

Prepared in cooperation with the Alaska Division of Geological & Geophysical Surveys

# The Geochemical Atlas of Alaska, 2016

Data Series 908  
Pamphlet accompanies maps



# **The Geochemical Atlas of Alaska, 2016**

By Gregory K. Lee, Douglas B. Yager, Jeffrey L. Mauk, Matthew Granitto,  
Paul D. Denning, Bronwen Wang, and Melanie B. Werdon

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Surveys

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**U.S. Department of the Interior**  
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**U.S. Geological Survey**  
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## Contents

|   |    |
|---|----|
| Abstract.....   | 1  |
| Introduction.....   | 1  |
| Methods.....  | 2  |
| Data Compilation.....   | 2  |
| U.S. Geological Survey Data .....   | 2  |
| National Uranium Resources Evaluation (NURE) Hydrogeochemical<br>and Stream Sediment Reconnaissance (HSSR) Data ..... | 3  |
| Alaska Division of Geological & Geophysical Surveys (ADGGS) Data .....  | 3  |
| Data Processing.....  | 3  |
| Georeferencing .....  | 3  |
| Selection of Best Values.....   | 4  |
| Replacement of Censored Data .....  | 4  |
| Censored Data Replacements for Sediments-Only Compilation .....   | 4  |
| Censored Data Replacements for Sediments-Plus-Soils Compilation .....   | 6  |
| Data Integration .....  | 6  |
| Distribution Modeling.....  | 7  |
| Treatment of Spatially Coincident Samples.....  | 7  |
| Interpolated Distribution Models .....  | 7  |
| Hydrologic Unit-Based Distribution Models .....   | 8  |
| Explanation of Map Sheets and Figures .....   | 8  |
| Map Sheets.....   | 8  |
| Description of Map Artifacts .....  | 9  |
| Figures .....   | 9  |
| Visualization Tips and Techniques .....   | 22 |
| Data Delivery .....   | 22 |
| Discussion and Conclusions.....   | 22 |
| Acknowledgments .....   | 23 |
| References Cited.....   | 23 |

## Figures

|  |    |
|--|----|
| 1–12. Maps showing:  |    |
| 1. U.S. Geological Survey (USGS) sediment and soil sample localities in Alaska .....   | 10 |
| 2. National Uranium Resource Evaluation (NURE) Hydrochemical and Stream<br>Sediment Reconnaissance (HSSR) sediment sample localities in Alaska ..... | 11 |
| 3. Alaska Division of Geological and Geophysical Surveys (ADGGS) sediment<br>sample localities .....   | 12 |
| 4. Sediment samples within 12-digit (subwatershed) hydrologic units in Alaska .....  | 13 |
| 5. Physiographic provinces of Alaska .....   | 14 |
| 6. Basement domain map of Alaska showing major tectonostratigraphic domains .....  | 15 |
| 7. General land status map of Alaska.....  | 16 |
| 8. Gravity anomalies in Alaska .....   | 17 |
| 9. Magnetic anomalies in Alaska .....  | 18 |
| 10. Aeroradiometric measurement values of potassium (K) in Alaska.....   | 19 |
| 11. Aeroradiometric measurement values of uranium (U) in Alaska .....  | 20 |
| 12. Aeroradiometric measurement values of thorium (Th) in Alaska .....   | 21 |

## Tables

1. Replacement values used for censored data for the Geochemical Atlas of Alaska, 2016 .....5
2. Map sheets for the Geochemical Atlas of Alaska, 2016 (table2.xlsx) ..... [Link](#)

## Sheets

This report contains 272 map sheets that represent four-fold distributions of 68 chemical elements. All sheets are alphabetically ordered according to element name and are listed and linked in table 2. Digital versions of the map sheets are provided as Portable Document Format (PDF) files, with nominal 11"x17" print size, in the `ds908_elements\<element name>` directories (folders). The underlying geochemical data are included in the `ds908_datafiles` directory on the DVD set, or in the ScienceBase data release at <http://dx.doi.org/10.5066/F7GF0RK5>. Brief descriptions of each of the four (A, B, C, D) map sheet variations for each element follow:

- A. Sheets 1A–68A have been derived from sediment data only. The combined element best-value concentrations have been interpolated and color-sliced according to 50, 75, 91, and 98 percentile levels ..... [Link](#)
- B. Sheets 1B–68B have been derived from sediment sample data only. Using Geographic Information System (GIS) functions, statewide hydrologic unit polygons that are identified with 12-digit hydrologic unit codes (HUCs) were assigned the means of element values for all sample points intersecting those polygons. The resulting mean element concentration in each hydrologic unit was symbolized with the same colors used for "A" sheets at the same 50, 75, 91, and 98 percentile intervals ..... [Link](#)
- C. Sheets 1C–68C have been derived from combined sediment and soil sample data. Standard scores were calculated for each of four separate sample-type datasets and those scores were merged. The combined standard scores were interpolated and color-sliced according to score ranges ..... [Link](#)
- D. Sheets 1D–68D have been derived from combined sediment and soil sample data. Geometric standard scores were calculated for each of four separate sample-type datasets and those scores were merged. The combined geometric standard scores were interpolated and color-sliced according to score ranges ..... [Link](#)

## Conversion Factors

International System of Units to Inch/Pound

| Multiply                            | By     | To obtain                      |
|-------------------------------------|--------|--------------------------------|
|                                     | Length |                                |
| meter (m)                           | 3.281  | foot (ft)                      |
| kilometer (km)                      | 0.6214 | mile (mi)                      |
|                                     | Area   |                                |
| square kilometer (km <sup>2</sup> ) | 247.1  | acre                           |
| square meter (m <sup>2</sup> )      | 10.76  | square foot (ft <sup>2</sup> ) |
| square kilometer (km <sup>2</sup> ) | 0.3861 | square mile (mi <sup>2</sup> ) |

Inch/Pound to International System of Units

| Multiply  | By     | To obtain |
|-----------|--------|-----------|
|           | Length |           |
| foot (ft) | 0.3048 | meter (m) |

## Datum

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84).

## Supplemental Information

Concentrations of chemical constituents in solid material are given in either parts per million (ppm) or percent (pct).

The gal (Gal or galileo) is defined as 1 centimeter per second squared (1 cm/s<sup>2</sup>). A milligal (mGal) is one thousandth of a gal.

T = Tesla, a unit of magnetic flux density; nT = nanotesla

## Abbreviations, Acronyms, and Initialisms

|         |  |
|---------|--|
| ADGGS   | Alaska Division of Geological & Geophysical Surveys        |
| AGDB2   | Alaska Geochemical Database version 2.0                    |
| AMRAP   | Alaska Mineral Resources Assessment Program                |
| ASC     | Alaska Science Center                                      |
| CMERSC  | Central Mineral and Environmental Resources Science Center |
| DL      | Detection limit, or lower limit of determination           |
| ERDAS   | Earth Resources Data Analysis System                       |
| EROS    | Earth Resources Observation and Science Center             |
| Esri    | Environmental Sciences Research Institute                  |
| HSSR    | Hydrogeochemical and Stream Sediment Reconnaissance        |
| GeoTIFF | Georeferenced (or geospatial) tagged image file format     |
| GIS     | Geographic Information System                              |
| HUC     | Hydrologic Unit Code                                       |
| IDW     | Inverse distance weighting                                 |
| IQR     | Interquartile range  |
| K-M     | Kaplan-Meier method  |
| NAD     | North American Datum                                       |
| NHD     | National Hydrography Dataset                               |
| NRCS    | Natural Resources Conservation Service                     |
| NURE    | National Uranium Resources Evaluation                      |
| pct     | percent  |
| PDF     | Portable Document Format                                   |
| ppm     | parts per million  |
| RGB     | red, green, blue   |
| USGS    | U.S. Geological Survey                                     |
| WBD     | Watershed Boundary Dataset                                 |
| WGS     | World Geodetic System                                      |

## Elements Mapped in this Report with Element Name and Abbreviation

|     |            |    |     |              |    |
|-----|------------|----|-----|--------------|----|
| 1.  | Aluminum   | Al | 38. | Nickel       | Ni |
| 2.  | Antimony   | Sb | 39. | Niobium      | Nb |
| 3.  | Arsenic    | As | 40. | Palladium    | Pd |
| 4.  | Barium     | Ba | 41. | Phosphorous  | P  |
| 5.  | Beryllium  | Be | 42. | Platinum     | Pt |
| 6.  | Bismuth    | Bi | 43. | Potassium    | K  |
| 7.  | Boron      | B  | 44. | Praseodymium | Pr |
| 8.  | Cadmium    | Cd | 45. | Rubidium     | Rb |
| 9.  | Calcium    | Ca | 46. | Samarium     | Sm |
| 10. | Carbon     | C  | 47. | Scandium     | Sc |
| 11. | Cerium     | Ce | 48. | Selenium     | Se |
| 12. | Cesium     | Cs | 49. | Silicon      | Si |
| 13. | Chlorine   | Cl | 50. | Silver       | Ag |
| 14. | Chromium   | Cr | 51. | Sodium       | Na |
| 15. | Cobalt     | Co | 52. | Strontium    | Sr |
| 16. | Copper     | Cu | 53. | Sulfur       | S  |
| 17. | Dysprosium | Dy | 54. | Tantalum     | Ta |
| 18. | Erbium     | Er | 55. | Tellurium    | Te |
| 19. | Europium   | Eu | 56. | Terbium      | Tb |
| 20. | Fluorine   | F  | 57. | Thallium     | Tl |
| 21. | Gadolinium | Gd | 58. | Thorium      | Th |
| 22. | Gallium    | Ga | 59. | Thulium      | Tm |
| 23. | Germanium  | Ge | 60. | Tin          | Sn |
| 24. | Gold       | Au | 61. | Titanium     | Ti |
| 25. | Hafnium    | Hf | 62. | Tungsten     | W  |
| 26. | Holmium    | Ho | 63. | Uranium      | U  |
| 27. | Indium     | In | 64. | Vanadium     | V  |
| 28. | Iron       | Fe | 65. | Ytterbium    | Yb |
| 29. | Lanthanum  | La | 66. | Yttrium      | Y  |
| 30. | Lead       | Pb | 67. | Zinc         | Zn |
| 31. | Lithium    | Li | 68. | Zirconium    | Zr |
| 32. | Lutetium   | Lu |     |              |    |
| 33. | Magnesium  | Mg |     |              |    |
| 34. | Manganese  | Mn |     |              |    |
| 35. | Mercury    | Hg |     |              |    |
| 36. | Molybdenum | Mo |     |              |    |
| 37. | Neodymium  | Nd |     |              |    |

# The Geochemical Atlas of Alaska, 2016

By Gregory K. Lee<sup>1</sup>, Douglas B. Yager<sup>1</sup>, Jeffrey L. Mauk<sup>1</sup>, Matthew Granitto<sup>1</sup>, Paul D. Denning<sup>1</sup>, Bronwen Wang<sup>2</sup>, and Melanie B. Werdon<sup>3</sup>

## Abstract

A rich legacy of geochemical data produced since the early 1960s covers the great expanse of Alaska; careful treatment of such data may provide significant and revealing geochemical maps that may be used for landscape geochemistry, mineral resource exploration, and geoenvironmental investigations over large areas. To maximize the spatial density and extent of data coverage for statewide mapping of element distributions, we compiled and integrated analyses of more than 175,000 sediment and soil samples from three major, separate sources: the U.S. Geological Survey, the National Uranium Resource Evaluation program, and the Alaska Division of Geological & Geophysical Surveys geochemical databases. Various types of heterogeneity and deficiencies in these data presented major challenges to our development of coherently integrated datasets for modeling and mapping of element distributions. Researchers from many different organizations and disparate scientific studies collected samples that were analyzed using highly variable methods throughout a time period of more than 50 years, during which many changes in analytical techniques were developed and applied. Despite these challenges, the U.S. Geological Survey has produced a new systematically integrated compilation of sediment and soil geochemical data with an average sample site density of approximately 1 locality per 10 square kilometers (km<sup>2</sup>) for the entire State of Alaska, although density varies considerably among different areas. From that compilation, we have modeled and mapped the distributions of 68 elements, thus creating an updated geochemical atlas for the State.

## Introduction

Landscape-scale geochemistry provides critical information for various types of investigations including mineral resource exploration, geoenvironmental assessment, agriculture, land-use planning, water quality evaluation, and human

and (or) animal health issues (Smith, Cannon, and others, 2013). Recent continental-scale programs have produced geochemical data for a wide range of elements using consistent sampling and analytical protocols in Europe, Australia, and the conterminous United States (Reimann and de Caritat, 2012; Smith, Cannon, and others, 2013). These studies have transformed our knowledge of the geochemical landscapes of these areas, thereby enabling informed discussions of global-scale geochemistry.

Parts of Alaska remain a relatively unexplored geologic and geochemical frontier; there is challenging topography with steep terrain and high relief, with elevations ranging from sea level to more than 20,000 ft. Alaska is the largest State in the United States, with land area greater than 1.5 million square kilometers (km<sup>2</sup>); much of the area is remote and inaccessible, with highly variable and extreme weather, bloodsucking and stinging insects, dangerous waters, animal hazards, extensive vegetation cover, difficult overland travel, and very limited transportation access and infrastructure. Furthermore, the high costs of access and field-work support needed to investigate the vast and remote areas of the State can be prohibitive. All of these factors have affected the ability of scientists and other investigators to comprehensively map the State and to collect geochemical samples. Only after the 1970s did 1:250,000-scale U.S. Geological Survey (USGS) topographic maps become available for the entire State. Detailed geologic and geochemical investigations became possible following the publication of base maps that had sufficient detail necessary to accurately record geologic and geochemical observations.

Nevertheless, since the 1960s the collection and analyses of large numbers of geochemical samples across the State has resulted in a robust dataset. The application of evolving analytical techniques to reanalyze archived samples for additional elements or to achieve lower determination limits and increased accuracy has further improved our progress. The only previous statewide geochemical mapping of Alaska was produced more than 30 years ago from data generated during the National Uranium Resource Evaluation (NURE) and the Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) program. The underlying analytical data for those maps were compiled from 61,923 sediment samples collected over much of the State, and those data were interpolated to produce an atlas of maps showing distributions of 41 elements (Weaver and others, 1983).

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<sup>2</sup>U.S. Geological Survey, Anchorage, Alaska.

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The primary purpose of this study is to provide a significantly updated geochemical atlas of Alaska that contains 272 maps illustrating the distributions of 68 elements (map sheets 1–68A, B, C, and D). These sheets are derived from the compilation and integration of data from 168,987 sediment and 6,869 soil samples previously collected by the USGS, the NURE-HSSR program, and the Alaska Division of Geological & Geophysical Surveys (Alaska DGGS, or ADGGS). The areal density of the combined sample sites differs greatly on a local scale, but averages approximately 1 site per 10 km<sup>2</sup> (around 3.6 km between sites) for the entire State. For comparison, recent continental-scale geochemical surveys have had sample locality densities that range from 1 site per 1,600 km<sup>2</sup> (in the conterminous United States: Smith, Cannon, and others, 2013), to 1 site per 2,500 km<sup>2</sup> (in Europe: Reimann and de Caritat, 2012), to 1 site per 5,000 km<sup>2</sup> (in Australia: Reimann and de Caritat, 2012). The use of legacy data in Alaska provides a much greater sample density than could be achieved from only more recent surveys.

Relational database functionality, along with statistical methods and geographic information system (GIS) applications for analyses and visualizations of large geochemical datasets have enabled the production of new maps for landscape geochemistry across the State. The GIS-compatible digital geochemical data compilation and derivative distribution models used to produce the map sheets are provided in the `ds908_datafiles` directory (electronic folder) in this report.

An additional objective of this study is to reveal the current status of geochemical coverage for Alaska. To guide future data development efforts, it is important to understand not only the breadth of our current geochemical knowledge, but also its limitations. Emerging technologies have created demands for elements that were, until recently, of little or no mineral exploration interest and it is likely that yet unforeseen needs and uses for other elements will similarly arise in the future. Many of the element maps produced for this atlas reveal areas in Alaska where there are insufficient data to support comprehensive geochemical mapping. Those deficiencies derive from: (1) insufficient sample coverage, (2) lack of analytical data for some elements in collected samples, and (3) analytical methods with high determination limits that result in extremely censored data for certain elements. The map sheets that display areas with geochemical data deficiencies can help inform planning priorities for future additional sample collection and the reanalysis of existing samples to aid in the continuing evolution and development of geochemical knowledge of Alaska.

## Methods

This section describes the geochemical data that were compiled, processed, and integrated for the study, and also outlines the procedures that were used for spatial modeling of distributions of those data. These element distribution models form the basis for the atlas map sheets that were produced for this study.

## Data Compilation

The detail to which geochemical trends in Alaska could be mapped in prior investigations was limited by sampling density and inconsistent analytical methods (Smith, Smith, and Horton, 2013). One objective was to provide a more comprehensive and robust update to the geochemical atlas produced by Weaver and others (1983). In pursuit of this, analytical data from three major databases were combined: USGS, NURE-HSSR, and ADGGS for a total of 175,856 samples. This is nearly 114,000 more samples than were used for the 1983 maps and distribution maps for 68 elements that were created have been included, 27 more than were provided in the earlier atlas compendium. These additional data have significantly improved the spatial density and extent of sample coverage across the State, and the determinations of additional elements have enhanced the scope of potential applications for this updated collection of map sheets and data compilation.

However, difficulties arise when combining data from different sample media, that have various geodetic datums, are from different laboratories, and that were derived from a variety of different analytical methods. For more than 50 years, the legacy data used in our compilation were produced from samples that were collected for a wide variety of studies and that were analyzed using 80 different laboratory techniques. Therefore, the data have highly variable accuracy, precision, and associated limits of determination due to the steady and significant improvements in analytical methods during those years. For example, older geochemical data often have relatively high limits of analytical detection so data for many elements are highly censored with some having more than 90 percent of their values at levels that are less than the lower determination limit. Thus, the heterogeneous nature of the data in our compilation presented challenges for geochemical data integration and modeling.

## U.S. Geological Survey Data

The USGS part of our compilation includes analyses of 92,694 sediment samples and 6,869 soil samples that are contained in the Alaska Geochemical Database version 2.0 (AGDB2, <http://pubs.usgs.gov/ds/759/>) compiled by Granitto and others (2013). The geochemical data for the USGS portion of the database were produced using 73 different analytical methods. These samples were collected as part of numerous and diverse USGS studies and projects carried out between 1962 and 2009. The samples were prepared and analyzed according to various USGS standard methods (Miesch, 1976; Arbogast, 1990, 1996; Taggart, 2002). Prior to the publication of the AGDB2, many analyses of geochemical samples were not readily accessible because those data were either stored on paper (hard copy) records, or in multiple and separate USGS legacy digital databases that were incomplete or that required recompilation or reformatting for input into GIS. Some historical hard copy data were physically recovered

from storage facilities that were targeted for decommission and were subsequently digitized. Those data are now digitally archived as part of the AGDB2, thus highlighting the importance of preserving data at risk of being lost, destroyed, or discarded over time. Due to the long time span and the variety of scientific purposes for acquisition of the USGS data, many different field and laboratory methods were used. The 73 analytical methods used to determine geochemical concentrations include various forms of atomic absorption spectroscopy, colorimetry, emission spectrography, fire assay, gravimetry, inductively coupled plasma-atomic emission and mass spectrometry, neutron activation analysis, and X-ray fluorescence spectrometry techniques. Granitto and others (2013) provide a complete list of analytical methods for the USGS data. Excepting aggregated best values, all data that are part of the AGDB2 are also archived in the USGS National Geochemical Database (<http://mrddata.usgs.gov/geochem/>), which stores geochemical data collected for water, sediment, soil, rock, and organic samples.

## National Uranium Resources Evaluation (NURE) Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) Data

The NURE program was initiated in 1973 by the U.S. Atomic Energy Commission, now the Department of Energy, with a primary goal of identifying uranium resources in the United States. The HSSR program was one of nine components of NURE. Between 1976 and 1979, the Los Alamos Scientific Laboratory (now the Los Alamos National Laboratory) carried out systematic sampling and analyses of stream and lake sediments, and surface waters in Alaska. Four analytical methods were used: quantitative emission spectrography, neutron activation analysis, energy-dispersive X-ray fluorescence spectrometry, and delayed neutron counting. The NURE-HSSR sampling program ended prematurely in 1980 from lack of funding and no database compilation was produced from the 894 data files that had been created in 47 formats.

In 1985, the NURE-HSSR sample archive, original field maps, field notes, and data tapes became the responsibility of the USGS. In 1995, the USGS began a new effort to recompile the NURE-HSSR data by examining and reformatting the data from the original 894 files, and compiling these into an enhanced version of the data that are archived and maintained in the USGS National Geochemical Database (Smith, 1997). Our compilation includes chemical determinations from 65,397 Alaska sediment samples that were retrieved from this enhanced version of the NURE-HSSR data.

## Alaska Division of Geological & Geophysical Surveys (ADGGS) Data

The Alaska Division of Geological & Geophysical Surveys (ADGGS) part of our compilation included analyses of 10,996 sediment samples collected as part of numerous

ADGGS studies and projects between 1960 and 2007. The geochemical data in the ADGGS portion of the database were produced using 29 different analytical methods, including 7 that were not used by the USGS. These data were provided by the ADGGS and are also available for download at <http://www.dggs.alaska.gov/webgeochem>.

## Data Processing

To create congruous integrated data for modeling and mapping of element distributions, several new variables were derived from the “raw” datasets obtained from the AGDB2, NURE-HSSR, and ADGGS databases: (1) all sample locality coordinates were transformed to a common geodetic datum, (2) a single concentration variable was created for each element in all datasets by selecting the “best value” reported for every sample, and (3) estimated “replacement” concentrations were calculated to make use of censored data. In addition, standard scores and geometric standard scores were calculated for all samples to provide bases for combining analytical data from the disparate sample media and laboratories: USGS sediments, USGS soils, NURE-HSSR sediments, and ADGGS sediments.

## Georeferencing

Consistent spatial reference among all samples was required to enable accurate spatial integration of the geochemical data. The USGS datasets contained geographic coordinates that were referenced to various geodetic datums, including the North American Datum of 1927 (NAD 27), the North American Datum of 1983 (NAD 83), and the World Geodetic System of 1984 (WGS 84); whereas the NURE-HSSR and ADGGS data coordinates are all referenced to NAD 27. WGS 84, which is nearly identical to NAD 83, was chosen as the common datum for all data in this study because it has become the most widely used for online map information, new GIS data, and is the default datum for Global Positioning System (GPS) instruments. The coordinate calculator function in Earth Resources Data Analysis System (ERDAS) Imagine 2015 software (Hexagon Geospatial, 2014) was used to transform the geographic coordinates of all sample localities to WGS 84 and those new coordinates were added to the NURE-HSSR, ADGGS, and USGS sediment and soil sample datasets.

All geographic coordinates of GIS-formatted (geodatabase and shapefile) sample data were also transformed into the Alaska Albers Equal Area Conic projection. This was done to facilitate spatial distribution modeling of element concentrations and to improve interoperability with other data layers inasmuch as the Alaska Albers Equal Area Conic projection is the projection standard adopted by many State and Federal agencies in Alaska for ease of data integration.

## Selection of Best Values

Many element concentrations in the USGS and ADGGS datasets had been determined using more than one analytical method and therefore some elements have as many as four values reported for a given sample as a result of these different techniques. Elements that have the greatest number of multiple determinations are silver (Ag), arsenic (As), gold (Au), bismuth (Bi), cadmium (Cd), copper (Cu), molybdenum (Mo), lead (Pb), antimony (Sb), and zinc (Zn). For statistical treatment, spatial analysis, and distribution modeling of data in this study, we derived and used a “best value” for each available element in each sample. Where multiple determinations exist, the best values were chosen by considering (1) the mass of the sample that was analyzed, (2) method of decomposition of the sample during preparation, (3) sensitivity and accuracy of the instrument used for analyses, (4) upper and lower limits of determination for a given element by a particular method, (5) the age of the method and stage of its development when a specific analysis was performed, and (6) the specific analytical laboratory and equipment used. Granitto and others (2013) provide a detailed description of these considerations and how they were used to determine best values.

## Replacement of Censored Data

Data for many elements in the Alaska datasets are highly censored. That is, the actual concentrations are outside the limits of analytical determination and are reported with qualifiers that indicate that the value is less than the lower limit of determination (detection limit), or in rare cases greater than the upper limit of determination. Most typically, censored (qualified) values in the Alaska data are only known to be below a certain value, the lower limit of determination, and they appear in the data as the detection limit preceded by a negative sign. These less-than-detection-limit values are naturally more common in data that were produced by older, less sensitive analytical methods but some elements are so scarce in nature that even more modern techniques remain unable to measure low levels of abundance. So that statistically and spatially censored data could be incorporated into our compilation, we systematically calculated “replacement” values to be substituted for those qualified values. This created completely uncensored renditions of the analytical data that can be modeled and mapped in various ways, including continuous interpolated grid “surfaces,” symbolized point plots, or by calculating polygon-based statistical attributes of the data. The replacement values are estimates of undetermined concentrations that retain the units of measurement of the original data.

Two variations of combined data were used in this study: (1) sediments only, and (2) sediments plus soils. Correspondingly, two systematic methods were applied to replace qualified values with estimated numerical concentrations and two sets of replaced variables resulted from these strategies.

The replacement values that were used for both compilations are listed in a spreadsheet table, `table1.xlsx`, found in `ds908_table1.xlsx` file online, or on disk 1 of the DVD set in the `ds908_datafiles` folder.

## Censored Data Replacements for Sediments-Only Compilation

For the sediments-only compilation, the USGS, NURE-HSSR, and ADGGS best-value sediment sample datasets were considered together. It became apparent that there was a wide range of censored values throughout the combined sediments data. In many cases, significant uncensored parts of element populations have concentration values that are less than some of the reported determination limits. There are also cases where the determination limits are actually greater than the median values for an element. These relatively high detection limits contribute to especially problematic uncertainty surrounding the actual element concentrations.

To account more reasonably for relatively high determination limits in the combined sediments-only best-values data, a two-fold strategy was applied for replacing qualified values. First, a lesser replacement value was substituted for censored values that are less than or equal to the median concentration of an element; and second, a greater replacement value was used for values with detection limits greater than the median.

The median value for each element was calculated by using one of two methods. For element data that are more than 40 percent censored, the Kaplan-Meier method was used in Minitab 15 statistical software (Minitab Inc., 2014) to provide estimates of mean, median, standard deviation, and percentile values. This method is a nonparametric statistical approach to calculating cumulative probability distributions from which summary statistics for censored data are calculated (Helsel, 2012). In the case of tin (Sn), the Kaplan-Meier method was used to compute more reasonable percentile statistics using only USGS data.

For data that are less than 40 percent censored, we substituted the lesser of half the minimum detection limit or half of the least determined value for qualified concentrations and then calculated statistics directly using Microsoft Excel 2013 spreadsheet software (Microsoft, Inc., 2013). This procedure was also used for the highly censored tellurium (Te) data because the Kaplan-Meier method could not be successfully applied in that case. Another unusual situation was encountered with the silicon (Si) data that predominantly included values of 10.1111, which was a replacement value used to identify censored semiquantitative emission spectroscopy data that had been reported as greater than the upper determination limit of 10 percent. These values were removed before calculating Si data statistics, and corresponding areas were subsequently symbolized in the Si map sheets as uncertain. Excepting silicon, greater-than-upper-determination-limit values, identified with trailing “1111” were rarely encountered in the data and no attempt was made to replace or eliminate them.

**Table 1.** Replacement values used for censored data for the Geochemical Atlas of Alaska, 2016.

[ADGGS, Alaska Department of Geology & Geophysical Surveys; NURE, National Uranium Resources Evaluation; HSSR, Hydrogeochemical and Stream Sediment Reconnaissance; USGS, U.S. Geological Survey; DL, detection limit or lower limit of determination; NA, not available]

| Element | ADGGS<br>sediments | NURE-HSSR<br>sediments | USGS<br>sediments | USGS<br>soils | Combined sediments<br>replacements for<br>DL≤median | Combined sediments<br>replacements for<br>DL>median |
|---------|--------------------|------------------------|-------------------|---------------|---|---|
| Ag_ppm  | 0.0111             | 2.11                   | 0.017511          | 0.00511       | 0.0111  | 0.0811  |
| Al_pct  | NA                 | 0.0044511              | 0.0019511         | NA            | 0.0019511   | 6.0311  |
| As_ppm  | 1.11               | 2.511                  | 0.311             | 0.0511        | 0.311   | 10.11   |
| Au_ppm  | 0.0002511          | 0.00511                | 0.000511          | 0.0002511     | 0.0002511   | 0.00211   |
| B_ppm   | NA                 | NA                     | 0.0511            | 0.111         | 0.0511  | NA  |
| Ba_ppm  | 5.11               | 1.511                  | 1.11              | 5.211         | 1.11  | 688.11  |
| Be_ppm  | 0.2511             | 0.511                  | 0.00511           | 0.00511       | 0.00511   | 1.11  |
| Bi_ppm  | 0.0311             | 2.11                   | 0.000511          | 0.01511       | 0.000511  | 0.211   |
| C_pct   | NA                 | NA                     | 0.0511            | 0.00511       | 0.0511  | NA  |
| Ca_pct  | 0.02511            | 0.015611               | 0.002511          | 0.0015511     | 0.002511  | 1.3511  |
| Cd_ppm  | 0.0111             | 2.11                   | 0.001511          | 0.001511      | 0.001511  | 0.211   |
| Ce_ppm  | 1.511              | 0.511                  | 0.02511           | 0.4511        | 0.02511   | 55.11   |
| Cl_pct  | NA                 | 0.000511               | NA                | NA            | 0.000511  | 0.00211   |
| Co_ppm  | 0.511              | 0.511                  | 0.111             | 0.511         | 0.511   | 16.711  |
| Cr_ppm  | 0.511              | 0.511                  | 0.511             | 0.511         | 0.511   | 91.11   |
| Cs_ppm  | 0.0511             | 0.0511                 | 0.01511           | 0.001511      | 0.01511   | 2.811   |
| Cu_ppm  | 0.2511             | 3.511                  | 0.1511            | 0.511         | 0.1511  | NA  |
| Dy_ppm  | 0.511              | 0.511                  | 0.11211           | 0.0711        | 0.11211   | 5.11  |
| Er_ppm  | NA                 | NA                     | 0.0711            | 0.03811       | 0.0711  | 2.4511  |
| Eu_ppm  | 0.0511             | 0.0511                 | 0.03311           | 0.02511       | 0.03311   | 1.211   |
| F_pct   | NA                 | NA                     | 0.00511           | 0.00511       | 0.00511   | NA  |
| Fe_pct  | 0.03511            | 0.0023511              | 0.0018511         | NA            | 0.0018511   | 3.9711  |
| Ga_ppm  | 1.11               | NA                     | 0.02511           | 0.4511        | 0.02511   | 16.111  |
| Gd_ppm  | NA                 | NA                     | 0.106511          | 0.0811        | 0.106511  | 4.5411  |
| Ge_ppm  | NA                 | NA                     | 0.33711           | 0.0511        | 0.03511   | 2.11  |
| Hf_ppm  | 0.0511             | 0.0511                 | 0.511             | 0.0111        | 0.0511  | 5.611   |
| Hg_ppm  | 0.00511            | NA                     | 0.00111           | 0.00511       | 0.00111   | 0.0811  |
| Ho_ppm  | NA                 | NA                     | 0.020511          | 0.01511       | 0.020511  | 0.8611  |
| In_ppm  | NA                 | NA                     | 0.00511           | 0.0111        | 0.00511   | 0.0511  |
| K_pct   | 0.00511            | 0.009611               | 0.000611          | 0.00511       | 0.000611  | 1.2211  |
| La_ppm  | 0.511              | 0.511                  | 0.1911            | 0.511         | 0.1911  | 27.11   |
| Li_ppm  | 0.511              | 0.511                  | 0.111             | 0.3411        | 0.111   | 23.11   |
| Lu_ppm  | 0.02511            | 0.0511                 | 0.0111            | 0.0311        | 0.0111  | 0.311   |
| Mg_pct  | 0.02511            | 0.0078511              | 0.002511          | 0.0111        | 0.002511  | 1.0611  |
| Mn_pct  | NA                 | 0.000211               | 0.0000511         | 0.000511      | 0.0000511   | 0.0711  |
| Mo_ppm  | 0.1311             | NA                     | 0.02511           | 0.02511       | 0.02511   | 0.8811  |
| Na_pct  | 0.00511            | 0.0003511              | 0.0000511         | NA            | 0.0000511   | NA  |
| Nb_ppm  | 0.511              | 1.11                   | 0.0511            | 0.04511       | 0.0511  | 9.11  |
| Nd_ppm  | NA                 | NA                     | 0.83511           | 0.4611        | 0.83511   | 23.11   |
| Ni_ppm  | 0.511              | 4.511                  | 0.3911            | 0.111         | 0.3911  | 31.11   |
| P_pct   | NA                 | NA                     | 0.00007511        | 0.002511      | 0.00007511  | 0.0611  |
| Pb_ppm  | 0.511              | 2.11                   | 0.12511           | 0.12511       | 0.12511   | 11.11   |
| Pd_ppm  | 0.000511           | NA                     | 0.0002511         | 0.000511      | 0.0002511   | 0.00111   |
| Pr_ppm  | NA                 | NA                     | 0.219511          | 0.111         | 0.219511  | 4.7811  |
| Pt_ppm  | 0.000511           | NA                     | 0.0002511         | 0.0002511     | 0.0002511   | 0.000511  |
| Rb_ppm  | 2.511              | 0.511                  | 0.111             | NA            | 0.111   | 13.311  |
| S_pct   | NA                 | NA                     | 0.00511           | 0.00511       | 0.00511   | 0.0411  |
| Sb_ppm  | 0.111              | 0.511                  | 0.02511           | 0.0511        | 0.02511   | 0.811   |
| Sc_ppm  | 0.0511             | 0.0511                 | 0.111             | 0.411         | 0.0511  | NA  |
| Se_ppm  | 0.511              | 2.511                  | 0.00511           | 0.0511        | 0.00511   | 0.511   |
| Si_pct  | NA                 | NA                     | 0.023211          | NA            | 0.023211  | NA  |
| Sm_ppm  | 0.0511             | 0.0511                 | 0.172511          | 0.111         | 0.0511  | 4.611   |
| Sn_ppm  | 0.411              | 4.511                  | 0.0511            | 0.0511        | 0.0511  | 1.11  |
| Sr_ppm  | 4.511              | 0.511                  | 0.0211            | 1.11          | 0.0211  | 182.11  |
| Ta_ppm  | 0.12511            | 0.511                  | 0.0511            | 0.02511       | 0.0511  | 0.611   |
| Tb_ppm  | 0.511              | 0.511                  | 0.01811           | 0.0111        | 0.01811   | 0.6211  |
| Te_ppm  | 0.02511            | NA                     | 0.02511           | 0.0111        | 0.02511   | 0.111   |

**Table 1.** Replacement values used for censored data for the Geochemical Atlas of Alaska, 2016.—Continued

[ADGGS, Alaska Department of Geology & Geophysical Surveys; NURE, National Uranium Resources Evaluation; HSSR, Hydrogeochemical and Stream Sediment Reconnaissance; USGS, U.S. Geological Survey; DL, detection limit or lower limit of determination; NA, not available]

| Element | ADGGS<br>sediments | NURE-HSSR<br>sediments | USGS<br>sediments | USGS<br>soils | Combined sediments<br>replacements for<br>DL≤median | Combined sediments<br>replacements for<br>DL>median |
|---------|--------------------|------------------------|-------------------|---------------|---|---|
| Th_ppm  | 0.511              | 0.111                  | 0.08511           | 0.0511        | 0.08511   | 5.211   |
| Ti_pct  | 0.00511            | 0.000711               | 0.00009511        | 0.00111       | 0.00009511  | 0.4811  |
| Tl_ppm  | 0.07511            | NA                     | 0.004511          | 0.0111        | 0.004511  | 0.411   |
| Tm_ppm  | NA                 | NA                     | 0.01311           | 0.0111        | 0.01311   | 0.3511  |
| U_ppm   | 0.0511             | NA                     | 0.0411            | 0.0411        | 0.0111  | 2.611   |
| V_ppm   | 1.11               | 0.511                  | 0.211             | 1.11          | 0.211   | 137.11  |
| W_ppm   | 0.211              | 5.11                   | 0.02511           | 0.01511       | 0.02511   | 1.11  |
| Y_ppm   | 1.511              | NA                     | 0.0211            | 0.0211        | 0.0211  | NA  |
| Yb_ppm  | 0.111              | 0.111                  | 0.08211           | 0.0411        | 0.08211   | 2.711   |
| Zn_ppm  | 0.511              | 0.511                  | 0.07511           | 0.1511        | 0.07511   | 65.11   |
| Zr_ppm  | 0.511              | 2.511                  | 0.111             | 0.211         | 0.111   | NA  |

After determining the median for each element, censored values were replaced with (a) the median, if the censored value were greater than the median, or (b) the lesser of either half the minimum detection limit or half of the least determined value, if the censored value were less than the median. For greater-than-median qualified values in the less censored data, the (a) replacements superseded the previous (b) substitutions that had been uniformly applied to determine basic statistics. In every case, replacement values were assigned a trailing “11” to permit their identification in the datasets.

Censored Data Replacements for Sediments-Plus-Soils Compilation

For the sediments-plus-soils compilation, each of the four (USGS sediments, USGS soils, NURE-HSSR sediments, and ADGGS sediments) individual best-value datasets were treated separately before combining them. For every element in each of the separate datasets, we replaced qualified concentrations below the lower detection limit with a single value: the lesser of half the minimum detection limit or half of the least unqualified value determined for the element. As with the sediments-only data, replacement values were assigned a trailing “11” for identification purposes.

Data Integration

Two different integration methods were used to combine the USGS, NURE-HSSR, and ADGGS data: (1) direct combination of the best values from the three sediment sample datasets followed by the two-fold censored data replacement strategy described above; and (2) transformation of the element data (with replacements) for each of the four separate sediments and soils datasets to standard normal forms by calculations of standard scores (also known as Z-scores) and geometric standard scores (geometric Z-scores), followed by merging those scores to create integrated sediments-plus-soils data. These two combination strategies resulted in separate variations of integrated geochemical data for subsequent modeling and mapping of element distributions for Alaska.

In the first integration method, direct combination of all sediments-only best values, was based on an assumption of reasonable consistency among sediment samples represented in the USGS, NURE-HSSR, and ADGGS datasets. Moreover, it was assumed that best values of concentrations in those three datasets are also adequately coherent. Soils data were not included in this direct combination integration of best values because we considered element concentrations in soil samples to be unacceptably dissimilar to sediments data, particularly after a cursory examination of basic statistics from those separate populations revealed insupportable discordance. Although the sediments-only integration suffers from less comprehensive spatial coverage (see A and B map sheets for the elements), particularly in the Yukon Delta area, an advantage is that units of concentration, in ppm or percent, are maintained.

For the second integration method, which incorporates both sediments and soils data, standard scores and geometric standard scores for each element concentration were calculated separately for each of the individual sediments and soils datasets after replacements of censored data as described above. The principal purpose of standardizing the data was to facilitate integration of soils and sediments data to provide more comprehensive spatial coverage of geochemical data points for Alaska. The standard score of each concentration value was calculated by subtracting, for every element in each sample, its mean concentration from its best-value concentration (including replacements) and dividing the result by the standard deviation of the element variable as follows:

$$Z = (X - \bar{X}) / \sigma_X \tag{1}$$

where  
Z     is the standard score of element concentration X,  
 $\bar{X}$     is the mean element concentration, and  
 $\sigma_X$    is the standard deviation of the element concentrations.

This transformation creates a standardized Z-score dataset with a mean of 0 and a standard deviation of 1.

Geometric standard scores were similarly calculated after transforming the data to natural logarithm values, and then applying the standardization formula to the natural log-transformed variables:

$$Z_G = (\ln X - \overline{\ln X}) / \sigma_{\ln X} \quad (2)$$

where

- $Z_G$  is the geometric standard score of element concentration  $X$ ,
- $\ln X$  is the natural logarithm of element concentration  $X$ ,
- $\overline{\ln X}$  is the mean of  $\ln X$ , and
- $\sigma_{\ln X}$  is the standard deviation of  $\ln X$ .

The resultant geometric  $Z$ -score dataset also has a mean of 0 and a standard deviation of 1.

Both standard and geometric standard score transformation versions are included for the reader's consideration in evaluation and interpretation of element distributions. The map sheets show that some elements are more effectively visualized with standard scores, and others seem better conceptualized using the geometric standard score mapping. Ahrens (1957, 1965) contended that elements are lognormally distributed in the crust, but Reimann and Filzmoser (2000) argued that normal or lognormal distributions of regional geochemical data are the exception rather than the rule.

In this study, we have not undertaken further statistical interpretations of the data, such as multivariate analysis, the efficacy of which would depend on more robust examination and characterizations of the element distributions. Instead, we have standardized the data and the log-transformed data from separate datasets to provide a reasonable approach for mitigating the heterogeneities in diverse constituents, particularly among different sample media.

The standard normal transformations of the data and the log-transformed data in each dataset facilitate harmonious integration of otherwise dissimilar datasets. By separately creating standard scores and geometric standard scores of element concentrations in each of the sediments and soils datasets, we have made no assumption of homogeneity among those data. By combining those standard normal dataset scores, each with mean=0 and standard deviation=1, we have produced consistent, integrated element distributions that mitigate heterogeneities typically inherent when combining disparate datasets. However, this method loses the original concentration units, that is, ppm or percent, for the transformed dimensionless scores.

## Distribution Modeling

From the two variations of integrated datasets, four models were created of statewide geochemical distribution for each of 68 elements. Three of those models were interpolated "surface" grids of combined best values, standard scores, or geometric standard scores. The fourth model displays the distribution of mean best-value concentrations of combined sediments-only data within mapped hydrologic units (stream catchments).

## Treatment of Spatially Coincident Samples

Many sample localities in the combined datasets are duplicated, not only because more than one sample was sometimes collected at the same site, but also because some of the samples have been reanalyzed, and in many cases, both the original and the reanalysis data occur in the database as separate co-located sample entities. For example, the database includes analyses of 1,589 stream-sediment samples that were originally collected and analyzed during the USGS Heavy Metals and Alaska Mineral Resource Assessment Program (AMRAP) projects (1966–1995), and were reanalyzed during 2007–2010 by the Federal Lands in Alaska–Geologic Studies project. Also included are analyses from 6,686 NURE-HSSR sediment samples that were originally collected and analyzed during the 1970s and were later reanalyzed by the USGS, including, in part, 4,804 samples for the National Geochemical Survey project between 1998 and 2008 (U.S. Geological Survey, 2004) and 1,640 for AMRAP projects. In both examples, the samples were issued a second laboratory identification number upon submission for reanalysis, thereby creating a second data record in the database for the same samples.

The duplicate sample localities can be recognized when the data are used in a GIS, and alternative treatments can be applied to the spatially coincident data. In this work, for each element concentration determined in more than one sample at a location, GIS was used to select the maximum value at each site to use for interpolation purposes.

## Interpolated Distribution Models

Interpolation of point data variables produces spatially continuous "surface" rasters with grid cell values that are calculated from not only sample site localities, but are also algorithmically estimated in intervening areas with no data points. Three of the integrated variables (sediments-only best values, sediments+soils standard scores, and sediments+soils geometric standard scores) were interpolated for 68 elements to produce 204 continuous-surface grids of geochemical distributions across the State. Inverse distance weighting (IDW) was applied to each of the integrated variables using ArcGIS 10.3.1 Geostatistical Analyst software applications (Esri, 2014). Using this method, a weighted average of values for all data points within 10 km of the center of each grid cell was calculated, with up to 20 neighboring points participating in the value calculation for each cell. A power of 2 was used for the weighting factor for data points included in the calculations; in other words, the inverse of the square of a point's distance from the center of a cell was used to weight its influence on the value for the cell. Thus, nearer data points have much greater influence in determining the weighted average than more distant samples. IDW is an exact interpolator that produces surface grids that honor the values of the input data points. That is, the value of the interpolated surface grid matches the value of the data points where they coincide. Also, the minimum and maximum values of IDW grids can occur

only at data points, so the interpolated values all lie within the range of analytically determined concentrations. The grid cell size for the interpolated surface models is 500 meters (m).

Interpolated surface grids of geochemical distributions can facilitate various types of spatial analysis such as multi-layer predictive modeling (Lee and others, 2001). The standard normal forms (standard scores or geometric standard scores) of concentration data also facilitate multiple-element combinations because the transformations result in dimensionless variables with identical means and deviations. In other words, standardization of variables in different datasets creates comparable distributions that can be congruously combined and compared. Use of standardized data can also alleviate mapping discontinuities across boundaries where dissimilar data join. For example, this approach for map symbolization was used by Yager and Folger (2004).

## Hydrologic Unit-Based Distribution Models

For many applications of geochemical information, it is convenient, useful, and sometimes crucial to be able to consider the chemical characteristics of drainage areas. For example, watershed boundaries may be used to delineate land management areas, mineral resource targets, or contaminants and their influences (Yager and others, 2012). For this study, we used hydrologic unit (HU) boundaries not only to provide geographic reference for map displays, but also to define areas to calculate the mean element concentrations of sediment samples collected within (and derived from) each of those watersheds.

As stated by the Federal Standards for Delineation of Hydrologic Unit Boundaries (<https://www.fgdc.gov/standards/projects/FGDC-standards-projects/hydro-unit-boundaries>) and found at the Hydrography page of The National Map (<http://nhd.usgs.gov/wbd.html>), “A hydrologic unit is a drainage area delineated to nest in a multi-level, hierarchical drainage system.” GIS-compatible hydrologic unit datasets can be obtained from the National Hydrography Dataset (NHD) or the companion Watershed Boundary Dataset (WBD) at <http://nhd.usgs.gov/> or from the Natural Resources Conservation Service (NRCS) through <http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/water/>. Each polygonal NHD/WBD hydrologic unit is identified by a unique hydrologic unit code (HUC, [http://nhd.usgs.gov/wbd\\_facts.html](http://nhd.usgs.gov/wbd_facts.html)) that consists of 2 to 12 digits based on the six levels of classification in the hydrologic unit system. Codes with larger numbers of digits identify smaller hydrologic units that are nested within larger drainage areas that are designated with shorter HUCs. Although development continues to provide more detailed hydrologic unit coverages, the currently available six classification levels of HUCs are (1) 2-digit HUCs to identify regions, for example, Alaska is region 19; (2) 4-digit HUCs to designate subregions; (3) 6-digit HUCs, which are assigned to basins; (4) 8-digit HUCs, which are associated with subbasins; (5) 10-digit HUCs to designate watersheds; and (6) 12-digit HUCs to identify subwatersheds. For example, the Rabbit Creek subwatershed near Anchorage

is identified with HUC 190204010701. A thorough description of the WBD is provided in U.S. Geological Survey and U.S. Department of Agriculture (2013).

We used 12-digit HUC identifiers to select 13,988 Alaska subwatershed polygons that cover the State. The subwatersheds cover areas that range from around 40 to 160 km<sup>2</sup>, with an average of approximately 100 km<sup>2</sup> (U.S. Geological Survey and U.S. Department of Agriculture, 2013); although St. Lawrence Island (4,774 km<sup>2</sup>) lacks hydrologic unit detail beyond the 8-digit HUC level. Several other of the subwatersheds are unusually large, notably Iliamna Lake (3,884 km<sup>2</sup>), Becharof Lake (1,804 km<sup>2</sup>), and Malaspina Glacier (2,754 km<sup>2</sup>). ArcGIS software functionality was used to compute and spatially join to each Alaska subwatershed polygon the mean concentrations of elements determined for sediment samples within those hydrologic units. No mean concentration value was assigned to subwatersheds lacking sediment samples or relevant element determinations. The result is a statewide GIS-based subwatershed model showing distributions of mean element concentrations that were derived from the integrated sediment sample data compilation.

## Explanation of Map Sheets and Figures

Map sheets contained in this report are listed in table 2 and are accessible in the `ds908_elements` directory (folder). They are provided in Adobe Portable Document Format (PDF) and can be viewed or printed using Adobe Reader software, freely available at <http://www.adobe.com>. The figures are found in the `ds908_full_size_figures` folder and the map sheets have been grouped into `ds908_elements\<element name>` folders. The GIS data that accompany this report are available through the USGS ScienceBase as a data release at <http://dx.doi.org/10.5066/F7GF0RK5> (Lee and others, 2016).

## Map Sheets

The 272 map sheets in this atlas depict the above-described models of spatial distributions of concentrations for 68 geochemical elements. They are shown as color images that have been semi-transparently draped over a greyscale-shaded topographic relief image of Alaska. Those areas of the maps that remain grey indicate the absence of data. The map areas designated as “uncertain” contain only censored data with detection limits greater than the median value for that element or, in the case of silicon (Si), an upper determination limit that is less than the median value. The nominal print size for the map sheets is 11”×17” at 1:8,175,000 scale. However, the map sheets may also be displayed or printed at other scales to suit the reader. Because these maps are offered as digital publications, users should be aware that, because of differences in rendering processes and pixel resolution, some slight distortion of scale may occur when viewing them on a computer screen or when printing them on an electronic plotter, even when they are viewed or printed at their nominal publication scale.

Map sheets are organized in alphabetical order by element name and are numbered 1–68. The PDF filenames begin with the publication number (DS908), and include both the element name and map sheet number. The A, B, C, and D suffixes for each map sheet correspond to the geochemical distribution models that they represent:

- A. Interpolated best values of element concentrations in sediment samples, displayed as color-coded percentiles at the 50th, 75th, 91st, and 98th percentile levels;
- B. Mean best-value element concentrations of sediment samples within hydrologic units (subwatersheds), also displayed as color-coded percentiles as in A sheets;
- C. Interpolated standard scores of concentrations in combined sediment and soil samples, color-sliced to show score intervals; and
- D. Interpolated geometric standard scores of element concentrations in combined sediment and soil samples, also color-sliced to show score intervals as in C sheets.

For reference, scores of 1, 1.5, 2, 2.5, and 3 correspond to distribution percentiles of approximately 84, 93, 98, 99, and 99.9, respectively.

Each A and B map sheet includes a table that shows the statistical distribution of the depicted element within the entire sediments-only dataset compilation. The concentration values at the 25th, 50th, 75th, 91st, and 98th percentiles are shown as well as the mean, the interquartile range (IQR), and the median plus IQR. The table also indicates whether the Kaplan-Meier method (K-M) was applied to estimate statistics for elements with a high percentage of censored data.

In addition, for the reader's convenience, color (RGB) georeferenced tagged image file format (GeoTIFF) images of the element distribution models have also been included in the 908\_elements\<element name> folders. These GeoTIFF files are also named according to the convention established for the map sheets: [publication identifier]\_[element name]\_[map sheet number]; for example, DS908\_Silver\_50A.tif. To ensure accurate color rendering, these images should be displayed with no stretch. The colors of these images correspond to the explanations of the associated map sheets.

## Description of Map Artifacts

As described above, our compilation and integration of Alaska geochemical data were derived from diverse datasets from numerous projects with widely varying scales, and employing a wide range of analytical methods. Those diversities have resulted in apparent discontinuity artifacts for some elements in the map sheet displays. These artifacts fall into categories as described below:

- Areas enclosing analytical data produced with a lower detection limit for a given element can be surrounded by areas with significantly greater detection limits for

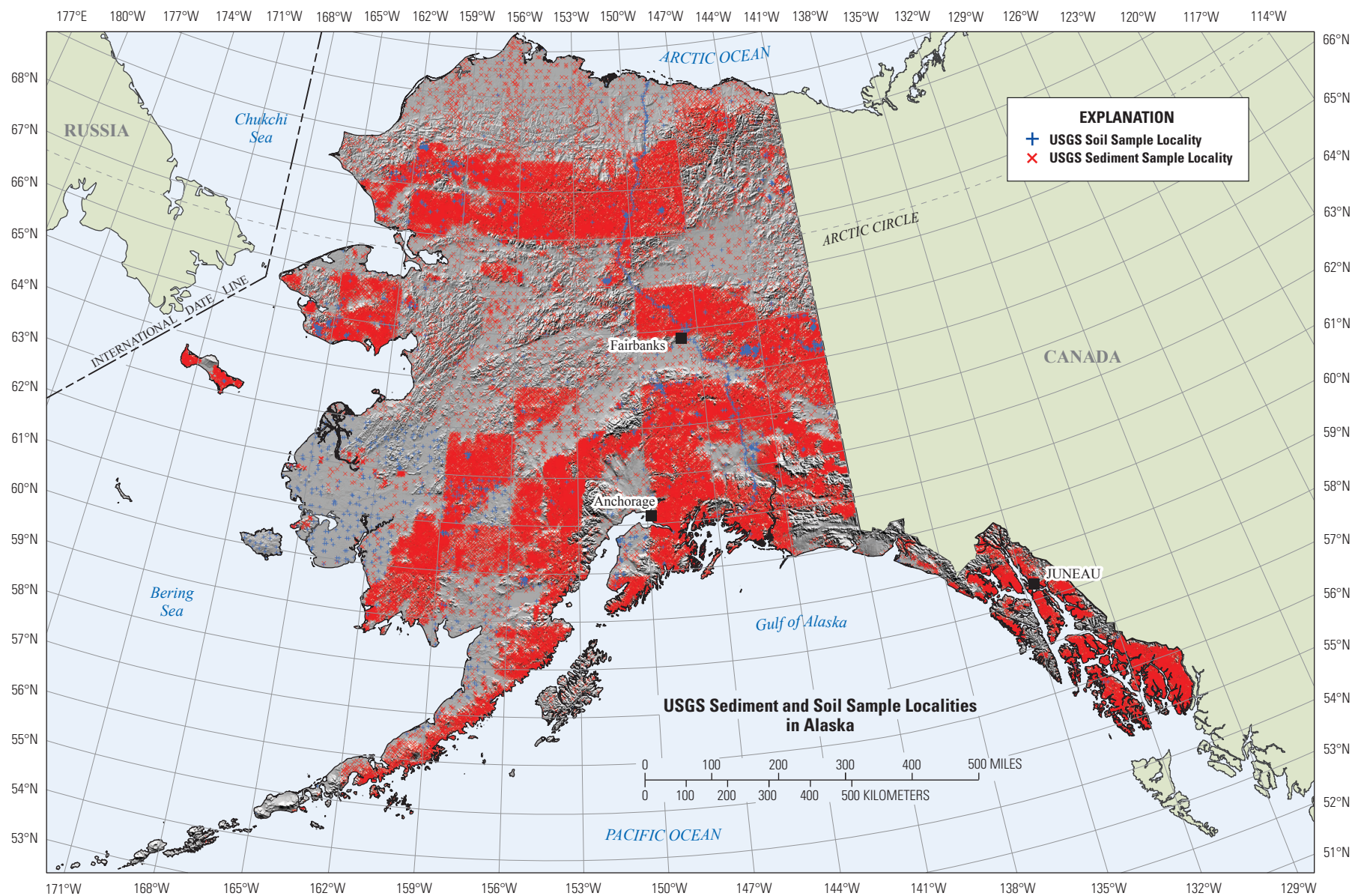
that element, creating what appears to be a low-level anomaly but in reality is a data artifact. These artifacts can commonly take the shape of 1:250,000-scale USGS quadrangles because geochemical reconnaissance projects in Alaska were often done for quadrangle-bounded study areas. The analytical methods used to determine concentrations within artifact areas are usually newer, more advanced and more sensitive than methods that were used in the surrounding areas.

- According to Weaver and others (1983), cesium (Cs), cobalt (Co), magnesium (Mg), and rare-earth elements (REE) displayed discontinuities at quadrangle boundaries because of analytical instrument calibration errors in NURE-HSSR determinations.
- Concentrations for a few elements were determined by one regional survey but not by others. NURE-HSSR analytical data include chlorine (Cl) and selenium (Se) determinations—analyses that were not usually applied to sediment samples in USGS or ADGGS regional studies.
- Fewer than half of Alaska's 1:250,000-scale USGS quadrangles had comprehensive regional reconnaissance studies under AMRAP, thereby creating the effect of areas with relatively high sampling densities adjacent to areas with low sampling densities.
- High titanium (Ti) values along the lower Kuskokwim River suggest the possibility that some sediment concentrate data might be included with the sediments in that area.

## Figures

Figures 1–3 show localities of USGS sediment and soil samples, NURE-HSSR sediment samples, and ADGGS sediment samples, respectively, that together form the basis for this study. Figure 4 shows the numbers of sediment samples within each 12-digit HUC-identified subwatershed used as the basis for the B sheets. Figures 5–7 provide supporting geographic and geologic information as context and reference for the geochemical map sheets: the principal physiographic provinces of Alaska including mountain ranges, lowland areas, major drainages, and major towns (fig. 5); tectonostratigraphic domains (fig. 6); and generalized land status and producing mines (fig. 7).

Figures 8–12 were provided by Richard W. Saltus, USGS, to illustrate geophysical results for Alaska: gravity anomalies that reflect regional contrasts in crustal density (fig. 8); magnetic anomalies that show variations in magnetic properties of rocks in the crust (fig. 9); aeroradiometric measurement values of potassium (K) (fig. 10); aeroradiometric measurement values of uranium (U) (fig. 11); and aeroradiometric measurement values of thorium (Th) (fig. 12).



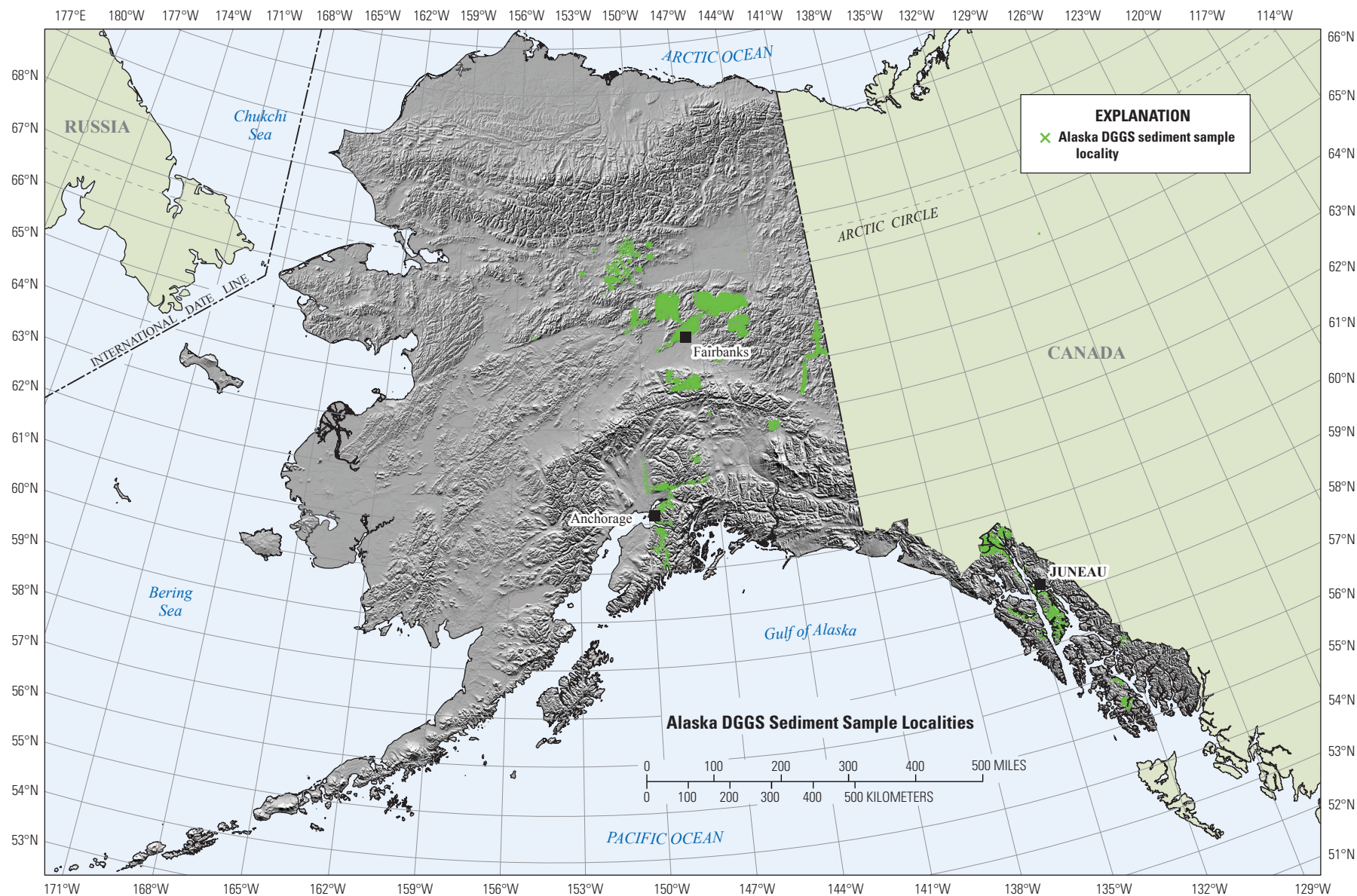
Base is a shaded-relief image derived from 300-m resolution digital elevation model, 1997, U.S. Geological Survey EROS Alaska Field Office, Anchorage, Alaska, available online at: <http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz>  
 Projection: Albers Equal-Area Conic. Datum: World Geodetic System 1984 (WGS 84). Country outlines modified from the Alaska Department of Natural Resources. Boundaries are approximate and for display purposes only

**Figure 1.** U.S. Geological Survey (USGS) sediment and soil sample localities in Alaska. ([Click here to access the full-size map version](#)).

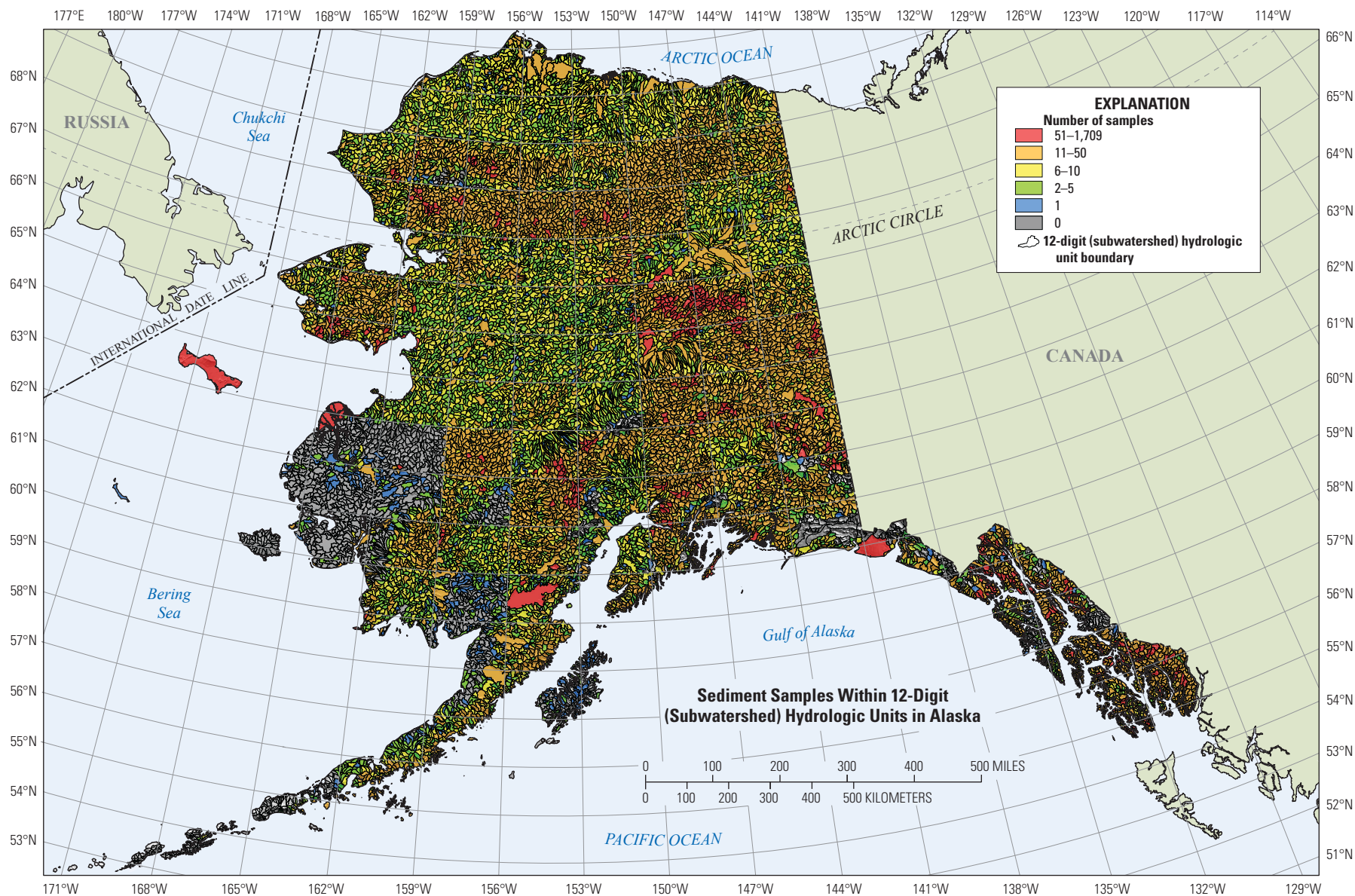


Base is a shaded-relief image derived from 300-m resolution digital elevation model, 1997, U.S. Geological Survey EROS Alaska Field Office, Anchorage, Alaska, available online at: <http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz>  
 Projection: Albers Equal-Area Conic. Datum: World Geodetic System 1984 (WGS 84). Country outlines modified from the Alaska Department of Natural Resources. Boundaries are approximate and for display purposes only

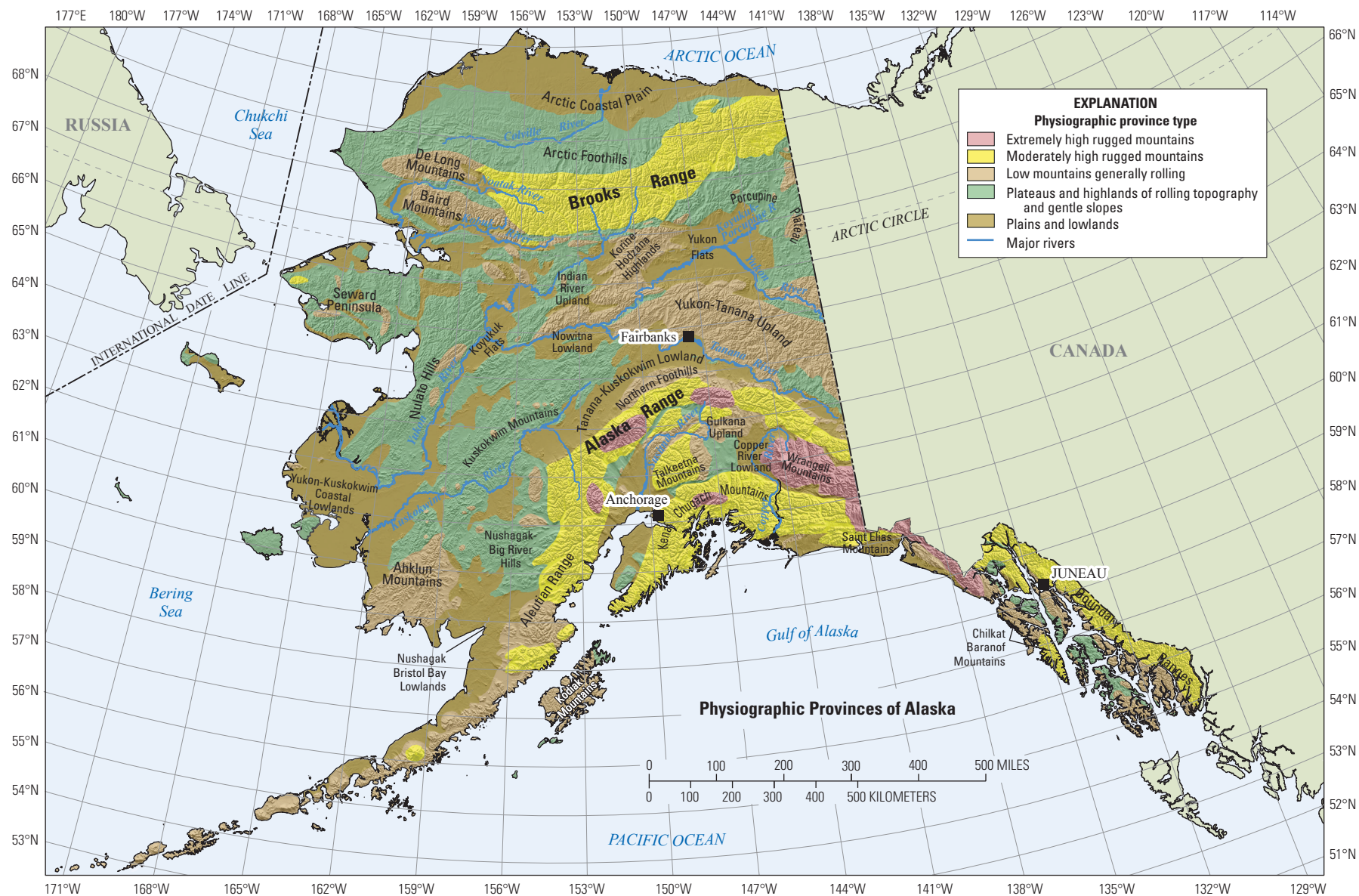
**Figure 2.** National Uranium Resource Evaluation (NURE) Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) sediment sample localities in Alaska. ([Click here to access the full-size map version](#)).



**Figure 3.** Alaska Division of Geological and Geophysical Surveys (ADGGS) sediment sample localities. ([Click here to access the full-size map version](#)).

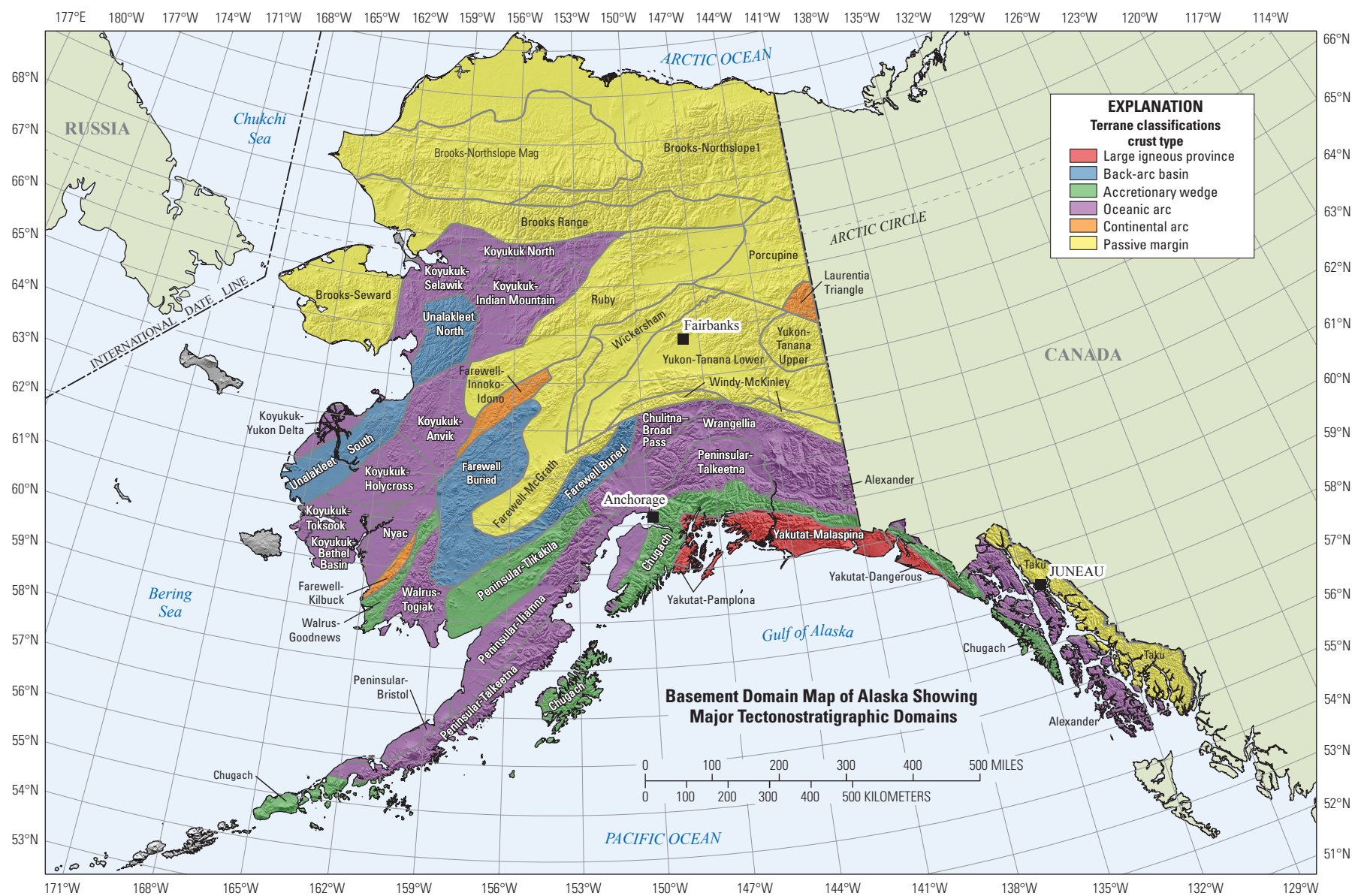


**Figure 4.** Sediment samples within 12-digit (subwatershed) hydrologic units in Alaska. ([Click here to access the full-size map version](#)).



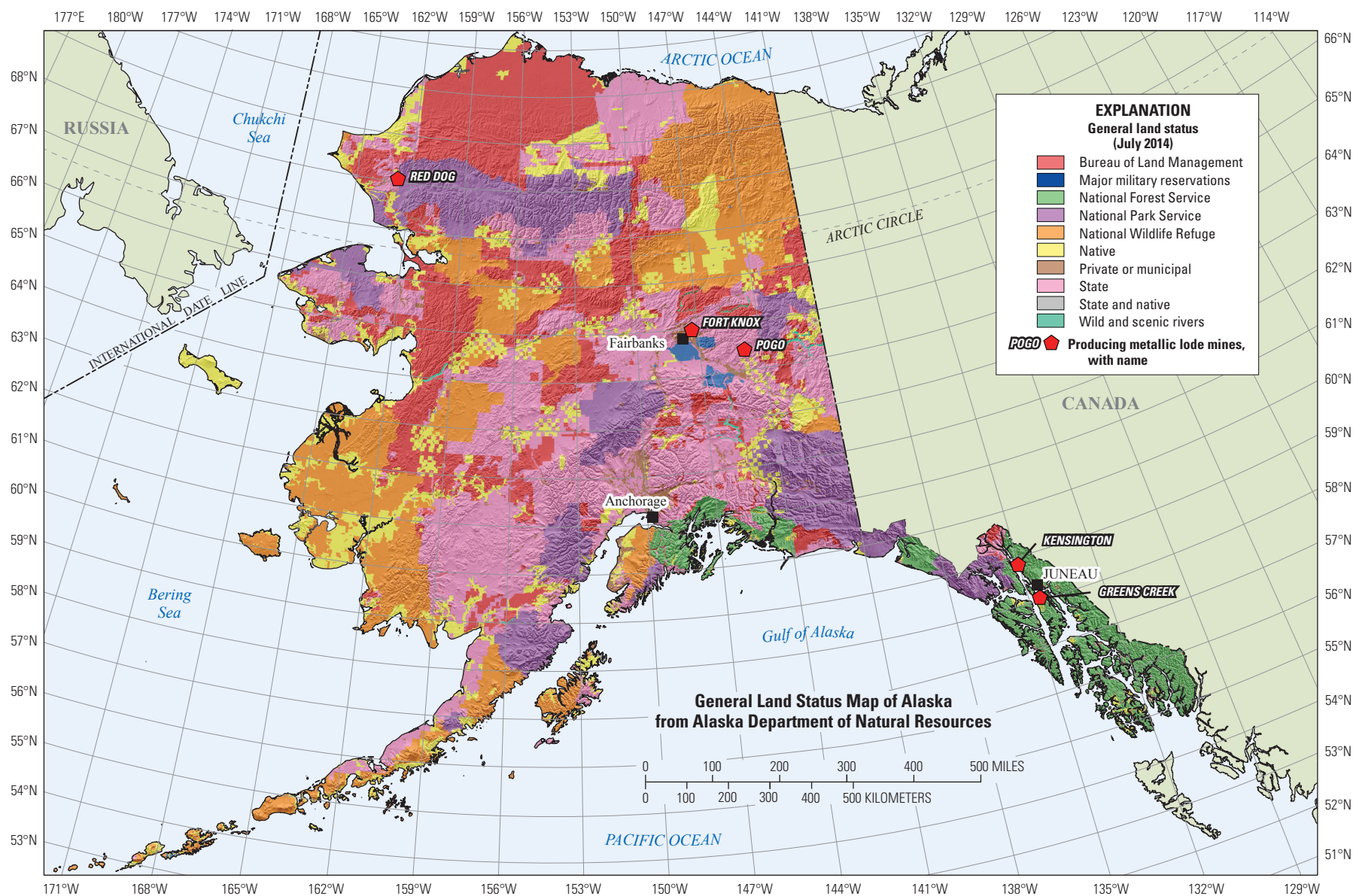
Base is a shaded-relief image derived from 300-m resolution digital elevation model, 1997, U.S. Geological Survey EROS Alaska Field Office, Anchorage, Alaska, available online at: <http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz>  
 Projection: Albers Equal-Area Conic. Datum: World Geodetic System 1984 (WGS 84). Country outlines modified from the Alaska Department of Natural Resources. Boundaries are approximate and for display purposes only

**Figure 5.** Physiographic provinces of Alaska. Adapted from Wahrhaftig (1965). ([Click here to access the full-size map version](#)).



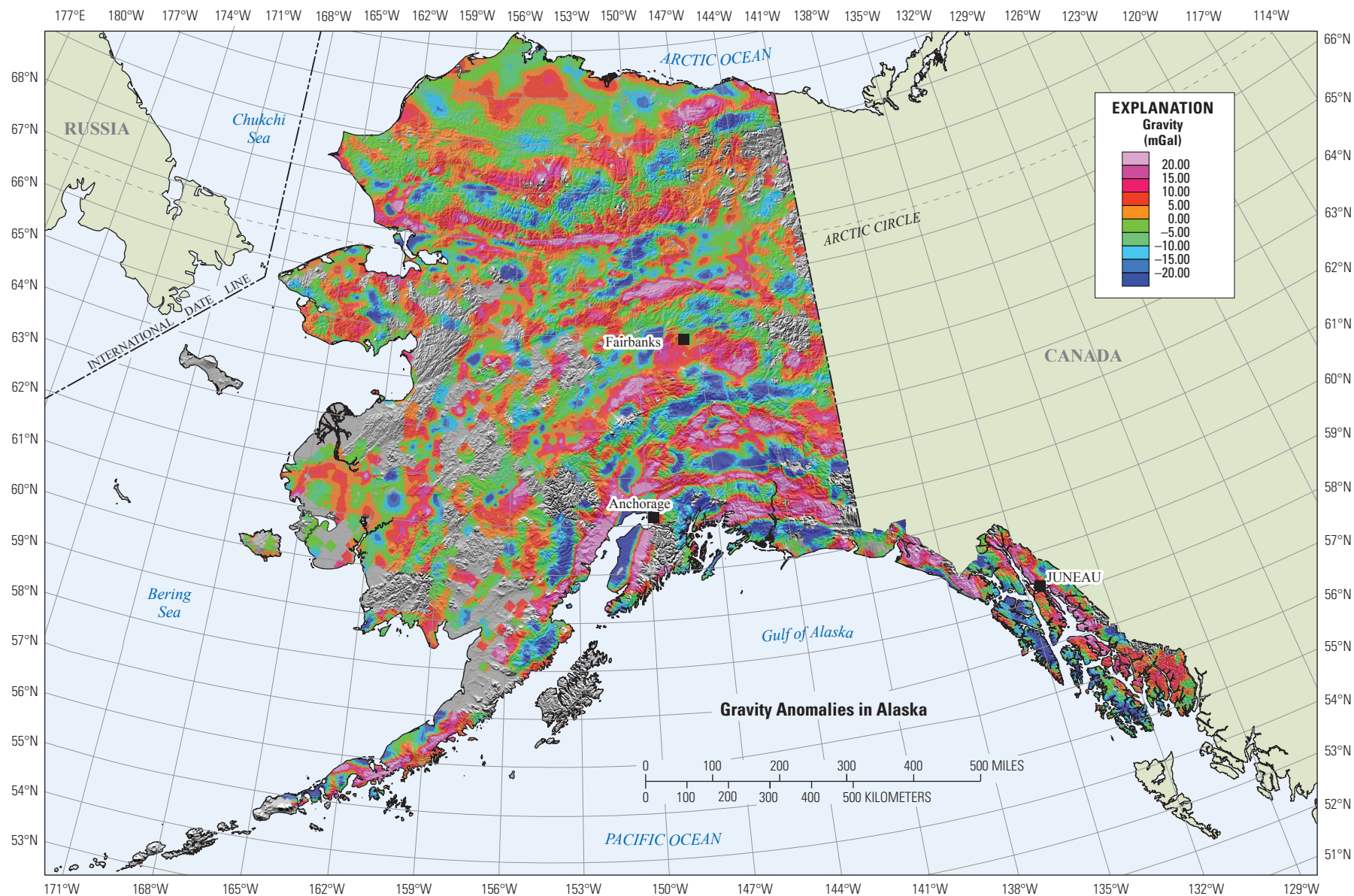
Base is a shaded-relief image derived from 300-m resolution digital elevation model, 1997, U.S. Geological Survey EROS Alaska Field Office, Anchorage, Alaska, available online at: <http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz>  
 Projection: Albers Equal-Area Conic. Datum: World Geodetic System 1984 (WGS 84). Country outlines modified from the Alaska Department of Natural Resources. Boundaries are approximate and for display purposes only

**Figure 6.** Basement domain map of Alaska showing major tectonostratigraphic domains. Modified from Lund and others (2015). ([Click here to access the full-size map version](#)).



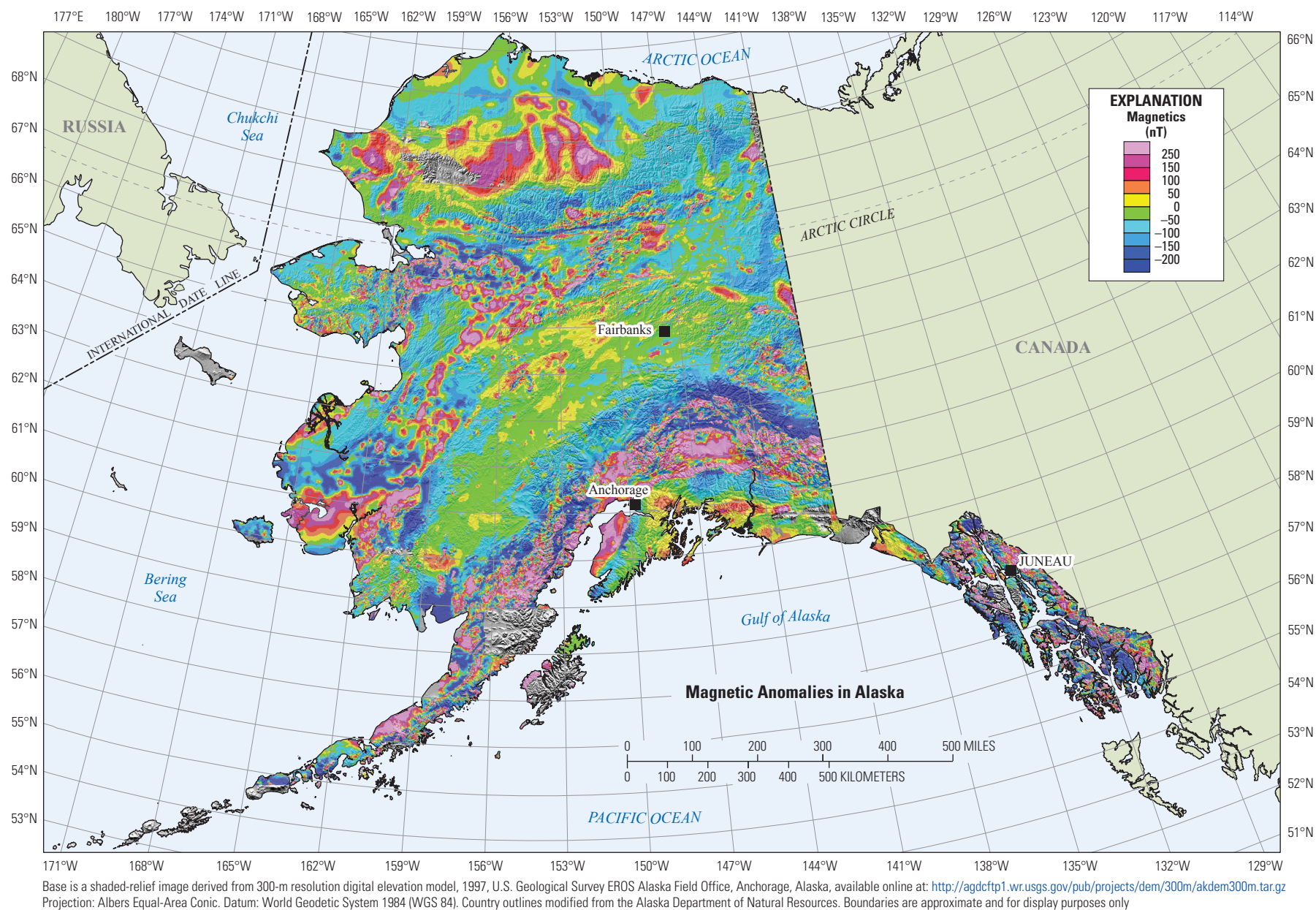
Base is a shaded-relief image derived from 300-m resolution digital elevation model, 1997, U.S. Geological Survey EROS Alaska Field Office, Anchorage, Alaska, available online at: <http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz>  
 Projection: Albers Equal-Area Conic. Datum: World Geodetic System 1984 (WGS 84). Country outlines modified from the Alaska Department of Natural Resources. Boundaries are approximate and for display purposes only

**Figure 7.** General land status map of Alaska. From Alaska Department of Natural Resources, accessed July 2014, at <http://dnr.alaska.gov/>. (Click here to access the full-size map version).

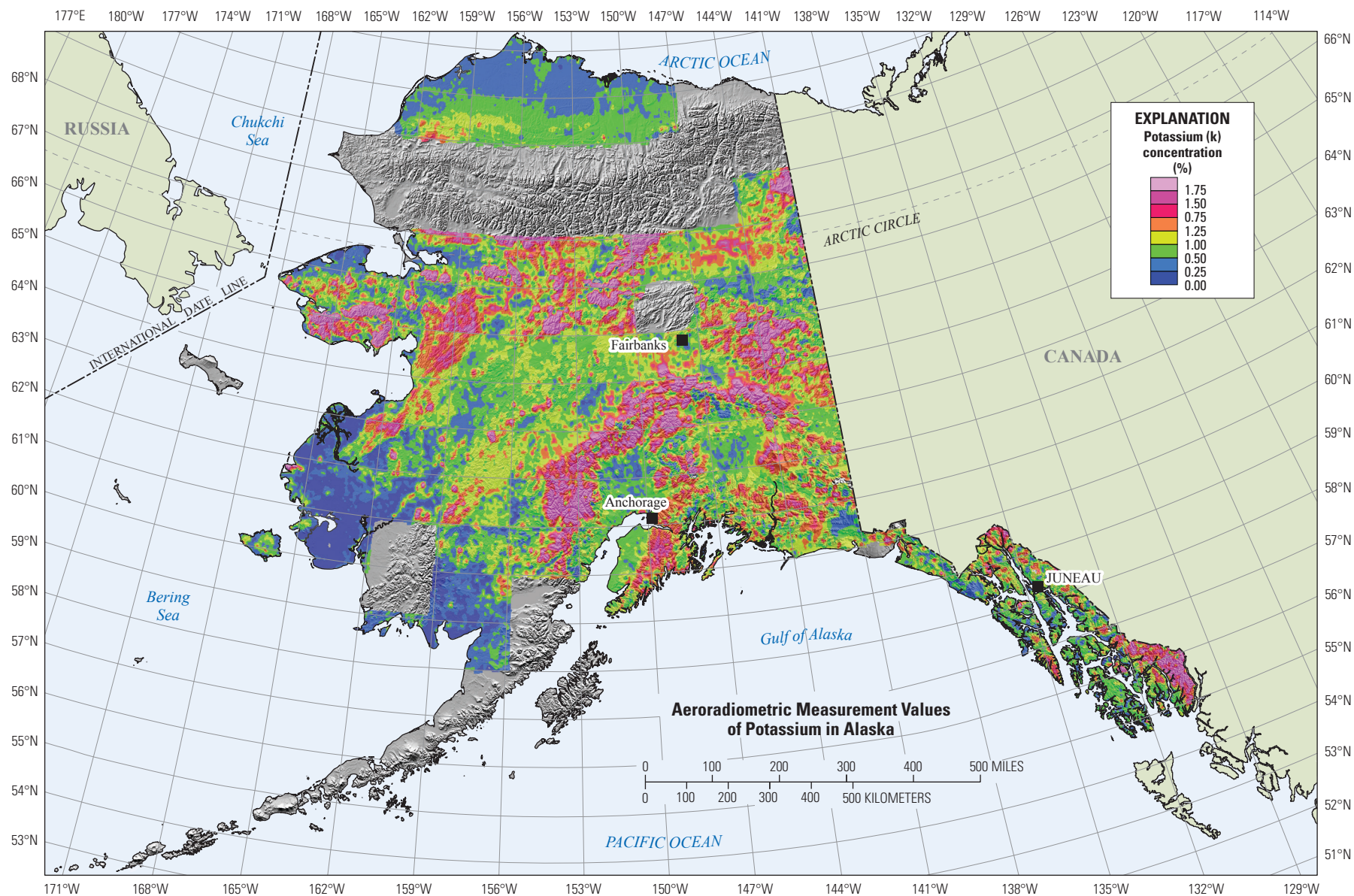


Base is a shaded-relief image derived from 300-m resolution digital elevation model, 1997, U.S. Geological Survey EROS Alaska Field Office, Anchorage, Alaska, available online at: <http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz>  
Projection: Albers Equal-Area Conic. Datum: World Geodetic System 1984 (WGS 84). Country outlines modified from the Alaska Department of Natural Resources. Boundaries are approximate and for display purposes only

**Figure 8.** Gravity anomalies in Alaska. This image depicts relative variations in the Earth's regional gravity field caused by density variations of rocks in the mid to upper crust. The values are based on a 200 km high-pass filter of complete Bouguer anomalies from the USGS 2006 data compilation; see Saltus and others (2008). Warmer colors indicate regions of relatively greater crustal rock density. ([Click here to access the full-size map version](#)).

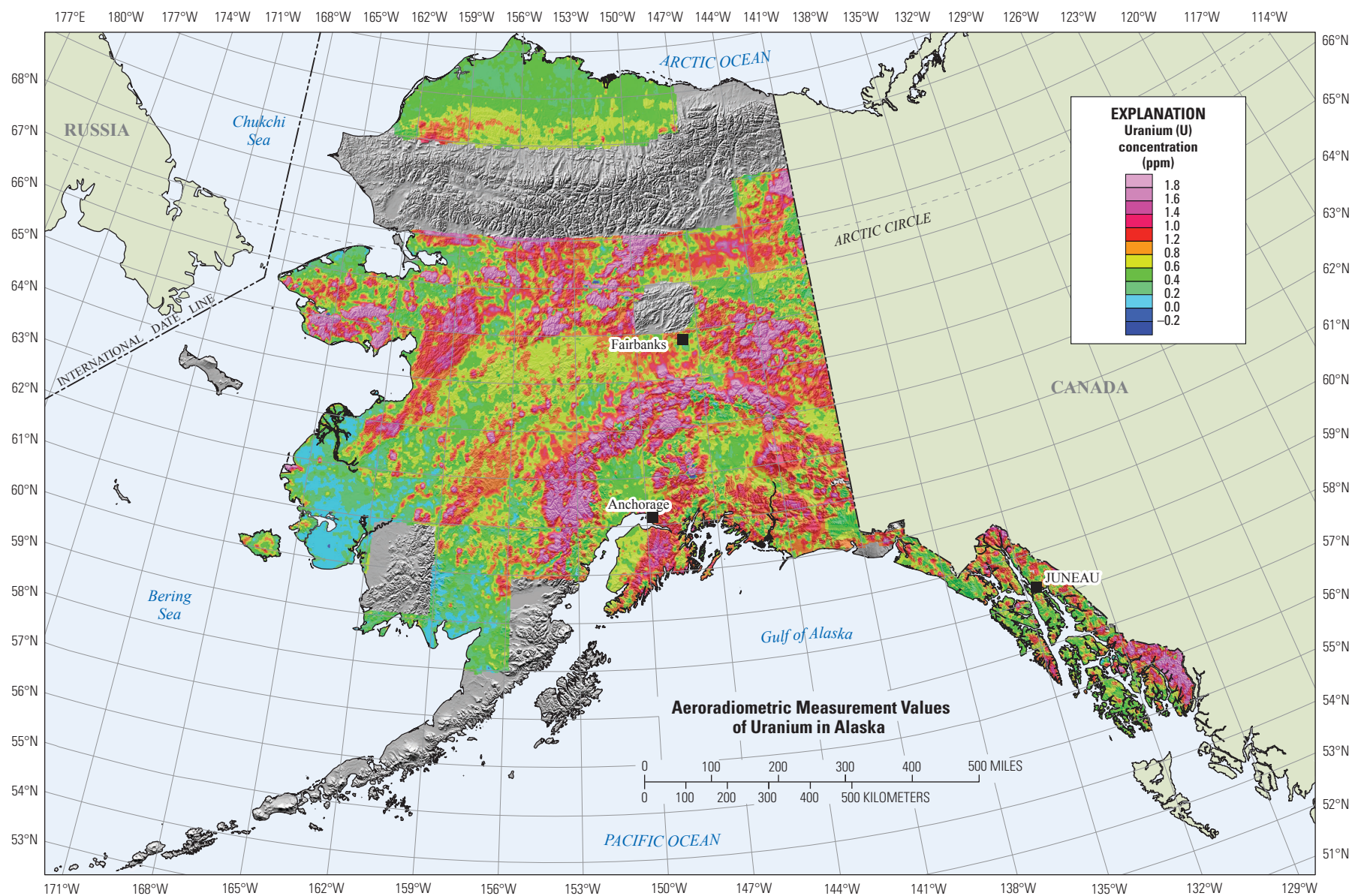


**Figure 9.** Magnetic anomalies in Alaska. This image depicts relative variations in the Earth's magnetic field caused by variations in the magnetic properties of rocks in the crust. The magnetic anomaly values are relative to the International Geomagnetic Reference Field (IGRF). Warmer colors indicate areas where the crust contains rocks with greater magnetism. For more information see Saltus and Simmons (1997). ([Click here to access the full-size map version](#)).



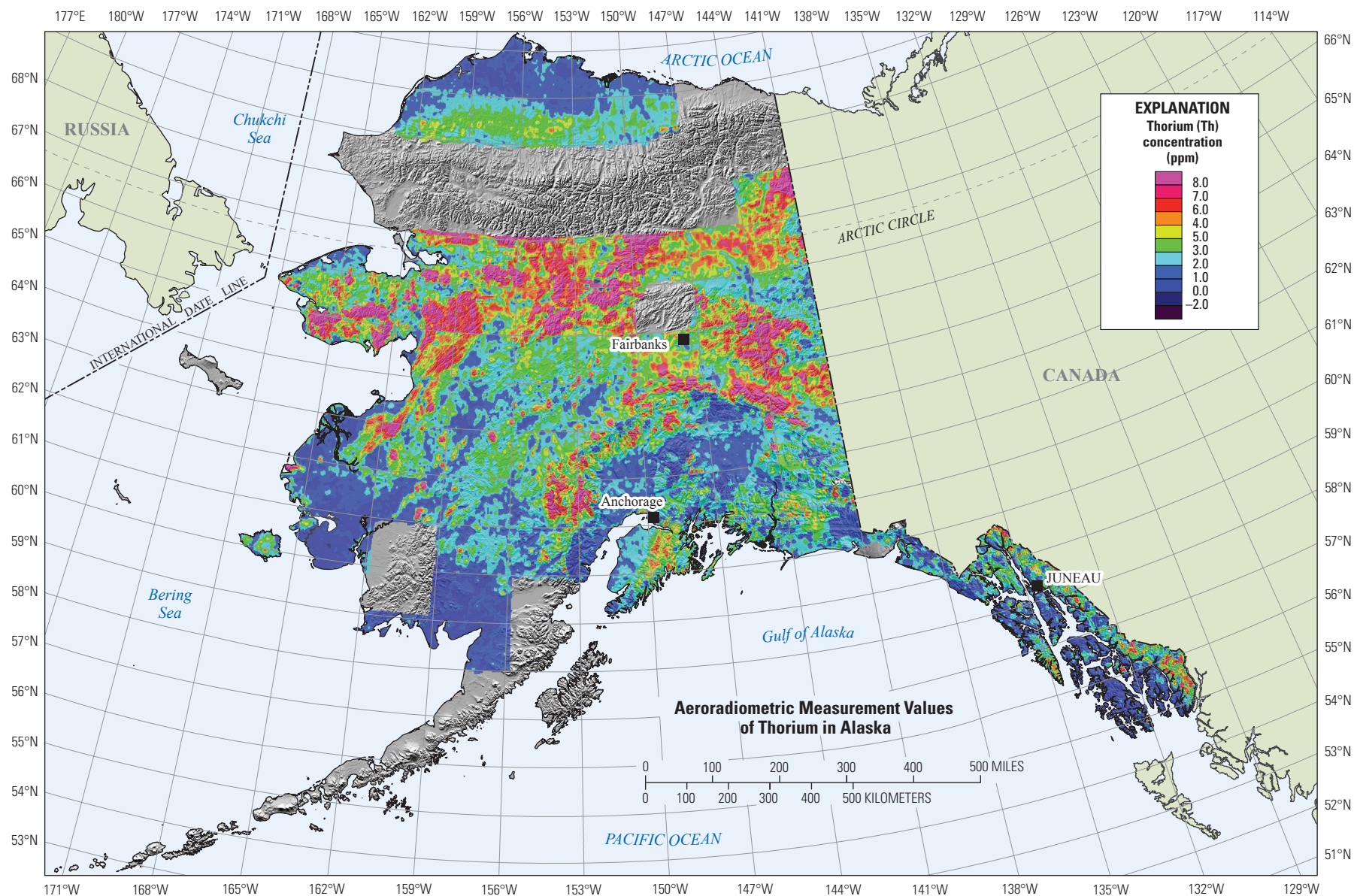
Base is a shaded-relief image derived from 300-m resolution digital elevation model, 1997, U.S. Geological Survey EROS Alaska Field Office, Anchorage, Alaska, available online at: <http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz>  
Projection: Albers Equal-Area Conic. Datum: World Geodetic System 1984 (WGS 84). Country outlines modified from the Alaska Department of Natural Resources. Boundaries are approximate and for display purposes only

**Figure 10.** Aeroradiometric measurement values of potassium (K) in Alaska. This image depicts the airborne measurement values of equivalent potassium (in percent) from the Alaska NURE program (1974–1983). Warmer colors indicate greater amounts of apparent potassium. For more information see Saltus and others (1999). ([Click here to access the full-size map version](#)).



Base is a shaded-relief image derived from 300-m resolution digital elevation model, 1997, U.S. Geological Survey EROS Alaska Field Office, Anchorage, Alaska, available online at: <http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz>  
Projection: Albers Equal-Area Conic. Datum: World Geodetic System 1984 (WGS 84). Country outlines modified from the Alaska Department of Natural Resources. Boundaries are approximate and for display purposes only

**Figure 11.** Aeroradiometric measurement values of uranium (U) in Alaska. This image depicts the airborne measurement values of equivalent uranium (in ppm) from the Alaska NURE program (1974–1983). Warmer colors indicate greater amounts of apparent uranium. For more information see Saltus and others (1999). ([Click here to access the full-size map version](#)).



Base is a shaded-relief image derived from 300-m resolution digital elevation model, 1997, U.S. Geological Survey EROS Alaska Field Office, Anchorage, Alaska, available online at: <http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz>  
Projection: Albers Equal-Area Conic. Datum: World Geodetic System 1984 (WGS 84). Country outlines modified from the Alaska Department of Natural Resources. Boundaries are approximate and for display purposes only

**Figure 12.** Aeroradiometric measurement values of thorium (Th) in Alaska. This image depicts the airborne measurement values of equivalent thorium (in ppm) from the Alaska NURE program (1974–1983). Warmer colors indicate greater amounts of apparent thorium. For more information see Saltus and others (1999). ([Click here to access the full-size map version](#)).

## Visualization Tips and Techniques

All included PDF files that depict map sheets and figures in this atlas can be displayed or printed using freely available Adobe Reader software. Note that the B sheets, by virtue of the large number of vector hydrologic unit boundaries that are included in these maps, will take much longer to display than the A, C, and D sheets. If any B sheet is magnified to 200 percent or more, the display should render more quickly.

A very convenient and excellent quasi-GIS multiple map overlay feature, described below, can be applied to all map sheet and figure PDFs in this atlas because all share a common registration. If multiple PDF selections of map sheets or figures are opened in maximized (full screen) Adobe Reader windows, they will perfectly overlaid each other so that you can toggle from one image to another by first hovering the cursor over the Adobe icon that can be seen on the bottom menu bar of the display, which will reveal a set of thumbnail views of each open PDF, and then, hovering the cursor over those thumbnails will immediately expand the image to fit the screen whenever the cursor passes over them. Moreover, the maps and figures will correctly overlaid each other when hover-selected so that the user can toggle, or “flicker” quickly from one map image to another by moving the cursor, all the while maintaining locational reference. Note that the latest Reader version (XI at this writing) defaults to a condition whereupon the first opened window may have a “Tools” panel that encompasses the right side of the window. This can be toggled off by selecting the Tools heading immediately above the panel; otherwise, the PDF selection for that window will not perfectly register with the other images. After saving the file and closing Reader with the Tools panel off and window maximized, subsequent openings of Reader should “store” these new preferences.

## Data Delivery

Spatial data used for this report can be found in the `ds908_datafiles` directory (folder), on disk 1 of the DVD set. The GIS data that accompany this report are also available through the USGS ScienceBase as a data release at <http://dx.doi.org/10.5066/F7GF0RK5> (Lee and others, 2016). There, the geochemical data compilation of best values used in this study has been provided in three formats: a spreadsheet, `AK_geochem_data.xlsx`; and two GIS-compatible formats, (1) point feature classes within a feature dataset, `AK_geochem_data` as part of a zipped Esri geodatabase, `AK_atlas_geochem.gdb.zip`, and (2) a zipped archive of an Esri shapefile, `AK_geochem_data.zip`. The hydrologic unit-based concentration means that were used to produce map sheets 1B–68B are provided as polygon feature classes within a feature dataset, `AK_WBD_means` in the zipped `AK_atlas_geochem.gdb.zip` geodatabase and as a zipped polygon shapefile, `AK_WBD_means.zip`. It should be noted that blanks (no data) are denoted by `<Null>` in the feature datasets, whereas in the shapefiles, which have no capacity for nulls or blanks, those no-data values are

denoted by -9999. In all cases the feature datasets and shapefiles have been clipped to contain data within the land area of the Alaska state boundary.

All interpolated grids of element distributions used in the production of map sheets 1A,C,D–68A,C,D are provided in ERDAS Imagine `.img` format and are named according to the convention established for the map sheets [publication identifier]\_[element name]\_[map sheet number]; for example, `DS908_Silver_50A.img`. These grids have also been clipped to the Alaska state boundary and are organized according to `ds908_elements\<element name>` folders.

The projection of all delivered GIS data, grids, and images is Alaska Albers Conical Equal Area with standard parallels at 55°N. and 65°N.; central meridian at 154°W.; projection origin at 50°N.; false easting and false northing = 0.0; and the geodetic datum is WGS 84.

## Discussion and Conclusions

The map sheets of this atlas have revealed several interesting aspects of the geochemical data of Alaska. First, although no interpretations of geochemical trends are provided in this report and are beyond the scope of this study, visual comparison of known geological features of the state (fig. 5), along with the physiographic (fig. 6) and terrane (fig. 7) features show spatial correlations with mapped geochemical element distributions. We therefore conclude that the modeled element distributions reliably reflect chemical landscapes in Alaska. So, for elements with spatially and analytically robust legacy data, important and valuable regional geochemical knowledge may be derived and visualized by combining disparate datasets from separate databases. In spite of the inherent difficulties of using legacy data, for Alaska the result has been to provide a sample resolution of approximately 1 site per 10 km<sup>2</sup>, which is two orders of magnitude more detailed than recent continental-scale surveys elsewhere (Reimann and de Caritat, 2012; Smith, Cannon, and others, 2013).

Despite this detail, many element maps show areas where there are insufficient or inadequate data. In this regard, our maps show not only areas without samples, but also areas in which samples were collected, but either (a) the samples were not analyzed for some elements, or (b) the determinations were censored because of high detection limits. For effective and efficient planning for the future improvement of geochemical data in Alaska, it will be important to understand the characteristics and locations of the present limitations in available data. In some places, additional information can only be gained by collecting and analyzing new samples. However, in many areas new or improved data can be obtained by reanalysis of previously collected and archived samples. The map sheets and accompanying data compilations may help guide future efforts to improve our knowledge and understanding of the geochemical landscape of the State of Alaska.

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