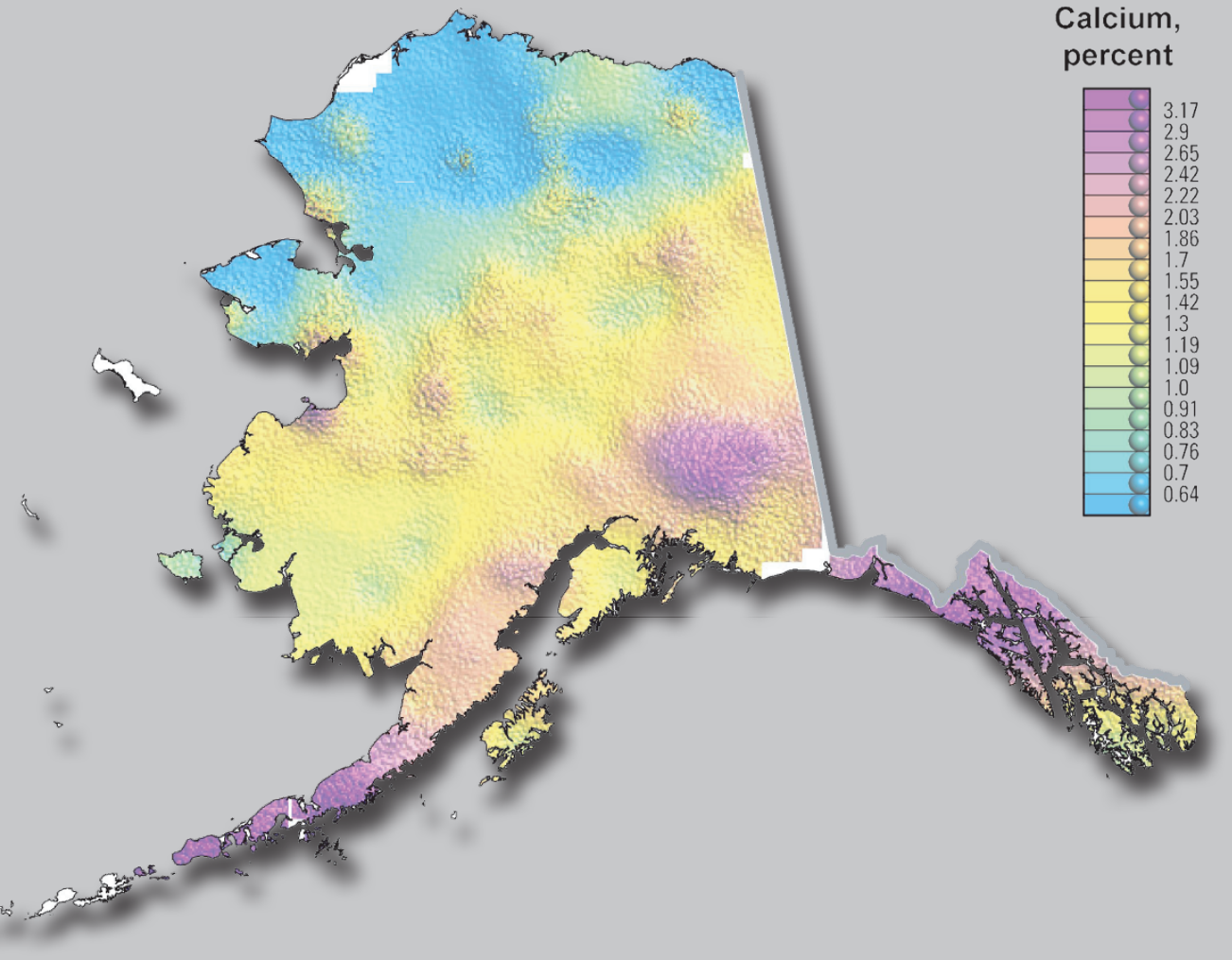
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Geochemical Landscapes of Alaska—New Map Presentations and Interpretations for 23 Elements in Surficial Materials



Professional Paper 1716

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

Cover—Geochemical map showing the distribution of calcium in surficial materials of Alaska. The map is based on 265 chemical analyses as reported by Gough and others (1988).

Geochemical Landscapes of Alaska—New Map Presentations and Interpretations for 23 Elements in Surficial Materials

By L.P. Gough, Bronwen Wang, D.B. Smith, and Nils Gustavsson

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U.S. Department of the Interior
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Suggested citation:
Gough, L.P. Wang, B., Smith, D.B., and Gustavsson, N., 2005, Geochemical landscapes of Alaska—New map presentations and interpretations for 23 elements in surficial materials: U.S. Geological Survey Professional Paper 1716, 36 p.

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Geochemical Landscapes of Alaska—New Map Presentations and Interpretations for 23 Elements in Surficial Materials

By L.P. Gough,[1] Bronwen Wang,[1] D.B. Smith,[1] and Nils Gustavsson[2]

Abstract

Geochemical patterns are presented for 23 elements, ash yield, and pH in soils and other unconsolidated surficial materials from 265 collection sites throughout Alaska. This is a new presentation of data originally published in 1988 and released now with additional interpretation based on landscape geochemical principles (such as the effects of regional soils groups, climate, and vegetation) that influence observed areal patterns. The additional interpretations are applied to subjects involving ecosystems and soil-forming processes in cold climates, and the effects of parent material on observed patterns. Mean concentrations of most elements, in this ultra-low-density sampling of surficial materials from the State of Alaska, correspond well with those reported in similar materials from the conterminous United States. The utility of low-density geochemical sampling in the interpretation of landscape geochemical patterns and of ecosystem processes is demonstrated by (1) showing interpretable relations among physical and chemical parameters (for example, latitude, elevation, temperature, and geochemistry), and (2) comparing our surficial material data with a much larger, published stream-sediment geochemical data set. A five-division ecoregion classification system is used to evaluate feldspar chemical weathering processes and to examine relations among climate (mean annual temperature and precipitation) and soil properties (chemistry, pH, and organic matter). Principal components analysis of these climatic and soil properties for 263 of the 265 sampling sites resulted in five factors that explain 77 percent of the total variance in the data. The factors were identified as (1) clay or reactive oxides, (2) physiographic or latitude, (3) soil organic matter, (4) carbonate and soil ion exchange, and (5) soil potassium feldspar. These data should prove useful in assessing geochemical baselines and in the interpretation of geochemical landscapes when the purpose is to identify broad regional patterns associated with surficial geology, mineral resource provinces, and geochemical areas of interest in human, animal, and plant health issues.

Introduction

Background and Objectives

The republication and reinterpretation of the Shacklette and Boerngen (1984) soils and surficial-materials geochemical maps for the conterminous United States by Gustavsson and others (2001) prompted us to conduct a similar exercise for Alaska using the data of Gough and others (1988). Since the publication of the 1984 and 1988 studies, not only have the computer-assisted graphical analysis and presentation of spatial data improved, but our knowledge and understanding of the principles of landscape geochemistry have also greatly advanced (see, for example, the discussions in Bølviken and others, 1992; Fortescue, 1992; Gustavsson and others, 2001). Although the interpretation of spatial geochemical patterns in soils and surficial materials was an objective of the study by Gough and others (1988), henceforth referred to simply as "the 1988 study," its major contribution was the presentation of geochemical spatial variability, of estimates of central tendency, and of typical ranges in the concentration of chemical elements.

The maps generated by Gustavsson and others (2001) present spatial geochemical patterns that can be interpreted variously as associated with geologic and physiographic features, variations in soils and climate, and the dispersion of contaminants. Similarly, the Alaska data, produced by using the same low sampling density[3] (approximately one sample per 6,000 km^2, fig. 1) as was presented by Shacklette and Boerngen (1984), have numerous potential uses including the broad-scale interpretation of bedrock weathering, the physiographic and climatic controls on trace–element dispersal, and the effects of permafrost and cold soil temperatures on landscape geochemical patterns. In general, there is much to be learned about the geochemical behavior of elements (especially trace elements) in northern climates as it relates to "geoecological" questions such as climate change and the occurrence of wildfires. By examining these data from a more holistic, landscape geochemistry perspective, we anticipate being able to better assess the importance of ecosystem processes on observed geochemical patterns.

[1] U.S. Geological Survey.

[2] Geological Survey of Finland, Espoo, Finland.

[3] Alaska's total area is approximately 1.7×10^6 km^2 (table 4); however, 52,000 km^2 is covered by inland water and 65,000 km^2 is snow and ice. In addition, much of the North Slope, the north side of the Seward Peninsula, and the Yukon–Kuskokwim Delta are very wet but not necessarily covered by water. These areas are generally not represented in this geochemical landscape study.

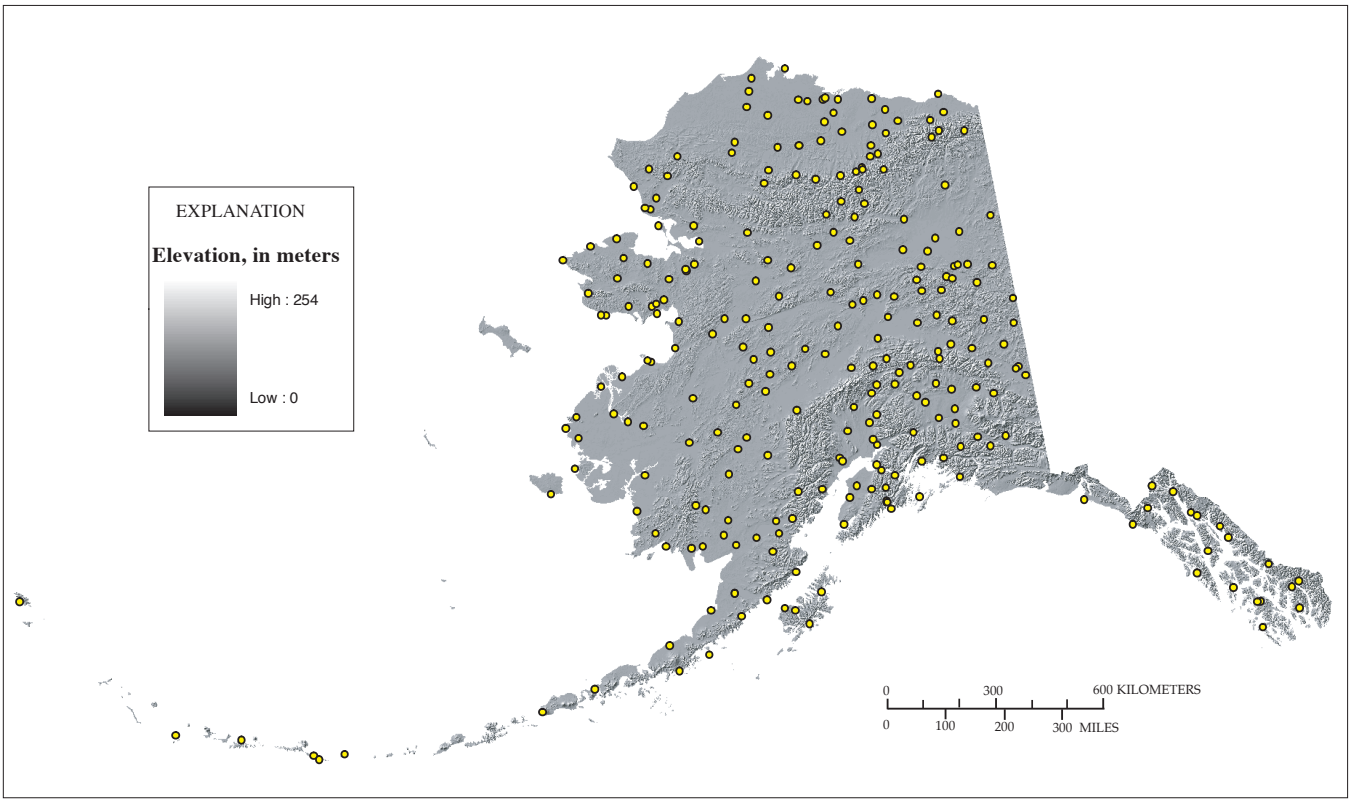


Figure 1. Shaded relief map of Alaska showing the location of 265 soil and surficial-materials sampling sites.

Gough and others (1988, p. 1) make the following statement concerning the need and utility of these types of broad regional studies:

> A single geochemical study cannot be expected to pro vide 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. 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.

As with the Shacklette and Boerngen (1984) data, the 1988 Alaska data represent the only statewide geochemical census, conducted for soils and surficial materials, using consistent and standardized sampling and analytical protocols. The U.S. Geological Survey (USGS)(2004) presents extensive geochemical coverage for Alaska as part of the National Geochemical Survey work but uses stream sediments as the preferred sampling medium. This latter study makes use of both archived and newly sampled material, and it, too, emphasizes the need for uniform analytical and sample-collection protocols. Soils are included in their work only in the Yukon-Kuskokwim Rivers lowland region of the State where stream sediments were unavailable.

The 1988 Alaska data for the major labile and most resistate elements and for uranium and thorium were generated using the extremely accurate and precise X-ray fluorescence and neutron activation methods, respectively (Taggert and others, 1981; Millard, 1976). Although conducted more than 20 years ago, the data generated using these methods are of very high quality. In this study we examine the concentration of 23 chemical elements, ash yield, and pH for soils and other unconsolidated surficial materials from throughout the State. Figure 2 shows the major geographic areas, physiographic features, and the names and approximate major ecoregion boundaries used in subsequent discussions.

Landscape Features— Ecoregions, Vegetation, and Soils

The climate of Alaska is complex and varied because of the extreme length and breadth of the latitudinal (2,100 km) and longitudinal (3,500 km) span. The extensive ocean coastline of the State helps moderate some regions, whereas interior Alaska has extreme continental climatic conditions with greater than 80˚C annual ambient temperature variations possible. Major mountain ranges divide large portions

of the State and greatly influence the regional effects of major weather systems.

The ecoregion concept is an integration of biotic and abiotic factors resulting in major geographic units that are differentiated on the landscape (Nowacki and others, 2002). These landscape units are, in turn, composed of a multitude of ecosystems, each defined by the interaction of climate, vegetation, fauna, soils, subsurface and surface geology, physiography, and hydrology (Bailey, 1998; McNab and Avers, 1994). In Alaska, the fundamental science that helps describe these landscape features is reported in publications such as Viereck and Little (1972) and Van Cleve and others (1991)—vegetation; Soil Survey Staff (1999)—soils; Plafker and Berg (1994)—bedrock geology; and Péwé (1975)—surficial geology.

Soil formation and the geochemical cycling of elements are very much affected by the climatic conditions of northern latitudes (Campbell and Claridge, 1992). Although the general types of parent materials available for soil formation are the same as those present in more temperate (midlatitude) regions, the processes that control soil development at high latitudes can be quite different. The growth of vegetation in high-latitude regions is generally slow, as is the decomposition of organic matter, resulting in large deposits of peat and organic materials in which many chemical elements may be immobilized. In addition, the source of protons necessary in the weathering of primary bedrock minerals changes with latitude and with organic acids (formed from the decomposition of organic matter) and becomes less important as latitude increases and carbonic acid becomes more important.

Because of the low temperatures, physical weathering of bedrock is an important component of soil development. The chemical and biologically mediated weathering of primary rock minerals is slowed; therefore, the release of elements and their mobility and transport also are slowed. For example, Macias and Chesworth (1992) report from the literature that hornblende weathering rates can be less than 1 μm per 1,000 years at high latitudes, whereas in the Western United States, basalts weather at rates from 10 to 20 μm per 1,000 years.

In addition, ground permanently frozen at depth (permafrost) occurs anywhere the mean annual air temperature is low enough to maintain a mean annual near-surface ground temperature at or below 0˚C (Ferrians, 1994). Permafrost is present in much of northern Alaska and occurs intermittently in central and southern Alaska; this ground thaws in summer from a few centimeters to tens of centimeters from the surface. Cryoturbation, the physical action that results from freeze-thaw cycles, becomes an important component of soil formation that results in particle-size fractionation and limits plant root development and available water for biological activity. In the summer in many permafrost areas, downward percolation of surface water is prevented or severely restricted, the soil is permanently moist or saturated, and ground water moves laterally, downslope across the landscape.

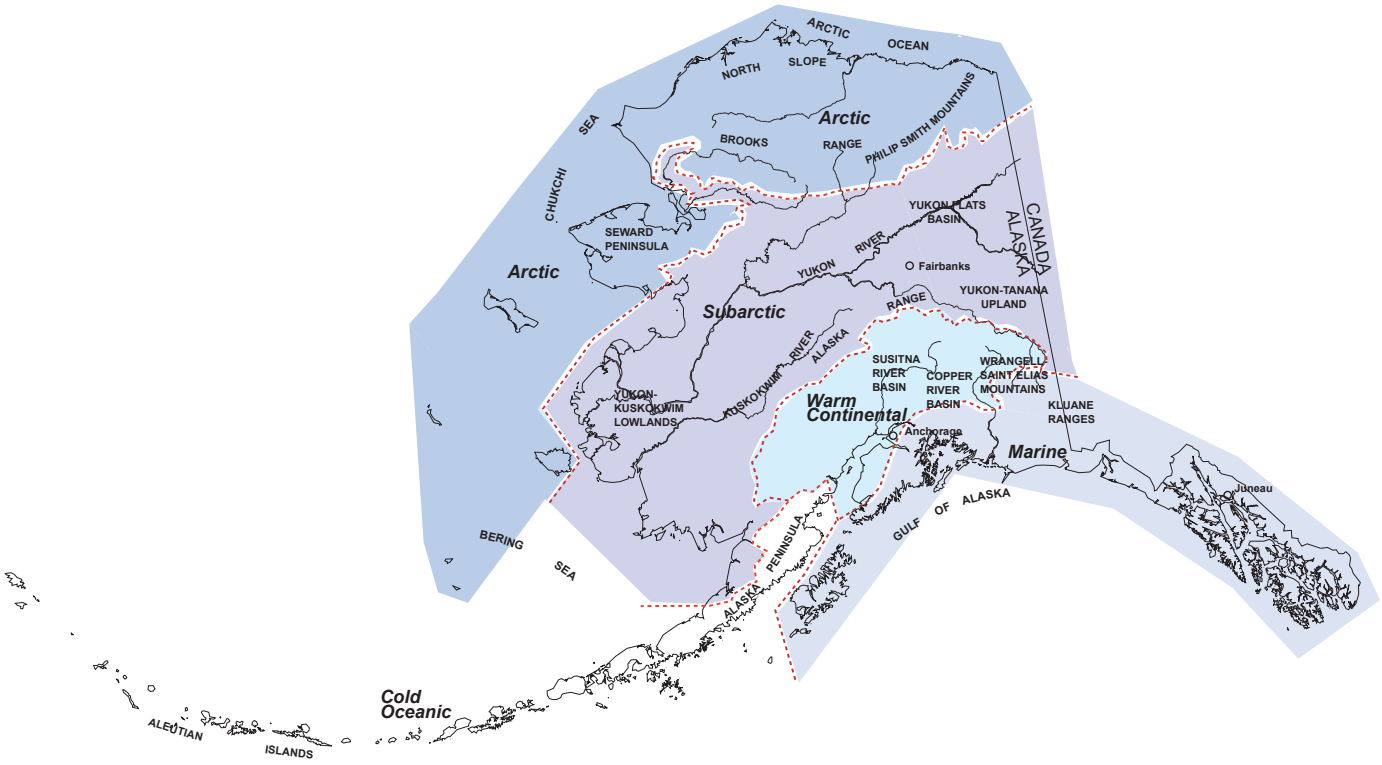


Figure 2. Ecoregion divisions and major geographic areas mentioned in discussions of landscape geochemistry in Alaska.

Methods

Sample Collection

Sampling for the 1988 study was organized on the basis of the 153 1:250,000-scale quadrangle maps that cover Alaska (Gough and others, 1988). About 20 percent of the quadrangles have the greater part of their areas covered either by water (island and coastal areas), or glaciers, or include foreign territory (Canada). The authors decided to eliminate these quadrangles from the sampling and target only the 120 remaining. This provided coverage for the State of approximately two samples per quadrangle (or one sample per 6,000 km^2), a coverage that was considered adequate for the study's purposes. Since publication of the 1988 study, a recount of the samples used showed 265 sampling locations (instead of the published number of 266). We therefore make that correction in subsequent discussions.

Because the 1988 study relied on the voluntary assistance of over 80 individuals in the collection of samples, the field protocol was kept simple. Participants collected a channel sample of unconsolidated surficial material to a depth of 20 cm. This material was below the surface horizon organic mat (typical of Alaska Gelisols and Inceptisols) and consisted of predominantly mineral material. The authors emphasize that the term "surficial material" is preferred over "soil" for these samples, as unweathered loess, sand dune or shore material, and even highly organic deposits are included. Unlike the U.S. Geological Survey (2004) study, stream sediments are not part of this sampling effort. In the 1988 study, sampling sites were selected to represent "normal" surficial materials and excluded locations obviously affected by contamination from human activities or

Table 1. Method of chemical analysis and summary information on the 23 elements, pH, and ash yield plotted as geochemical maps in figures 4–28.

[Data for silicon and titanium are also presented—these elements were used in the principal components analysis but not in the presentation of statewide surface geochemical maps. ppm, parts per million; %, percent]

Element, pH, ash yield	Method of analysis	Lower limit of detection (LLD)	Number of samples missing analysis	Number of samples with analysis below detection limit	Number of samples plotted
Al	X-ray fluorescence spectrometry	--[2]	0	0	265
Ba	ICPOES[1]	--	0	0	265
Ca	X-ray fluorescence spectrometry	--	2	0	263
Co	ICPOES[1]	--	0	0	265
Cr	ICPOES[1]	--	0	0	265
Cu	ICPOES[1]	--	0	0	265
Fe	X-ray fluorescence spectrometry	--	2	0	263
K	X-ray fluorescence spectrometry	--	2	0	263
La	ICPOES[1]	2.0, ppm	0	2	263
Li	ICPOES[1]	--	0	0	265
Mg	X-ray fluorescence spectrometry	--	2	0	263
Mn	X-ray fluorescence spectrometry	155, ppm	2	17	248
Na	X-ray fluorescence spectrometry	0.13, %	2	1	262
Nd	ICPOES[1]	4.0, ppm	0	3	262
Ni	ICPOES[1]	2.0, ppm	0	3	262
P	X-ray fluorescence spectrometry	0.022, %	2	2	265
Pb	ICPOES[1]	4.0, ppm	0	12	253
Sr	ICPOES[1]	--	0	0	265
Th	Neutron activation	1.2, ppm	0	9	256
U	Neutron activation	0.23, ppm	0	1	264
V	ICPOES[1]	--	0	0	265
Y	ICPOES[1]	--	0	0	265
Zn	ICPOES[1]	20, ppm	0	5	260
pH, standard units	Selective ion electrode		0	0	265
Ash yield, %	Gravimetric		0	0	265
Si	X-ray fluorescence spectrometry	--	0	0	0
Ti	X-ray fluorescence spectrometry	--	0	0	0

[1] Inductively coupled argon–plasma optical emission spectrometry.
[2] Unknown. No samples with values that reach the LLD.

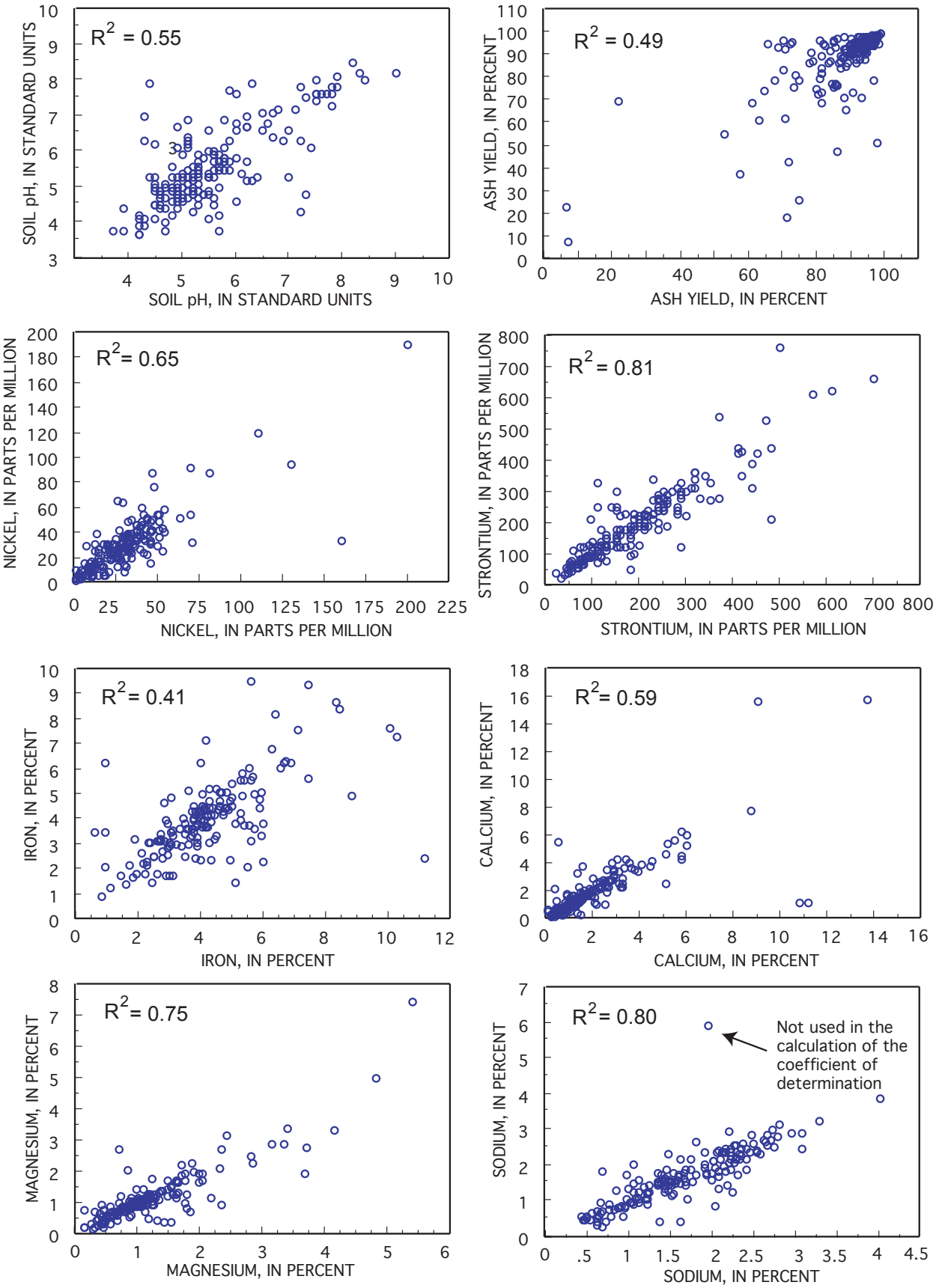


Figure 3. Simple linear regaression plots of the concentration of selected elements, soil pH, and ash yield in site-duplicated soil samples. Coefficients of determination (R^2) were calculated on the basis of 171 paired comparisons.

influenced by mines, mine tailings, or spoil material. In addition, locations with known mineral deposits were avoided.

The authors requested that collectors obtain a duplicate 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 duplicated at 171 of the 265 locations as well as duplicated in the laboratory. With more than 60 percent of the samples duplicated in the field and 11 percent of the samples duplicated in the laboratory (50 of 436), reliable estimates could be made of the variability in the concentration of elements at small geographic scales (less than 100 m) and of the error associated with sample-handling and laboratory procedures. The analysis of this variability, that is, understanding of the distribution and importance of scale-related geochemical variance, is discussed in Gough and others (1988). Sample descriptions, location, and other field parameters (for example, vegetation, physiography, geology) are also presented in Gough and others (1984).

Plant samples were also obtained from most of the 265 sampling sites and details on those collections are presented in Gough and others (1991). Whereas the analyses of the surficial material sample provided a measure of the total soil geochemistry at a location, analyses of the associated plant material permits an estimate of the concentrations of elements available for plant uptake and biogeochemical cycling.

Chemical Analysis and Summary Statistics

The sample-handling and analysis procedures used in the 1988 study are well documented and will not be repeated here (Gough and others, 1984; Gough and others, 1988; Gough and others, 1991). The analytical methods used for the 23 elements, soil pH, and sample ash yield discussed in

Table 2. Summary statistics for elements, pH, and ash yield in soil and surficial-materials samples from Alaska used in the plotting of figures 4–28.

[Data for silicon and titanium are also presented—these elements were used in the principal components analysis but not in the statewide presentation of surface geochemical maps. ppm, parts per million; %, percent; <, less than; --, no data]

Element (parameter), concentration units	Geometric mean (this study) n= ( )	Arithmetic mean (this study) n= ( )	Arithmetic mean from Gough and others (1988) n= ( )	Minimum value (this study)	Maximum value (this study)
Al, %	6.4 (265)	6.6 (265)	6.5 (416)	1.2	11
Ba, ppm	600 (265)	660 (265)	678 (437)	40	2,600
Ca, %	1.4 (263)	1.9 (263)	2.0 (416)	0.036	14
Co, ppm	13 (265)	15 (265)	14 (437)	2.0	55
Cr, ppm	50 (265)	64 (265)	64 (437)	5.0	370
Cu, ppm	23 (265)	28 (265)	29 (437)	4.0	170
Fe, %	3.8 (263)	4.2 (263)	3.8 (416)	0.60	14
K, %	1.2 (263)	1.3 (263)	1.3 (416)	0.22	3.7
La, ppm	--	--	21 (437)	<2.0	120
Li, ppm	25 (265)	31 (265)	30 (437)	2.0	110
Mg, %	1.0 (263)	1.2 (263)	1.2 (416)	0.13	5.4
Mn, %	--	--	0.067 (416)	<0.0155	0.85
Na, %	--	--	1.5 (416)	<0.13	4.0
Nd, ppm	--	--	27 (437)	<4.0	110
Ni, ppm	--	--	33 (437)	<2.0	320
P, %	--	--	0.086 (416)	<0.022	0.63
Pb, ppm	--	--	14 (437)	<4.0	310
Sr, ppm	170 (265)	190 (265)	198 (437)	23.0	710
Th, ppm	--	--	7.6 (437)	<1.2	76
U, ppm	--	--	2.8 (437)	<0.22	45
V, ppm	110 (265)	130 (265)	129 (437)	11	490
Y, ppm	14 (265)	16 (265)	15 (437)	2.0	100
Zn, ppm	--	--	79 (437)	<20	2,700
pH, standard units	--	5.5 (265)	5.6 (437)	3.7	9.0
Ash yield, %	85 (265)	87 (265)	85 (437)	6.6	100
Si, %	26 (265)	27 (265)	28 (416)	15	43
Ti, %	0.44 (265)	0.47 (265)	0.48 (416)	0.08	1.4

this report are summarized in table 1. Only elements from the 1988 study having less than about 5 percent of their analytical values below the detection limit are included in this study.

Two of the samples lack data for the major elements (examined by X-ray fluorescence) and are noted as "missing analysis" (table 1). Ten of the minor (trace) elements had from 1 to 17 values (0.1 to 6 percent) below the detection limit of the inductively coupled argon-plasma optical emission spectrometry (ICPOES) method used for at least one sample. These "censored" values were not used in the computation of the geochemical maps. Table 1 lists the lower detection limit, the number of samples below the detection limit for each element, and the number of samples used in the computation of the individual geochemical maps.

The calculation of the geochemical maps used only the data for the 265 primary surficial-material samples. We decided it was not appropriate to include the site-duplicated samples in these calculations—for example, by averaging the site-duplicate values with the primary sample values. Analysis of variance results from the 1988 study showed that most of the variance in the geochemical data occurred among the sampling sites. For most elements, soil pH, and ash yield, this value was more than 65–70 percent of the total variance. Much less of the total variance occurred between the site-duplicated samples collected at 171 of the 265 locations or between the duplicate analyses of individual samples (procedural variability due to sample preparation and analysis). Further, plots of the data for the 171 site-duplicated samples (examples of which are given for eight of the comparisons in figure 3) show, in general, moderate scatter and large coefficients of determination (R^2). Finally, the mean for the samples used in this study compared to the mean for all samples presented in the 1988 study are similar (table 2). This shows that the subset of 265 samples used here are adequate for the purposes of this study.

Data Treatment and Map Presentation

Colored surface maps (Gustavsson and others, 1997) showing smoothed and interpolated geochemical data were produced for 23 elements to show regional-scale trends in concentration. The software used also was used to produce the geochemical maps for the conterminous United States (Gustavsson and others, 2001). The procedure involved Bootstrap estimates (Efron and Tibshirani, 1991; Stuart and Ord, 1987) of the moving weighted median (Bjorklund and Lummaa, 1983) to achieve robustness against local outliers. A complete discussion of the methodology is given in Gustavsson and others (2001). The specific parameter values used in the computations are given in table 3.

The interpolated grid values (pixel values) are presented on a scale with 20 colors ranging from cyan (lowest 10 percent of values) to magenta (highest 1 percent of values). The color scale is tied at two percentiles of the empirical cumulative frequency curve of gridded values. The color-class intervals were derived by slicing the interval between these percentiles into equal-length slices on a logarithmic scale. When the analytical detection limit exceeded the lower percentile, the percentile was replaced by the detection limit.

Table 3. Parameter settings for computing regular grid using Bootstrap estimates of the moving, weighted median.

Parameter	Value
Pixel size (km × km)	4 × 4
Number of pixels	919 × 500
Window radius (km)	700
Weight halving distance (km)	50
Minimum distance to nearest sampling site (km)	190
Minimum number of points in window	3

The surface was illuminated by directed and ambient light in a lighting model presented by Strauss (1990). The resulting shaded-relief maps highlight subtle features, which may not be revealed on ordinary color maps. Shaded-relief maps are commonly produced by image-processing systems and by custom-written programs for geochemistry (Björklund and Gustavsson, 1987; Davenport and others, 1991).

To comprehensively show all possible effects due to relief shading of colors in the legend, each class is portrayed on an illuminated horizontal rectangle with a bubble (or hemisphere). All possible slopes on the map are represented on the surface of the bubble, and the reflection pattern shows where the directed light comes from. The directed light source was located in the northeast and 45 degrees from the zenith.

The "North American Datum 1927" was used for the maps, as well as for the latitude and longitude coordinates of the sampling sites. The maps were plotted in Albers' Conical Equal Area projection with standard parallels at latitude 55º N. and 65º N., the origin at latitude 50º N., and a central meridian at longitude 154º W. (Snyder, 1987). The software for interpolation and plotting was written at the Geological Survey of Finland except for basic graphical and statistical procedures, which were invoked from the UNIRAS FGL/GRAPHICS™ library and the IMSL STAT/LIBRARY™, respectively.

Results and Interpretation

Map Presentations and Their Relation to Major Alaska Landscape Features

The concentration values for 23 elements, ash yield, and soil pH in 265 samples are plotted on maps (figs. 4–28) using the coloring method previously described. This color scheme forms patterns that may or may not be possible to interpret but nevertheless show differences that are observable at several geographical scales. Sample density complicates the interpretation of regional patterns. As stated in the 1988 study, the degree of confidence in patterns of element abundance is

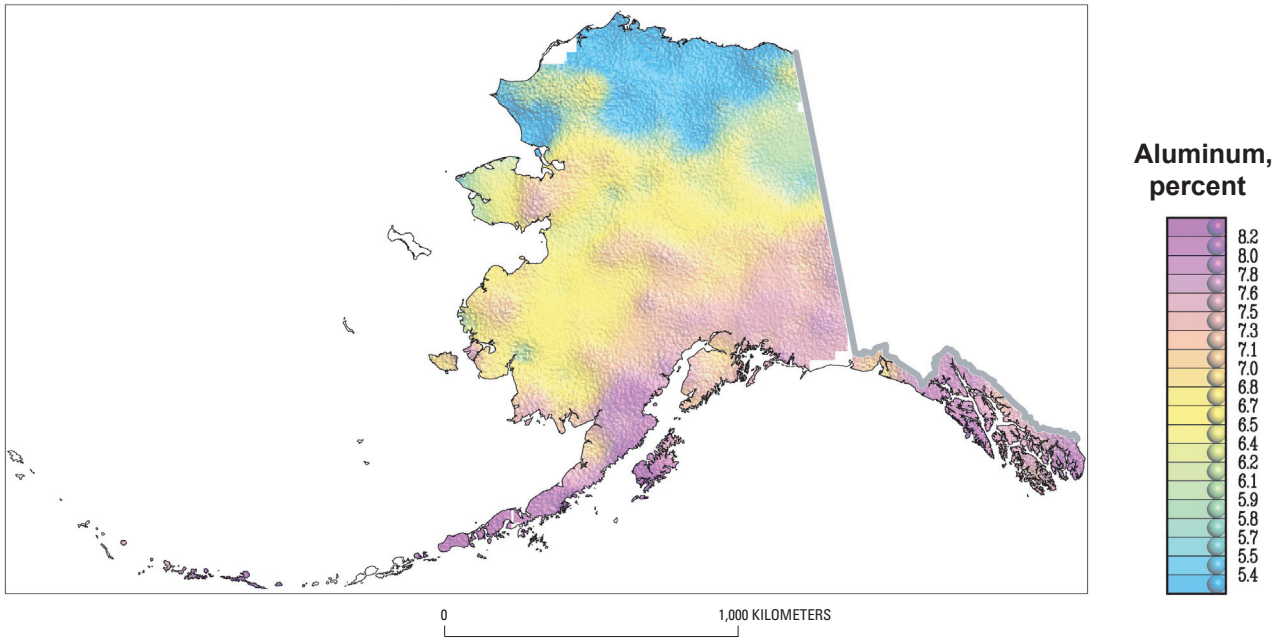


Figure 4. Colored surface map of aluminum distribution in soils and other surficial materials of Alaska.

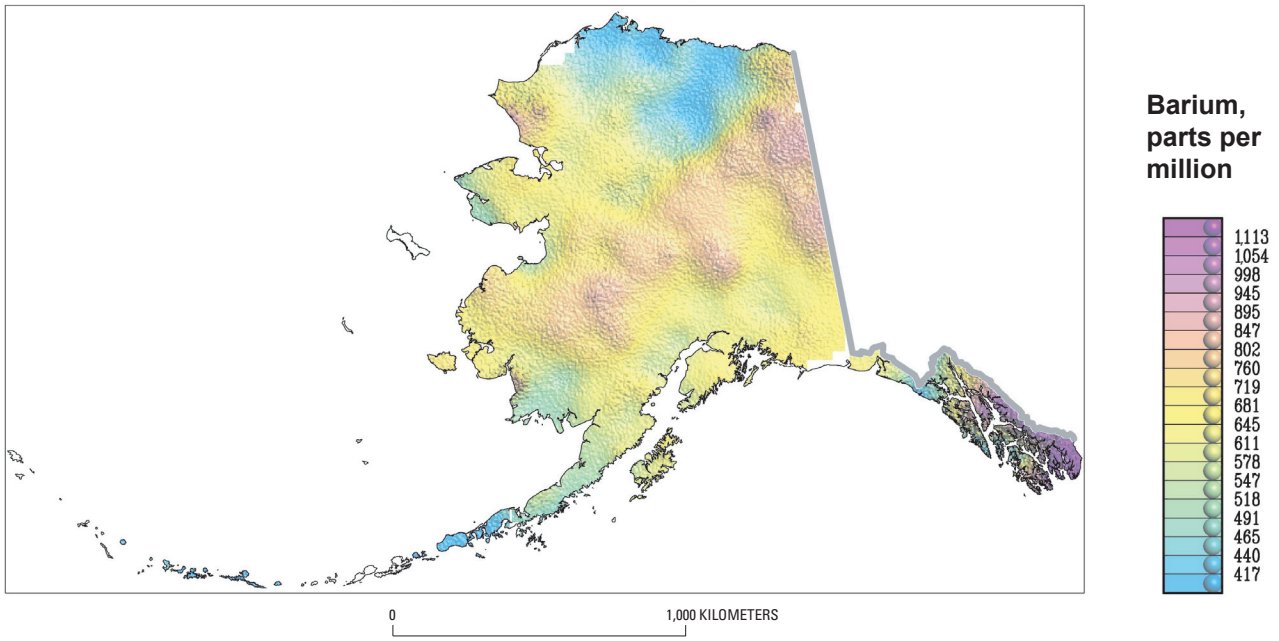


Figure 5. Colored surface map of barium distribution in soils and other surficial materials of Alaska.

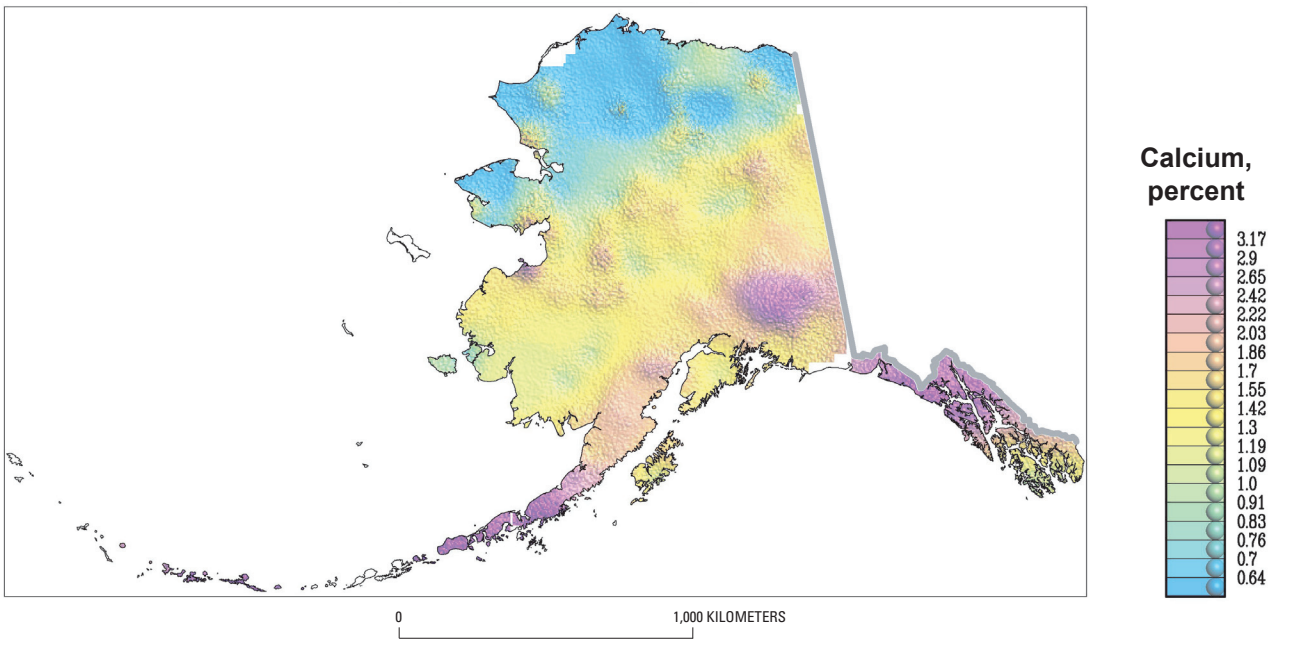


Figure 6. Colored surface map of calcium distribution in soils and other surficial materials of Alaska.

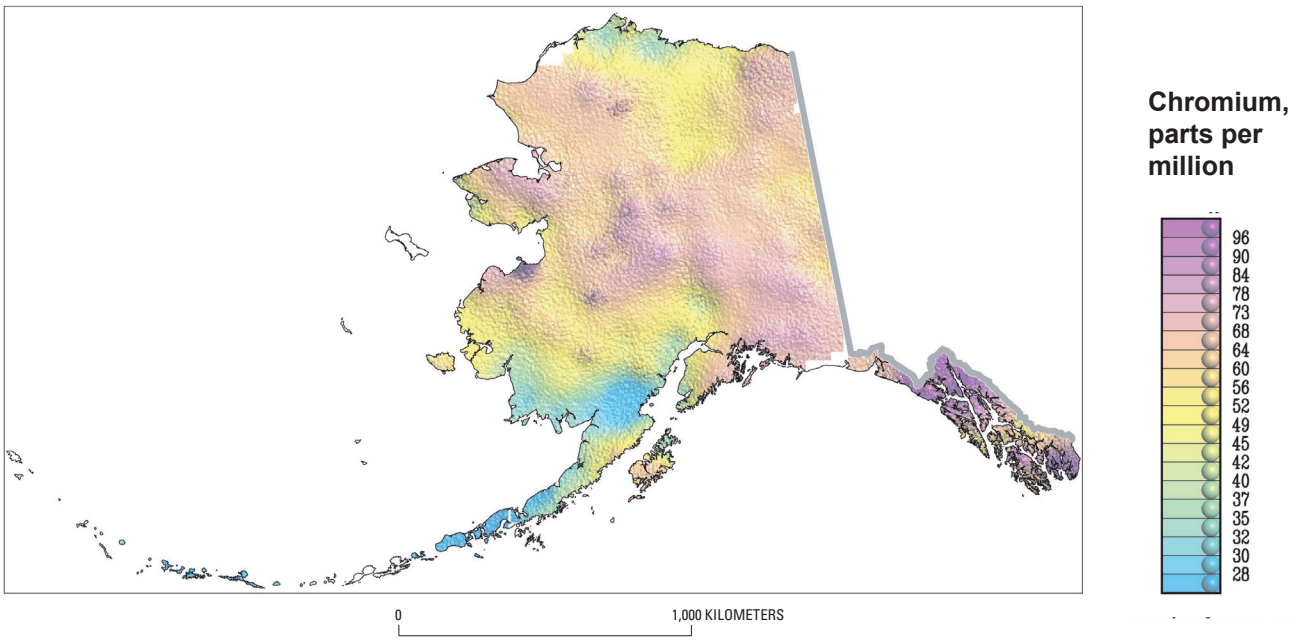


Figure 7. Colored surface map of chromium distribution in soils and other surficial materials of Alaska.

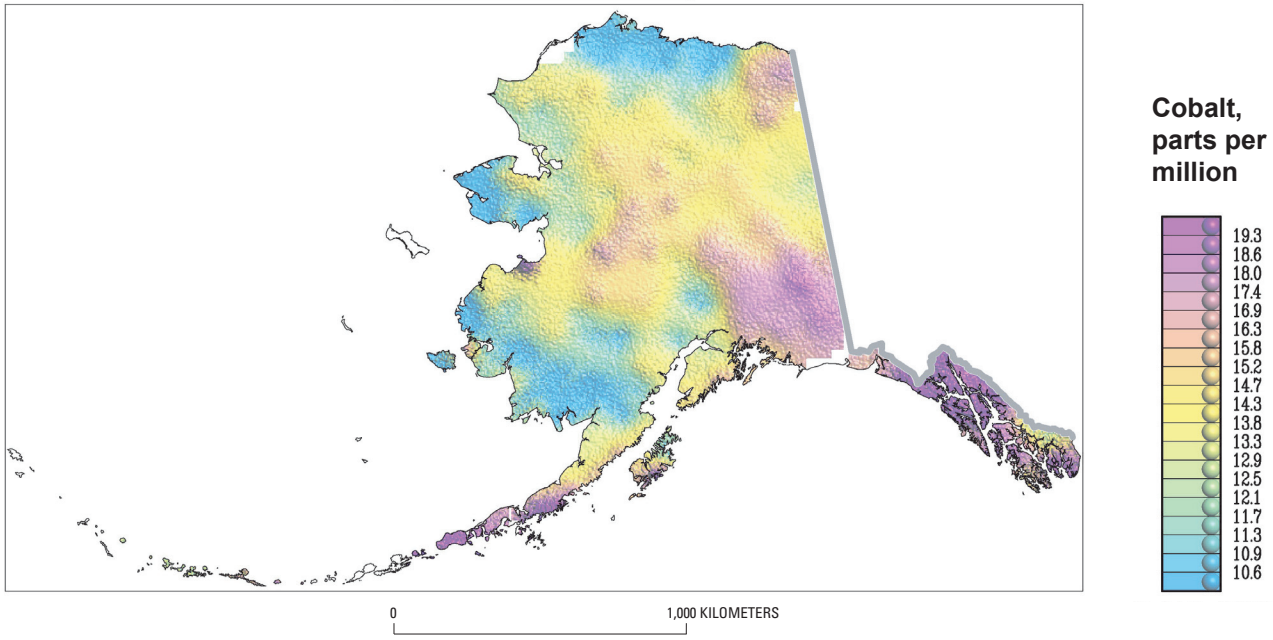


Figure 8. Colored surface map of colbalt distribution in soils and other surficial materials of Alaska.

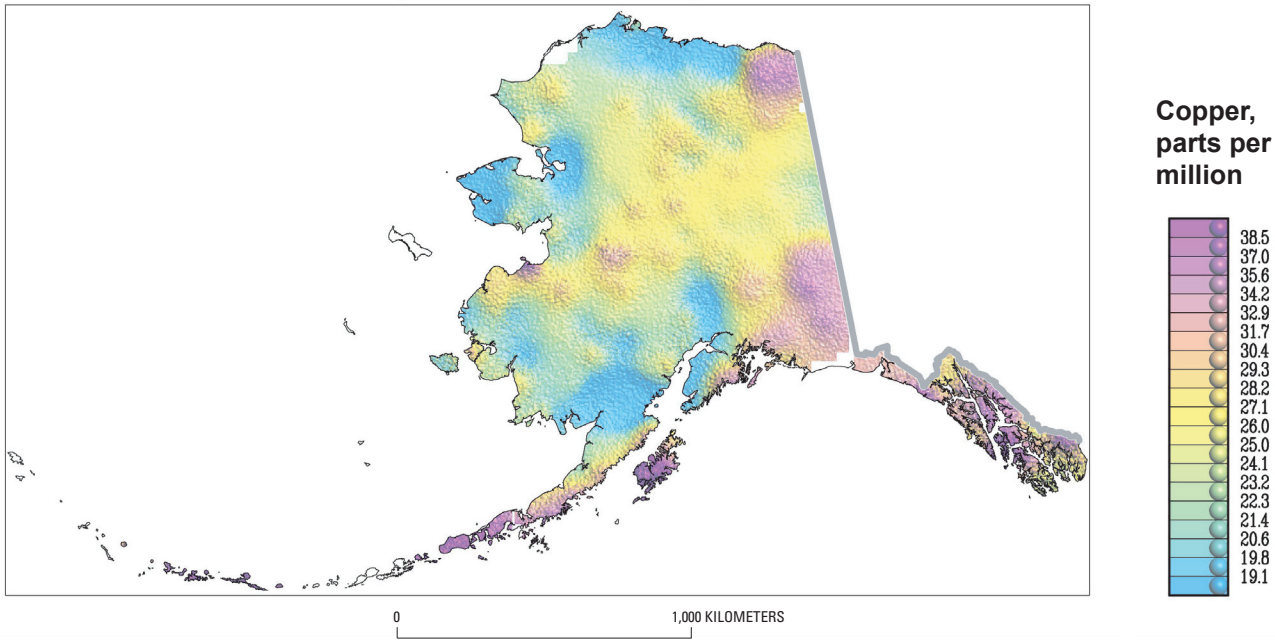


Figure 9. Colored surface map of copper distribution in soils and other surficial materials of Alaska.

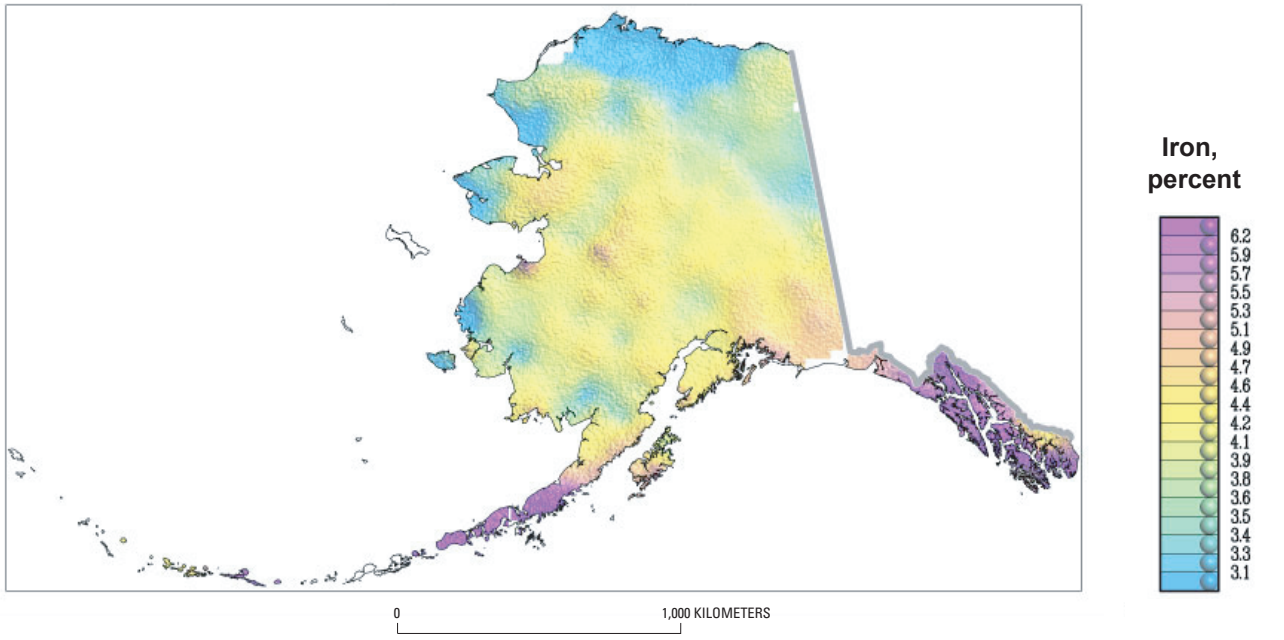


Figure 10. Colored surface map of iron distribution in soils and other surficial materials of Alaska.

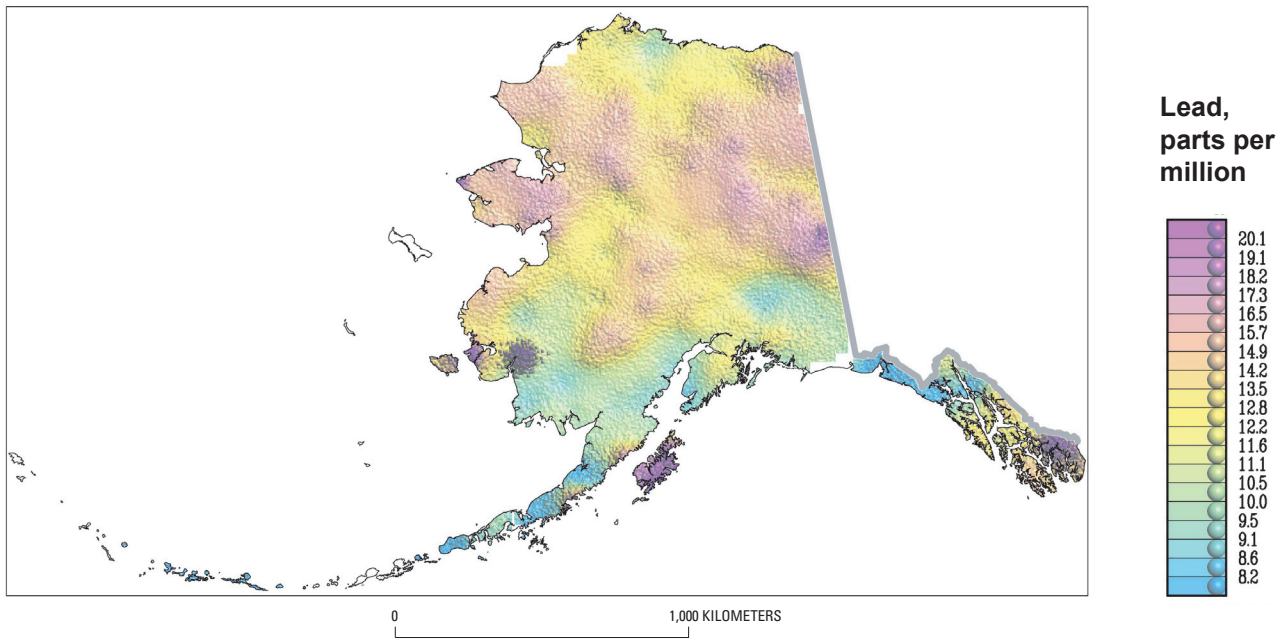


Figure 11. Colored surface map of lead distribution in soils and other surficial materials of Alaska.

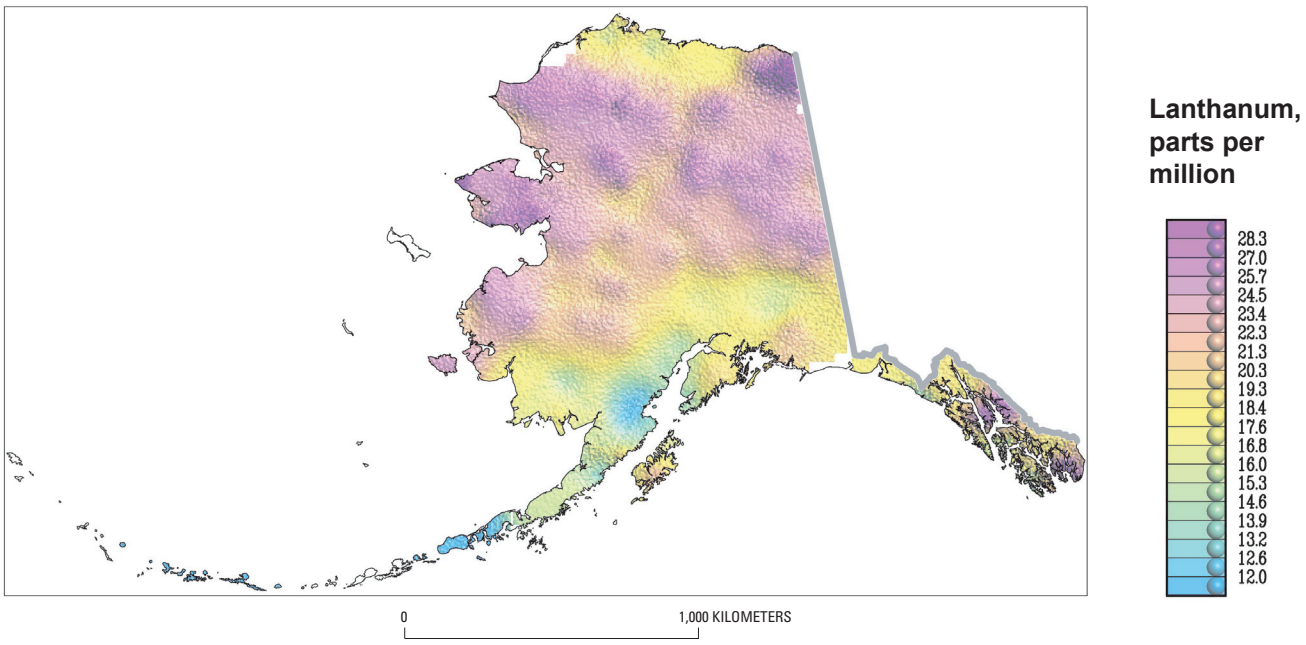


Figure 12. Colored surface map of lanthanum distribution in soils and other surficial materials of Alaska.

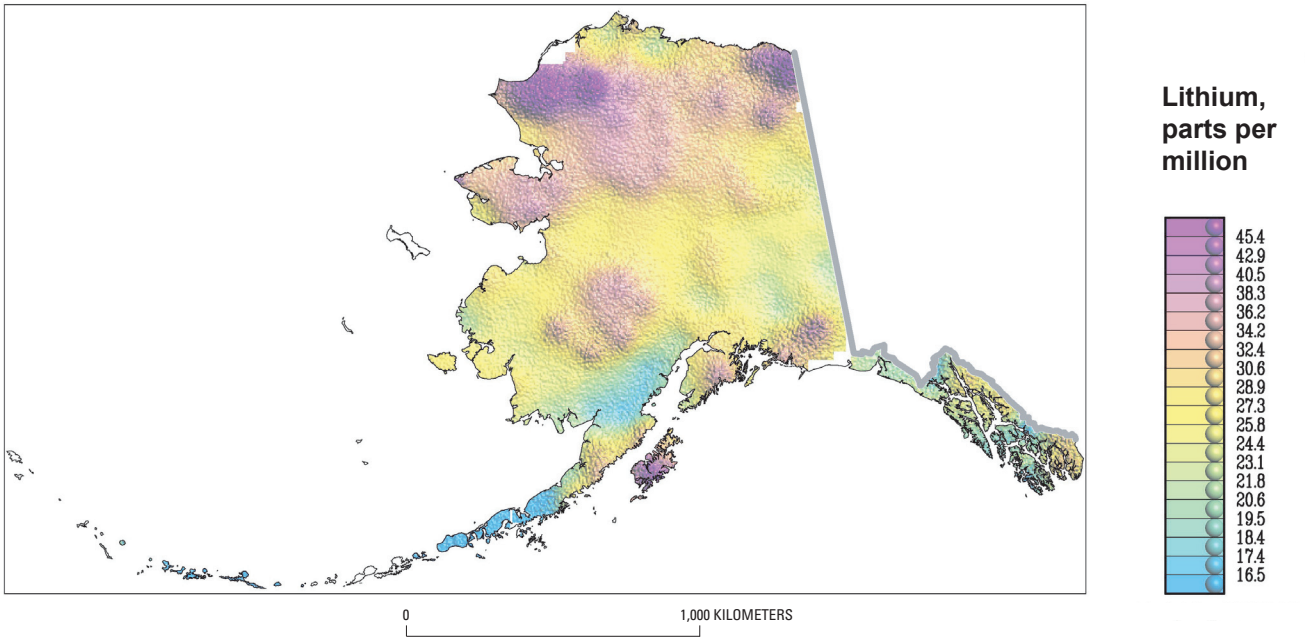


Figure 13. Colored surface map of lithium distribution in soils and other surficial materials of Alaska.

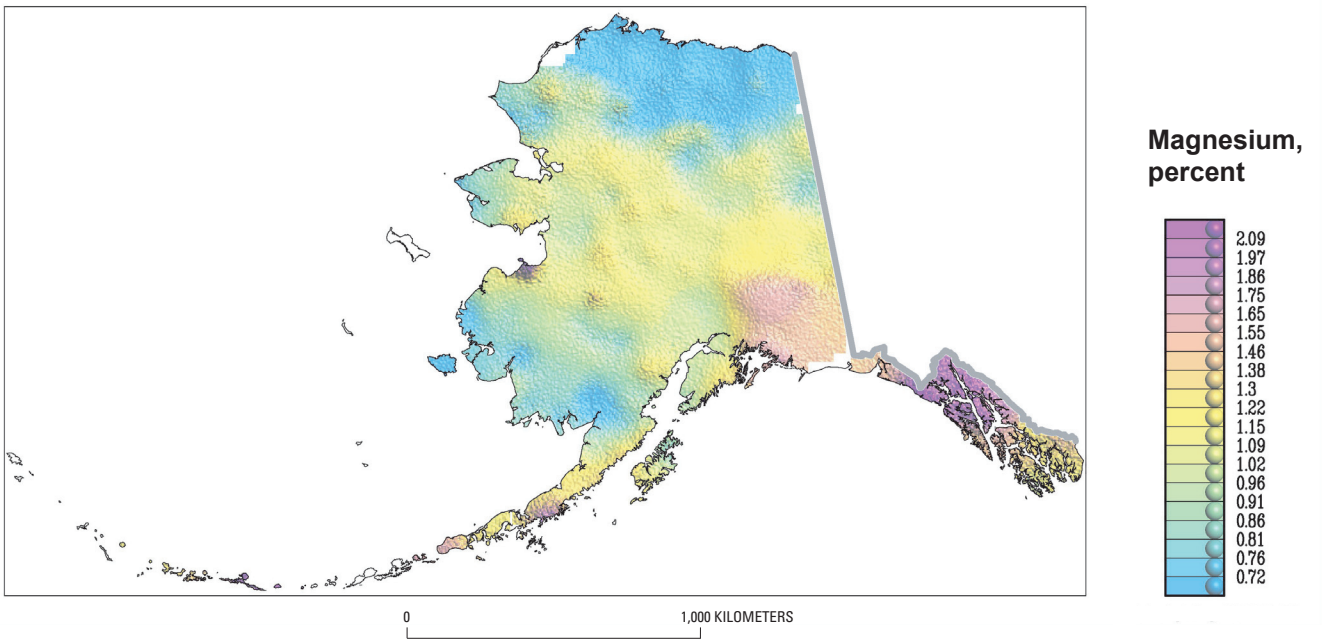


Figure 14. Colored surface map of magnesium distribution in soils and other surficial materials of Alaska.

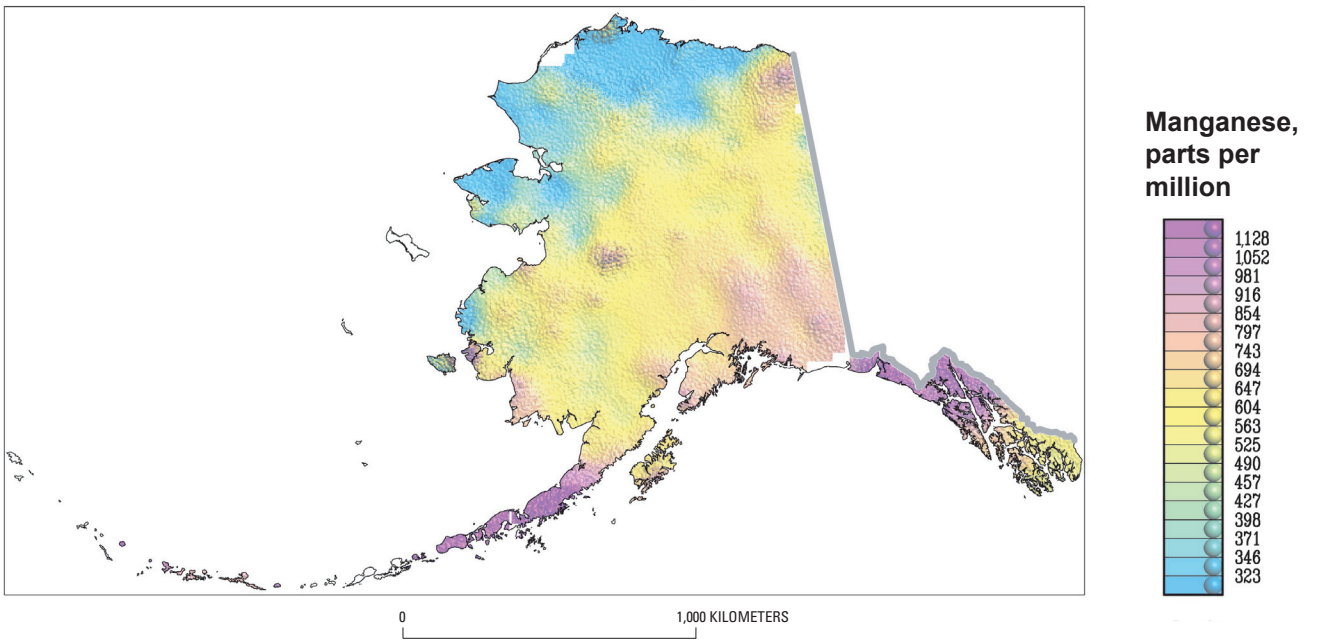


Figure 15. Colored surface map of manganese distribution in soils and other surficial materials of Alaska.

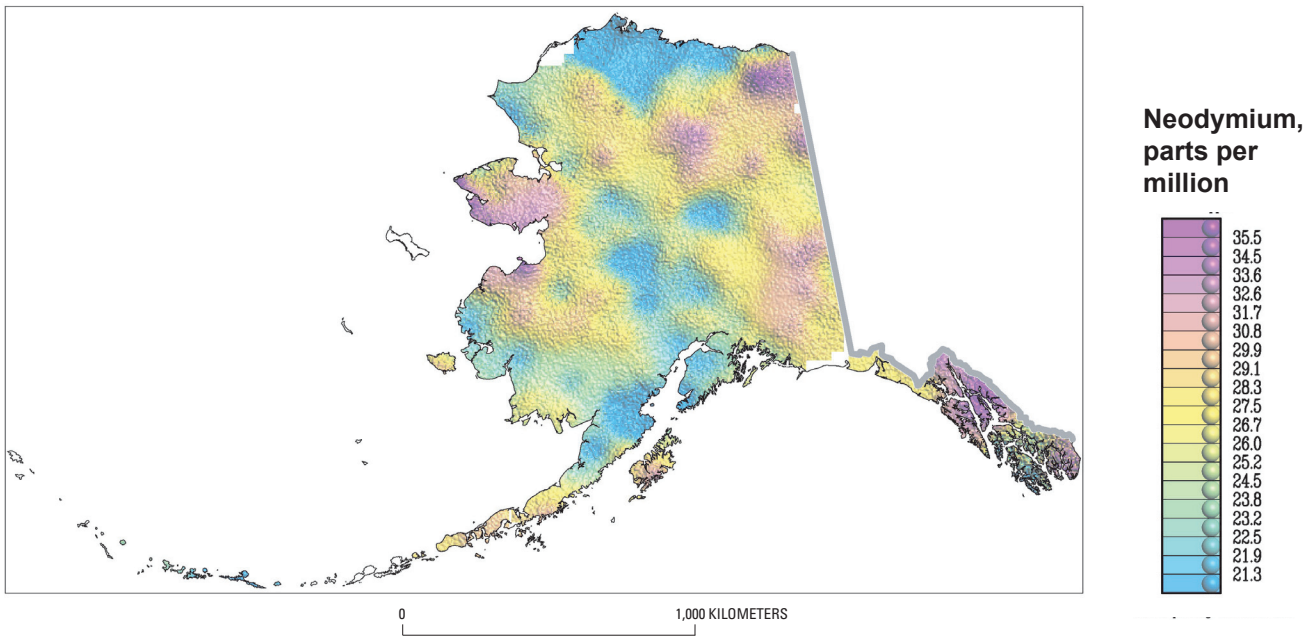


Figure 16. Colored surface map of neodymium distribution in soils and other surficial materials of Alaska.

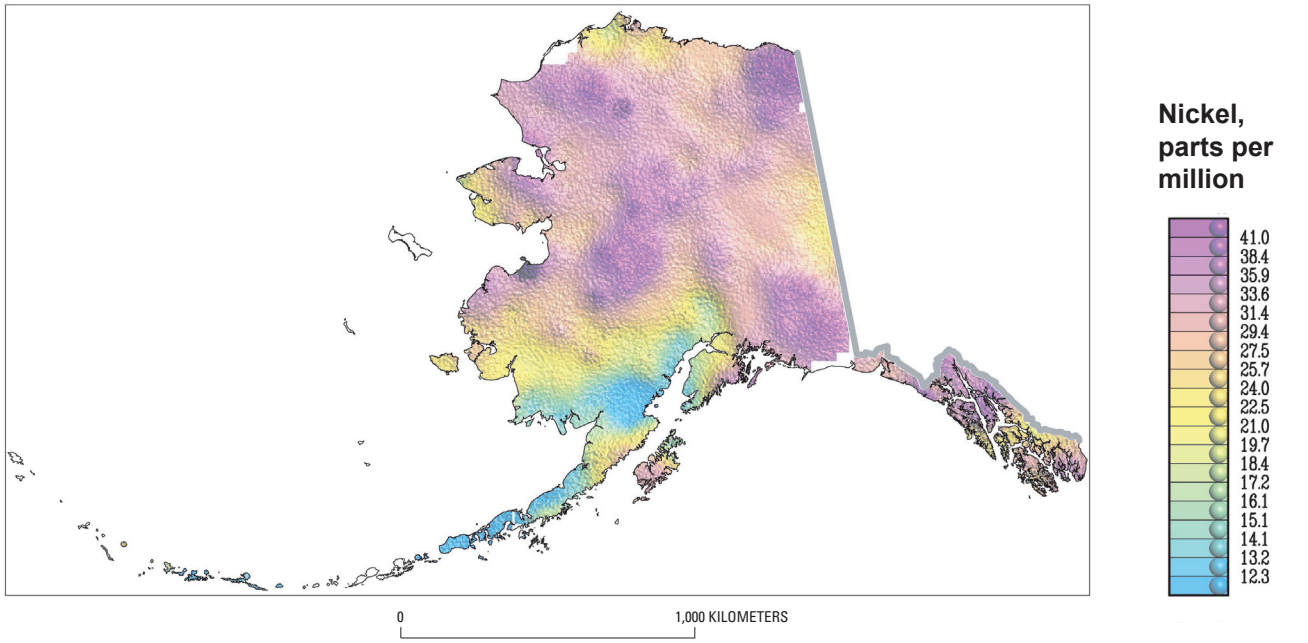


Figure 17. Colored surface map of nickel distribution in soils and other surficial materials of Alaska.

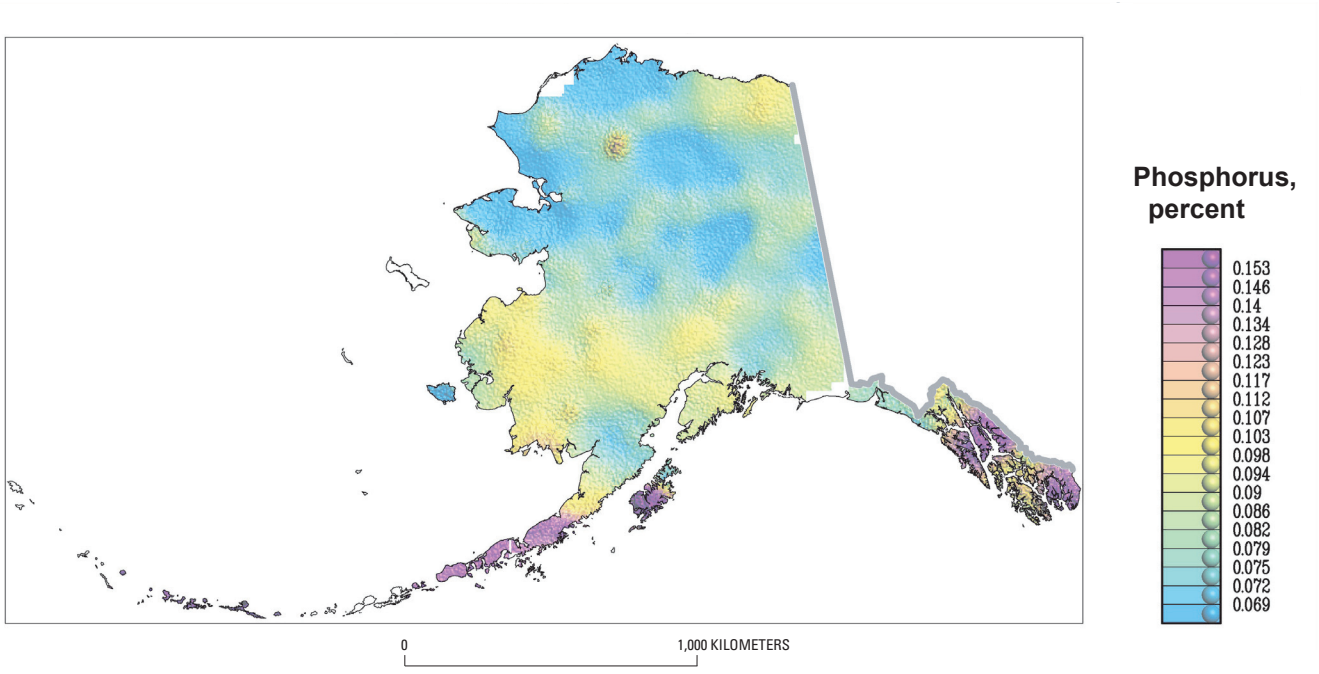


Figure 18. Colored surface map of phosphorus distribution in soils and other surficial materials of Alaska.

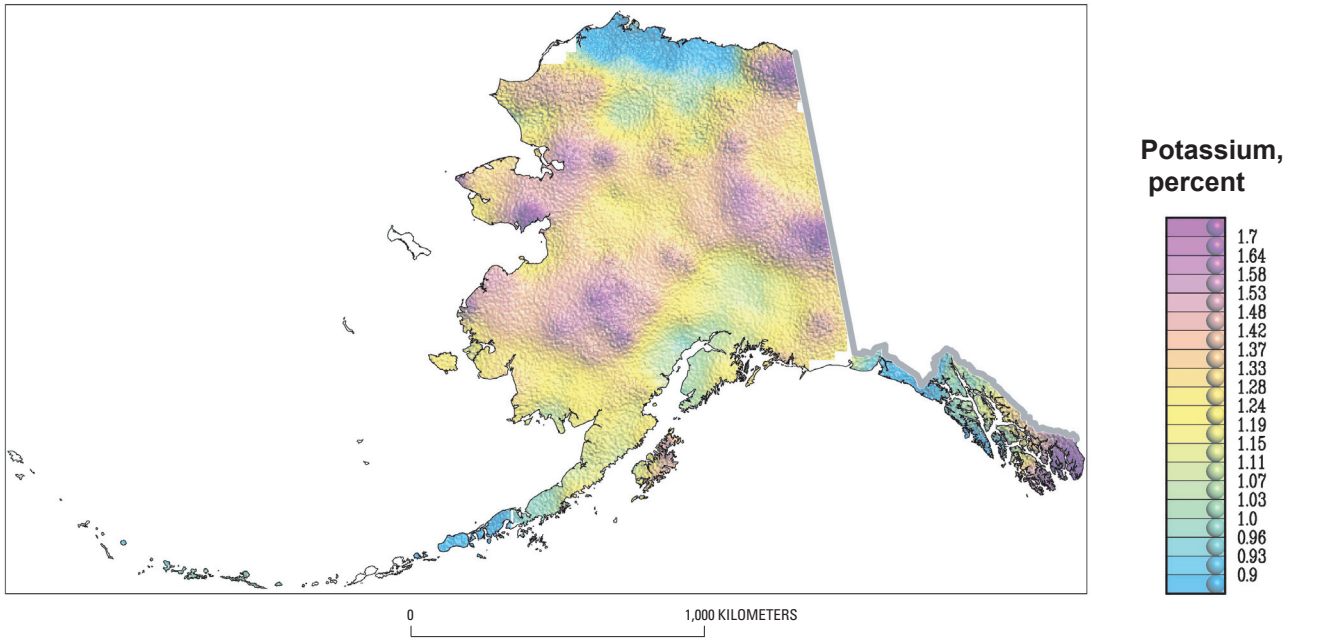


Figure 19. Colored surface map of potassium distribution in soils and other surficial materials of Alaska.

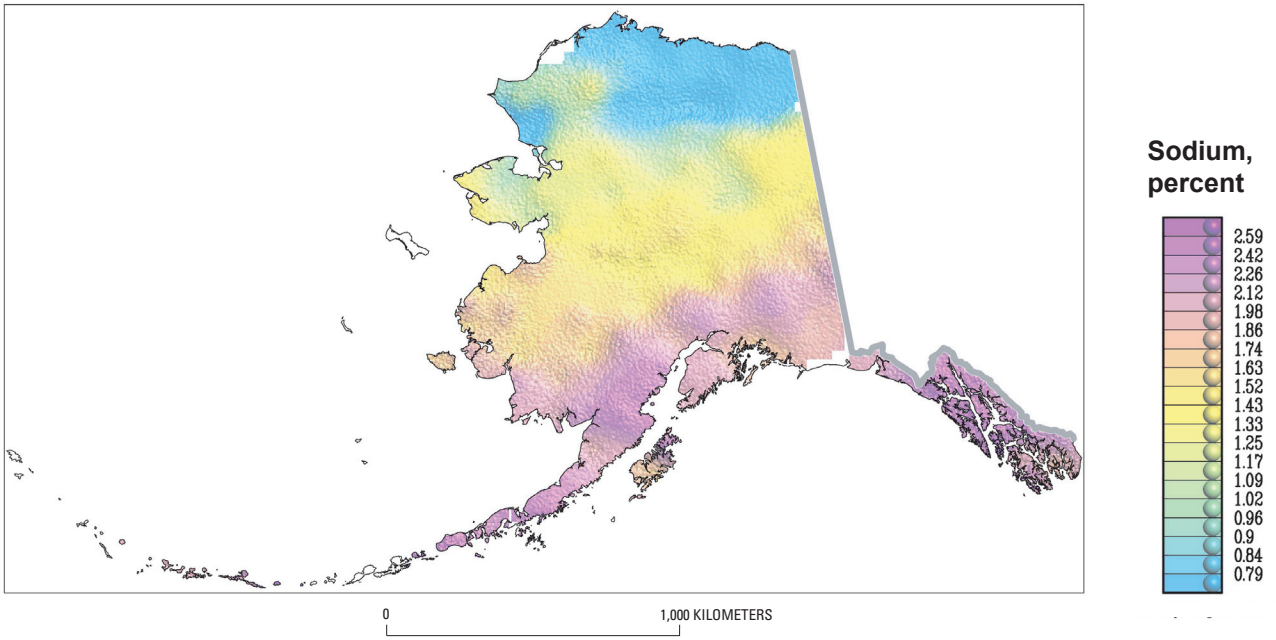


Figure 20. Colored surface map of sodium distribution in soils and other surficial materials of Alaska.

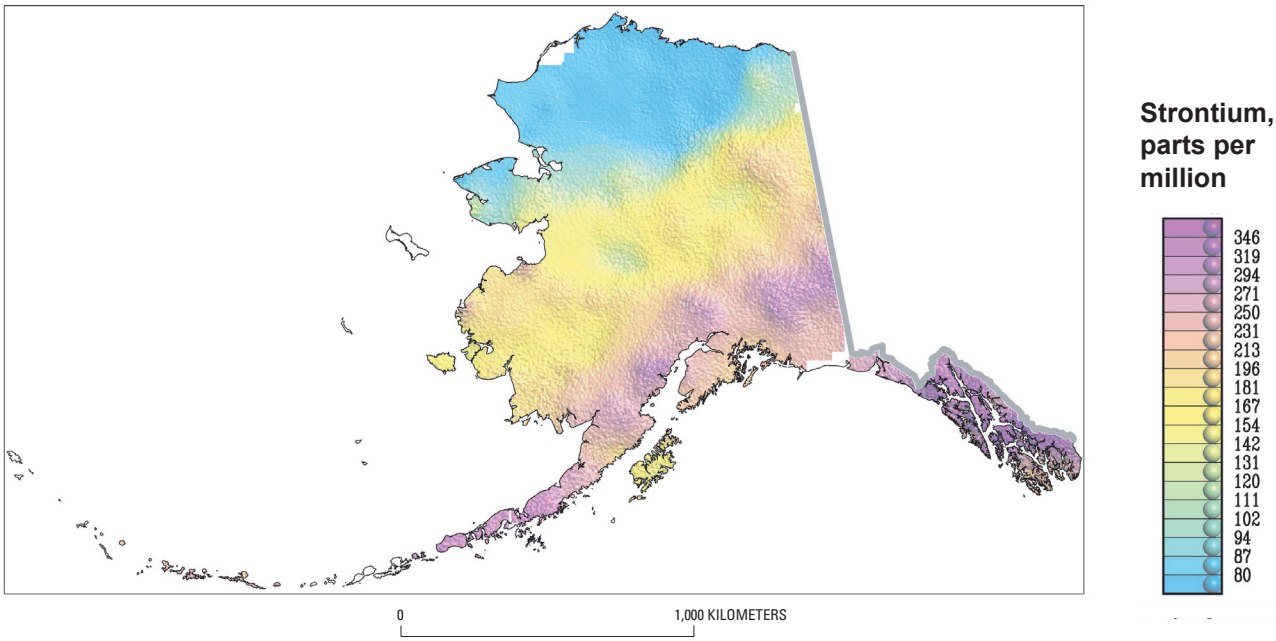


Figure 21. Colored surface map of strontium distribution in soils and other surficial materials of Alaska.

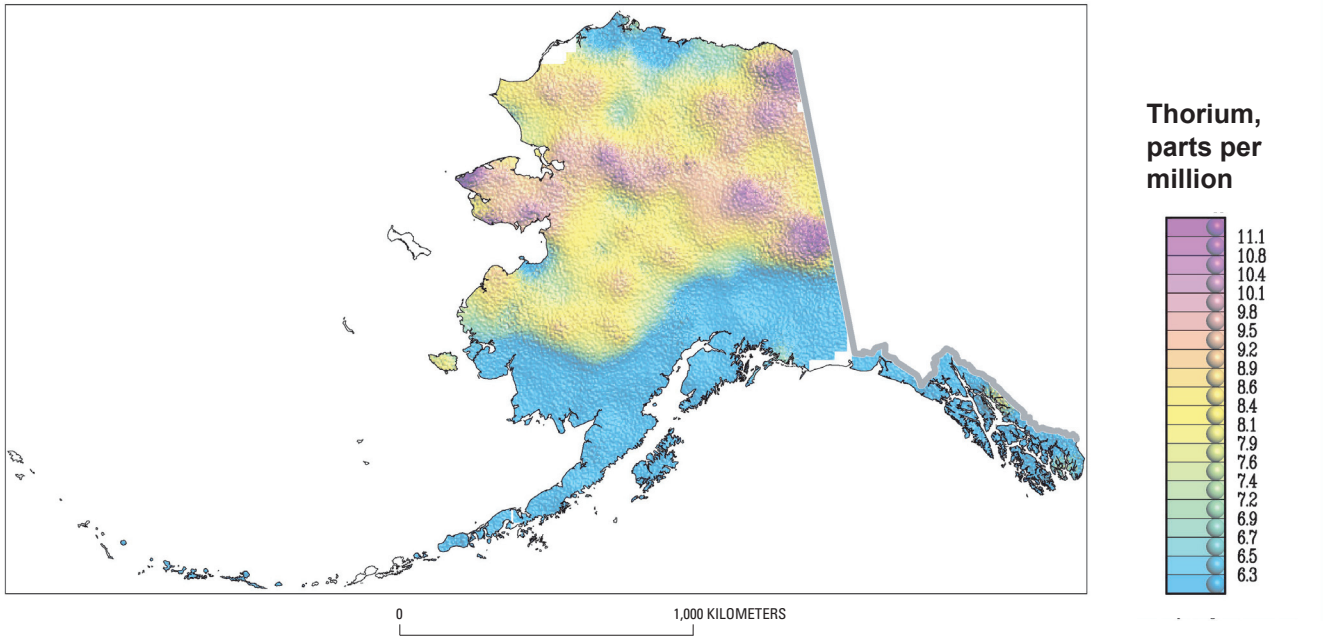


Figure 22. Colored surface map of thorium distribution in soils and other surficial materials of Alaska.

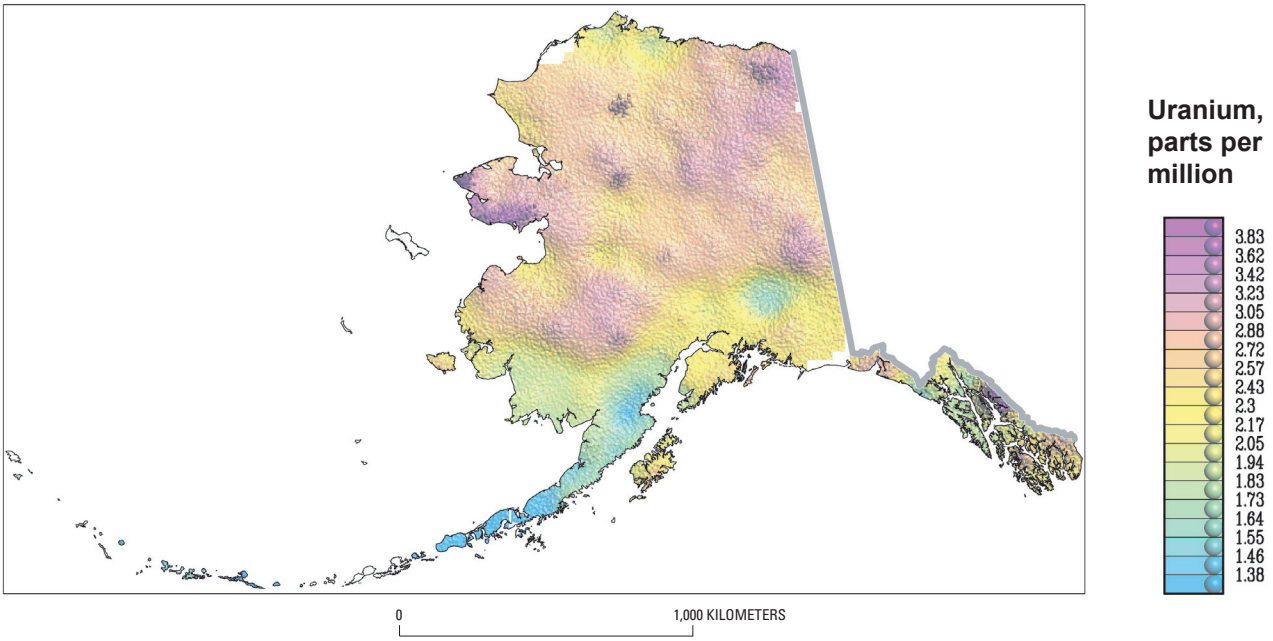


Figure 23. Colored surface map of uranium distribution in soils and other surficial materials of Alaska.

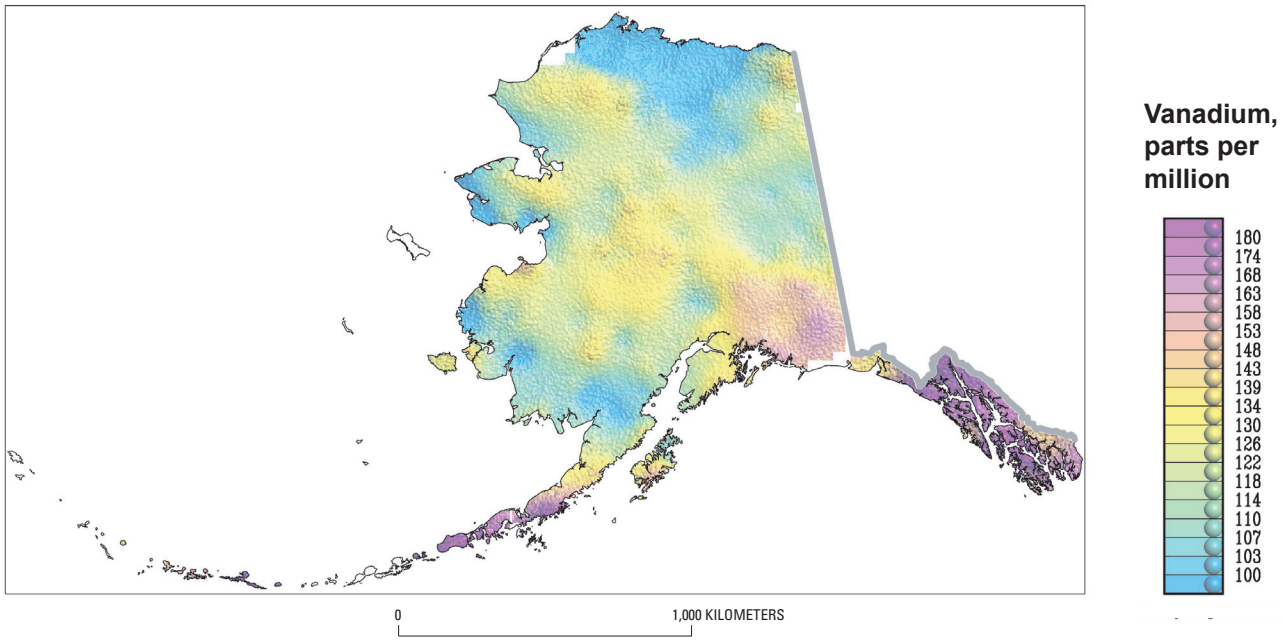


Figure 24. Colored surface map of vanadium distribution in soils and other surficial materials of Alaska.

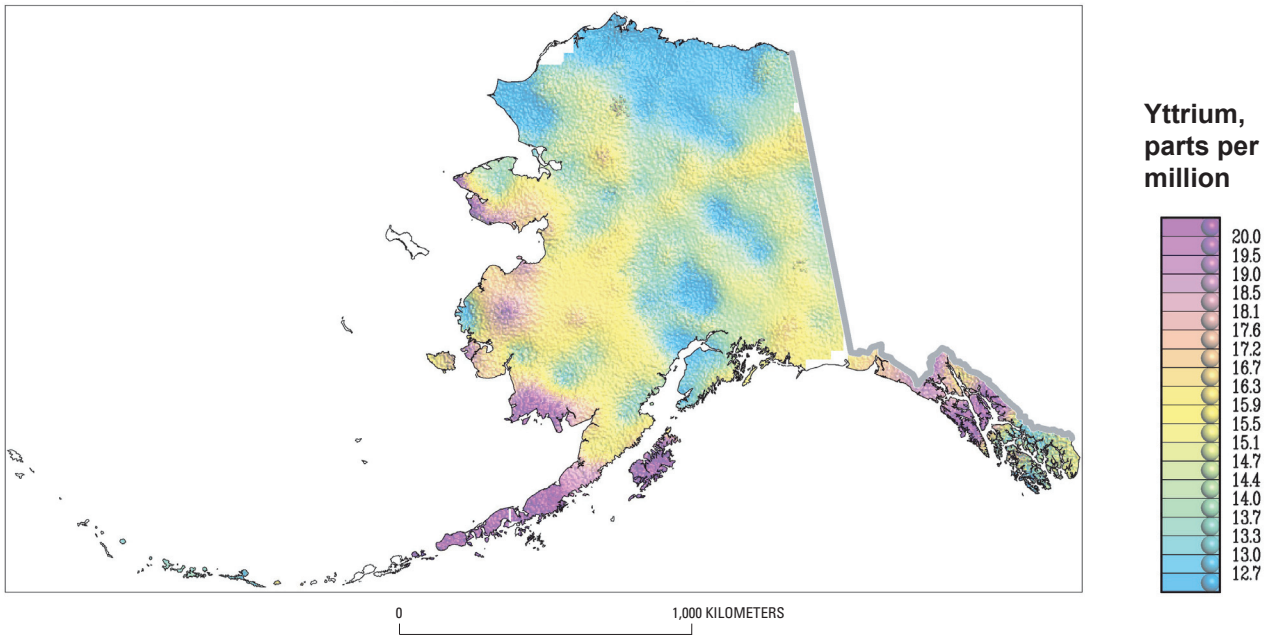


Figure 25. Colored surface map of yttrium distribution in soils and other surficial materials of Alaska.

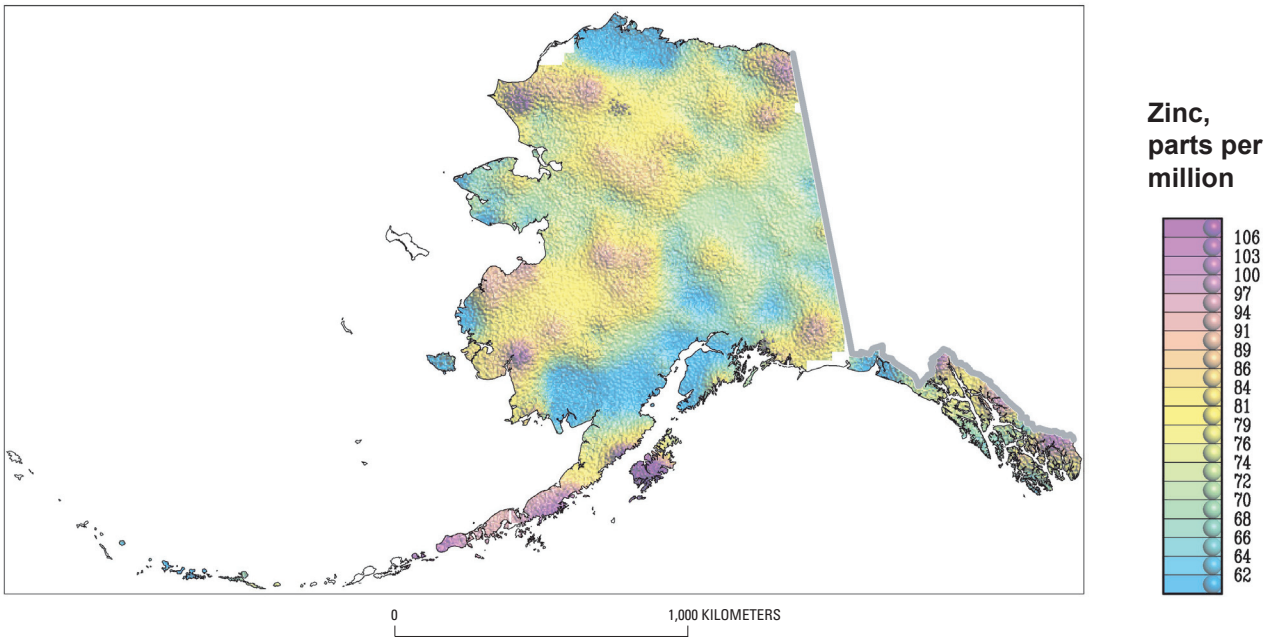


Figure 26. Colored surface map of zinc distribution in soils and other surficial materials of Alaska.

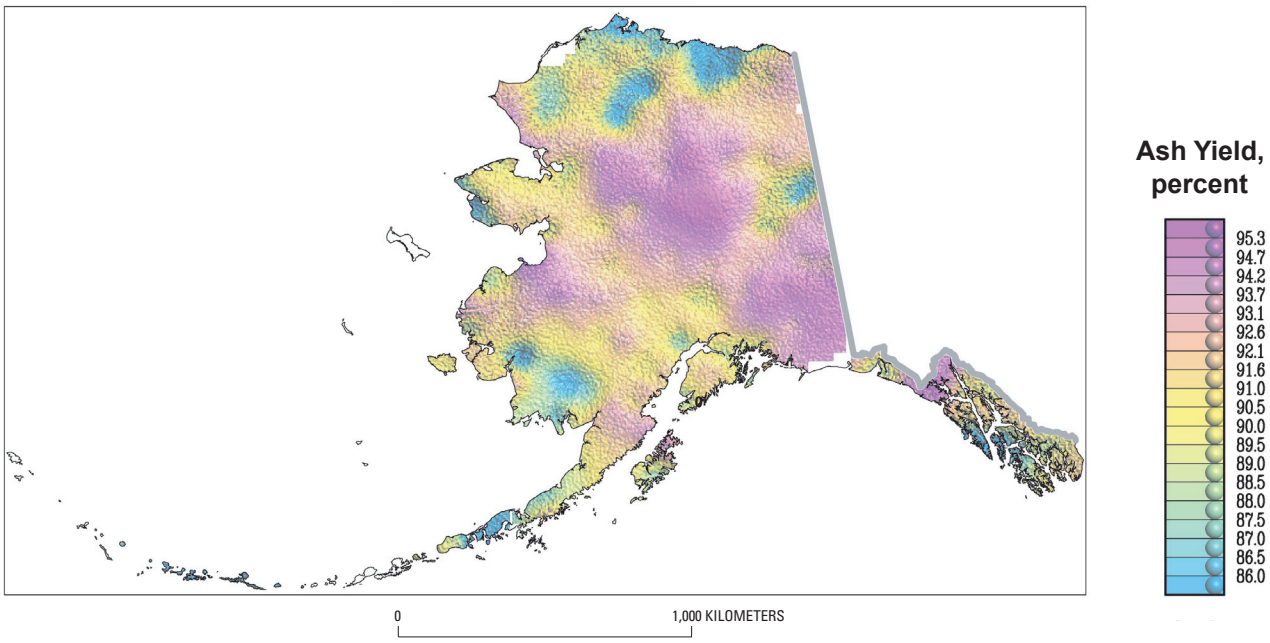


Figure 27. Colored surface map of ash yield of soils and other surficial materials of Alaska.

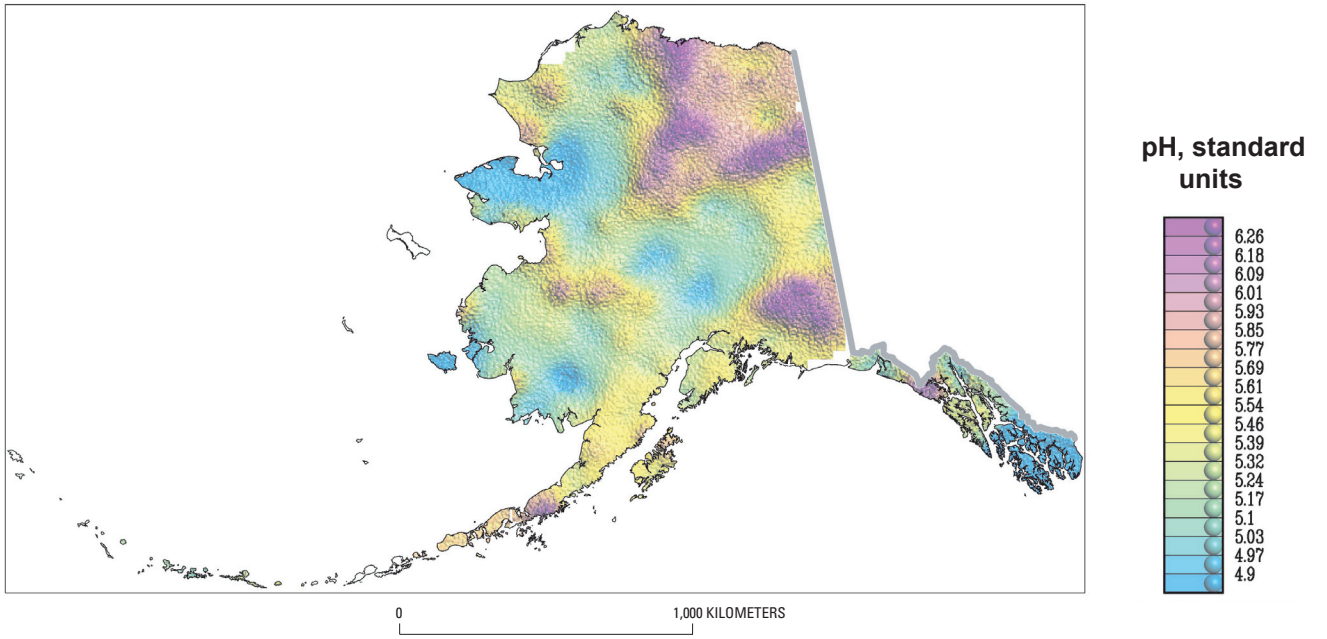


Figure 28. Colored surface map of pH of soils and other surficial materials of Alaska.

expected to be in proportion to the number of samples included in the area. As the number of samples decreases, the probability increases that the patterns are not reproducible. An interpretation of the partitioning of the variance components is illustrated by the values for calcium from the 1988 report (p. 11): "…87 percent of the total variance occurred among the [265] locations…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 duplicate samples at a location, thus indicating that calcium concentrations within locations are uniform and that sampling errors are small." This assessment of variance partitioning is the only measure of robustness for the low-density sampling data that we have; however, we feel confident that the "major" patterns shown in figures 4–28 are reproducible.

Some general observations can be made from these figures; for example, a prominent pattern is one of generally low concentrations of many elements in materials from Arctic oceanic tundra regions, as contrasted to their often high concentrations in samples from interior and southeastern Alaska. The pattern for sodium (fig. 20) is especially pronounced (see discussion in the section "Major Cation Landscape Correlation Patterns"). Similar but less distinct patterns are shown, for example, by the generally high values for magnesium (fig. 14) and low values for lead and zinc (figs. 11 and 26) in the coastal forest region of southeastern Alaska. Many elements occur at low concentrations in samples from the Alaska Peninsula and the Aleutian Islands (for example, chromium, lanthanum, and nickel, figs. 7, 12, and 17, respectively). In an attempt to interpret these and other patterns, we examine landscape units such as geology, ecoregions, vegetation zonation, soil types, climatic variables, and aspect. We also examine the role of chemical weathering and use factor analysis in order to identify patterns of element relationships. It is important to speculate about some of the observed regional patterns—for example, the relation of base metal patterns to mining districts or metallogenic provinces or of trace-element landscape features to human activity.

Bedrock as a Factor in Statewide Element Patterns

When weathered, some of the numerous primary minerals that make up the numerous bedrock types are variously decomposed. It is reasonable to assume that in areas that are mineralized or that are characterized by the presence of high concentrations of particular "marker" elements, the influence of bedrock could be noted in our samples (Gough and others, 1988). The importance of airborne silt (loess) to the geochemistry of soils in Alaska can confound the bedrock influence by introducing elements and minerals from lithologic units outside the area. In addition, chemical weathering soil-forming processes such as eluviation, illuviation, brunification, and podzolization can certainly mask subtle bedrock geochemical signatures (Campbell and Claridge, 1992). Under certain circumstances human activity can confound bedrock geochemical contributions. For example, the pattern for lead shown in figure 11 for the Yukon-Kuskokwim Lowlands (fig. 2) may be the result of lead shot from bird hunters (Grand and others, 1998; Wilson and others, 2004). This pattern, however, is greatly influenced by the lead values in only a few samples (fig. 1).

Several patterns appear to be bedrock related. Potassium, thorium, and uranium increase in concentration with differentiation in igneous melts. The map patterns for

potassium, thorium, and uranium (figs. 19, 22, and 23, respectively) are similar and correspond to the major granitic plutons throughout the State (for example, the late Cretaceous plutons of the Yukon-Tanana Upland [Foster and others, 1994] and the Kigluaik, Bendeleben, and Darby Mountains of the Seward Peninsula [Till and Dumoulin, 1994]). The pattern for nickel (fig. 17) may also show, in general, areas of igneous intrusions.

The statewide lead and zinc patterns (figs. 11 and 26, respectively) are difficult to interpret from strictly a bedrock geochemical perspective. However, the figure does show a high for the general western Brooks Range. This region has numerous, large Zn-Pb-Ag occurrences and deposits, including Red Dog and Lik, that are hosted in Mississippian limestones and dolostones (Kelley and Kelley, 1992).

Finally, the statewide pattern for barium (fig. 5) is intriguing in that the areas that show high concentrations of barium in soil in the interior (except for the Yukon Flats Basin, fig. 2) correspond roughly with flysch basins whose turbidite sources are lower Cretaceous and Jurassic marine sedimentary units (Dover, 1994).

Ecoregions and Vegetation Zonation

We classified each sampling site according to its occurrence within major ecoregion units (as presented by Nowacki and others, 2002). Table 4 gives the number of sites in our study that were assigned to each of the 32 units listed for Alaska. Each unit is represented by 1 to 19 samples; one unit (Kluane Ranges, a relatively small unit of dry, rugged mountains in the southeast corner of the State) lacked any sampling sites and was not represented.

In their most recent classification, Nowacki and others (2002) cluster the 32-ecoregion units into eight groups. For purposes of this study, however, we have adopted an earlier classification of Nowacki and Brock (1995) in which they use only five ecoregion divisions (analogous to the eight groups). This classification is simplified and more useful to our data presentation and discussion. We have combined the groups "Arctic Tundra" and "Bering Tundra" into the Arctic division, the "Bering Taiga" and "Intermontane Boreal" into the Subarctic division, and the "Alaska Range Transition" and "Coastal Mountains Transition" into the Warm Continental

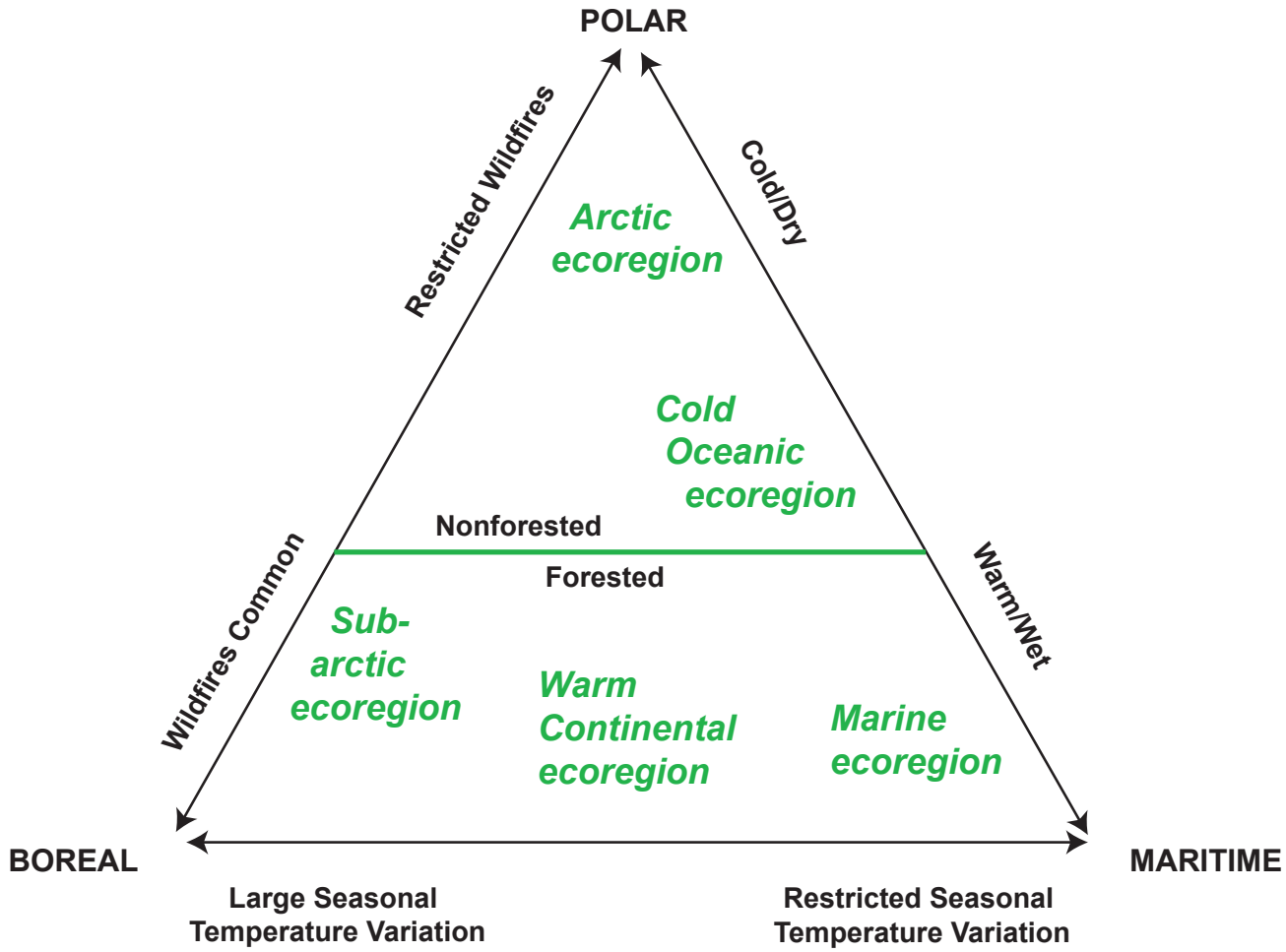


Figure 29. The relation among the five ecoregion divisions used in this report and polar, maritime, and boreal climatic and environmental characteristics of high-latitude regions (modified from Nowacki and Brock, 1995, and Nowacki and others, 2002).

Table 4. Number of sites in this study and their distribution among the major ecoregion groups in Alaska.

Ecoregion divisions[1]	Ecoregion groups[2]	Ecoregion units[2]	Number of sites	Approximate area, in kilometers^2 ($\times 10^6$)
Arctic				0.403
	Arctic Tundra			
		Beaufort Coastal Plain	16	
		Brooks Foothills	19	
		Brooks Range	17	
	Bering Tundra			
		Kotzebue Sound Lowlands	4	
		Seward Peninsula	15	
		Bering Sea Islands	1	
Subarctic				
	Bering Taiga			0.773
		Nulato Hills	9	
		Yukon-Kuskokwim Delta	9	
		Ahklun Mountains	5	
		Bristol Bay Lowlands	5	
	Intermontane Boreal			
		Kuskokwim Mountains	12	
		Yukon River Lowlands	5	
		Kobuk Ridges and Valleys	8	
		Ray Mountains	7	
		Tanana-Kuskokwim Lowlands	11	
		Yukon-Tanana Upland	14	
		Yukon-Old Crow Basin	11	
		Davidson Mountains	2	
		North Ogilvie Mountains	2	
Warm				0.215
	Alaska Range			
		Lime Hills	2	
		Cook Inlet Basin	12	
		Alaska Range	15	
		Copper River Basin	7	
	Coastal Mountains			
		Wrangell Mountains	1	
		Kluane Ranges	0	
Marine				0.212
	Coastal Rainforests			
		Kodiak Island	4	
		Gulf of Alaska Coast	9	
		Chugach-St. Elias Mountains	7	
		Northern Coast Mountains	3	
		Alexander Archipelago	13	
Cold				0.065
	Aleutian Meadows			
		Aleutian Islands	6	
		Alaska Peninsula	14	

[1] After Nowacki and Brock (1995).
[2] From Nowacki and others (2002).

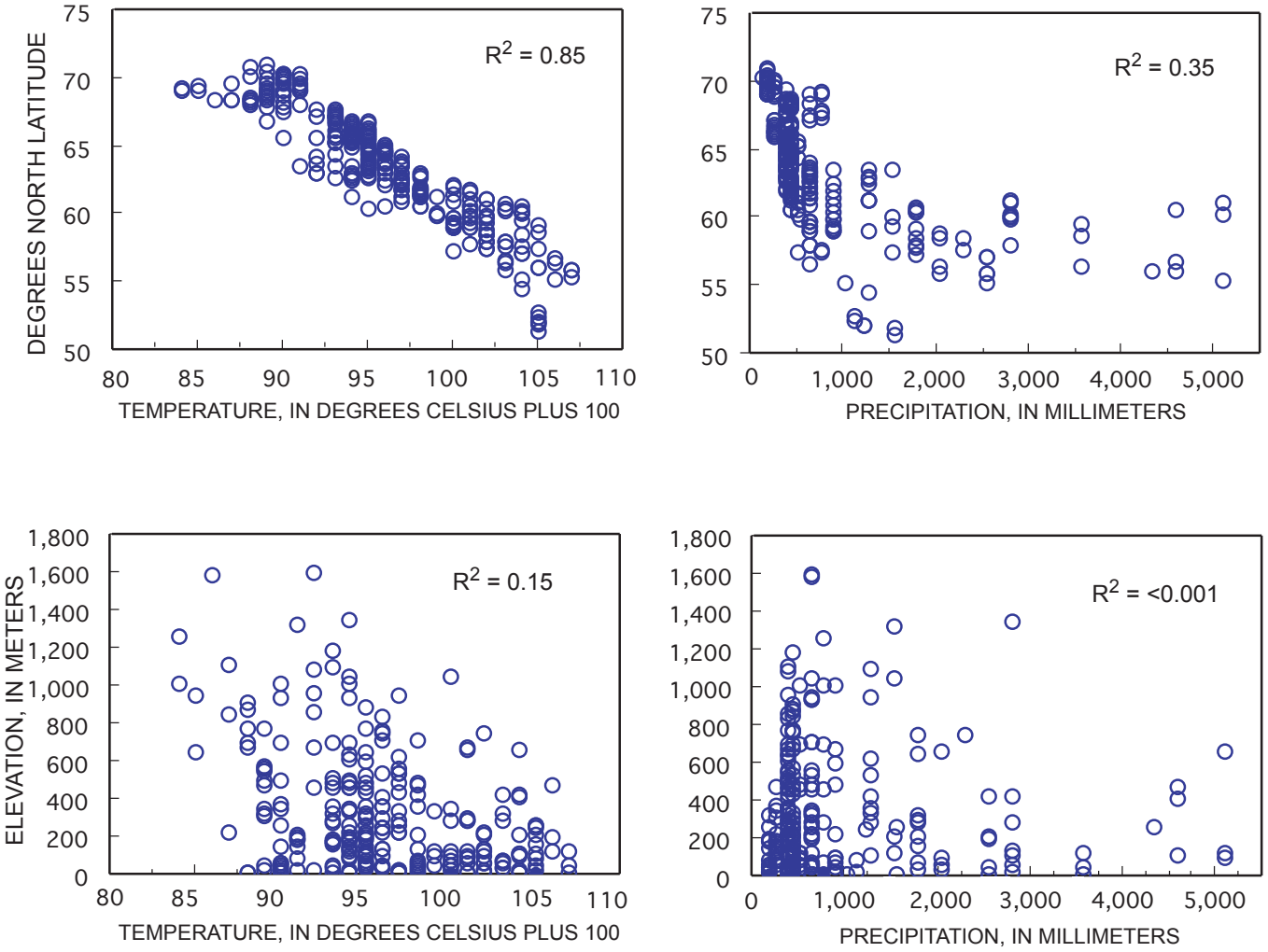


Figure 30. Simple linear regression plots of latitude relative to temperature and precipitation, and elevation relative to temperature and precipitation for the 265 soil and surficial-materials sampling sites.

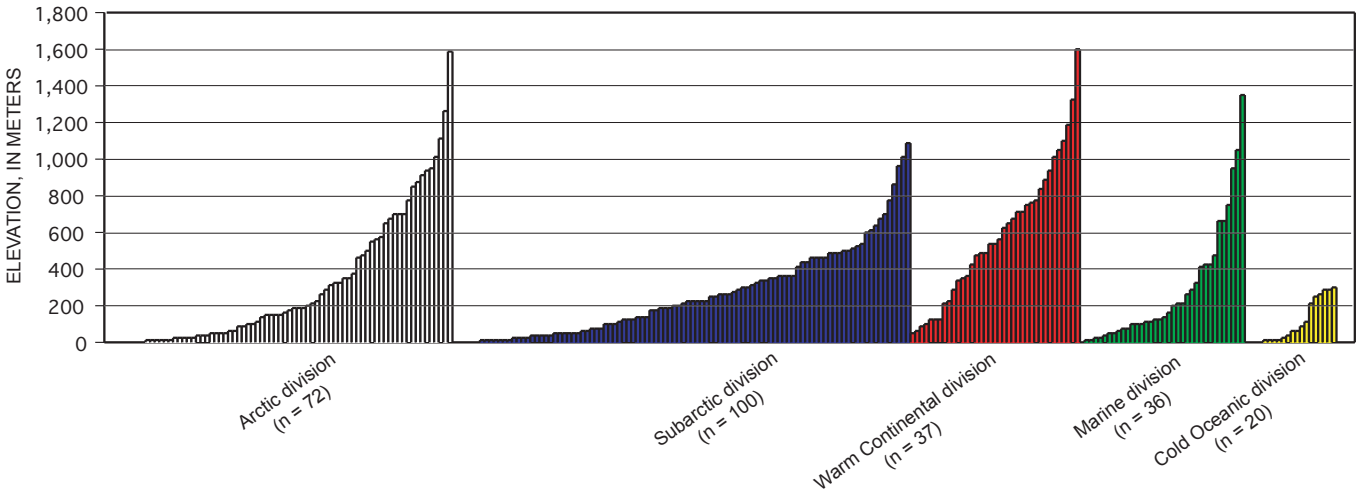


Figure 31. Plot of the elevation of individual soil and surficial-materials sampling sites segregated by ecoregion division.

division. The other two divisions, Marine and Cold Oceanic, correspond with the "Coastal Rainforests" and "Aleutian Meadows" groups, respectively (table 4). As with any classification, these groupings are subject to debate; they do, however, conform not only to the work of Nowacki and colleagues but also to works by Bailey (1995) and Gallant and others (1995). Table 4 shows the clustering of ecoregion units within groups and groups within divisions.

Nowacki and others (2002) present a ternary diagram of the relation among polar (nonforested, restricted wildfires, cold, and dry), maritime (forested, warm, wet, with restricted seasonal temperature variation), and boreal (forested, with wildfires, and with large seasonal temperature variation) environmental factors to their 32-ecoregion classification. Figure 29 is a modification of their diagram that more closely fits our purposes and shows the relation among the five ecoregion divisions we use and these same environmental factors.

The Cold Oceanic ecoregion division is characterized in the southwestern coastal areas of Alaska south of the Bering Strait by tundra vegetation of low shrubs, mosses, and lichens and the scarcity or absence of trees (Hultén, 1981; Nowacki and others, 2002). 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 skies, are the cause (Shacklette, 1969). The temperate maritime climatic belt of southern and southeastern Alaska (Marine ecoregion division) 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. The Subarctic ecoregion division, which has a cold and dry continental climate with great extremes in temperature, is prevalent in a large part of central Alaska. This region is characterized by white spruce-birch forests and well-developed bogs and muskegs (Van Cleve and others, 1983; Nowacki and others, 2002). A podzolized soil layer (typical of Spodosols) is present here; however Gelisols are most prevalent (Soil Survey Staff, 1999). Tundra vegetation is dominant over much of the North Slope and Bering Sea coast (Arctic ecoregion division) where the temperatures are low at all seasons, with even the warmest months having a mean temperature lower than 10ºC. This area is largely without trees but has an abundant shrub, bryophyte, and lichen ground cover. Tree line, both at high latitudes and at high elevations, is changing in response to climate change (global warming). The advance of trees along the ecotone between boreal forests and tundra is already having an effect on plant community structure, carbon cycling, and soil development (Grace and others, 2002). The high northern mountains are cold, very dry, and windy, and the mean temperature is below 3ºC. This area is a polar desert and has sparse, low-growing vegetation; the soils are mainly Gelisols and Inceptisols (Soil Survey Staff, 1999).

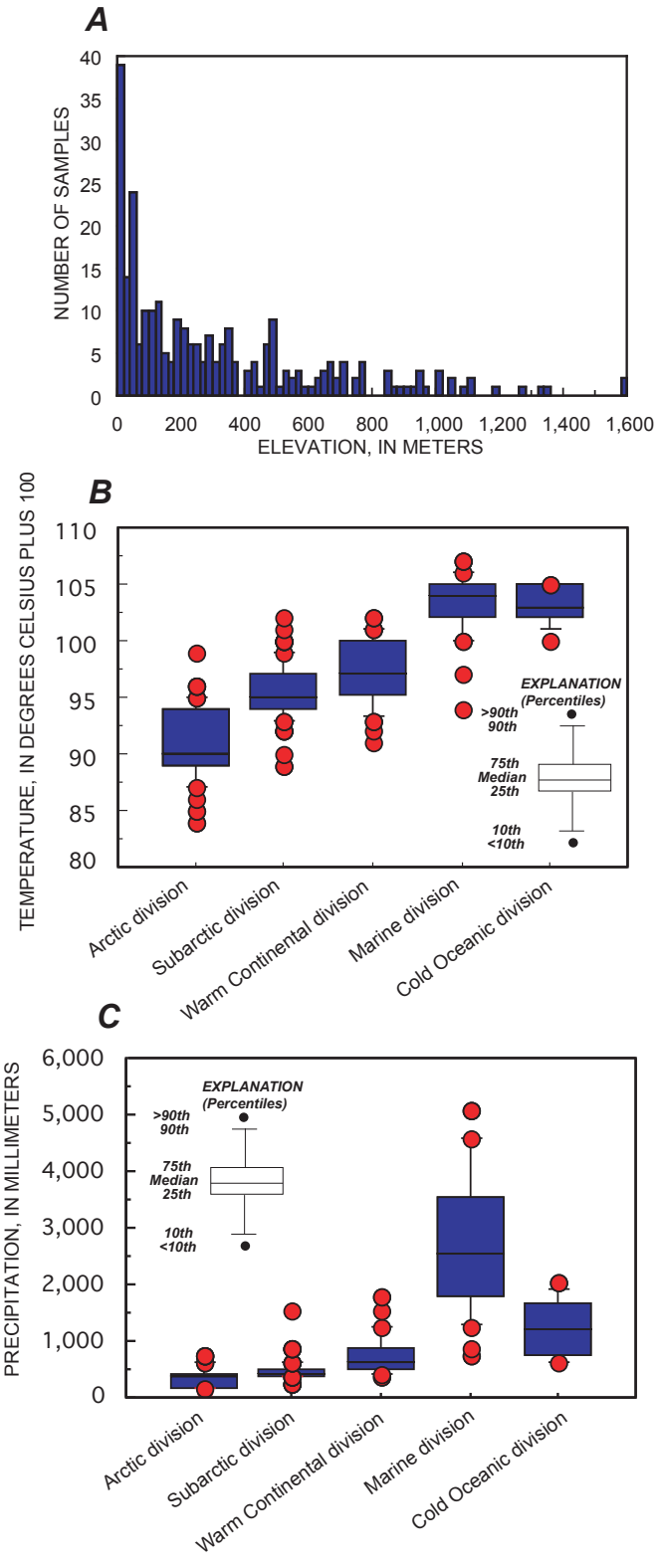


Figure 32. *A*, Graph showing the number of soil and surficial-materials sampling sites relative to elevation; *B*, box plots of temperature at soil and surficial-materials sampling sites segregated by ecoregion division; *C*, box plots of precipitation at soil and surficial-materials sampling sites segregated by ecoregion.

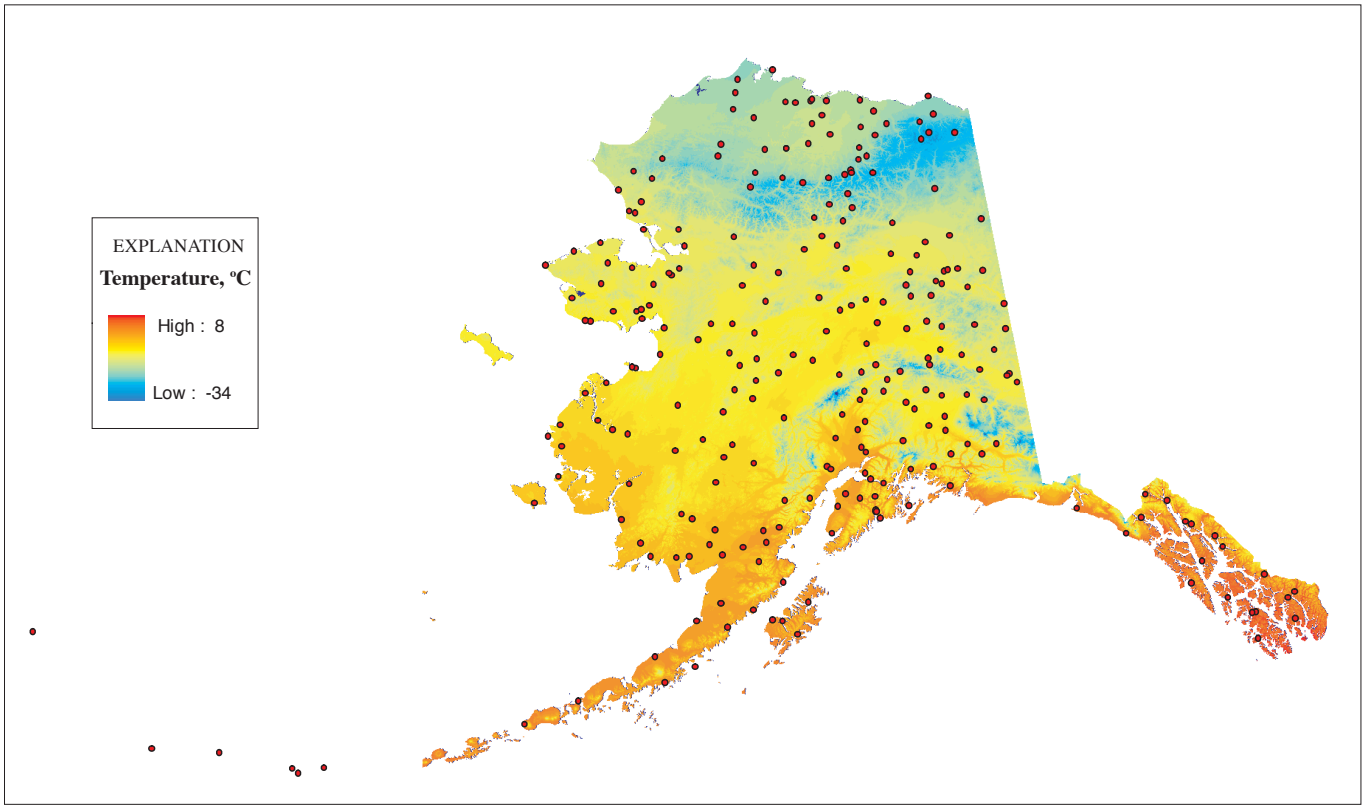


Figure 33. Temperature map of Alaska with the placement of the 265 soil and surficial-materials sampling sites.

Latitude, Elevation, Temperature, and Precipitation

The soil-sampling sites are widely distributed over Alaska and range from about 51.4° to 71.1° N. latitude and about 131.1° to 179.2° W. longitude. This range encompasses a wide variety of climatic and environmental conditions (figs. 29, 30, and 31). To investigate the effects of the physical landscape on the geochemical distribution and processes in these soils, values for mean annual ambient temperature, mean annual precipitation, and elevation were ascribed to each data point by using the statewide temperature, precipitation, and digital elevation models (http://agdc.usgs.gov).

The number of data points representing each of the five ecoregions varied from 20 (Cold Oceanic) to 100 (Subarctic) (fig. 31) and is proportional to the land cover of the divisions (table 4); that is, the larger ecoregions are represented by larger numbers of samples. Figure 32*A* is a frequency distribution of the number of samples collected compared to elevation and shows that most samples came from areas with elevations less than about 500 m (with a range of less than 1 to more than 1,600 m). In figure 31 the samples are arranged within each ecoregion by increasing elevation, and except for the Cold Oceanic ecoregion division, all have some data points that were collected at 1,000 m or greater. This elevation spread in the data produces wide variation in the types of plant communities and soils present. For example, even in the Marine ecoregion division, which is perceptually dominated by rainforests and deep, organic-rich soils, some of the sampling sites were above tree line (which, depending on aspect, varies from about 500 to 800 m).

Within the soils dataset, the mean annual ambient temperature varied among the sites from –16°C to 7°C with a median value of –5°C. Figure 33 shows the continuum of mean annual temperatures for the State and the distribution of data points. Figure 32*B* is a box plot showing the median and distribution of temperatures for the sites within each of the five-ecoregion divisions (table 4). Except for the Cold Oceanic division, the ecoregions show large variability in their temperature data. Mean annual ambient temperature is used in soil taxonomy in conjunction with mean annual soil temperature to define soil groups. Figure 30 gives the relation between latitude and ambient annual temperature for the study sites; as expected, a fairly linear relation exists ($R^2 = 0.85$). Figure 30 also shows the relation between elevation and ambient annual temperature. Although in general, ambient temperature decreases with decreasing elevation, this relation is not strong ($R^2 = 0.15$) and is certainly mediated by latitude, the proximity to maritime influences, and other geographic and environmental factors.

Soil temperatures in the high latitudes can vary greatly. Many Alaska soils are underlain by permafrost (Gelisols), experience cryoturbation, and have only a shallow (tens of

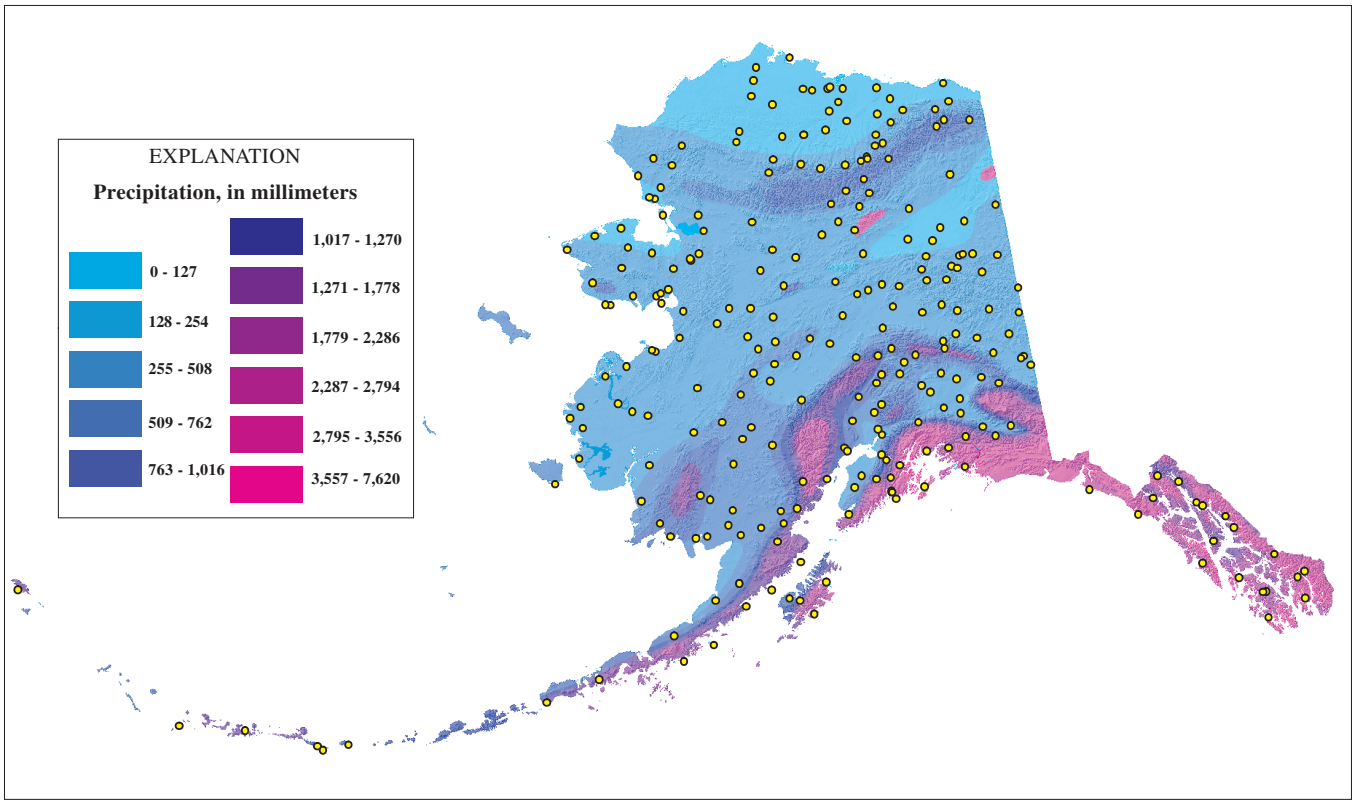


Figure 34. Precipitation map of Alaska with the placement of the 265 soil and surficial-materials sampling sites.

centimeters) active layer. In the summer months these soils, when insulated by a thick (about 8 cm) mat of bryophytes and lichens, seldom are exposed to soil temperatures much above 1 to 3ºC. Conversely, in mid-July we have measured soil temperatures in a year-old burned forested area, with low surface albedo (fire-blackened surface) and with no vegetative canopy, as follows: 1 cm depth, 26.0ºC; 2.5 cm, 19.4ºC; 7.5 cm, 5.3ºC; 22.5 cm, 2.8ºC; and 51.0 cm, 0.2ºC (permafrost was at 52-cm depth).

Mean annual precipitation for the data points ranged from 130 to 5,100 mm. Figure 32*C* displays box plots for the range of precipitation values for each of the five ecoregions, and figure 34 shows the continuum of precipitation across the State with the position of our data points. Examination of the box plots for temperature and precipitation (fig. 32*B*, 32*C*) helps one visualize the climatic variability that is inherent in the figure 29 ternary diagram. Figure 30 shows the relation between latitude and precipitation and elevation and precipitation. The former shows a downward linear trend ($R^2 = 0.35$), whereas elevation and precipitation appear to be totally independent. This may seem counterintuitive; however, some of the wettest places in Alaska are at lower elevations in the Marine ecoregion division. Also, our sites do not include elevations above 2,000 m where precipitation is heavy and areas of snow and ice can persist year-round.

Soils, Surficial Materials, and Geomorphology

The most recent Natural Resources Conservation Service (NRCS) broad-scale characterization of Alaska soils is included in their 1999 compilation (Soil Survey Staff, 1999). This publication incorporates the latest soil-classification system but unfortunately does not have the regional detail that was included in an earlier publication (Reiger and others, 1979). In addition, State and Federal agencies, native groups, and local soil conservation groups have jointly published a number of more local soil surveys (see, for example, Van Patten, 1990). These studies variously divide the State into 15 land-resource areas based on soil type that in turn reflect surficial geology, geomorphology, climate, and vegetation. At present only a very small percentage of Alaska's large land area has some soil map coverage and the areas that have been mapped are of possible agricultural interest (crop and range lands), are related to resource development (oil and gas drilling), or have an engineering interest (infrastructure construction). Of the 12 global soil orders in the classification system, Alaska has 6 (Soil Survey Staff, 1999). Of these, Gelisols, Inceptisols, and Spodosols are dominant, covering most of the land surface both north and south of the Alaska Range.

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 or to the development of mined lands (Gough and others, 1982; Severson and Gough, 1983; McKendrick, 1991; Helm

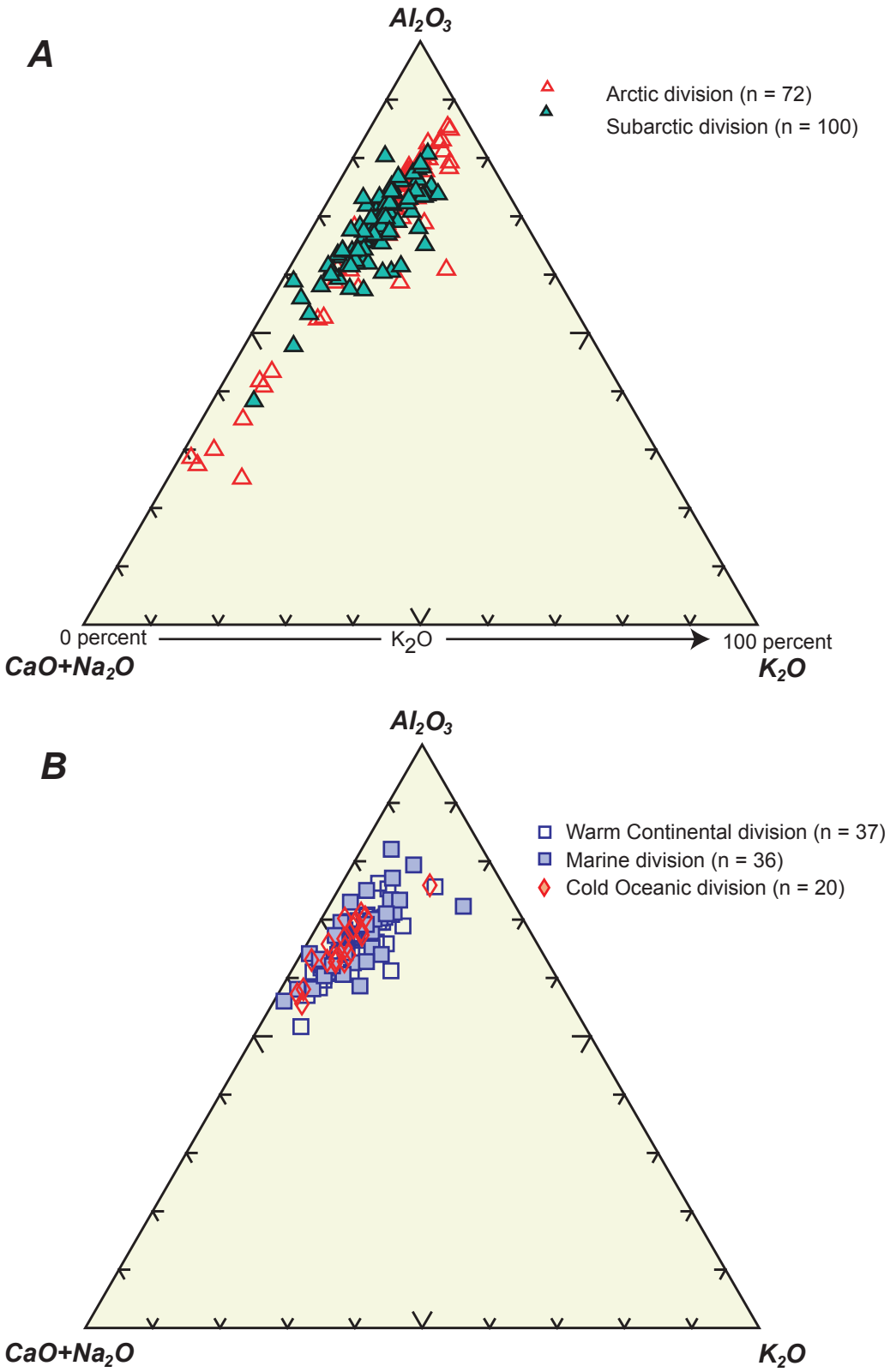


Figure 35. Feldspar weathering ternary plots of sampling sites segregated by ecoregion division. *A*, gives the segregation of the Arctic and Subarctic sampling sites; *B*, gives the segregation of the Warm Continental, Marine, and Cold Oceanic sampling sites.

Table 5. Eigenvalues in a five-factor principal components analysis using the log concentration of major soil cations and soil organic matter, soil pH, and regional environmental parameters including latitude.

Factor	Eigen-value	Percentage of total variance explained	Cumulative percent
1	5.37	34	34
2	2.08	13	47
3	1.97	12	59
4	1.76	11	70
5	1.04	7	77

Table 6. Factor analysis results for 263 surficial-materials samples using the log concentration of 10 major soil cations, organic matter, and pH and four regional environmental parameters including latitude.

[Within each factor, the variables with loadings identified as important in the discussion are in bold type]

Factor analysis summary	
Factor extraction method: Principal components	
Transformation method: Orthotran/varimax	
Variables: (1) total log concentrations of Al, Ca, Fe, Mg, Mn, P, K, Si, Na, and Ti; (2) sample organic matter and pH; (3) sample elevation, temperature, precipitation, and latitude	
Solution type: Orthogonal	
Number of variables:	16
Number of factors:	5
Number of cases:	263
Degrees of freedom:	135
Bartlett's chi square:	3,149
p-value:	<0.0001

Variable	Factor 1	2	3	4	5
	Factor loading				
Precipitation	0.142	**0.552**	–0.010	–0.169	–0.242
Temperature	–0.097	**0.885**	0.002	–0.048	–0.041
Elevation	0.376	**–0.513**	–0.057	0.097	0.033
Latitude	0.002	**–0.789**	0.042	0.023	–0.016
Soil organic matter[1]	–0.268	–0.090	**0.902**	–0.104	–0.003
Soil pH	–0.064	–0.246	–0.130	**0.833**	0.008
Aluminum	**0.426**	0.295	–0.026	–0.067	**0.445**
Calcium	–0.012	0.161	0.248	**0.775**	–0.016
Iron	**0.821**	–0.036	0.001	–0.085	–0.109
Magnesium	0.370	–0.001	–0.007	**0.417**	–0.053
Manganese	**0.516**	0.003	0.157	0.249	0.011
Phosphorus	0.139	–0.101	**0.710**	0.064	0.109
Potassium	–0.058	–0.066	–0.027	–0.010	**0.906**
Silicon	–0.104	–0.045	**–0.686**	–0.150	0.188
Sodium	0.001	**0.679**	–0.211	0.139	–0.287
Titanium	**0.765**	0.001	0.068	–0.251	–0.036

[1] Weight percent lost on ignition (500°C).

and Carling, 1993). These investigations have emphasized chemical characteristics of soil, as this type of information is necessary for the proper management of reintroduced plant rehabilitation species, pasture enhancement, and small grain production. The intent of these studies usually is to identify characteristics of soil types, including their major-element content, on a very local scale. Attention to the trace-element chemistry of soils in these surveys has been limited and usually includes only the essential trace elements of interest to soil fertility assessments.

Landscape Controls and the Weathering Profile

As noted, within the large area of Alaska, great differences in climate exist. The mean annual temperature and mean annual precipitation, both of which are fundamental to the formation of mature soils, decrease from south to north (figs. 33 and 34). In mountainous areas, precipitation and temperature both exhibit a strong orographic effect. Mean annual temperatures range from –34°C in the extremely high elevation regions of the Alaska Range and Wrangell–Saint Elias Mountains to 8ºC in the lower elevations of southeast Alaska. Precipitation ranges from less than 130 mm in the high Arctic to more than 2,500 mm annually in the mountains of the Marine ecoregion division. The combination of extreme relief and moist marine air results in the very high precipitation that feeds the glaciers of southeast and south-central Alaska. In contrast, the Seward Peninsula receives only 250 to 430 mm of precipitation annually, despite being nearly surrounded on three sides by ocean. The wide variation in climate greatly influences the geochemical cycles. A cold climate reduces the rate of chemical weathering and, at the same time, 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 and biological weathering is more intense.

Feldspar minerals account for between 70 and 80 percent of minerals in the Earth's upper crust (Nesbitt and Young, 1984). Unlike minerals such as quartz, muscovite, and hydrous aluminum silicates, feldspars are considered labile and decompose (weather) relatively easily (van Breemen and Buurman, 1998). Nesbitt (1992) discusses the use of feldspar weathering models to predict gross compositional trends in weathering profiles (profiles that develop over time, due to weathering, of a 3-dimensional soil pedon). We hypothesize that this same approach may be used to segregate soil-weathering profiles on the basis of their decomposition patterns as influenced by climatic and biologic influences, that is, by ecosystem factors. It may be possible, therefore, to predict decomposition weathering products based on patterns of feldspar weathering within ecoregions. This assumes, however, that the influence of ecoregion processes are more important to the characterization of weathering profiles than is parent material or the very slow decomposition rates characteristic of arctic and subarctic environments.

Figures 35*A* and 35*B* are ternary plots reflecting the weathering of feldspar minerals. The plots are A-CN-K diagrams (Nesbitt, 1992) so-named because Al_2O_3 is at one apex, $CaO + Na_2O$ at another apex, and K_2O at the third apex. In order to plot the data based on these three parameters, concentrations of aluminum, calcium, sodium, and potassium in soil were converted to their equivalent concentration as oxides. Each sample was then evaluated and an ecoregion assigned to it on the basis of the sample's physical location. As previously discussed, there are a number of ecoregion classification systems available for Alaska; for our purposes, however, each sample was classified as belonging either to the Arctic, Subarctic, Warm Continental, Marine, or Cold Oceanic division (fig. 29; table 4).

Figure 35*A* is an A-CN-K plot of the total oxides in soil from Arctic and Subarctic sites. The scale for the plot is in percent, equaling 100 percent at each apex for the indicated oxide(s). The Subarctic samples are rather tightly clustered near the top, left side indicating a loss to weathering (leaching) of calcium, sodium, and potassium relative to aluminum (Al_2O_3). In contrast, the Arctic samples are scattered over the top and left side and extending toward the $CaO+Na_2O$ apex of the diagram indicating, at least for some samples, less weathering of the calcium and sodium oxides and subsequent loss to leaching. The position of Arctic samples on the left is near the location of plagioclase (primary mineral) and(or) smectite (secondary mineral). For samples in both ecoregions there is, in general, relatively more $CaO+Na_2O$ than K_2O (samples seem to be "pulled" to the left). In general, there is no major distinction among the samples between the two ecoregions; however, the lack of dissolution (weathering) of the oxides of calcium and sodium in some Arctic soils reflects cooler, dryer, less biologically active soils. Water draining cool-subalpine, podzolized soils in the alps revealed that feldspars are dissolved relatively quickly (tens of years) with calcic plagioclases less stable than sodic, which are less stable than potassic (Legros, 1992).

Figure 35*B* is an A-CN-K plot of the oxides in soil from the remaining three ecoregion divisions—Warm Continental, Marine, and Cold Oceanic. Virtually no distinction can be made among the ecoregions with the samples essentially stacked on top of each other. As with the Arctic and Subarctic samples, the individual points are clustered on the top left side of the plot, showing the loss of calcium, sodium, and potassium relative to aluminum.

In examining these plots, several caveats must be noted. No attempt is made to factor in the geochemistry of the bedrock for each of the samples; therefore, the assumption is made that environmental factors and consequently weathering processes are more important to the interpretation of the figure 29 plots than is bedrock. We do not know the relative proportion of primary (bedrock) to secondary (result of weathering) oxides in these samples.

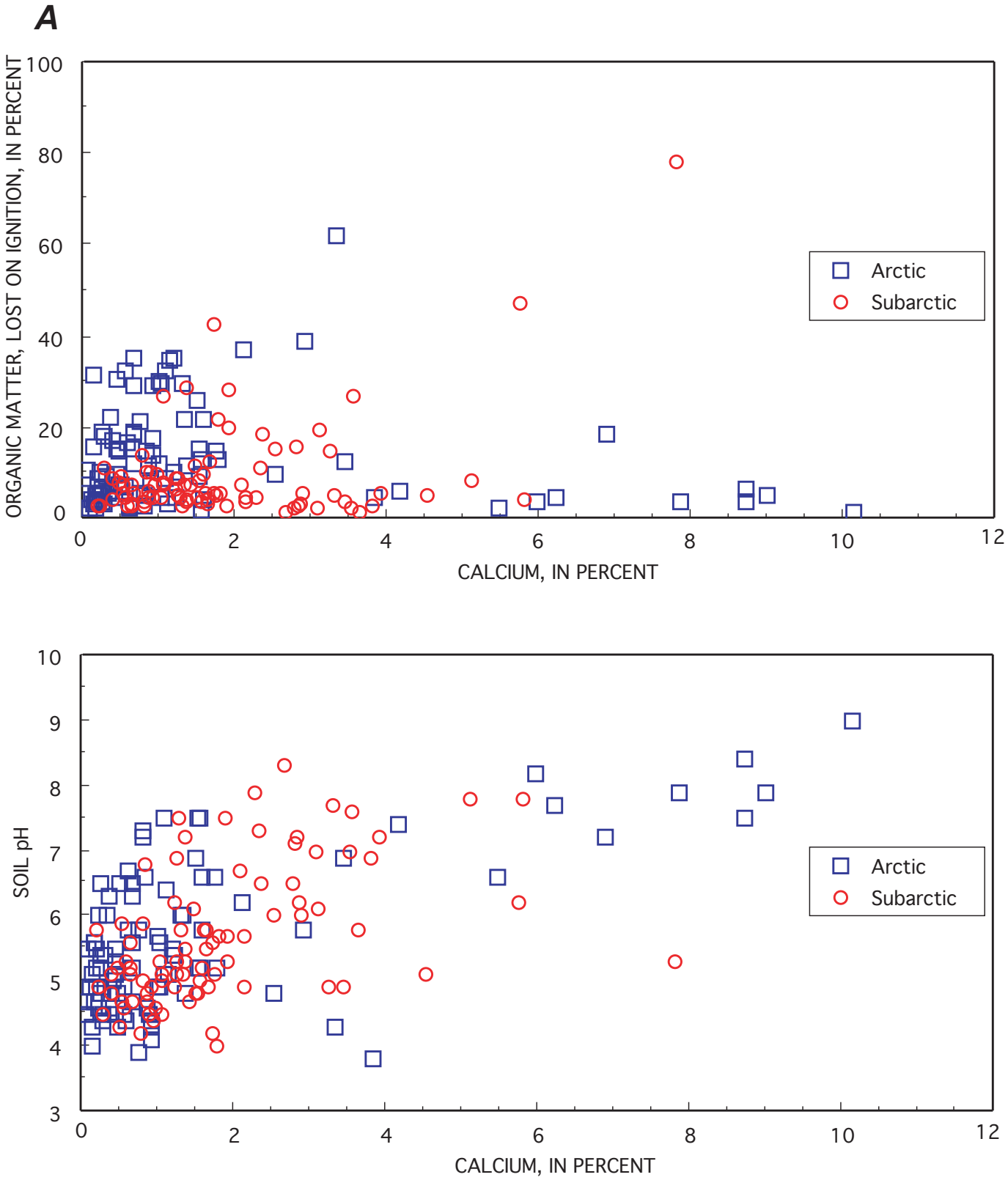


Figure 36*A*. Relation between soil organic matter and soil pH and total percent calcium in soils and surficial materials from the Arctic and Subarctic ecoregions.

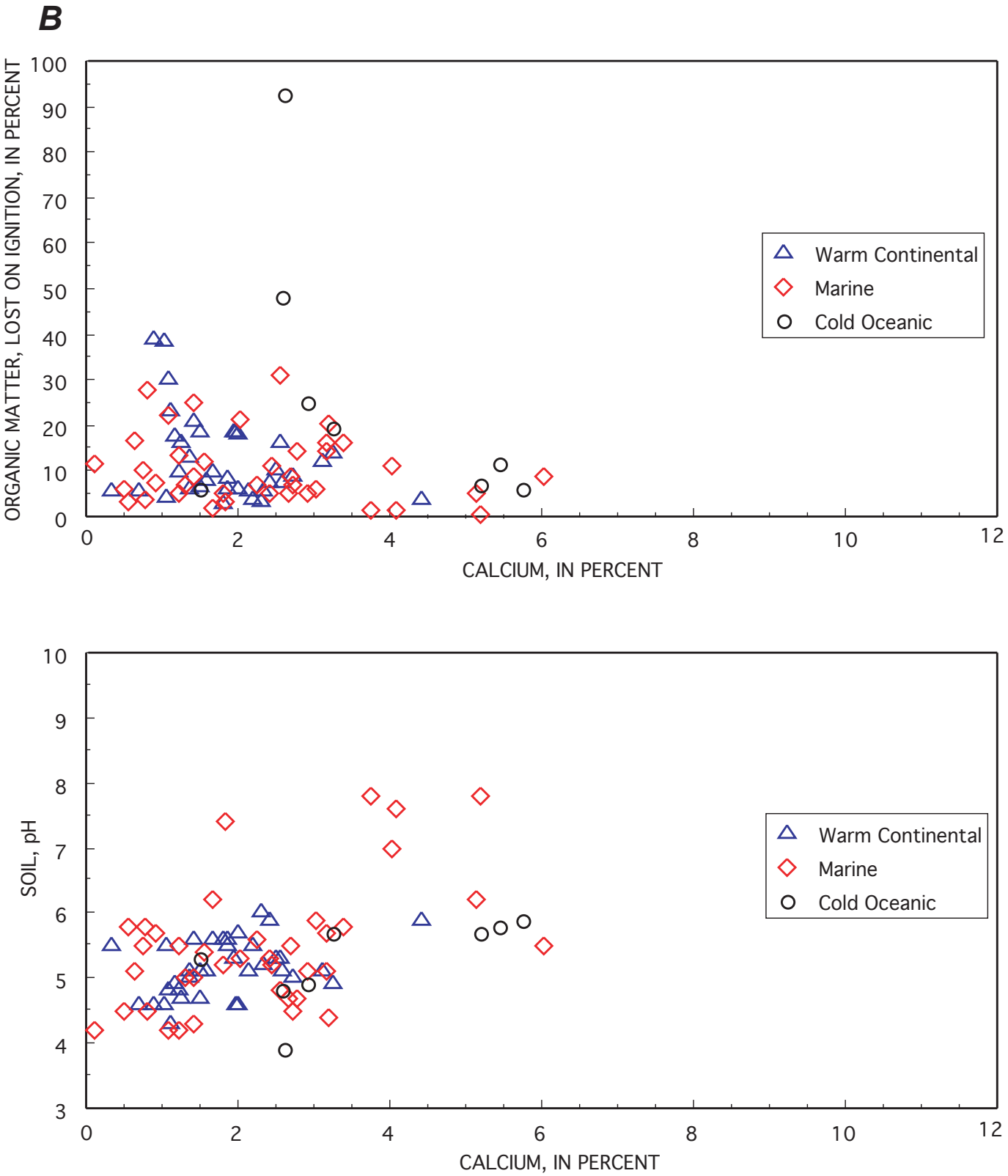


Figure 36*B*. Relation between soil organic matter and soil pH and total percent calcium in soils and surficial materials from the Warm Continental, Marine, and Cold Oceanic ecoregions.

Major Cation Landscape Correlation Patterns

In the 1988 study, we found that the variability in element concentrations of Alaska surficial-materials samples was, for most elements, largely due to heterogeneity among sampling locations, with only a small part of the variance due to sampling error (between samples collected 100 m apart at a location; Gough and others, 1988). The geochemical consistency within sampling locations in Alaska is an expression of (1) the influence of climatic/physiographic variables, (2) geochemical and biogeochemical cycling processes, and (3) parent material uniformity within small geographic areas.

Principal components analysis (PCA) was conducted to better understand the relation among important soil and climatic variables. This technique was used both to reduce the number of interpretable variables and to identify possible regional structure within the data. The variables of interest were the reactive (labile) major cations (plus silica and titanium), soil pH, soil "organic matter" (the weight percent lost on ignition at 500ºC, fundamentally organic carbon), and the climatic/physiographic variables (mean annual temperature, mean annual precipitation, elevation, and latitude). Because of missing values for 2 of the 265 samples, the PCA computation used data for 263 sites. We used logarithmic-transformed data of the major cations in the PCA because the frequency distribution of these data was more nearly normal. The PCA cannot accommodate incomplete data sets. Prior to computation, therefore, an arbitrary value of 0.7 times the detection limit was substituted for 1 and 17 censored values for Na and Mn, respectively (table 1).

Table 5 lists the eigenvalues and percent variance explained for the generation of PCA factors. The PCA computation yielded five factors, all of which had eigenvalues greater than 1.0. The sum of the total variance in the factor solution explained by these five factors was about 77 percent. Table 6 lists the loadings generated from the use of the five-factor model in an orthotransformed, varimax rotation solution. We interpret the factors in table 6 as follows: Factor 1—clay or reactive oxide factor with important positive loadings on Al, Fe, Mn, and Ti. (Statewide surface geochemical maps for Si and Ti were not generated and are therefore not presented in this report.) Factor 2—physiographic (latitude) factor with important positive loadings on precipitation, temperature, and Na and important negative loadings on latitude and elevation. Factor 3—organic matter factor with large positive loadings on organic matter and P and negative loading on Si. Factor 4—carbonate factor: positive loadings on pH, Ca, and Mg. Factor 5—potassium feldspar factor: positive loadings for Al and K.

Factor 1—The positive loadings on this factor of Al, Fe, Mn, and Ti make this appear to be a factor dominated by clay or sorption processes and the presence of amorphous soil (hydr)oxides. This soil phase is responsible for the sorption of soil cations that can be made bioavailable by shifts in soil pH and redox. Figures 4 (aluminum), 10 (iron), and 15 (manganese) show similar statewide concentration patterns from high to low concentrations progressing south to north. This seems reasonable from a soils formation perspective. The warmer temperatures in the south result in organic matter decomposition rates that favor production of organic acids, which in turn mobilize these elements and produce clay minerals and (hydr)oxides. Once formed, the clays and (hydr)oxides resist further mobilization and accumulate in the B soil horizon. The general statewide patterns show the importance of soil-formation processes over the more local influence of bedrock geochemistry.

Factor 2—The inverse relation of latitude with temperature and precipitation is shown diagrammatically for the entire State in figures 33 and 34, respectively, and as plots of individual site values in figure 30. Although not graphically portrayed in figure 30, this factor also shows a fairly strong inverse relation of elevation with temperature and precipitation. Figure 20 is a diagram of sodium in surficial materials over the State and again the inverse relation with latitude is obvious. The trend of decreasing soil sodium concentrations with increasing latitude might be the result of marine input (Steinnes and others, 1992) from low-pressure cyclonic systems that typically track in a southwest-to-northeast arc across the Gulf of Alaska. The fact that similar coastal trends are not observed along the Bering and Chukchi Sea coasts is problematic but may be because of the formation of sea ice in these areas that would reduce the amount of time during the year that marine sodium could be aerially transported. Other elements, such as calcium and magnesium (figs. 6 and 14, respectively), that can be oceanic in origin have only small positive loadings on this factor.

Factor 3—This factor is identified as being related to soil organic matter as it has large, positive loadings on loss on ignition (LOI) and phosphorus. The latter, along with nitrogen and potassium, are major constituents of soil organic matter. Soil organic matter is dependent on topography that, in turn, helps dictate the makeup of vegetation communities (Van Cleve and Yarie, 1986). We estimate that the soil organic matter at most of our sites varied from 3 to 10 kg/m^2 with the higher amounts in the more poorly drained sites. Silicon, a major constituent of soil mineral matter (geometric mean of 26 percent in our samples), has a large negative loading on this factor.

Factor 4—The positive relation of soil pH with calcium and magnesium identifies factor 4 as being related to soil carbonate levels and the buffering capacity of these major soil cations. In addition, the mobility of elements in soil is greatly influenced by pH. Figures 36*A* and 36*B* show the relation between surficial-materials organic matter (lost on ignition at 500ºC) and calcium content, and of surficial-materials pH and calcium content, in samples from the five ecoregions. Whereas the relation of LOI to calcium shows a scattering of points, the pH to calcium plot does show a slightly upward trend (increasing pH to increasing calcium content).

In the subarctic boreal forests of interior and south-central Alaska, evapotranspiration can exceed total precipitation, resulting in reduced soil leaching and the formation of calcic soils, some even with a caliché layer (Van Cleve and others, 1991). This type of alkalization is hydrologic and not necessarily related to local parent material since high calcium concentrations can be found in soils with shallow water tables regardless of lithologic origin (Mark Clark, U.S. Department

of Agriculture, Natural Resources Conservation Service, oral commun., 2004). In addition, the transport of carbonate and micaceous loess from braided stream valleys, especially during summer months, to upland sites (Foster and Keith, 1969) is also a source of major cation input to soils (Van Cleve and others, 1983). These calcium-rich loess mantles often mask underlying bedrock; however, this masking influence decreases with distance from the braided stream and lacustrine source areas.

The map of calcium distribution in surficial materials (fig. 6) shows a major high-calcium region in the Copper River Basin of south-central Alaska. This pattern is probably a reflection of lacustrine materials and associated loess deposits throughout the area. The moderately high calcium pattern throughout central Alaska may be a reflection of the upward movement of major soil cations (due to evaporation and low precipitation) and to the location of some of the sampling sites in alluvial plains. The high areas in the southeast and in the Alaska Peninsula, regions dominated by intrusive and volcanic rocks that form soils with low base-exchange capacity, are problematic. Equally difficult to explain is the low-calcium area of the Brooks Range, which has extensive calcareous and dolomitic lithologic units. The mountains that make up the Brooks Range vary in the loess mantle material that contributes to the soils in this region. Whether these soils are mostly composed of residuum or loess, one would expect higher calcium values than are portrayed in figure 6.

Figure 37 is the calcium concentration map for 58,410 samples (mostly stream sediments), collected as part of a number of sampling efforts, as reported by the USGS National Geochemical Survey (U.S. Geological Survey, 2004). Gough and others (1988) report a geometric mean of 1.3 percent for surficial-materials, and the U.S. Geological Survey (2004) report gives a geometric mean for sediments of 1.6 percent. The map (fig. 37), when compared with the surficial-materials calcium concentration map (fig. 6), shows similar patterns. Unlike the soils map, however, the stream-sediment map shows the influence of carbonaceous lithologic units in the Brooks Range extending into northeast Alaska (Philip Smith Mountains area and northward). Stream-sediment sample signatures do not have the loess mantle overprint that the surficial-materials samples may have. Like the soils map, figure 36 shows an unexplained high calcium region that includes the southeastern part of the State and the Alaska Peninsula.

Factor 5—Although weak, this is named the "potassium feldspar" factor because of the positive loadings for aluminum and potassium and the small but negative loading of calcium and sodium (fig. 35; table 6). Assuming that this factor is reasonably well defined as potassium feldspar, then factor 5 gives strength to the interpretation of figure 35 and the dissolution of major cation oxides as being an important soil chemical weathering process in northern climates.

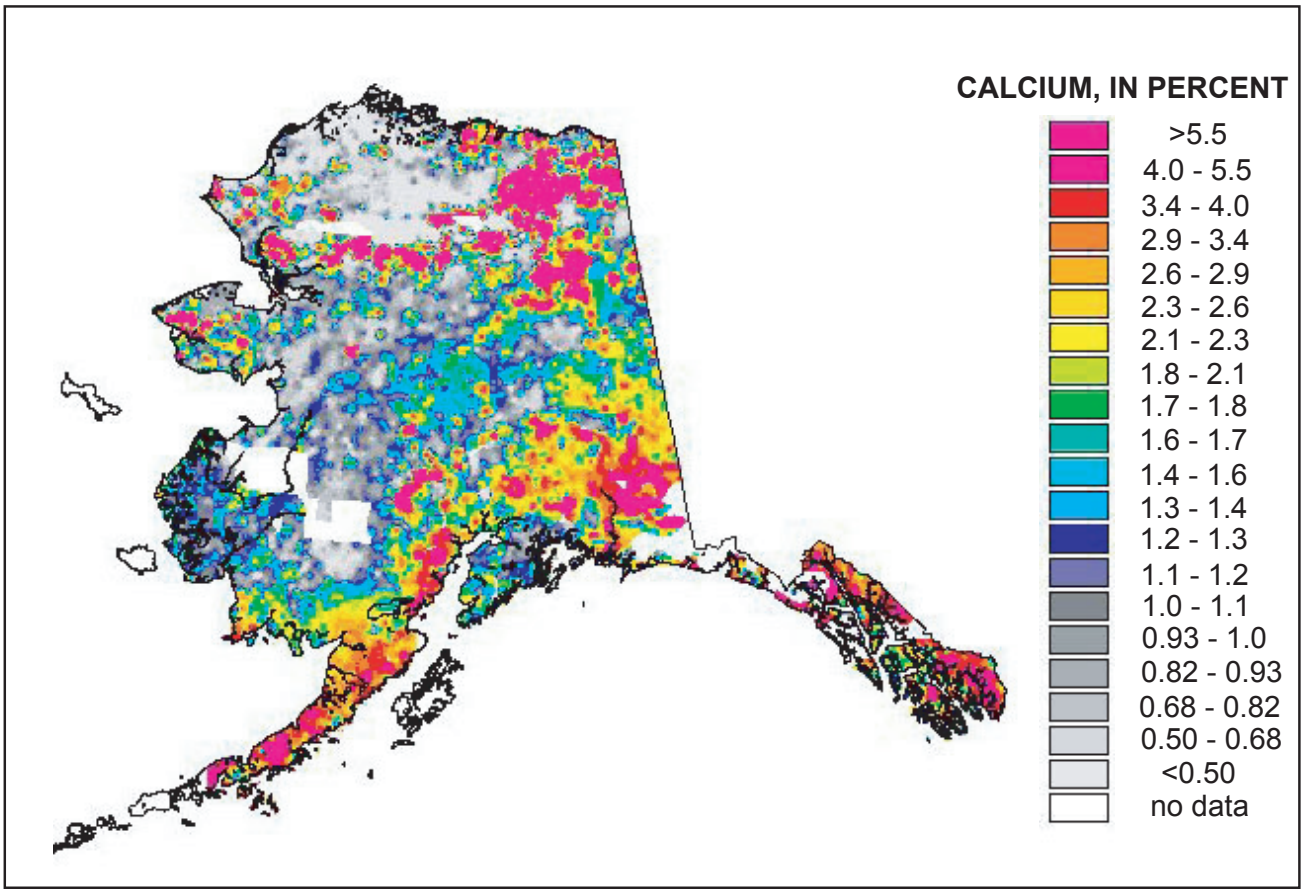


Figure 37. Colored surface map of calcium in stream sediments of Alaska (modified from U.S. Geological Survey, 2004).

Conclusions

Originally, the data for the generation of the maps presented in this report were to be used as estimates of central tendency for the concentration of elements in surficial materials collected from throughout the State of Alaska. Although we do not presume to know the precise stability (or reproducibility) of these maps, generated by an ultra-low-density geochemical survey, some measure of their relative stability can be ascertained in several ways—by comparison with some future repeat sampling effort, by more precise measures of regional geochemical variability (also usually the result of additional, more intense sampling), or by the interpretation of regional landscape patterns that correspond with known trends derived independently using other techniques (for example, the comparison of the soil calcium concentration map with a calcium map derived from the analysis of over 58,000 stream sediments, figs. 6 and 37; or, as was done in Gustavsson and others, 2001, a comparison of soil potassium concentrations with potassium patterns generated using aerial gamma-ray surveys). Gustavsson and others (2001) evaluated their maps by their ability to show regional geochemical patterns that (1) indicate large underlying geologic features, (2) reflect the influence of human activity, (3) agree with major features of the geochemical landscape obtained with higher sample density, and (4) correlate with known physical, chemical, and biological landscape features. The maps presented in this report vary in their ability to adequately address one or more of these criteria. For example, except for a possible lead shot influence in the Yukon-Kuskokwim Lowlands, the maps do not show the influence of human activity. The maps do, however, present several geochemical trends that are reflective of underlying geologic features (potassium, thorium, and uranium are correlative with granitic plutons; barium is correlative with interior flysch basins). They also show the difficulty of dealing with soils whose bedrock signatures can be masked by the ubiquitous presence of heterogeneous wind-borne silt. Perhaps more important is the ability of these maps to assist in the understanding of physical and chemical weathering processes in high-latitude regions. Future interpretation may yield additional insight into landscape patterns not perceived in this report.

As originally stated in the 1988 study, these data should prove useful in assessing geochemical baselines and in the interpretation of geochemical landscapes when the purpose is to identify broad regional patterns associated with surficial geology, mineral resource provinces, and geochemical areas of interest in human, animal, and plant health issues. In addition, we reinterpret these landscape data in the context of ecoregions and their associated soils, climate, and physical, chemical, and biological features.

Acknowledgments

We gratefully acknowledge the assistance of Gregory Nowacki, U.S. Department of Agriculture (USDA), Forest Service, for his thoughts concerning the ecoregion classification used in the report and Joe White and Mark Clark, USDA, Natural Resources Conservation Service, for assistance with Alaska State soil-classification questions. Very helpful critical reviews to the manuscript were provided by Martin Goldhaber and Jeffrey Grossman, USGS. Alison Till and Warren Day, USGS, assisted with the interpretation of statewide geochemical patterns. GIS and map production assistance was provided by Keith Labay, Anchorage, Alaska.

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