Element Concentrations in Soils and Other Surficial Materials of Alaska

By L. P. GOUGH, R. C. SEVERSON, *and* H. T. SHACKLETTE

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ELEMENT CONCENTRATIONS IN SOILS AND OTHER SURFICIAL MATERIALS OF ALASKA

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ABSTRACT

Mean concentrations of 35 elements, ash yields, and pH have been estimated for samples of soils and other unconsolidated surficial materials from 266 collection locations throughout Alaska. These background values can be applied to studies of environmental geochemistry and health, wildlife management, and soil-forming processes in cold climates and to computation of element abundances on a regional or worldwide scale. Limited data for an additional eight elements are also presented.

Materials were collected using a one-way, three-level, analysis-of-variance sampling design in which collecting procedures were simplified for the convenience of the many volunteer field workers. The sample collectors were asked to avoid locations of known mineral deposits and obvious contamination, to take samples at a depth of about 20 cm where possible, and to take a replicate sample about 100 m distant from the first sample collected. With more than 60 percent of the samples replicated and 14 percent of the samples split for duplicate laboratory analyses, reliable estimates were made of the variability in element concentrations at two geographic scales and of the error associated with sample handling and laboratory procedures.

Mean concentrations of most elements in surficial materials from the state of Alaska correspond well with those reported in similar materials from the conterminous United States. Most element concentrations and ranges in samples of stream and lake sediments from Alaska, however, as reported in the literature, do not correspond well with those found in surficial materials of this study. This lack of correspondence is attributed to (1) a merger of two kinds of sediments (stream and lake) for calculating means; (2) elimination from the sediment mean calculations of values below the limit of quantitative determination; (3) analytical methods different from those of the surficial-materials study; and (4) most importantly, the inherent differences in chemistry of the materials.

The distribution of variability in element concentrations of Alaskan surficial-material samples was, for most elements, largely among sampling locations, with only a small part of the variability occurring between replicate samples at a location. The geochemical uniformity within sampling locations in Alaska is an expression of uniform geochemical cycling processes within small geographic areas.

The concentration values for 35 elements in 266 samples were plotted on maps by symbols representing classes of concentration frequency distributions. These plotted symbols form patterns that may or may not be possible to interpret but nevertheless show differences that are observable at several geographical scales. The largest pattern is one of generally low concentrations of many elements in materials from arctic and oceanic tundra regions, as contrasted to their often high concentrations in samples from interior and southeastern Alaska. The pattern for sodium is especially pronounced. Intermediate-sized patterns are shown, for example, by the generally high values for magnesium and low values for silicon in the coastal forest region of southeastern Alaska. Many elements occur at low concentrations in samples from the Alaskan peninsula and the Aleutian Islands. The degree of confidence in patterns of element abundance is expected to be in direct proportion to the number of samples included in the area. As the patterns become smaller, the probability increases that the patterns are not reproducible.

INTRODUCTION

BACKGROUND, OBJECTIVES, AND LITERATURE REVIEW

Favorable response to reports on the geochemistry of unconsolidated surficial materials of the conterminous United States (informally called the "50-mile geochemical survey" because of the approximate distance between sampling sites) (Shacklette and Boerngen, 1984, updated and expanded from Shacklette, Hamilton, and others, 1971; Shacklette, Boerngen, and Turner, 1971; Shacklette and others, 1973; and Shacklette and others, 1974) led us, in 1975, to initiate a companion survey of Alaska. The principal objectives of this study were to (1) establish estimates of central tendency and of typical ranges in the concentration of chemical elements in soils and other surficial materials, and (2) present element concentration maps which display broad patterns that may or may not be interpretable at various geographical scales.

A single geochemical study cannot be expected to provide support for all aspects of the chemistry of natural materials, but most geochemical studies can contribute useful data to more than one scientific discipline. Baseline-type studies establish present geochemical conditions with which future conditions can be compared. They also help to define large-scale geochemical patterns and suggest relationships between rock weathering and soil development. In addition, baseline data can be applied to environmental assessments. For example, data from such studies have been applied in

health-related investigations (Shacklette and others, 1970; Hopps and Cannon, 1972; Ebens and others, 1973; Gough and others, 1979; Berrow and Reaves, 1984) and recently have contributed significantly to a better understanding of nutritional problems in wildlife management (Jones and Hanson, 1985). Baseline values in element compositions of natural materials, values derived from many specific regional studies, are the only means of establishing reliable worldwide norms of element concentrations in natural materials (Kabata-Pendias and Pendias, 1984). Moreover, in geochemical exploration for mineral deposits, the "normal" element concentrations in a sampling medium must be understood in order to identify abnormal concentrations (Levinson, 1980).

In general, studies of the chemical composition of the soils and unconsolidated surficial materials of Alaska have been related to the increasing importance of agriculture in the state. These investigations have emphasized physical and chemical characteristics of soil, as this type of information is necessary for the proper management of pasture and small grain production. When chemical element information is included, these studies have generally focused on the macronutrient elements. The intent is usually to identify characteristics of soil types on a very local scale; and it is not possible, therefore, to make generalizations of element concentrations in soils for the state as a whole, or even for major geographic regions within the state.

For a number of years very intensive geochemical surveys have been an integral part of the regional approach to "Level III" studies by the Alaska Mineral Resources Appraisal Program (AMRAP) (U.S. Geological Survey, 1984). The objectives, sampling design, sample media, and sample handling procedures of these studies, however, preclude their use as a data base for characterizing the geochemistry of surficial materials for Alaska (see, for example, Foster and others, 1976; Reiser and others, 1979). Most of the material sampled thus far in the AMRAP studies has been either rocks, stream sediments, or heavy-mineral panned concentrates of stream-sediment samples (Marsh and Cathrall, 1981).

In this study we examine the concentration of 35 chemical elements, ash yields, and pH for soils and other unconsolidated surficial materials from throughout the state. The methodology used to collect, store, and prepare the samples was uniform; however, probably of similar importance, the samples were analyzed at one time in a randomized order, making it possible to look for element distribution patterns on a broad regional scale.

SOILS, CLIMATE, VEGETATION, AND GEOCHEMICAL CYCLING

The major regional groups of surficial deposits in Alaska are given in figure 1 (Péwé, 1975); these deposits represent the parent materials from which the soils that we collected have developed or that are still developing. Although the general types of parent materials available for soil formation are the same as those present in more temperate (mid-latitude) regions, the processes that control soil development at high latitudes can be quite different. A cold climate reduces the rate of chemical weathering and, at the same time, also reduces the loss by leaching and surface runoff of elements in solution. The action of the freeze-thaw cycle not only increases the rate of physical weathering but may also cause mixing of soil horizons, thereby bringing parent materials to the surface where chemical weathering is more intense. Although the growth of vegetation in high-latitude regions is generally slow, the rate of decomposition is even slower, resulting in large deposits of organic materials in which many chemical elements may be immobilized. Ground permanently frozen at depth (permafrost) is present in much of northern Alaska and occurs intermittently in central Alaska (fig. 2); this ground thaws in summer from a few centimeters to tens of centimeters from the surface. In many of these areas, downward percolation of surface water is prevented or severely restricted and the soil is permanently moist or saturated.

Within the large area of Alaska, great differences in climate are found. The climates of cold regions were described by Rieger (1983, p. 1) as follows: "Two major climatic types, the maritime type and the continental type, can be recognized, but each of these has varying degrees of expression, and climates intermediate between the two types are common. In maritime climates precipitation is high and fairly uniformly distributed over the year, and temperature differences between winter and summer months generally are not great. Cold continental climates have relatively low annual precipitation, most of which occurs in a short warm summer, and have long cold winters."

The cold maritime climate is characterized in the northwestern coastal areas of Alaska below the Bering Strait by the tundra vegetation of low shrubs, mosses, and lichens and the scarcity or absence of trees (Küchler, 1966; Hultén, 1981) (fig. 2). Parts of the Alaskan Peninsula and all of the Aleutian Islands are also without trees, but have well-developed tundra vegetation; the reason for the absence of trees here is unknown, but probably factors other than low temperature, such as severe winds and prevalent overcast

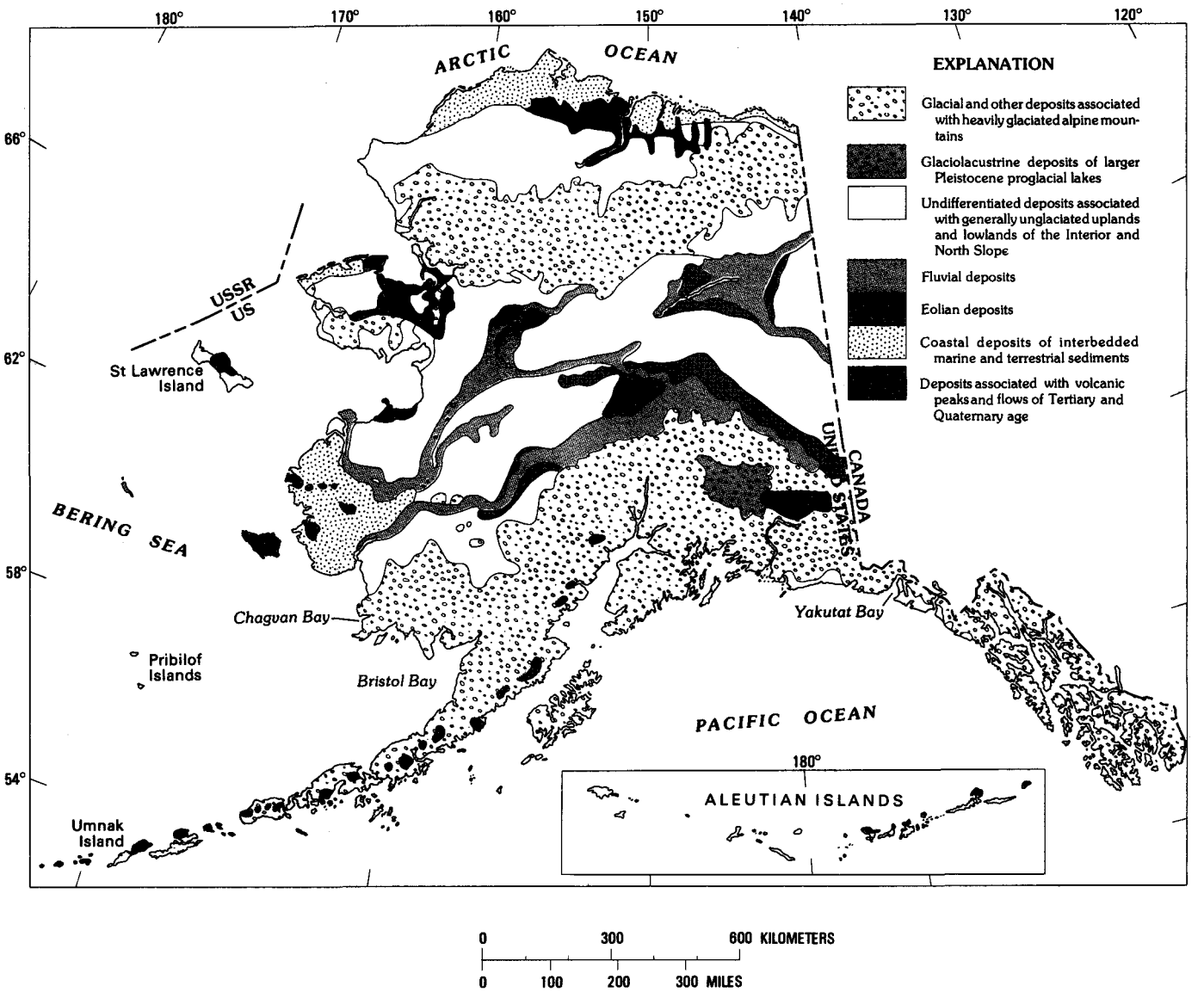

FIGURE 1.—Major regional groups of surficial deposits in Alaska. From Péwé (1975), modified from Karlstrom (1960).

skies, are responsible (Shacklette, 1969). The temperate maritime climatic belt of southern and southeastern Alaska is characterized by luxuriant sitka spruce-western hemlock forests and has a dense understory of shrubs (Viereck and Little, 1972). A highly organic mineral soil is formed, and an abbreviated geochemical cycle predominates, in which many elements are held in, or tightly bound to, the organic material.

A cold and dry continental climate, with great extremes in temperature, is prevalent in a large part of Alaska. This region is characterized by white spruce-birch forests and well-developed bogs and muskegs (Van Cleve and others, 1983). A podzolized soil layer (typical of Spodosols) is often found here. Tundra vegetation is prevalent over much of the North Slope where the temperatures are low at all seasons, with even the warmest months having a mean temperature lower than 10 °C. This area is largely without trees, but has an abundant ground cover of vegetation. The high northern mountains are cold, very dry, and windy; and the mean temperature is lower than 3 °C. This area is designated high arctic or polar desert, has sparse low-growing vegetation, and has little or no soil development (Histosols and Inceptisols).

There has been a very limited data base of "typical" element concentrations that could be used to characterize even small areas of natural soils and other surficial materials and to compare the element content

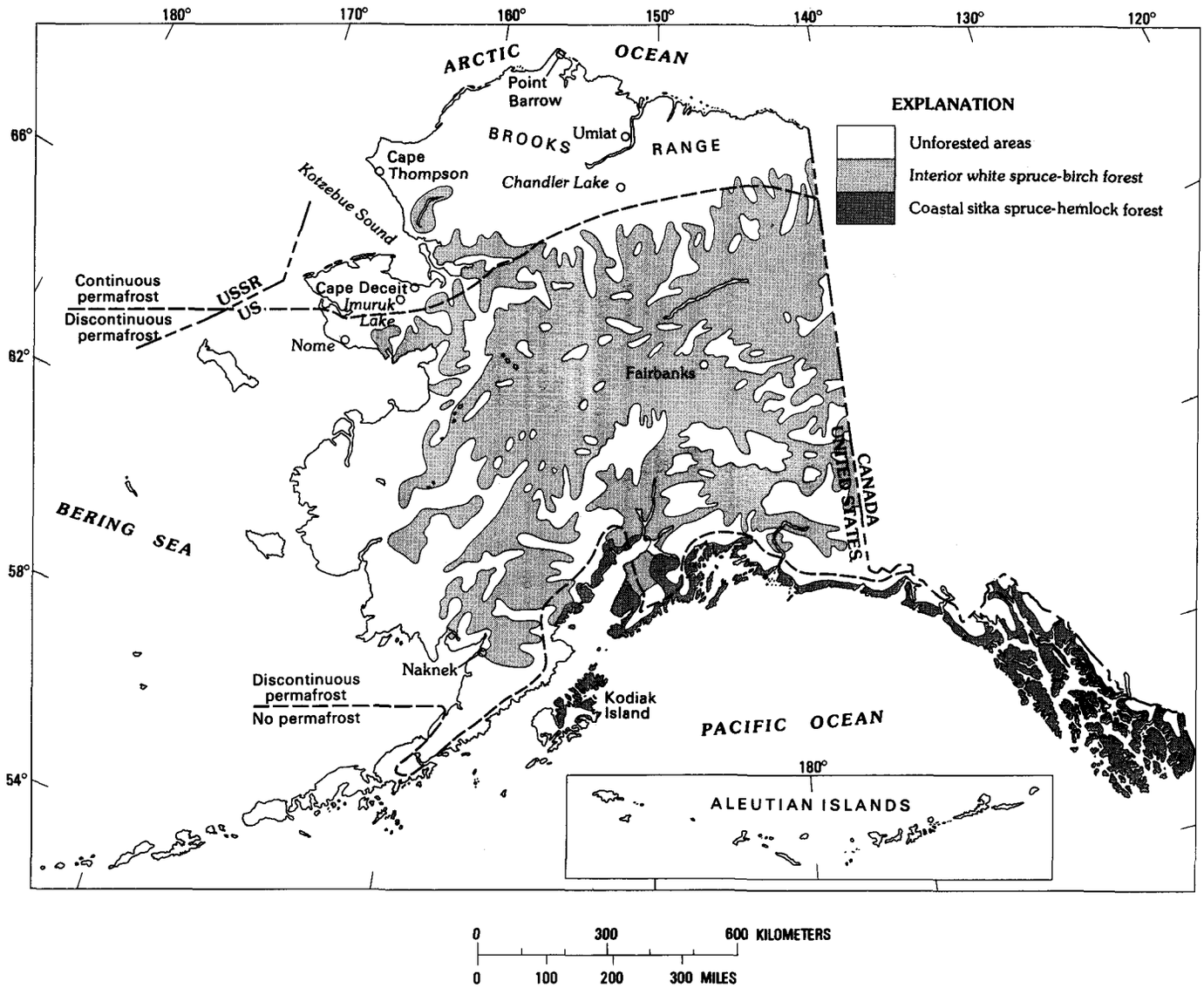

FIGURE 2.—Major forest types and unforested areas in Alaska. Modified from Péwé (1975) after Sigafoos (1958) and Hopkins (1959). Approximate limits of permafrost modified from Péwé (1975).

of Alaskan soils with that of soils from other regions. Land suitable for agriculture constitutes a very small fraction of the total area of Alaska, and crops are grown only at the most favorable locations. Soil analyses that have been done for major nutritive elements in cultivated fields (Laughlin and others, 1983) are not useful in determining large-scale geochemical tendencies. Likewise, the many soil samples analyzed in geochemical prospecting for mineral deposits are intentionally biased and are not necessarily representative of the areas in which they were obtained.

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COLLECTION OF SAMPLES AND ANALYSIS OF GEOCHEMICAL DATA

SAMPLING PLAN

This study progressed slowly on a nonfunded, time-available basis for about 6 years. During fiscal years 1982 and 1983, however, some funds were made available through the U.S. Geological Survey Energy Lands Program and AMRAP to complete the field-work phase of the study.

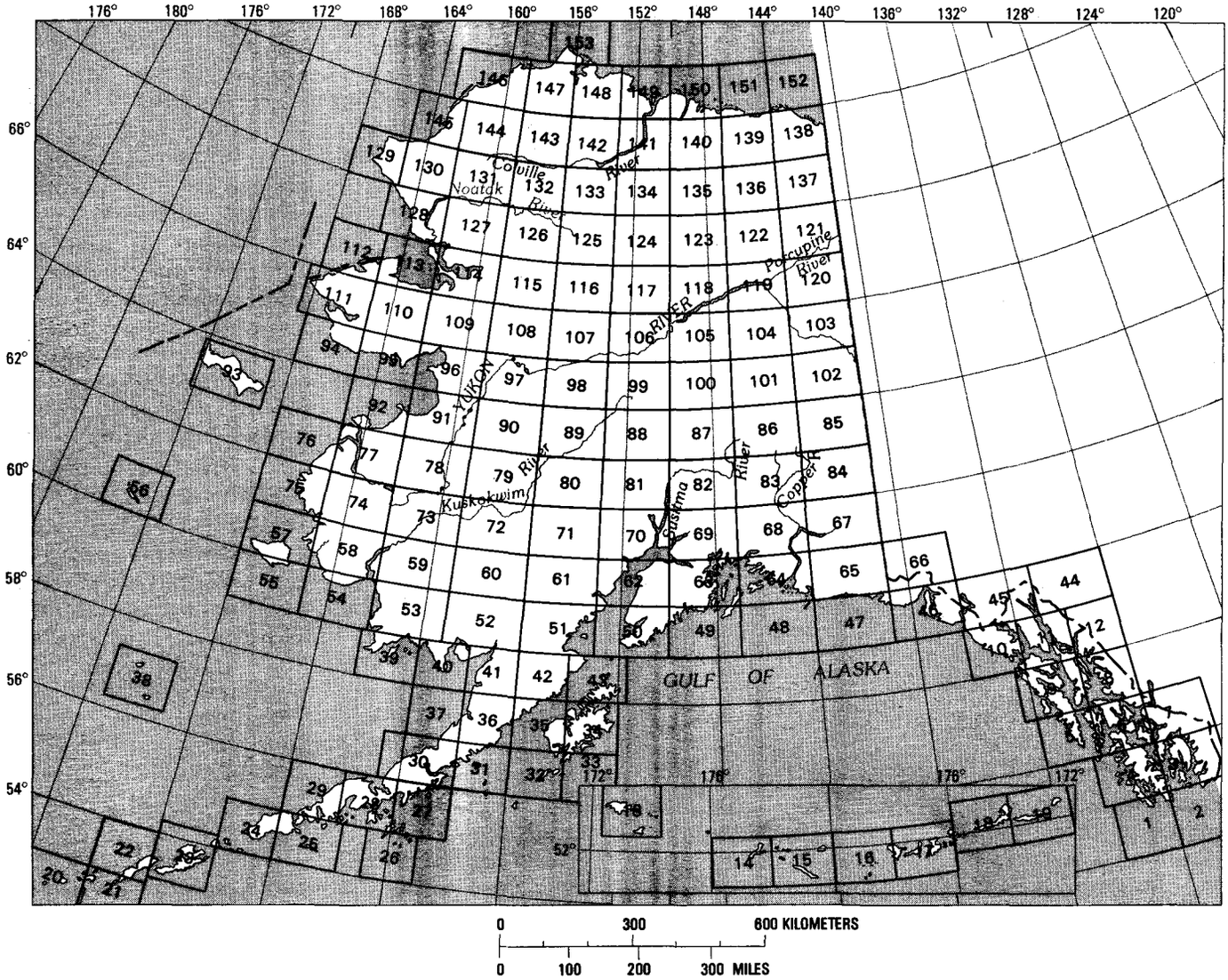
The design for the sampling phase of this study was made simple because, as with the similar studies of the conterminous United States, the acquisition of many of the samples depended on the voluntary cooperation of field personnel (only about 40 percent of the total number of samples was obtained by the authors).

This study was organized on the basis of the 153 1:250,000-scale quadrangle areas that cover Alaska (fig. 3). About 20 percent of the quadrangles have the greater part of their areas covered either by water (island and coastal areas), glaciers, or foreign territory (Canada). If these latter quadrangles are deleted as target areas, then two replicated sites from each of the 120 remaining quadrangles provide a coverage of the state that we judged as adequate for the purposes of this study. Figure 4 shows the coverage (along with sampling location numbers) that was actually obtained. A comparison of figures 3 and 4 shows that, whereas 114 (of 120) quadrangles were visited and a total of 266 locations were sampled, some quadrangles were sampled more intensively than others. We requested that samplers collect a replicate soil sample at a location approximately 100 m distant from the point where the first sample was collected because of the possibility of large geochemical variability within locations. Samples were replicated at 171 of the 266 locations; thus, a total of 437 samples was obtained. Of this total, 50 samples were randomly selected in the laboratory for duplicate analysis, and a grand total of 487 analyses was generated. With more than 60 percent of the samples replicated (171 of 266) and 14 percent of the samples split (50 of 437), reliable estimates could be made of the variability in the concentration of elements at small geographic scales (<100 m) and of the error associated with sample handling and laboratory procedures.

A sampling plan was designed that required a minimum of effort for the volunteer collectors, but which provided an adequate level of geochemical information. At each site we requested that a sample of soil or other unconsolidated surficial material be collected at a depth of about 20 cm (or until permafrost, bedrock, or impenetrable consolidated material was reached). We use the term "surficial material" for purposes of this survey to avoid the technical problem of defining a "soil" and to include many types of unconsolidated deposits. Most samples, by common definition, are mineral soils; but unweathered loess, sand dune or shore materials, and even highly organic deposits are included in this study. We emphasize that unconsolidated river or lake sediments were specifically excluded.

Sampling locations were selected to represent "normal" surficial materials—that is, locations obviously affected by pollution or mines and spoil material, or nearer than 100 m from roadways, were avoided, as were locations of known mineral deposits. The samplers were asked to make notes on the geology, pedology, physiography, and vegetation at each location, also to give a physical description, in general terms, of the material that was sampled. This information, with the latitude and longitude of each location and the chemical analyses of the surficial material for each location, is presented in detail in an open-file report by Gough and others (1984)[1]. Plant samples were also obtained from most of the 266 sampling locations. Whereas the analyses of a soil sample provided a measure of the total concentration of each element at a location, analyses of the associated plant material will permit an estimate to be made of the concentrations of elements that exist in a form available for plant uptake and biogeochemical cycling. Chemical analyses of the plant samples have not yet been completed.

[1]Open-file reports can be obtained from Open-File Services Section, U.S. Geological Survey, M.S. 306, Box 25046, Denver, CO 80225.



1	Dixon Entrance	23	Unalaska	45	Skagway	67	McCarthy	89	Medfra	111	Teller	133	Killik River
2	Prince Rupert	24	Unimak	46	Yakutat	68	Valdez	90	Ophir	112	Shishmaref	134	Chandler Lake
3	Ketchikan	25	False Pass	47	Icy Bay	69	Anchorage	91	Unalakleet	113	Kotzebue	135	Philip Smith Mts.
4	Craig	26	Simeonof Island	48	Middleton Island	70	Tyonek	92	St. Micheal	114	Selawik	136	Arctic
5	Port Alexander	27	Stepovak Bay	49	Blying Sound	71	Lime Hills	93	St. Lawrence	115	Shungnak	137	Table Mtn.
6	Petersburg	28	Port Moller	50	Seldovia	72	Sleetmute	94	Nome	116	Hughes	138	Demarcation Point
7	Bradfield Canal	29	Cold Bay	51	Iliamna	73	Russian Mission	95	Solomon	117	Bettles	139	Mt. Michelson
8	Sumdum	30	Chignik	52	Dillingham	74	Marshall	96	Norton Bay	118	Beaver	140	Sagavanirktok
9	Sitka	31	Sutwik Island	53	Goodnews	75	Hooper Bay	97	Nulato	119	Fort Yukon	141	Umiat
10	Mt. Fairweather	32	Trinity Islands	54	Kuskokwim Bay	76	Black	98	Ruby	120	Black River	142	Ikpikpuk River
11	Juneau	33	Kaguyak	55	Cape Mendenhall	77	Kwiguk	99	Kantishna River	121	Coleen	143	Lookout Ridge
12	Taku River	34	Kodiak	56	St. Matthew	78	Holy Cross	100	Fairbanks	122	Christian	144	Utukok River
13	Attu	35	Karluk	57	Nunivak Island	79	Iditarod	101	Big Delta	123	Chandalar	145	Point Lay
14	Kiska	36	Ugashik	58	Baird Inlet	80	McGrath	102	Eagle	124	Wiseman	146	Wainwright
15	Rat Islands	37	Bristol Bay	59	Bethel	81	Talkeetna	103	Charley River	125	Survey Pass	147	Meade River
16	Gareloi Island	38	Pribilof Islands	60	Taylor Mts.	82	Talkeetna Mts.	104	Circle	126	Ambler River	148	Teshekpuk
17	Adak	39	Hagemeister Island	61	Lake Clark	83	Gulkana	105	Livengood	127	Baird Mts.	149	Harrison Bay
18	Atka	40	Nushagak Bay	62	Kenai	84	Nabesna	106	Tanana	128	Noatak	150	Beechey Point
19	Seguam	41	Naknek	63	Seward	85	Tanacross	107	Melozitna	129	Point Hope	151	Flaxman Island
20	Amukta	42	Mt. Katmai	64	Cordova	86	Mt. Hayes	108	Kateel River	130	DeLong Mts.	152	Barter Island
21	Samalga Island	43	Afognak	65	Bering Glacier	87	Healy	109	Candle	131	Misheguk Mts.	153	Barrow
22	Umnak	44	Atlin	66	Mt. St. Elias	88	Mt. McKinley	110	Bendeleben	132	Howard Pass		

From Orth, 1967

FIGURE 3.—Location of 1:250,000-scale topographic maps.

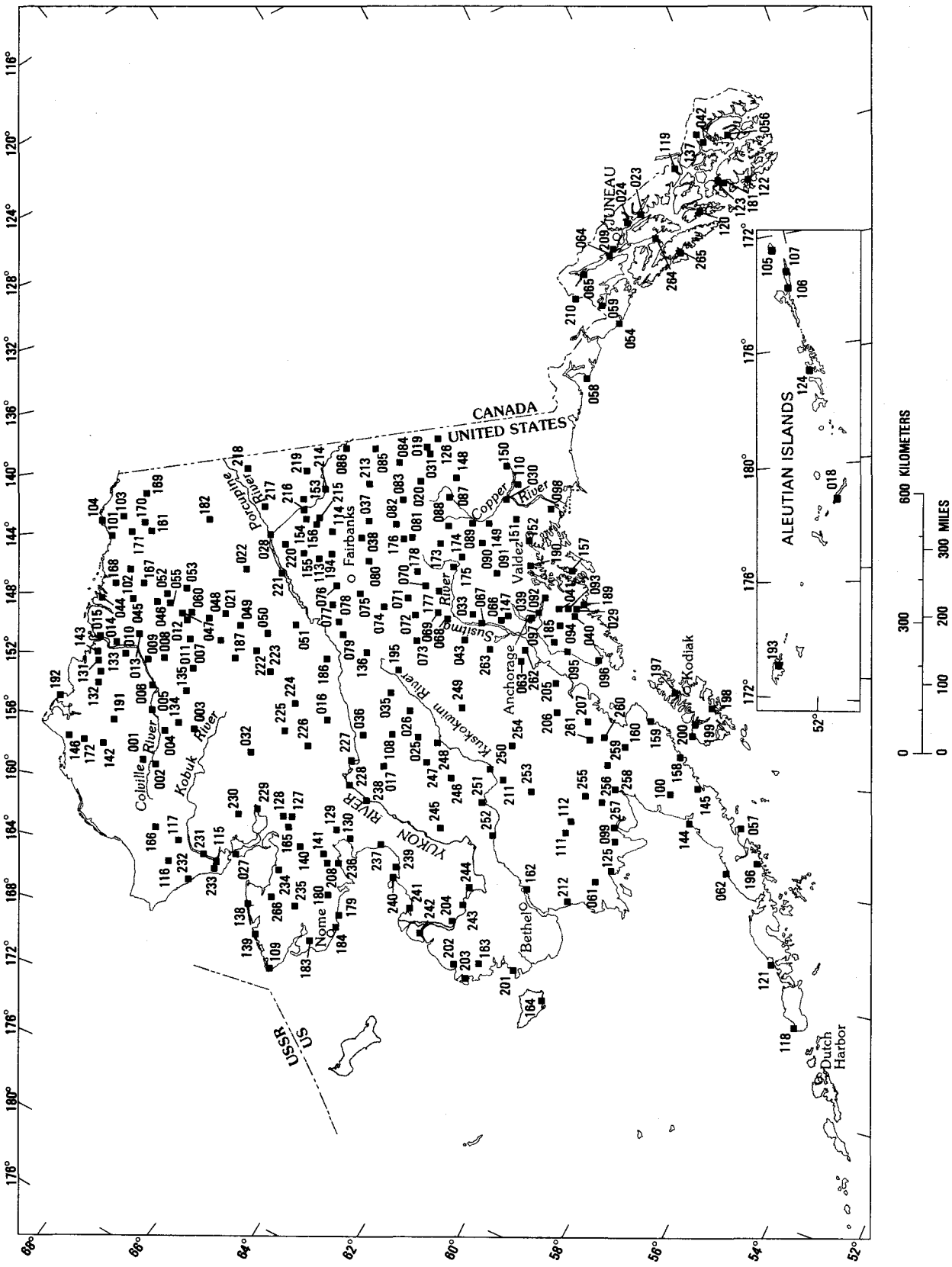


FIGURE 4.—Sampling sites and field identification numbers for soils and other surficial materials, Alaska. Site data are given in Gough and others (1984).

CHEMICAL-ANALYSIS PROCEDURES

In the laboratory the samples were dried at ambient temperature, and the texture and color of the material were noted. The material was then crushed in a mechanical mortar and sieved through a 2-mm screen. The minus-2-mm fraction was used for pH determinations; the remaining material was pulverized to pass a 200-mesh sieve. A 5-g portion was dried at 105 °C, then ashed at 550 °C to obtain an ash-yield value. Following a randomization of all samples, chemical analyses were performed on both the ashed and unashed minus-200-mesh fractions by the methods given in table 1. The samples were scanned for concentrations of 47 elements, but concentrations for bismuth, cadmium, erbium, europium, gadolinium, praseodymium, samarium, and silver were only rarely found above the lower limit of analytical determination. Because so few values are in the detectable range for these elements using the methods given in table 1, the elements do not appear in the summary tables but do appear in figure 40. Some elements were looked for in all samples, but were not found. These elements, analyzed by inductively coupled argon-plasma optical emission spectrometry, and their approximate lower limits of determination in parts per million (in parentheses) are as follows: gold (8), holmium (4), tantalum (40), and terbium (20).

DATA PRESENTATION

CLASSIFICATION OF GEOCHEMICAL VARIABILITY

The distribution of the variability of element concentrations was determined by the use of a three-level analysis-of-variance procedure similar to one described in mathematical detail by Miesch (1976). The total chemical variation within samples of surficial materials has been viewed as the sum of three components: (1) the spatial variability among sampling locations that are separated by more than 100 m, (2) the spatial variability between sites that are separated by 100 m or less within a location, and (3) the procedural variability due to all other causes that arise from sample preparation and analysis. The results of this test are given in table 2.

PRESENTATION AND EXPLANATION OF SUMMARY STATISTICS

Summary data for 35 elements, ash yield, and pH values are reported in table 3, in which the element concentrations found in samples of soil and other surficial materials from Alaska are compared with those reported for similar samples from the conterminous

TABLE 1.—*Analytical methodology and references for soil analyses*

Parameter	Method	References and remarks
Concentrations of Al, Ca, Fe, K, Mg, Mn, Na, P, Si, and Ti.	X-ray FS[1]	Taggert and others, 1981.
Concentrations of Ag, As, Ba, Be, Bi, Cd, Ce, Co, Cr, Cu, Dy, Er, Eu, Ga, Gd, La, Li, Mo, Nb, Nd, Ni, Pb, Pm, Sc, Sm, Sn, Sr, V, Y, Yb, and Zn.	Argon-plasma OES[2]	Crock and others, 1983.
Th and U	Neutron activation	Millard, 1975, 1976.
Ash	Gravimetric	Aliquots of dry soils weighed and burned to ash, and the ash weighed and calculated as percentage of dry weight.
pH	Selective ion electrode.	Crock and Severson, 1980.

[1]X-ray fluorescence spectrographic.

[2]Inductively coupled argon-plasma optical emission spectrometry.

TABLE 2.—*Estimates of logarithmic variance for surficial materials from Alaska*

Element, ash, or pH	Total $\log_{10}$ variance	Percentage of total variance between: Locations	Replicate samples at each location	Replicate analytical splits	Element, ash, or pH	Total $\log_{10}$ variance	Percentage of total variance between: Locations	Replicate samples at each location	Replicate analytical splits
Al.....	0.02034	85	14	1	Nd.....	0.05725	53	8	39
As.....	.04913	48	31	21	Ni.....	.11618	82	12	6
Ba.....	.04940	74	20	6	P.....	.03825	80	19	1
Be.....	.03491	84	7	9	Pb.....	.06212	46	13	41
Ca.....	.17545	87	11	2	Sc.....	.05067	69	16	15
Ce.....	.07214	72	17	11	Si.....	.00656	73	26	1
Co.....	.04893	73	13	14	Sn.....	.02281	47	27	26
Cr.....	.09316	76	16	2	Sr.....	.08590	86	0	14
Cu.....	.06598	67	22	11	Th.....	.06858	74	6	20
Dy.....	.04263	7	0	93	Ti.....	.00655	73	26	1
Fe.....	.03273	68	31	<1	U.....	.07744	71	24	5
Ga.....	.02895	55	0	45	V.....	.05256	71	19	10
K.....	.03978	84	14	2	Y.....	.03770	62	31	7
La.....	.05269	71	22	7	Yb.....	.04411	58	17	25
Li.....	.05810	79	13	8	Zn.....	.04877	39	20	41
Mg.....	.07153	85	15	<1	Ash.....	.01440	70	30	<1
Mn.....	.09896	69	29	1	pH.....	.00646	69	22	9
Mo.....	.02711	39	26	35					
Na.....	.05910	89	0	11					
Nb.....	.05056	58	6	36					

United States by Shacklette and Boerngen (1984) and for the element concentration in stream and lake sediments from Alaska by the National Uranium Resource Evaluation program (NURE) (Los Alamos National Laboratory, 1983). The surficial-materials data are expressed on a dry-weight basis (forced air at ambient temperature) which, according to Brooks (1983, p. 167–168), is the common method for reporting concentrations of elements in soils. The stream- and lake-sediment data are also expressed on a dry-weight basis, but these samples were oven-dried at about 100 °C. The mean values expressed on a dry-weight basis (table 2) can be converted to an ash-weight basis using the formula: $C_a=(C_d/A)\times 100$, where C_a equals the concentration in the ash, C_d is the concentration in the dry material, and A is the mean percent ash yield (ash percentage of dry weight). Conversions, using the same formula, of concentration values for individual samples can be made by consulting the element-concentration and ash-yield values given in Gough and others (1984).

In table 3, both arithmetic and geometric means are given. Arithmetic means are provided to make these data more readily comparable with data generally reported in the literature. These arithmetic means for samples of surficial materials were derived from the estimated geometric means 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 3 are best used as estimates of geochemical abundance (Miesch, 1967, p. B1). Geometric means, however, are better "maximum likelihood estimators" for most geochemical data because of the tendency for concentrations of elements in natural materials, particularly the trace elements, to have positively skewed frequency distributions (Miesch, 1967, p. B2). Therefore, the analytical data for surficial materials, as received from the laboratory, were transformed to logarithms; and the geometric mean (antilogarithm of the mean of logarithmic values) is reported as our best estimator of central tendency. In table 3 the data for samples of surficial materials include detection ratios; geometric means and deviations; and observed ranges for element concentrations, ash yields, and pH values, whereas the sediment data provide detection ratios, arithmetic means, and observed ranges only.

In geochemical background studies, the magnitude of scatter to be expected around the mean is as important as the mean. In lognormal distributions, the geometric deviation (antilogarithm of the standard deviation of the logarithmic data) measures this scatter, and this deviation may be used to estimate the range of variation expected for an element in the material being studied. About 68 percent of the samples in a randomly selected suite should fall within the limits defined by M/D and MXD, where M represents the

TABLE 3.—*Summary statistics for elements in samples of surficial materials from Alaska and the conterminous United States, and in samples of stream and lake sediments from Alaska*

[Ratio, number of samples in which the element was found in measurable concentrations to number of samples analyzed. Means are reported in parts per million (μg/g) dry-weight base; and means and deviations are geometric, except as indicated. Range, observed range of concentrations. Leaders (--), no data available]

Element, ash, or pH	Soils and other surficial materials: Alaska: Detection ratio	GM[3]	GD[4]	AM[5]	Range	Conterminous United States[1]: Detection ratio	GM[3]	GD[4]	AM[5]	Range	Stream and lake sediments from Alaska[2]: Detection ratio	Mean[6]	Median[6]	Range[6]
Al, percent	416:416	6.2	1.38	6.5	1.2 - 10	1091:1247	4.7	2.48	7.2	0.5 - >10	61643:61923	5.8	6.2	0.10 - 82
As.....	154:437	6.7	2.31	9.6	<10 - 750	1249:1257	5.2	2.23	7.2	<.1 - 97	38622:52251	17.3	12.0	5.0 - 1796
Ba.....	437:437	595	1.67	678	39 - 3100	1319:1319	440	2.14	580	10 - 5000	54272:61923	811	707	3 - 65000
Be.....	245:437	1.5	1.49	1.35	<1 - 7	479:1313	.63	2.38	.92	<.1 - 15	10963:15660	2	2	1.0 - 12
Ca, percent	416:416	1.3	2.61	2.0	.04 - 10	1291:1291	.92	4.00	2.4	.01 - 32	55637:61923	2.6	1.5	.04 - 41
Ce.....	427:437	28	1.84	33	<5 - 180	151:1171	63	1.78	75	<150 - 300	57691:61923	68	61	2 - 1141
Co.....	436:437	13	1.67	14	<2 - 55	1101:1311	6.7	2.19	9.1	<.3 - 70	58535:61923	18	16	.7 - 1000
Cr.....	437:437	50	2.00	64	5 - 390	1319:1319	37	2.37	54	1 - 2000	57532:61923	115	92	1 - 15000
Cu.....	437:437	24	1.81	29	3 - 810	1301:1311	17	2.44	25	<1 - 700	56227:61923	37	32	7 - 14000
Dy.....	322:437	2.5	2.12	6.8	4 - 12	--	--	--	--	--	57437:61923	5	5	1 - 9
Fe, percent	416:416	3.5	1.52	3.8	.55 - 10	1315:1317	1.8	2.38	2.6	.01 - >10	61331:61923	3.7	3.5	.05 - 49
Ga.....	430:437	15	1.44	16	<4 - 32	1198:1316	13	2.03	17	<5 - 70	--	--	--	--
K, percent	416:416	1.2	1.57	1.3	.09 - 4.1	1314:1314	--	--	1.5	.05 - 6.3	51384:61923	5.1	1.3	.07 - 12.5
La.....	434:437	19	1.68	21	<2 - 120	756:1293	30	1.92	37	<30 - 200	49039:61923	36	32	1 - 900
Li.....	436:437	26	1.74	30	<2 - 130	1210:1258	20	1.85	24	<5 - 140	15554:15660	29	25	1 - 260
Mg, percent	416:416	.98	1.84	1.2	.13 - 7.4	1305:1306	.44	3.28	.90	<.05 - >10	55963:61923	1.3	1.1	.04 - 46
Mn, percent	384:416	.051	2.07	.067	<.02 - 0.4	1314:1317	.033	2.77	.06	<.02 - 0.7	61884:61923	.08	.06	.0004 - 10
Mo.....	78:437	.86	2.48	1.3	<2 - 15	89:298	.59	2.72	.98	<3 - 15	--	--	--	--
Na, percent	415:416	1.2	1.74	1.5	<.07 - 3.6	1107:1193	.59	3.27	1.2	<.05 - 5	61866:61923	1.2	1.2	.007 - 16
Nb.....	393:437	8.0	1.64	9.0	<4 - 44	740:1296	9.3	1.75	11	<10 - 100	--	--	--	--
Nd.....	431:437	23	1.73	27	<4 - 120	339:870	40	1.68	46	<70 - 300	--	--	--	--
Ni.....	433:437	24	2.17	33	<3 - 320	1190:1318	13	2.31	19	<5 - 700	47426:61923	37	32	9 - 1800
P, percent	411:416	.078	1.55	.086	<.02 - 0.34	904:906	.026	2.69	.04	<.02 - 0.7	--	--	--	--
Pb.....	417:437	12	1.74	14	<4 - 310	1134:1319	16	1.86	19	<10 - 700	34138:61923	12	9	4 - 10000
Sc.....	431:437	13	1.67	14	<2 - 39	1074:1304	7.5	1.82	8.9	<5 - 50	61603:61923	14	14	.10 - 129
Si, percent	416:416	28	1.20	28	10 - 43	406:406	--	--	31	<1.7 - 45	--	--	--	--
Sn.....	111:437	2.6	1.81	3.1	<4 - 41	341:355	.89	2.36	1.3	<.1 - 10	964:61923	57	15	9 - 29000
Sr.....	437:437	159	1.93	198	21 - 760	1279:1318	120	3.30	240	<5 - 3000	3598:52251	489	455	40 - 5500
Th.....	418:437	6.1	1.95	7.6	<1.6 - 76	297:297	8.6	1.53	9.4	2.2 - 31	56133:61923	9.1	7.9	.30 - 318
Ti, percent	416:416	.48	1.48	.52	.09 - 1.5	1313:1317	.24	1.89	.29	.09 - 2.0	57402:61923	.45	.44	.0014 - 10
U.....	436:437	2.3	1.86	2.8	<.22 - 45	354:354	2.3	1.73	2.7	.29 - 11	61909:61923	3.5	2.8	.02 - 335
V.....	437:437	112	1.69	129	11 - 490	1294:1319	58	2.25	80	<7 - 500	60750:61923	120	119	2.0 - 2000
Y.....	434:437	14	1.55	15	<4 - 100	1236:1319	21	1.78	25	<10 - 200	--	--	--	--
Yb.....	362:437	1.4	1.60	1.6	<1 - 6	206:1250	2.6	1.79	3.1	<1 - 50	37692:61923	4.3	4.0	.2 - 90
Zn.....	427:437	70	1.64	79	<20 - 2700	1239:1248	48	1.95	60	<5 - 2500	28739:61923	157	140	14 - 4700
Ash[7].....	437:437	85	1.33	88	6.6 - 99.7	--	--	--	--	--	--	--	--	--
pH[8].....	437:437	5.5	1.20	5.6	3.7 - 9.0	--	--	--	--	--	--	--	--	--

[1]Data from Shacklette and Boerngen, 1984.
[2]Data from Los Alamos National Laboratory, 1983.
[3]Geometric mean.
[4]Geometric deviation.
[5]Arithmetic mean, calculated by method of Sichel, 1952.
[6]Data for uncensored values only; mean is presumed to be arithmetic; many values have been rounded; parts per million converted to percentage when appropriate for comparisons with other data given.
[7]Percentage of dry weight.
[8]Standard units.

geometric mean and D the geometric deviation. About 95 percent should fall between M/D^2 and MXD^2, and about 99.7 percent between M/D^3 and MXD^3 (U.S. Geological Survey, 1975).

The analytical data for some elements include values that are below, or above, the limits of analytical determination; and these values are expressed as less than (<) or greater than (>) a stated value[2]. These data are said to be "censored," and for these the mean was computed by using a technique described by Cohen (1959) and applied to geochemical studies by Miesch (1967, 1976). This procedure includes both the censored and the noncensored values in the calculations of the expected mean and variance. The censoring may be so severe in certain sets of data that a reliable adjustment cannot be made; with the data sets used in this study, however, only a few such circumstances occurred (fig. 40). In some cases the inclusion of censored data may result in estimates of the mean that are lower than the limit of determination. For example, in table 3 the geometric mean for arsenic concentrations in soils from Alaska is estimated to be 6.7 ppm, although the lower limit of determination of the analytical method that was used is 10 ppm.

The detection ratios in table 3—that is, the ratio of the number of samples in which the element was found in measurable concentrations to the total number of samples analyzed—identify the number of censored values that were used in calculating the mean. This number is found by subtracting the left value in the ratio from the right.

MAPS OF GEOCHEMICAL VALUES

The distribution of the sampling locations for surficial materials and the concentrations of elements determined in samples from those locations are presented on maps of Alaska (figs. 5–40). Figure 40 identifies the locations where measurable amounts of one or more of eight elements—bismuth, cadmium, erbium, europium, gadolinium, praseodymium, samarium, and silver—were found. Because of the large number of censored values, reliable mean concentrations of these elements could not be calculated. Each of the remaining maps (figs. 5–39) gives the locations where samples were collected and the concentration of the elements in samples at these locations.

The map symbols represent a class of values determined from the frequency distributions using all samples, usually 437 (266 sites plus 171 site replicates). Eleven of the frequency distributions are based on a total of 416 samples because 21 of them had an insufficient amount of material to perform x-ray fluorescence; this is true for aluminum, calcium, cerium, iron, magnesium, manganese, phosphorus, potassium, silicon, sodium, and titanium. The untransformed element-concentration values were used to calculate the distributions; if a location had a replicate sample, we chose to plot only the value of the sample from the initial site. The element maps, therefore, represent 266 sampling sites. Using the histograms, we divided the ranges of reported values for the elements into classes so that a nearly equal percentage of the values fell into each class. For most elements, we selected five classes; the limited range in values for some elements, however, prohibited the use of more than two or three classes to represent the total distribution. For many other elements that showed a high content in a few samples (positively skewed frequency distribution), the class interval was expanded at the high end of the range to accommodate these samples on an arithmetic scale. Symbols representing the classes were drawn on the maps by an automatic plotter that was guided by computer classification of the data, including the latitude and longitude of the sampling locations. A histogram on each map gives the frequency distribution of the analytical values and shows the symbol that represents each class of values.

RESULTS AND DISCUSSION

DISTRIBUTION OF GEOCHEMICAL VARIABILITY

The results of the three-level analysis-of-variance sampling design are given in table 2. An interpretation of the partitioning of the variance components is illustrated by the values for calcium. The total $\log_{10}$ variance is equal to 0.17545; of this, 87 percent of the total variance occurred among the 266 locations. We have intentionally not reported tests of significance for the analysis of variance; however, these data show that differences in concentrations of calcium between locations are reproducible and are largely due to natural causes. Only 11 percent of the variance is between replicate samples at a location, thus indicating that calcium concentrations within locations are uniform and that sampling errors are small.

The variance attributed to analytical procedures in determining calcium is only 2 percent; therefore, precision of the analytical method is good, and the error associated with laboratory procedures does not obscure natural geochemical trends. Analytical-error variance

[2]The limits of determination for those elements with censored values are given in the "observed range" column, table 3.

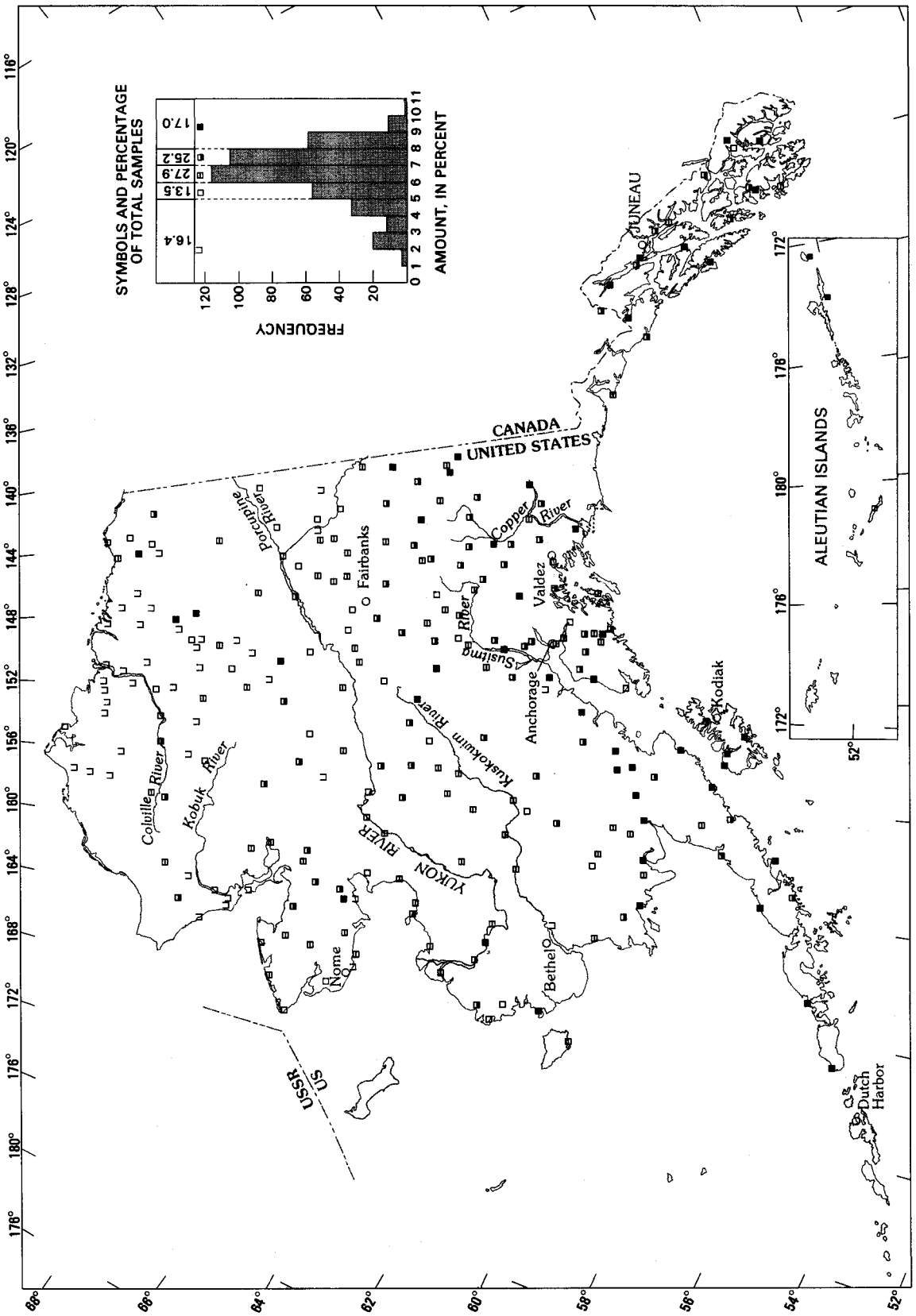


FIGURE 5.—Aluminum content of surficial materials.

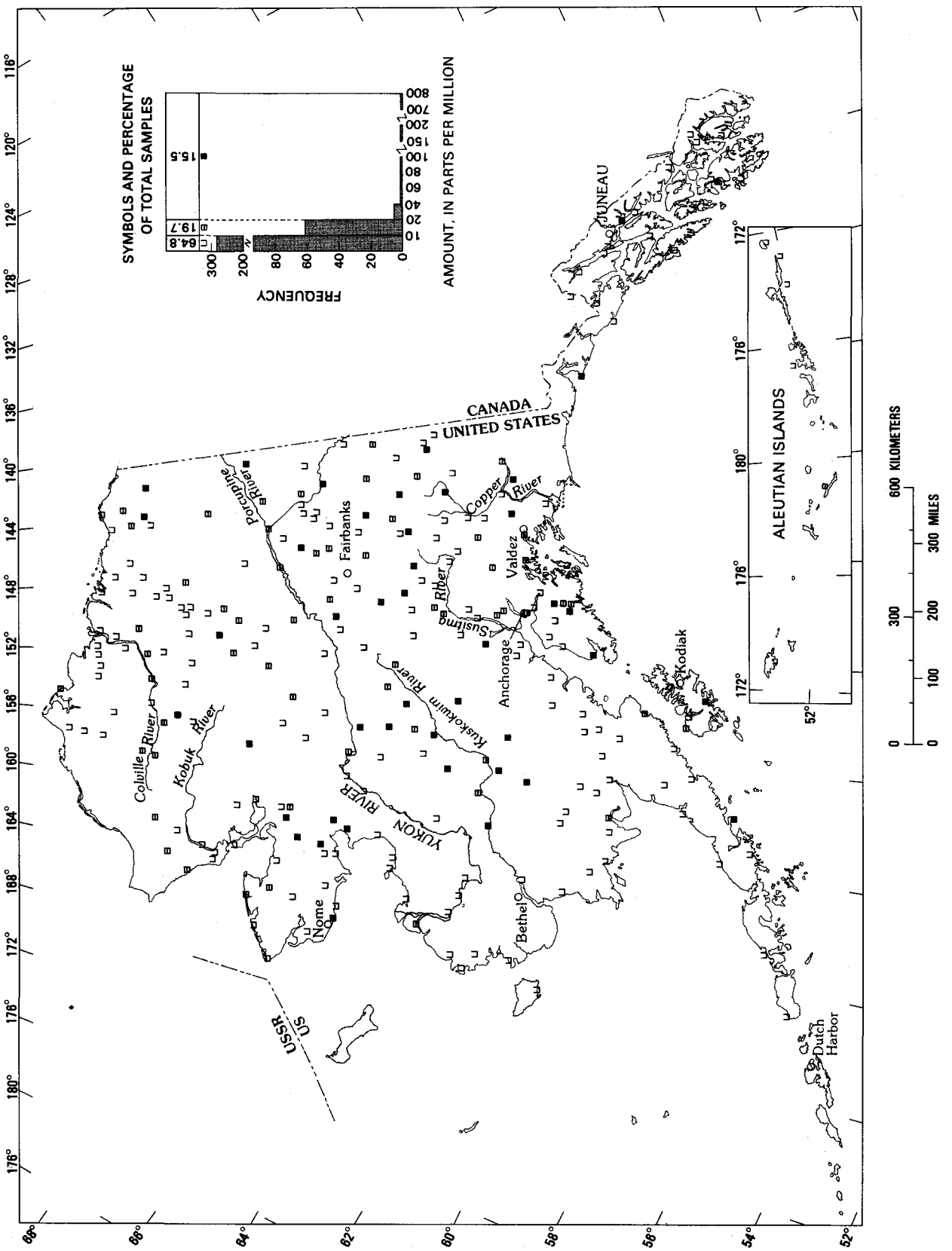


FIGURE 6.—Arsenic content of surficial materials.

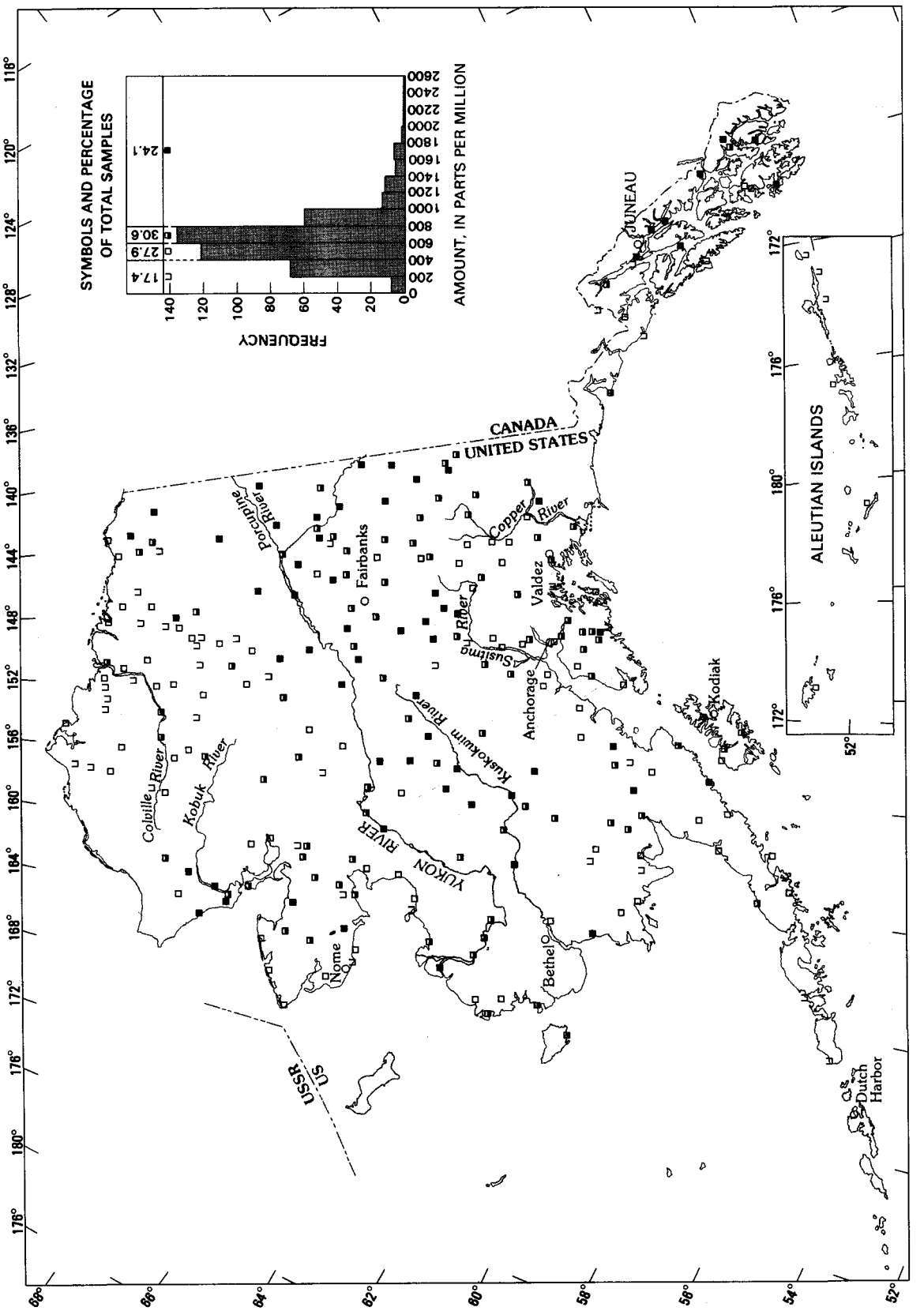


FIGURE 7.—Barium content of surficial materials.

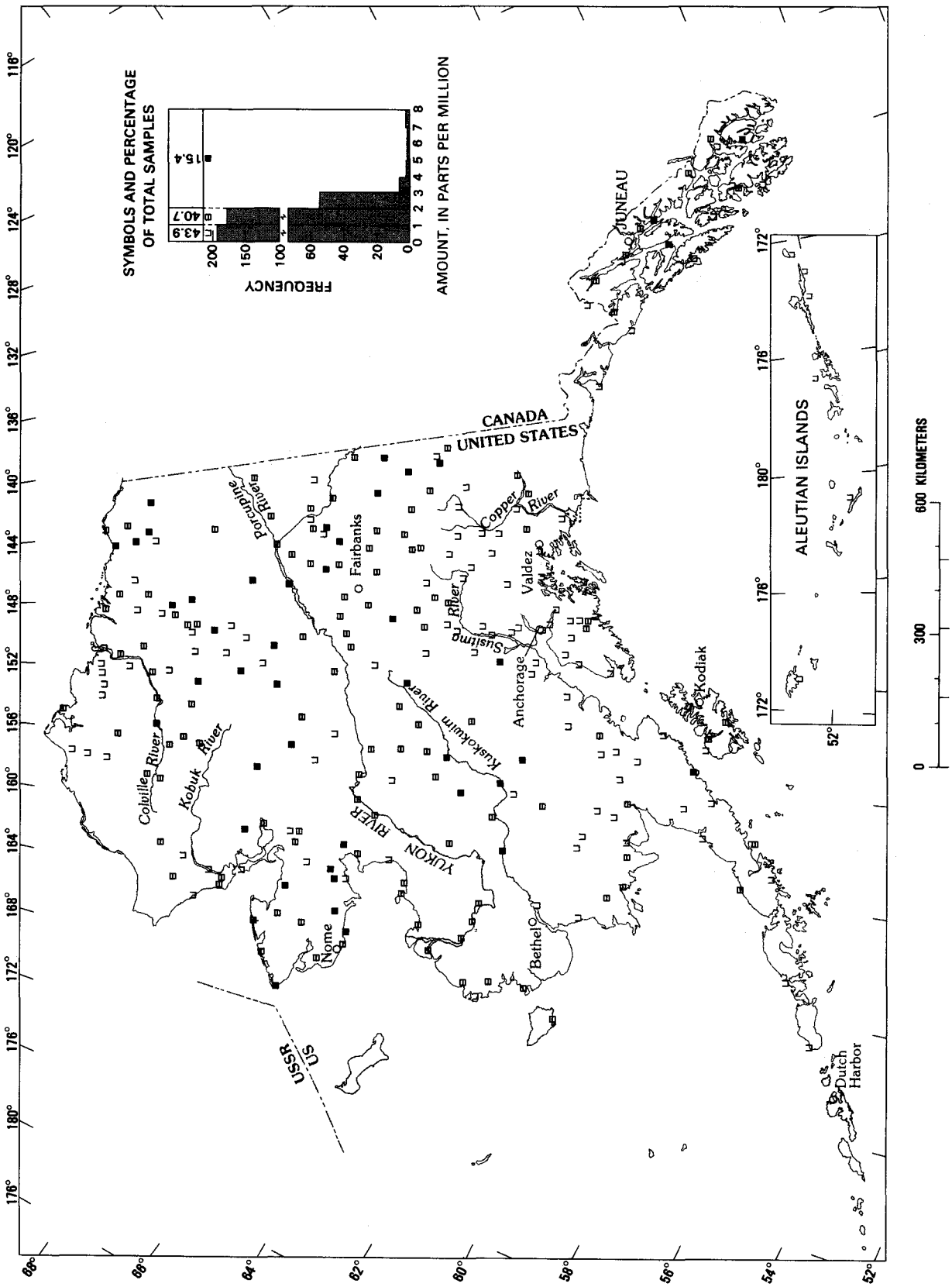


FIGURE 8.—Beryllium content of surficial materials.

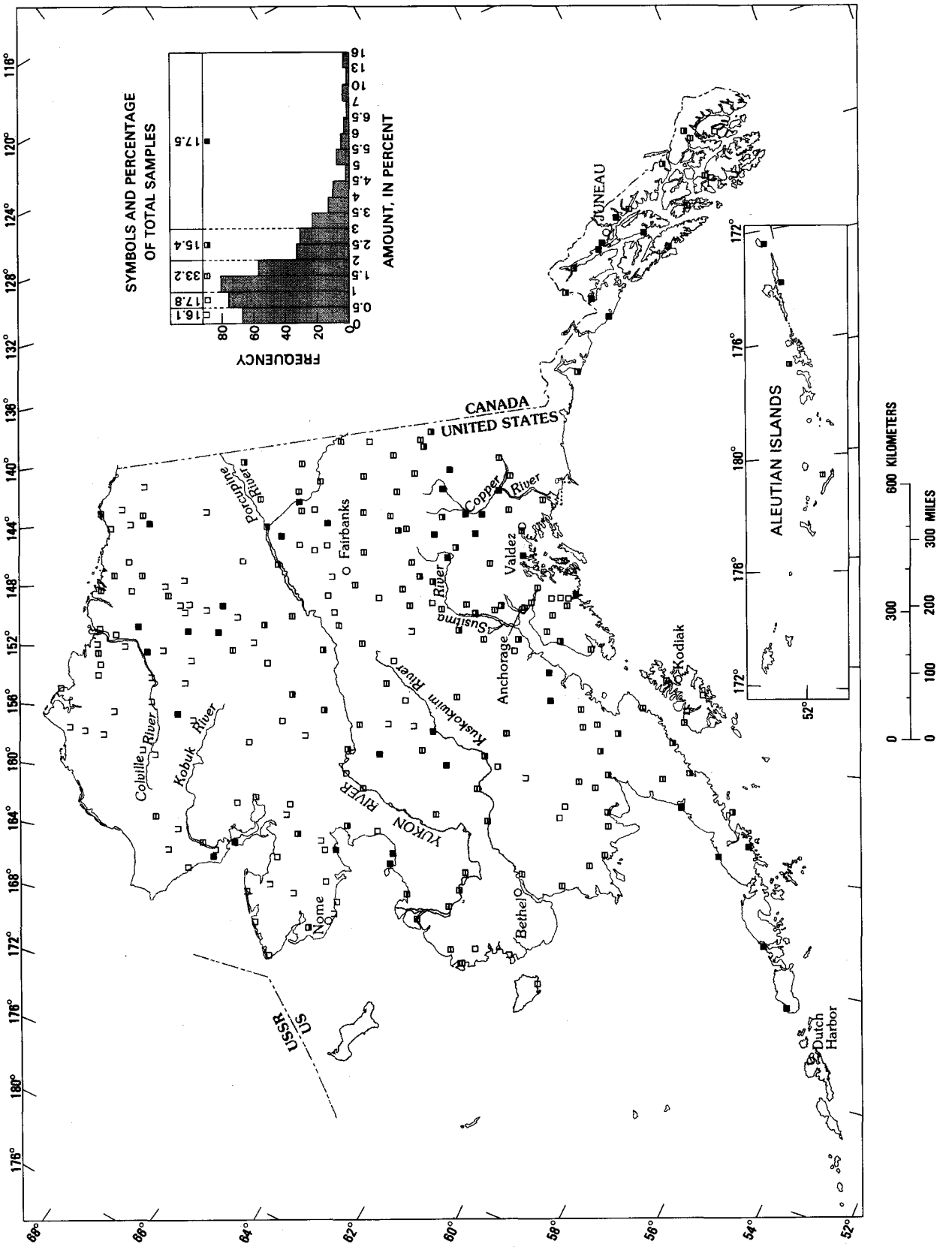


FIGURE 9.—Calcium content of surficial materials.

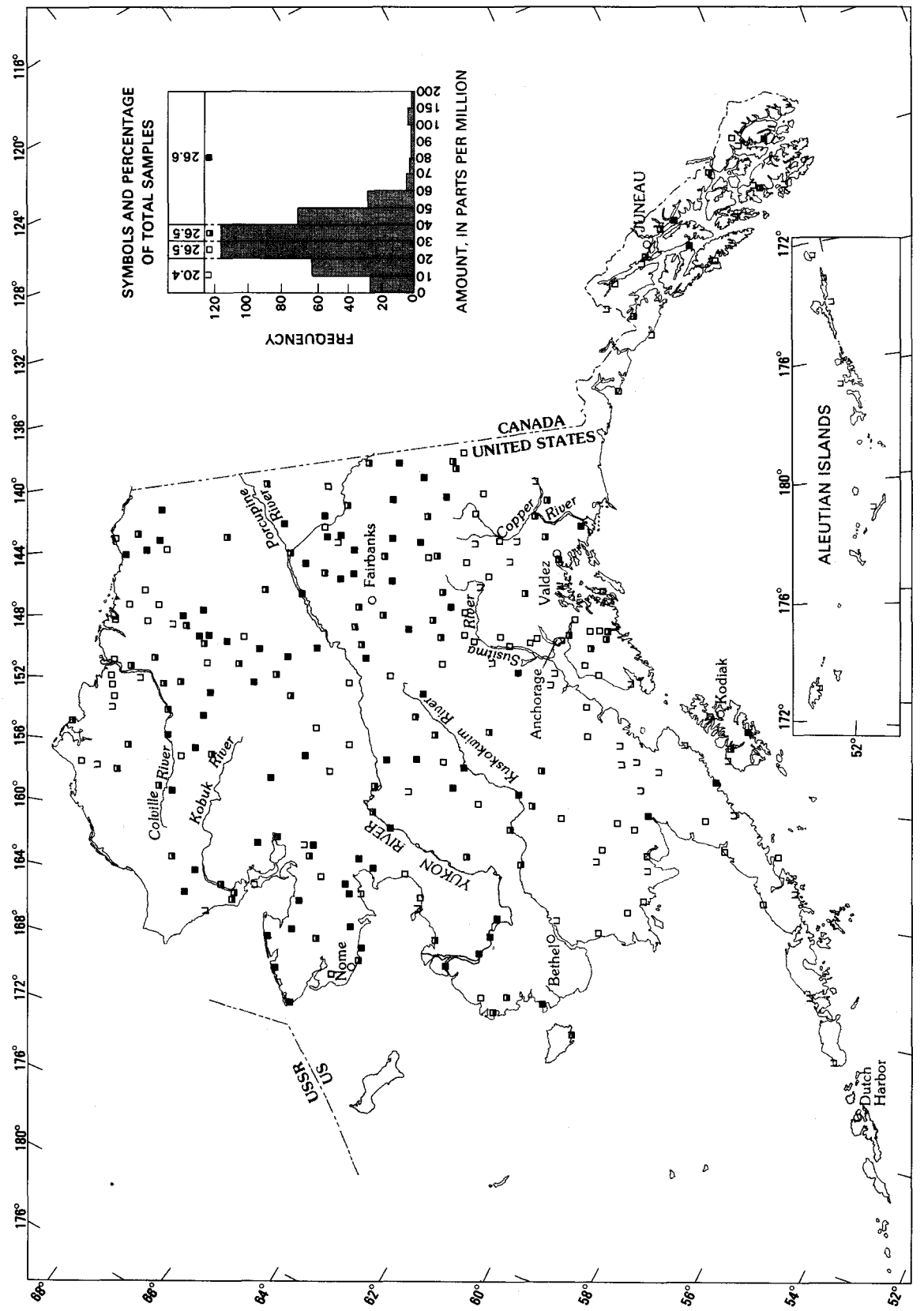


FIGURE 10.—Cerium content of surficial materials.

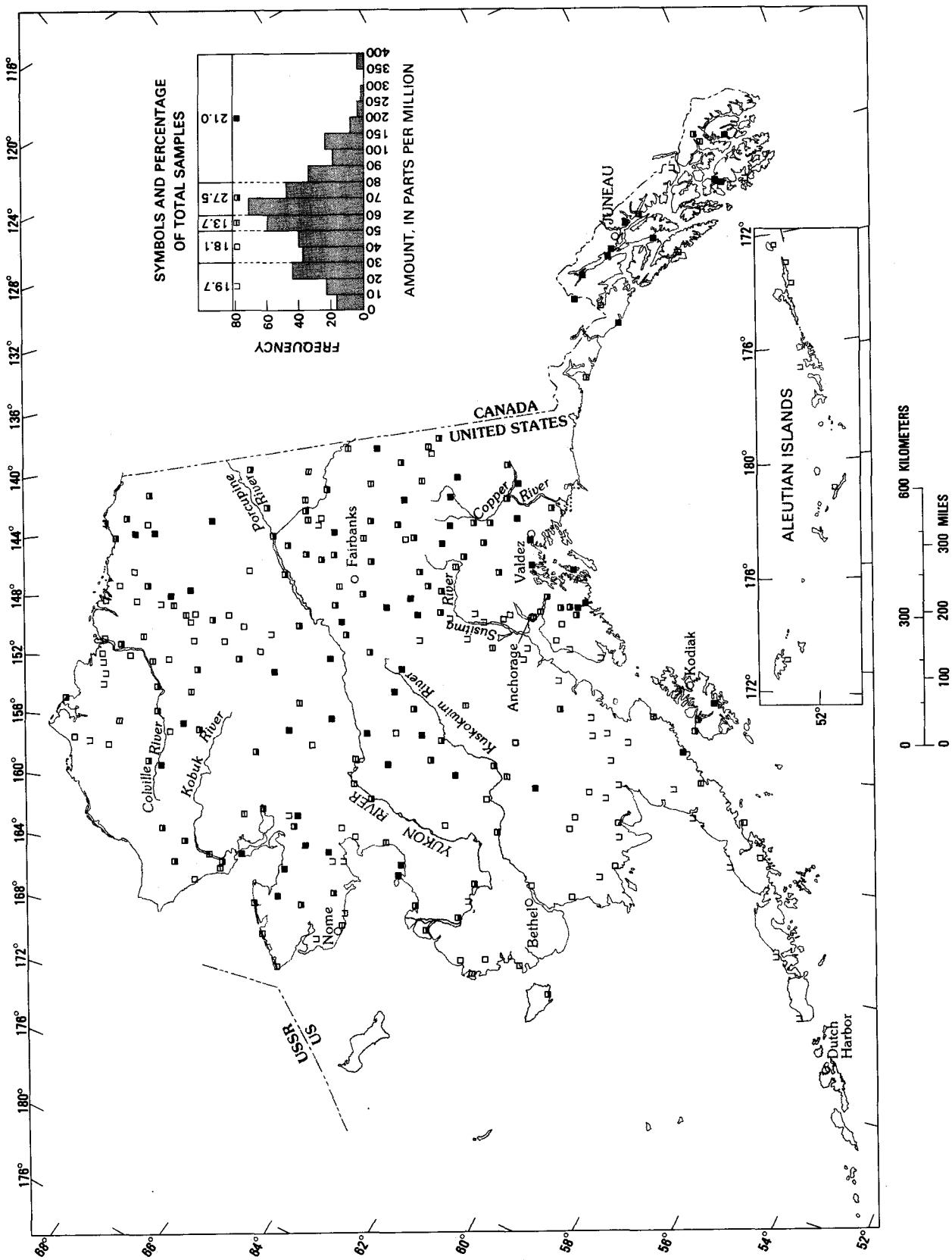


FIGURE 11.—Chromium content of surficial materials.

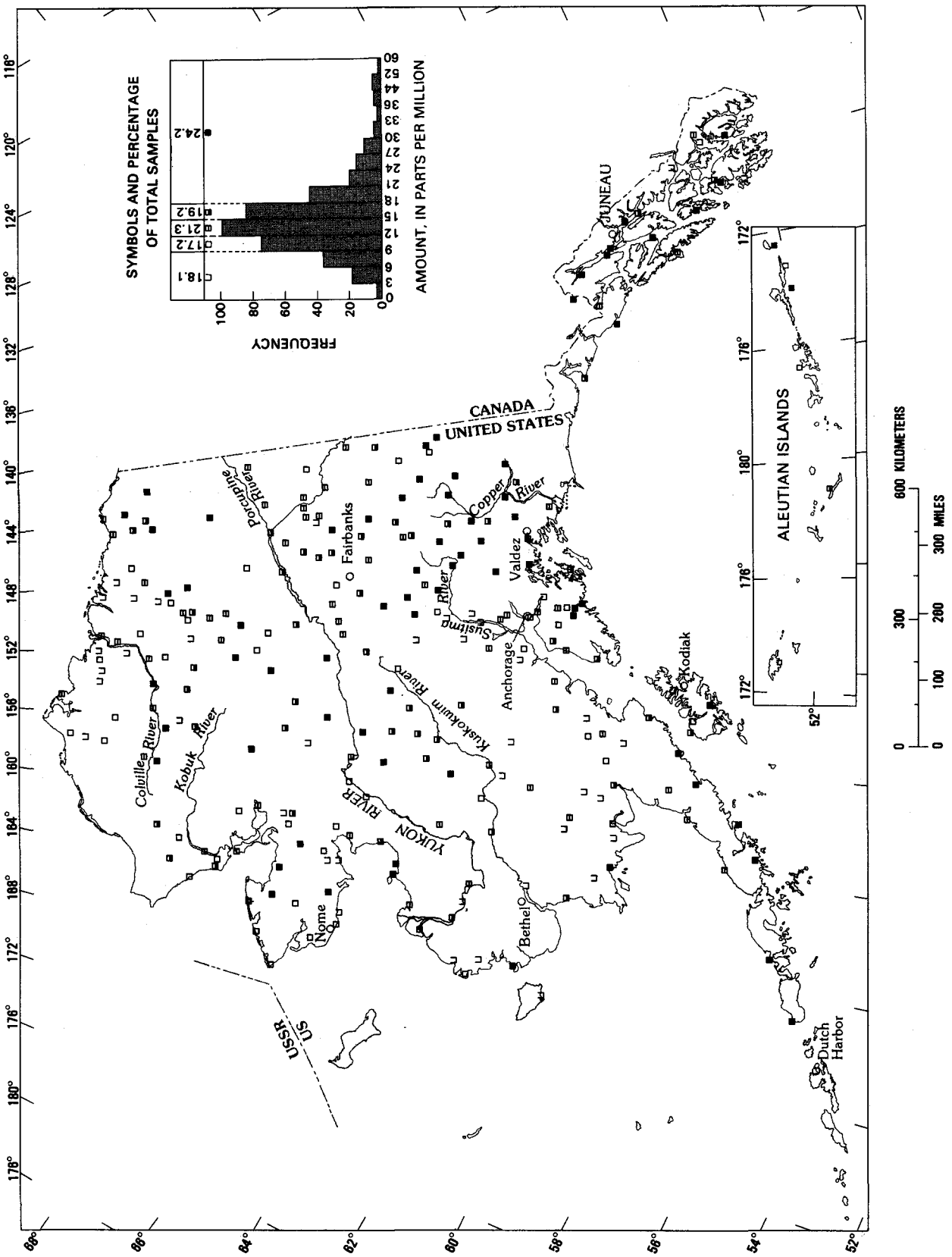


FIGURE 12.—Cobalt content of surficial materials.

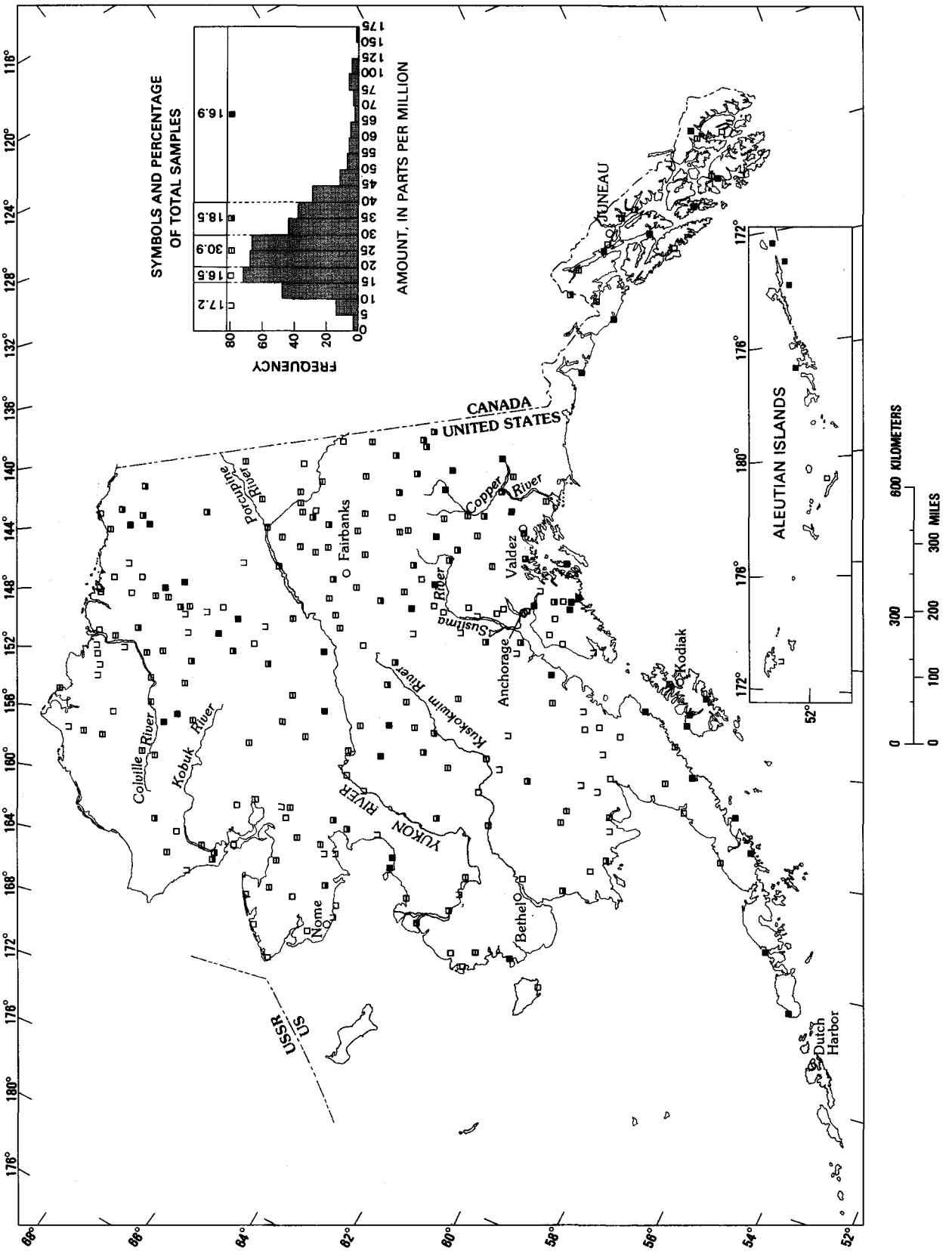


FIGURE 13.—Copper content of surficial materials.

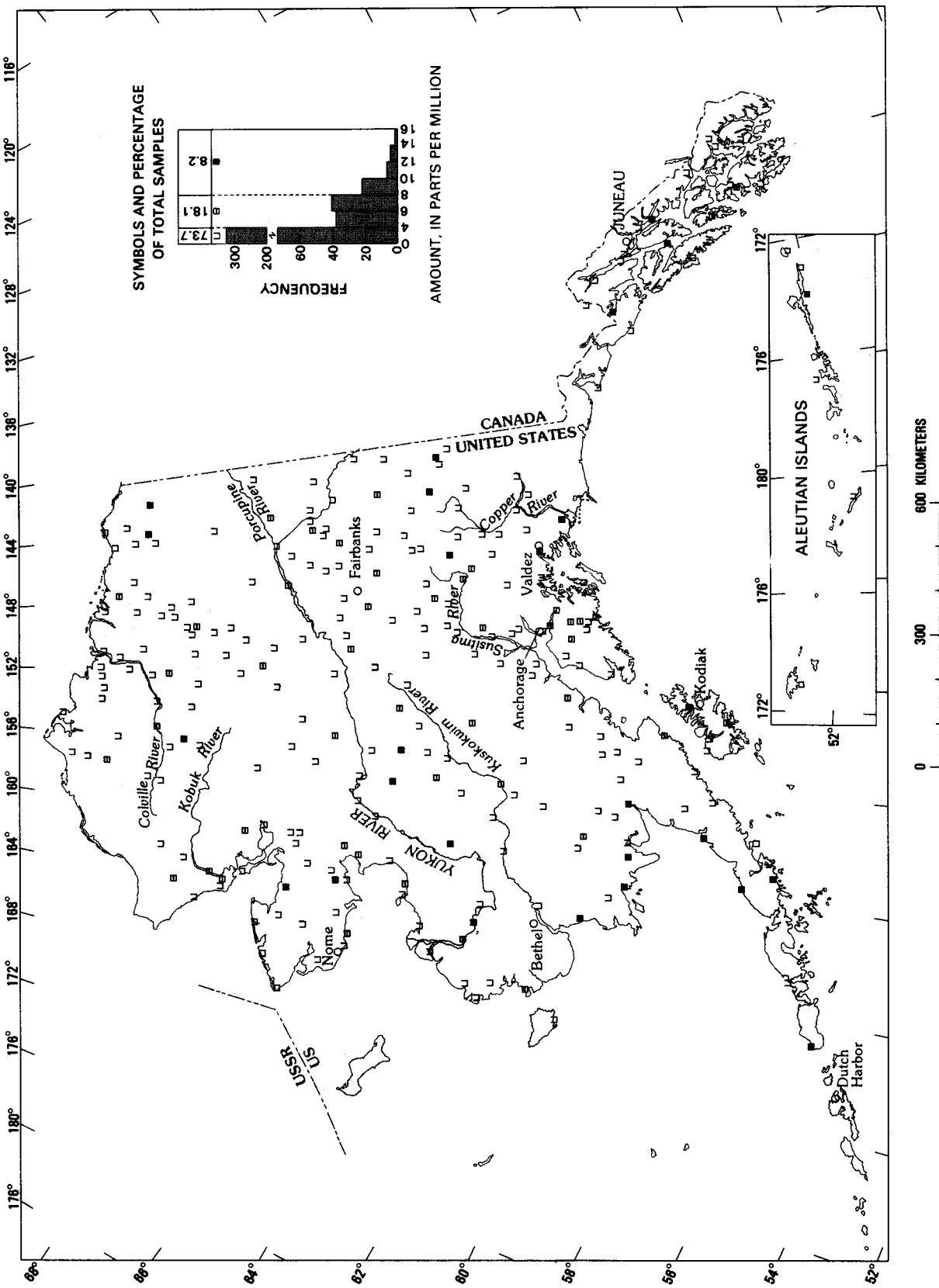


FIGURE 14.—Dysprosium content of surficial materials.

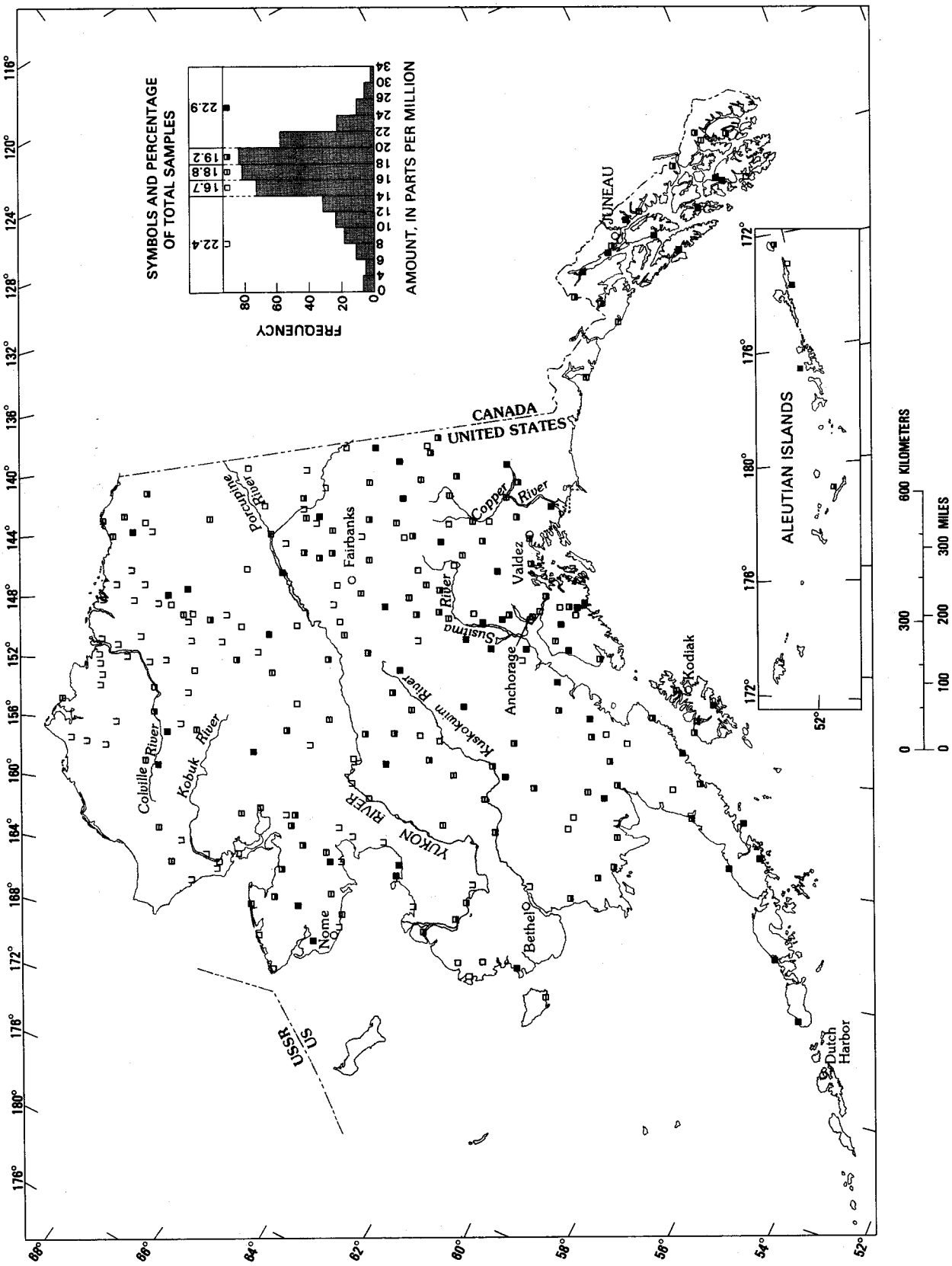


FIGURE 15.—Gallium content of surficial materials.

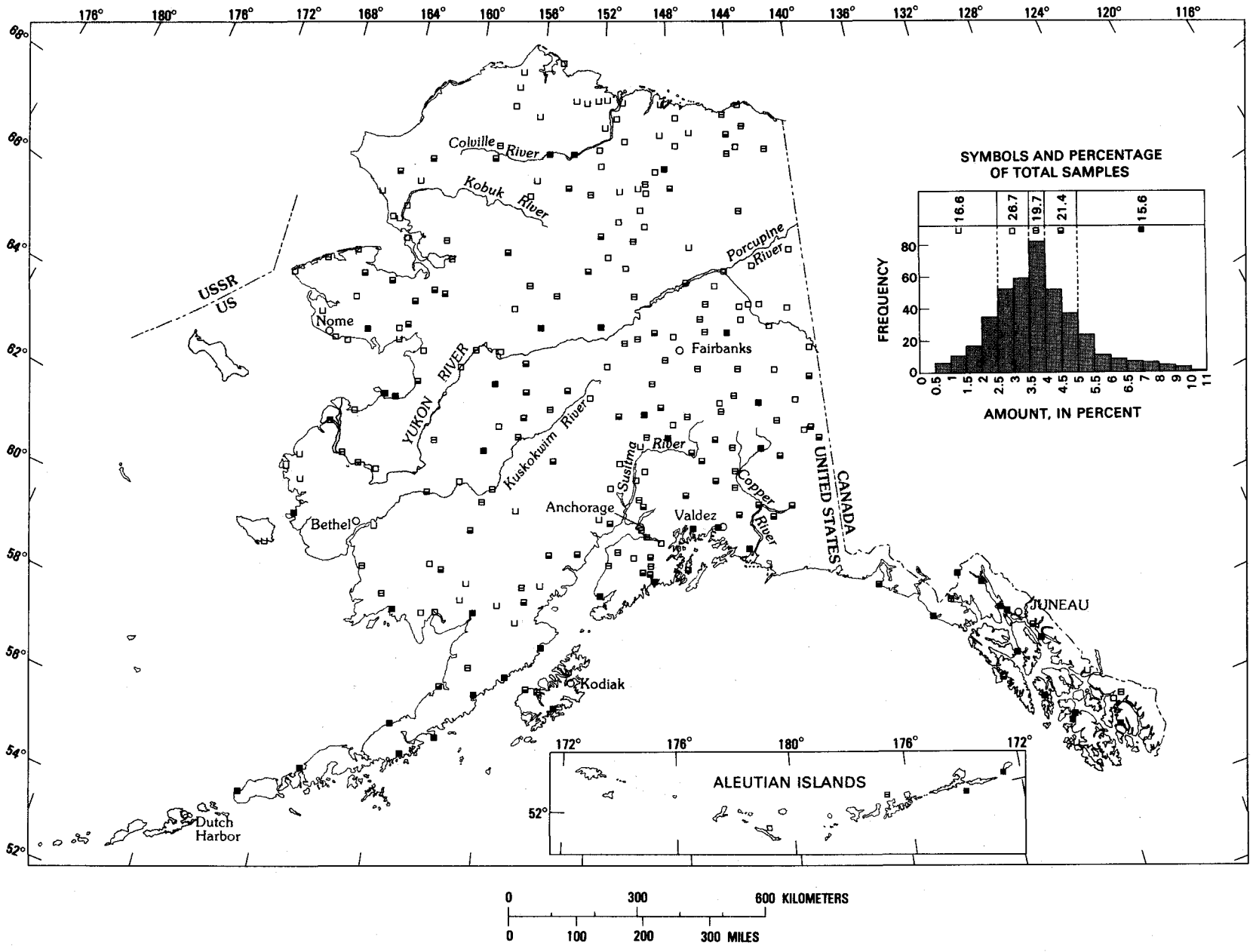


FIGURE 16.—Iron content of surficial materials.

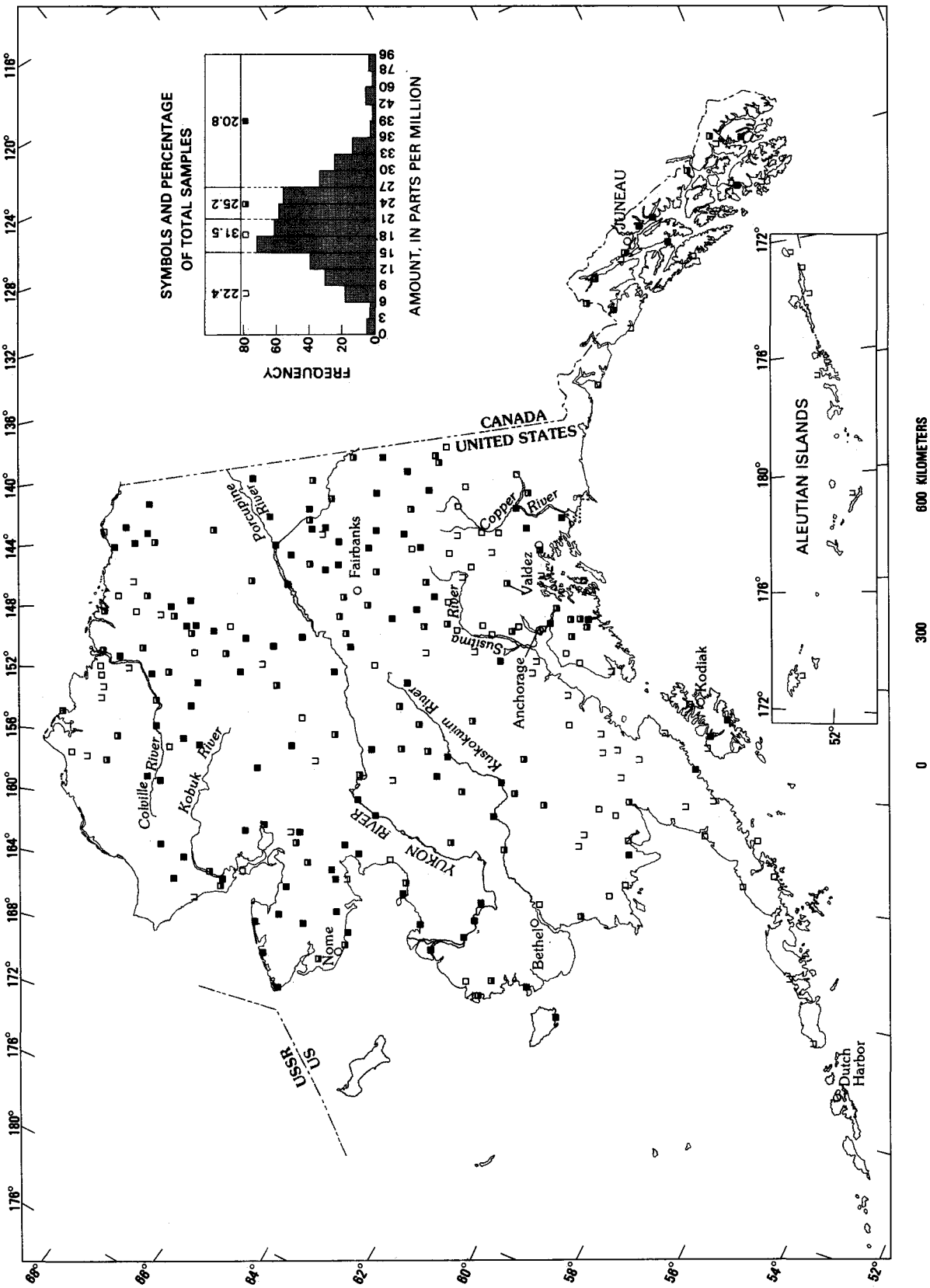


FIGURE 17.—Lanthanum content of surficial materials.

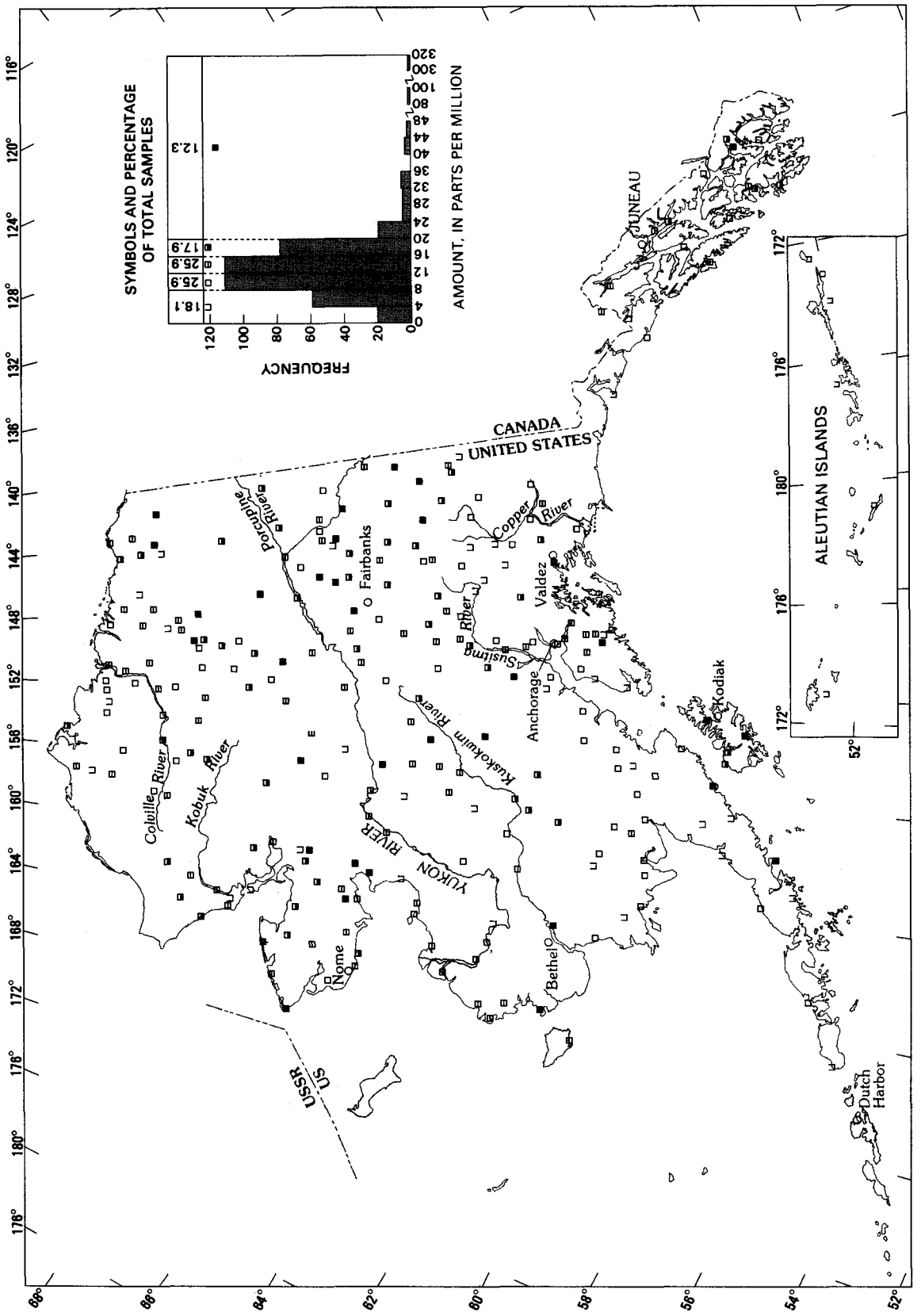


FIGURE 18.—Lead content of surficial materials.

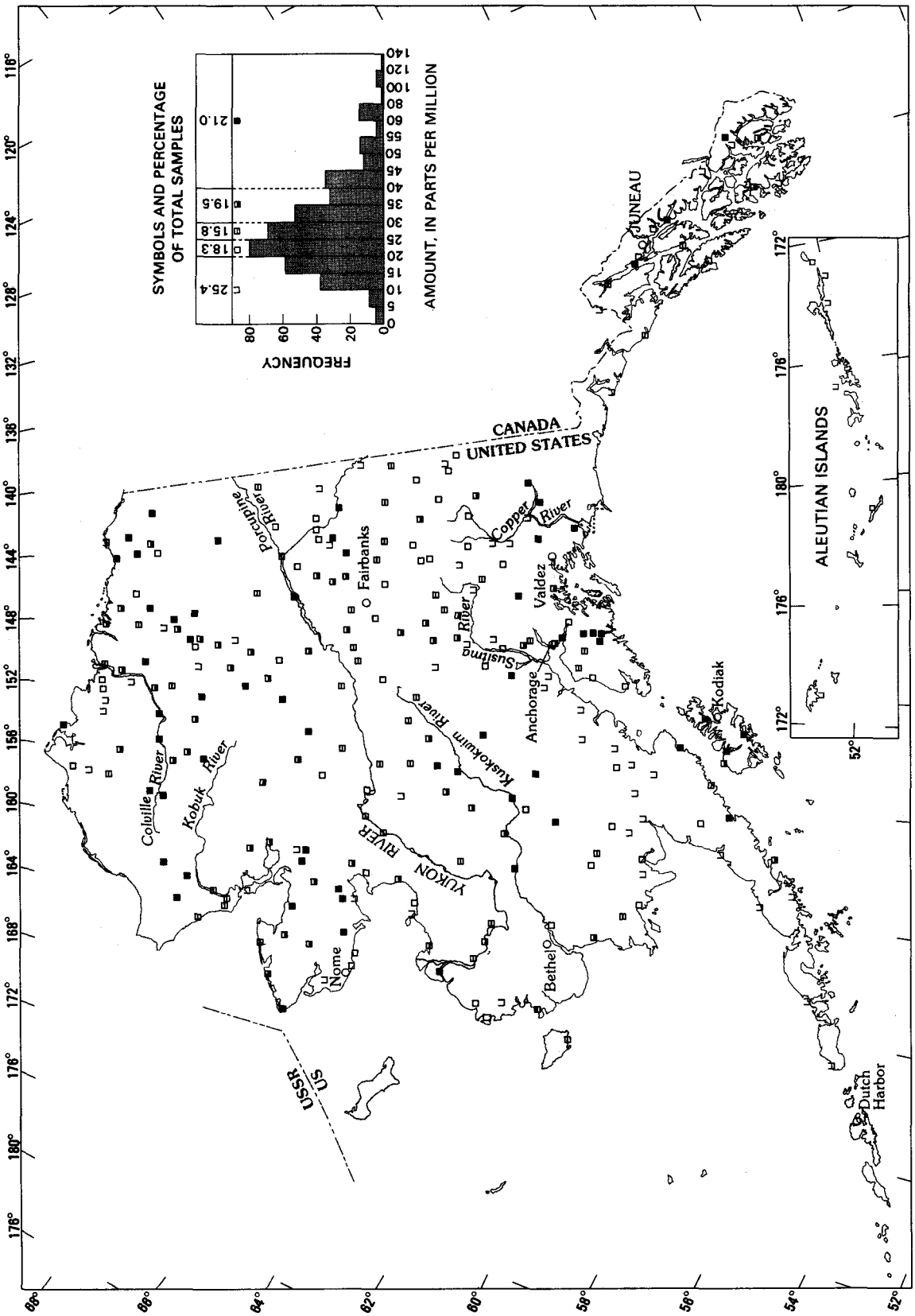


FIGURE 19.—Lithium content of surficial materials.

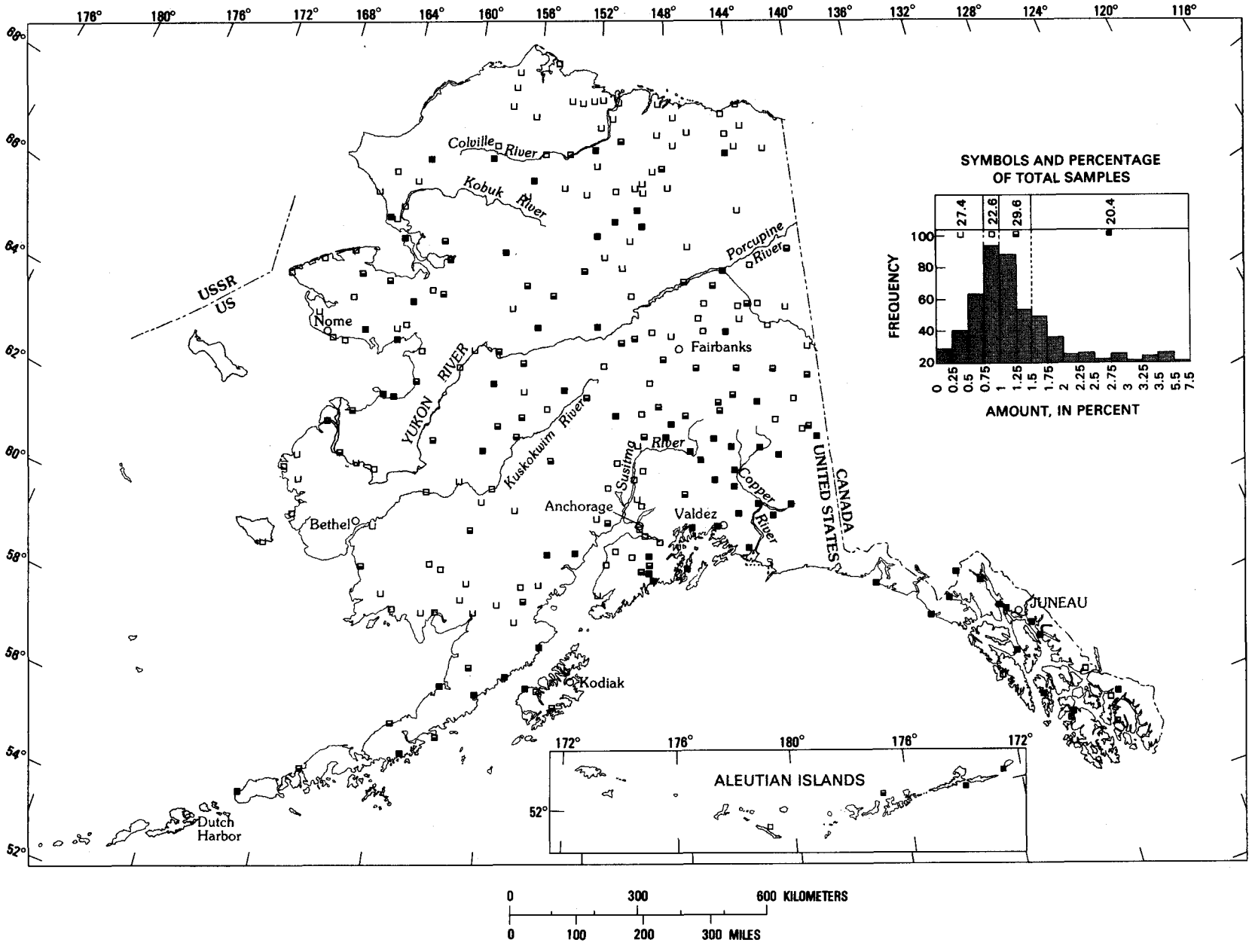


FIGURE 20.—Magnesium content of surficial materials.

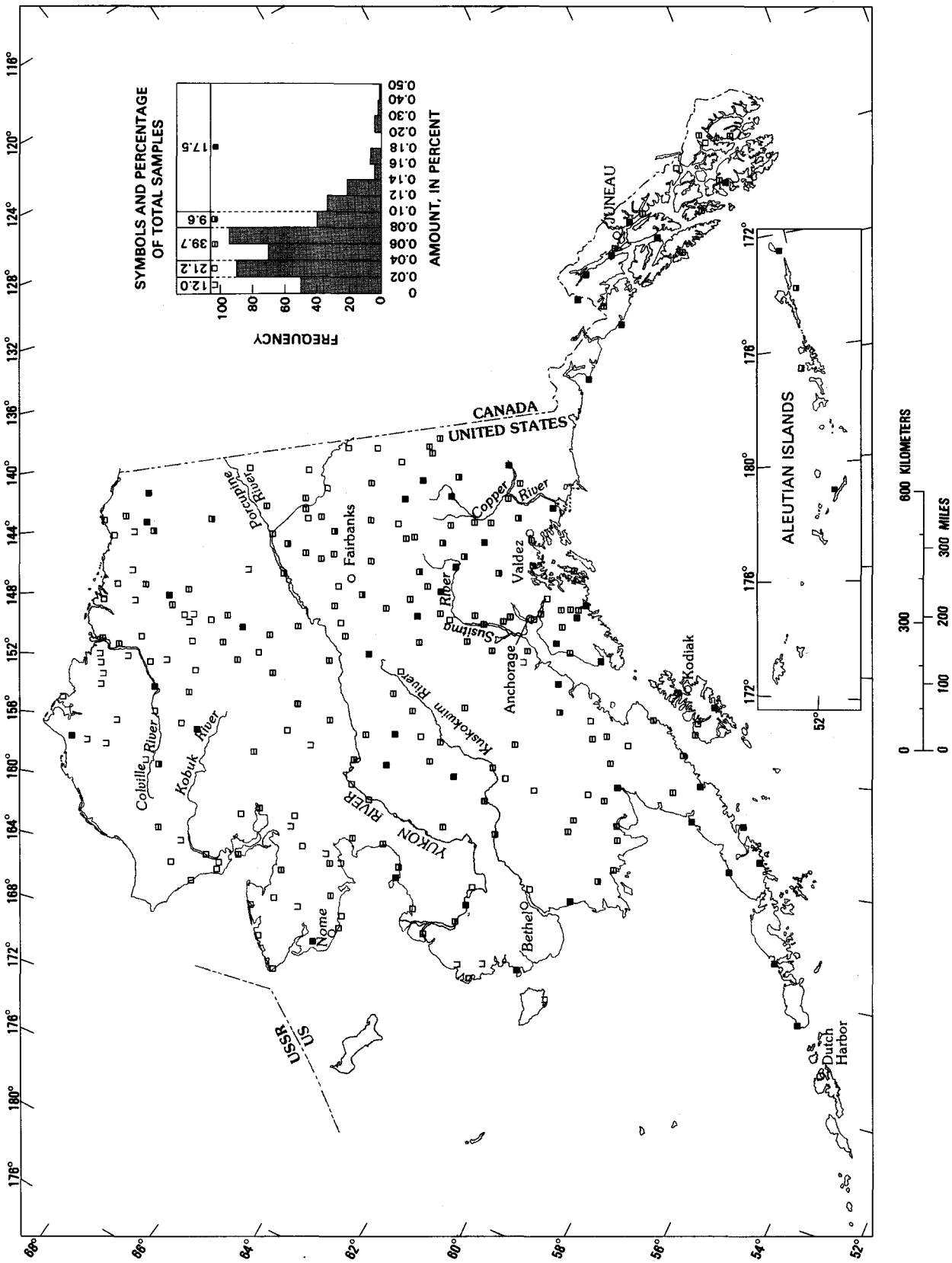


FIGURE 21.—Manganese content of surficial materials.

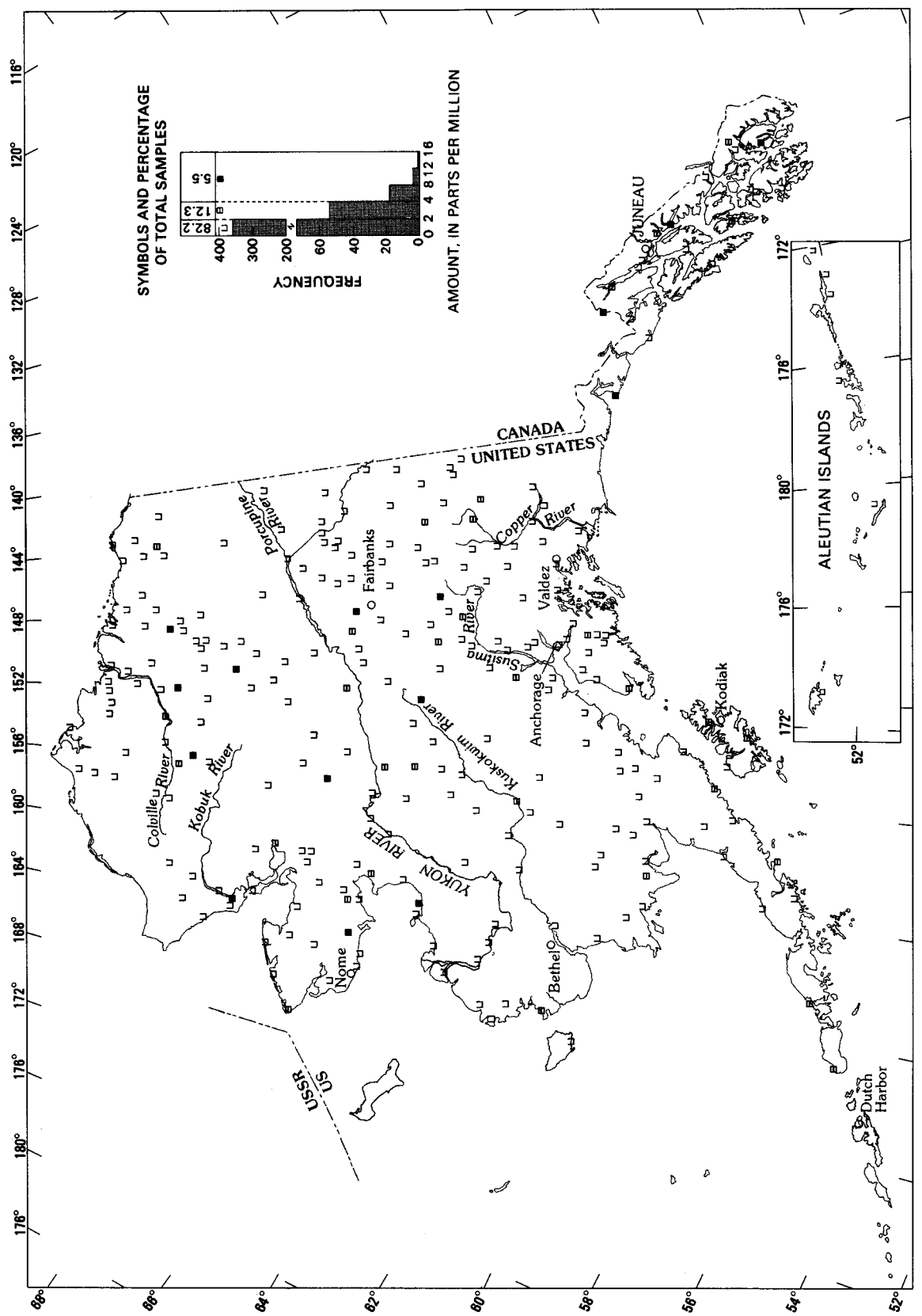


FIGURE 22.—Molybdenum content of surficial materials.

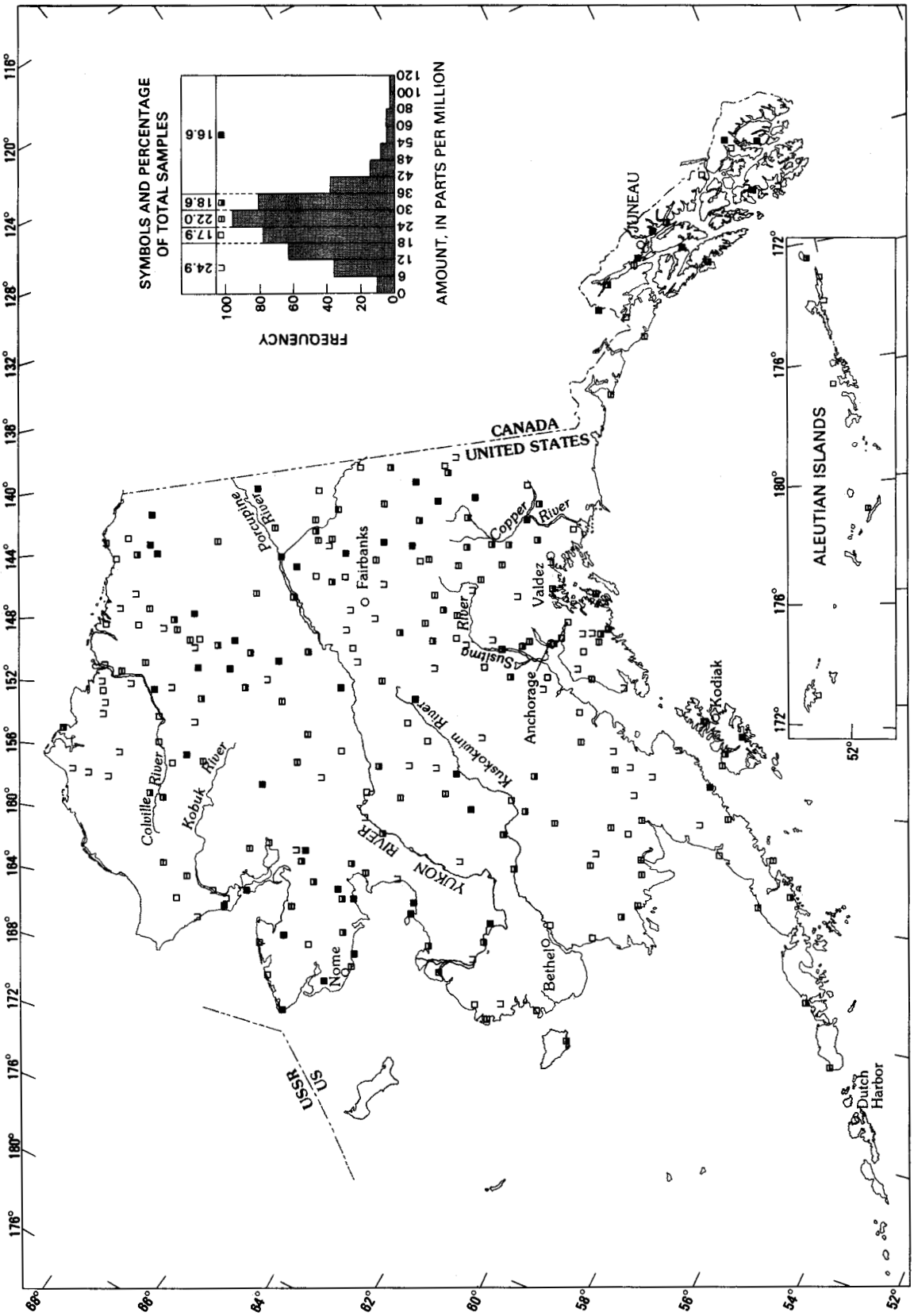


FIGURE 23.—Neodymium content of surficial materials.

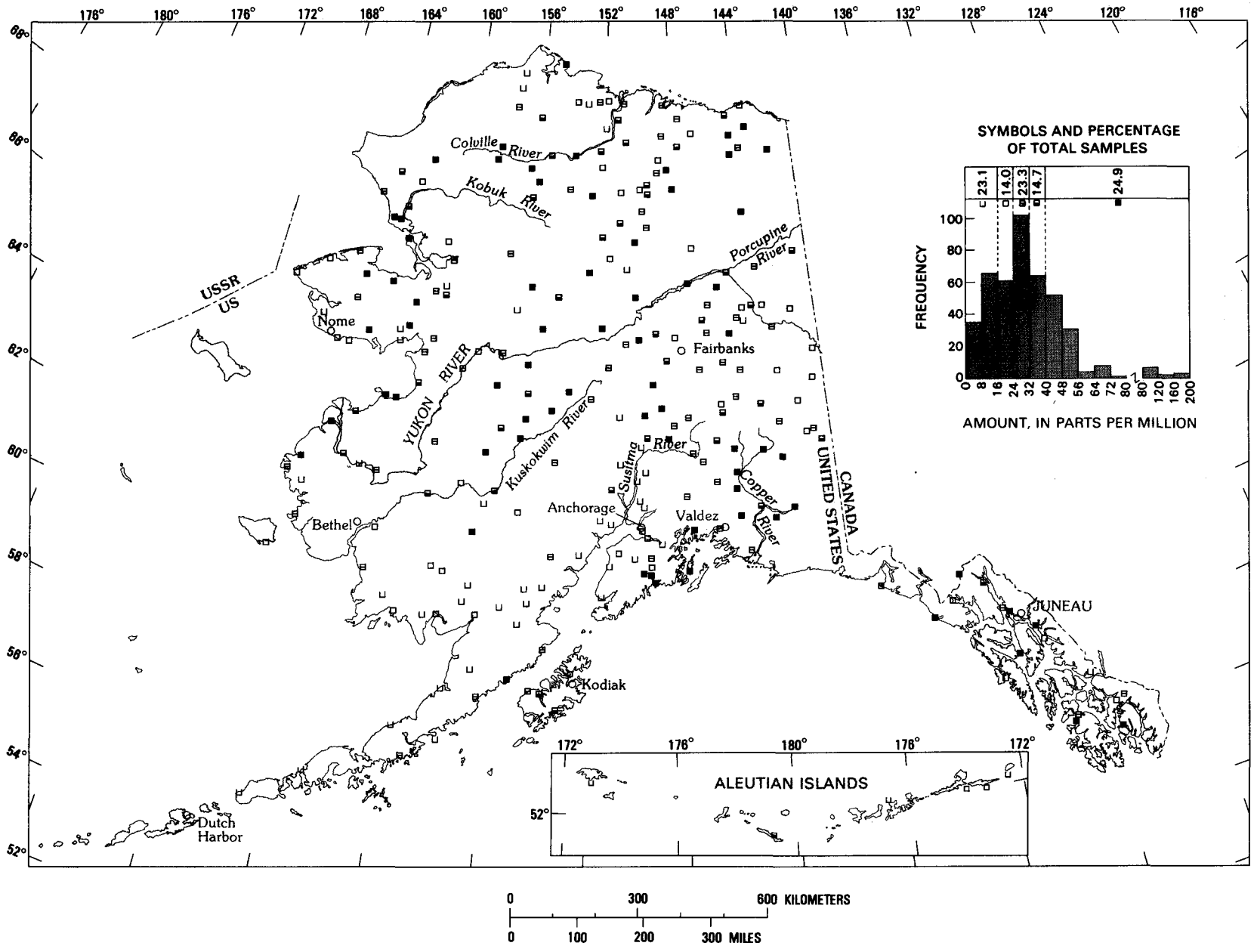


FIGURE 24.—Nickel content of surficial materials.

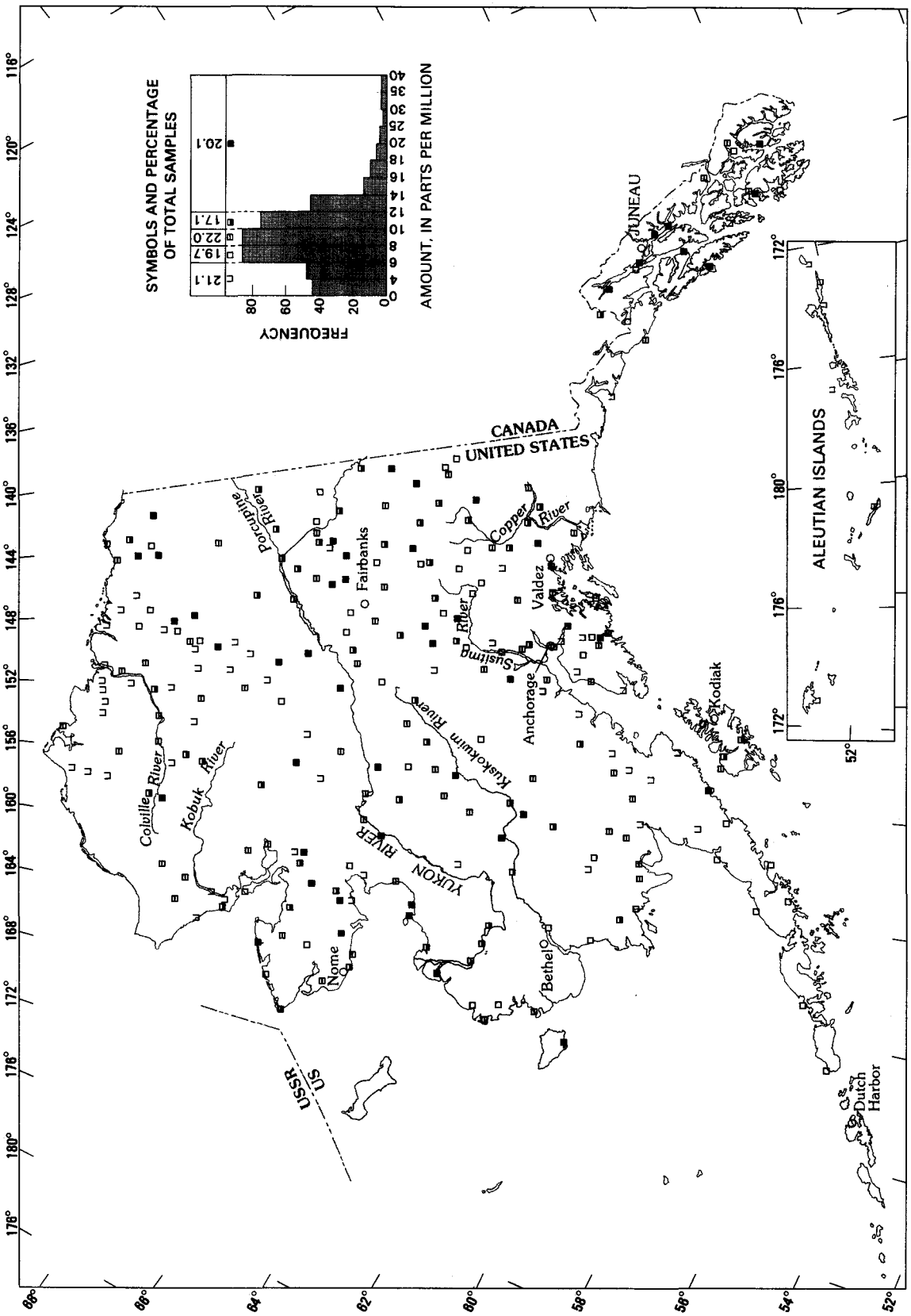


FIGURE 25.—Niobium content of surficial materials.

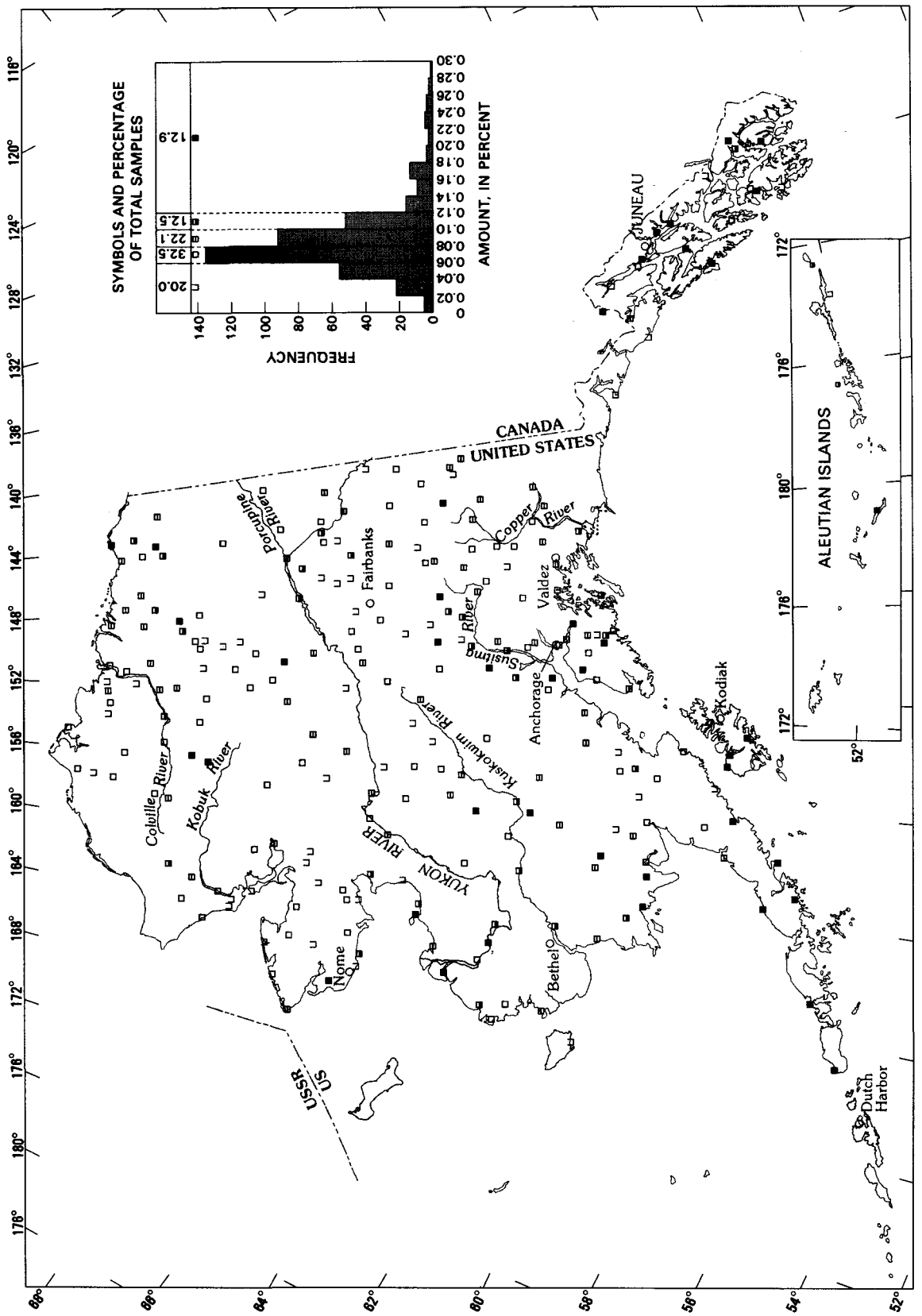


FIGURE 26.—Phosphorus content of surficial materials.

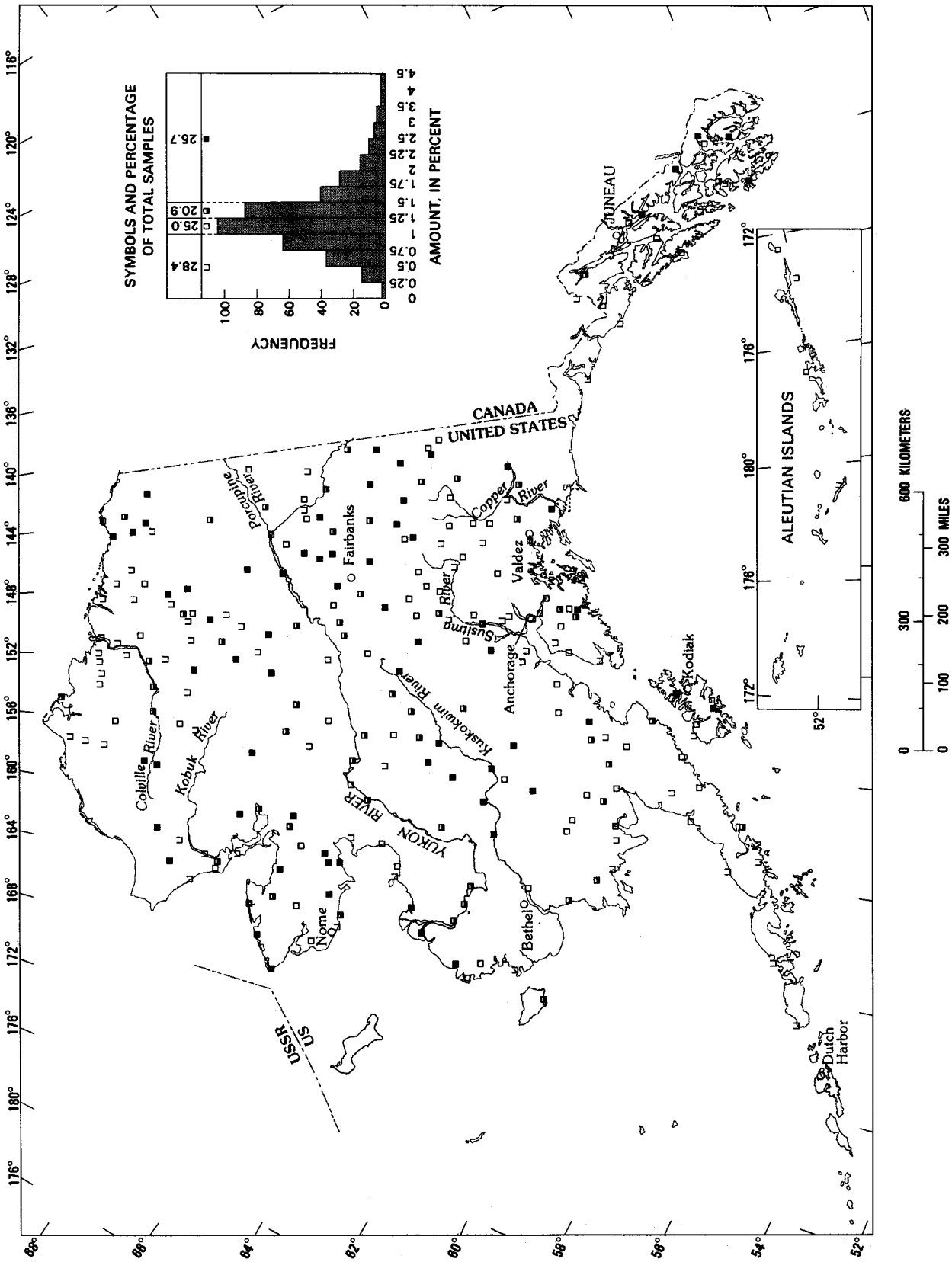


FIGURE 27.—Potassium content of surficial materials.

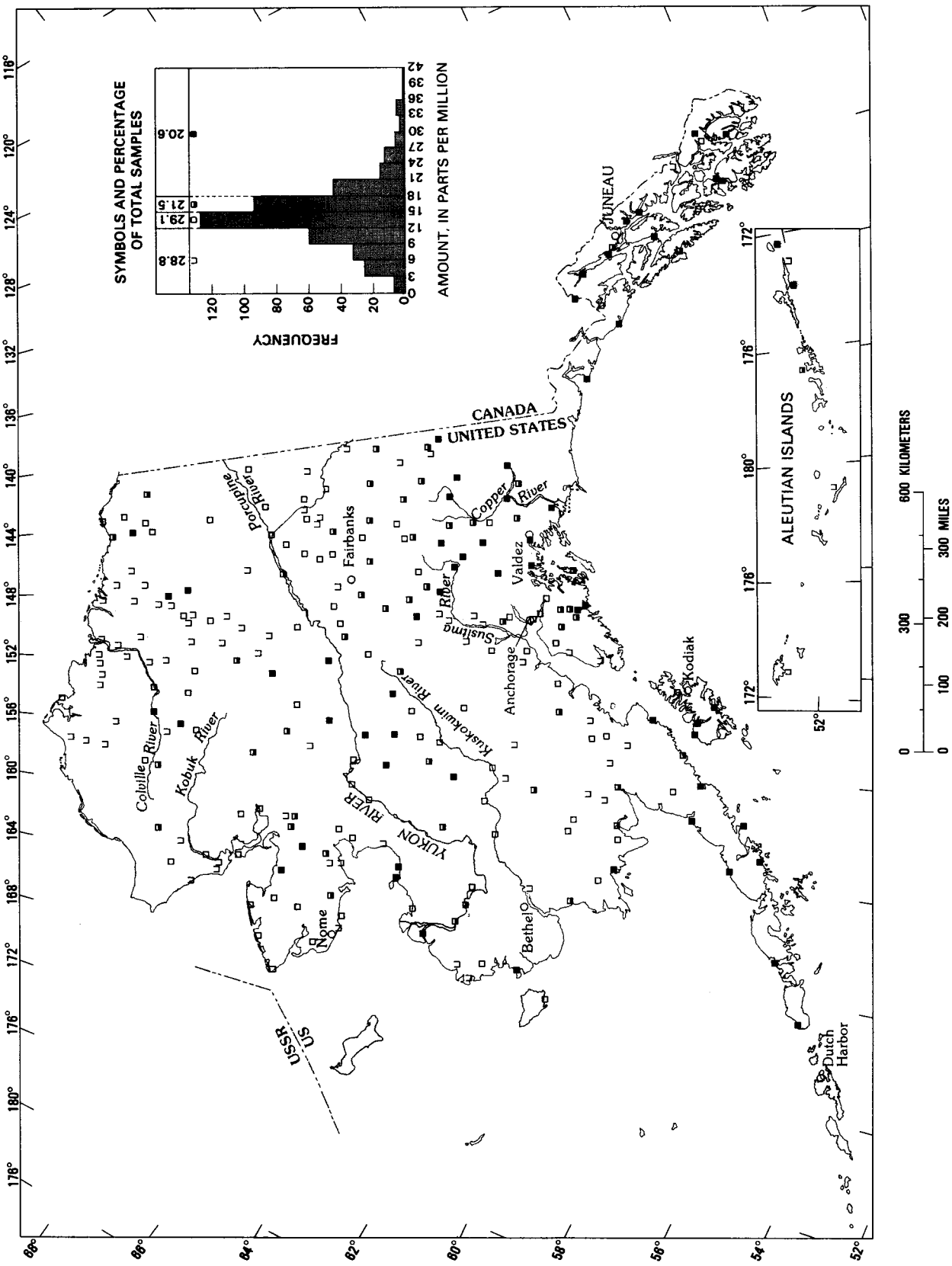


FIGURE 28.—Scandium content of surficial materials.

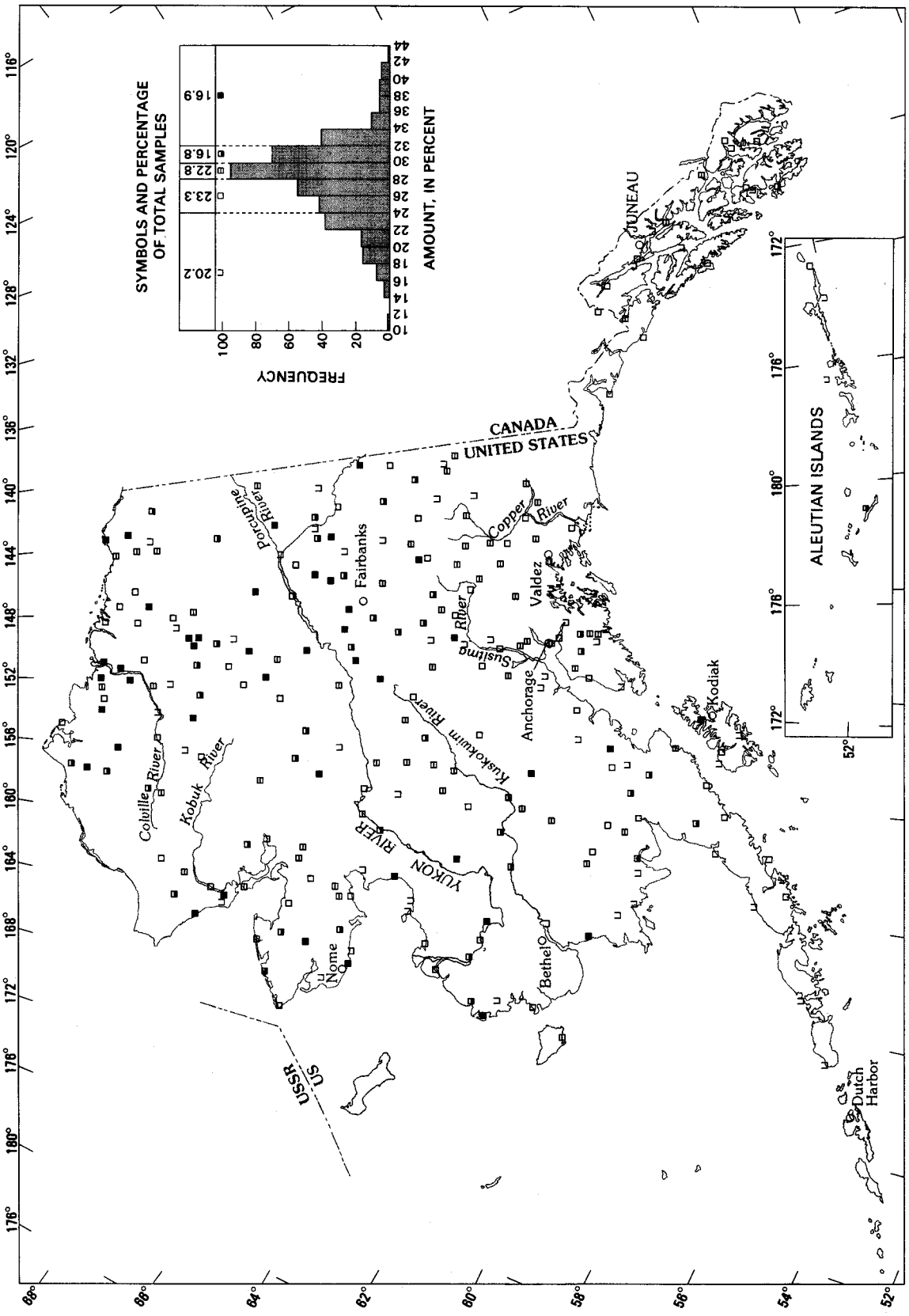


FIGURE 29.—Silicon content of surficial materials.

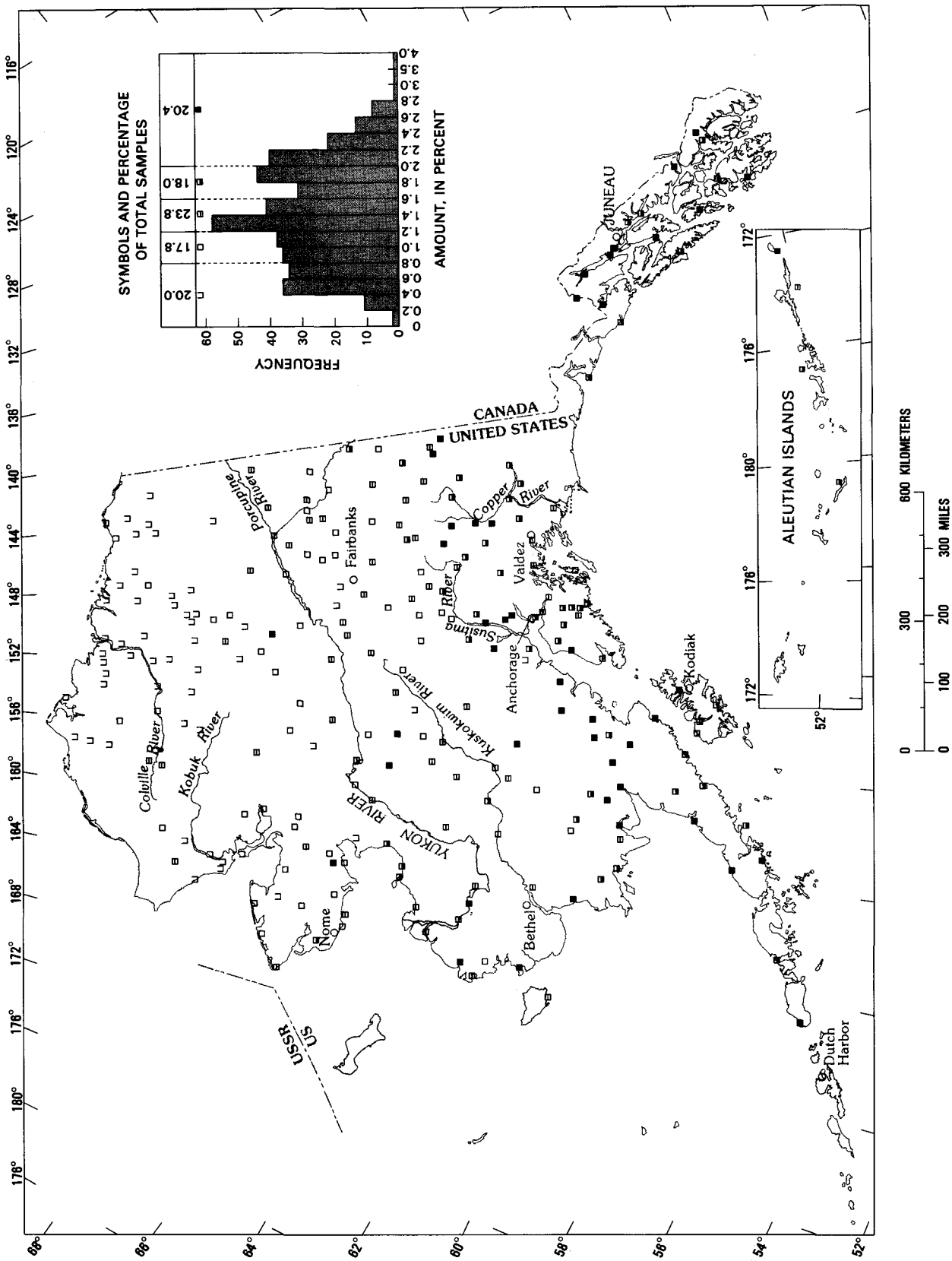


FIGURE 30.—Sodium content of surficial materials.

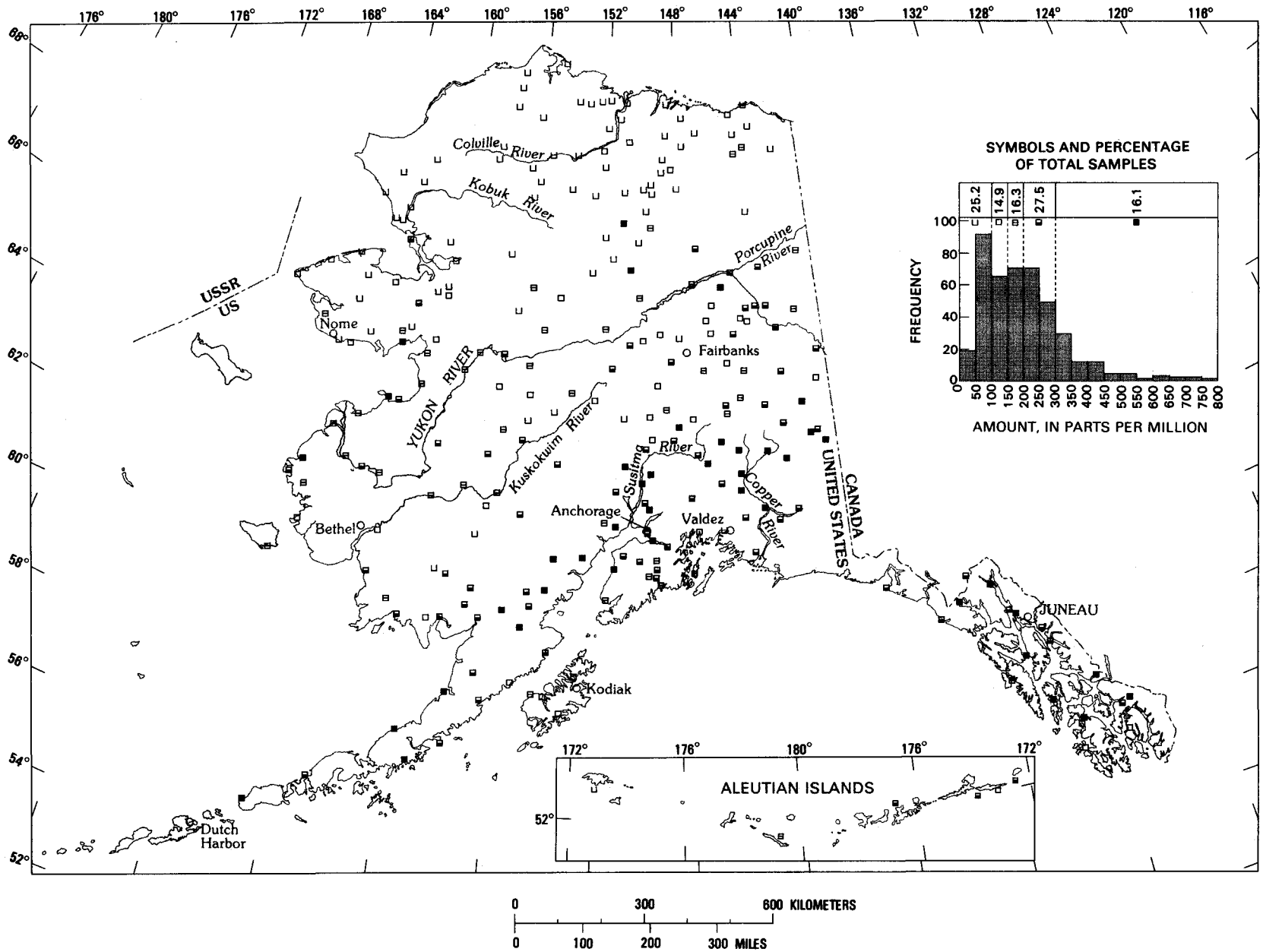


FIGURE 31.—Strontium content of surficial materials.

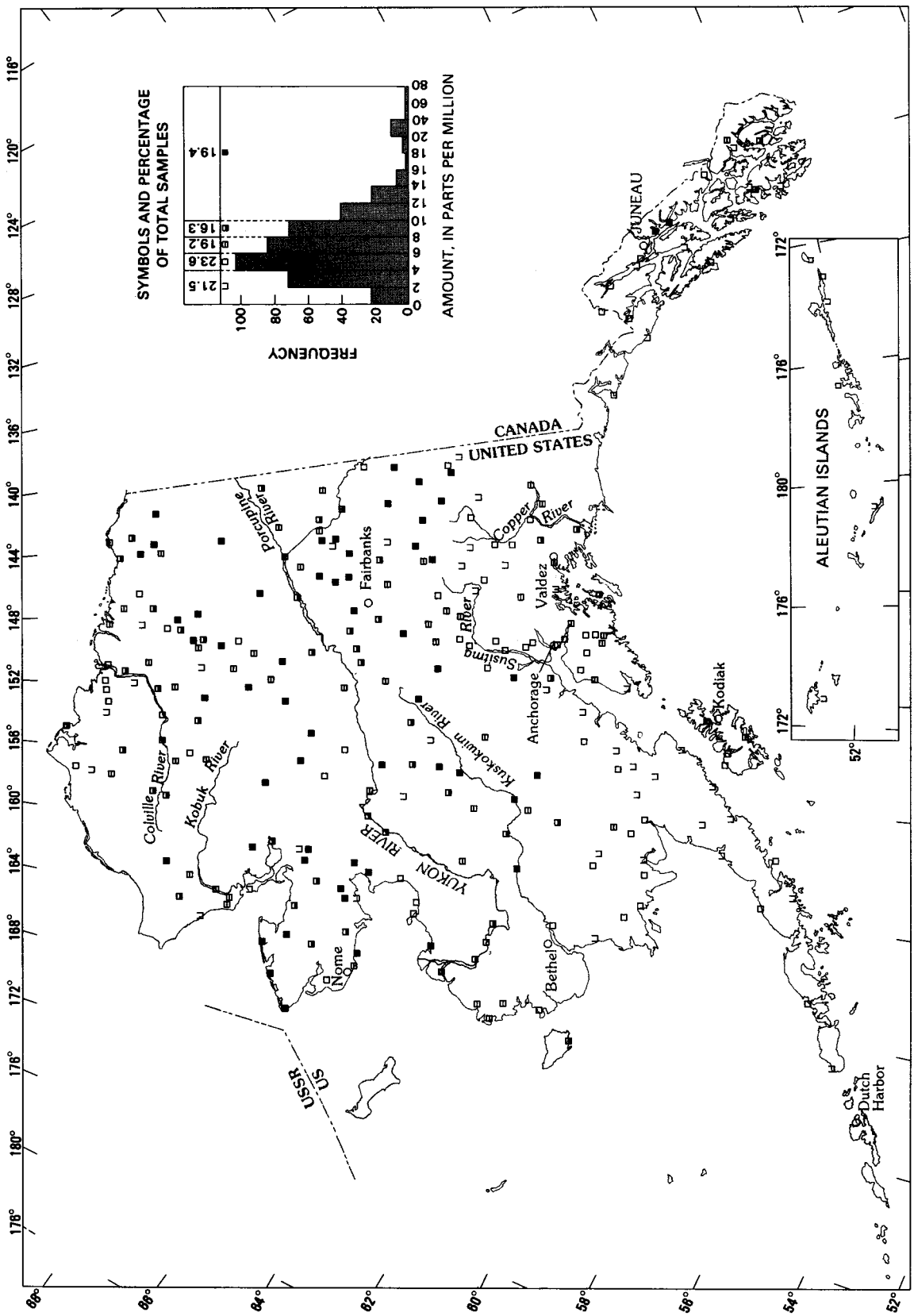


FIGURE 32.—Thorium content of surficial materials.

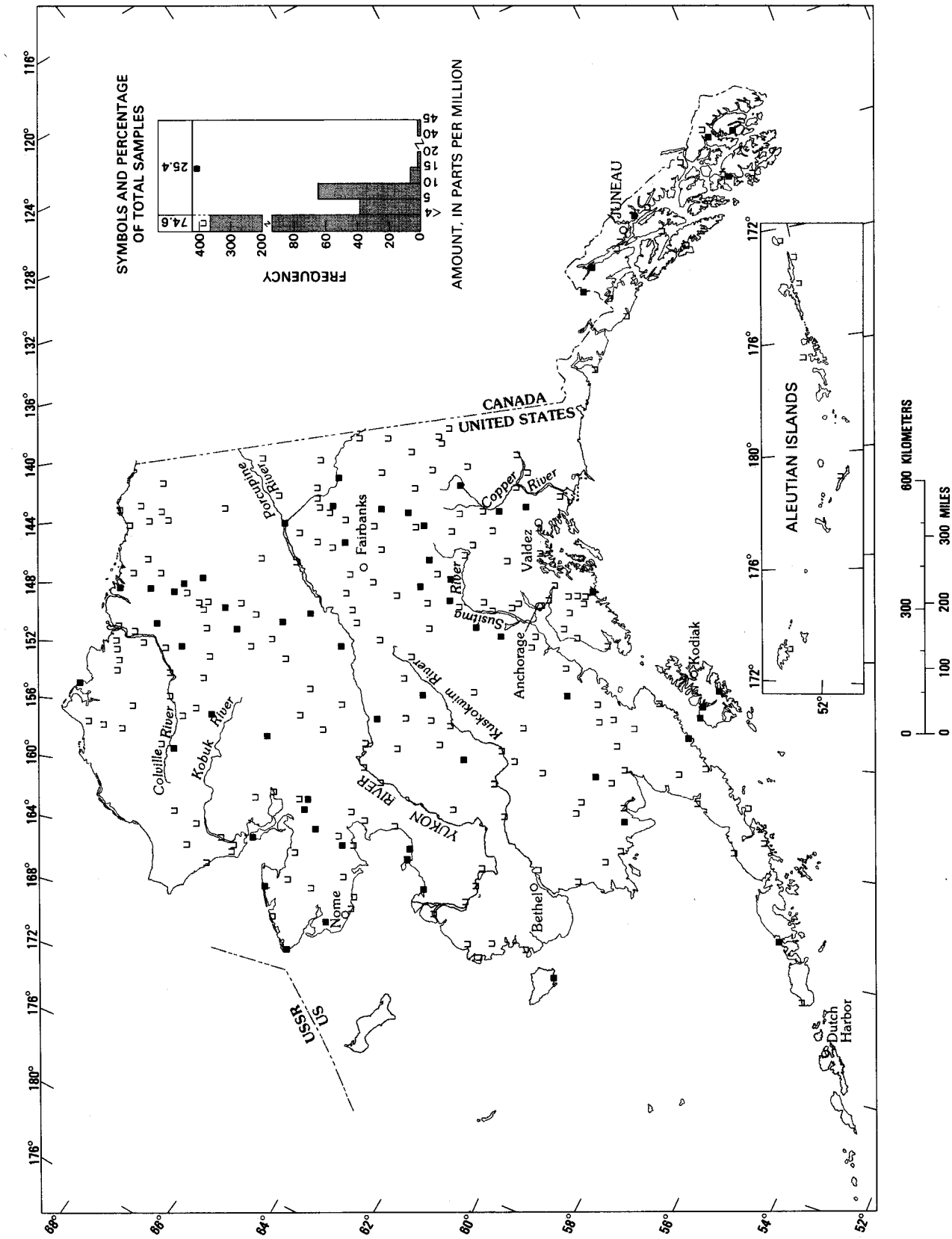


FIGURE 33.—Tin content of surficial materials.

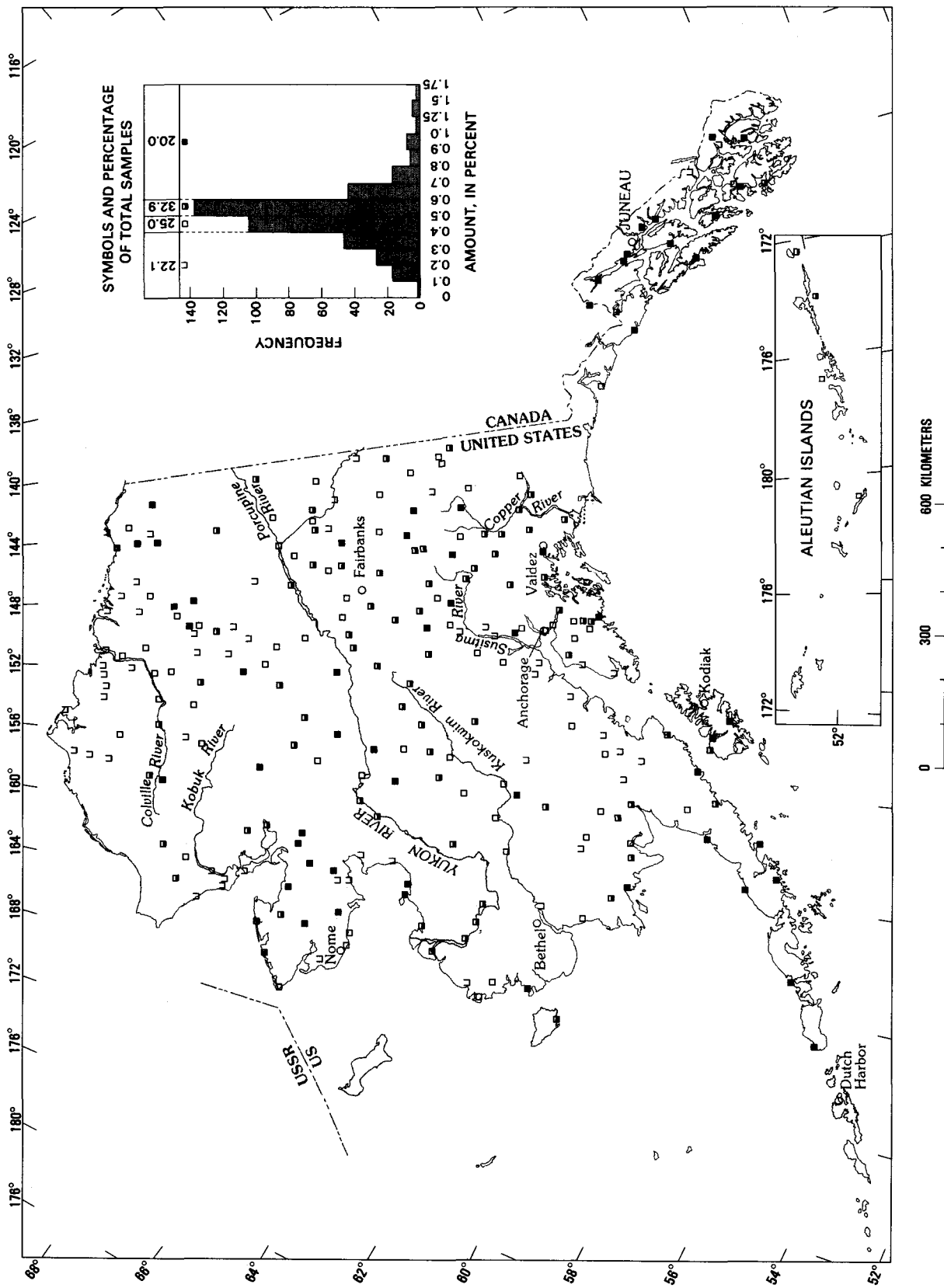


FIGURE 34.—Titanium content of surficial materials.

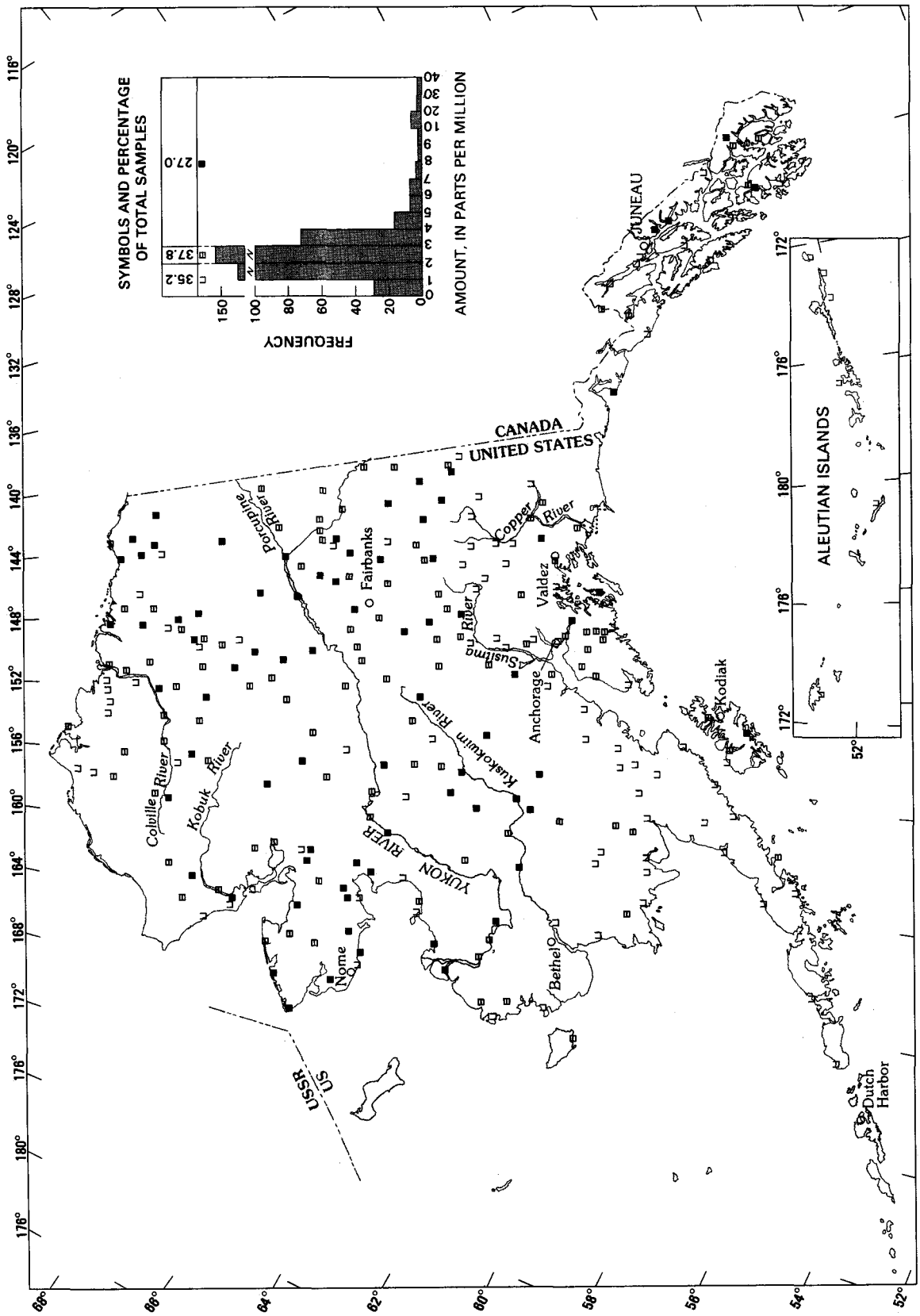


FIGURE 35.—Uranium content of surficial materials.

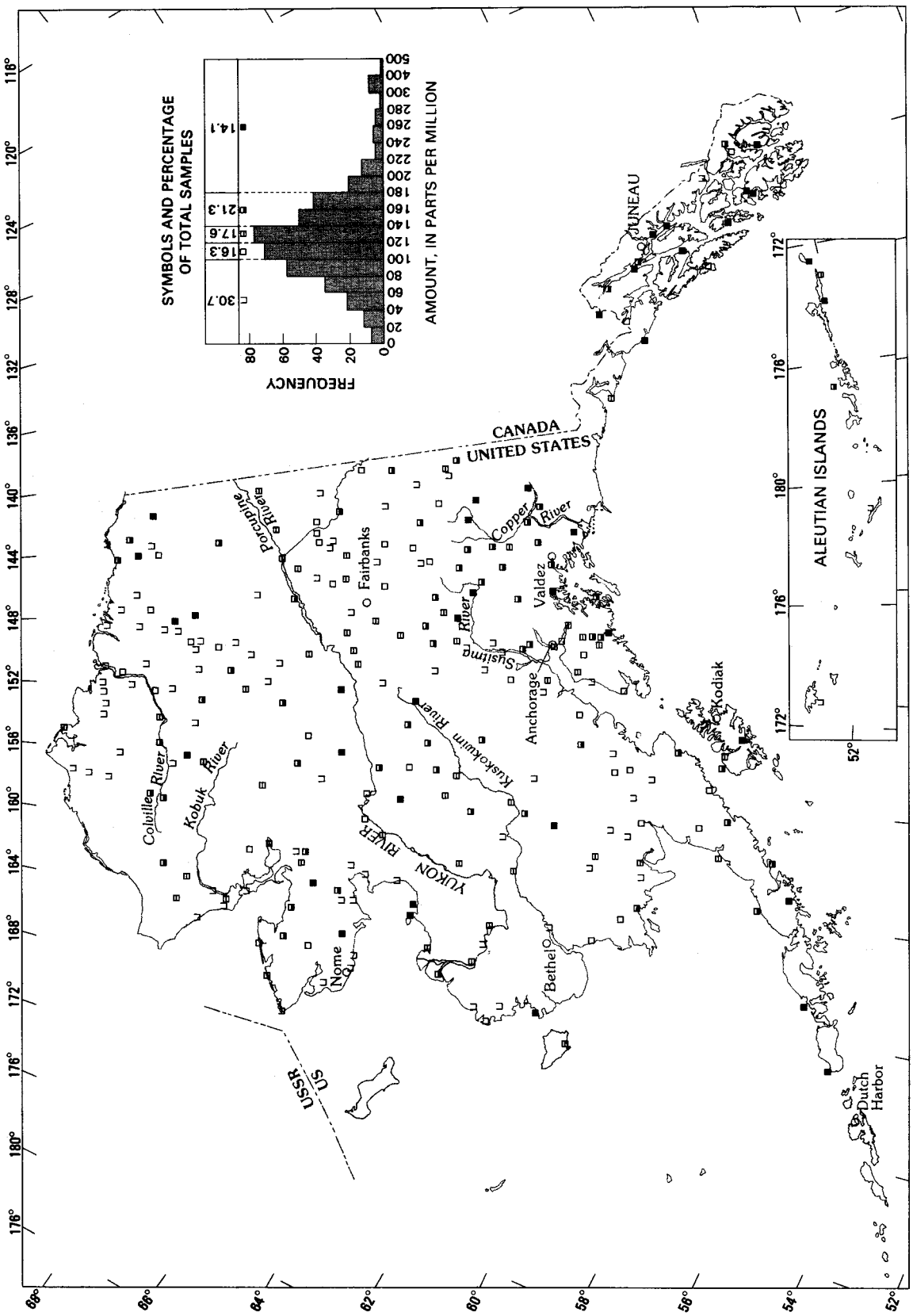


FIGURE 36.—Vanadium content of surficial materials.

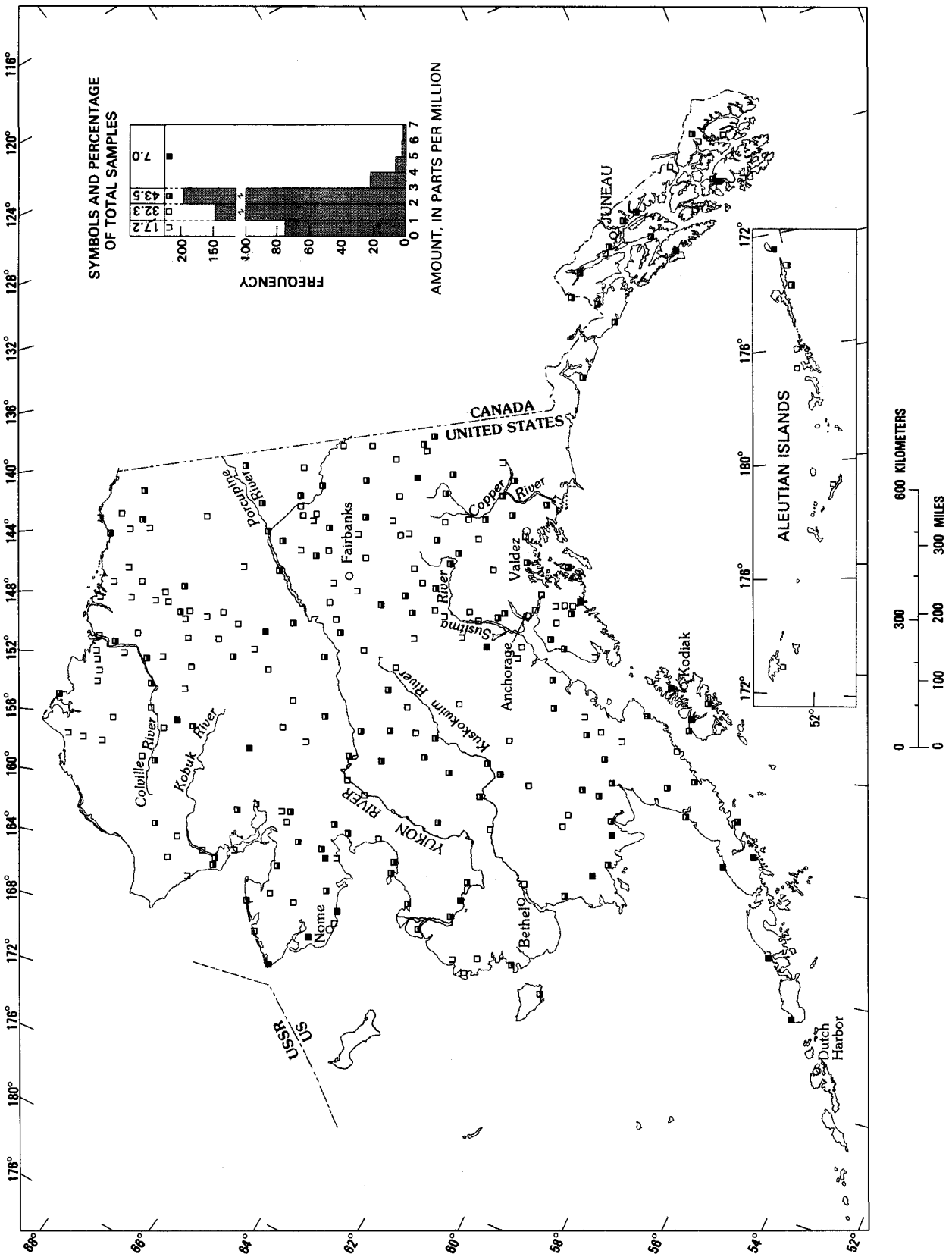


FIGURE 37.—Ytterbium content of surficial materials.

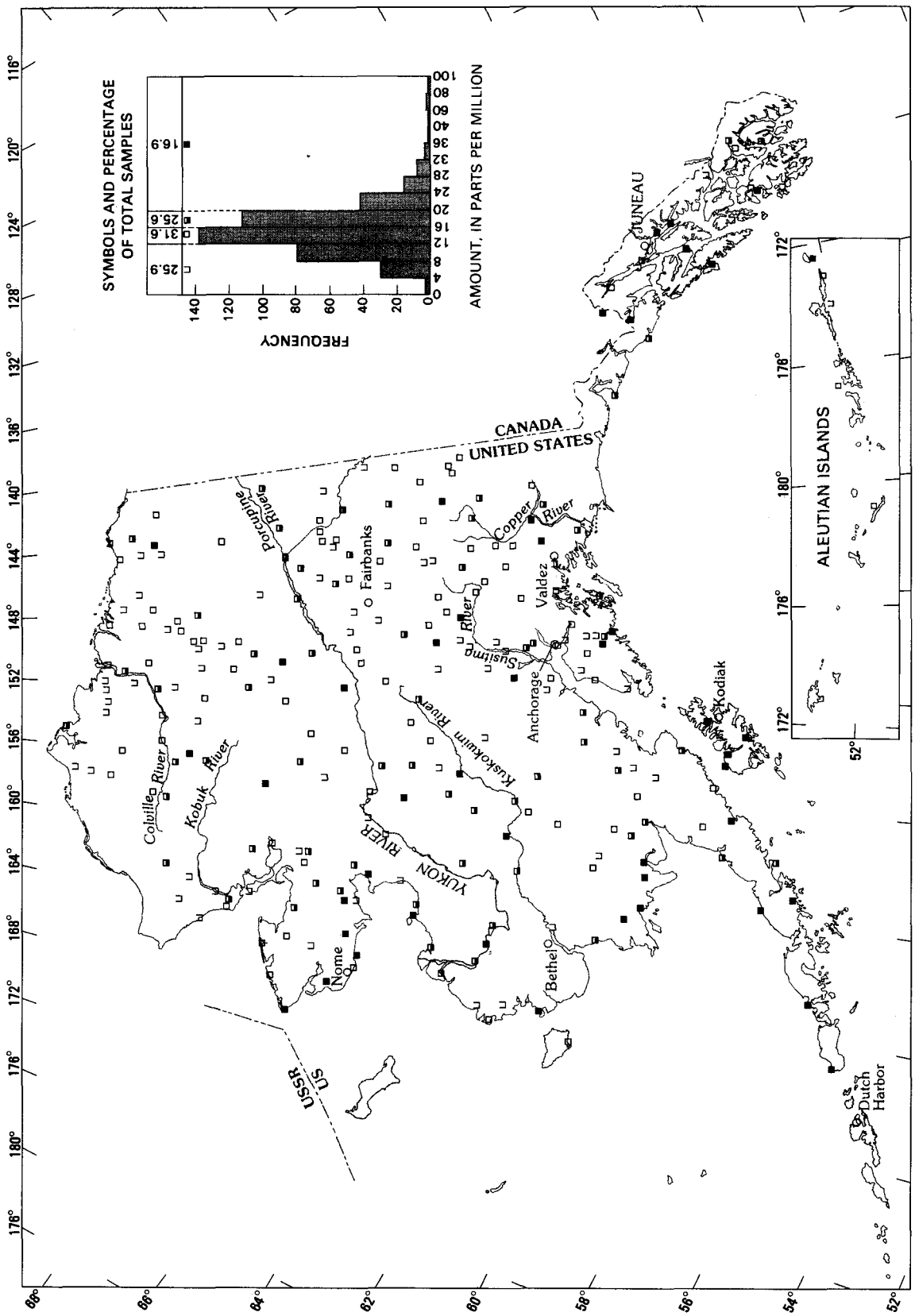


FIGURE 38.—Yttrium content of surficial materials.

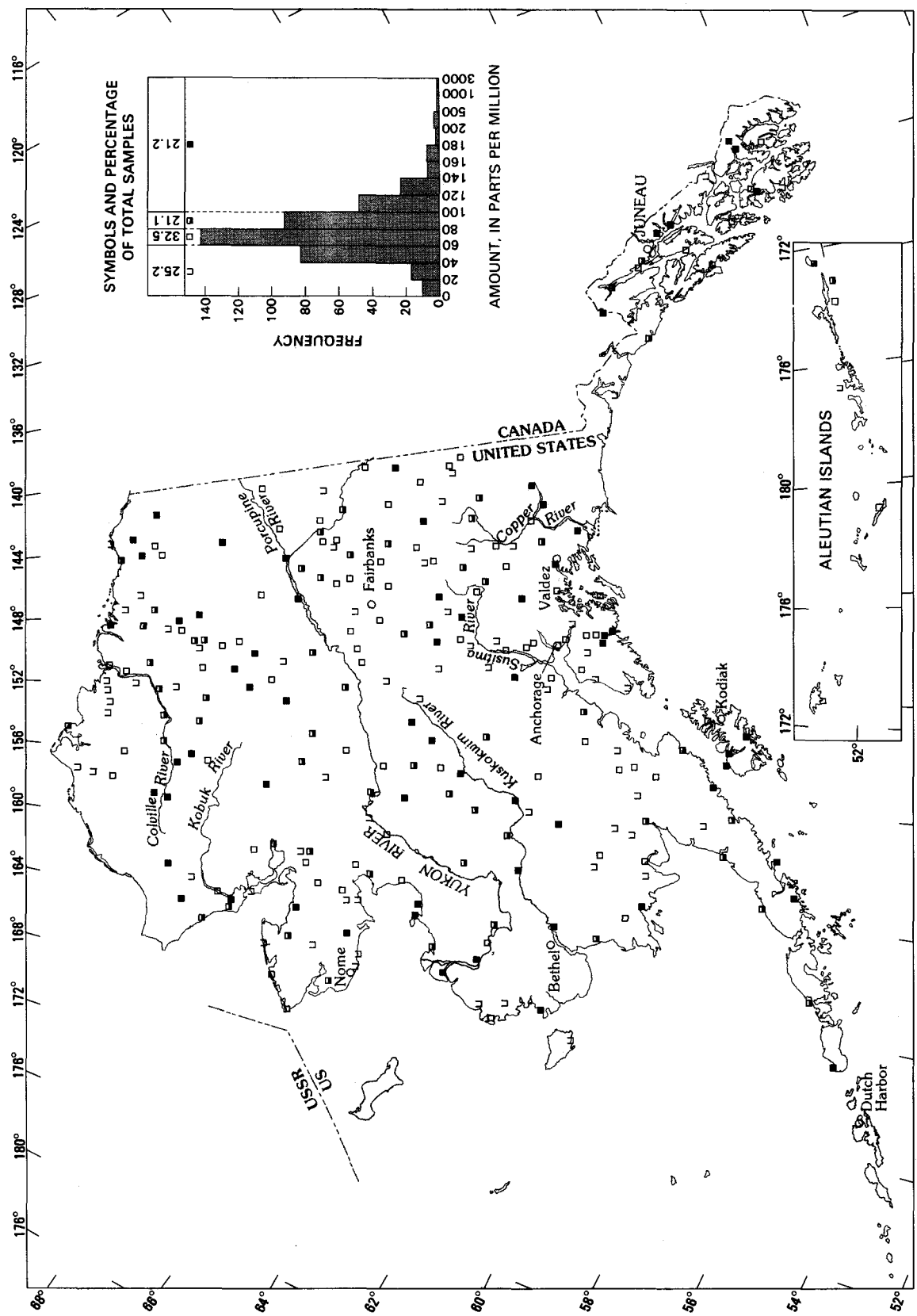


FIGURE 39.—Zinc content of surficial materials.

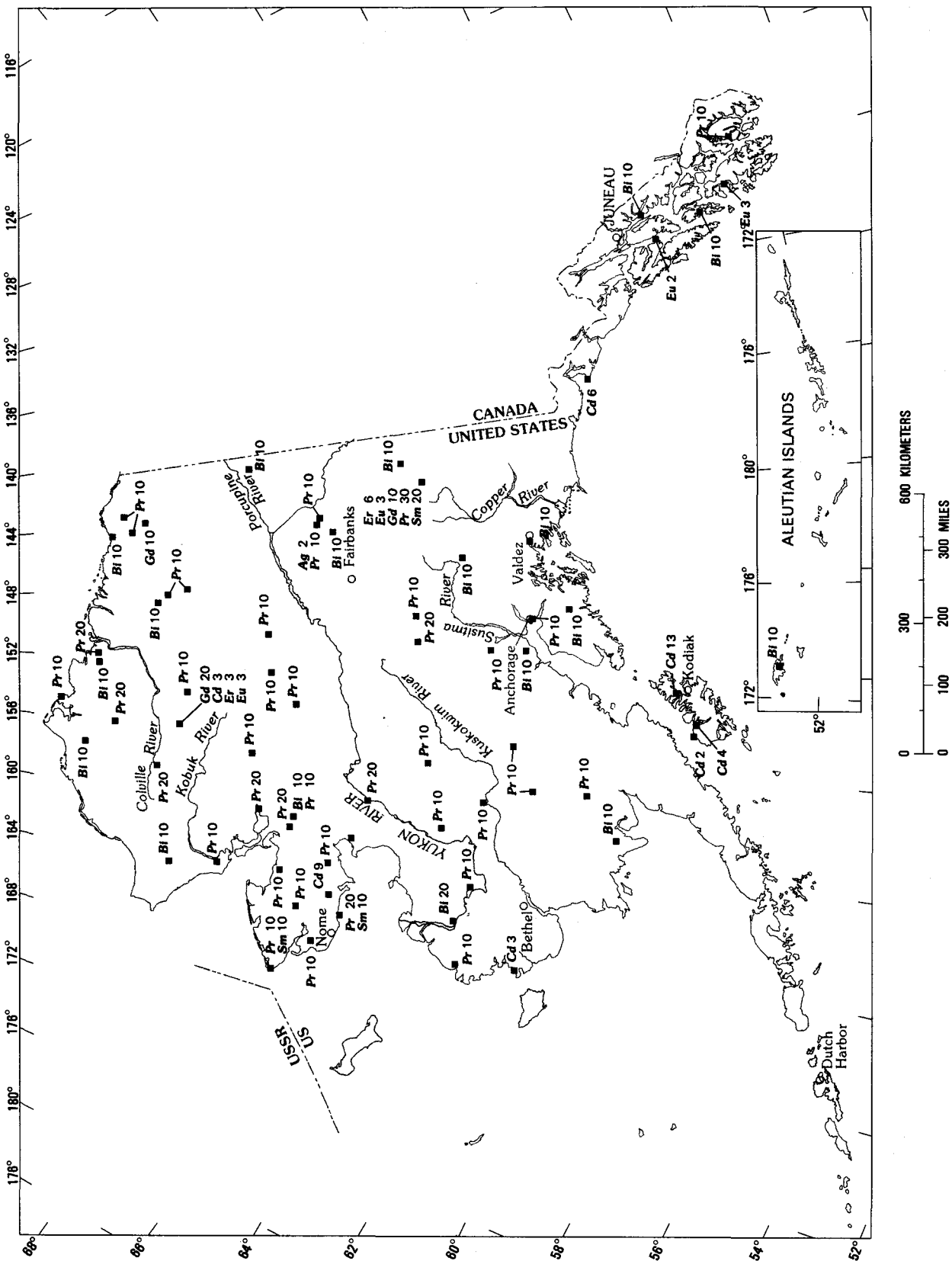


FIGURE 40.—Content, in parts per million (μg/g), of bismuth, cadmium, erbium, europium, gadolinium, praseodymium, samarium, and silver in surficial materials from Alaska. Boxes represent sampling sites.

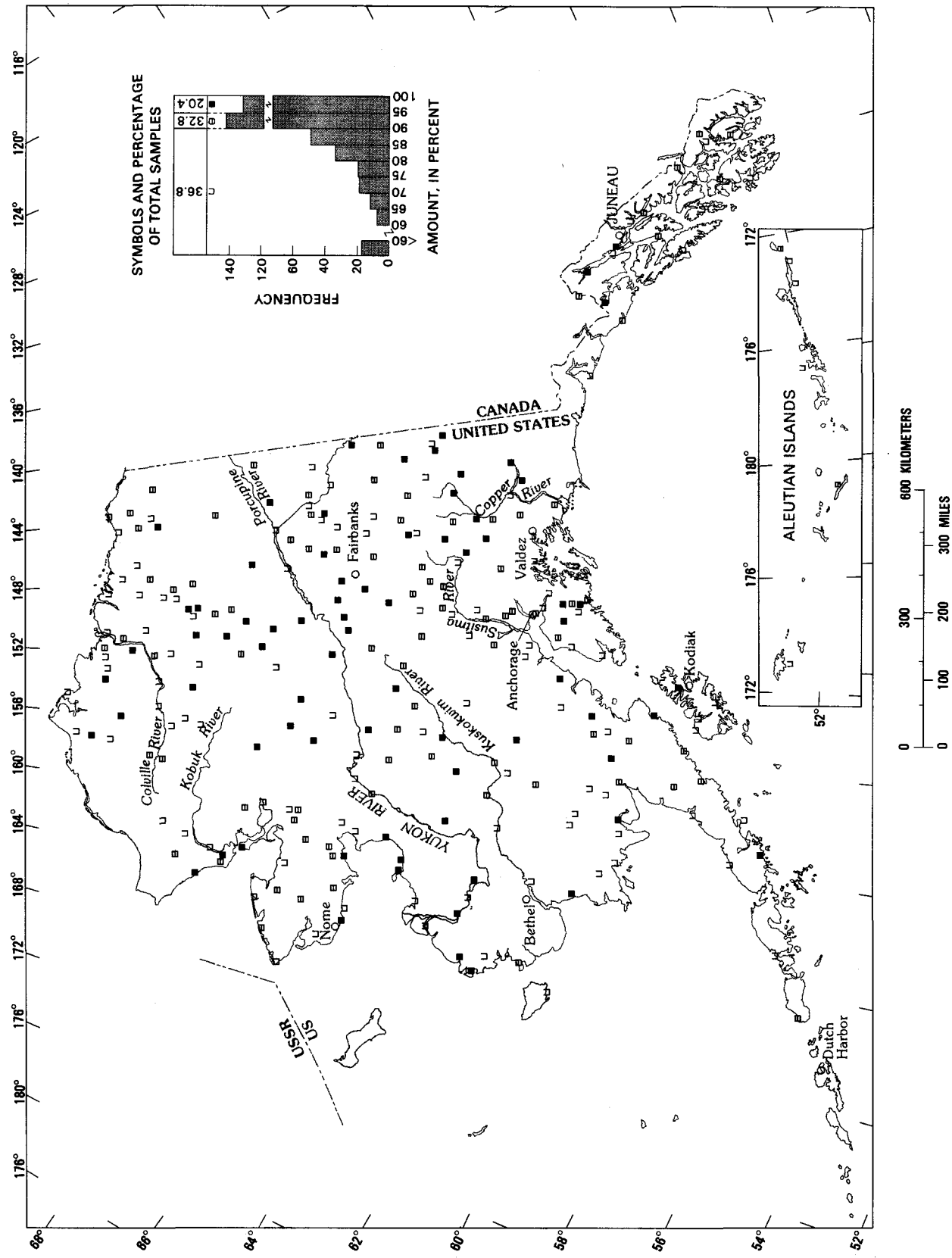


FIGURE 41.—Ash content of surficial materials.

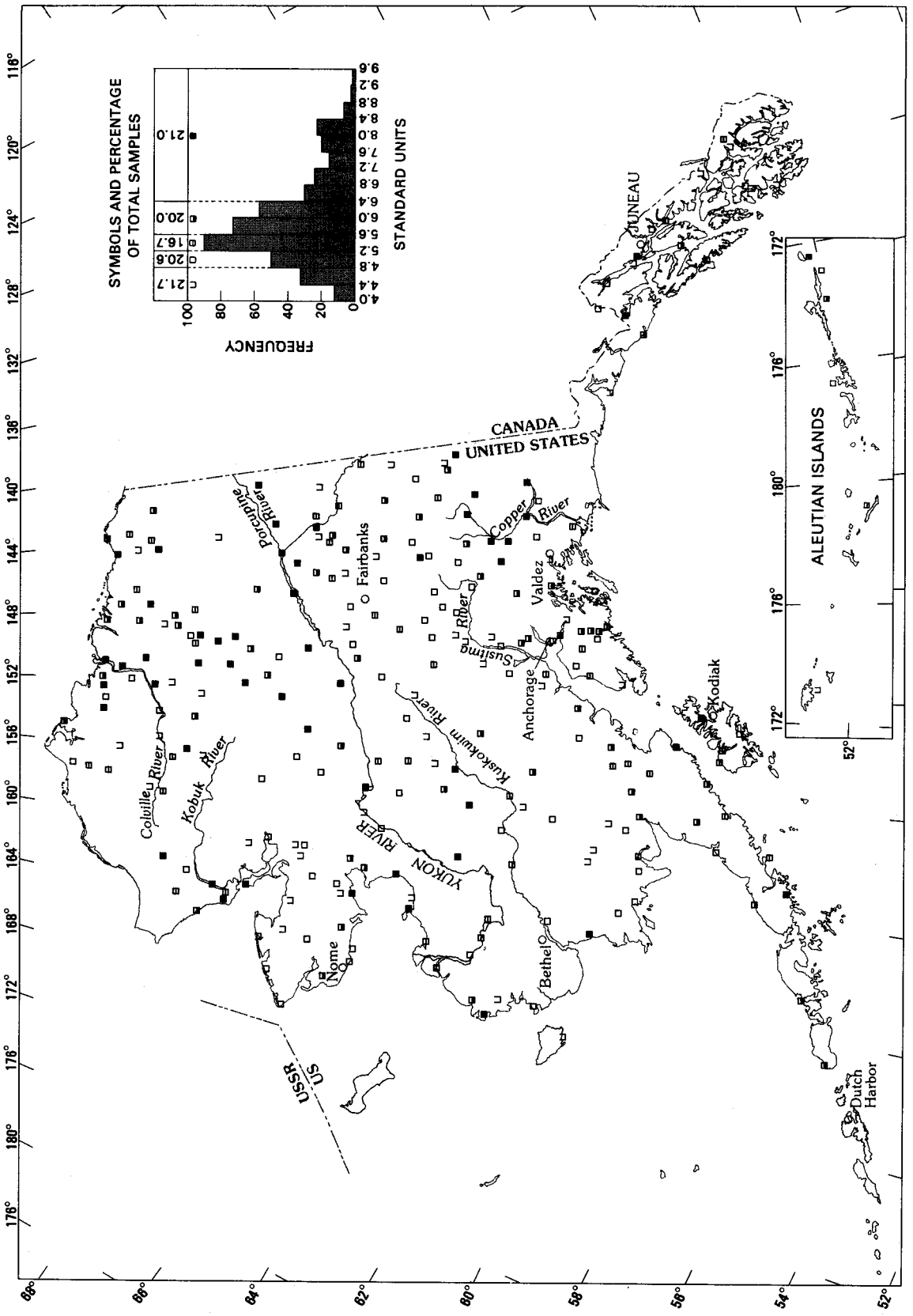


FIGURE 42.—pH values for surficial materials.

components in excess of 50 percent are considered excessive, and interpretation of the data for these elements must be made with caution. For example, the variance for replicate analytical splits in the dysprosium data (table 2) is 93 percent; therefore, the definition of geochemical differences between samples cannot be made until a more precise analytical method is used.

The data in table 2 are useful because they show that for most elements (84 percent) more than 50 percent of the total variability in the data occurs at the "between locations" level and that generally less than 30 percent of the variability is found at the "between replicate samples at each site" level (samples collected about 100 m apart). We see this difference as an indication that our samples are indeed diverse, and it supports our opinion that this suite of 437 surficial materials is highly heterogeneous. We have no example of variability within a location that exceeds 50 percent of the total variability. It follows, therefore, that the sites within locations contain relatively homogeneous surficial materials which probably reflect uniform soil-development processes.

COMPARISONS OF GEOCHEMICAL DATA

The analytical data of this study are summarized in table 3, along with data on surficial materials from the conterminous United States (Shacklette and Boerngen, 1984) and concentrations of elements in stream and lake sediments from Alaska (Los Alamos National Laboratory, 1983). The first two geochemical data sets are fairly similar because of the type of materials sampled, use of the same laboratories, and utilization of comparable statistical methods and data-presentation formats. Except for the determination of thorium and uranium (by neutron activation) and of calcium, iron, potassium, and titanium (by X-ray fluorescence), the analytical methodology for these two data sets differs (table 1); our discussion reflects the caution dictated by this difference. The Alaska samples were analyzed using the quantitative ICP-OES method (table 1), whereas the conterminous United States samples were analyzed using a semiquantitative emission spectrographic method (Neiman, 1976). Comparisons of the two surficial-materials data sets with those of the stream and lake sediments are more difficult to make because of the difference in the sample media. In addition, the sediment geochemical data include two types of materials; and the analytical methods, limits of determination, and statistical procedures used were very different from those used in the studies of surficial materials.

Despite these constraints, a comparison of the geometric means of analytical values in the samples of surficial materials from Alaska and from the conterminous United States shows a close correspondence for most elements. Means for only six elements—beryllium, cerium, magnesium, phosphorus, tin, and titanium—show as much as a twofold, but less than a threefold, difference. In an unreported test of stability of the grand mean values for surficial materials (H. T. Shacklette, unpub. data, 1982) from the conterminous United States listed in Shacklette and Boerngen (1984), the means of element values for the first 400 samples collected were essentially the same as those calculated for the entire data set of approximately 1,300 samples. This result indicated that samples collected from the first 400 sites (randomly selected geographically) were adequate for establishing grand means, although the 900 additional samples gave a more precise representation of the variation and the regional geochemical patterns. From this result and from the close correspondence of these mean values with those of the Alaskan study, it is reasonable to expect that the means for the elements reported in approximately 437 Alaskan samples are relatively stable for the state as a whole; however, as with the conterminous United States data, a greater density of sampling sites in Alaska, with a larger number of samples, would give a better estimation of the natural variation and of regional geochemical patterns.

The differences in geometric deviations in studies of the mean values of the conterminous United States and Alaskan surficial materials are believed to be, in part, caused by differences in the number of samples of the two sets, the study having the greater number of samples showing the greater deviations for many elements. Another cause is the difference in analytical methods as reflected by their lower or upper detection limits. A third cause is that the conterminous United States sample set represents a broader region, and we suspect that greater geochemical diversity is present than is found in the smaller area of Alaska. This greater geochemical diversity is not shown in the summary statistics, however, except as may be suggested by the extremes in range.

The calculated arithmetic means of the surficial materials should be used in comparing these means with those given for the sediments which we will presume are also arithmetic. By not transforming their element data for sediments to logarithms before calculating the means, Los Alamos National Laboratory (1983) estimates of central tendency could be biased: in a frequency distribution with positive skewness, the arithmetic mean overestimates the median.

In calculating element means for the sediment samples, the investigators (Los Alamos National Laboratory, 1983) chose to reject all censored values. This

procedure introduced a bias in the means that is reported, the severity of which depends on the percentage of censored ("less than") values that were found, and produced results in calculated means that are higher than would be determined if actual values for the omitted samples were known. In contrast, the mean values calculated by using the technique of Cohen (1959) for elements in samples of surficial materials included all samples; therefore, these mean values are better estimates of central tendency.

There are two additional causes of differences between surficial materials and sediment means reported in table 3: the great difference in the number of samples, and the actual differences in the chemistry of two different types of materials (surficial materials and sediments). Those elements having very few censored values (high detection ratios) in the two data sets show close correspondence between their calculated means. For example, scandium has identical mean concentrations (14 ppm) in both surficial materials and sediments. Correspondence of the means is also close for some other elements having high detection ratios, such as aluminum, beryllium, calcium, cobalt, iron, lithium, lead, manganese, nickel, titanium, uranium, and vanadium. The means for arsenic, tin, and ytterbium, which have many censored values in both kinds of materials, do not correspond well. The extremely high tin value (or values) of 29,000 ppm, reported by Los Alamos National Laboratory (1983), suggests a "nugget" effect inasmuch as cassiterite (SnO_2) is commonly found in stream sediments in some parts of Alaska; this supposition, however, cannot be supported by data given in the sediment report because the element values for lake sediments and stream sediments were merged for calculating mean concentrations. The difference in zinc means between sediments and surficial materials (157 and 79 ppm, respectively) and the extreme range of concentration in the sediments also suggest that the high values in some stream sediments may be due to particles of zinc minerals. Two elements, potassium and strontium, have relatively high detection ratios in both kinds of samples, but the mean concentrations in sediments are much higher than are typically found in soils. The reasons for these high sediment means are not known.

THE INTERPRETATION OF GEOCHEMICAL TRENDS

The data presented on maps in this report may indicate regional variation in the abundance of certain elements; single values or small clusters of values may have little importance if considered alone. The following are examples of areal geochemical patterns at three scales. Samples from the area of continuous permafrost (fig. 2), the tundra of the Arctic coastal plain, and the Brooks Range have concentrations of sodium that are mostly in the lowest frequency class (<0.1 to 0.6 percent, fig. 30); all are lower than 1.2 percent, even though the organic content (as indicated by ash percentage, fig. 41) and pH (fig. 42) vary throughout the entire range of ash percentage and pH among the samples. Strontium (fig. 31) and scandium (fig. 28) concentrations follow the same general trend. Thorium (fig. 32) and uranium (fig. 35) are generally low in samples from the Aleutian Islands, Kodiak Island, the Alaskan peninsula, and coastal sites south of the Yukon delta.

A distinctive small-scale geochemical pattern is illustrated by the data for five adjacent sampling sites at the mouth of the Colville River (sites 015, 131, 132, 133, and 143, fig. 4). Surficial materials from these sites have concentrations of the following elements in the lowest, or next to lowest, frequency class, as shown on maps for the following elements: aluminum, arsenic, beryllium, cerium, chromium, copper, dysprosium, gallium, iron, magnesium, molybdenum, neodymium, niobium, potassium, scandium, sodium, strontium, thorium, tin, titanium, uranium, vanadium, ytterbium, yttrium, and zinc. Yet samples from this suite ranged from the lowest to the highest in ash yield and pH. Thus, the samples ranged from moderately organic (ash yield of 61.0 percent) to low organic (ash yield of 97.0 percent), and from acidic (pH 5.8) to slightly basic (pH 7.3)(Gough and others, 1984), and the content of the elements mentioned above seems to be independent of soil type or pH.

Apparent anomalies at the location level are shown by samples from two sites, 020 in eastern Alaska near the Yukon boundary and 134 in northern Alaska near the south side of the Colville River (fig. 4). These samples have high concentrations of elements not commonly found in surficial materials. Material sampled at site 020 in the Tanacross quadrangle (number 85, fig. 3) was described (Gough and others, 1984, p. 15) as "colluvium from biotite gneiss and schist; dark brown organic loam with mica-like fine sand"; the sample contained erbium, europium, gadolinium, praseodymium, and samarium in measurable concentrations. The material sampled at site 134 in the Killik River quadrangle (number 133, fig. 3) was described (Gough and others, 1984, p. 20) as "terrace cut on bedrock of Lisborne Limestone of Mississippian age; dark brown silty material high in organic matter"; the sample was found to contain cadmium, erbium, europium, and gadolinium.

The data from this study are presented as estimates of central tendency for concentrations of elements in unconsolidated surficial materials, and the figures are

not meant to be interpreted as stable geochemical maps. Any so-called trends that we have discussed, or others that the reader may suspect after examining the figures, are to be interpreted with caution. The degree of confidence in patterns of element abundance is expected to be in direct proportion to the number of samples included in the area. As the patterns become ever smaller, the probability increases that the patterns are not reproducible.

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