Elemental Composition of Surficial Materials in the Conterminous United States

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By HANSFORD T. SHACKLETTE, J. C. HAMILTON,
JOSEPHINE G. BOERNGEN, and JESSIE M. BOWLES

STATISTICAL STUDIES IN FIELD GEOCHEMISTRY

*An account of the amounts of certain chemical
elements in samples of soils and other regoliths*

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, Secretary

GEOLOGICAL SURVEY

William T. Pecora, Director

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ABSTRACT

Samples of soils or other regoliths, taken at a depth of approximately 8 inches from locations about 50 miles apart throughout the conterminous United States, were analyzed for their content of elements. In this manner, 863 sample sites were chosen, and the results of the sample analyses for 35 elements were plotted on maps. The arithmetic and geometric mean, the geometric deviation, and a histogram showing frequencies of analytical values are given for 30 elements.

Surficial materials of the western half of the United States generally contain more calcium, magnesium, strontium, potassium, sodium, aluminum, and barium, but contain less titanium and zirconium than do those of the eastern half. Surficial materials in the Atlantic Coastal Plain tend to have much lower concentrations of most metals than are common in those of other regions, whereas these materials in the Basin and Range province, in parts of the Rocky Mountains, and in Maine and adjacent States generally have high metal concentrations. Some smaller patterns of element abundance can be noted, but the degree of confidence in the validity of these patterns decreases as the patterns become less extensive.

INTRODUCTION

The abundances of certain chemical elements in soils and other surficial materials are determined not only by the element content of the bedrock or other deposits from which the materials originated, but also by the effects of climatic and biological factors that have acted on the materials for various periods of time. The diversity of these factors in a large area is expected to result in a corresponding diversity in the element contents of the surficial materials.

At the beginning of this study, few data were available on the abundance of the elements in surficial materials of the United States as a whole. Most of the early reports discussed only the elements that were of economic importance to mining or agriculture in a metallogenic area or State; and the data, for the most part, cannot be evaluated with reference to average, or "normal," amounts in undisturbed materials because they were based on samples of deposits expected to have anomalous amounts of certain elements, or were based only on samples from cultivated fields.

We began a sampling program in 1961 that was designed to give estimates of the range of element abundance in surficial materials that were unaltered or very little altered from their natural condition, and in plants that grew on these deposits, throughout the conterminous United States. Because of the great amount of travel necessary to complete this program, geologists and others of the U.S. Geological Survey were asked to assist by collecting samples when traveling to and from project areas and to contribute appropriate data that they might have collected for other purposes. The response to this request, together with the samples and data that we collected, resulted in obtaining samples of surficial materials and plants from 863 sites. The locations of these sites are shown on the maps of element distributions in this report.

The elemental compositions of only the surficial materials are given in this report; the data on analyses of the plant samples are held in files of the U.S. Geological Survey.

REVIEW OF THE LITERATURE

The literature on the chemical analysis of soils and other surficial materials in the United States is extensive and deals largely with specific agricultural problems of regional interest. Many of the papers were written by soil scientists and chemists associated with State agricultural experiment stations and colleges of agriculture, and most reports considered only elements that were known to be nutritive or toxic to plants or animals.

Chemists with the U.S. Department of Agriculture prepared most early reports of element abundance in soils for large areas of the United States. (See Robinson, 1914; Robinson and others, 1917.) The 1938 yearbook of agriculture was devoted to reports on soils of the United States; in this book McMurtrey and Robinson (1938) discussed the importance and abundance of trace elements in soils. Amounts of the major elements in soil samples from a few soil profiles distributed throughout the United States were compiled by the soil scientist C. F. Marbut (1935) to illustrate characteristics of soil units.

The use of soil analysis in geochemical prospecting began in this country in the 1940's, and many reports were published on the element amounts in soils from areas where mineral deposits were known or suspected to occur. Most of these reports included only a few elements in soils from small areas. This early geochemical work was discussed by Webb (1953) and by Hawkes (1957). In succeeding years, as soil analyses became an accepted method of prospecting and as analytical methods were improved, many elements in soils were analyzed; still, the areas studied were commonly small.

An estimate of the amounts of elements in average, or "normal," soils is useful in appraising the amounts of elements in a soil sample as related to agricultural, mineral prospecting, or health and disease investigations. Swaine (1955) gave an extensive bibliography of trace-element reports on soils of the world, and he also summarized reports of the average amounts of elements as given by several investigators. The most comprehensive list of average amounts of rare and dispersed elements in soils is that of Vinogradov (1959), who reported the analytical results of extensive studies of soils in the Soviet Union, as well as analyses of soils from other countries. He did not state the basis upon which he established the average values; however, these values are presumably the arithmetic means of element amounts in samples from throughout the world. Hawkes and Webb (1962) gave average amounts of certain elements in soils as useful guides in mineral exploration. In their discussions of the principles of geochemistry, Goldschmidt (1954) and Rankama and Sahama (1955) reported the amounts of various elements present in soils and in other surficial materials.

A recent report on the chemical characteristics of soils was edited by Bear (1964). In this book, the chapter on chemical composition of soils by Jackson (1964) and the chapter on trace elements in soils by Mitchell (1964) give the ranges in values or the average amounts of some soil elements.

The average amounts of elements in soils and other surficial materials of the United States, as determined in the present study, are given in table 1, with the average values or ranges in values that were reported by Vinogradov (1959), Hawkes and Webb (1962), Jackson (1964), and Mitchell (1964). The averages from the present study in table 1 are the arithmetic means. Although the averages were computed by the methods described by Miesch (1967), the values obtained are directly comparable with the arithmetic means derived by common computational procedures.

COLLECTION AND ANALYSIS OF GEOCHEMICAL DATA

SAMPLING PLAN

The sampling plan was designed with the emphasis on practicality—in keeping with the expenditures

TABLE 1.—*Average contents, and range in contents, reported for elements in soils and other surficial materials*

[Data are in parts per million; each average represents arithmetic mean; _____, no data available]

Element	Present report		Hawkes and Webb (1962) (elements useful in geochemical prospecting)		Vinogradov (1959) (presumably, averages from worldwide sampling)	Jackson (1964)	Mitchell (1964)
	Average	Range	Average	Range		"Typical" average, or range in values	Range in content of Scottish surface soils
Al	66,000	700->100,000	_____		71,300	10,000-60,000	_____
B	34	<20-300	10	_____	10	30	_____
Ba	554	15-5,000	500	100-3,000	500	_____	400-3,000
Be	1	<1-7	6	_____	6	_____	<5-5
Ca	24,000	<150-320,000	_____		13,700	7,000	_____
Ce	86	<150-300	_____		50	_____	_____
Co	10	<3-70	8	1-40	8	_____	<2-80
Cr	53	1-1,500	200	5-1,000	200	_____	5-3,000
Cu	25	<1-300	20	2-100	20	_____	<10-100
Fe	25,000	100->100,000	_____	14,000-40,000	38,000	7,000-42,000	_____
Ga	19	<5-70	_____		30	_____	15-70
K	23,000	50-70,000	_____		13,600	400-28,000	_____
La	41	<30-200	40	_____	40	_____	<30-200
Mg	9,200	50-100,000	_____		6,300	<6,000	_____
Mo		<3-7	2	0.2-5	2	1-10	<1-5
Mn	560	<1-7,000	850	200-3,000	850	_____	200-5,000
Na	12,000	<500-100,000	_____		6,300	_____	_____
Nb	13	<10-100	_____				
Nd	45	<70-300	_____				
Ni	20	<5-700	40	5-500	40	_____	10-800
P	420	20-6,000	_____		800	500	_____
Pb	20	<10-700	10	2-200	10	_____	<20-80
Sc	10	<5-50	_____		7	_____	<3-15
Sr	240	<5-3,000	_____		300	_____	60-700
Ti	3,000	300-15,000	4,600	1,000-10,000	4,600	1,200-6,000	_____
V	76	<7-500	100	20-500	100	_____	20-250
Y	29	<10-200	_____		50	_____	25-100
Yb	4	<1-50	_____				
Zn	54	<25-2,000	50	10-300	50	_____	_____
Zr	240	<10-2,000	_____		300	_____	200->1,000

of time and funds available—and its variance from an ideal plan has been recognized from the beginning. Because the collection of most samples was, by necessity, incidental to other duties of the samplers, the instructions for sampling were simplified as much as possible, so that sampling methods would be consistent within the wide range in kinds of sites to

be sampled. The samples, other than those from certain project areas, were collected by U.S. Geological Survey personnel along their routes of travel to areas of other types of field studies.

The locations of the routes that were sampled depended on both the network of roads that existed and the destinations of the samplers. Sampling intensity

was kept at a minimum by selecting only one sample site every 50 miles along the routes. The specific sample sites were selected, insofar as possible, to represent surficial materials that were very little altered from their natural condition and that supported native or cultivated plants suitable for sampling. In practice, this site selection necessitated sampling away from roadcuts and fills. In some areas, only cultivated fields were available for sampling.

Contamination of the sample sites by vehicular emissions was seemingly insignificant, even though many sites were within 100 yards or less of the roads. However, we had no adequate way of measuring any contamination that may have occurred. (See Cannon and Bowles, 1962.) Many of the sampled routes had only light vehicular traffic, and some were new interstate highways. Routes through congested areas generally were not sampled; therefore, no gross contamination of the samples was expected.

The study areas that were sampled were as follows: Wisconsin and parts of contiguous States, southeastern Missouri, Georgia, and Kentucky, sampled by Shacklette; Kentucky, sampled by J. J. Connor and R. R. Tidball; Nevada, New Mexico, and Maryland, sampled by H. L. Cannon; and various locations in Arizona, Colorado, Montana, New Mexico, Utah, and Wyoming, sampled by F. A. Branson and R. F. Miller. Sampling techniques used in these areas varied according to the primary objectives of the studies being conducted, but, generally, these techniques were closely similar to the methods used in sampling along the roads.

In general, the sampling within study areas was more intensive than that along the travel routes. To make the sampling intensity of the two sampling programs more nearly equal, only the samples from selected sites in the study areas were used for this report. The selected sites were approximately 50 miles apart. Where two or more samples were collected from one site, they were assigned numbers, and one of these samples was randomly chosen for evaluation in this study.

SAMPLING MEDIA

The material sampled at most sites could be termed "soil" because it was a mixture of comminuted rock and organic matter, it supported ordinary land plants, and it doubtless contained a rich microbiota. Some of the sampled deposits, however, were not soils as defined above, but were other kinds of regoliths. These regoliths included desert sands, sand dunes, some loess deposits, and beach and alluvial deposits that contained little or no visible organic matter. In some places the distinctions between soils and other regoliths are vague because the material of the deposits is transitional between the two. Samples were collected from a few deposits consisting of mostly organic materials that would ordinarily be classified as peats, rather than soils.

To unify sampling techniques, the samplers were asked to collect the samples at a depth of approximately 8 inches below the surface of the deposits. This depth was chosen as our estimate of a depth below the plow zone that would include parts of the zone of illuviation in most well-developed zonal soils, and as a convenient depth for sampling other surficial materials. Where the thickness of the material was less than 8 inches, as in shallow soils over bedrock or in lithosols over large rock fragments, samples were taken of the material that lay just above the rock deposits. About half a pint of this material was collected, put in a paper envelope, and shipped to the U.S. Geological Survey laboratories in Denver.

CHEMICAL ANALYSIS PROCEDURES

The soil samples were oven dried in the laboratory and then sifted through a 200-mesh sieve. Finally, the sifted, minus-200-mesh fraction of the sample was used for analysis. Some of the samples having a high clay content formed a hard mass when dried and had to be pulverized in a ceramic mill before being sieved.

Contents of zinc and phosphorus were determined by the colorimetric methods described by Ward, Lakin, Canney, and others (1963). Analyses for amounts of calcium were made by the EDTA titration method, and analyses for potassium by flame photometry.

Quantities of the other elements were determined by semiquantitative spectrographic analysis (Myers and others, 1961). The values obtained by spectrography were reported in geometric brackets having the boundaries 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, and so forth, percent; 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 limits of detection of the analytical methods that were used are given in table 2.

The values given in table 2 are the approximate lower limits of determination. 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.

METHODS OF STATISTICAL ANALYSIS

The values obtained by analysis for each element in each sample, 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, as well as 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.

By examining the table of frequencies, we were able to divide the range of reported values for most elements into five classes, so that approximately 20 percent of the values fell into each class. (See figs. 2–31.) However, the limited ranges in values for some elements prohibited use of more than two or three classes to represent the total distribution. Class-interval code numbers for each element were then assigned to each analytical value: values in

the lowest class were assigned the code number 1; values in the highest class were assigned the code number 5.

These class-code numbers, together with the latitude and longitude of the site where the sample was collected, were then directed from the computer to the automatic plotter, which located each sample site on base maps of the United States by printing the class code for each element at each sample site. These class-code numbers on the base maps were then replaced with symbols, as shown in figures 2–31.

The geometric means and geometric deviations given in figures 2–31 and in table 3 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 mean and standard deviations of the logarithms were estimated by means of a censored-distribution technique devised by Cohen (1959). The geometric mean is a measure of central tendency of the frequency distribution 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. Approximately 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 aluminum content of surficial materials of the United States is 4.5 percent and the geometric deviation is 2.41 (fig. 2; table 3). It is estimated that approximately two-thirds of the samples have aluminum contents in the range $4.5 \div 2.41$ (1.87 percent) to 4.5×2.41 (10.84 percent), and about 95 percent have aluminum contents in the range $4.5 \div (2.41)^2$ (0.78 percent) to $4.5 \times (2.41)^2$ (26.1 percent).

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 Shacklette, Sauer, and Miesch (1970).

The arithmetic means of the analytical data given in table 1 were derived from the estimated geometric means and geometric deviations by using a technique described by Miesch (1967), which is based on methods devised by Cohen (1959) and Sichel (1952). The arithmetic means in table 1, unlike the geometric means shown in figures 2–31 and in table 3, are estimates of geochemical abundance (Miesch, 1967) and are directly comparable to arithmetic means com-

TABLE 2.—*Analytical limits of detection*

[Data reported in parts per million. Analyses made by semiquantitative spectrographic method, except as indicated]

Element	Lower limit of detection (ppm)	Element	Lower limit of detection (ppm)
Aluminum (Al)	10	Molybdenum (Mo)	3
Barium (Ba)	2	Neodymium (Nd)	70
Beryllium (Be)	1	Nickel (Ni)	5
Boron (B)	20	Niobium (Nb)	10
Calcium (Ca)	[1] 150	Phosphorus (P)	[2] 2
Cerium (Ce)	150	Potassium (K)	[3] 50
Chromium (Cr)	1	Scandium (Sc)	5
Cobalt (Co)	3	Sodium (Na)	500
Copper (Cu)	1	Strontium (Sr)	5
Gallium (Ga)	5	Titanium (Ti)	2
Iron (Fe)	10	Vanadium (V)	7
Lanthanum (La)	30	Ytterbium (Yb)	1
Lead (Pb)	10	Yttrium (Y)	10
Magnesium (Mg)	50	Zinc (Zn)	[2] 25
Manganese (Mn)	1	Zirconium (Zr)	10

[1] Analyzed by EDTA titration method.
[2] Analyzed by colorimetric method.
[3] Analyzed by flame photometry.

monly employed in presentations of geochemical averages in the literature. Arithmetic means are always larger than corresponding geometric means (Miesch, 1967, p. B1) and are estimates of the fractional part of a single specimen that consists of the element of concern rather than of the typical concentration of the element in a suite of samples.

RESULTS

The results of this study are presented on maps of the conterminous United States which give, for each element, the locations of the sample sites, and the concentration of the element at the site. Several elements were detected in only a few samples. The lower detection limits, in parts per million, of the semiquantitative spectrographic method for these elements are as follows: Antimony, 150; bismuth, 10; lithium, 50; silver, 0.5; and tin, 10. The localities of these samples and the contents of these elements in the samples are given in figure 1.

The concentrations of 30 elements were sufficiently large to be detected in samples from many sites. The results of analyses of these samples are given in figures 2–31; the concentrations of elements are indicated by symbols, as classified in the accompanying frequency histograms. Although we intended to analyze these 30 elements in all samples, through error, certain elements were omitted in the analyses of a few samples.

Some elements were looked for in all samples but were not found. These elements, analyzed by the semiquantitative spectrographic method, and their lower detection limits, in parts per million, are as follows: Arsenic, 1,000; cadmium, 20; germanium, 10; gold, 20; hafnium, 100; indium, 10; platinum, 30; palladium, 1; rhenium, 30; tantalum, 200; tellurium, 2,000; thallium, 50; thorium, 200; and uranium, 500. If lanthanum or cerium was found in a sample, the following elements, with their stated lower detection limits, were looked for in the same sample but were not found: Dysprosium, 50; erbium, 50; gadolinium, 50; holmium, 20; lutetium, 30; terbium, 300; and thulium, 20.

DISCUSSION AND CONCLUSIONS

The data presented in this report may reveal evidence of regional variations in abundances of elements; single values or small clusters of values on the maps may have little significance when considered alone. Apparent differences in values shown between certain sample routes, such as those across the Great Plains and the Central States, suggest the possibility of systematic errors in sampling or in laboratory analysis. Some gross patterns, neverthe-less, are evident in compositional variation of regoliths, as shown in figures 2–31.

The lower abundances of some elements (notably calcium, magnesium, strontium, potassium, sodium, aluminum, and barium) and the greater abundances of titanium and zirconium in regoliths of the Eastern United States indicate a regional pattern of the largest scale. The abundances of these elements differ markedly on either side of a line extending from western Minnesota southward through east-central Texas. This line is generally about the 97th meridian and corresponds to the boundary proposed by Marbut (1935, p. 14), which divides soils of the United States into two major groups—the pedalfers which lie to the east, and the pedocals to the west. Marbut (1928) attributed the major differences in chemical and physical qualities of these two major groups to the effects of climate. A line approximating the 97th meridian also separates the Orders, Sub-orders, and Great Groups of moist to wet soils in the Eastern United States from the same categories of dry soils which lie to the west, as mapped by the [U.S.] Soil Conservation Service (1969). Geometric mean compositions of regoliths west and east of the 97th meridian are given in table 3.

Superimposed upon this large-scale compositional variation pattern are several features of intermediate scale. Most notable of these are (1) the low concentrations of many elements in soils of the Atlantic Coastal Plain, and (2) the general exception to this low concentration in the part of the Coastal Plain crossed by the Mississippi River.

Several small-scale features of compositional variation have been noted; among them, the low concentrations of many elements in regoliths of lower Michigan, northern Nebraska, and the part of Texas adjacent to the southeast corner of New Mexico are prominent. In contrast, large amounts of some elements tend to occur in regoliths of Maine, parts of the Rocky Mountains, and the Basin and Range province.

The concentrations of certain elements, especially boron, cerium, neodymium, niobium, ytterbium, and yttrium, do not exhibit well-defined patterns of distribution; and the regional concentrations of some other elements cannot be evaluated, because they are not present in detectable amounts in most of the samples. The degree of confidence in regional patterns of element abundance is expected to be in direct proportion to the number of samples included in the region. As the patterns become smaller, the probability increases that the observed character-

TABLE 3.—*Geometric mean compositions, and geometric deviations, of samples of soils and other surficial materials in the conterminous United States*

[Geometric means reported in parts per million. Too few molybdenum values were available to make a statistical evaluation]

Element	The conterminous United States N ≈ 863		Western United States (west of 97th meridian) N ≈ 492		Eastern United States (east of 97th meridian) N ≈ 371	
	Geometric mean	Geometric deviation	Geometric mean	Geometric deviation	Geometric mean	Geometric deviation
Al	45,000	2.41	54,000	2.02	33,000	2.70
B	26	2.05	22	2.09	32	1.92
Ba	430	2.06	560	1.80	300	2.19
Be	0.6	2.49	0.6	2.47	0.6	2.53
Ca	8,800	3.92	18,000	2.93	3,200	2.87
Ce	75	1.67	74	1.64	78	1.70
Co	7	2.21	8	2.01	7	2.55
Cr	37	2.32	38	2.16	36	2.52
Cu	18	2.28	21	2.00	14	2.54
Fe	18,000	2.30	20,000	1.90	15,000	2.76
Ga	14	2.11	18	1.71	10	2.53
K	12,000	2.71	17,000	1.60	7,400	3.56
La	34	1.85	35	1.81	33	1.90
Mg	4,700	3.19	7,800	2.21	2,300	3.39
Mn	340	2.70	389	1.94	285	3.65
Na	4,000	4.11	10,200	1.98	2,600	4.11
Nb	12	1.66	11	1.74	13	1.54
Nd	39	1.72	36	1.81	44	1.61
Ni	14	2.26	16	2.03	13	2.60
P	250	2.74	320	2.33	180	3.03
Pb	16	1.96	18	1.93	14	1.96
Sc	8	1.79	9	1.74	7	1.85
Sr	120	3.39	210	2.12	51	3.56
Ti	2,500	1.87	2,100	1.82	3,000	1.84
V	56	2.16	66	1.91	46	2.41
Y	24	1.77	25	1.66	23	1.93
Yb	3	1.81	3	1.67	3	2.03
Zn	44	1.86	51	1.78	36	1.89
Zr	200	1.90	170	1.78	250	1.95

istics which form the patterns are the result of chance.

Some small- and intermediate-scale features of element-abundance patterns are known to reflect geological characteristics of the areas that the soils overlie. A few soil samples with high phosphorous content, for example, are associated with phosphate deposits in Florida, and a single sample with high copper content from the Upper Peninsula of Michigan is known to be of soil that occurs over a copper deposit. Samples from most of the regoliths overlying basic volcanic rocks of Washington and Oregon contained higher than average concentrations of iron and of a few other elements.

These data do not provide consistent evidence of north-south trends in elemental compositions that might be expected to relate to differences in temperature regimes under which the surficial materials developed. There is, moreover, no evidence of significant differences in element abundances between glaciated and nonglaciated areas (the general area of continental glaciation includes the northern tier of States from Montana to Maine and south in places to about lat 40° N.).

The world averages of abundance for some elements in soils, as given by Vinogradov (1959) and by others (table 1), do not correspond to the averages of abudance for those elements in soils of the United States, according to the data presented in this report. The world averages are too low for the amounts of boron, calcium, cerium, lead, magnesium, potassium, and sodium in United States soils, and too high for beryllium, chromium, gallium, manganese, nickel, phosphorus, titanium, vanadium, and yttrium. This report presents, for the first time, averages of the abundance of niobium, neodymium, and yttrium in soils.

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FIGURES 1-31

FIGURE 1.—Location of sample sites in the conterminous United States where elements not commonly
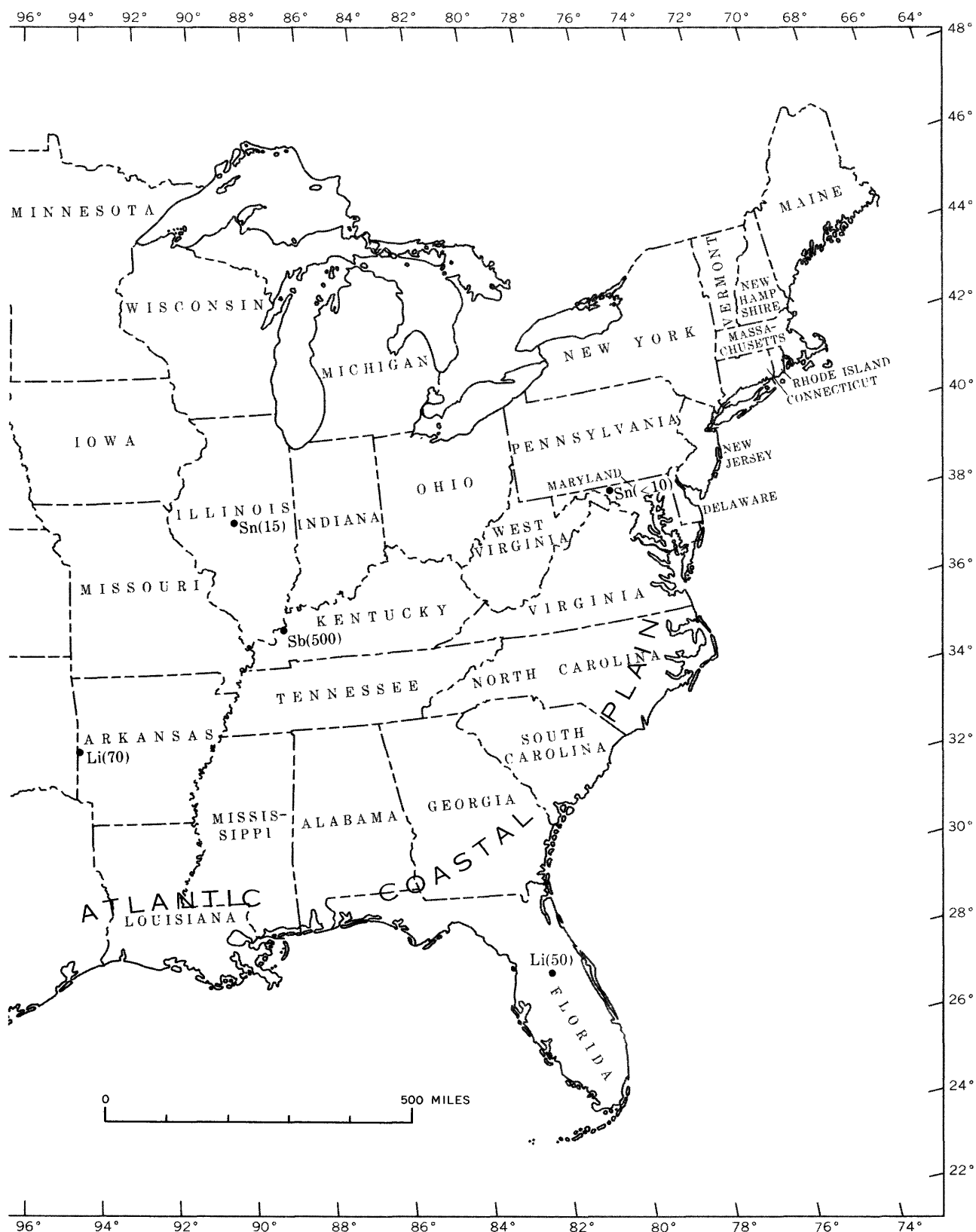
detected in surficial deposits were found, and the amounts of the elements, in parts per million, present.
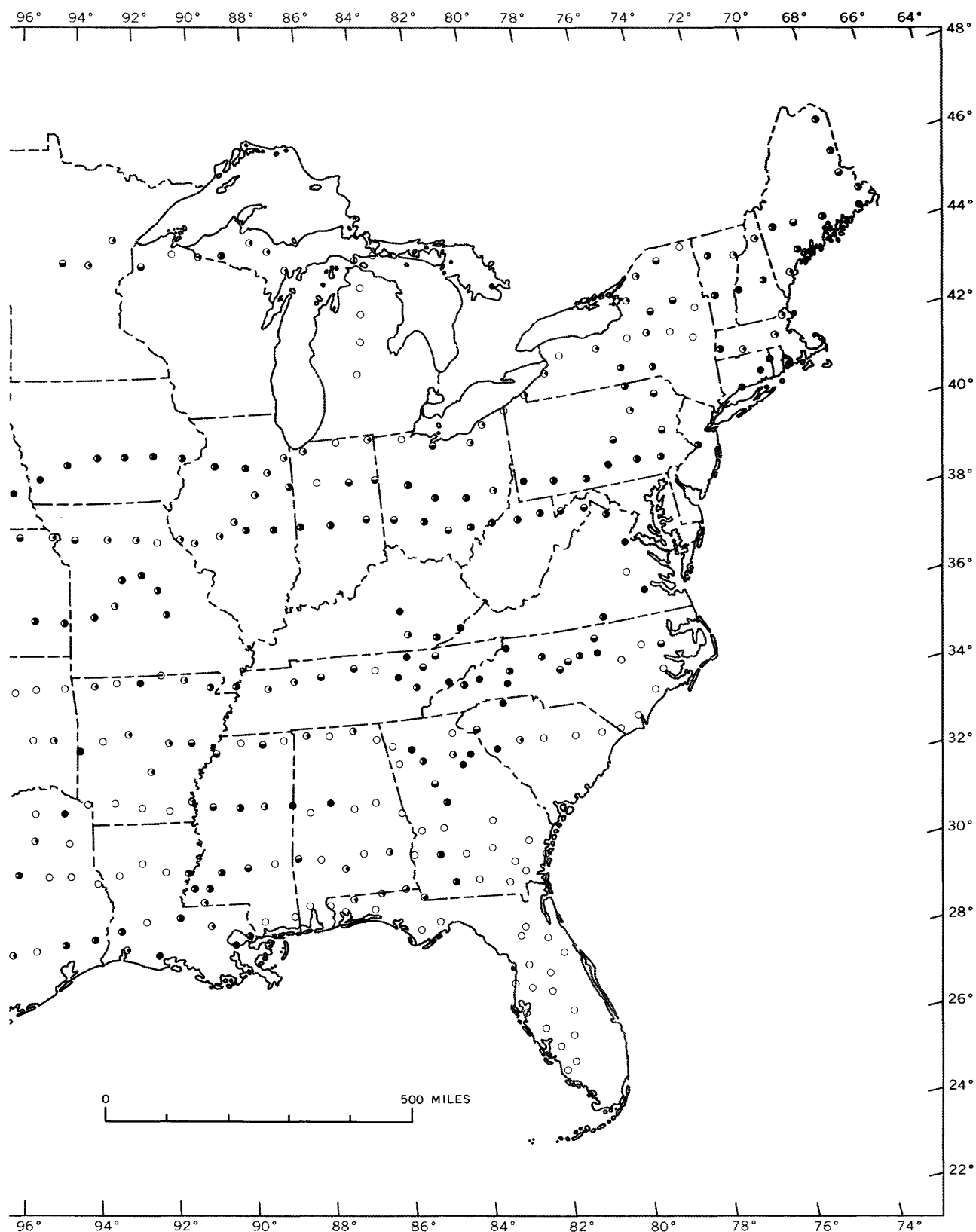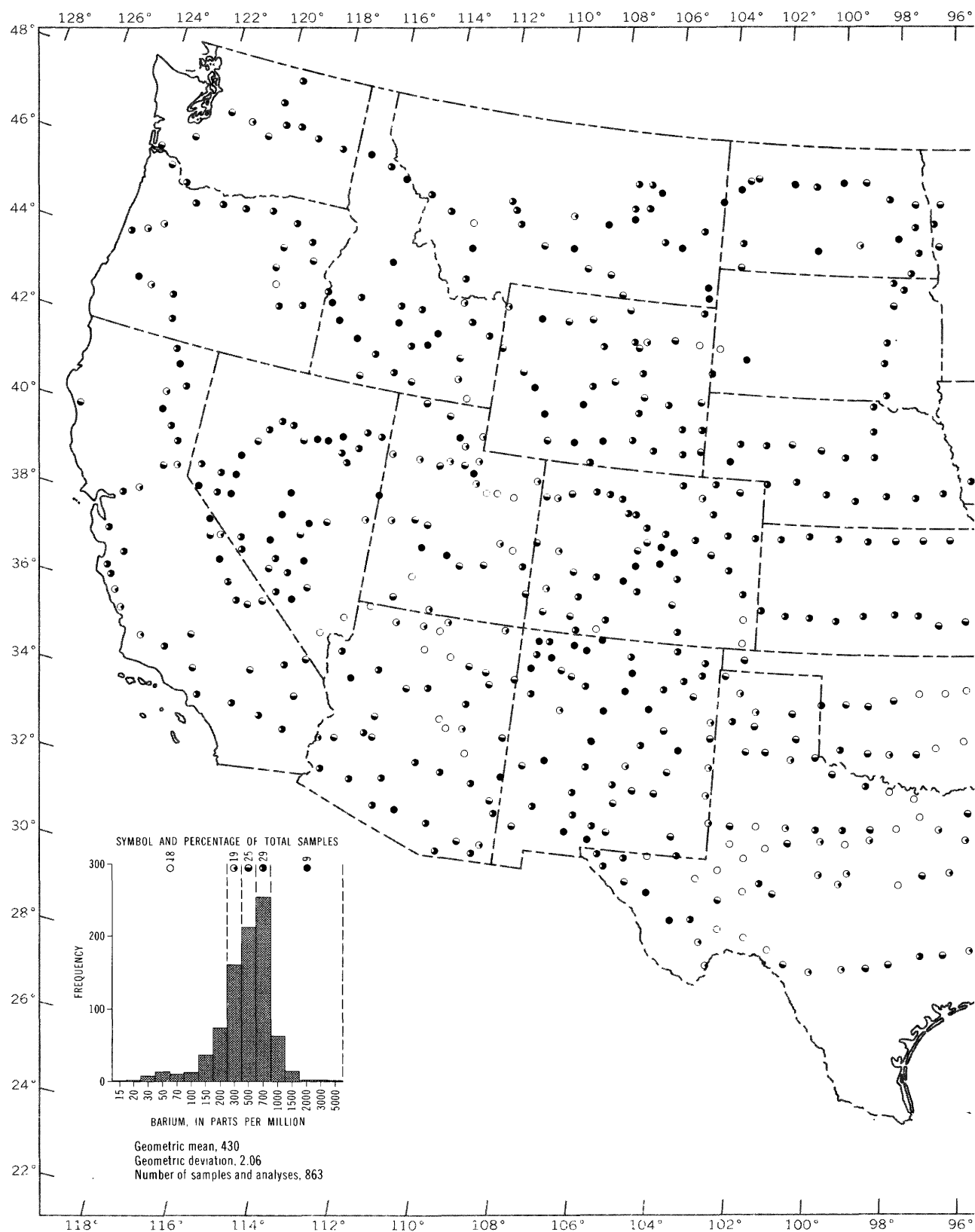
SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

ALUMINUM, IN PERCENT

Geometric mean, 4.5
Geometric deviation, 2.41
Number of samples and analyses, 791
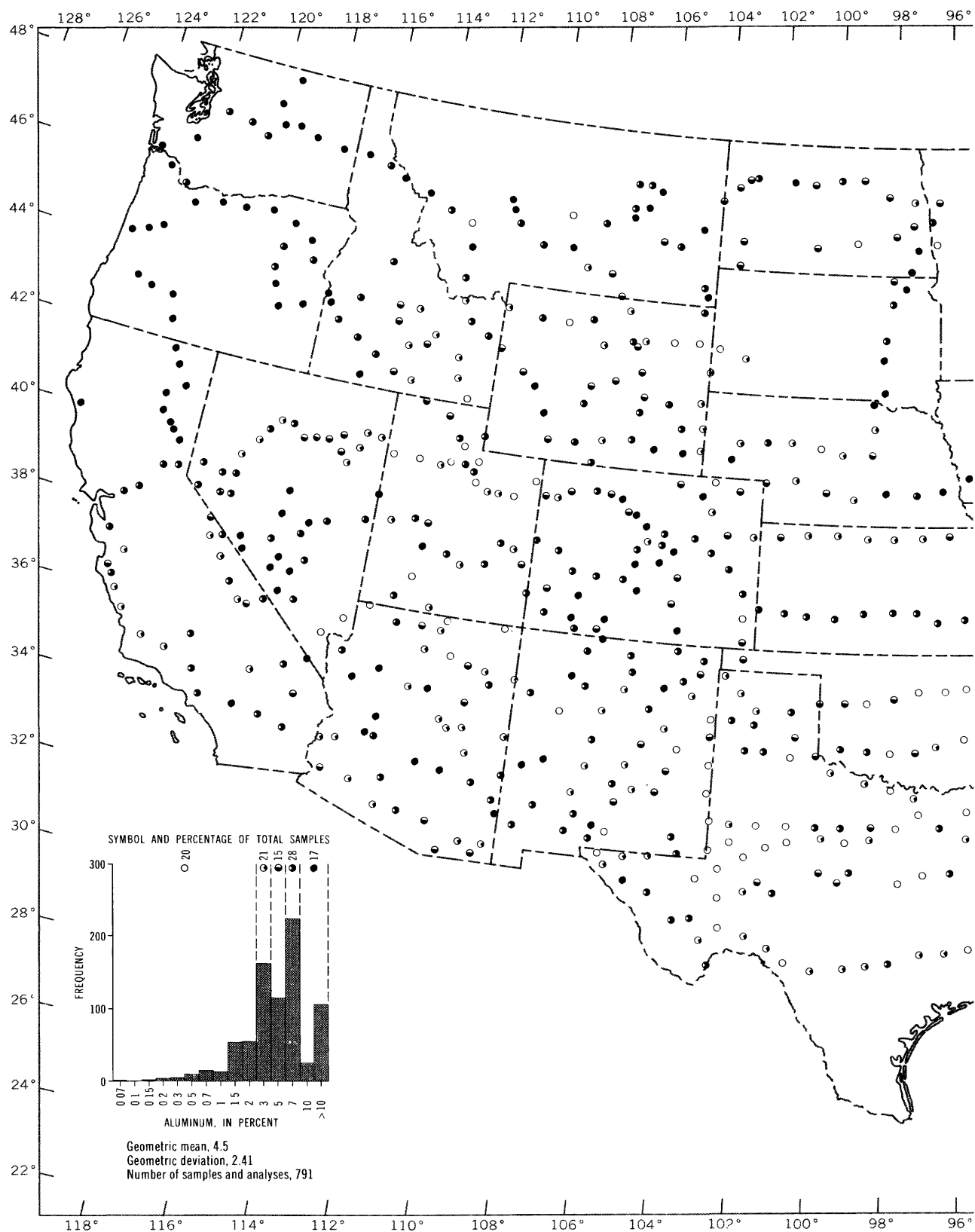
FIGURE 2.—Aluminum content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

BARIUM, IN PARTS PER MILLION

Geometric mean, 430
Geometric deviation, 2.06
Number of samples and analyses, 863
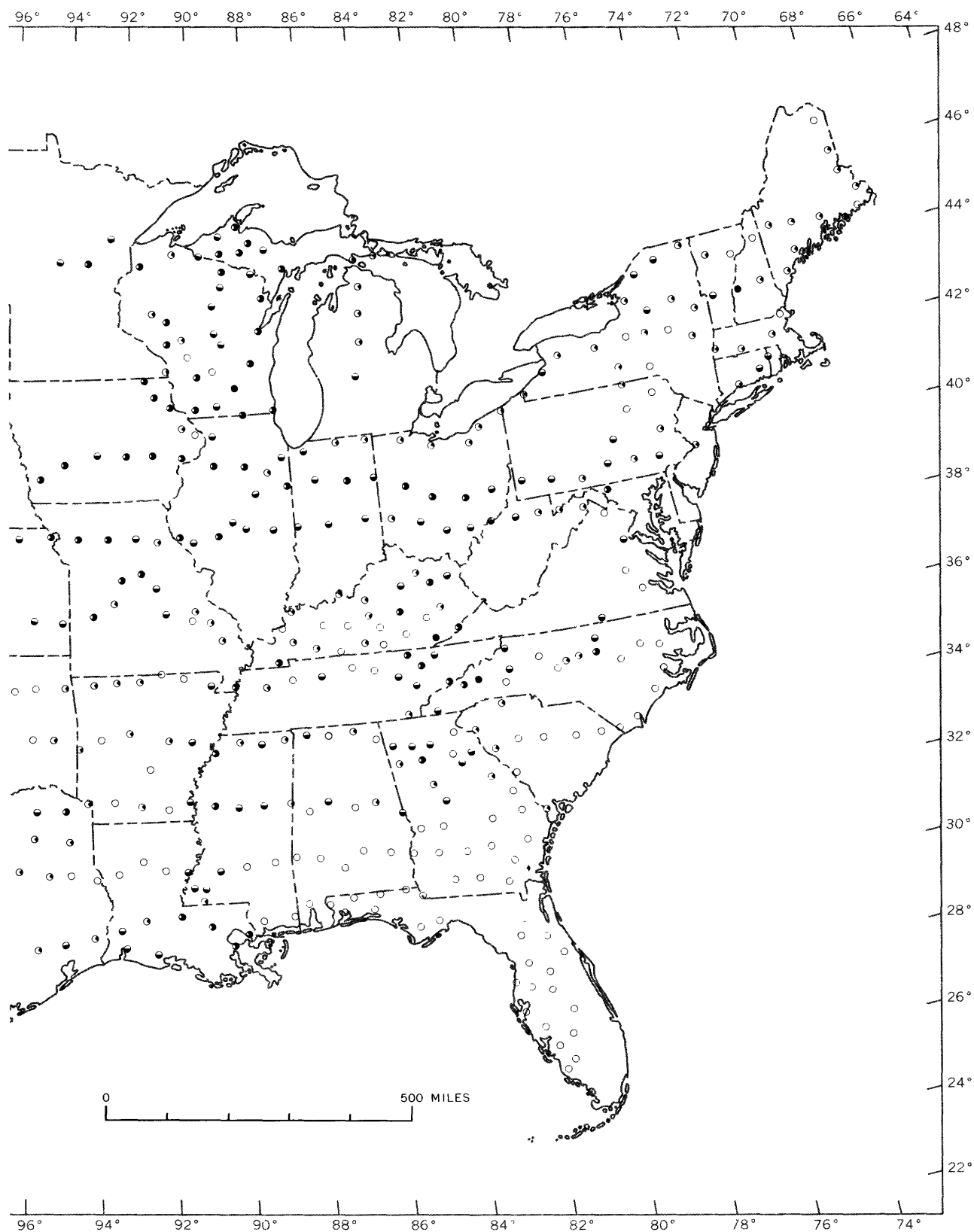
FIGURE 3.—Barium content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

BERYLLIUM, IN PARTS PER MILLION

Geometric mean, 0.6 ppm
Geometric deviation, 2.49
Number of samples and analyses, 847
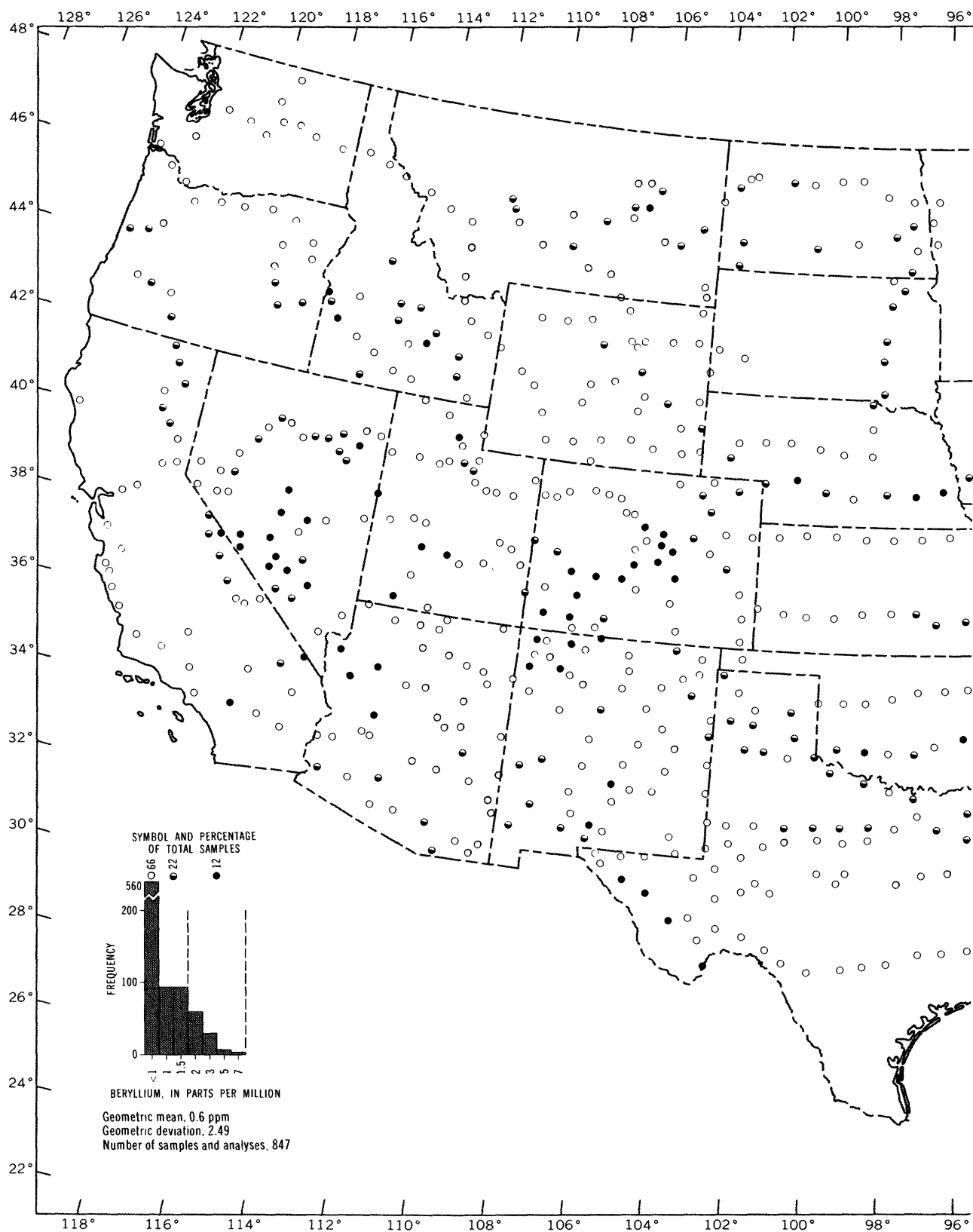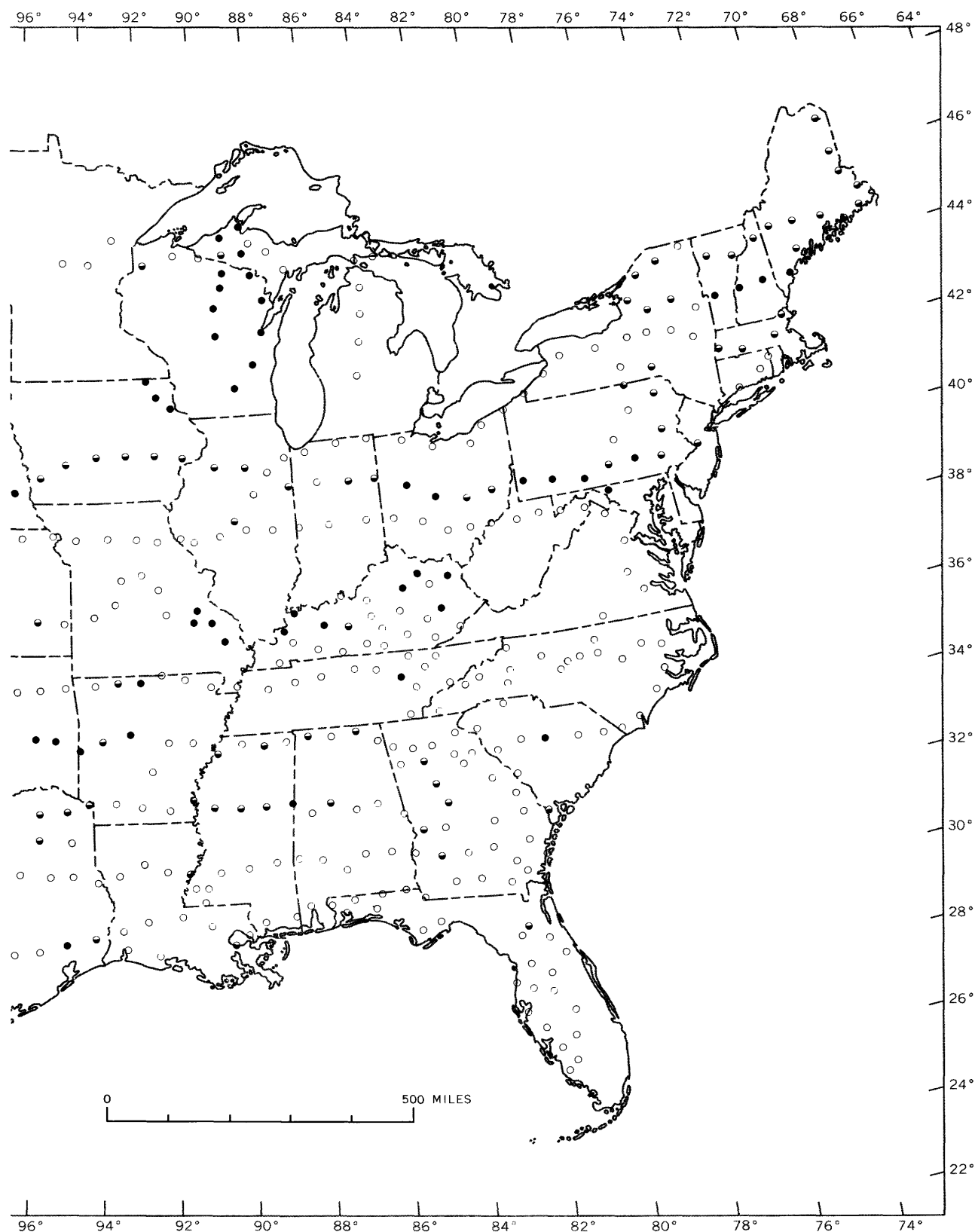
FIGURE 4.—Beryllium content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

BORON, IN PARTS PER MILLION

Geometric mean, 26
Geometric deviation, 2.05
Number of samples and analyses, 863
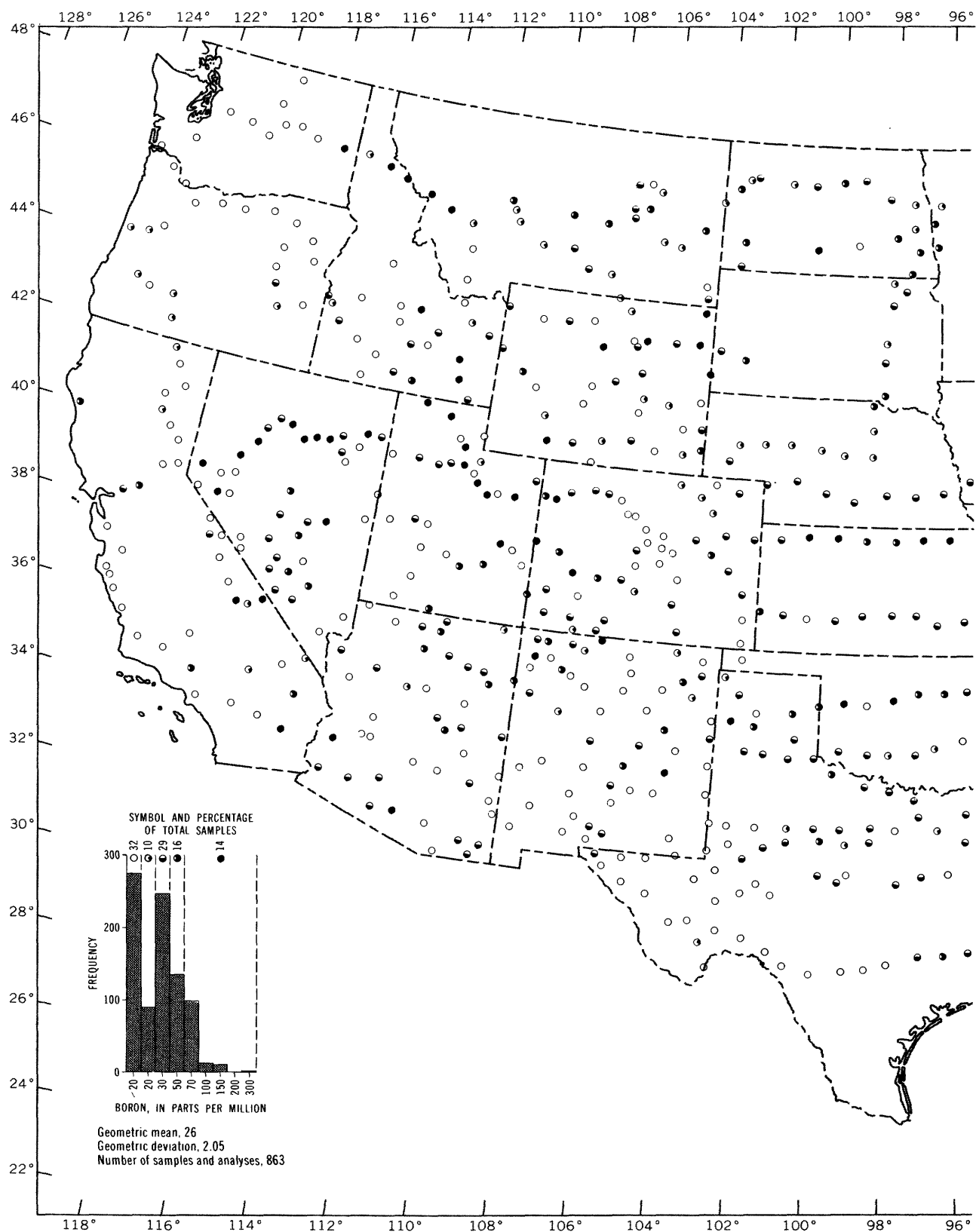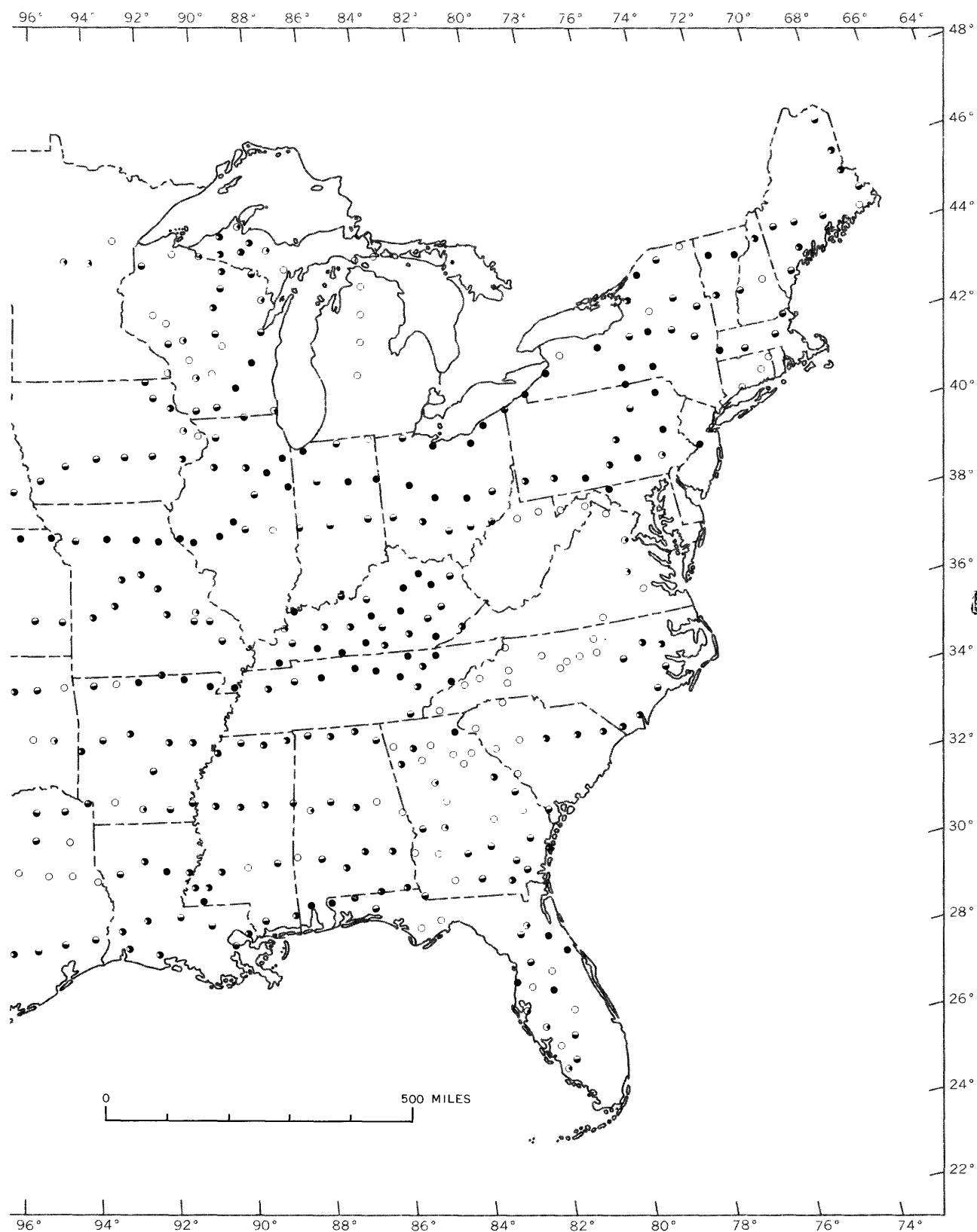
FIGURE 5.—Boron content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

CALCIUM, IN PERCENT

Geometric mean, 0.88
Geometric deviation, 3.92
Number of samples and analyses, 855
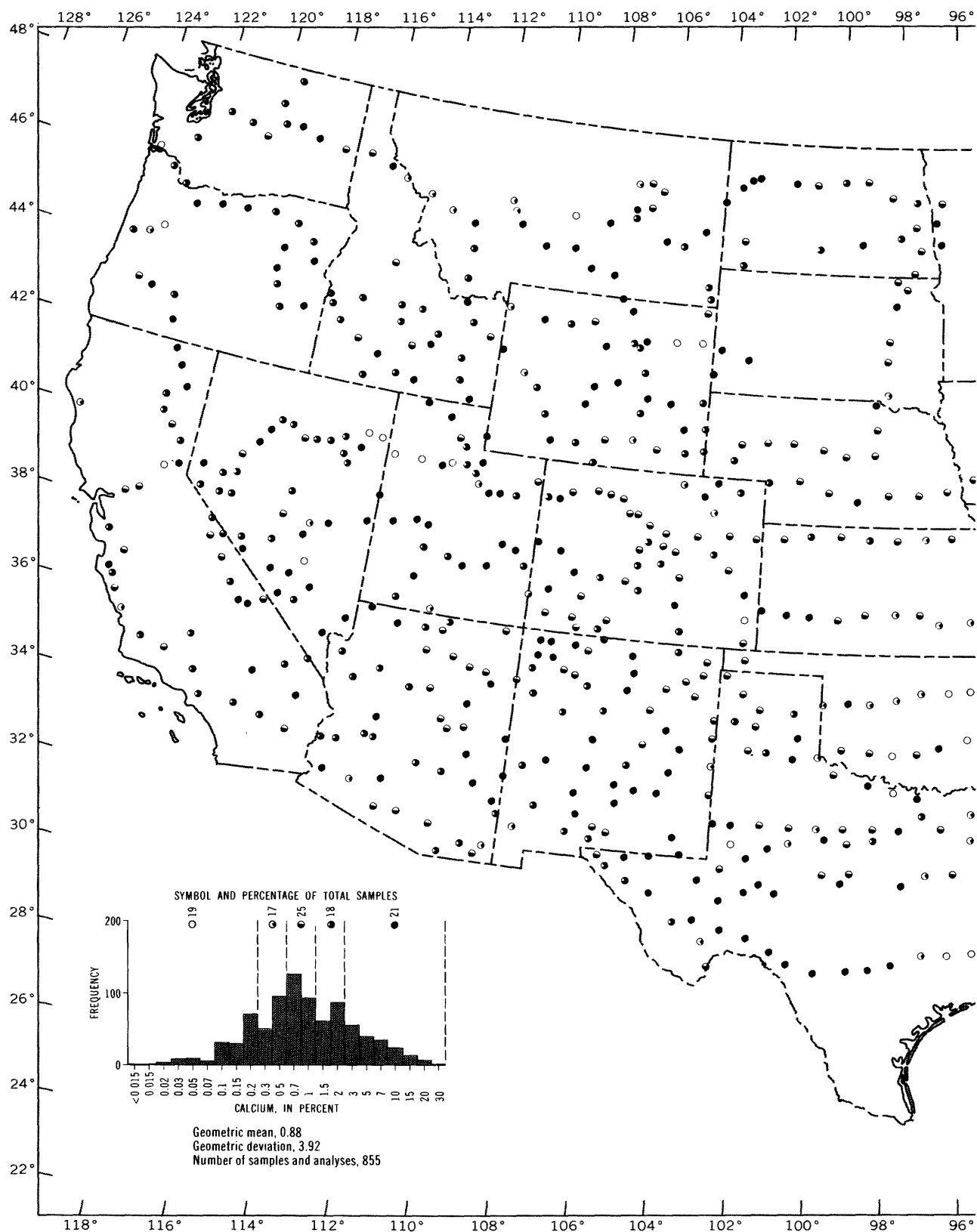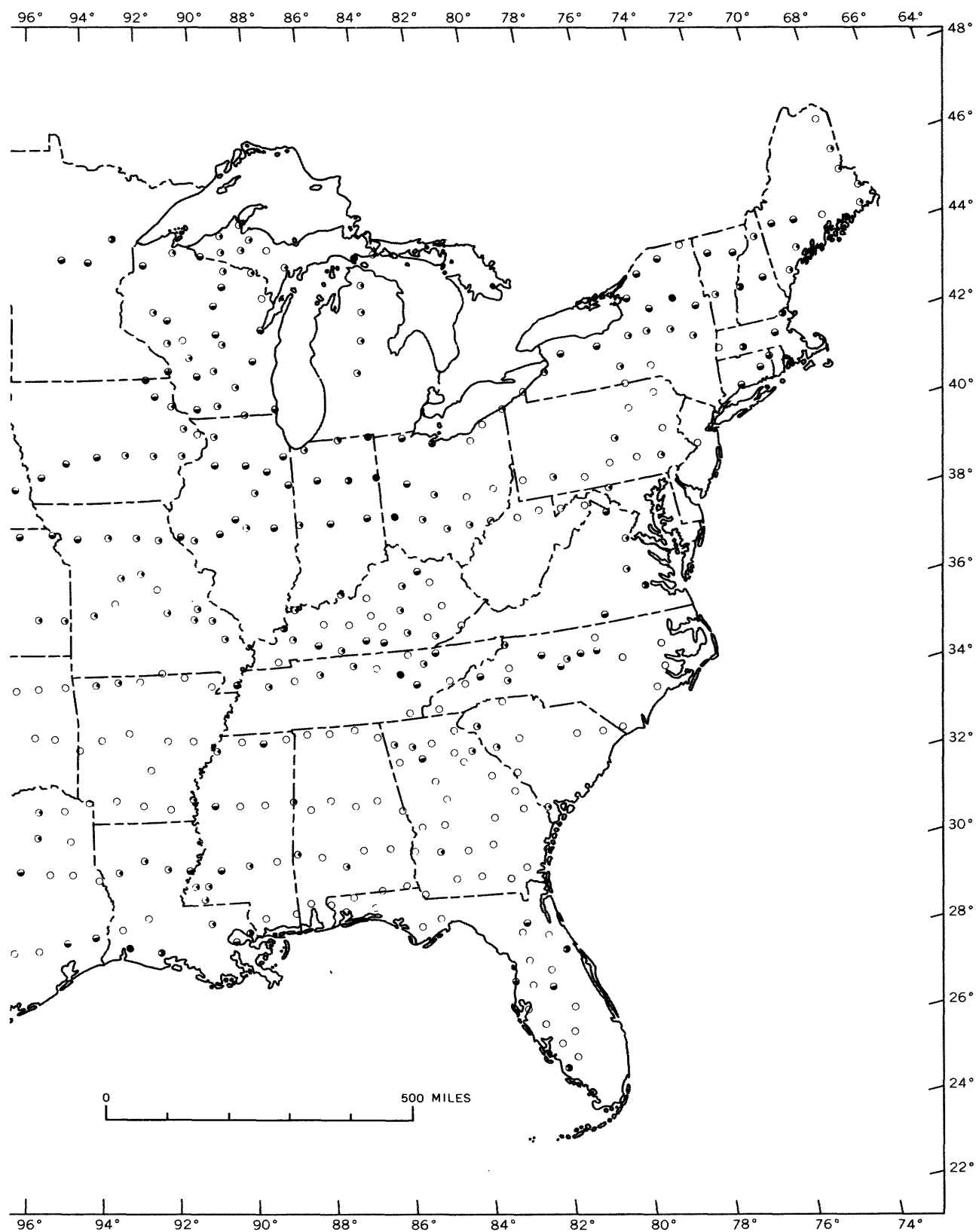
FIGURE 6.—Calcium content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

○ 82　　● 18

CERIUM, IN PARTS PER MILLION

Geometric mean, 75
Geometric deviation, 1.67
Number of samples and analyses, 753
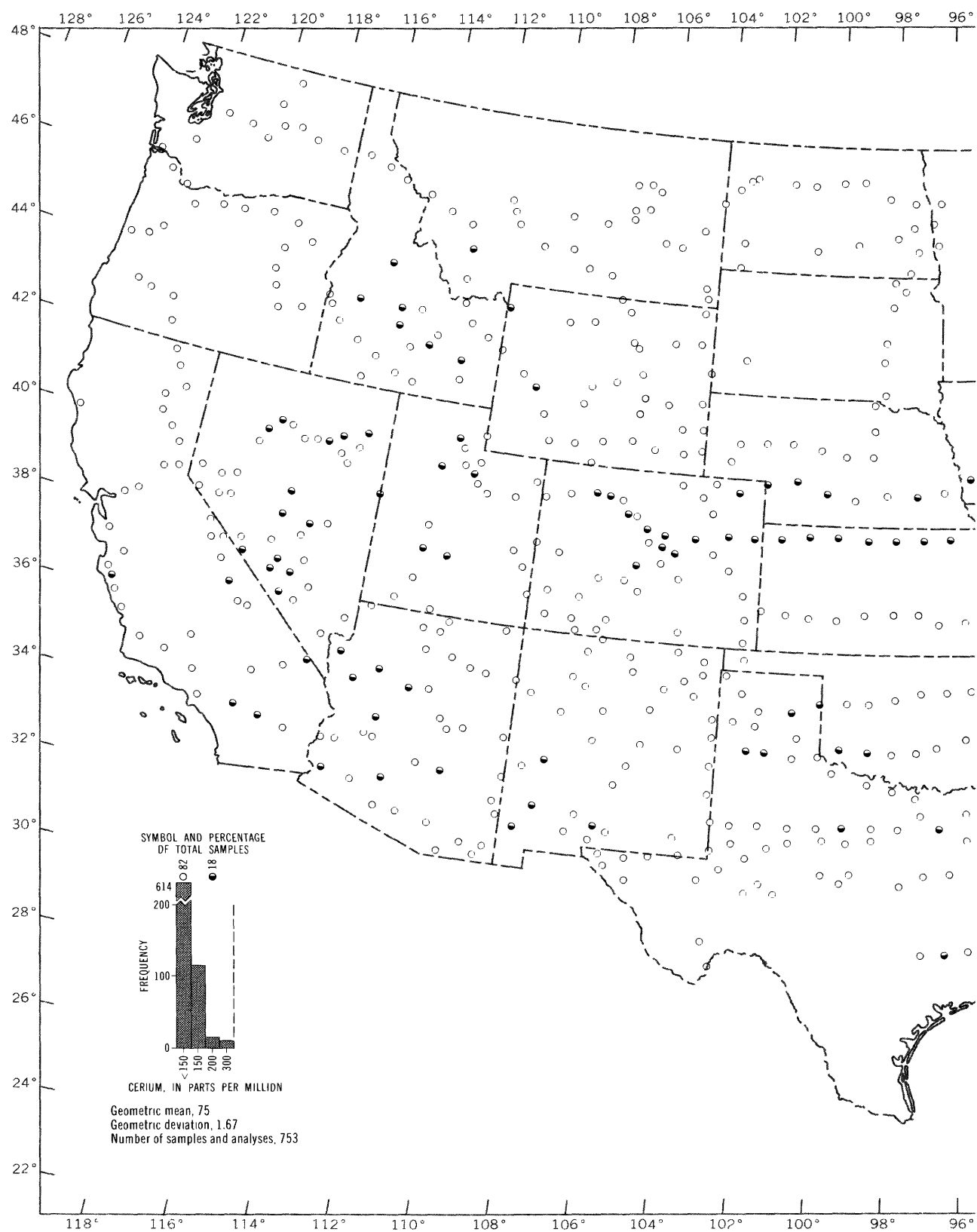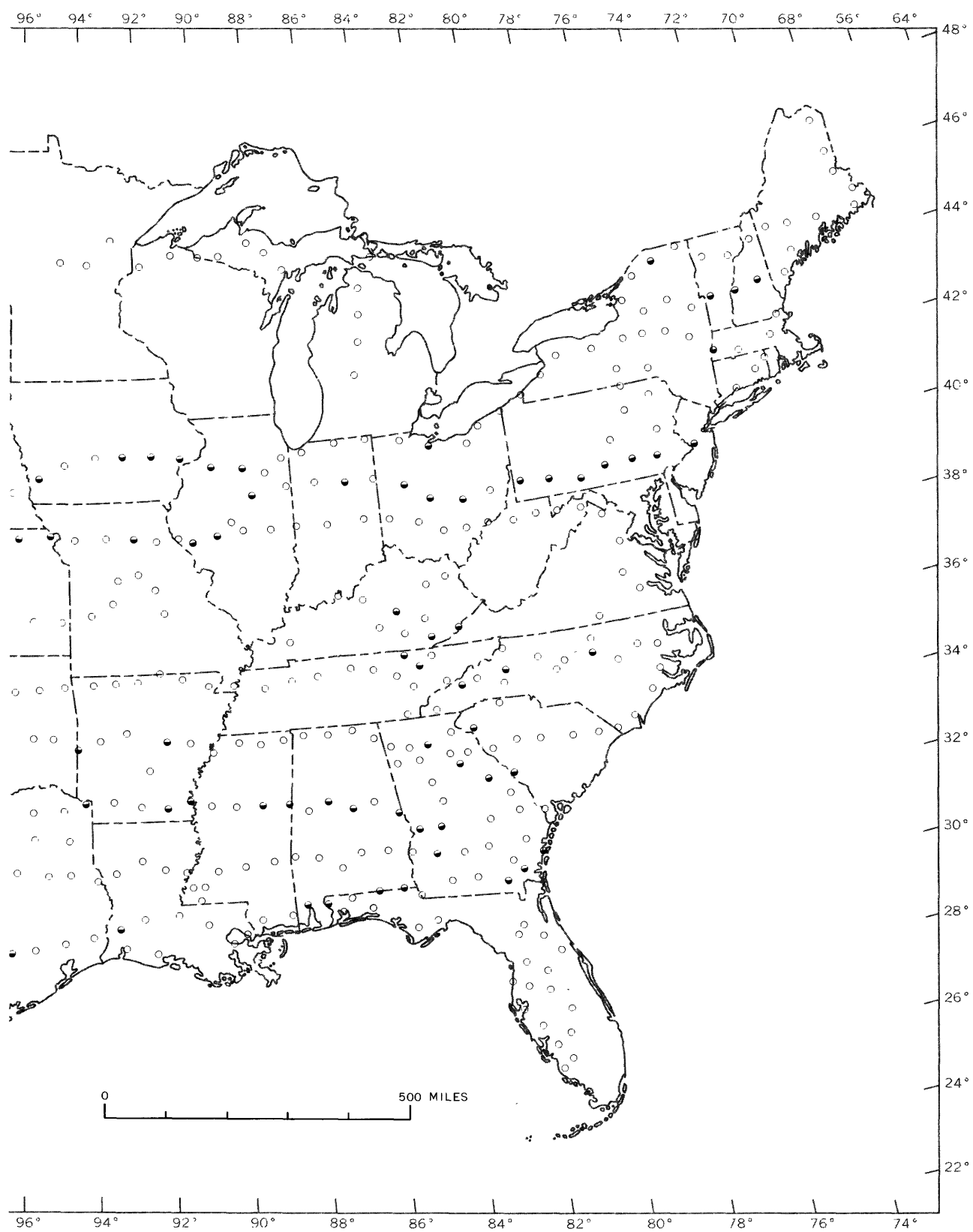
FIGURE 7.—Cerium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

CHROMIUM, IN PARTS PER MILLION

Geometric mean, 37
Geometric deviation, 2.32
Number of samples and analyses, 863
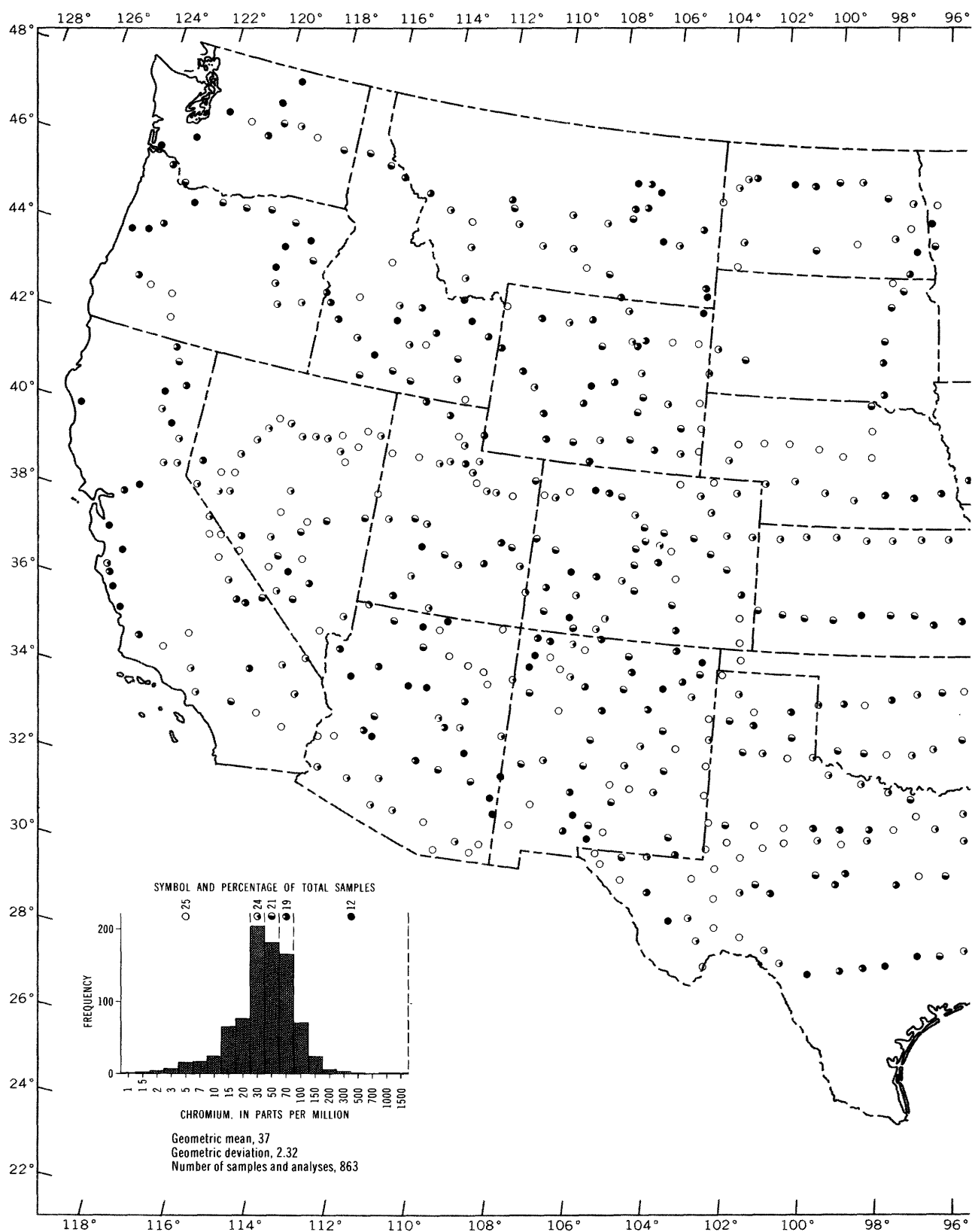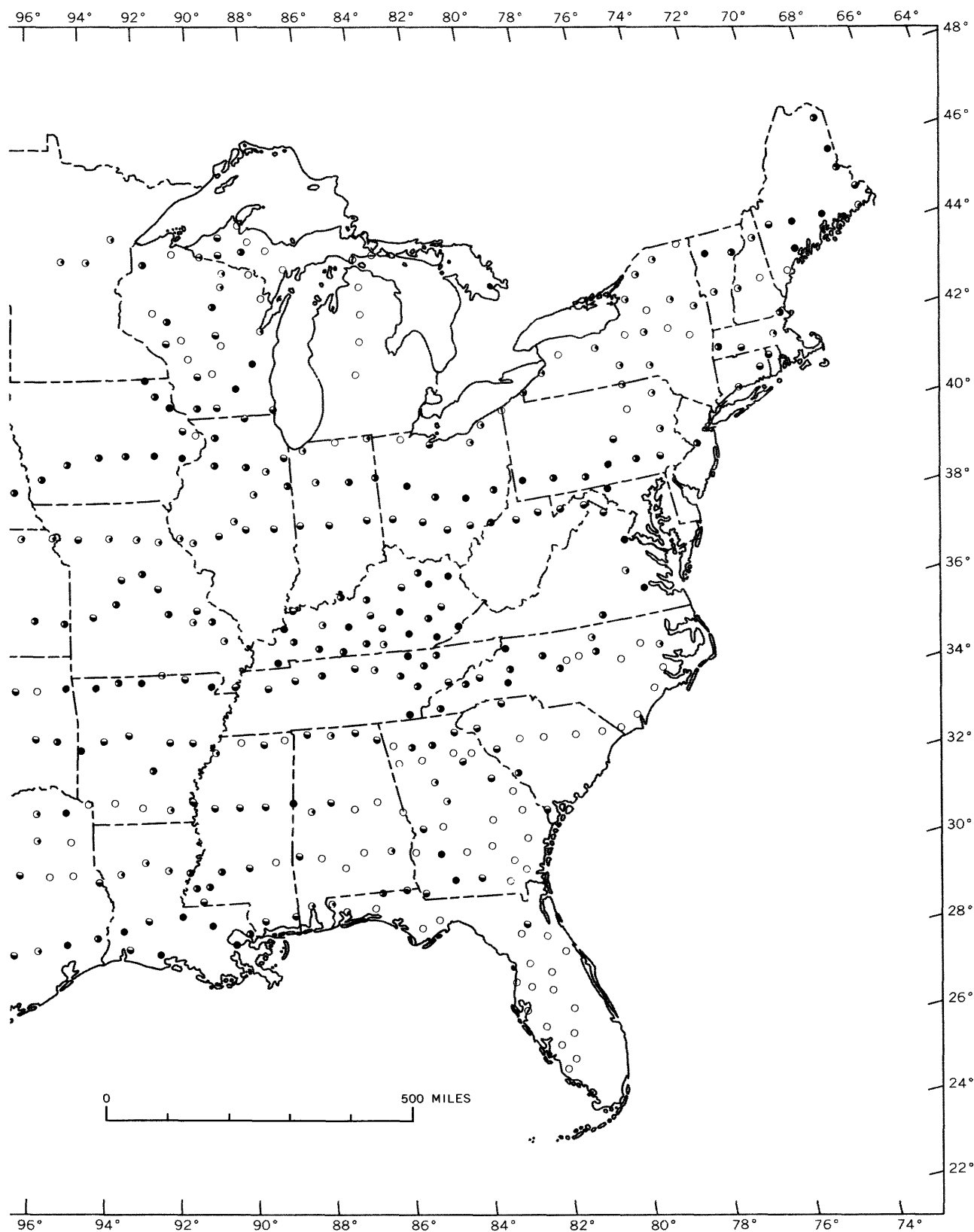
FIGURE 8.—Chromium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

COBALT IN PARTS PER MILLION

Geometric mean, 7
Geometric deviation, 2.21
Number of samples and analyses, 855
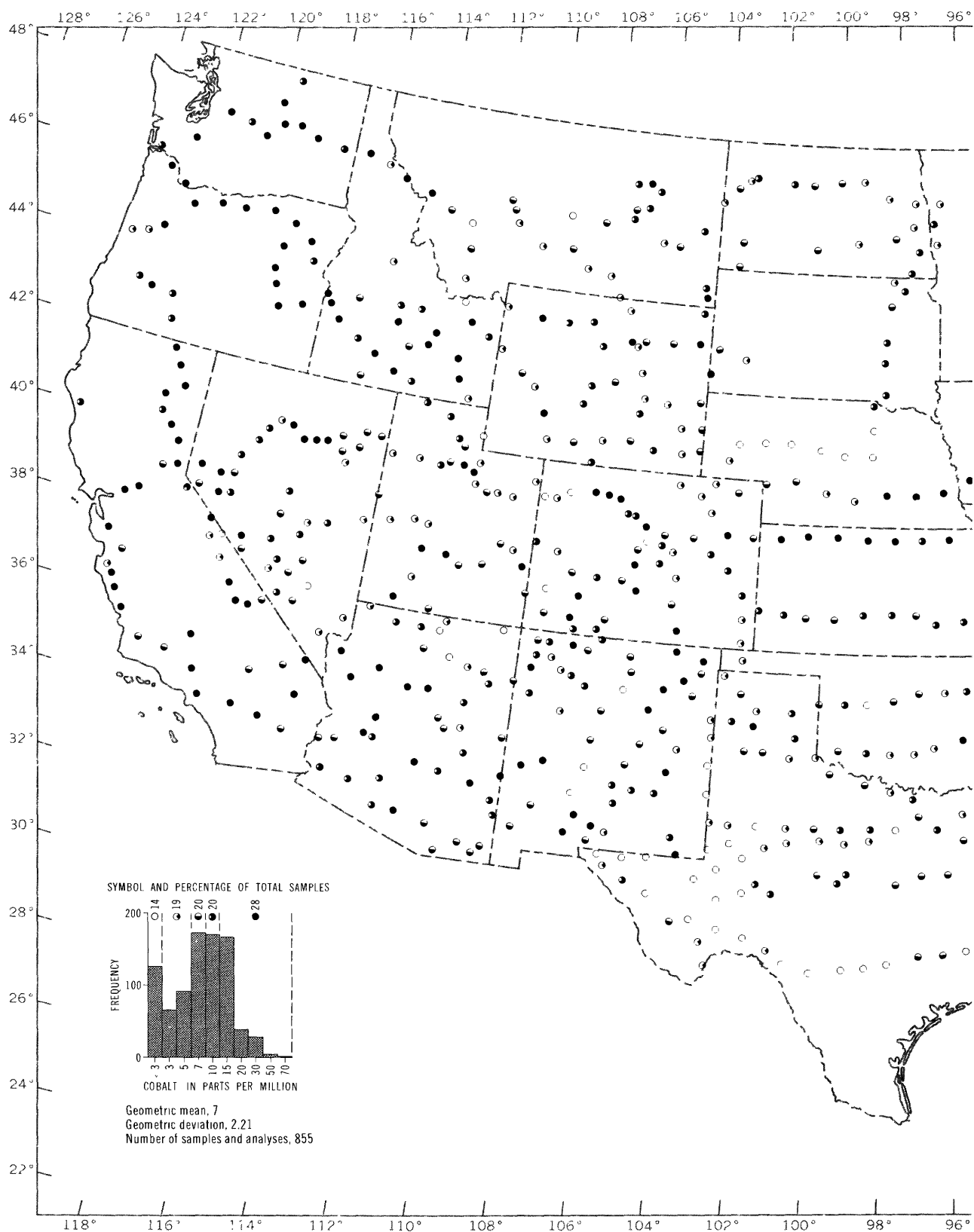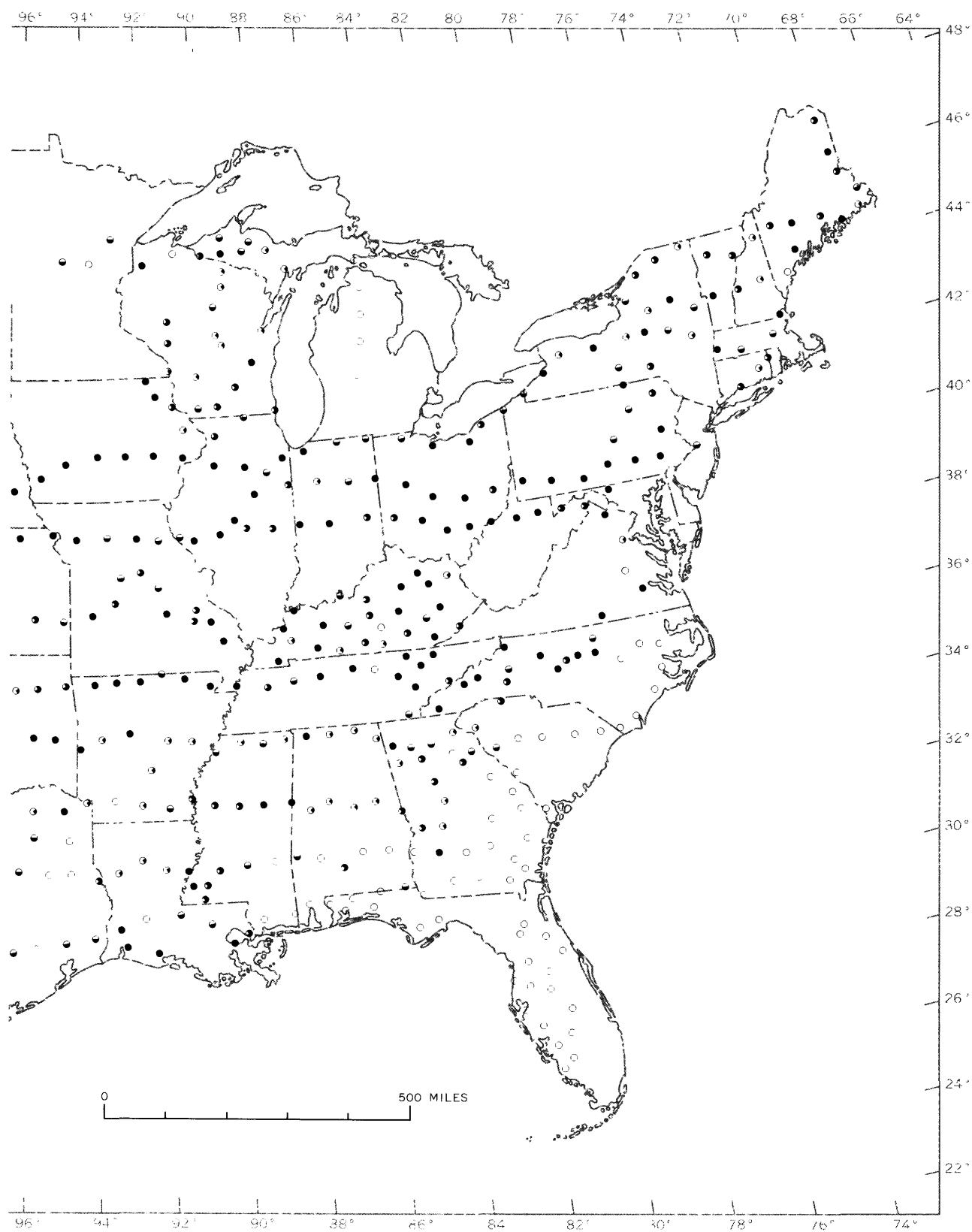
FIGURE 9.—Cobalt content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

○ 25   ◉ 21   ◉ 19   ◉ 21   ● 14

FREQUENCY

200

100

0

<1 1 1.5 2 3 5 7 10 15 20 30 50 70 100 150 200 300

COPPER, IN PARTS PER MILLION

Geometric mean, 18
Geometric deviation, 2.28
Number of samples and analyses, 855
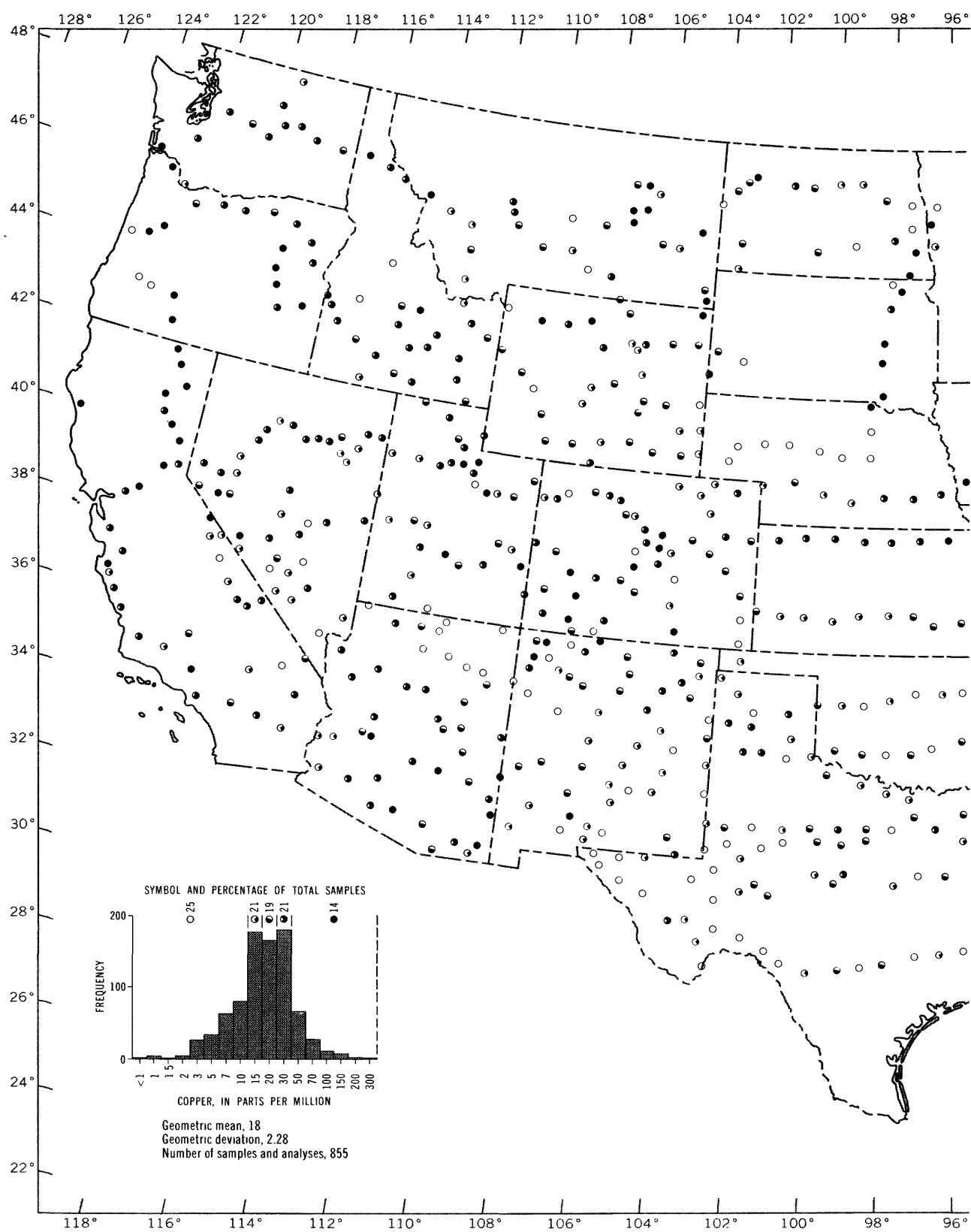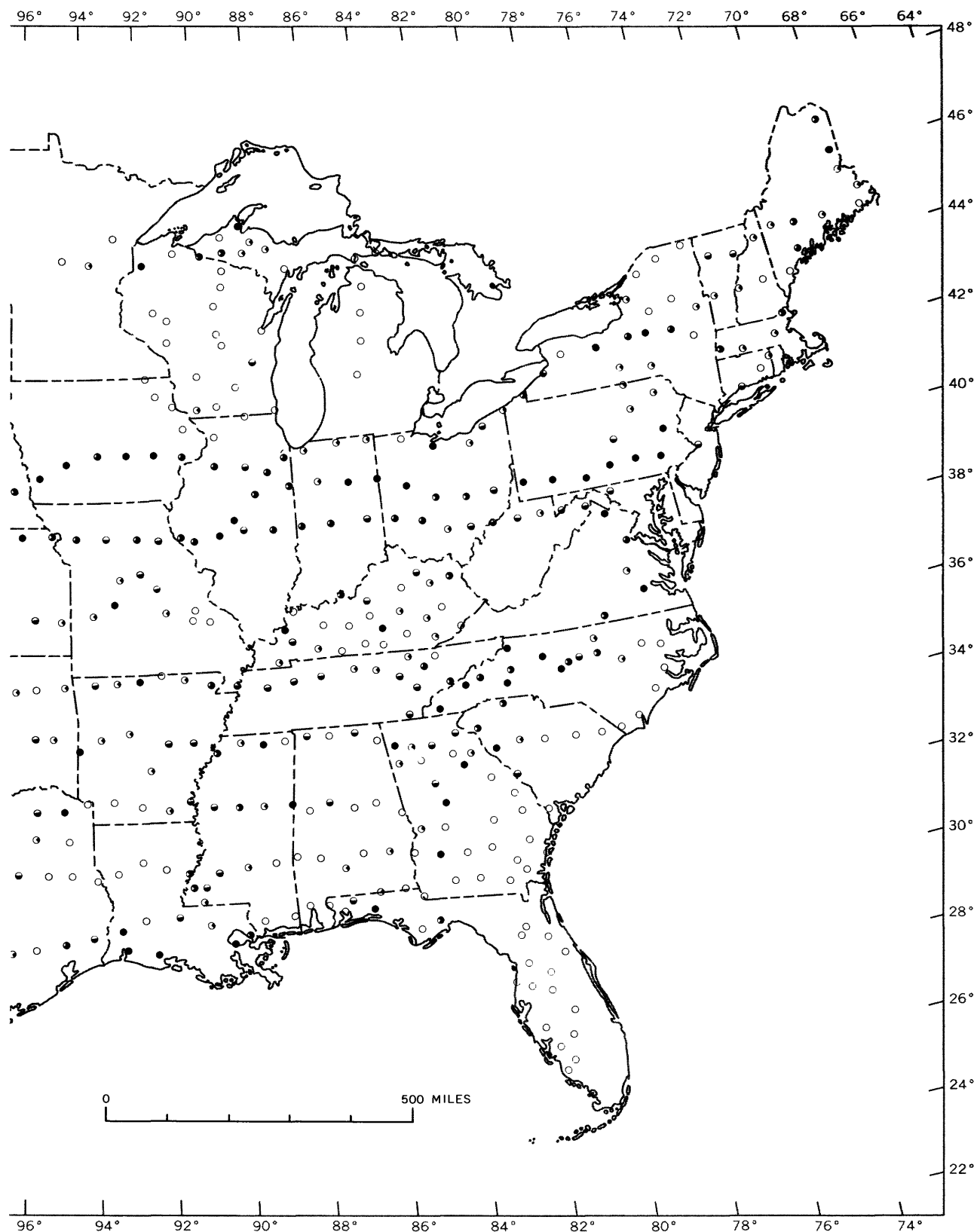
FIGURE 10.—Copper content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

| ○ 21 | ◑ 11 | ◑ 20 | ◐ 18 | ● 29 |

GALLIUM, IN PARTS PER MILLION

Geometric mean, 14
Geometric deviation, 2 11
Number of samples and analyses, 860
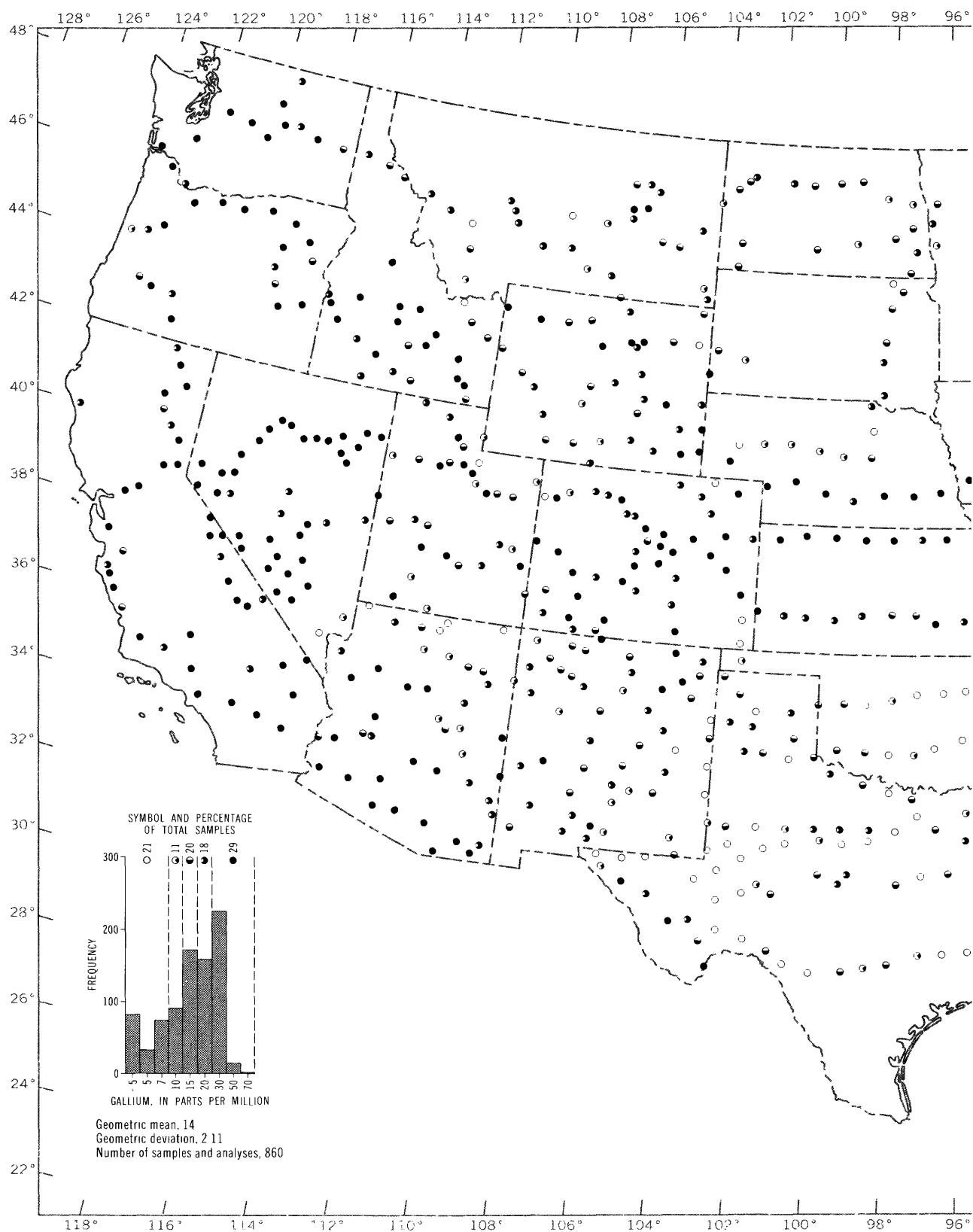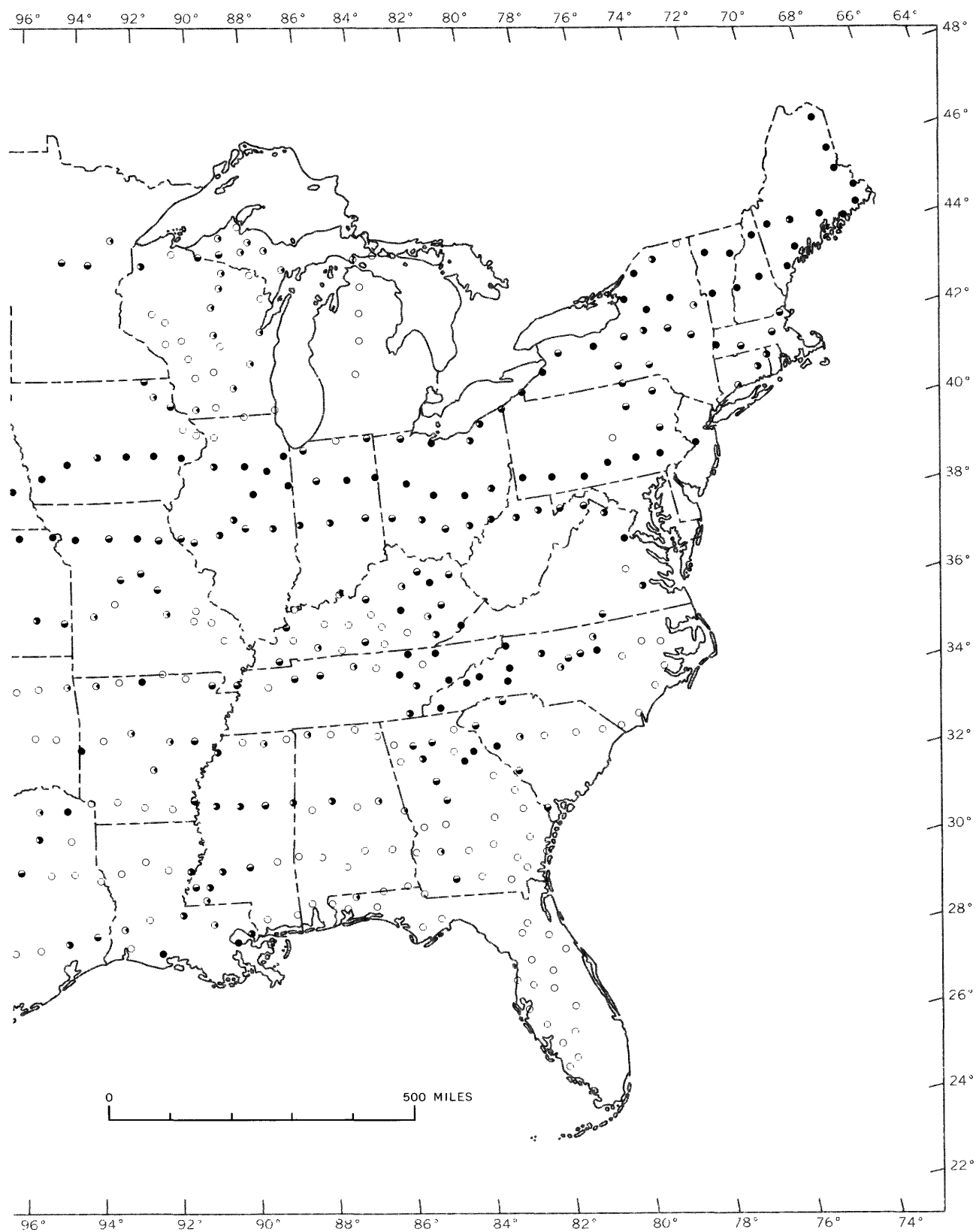
FIGURE 11.—Gallium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

IRON, IN PERCENT

Geometric mean, 1.8
Geometric deviation, 2.30
Number of samples and analyses, 861
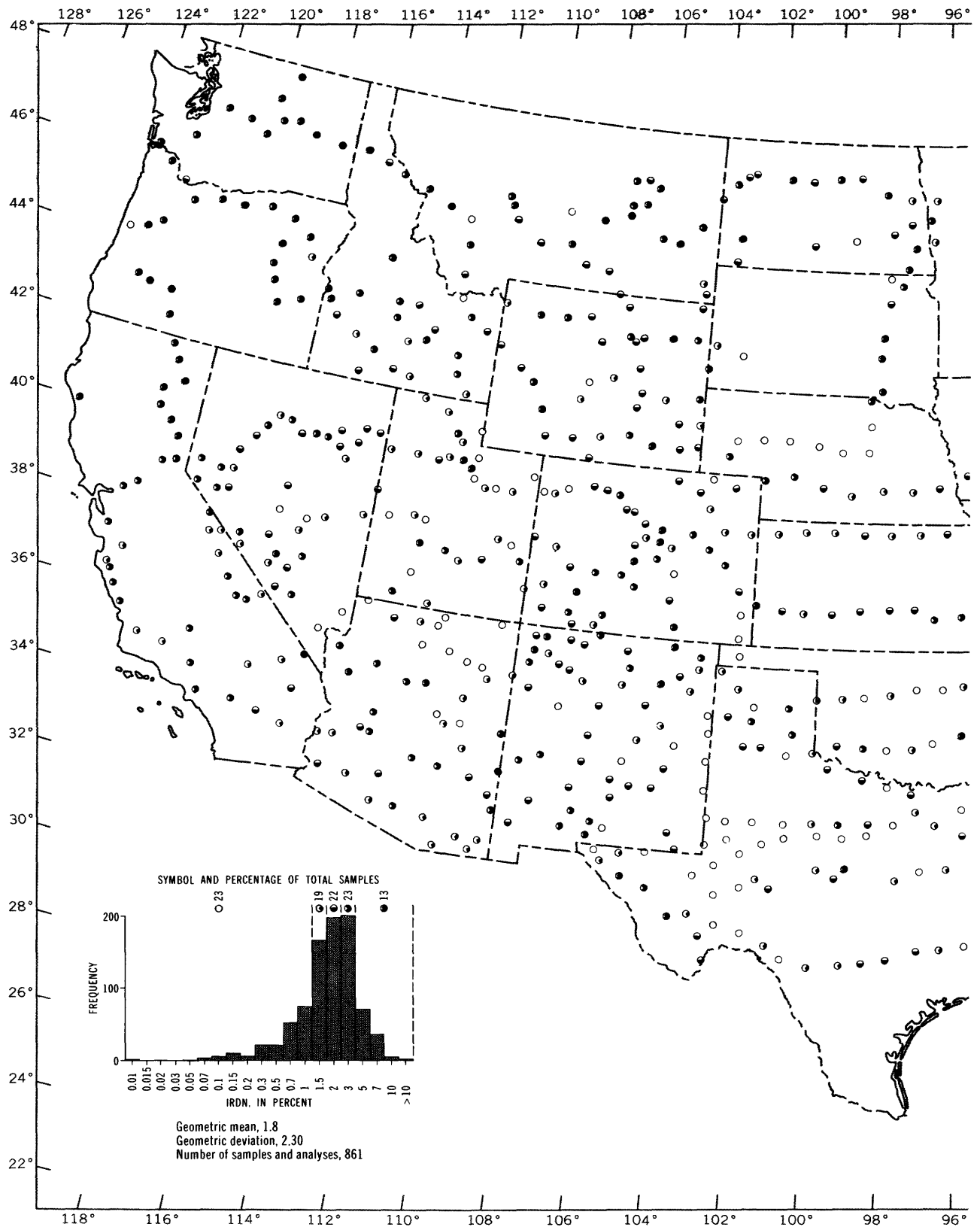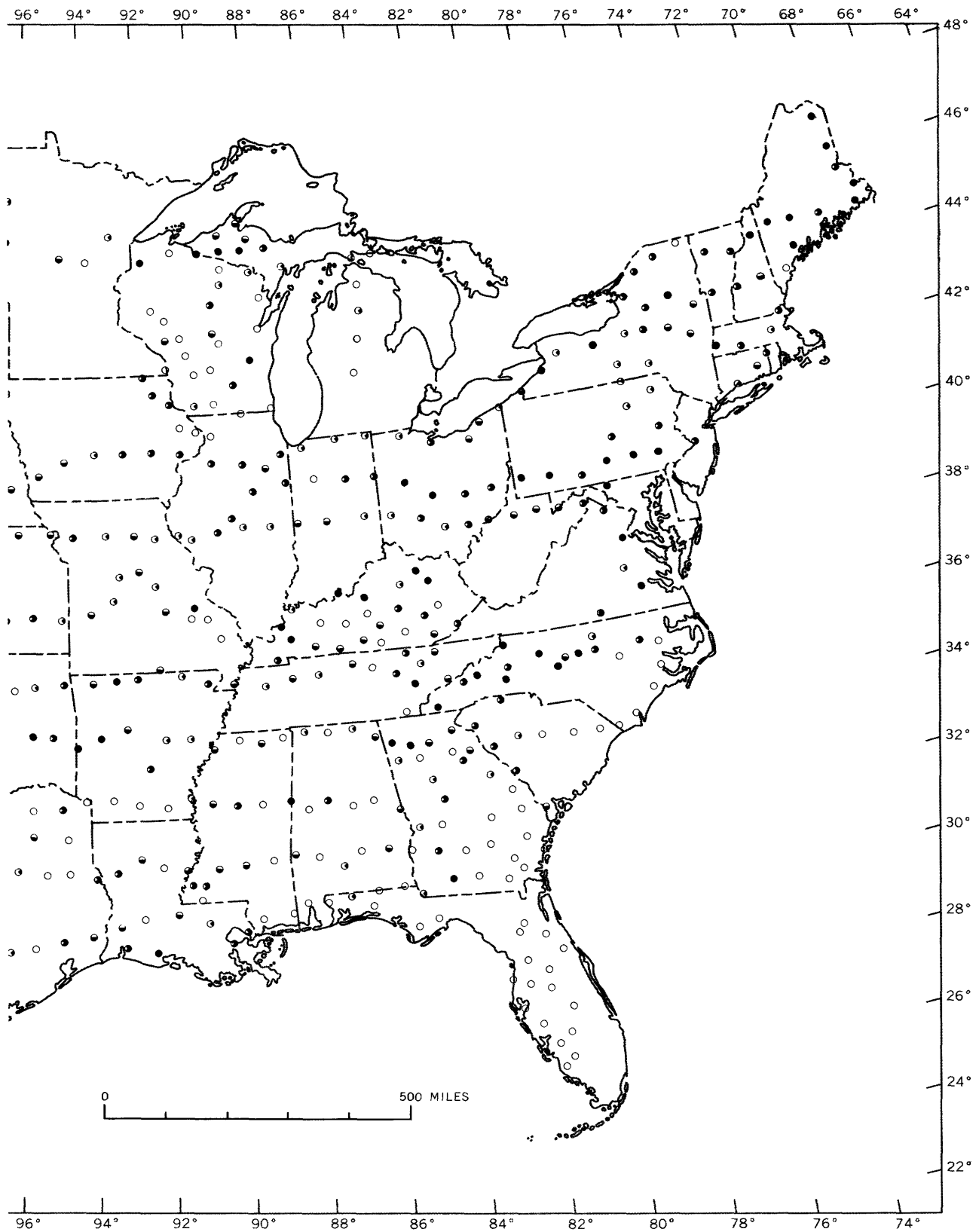
FIGURE 12.—Iron content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

LANTHANUM, IN PARTS PER MILLION

Geometric mean 34
Geometric deviation 1 85
Number of samples and analyses, 837
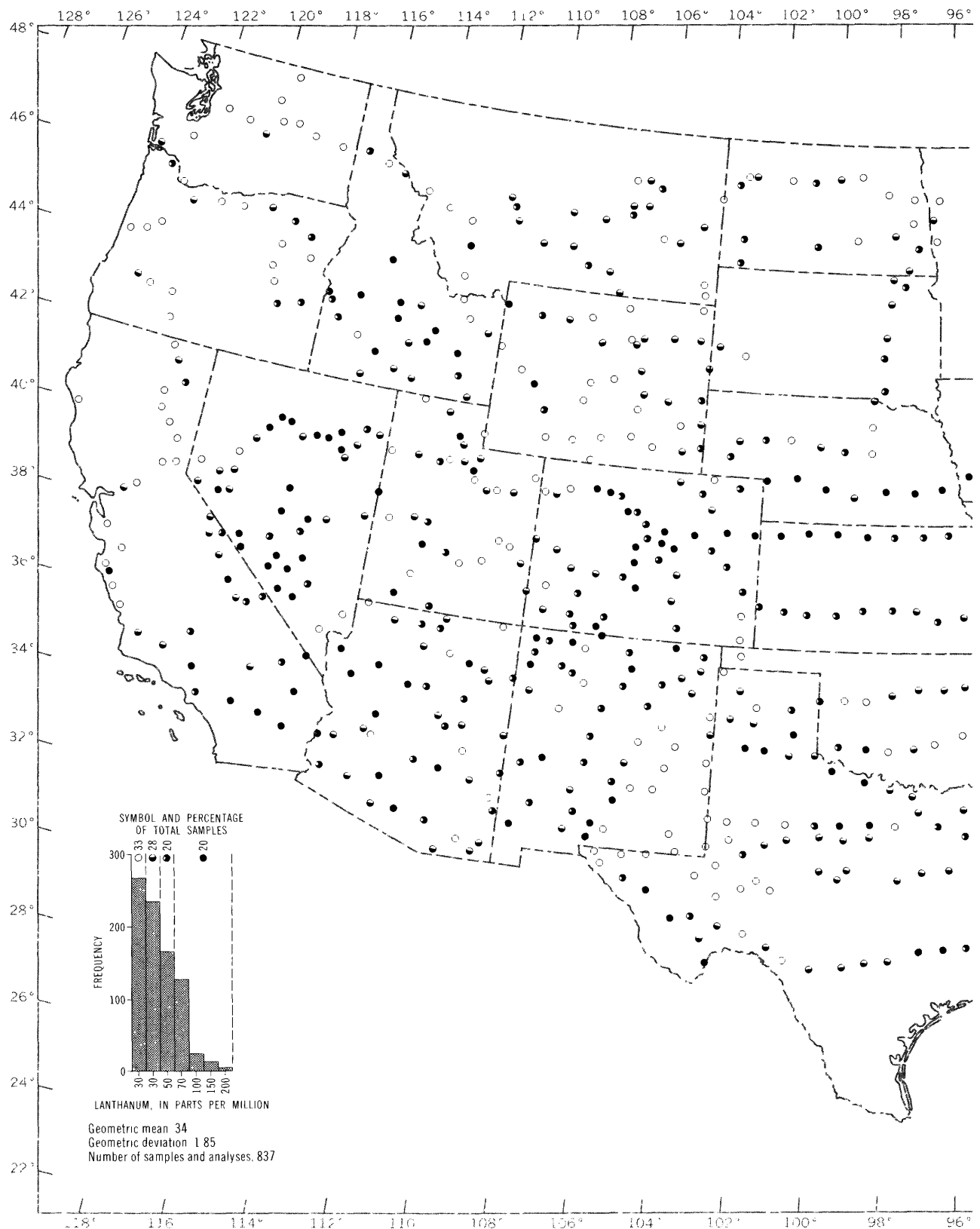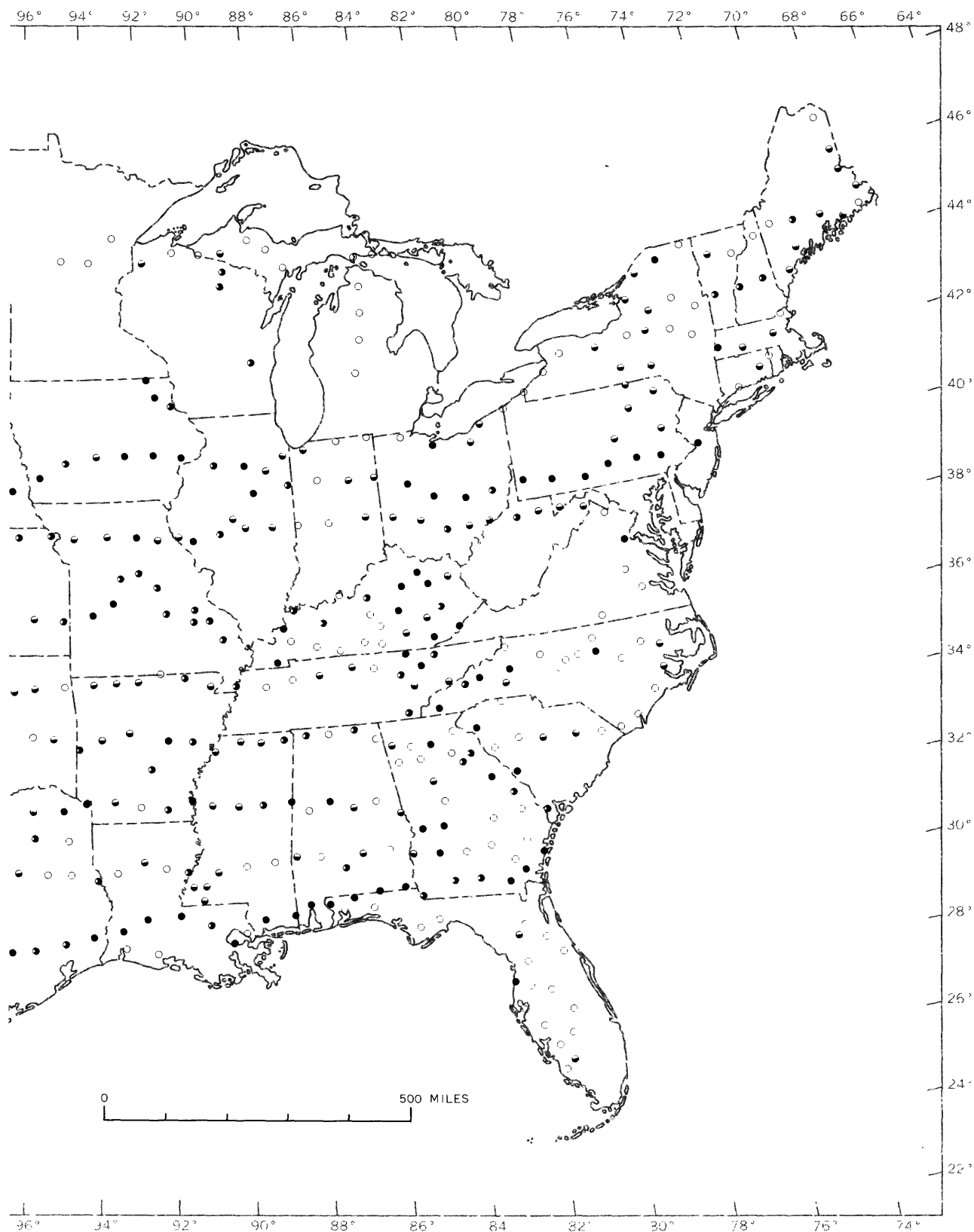
FIGURE 13.—Lanthanum content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

LEAD, IN PARTS PER MILLION

Geometric mean, 16
Geometric deviation, 1.96
Number of samples and analyses, 863
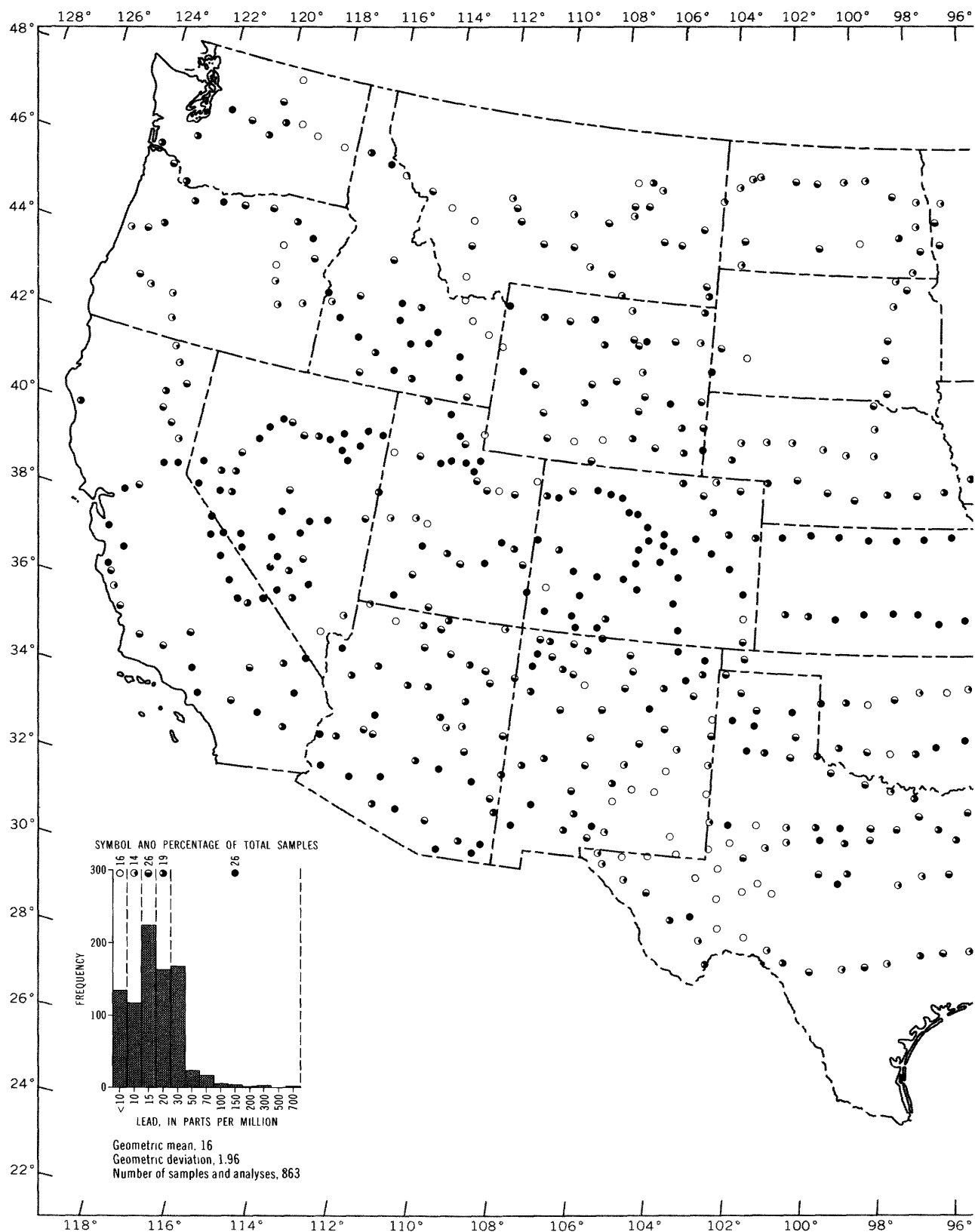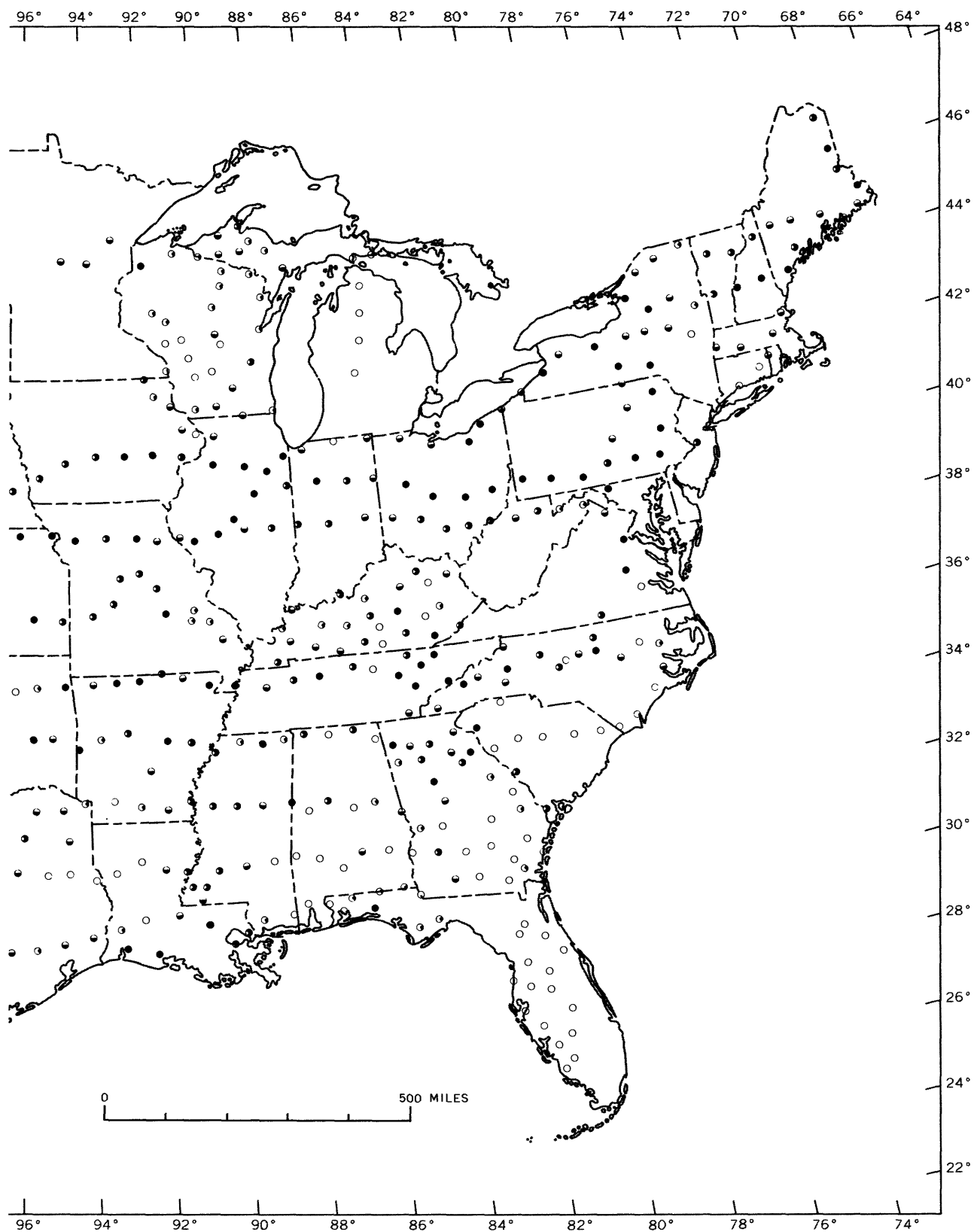
FIGURE 14.—Lead content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

MAGNESIUM, IN PERCENT

Geometric mean, 0 47
Geometric deviation, 3 19
Number of samples and analyses. 850
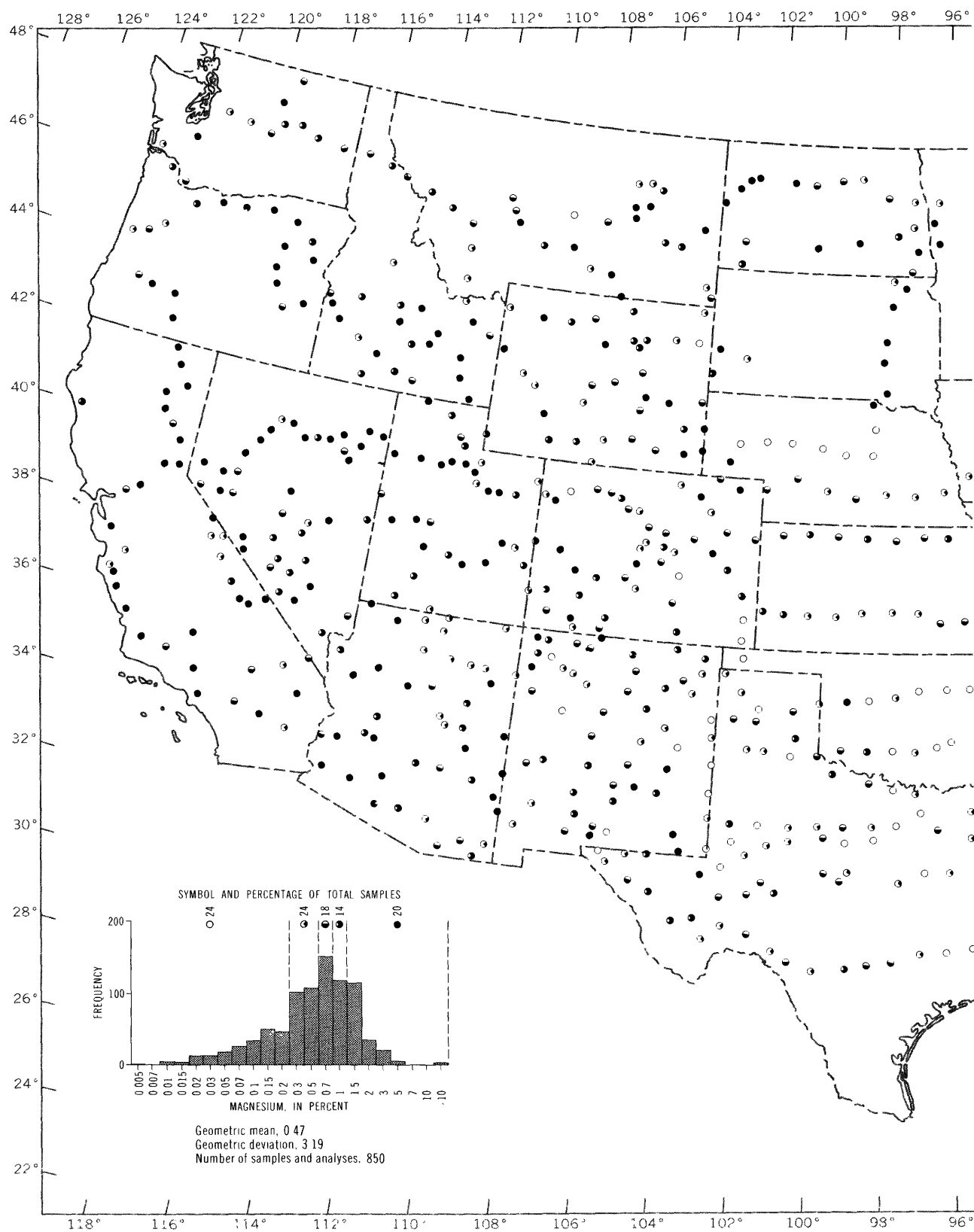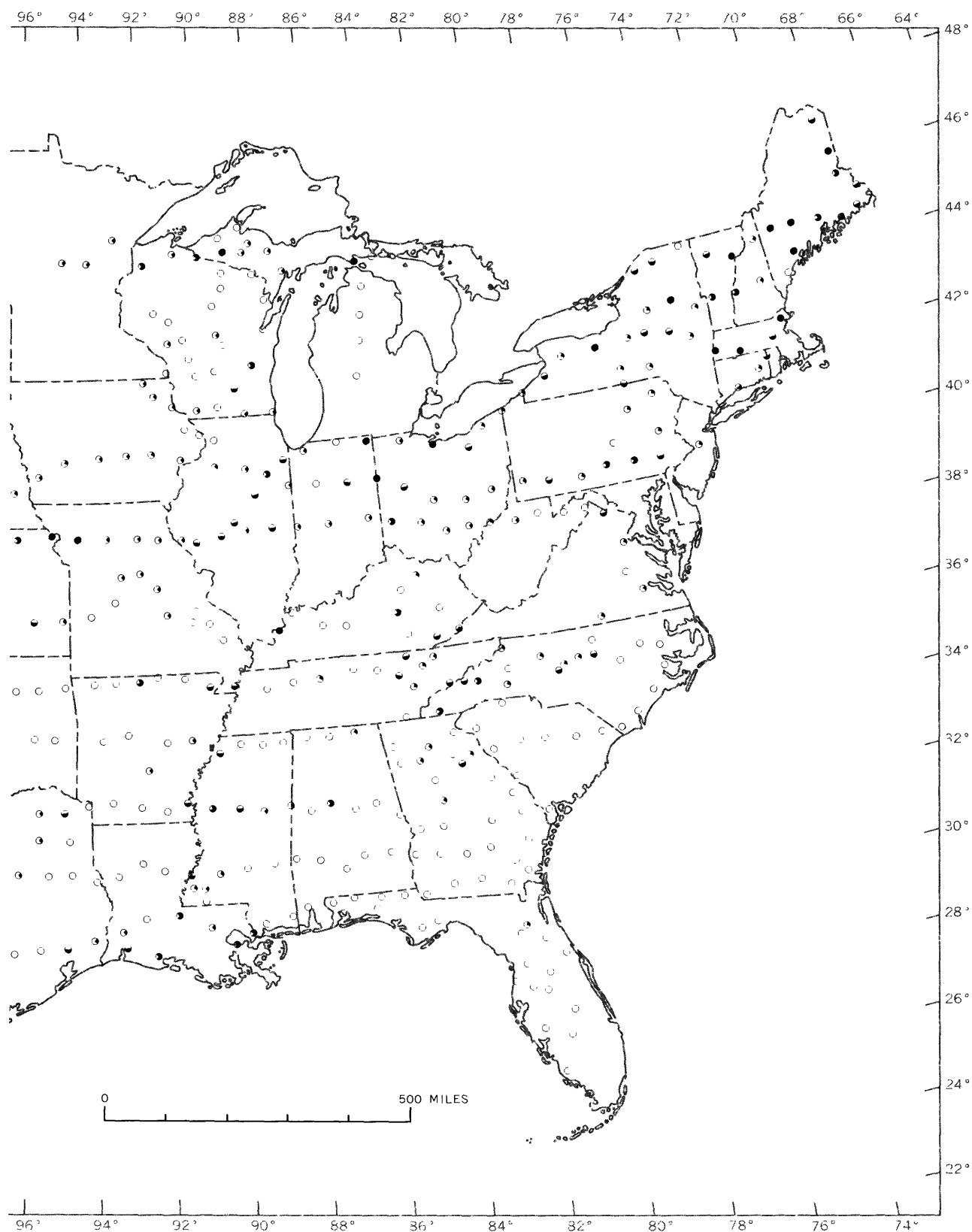
FIGURE 15.—Magnesium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

MANGANESE, IN PARTS PER MILLION

Geometric mean, 340
Geometric deviation, 2.70
Number of samples and analyses, 861
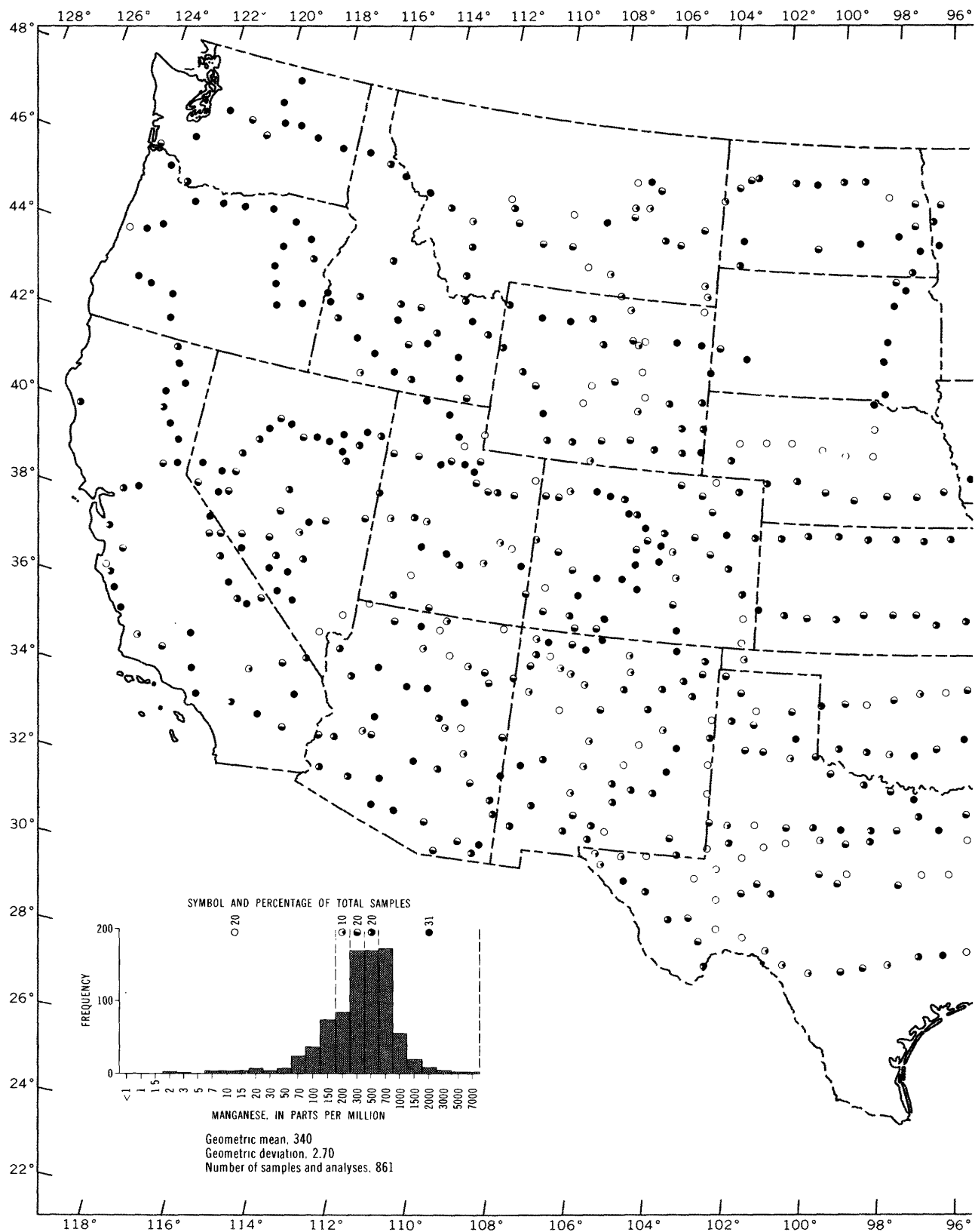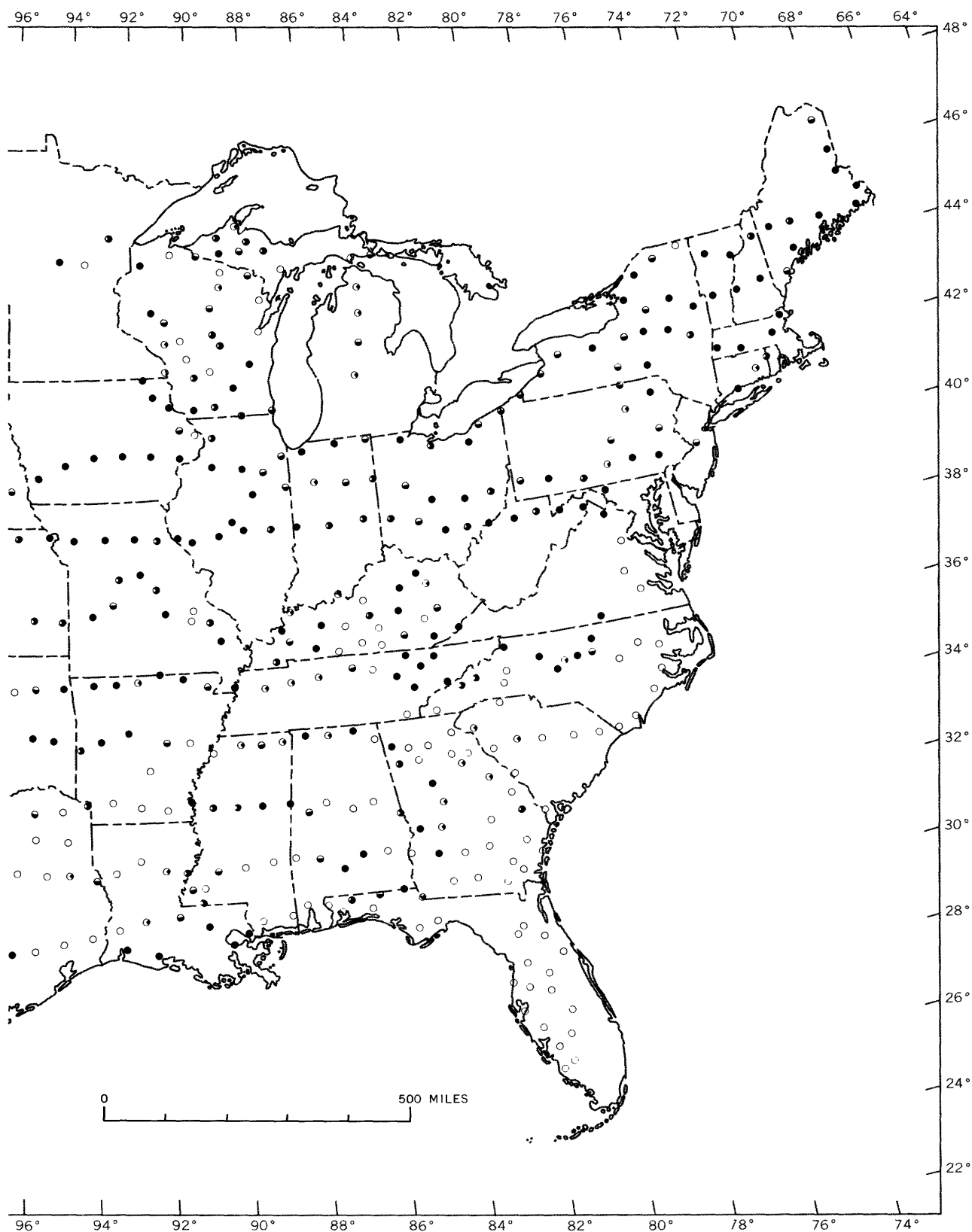
FIGURE 16.—Manganese content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

MOLYBDENUM IN PARTS PER MILLION

Geometric mean and geometric
deviation not computed be
cause of insufficient data

Number of samples and analyses, 844
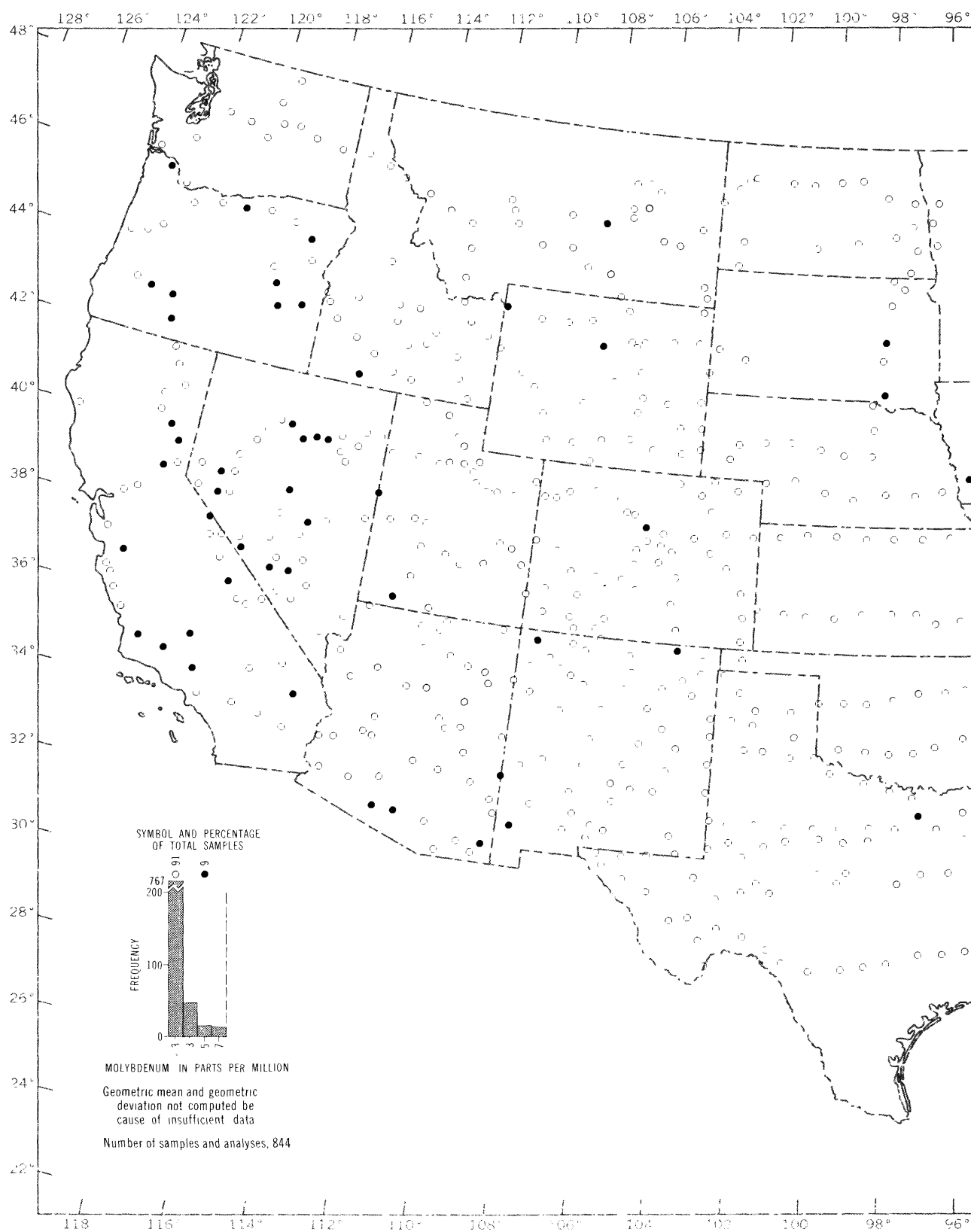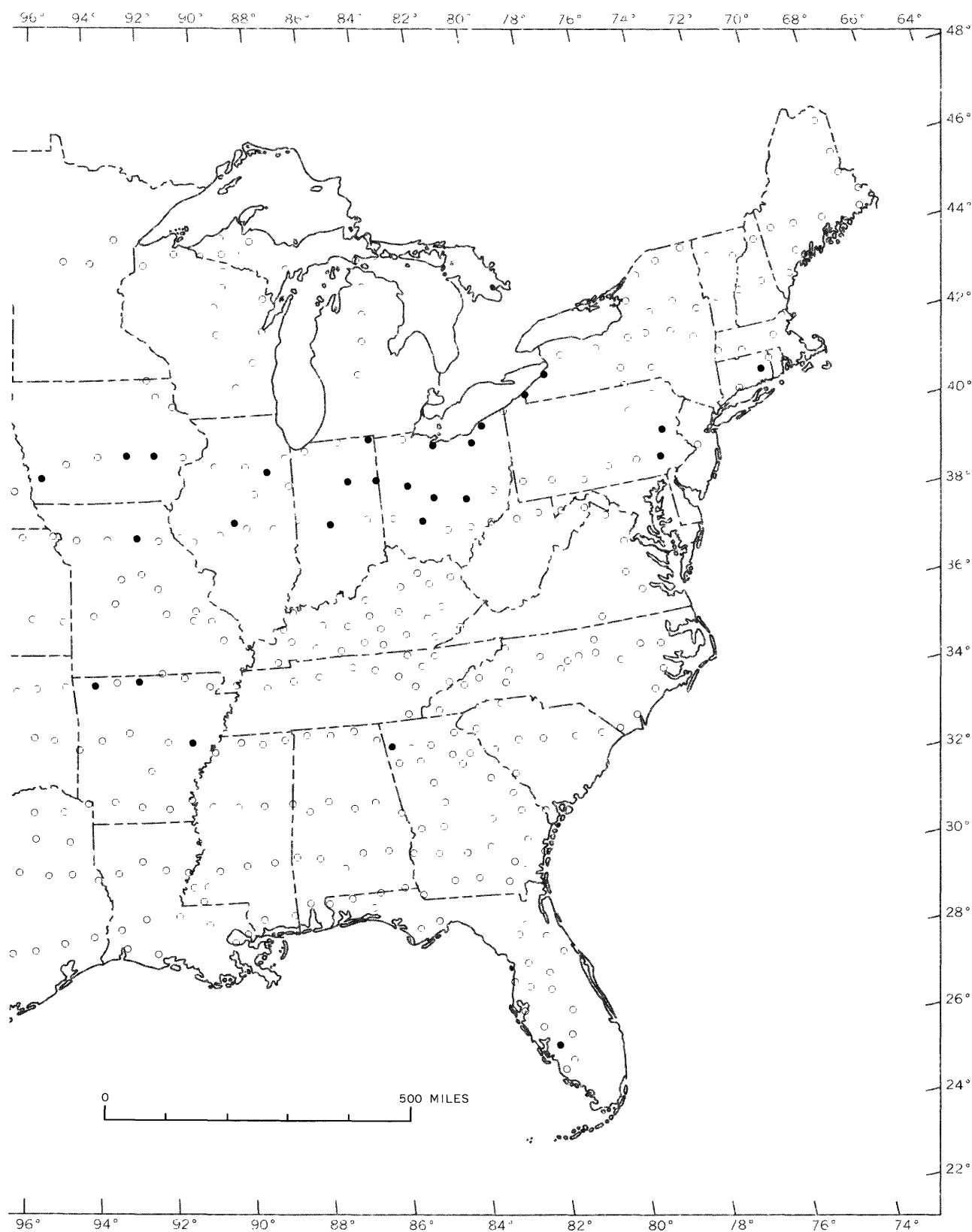
FIGURE 17.—Molybdenum content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

○ 74   ◐ 23   ● 3

NEODYMIUM, IN PARTS PER MILLION

Geometric mean, 39
Geometric deviation, 1.72
Number of samples and analyses, 616
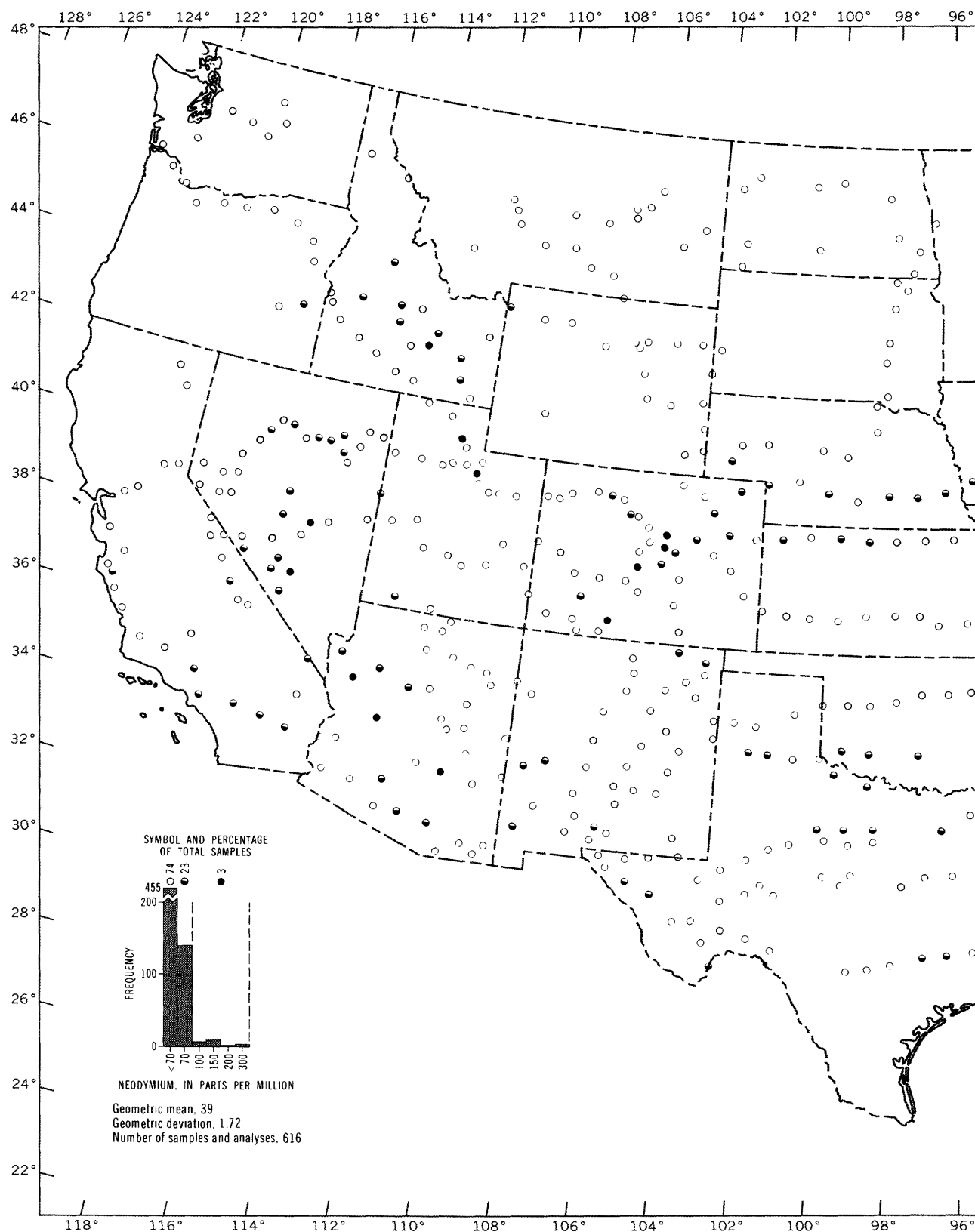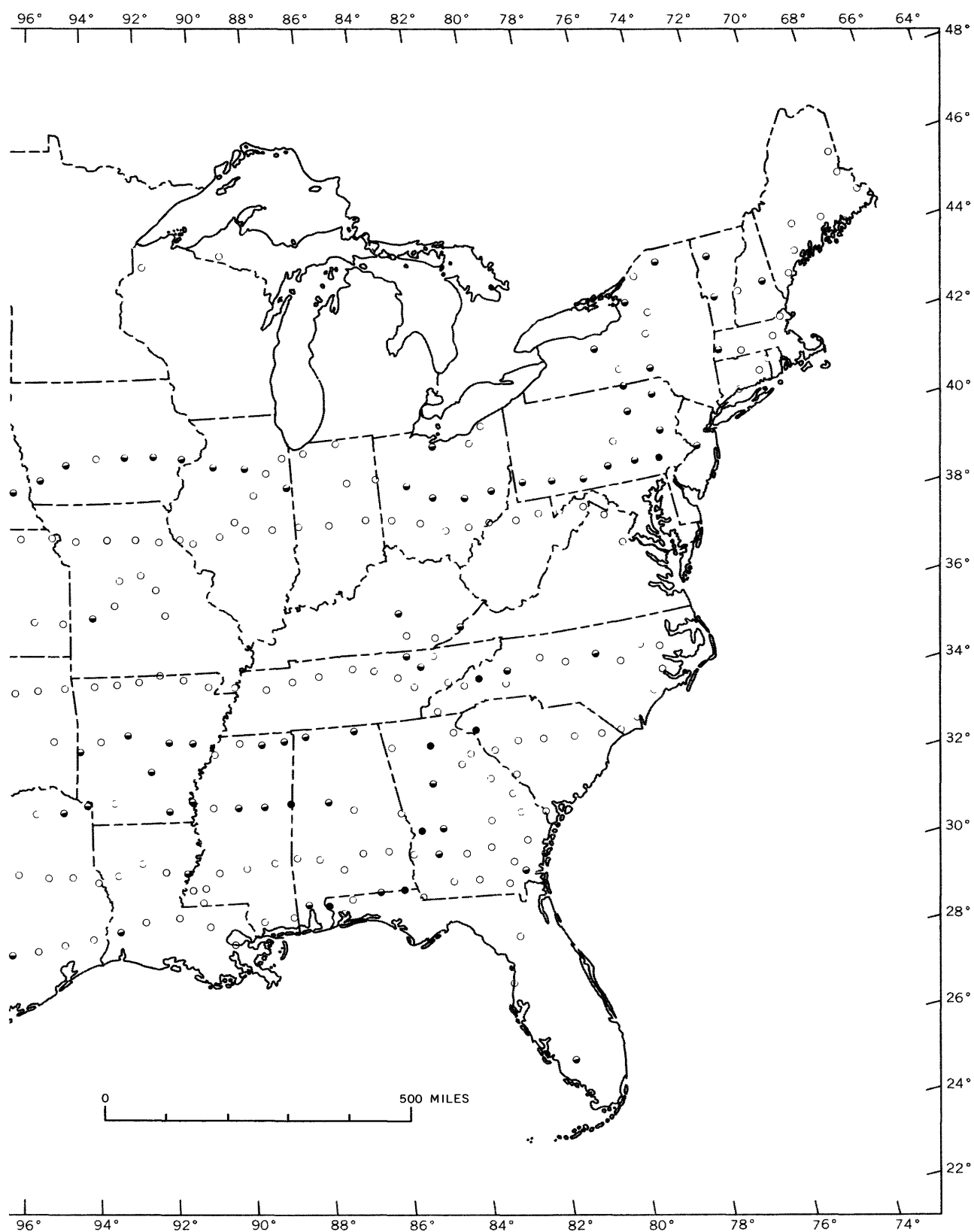
FIGURE 18.—Neodymium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

NICKEL IN PARTS PER MILLION

Geometric mean, 14
Geometric deviation, 2 26
Number of samples and analyses, 862
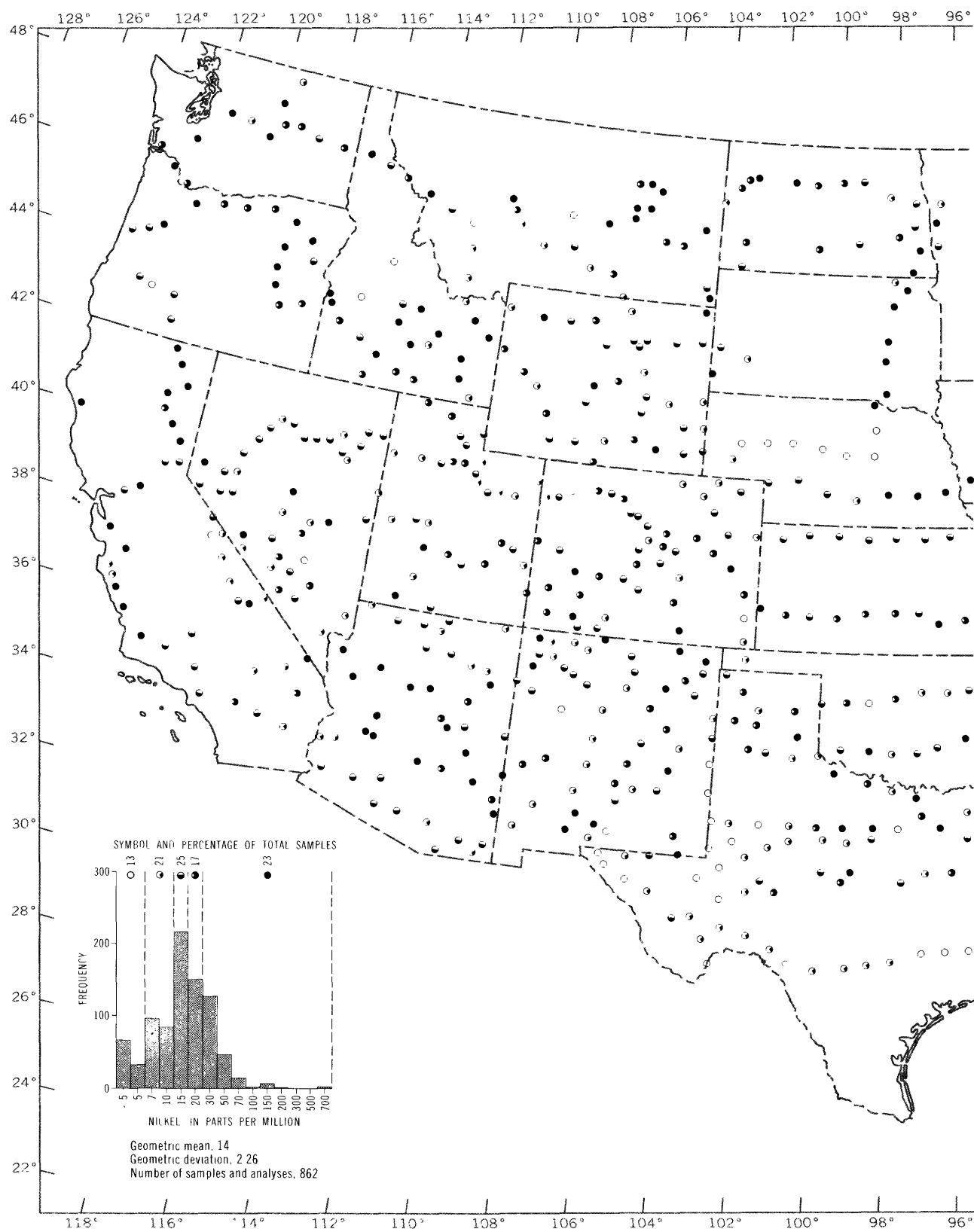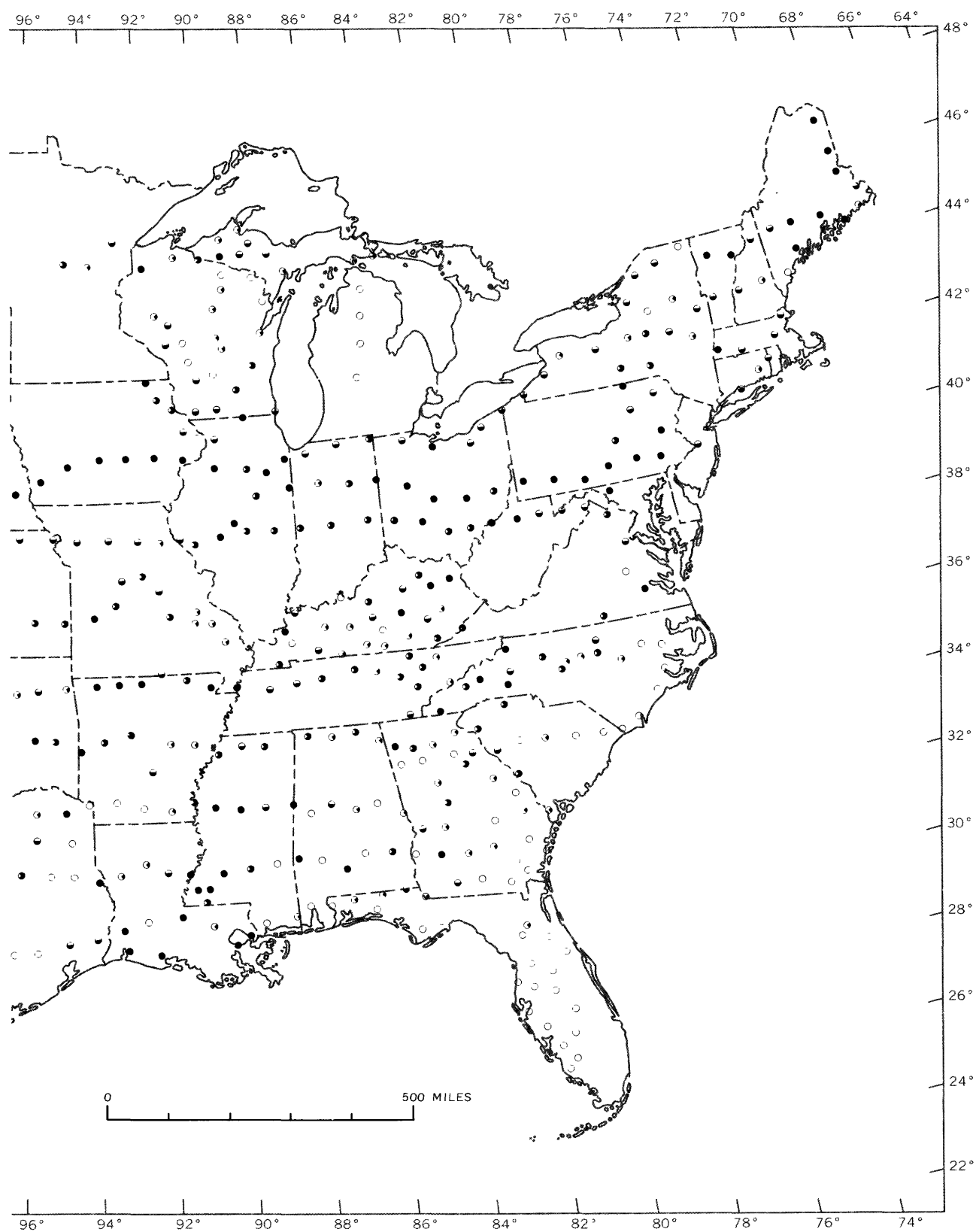
FIGURE 19.—Nickel content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

NIOBIUM, IN PARTS PER MILLION

Geometric mean, 12
Geometric deviation, 1.66
Number of samples and analyses, 813
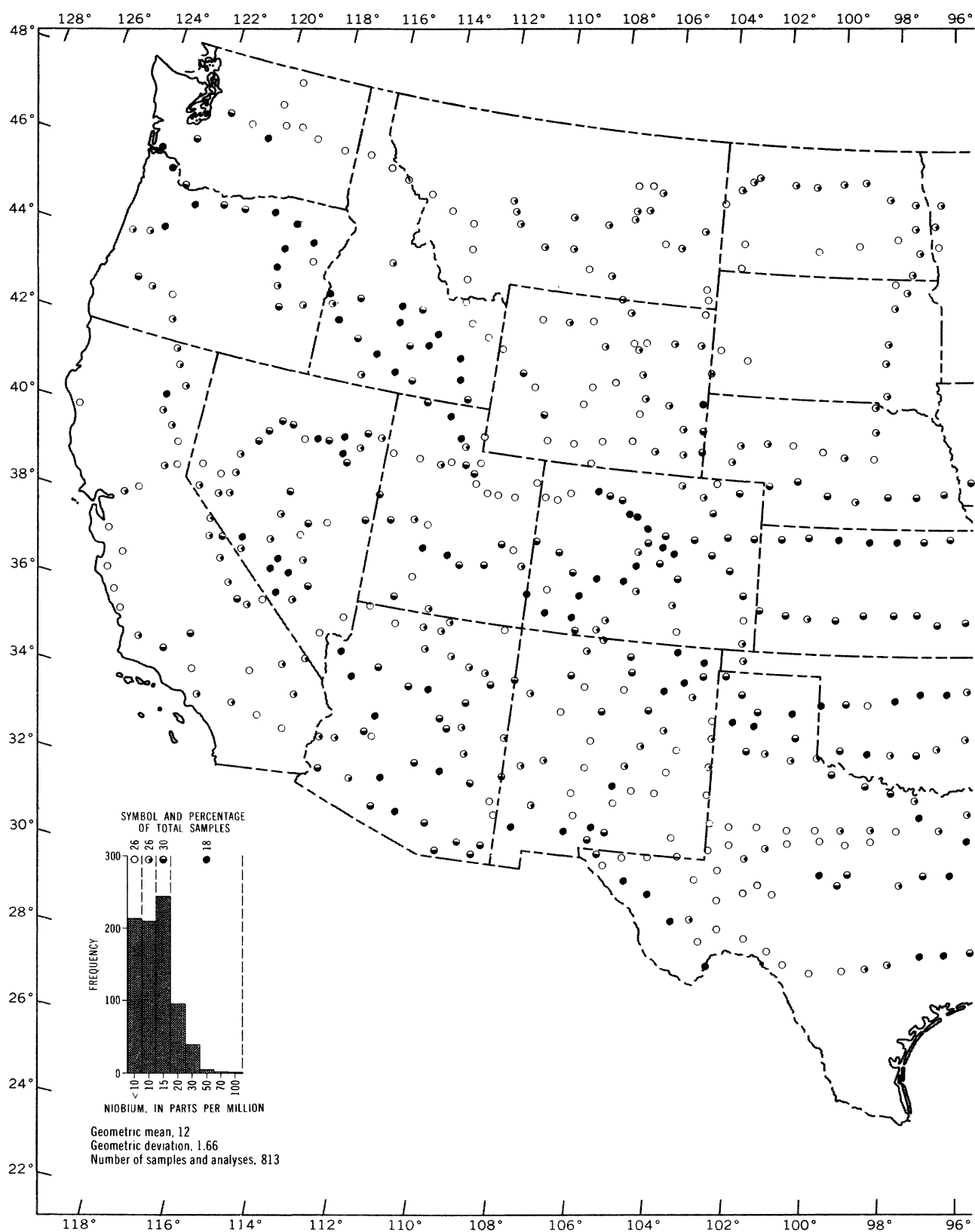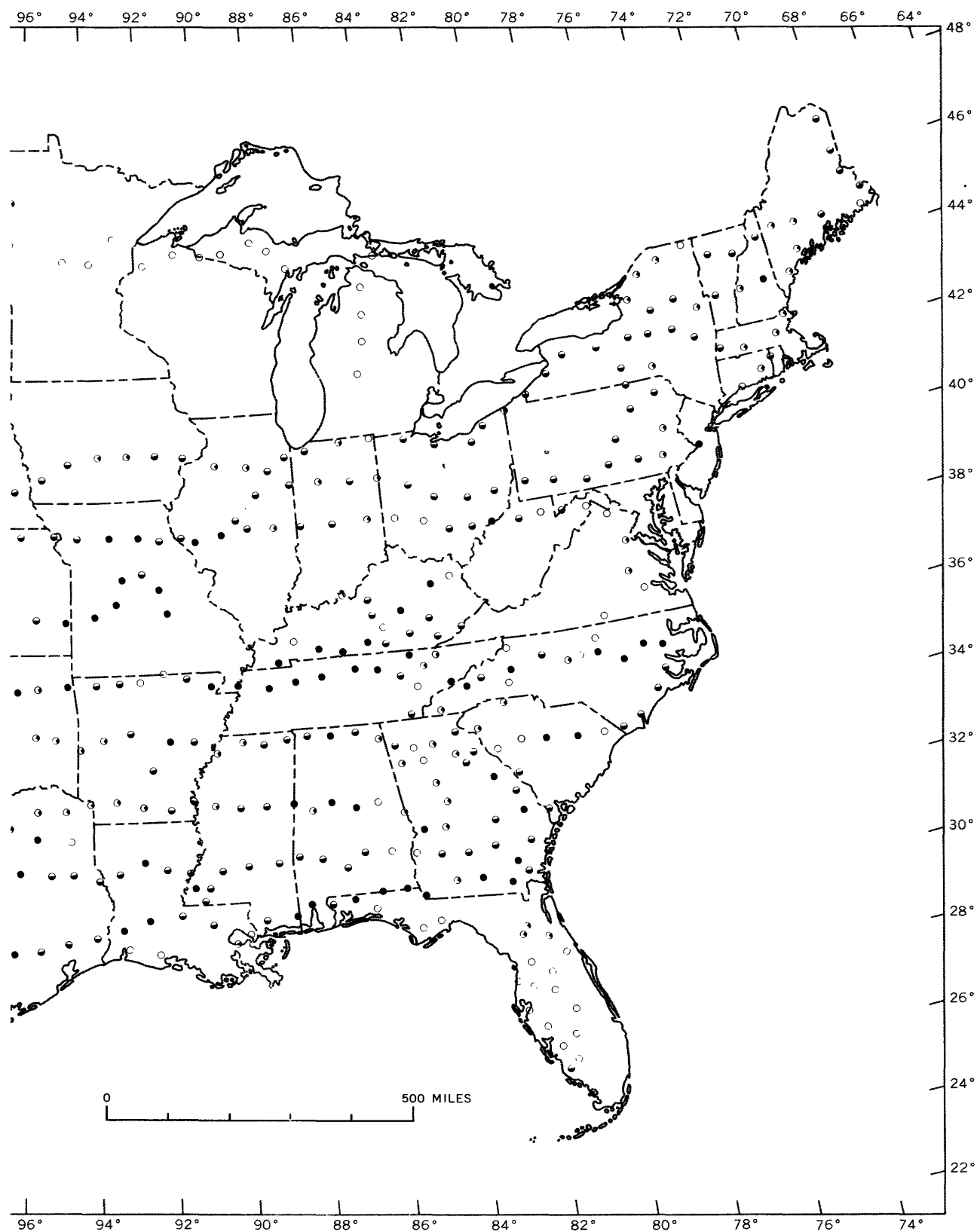
FIGURE 20.—Niobium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLE

PHOSPHORUS IN PERCENT

Geometric mean 0 025
Geometric deviation 2 74
Number of samples and analyses 856
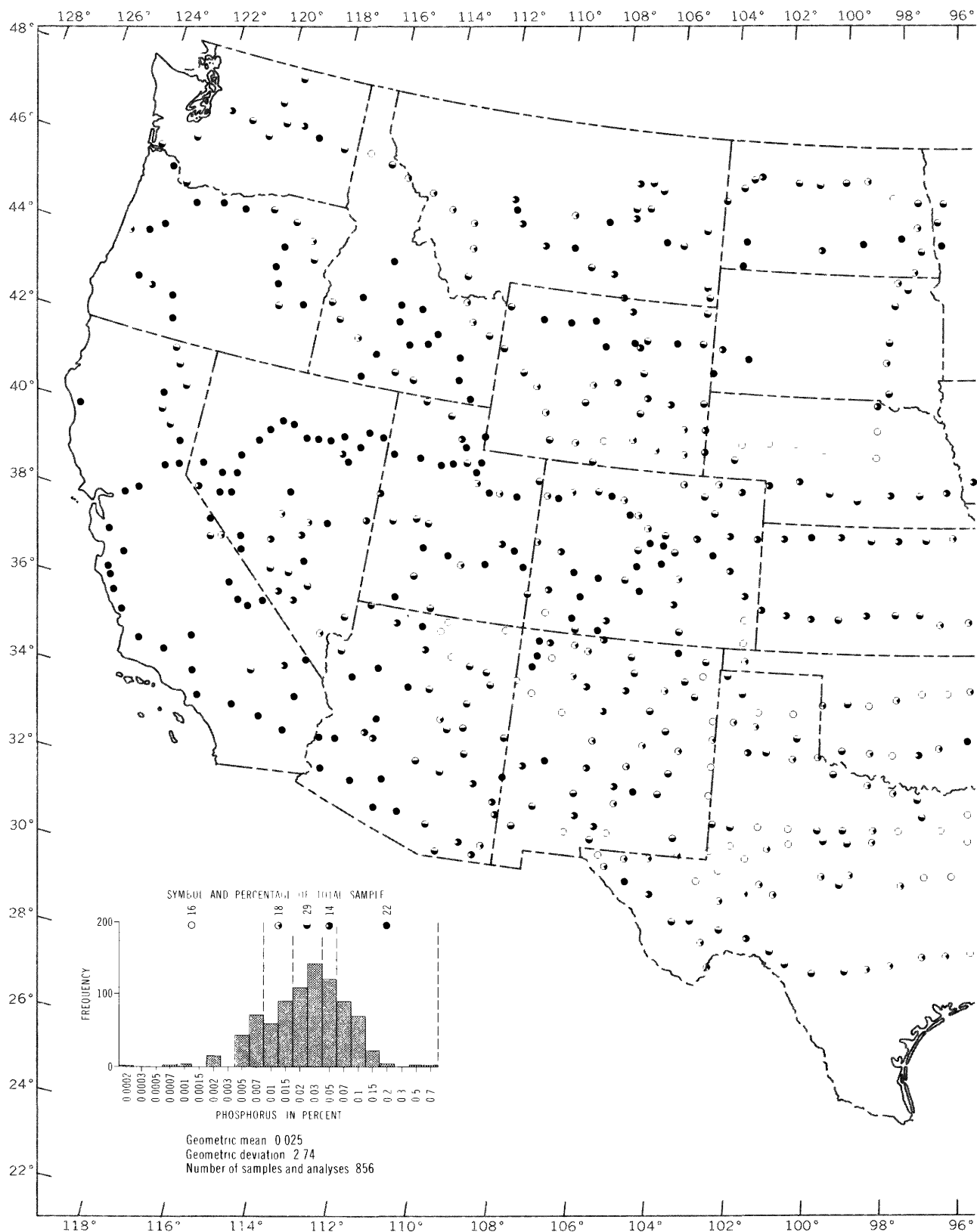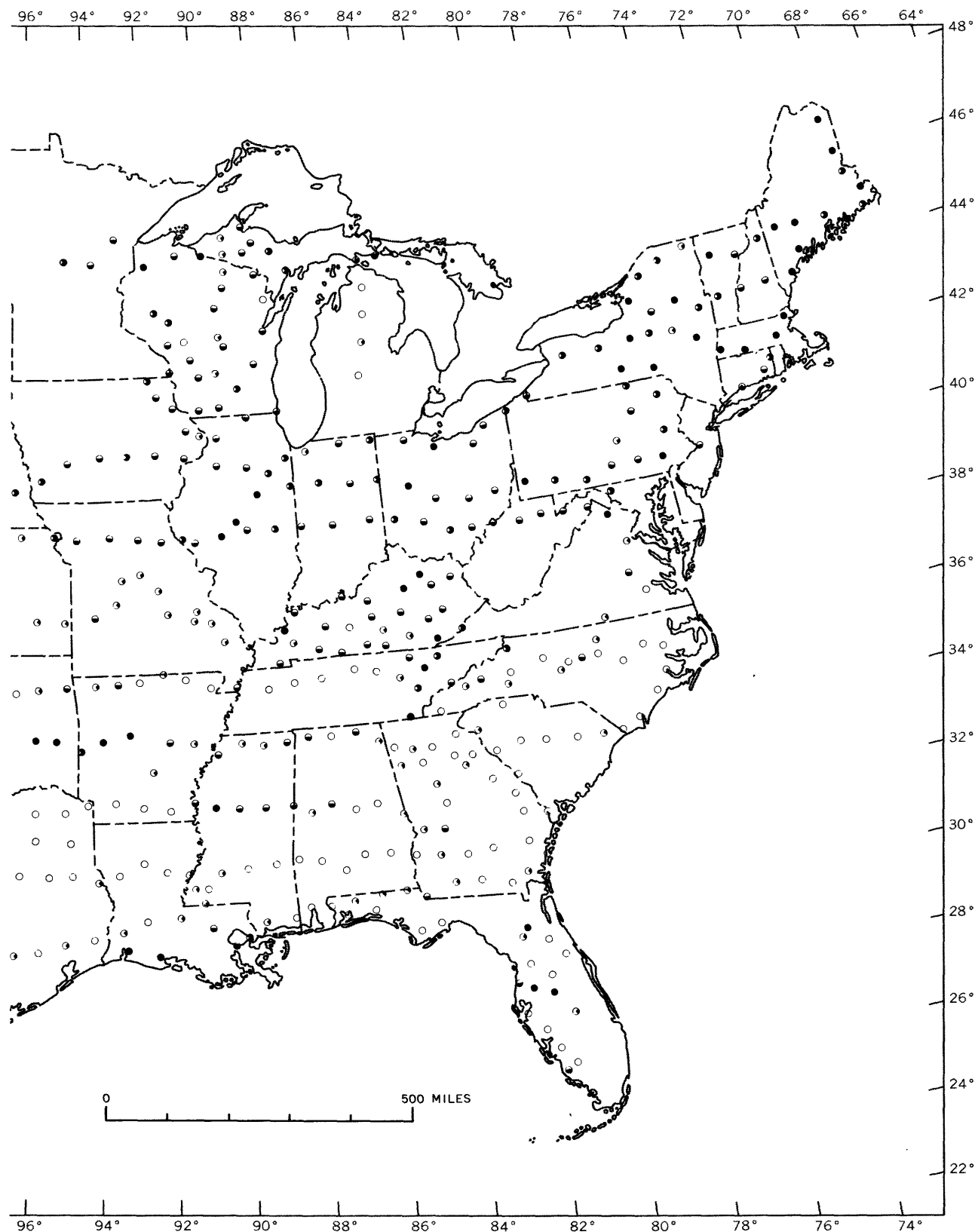
FIGURE 21.—Phosphorus content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

Geometric mean, 1.2
Geometric deviation, 2.71
Number of samples and analyses 861
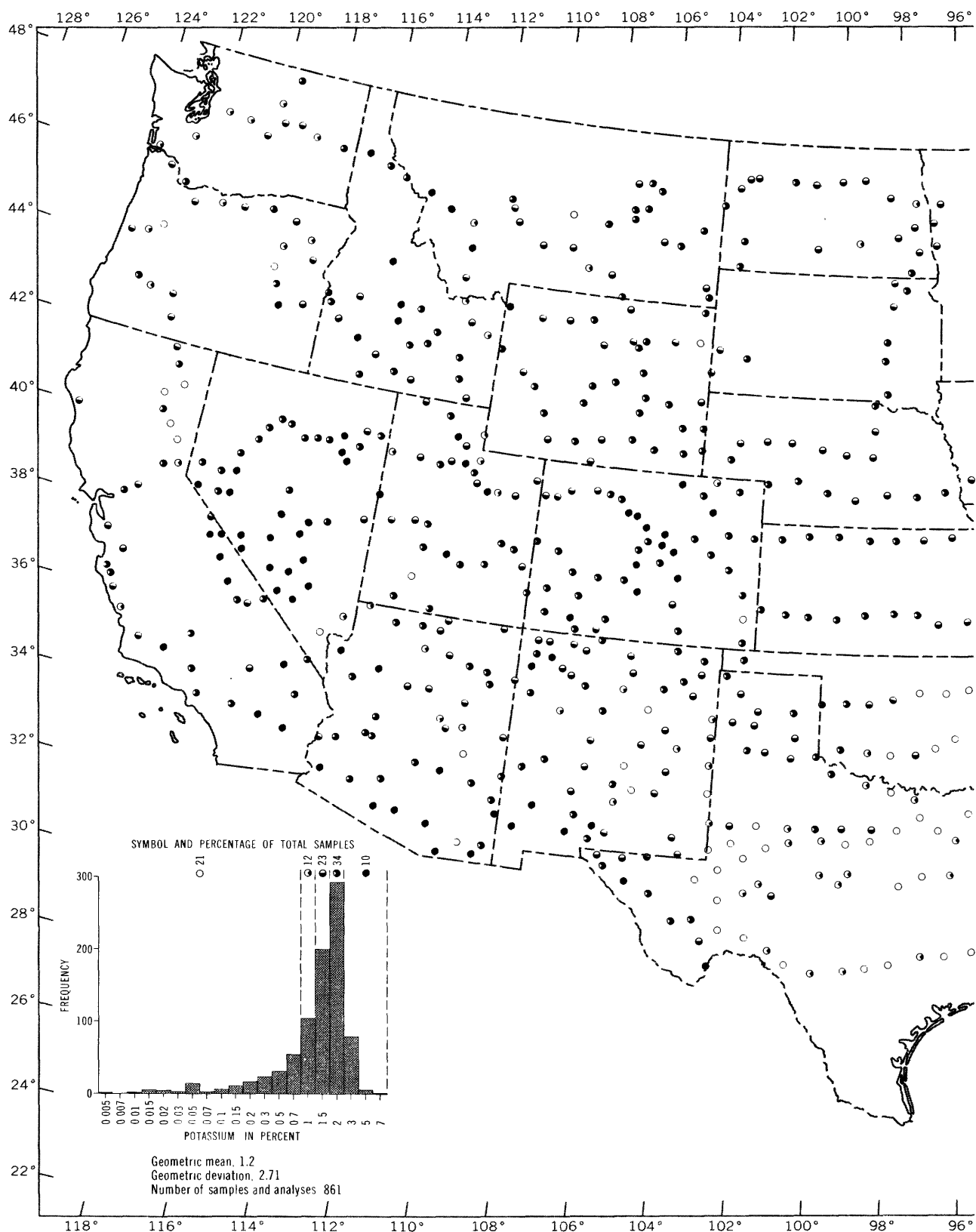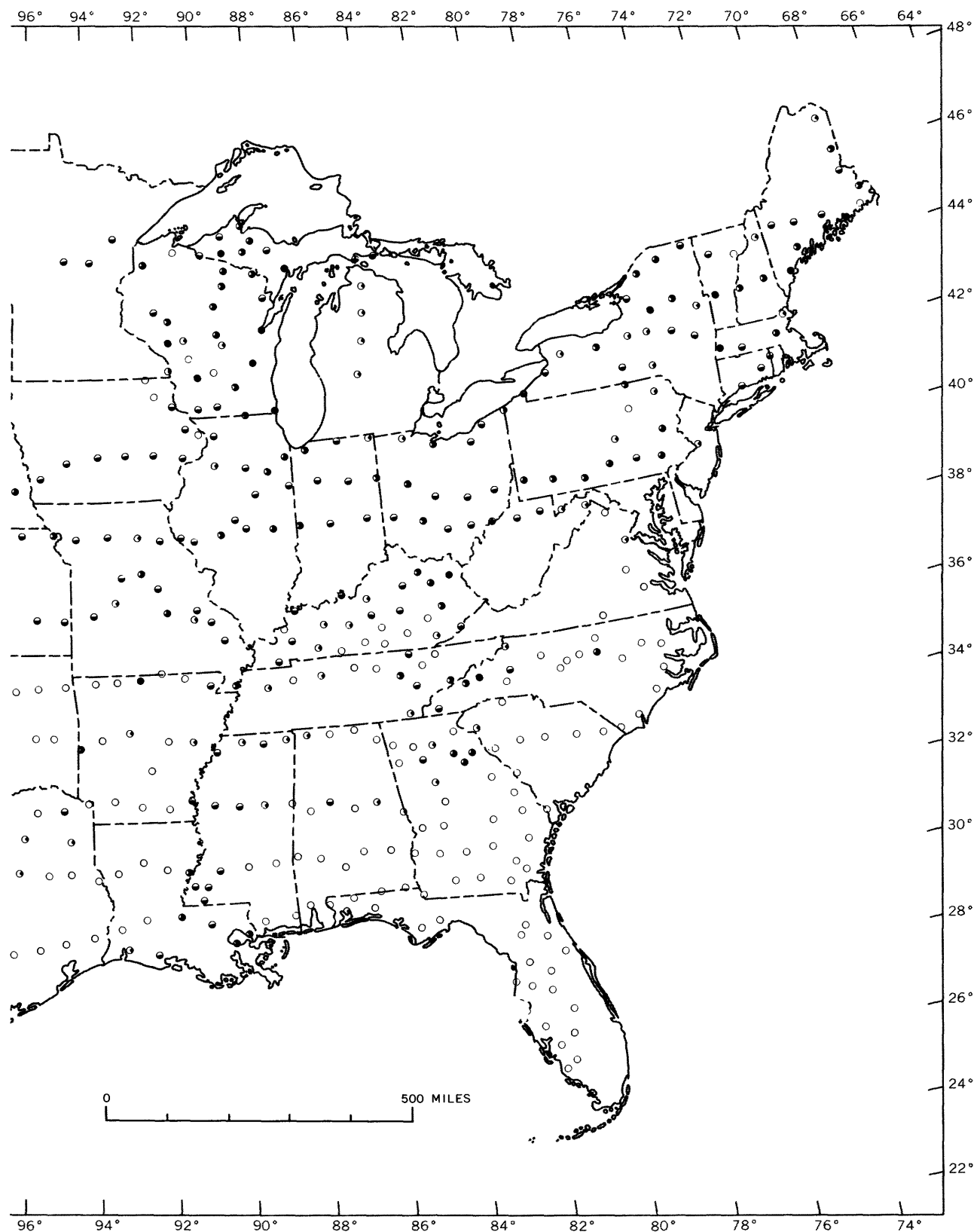
FIGURE 22.—Potassium content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

SCANDIUM, IN PARTS PER MILLION

Geometric mean, 8
Geometric deviation 1 79
Number of samples and analyses 848
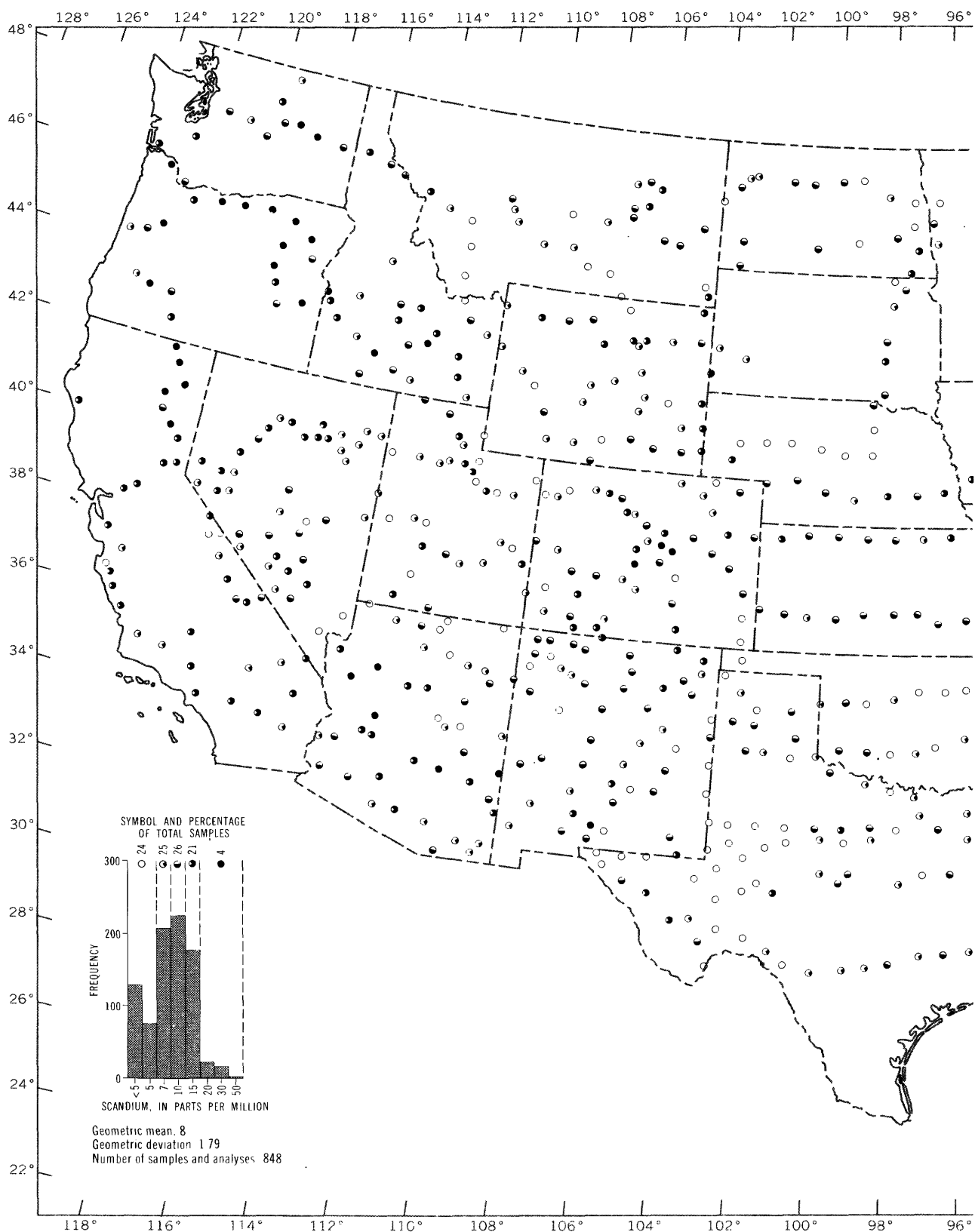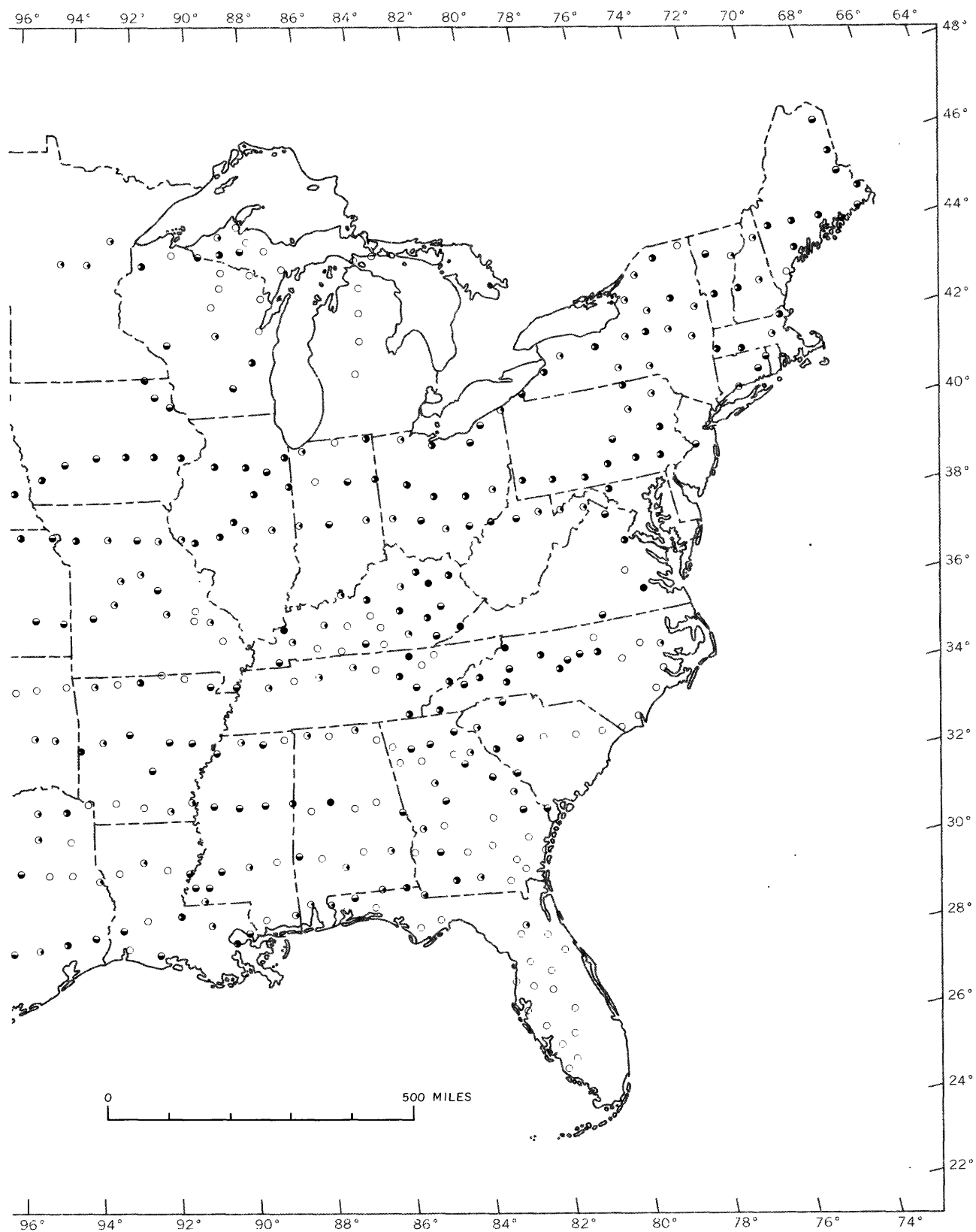
FIGURE 23.—Scandium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

Geometric mean, 0.40
Geometric deviation, 4.11
Number of samples and analyses, 788
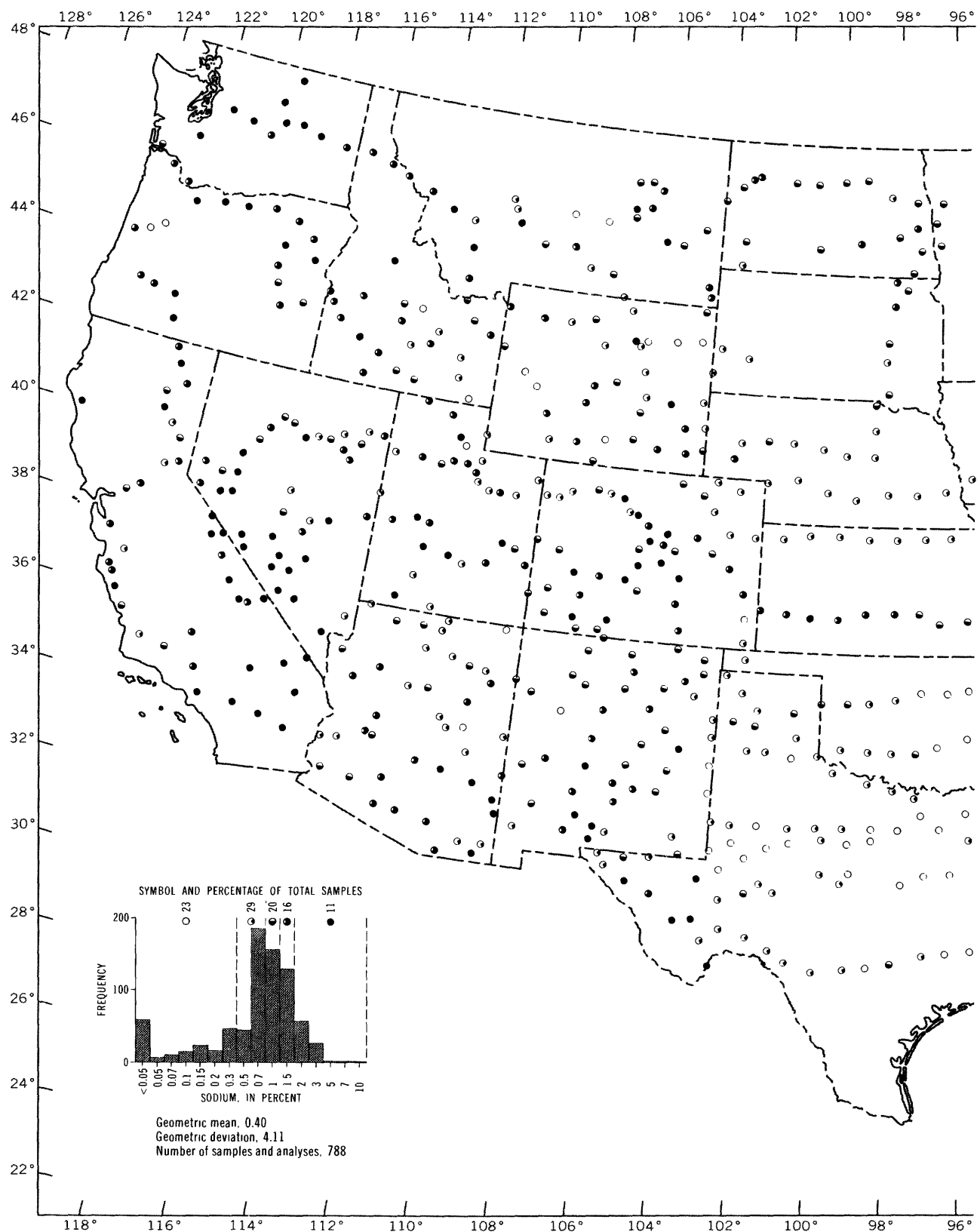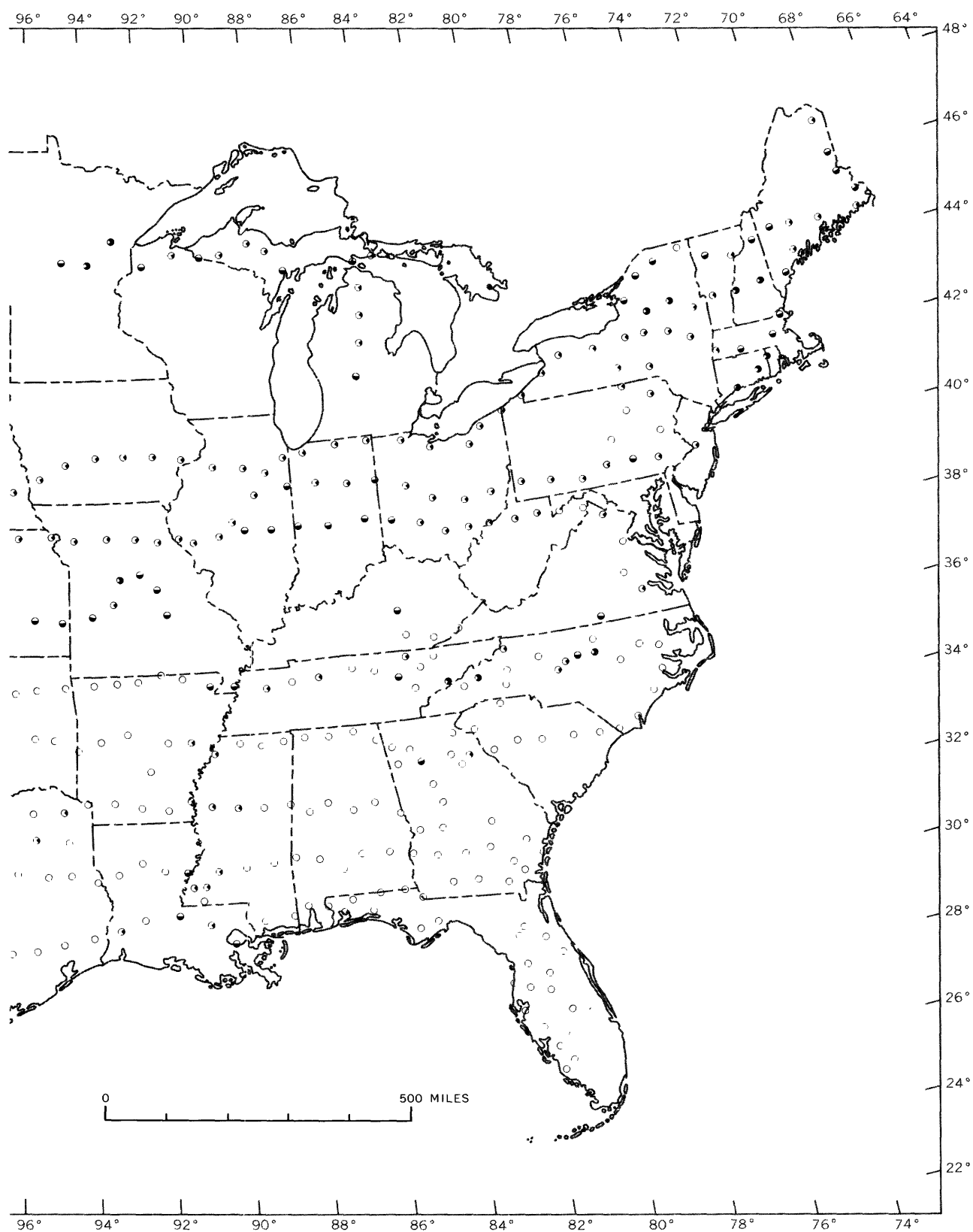
FIGURE 24.—Sodium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

STRONTIUM, IN PARTS PER MILLION

Geometric mean, 120
Geometric deviation, 3.39
Number of samples and analyses, 862
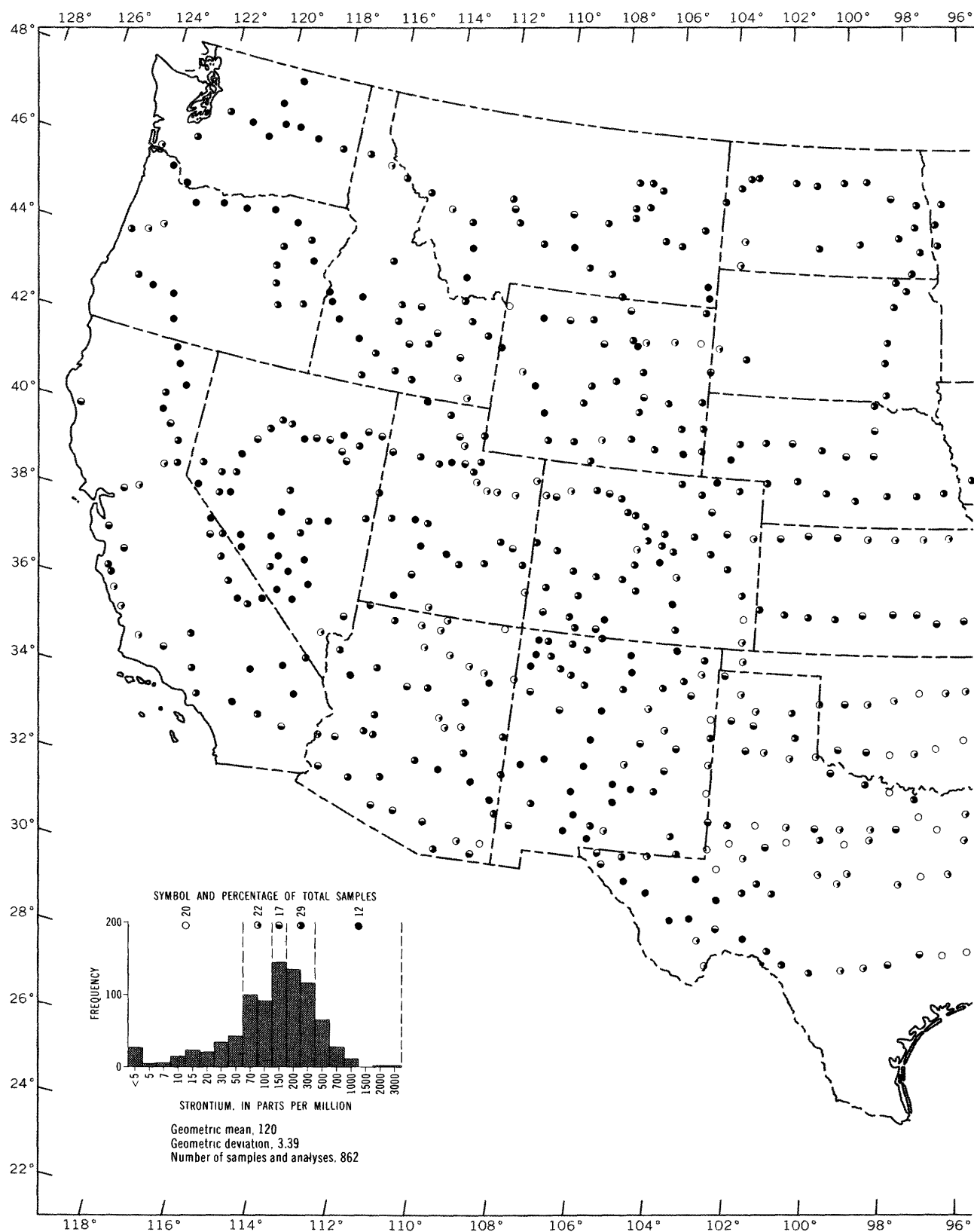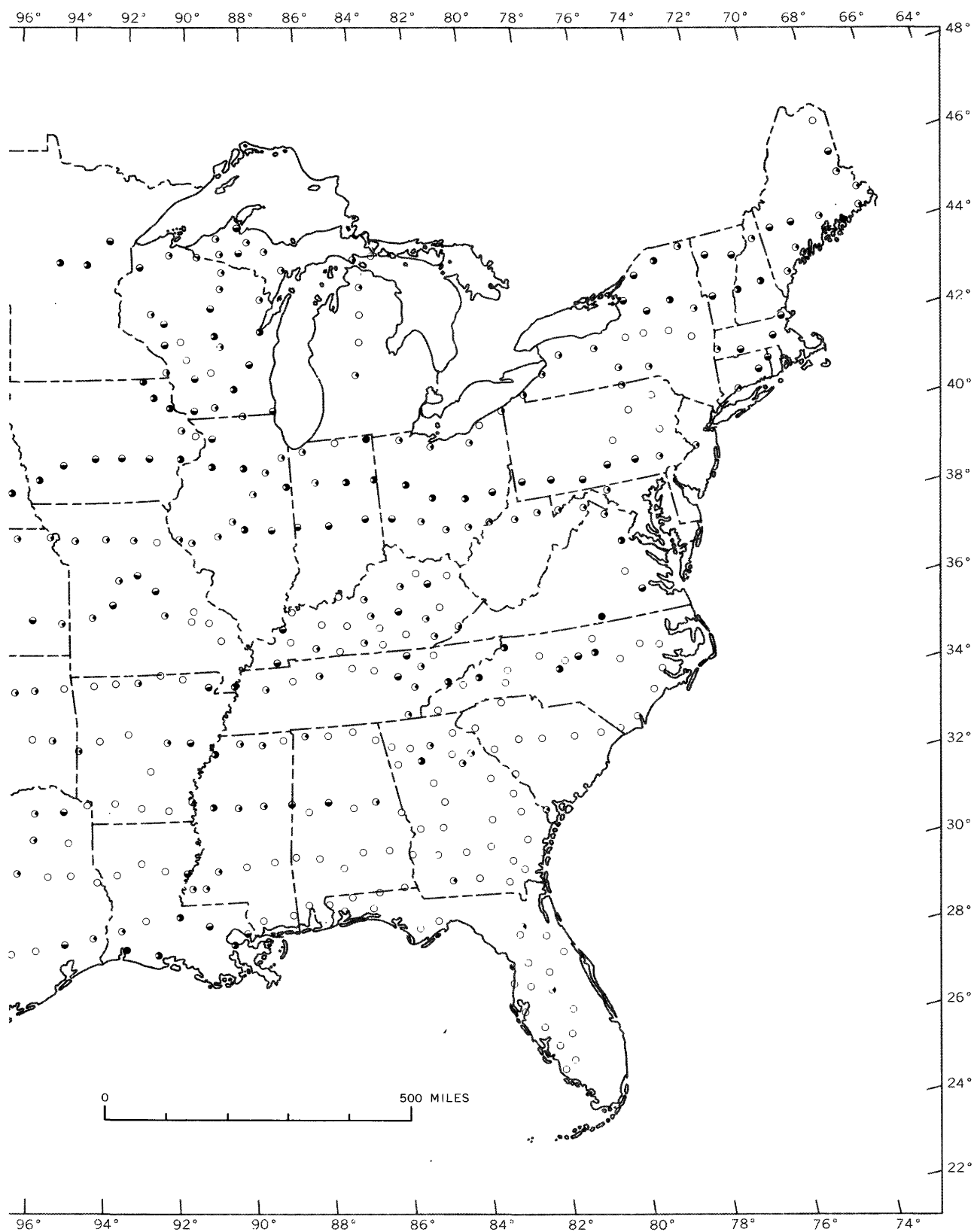
FIGURE 25.—Strontium content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

TITANIUM, IN PERCENT

Geometric mean, 0.25
Geometric deviation, 1.87
Number of samples and analyses, 861
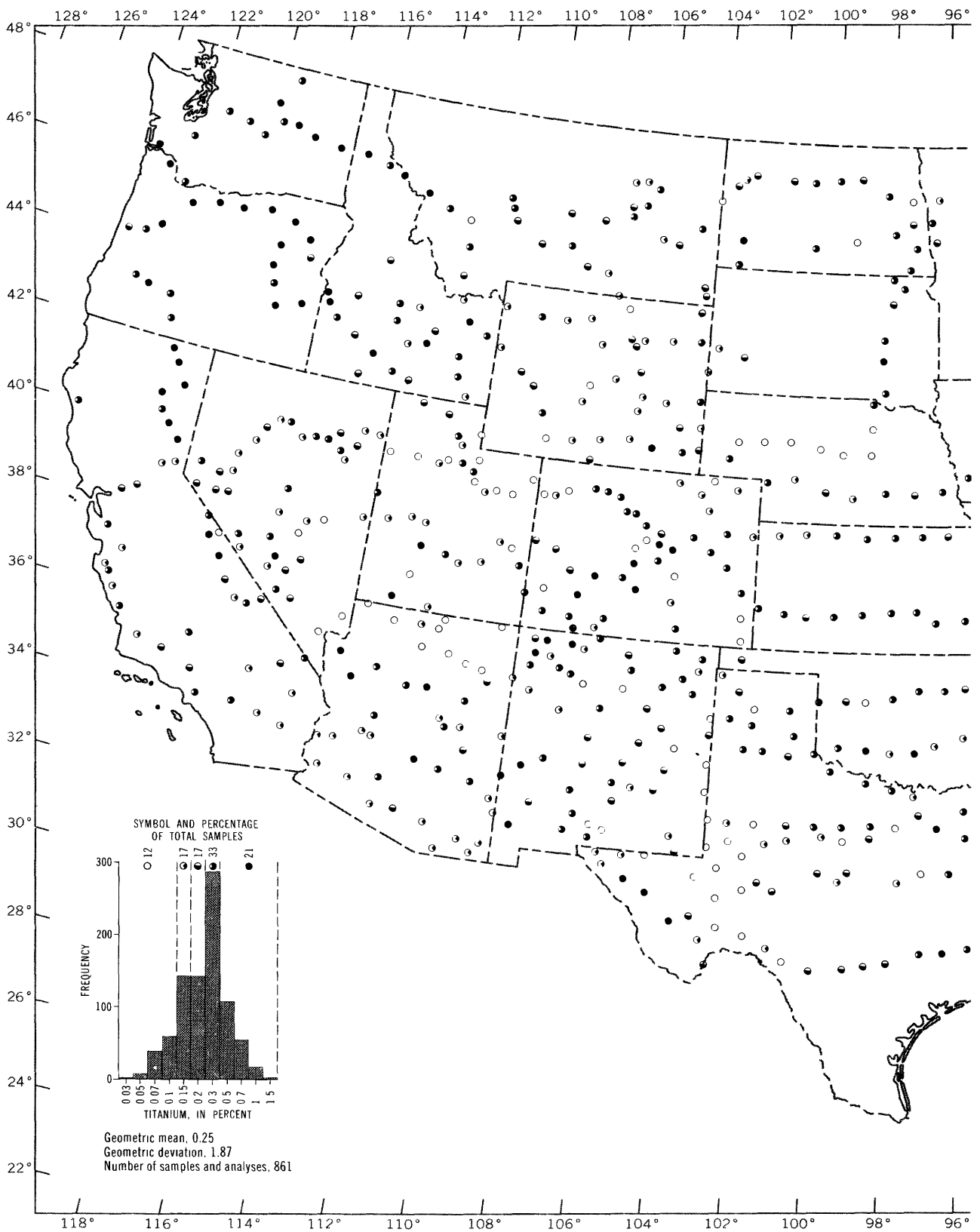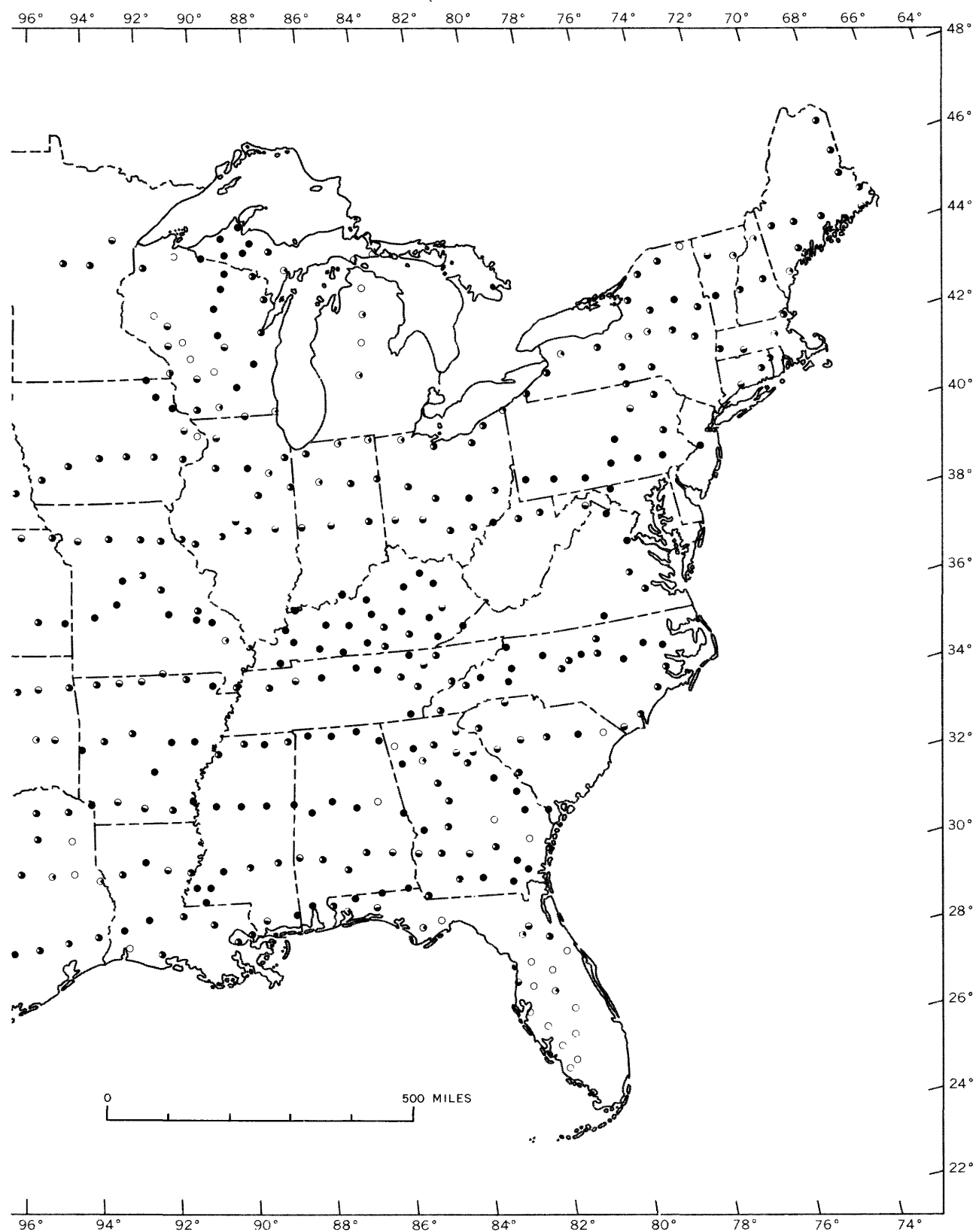
FIGURE 26.—Titanium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

VANADIUM, IN PARTS PER MILLION

Geometric mean, 56
Geometric deviation, 2 16
Number of samples and analyses, 863
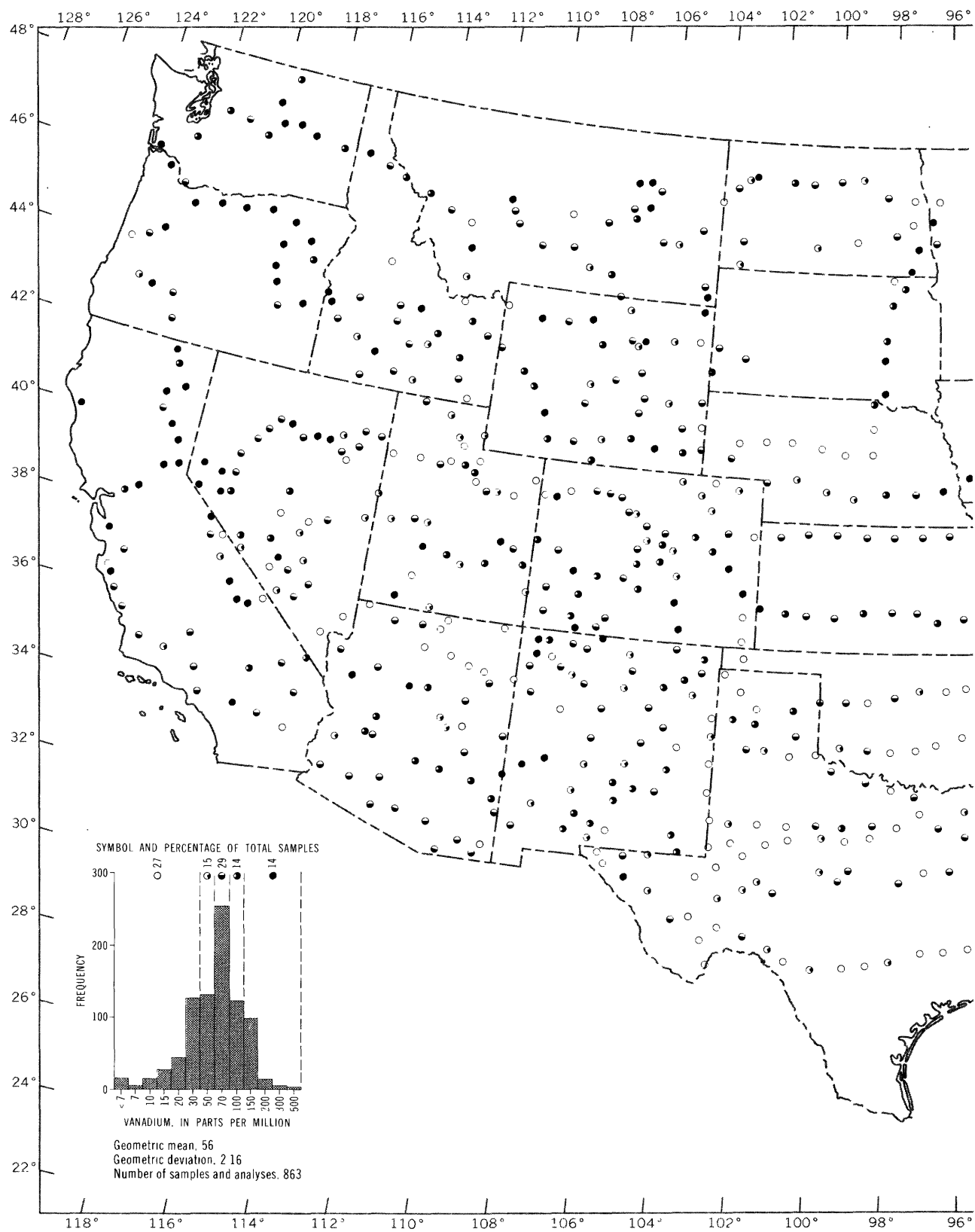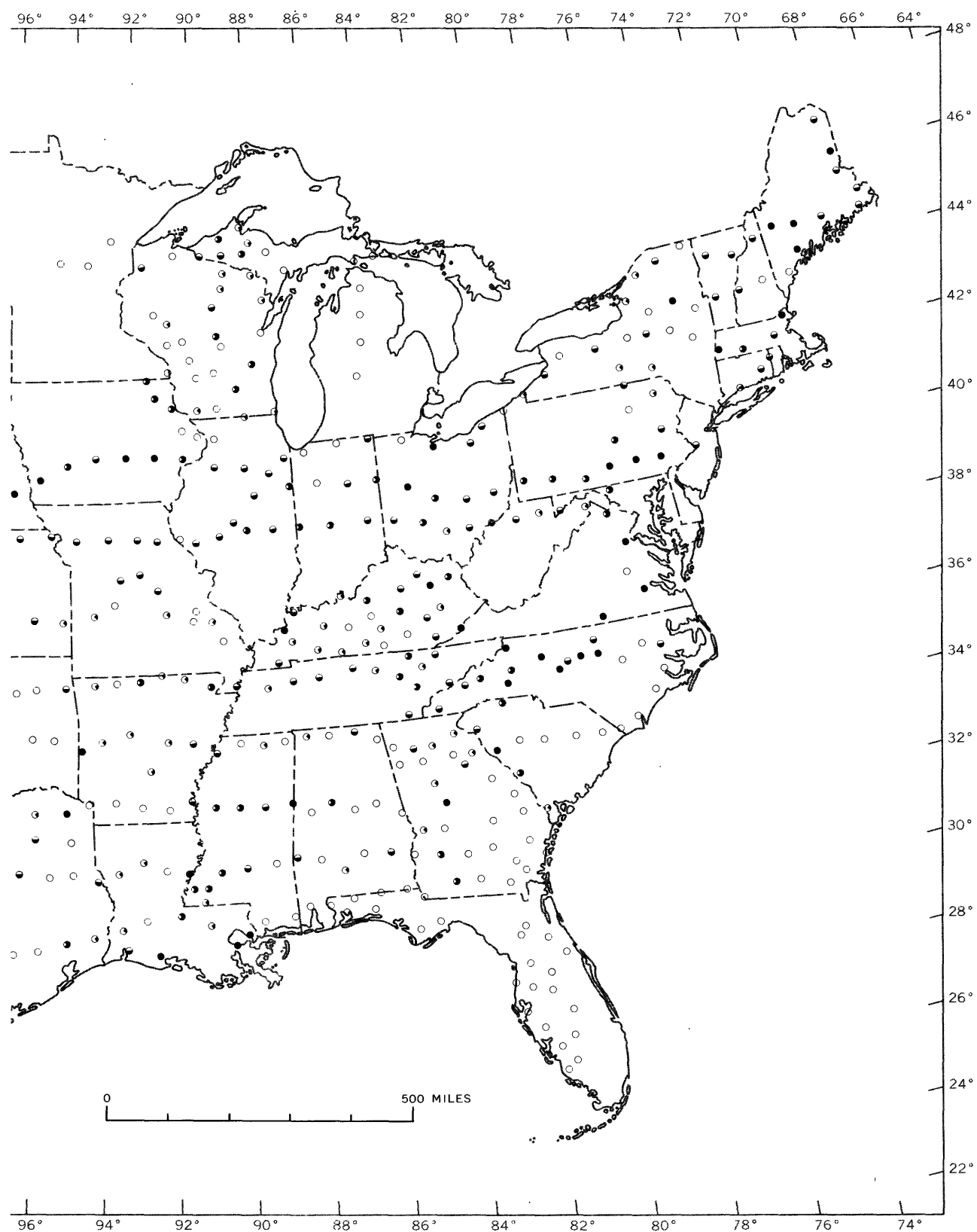
FIGURE 27.—Vanadium content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

○ 16   ◔ 15   ◕ 38   ◑ 19   ● 12

YTTERBIUM, IN PARTS PER MILLION

Geometric mean, 3.0
Geometric deviation, 1.81
Number of samples and analyses. 795
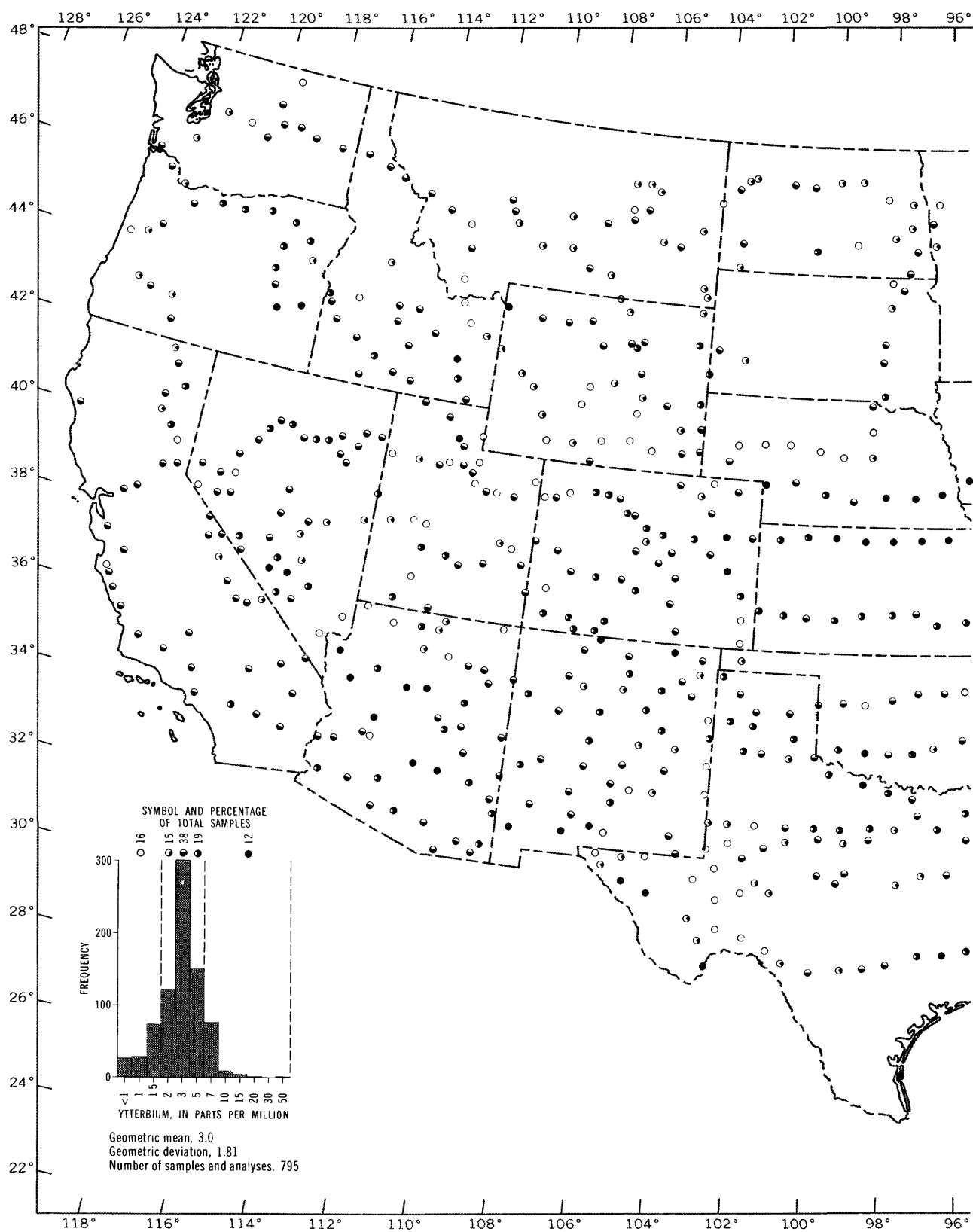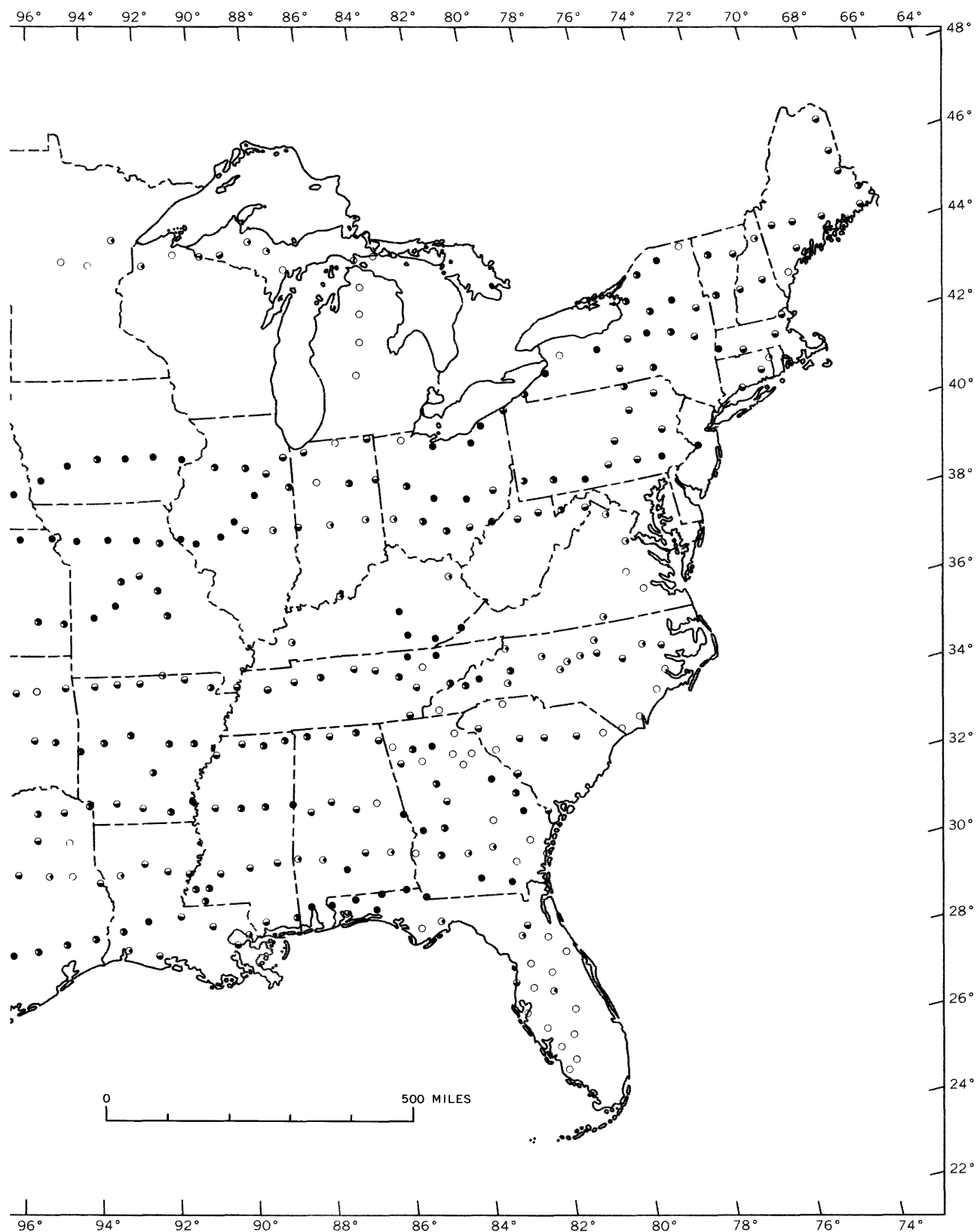
FIGURE 28.—Ytterbium content of surficial materials.

SYMBOL AND PERCENTAGE
OF TOTAL SAMPLES

Geometric mean, 24
Geometric deviation, 1.7
Number of samples and analyses, 863
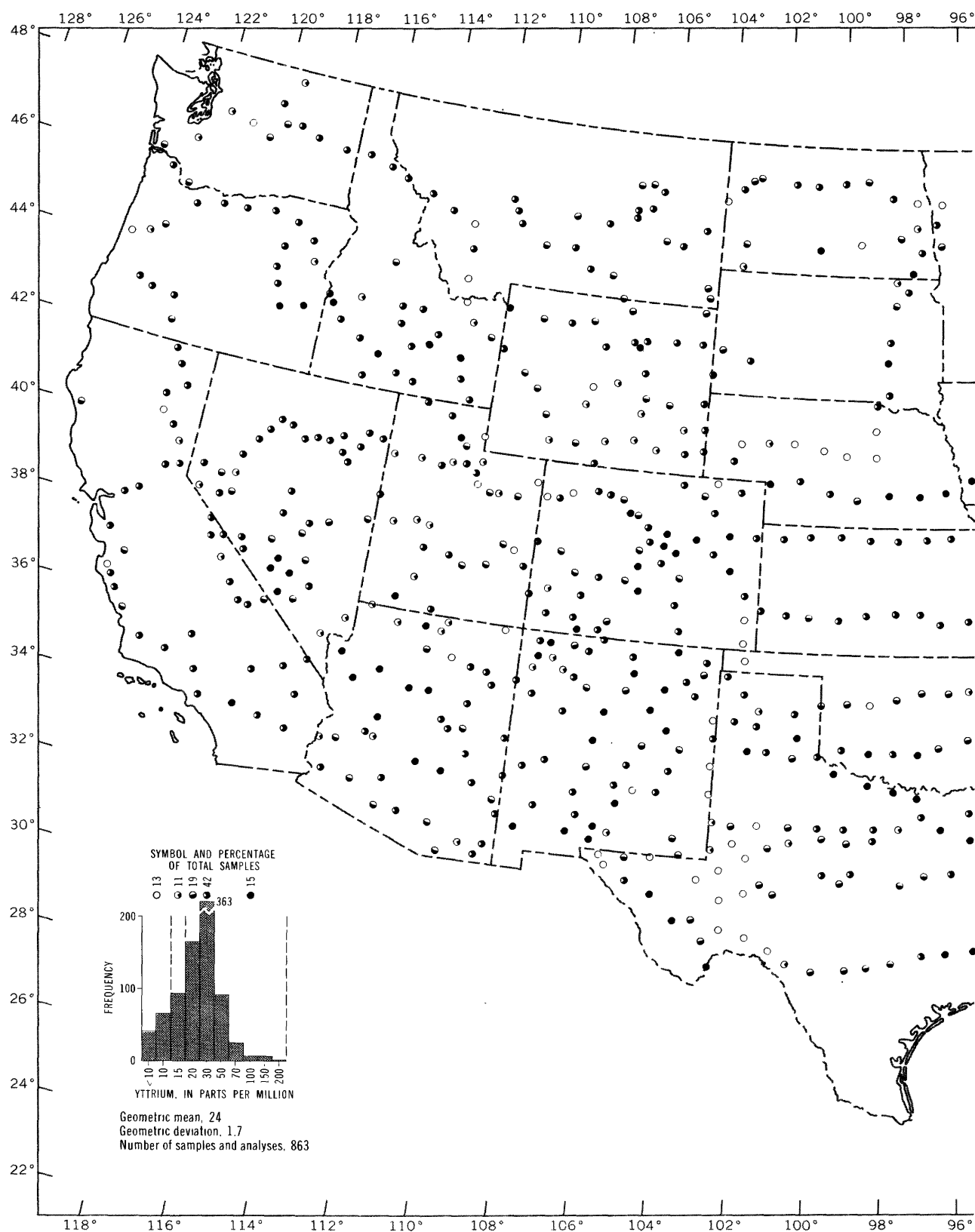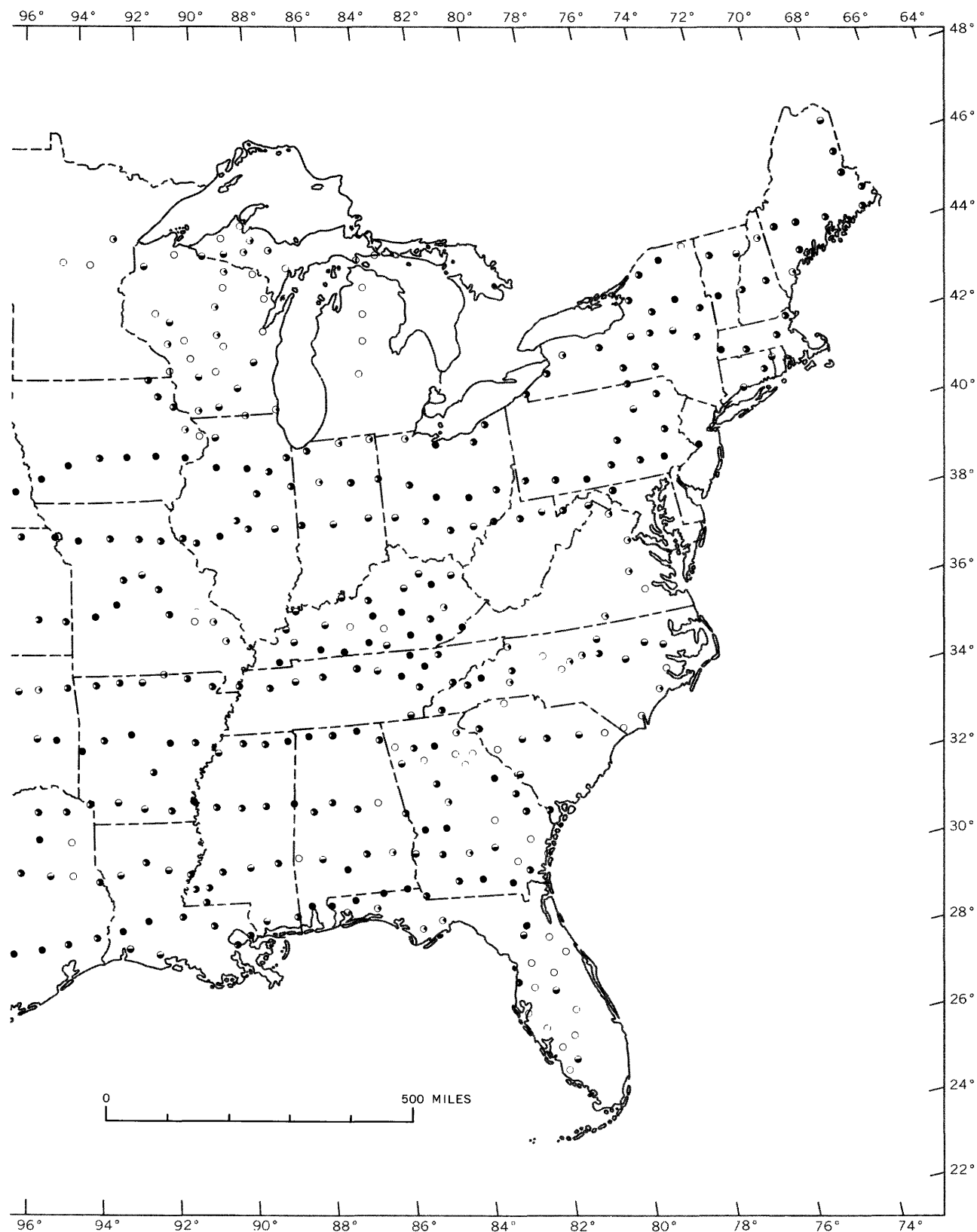
FIGURE 29.—Yttrium content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

ZINC, IN PERCENT

Geometric mean, 0.0044
Geometric deviation 1.86
Number of samples and analyses, 863
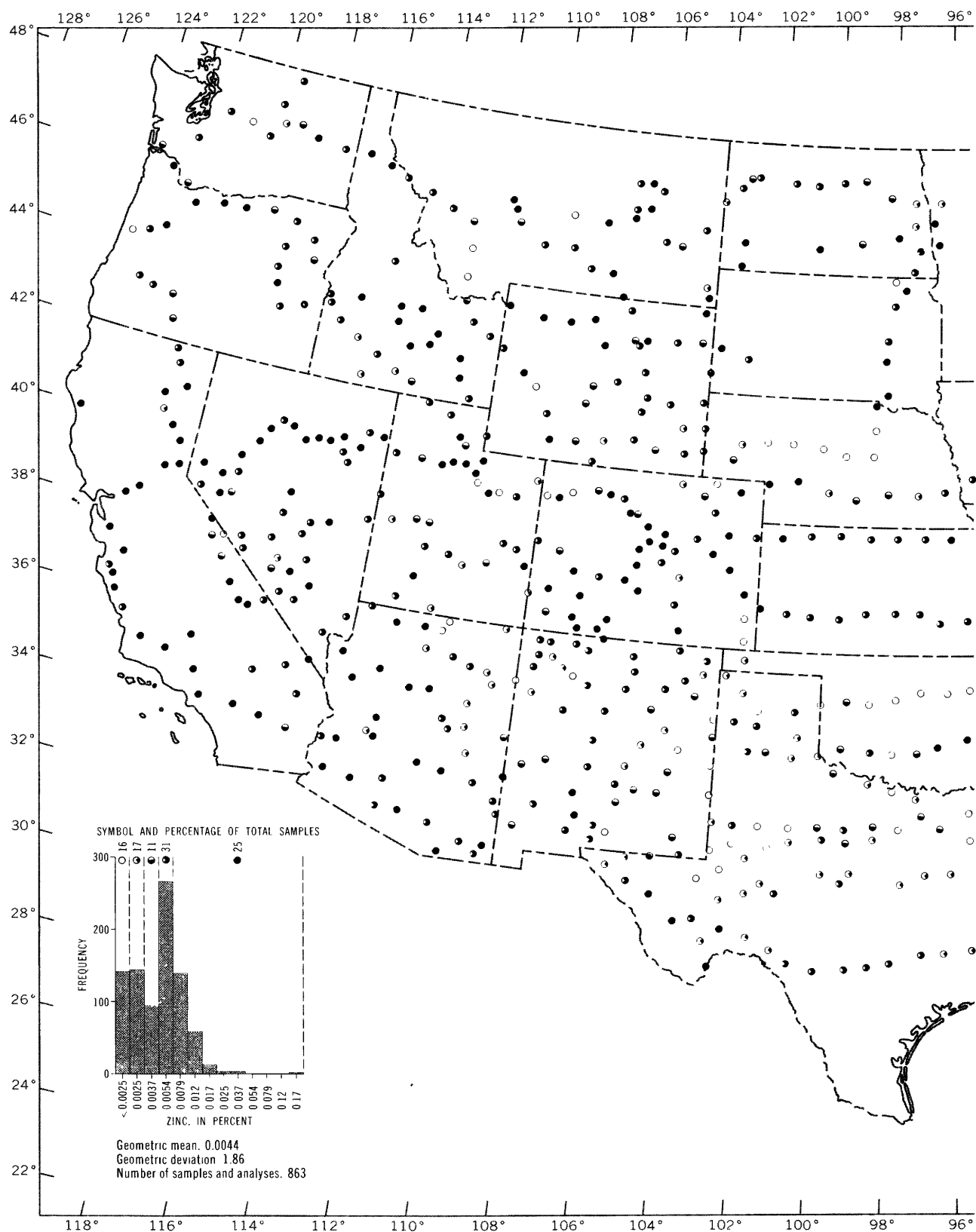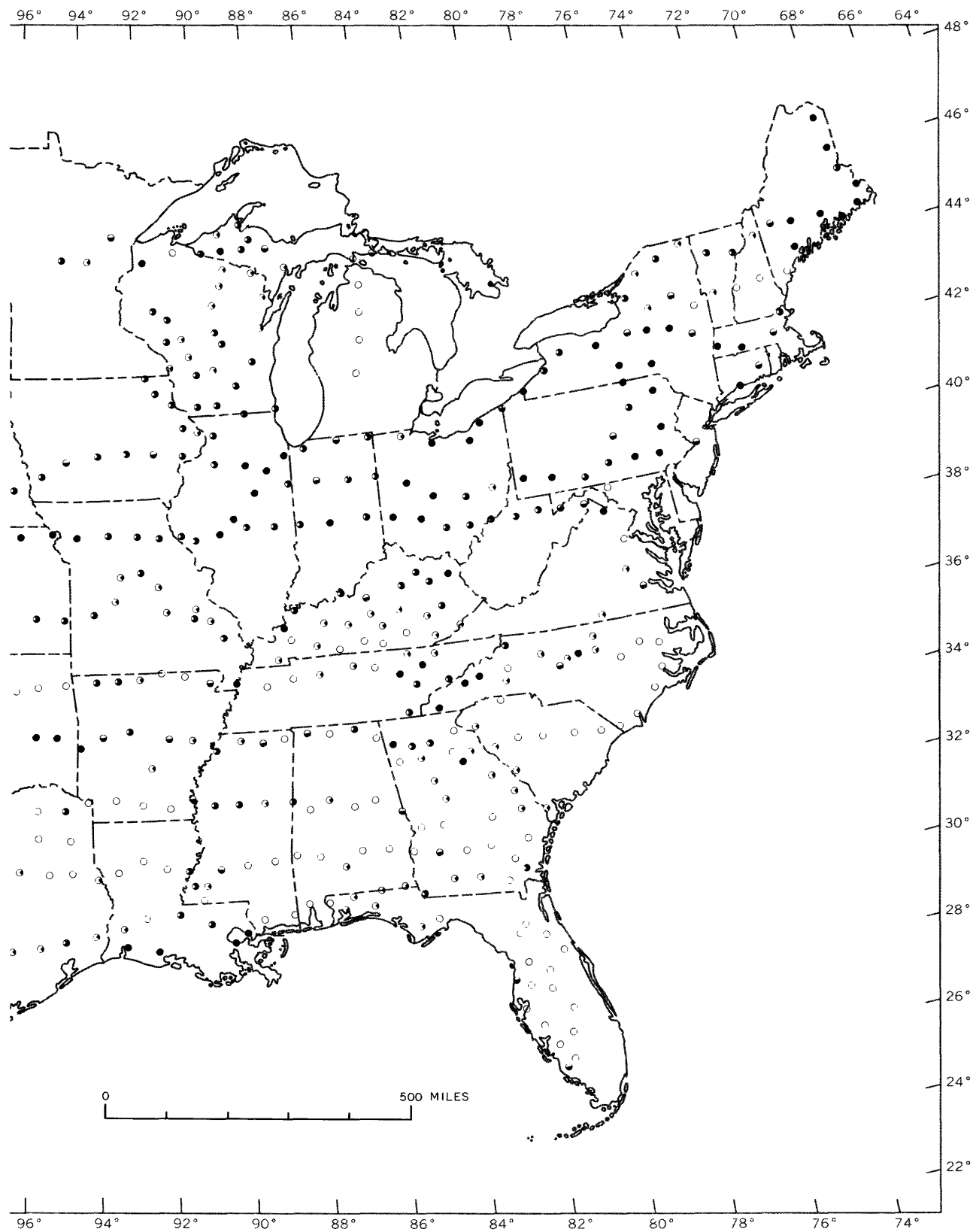
FIGURE 30.—Zinc content of surficial materials.

SYMBOL AND PERCENTAGE OF TOTAL SAMPLES

ZIRCONIUM, IN PARTS PER MILLION

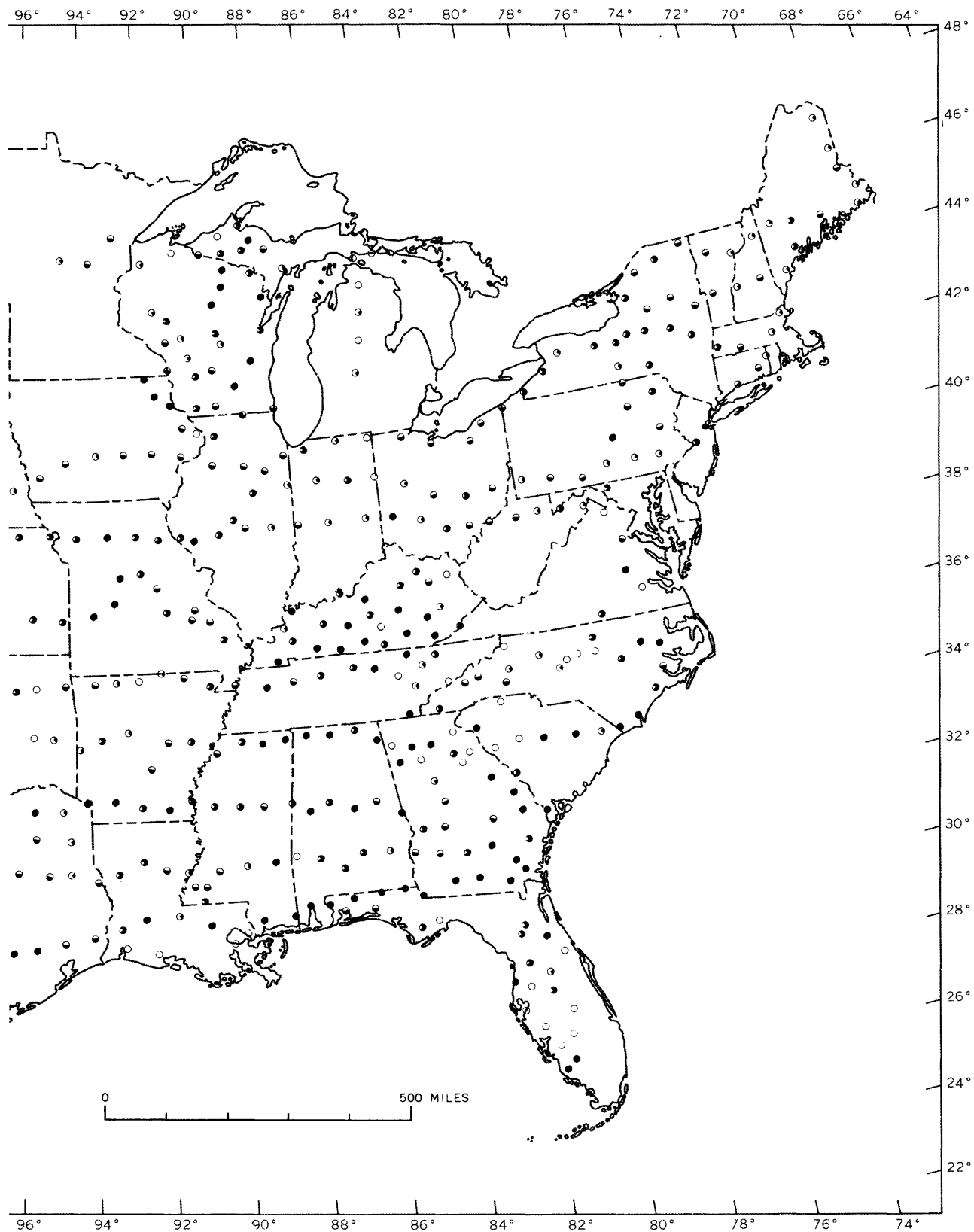Geometric mean, 200
Geometric deviation, 1.90
Number of samples and analyses, 863
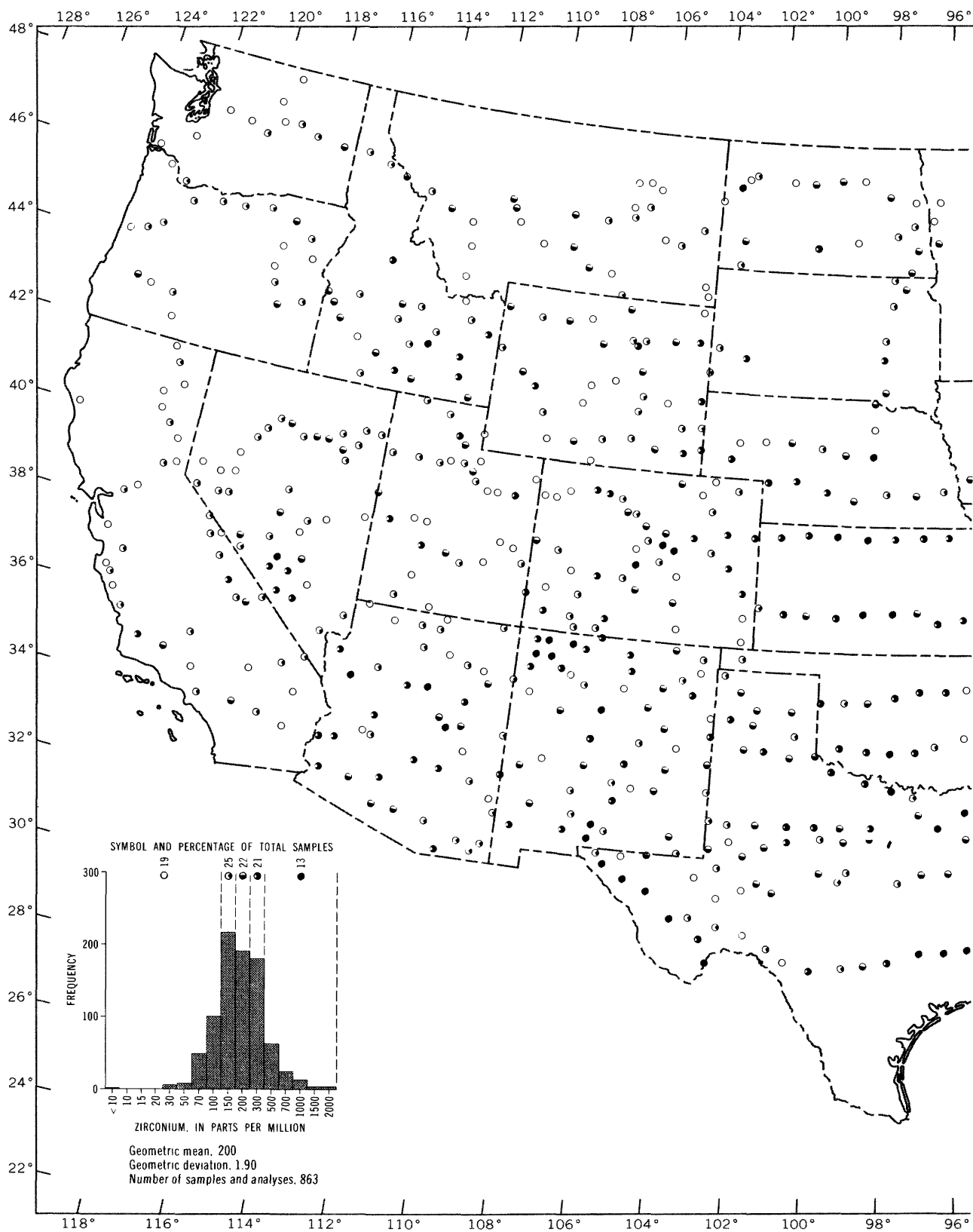
FIGURE 31.—Zirconium content of surficial materials.