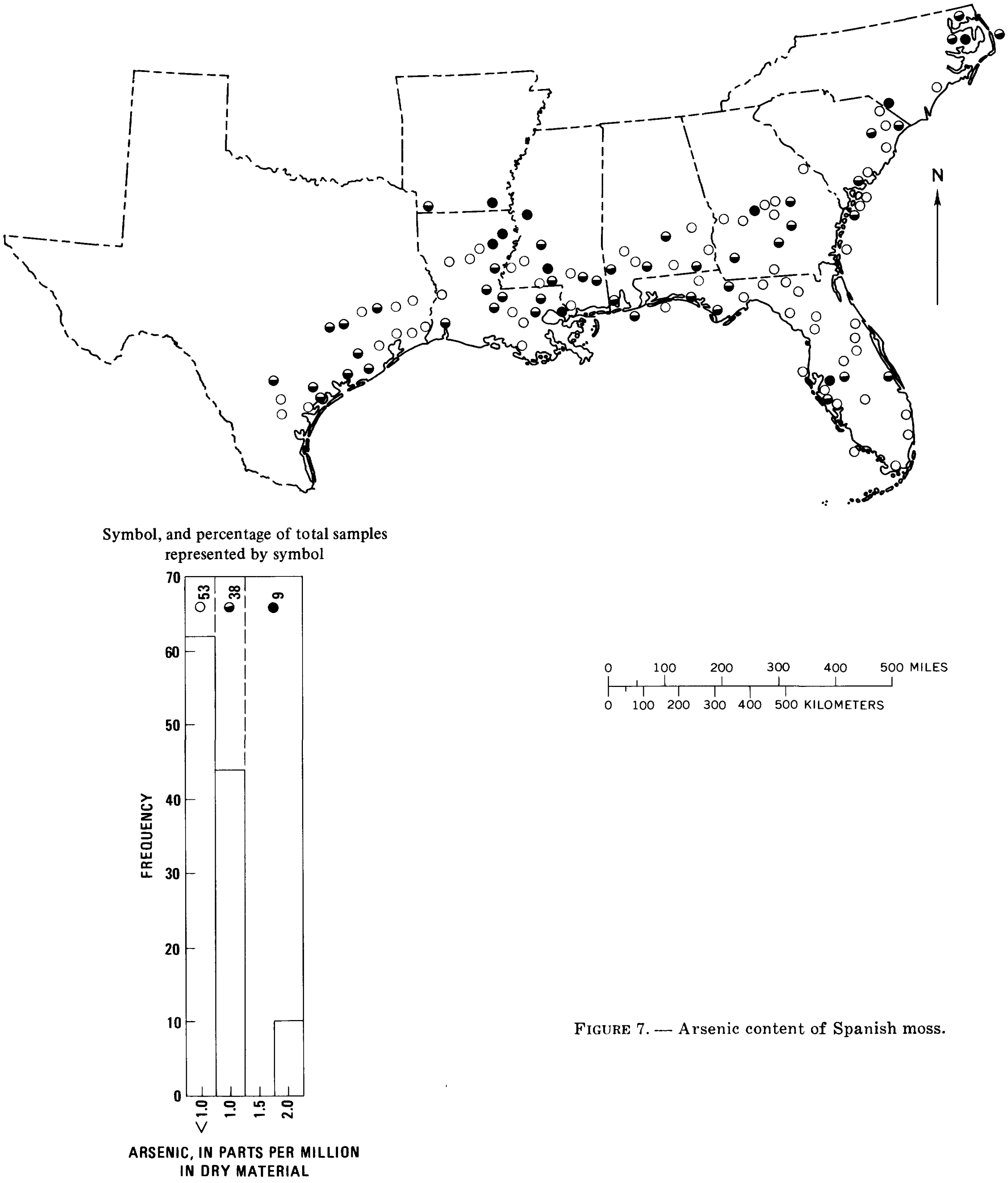
Geometric mean, 4.6
Geometric deviation, 1.46
Number of samples and analyses, 123

FIGURE 5. — Ash yield of Spanish moss.



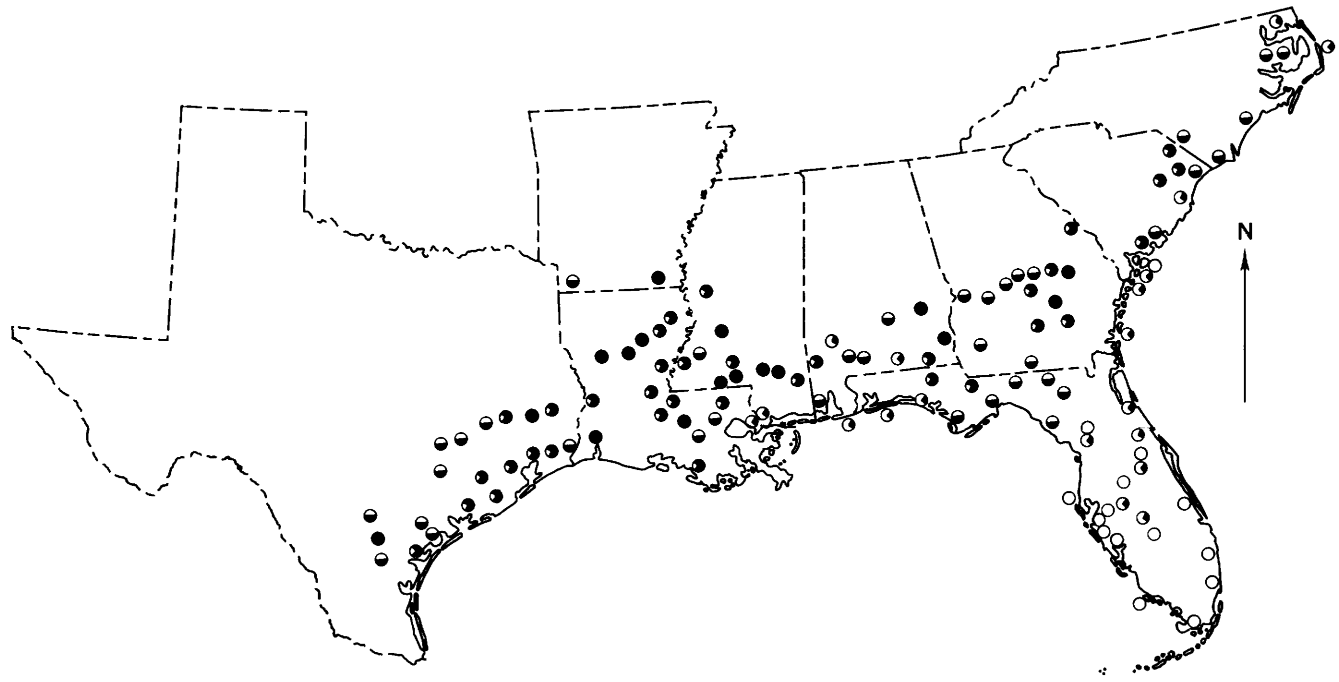
Geometric mean, 4.08
Geometric deviation, 2.21
Number of samples and analyses, 123

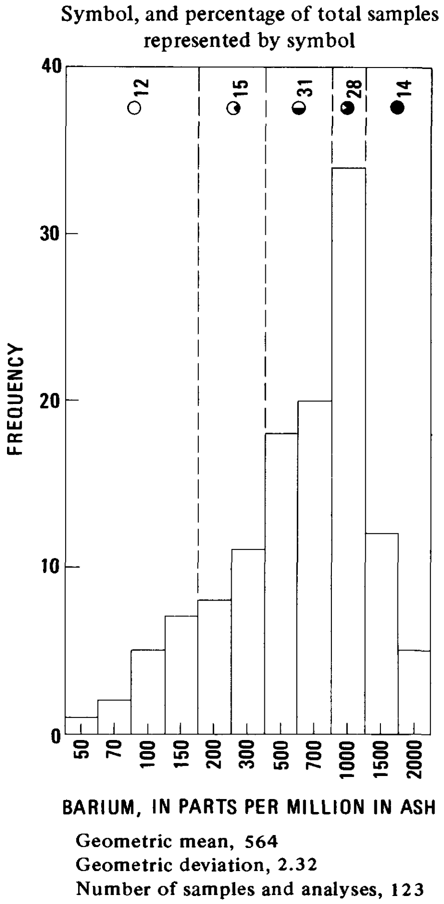
FIGURE 6. — Aluminum content of Spanish moss.



Geometric mean, 0.79
Geometric deviation, 1.55
Number of samples and analyses, 116

FIGURE 7. — Arsenic content of Spanish moss.





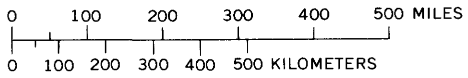
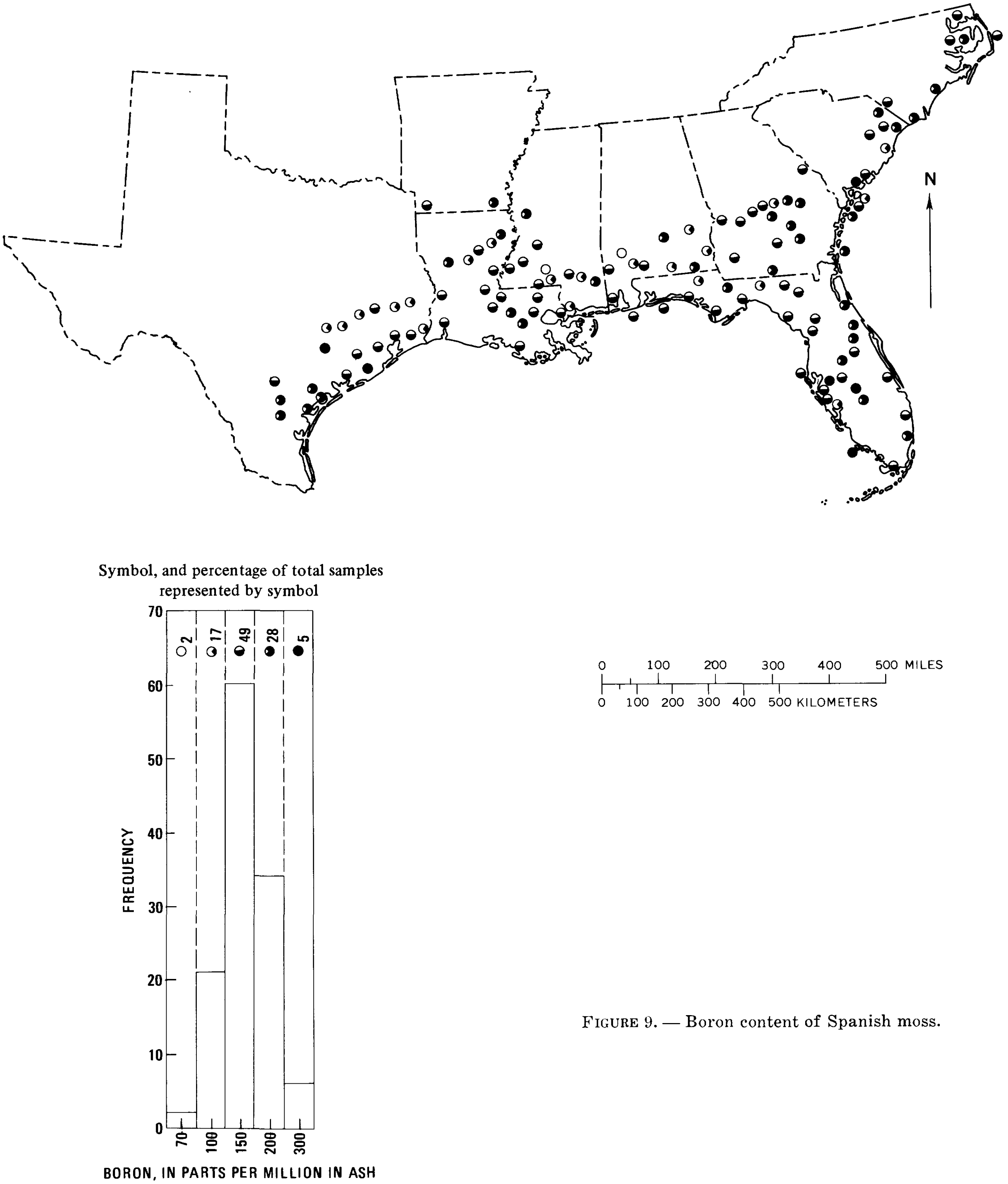
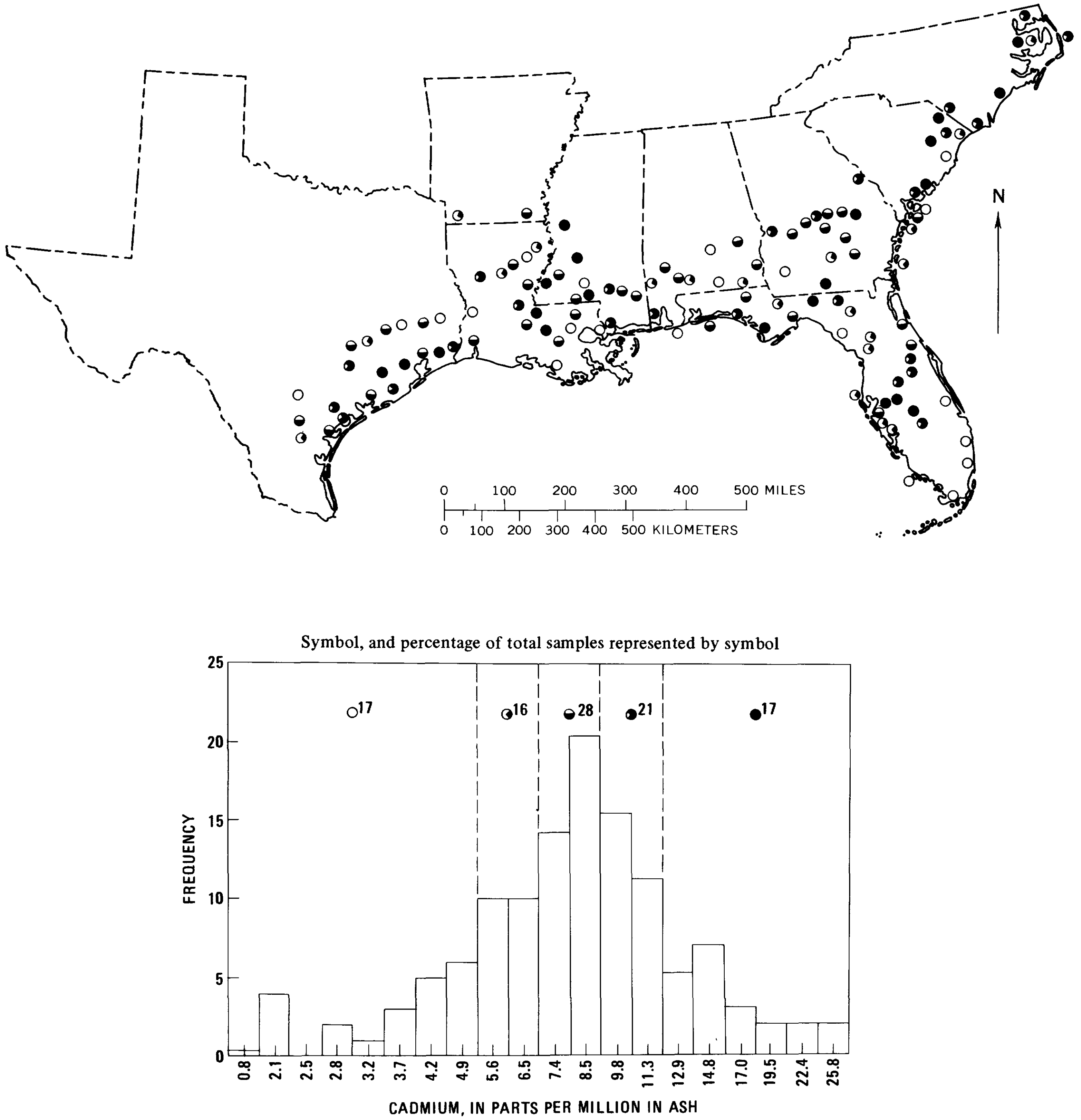


FIGURE 8. — Barium content of Spanish moss.



Geometric mean, 150
Geometric deviation, 1.34
Number of samples and analyses, 123

FIGURE 9. — Boron content of Spanish moss.



Geometric mean, 7.9
Geometric deviation, 1.65
Number of samples and analyses, 122

FIGURE 10. — Cadmium content of Spanish moss.

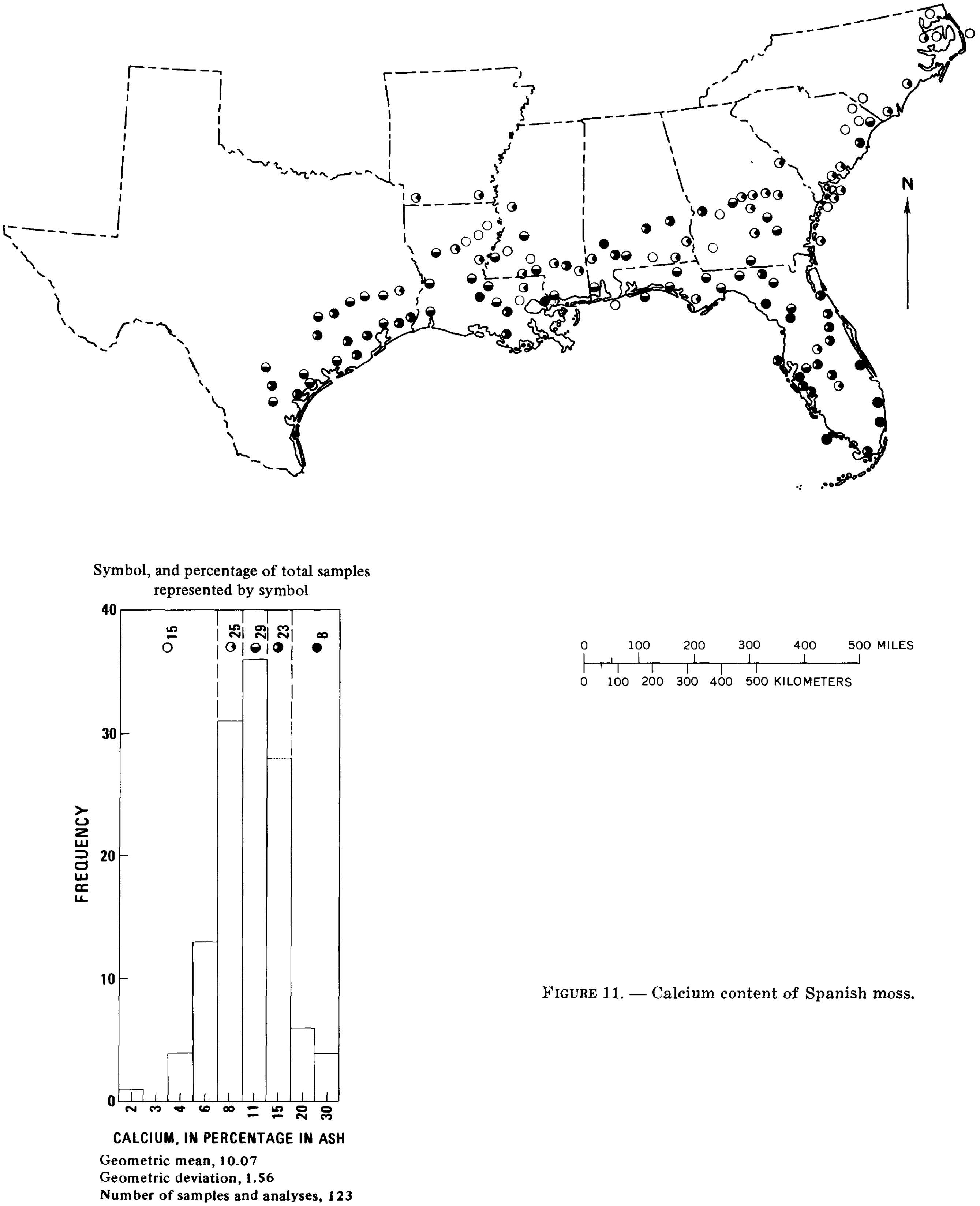
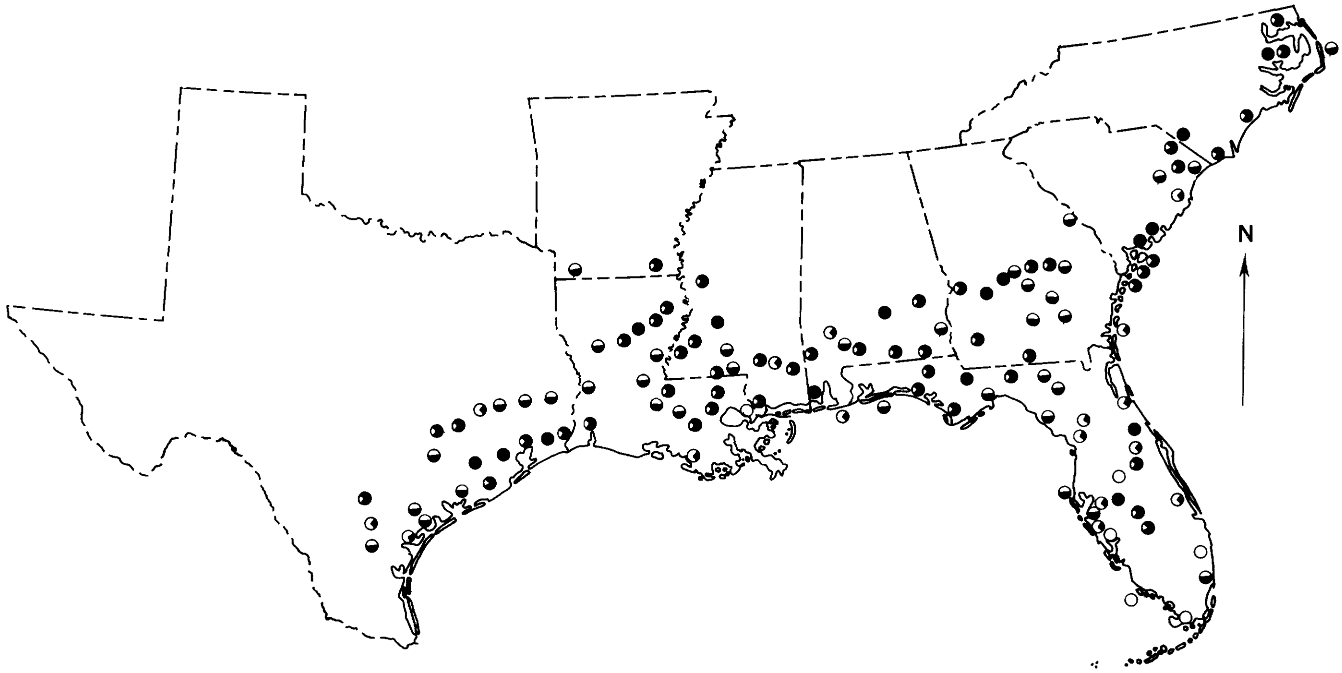
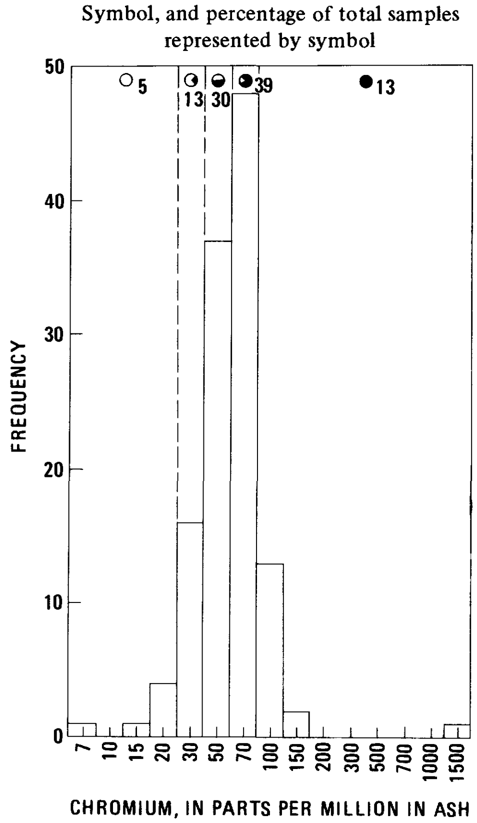


FIGURE 11. — Calcium content of Spanish moss.





Geometric mean, 57
Geometric deviation, 1.73
Number of samples and analyses, 123

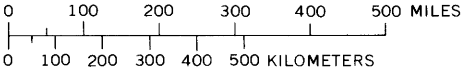
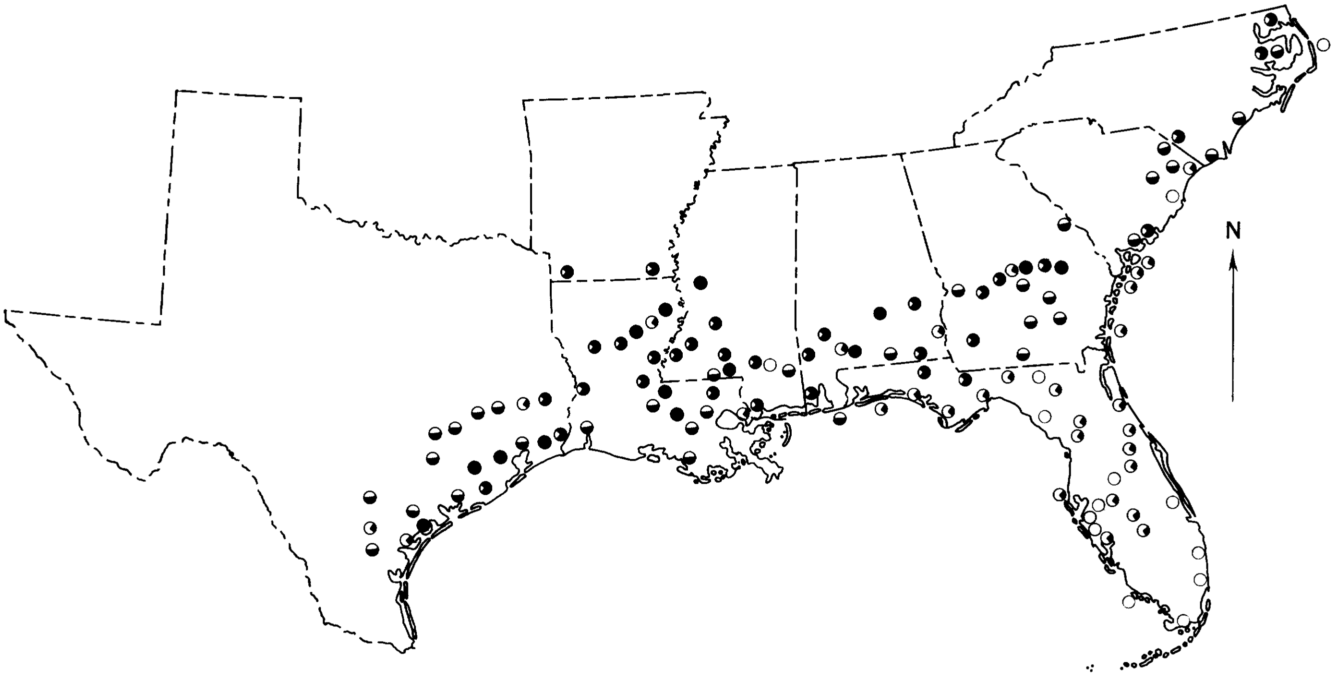
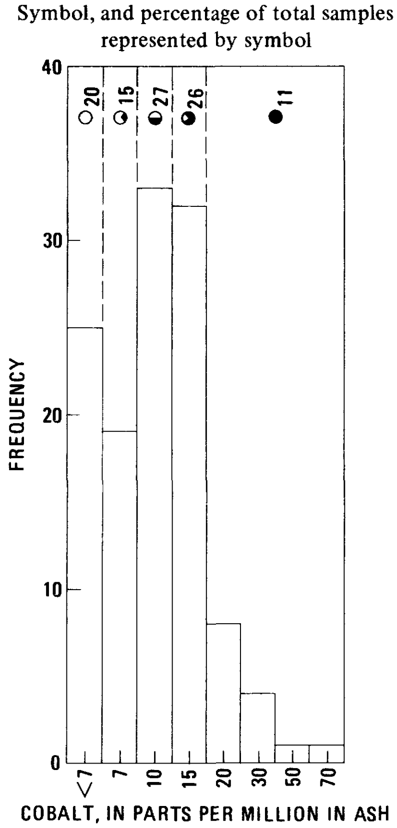


FIGURE 12. — Chromium content of Spanish moss.





Geometric mean, 9.8
Geometric deviation, 1.83
Number of samples and analyses, 123

FIGURE 13. — Cobalt content of Spanish moss.

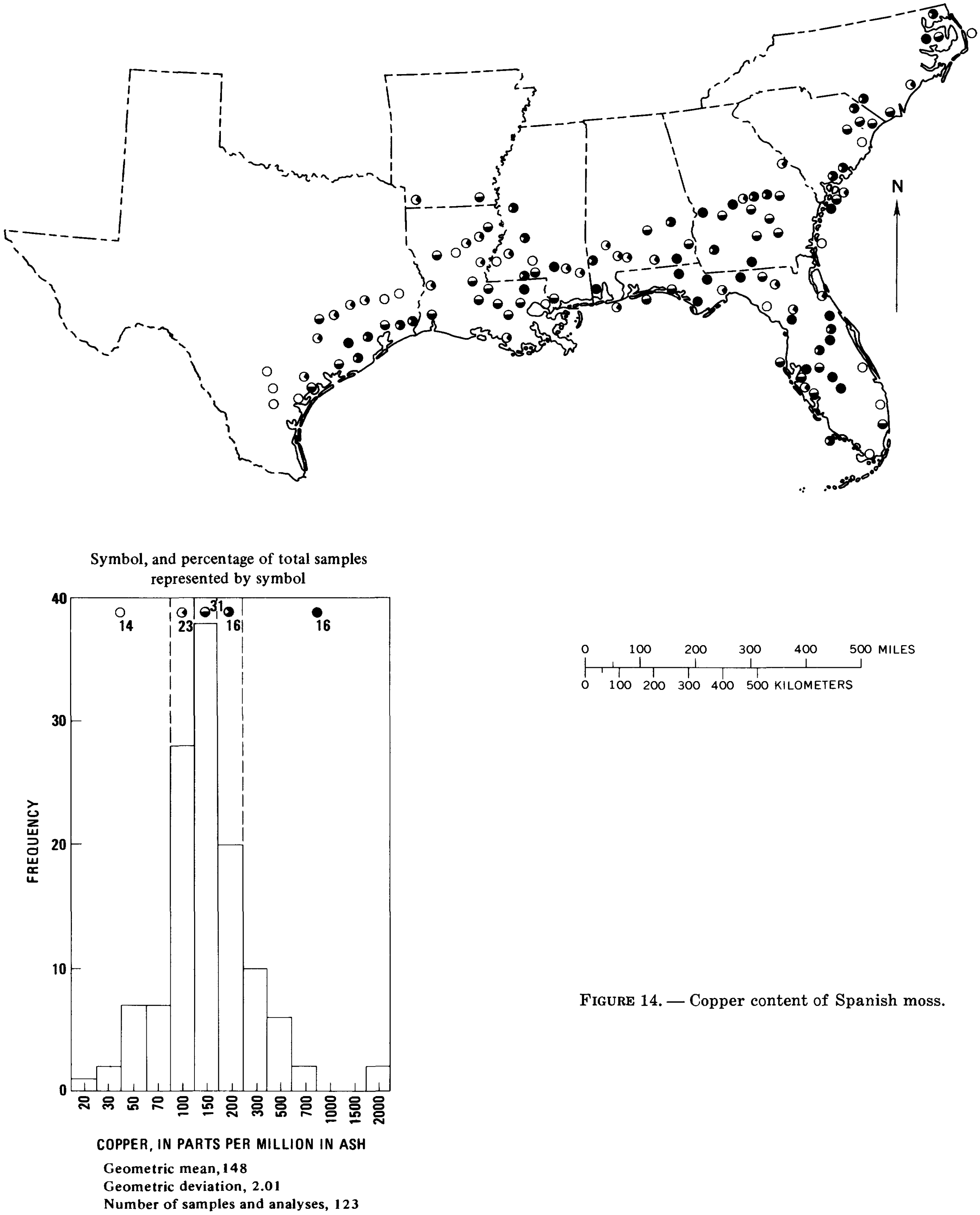
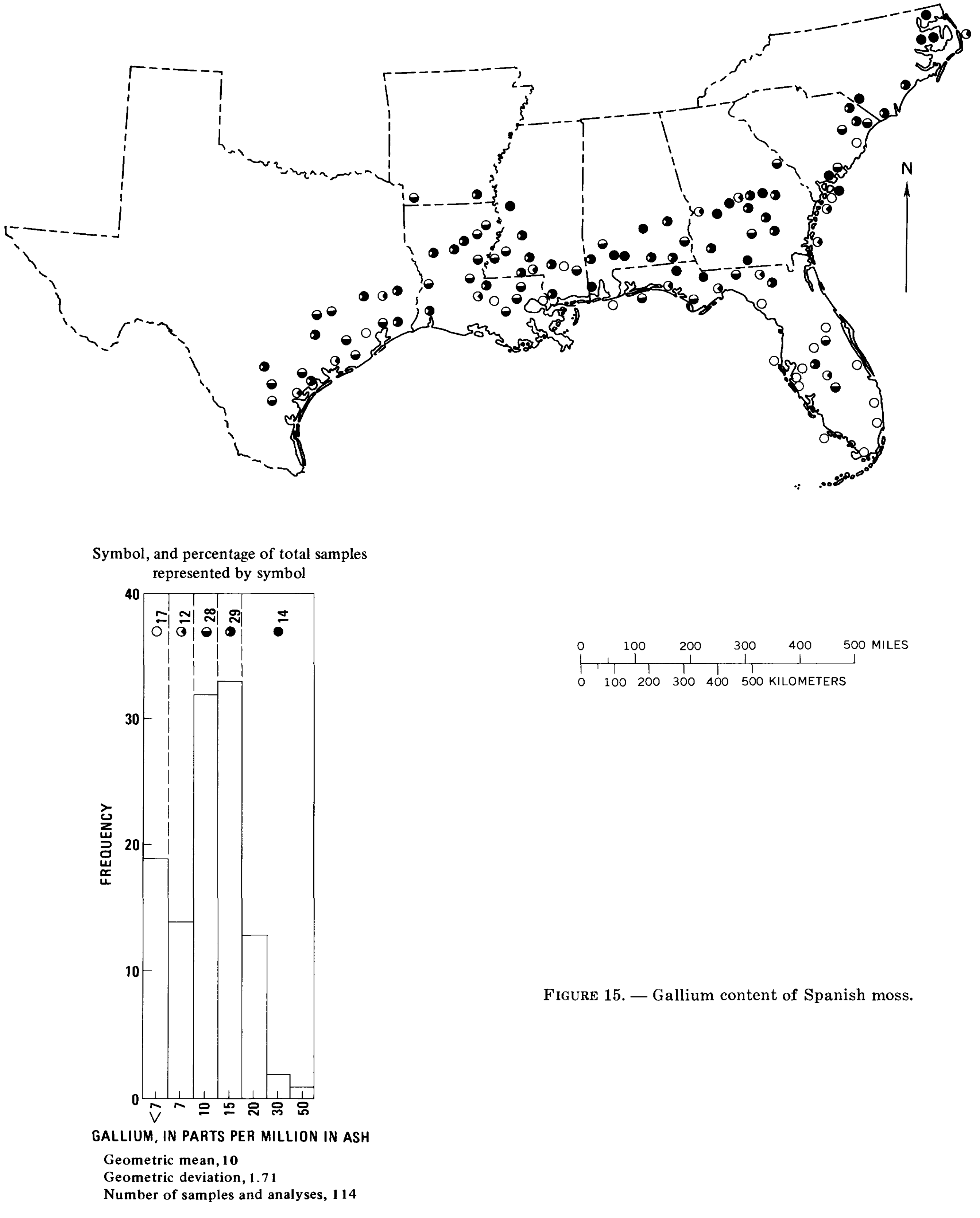
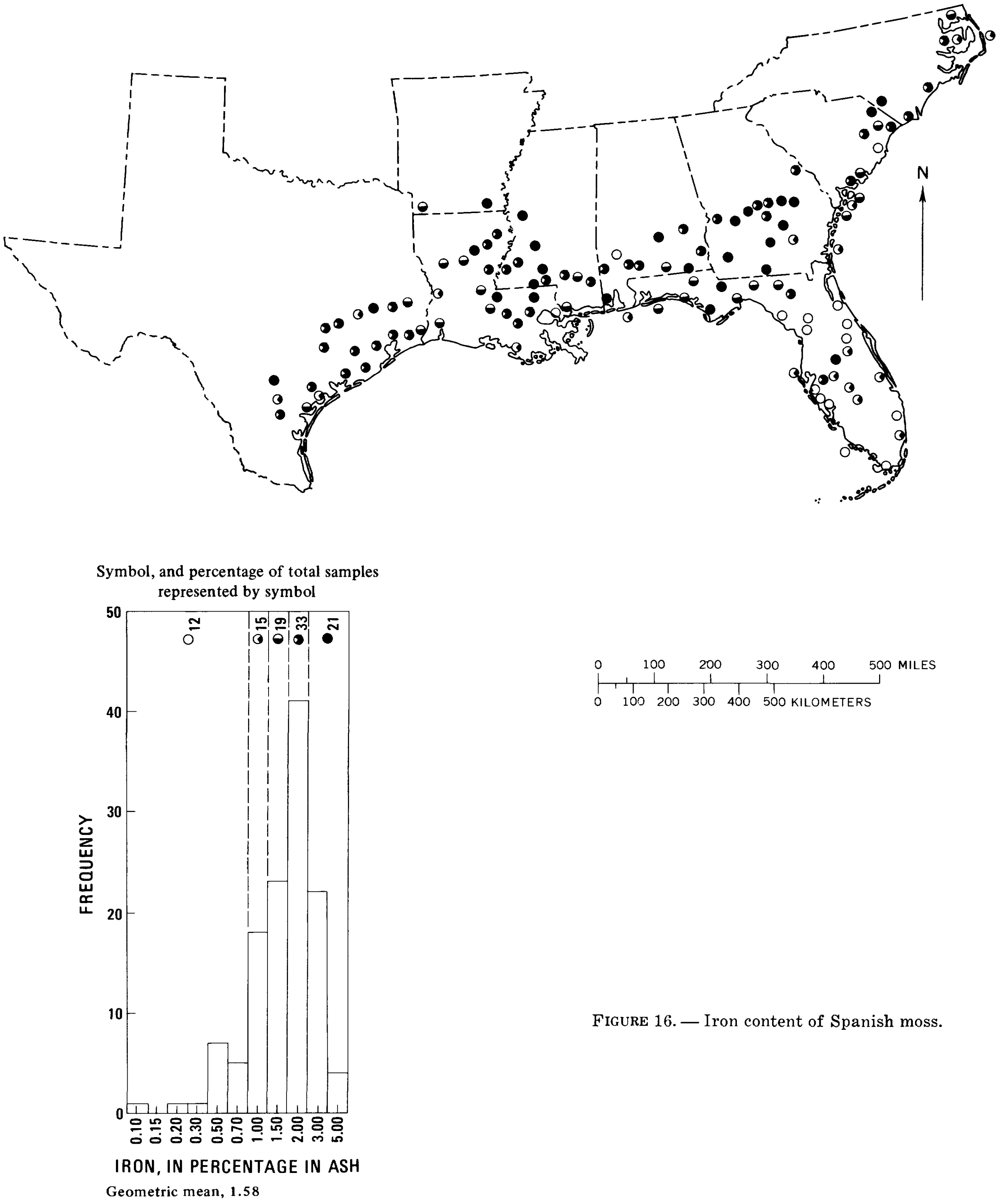


FIGURE 14. — Copper content of Spanish moss.



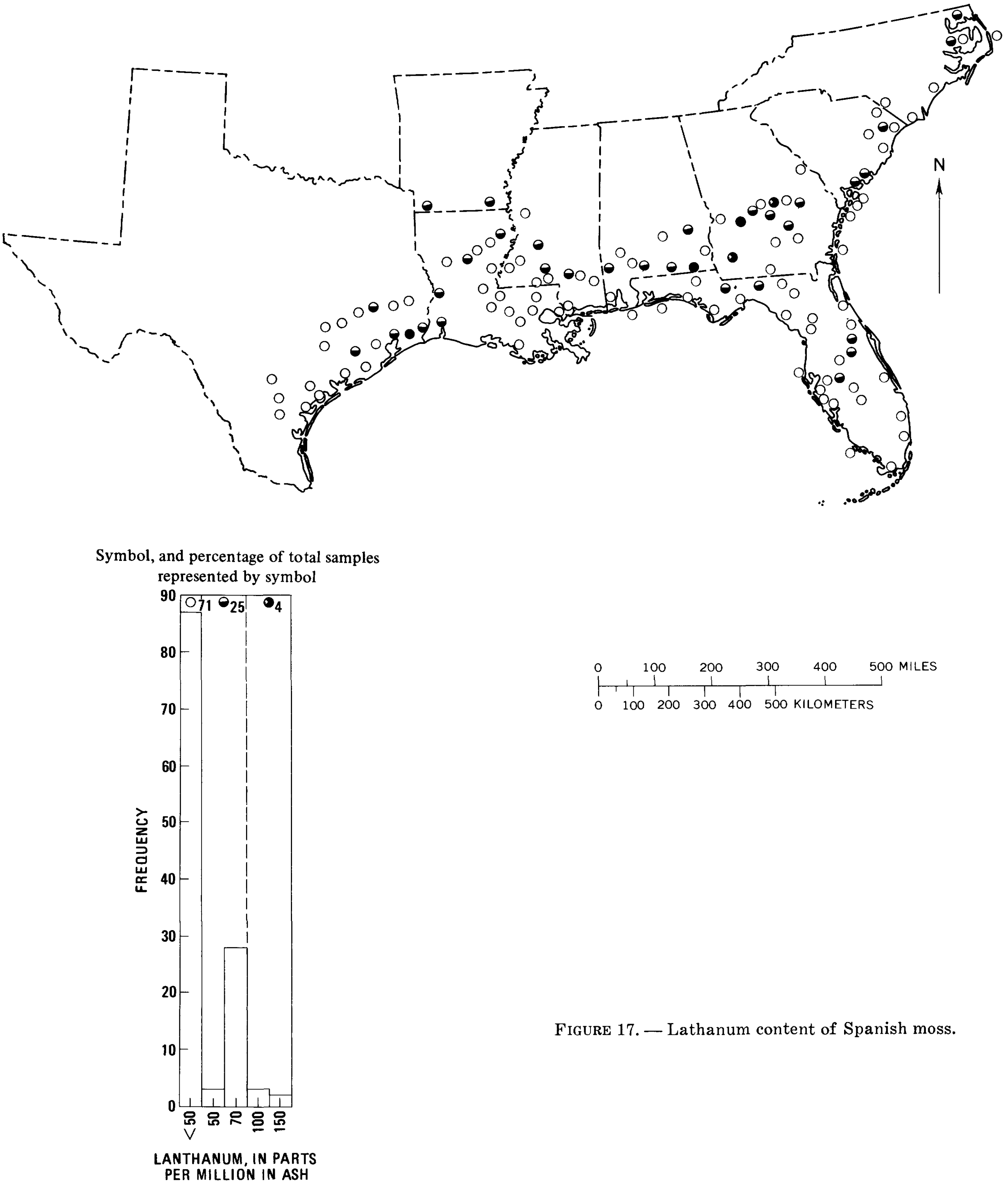
Geometric mean, 10
Geometric deviation, 1.71
Number of samples and analyses, 114

FIGURE 15. — Gallium content of Spanish moss.



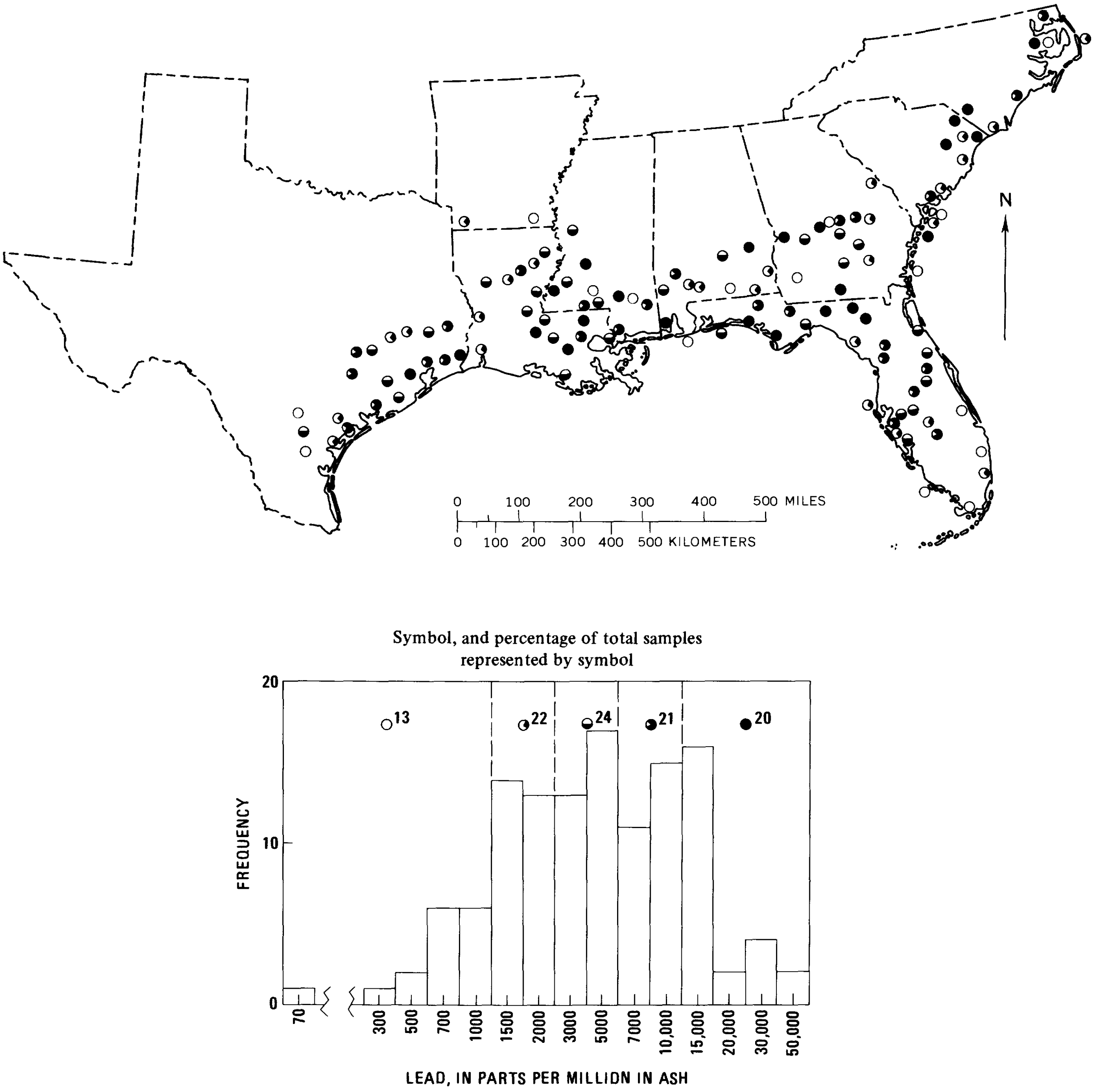
Geometric mean, 1.58
Geometric deviation, 1.87
Number of samples and analyses, 123

FIGURE 16. — Iron content of Spanish moss.



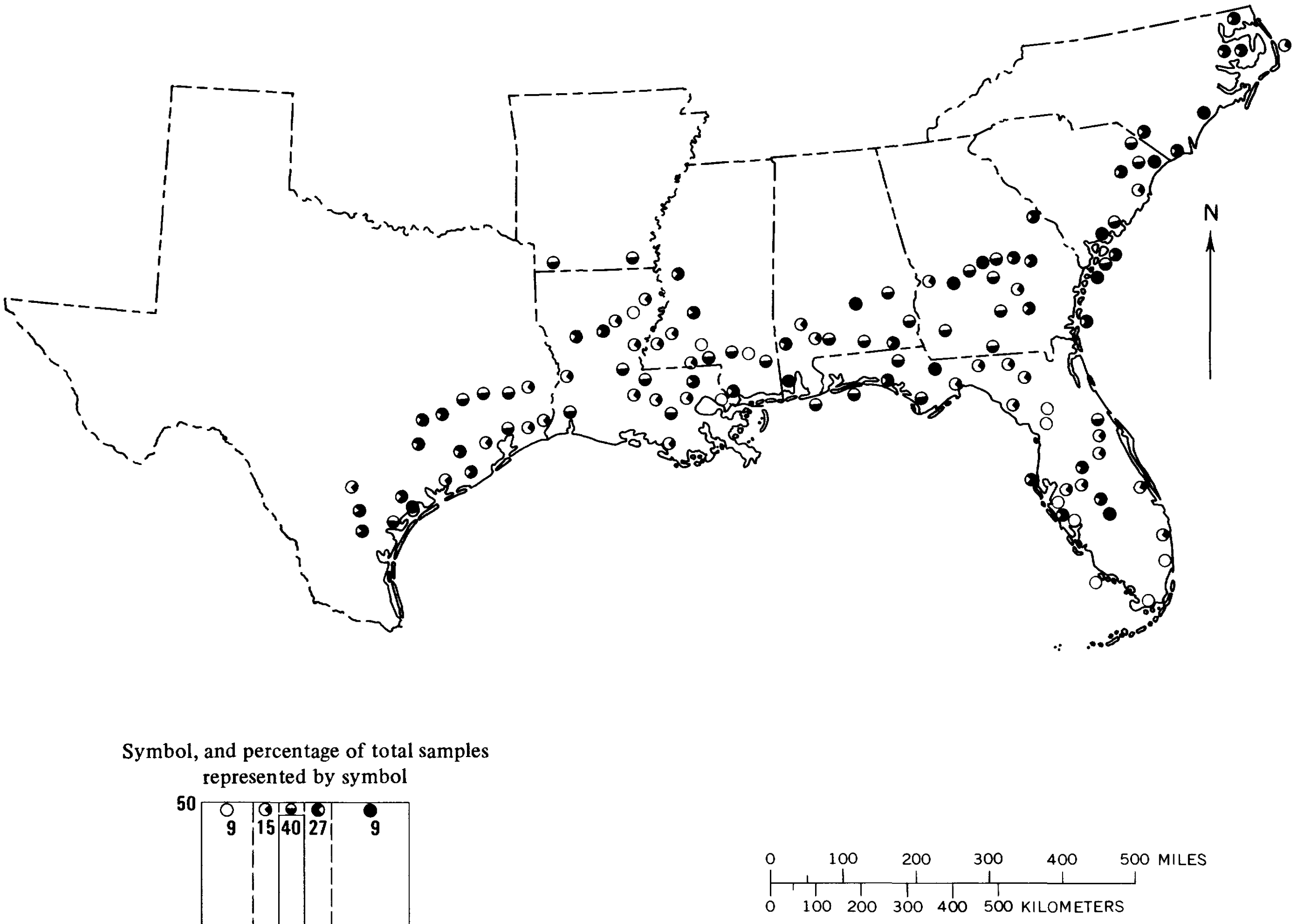
Geometric mean, 14
Geometric deviation, 3.80
Number of samples and analyses, 123

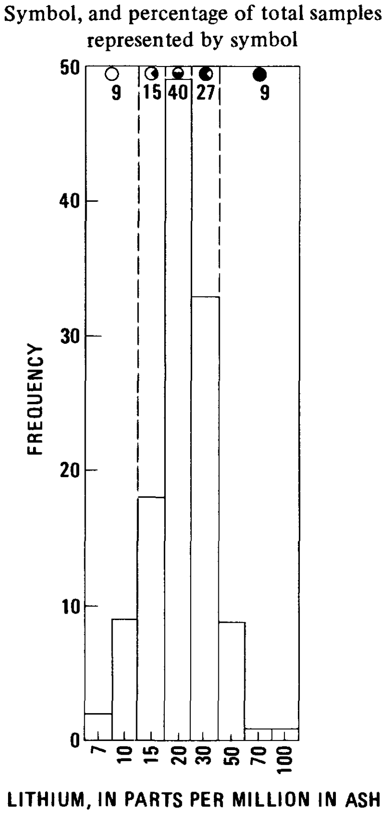
FIGURE 17. — Lathanum content of Spanish moss.



Geometric mean, 4,170
Geometric deviation, 3.16
Number of samples and analyses, 123

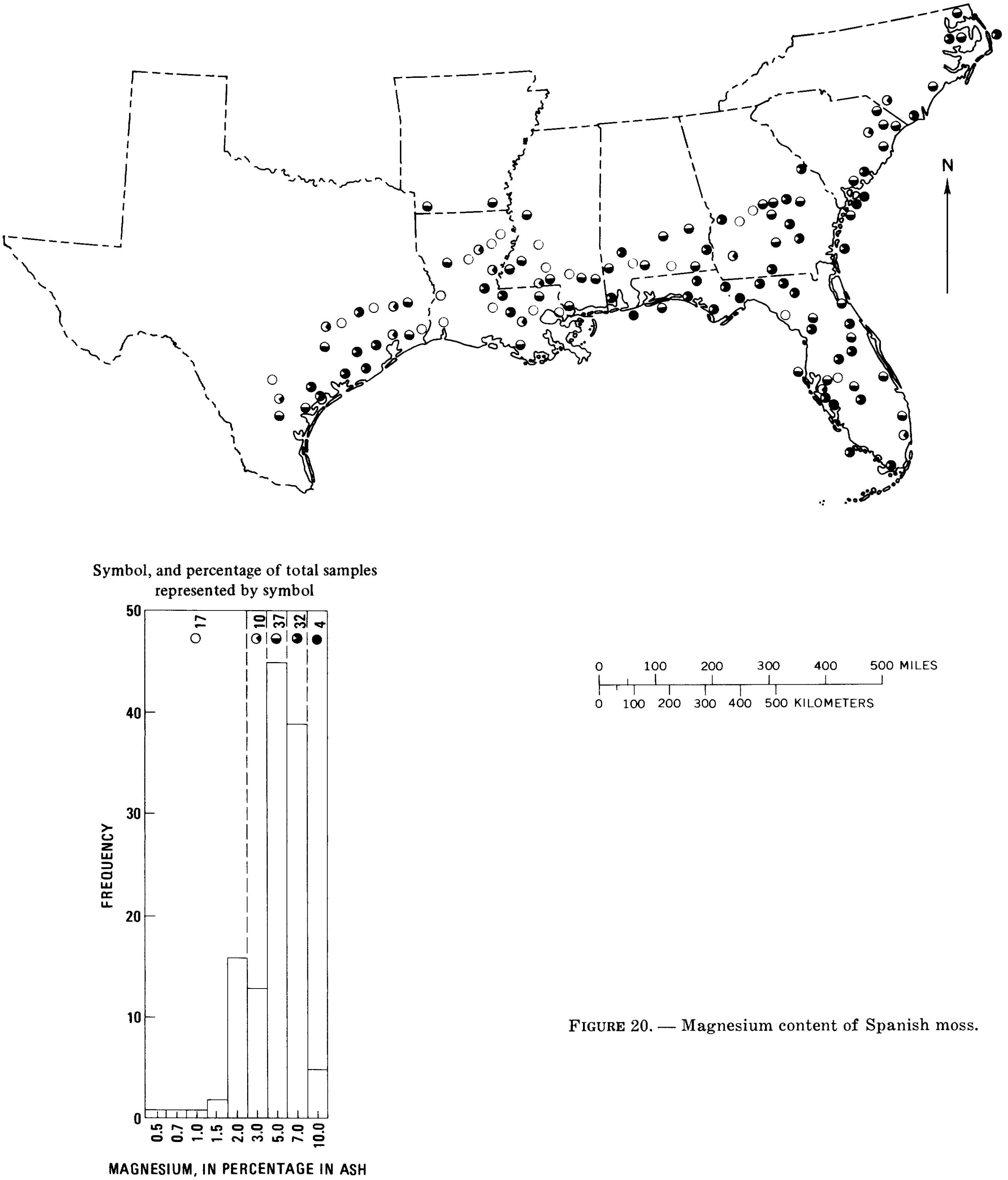
FIGURE 18. — Lead content of Spanish moss.





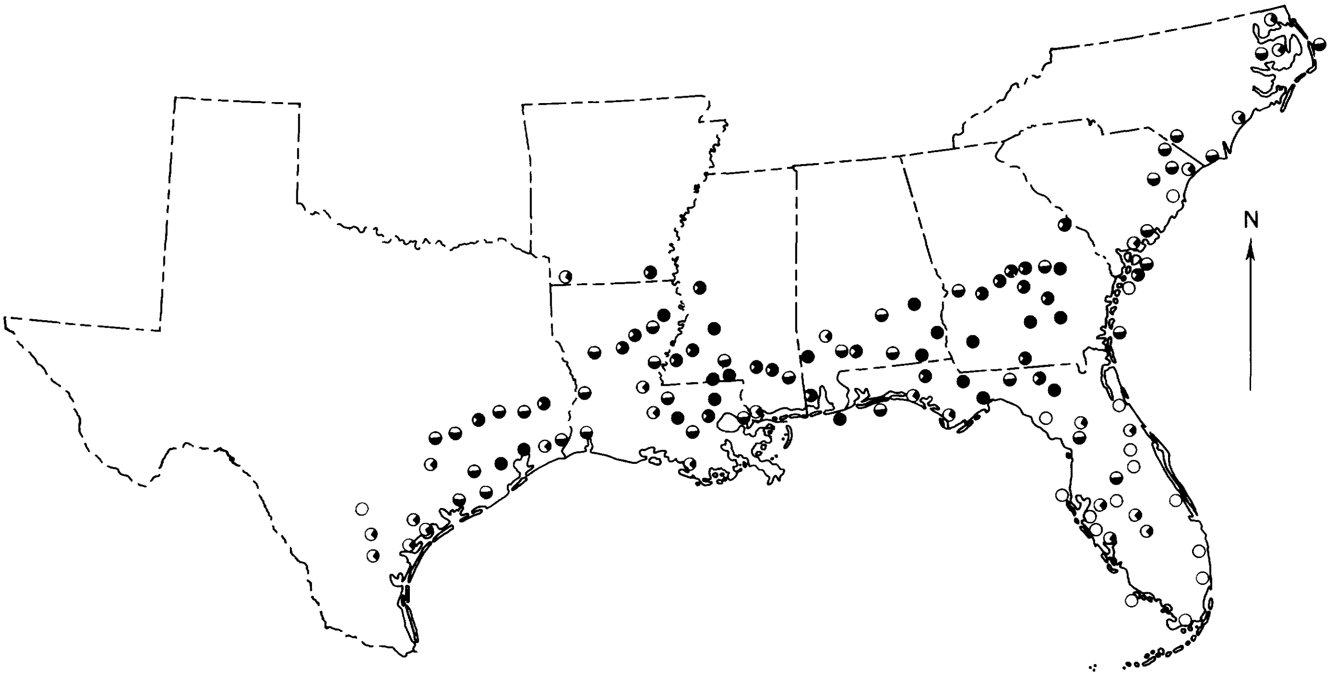
Geometric mean, 22.4
Geometric deviation, 1.53
Number of samples and analyses, 122

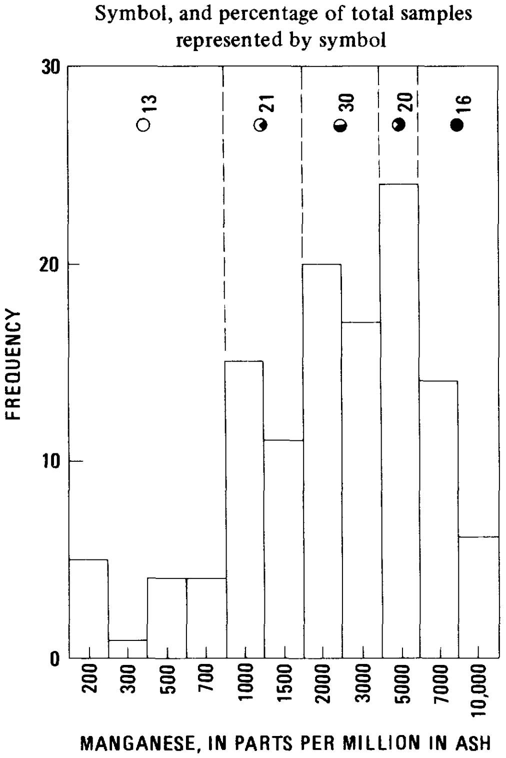
FIGURE 19. — Lithium content of Spanish moss.



Geometric mean, 4.5
Geometric deviation, 1.73
Number of samples and analyses, 123

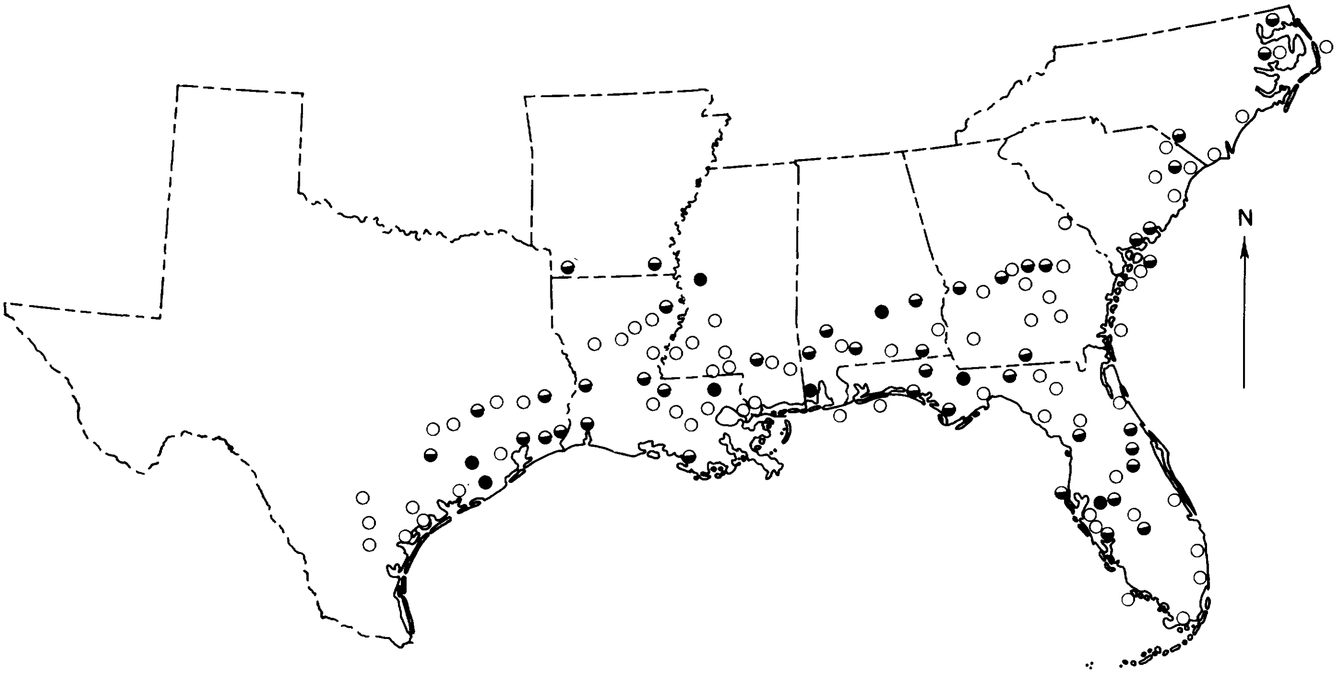
FIGURE 20. — Magnesium content of Spanish moss.

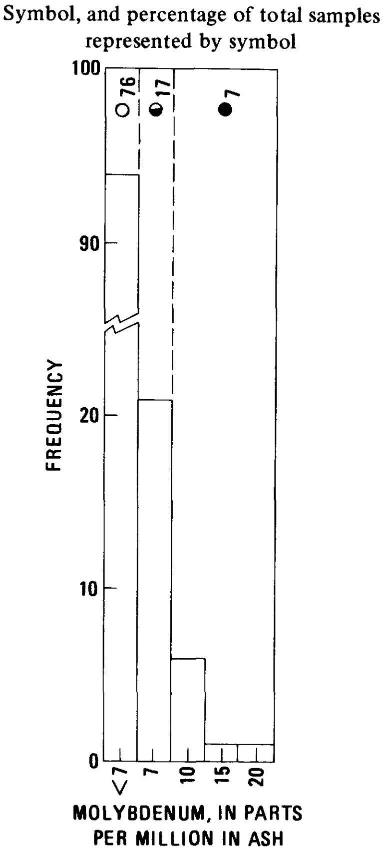




Geometric mean, 2,300
Geometric deviation, 2.60
Number of samples and analyses, 123

FIGURE 21. — Manganese content of Spanish moss.





Geometric mean, 3.7
Geometric deviation, 1.80
Number of samples and analyses, 123

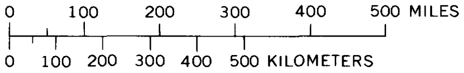
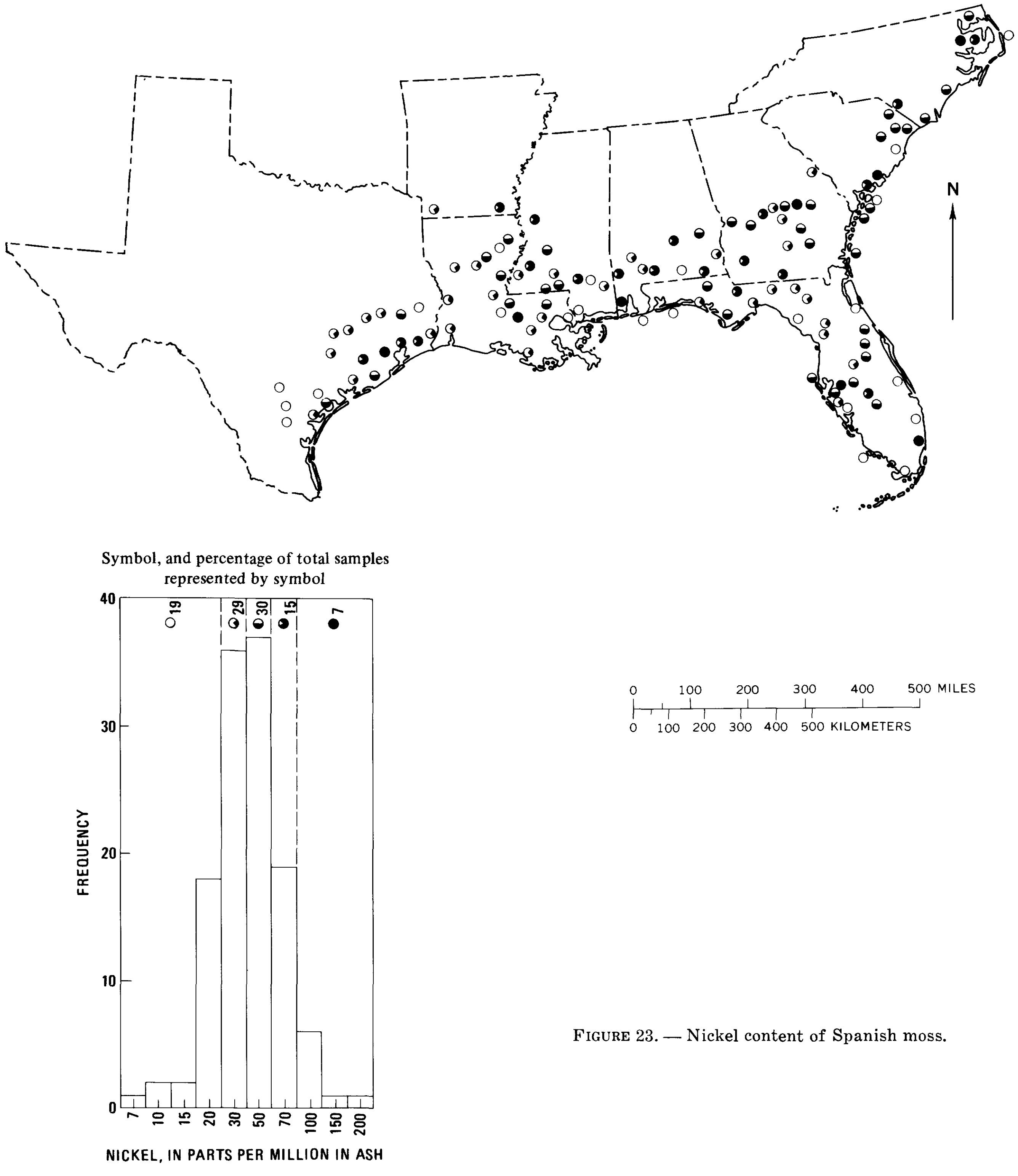


FIGURE 22. — Molybdenum content of Spanish moss.



Geometric mean, 39
Geometric deviation, 1.74
Number of samples and analyses, 123

FIGURE 23. — Nickel content of Spanish moss.

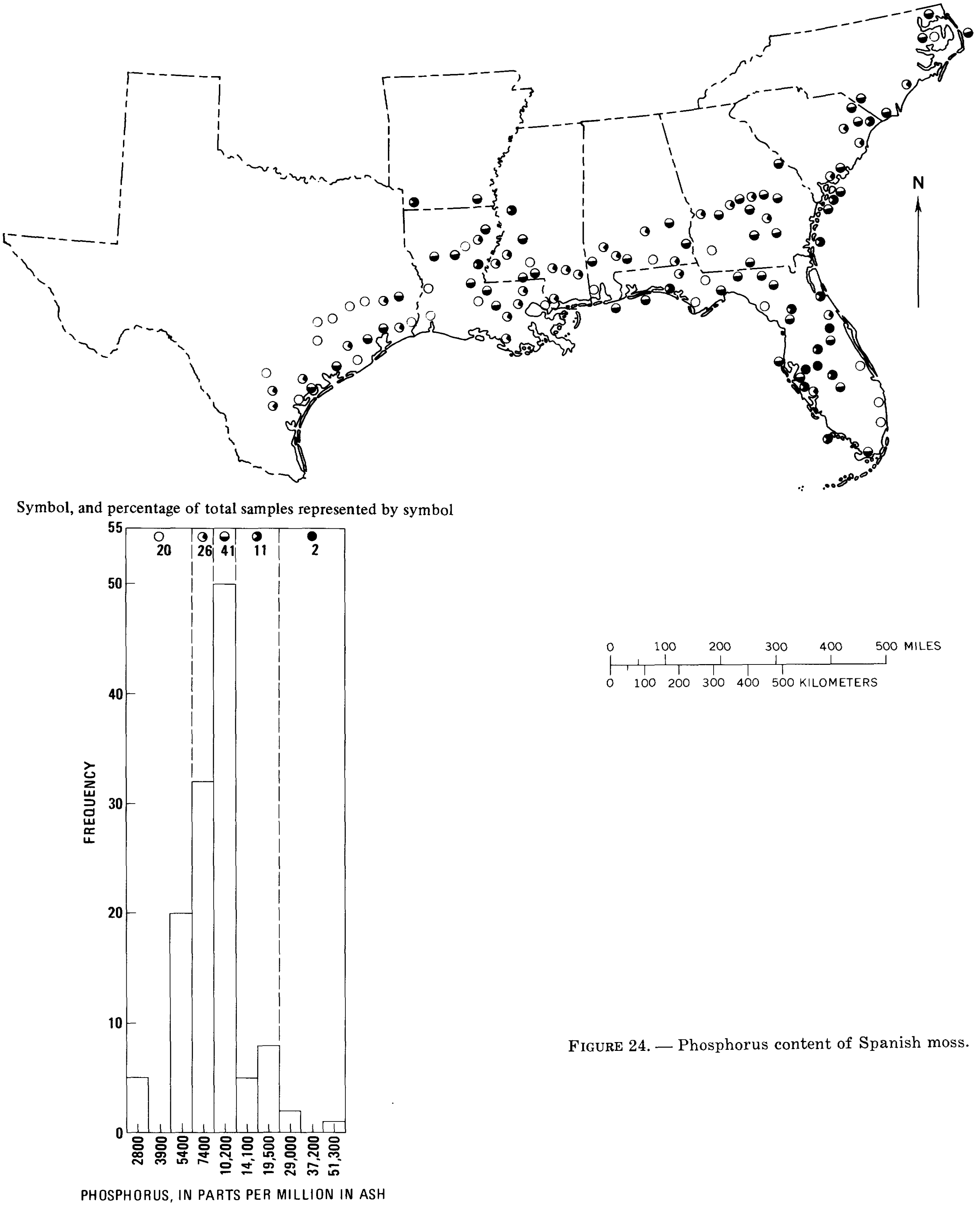
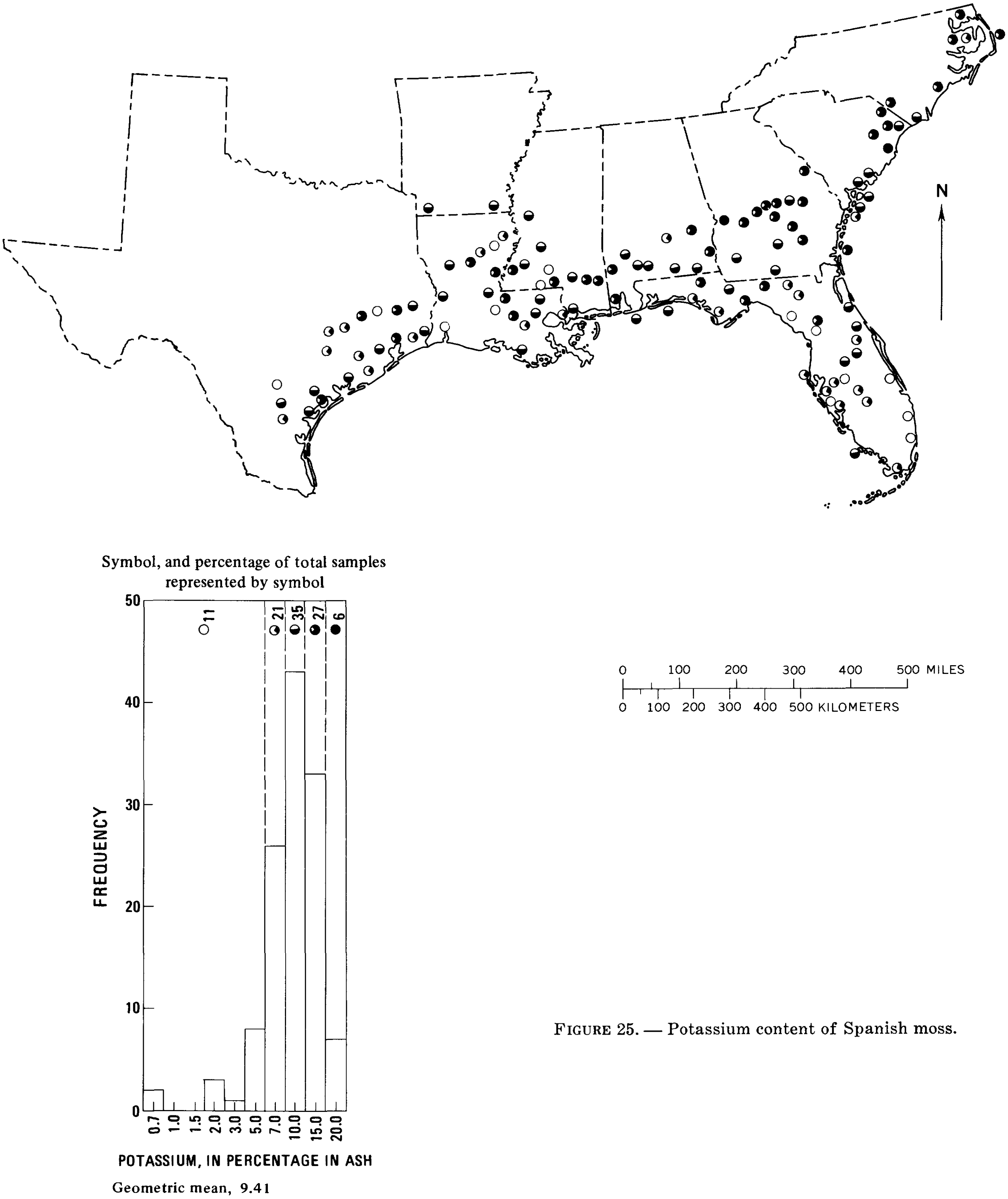


FIGURE 24. — Phosphorus content of Spanish moss.

Geometric mean, 9,371
Geometric deviation, 1.55
Number of samples and analyses, 123



Geometric mean, 9.41
Geometric deviation, 1.74
Number of samples and analyses, 123

FIGURE 25. — Potassium content of Spanish moss.

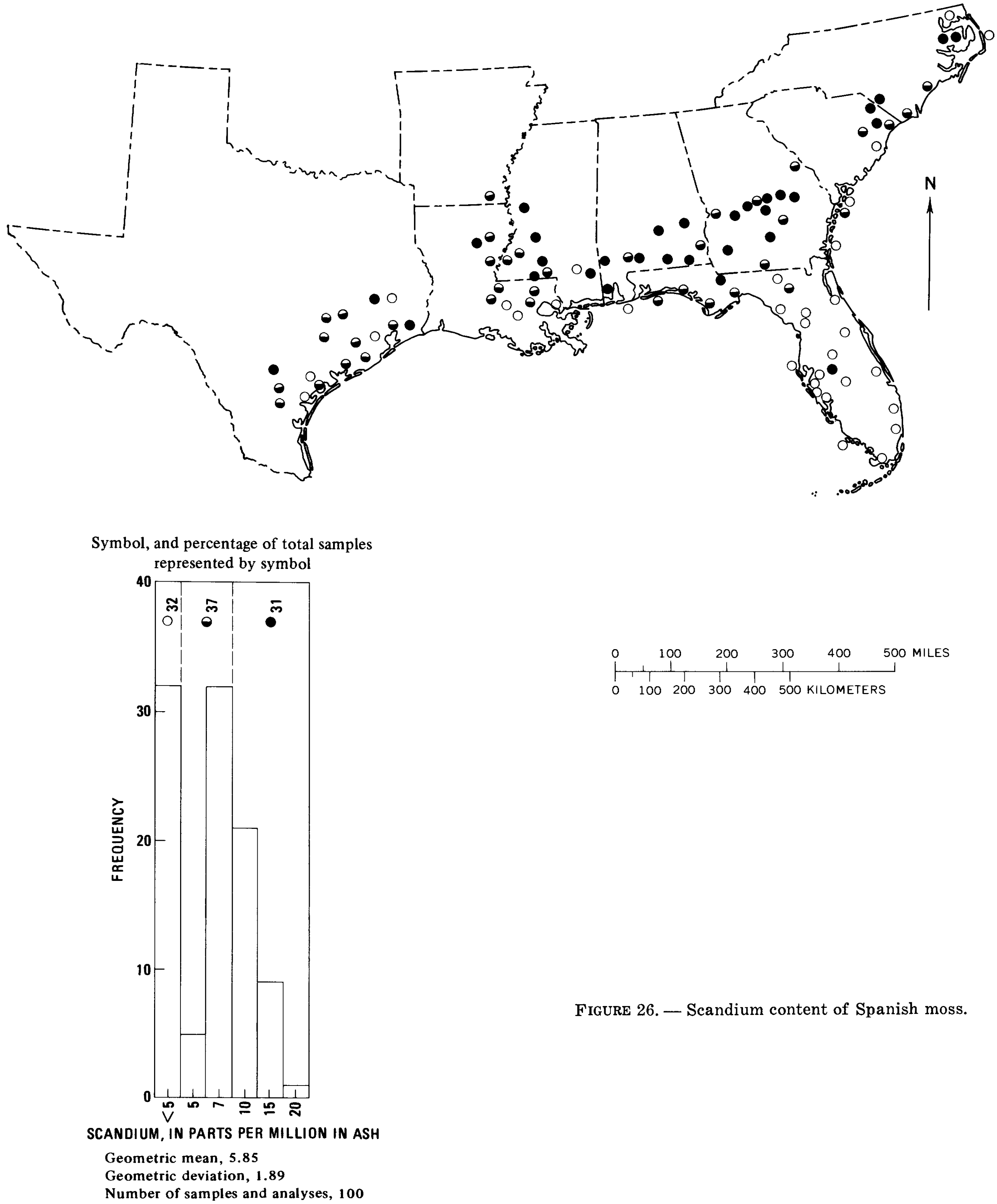
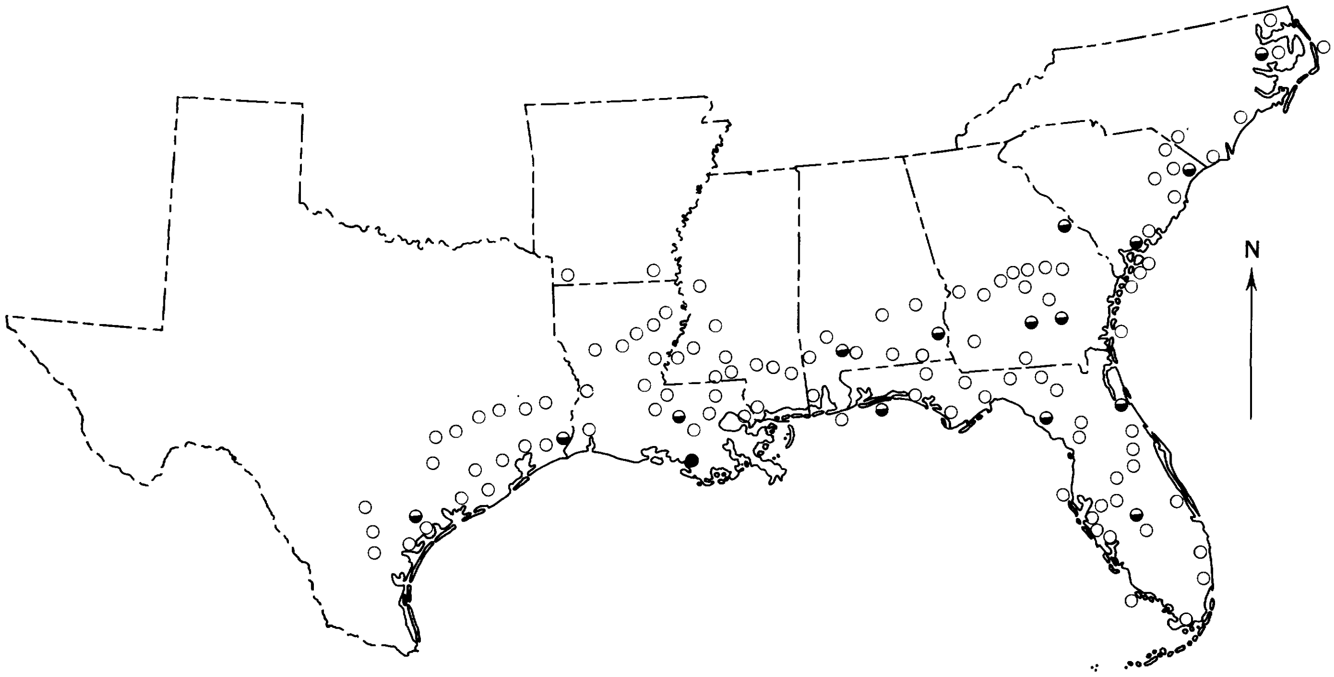
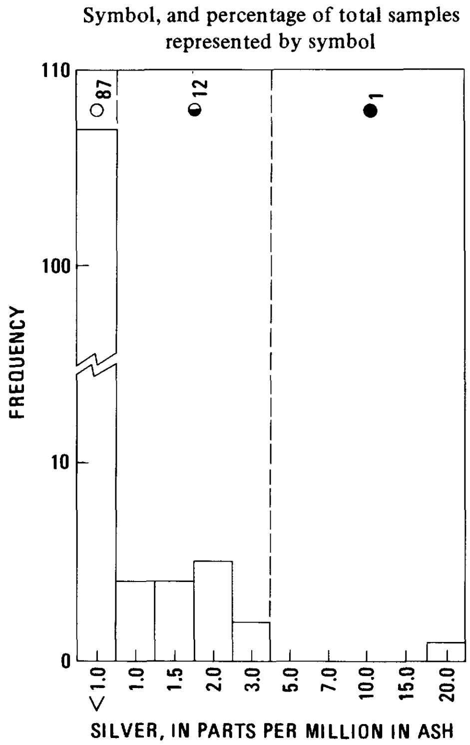


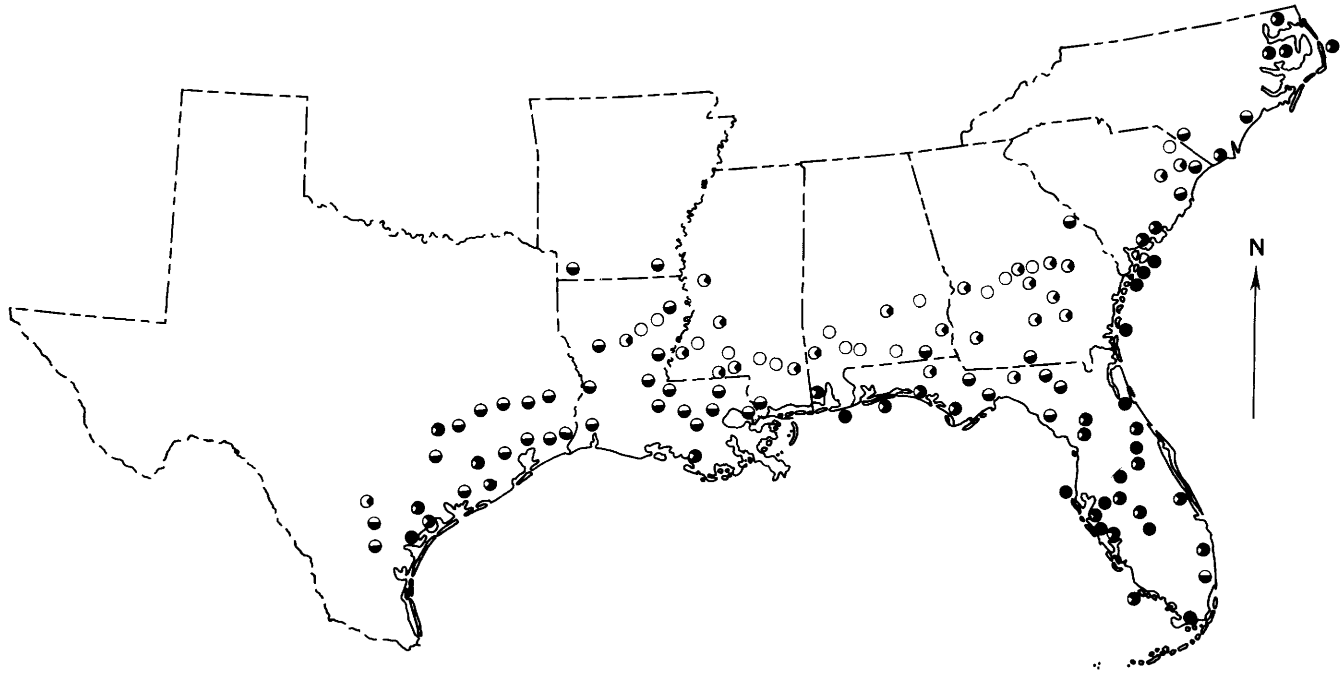
FIGURE 26. — Scandium content of Spanish moss.

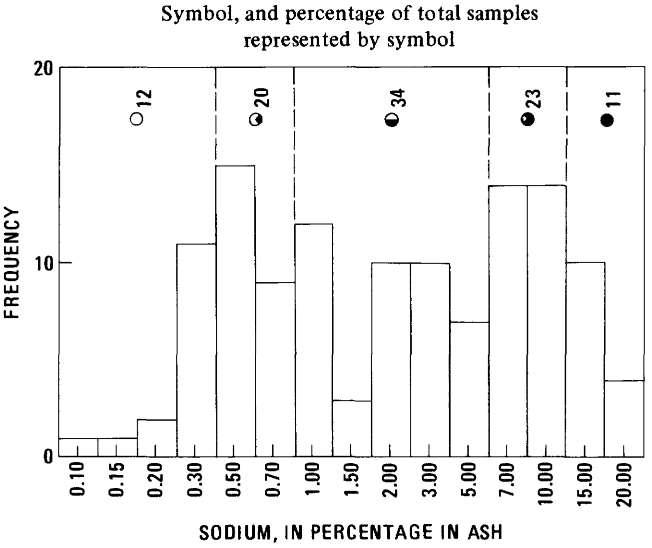




Geometric mean, 0.12
Geometric deviation, 5.42
Number of samples and analyses, 123

FIGURE 27. — Silver content of Spanish moss.





Geometric mean, 2.2
Geometric deviation, 4.05
Number of samples and analyses, 123

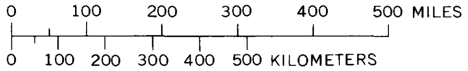
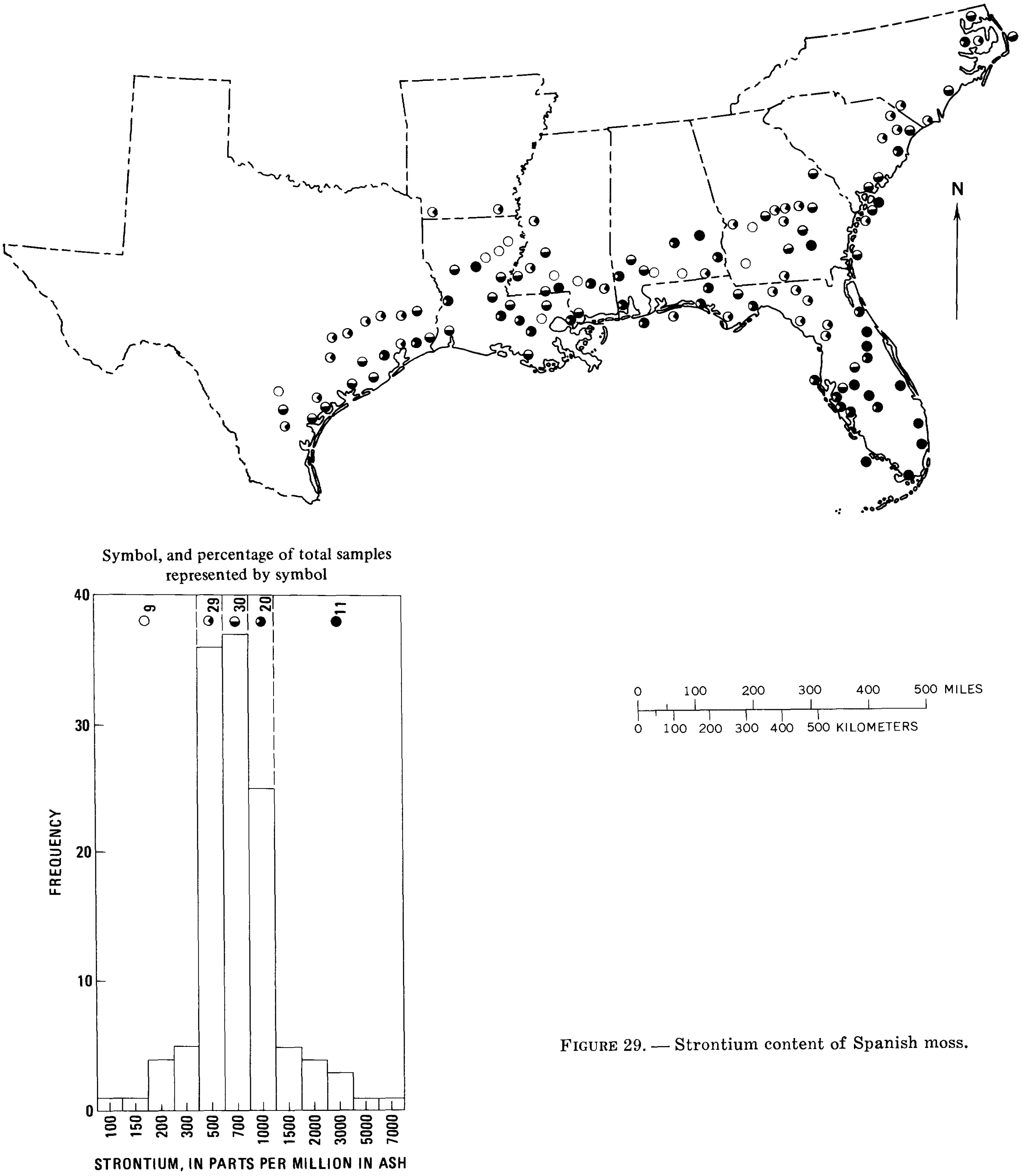
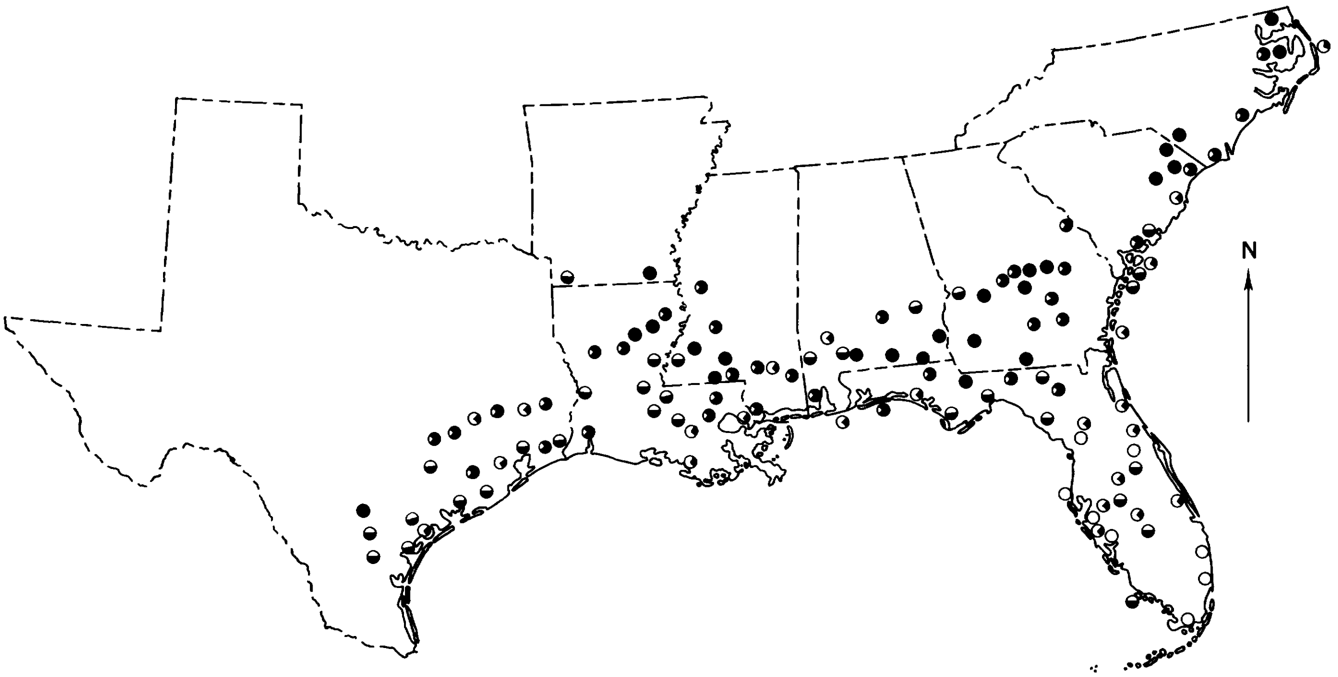


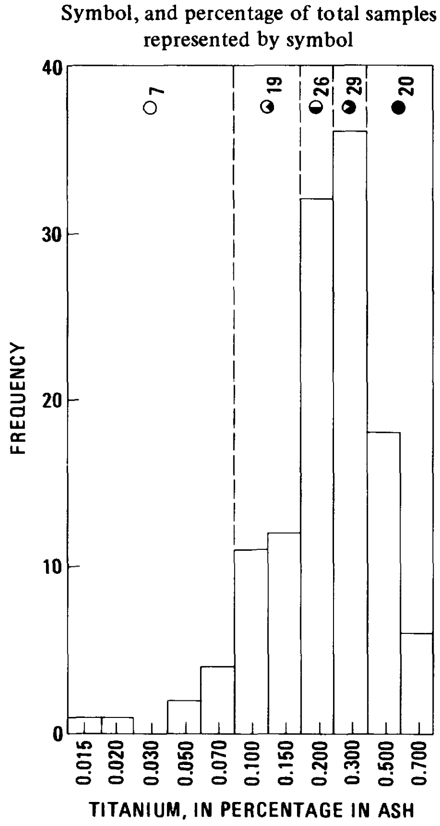
FIGURE 28. — Sodium content of Spanish moss.



Geometric mean, 704
Geometric deviation, 1.85
Number of samples and analyses, 123

FIGURE 29. — Strontium content of Spanish moss.





Geometric mean, 0.23
Geometric deviation, 1.96
Number of samples and analyses, 123

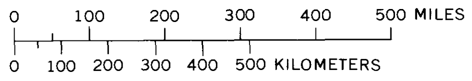
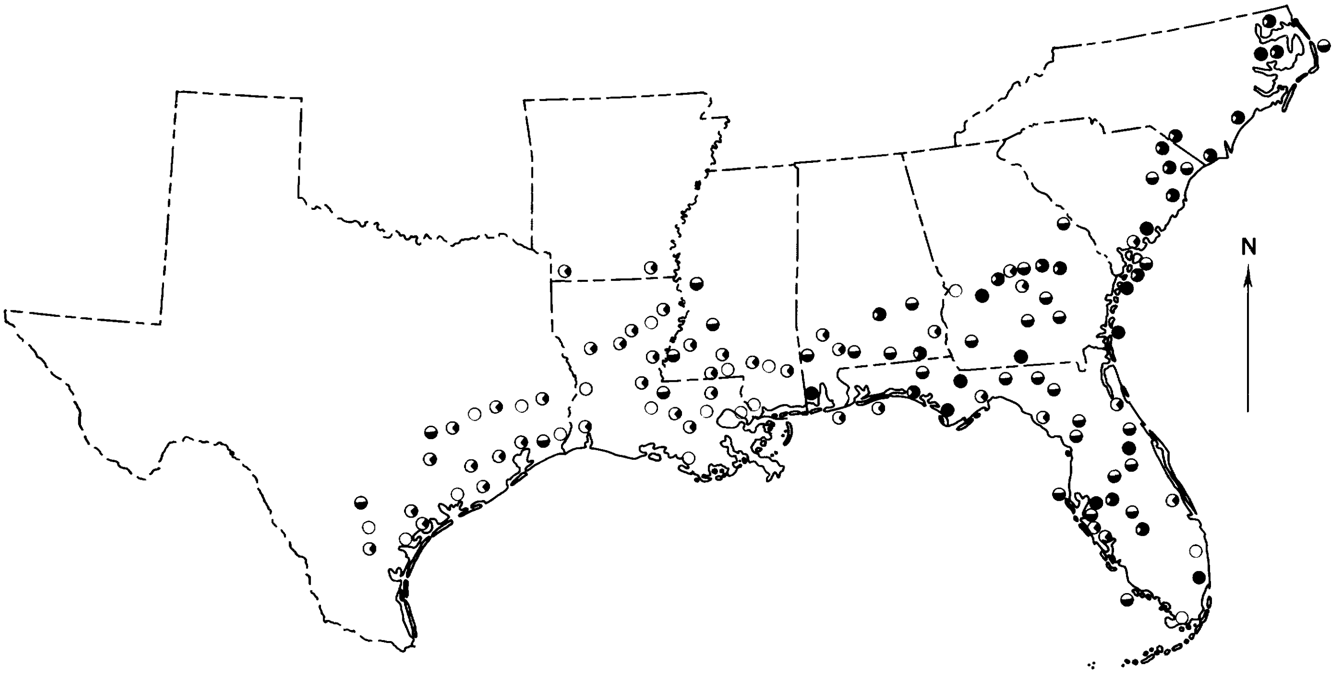
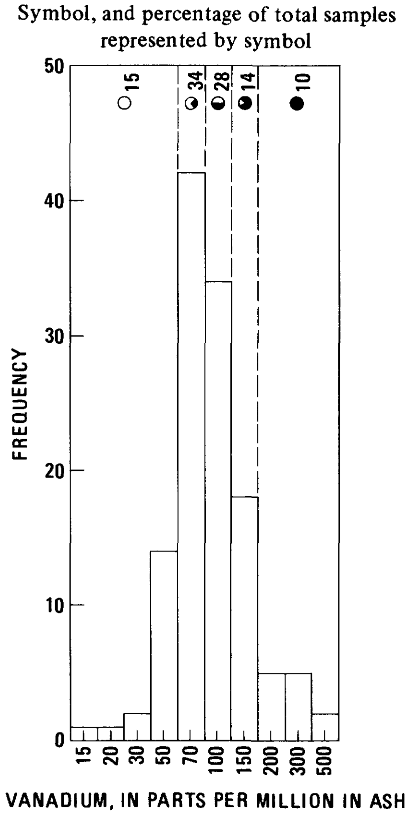


FIGURE 30. — Titanium content of Spanish moss.





Geometric mean, 91
Geometric deviation, 1.73
Number of samples and analyses, 123

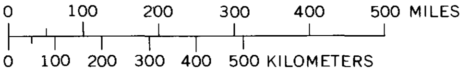
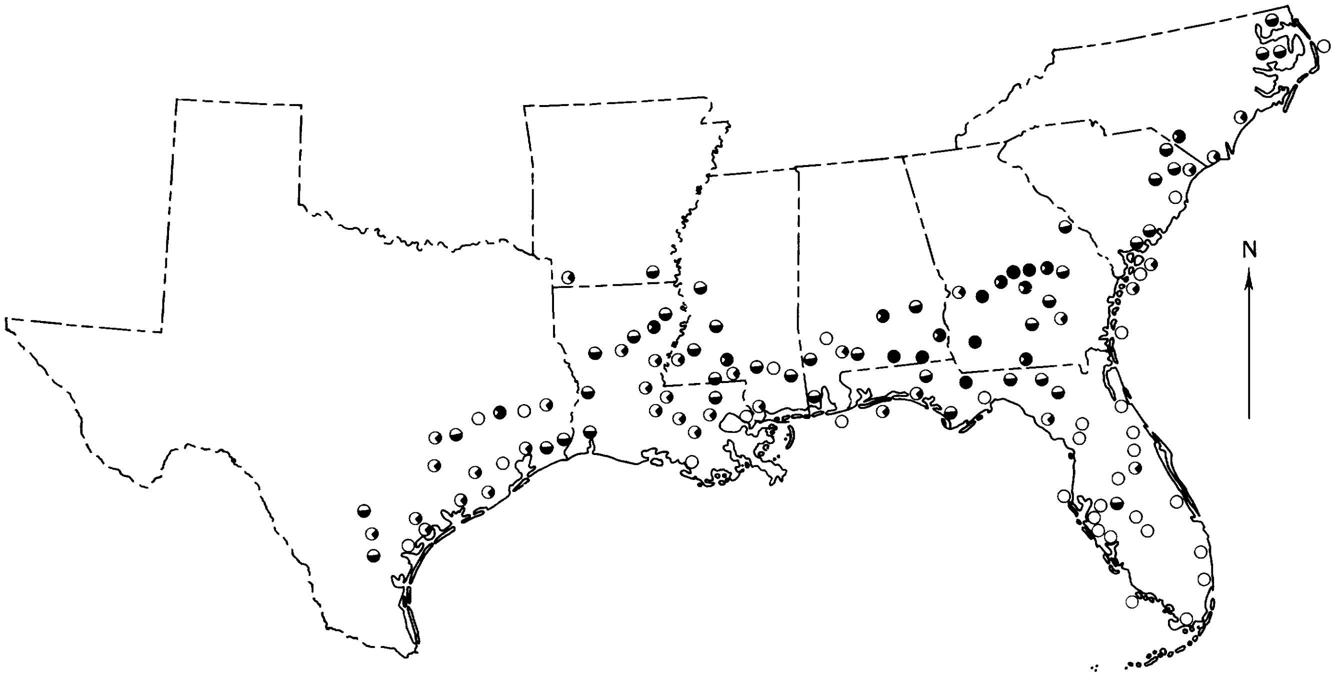
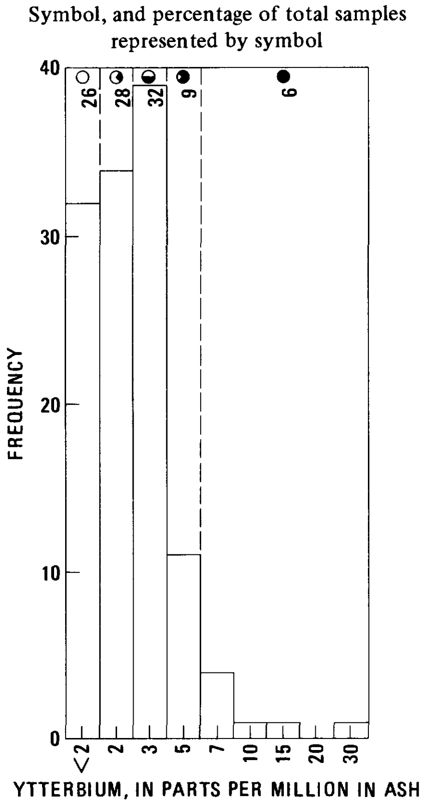


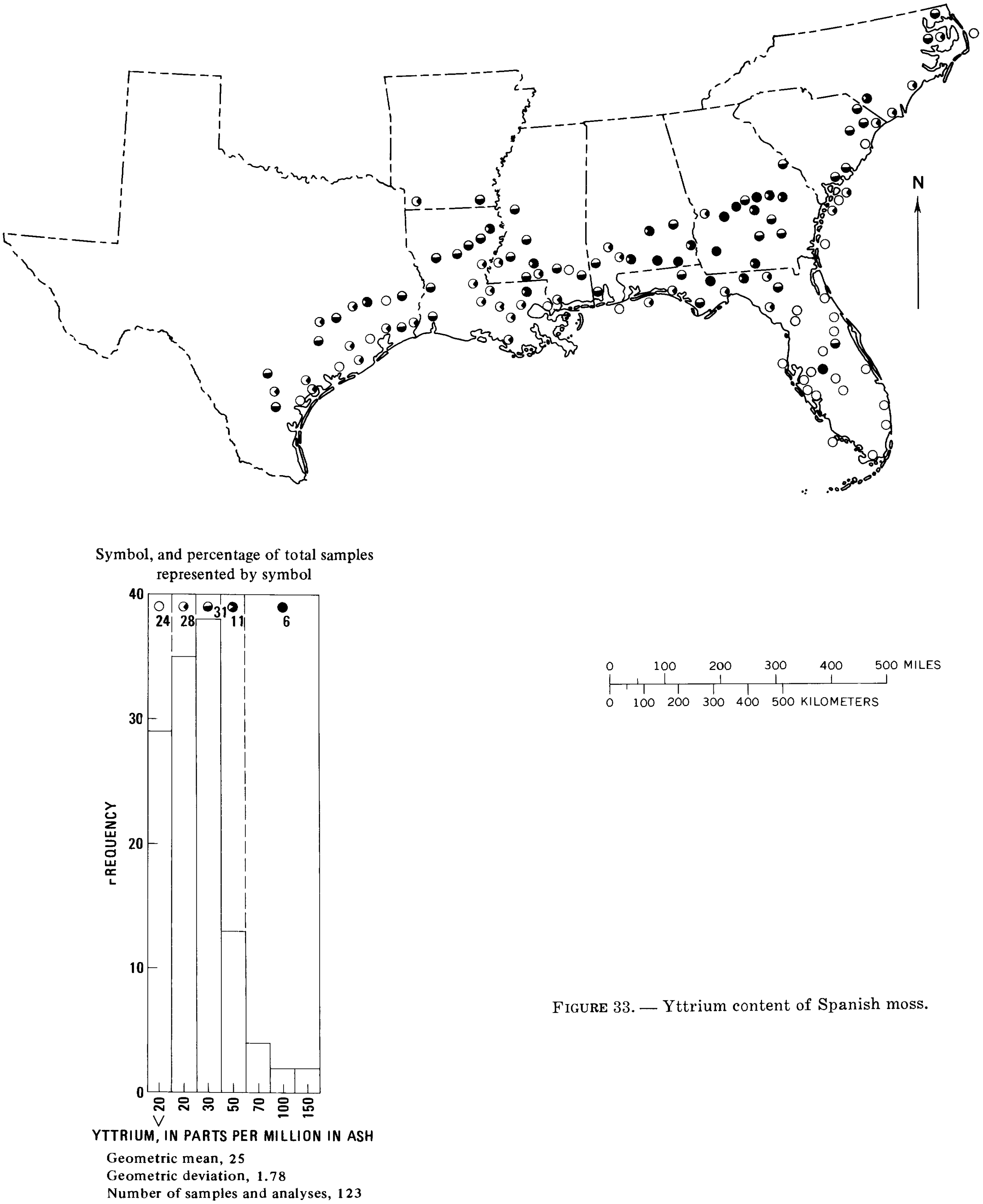
FIGURE 31. — Vanadium content of Spanish moss.





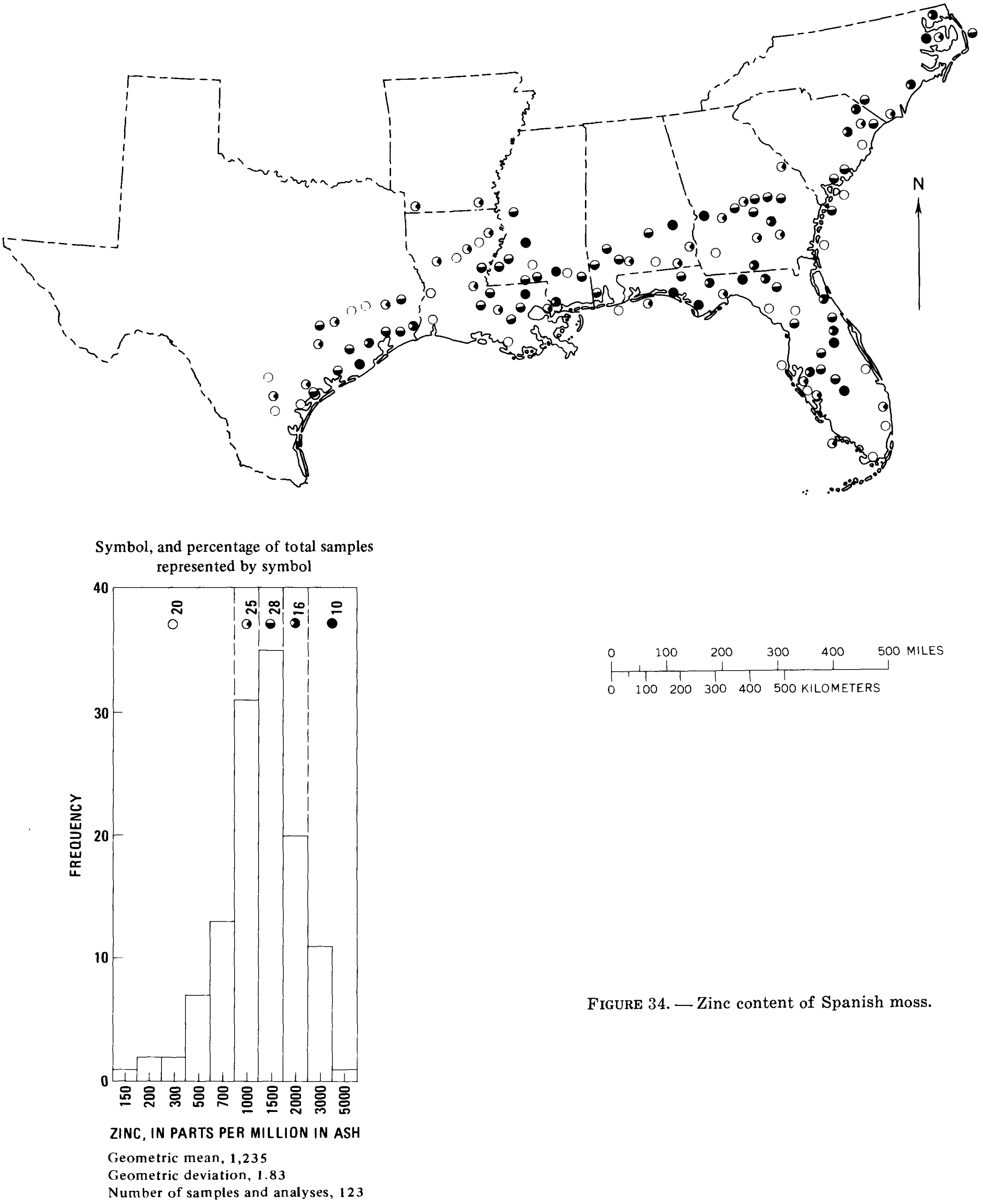
Geometric mean, 2.4
Geometric deviation, 1.81
Number of samples and analyses, 123

FIGURE 32. — Ytterbium content of Spanish moss.



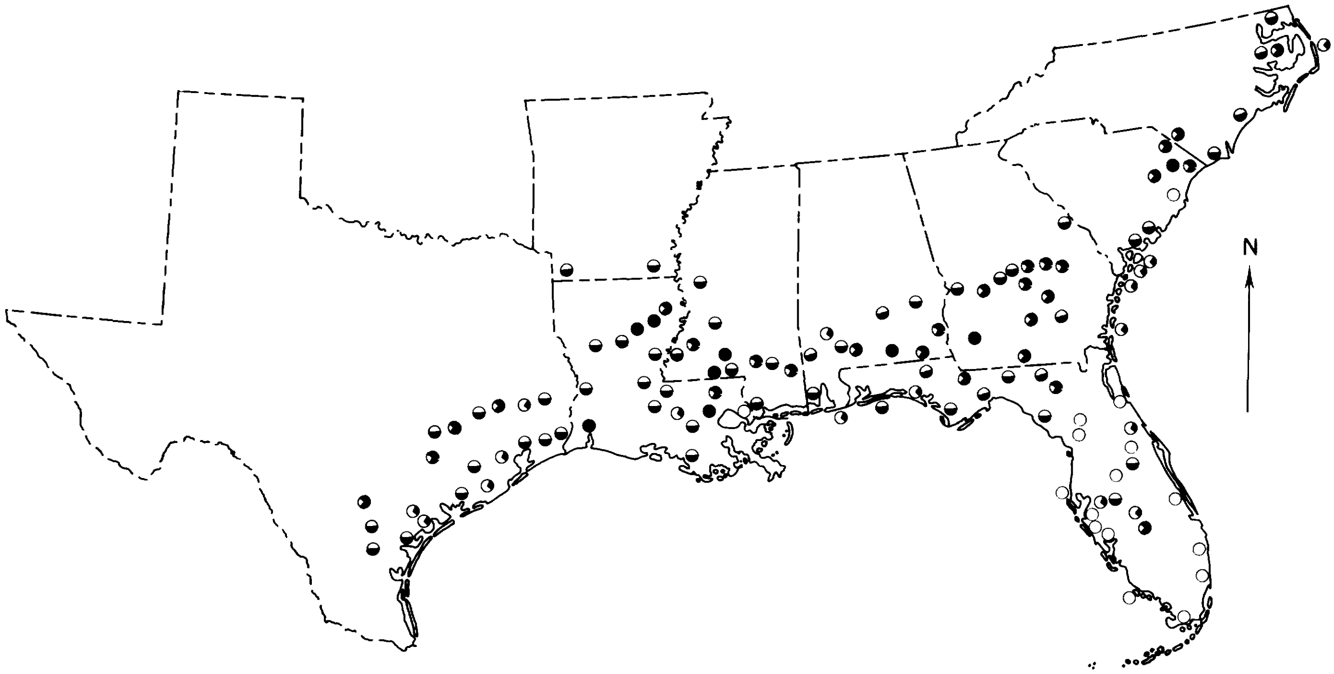
Geometric mean, 25
Geometric deviation, 1.78
Number of samples and analyses, 123

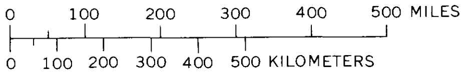
FIGURE 33. — Yttrium content of Spanish moss.



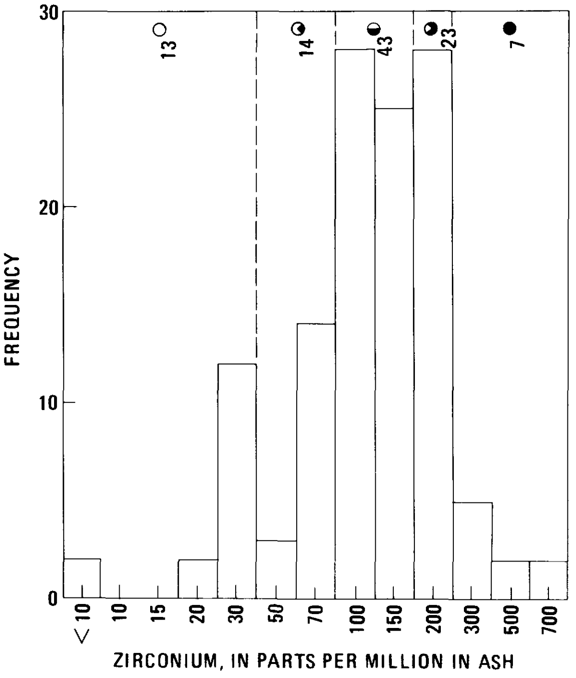
Geometric mean, 1,235
Geometric deviation, 1.83
Number of samples and analyses, 123

FIGURE 34. — Zinc content of Spanish moss.





Symbol, and percentage of total samples represented by symbol



Geometric mean, 110
Geometric deviation, 2.12
Number of samples and analyses, 123

FIGURE 35. — Zirconium content of Spanish moss.

DISCUSSION OF RESULTS

Although most species of flowering plants are believed to absorb only minor amounts of nutritive elements through their leaves (Fried and Broeshart, 1967, p. 119) and therefore must depend largely on absorption by roots, Spanish moss must obtain all nutritive elements by means of leaf and stem absorption. Some gases, including carbon dioxide, oxygen, sulfur dioxide (Berger, 1965, p. 232), chlorine (Berger, 1965, p. 248), and ammonia (Hutchinson and others, 1972), that come in contact with ordinary plant leaves are absorbed directly and are used in metabolic processes. These gases are thought to be similarly utilized by Spanish moss, although such utilization has not been proved experimentally. Particulate matter and materials in solution that become lodged on Spanish moss plants are analogous in function to the soil in which ordinary rooted plants grow. Analyses of Spanish moss samples reveal not only the chemical elements in the plant tissue but also those that are lodged on the plant surfaces, and the concentrations of elements in the two groups cannot be differentiated with certainty. Metabolic processes probably have only a minor effect on the concentrations of most elements discussed in this report. This effect may be largely the immobilization of certain nutritive elements in tissues of the plant, so loss of these elements through leaching by rainfall is reduced. However, both essential and nonessential elements may be held by chemical bonding to organic molecules in the plant, as was suggested by Goodman and Roberts (1971, p. 289). Therefore, the action of Spanish moss in accumulating airborne materials probably consists of more than simple atmospheric filtration.

Dissemination of Spanish moss occurs most commonly by wind transport of vegetative fragments of the plant rather than by seed dispersion. Most masses of Spanish moss that were collected as samples probably originated from such fragments, and for this and other reasons they cannot be traced back to their origins or ages as individual plants. A sample of Spanish moss, a perennial plant, is a composite of tissues of different ages, and there is no practical method of determining the age of the oldest tissue that is included. The increase in mass of a plant of this type tends to be exponential rather than linear; therefore, the samples are weighted to a substantial but unknown degree in favor of tissues of more recent growth. Although the effects of this loading cannot be measured readily, they must be considered in evaluating the role of this plant as an integrator of time increments of airborne materials. For these reasons, analyses of Spanish moss samples probably reflect most strongly the atmospheric burdens of recent months or years, although some portion of a sample may be 10 or more years old.

In order to determine if the morphological and physiological features which adapt Spanish moss to an epiphytic habitat result in accumulations of kinds and amounts of elements different from the accumulations in ordinary soil-rooted (terrestrial) plants, comparisons can be made by using data that are now available. A study of the chemical composition of soil samples from 912 sites throughout the conterminous United States (Shacklette, Hamilton, Boerngen, and Bowles, 1971; Shacklette, Boerngen, and Turner, 1971) did not report analyses of the plants that were sampled concurrently with the soil samples. Summary analytical data for these plant samples and for Spanish moss samples are given in table 3.

The terrestrial plants that were sampled included a wide variety of life forms—trees, shrubs, broadleafed herbs, and grasses—as well as different plant parts. Element concentrations in these plant samples ranged widely; moreover, the suite of samples was heavily weighted in favor of woody plants (trees and shrubs). For these reasons, we believe that in comparing element concentrations in this heterogeneous group (terrestrial plants) with those of an entirely homogeneous group (Spanish moss), geometric mean values in Spanish moss are better compared with the central two-thirds ranges of the terrestrial plant analyses than with the geometric means.

The average percentages of ash obtained by burning dry plants of the two groups are very similar. However, the typical concentrations of aluminum, cobalt, chromium, gallium, iron, sodium, lead, titanium, vanadium, and zirconium in ash of Spanish moss samples exceed the upper limit of the expected 67-percent range in ash of the soil-rooted plants. The extremely high concentrations of lead in Spanish moss undoubtedly reflect the fact that most samples were collected at sites near highways. Some samples of Spanish moss had a greater concentration of one or more of the elements chromium, copper, gallium, lead, vanadium, and zirconium than was found in any sample of soil-rooted plants. One sample of Spanish moss contained 15 ppm germanium in ash, an element that is very rarely reported to occur in plants.

No element concentrations in Spanish moss were unusually low, although concentrations of the macronutrient elements potassium and phosphorus are near the lower end of the expected 67-percent range

TABLE 3. — *Chemical composition of Spanish moss samples and samples of soil-rooted plants from the conterminous United States*

[Geometric means and ranges of elements reported as parts per million in ash. GM, geometric mean; GD, geometric deviation; ratio, number of samples in which the element was detected to total number of samples; ......, no data available]

Element, and ash	Spanish moss				Soil-rooted plants				
	GM	GD	Range	Ratio	GM	GD	Range	Ratio	Central 67-percent range
Ag	0.12	5.42	<1-20	16:123	......	......	<1-70	88:1,125	......
Al	41,000	2.21	1,500->100,000	120:123	6,500	3.52	<150->100,000	1,109:1,117	1,900-23,000
As	.79	1.55	<1-2	54:116	......	......	......	......	......
B	150	1.34	70-300	123:123	240	2.10	<30-3,000	1,135:1,150	110-500
Ba	560	2.32	50-2,000	123:123	390	3.75	2-70,000	1,151:1,151	100-1,500
Be	......	......	[1]2	3:123	......	......	<2-100	8:1,153	......
Bi	......	......	......	......	......	......	<20-30	4:1,125	......
Ca	100,000	1.56	18,000-320,000	123:123	120,000	2.69	1,600-430,000	988:988	45,000-320,000
Cd	7.9	1.65	.8-27	122:122	......	......	......	......	......
Ce	......	......	200-300	3:123	......	......	1,000-1,500	2:1,117	......
Co	9.8	1.83	<7-70	98:123	.94	5.83	<5-300	232:1,122	.16-5.5
Cr	57	1.73	7-1,500	123:123	9.6	2.85	<1-700	1,096:1,139	3.4-27
Cu	150	2.01	20-2,000	123:123	100	1.98	5-1,500	1,153:1,153	51-200
Fe	16,000	1.87	1,000-50,000	123:123	3,600	2.52	100-70,000	1,153:1,153	1,400-9,100
Ga	10	1.71	<7-50	95:114	.20	9.83	<3-30	150:1,105	.02-2.0
Ge	......	......	[1]15	1:123	......	......	......	......	......
Hg[2]	......	......	<.5-.7	8:116	......	......	......	......	......
K	94,000	1.74	6,000-200,000	123:123	130,000	1.82	8,800-450,000	1,006:1,006	71,000-240,000
La	14	3.80	<50-150	36:123	......	......	<50-1,500	46:1,125	......
Li	22	1.53	8-90	122:122	......	......	......	......	......
Mg	45,000	1.73	5,000-100,000	123:123	30,000	2.05	1,000->100,000	1,120:1,153	15,000-62,000
Mn	2,300	2.60	200-10,000	123:123	1,100	4.38	30-100,000	1,153:1,153	250-4,800
Mo	3.7	1.80	<7-20	29:123	4.2	3.94	<2-500	459:1,124	1.1-17
Na	22,000	4.05	1,100-240,000	123:123	4,600	4.00	400-360,000	277:277	1,200-18,000
Nb	......	......	15-20	2:123	......	......	[1]30	1:1,120	......
Nd	76	1.46	[1]150	4:36	32	6.21	<150-1,500	11:50	5.2-200
Ni	39	1.74	7-200	123:123	16	2.84	<5-500	1,028:1,139	5.6-45
P	9,400	1.55	2,400-48,000	123:123	20,000	2.27	1,600-400,000	991:991	8,800-45,000
Pb	4,200	3.16	70-50,000	123:123	86	6.17	<10-15,000	980:1,145	14-530
Sc	5.9	1.89	<5-20	68:100	......	......	<7-30	43:1,153	......
Se[2]	......	......	[1]1	4:123	......	......	......	......	......
Sn	21	1.80	20-30	6:123	......	......	<10-70	22:1,152	......
Sr	700	1.85	100-7,000	123:123	880	3.78	<10-20,000	1,145:1,152	230-3,300
Ti	2,300	1.96	150-7,000	123:123	260	3.49	<7-15,000	1,122:1,149	75-910
V	91	1.73	15-500	123:123	11	4.15	<7-300	694:1,123	2.7-46
Y	25	1.78	<20-150	94:123	......	......	<10-700	161:1,128	......
Yb	2.4	1.81	<2-30	91:123	......	......	<1-70	101:1,109	......
Zn	1,200	1.83	140-4,600	123:123	450	2.73	<25-5,800	642:643	170-1,235
Zr	110	2.12	<20-700	121:123	14	3.45	<20-500	470:1,152	4.1-48
Ash, percent[2]	4.6	1.46	2.2-34	123:123	5.3	1.98	.43-65	1,152:1,152	2.7-11

[1] All analyses were the same in samples in which the element was detected.
[2] Analyses reported on dry weight basis.

for soil-rooted plants and concentrations of magnesium and calcium are nearer the center of the range. Cerium, potassium, and niobium were the only elements that occurred at lower levels in a Spanish moss sample than in any sample of soil-rooted plants represented in table 3.

The capability of Spanish moss to serve as a long-term integrator of local airborne element loads is suggested by data in figure 3. In most plant ash, tin generally occurs in concentrations below the limit of analytical detection, and tin was quantitatively recorded in only six of the 123 Spanish moss samples. Four of the six samples were collected in the Houston-Galveston area in Texas. Because all 123 samples were analyzed in a sequence randomized with respect to geographic location, the probability of four samples in a localized area containing detectable concentrations of tin by chance alone is quite small. We hypothesize, therefore, that the atmosphere in this area carries unusually high concentrations of tin. This hypothesis seems confirmed by the fact that a tin smelter, the only one in the United States, is located at Texas City, Tex. (Lewis, 1971, p. 1066), across the bay from Galveston.

In order to characterize possible differences in the local airborne element load, analyses of five samples from each of four kinds of areas, classified according to their principal economic uses, were examined, and the elements that occurred in concentrations greater than the geometric mean are shown in table 4. More complete descriptions of the sample localities are given in table 1.

Table 4 shows that high concentrations of arsenic, cadmium, chromium, cobalt, copper, lead, nickel, and vanadium in Spanish moss samples occur in areas where high rates of vehicular and industrial emissions are expected.

The influence of ocean spray on sodium concentrations in the samples is indicated in figure 28. All samples (except one from Texas) that have greater-than-average sodium concentrations are from locations where airborne saltwater is expected

TABLE 4.—*Elements found in concentrations greater than average in Spanish moss samples from four kinds of sites*

Locality (fig. 3)	Locality			Elements
	State	County or parish	Area	
Rural sites (agricultural and recreational uses)				
32	Georgia	Irwin		Al, Ba, Fe, Mn, Sc, Li, and Zr.
35	do	Glynn	St. Simons Island	B, Li, Mg, P, K, Na, and V.
59	Texas	Karnes	San Antonio River	Al, Cr, Ga, Fe, Sc, Ti, and Zr.
72	Florida	Dade	Paradise Key	Ca, Mg, and Na.
294	Arkansas	Lafayette		Co and P.
Sites near highways with heavy traffic				
213	North Carolina	Robeson	Interstate 95	Al, As, Cd, Cr, Co, Cu, Ga, Fe, Pb, Li, Ni, K, Sc, Ti, V, Yb, Y, and Zr.
224	Florida	Hamilton	Interstate 75	Cd, Ca, Pb, Mg, Mn, and Zn.
233	Alabama	Mobile	Interstate 10	Cd, Co, Cr, Cu, Ga, Fe, Pb, Li, Mg, Mn, Mo, Ni, K, Sc, Na, Sr, Ti, and V.
250	do	Lowndes	Interstate 65	Al, B, Ca, Cr, Co, Ga, Fe, Li, Mo, Ni, Sc, Sr, Ti, V, Yb, and Y.
268	Texas	Harris	Interstate 10	Ba, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Ni, Sr, and Zn.
Urban sites (residential and business uses)				
54	Florida	Dixie	Cross City	Ca.
58	do	Palm Beach	West Palm Beach	Ca, Na, and Sr.
71	Louisiana	East Baton Rouge	Baton Rouge	Ba, B, Cd, Co, Fe, Mg, Mn, Ni, K, and Sr.
206	Florida	Manatee	Bradenton	Ca, Li, Mg, P, Na, and Sr.
243	Mississippi	Marion	Columbia	Ba, Cd, Co, Fe, Mn, K, Sr, and Ti.
Urban sites (industrial and other uses)				
201	Florida	Hillsboro	Limona industrial park	As, B, Cd, Cu, Fe, Mo, Ni, P, Na, V, and Zn.
216	South Carolina	Charleston	Charleston	Cd, Cr, Co, Cu, Mg, Ni, Na, and V.
230	Florida	Bay	Panama City	Al, Cd, Cr, Cu, Fe, Pb, Mg, Na, V, and Zn.
270	Texas	Jefferson	Beaumont	Al, Ba, Cd, Ca, Cr, Co, Cu, Ga, Fe, La, Pb, Ni, Sc, Sr, and Ti.
287	Mississippi	Adams	Near Natchez	Ba, Cd, Cr, Co, Fe, Pb, Mn, and K.

to be present at times, and no sample that contains less-than-average amounts of sodium is from such a location. Elements that are common constituents of soil dust, such as aluminum, calcium, magnesium, and iron, are found in samples from all areas.

Multivariate statistical analysis methods are being used to provide further interpretations of element distribution patterns in these Spanish moss samples, and the results of this study are planned to be presented in a subsequent paper.

SUMMARY AND CONCLUSIONS

1. Airborne chemical elements, which are accumulated by many species of plants, may contribute to the nutrition of the plant or may produce toxic effects. These elements are carried as gases, solutes, or particulate matter and may be actively or passively accumulated by the plant.

2. The concentration of airborne elements in the plant is thought to be determined by the concentrations present in air or airborne materials, the inherent ability of the plant to absorb the elements, the ratio of plant surface to total mass, and the length of time that the plant is exposed to the air.

3. Perennial plants which have a high surface-to-mass ratio and which have no direct connection to the soil by means of a conductive system are effective integrators of airborne materials over time. Analyses of lichens, mosses, and Spanish moss have been used to estimate the degree of atmospheric contamination.

4. Elemental analyses of Spanish moss samples collected from rural, residential, highway, and industrial locations reflect significant differences in concentrations of metals. Samples from industrial and highway locations can be characterized as containing greater-than-average amounts of arsenic, cadmium, chromium, cobalt, copper, lead, nickel, and vanadium. The high levels of lead found in some samples from highway locations are especially noteworthy. Of 123 samples analyzed, only six were found to contain tin; four of these grew in the Houston-Galveston area and are believed to reflect the presence, in the area, of a tin smelter, the only one in the United States.

5. Many samples from sites near the seashore contained greater-than-average amounts of sodium that is thought to have been derived from ocean spray. Samples from rural locations commonly contain low concentrations of the metals usually associated with urban or industrial activities.

6. Results of this study indicate that elemental analysis of Spanish moss can be used as an economical and rapid method of estimating the kind and relative concentration of airborne chemical elements among locations over a period of months or years.

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