

# **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Open-File Report 2015–1025

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



**Cover:** Overlooking North Fork Lake Creek and Colorado highway 82 east of Independence Pass, with Star Mountain (12,920 ft) in the background. Photograph by Stuart A. Giles.



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By Robert G. Eppinger, Stuart A. Giles, and Terry L. Klein

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft²)	0.09290	square meter (m²)
square mile (mi²)	2.590	square kilometer (km²)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m²)	10.76	square foot (ft²)
square kilometer (km²)	0.3861	square mile (mi²)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:  
°F = (1.8 × °C) + 32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:  
°C = (°F - 32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).





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## Introduction

The U.S. Geological Survey (USGS) recently completed a series of geologic, mineral resource, and environmental assessment studies in the Rocky Mountains of central Colorado, from Leadville eastward to the range front and from New Mexico to the Wyoming border. Regional stream-sediment geochemical maps, useful for assessing mineral resources and environmental effects of historical mining activities, were produced as part of the study. The data portrayed in this 56-parameter portfolio of landscape geochemical maps serve as a geochemical baseline for the region, indicate element abundances characteristic of various lithologic terranes, and identify gross anthropogenic effects of historical mining. However, although reanalyzed in this study by modern, sensitive methods, the majority of the stream-sediment samples were collected in the 1970s. Thus, metal concentrations portrayed in these maps represent stream-sediment geochemistry at the time of collection.

## Stream-Sediment Sampling and Analytical Methods

Nearly 1,200 sediment samples collected in the late 1970s by the National Uranium Resource Evaluation (NURE) program were retrieved from the USGS sample archive and resubmitted for geochemical analysis by 42-element inductively coupled plasma emission and mass spectrometry using the methods described in Taggart (2002). These new data were combined with similar new data from recently collected USGS samples (Church and others, 2012) and with a subset of previously reanalyzed NURE samples (Grossman, 1998) to create a geospatial dataset of 1,479 stream-sediment samples and the associated suite of 56 geochemical landscape maps presented here. Mapped elements are Ag, Al, As, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Eu, Fe, Ga, Hg, Ho, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Rb, S, Sb, Sc, Se, Sn, Sr, Te, Th, Ti, Tl, U, V, W, Y, Yb, and Zn. Other mapped parameters are pH and specific conductance (both measured on stream waters at the sediment

sample site), the results of multielement R-mode factor analysis (discussed below), and scintillometry measurements that estimate radioactive element content. The latter were taken at sediment sample sites during the original NURE program. A history and details of the NURE program are found in Smith (2006).

The 48 major, minor, and trace elements were determined either by inductively coupled plasma–atomic emission spectrometry (ICP–AES) or inductively coupled plasma–mass spectrometry (ICP–MS), except for Hg and Se, which were analyzed by cold-vapor atomic absorption and decomposed by using hydride-generation atomic absorption, respectively. For the ICP methods, each sample was decomposed by using a mixture of hydrochloric, nitric, perchloric, and hydrofluoric acids at low temperature, followed by analysis by ICP–AES and ICP–MS. Although the four-acid digestion technique may not completely digest some oxide minerals that contain elements such as Cr, Sn, and the rare-earth elements, resulting data still are useful for identifying samples that have high concentrations of those elements. The ICP–AES technique begins with calibration by standardizing with digested rock reference materials and multielement solution standards. The ICP–MS technique begins with calibration with aqueous standards, and internal standards are used to compensate for matrix effects and internal drifts. Data reproducibility for all 48 elements is  $\pm 15$  percent at five times the lower limit of determination, and the calculated relative standard deviation of duplicate samples is no greater than 15 percent. Details on all techniques used appear in Taggart (2002).

The five-factor analysis maps represent factor scores generated using R-mode factor analysis, a multivariate statistical procedure based on a linear correlation matrix of the analyzed data and used to generate multi-element “factors” that may describe geologic processes (Howarth and Sinding-Larsen, 1983; Tabachnick and Fidell, 2007). An orthogonal varimax rotation and five-factor model were chosen and used on a log-normalized dataset after removing highly censored elements (those with 20 percent or more of the analytical values lying below the lower determination limit). Elements within a given factor behave similarly in their gross spatial distributions. Factor 1 explains the most variance for elements within the dataset, and each of the subsequent four factors (in numerical sequence) explains progressively less variance.

## Geologic Setting of Central Colorado

The study area in Colorado is in the central Rocky Mountains and includes prominent mountain ranges, such as the Front Range, the Sawatch Range, the Wet Mountains, the Mosquito Range, and the Sangre de Cristo Mountains. Intermontane parks interspersed between the ranges include North, Middle, and South Parks, and the San Luis Valley. Figure 1 shows major lithologies and mining districts within the study area. Similar lithologies of various ages are combined in the figure rather than a traditional geologic map display, where lithologies are differentiated by age, since the geochemical element-distribution maps that follow are more a reflection of rock type than rock age. A brief discussion follows of the various rock units combined in the lithologic map shown in figure 1 (modified from Church and others, 2012).

Major rock types range from late Paleoproterozoic crystalline rocks to Paleozoic and Mesozoic sedimentary rocks and thence to Laramide to mid-Tertiary plutonic rocks. The Paleoproterozoic basement rocks are composed of metamorphosed and deformed 1.75–1.73 giga-annum (Ga) island-arc volcanic rocks in the south-central part of the study area (Bickford and others, 1989a; Van Schmus and others, 1993). Those rocks are intruded by intermediate-composition plutonic rocks of similar age (Reed and others, 1987). Throughout much of the rest of the area, the basement rocks are composed of 1.73–1.71 Ga metasedimentary rocks derived from erosion of the Archean Wyoming craton to the north or from retreating Paleoproterozoic arc complexes to the southeast. Plutonic rocks of 1.72–1.68 Ga intruded all of the older rocks in the area. Mesoproterozoic plutonic rocks (1.44–1.39 Ga) of intermediate to felsic composition are abundant throughout the area (Anderson, 1983). The 1.1-Ga Pikes Peak batholith is the youngest and largest of all the Proterozoic granitoid bodies in central Colorado (Barker and others, 1975; Smith and others, 1999).

Paleozoic carbonate sedimentary rocks formed a thin cover (less than 2 kilometers (km) thick) on basement rocks from Cambrian to Pennsylvanian time (DeVoto, 1990). Late Cambrian plutonic rocks and carbonatites were emplaced in the south-central part of the area and are related to rifting of the continental margin to the southeast in Oklahoma (Bickford and others, 1989b). In Pennsylvanian and Permian time, parts of the area covered by Paleozoic formations were uplifted and the sedimentary and basement rocks were eroded into adjacent basins, creating locally thick accumulations (3–4 km) of conglomerate and red beds (Lindsey and others, 1986). The region stabilized during the remainder of Mesozoic time as marine shale and limestone were deposited in seaways throughout the region (in units as much as 3 km thick). In latest Cretaceous time, the region was deformed by the Laramide orogeny, which created monoclinial uplifts and adjacent depositional basins (Dickinson and Snyder, 1978).

From Cretaceous to early Tertiary time, plutons ranging from mafic to intermediate composition intruded the basement rocks and created sills and laccoliths in the Paleozoic and Mesozoic strata (Simmons and Hedge, 1978). Hydrothermal alteration accompanied some of those plutons, and some plutons contain mineral deposits of base

and precious metals that were mined beginning in the mid-1800s (Sims and others, 1963; Rice and others, 1985). The superposition and localization of Cretaceous-Tertiary magmatism and concurrent hydrothermal mineralization within preexisting Proterozoic basement structures define the Colorado Mineral Belt (Tweto and Sims, 1963; Wilson and Sims, 2003; fig. 1). Volcanoes erupted and formed calderas across the southern part of the study area during middle Tertiary time and formed large volcanic fields such as those in the San Juan Mountains to the southwest of the study area (Steven and Lipman, 1976). Silica-undersaturated subvolcanic rocks were emplaced in the east-central part of the study area (Lindgren and Ransome, 1906; Kelley and Ludington, 2002). Plutons of predominantly felsic composition were emplaced during middle Tertiary time (Mutschler and others, 1981).

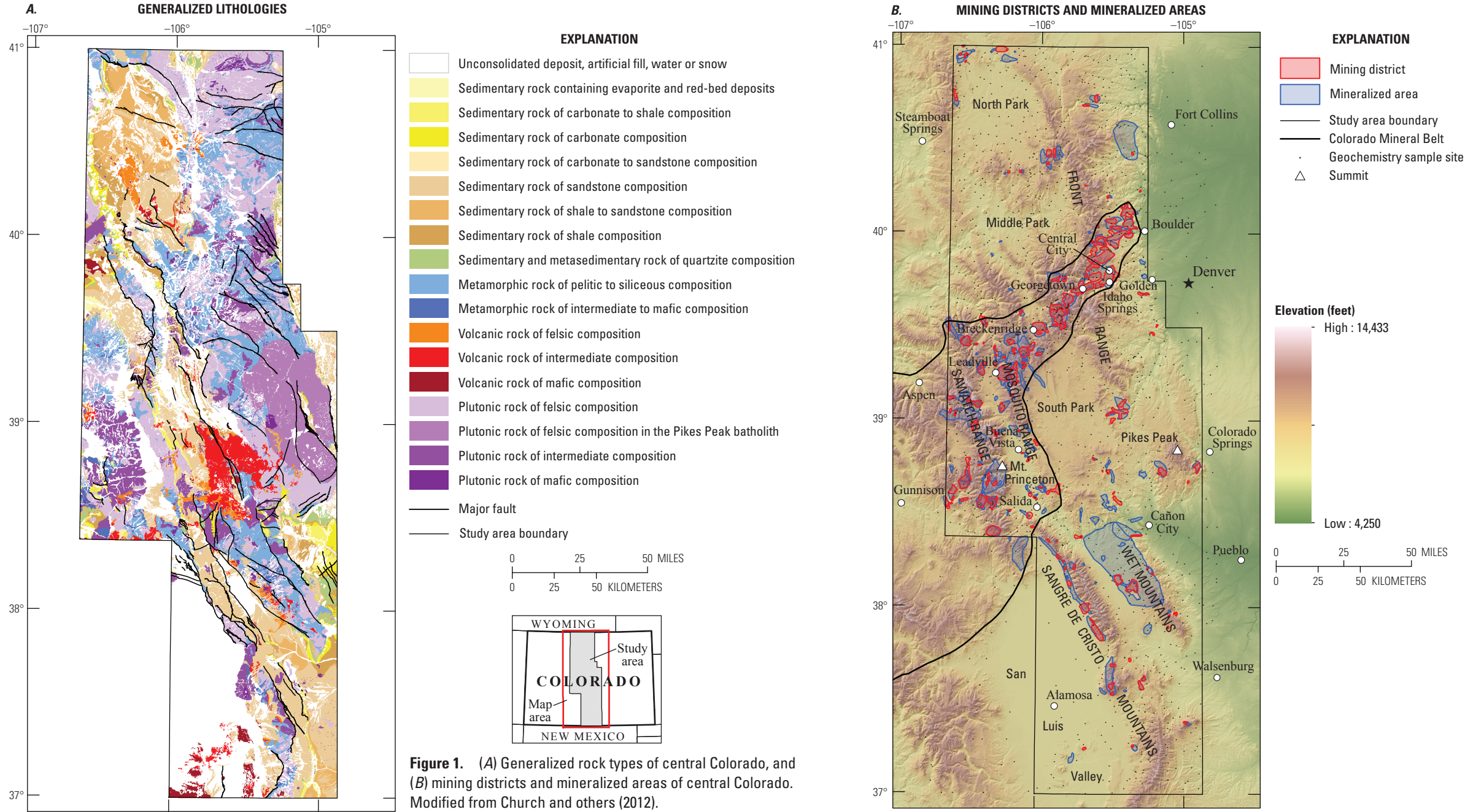
During late Tertiary time, extensional faulting related to development of the Rio Grande Rift disrupted much of the area, creating block-faulted mountain ranges and basins. Pleistocene glaciation followed that sculpted modern valleys and mountain peaks. Quaternary sedimentary deposits blanket the modern valleys.

## Mineral Deposits of Central Colorado

The Colorado Mineral Belt (CMB; Tweto and Sims, 1963) is a northeast-trending structure that crosses the central part of the state. The CMB contains most of the state's metal producing areas, both in terms of the volume of metal produced and the number of producing mines. The metal producing areas are spatially associated with Late Cretaceous to latest Paleogene epizonal plutons, dikes, and sills that generally range in composition from intermediate to felsic. Those rocks intrude Proterozoic igneous and metamorphic rocks (metasedimentary and metavolcanic) and Phanerozoic clastic and carbonate sedimentary rocks that are as young as Late Cretaceous. In the study area, plutons related to the CMB range in age from 70 mega-annum (Ma) to about 25 Ma (Bookstrom and others, 1987; Cunningham and others, 1994). Mineral deposits within the CMB consist of precious-metal and polymetallic vein deposits (Ag, Au, Cu, Pb, and Zn), carbonate replacement deposits (Ag, Cu, Pb, and Zn), base- and precious-metal skarn deposits (Ag, Au, Cu, Pb, and Zn), and porphyry molybdenum and copper-molybdenum deposits (Cu and Mo). Most historical mines exploited polymetallic veins of limited areal extent, producing gold, silver, copper, lead, and zinc (Lovering and Goddard, 1950; Pearson, 1980). Mining district boundaries shown in figure 1 and on subsequent maps largely are taken from Wilson (2003), although some boundaries were modified by combining districts for simplicity during this study.

Mineral deposits in the study area are classified by mineral deposit type (Cox and Singer, 1986). Table 1 shows characteristics of these mineral deposits, such as exploited metals, gangue mineralogy, and hydrothermal alteration type. In sampled catchments, polymetallic veins were the deposit type most commonly found. Polymetallic veins may constitute a surface expression of, and overlie, many larger mineral deposit types, such as porphyry systems that occur within the study area (Cox, 1986a, 1986b; Ludington, 1986; Cox and





4      **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

**Table 1.**    Characteristics of the principal mineral deposit types found in central Colorado.

[Metals, minerals, and alteration types are listed in approximate order of abundance]

Deposit type	Metals	Major ore minerals	Minor ore minerals	Gangue minerals	Alteration type and style
Cenozoic					
Polymetallic veins	Ag, Au, Pb, Zn, Cu	Pyrite, galena, sphalerite, tetrahedrite, chalcopyrite	Argentite, ruby silver	Quartz, calcite, siderite, dolomite	Argillization, sericitization, silicification, propylitization
Porphyry Mo or Cu-Mo	Mo, Cu, Sn, W	Molybdenite, chalcopyrite, pyrite	Cassiterite, huebnerite,	Quartz, fluorite, sericite, topaz	Silicification, sericitization, potassium feldspar, propylitization
Polymetallic replacement and skarn	Ag, Pb, Zn, Cu	Galena, sphalerite, tetrahedrite, pyrite	Chalcopyrite, pyrrhotite	Dolomite, barite, siderite, fluorite	Regional dolomitization, local silicification
Fluorite veins	F	Fluorite	Base metal sulfides, pyrite	Quartz, calcite, barite, manganese oxide	Argillization, sericitization, silicification
Tungsten veins	W	Ferberite	Pyrite, sphalerite, tetrahedrite, scheelite	Quartz, calcite, siderite, barite	Silicification, argillization, sericitization, potassium feldspar, propylitization
Uranium veins	U, Th, V	Uraninite, torbernite, coffinite	Base-metal sulfides, pyrite	Calcite, ankerite, quartz	Argillization, sericitization
Alkaline Au-telluride veins	Au, Ag, Te	Gold, silver, and base metal telluride minerals, native gold	Pyrite	Quartz, chalcedony, fluorite, calcite, dolomite, hematite, apatite	Argillization, silicification, sericitization, potassium feldspar, biotitization
Cambrian					
Thorium veins	Th, Pb, Zn, Ba	Thorite, galena, sphalerite	Pyrite	Calcite, quartz, barite	Fenitization
Proterozoic					
Stratabound Cu-Zn	Cu, Zn	Chalcopyrite, sphalerite, pyrrhotite, pyrite, gahnite	Galena, arsenopyrite	Amphiboles, chlorite, garnet, sillimanite, epidote, anthophyllite, pyroxene	Argillization (metamorphosed to high temperature aluminosilicates minerals)
Pegmatite minerals	various	Feldspar, mica, beryl, quartz			None



Singer, 1986). These polymetallic vein deposits were the target of historical mining for gold, silver, and lead in the latter 19th and early 20th centuries in Colorado (Henderson, 1926). The areal extent and abundance of polymetallic vein deposits reflect the exploration history, level of erosion, and exposure in the study area. Gold is the dominant economic metal in the polymetallic vein deposits, with minor silver and some molybdenite. Porphyry molybdenum and copper-molybdenum deposits are known in the study area, but only at the Climax and Henderson mines have the porphyry molybdenum deposits been exploited. Limestone replacement and skarn deposits also have been exploited in the western and southwestern part of the study area, producing a large amount of silver, lead, and zinc in the Leadville and Gilman areas. Thorium-rich vein deposits are associated with the Cambrian mafic and ultramafic Wet Mountains alkaline igneous complex in the northern and central Wet Mountains (Armbrustmacher, 1984). Those deposits also contain minor amounts of base metals and barium. A relatively small number of uranium vein deposits and fluorite vein deposits occur throughout the study area. Relatively small stratabound copper-zinc deposits also occur throughout the study area in Proterozoic metasedimentary rocks. Granite pegmatite deposits, widely scattered within the northern two-thirds of the study area, have been exploited locally and are associated with large Proterozoic plutons.

## Geographic Information System and Spatial Analysis of Geochemistry Data

The stream-sediment geochemical data used in this study were acquired from multiple sources in diverse formats, mainly as Microsoft (MS) Excel spreadsheets or in MS Access databases. The data were prepared for inclusion in a geographic information system (GIS) by normalizing all field names and consolidating the data into a single MS Access database, then by using that database as the source for generating shapefiles (and later geodatabase feature classes) by using Esri ArcGIS 10.0 software. Owing to the point-source nature of geochemical data, the initial shapefiles were point-based features, with fields for various sample identification labels (IDs) and source reference information, dates of collection and analysis, geographic coordinates, analytical method and censored data information, and the results of field measurements and laboratory analyses. Factor analysis was conducted outside of the GIS on the same data, and the results then were imported into the GIS as a separate table.

Once all the data were assembled within the GIS, each element and factor was classified by percentiles, because percentiles are reproducible and resistant to skewing effects from statistical outliers. The data then were symbolized using color-coded, proportionally scaled circles to emphasize high values (or low values in the case of pH), and saved as symbol layer files. Once all elements, factors, and field measurements were classified and symbolized, the Geostatistical Analyst extension in ArcGIS was used to generate raster prediction surfaces and statistics using the inverse distance weighting (IDW) interpolation method. The IDW method was chosen

because it assumes that relations in elemental concentrations decrease with increasing distance between the sampled points and also because it is exact; widely differing concentrations in close proximity do not generate false extremes, because minimum and maximum concentrations occur only at sample points. The resulting raster surfaces then were classified and colored identically to the matching element point layers. Due to dynamic association with the active GIS analytical data, each prediction raster was converted into a polygon shapefile in order to preserve predicted class divisions as filled contours.

The geochemical GIS files used to make the symbolized layers, to conduct the IDW analysis, and to construct each map are available with this report, available for download at <http://dx.doi.org/10.3133/ofr20151025>. The IDW prediction surface shapefiles themselves are not included due to changes in GIS software that allow a more accurate spatial analysis of the geochemistry data since those shapefiles were first produced. Also included is a shapefile of the study area boundary (108 samples lie outside the boundary but are included in the prediction analysis). The relevant GIS files also are provided at the URL above as feature classes in an ESRI ArcGIS 10.0 geodatabase.

## Geochemistry Maps and Discussions

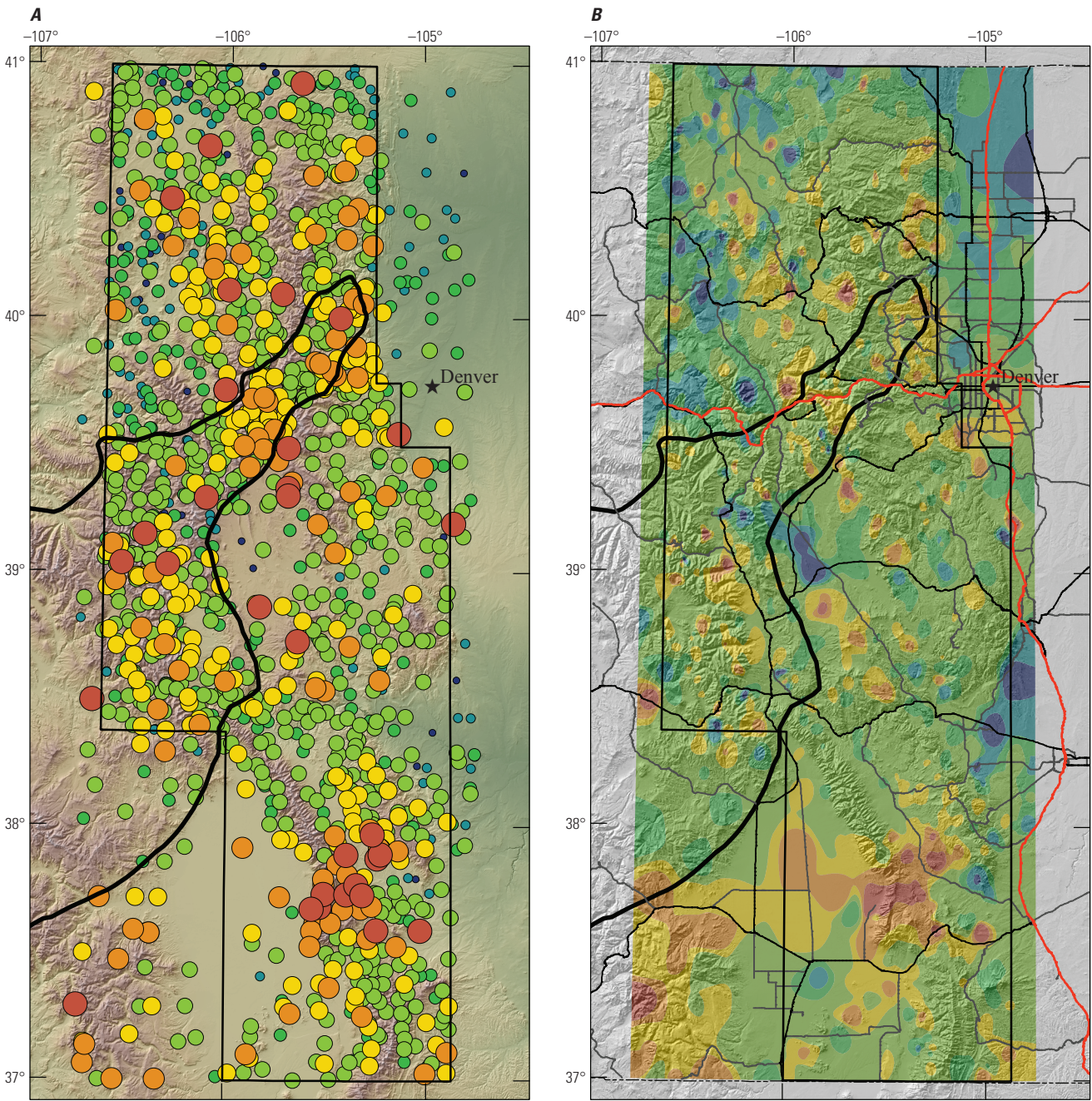
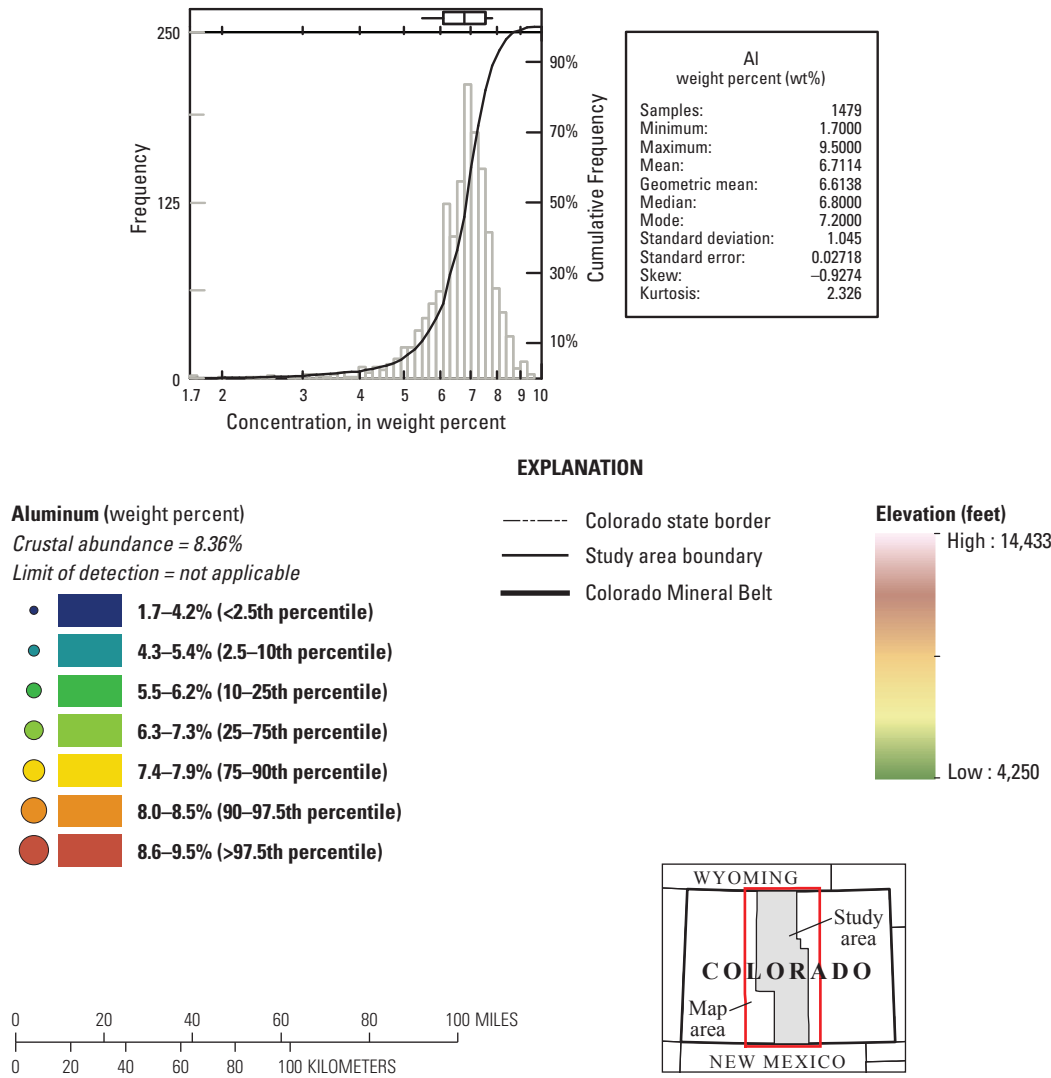
Each map includes a histogram, summary statistics, a symbolized point layer of the stream-sediment sample distribution, and a prediction surface calculated from the point-source concentrations. Each summary statistics graph displays a frequency histogram and a cumulative frequency curve. The graph's left axis is labeled frequency, the right axis is labeled cumulative frequency, the bottom axis is labeled concentration, and both top and bottom axes show units of measure, unless otherwise noted. A boxplot on the top axis identifies the 10th, 25th, 50th, 75th, and 90th percentiles, calculated on the respective number of samples. For some elements with a high percentage of analytical results below the detection limit ("nondetects"), the left side of the boxplot may be truncated because nondetects cluster on the far left side of the frequency histogram (for example, bismuth, fig. 12). Each map is accompanied by a short description of the geochemical and areal distribution of the mapped constituent, including observations concerning the geologic association, nearby mining districts, crustal abundances, and geochemical characteristics of the respective element, the latter two based on information in Rankama and Sahama (1950), Wedepohl (1969–1978), Rose and others (1979), Levinson (1980), and Reimann and de Caritat (1998). Several first-order geologic features are apparent in the geochemical maps. These include (1) the northeast-trending CMB (highlighted by the elements Ag, As, Bi, Cd, Cu, Hg, In, Mo, Pb, Sb, Te, Tl, and Zn); (2) the Mesoproterozoic Pikes Peak batholith (Be, Th, and the rare-earth elements); (3) gabbros and mafic metavolcanic rocks in northern and central Colorado (Cr, Ni, and V); (4) the Thirtynine Mile volcanic field (Ba and Sr); and (5) the Boulder County tungsten district (W).







Central Colorado Stream-Sediment  
Geochemistry—Aluminum



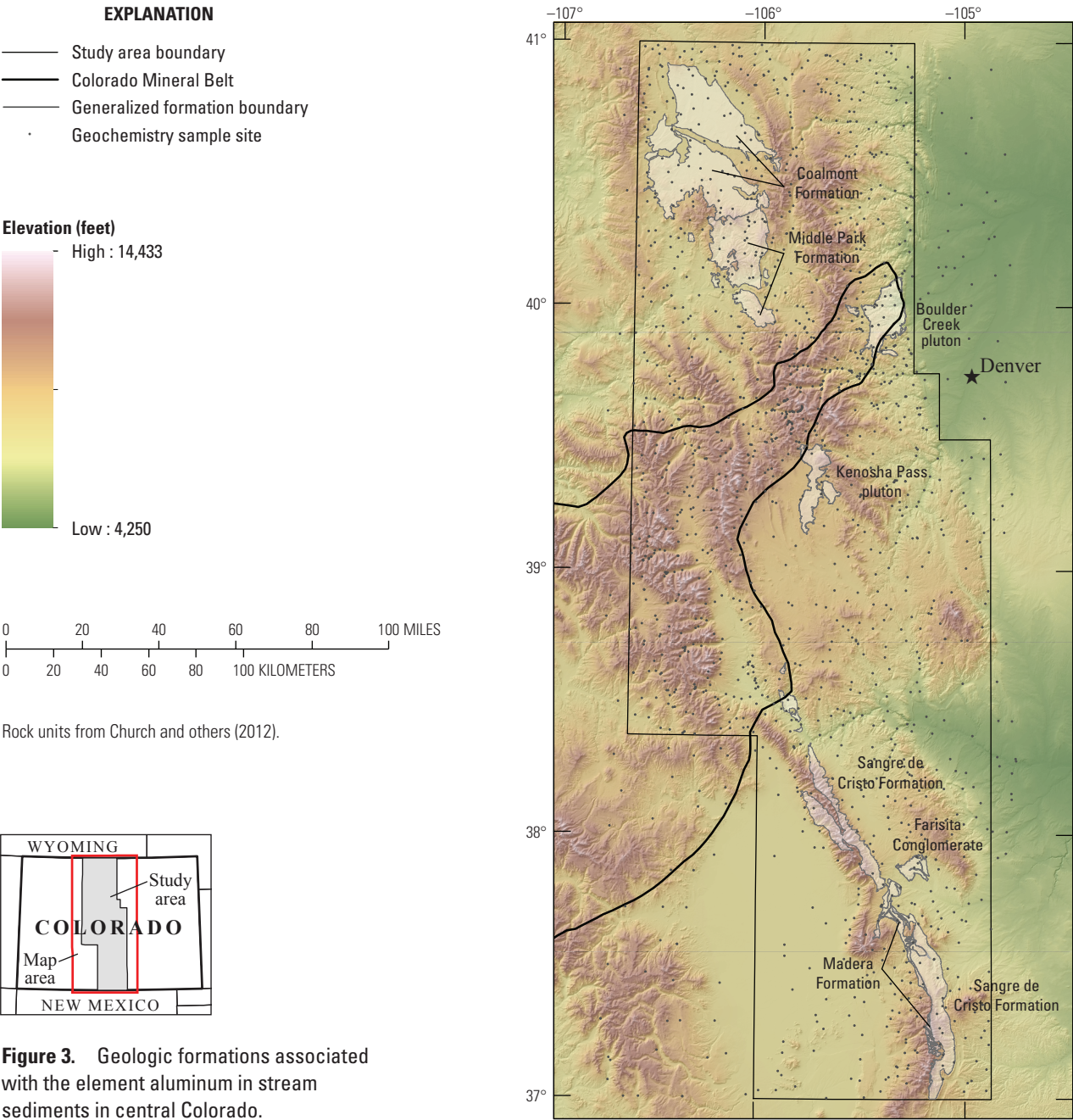
**Figure 2.** Maps of central Colorado stream-sediment geochemistry—aluminum (Al). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



8      **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Aluminum (Al) content in igneous rocks generally is proportional to feldspar content. In sedimentary rocks, aluminum is the result of weathering of silicate minerals, in particular feldspar, and their aluminum content is directly proportional to their clay mineral content.

Stream-sediment samples with high aluminum concentrations (>90th percentile) in the study area (fig. 2) are associated with source areas containing abundant feldspar, such as coarse-grained Proterozoic felsic and intermediate-composition plutons, intermediate volcanic rocks, Pennsylvanian and Permian arkosic, clastic sedimentary rocks, immature basin-filling sediments of Tertiary and Quaternary age, and alluvial fan and some periglacial deposits with proximal source units predominantly composed of the previously mentioned Proterozoic and Phanerozoic rocks (fig. 3). Samples with the lowest concentrations (<25th percentile) are associated with Phanerozoic carbonate-rich and mature clastic sedimentary rock units.

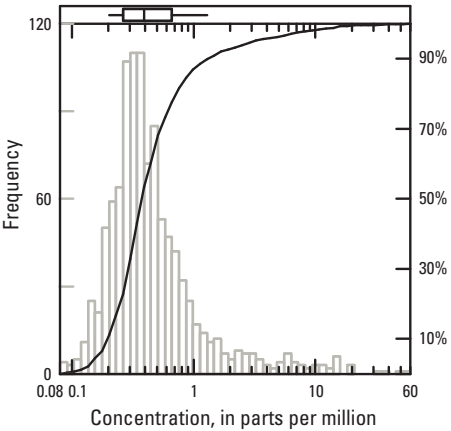


**Figure 3.** Geologic formations associated with the element aluminum in stream sediments in central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Antimony



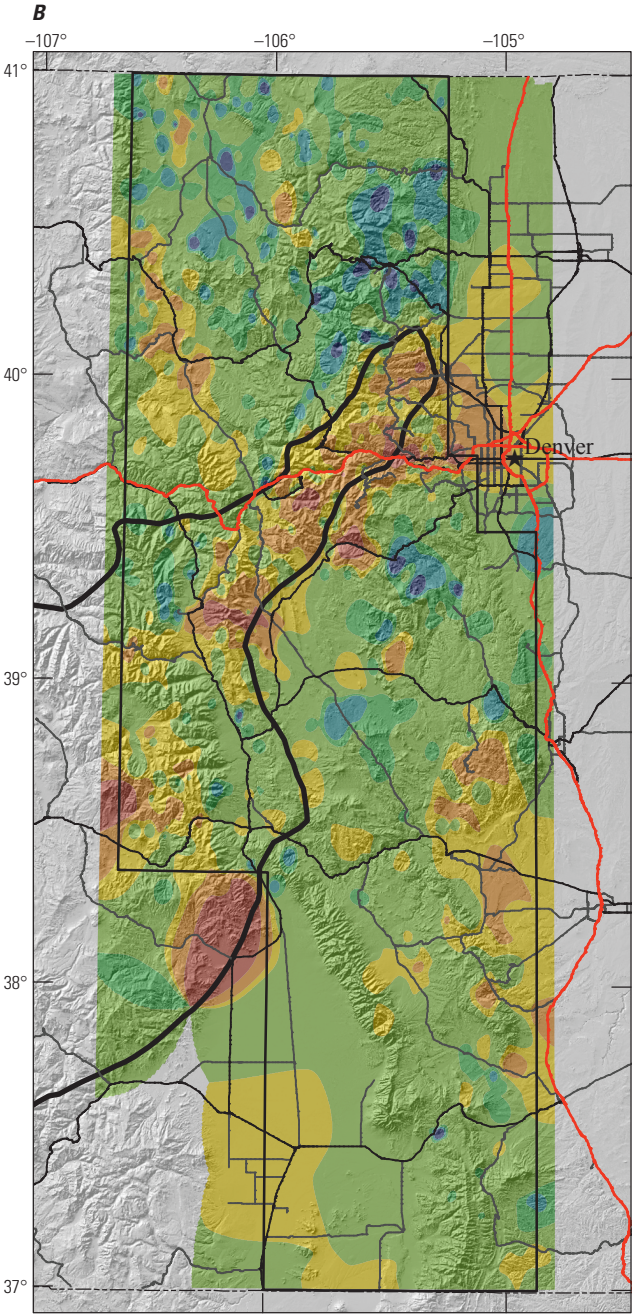
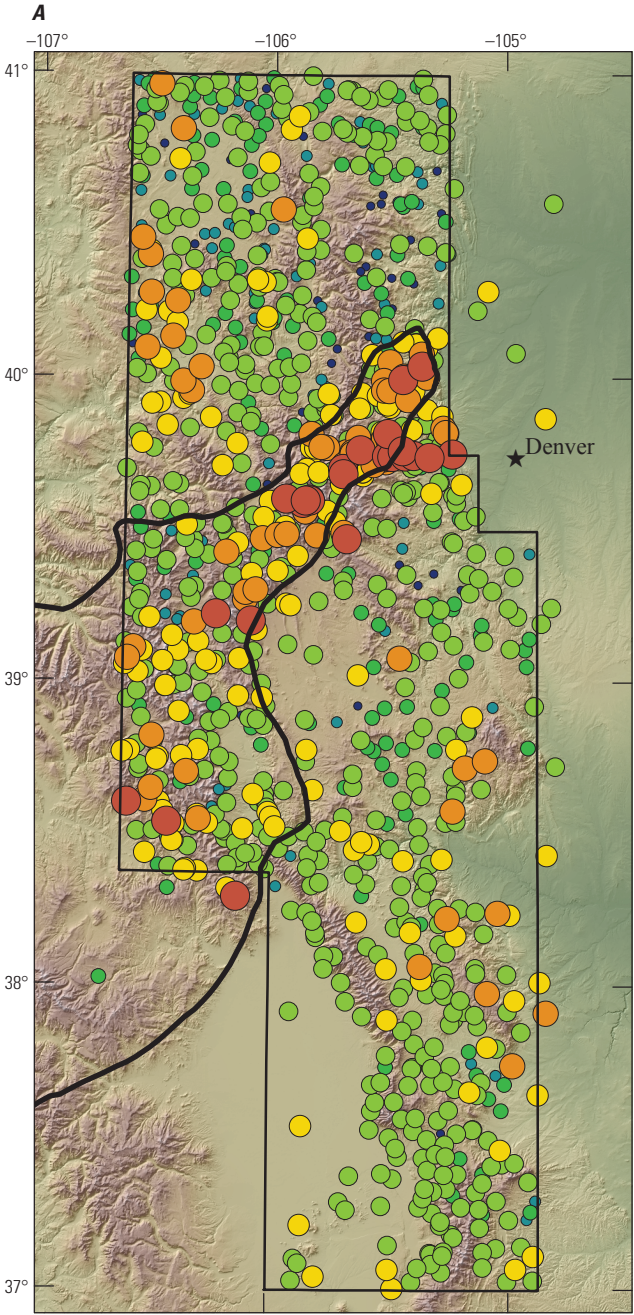
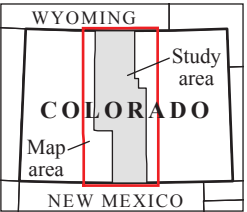
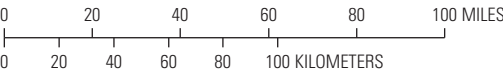
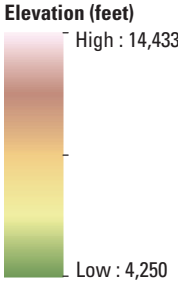
Sb parts per million (ppm)	
Samples:	1064
Minimum:	0.0800
Maximum:	59.0000
Mean:	1.0288
Geometric mean:	0.4627
Median:	0.3800
Mode:	0.2800
Standard deviation:	3.358
Standard error:	0.103
Skew:	10.3
Kurtosis:	137

**Antimony** (parts per million)  
Crustal abundance = 0.20 ppm  
Limit of detection = 0.080 ppm

- <0.15 ppm (<2.5th percentile)
- 0.15–0.20 ppm (2.5–10th percentile)
- 0.21–0.27 ppm (10–25th percentile)
- 0.28–0.62 ppm (25–75th percentile)
- 0.63–1.3 ppm (75–90th percentile)
- 1.4–7.2 ppm (90–97.5th percentile)
- 7.3–59 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt



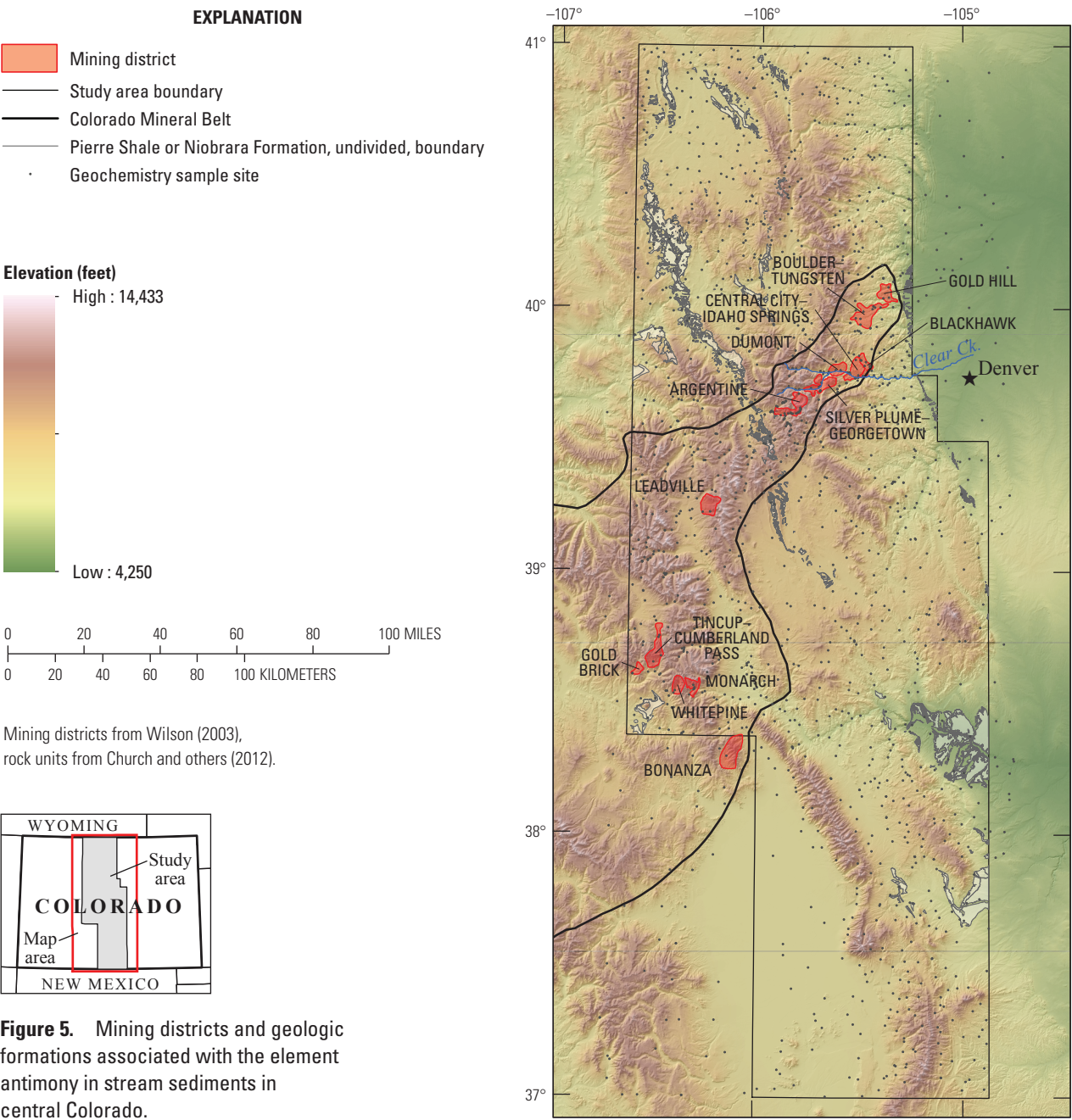
**Figure 4.** Maps of central Colorado stream-sediment geochemistry—antimony (Sb). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



10      **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Antimony (Sb) is a strongly chalcophile element, is associated primarily with hydrothermal base- and precious-metal deposits, and commonly is found as a syngenetic or diagenetic component in organic-rich (black) shales. It is contained primarily in stibnite in low-temperature hydrothermal deposits and in tetrahedrite and sulfosalt minerals at higher temperatures. It is relatively mobile in fresh water, and iron-oxyhydroxide precipitates are commonly enriched in antimony.

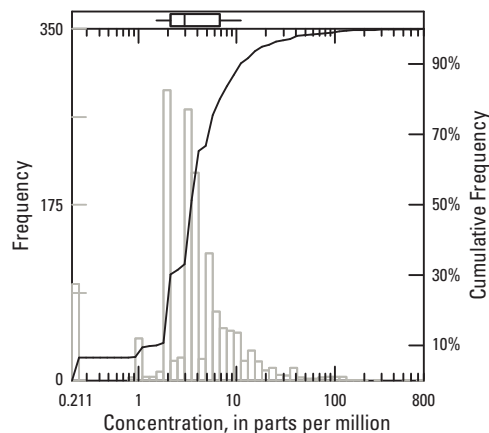
High concentrations of antimony (>90th percentile) are found in stream-sediment samples within the Colorado Mineral Belt (figs. 4 and 5). The largest cluster of samples with high concentrations is around the Blackhawk and Central City–Idaho Springs districts and reveals downstream dispersion eastward along Clear Creek to the range front. Within the Colorado Mineral Belt, there are also clusters around the Argentine, Gold Brick, Tincup–Cumberland Pass, Whitepine, and Monarch districts. Other areas yielding high concentrations of antimony include the Boulder-Tungsten, Dumont, Gold Hill, Leadville, and Silver Plume–Georgetown districts. Just outside the study area boundary in the southern part of the mineral belt, a single sample containing anomalous antimony and several other metals came from the Bonanza district (see copper discussion, fig. 27). A large cluster of samples with high antimony concentrations (90 to 97.5th percentile) in the northwestern part of the study area is underlain largely by the Late Cretaceous Niobrara Formation and the Pierre Shale. A similar cluster of samples with high concentrations (90 to 97.5th percentile) occurs along the southeastern edge of study area in an area underlain by varied Proterozoic plutons and metasedimentary rocks and Cretaceous sedimentary rocks.







# Central Colorado Stream-Sediment Geochemistry—Arsenic



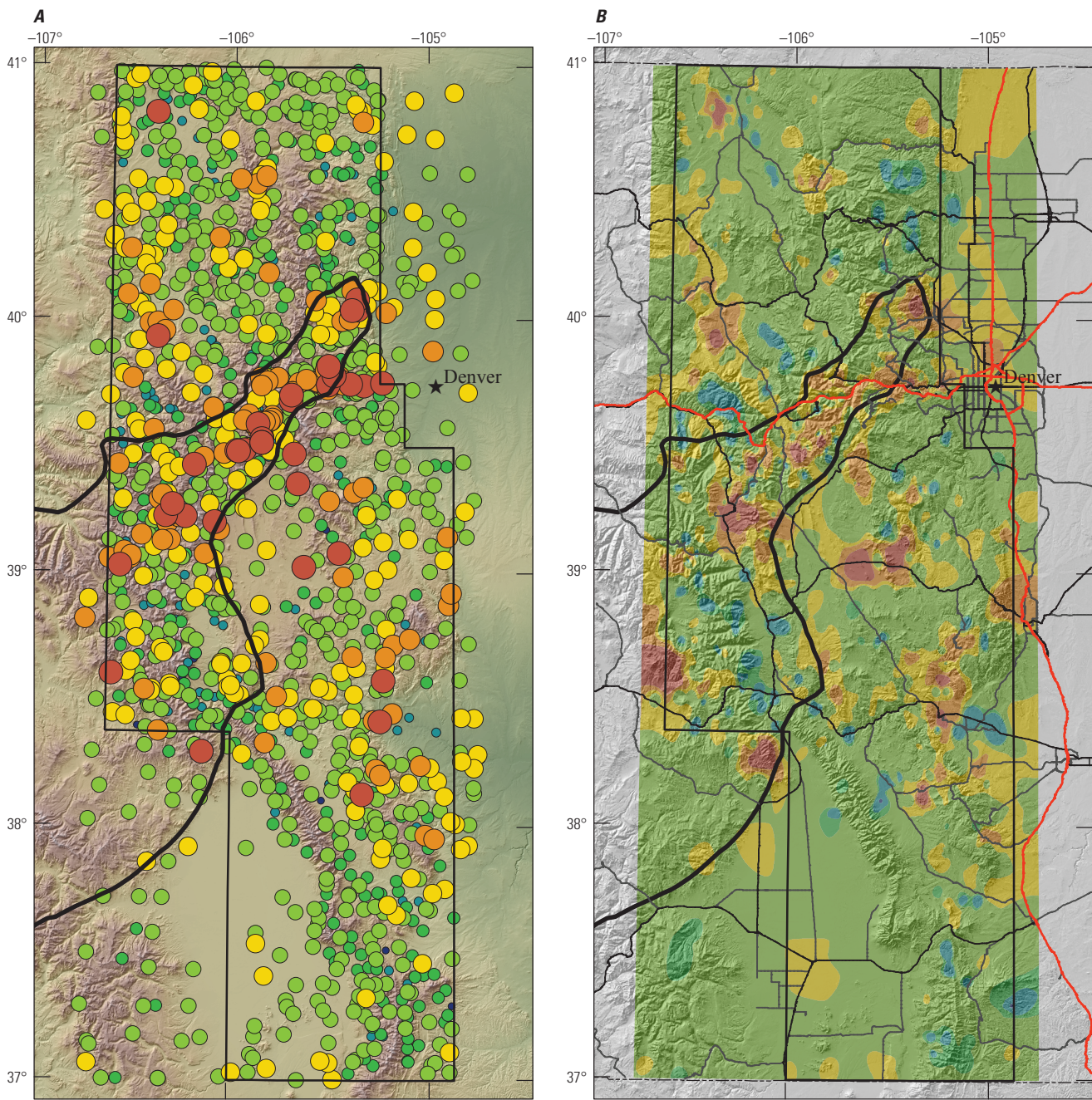
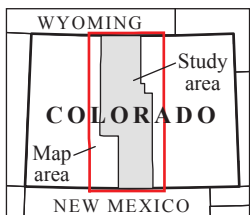
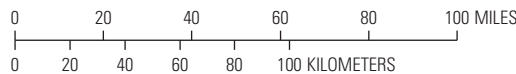
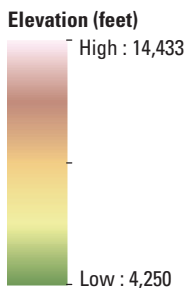
As parts per million (ppm)	
Samples:	1479
Minimum:	<1
Maximum:	730.0000
Mean:	7.4957
Geometric mean:	3.4622
Median:	3.0000
Mode:	2.0000
Standard deviation:	28.2
Standard error:	0.7332
Skew:	17.86
Kurtosis:	397.3

## EXPLANATION

**Arsenic (parts per million)**  
Crustal abundance = 1.8 ppm  
Limit of detection = 1 ppm

- <1 ppm (undetected) (<2.5th percentile)
- 1.0–1.5 ppm (2.5–10th percentile)
- 1.6–2.0 ppm (10–25th percentile)
- 2.1–5.5 ppm (25–75th percentile)
- 5.6–11 ppm (75–90th percentile)
- 12–38 ppm (90–97.5th percentile)
- 39–730 ppm (>97.5th percentile)

- Colorado state border
- Study area boundary
- Colorado Mineral Belt



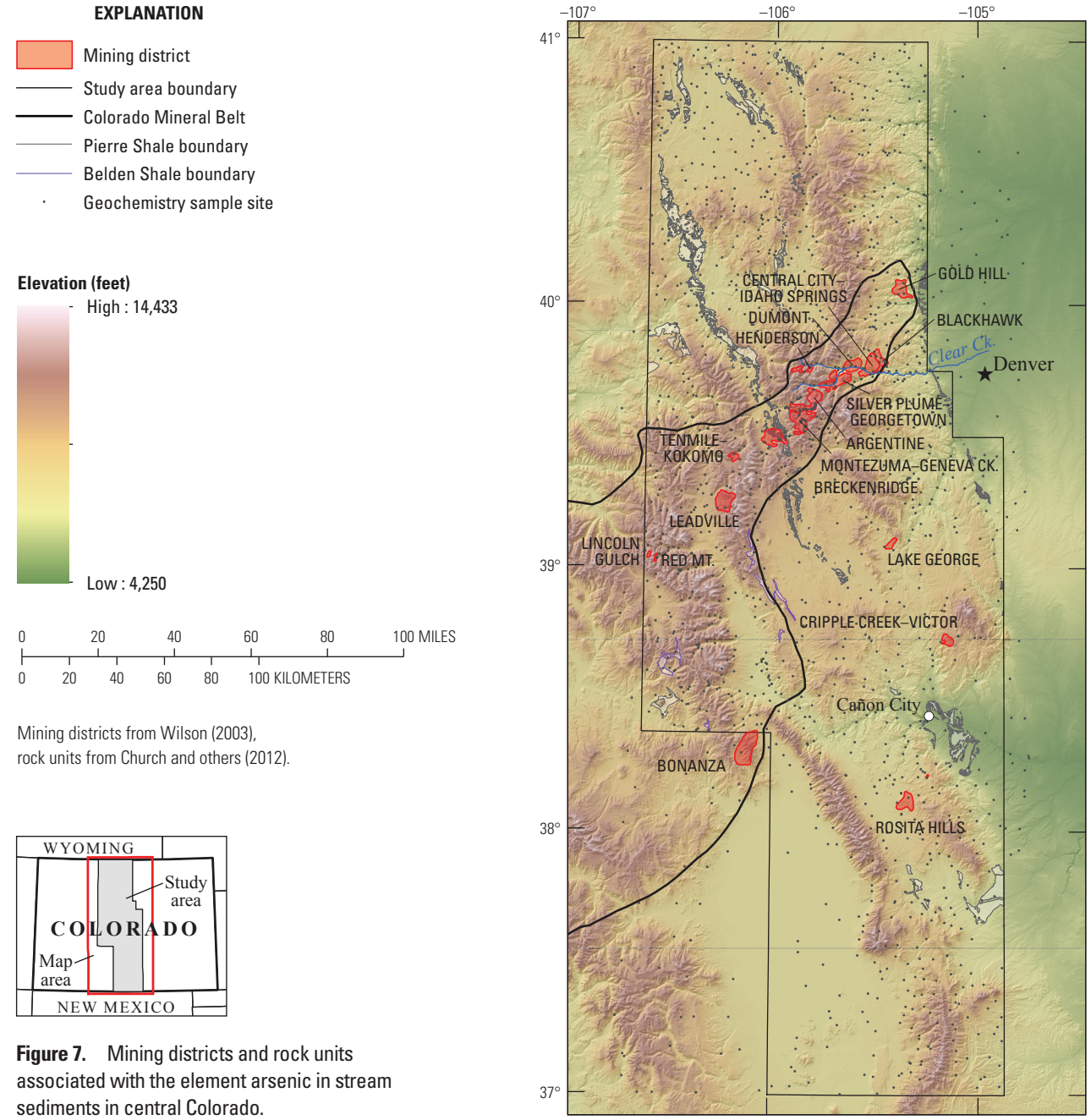
**Figure 6.** Maps of central Colorado stream-sediment geochemistry—arsenic (As). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



12     **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Arsenic (As) is a strongly chalcophile element associated primarily with hydrothermal deposits and as a syngenetic or diagenetic component in many organic-rich (black) shales. It is contained in various sulfide and sulfarsenide minerals and commonly coprecipitates with iron oxyhydroxides in streams.

High concentrations (>90th percentile) of arsenic are found in stream-sediment samples within the Colorado Mineral Belt (figs. 6 and 7). The largest cluster of samples with high concentrations is around the Blackhawk and Central City–Idaho Springs districts and reveals downstream dispersion eastward along Clear Creek to the range front. Elsewhere in the Colorado Mineral Belt, samples having high arsenic concentrations (>90th percentile) are associated with the Argentine, Breckenridge, Dumont, Gold Hill, Henderson, Leadville, Lincoln Gulch, Montezuma–Geneva Creek, Red Mountain, Tenmile-Kokomo, and Silver Plume–Georgetown districts. South of the mineral belt, clusters occur around the Lake George, Cripple Creek–Victor, and Rosita Hills districts. Clusters of samples having lower-level (90 to 97.5th percentile) arsenic concentrations in the northern part of the study area are underlain by diverse sedimentary and igneous rock types. Many such samples are underlain by Cretaceous sedimentary rock units that contain substantial amounts of organic-rich shales, such as the Belden and Pierre Shales. Just outside the study area boundary in the southern part of the mineral belt, a single sample containing anomalously high arsenic and several other metals represents the Bonanza district (see copper discussion on fig. 27). A small cluster of samples near Cañon City that contains anomalous As concentrations in stream sediments might reflect anthropogenic contamination related to several historic smelters that operated in the Cañon City–Florence area in the late 19th and early 20th centuries (Henderson, 1926). While few in number, these samples also contain anomalous concentrations of several ore-related elements, including Ag, As, Cd, Co, Cr, Cu, In, Mn, Pb, S, W, and Zn. Maps for those elements show the same small cluster near Cañon City. Isolated samples obtained near Denver that contain elevated arsenic concentrations are described in the discussion of copper (figs. 26 and 27).

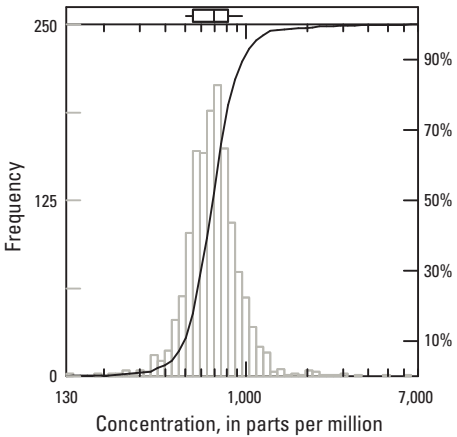


**Figure 7.** Mining districts and rock units associated with the element arsenic in stream sediments in central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Barium



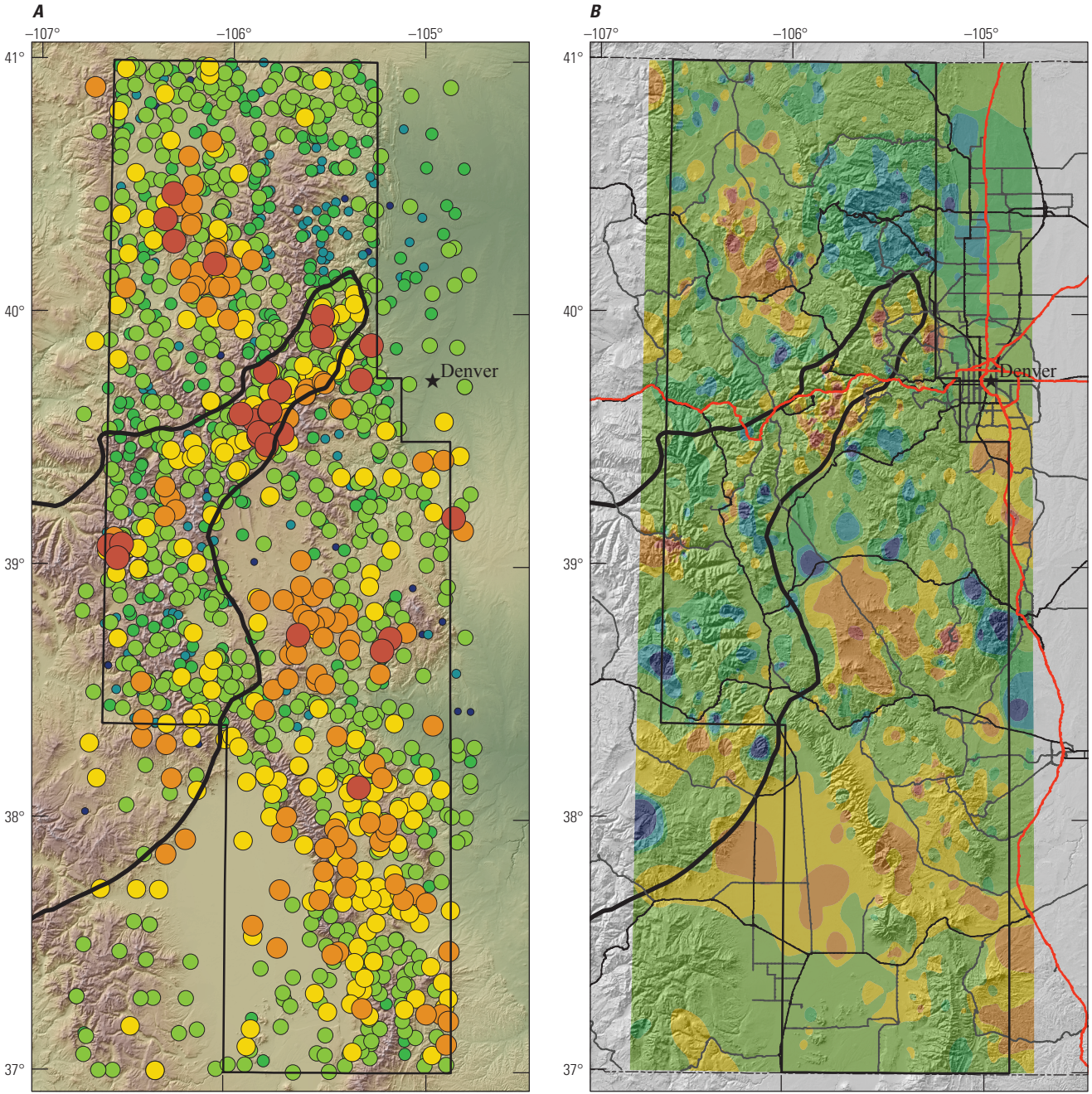
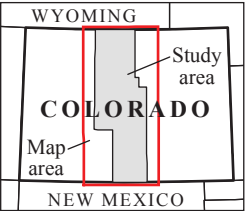
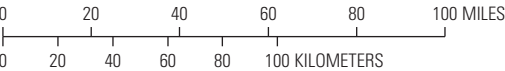
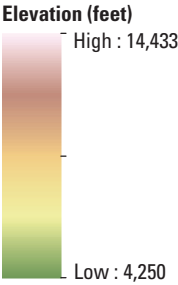
Ba parts per million (ppm)	
Samples:	1479
Minimum:	130.0000
Maximum:	6100.0000
Mean:	727.5930
Geometric mean:	688.3731
Median:	690.0000
Mode:	710.0000
Standard deviation:	313.9
Standard error:	8.162
Skew:	6.817
Kurtosis:	86.21

**Barium** (parts per million)  
*Crustal abundance = 390 ppm*  
*Limit of detection = not applicable*

- 130–376 ppm (<2.5th percentile)
- 377–495 ppm (2.5–10th percentile)
- 496–580 ppm (10–25th percentile)
- 581–800 ppm (25–75th percentile)
- 801–970 ppm (75–90th percentile)
- 971–1,300 ppm (90–97.5th percentile)
- 1,310–6,100 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt



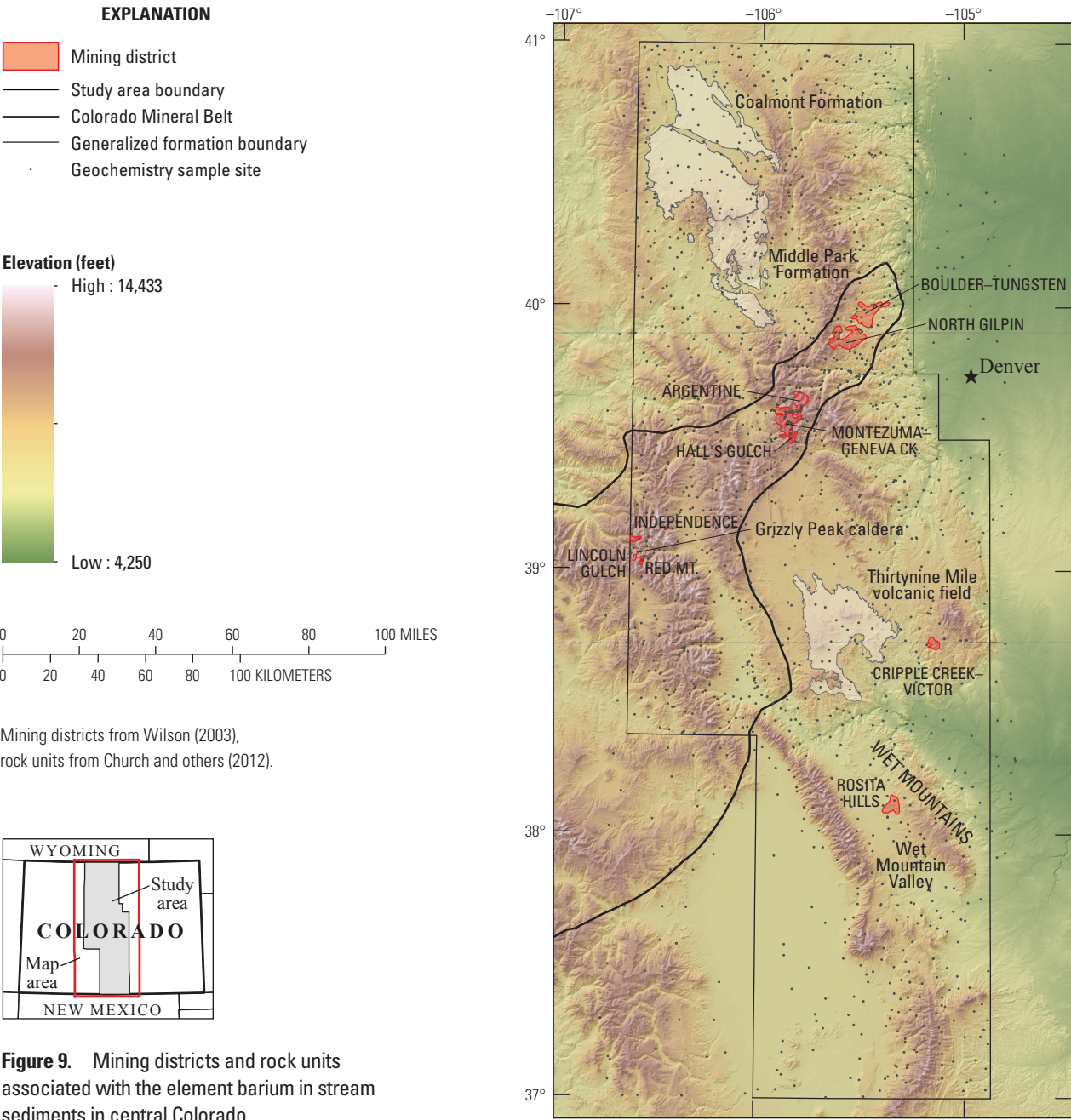
**Figure 8.** Maps of central Colorado stream-sediment geochemistry—barium (Ba). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



14     **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Barium (Ba) in igneous rocks is present mainly where it substitutes chemically for potassium in potassium feldspar, muscovite, and biotite. However, the barium content of those minerals in end-stage differentiates (such as granite pegmatites) generally is relatively low compared to that of less-evolved rocks. Barium also may occur as barite in hydrothermal vein systems and in some stratabound deposits. Barium is variably mobile during weathering and may be concentrated in clay minerals.

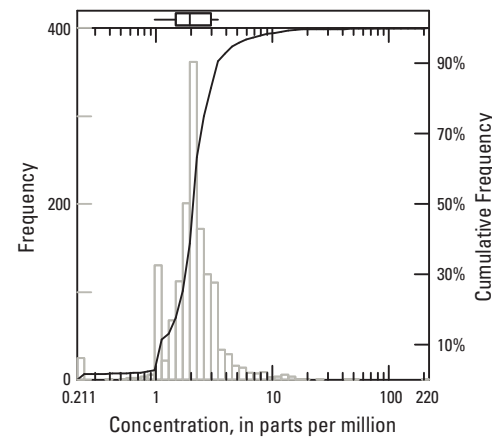
Stream-sediment samples with high barium concentrations (>90th percentile) highlight the northeastern Colorado Mineral Belt, particularly the Argentine, Boulder-Tungsten, Halls Gulch, Montezuma–Geneva Creek, and North Gilpin districts (figs. 8 and 9). Along the west-central edge of the study area within the mineral belt, samples with high barium concentrations (>90th percentile) also are associated with the Independence, Lincoln Gulch, and Red Mountain districts surrounding the Grizzly Peak caldera. Isolated samples with high concentrations of barium (>97.5th percentile) are associated with the Cripple Creek–Victor and Rosita Hills districts. These high concentrations likely are related to the occurrence of barite or barium substituting for potassium in alteration minerals such as muscovite in these epithermal, precious-metal and base-metal hydrothermal systems. In the northern part of the study area, a large, diffuse anomaly (>90th percentile) is underlain largely by basin-filling sedimentary rocks of the Coalmont and Middle Park Formations, where the anomaly may be related to high content of feldspar or clay minerals. In the southern part of the study area, diffuse clusters (90 to 97.5th percentile) are underlain by rocks of the alkali-calcic, intermediate-composition Thirtynine Mile volcanic field. Diffuse clusters also are found in and around the Wet Mountains and the Wet Mountain Valley. In the southern part of the area, a large diffuse cluster of high-barium samples (90 to 97.5th percentile) is underlain by varied Cretaceous and younger sedimentary rocks and basin-fill deposits where barium may be associated with clay minerals.







Central Colorado Stream-Sediment  
Geochemistry—Beryllium



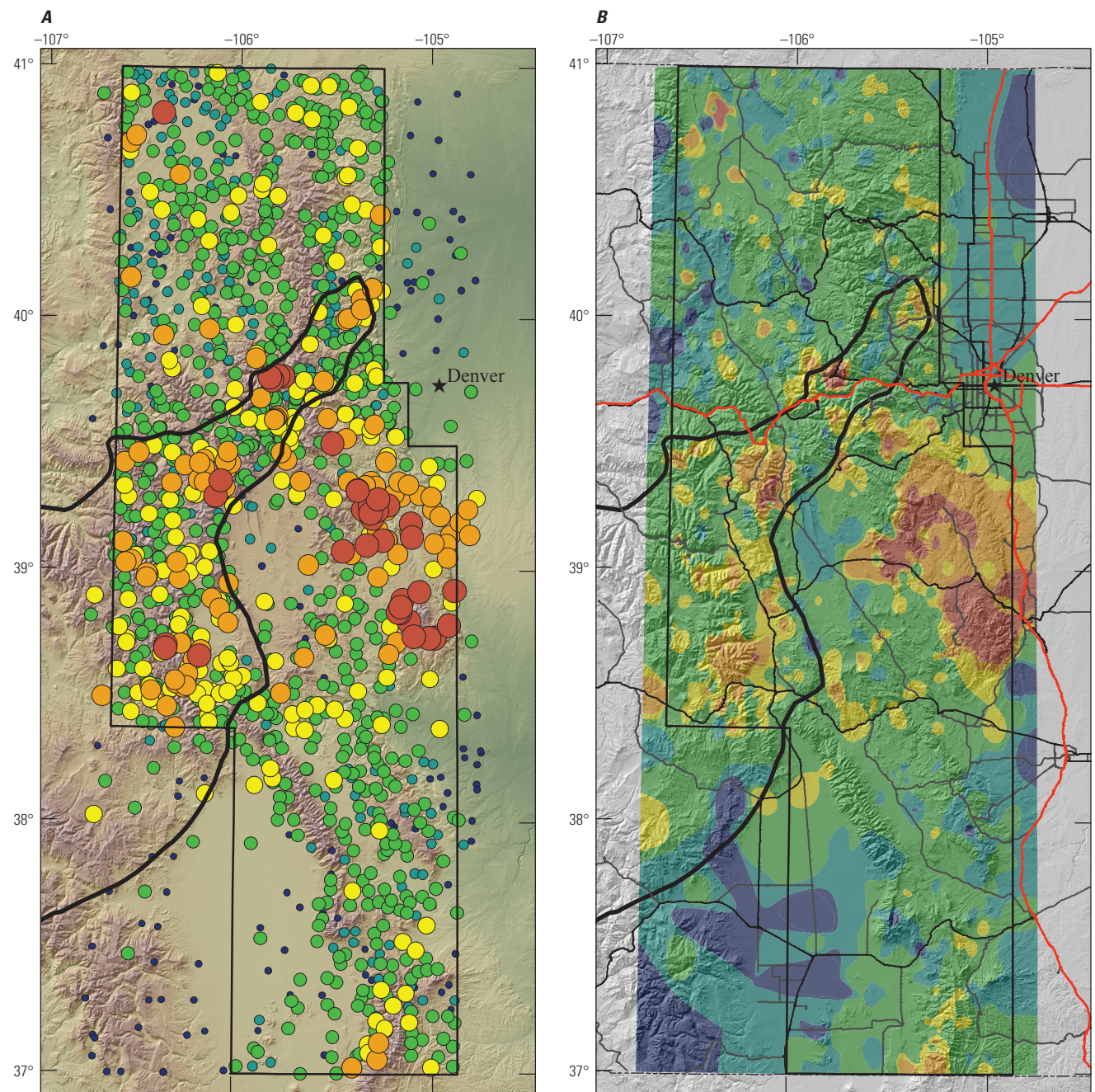
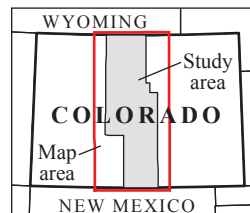
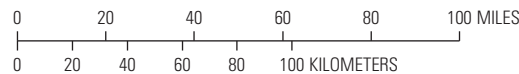
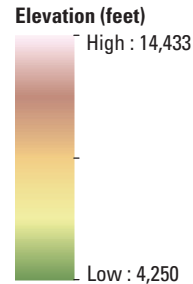
Be parts per million (ppm)	
Samples:	1479
Minimum:	<1
Maximum:	200.111
Mean:	2.5468
Geometric mean:	2.0379
Median:	2.0000
Mode:	2.0000
Standard deviation:	5.673
Standard error:	0.1475
Skew:	29.41
Kurtosis:	998

**Beryllium** (parts per million)  
Crustal abundance = 2.00 ppm  
Limit of detection = 1 ppm

- <1 ppm (<10th percentile)
- 1.001–1.600 ppm (10–25th percentile)
- 1.601–2.600 ppm (25–75th percentile)
- 2.601–3.300 ppm (75–90th percentile)
- 3.301–7.200 ppm (90–97.5th percentile)
- 7.201–200.1 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt



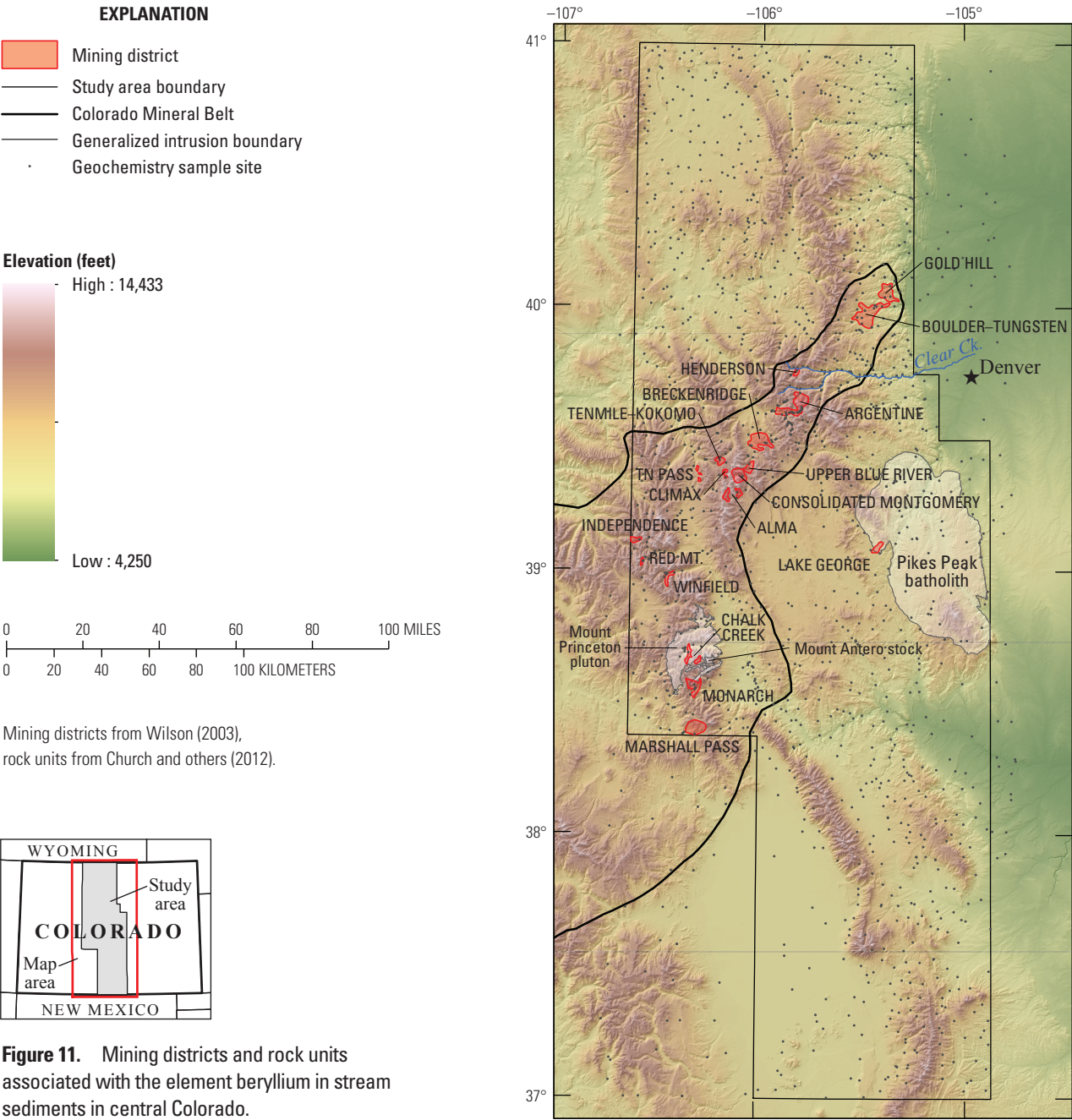
**Figure 10.** Maps of central Colorado stream-sediment geochemistry—beryllium (Be). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



16      **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Beryllium (Be) is most abundant in late-stage igneous differentiates, especially in rocks of alkali compositions such as alkali granite and nepheline syenites where Be commonly occurs in alkali feldspars, mica, and beryl. Beryllium is relatively immobile during weathering when present as beryl.

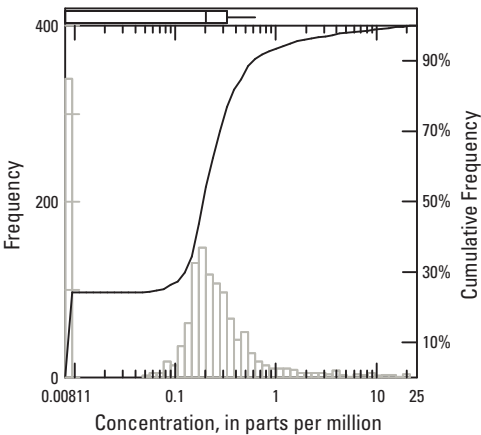
The largest cluster of stream-sediment samples with high (>90th percentile) beryllium concentrations is underlain by the Mesoproterozoic Pikes Peak batholith in the east-central part of the study area (figs. 10 and 11). The Eocene Mount Princeton pluton in the Sawatch Range contains many beryl occurrences that may explain the presence of multiple samples with high barium concentrations (>90th percentile). The Mount Antero stock, which intrudes the Mount Princeton pluton, also may contribute to the high beryllium concentrations (>90th percentile) in nearby samples. In the Colorado Mineral Belt, small clusters of samples with high concentrations (>97.5th percentile) occur over and downstream of the Oligocene Henderson porphyry-Mo deposit and in the Alma and Chalk Creek districts. Within the northeast part of the mineral belt, lower level clusters (90 to 97.5th percentile) also are found around the Argentine, Boulder-Tungsten, Breckenridge, Climax, Consolidated Montgomery, Gold Hill, Tenmile-Kokomo, Tennessee Pass, and Upper Blue River districts. In the western part of the study area within the mineral belt, samples with high beryllium concentrations (90 to 97.5th percentile) are associated with the Independence, Monarch, Red Mountain, Marshall Pass, and Winfield districts. Near the Lake George district, one sample (>97.5th percentile) overlies a greisen deposit in the Redskin stock within the west-central part of the Mesoproterozoic Pikes Peak batholith.







Central Colorado Stream-Sediment  
Geochemistry—Bismuth



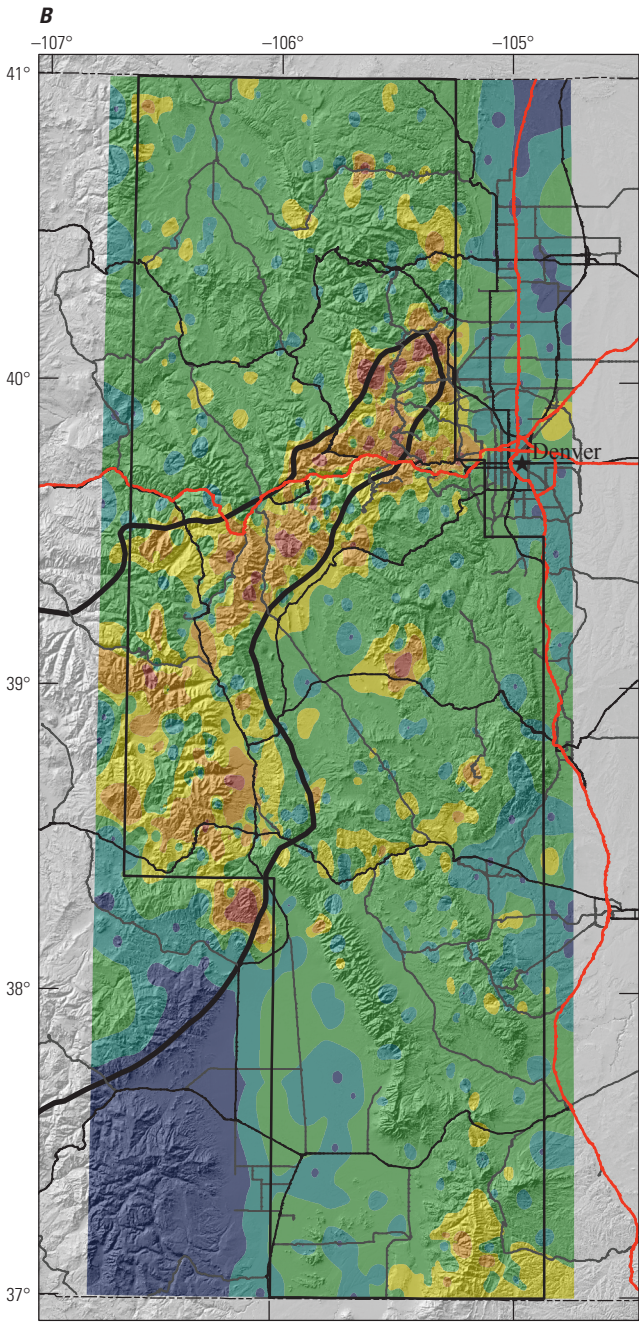
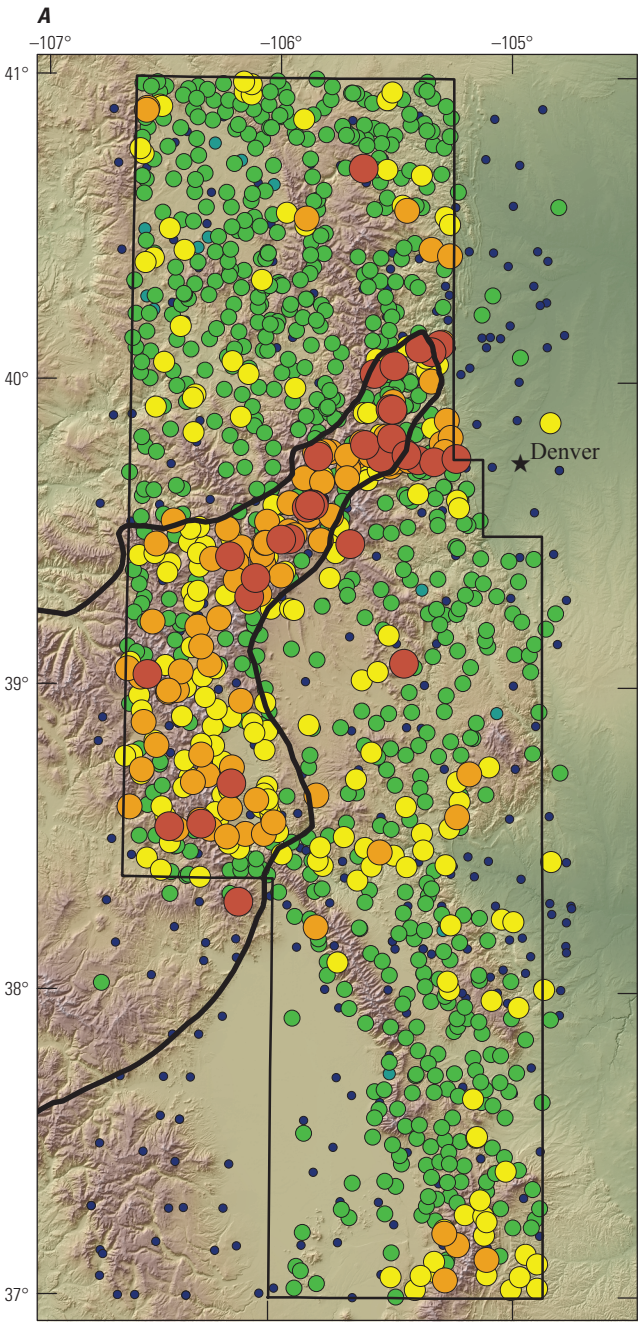
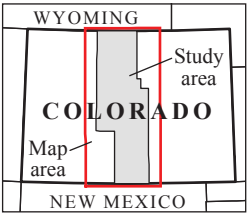
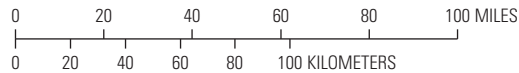
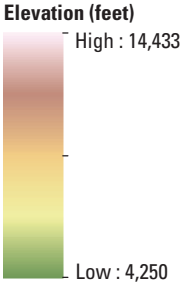
Bi parts per million (ppm)	
Samples:	1403
Minimum:	<0.04
Maximum:	21.0000
Mean:	0.5008
Geometric mean:	0.1234
Median:	0.1900
Mode:	0.0082
Standard deviation:	1.711
Standard error:	0.04567
Skew:	8.019
Kurtosis:	74.54

EXPLANATION

**Bismuth (parts per million)**  
Crustal abundance = 0.0082 ppm  
Limit of detection = 0.04 ppm

- <0.04 ppm (<10th percentile)
- 0.04–0.070 ppm (10–25th percentile)
- 0.071–0.31 ppm (25–75th percentile)
- 0.32–0.61 ppm (75–90th percentile)
- 0.62–3.7 ppm (90–97.5th percentile)
- 3.8–21 ppm (>97.5th percentile)

- Colorado state border
- Study area boundary
- Colorado Mineral Belt



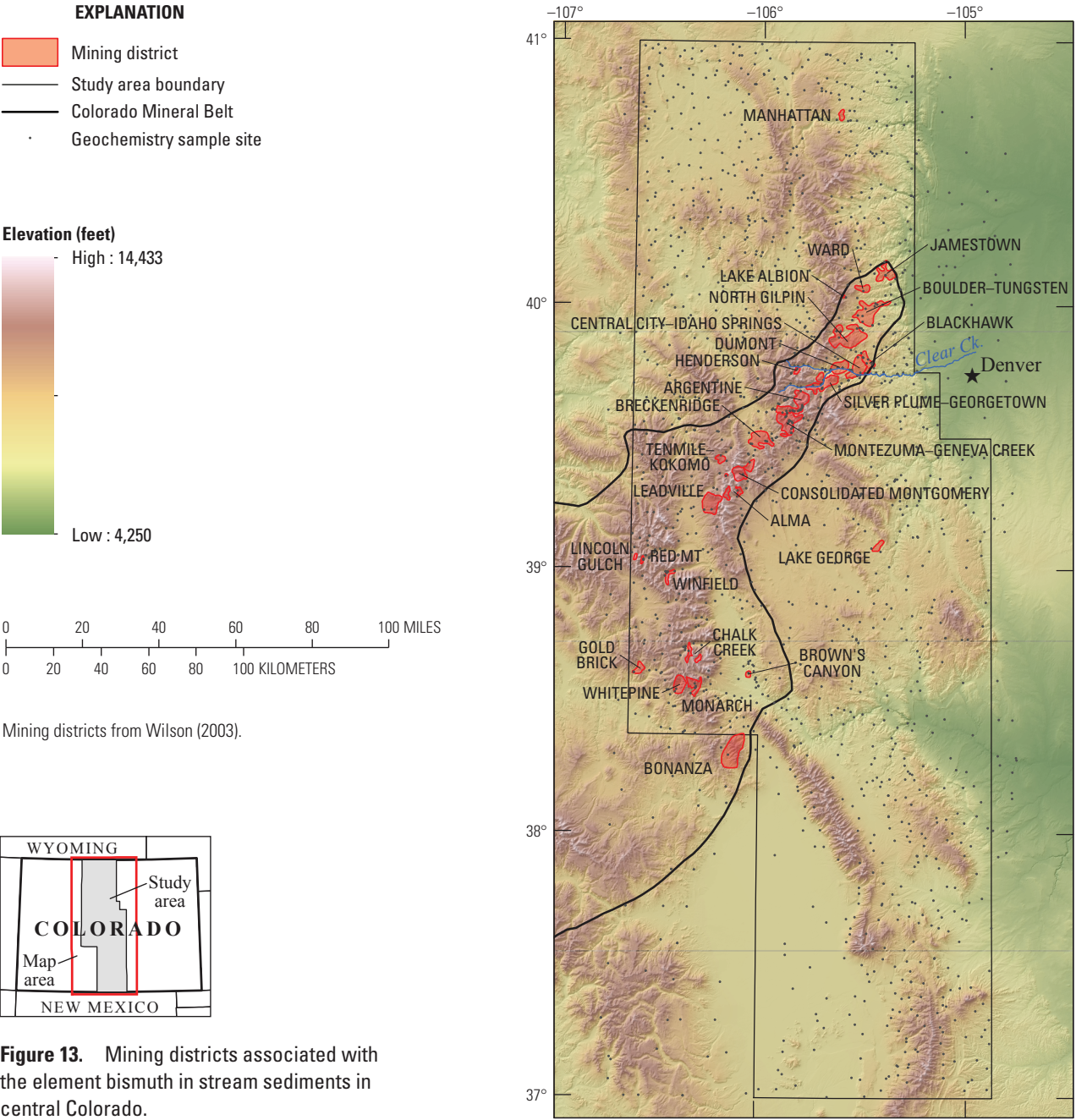
**Figure 12.** Maps of central Colorado stream-sediment geochemistry—bismuth (Bi). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



18      **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Bismuth (Bi) is strongly chalcophile in its geochemistry and is similar to antimony in its behavior. Bismuth, probably in bismuthinite or sulfosalt and telluride minerals, commonly is associated with lead-rich minerals in hydrothermal deposits. It is relatively immobile during weathering.

Samples having high (>90th percentile) bismuth concentrations correlate well with areas of hydrothermal metal deposits in the entire Colorado Mineral Belt within the study area (figs. 12 and 13). Stream-sediment samples with high bismuth concentrations (>90th percentile) are found in a well-defined dispersion train along Clear Creek below the Blackhawk and Central City–Idaho Springs districts eastward to the range front. Other areas having samples with high (>90th percentile) bismuth concentrations in the mineral belt include the Alma, Argentine, Bonanza, Boulder-Tungsten, Breckenridge, Browns Canyon, Chalk Creek, Consolidated Montgomery, Dumont, Gold Brick, Henderson, Jamestown, Lake Albion, Leadville, Lincoln Gulch, Monarch, Montezuma–Geneva Creek, North Gilpin, Red Mountain, Silver Plume–Georgetown, Tenmile–Kokomo, Ward, Whitepine, and Winfield districts. Outside the mineral belt, samples with high (>97.5th percentile) bismuth concentrations are found in the vicinity of the Lake George and Manhattan districts.

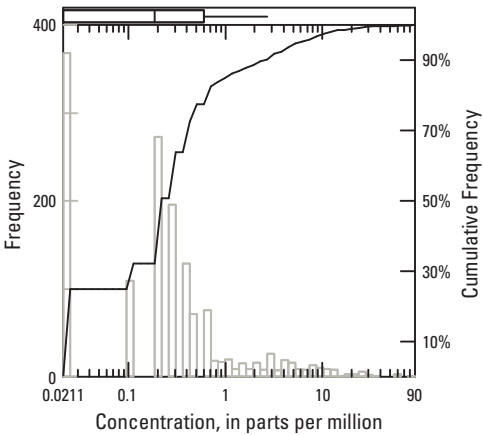


**Figure 13.** Mining districts associated with the element bismuth in stream sediments in central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Cadmium



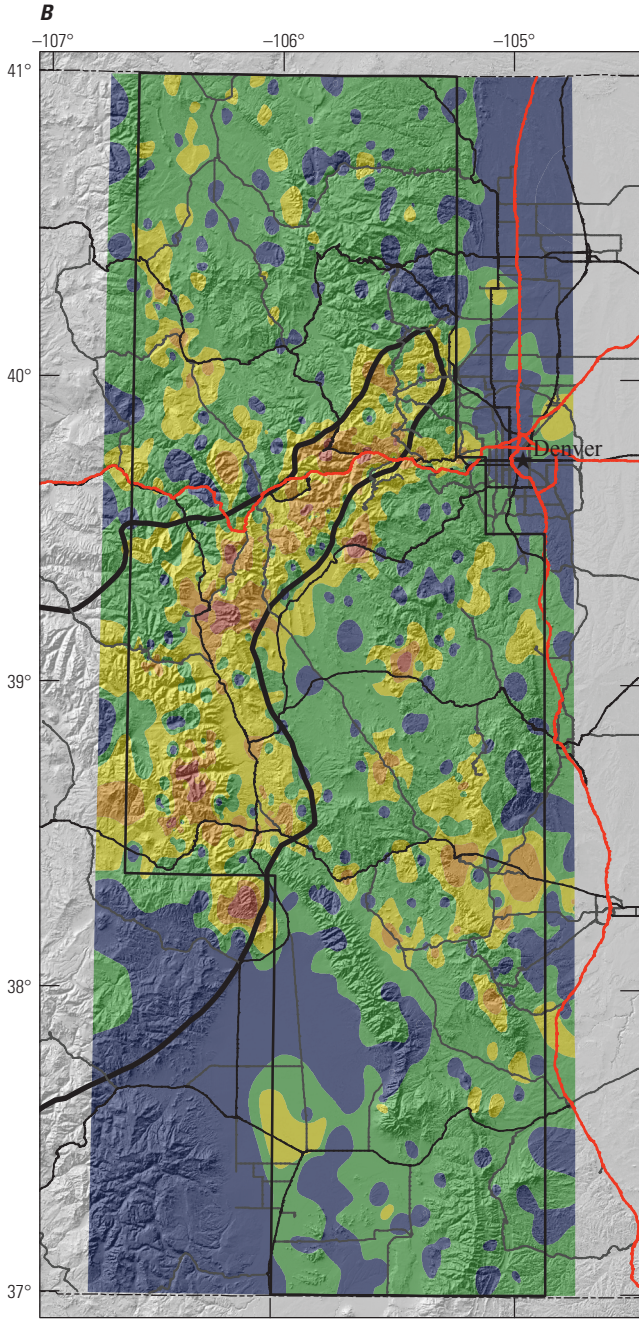
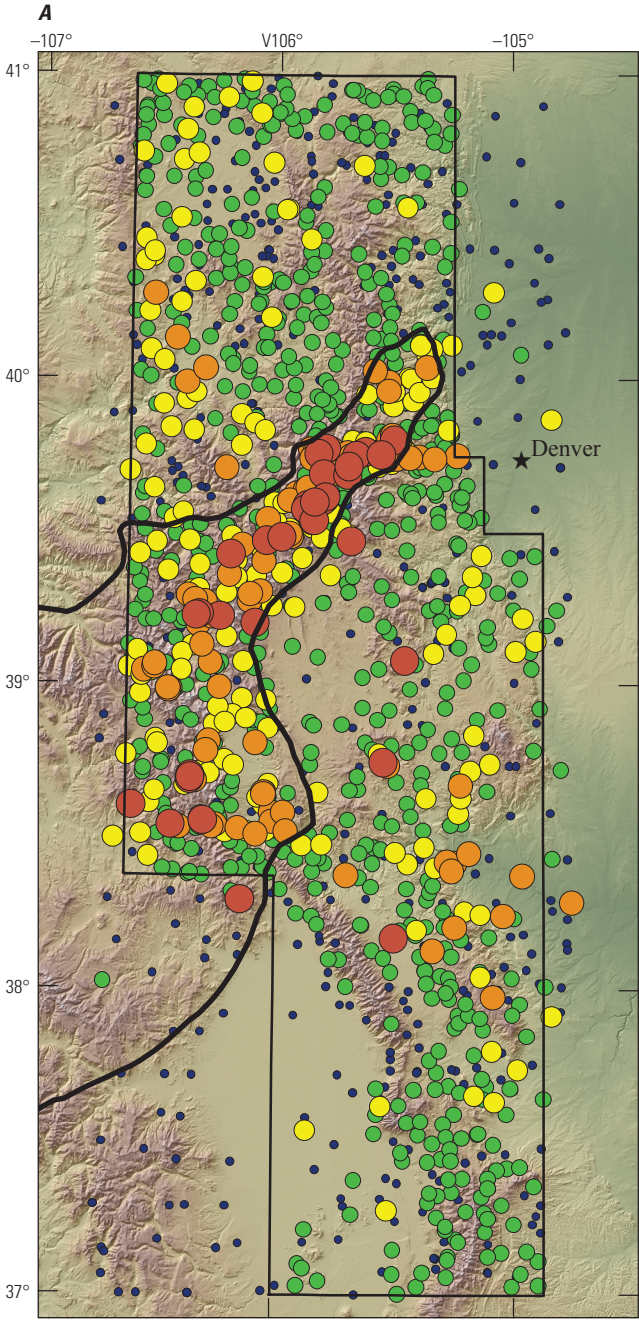
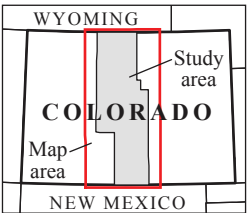
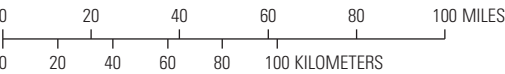
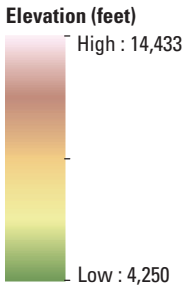
Cd parts per million (ppm)	
Samples:	1479
Minimum:	<0.1
Maximum:	84.0000
Mean:	1.2462
Geometric mean:	0.2223
Median:	0.2000
Mode:	0.0222
Standard deviation:	4.647
Standard error:	0.1208
Skew:	9.882
Kurtosis:	130.3

**Cadmium** (parts per million)  
Crustal abundance = 0.16 ppm  
Limit of detection = <0.1 ppm

- <0.1ppm (<25th percentile)
- 0.101–0.500 ppm (25–75th percentile)
- 0.501–2.60 ppm (75–90th percentile)
- 2.61–10.8 ppm (90–97.5th percentile)
- 10.9–84.0 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

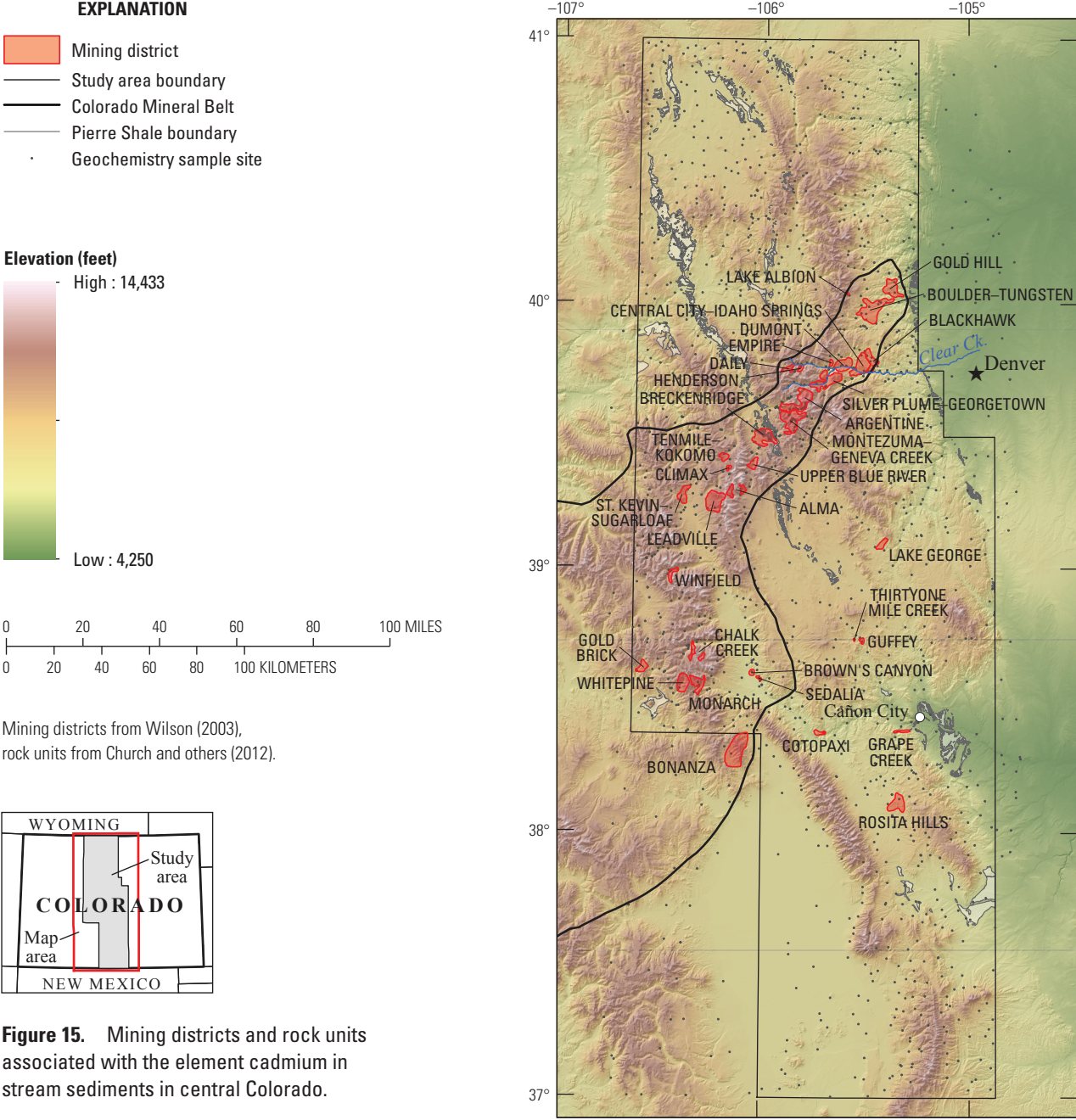


**Figure 14.** Maps of central Colorado stream-sediment geochemistry—cadmium (Cd). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Cadmium (Cd) is strongly chalcophile in its geochemistry and is similar to zinc and bismuth in its behavior. Cadmium commonly substitutes for zinc in sphalerite. It is relatively mobile during weathering and may be adsorbed on manganese- and iron-hydroxide precipitates or be present in organic matter. Organic-rich shales or carbonate rocks commonly are enriched in cadmium.

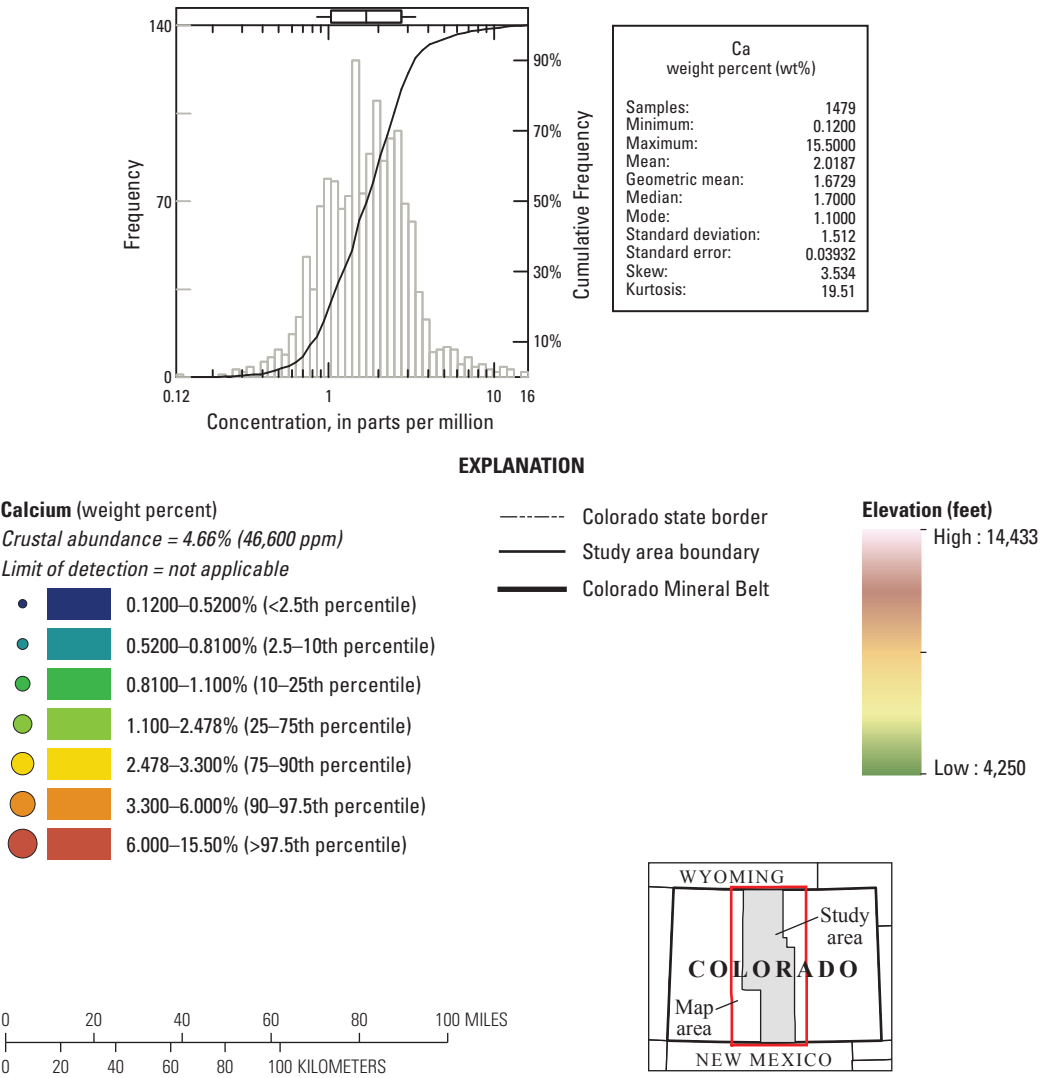
Stream-sediment samples containing cadmium (>90th percentile) identify the entire Colorado Mineral Belt (figs. 14 and 15). The presence of cadmium indicates occurrence of sphalerite or complex sulfide minerals in polymetallic veins and replacement deposits that constitute the majority of deposits in the mineral belt. A lower-level (90 to 97.5th percentile) dispersion train is evident below the Blackhawk and Central City–Idaho Springs districts along Clear Creek eastward to the range front. Other districts in the mineral belt associated with high cadmium concentrations (>90th percentile) are the Alma, Argentine, Bonanza, Boulder-Tungsten, Breckenridge, Browns Canyon, Chalk Creek, Climax, Daily, Dumont, Empire, Gold Brick, Gold Hill, Henderson, Lake Albion, Leadville, Monarch, Montezuma–Geneva Creek, Sedalia, Silver Plume–Georgetown, St. Kevin–Sugarloaf, Tenmile-Kokomo, Upper Blue River, Whitepine, and Winfield districts. Outside the mineral belt, low-level clusters or single samples of high cadmium concentrations (90 to 97.5th percentile) are found around the Cotopaxi, Guffey, Lake George, Thirtyone Mile Creek, and Rosita Hills districts and downstream of the Grape Creek district. A number of samples with high concentrations (90th to 97.5th percentile) are underlain by the organic-rich Pierre Shale in the southeastern and northwestern parts of the study area.



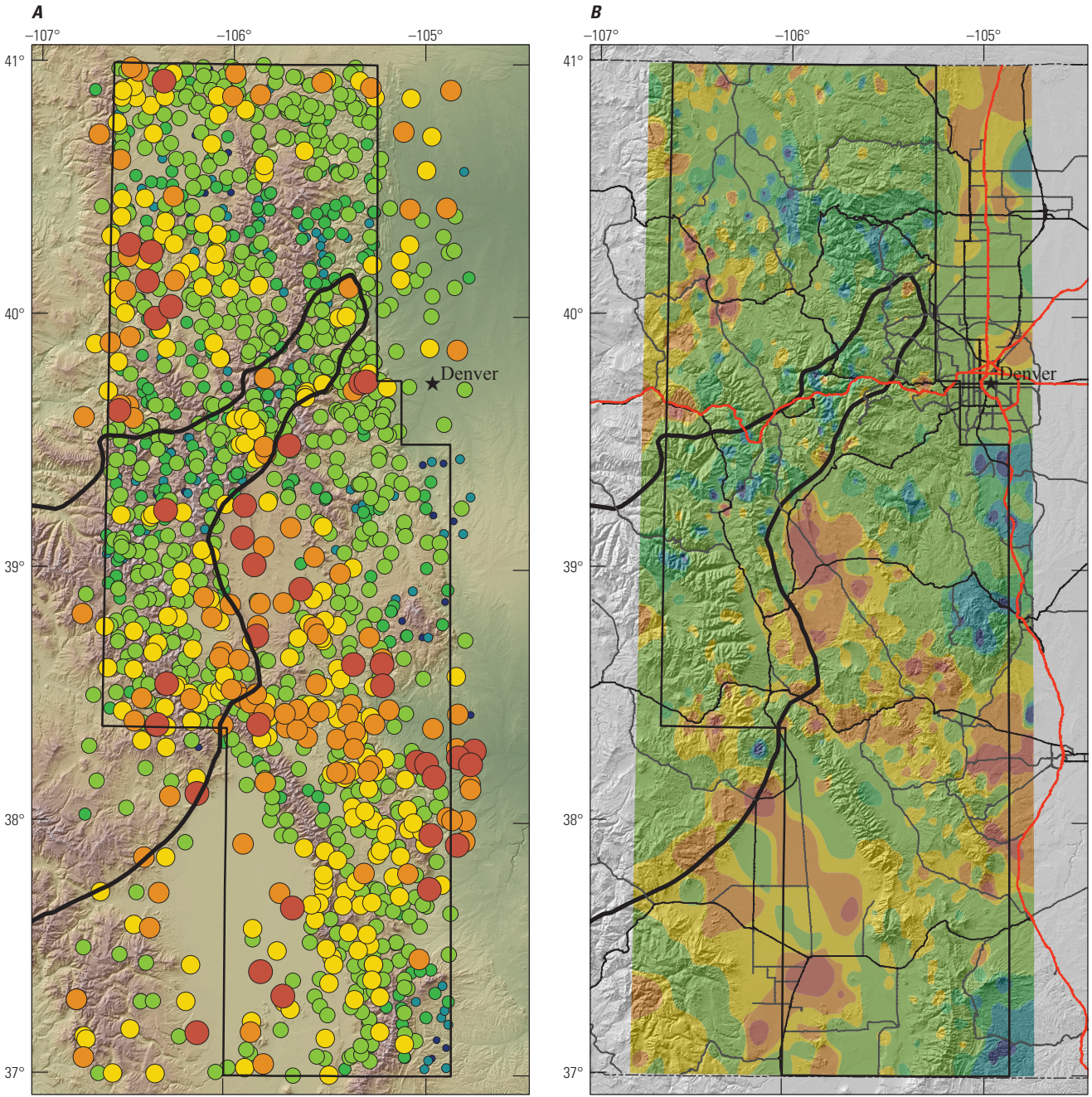




Central Colorado Stream-Sediment  
Geochemistry—Calcium



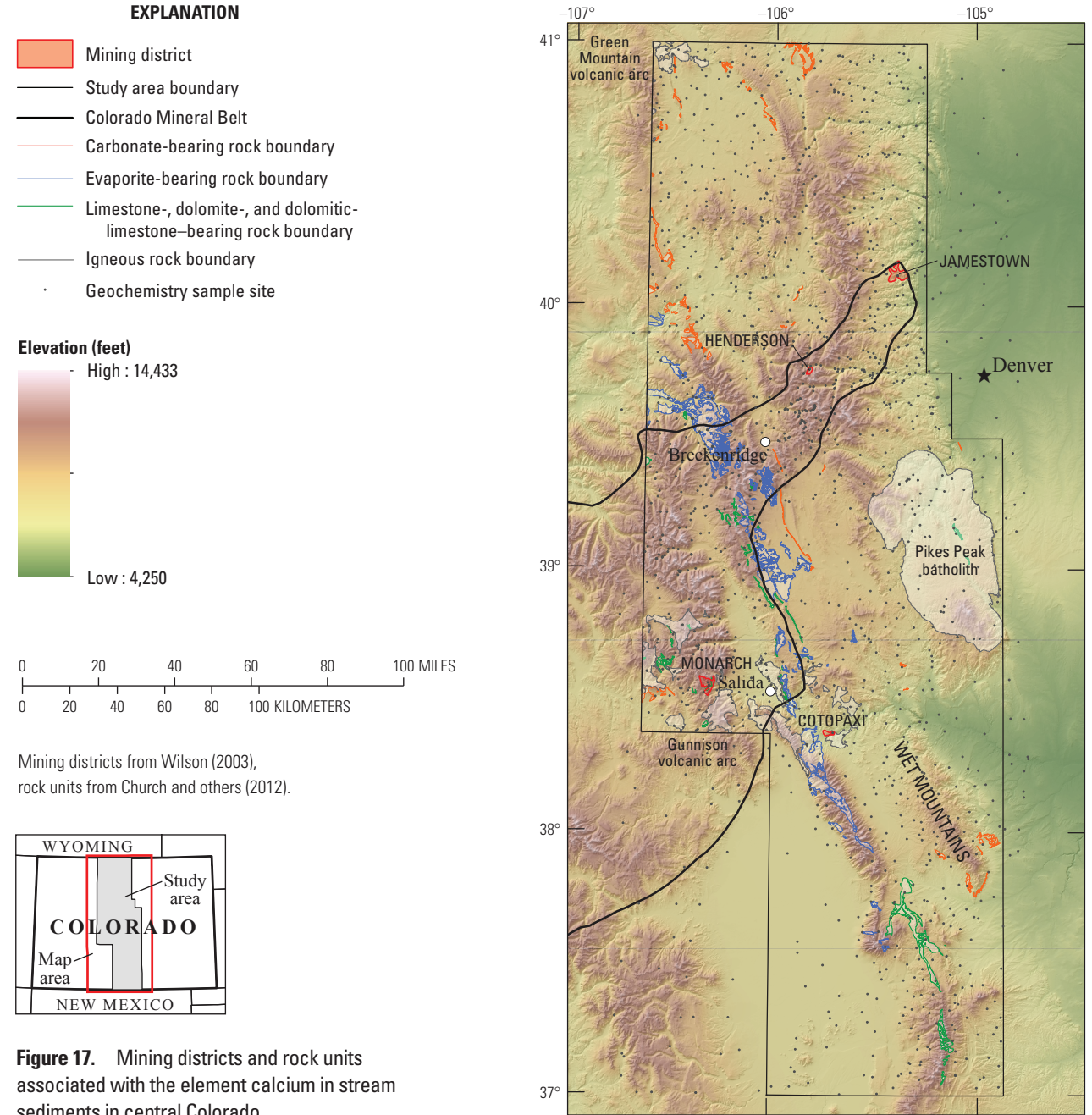
**Figure 16.** Maps of central Colorado stream-sediment geochemistry—calcium (Ca). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Calcium (Ca) is the principal cation in the common minerals calcium plagioclase, calcite, dolomite, and gypsum. Calcium concentrations are highest in intermediate to mafic igneous rocks, carbonate-rich sedimentary rocks, and in evaporites. It is mobile during weathering and primarily is precipitated in carbonates.

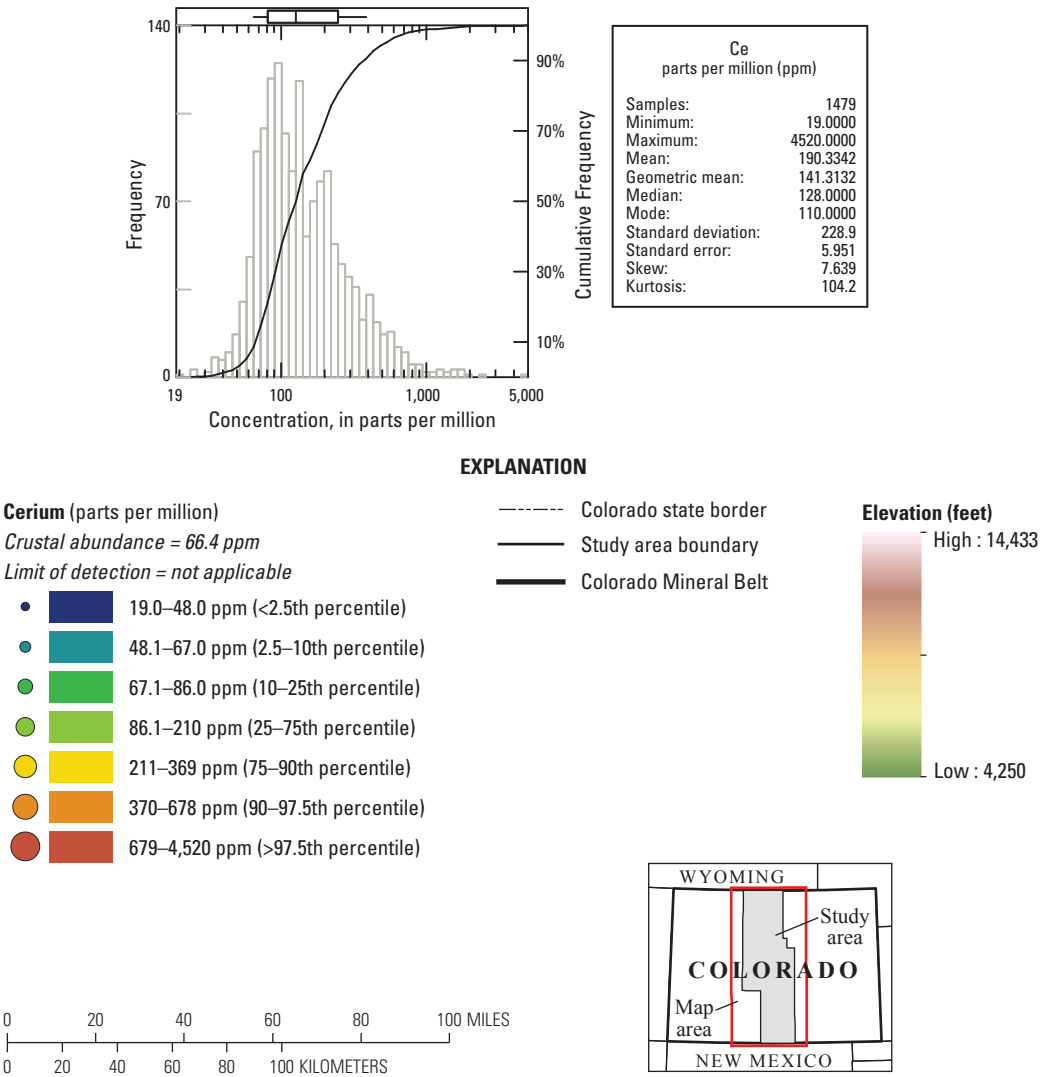
Stream-sediment samples having high calcium concentrations (>90th percentile) in the study area are associated with four diverse groups of bedrock units (figs. 16 and 17). These units are (1) Pennsylvanian to Cretaceous carbonate-bearing sedimentary rocks such as the Chugwater, Niobrara, and Morrison Formations; (2) Paleozoic limestone-, dolomite- and dolomitic limestone-bearing units, such as the Madera, Manitou, Leadville, and Minturn Formations; (3) evaporite-bearing units such as the Eagle Valley and Minturn Formations; and (4) mafic and ultramafic metavolcanic rocks that are part of the Proterozoic volcanic-arc rocks of the Green Mountain arc in the far northern part of the study area plus the eastern Gunnison arc near Salida and extending into the northern Wet Mountains. Also in this last group are mafic metavolcanic and metagabbroic rocks east of Breckenridge. Within the Colorado Mineral Belt, calcium concentrations generally fall below the 90th percentile, with the exception of high calcium concentrations associated with samples from the Monarch (>97.5th percentile), Henderson, and Jamestown (both 90–97.5th percentile) districts. Low Ca concentrations are evident in samples underlain by the Pikes Peak batholith, reflecting predominance of potassium feldspar relative to plagioclase in that batholith.



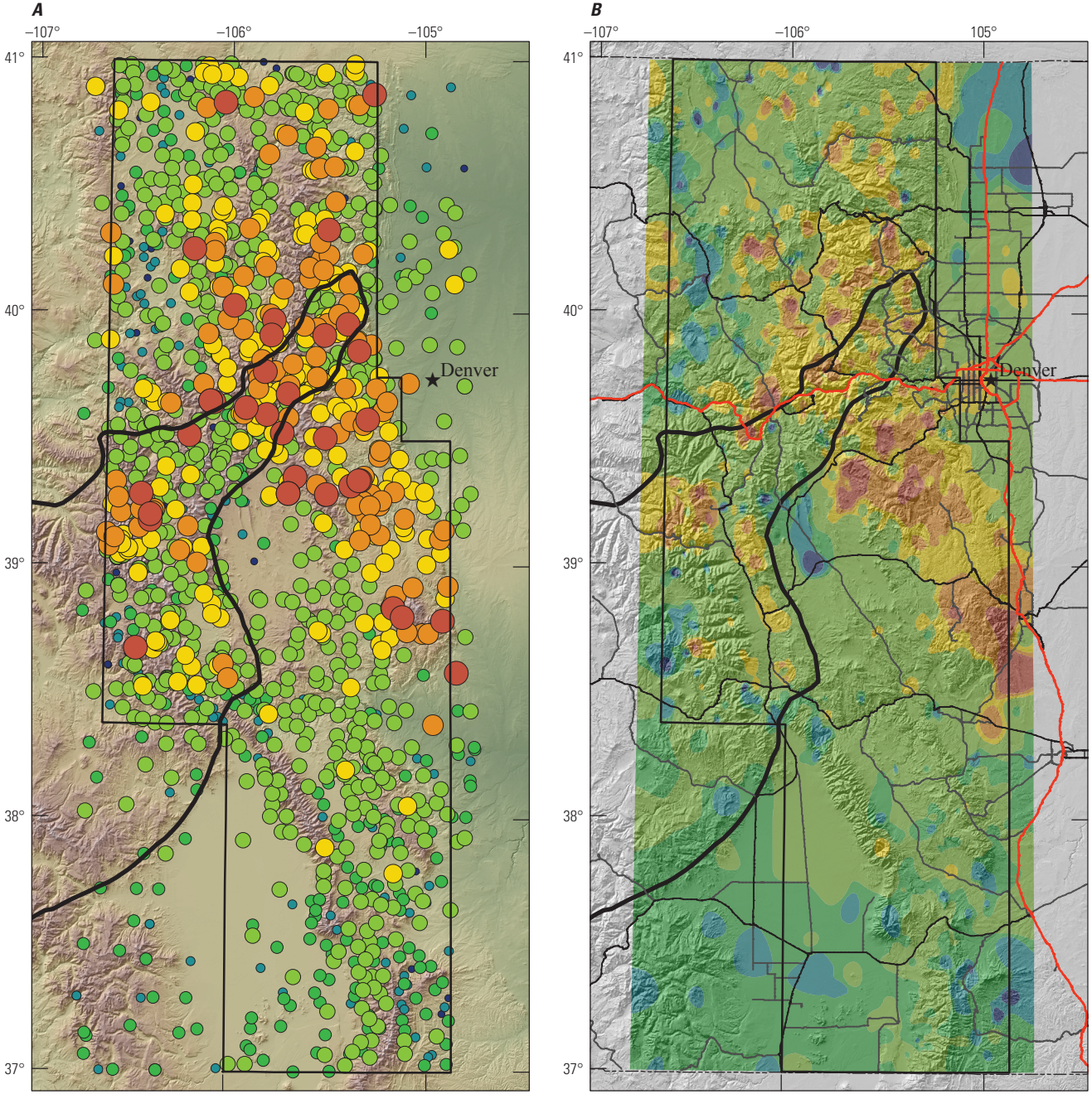




Central Colorado Stream-Sediment  
Geochemistry—Cerium



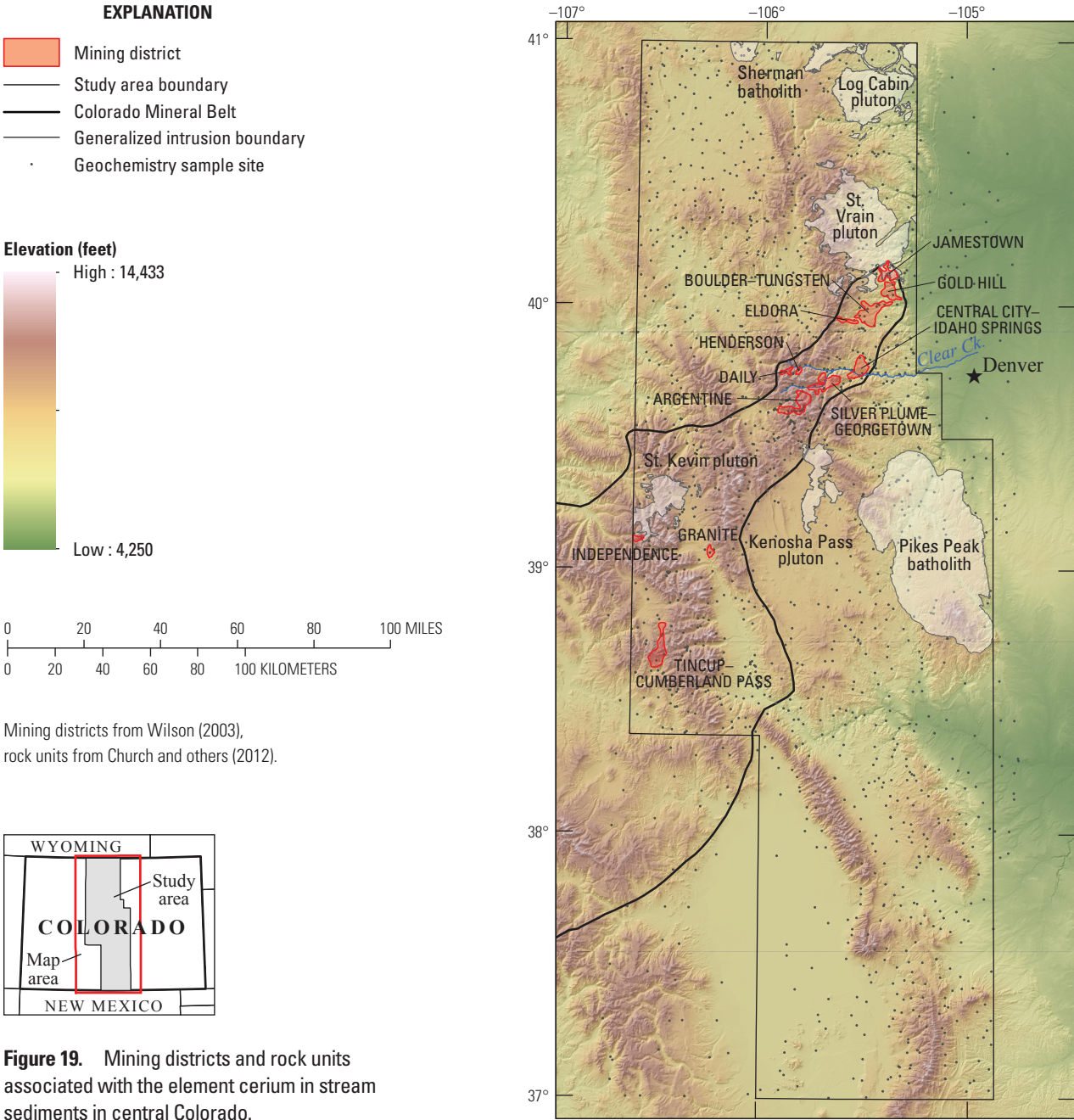
**Figure 18.** Maps of central Colorado stream-sediment geochemistry—cerium (Ce). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Cerium (Ce) is one of 15 metallic elements called rare earth elements (REEs). The REEs include **cerium**, dysprosium, erbium, **europium**, gadolinium, **holmium**, **lanthanum**, lutetium, **neodymium**, praseodymium, promethium, samarium, terbium, thulium, and **ytterbium**. **Yttrium** is very similar to and commonly grouped with the REEs. The report contains geochemical maps of elements shown in bold in the previous sentences. All of these elements are similar geochemically and typically are found together, although in different elemental abundances. Despite their name, the REEs are relatively plentiful in the Earth’s crust. The REEs are strongly lithophile in igneous rocks and typically are concentrated in the most evolved rocks, such as granites and granite pegmatites. The REEs content generally is highest in alkaline rocks and carbonatites. With exception of europium, REEs (with their large ionic radii and trivalent charge) are concentrated in residual liquids during differentiation and commonly are concentrated in late trace minerals, such as fluorite, apatite, zircon, sphene, garnet, epidote-group minerals, monazite, xenotime, allanite, and thorite. The REE-bearing minerals typically are resistant to weathering. In sediments and sedimentary rocks, REEs are concentrated in heavy-mineral residual or alluvial placer deposits, in highly weathered deposits such as karst (for example, bauxite), and in phosphorite.

Highest concentrations of cerium (>90th percentile) are found in stream-sediment samples eroded from felsic igneous intrusions of various ages from Precambrian to Tertiary (figs. 18 and 19). Samples from areas underlain by Mesoproterozoic felsic igneous bodies in the northern two-thirds of the study area, including the Pikes Peak and Sherman batholiths and the Kenosha Pass, St. Vrain, St. Kevin, and Log Cabin plutons, consistently show the highest concentrations of cerium. Samples obtained over or near plutons of similar age and composition in the southern one-third show moderate concentrations of Ce, generally in the 90th to 97.5th percentile. Mining districts having spatial associations with high (>90th percentile) cerium values all are located in the Colorado Mineral Belt and include the Argentine, Boulder-Tungsten, Central City–Idaho Springs, Daily, Eldora, Gold Hill, Granite, Henderson, Independence, Jamestown, Silver Plume–Georgetown, and Tincup–Cumberland Pass districts.

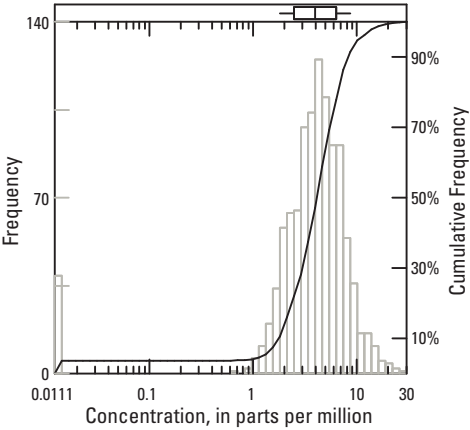


**Figure 19.** Mining districts and rock units associated with the element cerium in stream sediments in central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Cesium



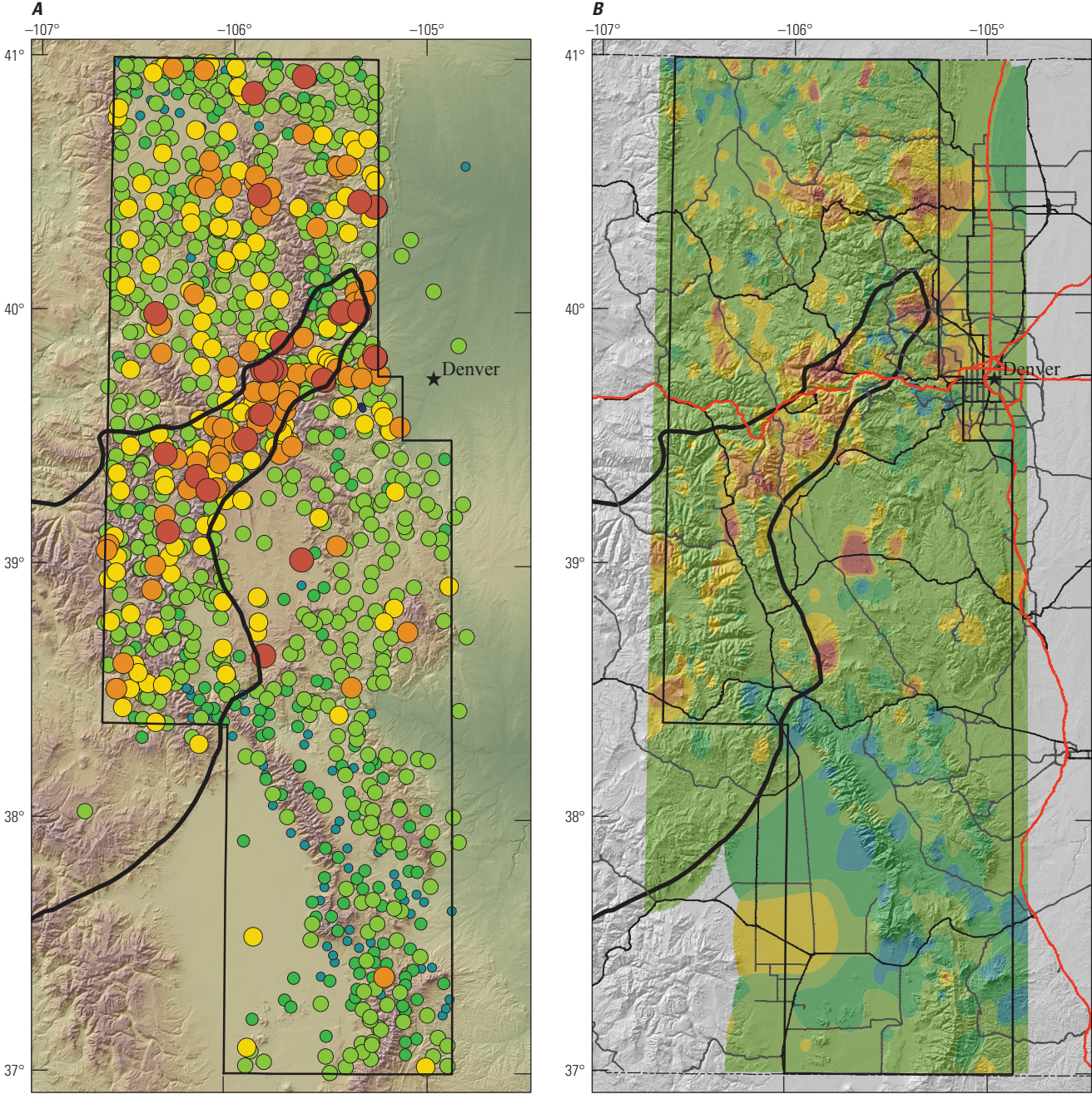
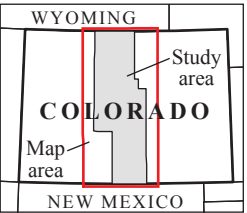
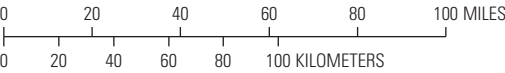
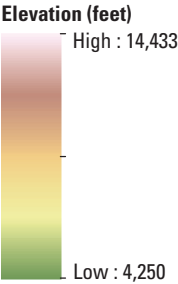
Cs parts per million (ppm)	
Samples:	1064
Minimum:	<0.05
Maximum:	28.0000
Mean:	4.7043
Geometric mean:	3.3523
Median:	4.2000
Mode:	<0.05
Standard deviation:	3.183
Standard error:	0.09758
Skew:	2.095
Kurtosis:	7.867

**Cesium** (parts per million)  
*Crustal abundance = 2.6 ppm*  
*Limit of detection = 0.05 ppm*

- <0.05 ppm (<2.5th percentile)
- 0.05–1.80 ppm (2.5–10th percentile)
- 1.81–2.60 ppm (10–25th percentile)
- 2.61–6.00 ppm (25–75th percentile)
- 6.01–8.30 ppm (75–90th percentile)
- 8.31–12.0 ppm (90–97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

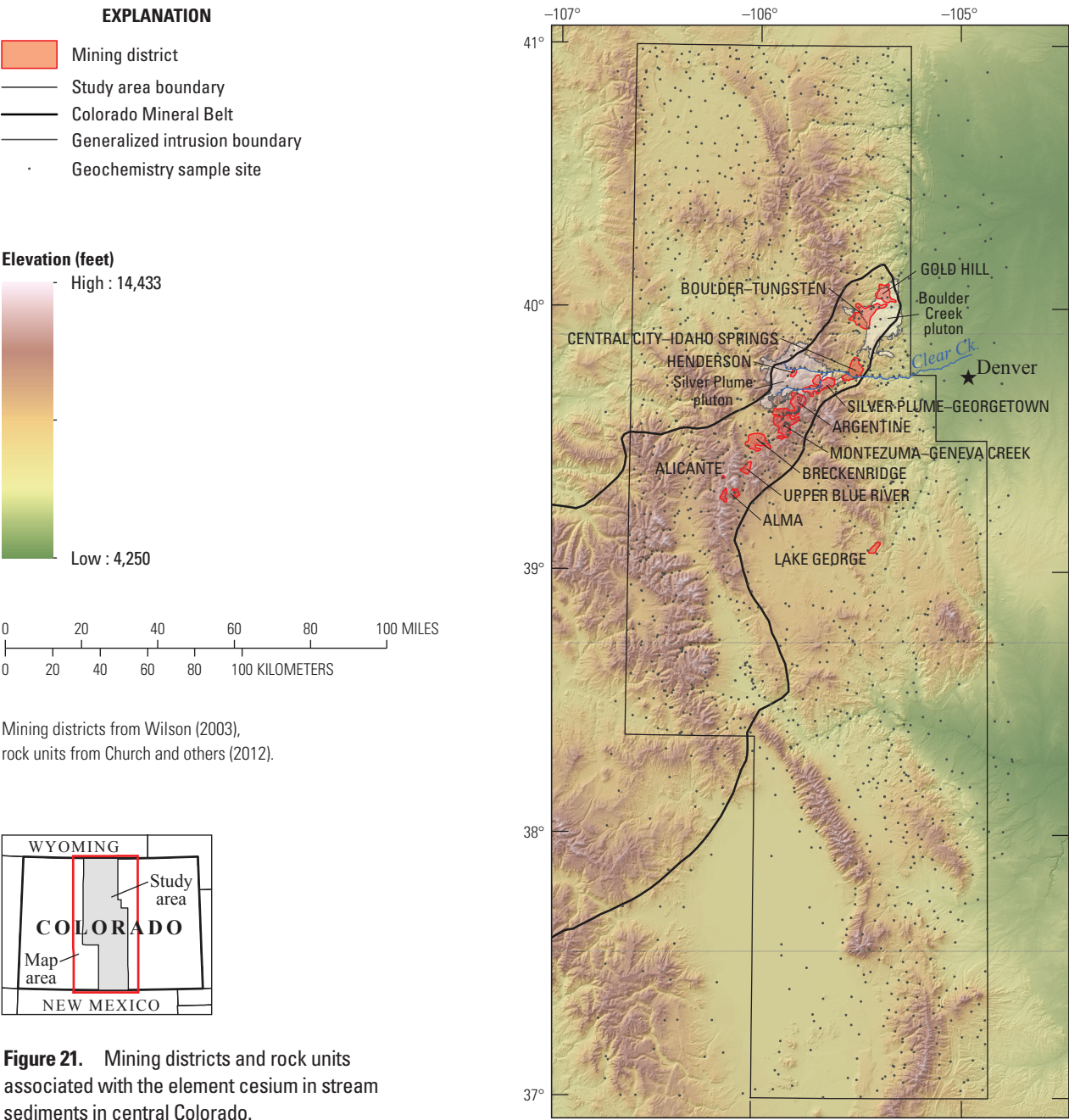


**Figure 20.** Maps of central Colorado stream-sediment geochemistry—cesium (Cs). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Cesium (Cs) typically is concentrated in highly evolved igneous rocks (such as granite pegmatites) in silica-undersaturated rocks, and in hydrothermal potassium feldspar. It is found primarily in the minerals leucite, mica, potassium feldspar, and beryl. During weathering, cesium is mobile and clay minerals can become enriched.

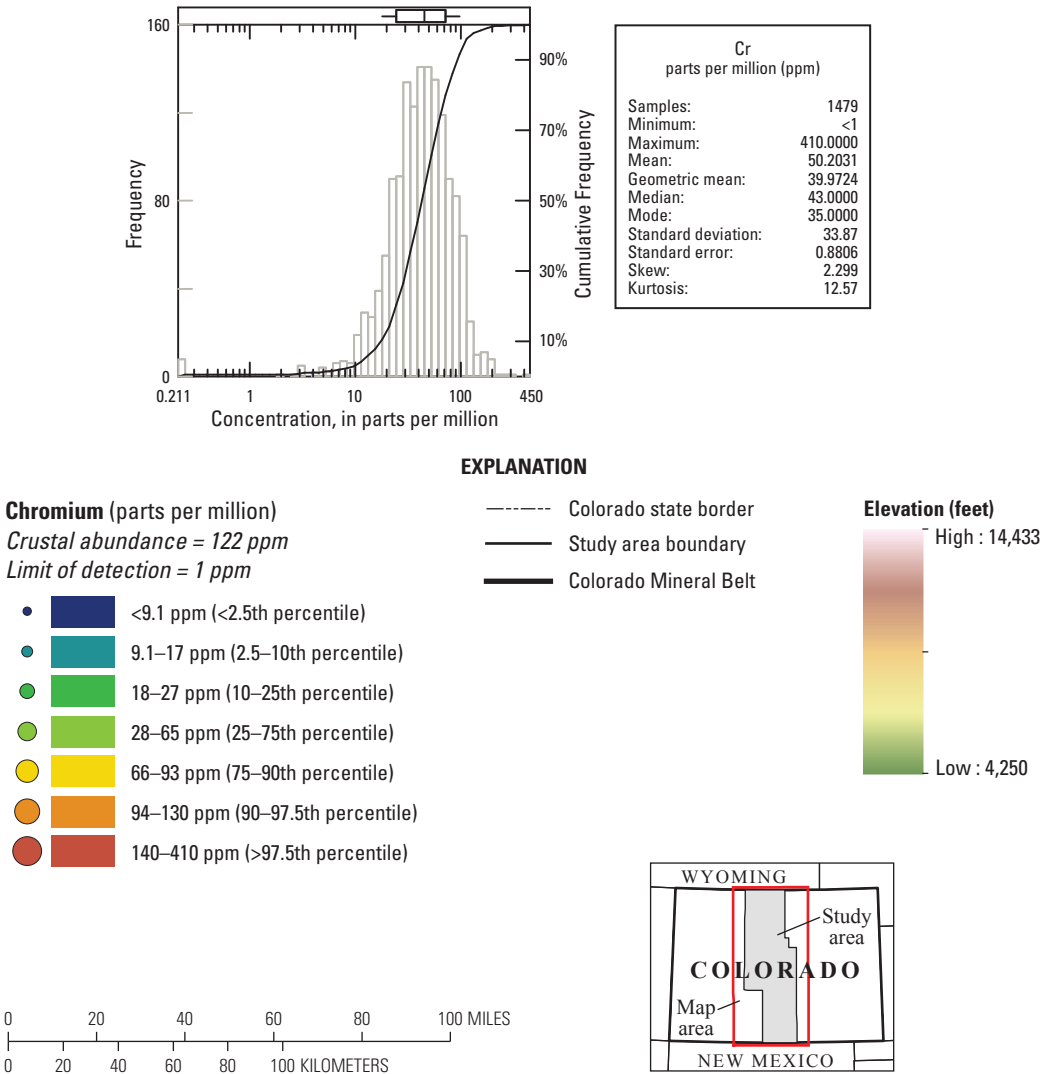
A strong cluster of stream-sediment samples with high cesium concentrations (>90th percentile) identifies varied felsic igneous rocks within the northern end of the Colorado Mineral Belt (figs. 20 and 21). Mining districts having samples associated with high cesium concentrations (>97.5th percentile) in the mineral belt include the Alicante, Alma, Argentine, Breckenridge, Boulder-Tungsten, Central City–Idaho Springs, Gold Hill, Montezuma–Geneva Creek, Silver Plume–Georgetown, and Upper Blue River districts, with several of the highest concentrations (20–23 ppm) from samples within and just downstream of the Henderson district. Outside the mineral belt, high cesium concentrations were found in a few samples near the Lake George district. Scattered sample locations with high cesium concentrations (>90th percentile) in the northern part of the study area also are underlain by various felsic igneous rocks.



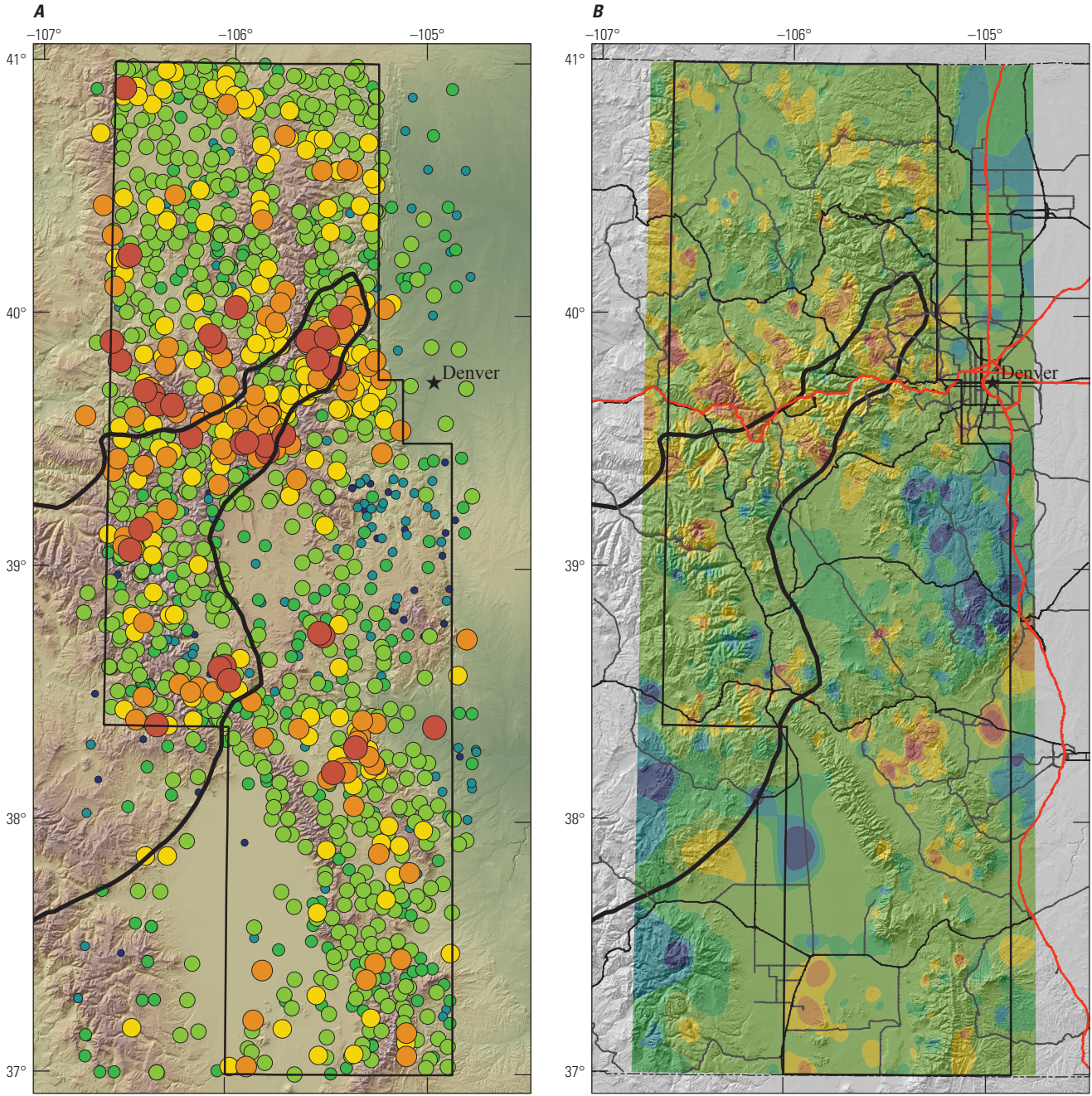




Central Colorado Stream-Sediment  
Geochemistry—Chromium



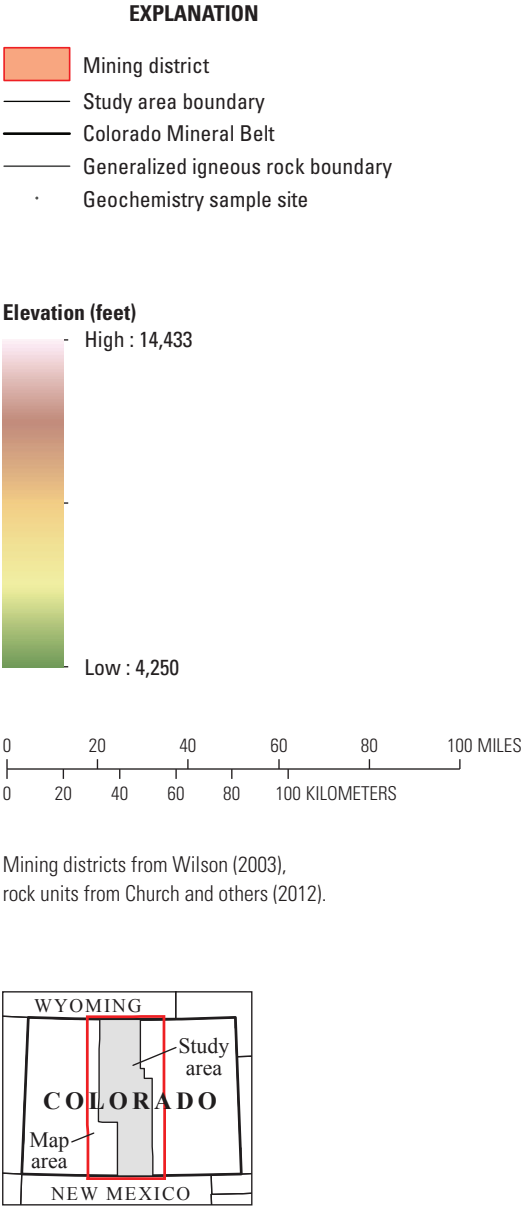
**Figure 22.** Maps of central Colorado stream-sediment geochemistry—chromium (Cr). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



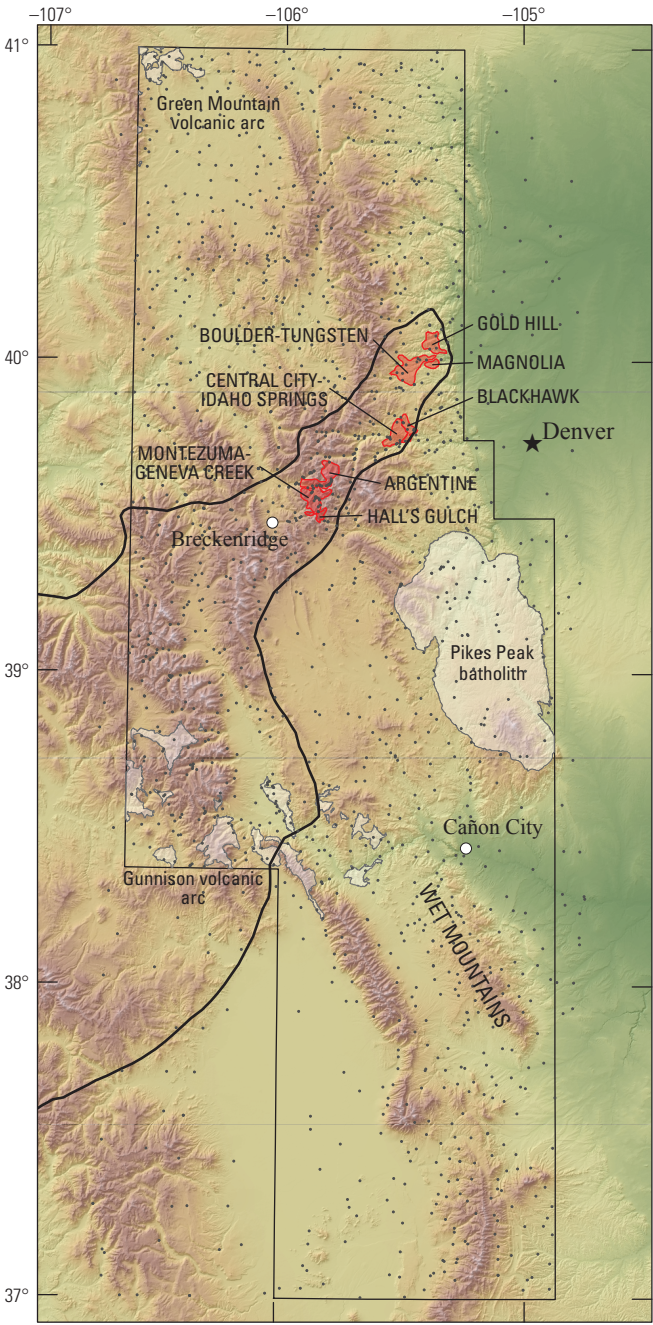


Chromium (Cr) is most abundant in igneous rocks of ultramafic and mafic compositions, where it typically resides in the minerals chromite, olivine, pyroxene, and some garnets. The abundance of chromium in most other rocks is very low. Chromite is insoluble during weathering and may be concentrated in residual, alluvial, and marine placer deposits.

High chromium concentrations (90th to >97th percentile) in stream-sediment samples correspond roughly with the occurrence of early Proterozoic and Cambrian mafic and ultramafic rocks (figs. 22 and 23). These types include the Proterozoic Green Mountain volcanic-arc rocks in the northern part of the Colorado Mineral Belt area and the Gunnison arc rocks of the west-central part of the area, and the mafic metavolcanic and gabbroic rocks in the western Front Range just east of Breckenridge. Several high-chromium samples also occur near the Cambrian mafic and ultramafic rocks in the northern Wet Mountains. Within and around the mineral belt, however, many samples with concentrations in the upper percentile ranges (>90th percentile) were taken from areas with bedrock compositions typically low in chromium (such as felsic igneous and sedimentary rocks); nevertheless, samples with high chromium concentrations likely are related to volumetrically minor mafic dikes. Clusters of stream-sediment samples with high chromium concentrations (>97.5th percentile) are present in the northern end of the mineral belt in the Boulder-Tungsten, Gold Hill, Magnolia, Blackhawk, and Central City–Idaho Springs districts, as well as farther southwest in the mineral belt in the Argentine, Halls Gulch, and Montezuma–Geneva Creek districts. The Mesoproterozoic Pikes Peak batholith is noticeably depleted in chromium, reflecting the evolved granitic composition of the batholith.



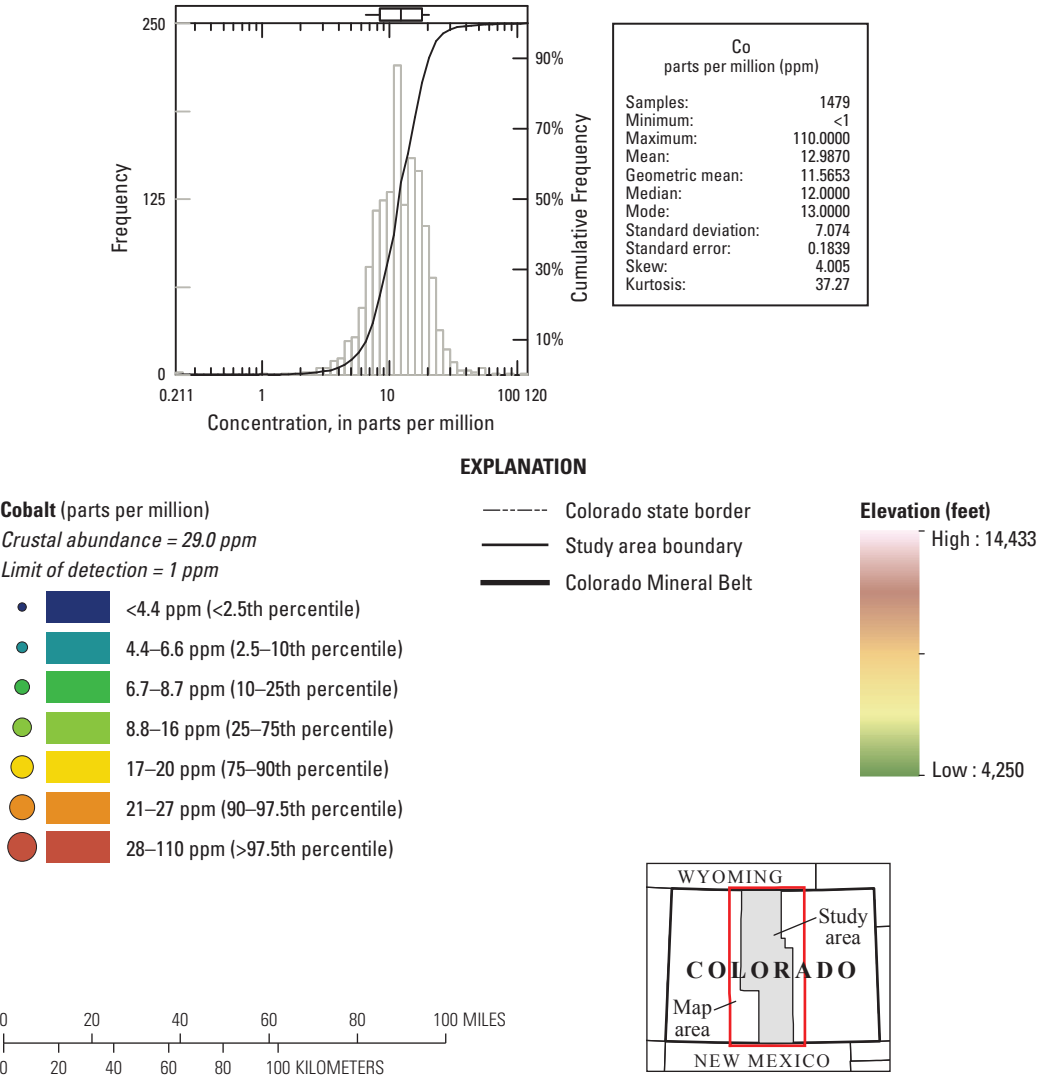
**Figure 23.** Mining districts and rock units associated with the element chromium in stream sediments in central Colorado.



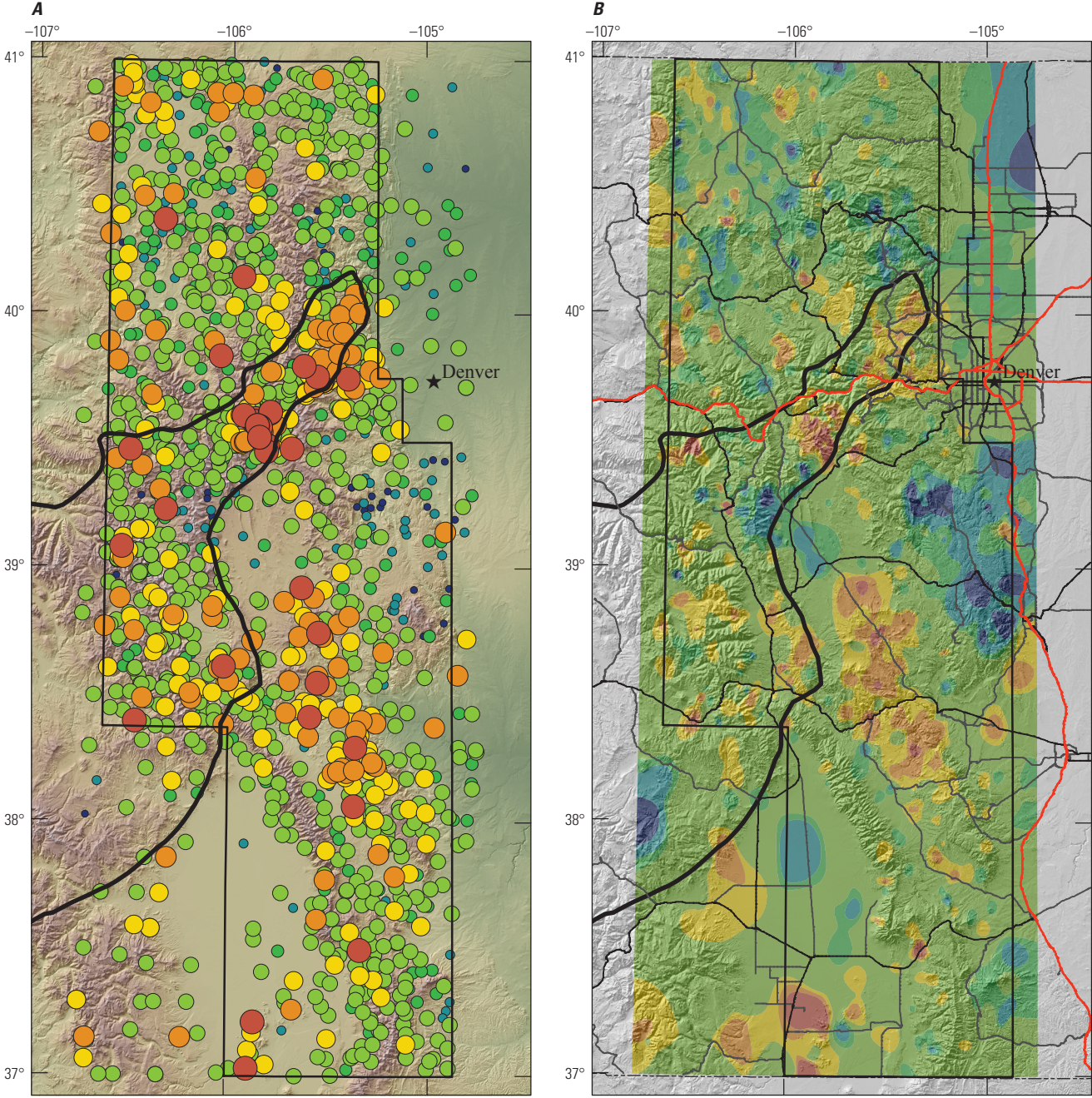




Central Colorado Stream-Sediment  
Geochemistry—Cobalt



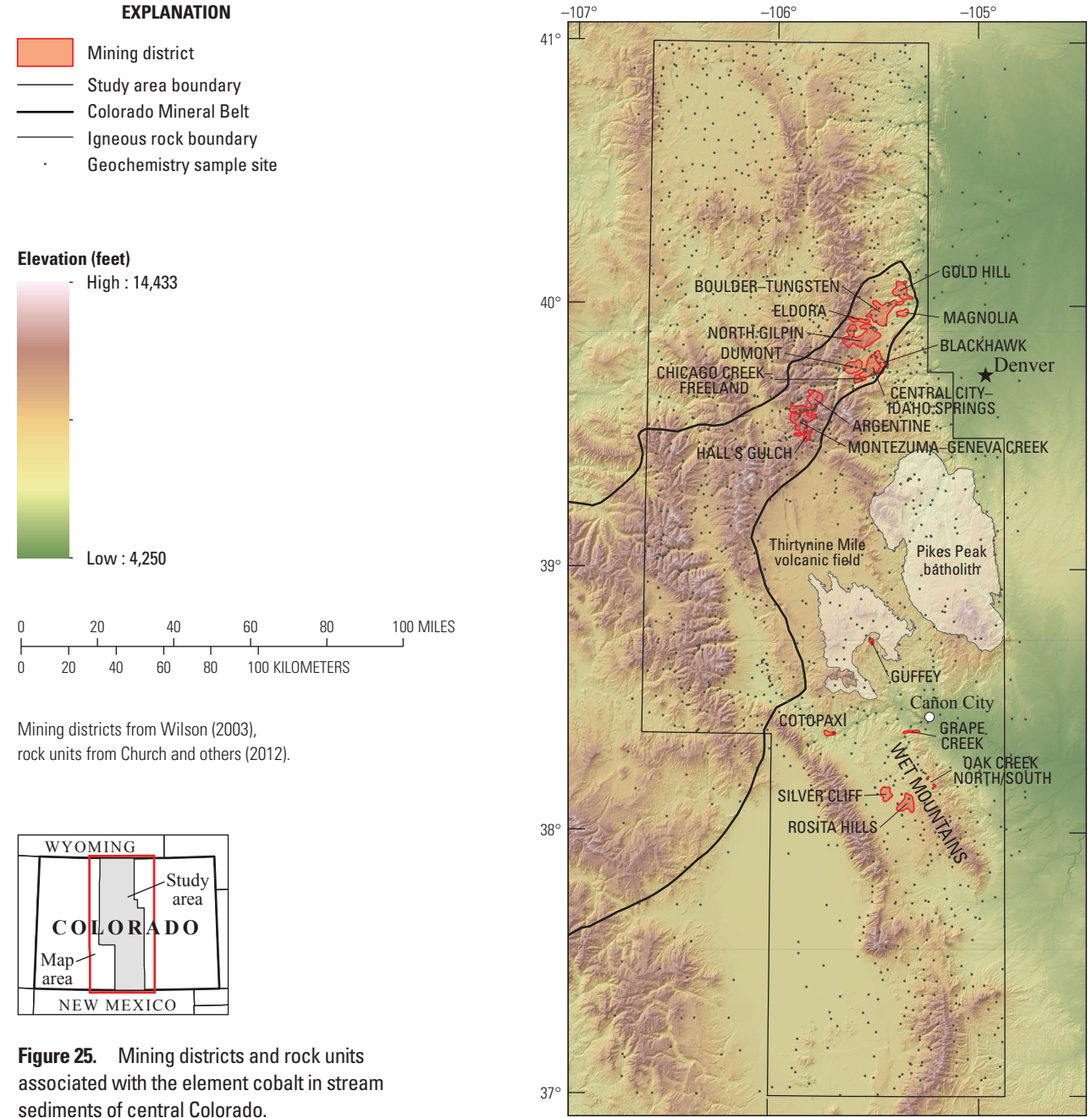
**Figure 24.** Maps of central Colorado stream-sediment geochemistry—cobalt (Co). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Cobalt (Co) is most abundant in ultramafic to mafic igneous rocks, where it is present in the minerals olivine and pyroxene, in related serpentinitic alteration products, and in magmatic sulfide minerals. Cobalt also is concentrated in some hydrothermal sulfide deposits, in some bog iron and siderite deposits, and in pyritic shales. Cobalt is moderately mobile during weathering and may be concentrated in manganese- and iron-oxyhydroxide minerals in the aqueous environment, particularly in areas of natural or anthropogenic acid-rock drainage.

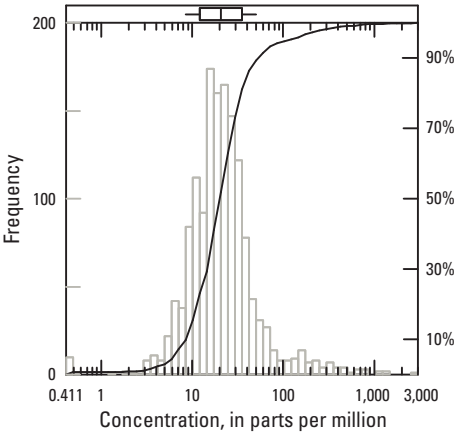
Within the Colorado Mineral Belt, a prominent cluster of stream-sediment samples with high cobalt concentrations (>97.5th percentile) identifies mafic to intermediate igneous rock types within the Argentine, Halls Gulch, and Montezuma–Geneva Creek districts (figs. 24 and 25). Samples from the northeastern end of the mineral belt have slightly lower cobalt concentrations (90 to 97.5th percentile) and highlight the Blackhawk, Boulder-Tungsten, Central City–Idaho Springs, Chicago Creek–Freeland, Dumont, Eldora, Gold Hill, Magnolia, and North Gilpin districts. Outside the mineral belt, high cobalt concentrations (>90th percentile) are found in samples from areas overlying or near intermediate and mafic volcanic and subvolcanic intrusive rocks of the Thirtynine Mile volcanic field, as well as throughout the northern Wet Mountains, where Cambrian alkaline mafic and ultramafic plutons and dikes are present. Samples with high cobalt concentrations in districts outside the mineral belt arise from Mesoproterozoic stratabound base-metal deposits in the Cotopaxi, Grape Creek, Guffey, Oak Creek, Rosita Hills, and Silver Cliff districts. Other scattered samples with high cobalt concentrations may indicate volumetrically minor mafic to intermediate igneous rocks. The Mesoproterozoic Pikes Peak batholith is depleted noticeably in cobalt, reflecting the evolved granitic composition of that batholith.







Central Colorado Stream-Sediment  
Geochemistry—Copper



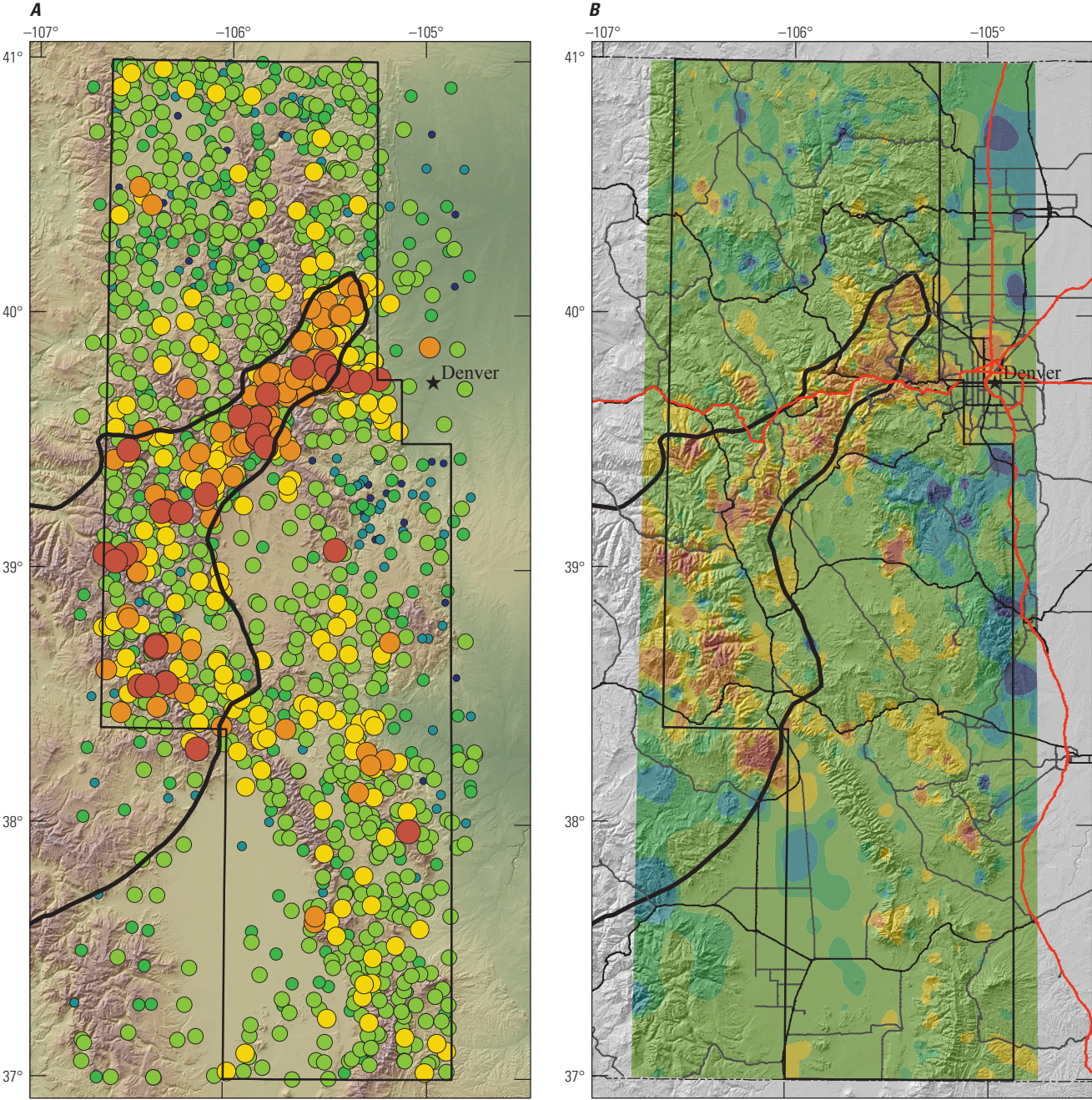
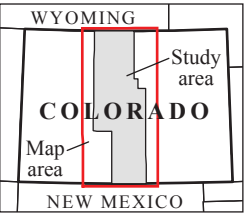
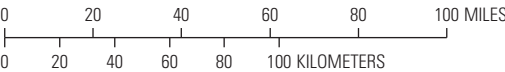
Cu parts per million (ppm)	
Samples:	1479
Minimum:	<2
Maximum:	2600.0000
Mean:	39.5433
Geometric mean:	21.0740
Median:	20.0000
Mode:	12.0000
Standard deviation:	113.4
Standard error:	2.948
Skew:	12.48
Kurtosis:	216.6

**Copper** (parts per million)  
Crustal abundance = 68.0 ppm  
Limit of detection = 2 ppm

- <4.4 ppm (<2.5th percentile)
- 4.4–8.5 ppm (2.5–10th percentile)
- 8.6–13 ppm (10–25th percentile)
- 14–31 ppm (25–75th percentile)
- 32–54 ppm (75–90th percentile)
- 55–220 ppm (90–97.5th percentile)
- 230–2,600 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

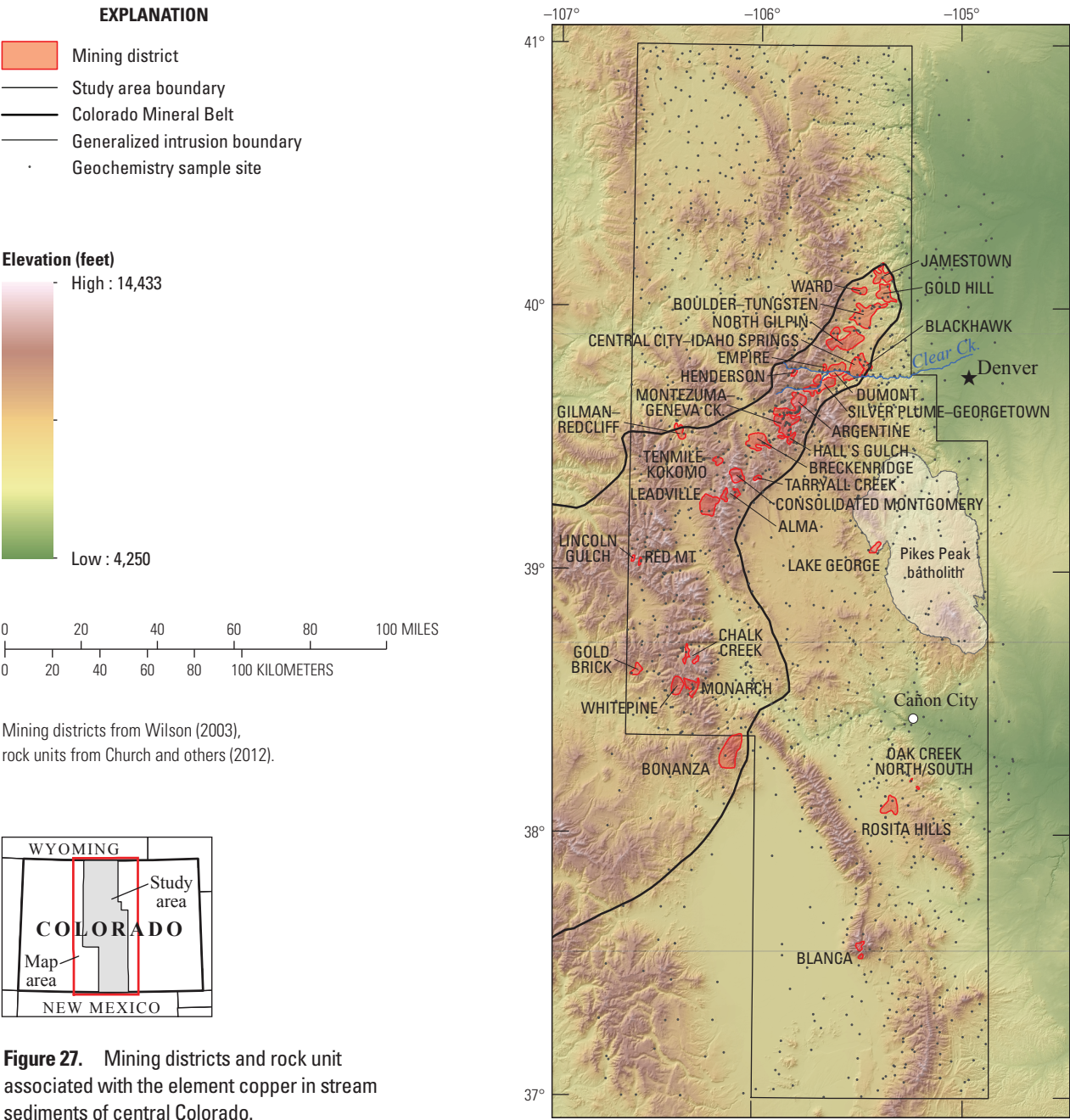


**Figure 26.** Maps of central Colorado stream-sediment geochemistry—copper (Cu). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Copper (Cu) is abundant in mafic igneous rocks where it is present in the minerals pyroxene, amphibole, biotite, and chalcopyrite. Copper can be highly concentrated in hydrothermal sulfide deposits, in bog iron and siderite deposits, pyritic shales, and stratabound sulfide deposits in sedimentary rocks. Copper is mobile during weathering and may be concentrated in manganese- and iron-oxyhydroxide minerals in streams.

Stream-sediment samples with high concentrations of copper (>90th percentile) strongly identify mineralized areas within the entire CMB (figs. 26 and 27). A well-defined dispersion train of samples with high copper concentrations along Clear Creek extends downstream from the Blackhawk and Central City–Idaho Springs districts eastward to the range front. Other mining districts within the Colorado Mineral Belt from which samples bearing high concentrations of copper (>90th percentile) were obtained include the Alma, Argentine, Boulder-Tungsten, Breckenridge, Chalk Creek, Consolidated Montgomery, Dumont, Empire, Gilman-Redcliff, Gold Brick, Gold Hill, Halls Gulch, Henderson, Jamestown, Leadville, Lincoln Gulch, Monarch, Montezuma–Geneva Creek, North Gilpin, Red Mountain, Silver Plume–Georgetown, Tarryall Creek, Tenmile-Kokomo, Ward, and Whitepine districts. South of the mineral belt, high copper concentrations are found in samples from the Blanca, Lake George, Oak Creek, and the Rosita Hills districts. Conversely, stream sediments from samples collected over and near the Pikes Peak batholith are uniformly lower in copper content. Just outside the study area boundary in the southern part of the mineral belt, a single sample containing anomalous copper was obtained from the Bonanza district, where a variety of base-metal ores were mined (Knepper and Marrs, 1971). The same sample is anomalous in Ag, As, Bi, Cd, Cu, Hg, In, Pb, S, Sb, Sn, Te, Tl, W, and Zn. Also, outside the study area and just north of Denver, a sample contains anomalous copper. That sample and a few adjacent samples contain variously anomalous concentrations of As, Bi, Cd, Cu, Hg, Mo, Pb, Sb, and Zn, the same suite of metals found in an in-depth soil study around Denver by Smith and others (2011), who attributed the metals to historical anthropogenic mining-related activities.

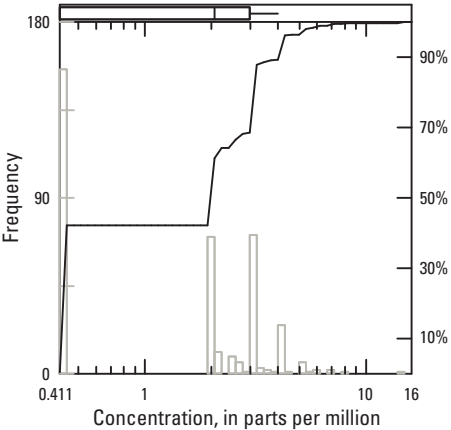


**Figure 27.** Mining districts and rock unit associated with the element copper in stream sediments of central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Europium



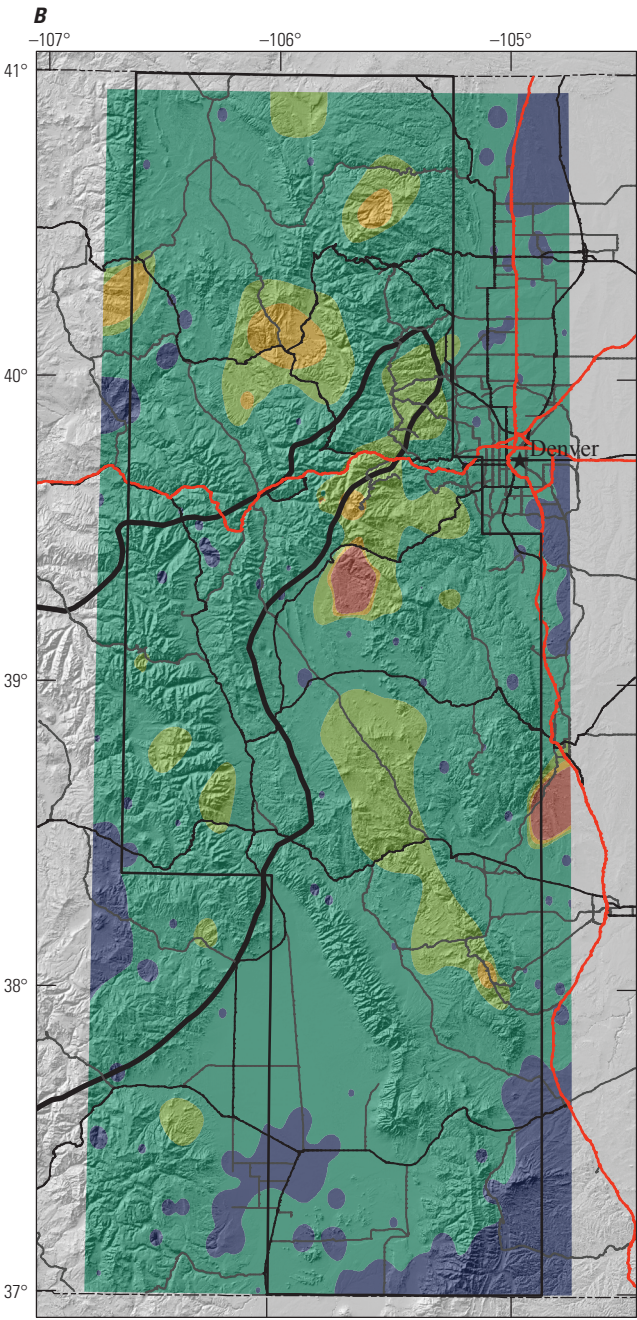
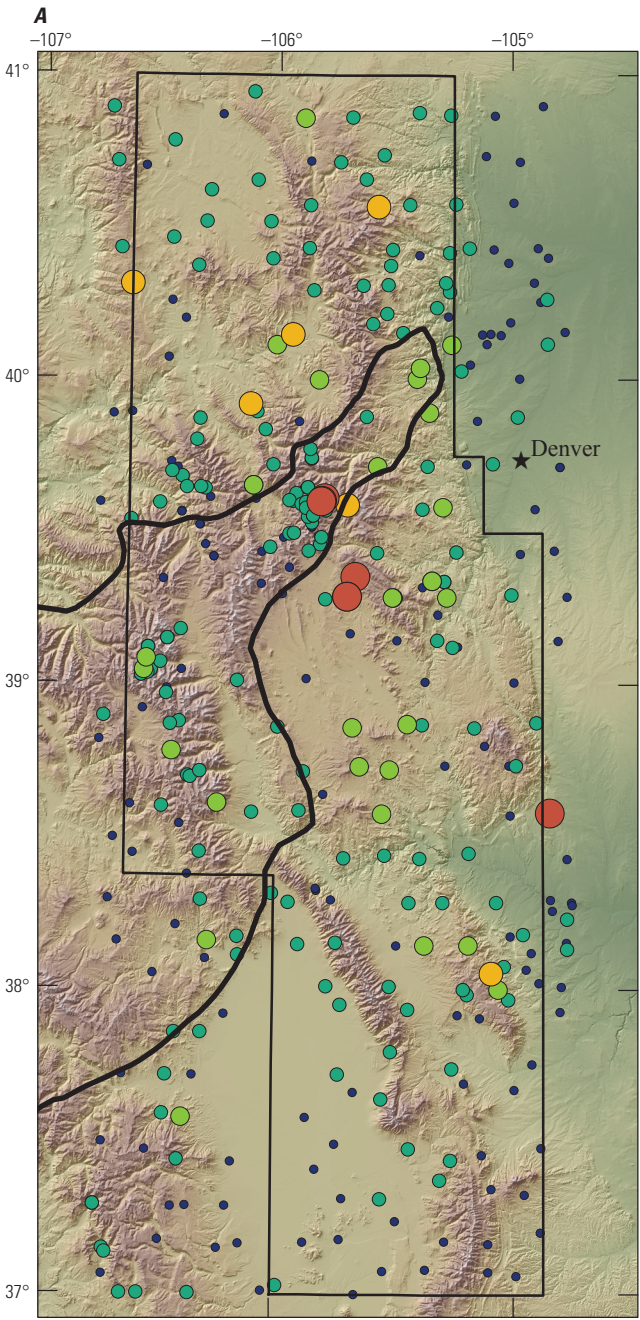
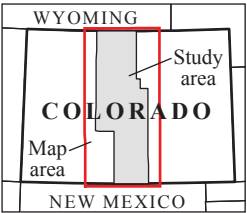
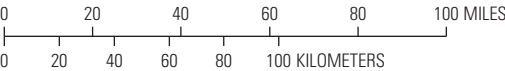
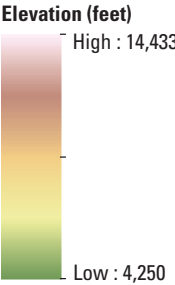
Eu parts per million (ppm)	
Samples:	369
Minimum:	<2
Maximum:	14.0000
Mean:	1.8708
Geometric mean:	1.2366
Median:	2.0000
Mode:	0.4111
Standard deviation:	1.574
Standard error:	0.08196
Skew:	1.784
Kurtosis:	9.01

**Europium** (parts per million)  
Crustal abundance = 2.14 ppm  
Limit of detection = 2 ppm

- <2 ppm (<25th percentile)
- 2.0–3.0 ppm (25–75th percentile)
- 3.1–4.0 ppm (75–90th percentile)
- 4.1–5.0 ppm (90–97.5th percentile)
- 5.1–14 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt



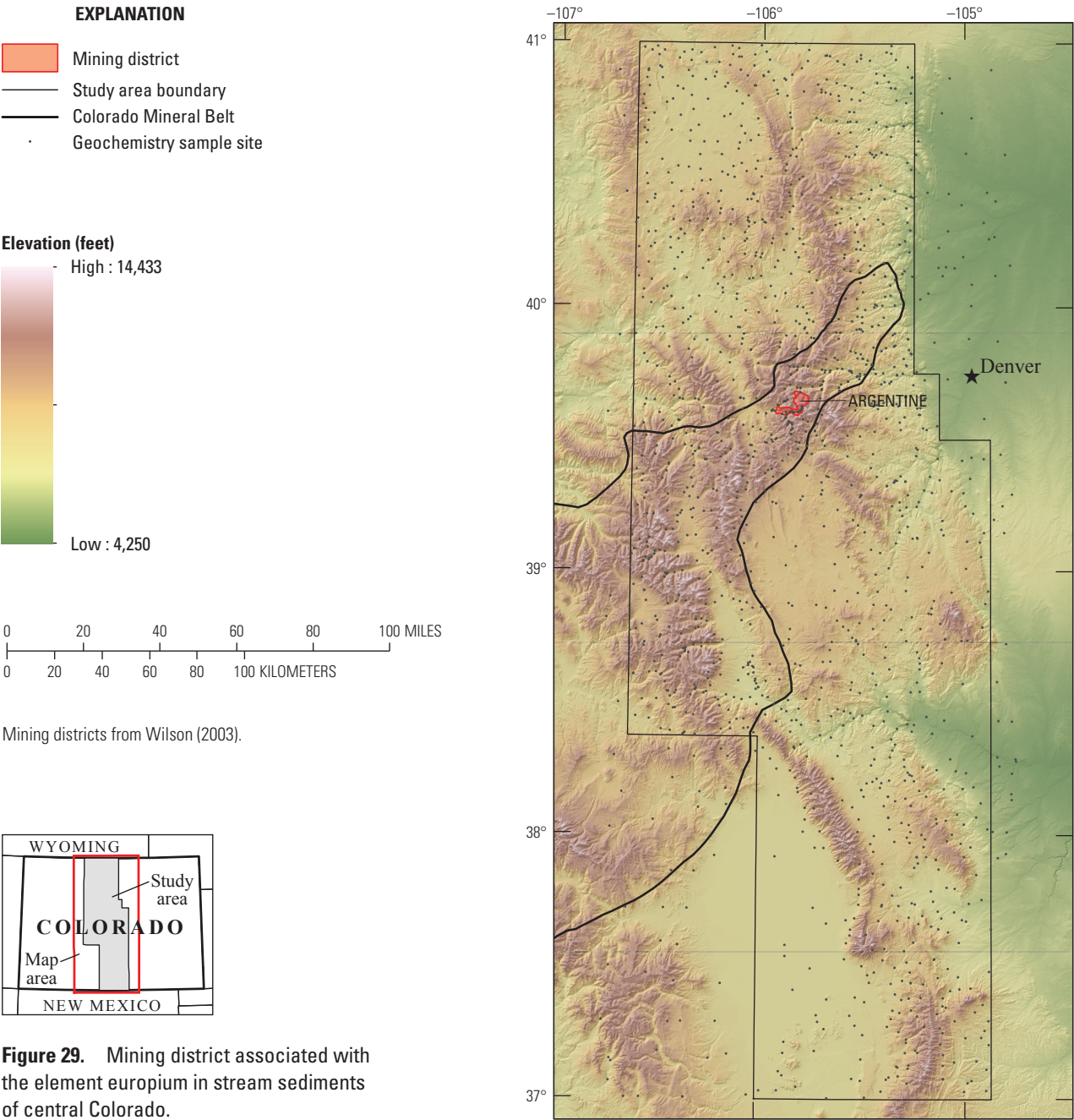
**Figure 28.** Maps of central Colorado stream-sediment geochemistry—europium (Eu).  
(A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



34      **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Europium (Eu) is one of 15 metallic elements called rare earth elements (REEs). The REEs, including europium, are strongly lithophile in igneous rocks. Most REEs, with their large ionic radii and trivalent charge, are concentrated in residual liquids during differentiation and crystallize in trace minerals in evolved rocks. However, because of its divalent rather than trivalent charge and its suitable (smaller) ionic size, europium preferentially substitutes for calcium in early-crystallizing plagioclase. Thus, the remaining REE-bearing melt may be relatively depleted in europium as it crystallizes. See the cerium map (fig. 19) for further discussion on the geochemical behavior of the REEs.

In this study, only a small subset of samples (369 out of 1,479) from the Grossman (1998) and the Church and others (2012) studies were analyzed for europium. Concentrations of europium in the study area (fig. 28) are low overall. The limited number of analyses and the narrow concentration range for europium (2–8 parts per million, single outlier at 14 parts per million) results in this element being a poor discriminator of rock associations. Within the Colorado Mineral Belt, only the Argentine district is associated spatially with samples containing relatively high europium concentrations (figs. 28 and 29). Both within and outside the mineral belt, samples with relatively high europium concentrations also are enriched in Ce, La, and Y. These REE patterns and related geologic associations are better elucidated by maps of Ce, La, and Y, because many more samples ( $n = 1,479$ ) were analyzed for those elements.

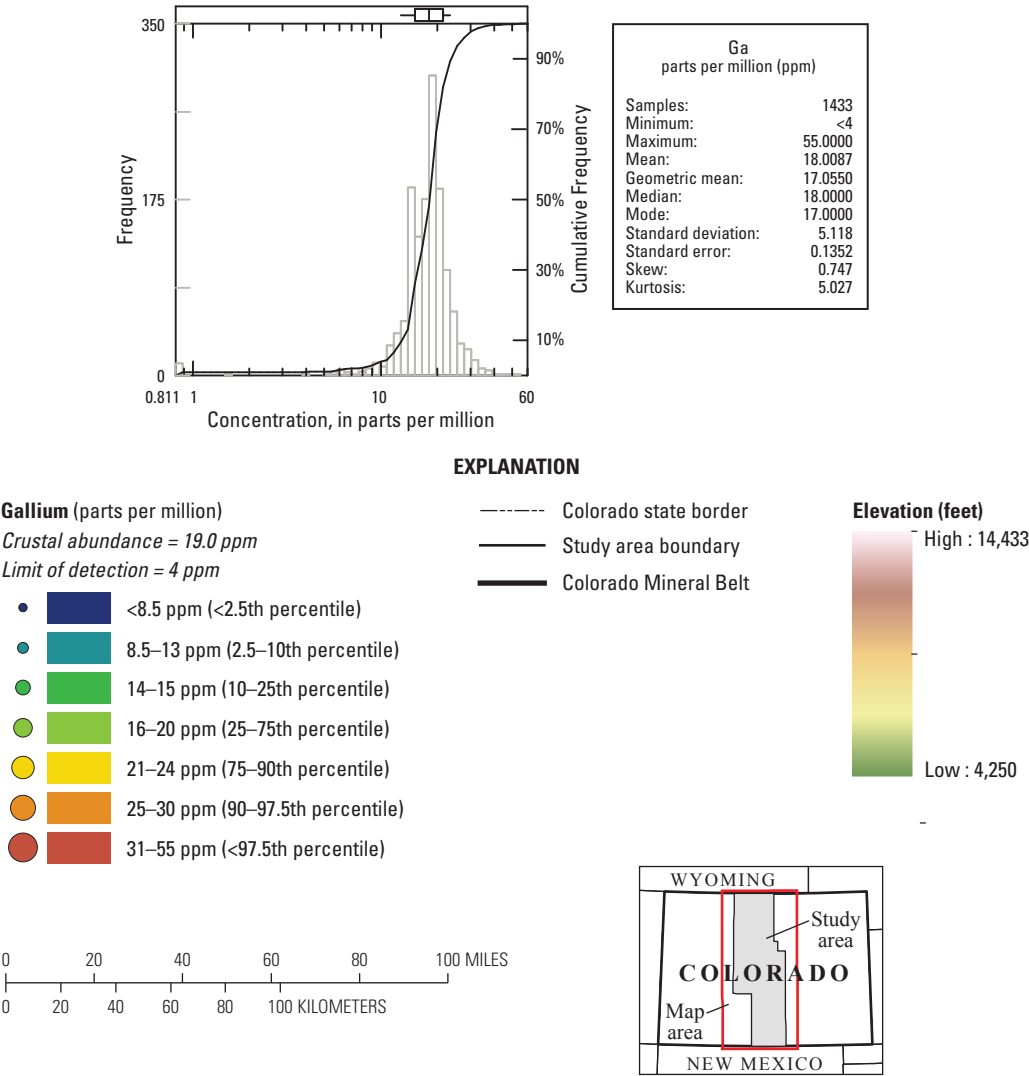


**Figure 29.** Mining district associated with the element europium in stream sediments of central Colorado.

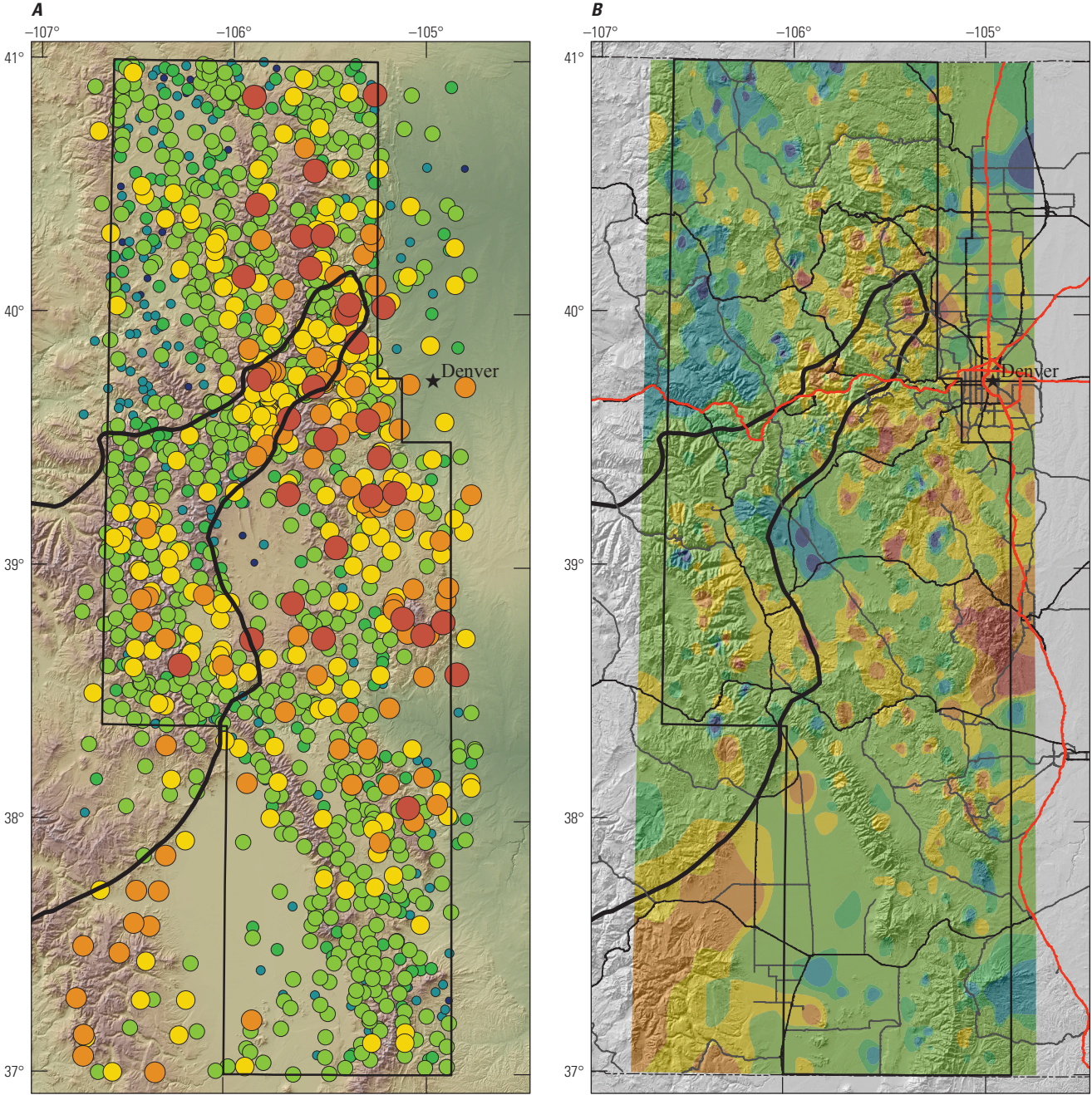




Central Colorado Stream-Sediment  
Geochemistry—Gallium



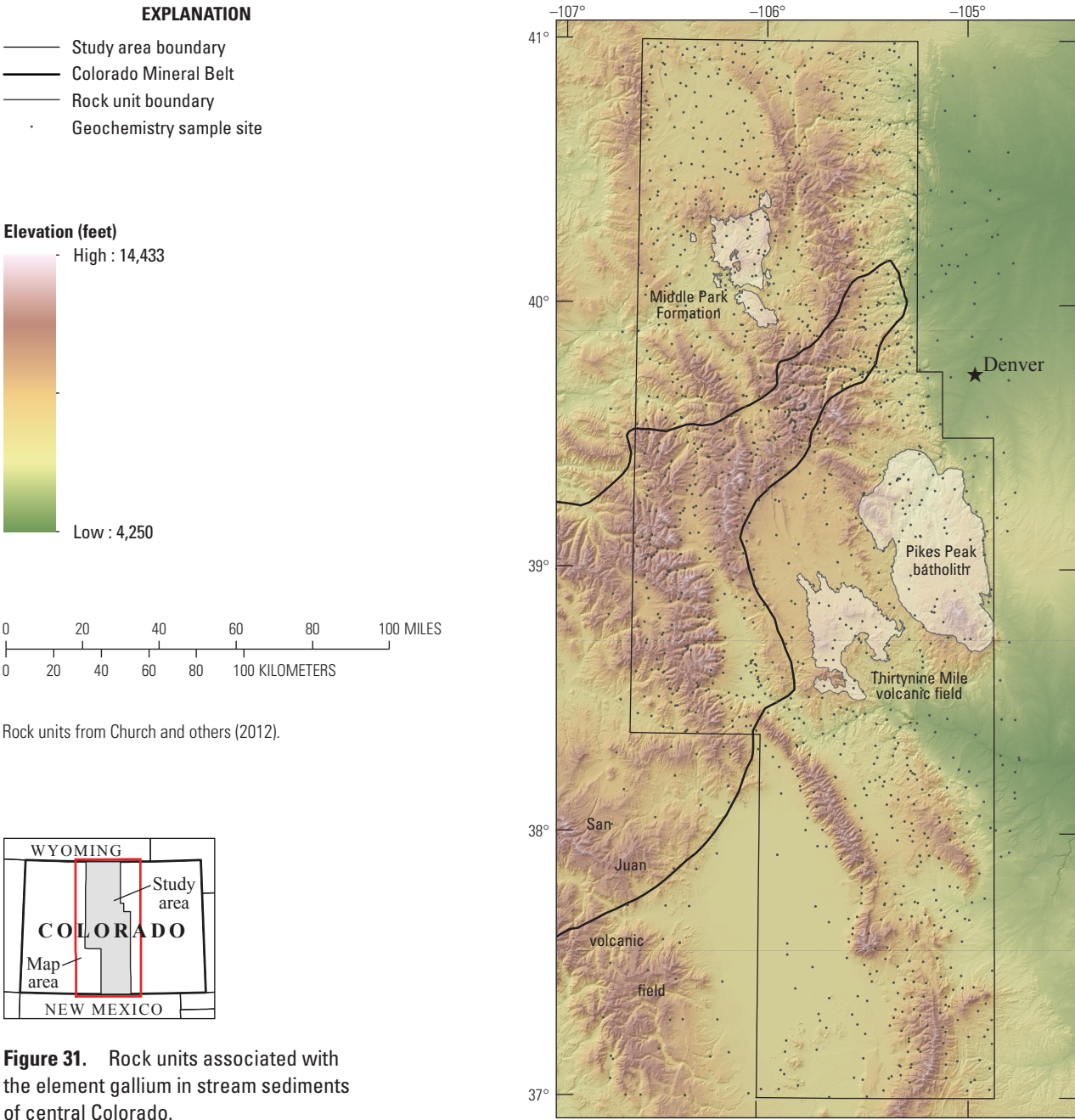
**Figure 30.** Maps of central Colorado stream-sediment geochemistry—gallium (Ga). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Gallium (Ga) in igneous rocks substitutes for aluminum in silicate mineral structures. The highest proportion of aluminum and therefore gallium is found in alkaline and alkali-calcic intermediate rocks. Gallium also may be concentrated in late-stage granite pegmatites. During weathering gallium is concentrated with aluminum in clay minerals.

A general but tenuous correlation links samples containing high gallium concentrations with felsic and intermediate plutonic rocks (figs. 1 and 30). The highest gallium concentrations (90th to >97th percentile) in the study area are associated with stream-sediment samples derived from rocks of the Mesoproterozoic Pikes Peak batholith and many other middle and early Proterozoic granitic and intermediate plutons (figs. 30 and 31). Samples from areas near and overlying the alkali-calcic to alkali-, intermediate to mafic volcanic rocks of the Thirtynine Mile volcanic field, the eastern San Juan volcanic field (just southwest of the study area), and Middle Park show similar gallium concentrations. Those gallium concentrations generally are low to moderate (75th percentile and below) in most sedimentary rocks and associated unconsolidated sediments in the study area.

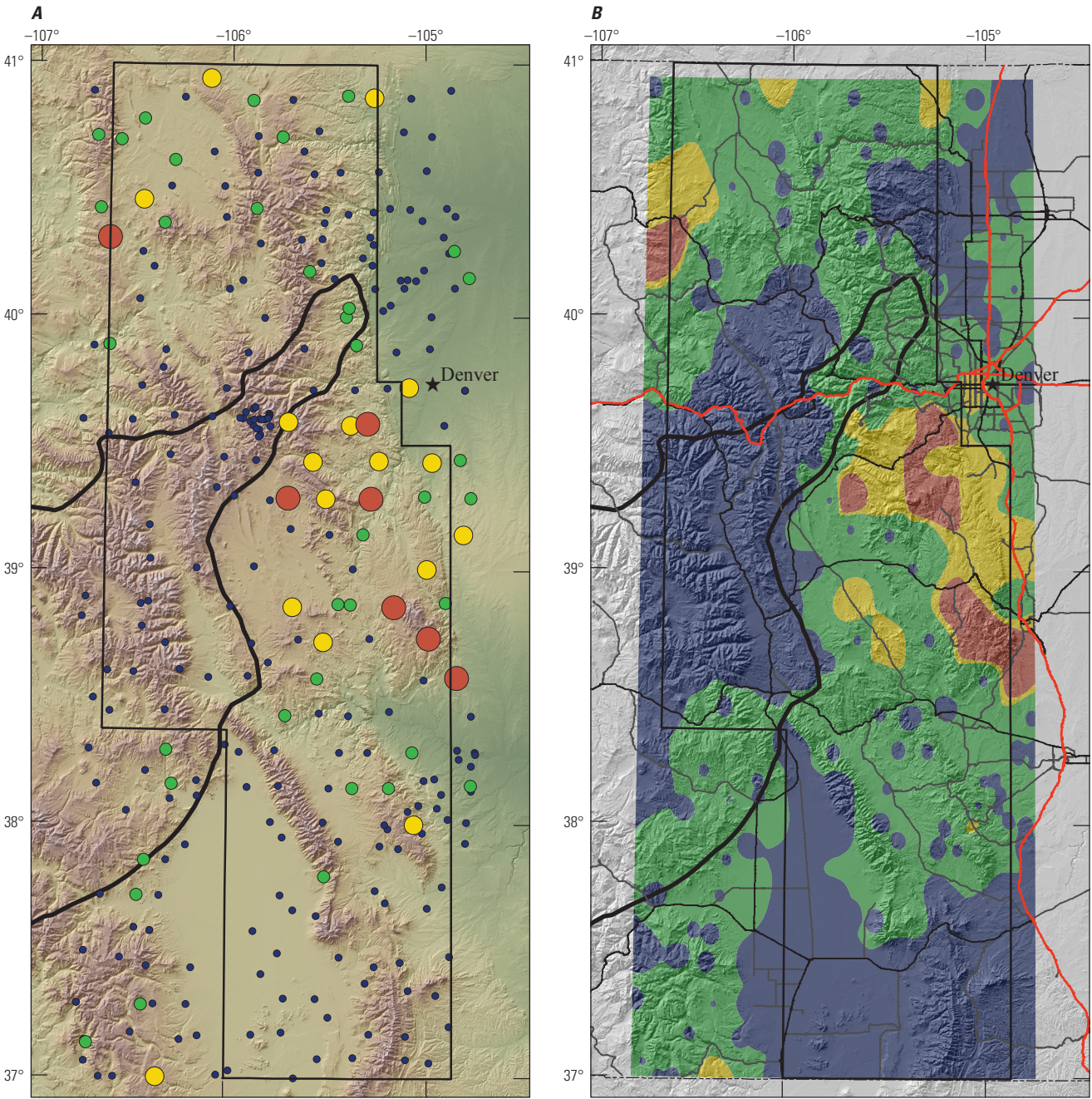
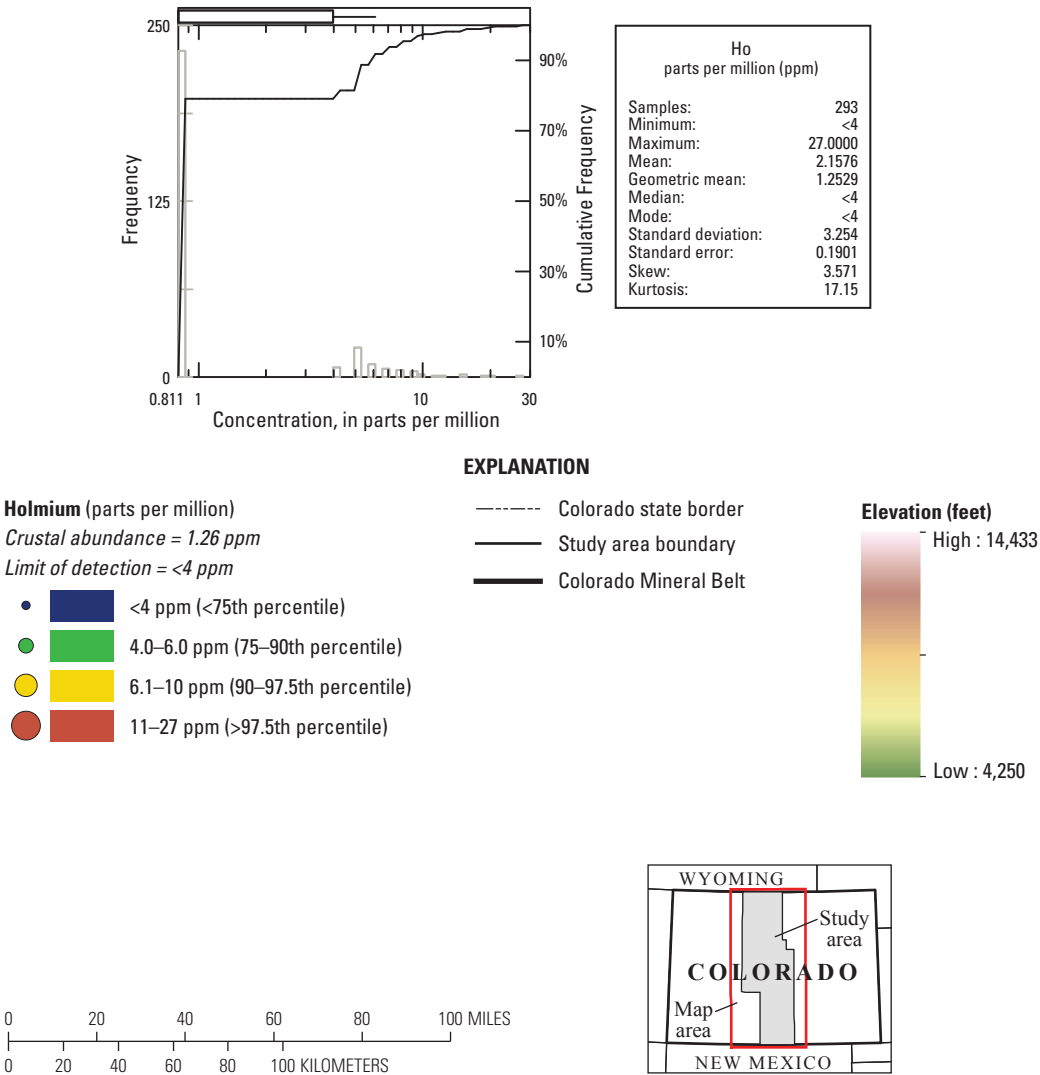


**Figure 31.** Rock units associated with the element gallium in stream sediments of central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Holmium



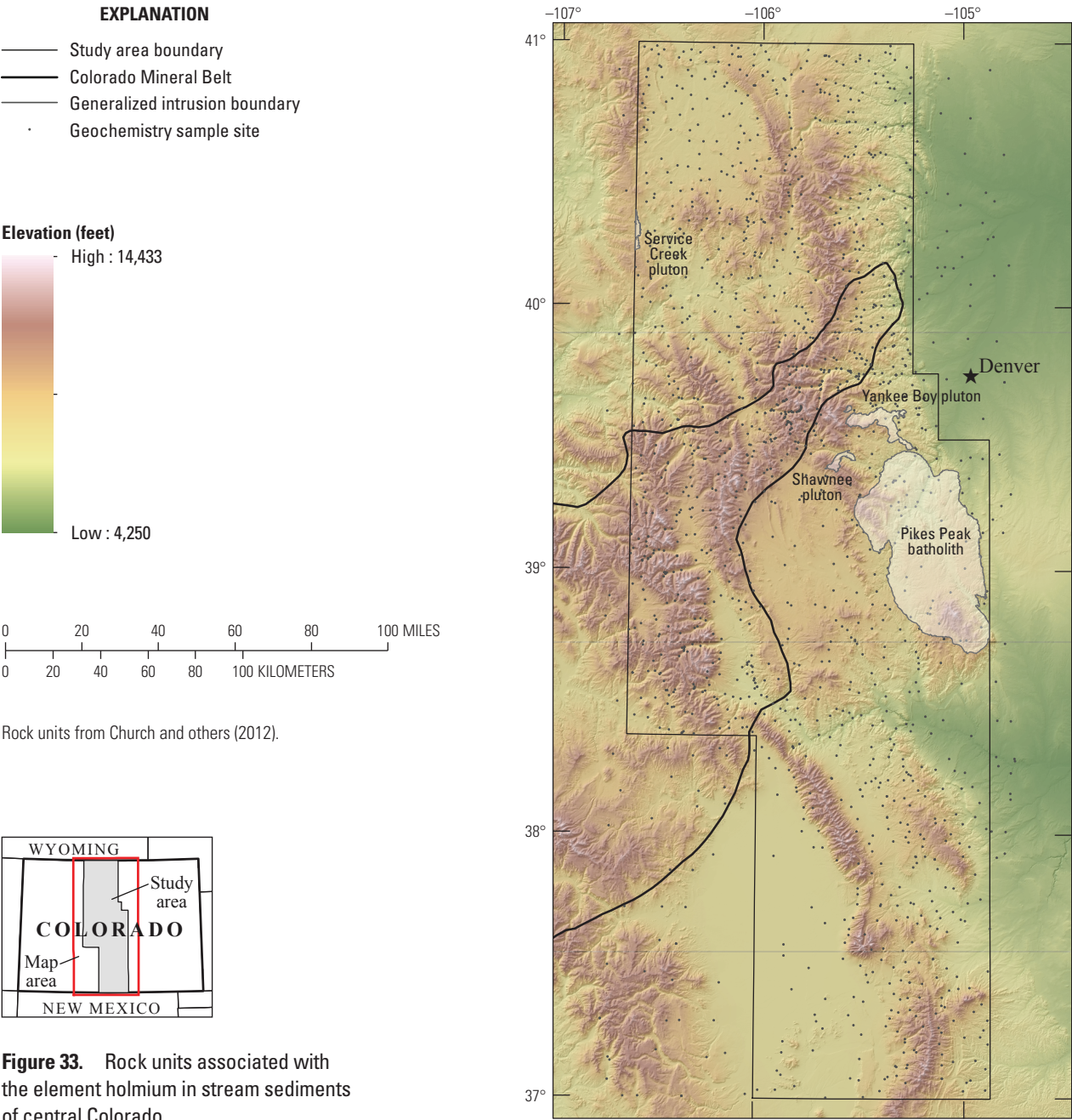
**Figure 32.** Maps of central Colorado stream-sediment geochemistry—holmium (Ho). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



38      **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Holmium (Ho) is one of 15 metallic elements called rare earth elements (REEs). The REEs, including holmium, are strongly lithophile in igneous rocks. See the cerium map (fig. 19) for further discussion on the geochemical behavior of the REEs.

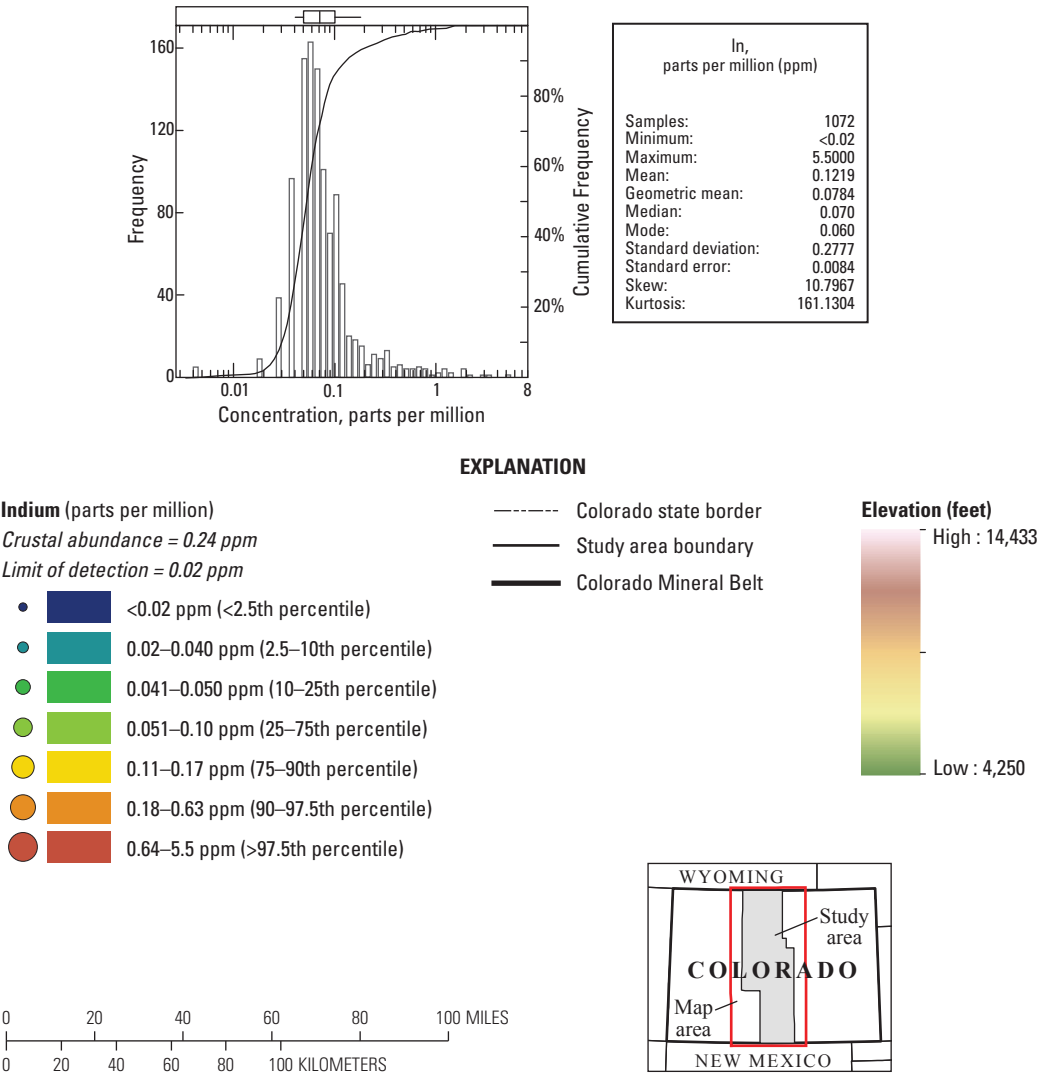
In this study, only a small subset of samples (293 out of 1,479) from the Grossman (1998) study were analyzed for holmium (fig. 32). The highest concentrations of holmium (>90th percentile) are found in samples from the main phase of the Mesoproterozoic Pikes Peak batholith, and in samples overlying the Mesoproterozoic Yankee Boy and Shawnee plutons immediately north of the Pikes Peak batholith; and in addition in one sample from the Paleoproterozoic Service Creek pluton in the Park Range (figs. 32 and 33). Map patterns of samples having relatively high holmium concentrations agree fairly well with patterns for Ce, La, and Y. The REE patterns and related geologic associations are better elucidated by maps of Ce, La, and Y, however, because many more samples ( $n = 1,479$ ) were analyzed for those elements.



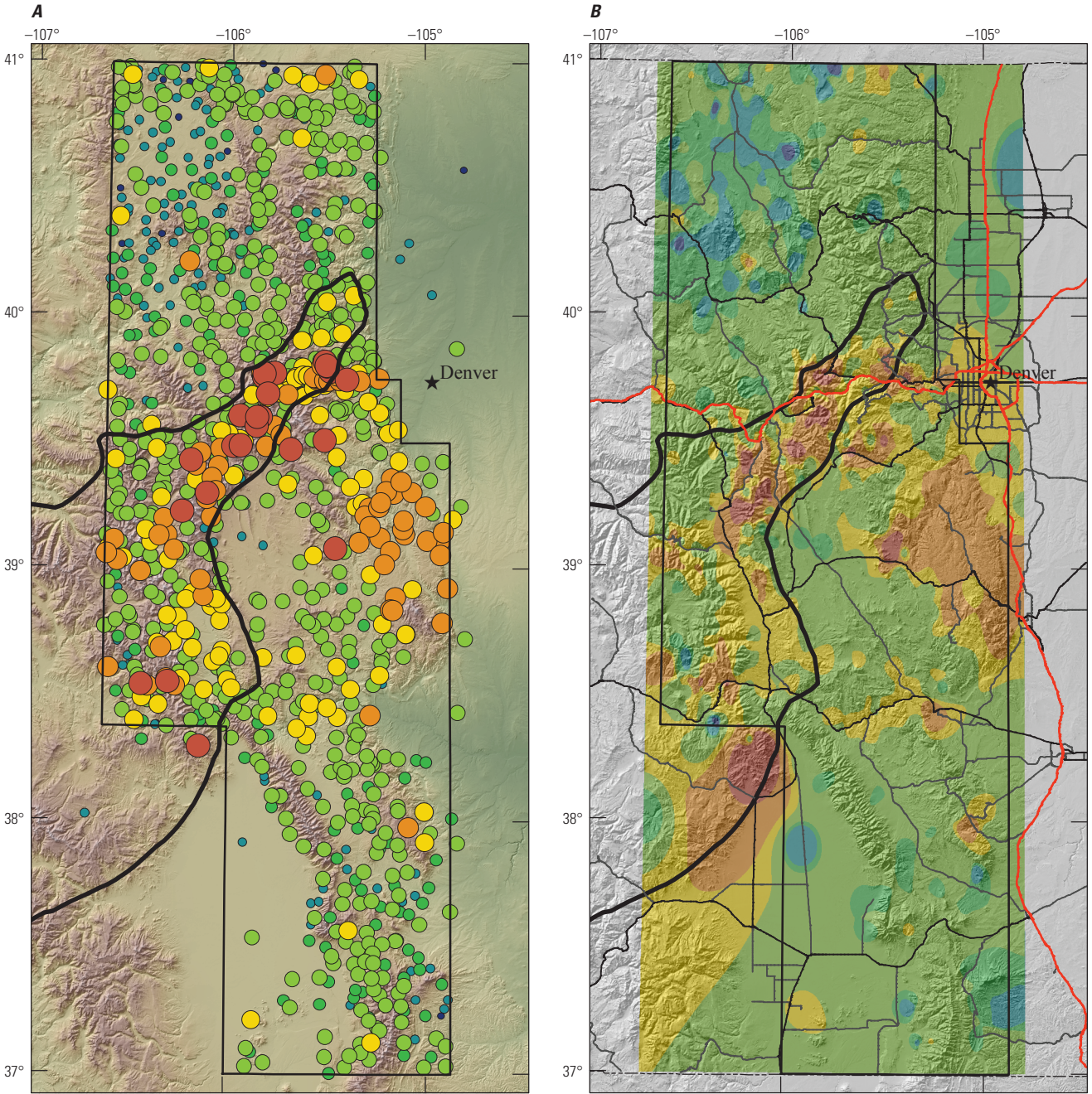




Central Colorado Stream-Sediment  
Geochemistry—Indium



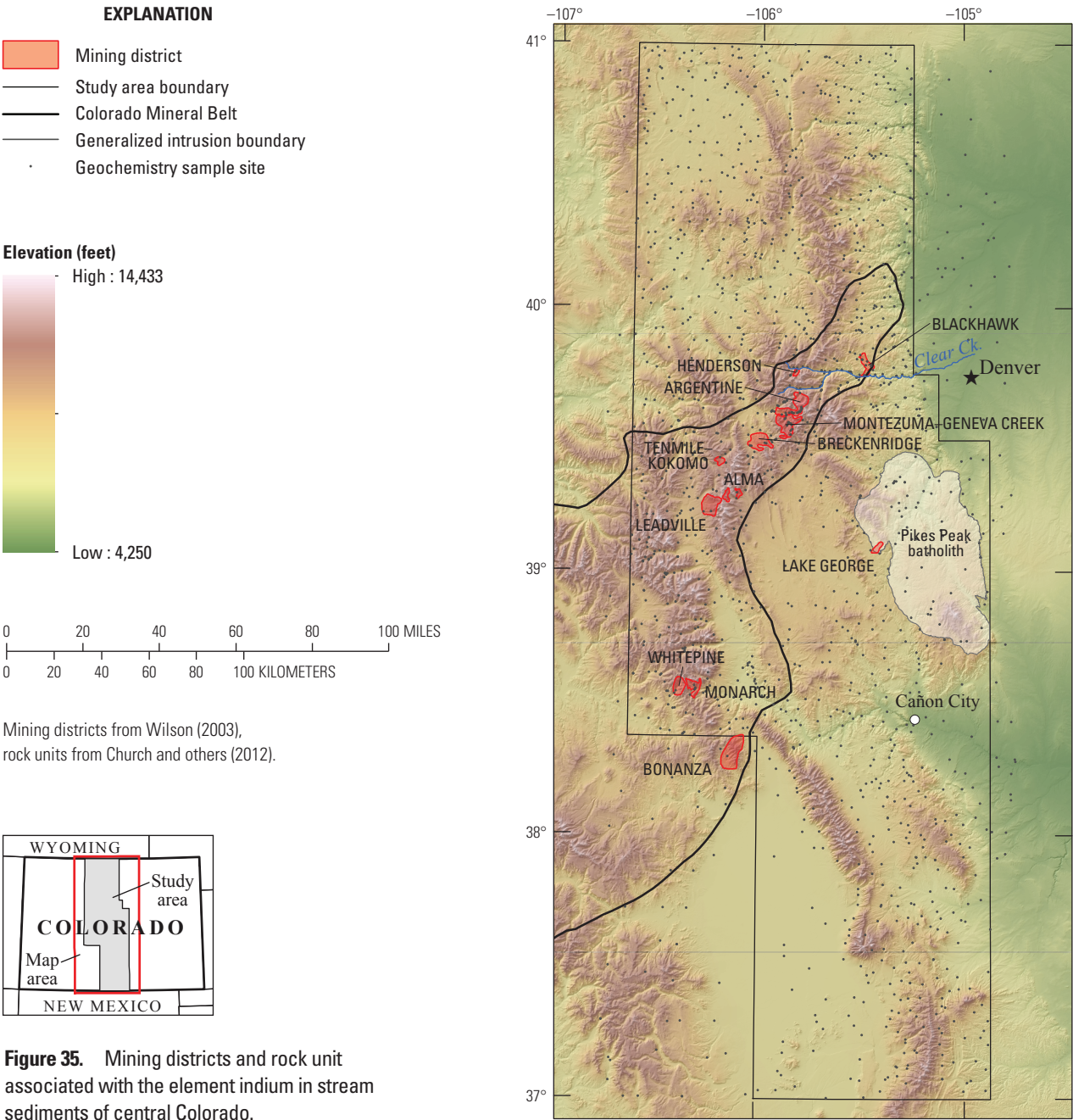
**Figure 34.** Maps of central Colorado stream-sediment geochemistry—indium (In). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Indium (In) is concentrated in late-stage igneous differentiates such as granite pegmatites and greisens and may be concentrated in hydrothermal deposits, primarily in sphalerite. It is also concentrated in some pyritic marine shales. During weathering indium is moderately mobile and may be concentrated in iron and manganese oxyhydroxides and in iron carbonates.

The highest indium (>97.5th percentile) concentrations in the study area are largely confined to stream-sediment samples within the Colorado Mineral Belt and, in general, anomalous indium (90th to 97.5th percentile) either was found in samples from within the mineral belt or in samples overlying the Mesoproterozoic Pikes Peak batholith (figs. 34 and 35). A single sample (>97.5th percentile) from the Lake George district on the western side of the Pikes Peak pluton may be related to a greisen deposit there. A dispersion train of indium from the Blackhawk district down Clear Creek to the range front is evident. Within the mineral belt, clusters of samples with high indium concentrations (>97.5th percentile) also are found in the Alma, Argentine, Breckenridge, Henderson, Leadville, Monarch, Montezuma–Geneva Creek, Tenmile-Kokomo, and Whitepine districts. Just outside the study area boundary in the southern part of the mineral belt, a single sample containing anomalous indium and several other metals came from the Bonanza district (see copper discussion, fig. 27).

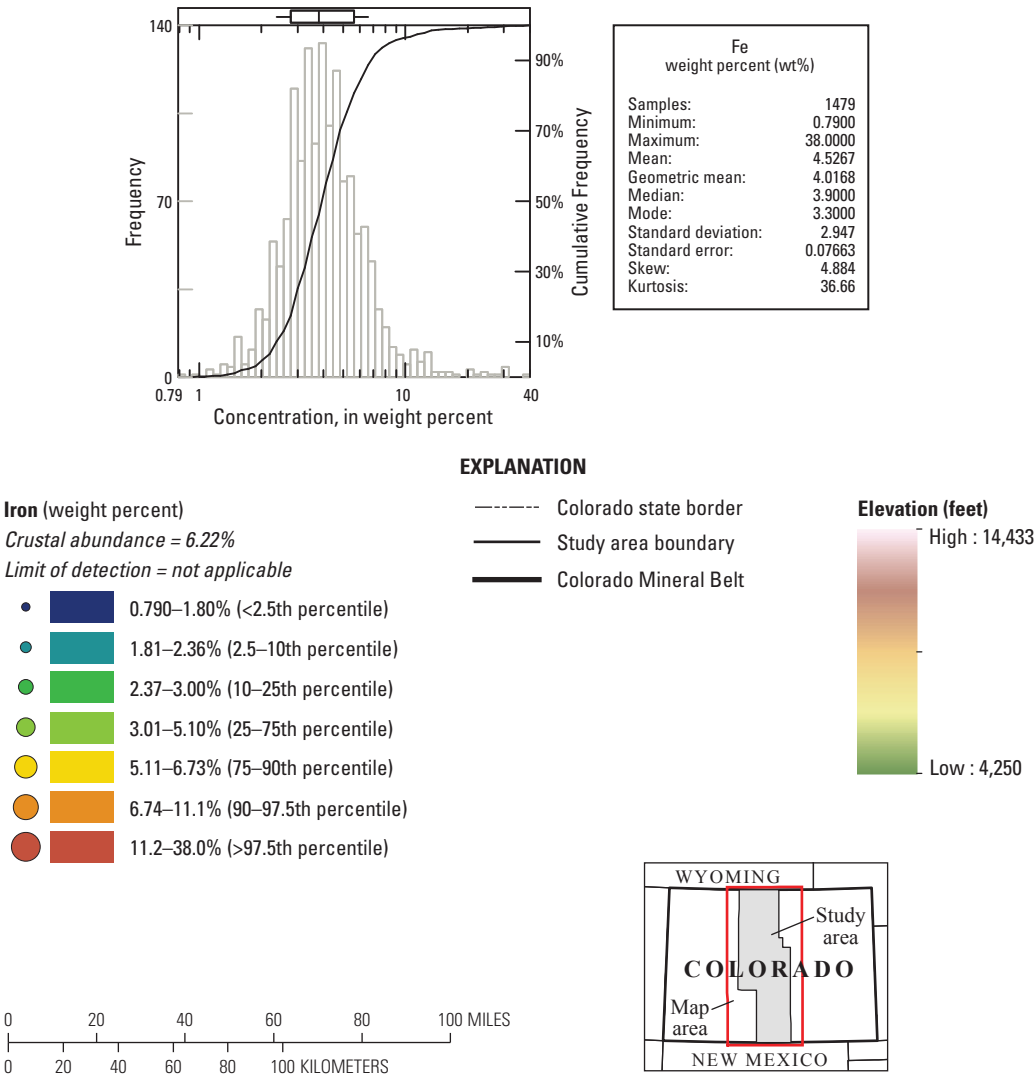


**Figure 35.** Mining districts and rock unit associated with the element indium in stream sediments of central Colorado.

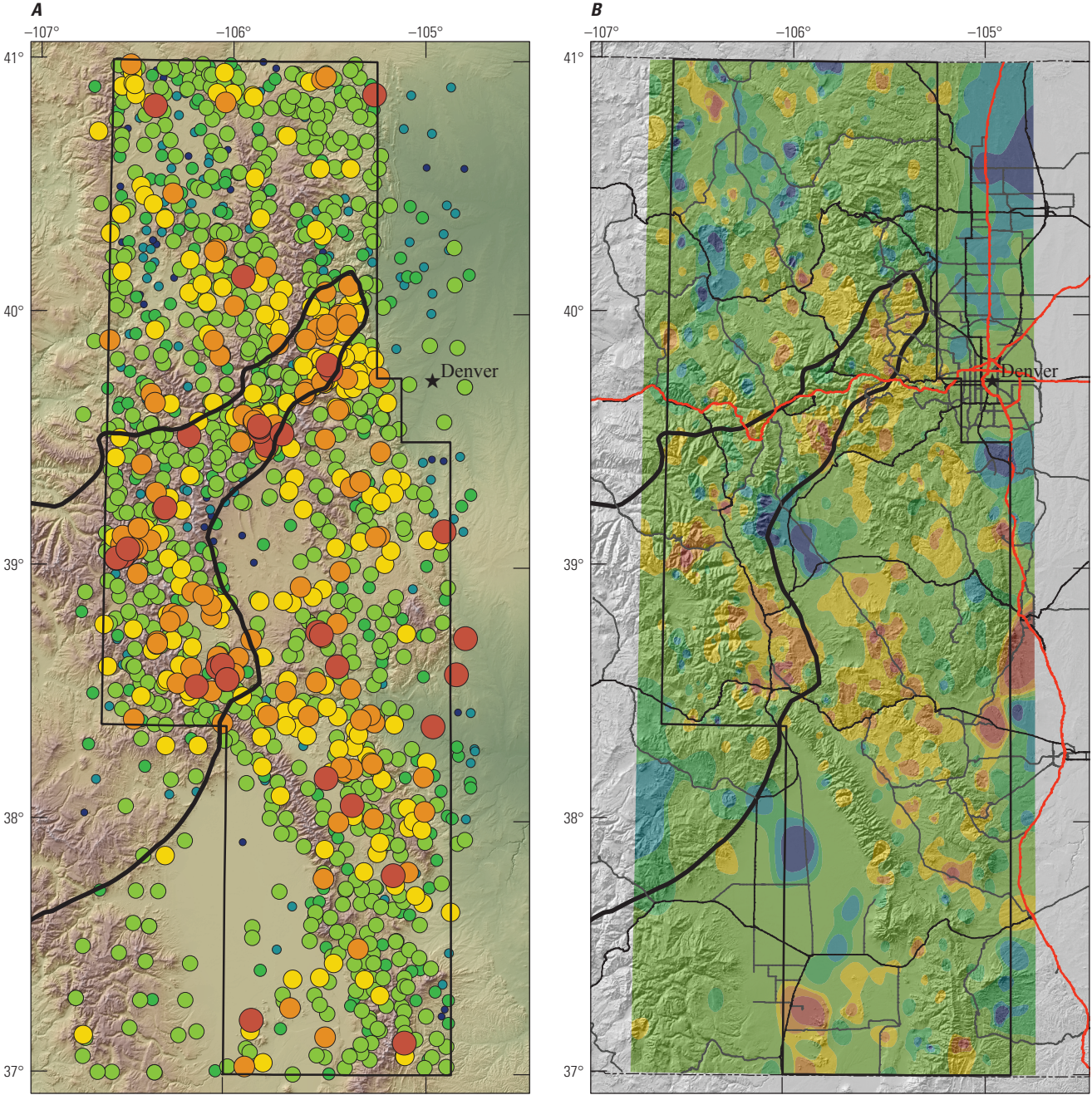




Central Colorado Stream-Sediment  
Geochemistry—Iron



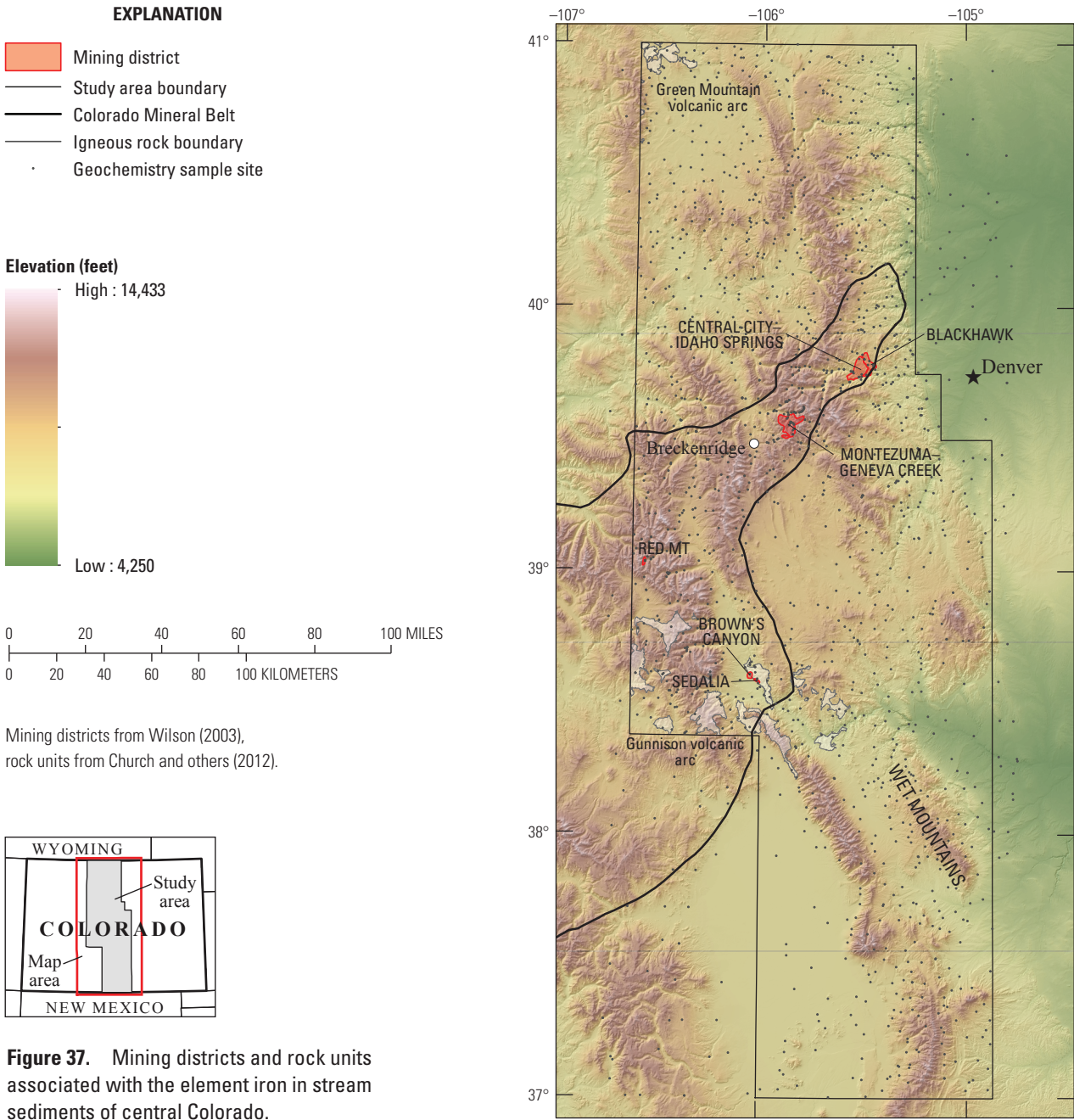
**Figure 36.** Maps of central Colorado stream-sediment geochemistry—iron (Fe). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Iron (Fe) content of rocks is highest in mafic and ultramafic igneous rocks, iron formations, and ironstone. In the secondary environment, iron is weathered easily from many silicate and sulfide minerals and is readily transported in acidic, reduced groundwater and in surface water. It is precipitated from groundwater and surface water by oxidation.

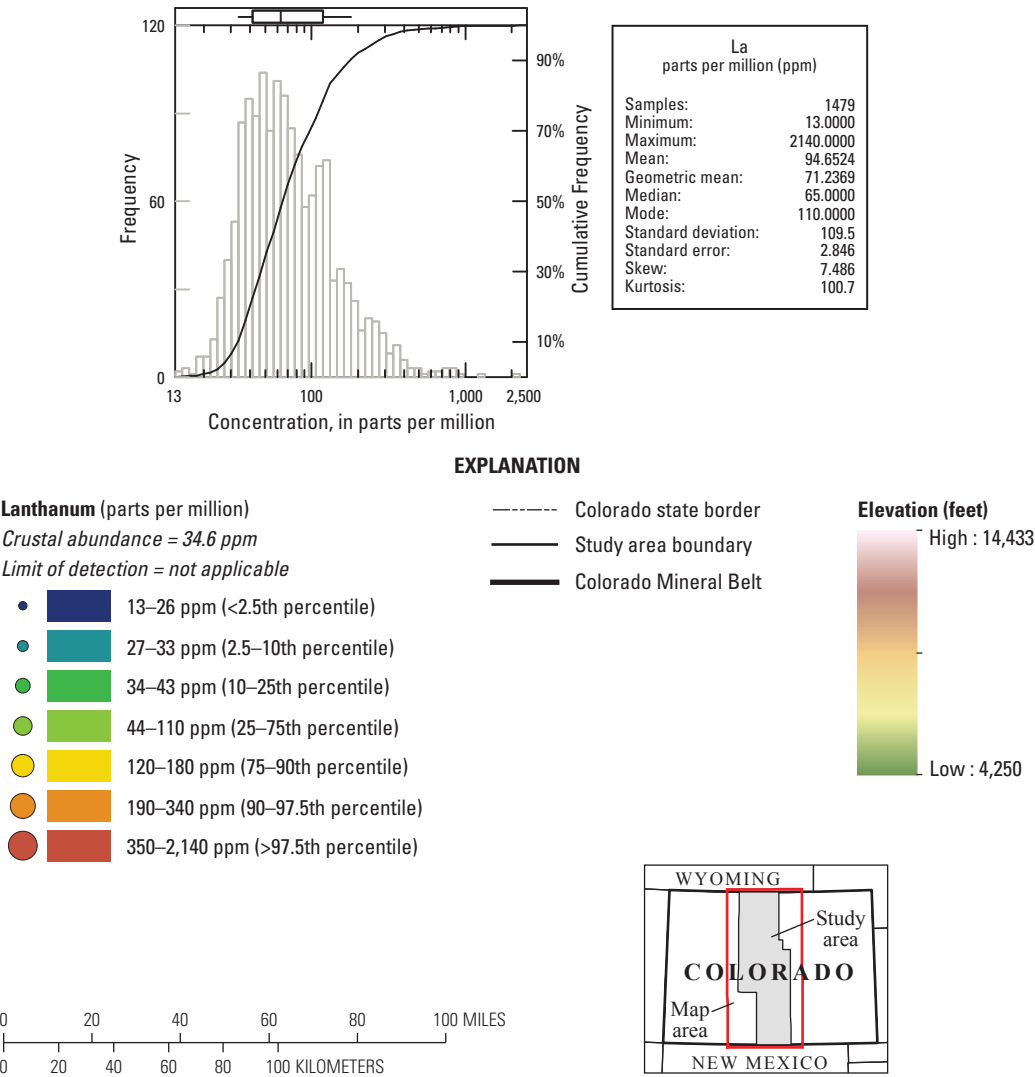
High iron concentrations (>90th percentile) identify scattered stream-sediment samples obtained throughout the Colorado Mineral Belt; four strong clusters (>97.5th percentile) of samples lie over the Blackhawk, Browns Canyon, Central City–Idaho Springs, Montezuma–Geneva Creek, Red Mountain, and Sedalia districts (figs. 36 and 37). Samples having lower iron concentrations (75th to >97.5th percentile) are common in the mafic and ultramafic metavolcanic rocks that are part of the Proterozoic volcanic rocks of the Gunnison volcanic arc and the northern Wet Mountains in the central part of the study area, in the Green Mountain volcanic arc in the far northern part of the study area, and in the mafic metavolcanic and metagabbroic enclave near Swandyke (east of Breckenridge).



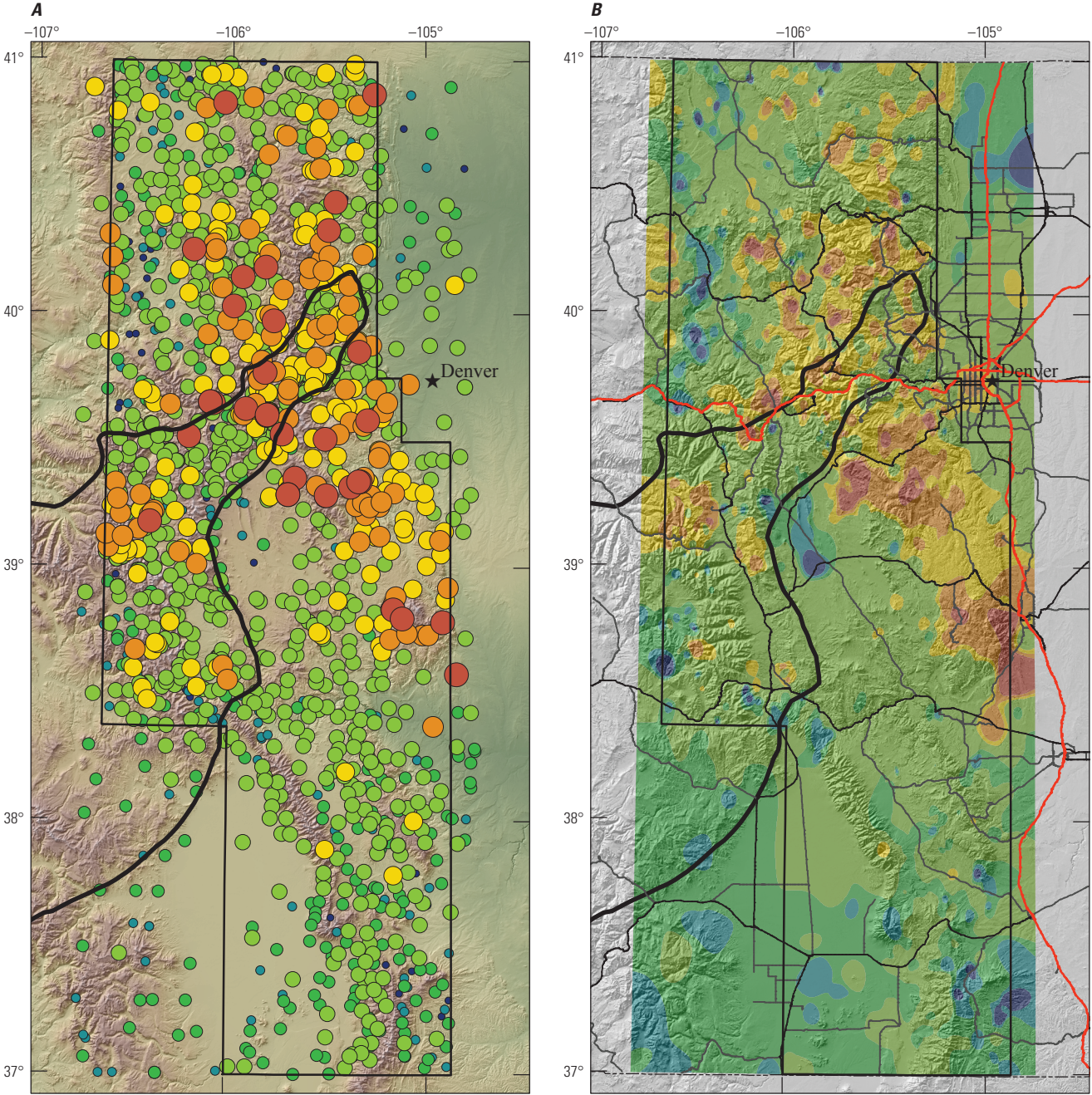




Central Colorado Stream-Sediment  
Geochemistry—Lanthanum



**Figure 38.** Maps of central Colorado stream-sediment geochemistry—lanthanum (La). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.

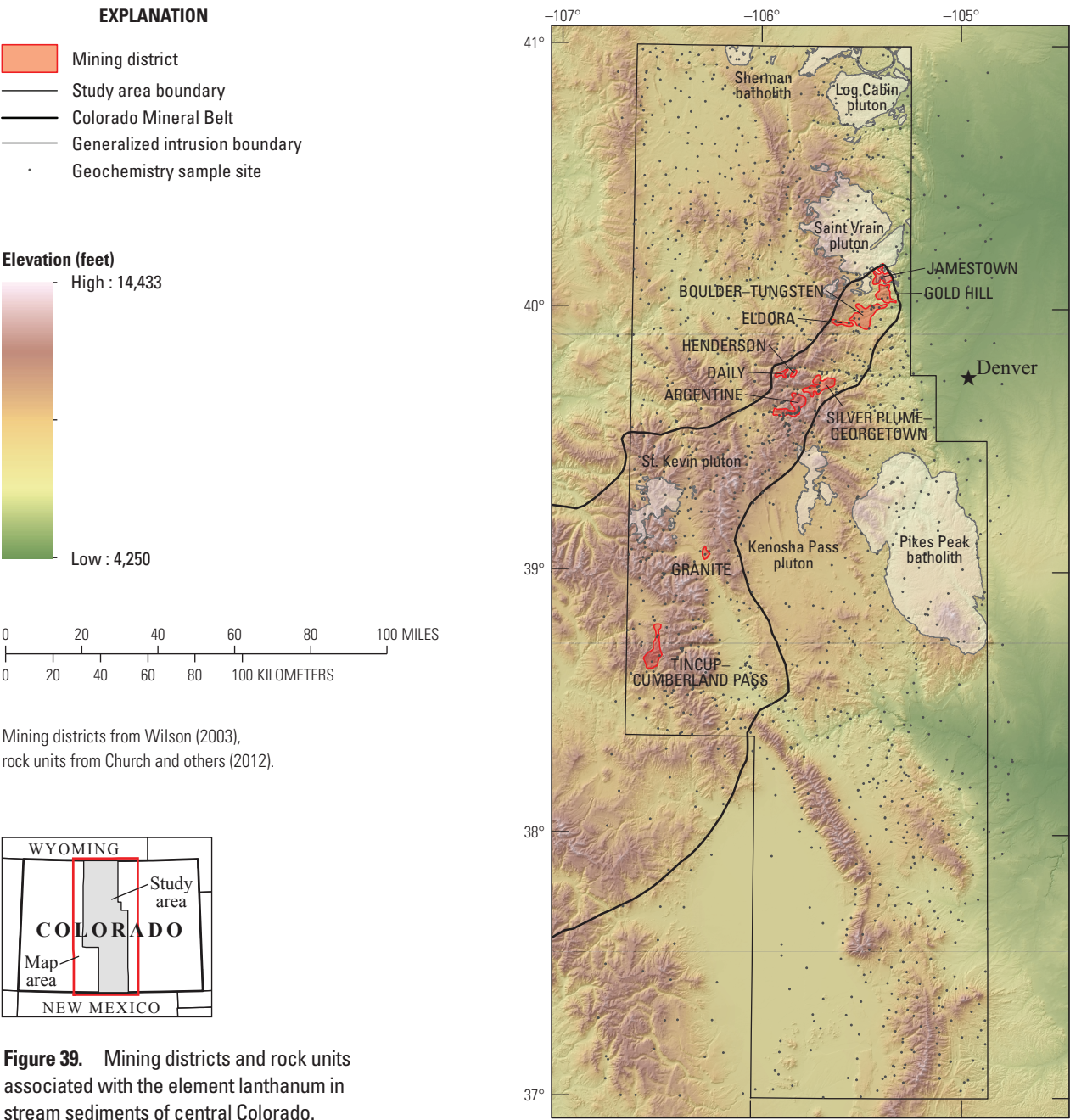




44     **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Lanthanum (La) is one of 15 metallic elements called rare earth elements (REEs). The REEs, including lanthanum, are strongly lithophile in igneous rocks. See the cerium map (fig. 19) for further discussion on the geochemical behavior of the REEs.

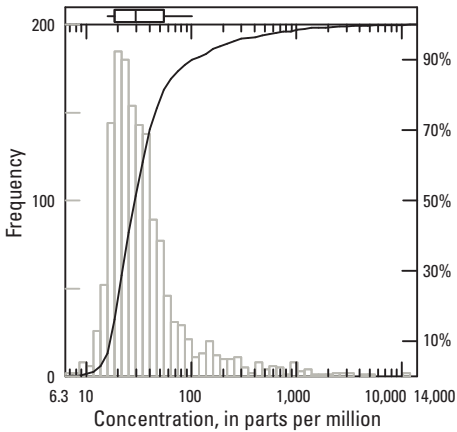
Highest concentrations of lanthanum (>90th percentile) are found in stream-sediment samples obtained from over the main phase of the Mesoproterozoic Pikes Peak batholith and in samples from sites underlain by various felsic igneous intrusions from Precambrian to Tertiary in age (figs. 38 and 39). Samples from over Mesoproterozoic felsic igneous rocks in the northern two-thirds of the study area, including the Pikes Peak and Sherman batholiths and the Kenosha Pass, St. Vrain, St. Kevin, and Log Cabin plutons show consistently high La concentrations. In contrast, samples derived from plutons of similar age and composition in the southern one-third have relatively lower La concentrations, generally in the 25th to 75th percentile range. Mining districts spatially associated with samples having high concentrations of lanthanum (>90th percentile) all are located in the Colorado Mineral Belt and include the Argentine, Boulder-Tungsten, Daily, Eldora, Gold Hill, Granite, Henderson, Jamestown, Silver Plume–Georgetown, and Tincup–Cumberland Pass districts.







Central Colorado Stream-Sediment  
Geochemistry—Lead



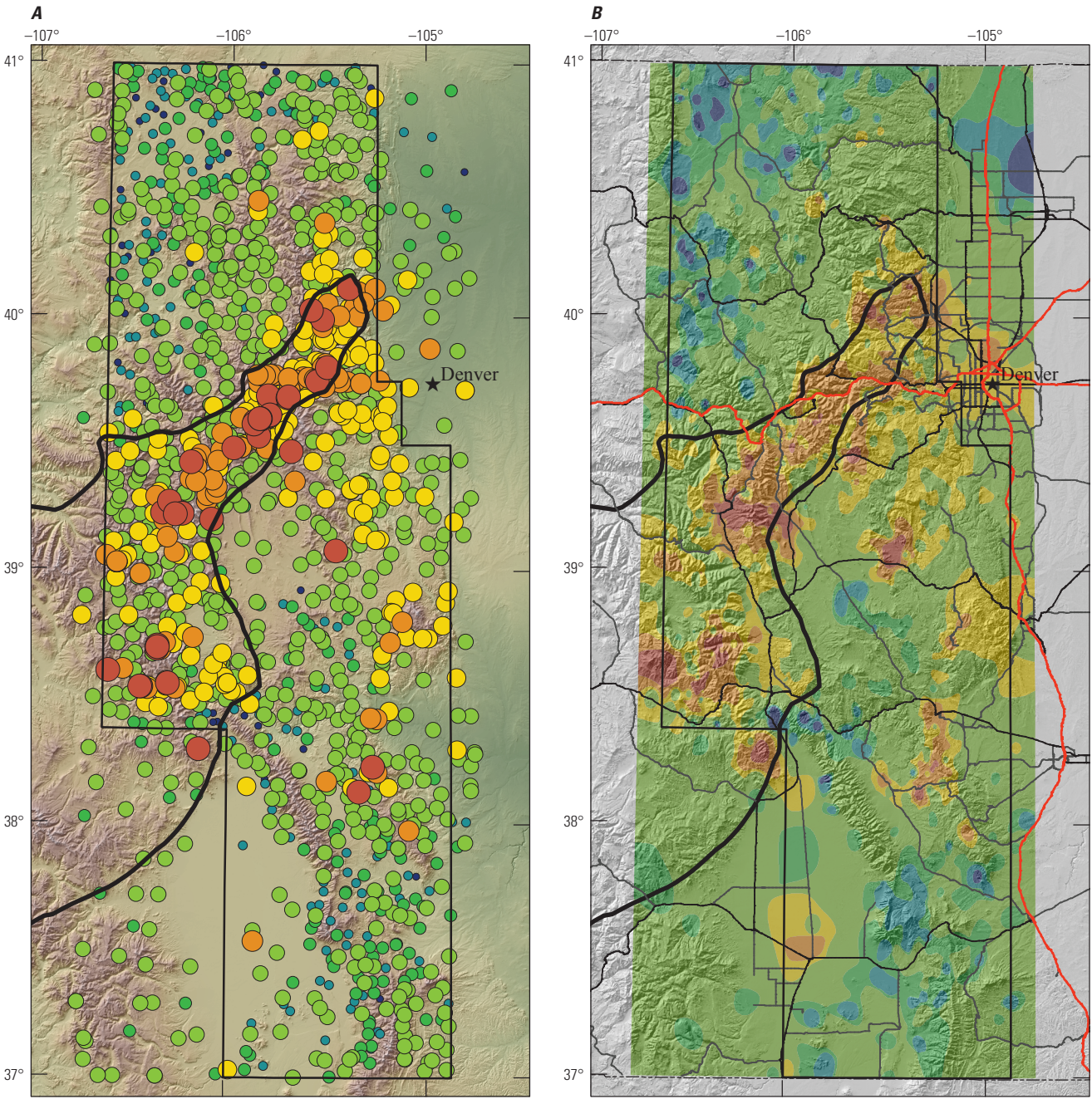
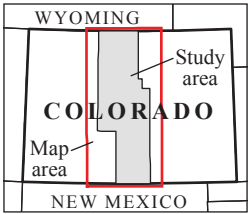
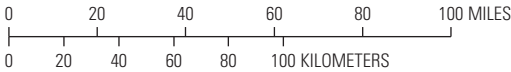
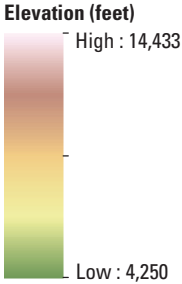
Pb parts per million (ppm)	
Samples:	1479
Minimum:	6.3000
Maximum:	12000.0000
Mean:	97.8688
Geometric mean:	36.1246
Median:	29.0000
Mode:	19.0000
Standard deviation:	513.4
Standard error:	13.35
Skew:	16.88
Kurtosis:	345.2

**Lead** (parts per million)  
Crustal abundance = 13.0 ppm  
Limit of detection = not applicable

- 6.3–13 ppm (<2.5th percentile)
- 14–17 ppm (2.5–10th percentile)
- 18–20 ppm (10–25th percentile)
- 21–45 ppm (25–75th percentile)
- 46–100 ppm (75–90th percentile)
- 110–600 ppm (90–97.5th percentile)
- 610–12,000 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

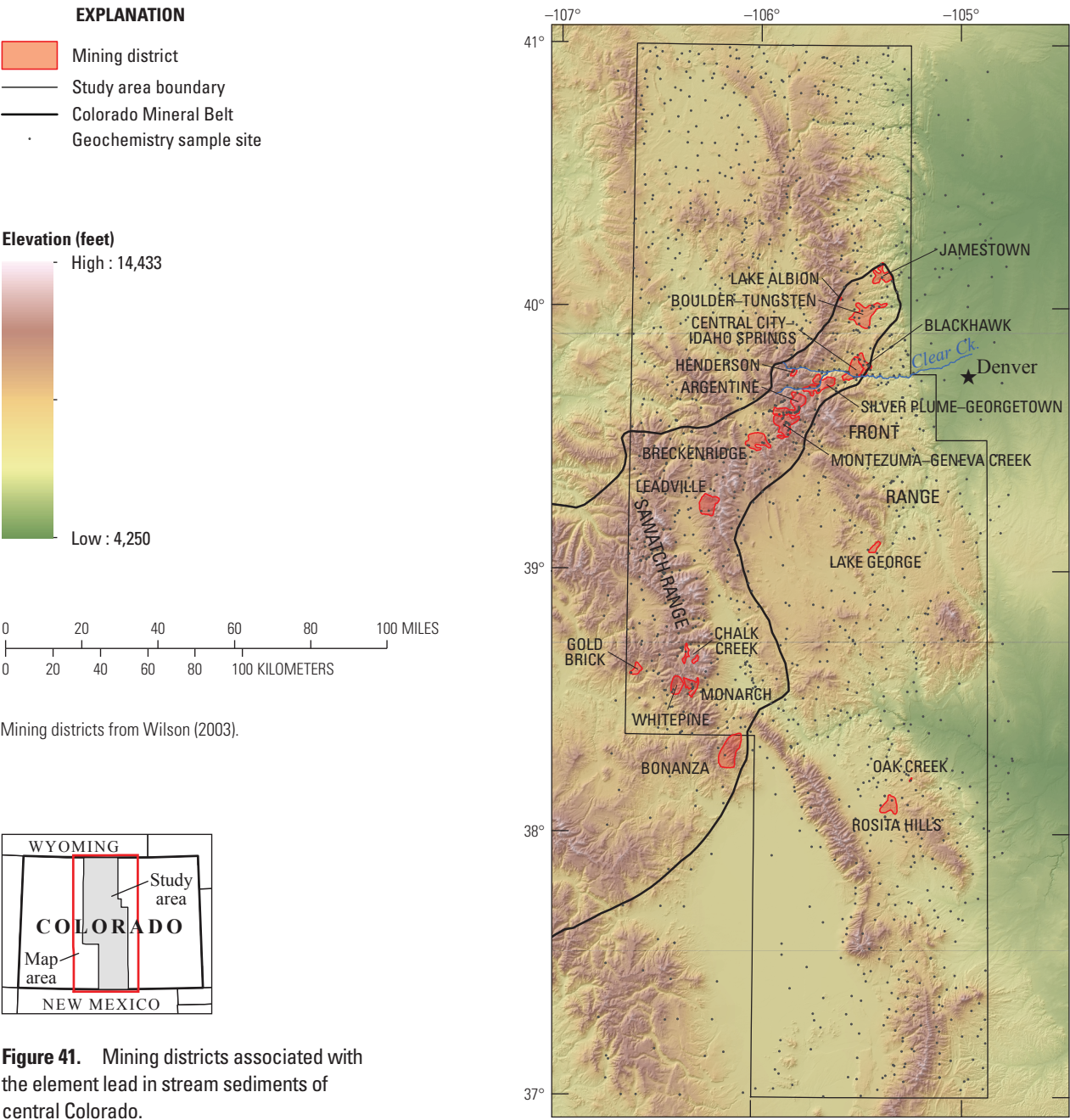


**Figure 40.** Maps of central Colorado stream-sediment geochemistry—lead (Pb).  
(A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Lead (Pb) substitutions are common in potassium feldspar, and lead is more abundant in granitic than in mafic rocks. Because lead substitutes for calcium and strontium at low temperatures, it becomes slightly more abundant in some carbonate rocks. Lead is found in many hydrothermal sulfide deposits as galena or with other base metals in complex sulfide minerals such as tetrahedrite. Weathering products, anglesite and cerussite, commonly are formed over primary hydrothermal deposits and are relatively insoluble.

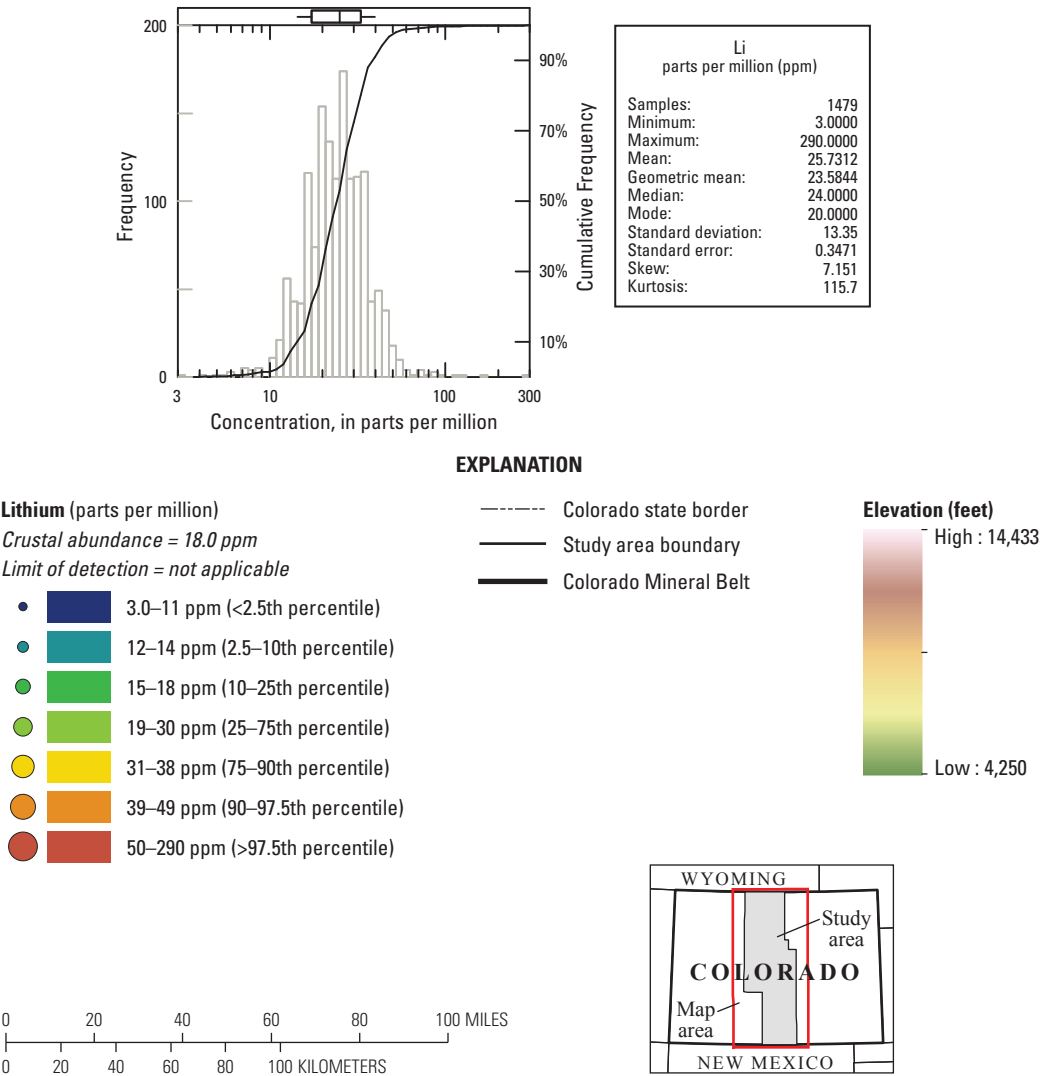
Stream-sediment samples with high lead concentrations (>90th percentile) are almost exclusively confined to the Colorado Mineral Belt. Dispersion trains along Clear Creek from the Henderson district eastward to the range front are evident (figs. 40 and 41). Clusters of samples with high lead concentrations (>97.5th percentile) are associated with the Argentine, Leadville (two samples >1% Pb), and Montezuma–Geneva Creek districts. Isolated samples with high lead concentrations (>97.5th percentile) were obtained in the Blackhawk, Bonanza, Boulder-Tungsten, Breckenridge, Central City–Idaho Springs, Chalk Creek, Gold Brick, Jamestown, Lake Albion, Lake George, Monarch, Oak Creek, Rosita Hills, Silver Plume–Georgetown, and Whitepine districts. Samples with moderate lead concentrations (75th to 90th percentile) commonly overlie many of the potassium feldspar–bearing granitic plutons in the study area, as seen in the southern Front Range and the Sawatch Range. Isolated samples obtained near Denver that contain elevated lead concentrations are described in the discussion of copper (figs. 26 and 27).



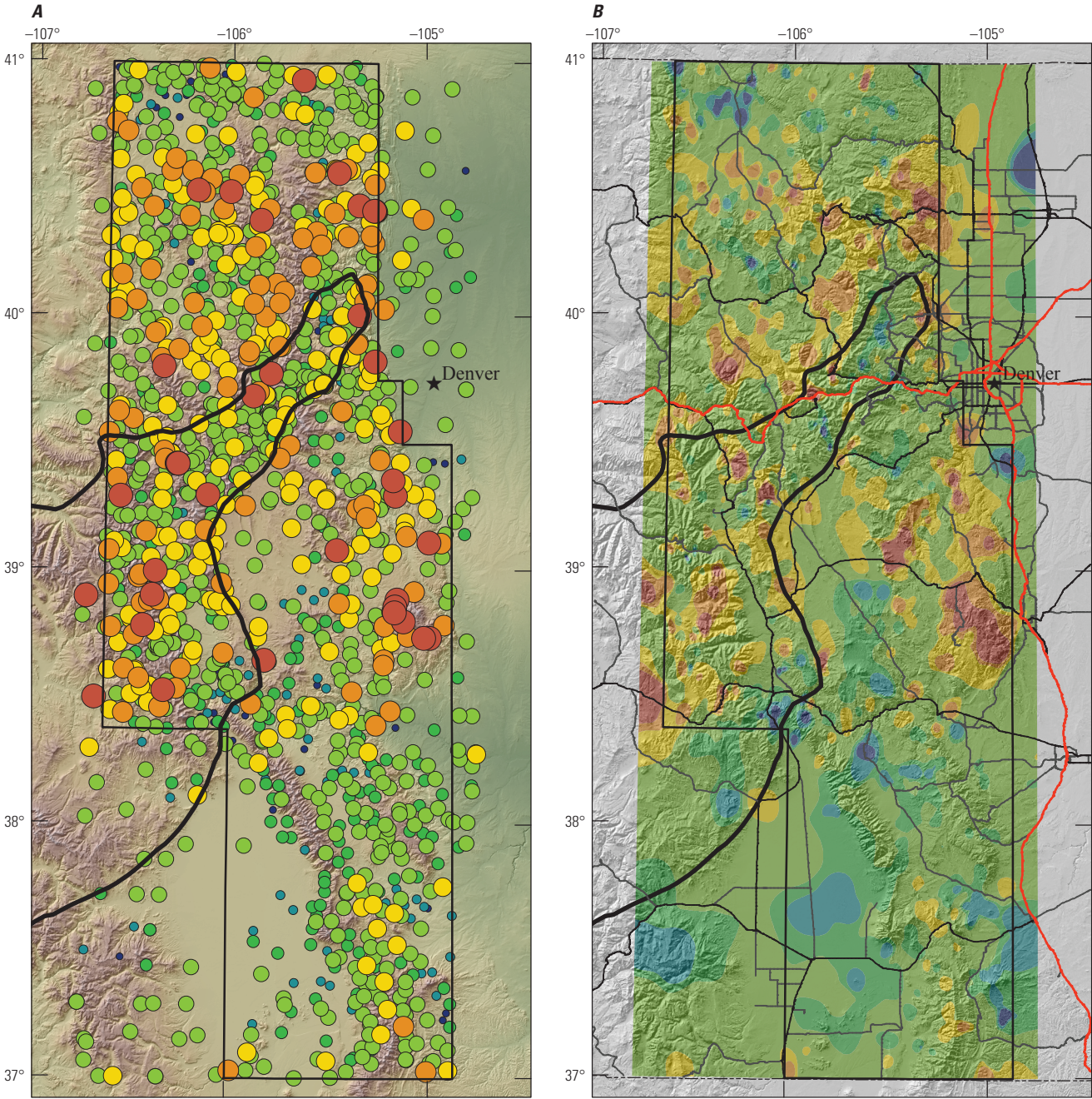




Central Colorado Stream-Sediment  
Geochemistry—Lithium



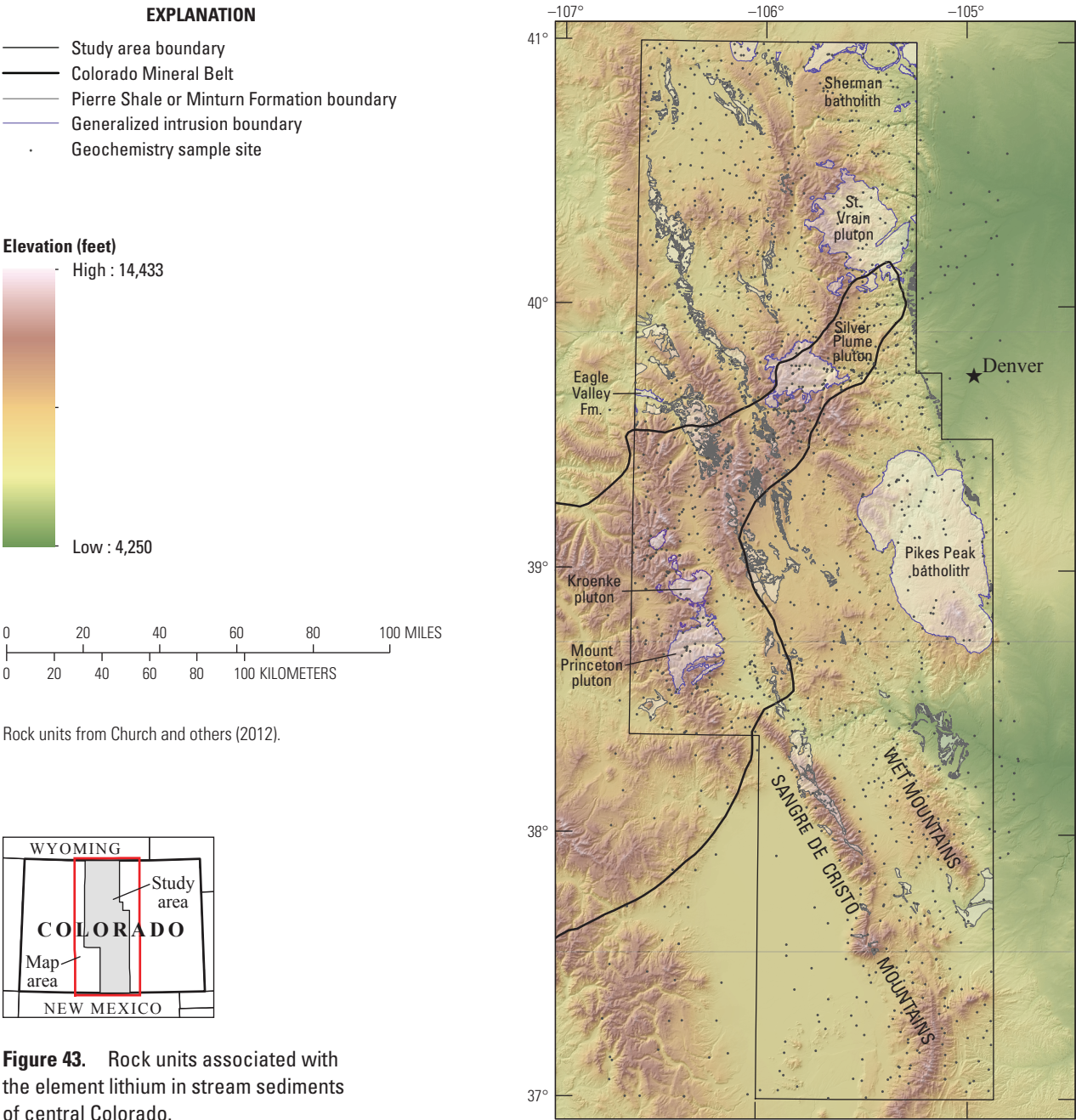
**Figure 42.** Maps of central Colorado stream-sediment geochemistry—lithium (Li). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Lithium (Li) typically is concentrated in evolved igneous rocks (granites and granite pegmatites) in micas and accessory minerals, in evaporite-bearing sedimentary rock units, and in clay minerals. Lithium is moderately mobile in surface water.

In the central and northern parts of the study area, the distribution of stream-sediment samples with high (>90th percentile) concentrations of lithium is controlled strongly by Proterozoic granitic rocks and pegmatites, such as the Pikes Peak and Sherman batholiths and the St. Vrain, Kroenke, Silver Plume, and Mount Princeton plutons. To the south, lithium concentrations are relatively low (<75th percentile) in samples from Mesoproterozoic granitic rocks of the Wet Mountains and the Sangre de Cristo Mountains, suggesting that those rocks may have been derived from a magmatic source different from that of rocks of similar age and composition in the northern part of the study area (figs. 42 and 43). Samples derived from sedimentary rock units with high clay content, such as the Pierre Shale and the Minturn Formation, and from evaporite-bearing units such as the Eagle Valley Formation, also show relatively high lithium concentrations; many samples fall above the 90th percentile.

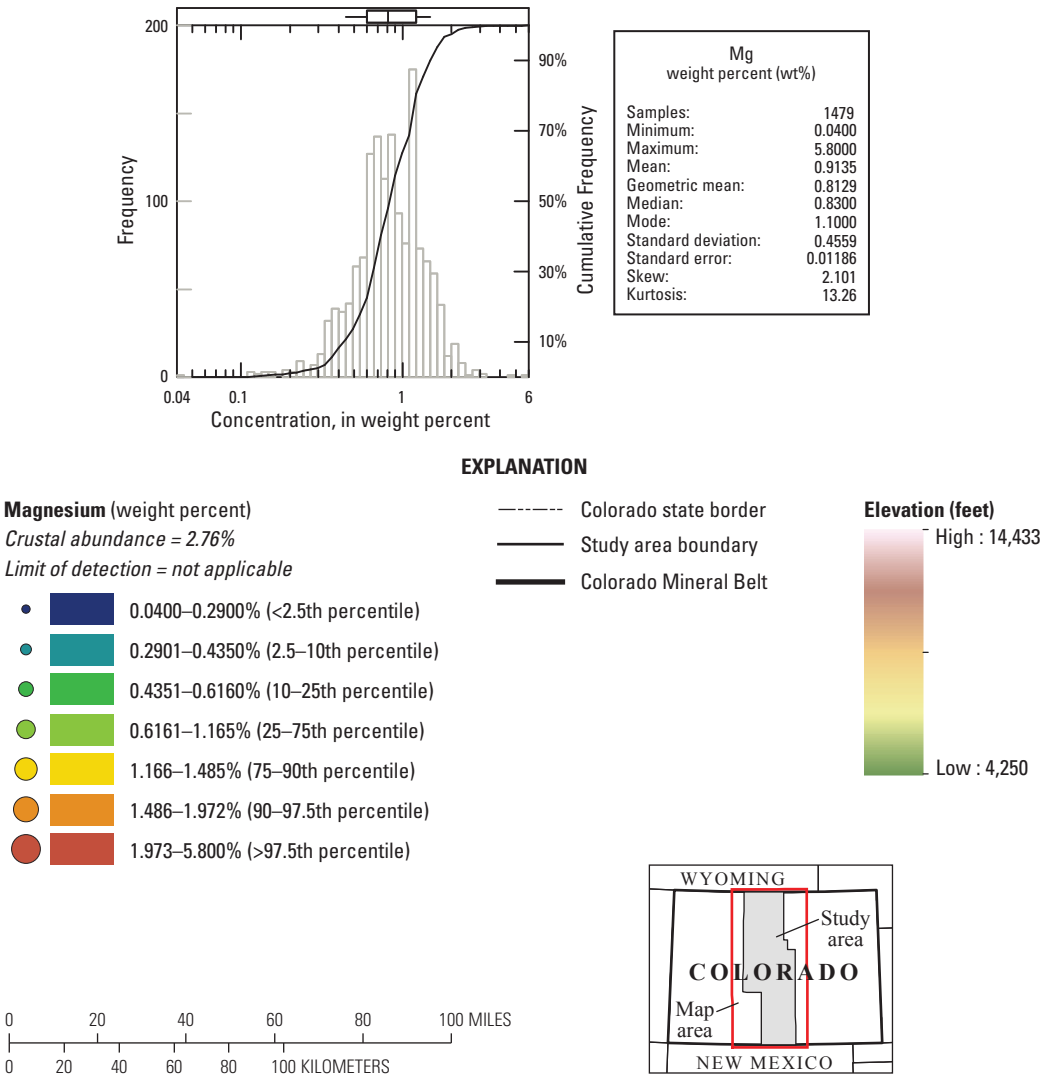


**Figure 43.** Rock units associated with the element lithium in stream sediments of central Colorado.

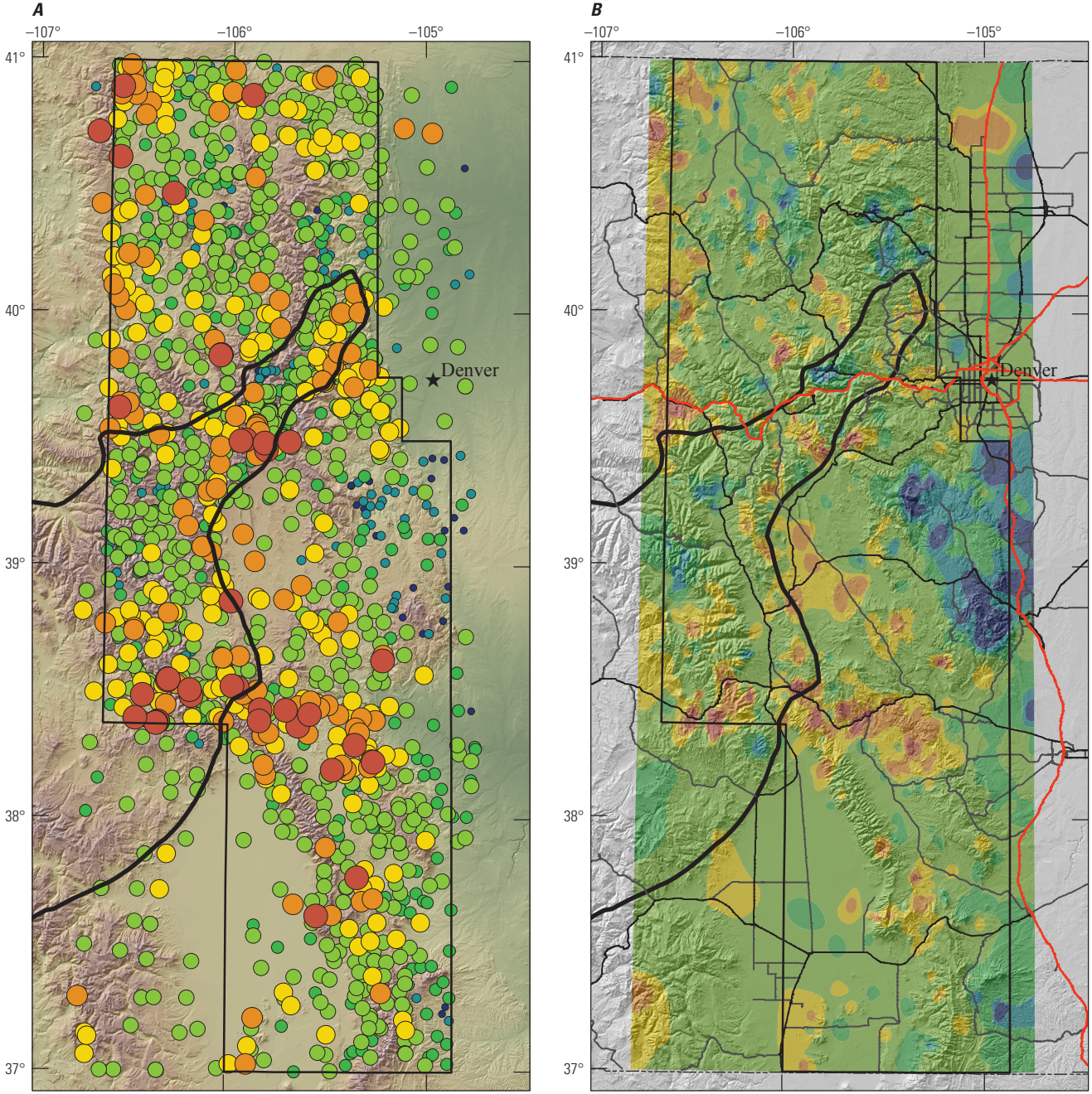




Central Colorado Stream-Sediment  
Geochemistry—Magnesium



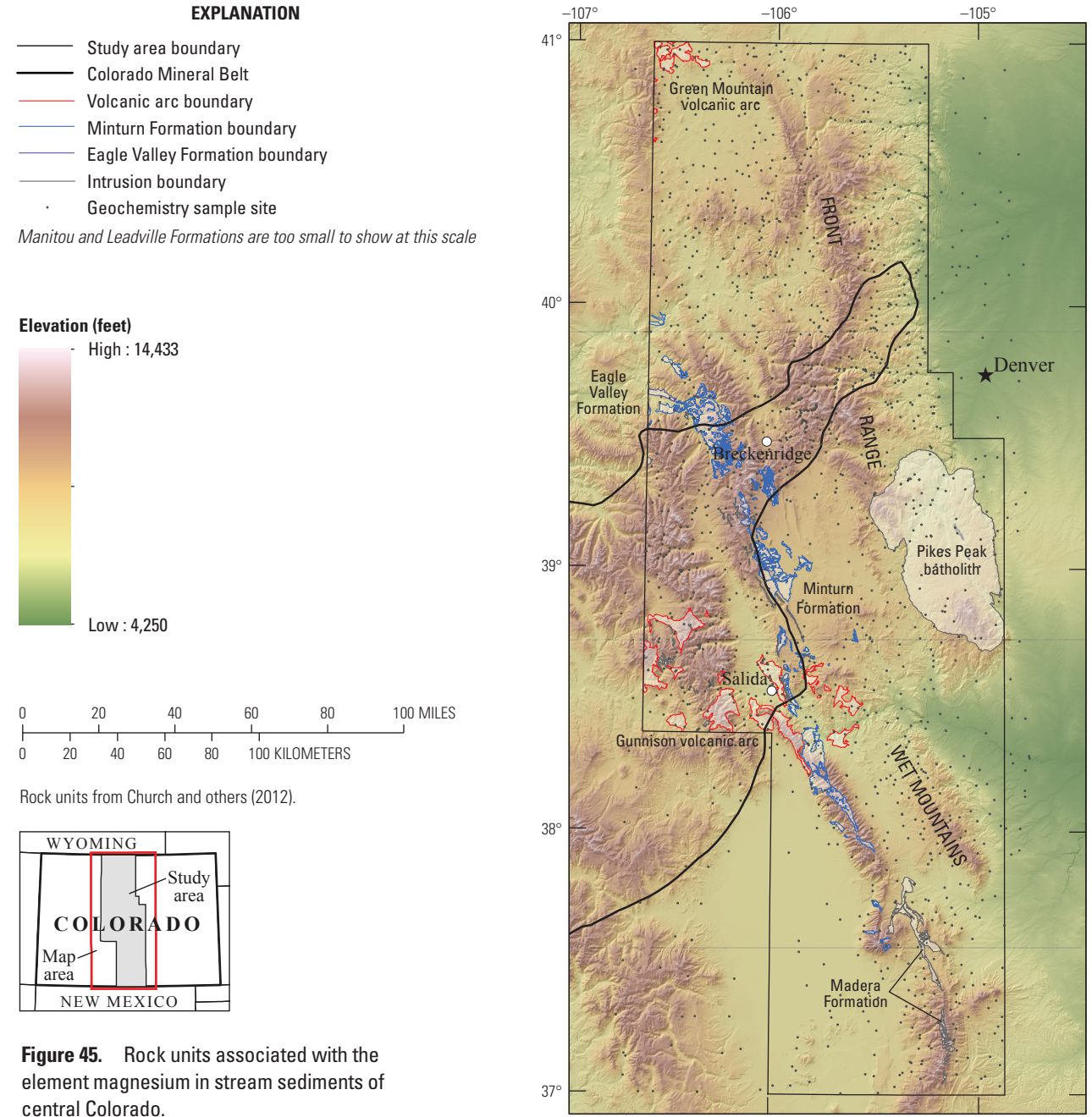
**Figure 44.** Maps of central Colorado stream-sediment geochemistry—magnesium (Mg). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Magnesium (Mg) is the principal cation in the common igneous minerals olivine, pyroxene, some amphibole and serpentine minerals, chlorite, and dolomite. Magnesium concentrations are highest in ultramafic igneous rocks and in dolomitic carbonate-rich sedimentary rocks.

The distribution of stream-sediment samples with high magnesium concentrations (fig. 44) is similar to the distribution of samples with high calcium concentrations (fig. 16) in the study area. Samples having high magnesium concentrations (>90th percentile) are associated with two diverse groups of bedrock units: (1) Paleozoic dolomites, dolomitic limestone, and evaporite-bearing units such as the Madera, Manitou, Leadville, Minturn, and Eagle Valley Formations (fig. 45); and (2) mafic and ultramafic metavolcanic rocks that are part of the Proterozoic volcanic arc rocks of the eastern Gunnison arc, near Salida and extending into the northern Wet Mountains, and the Green Mountain volcanic arc in the far northern part of the study area. Also included are the mafic metavolcanic and metagabbroic rock enclaves in the western Front Range near Swandyke, east of Breckenridge. The Mesoproterozoic Pikes Peak batholith is depleted noticeably in magnesium, reflecting that batholith's evolved granitic composition.

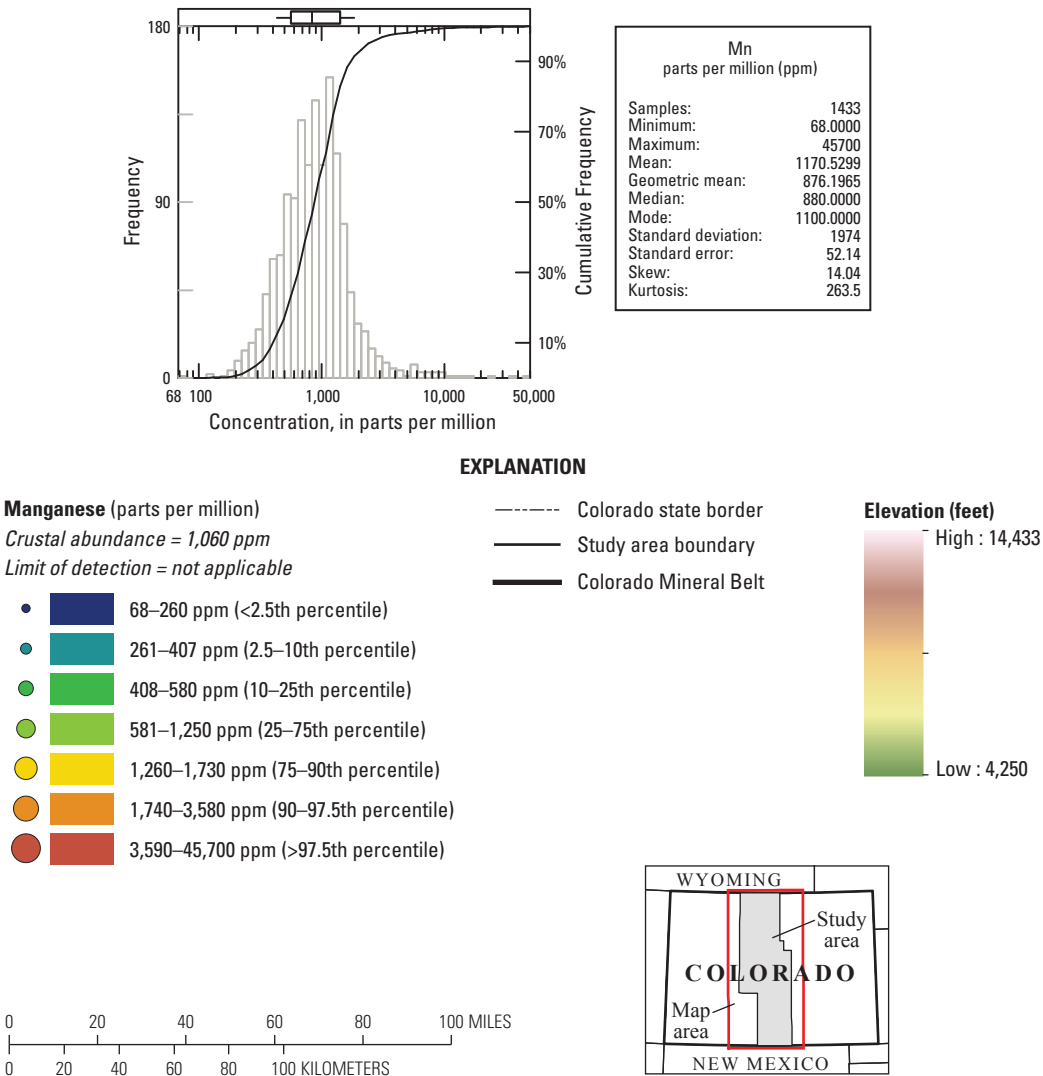


**Figure 45.** Rock units associated with the element magnesium in stream sediments of central Colorado.

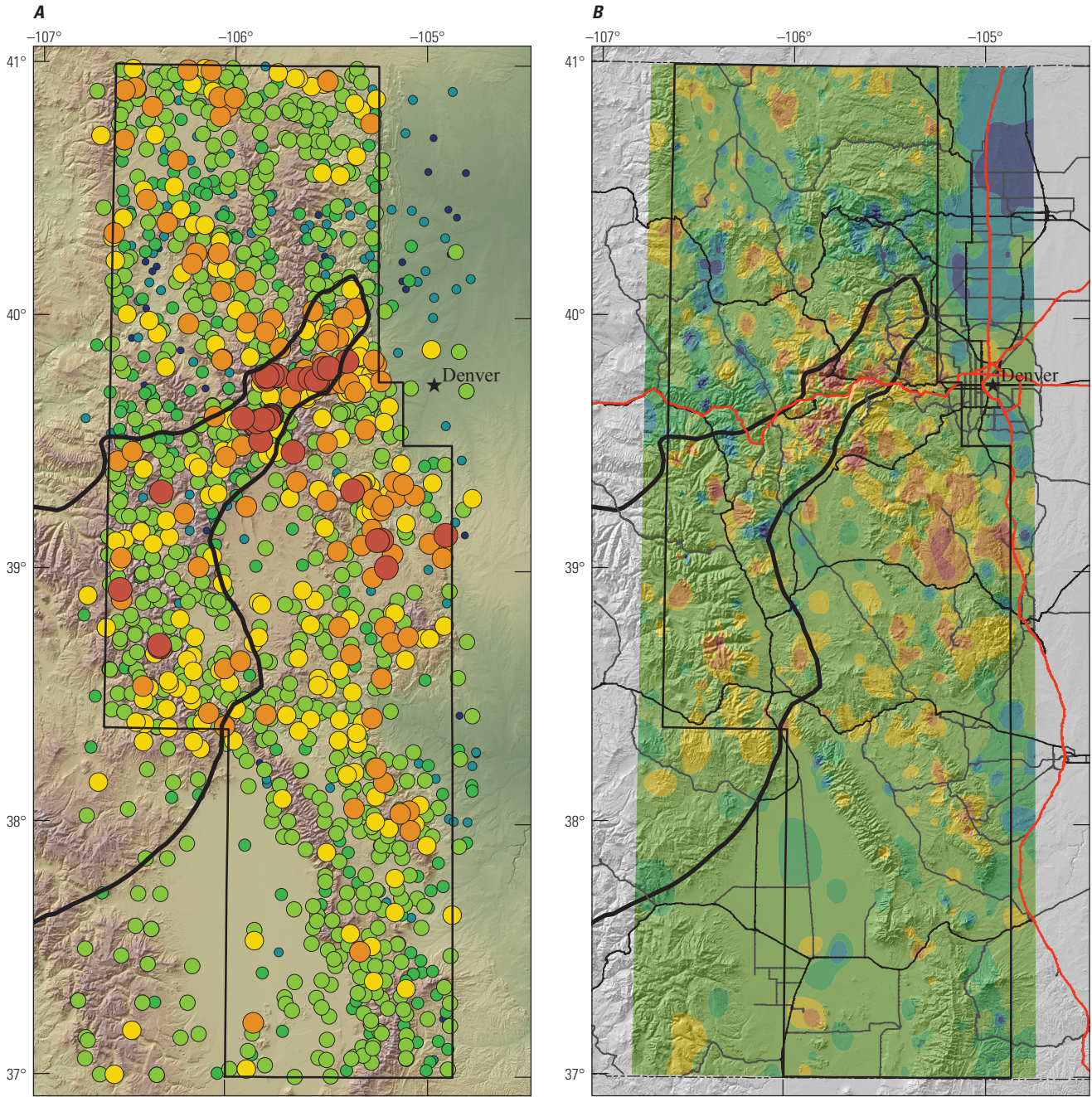




Central Colorado Stream-Sediment  
Geochemistry—Manganese



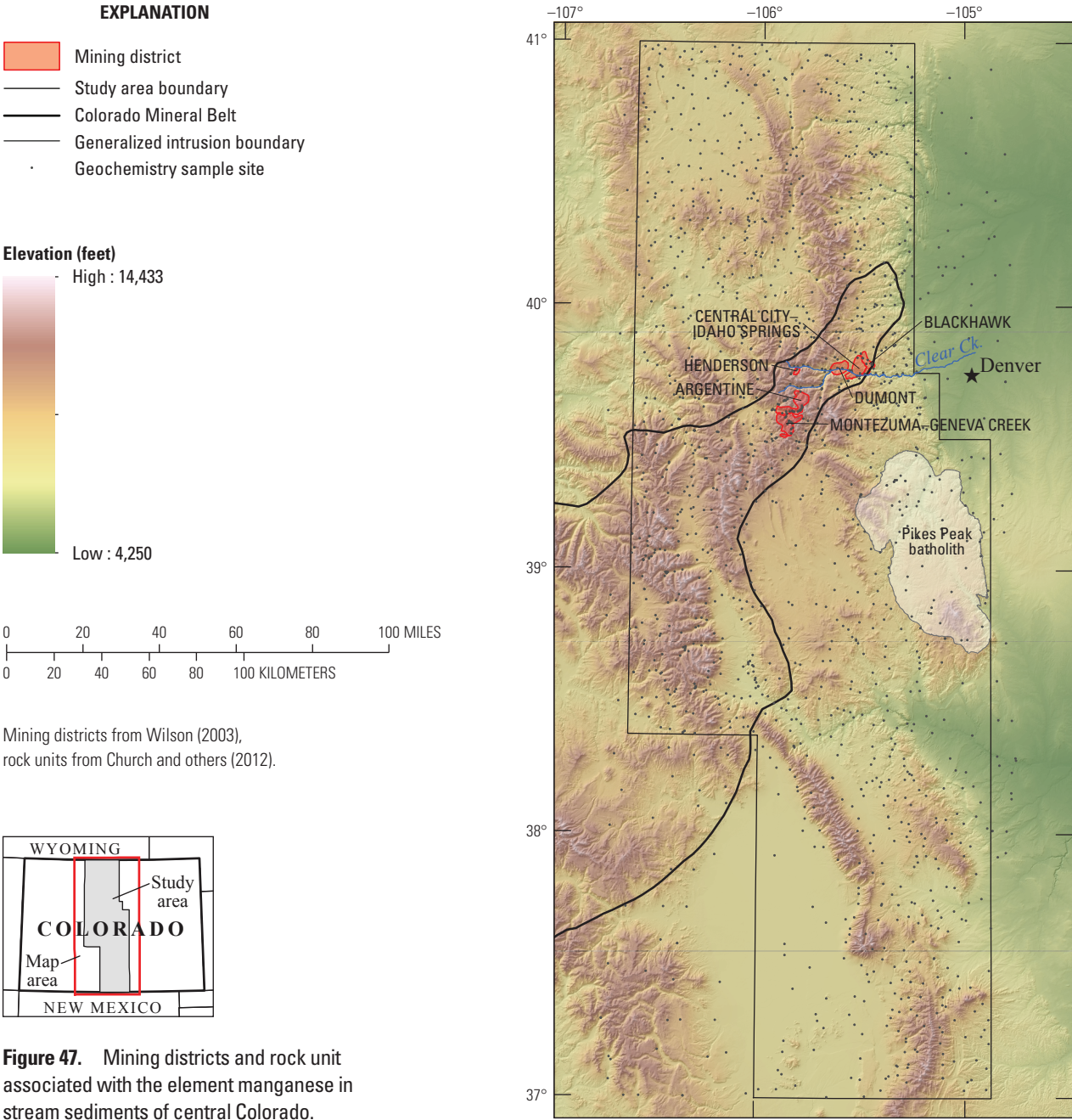
**Figure 46.** Maps of central Colorado stream-sediment geochemistry—manganese (Mn). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Manganese (Mn) concentrations vary only slightly in igneous rocks relative to composition. In hydrothermal base- and precious-metal vein systems, manganese may be present as rhodochrosite and rhodonite and in calcite. Manganese is mobile in the weathering environment and is similar to iron in its behavior, where it is transported in the reduced state in surface water and groundwater and precipitated by oxidation.

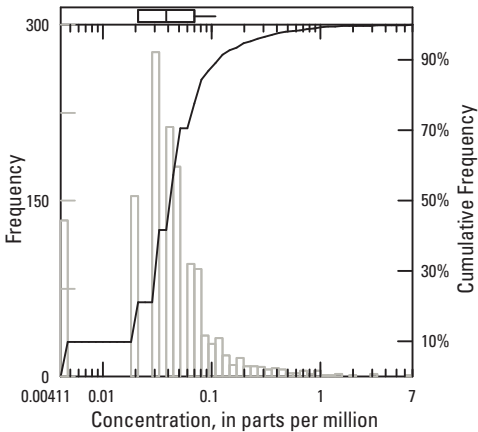
Within the northern end of the Colorado Mineral Belt, clusters of stream-sediment samples with high manganese concentrations (>97.5th percentile) identify the Argentine, Blackhawk, Central City–Idaho Springs, Dumont, Henderson, and Montezuma–Geneva Creek districts (figs. 46 and 47). A possible dispersion train of manganese (>90th percentile) is evident along Clear Creek from the Henderson district eastward to the range front. Those high concentrations probably are related to weathering of exposures of hydrothermally mineralized rocks, as well as mine and mill waste from historical mining activities. Outside the mineral belt, a large cluster of samples with high manganese concentrations (>90th percentile) overlying the Mesoproterozoic Pikes Peak batholith probably is related to lithology. Similarly, a large, diffuse group of samples with high manganese concentrations (90th to 97.5th percentile) overlies many Cretaceous and younger sedimentary units north of the mineral belt and extends nearly to the Colorado–Wyoming border.







Central Colorado Stream-Sediment  
Geochemistry—Mercury



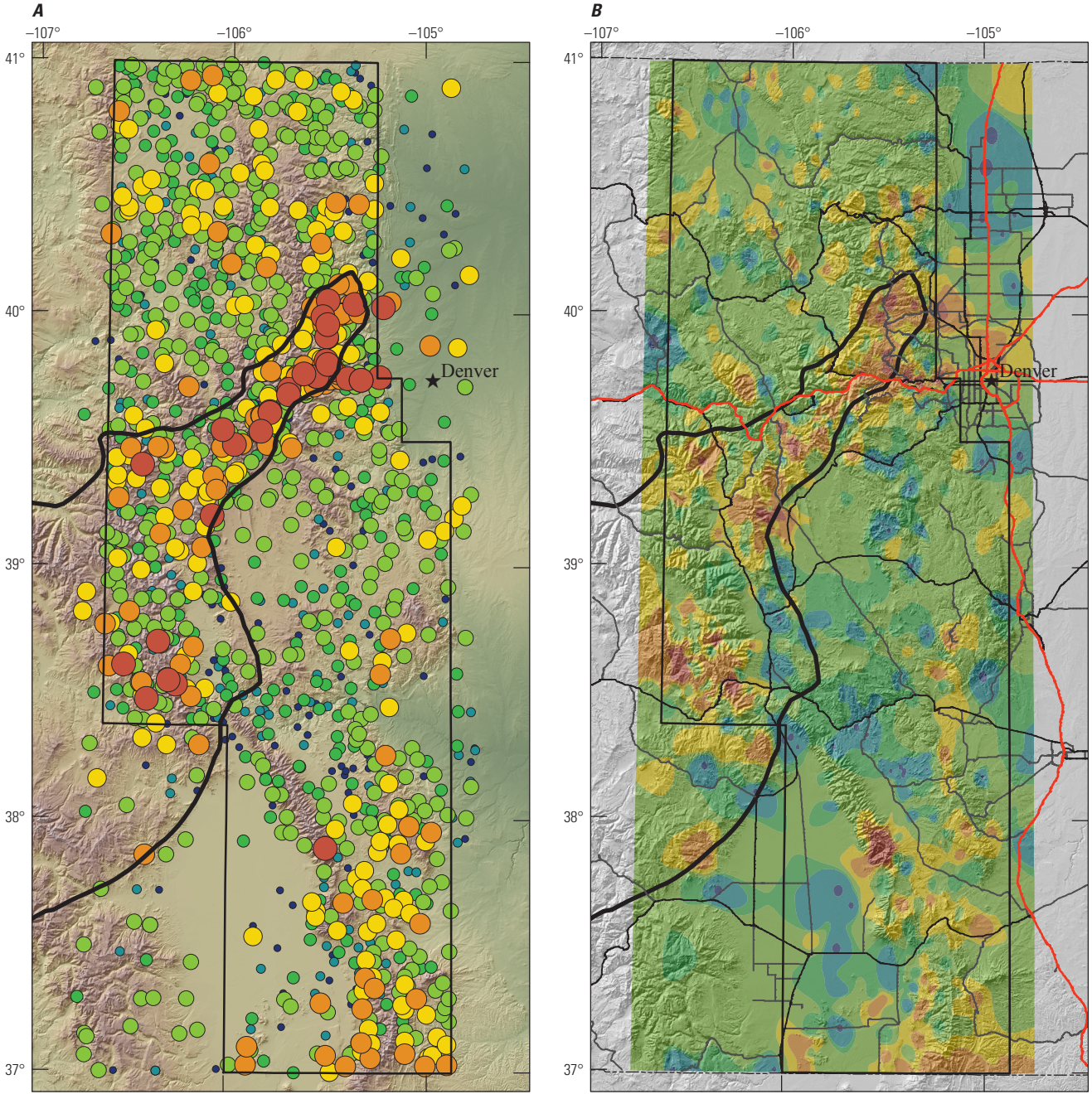
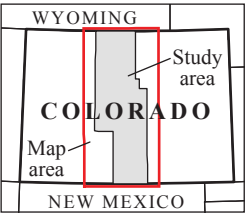
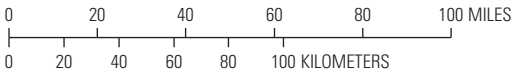
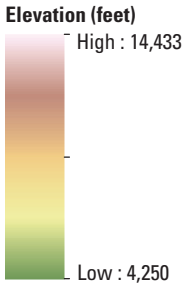
Hg parts per million (ppm)	
Samples:	1355
Minimum:	<0.02
Maximum:	6.3000
Mean:	0.0774
Geometric mean:	0.0391
Median:	0.0400
Mode:	0.0300
Standard deviation:	0.2427
Standard error:	0.006593
Skew:	16.42
Kurtosis:	358.9

**Mercury** (parts per million)  
Crustal abundance = 0.086 ppm  
Limit of detection = 0.02 ppm

- <0.02 ppm (<2.5th percentile)
- 0.020 ppm (2.5–10th percentile)
- 0.021–0.030 ppm (10–25th percentile)
- 0.031–0.060 ppm (25–75th percentile)
- 0.061–0.11 ppm (75–90th percentile)
- 0.12–0.40 ppm (90–97.5th percentile)
- 0.41–6.3 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

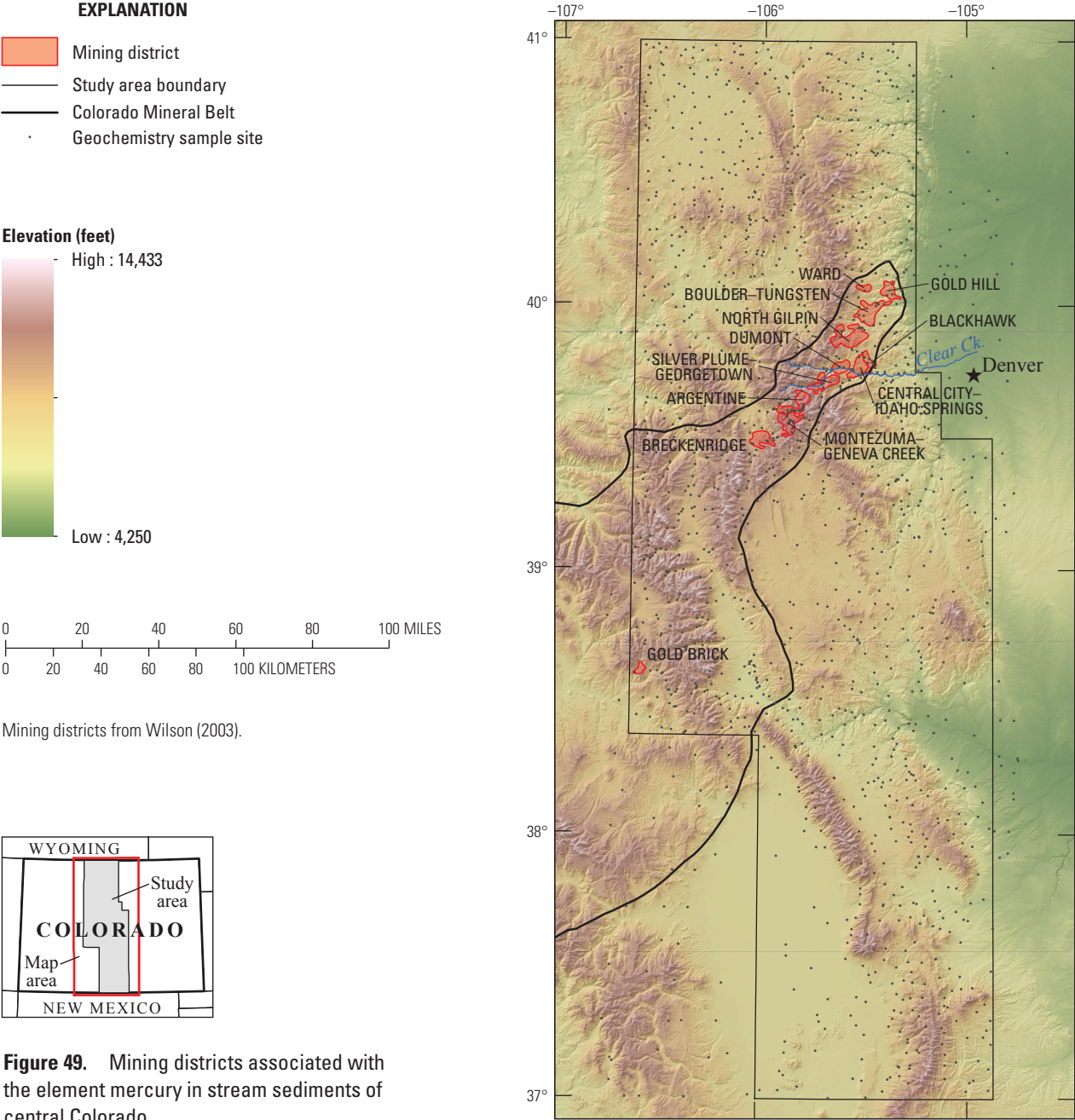


**Figure 48.** Maps of central Colorado stream-sediment geochemistry—mercury (Hg). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Mercury (Hg) is strongly chalcophile in its geochemical association. It is found in sulfide minerals, as a native metal in some hydrothermal deposits, and from anthropogenic sources. Organic-rich shale and coal may be enriched in mercury. Low concentrations of mercury are produced in emissions from some coal-fired power plants. Mercury has a relatively low solubility as a native metal but is very soluble when oxidized, particularly as a chloride, and in some organic complexes.

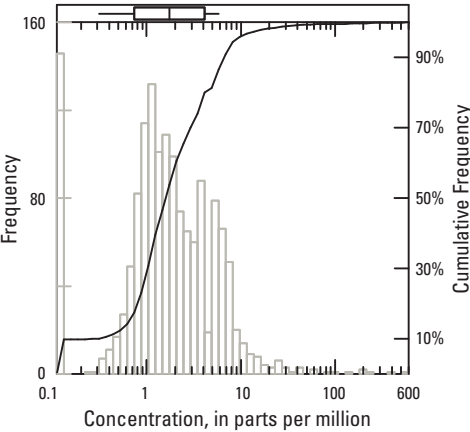
The highest mercury concentrations (>97.5th percentile) arise from stream-sediment samples nearly exclusive to the Colorado Mineral Belt (figs. 48 and 49). The single highest concentration (6.3 parts per million, ppm) was determined from a sediment sample taken downstream of the Gold Brick district in the Sawatch Range. At the north end of the mineral belt, high mercury concentrations (>97.5th percentile) are found in samples from the Argentine, Blackhawk, Boulder-Tungsten, Breckenridge, Central City–Idaho Springs, Dumont, Gold Hill, Montezuma–Geneva Creek, North Gilpin, Silver Plume–Georgetown, and Ward districts. A strong dispersion train is evident from the Blackhawk and Central City–Idaho Springs districts eastward to the range front. These relatively high mercury concentrations likely are due largely to mercury’s use in amalgamation, a gold and silver extraction process common during ore milling in the late 1800s and early 1900s. Low concentrations of naturally occurring mercury also are possible in many of the hydrothermally mineralized areas. Outside of the mineral belt, sporadic and isolated moderately anomalous (90th to 97.5th percentile) mercury-bearing samples to the north and to the far south are underlain by varied rock types, generally are found distal to known mineral deposits, and have an undetermined origin. Isolated samples near Denver that contain elevated mercury concentrations are described in the discussion of copper (figs. 26 and 27).







Central Colorado Stream-Sediment  
Geochemistry—Molybdenum



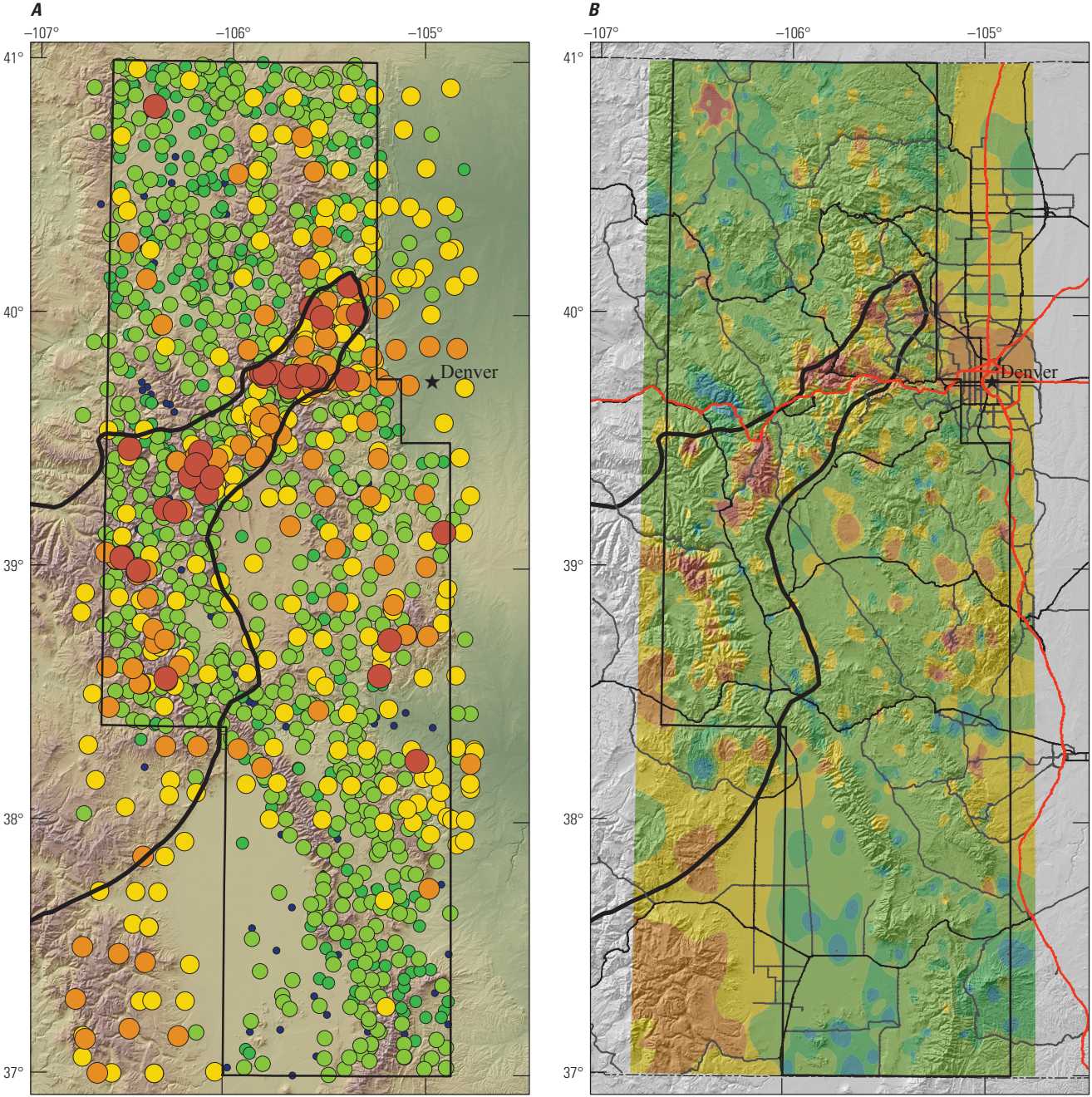
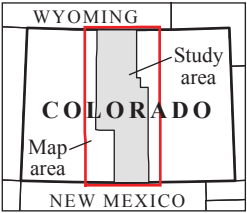
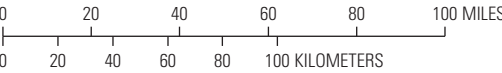
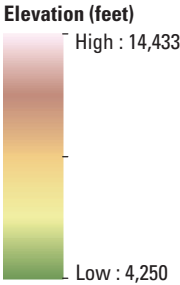
Mo parts per million (ppm)	
Samples:	1479
Minimum:	<0.1
Maximum:	540.0000
Mean:	4.0953
Geometric mean:	1.5796
Median:	1.6000
Mode:	0.1111
Standard deviation:	20.05
Standard error:	0.5214
Skew:	18.99
Kurtosis:	430

**Molybdenum** (parts per million)  
Crustal abundance = 1.2 ppm  
Limit of detection = 0.1 ppm

- <0.113 ppm (<2.5th percentile)
- 0.113–0.310 ppm (2.5–10th percentile)
- 0.311–0.920 ppm (10–25th percentile)
- 0.921–3.60 ppm (25–75th percentile)
- 3.61–6.00 ppm (75–90th percentile)
- 6.01–14.0 ppm (90–97.5th percentile)
- 14.1–540 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

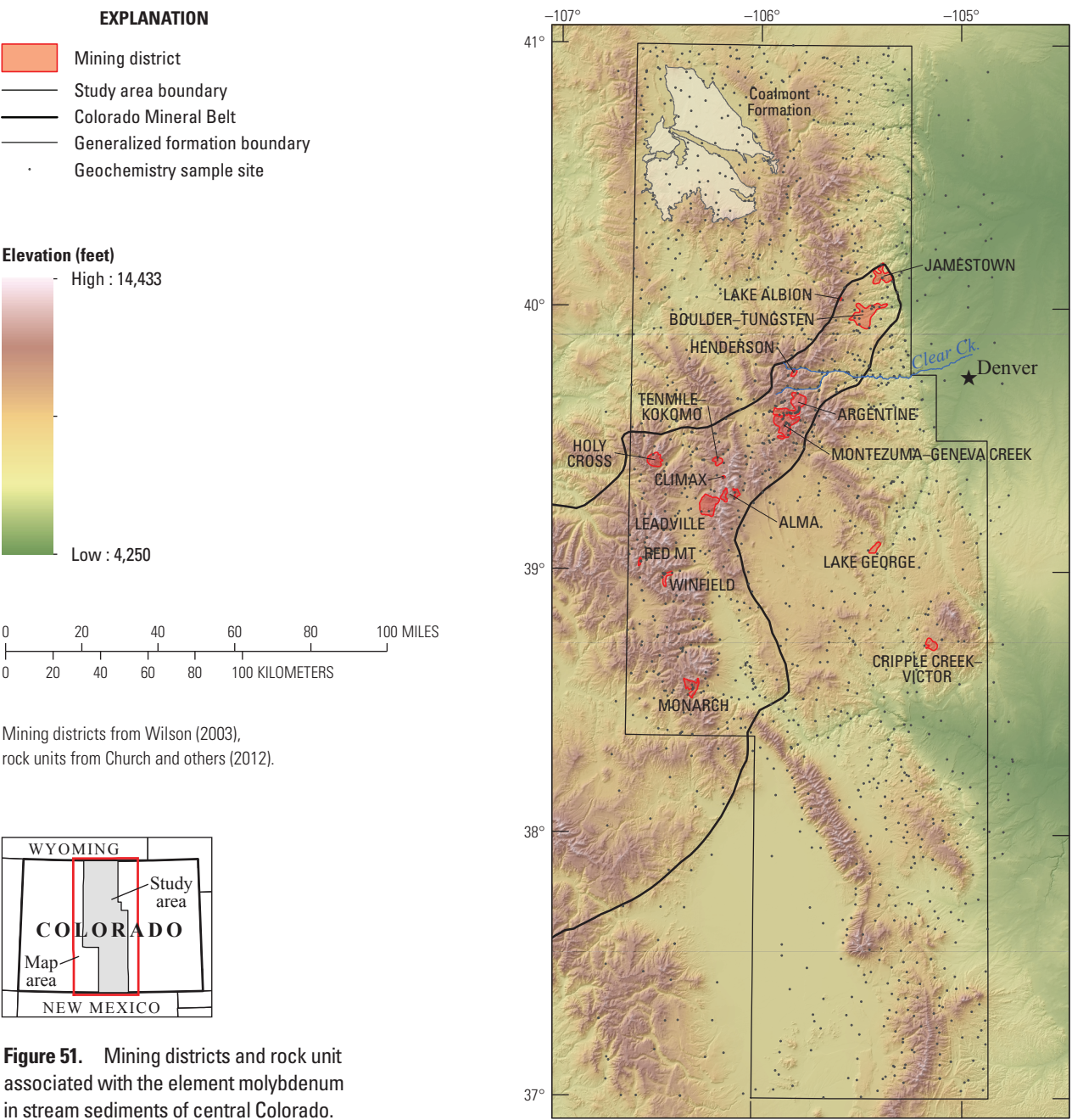


**Figure 50.** Maps of central Colorado stream-sediment geochemistry—molybdenum (Mo). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Molybdenum (Mo) is more abundant in highly evolved igneous rocks such as granites and granitic pegmatites and in organic-rich shales. It commonly is found in hydrothermal vein and disseminated deposits associated with felsic igneous intrusions and may be concentrated in some stratabound deposits such as uranium-vanadium sediment-hosted deposits. Molybdenum is mobile in the weathering environment and may be concentrated by adsorption onto iron oxyhydroxides, by formation of ferrimolybdate, and by precipitation in carbonate-rich environments.

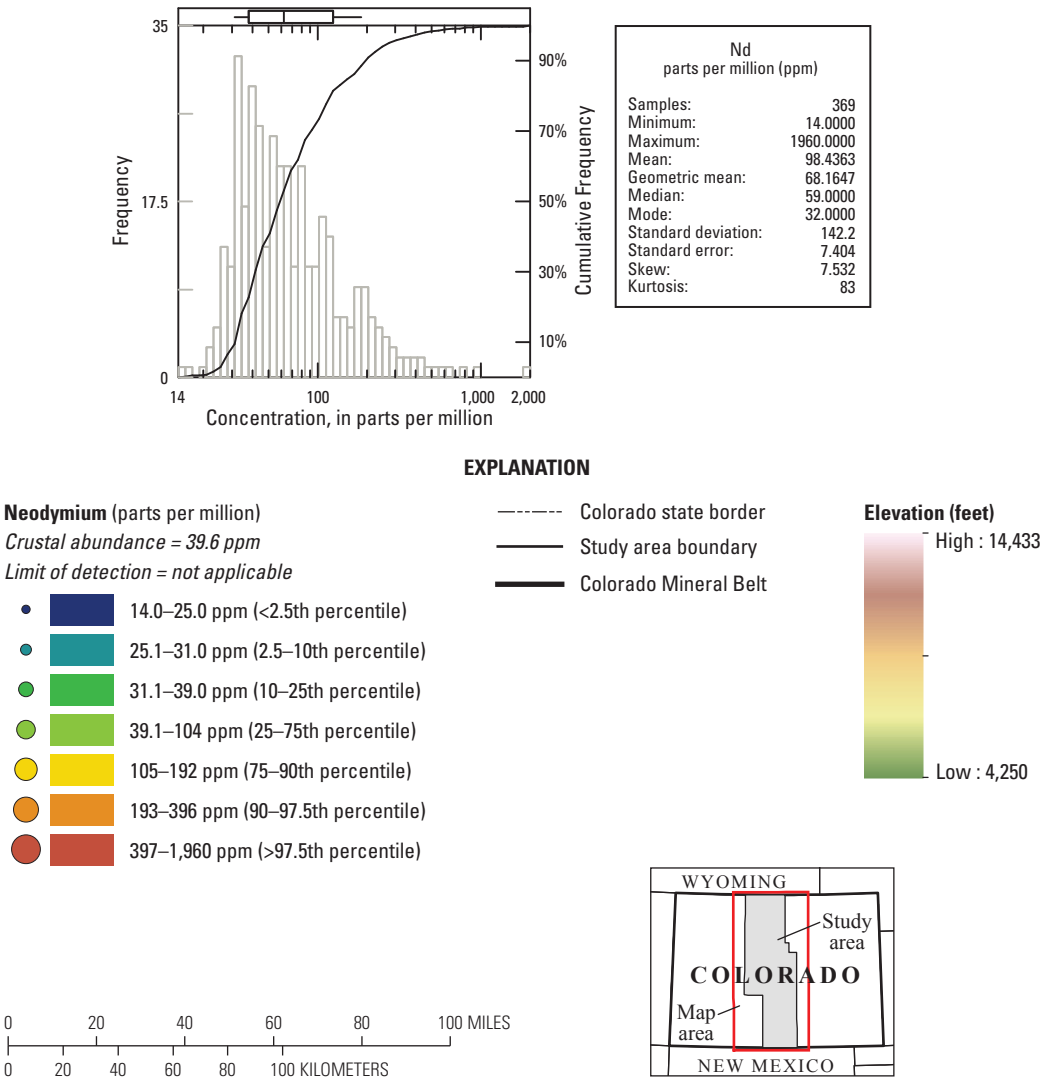
For unexplained reasons, the single highest molybdenum concentration (540 parts per million, ppm) is from an isolated sample taken within the Tertiary Coalmont Formation (figs. 50 and 51) in the northwest part of the study area. Anomalous molybdenum is found in numerous stream-sediment samples within the Colorado Mineral Belt. In the northern part of the mineral belt, a persistent dispersion pattern is evident from the Henderson district along Clear Creek to the range front. Three samples with high Mo concentrations (150–360 ppm) were obtained immediately downstream of the Henderson mine, a large porphyry molybdenum deposit. Another cluster of samples with high molybdenum concentrations (>97.5th percentile) surrounds the porphyry molybdenum deposit at the Climax mine, and the two highest-concentration samples from that deposit (190 ppm) were obtained immediately downstream. Also within the mineral belt, scattered samples with high concentrations (>97.5th percentile) occur in the Alma, Boulder-Tungsten, Holy Cross, Jamestown, Lake Albion, Leadville, Monarch, Red Mountain, Tenmile-Kokomo, and Winfield districts. A cluster of sample locations with lower molybdenum concentrations (90th to 97.5th percentile) is found downstream from the Argentine and Montezuma–Geneva Creek districts. South of the mineral belt, isolated samples with high molybdenum concentrations (>90th percentile) are present near the Lake George greisen deposit and the Cripple Creek–Victor gold-telluride deposits. Isolated samples near Denver that contain elevated molybdenum concentrations are described in the discussion of copper (figs. 26 and 27).



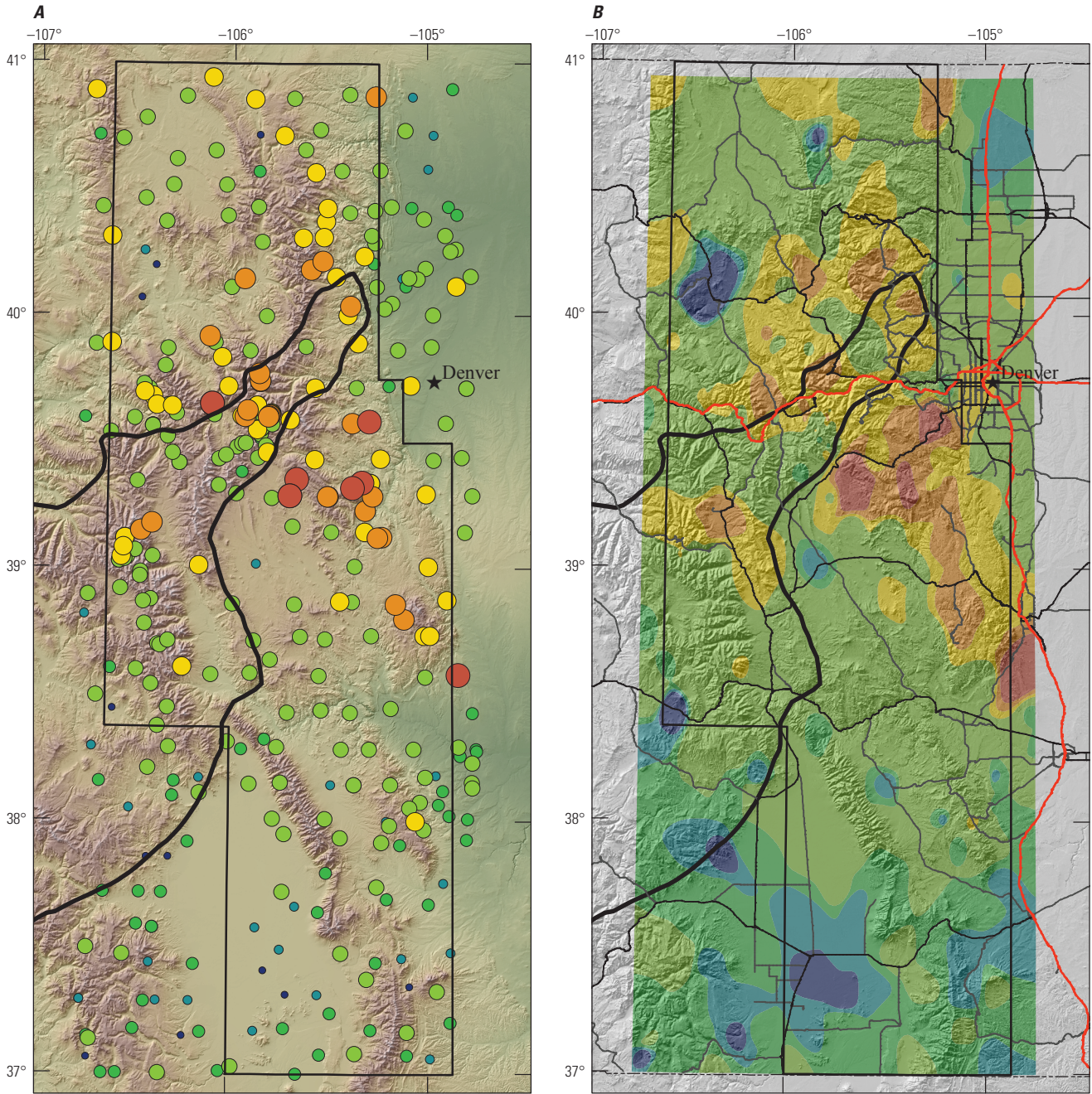




Central Colorado Stream-Sediment  
Geochemistry—Neodymium



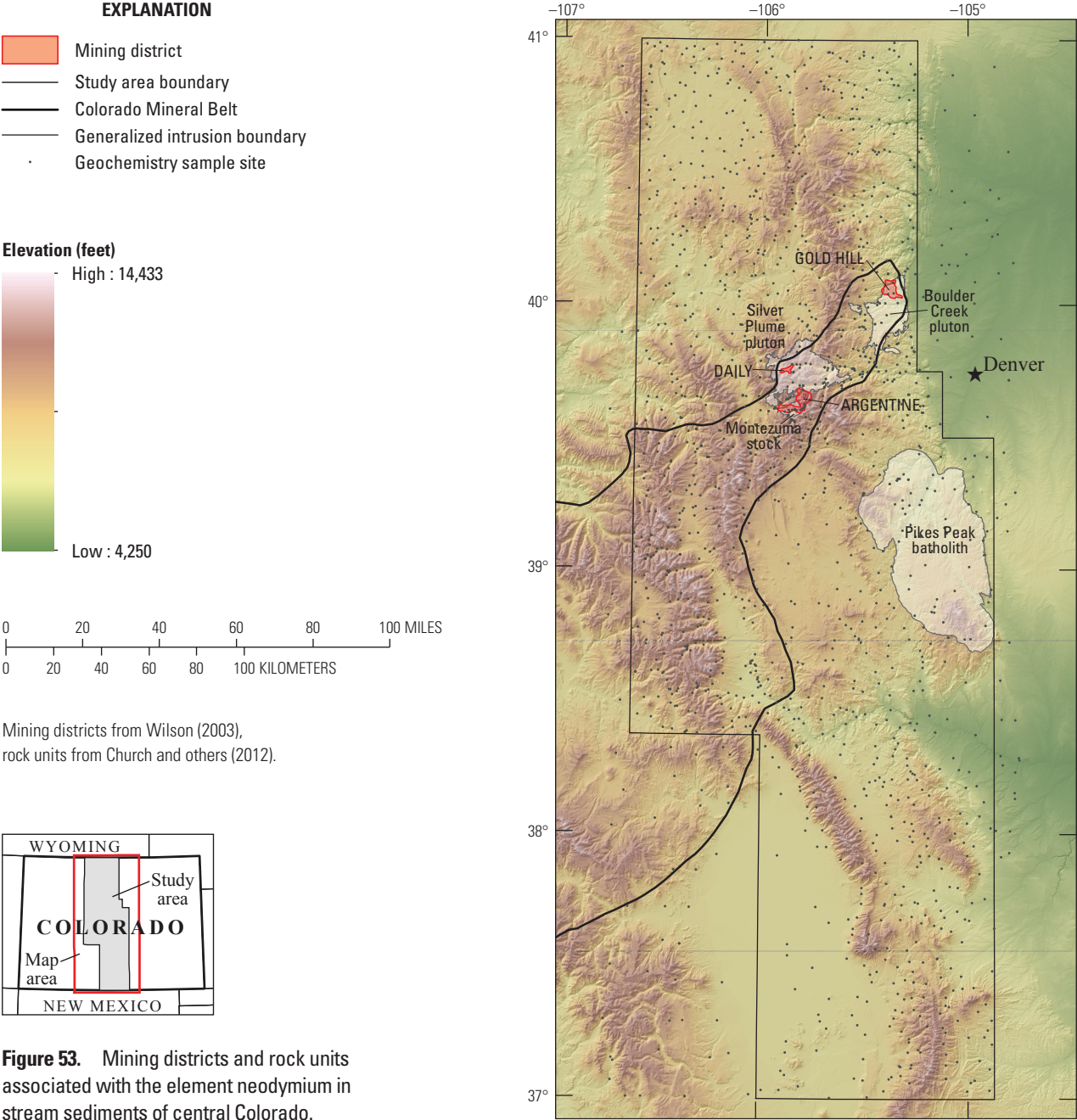
**Figure 52.** Maps of central Colorado stream-sediment geochemistry—neodymium (Nd). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Neodymium (Nd) is one of 15 metallic elements called rare earth elements (REEs). The REEs, including neodymium, are strongly lithophile in igneous rocks. See the cerium map (fig. 19) for further discussion of the geochemical behavior of the REEs.

In this study, only a small subset of samples (369 out of 1,479) from the Church and others (2012) and Grossman (1998) studies were analyzed for neodymium (fig. 52). The highest concentrations (>90th percentile) of neodymium in the study area are found in samples from the main phase of the Pikes Peak batholith and in samples obtained from areas underlain by felsic igneous intrusions of various ages from Precambrian to Tertiary, such as the Boulder Creek and Silver Plume plutons and the Montezuma stock (figs. 52 and 53). Mining districts spatially associated with high neodymium concentrations (>90th percentile) all are located in the Colorado Mineral Belt and include the Argentine, Daily, and Gold Hill districts. Both within and outside of the mineral belt, samples with relatively high neodymium concentrations also are enriched in Ce, La, and Y. The REE patterns and related geologic associations are better elucidated by maps of Ce, La, and Y, because many more samples ( $n = 1,479$ ) were analyzed for those elements.

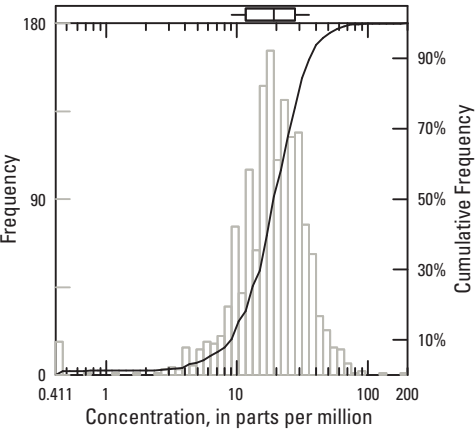


**Figure 53.** Mining districts and rock units associated with the element neodymium in stream sediments of central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Nickel



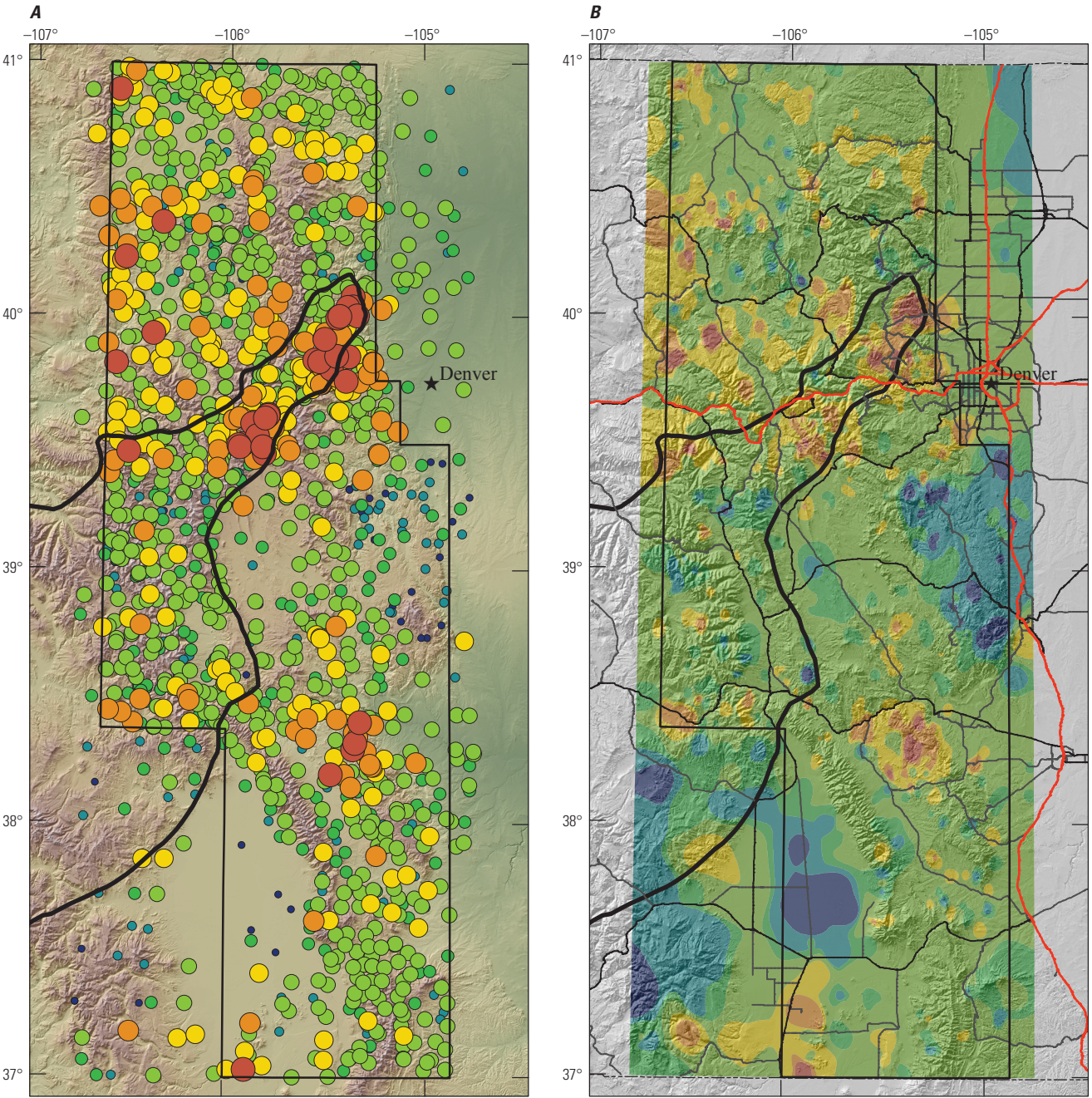
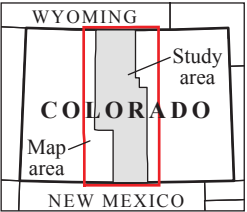
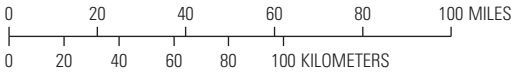
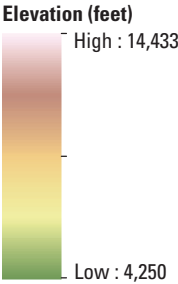
Ni parts per million (ppm)	
Samples:	1479
Minimum:	<2
Maximum:	180.0000
Mean:	21.4429
Geometric mean:	17.8532
Median:	19.0000
Mode:	16.0000
Standard deviation:	12.8
Standard error:	0.3329
Skew:	2.719
Kurtosis:	20.93

**Nickel** (parts per million)  
Crustal abundance = 99.0 ppm  
Limit of detection = 2 ppm

- <4.0 ppm (<2.5th percentile)
- 4.1–9.0 ppm (2.5–10th percentile)
- 9.1–13 ppm (10–25th percentile)
- 14–27 ppm (25–75th percentile)
- 28–36 ppm (75–90th percentile)
- 37–52 ppm (90–97.5th percentile)
- 53–180 ppm (<97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

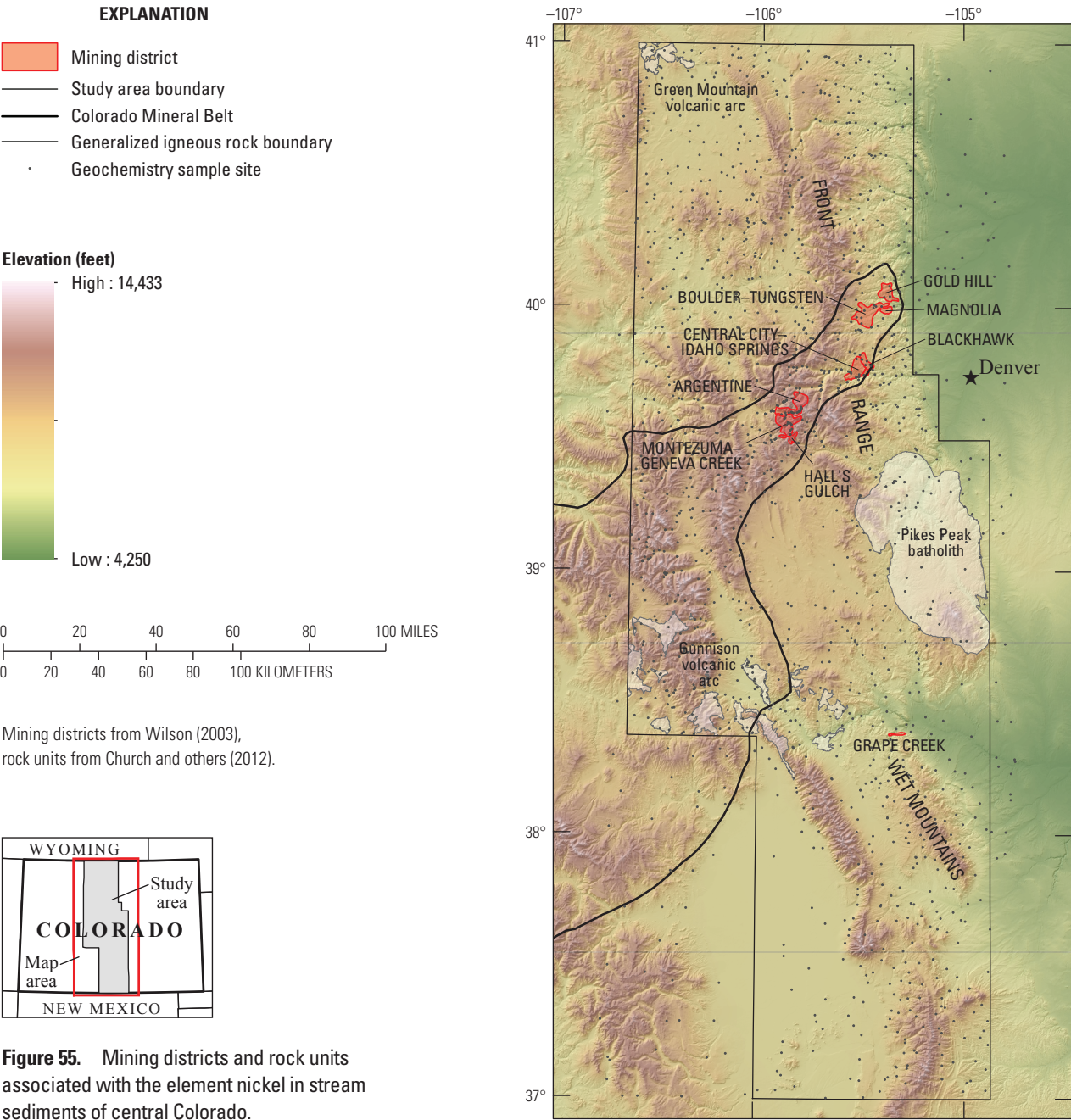


**Figure 54.** Maps of central Colorado stream-sediment geochemistry—nickel (Ni). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Nickel (Ni) is most abundant in ultramafic to mafic igneous rocks where it is present in olivine and pyroxene, in common serpentine alteration products after olivine and pyroxene, and in magmatic sulfide minerals. Nickel is relatively immobile in the weathering environment.

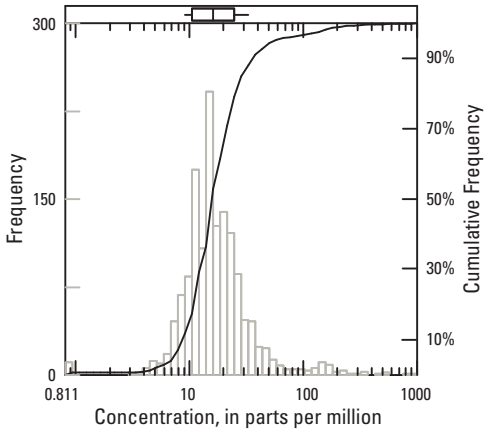
Clusters of stream-sediment samples with high nickel concentrations (>97.5th percentile) in the northern end of the Colorado Mineral Belt surround the Boulder-Tungsten, Gold Hill, and Magnolia districts, flank the Blackhawk and Central City–Idaho Springs districts, and are found in the Argentine, Halls Gulch, and Montezuma–Geneva Creek districts (figs. 54 and 55). Anomalous nickel in the mineral belt probably is related to volumetrically minor Proterozoic mafic dikes present in much of the area. South of the mineral belt, a group of samples with high nickel concentrations (>97.5th percentile) characterizes the northern Wet Mountains and the Grape Creek district and may reflect Cambrian ultramafic and mafic alkaline complex rocks. Proterozoic metavolcanic and metagabbroic rocks of the Gunnison volcanic arc can be traced westward by a widely dispersed group of samples with nickel concentrations in the 90th to 97.5th percentile range. The Proterozoic Green Mountain volcanic arc rocks in the northern part of the area also are indicated by anomalous nickel. Other scattered samples north of the mineral belt that contain high nickel concentrations (>97.5th percentile) are of unknown rock association (perhaps mafic dikes?). A region of relatively low nickel concentrations (<10th percentile) highlights the evolved granitic rocks of the Pikes Peak batholith in the southern Front Range.







Central Colorado Stream-Sediment  
Geochemistry—Niobium



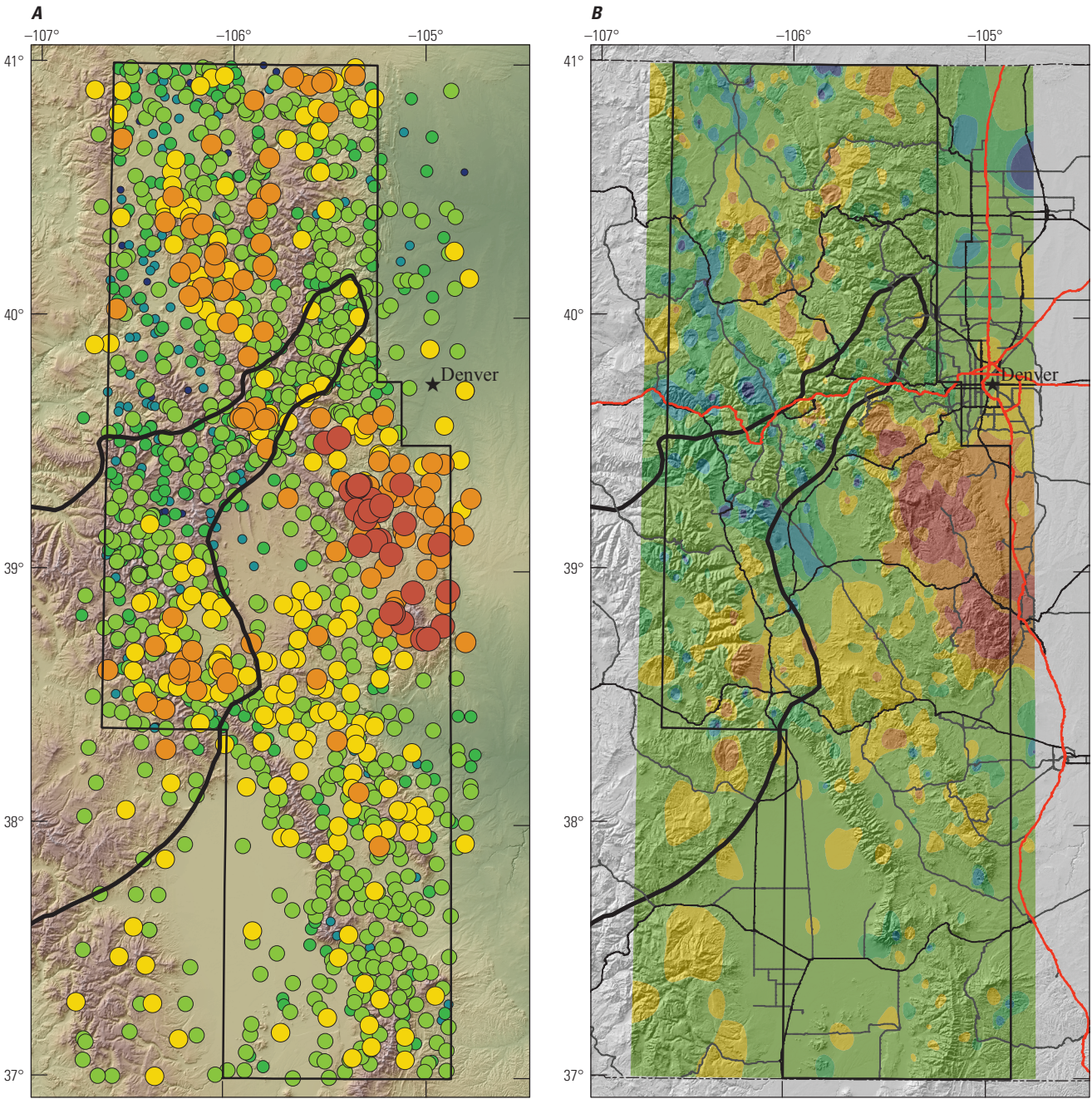
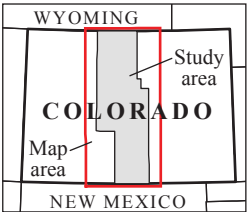
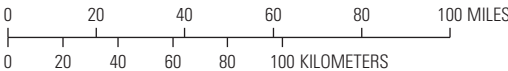
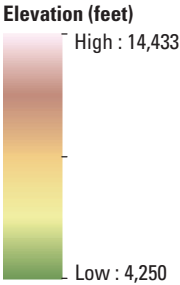
Nb parts per million (ppm)	
Samples:	1479
Minimum:	<4
Maximum:	914.0000
Mean:	25.1574
Geometric Mean:	17.1755
Median:	16.0000
Mode:	11.0000
Standard deviation:	48.5
Standard error:	1.261
Skew:	10.5
Kurtosis:	150.1

EXPLANATION

**Niobium** (parts per million)  
Crustal abundance = 20.0 ppm  
Limit of detection = 4 ppm

- <5.70 ppm (<2.5th percentile)
- 5.71–8.70 ppm (2.5–10th percentile)
- 8.71–12.0 ppm (10–25th percentile)
- 12.1–23.0 ppm (25–75th percentile)
- 23.1–35.0 ppm (75–90th percentile)
- 35.1–140 ppm (90–97.5th percentile)
- 141–914 ppm (>97.5th percentile)

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

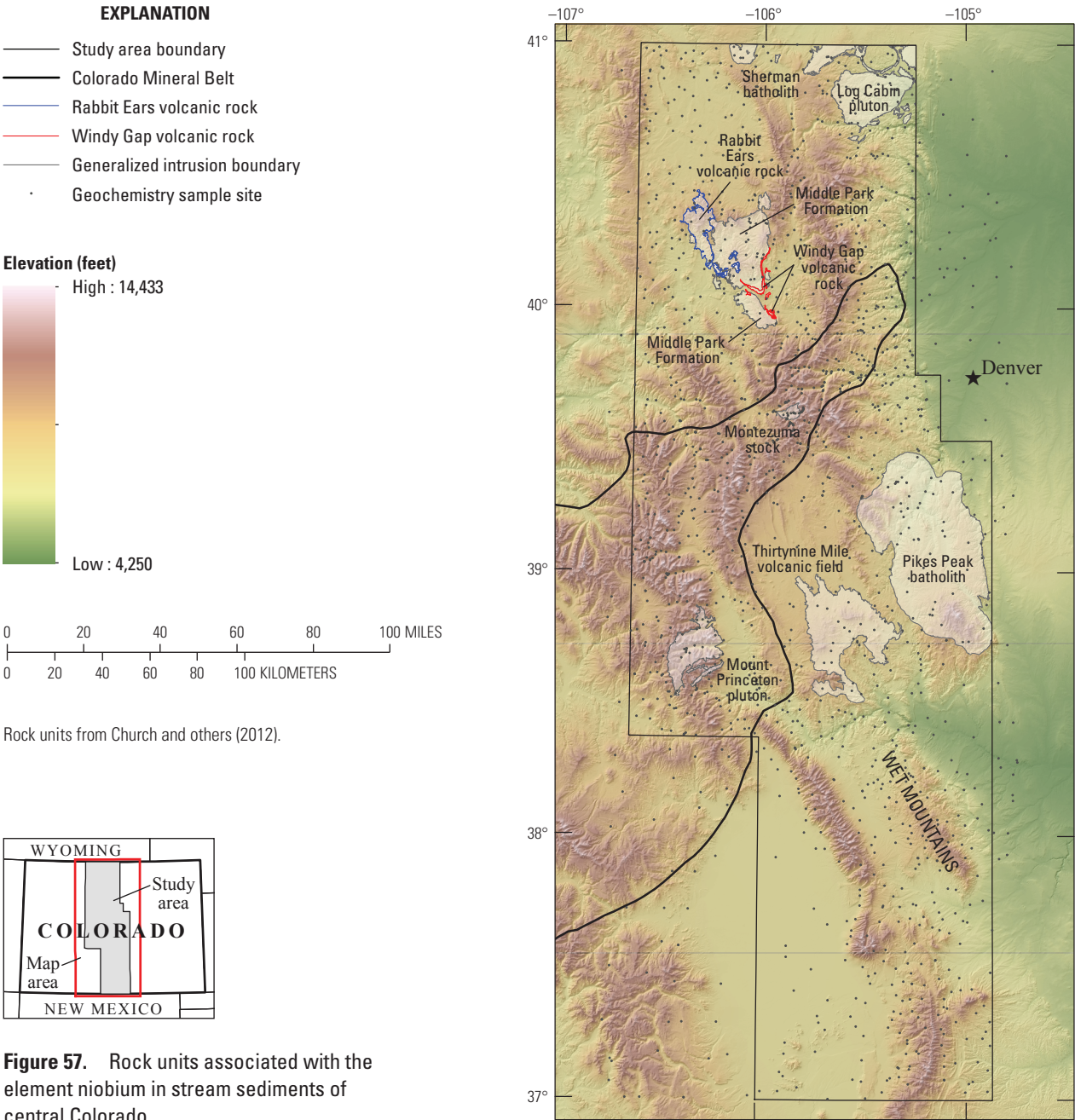


**Figure 56.** Maps of central Colorado stream-sediment geochemistry—niobium (Nb). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Niobium (Nb) is a lithophile element with its highest concentrations in some granite pegmatites, alkali granites and rhyolites, and alkaline intermediate to ultramafic igneous intrusive complexes. It is present as a trace element in biotite, rutile, sphene, and zircon. Sedimentary rocks generally contain relatively low niobium concentrations. Niobium distributions commonly mimic those of rare earth elements (REEs). Niobium is relatively immobile in the weathering environment.

In the study area, high niobium concentrations reflect underlying lithologies rather than mineral deposits. The highest niobium concentrations in the study area (>90th percentile) are found in stream-sediment samples that form a wide anomaly surrounding the Pikes Peak batholith (figs. 56 and 57), similar in distribution to the heavy REEs yttrium and ytterbium. Niobium concentrations also generally are high (>90th to 97.5th percentile) in (1) alkalic-calcic to alkaline dikes and volcanic rocks of the Cenozoic Rabbit Ears volcanic complex and sediments in the Late Cretaceous to Paleocene Middle Park Formation, which contains material derived from alkaline Laramide volcanic rocks (Windy Gap volcanic series) in the northern part of the study area; (2) the granitic Log Cabin pluton and Sherman batholith near the Wyoming border; (3) the Eocene Montezuma stock in the central Front Range; (4) the alkalic granitic Mount Princeton pluton of the Sawatch Range; (5) some parts of the alkalic-calcic to alkaline Thirtynine Mile volcanic field in the central part of the study area; and (6) alkaline igneous rocks in the Wet Mountains.

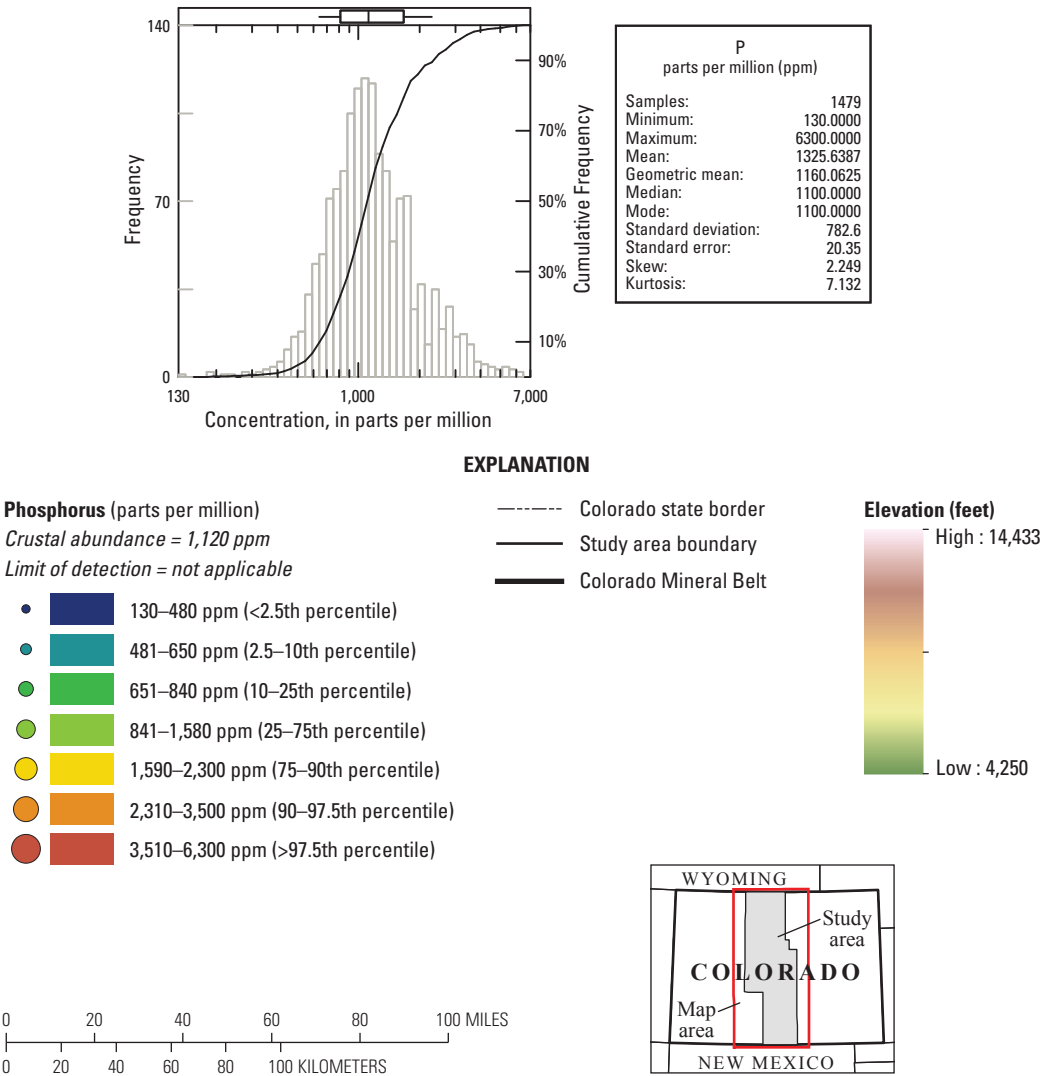


**Figure 57.** Rock units associated with the element niobium in stream sediments of central Colorado.

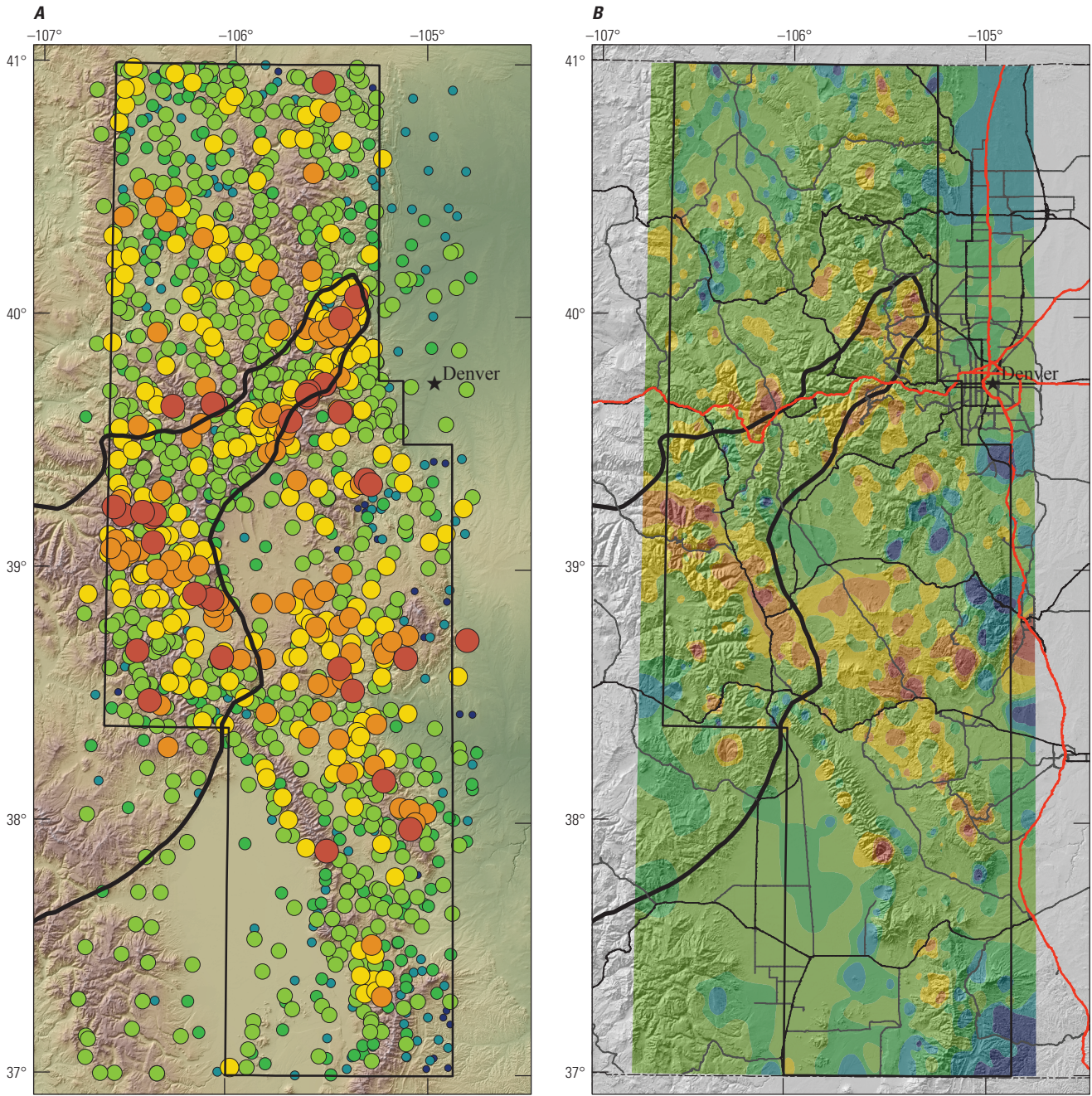




Central Colorado Stream-Sediment  
Geochemistry—Phosphorus



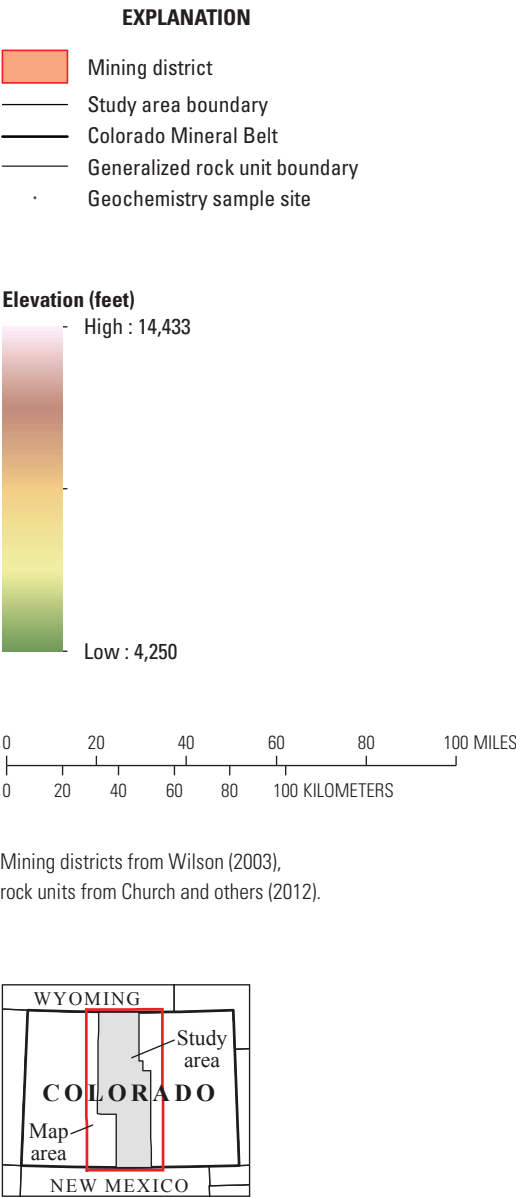
**Figure 58.** Maps of central Colorado stream-sediment geochemistry—phosphorus (P). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



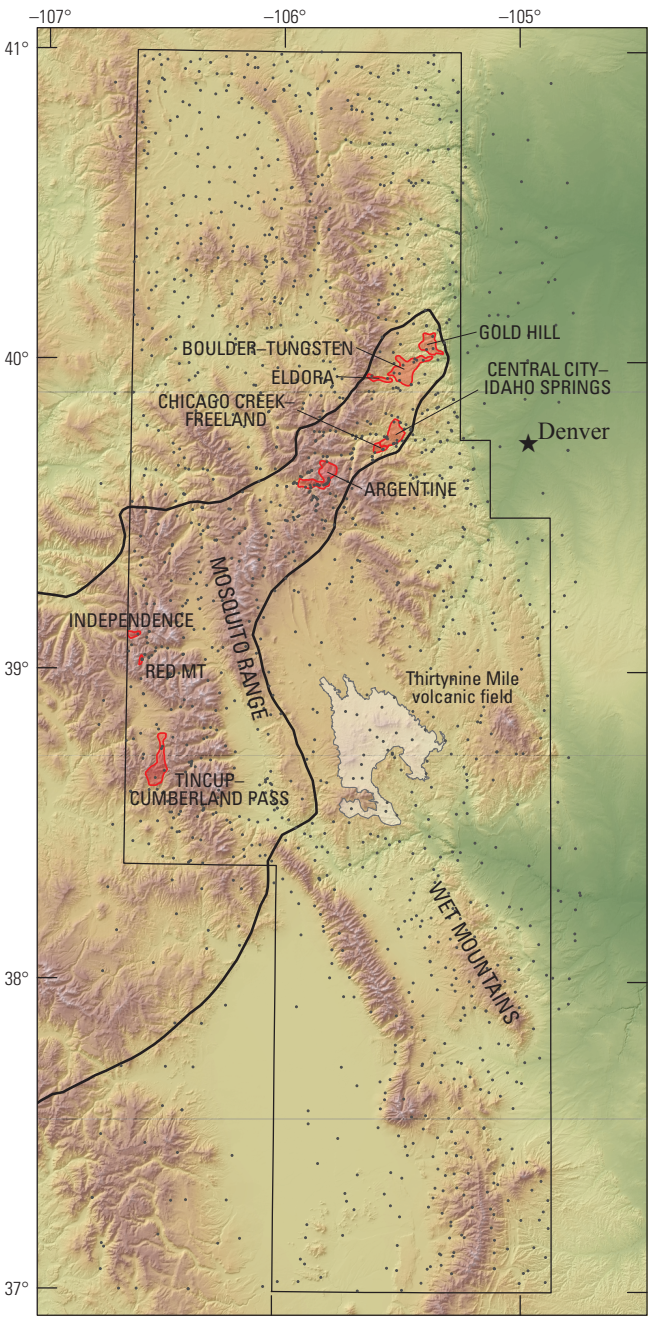


Phosphorus (P) is generally most abundant in mafic igneous rocks and in sedimentary rocks such as phosphorites and shales. Apatite, monazite, and xenotime are the most common phosphate minerals in all rock types, and these minerals are generally resistant to weathering. Phosphate in commercial fertilizers and in sewage effluent can contribute to phosphorus concentrations in downstream sediments and waters.

Within the Colorado Mineral Belt, high phosphorus concentrations (>90th percentile) are present in stream-sediment samples from the northeastern and west-central parts of the belt, including the Argentine, Boulder-Tungsten, Central City–Idaho Springs, Chicago Creek–Freeland, Gold Hill, Independence, Red Mountain, and Tincup–Cumberland Pass districts (figs. 58 and 59). A few scattered clusters occur in the south-central part of the study area and are associated mainly with the intermediate to mafic, alkaline to alkalic-calcic Thirtynine Mile volcanic field and probably with the Cambrian Wet Mountain alkaline complex. Several sample locations with high phosphorus concentrations (>97.5th percentile) lie over Mesoproterozoic granitic rocks in the southern Mosquito Range.



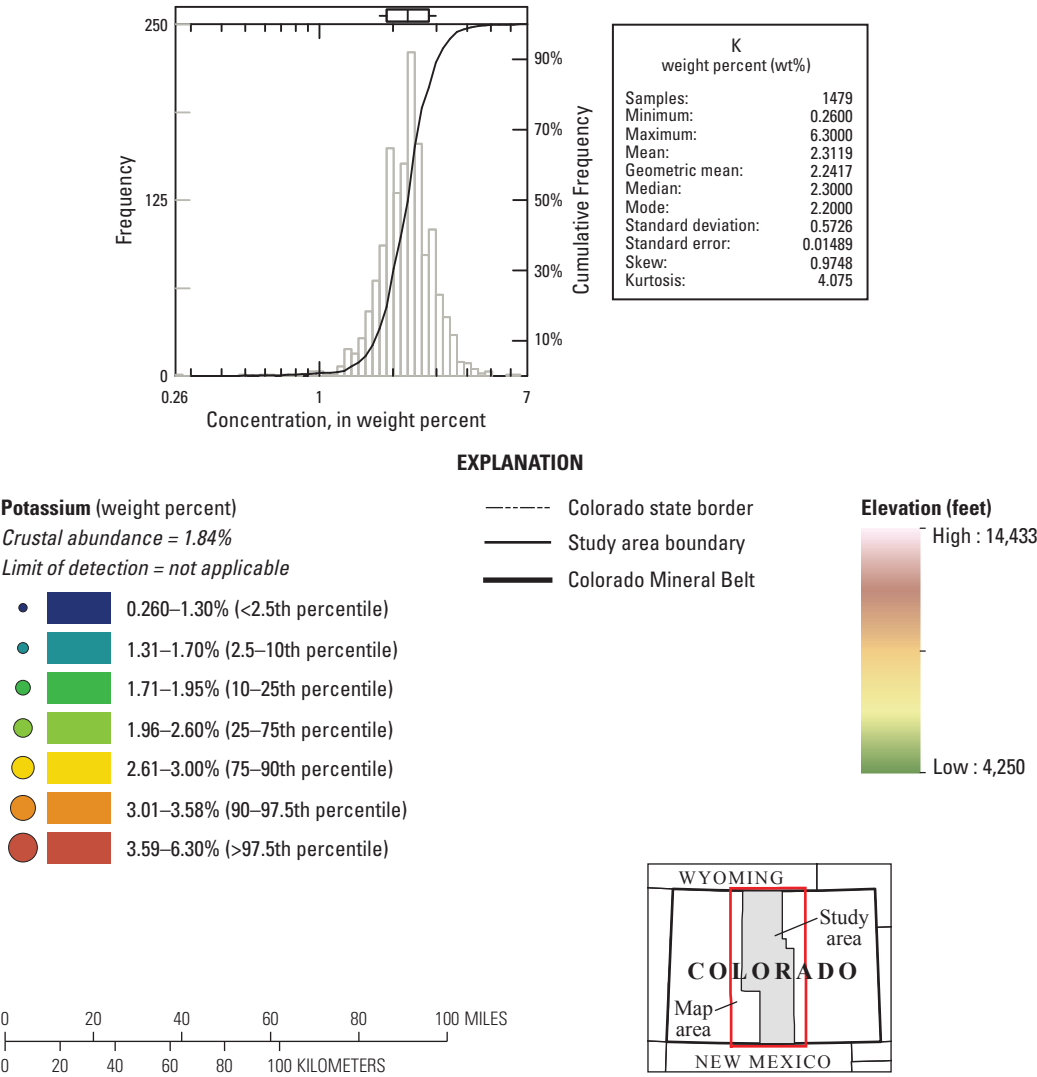
**Figure 59.** Mining districts and rock unit associated with the element phosphorus in stream sediments of central Colorado.



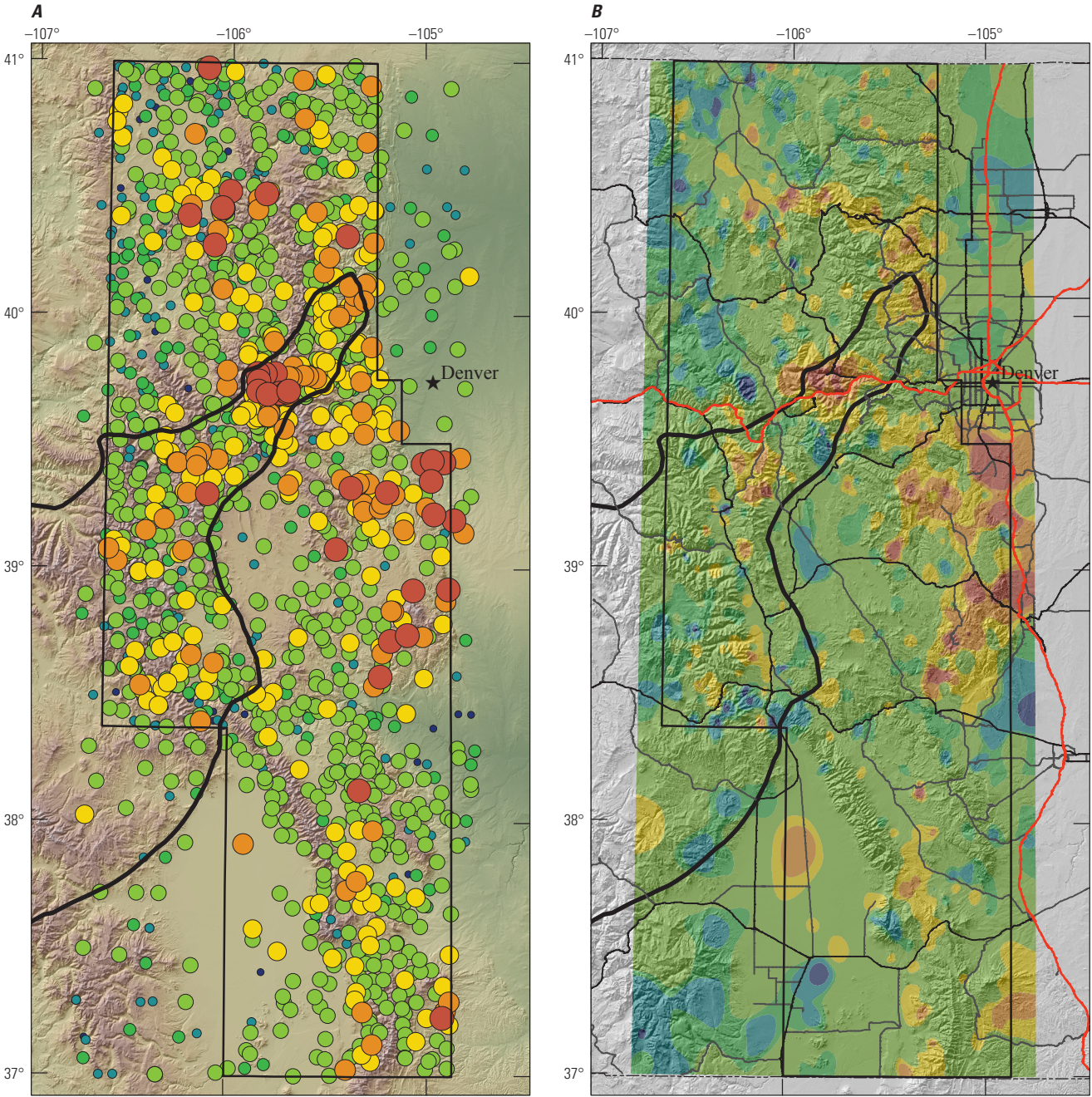




Central Colorado Stream-Sediment  
Geochemistry—Potassium



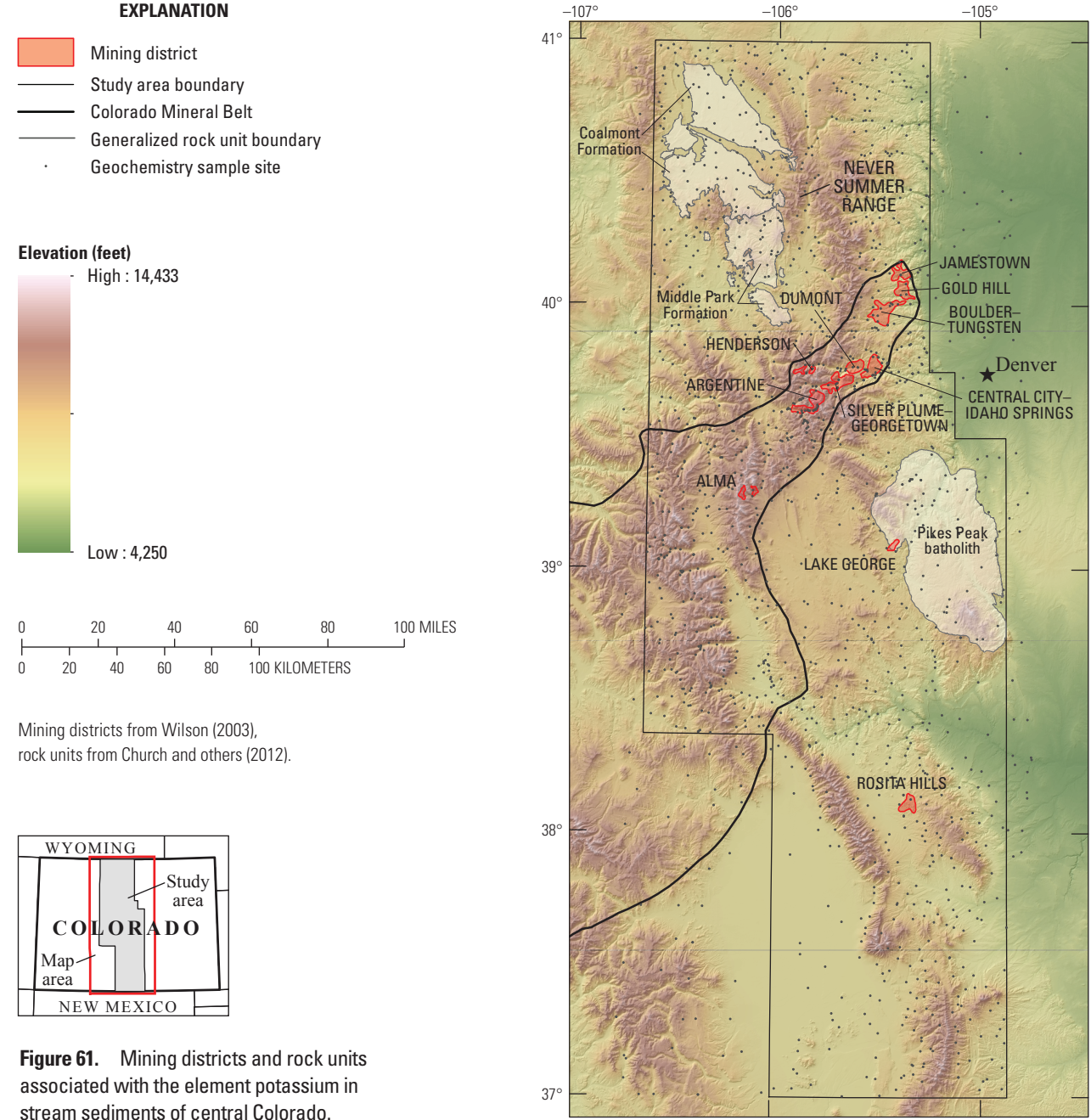
**Figure 60.** Maps of central Colorado stream-sediment geochemistry—potassium (K). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Potassium (K) in igneous rocks is most abundant in felsic rocks, where it is found primarily in potassium feldspar, muscovite, and biotite. Potassium concentrations are low in most sedimentary rocks with the exception of evaporites, immature sedimentary rocks, and illite-bearing rocks. Hydrothermally altered rocks containing sericite (muscovite), biotite, alunite, and jarosite have substantial amounts of potassium. Potassium feldspar is one of the first silicate minerals to dissolve during weathering, and potassium is very soluble (and mobile) in surface water.

North of the Colorado Mineral Belt, a cluster of stream-sediment samples with high potassium concentrations (>97.5th percentile) is associated with numerous Tertiary igneous dikes that intrude the Coalmont and Middle Park Formations and with rhyolitic ash-flow tuffs near the Never Summer Range (figs. 60 and 61). South of the mineral belt, samples with consistently high potassium concentrations (>90th percentile) lie over and surround the Pikes Peak batholith and likely are due to potassium feldspar in the stream sediment. Within the mineral belt, a cluster of high potassium concentrations (>97.5th percentile) is present in samples from the Henderson and Silver Plume–Georgetown districts. Samples with lower level potassium concentrations (90th to 97.5th percentile) encompass a larger area including the Argentine, Central City–Idaho Springs, and Dumont districts. This relation may reflect potassically altered rocks. Another lower level cluster of potassium concentrations (90th to 97.5th percentile) appears in samples from the Boulder-Tungsten, Gold Hill, and Jamestown districts. Outside of the mineral belt, the Lake George and Rosita Hills districts also have samples that contain high potassium concentrations. Within the mining districts, the high potassium concentrations likely are due to hydrothermal alteration minerals or related weathering products in the stream sediment.

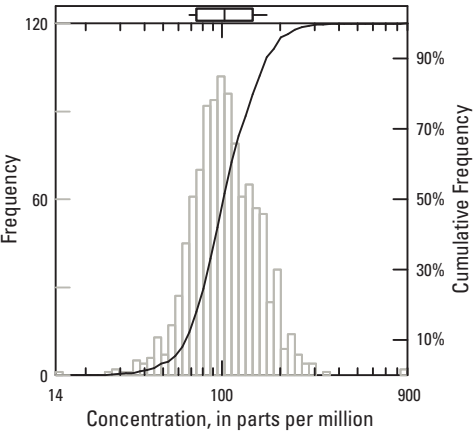


**Figure 61.** Mining districts and rock units associated with the element potassium in stream sediments of central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Rubidium



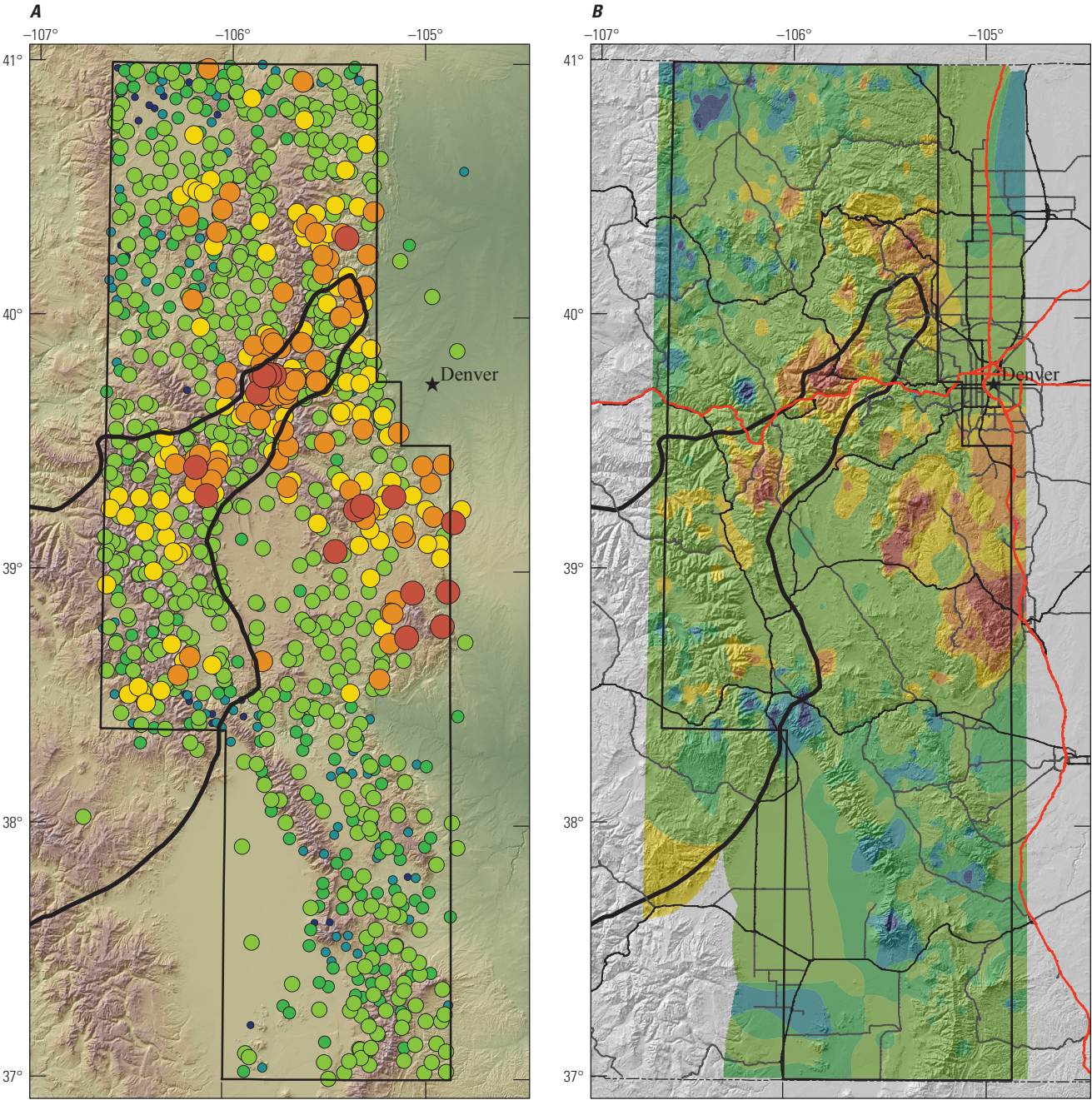
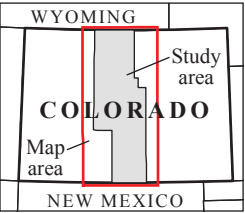
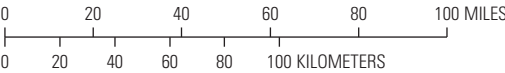
Rb parts per million (ppm)	
Samples:	1064
Minimum:	14.0000
Maximum:	850.0000
Mean:	113.3391
Geometric mean:	104.2883
Median:	100.0000
Mode:	110.0000
Standard deviation:	54.76
Standard error:	1.679
Skew:	5.14
Kurtosis:	60.71

**Rubidium** (parts per million)  
*Crustal abundance = 78.0 ppm*  
*Limit of detection = not applicable*

- 14–47 ppm (<2.5th percentile)
- 48–66 ppm (2.5–10th percentile)
- 67–81 ppm (10–25th percentile)
- 82–140 ppm (25–75th percentile)
- 141–170 ppm (75–90th percentile)
- 171–230 ppm (90–97.5th percentile)
- 231–850 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

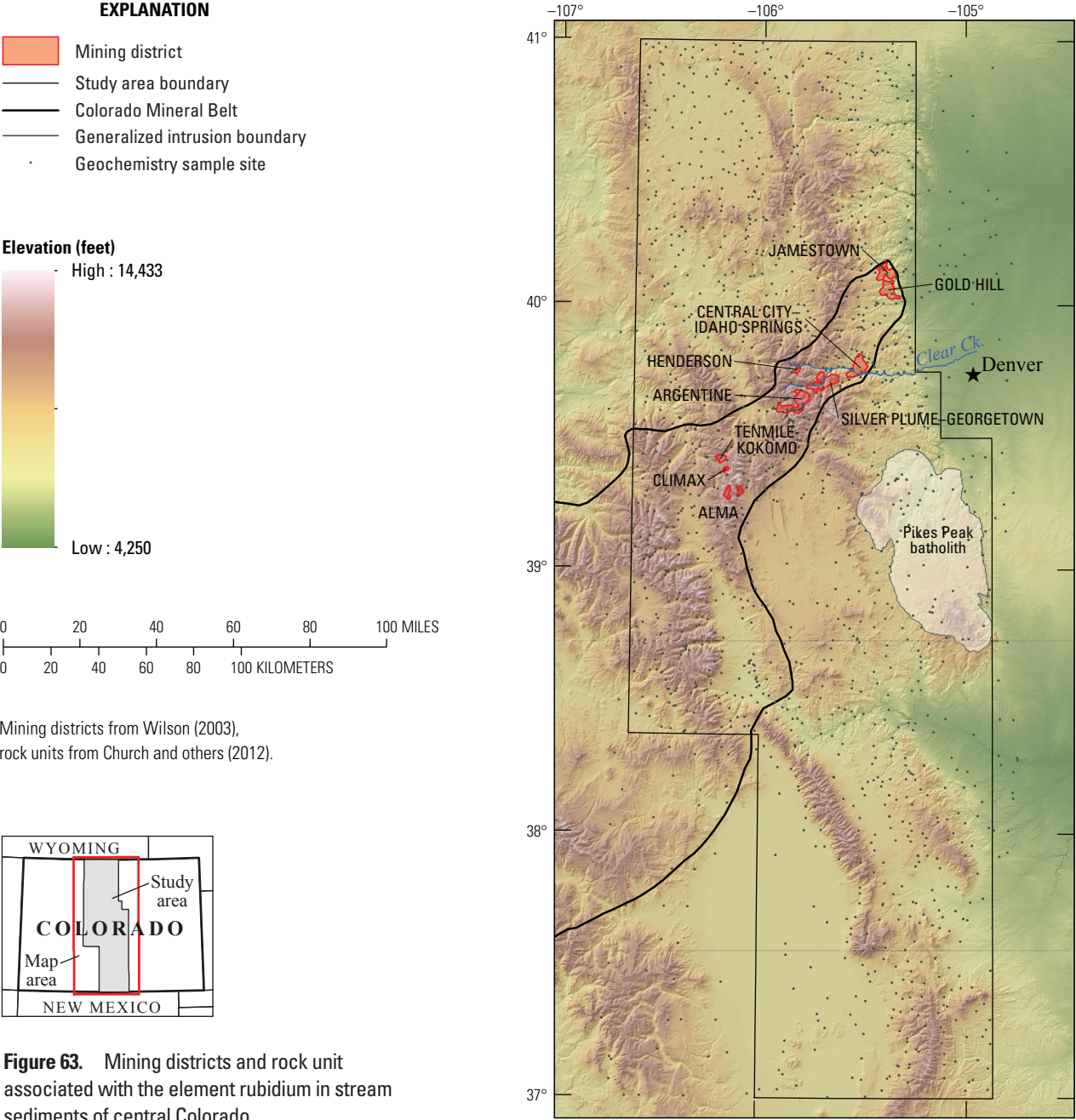


**Figure 62.** Maps of central Colorado stream-sediment geochemistry—rubidium (Rb). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Rubidium (Rb) substitutes for potassium in igneous rocks and is most abundant in felsic rocks, especially those of alkaline composition. It is found primarily in potassium feldspar, muscovite, and biotite. In sedimentary rocks, immature sedimentary rocks, illite-rich rocks, and in some evaporates may be enriched in rubidium. The behavior of rubidium, in terms of solubility and mobility, is similar to that of potassium in the weathering environment.

Rubidium distribution likewise is similar to that of potassium. Within the Colorado Mineral Belt, a cluster of high rubidium concentrations (>97.5th percentile) is present in stream-sediment samples in and downstream from the Henderson district (figs. 62 and 63). Samples with smaller rubidium concentrations (90th to 97.5th percentile) identify the Alma, Argentine, Central City–Idaho Springs, Climax, Gold Hill, Jamestown, Silver Plume–Georgetown, and Tenmile-Kokomo districts. Those high concentrations are likely due to the presence of potassium-altered rocks in the hydrothermal systems and to the presence of felsic intrusive igneous rocks. In the south-central part of the study area, a large cluster of samples with high potassium concentrations (>90th percentile) lies over the Pikes Peak batholith, probably owing to unweathered potassium feldspar in stream sediments.

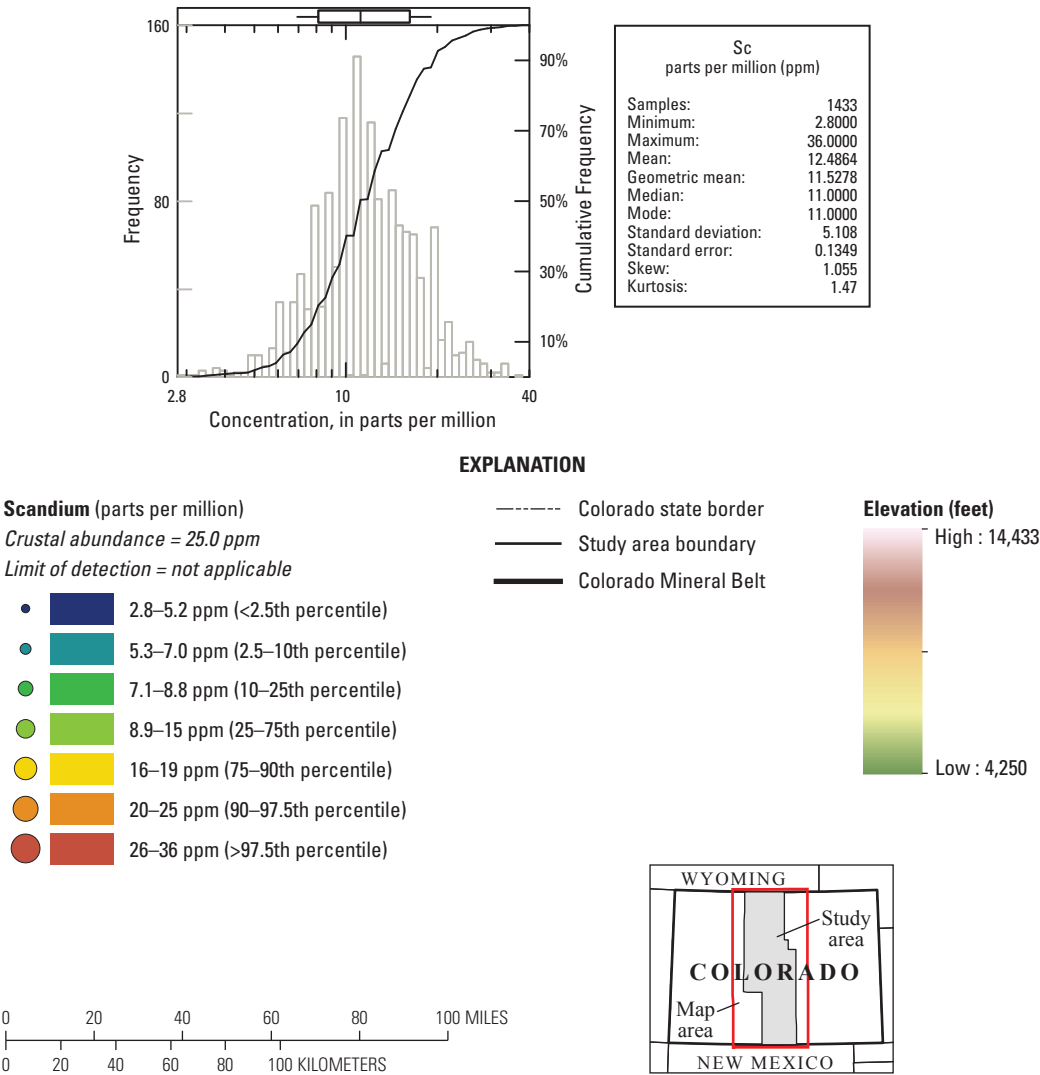


**Figure 63.** Mining districts and rock unit associated with the element rubidium in stream sediments of central Colorado.

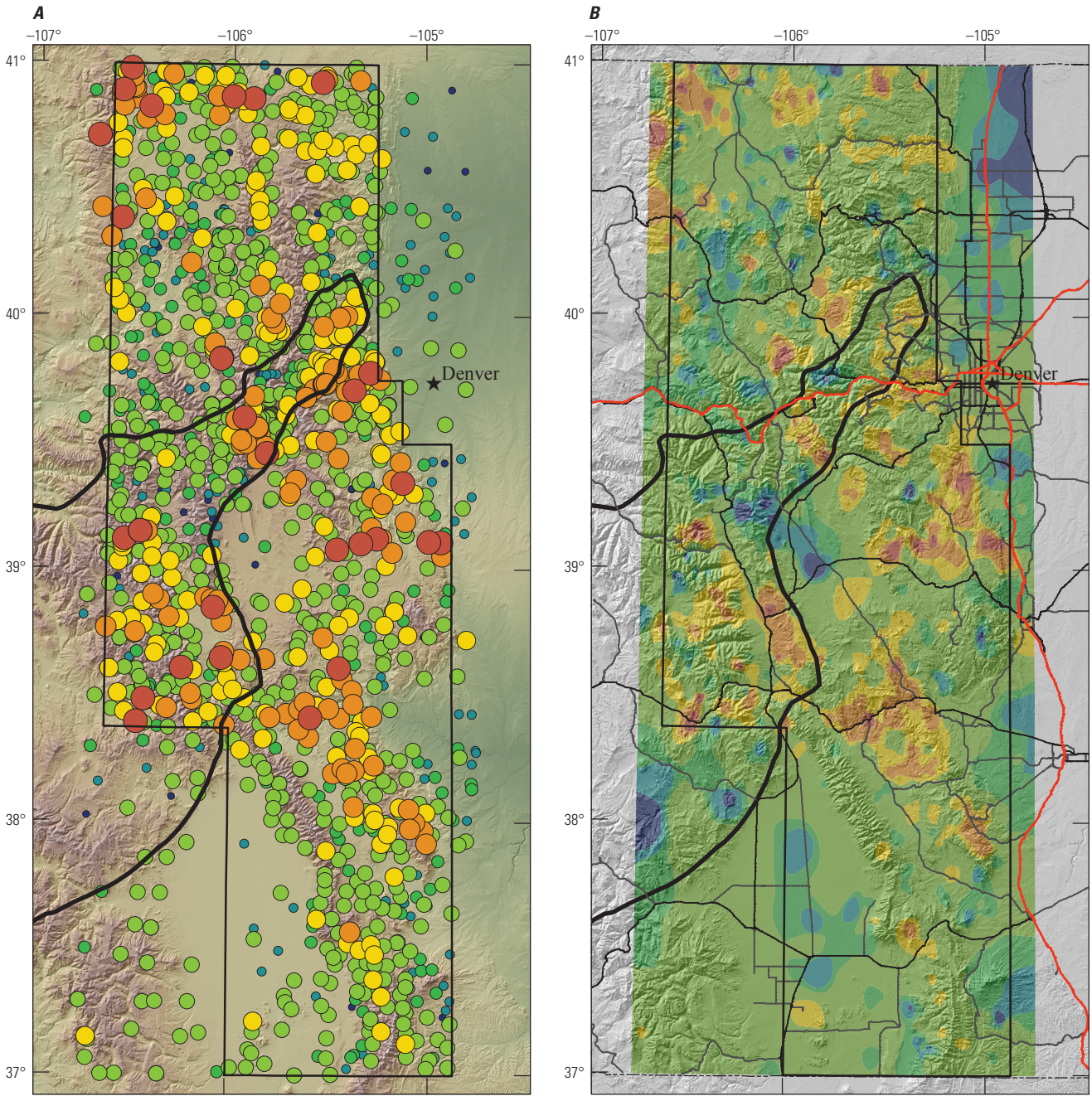




Central Colorado Stream-Sediment  
Geochemistry—Scandium



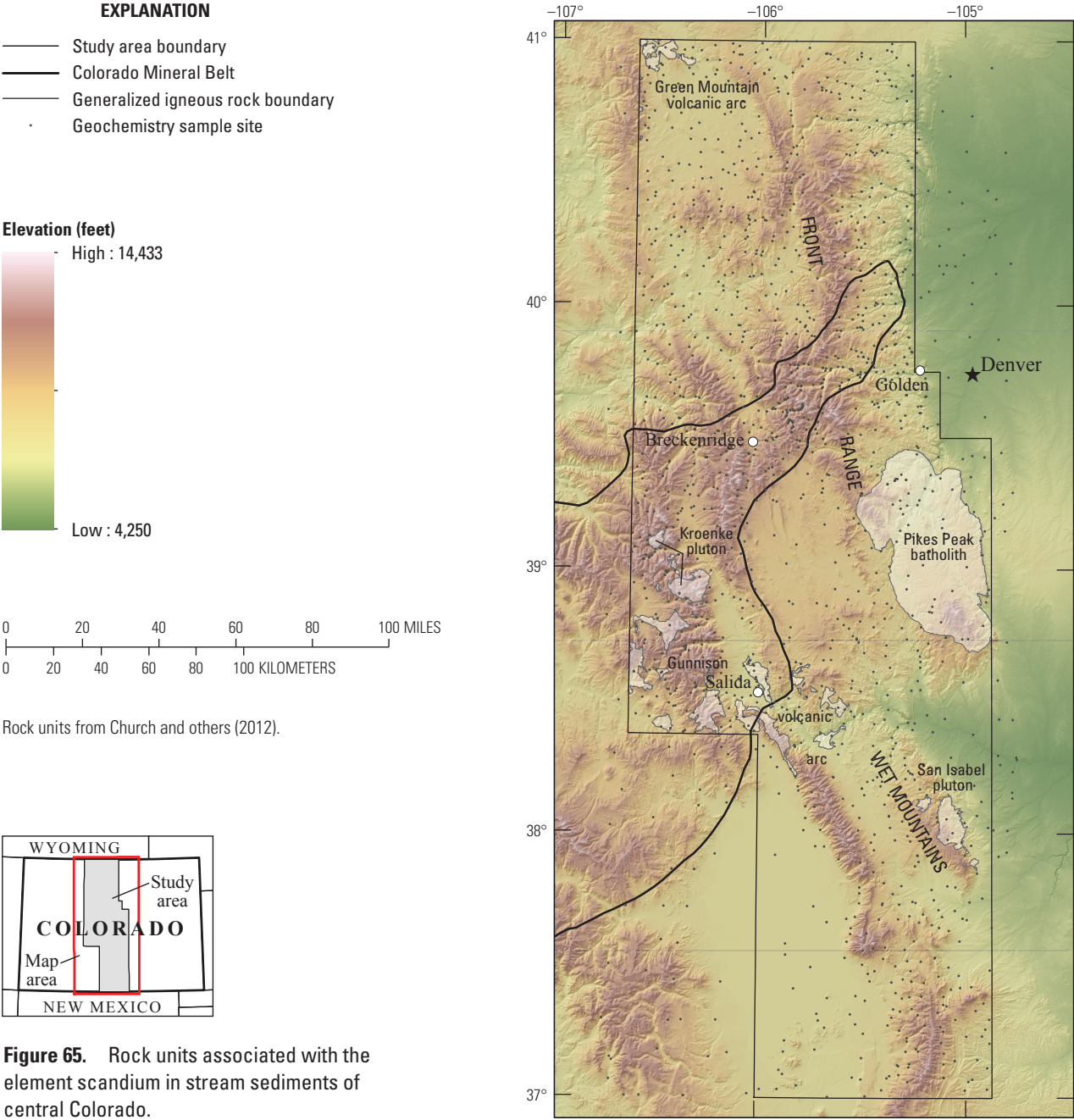
**Figure 64.** Maps of central Colorado stream-sediment geochemistry—scandium (Sc). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Scandium (Sc) concentrations are highest in mafic and ultramafic igneous rocks where the element is concentrated in minerals of the pyroxene and amphibole groups and in biotite. Scandium also may be concentrated by igneous differentiation into some granites and granite pegmatites in minerals of the garnet group, in tourmaline, and in beryl. Scandium concentrations in sedimentary rocks generally are quite low. It is a relatively immobile element in the weathering environment.

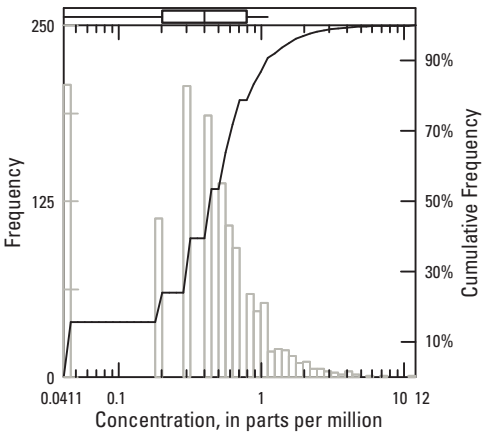
In the study area, high scandium concentrations (>90th percentile) generally are related to the rock type and not related to mineral deposits. High scandium concentrations are found in stream-sediment samples derived from several groups of Proterozoic igneous and meta-igneous rocks (figs. 64 and 65), such as a widespread group of mafic and ultramafic metavolcanic rocks that are part of the eastern Gunnison volcanic arc, near Salida and extending into the northern Wet Mountains; the Green Mountain arc in the far northern part of the study area; and mafic metavolcanic and metagabbroic rock enclaves near Swandyke, east of Breckenridge, and in the Front Range immediately west of Golden. Finally, samples from areas that lie over several Proterozoic granitic bodies also contain high concentrations, including the Kroenke pluton in the Sawatch Range, the San Isabel pluton in the southern Wet Mountains, and the main phase of the Pikes Peak batholith in the southern Front Range.







Central Colorado Stream-Sediment  
Geochemistry—Selenium



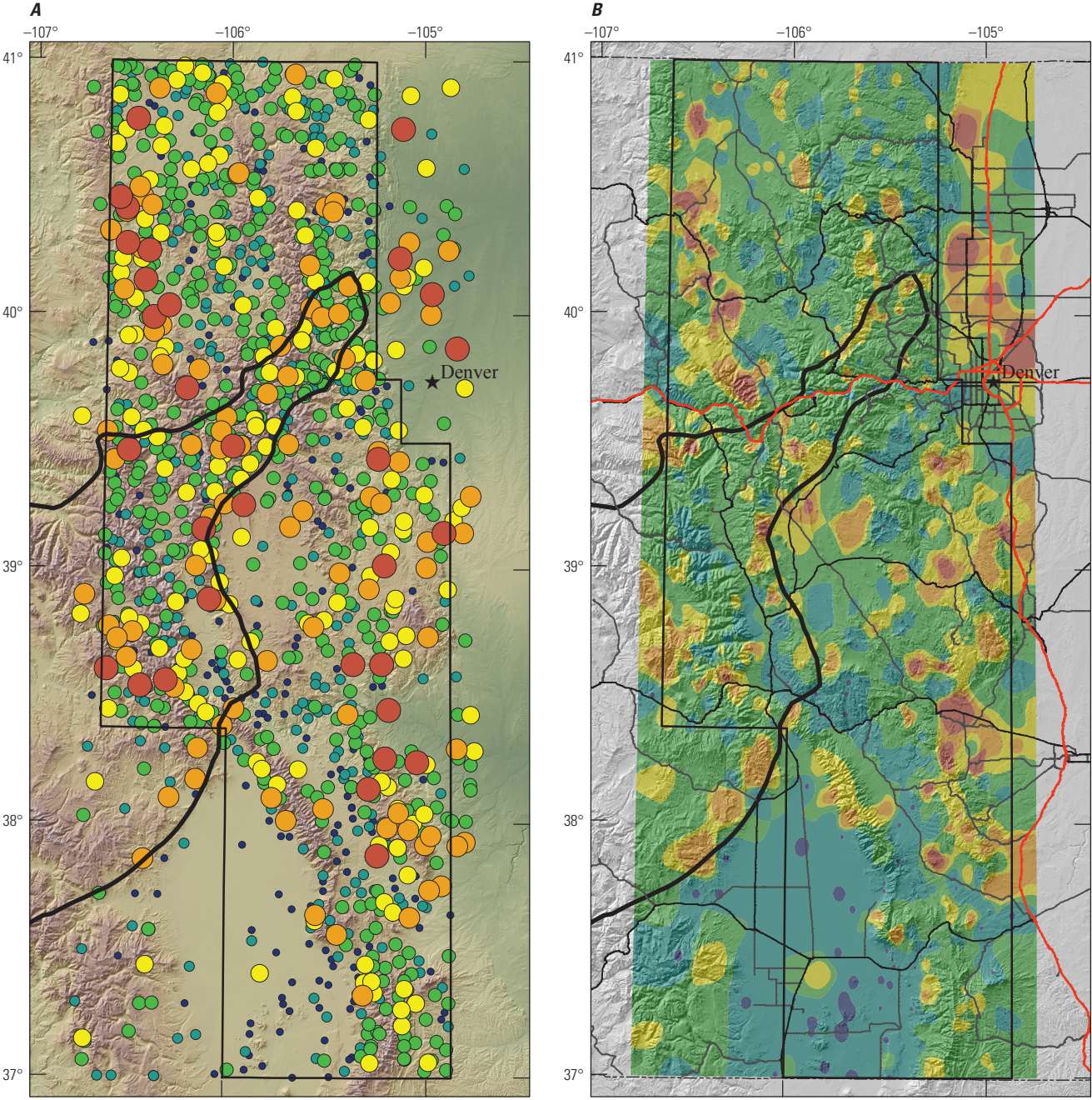
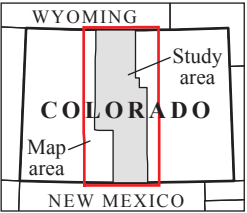
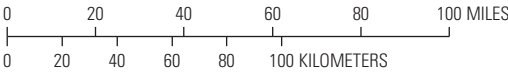
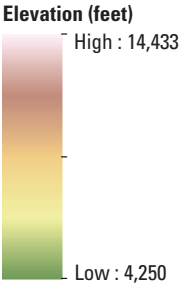
Se parts per million (ppm)	
Samples:	1334
Minimum:	<0.2
Maximum:	11.0000
Mean:	0.5692
Geometric mean:	0.3523
Median:	0.4000
Mode:	0.0411
Standard deviation:	0.6579
Standard error:	0.01801
Skew:	5.852
Kurtosis:	63.77

**Selenium** (parts per million)  
Crustal abundance = 0.050 ppm  
Limit of detection = 0.2 ppm

- <0.2 ppm (<10th percentile)
- 0.20–0.30 ppm (10–25th percentile)
- 0.31–0.70 ppm (25–75th percentile)
- 0.71–1.1 ppm (75–90th percentile)
- 1.2–2.0 ppm (90–97.5th percentile)
- 2.1–11 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

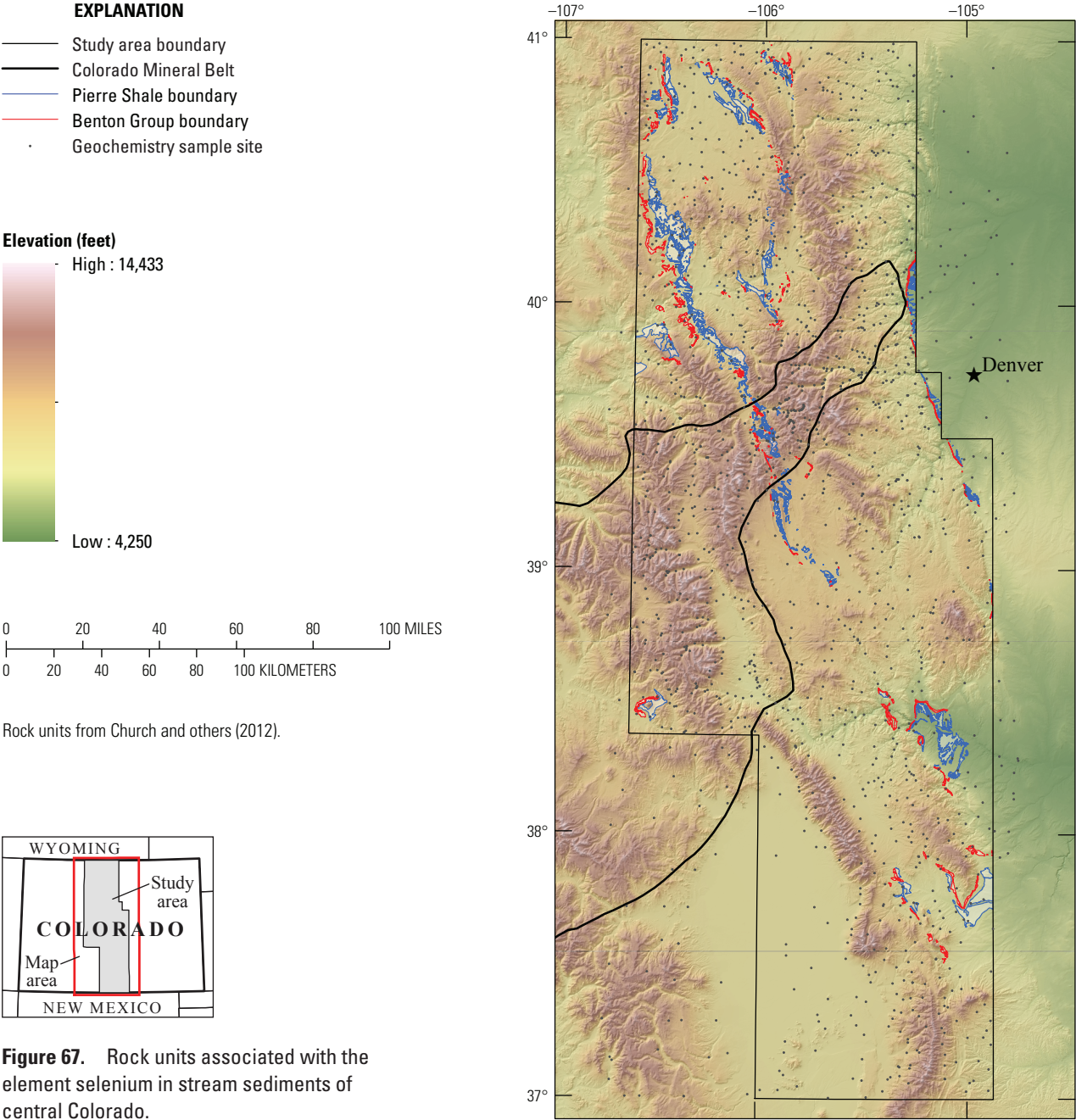


**Figure 66.** Maps of central Colorado stream-sediment geochemistry—selenium (Se). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Selenium (Se) is similar to sulfur in its geochemistry. Sulfide mineral-rich rocks and hydrothermal veins, especially those formed at low temperatures, may be enriched in selenium, as also may be organic-rich sedimentary rocks. During weathering, it is immobile in acidic conditions and concentrated in iron oxyhydroxides, clay minerals, and organic material. Under alkaline conditions, selenium is very mobile in surface water.

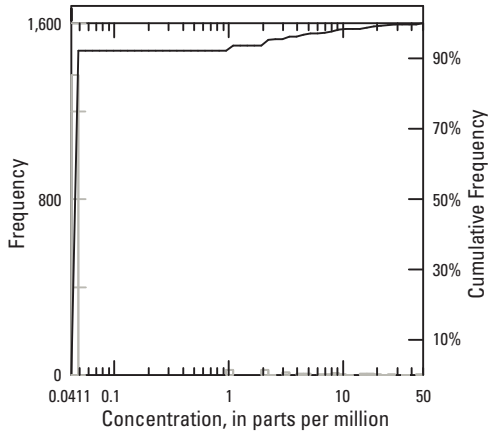
Stream-sediment samples having relatively high selenium concentrations are scattered throughout the study area and probably reflect various rock types rather than mineral deposits. The most consistent bedrock relation with selenium is shown by clusters of samples with high selenium concentrations (>90th percentile), which lie over Cretaceous sedimentary rock units that contain substantial amounts of organic-rich shales, such as the Benton and Pierre Shales (figs. 66 and 67). Such clusters lie in the northwestern, southeastern, and west-central parts of the study area. Other scattered samples with high selenium concentrations (>90th percentile) occur throughout the area with no clear relation either to bedrock or to mineral deposits.







Central Colorado Stream-Sediment  
Geochemistry—Silver



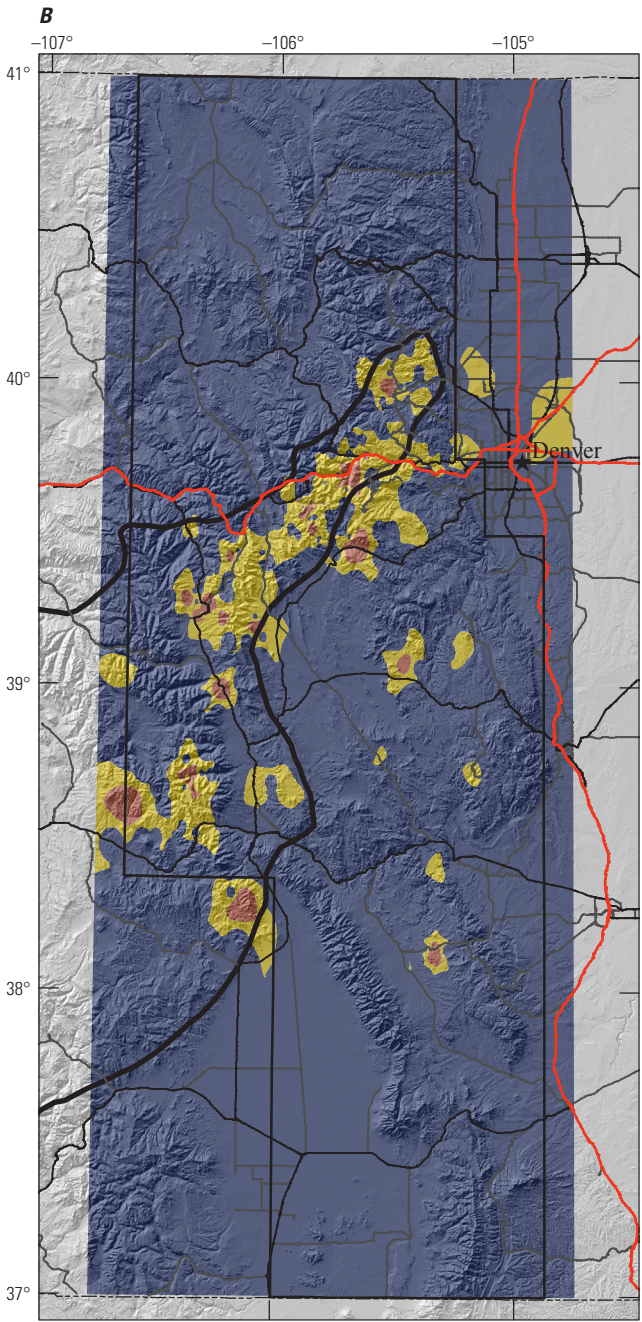
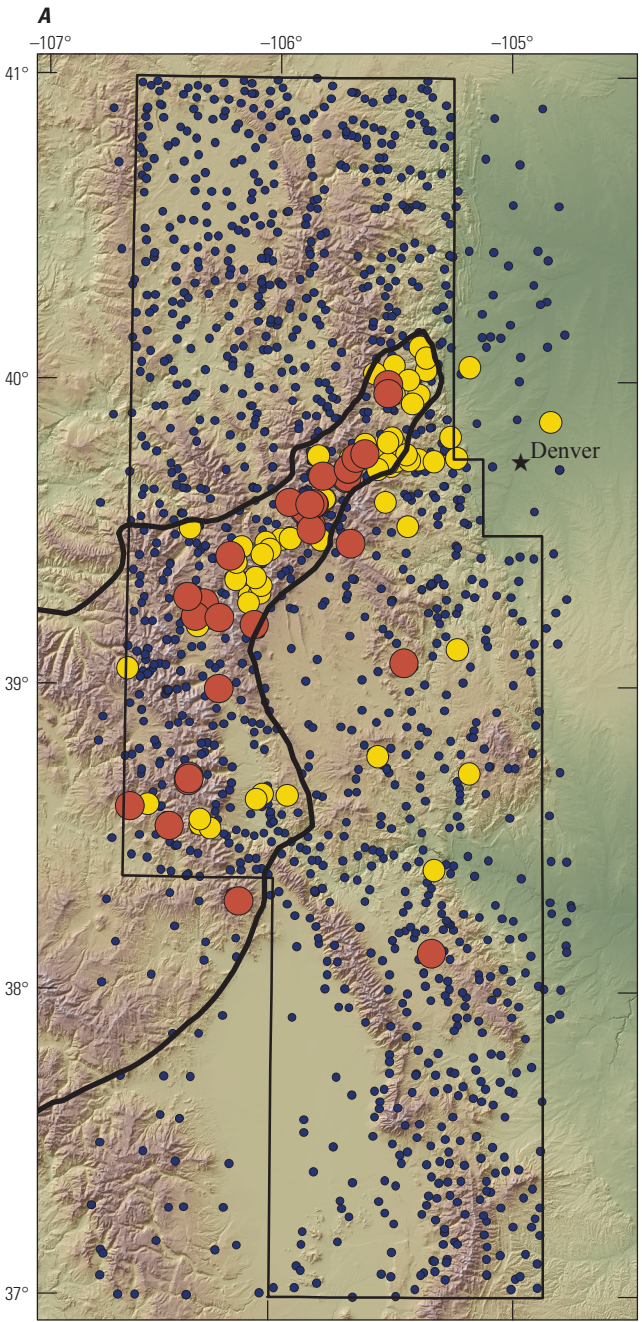
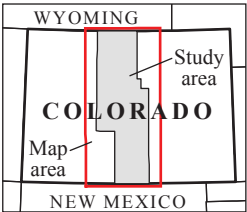
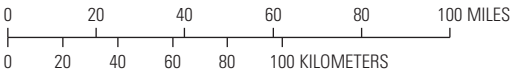
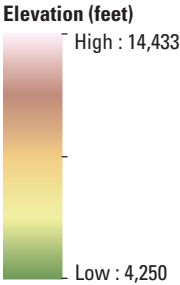
Ag parts per million (ppm)	
Samples:	1479
Minimum:	<0.2
Maximum:	48.0000
Mean:	0.6373
Geometric mean:	0.0605
Median:	<0.2
Mode:	<0.2
Standard deviation:	3.463
Standard error:	0.09006
Skew:	9.002
Kurtosis:	96.45

**Silver** (parts per million)  
Crustal abundance = 0.080 ppm  
Limit of detection = 0.2 ppm

- <0.2 ppm (<90th percentile)
- 0.2–7 ppm (90–97.5th percentile)
- 7–48 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

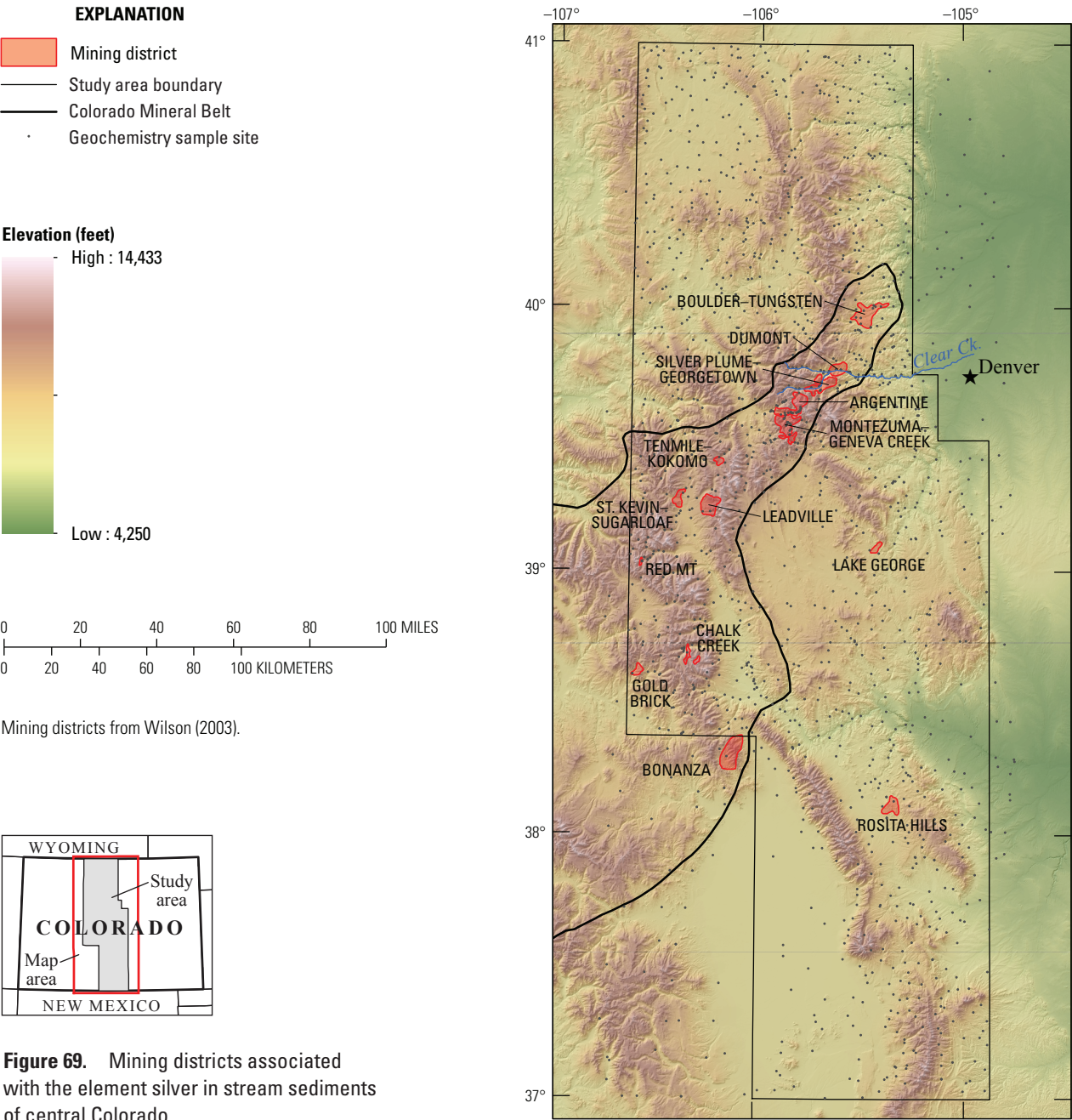


**Figure 68.** Maps of central Colorado stream-sediment geochemistry—silver (Ag). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Silver (Ag) is a strongly chalcophile element concentrated primarily in sulfide and telluride hydrothermal deposits. It is present primarily in sulfide, sulfosalt, and telluride minerals or as chloride or sulfate minerals following weathering of the primary minerals. Native silver is common in some deposits. Locally, silver is found in stratabound sediment-hosted deposits where it is deposited from percolating groundwater as silver chloride. Silver is mobile in surface water and may be adsorbed by manganese and iron oxyhydroxides and organic matter.

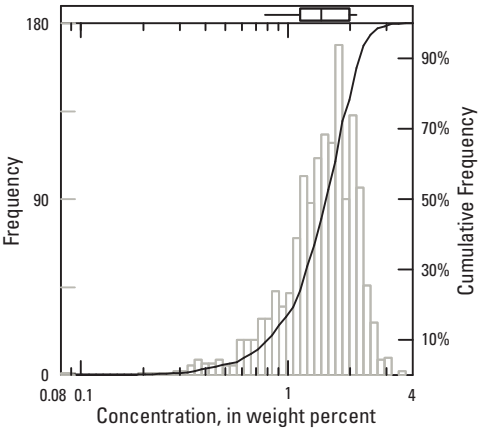
Silver was not detected in the majority of the stream-sediment samples (analyzed at 0.2 parts per million (ppm), the limit of detection), so discussion of silver distributions is limited to those samples in and above the 90th percentile. Stream-sediment samples having high silver concentrations (>90th percentile) strongly delineate the Colorado Mineral Belt (figs. 68 and 69). The highest concentrations (>97.5th percentile) are from samples that lie over known mining districts throughout the study area, including the Argentine, Boulder-Tungsten, Chalk Creek, Dumont, Goldbrick, Lake George, Leadville, Montezuma–Geneva Creek, Red Mountain, Rosita Hills, St. Kevin–Sugarloaf, and Tenmile–Kokomo districts. A lower-level (90th to 97.5th percentile) dispersion train of silver is evident in samples from the Silver Plume-Georgetown district downstream along Clear Creek to the range front. Just outside the study area boundary in the southern part of the mineral belt, a single sample containing anomalous silver and several other metals was obtained from the Bonanza district (see copper discussion, fig. 27).







Central Colorado Stream-Sediment  
Geochemistry—Sodium



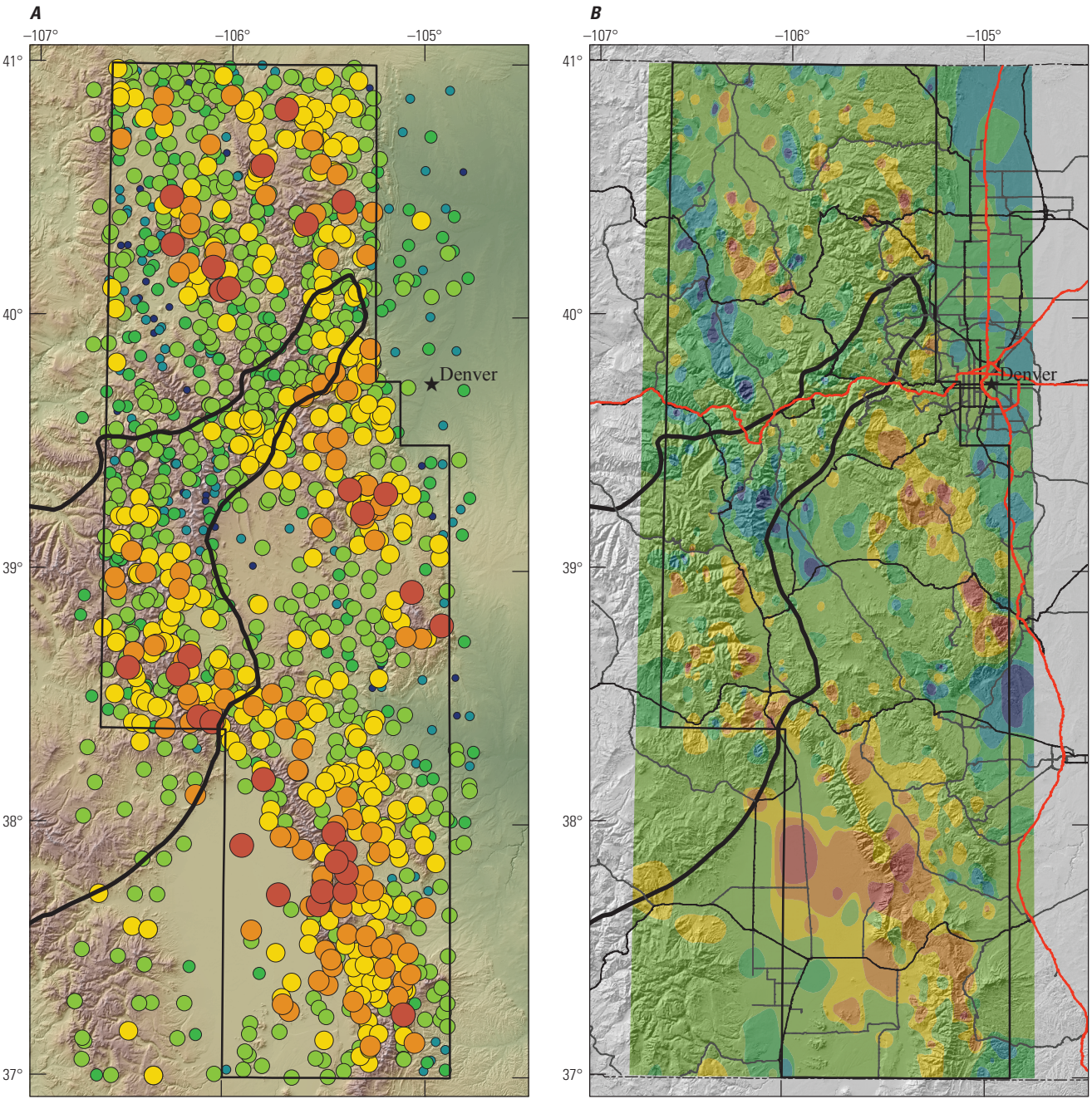
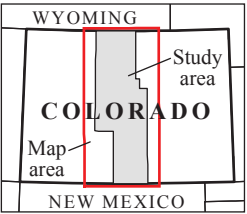
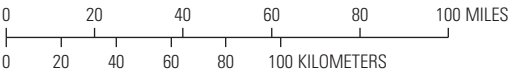
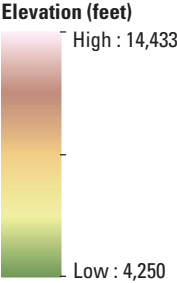
Na weight percent (wt%)	
Samples:	1479
Minimum:	0.0800
Maximum:	3.6000
Mean:	1.5218
Geometric mean:	1.4049
Median:	1.5000
Mode:	1.5000
Standard deviation:	0.5452
Standard error:	0.01418
Skew:	0.1052
Kurtosis:	-0.05621

**Sodium (weight percent)**  
Crustal abundance = 2.27%  
Limit of detection = not applicable

- 0.0800–0.4500% (<2.5th percentile)
- 0.4501–0.8000% (2.5–10th percentile)
- 0.8001–1.175% (10–25th percentile)
- 1.176–1.790% (25–75th percentile)
- 1.791–2.200% (75–90th percentile)
- 2.201–2.600% (90–97.5th percentile)
- 2.601–3.600% (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

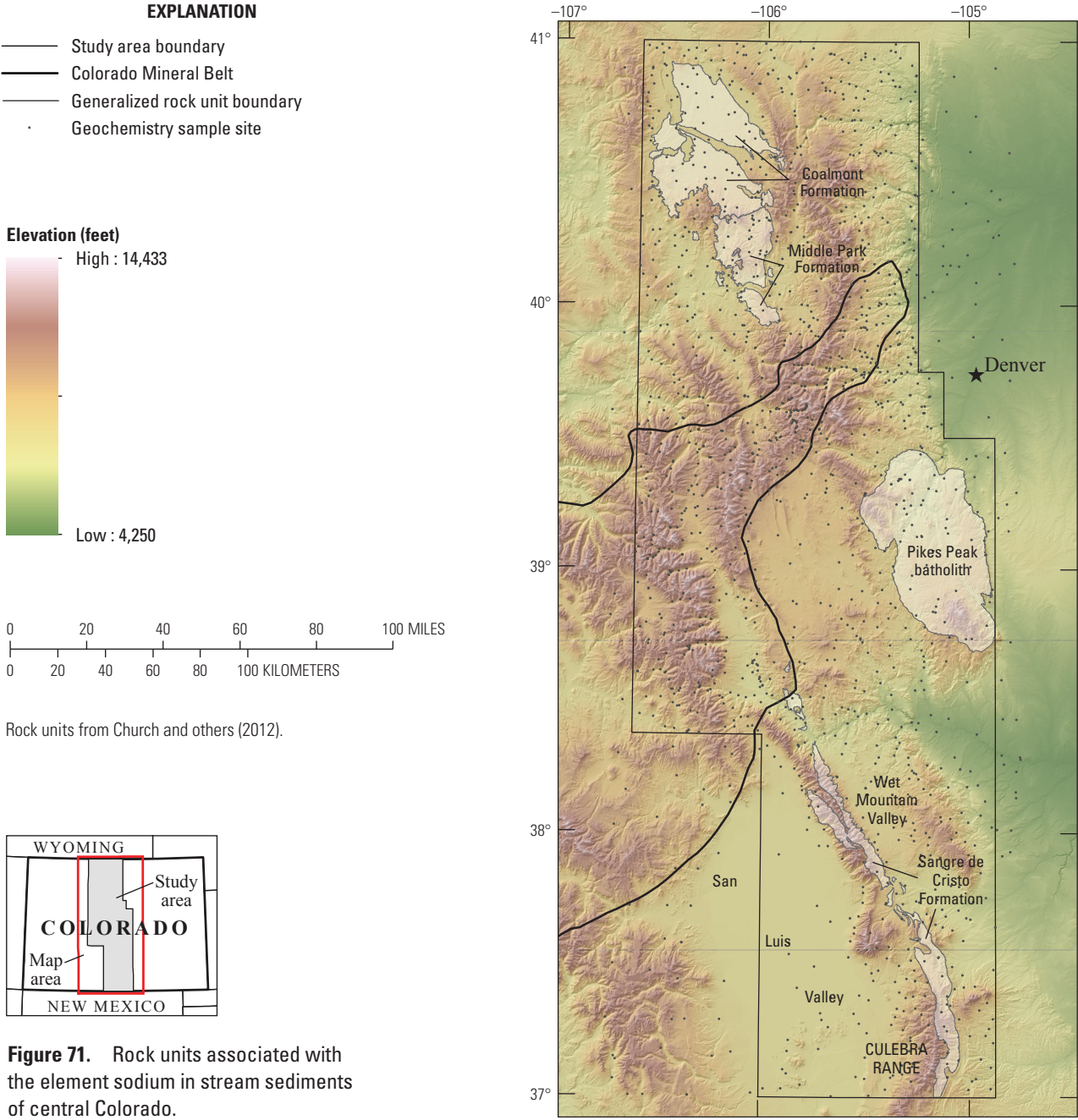


**Figure 70.** Maps of central Colorado stream-sediment geochemistry—sodium (Na). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Sodium (Na) is most abundant in felsic igneous rocks where it is the principal cation in albite. Albite is one of the first silicate minerals to dissolve during weathering, and sodium is one of the elements most soluble in surface water. Sodium concentrations are low in most sedimentary rocks, with the exception of evaporites. Sodium is extremely mobile in the weathering environment. Under wet or humid conditions, sodium is extremely mobile and easily moved by streams. Sodium then is redistributed downstream as evaporation proceeds.

High sodium concentrations in the study area generally are related to bedrock type and particularly to weathering, rather than to mineral deposits. Sodium is most abundant (>75th percentile) over many granitic bodies, such as the Pikes Peak batholith, probably owing to the presence of variably weathering albite in immature sediment derived from the igneous rock (figs. 70 and 71). A diffuse cluster of stream-sediment samples with high sodium concentrations (>90th percentile) is associated with the Middle Park and Coalmont Formations in the north-central part of the study area. In the southern third of the study area, many samples with high sodium concentrations (>90th percentile) correlate with basin-fill deposits in the Wet Mountain Valley, the San Luis Valley, and the Sangre de Cristo Formation on the eastern flank of the Culebra Range. In many (perhaps most) cases, sodium may have been removed by streams from highland areas and concentrated by evaporation at lower elevations in basin-fill deposits.

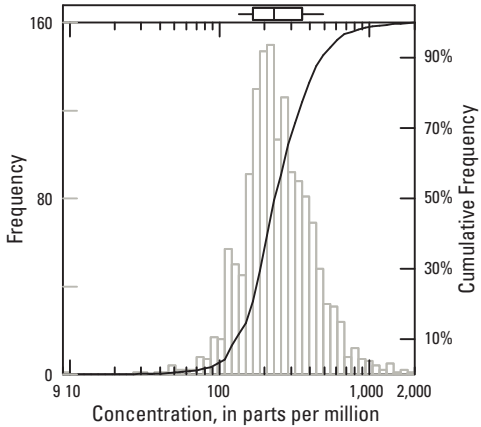


**Figure 71.** Rock units associated with the element sodium in stream sediments of central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Strontium



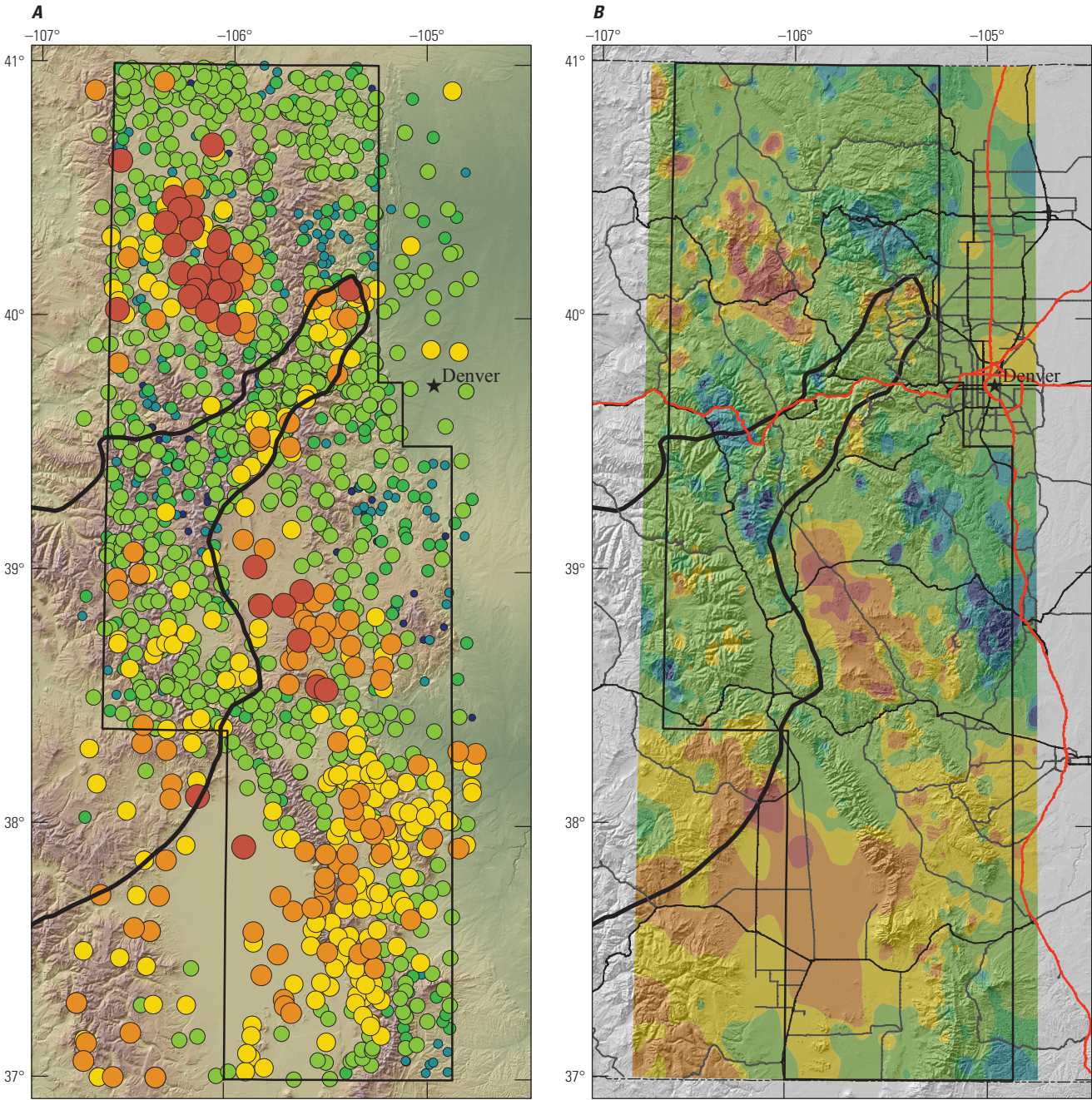
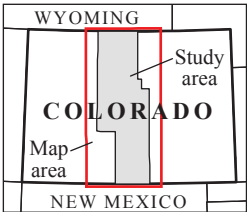
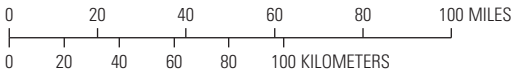
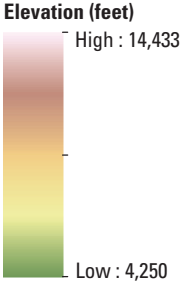
Sr parts per million (ppm)	
Samples:	1479
Minimum:	9.0000
Maximum:	1800.0000
Mean:	283.0230
Geometric mean:	243.0534
Median:	236.0000
Mode:	190.0000
Standard deviation:	184.8
Standard error:	4.806
Skew:	2.985
Kurtosis:	14.23

**Strontium (parts per million)**  
Crustal abundance = 384 ppm  
Limit of detection = not applicable

- 9.00–91.0 ppm (<2.5th percentile)
- 91.1–130 ppm (2.5–10th percentile)
- 131–174 ppm (10–25th percentile)
- 175–336 ppm (25–75th percentile)
- 337–470 ppm (75–90th percentile)
- 471–790 ppm (90–97.5th percentile)
- 791–1,800 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

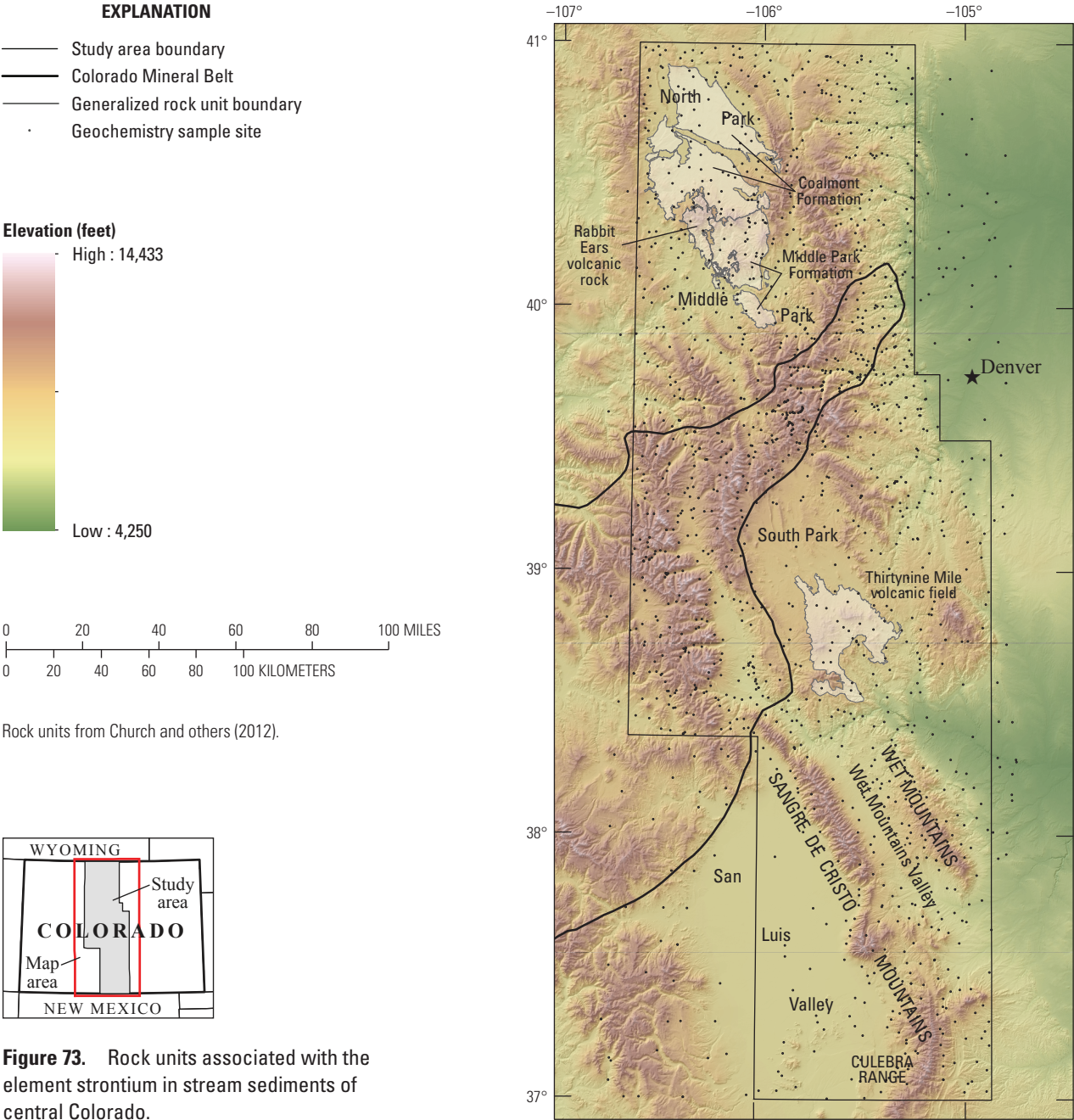


**Figure 72.** Maps of central Colorado stream-sediment geochemistry—strontium (Sr). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Strontium (Sr) is an alkali-earth element similar to calcium and barium in its geochemistry. In igneous rocks it is found mostly in plagioclase and is most abundant in feldspars of intermediate compositions. It also occurs to a limited extent in apatite, calcic pyroxenes and amphiboles, and in some potassium feldspars. In sedimentary rocks, carbonate and evaporite rocks may be enriched in strontium. It is relatively mobile during weathering. Like sodium, under wet or humid conditions, strontium is mobile and easily moved by streams. Strontium can then be redistributed downstream as evaporation proceeds.

High strontium concentrations in the study area generally are related to bedrock type and surface-water evaporation rather than to mineral deposits. A cluster of stream-sediment samples having high strontium concentrations (>90th percentile) in the northern part of the study area lies over rocks of the Coalmont and particularly the Middle Park Formations, and the alkalic-calcic to alkaline, intermediate to felsic composition Rabbit Ears volcanic sequence (figs. 72 and 73). Another cluster of samples with high strontium concentrations (>90th percentile) lies over the alkalic-calcic to alkaline, intermediate-composition volcanic and shallow intrusive rocks of the Thirtynine Mile volcanic field. In the southern part of the study area many samples with high strontium concentrations (in the 90th to 97.5th percentile range) lie over alkalic-calcic, intermediate-composition volcanic rocks present in the Wet Mountains and the northern Culebra Range; adjacent Cenozoic basins containing rocks derived from similar intermediate-composition volcanic sources; and some Proterozoic intermediate-composition units in the southern Sangre de Cristo Mountains. High strontium concentrations in stream sediments in basins, such as the Wet Mountain Valley, North Park, Middle Park, and South Park basins, might be related to near-surface redistribution as streams pick up strontium in adjacent highlands and deposit it in adjacent valleys by evaporation. Strontium distribution is similar to that of barium, except that many hydrothermal-vein systems in the Colorado Mineral Belt are enriched in barium.

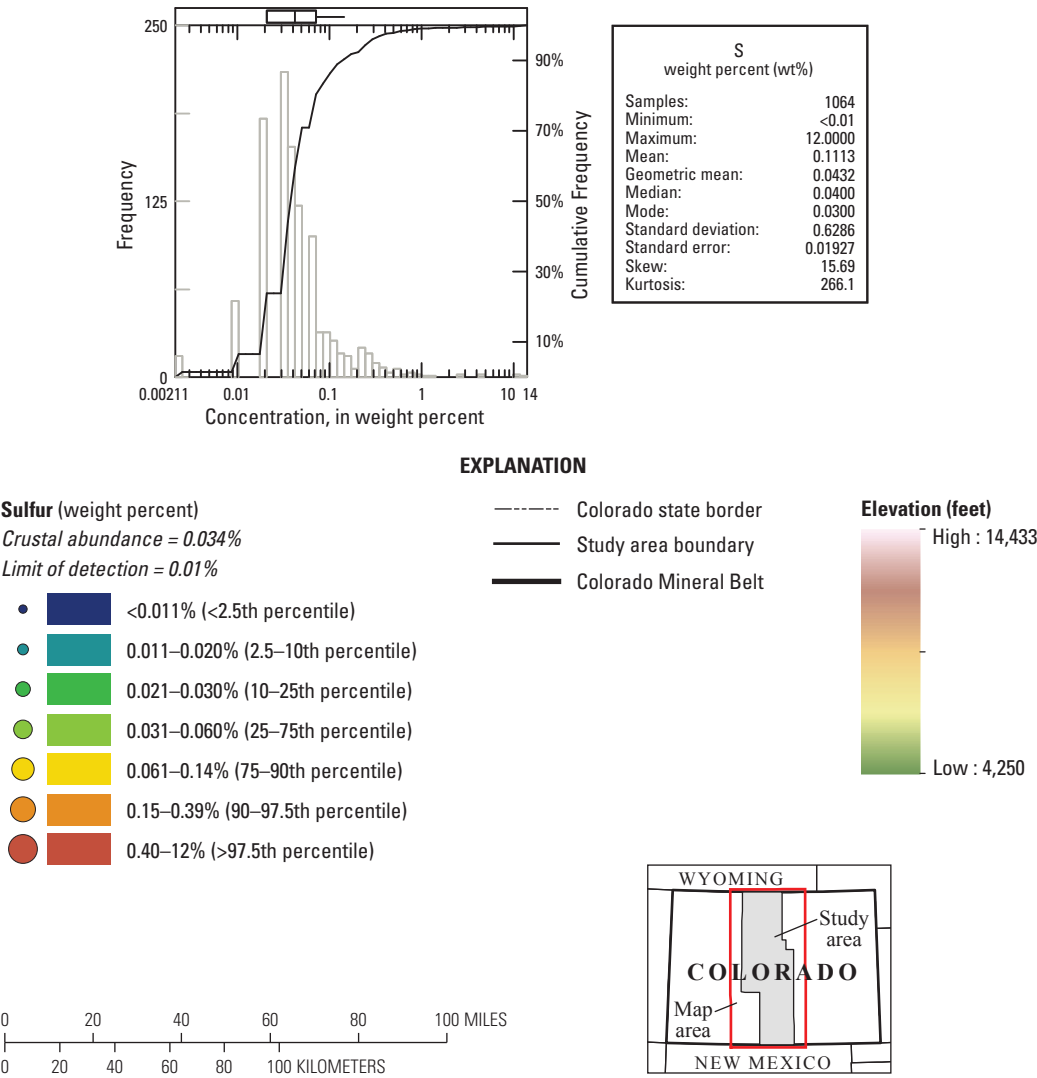


**Figure 73.** Rock units associated with the element strontium in stream sediments of central Colorado.

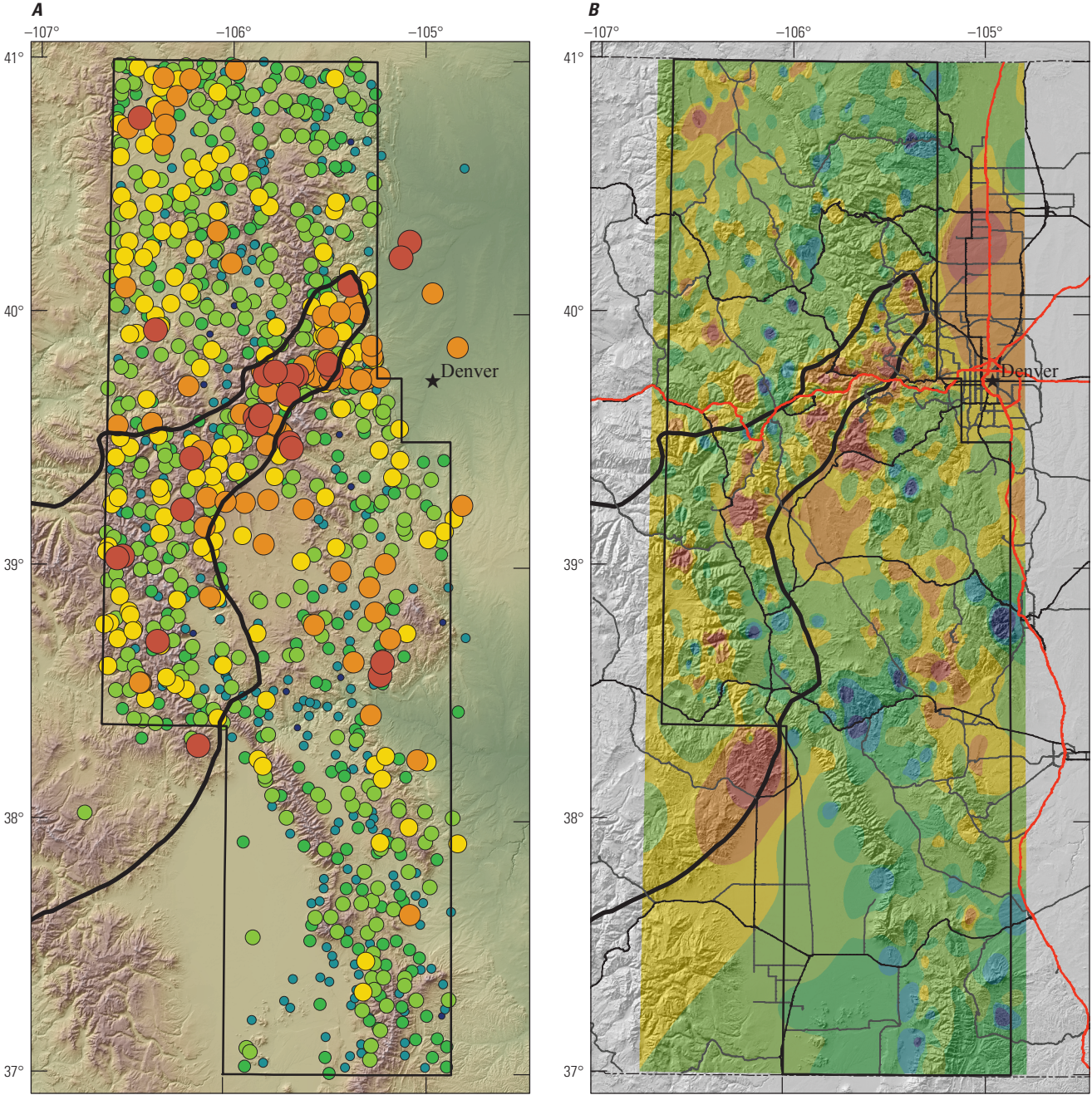




Central Colorado Stream-Sediment  
Geochemistry—Sulfur



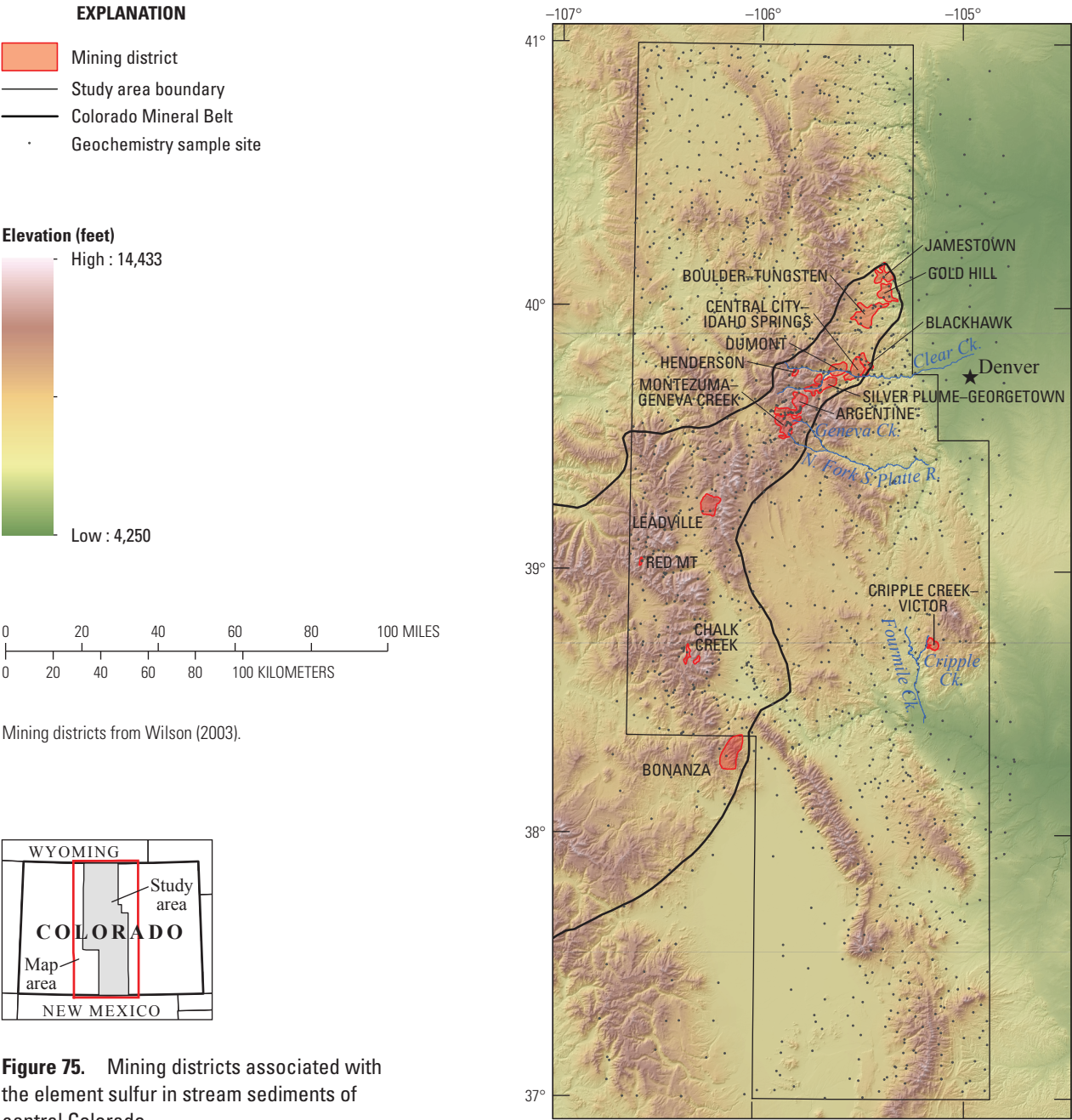
**Figure 74.** Maps of central Colorado stream-sediment geochemistry—sulfur (S). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





In ultramafic rocks, sulfur (S) is concentrated in magmatic sulfide minerals as part of the igneous differentiation process. Sulfur also is precipitated from hydrothermal fluids as various iron and base-metal sulfides common in hydrothermal mineral deposits. In addition, sulfur can precipitate from low-temperature groundwater and seawater where reducing conditions, typically related to bacterial action, enable precipitation of sulfide minerals. During weathering of sulfide minerals, the sulfate anion is released and mobilized in surface water. Relatively insoluble or slightly soluble alkali-earth sulfate minerals, such as gypsum, barite, and anglesite, may form under evaporitic conditions.

A large cluster of stream-sediment samples with high sulfur content (>90th percentile) at the northern end of the Colorado Mineral Belt is associated with the Argentine, Boulder-Tungsten, Central City–Idaho Springs, Dumont, Gold Hill, Henderson, Jamestown, Montezuma–Geneva Creek, and Silver Plume–Georgetown districts (figs. 74 and 75). Two samples with the highest concentrations (11 and 12 percent) were obtained in the Blackhawk district. Isolated samples with high sulfur concentrations (>97.5th percentile) were taken near the Bonanza, Chalk Creek, Leadville, and Red Mountain districts. Dispersion trains are apparent in several stream reaches including from the Henderson district along Clear Creek to the range front, along Geneva Creek from the Montezuma–Geneva Creek district to the North Fork of the South Platte River, and along Cripple Creek and Fourmile Creek below the Cripple Creek–Victor district.

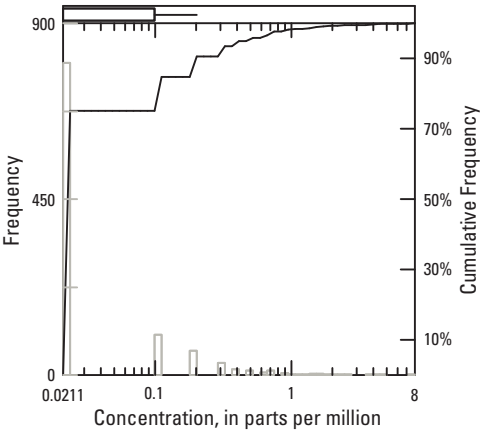


**Figure 75.** Mining districts associated with the element sulfur in stream sediments of central Colorado.





Central Colorado Stream-Sediment  
Geochemistry – Tellurium



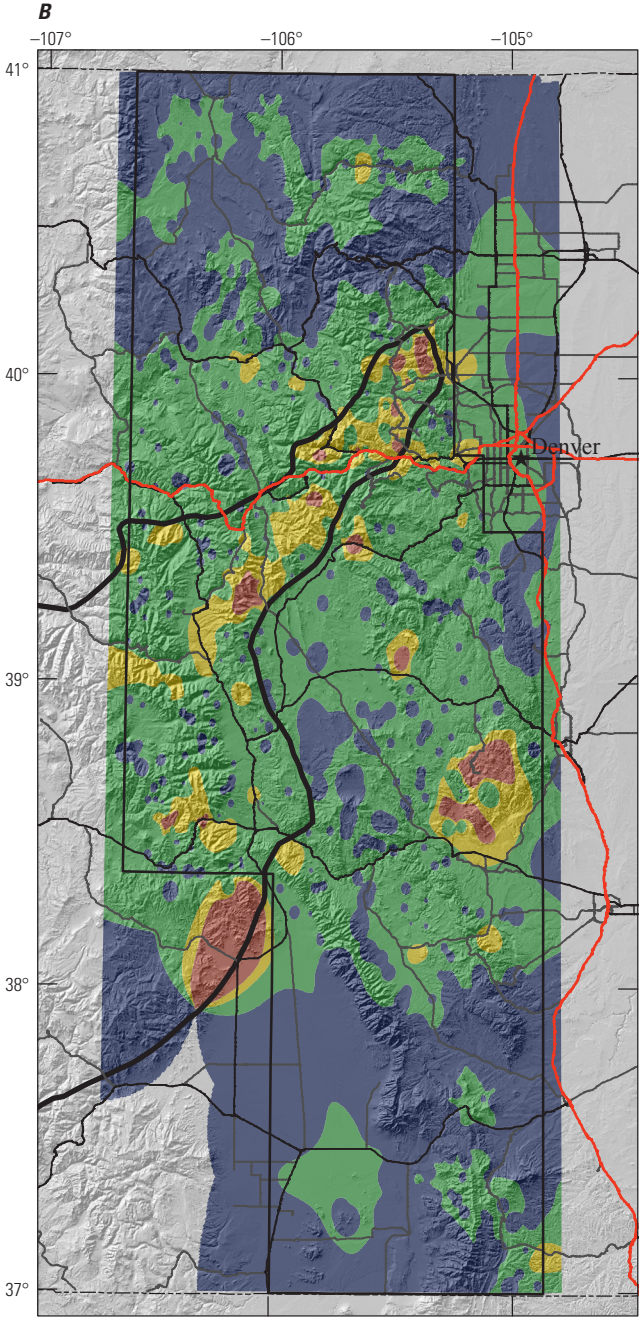
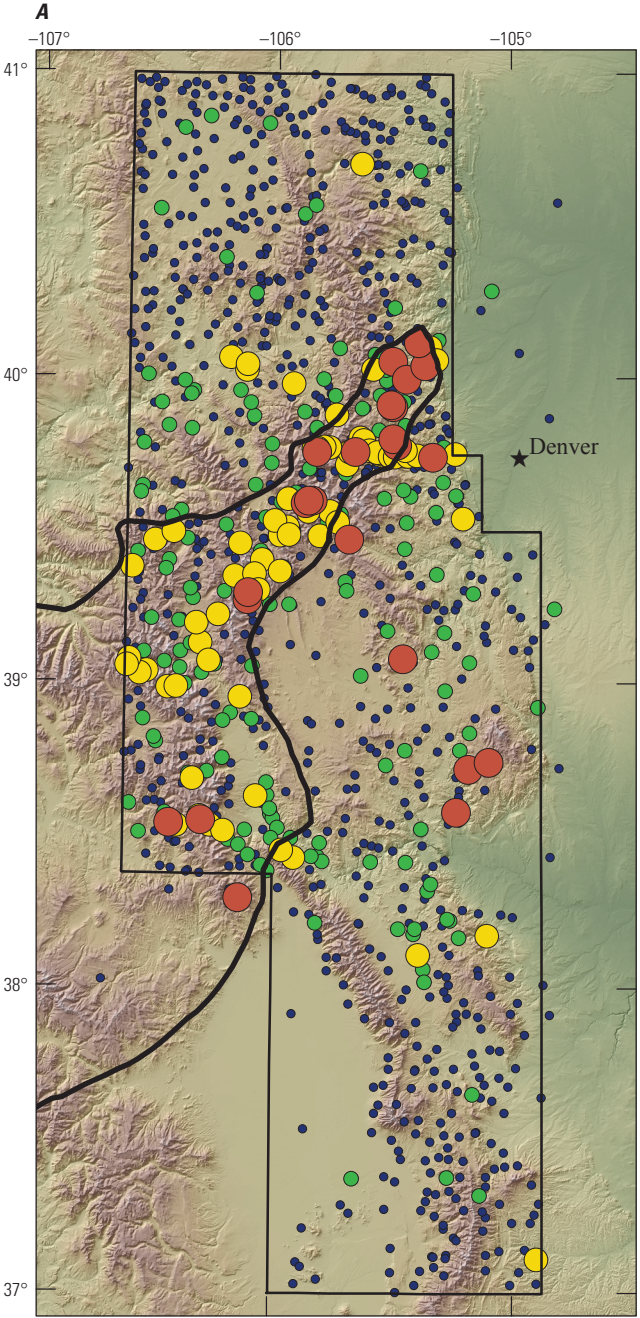
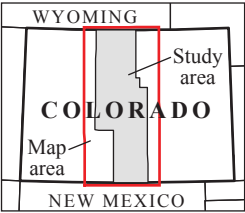
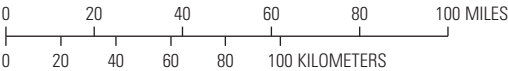
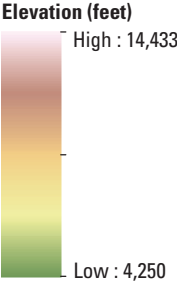
Te parts per million (ppm)	
Samples:	1064
Minimum:	<0.1
Maximum:	7.9000
Mean:	0.1141
Geometric mean:	0.0382
Median:	<0.1
Mode:	<0.1
Standard deviation:	0.3943
Standard error:	0.01209
Skew:	11.35
Kurtosis:	176.7

**Tellurium** (parts per million)  
Crustal abundance = 0.004 ppm  
Limit of detection = <0.1 ppm

- <0.1 ppm (<75th percentile)
- 0.1–0.2 ppm (75–90th percentile)
- 0.21–0.70 ppm (90–97.5th percentile)
- 0.71–7.9 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

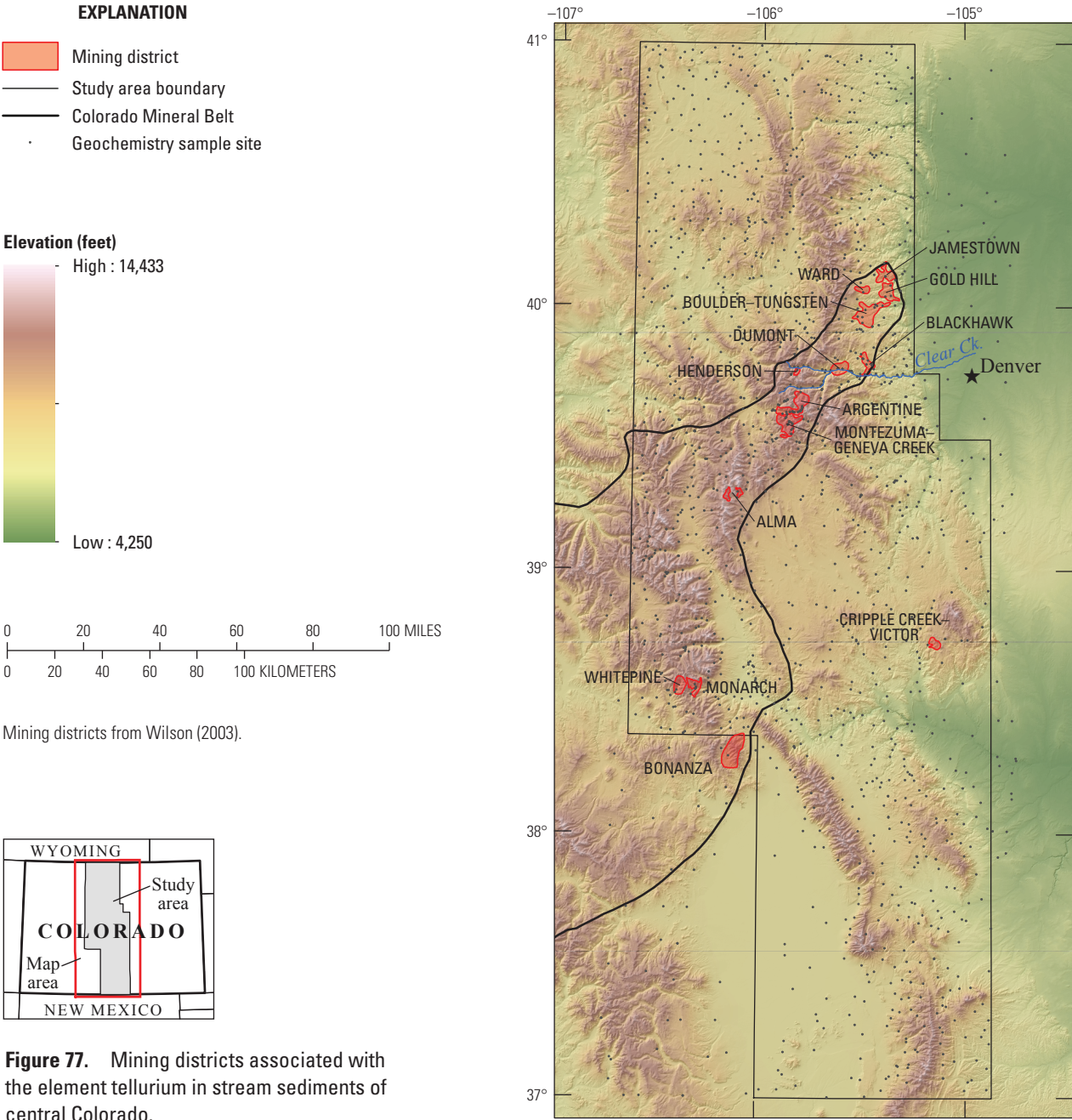


**Figure 76.** Maps of central Colorado stream-sediment geochemistry—tellurium (Te).  
(A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Tellurium (Te) is similar to sulfur in its geochemistry, although it is much less soluble during weathering. Sulfide minerals in hydrothermal systems or in relatively low-sulfur, precious-metal telluride hydrothermal deposits may be enriched in tellurium.

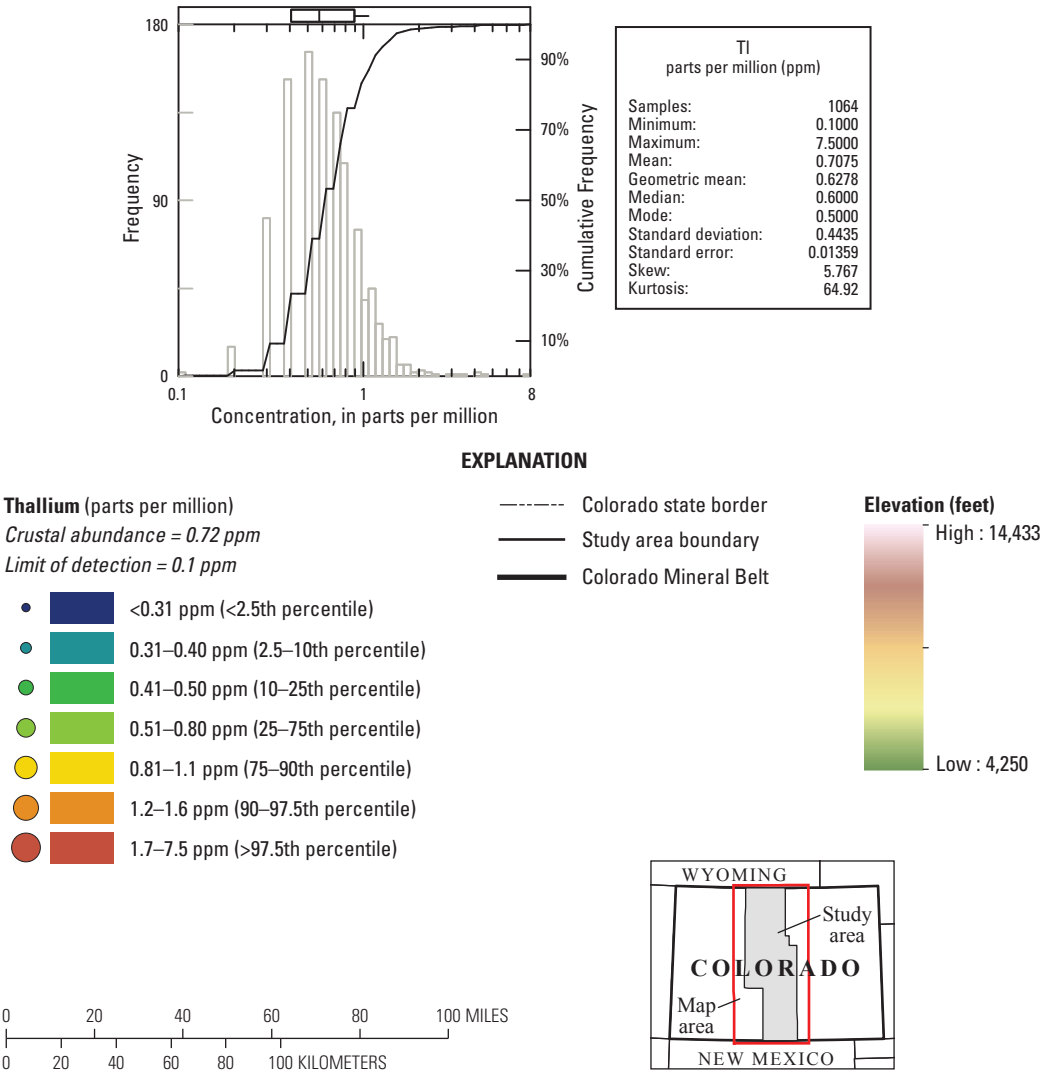
Tellurium was not detected in the majority of stream-sediment samples from the study area (<75th percentile). Samples containing high tellurium (>97.5th percentile) are largely confined to the northern end of the Colorado Mineral Belt in the Argentine, Blackhawk, Boulder-Tungsten, Dumont, Gold Hill, Henderson, Jamestown, Montezuma–Geneva Creek, and Ward districts (figs. 76 and 77). A dispersion train may extend from the Henderson district eastward along Clear Creek to the range front. South of the mineral belt, samples from the Cripple Creek–Victor gold-silver telluride deposits contain some of the highest tellurium concentrations (1.9 to 4.7 parts per million, ppm). The single highest tellurium concentration (7.9 ppm) is from a sample obtained downstream of the Alma district. High tellurium concentrations (>97.5th percentile) are also present in samples taken near the Monarch and Whitepine districts. Just outside the study-area boundary in the southern part of the mineral belt, a single sample containing anomalous tellurium and several other metals is from the Bonanza district (see copper discussion with fig. 27).



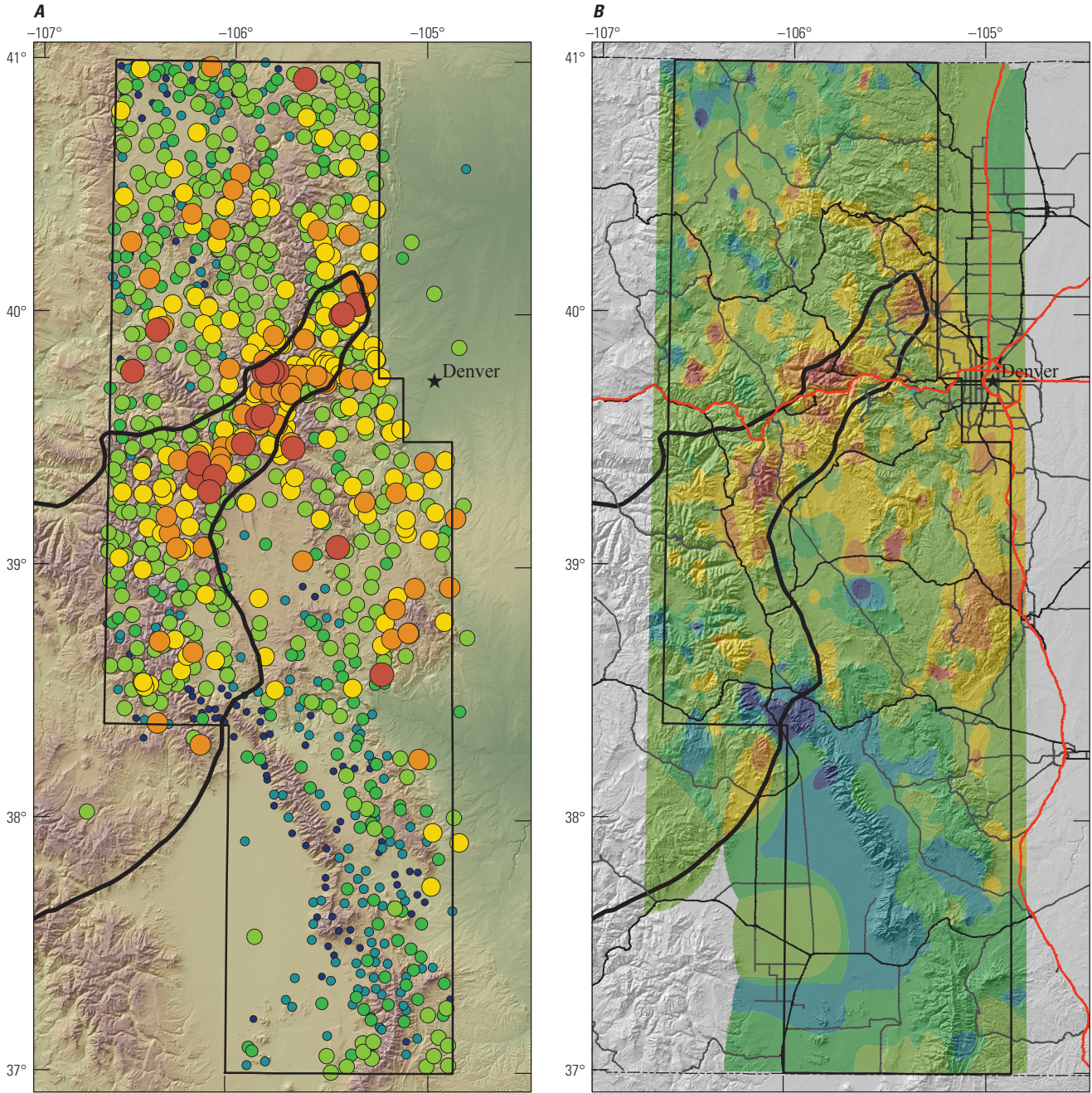




Central Colorado Stream-Sediment  
Geochemistry—Thallium



**Figure 78.** Maps of central Colorado stream-sediment geochemistry—thallium (TI). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.

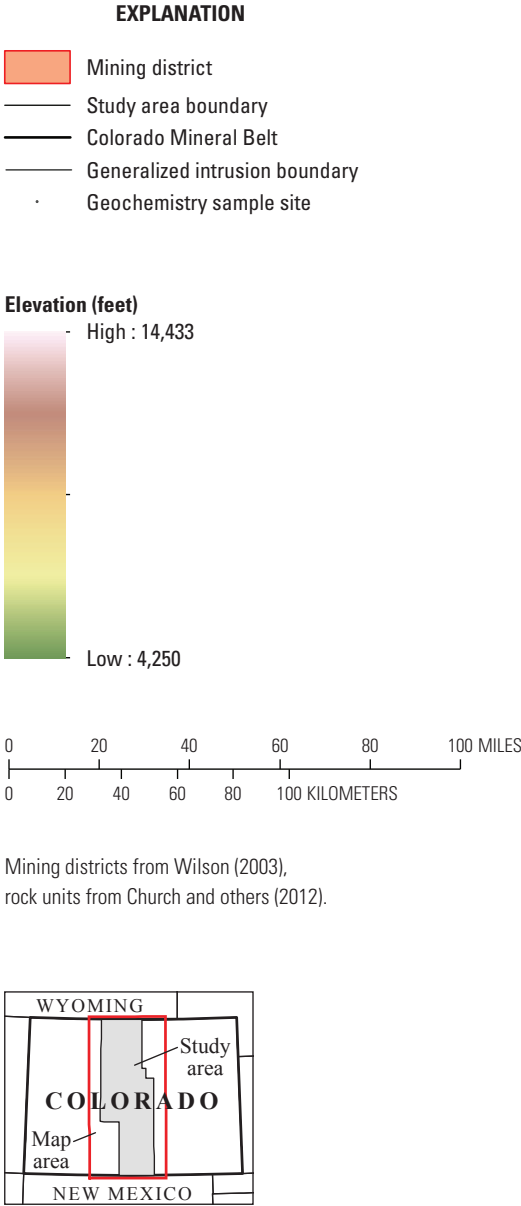




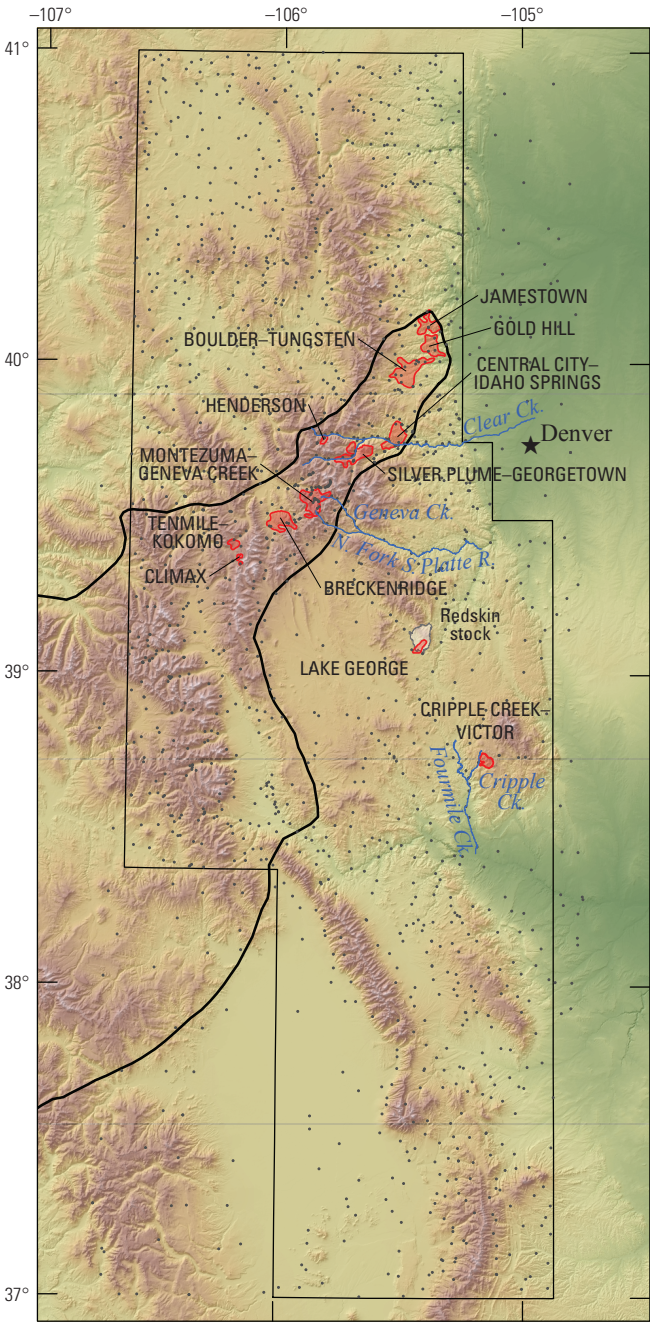
84      **Geochemical Maps of Stream Sediments in Central Colorado, from New Mexico to Wyoming**

Geochemically, thallium (Tl) has strong affinity for sulfur and most commonly is found as a trace constituent in the lead sulfide, galena. Thallium also is locally concentrated in organic-rich shales. It is relatively mobile in the weathering environment and can be concentrated in clay minerals and manganese oxides through adsorption.

Stream-sediment samples having the highest thallium concentrations (>97.5th percentile) are confined largely within the northern two-thirds of the Colorado Mineral Belt, with clusters around the Boulder-Tungsten, Breckenridge, Climax, Gold Hill, Henderson, Montezuma–Geneva Creek, and Tenmile-Kokomo districts (figs. 78 and 79). Lower concentrations (90th to 97.5th percentile) are found in samples from the Central City–Idaho Springs, Jamestown, and Silver Plume–Georgetown districts. Dispersion trains of thallium are evident along Clear Creek from the Henderson district eastward to the range front, and from the Montezuma–Geneva Creek district eastward along Geneva Creek to the North Fork of the South Platte River. South of the mineral belt, a single sample with a high Tl value (>97.5th percentile) was collected over the greisen deposit in the Proterozoic Redskin stock near the Lake George district, and a small sample cluster with high concentrations (>90th percentile) lies over the Cripple Creek–Victor alkaline gold-silver telluride deposits with dispersion downstream along Cripple Creek and Fourmile Creek.



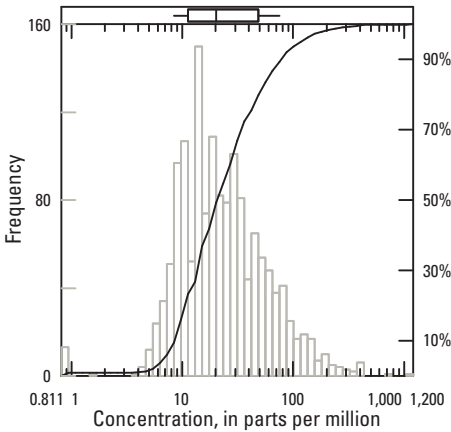
**Figure 79.** Mining districts and rock unit associated with the element thallium in stream sediments of central Colorado.







Central Colorado Stream-Sediment  
Geochemistry—Thorium



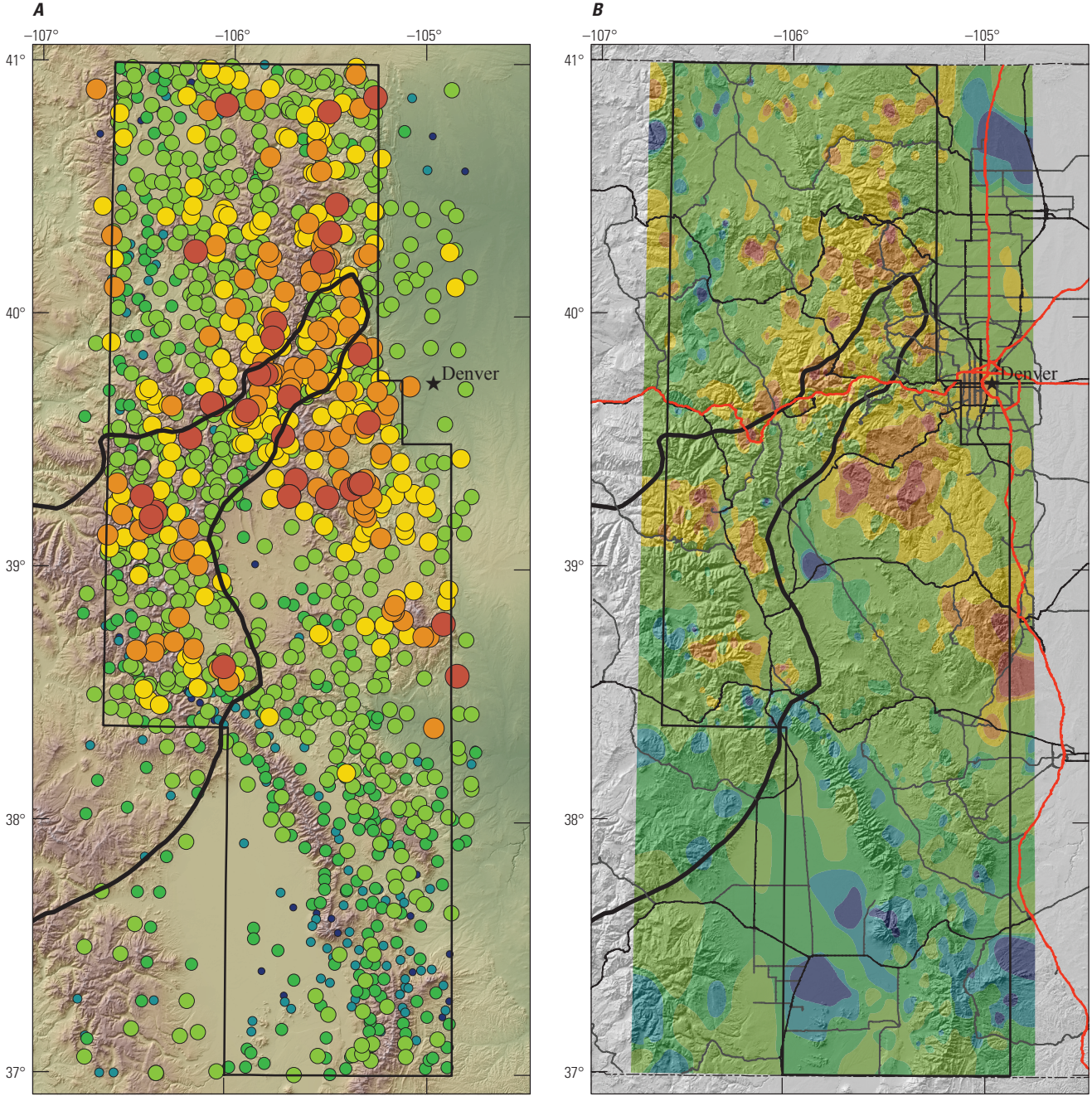
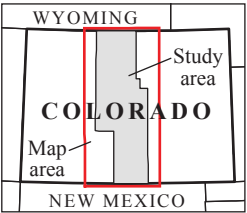
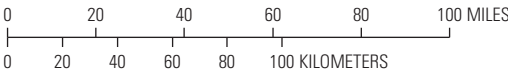
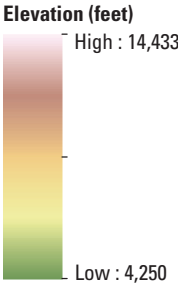
Th parts per million (ppm)	
Samples:	1479
Minimum:	<4.0
Maximum:	1110.0000
Mean:	36.9252
Geometric mean:	22.9170
Median:	21.0000
Mode:	11.0000
Standard deviation:	56.4
Standard error:	1.467
Skew:	7.938
Kurtosis:	109.8

**Thorium** (parts per million)  
Crustal abundance = 8.10 ppm  
Limit of detection = <4.0 ppm

- <5.8 ppm (<2.5th percentile)
- 5.8–8.6 ppm (2.5–10th percentile)
- 8.7–12 ppm (10–25th percentile)
- 13–41 ppm (25–75th percentile)
- 42–77 ppm (75–90th percentile)
- 78–160 ppm (90–97.5th percentile)
- 170–1,100 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

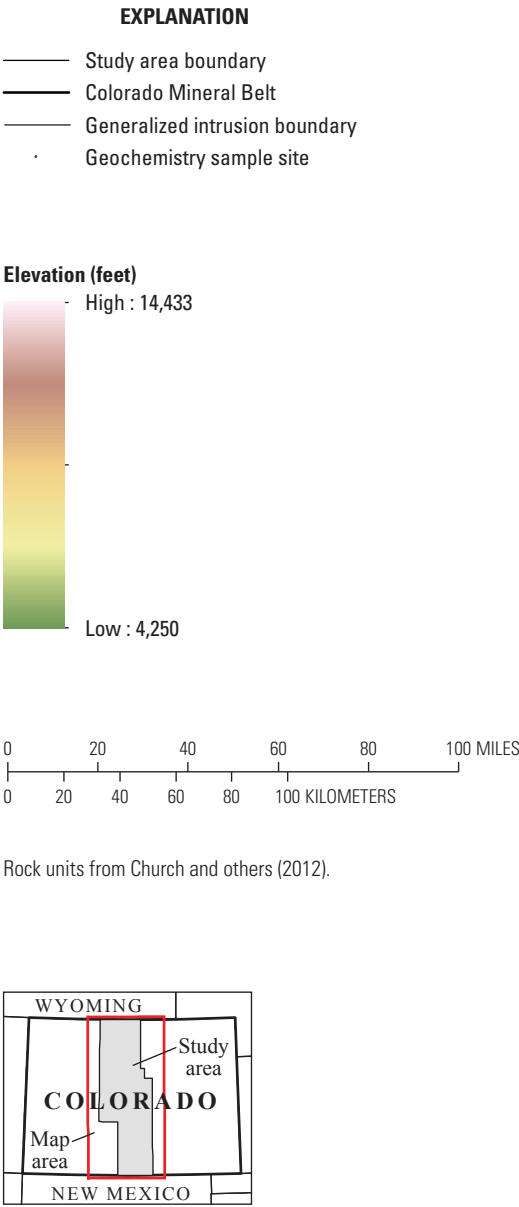


**Figure 80.** Maps of central Colorado stream-sediment geochemistry—thorium (Th). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.

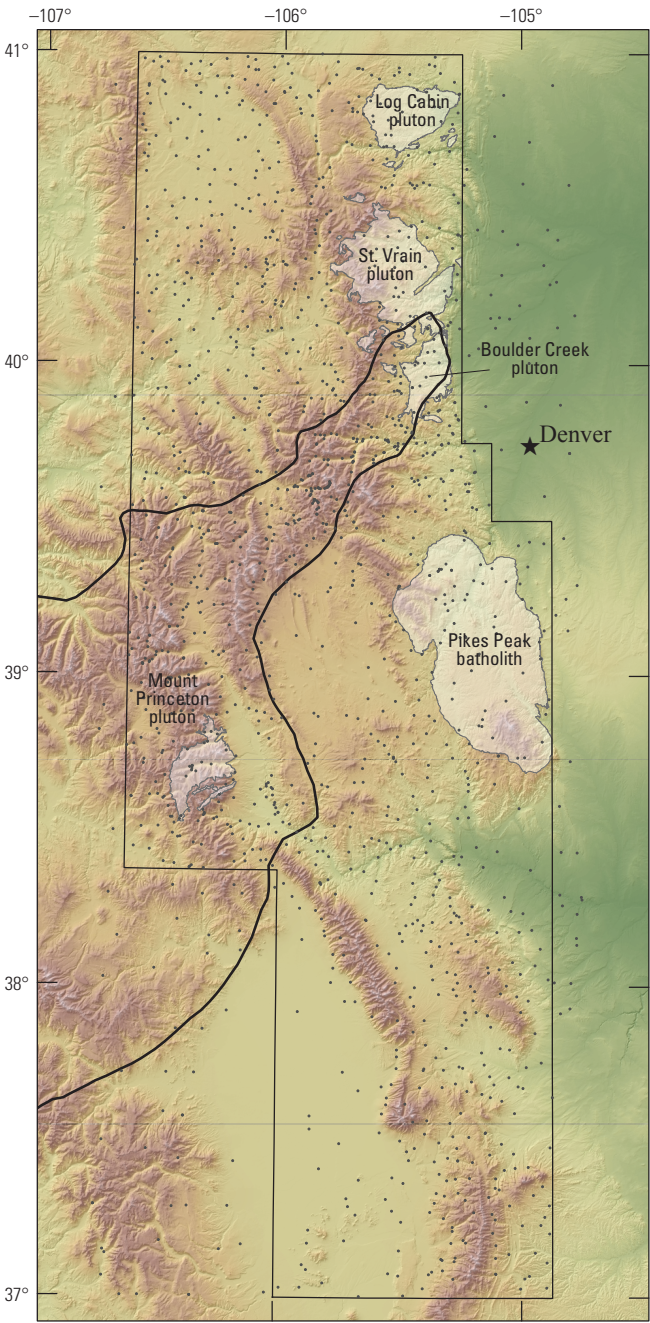


Thorium (Th) in igneous rocks is strongly lithophile and is concentrated in evolved igneous rocks such as granites and granitic pegmatites. It is present most commonly in the minerals monazite, allanite, sphene, and zircon, although some pegmatites may contain the thorium minerals thorite and thorianite. Thorium-bearing minerals generally are resistant to weathering. Thorium generally accumulates with heavy minerals in sediments, where it may form placer deposits. It is much less mobile than uranium during weathering.

High thorium concentrations (>90th percentile) in stream-sediment samples are widely scattered in the northern two-thirds of the study area (figs. 80 and 81). These samples represent Proterozoic granitic rocks such as the Boulder Creek, Log Cabin, and St. Vrain plutons, the Pikes Peak batholith, and parts of the Eocene Mount Princeton pluton. Spatial overlap of several mining districts and samples with high thorium concentrations do occur, but the high thorium values are more likely related to accessory minerals in Proterozoic and younger felsic intrusive rocks than to mineralization.



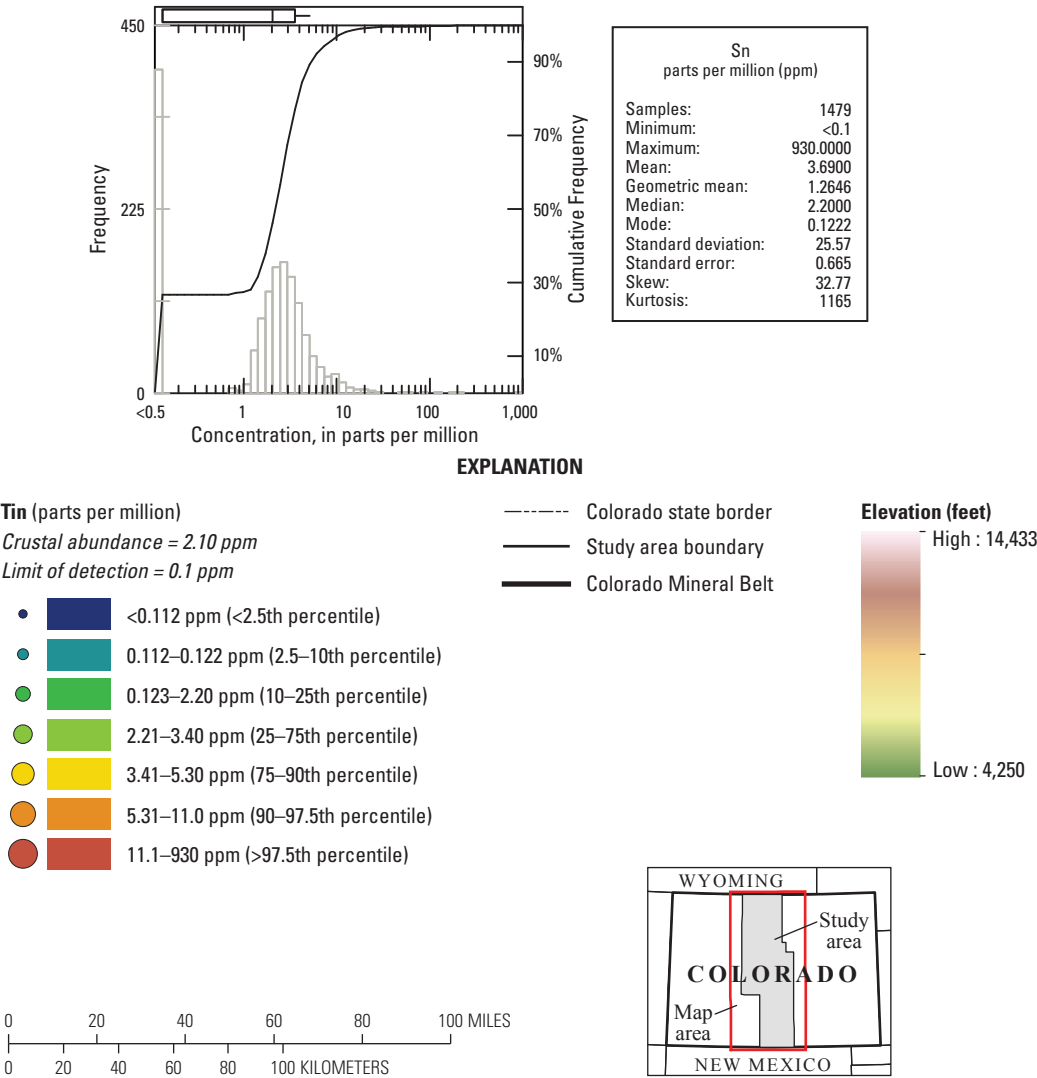
**Figure 81.** Rock units associated with the element thorium in stream sediments of central Colorado.



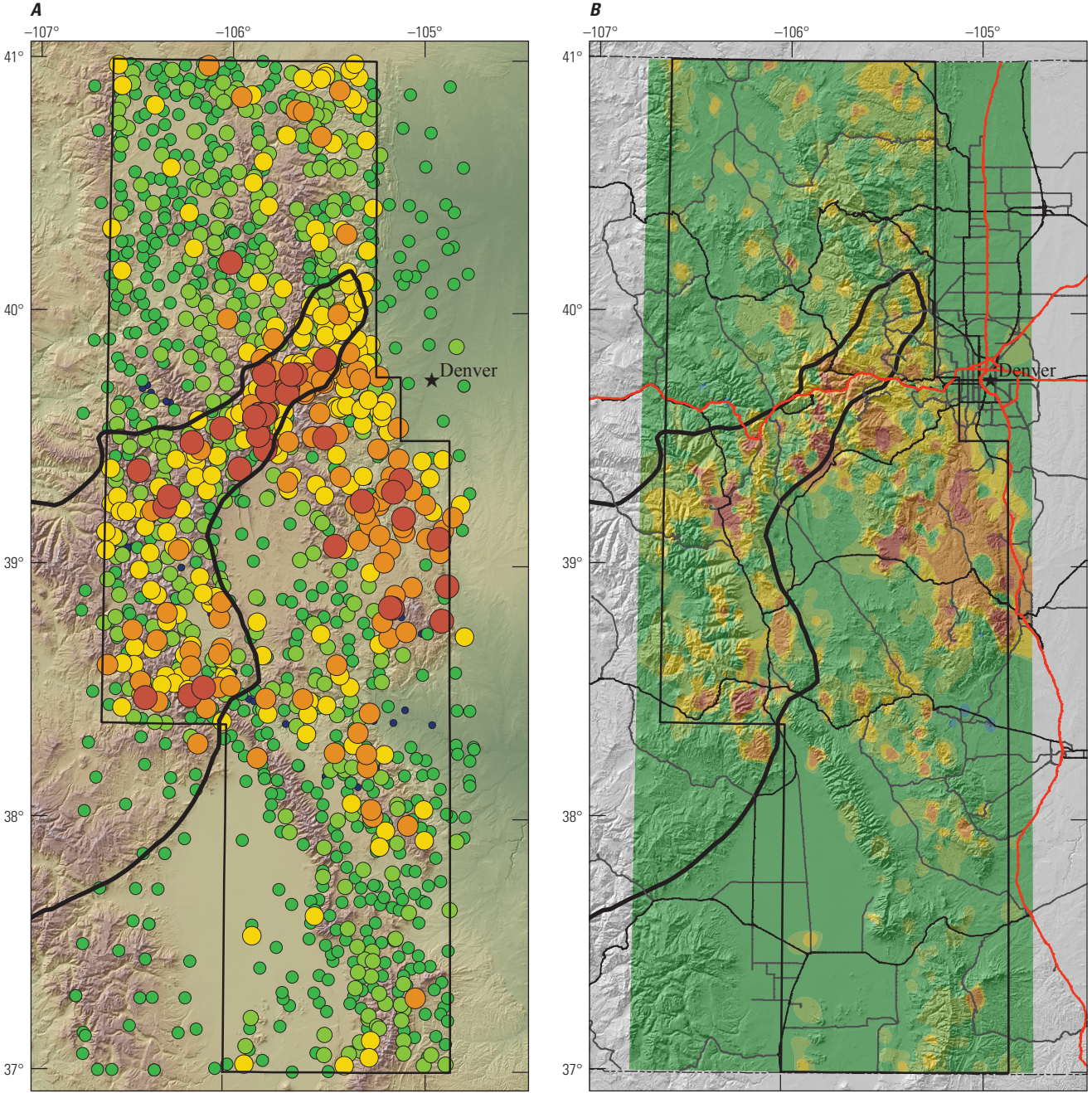




Central Colorado Stream-Sediment  
Geochemistry—Tin



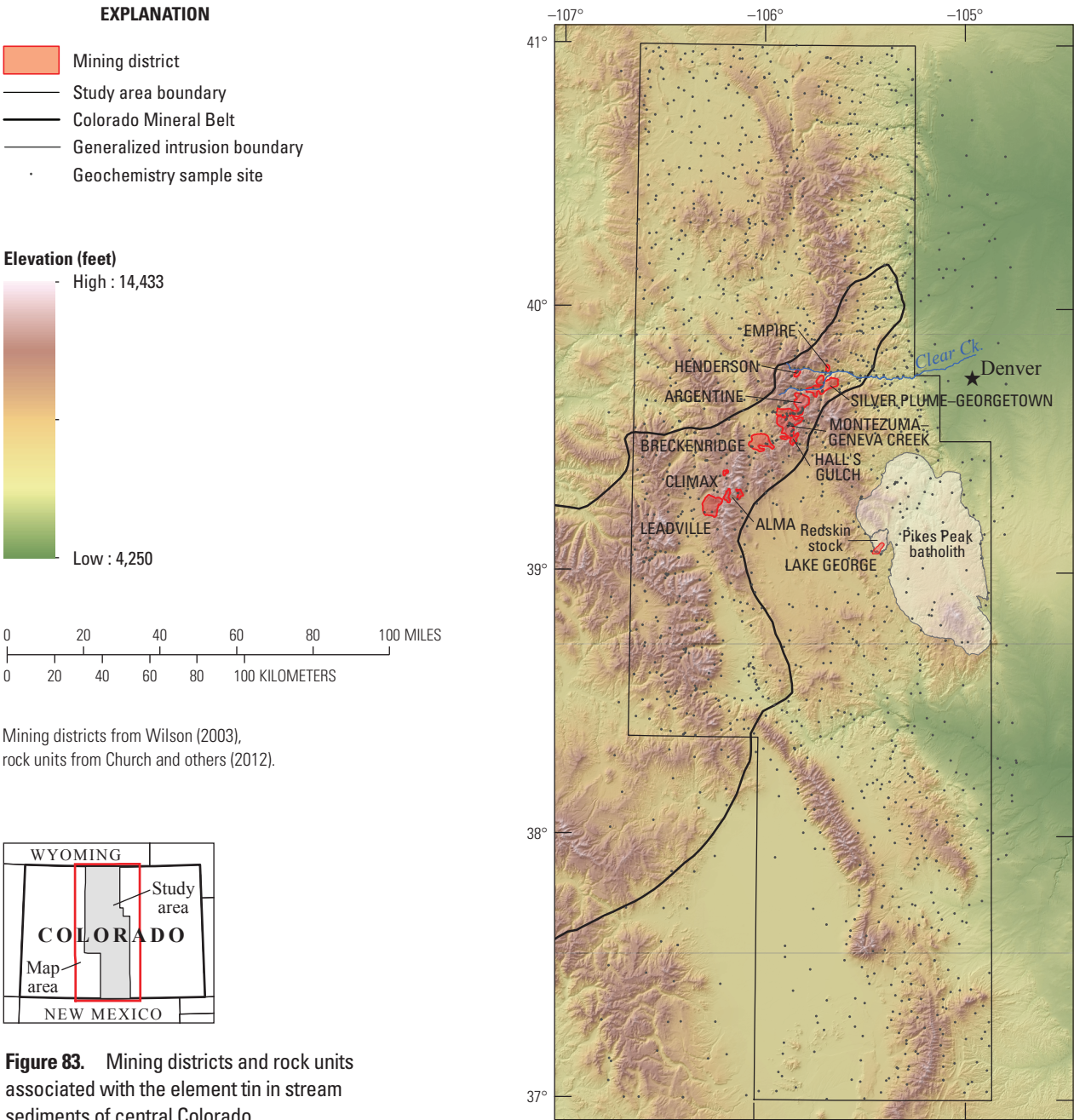
**Figure 82.** Maps of central Colorado stream-sediment geochemistry—tin (Sn). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Tin (Sn) is highly abundant in highly evolved igneous rocks such as granite and granite pegmatites, especially where those rocks are also fluorine rich. The most common tin-bearing mineral is cassiterite, which is insoluble during weathering. Because of its high density, cassiterite commonly becomes abundant in heavy-mineral placer deposits.

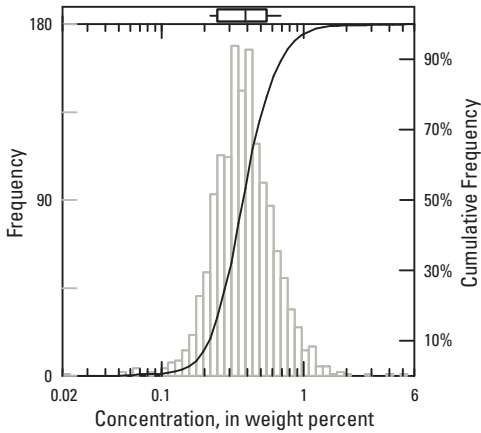
High tin concentrations (>97.5th percentile) are present in stream-sediment samples in the Colorado Mineral Belt near the Alma, Argentine, Breckenridge, Empire, Halls Gulch, Henderson, Leadville, Montezuma–Geneva Creek, and Silver Plume–Georgetown districts, as well as downstream from the Climax deposit (figs. 82 and 83). A dispersion train is evident along Clear Creek from the Henderson and Empire districts eastward to the range front. South of the Colorado Mineral Belt, samples with high tin concentrations (>90th percentile) overlie the Mesoproterozoic Pikes Peak batholith and a greisen deposit in the Redskin stock (Lake George district). Scattered throughout the study area are many other sample locations that have high tin concentrations (>90th percentile) but no apparent geologic source.







Central Colorado Stream-Sediment  
Geochemistry—Titanium



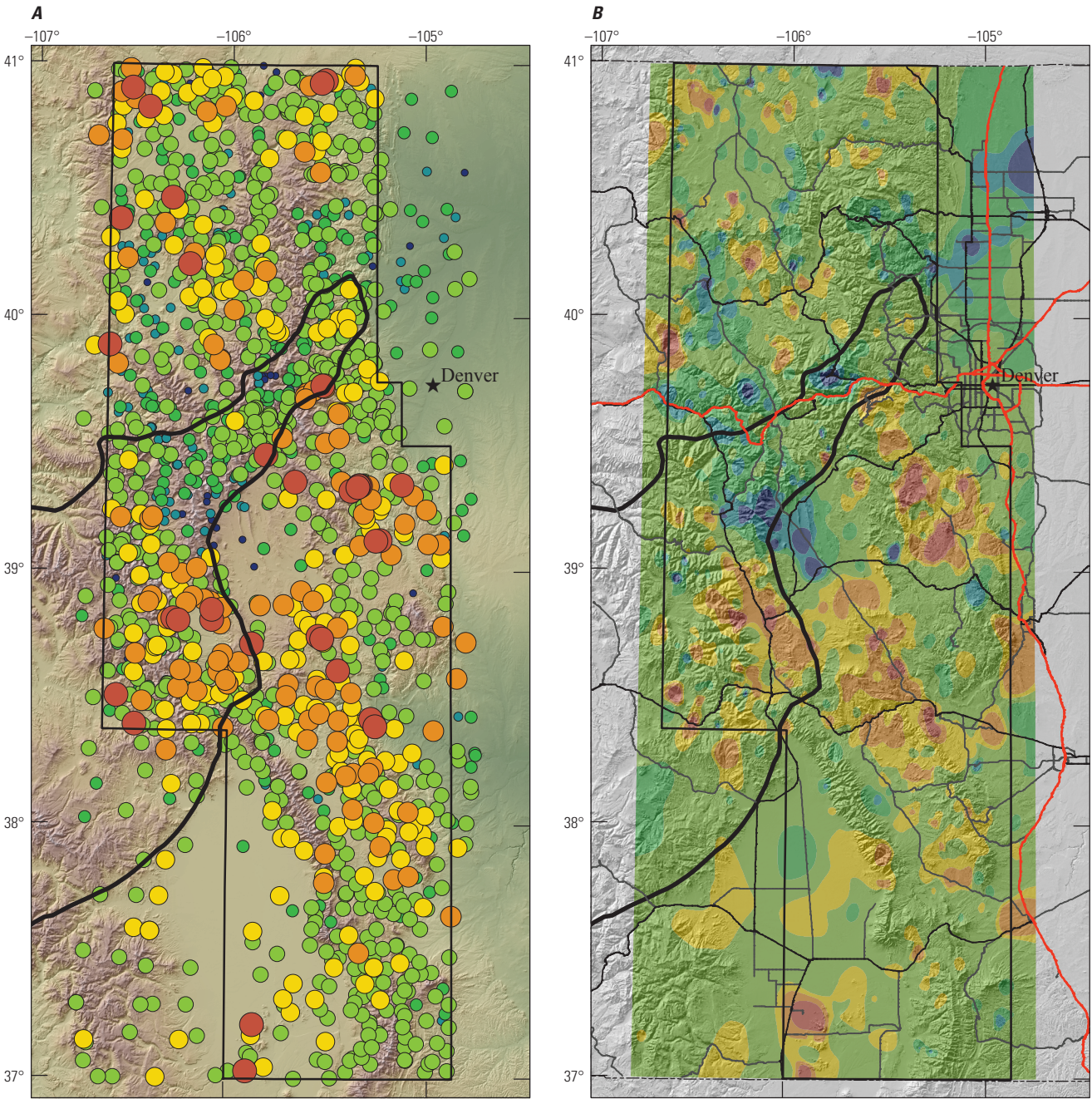
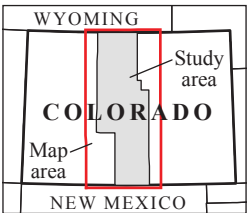
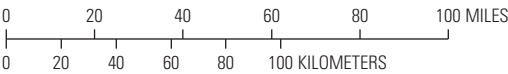
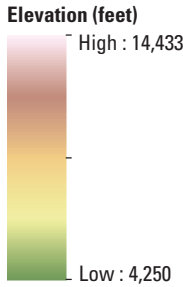
Ti weight percent (wt%)	
Samples:	1479
Minimum:	0.0200
Maximum:	5.2000
Mean:	0.4284
Geometric mean:	0.3767
Median:	0.3700
Mode:	0.3300
Standard deviation:	0.276
Standard error:	0.007177
Skew:	6.304
Kurtosis:	83.4

**Titanium (weight percent)**  
Crustal abundance = 0.632%  
Limit of detection = not applicable

- 0.020–0.15% (<2.5th percentile)
- 0.16–0.21% (2.5–10th percentile)
- 0.22–0.28% (10–25th percentile)
- 0.29–0.51% (25–75th percentile)
- 0.52–0.69% (75–90th percentile)
- 0.70–1.0% (90–97.5th percentile)
- 1.1–5.2% (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

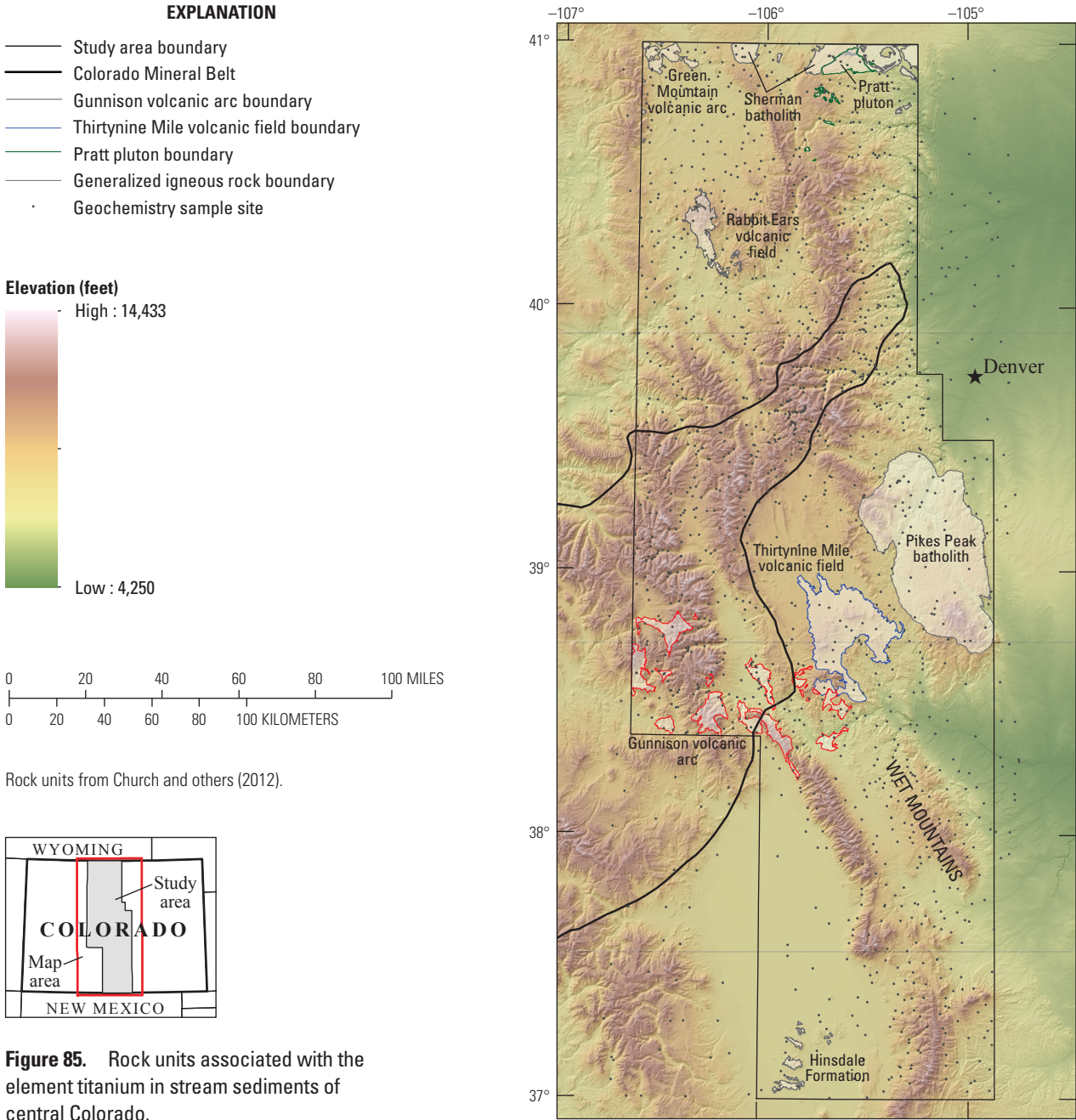


**Figure 84.** Maps of central Colorado stream-sediment geochemistry—titanium (Ti). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Titanium (Ti) in igneous rocks is present most commonly in the minerals ilmenite, rutile, and sphene, as well as in titaniferous magnetite. It is also commonly incorporated to a limited extent into pyroxenes, amphiboles, and biotite. Titanium is most concentrated in mafic rocks, especially those of alkaline composition. Titanium minerals in sediments are commonly concentrated in placer and paleoplacer deposits because those minerals are resistant to weathering and have a high density.

In the study area, high titanium concentrations (>90th percentile) generally are associated with rock type and not related to mineral deposits. Stream-sediment samples showing high titanium concentrations (>90th percentile) are associated with Proterozoic mafic to ultramafic metavolcanic rocks and metagabbros in the Gunnison volcanic arc (in the central part of the Colorado Mineral Belt) and in the Green Mountain volcanic arc in the northwestern corner of the study area (figs. 84 and 85). Samples with similar high concentrations represent areas containing mafic dikes and shallow intrusive rocks in the alkalic-calcic to alkaline Thirtynine Mile volcanic field, and a few sample sites are associated with the Rabbit Ears volcanic rocks. A cluster of sample locations with high Ti concentrations (90th to 97.5th percentile) lies near diverse alkaline mafic and ultramafic rocks in the Wet Mountains. Near the Colorado–New Mexico border, two samples with high concentrations (>97.5th percentile) appear to be related to mafic volcanic rocks in the Oligocene Hinsdale Formation. Sample locations with scattered high concentrations (>97.5th percentile) overlie parts of the Proterozoic granitic Pikes Peak batholith, Sherman batholith, and Pratt pluton and perhaps are related to late-stage pegmatite dikes.

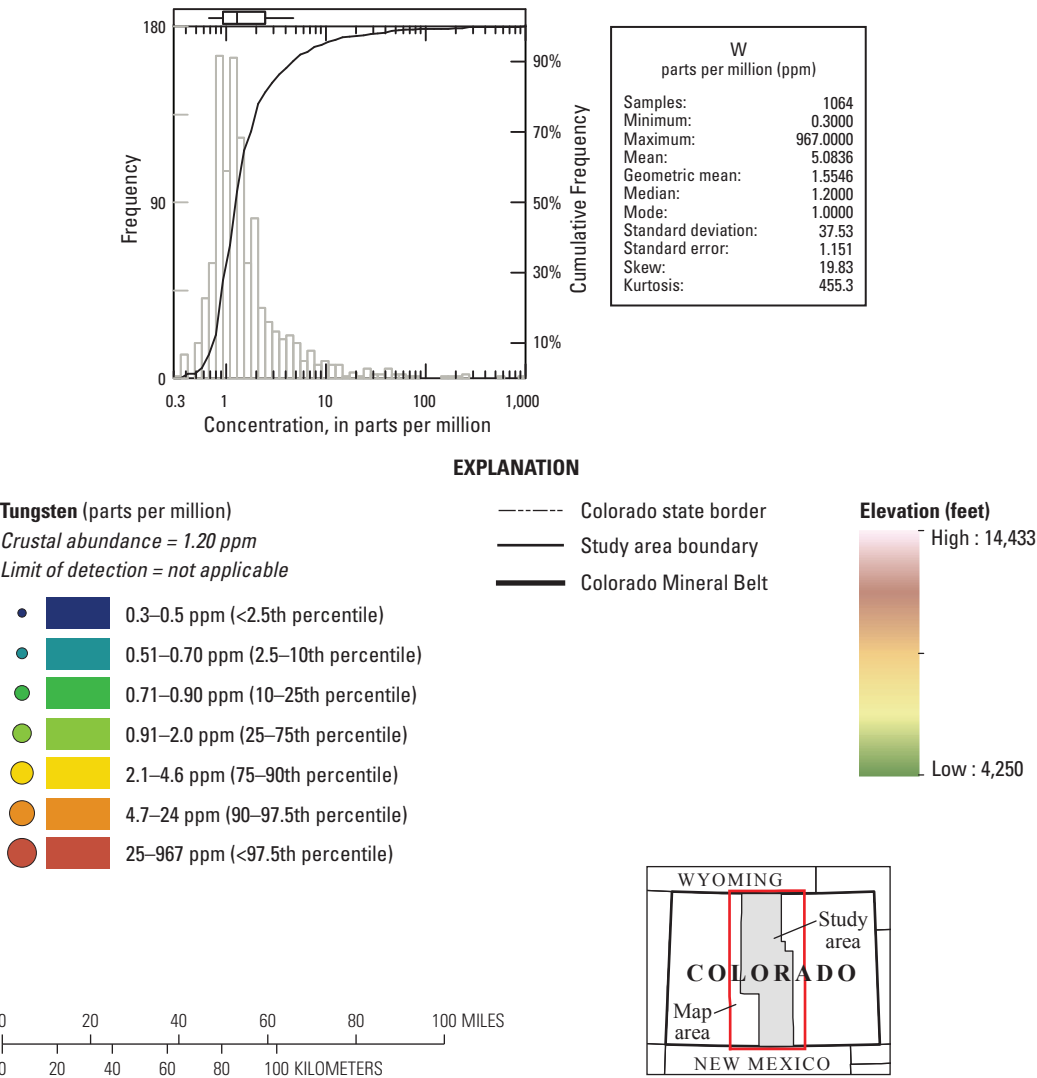


**Figure 85.** Rock units associated with the element titanium in stream sediments of central Colorado.

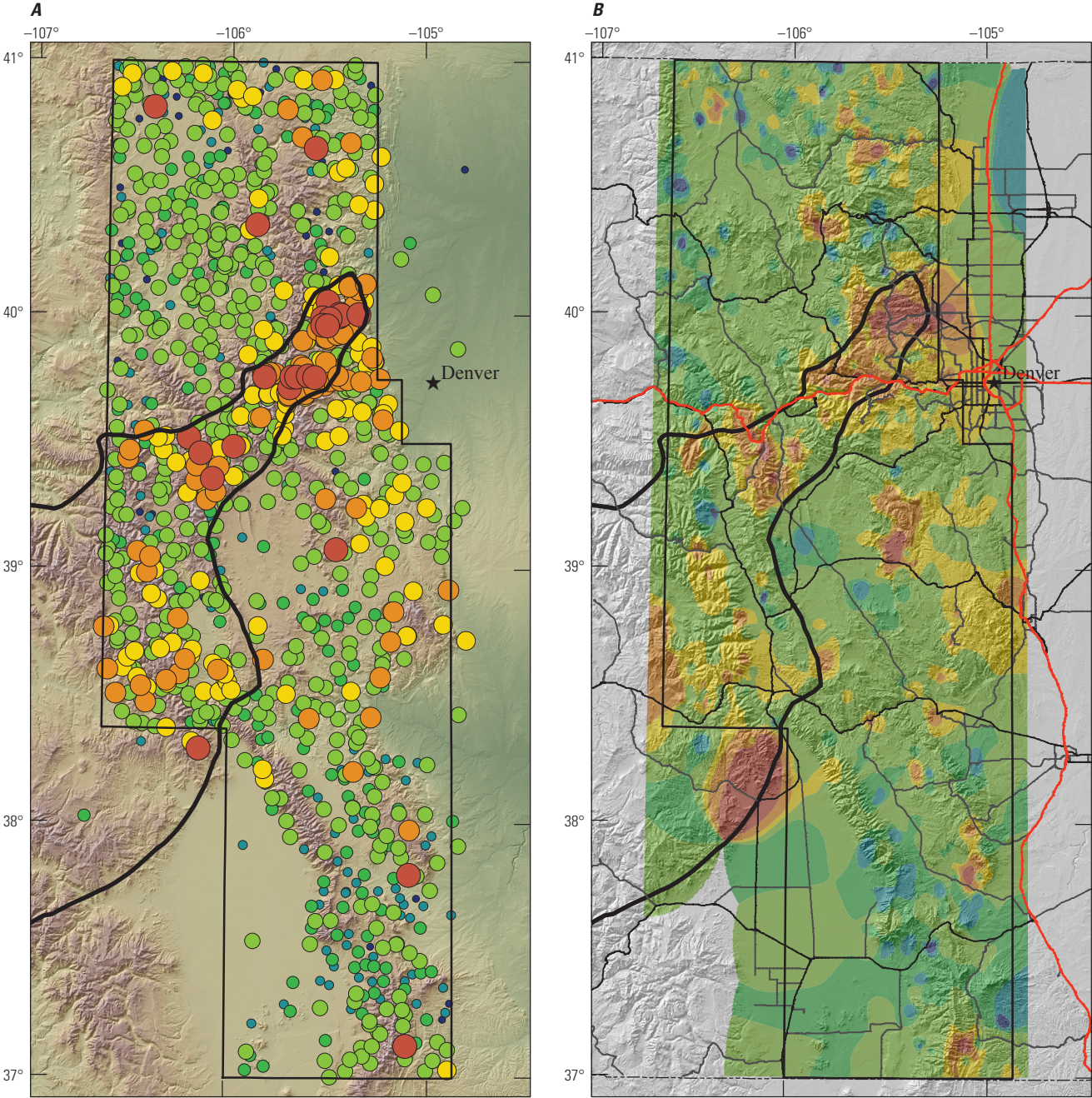




Central Colorado Stream-Sediment  
Geochemistry—Tungsten



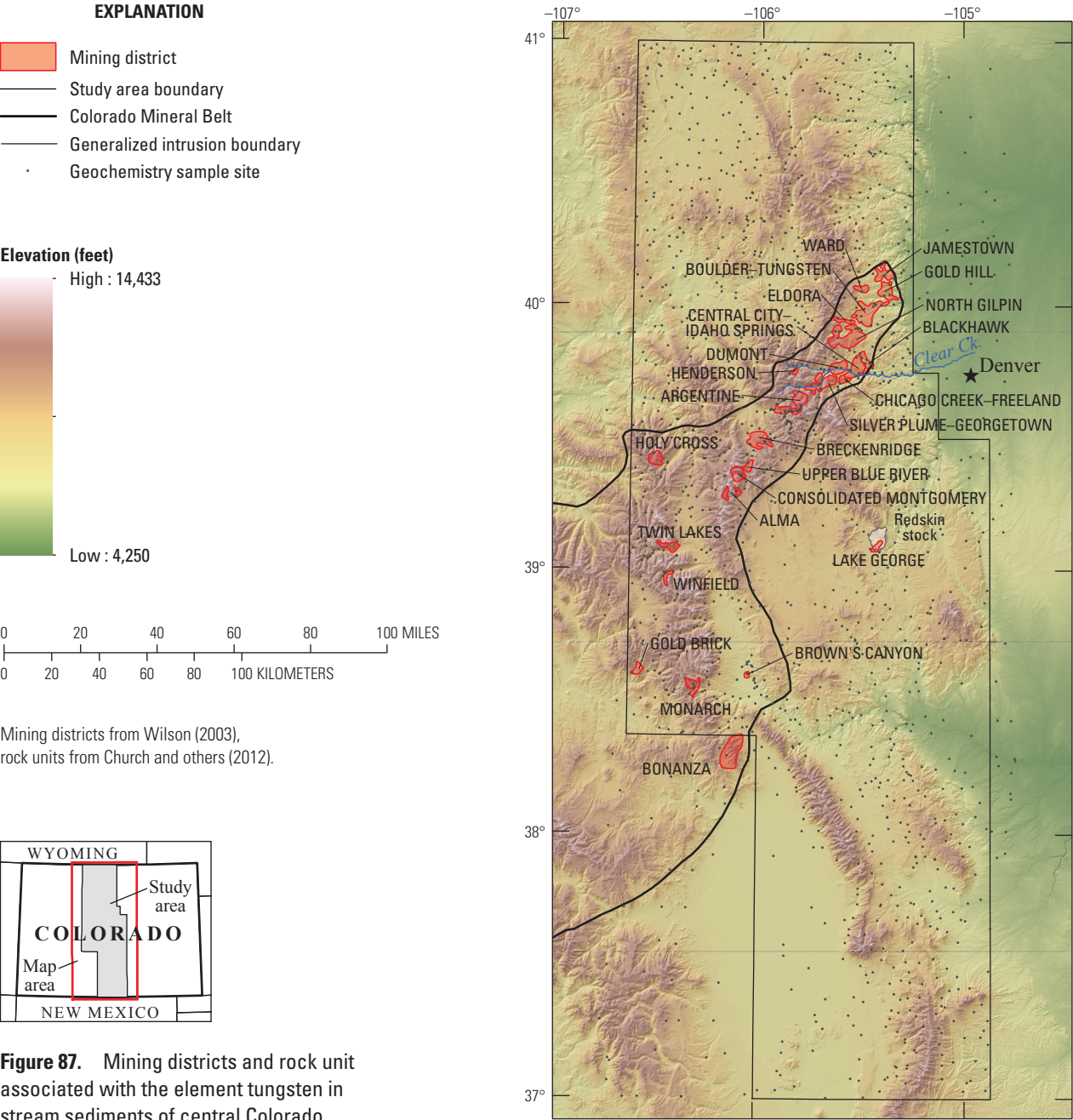
**Figure 86.** Maps of central Colorado stream-sediment geochemistry—tungsten (W). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Tungsten (W) is more abundant in highly evolved igneous rocks such as alkali granite and granite pegmatites, especially where they are enriched in fluorine. The most common tungsten-bearing minerals are wolframite and scheelite, which are insoluble during weathering. Placer deposits commonly are enriched in these high-density minerals.

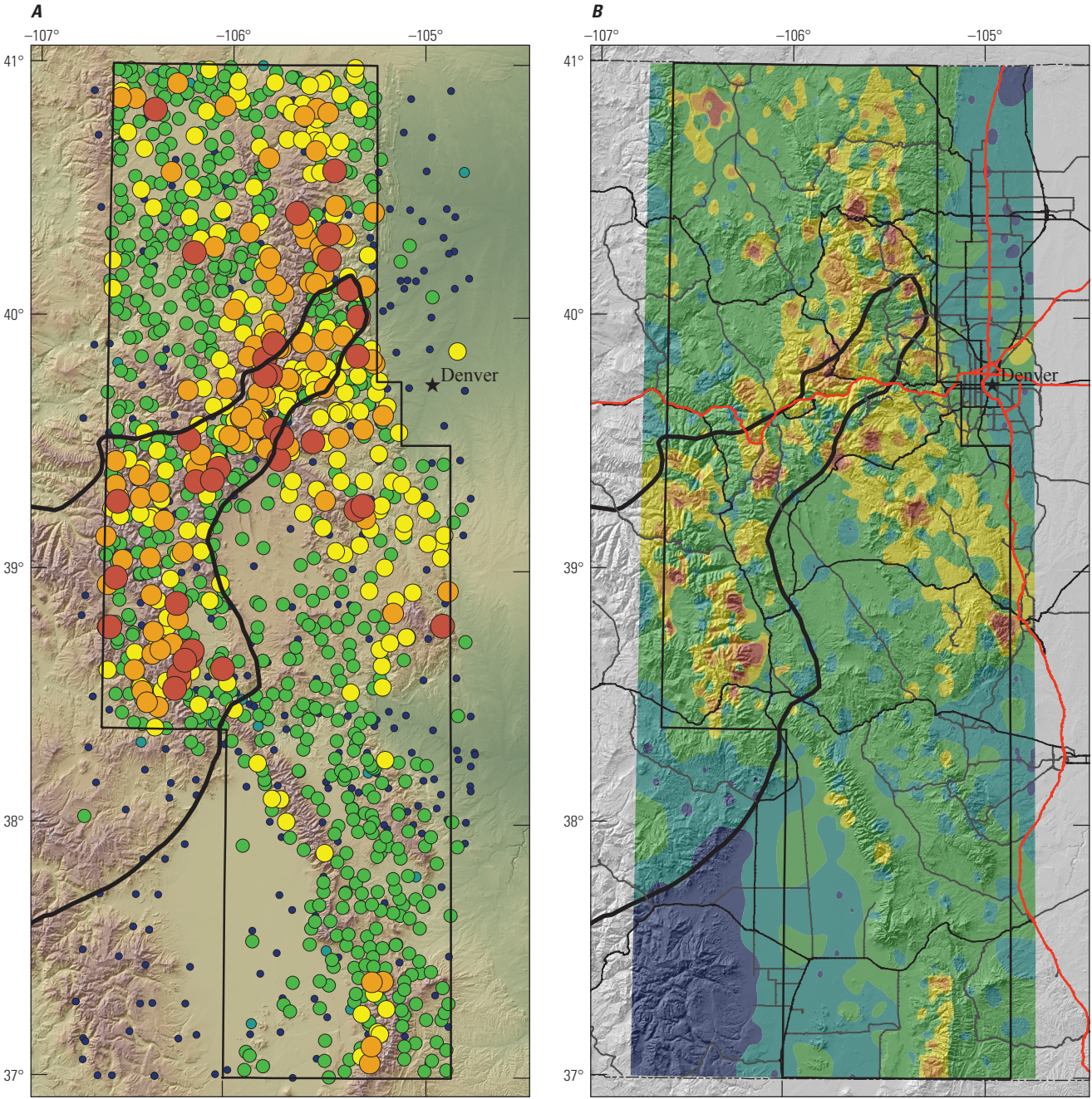
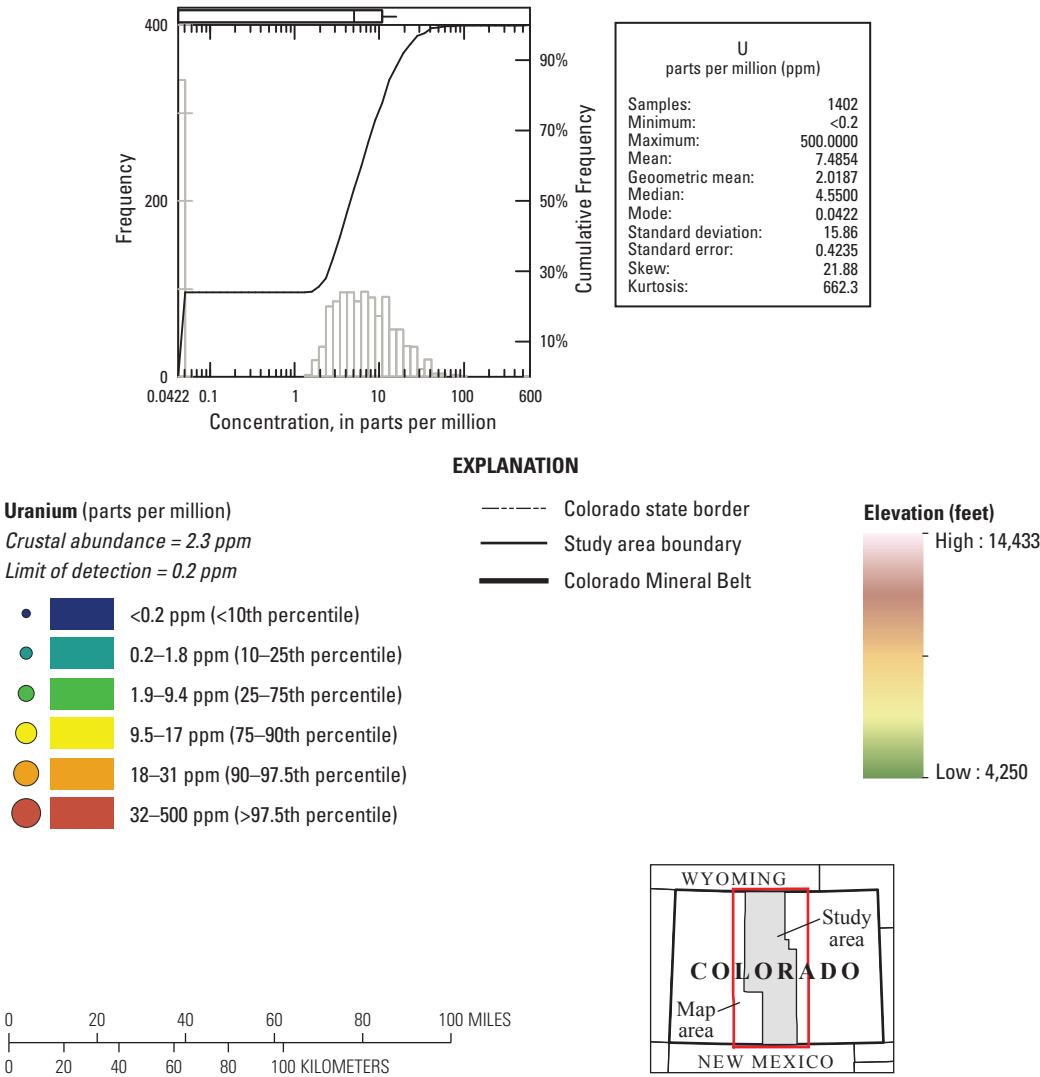
High tungsten concentrations (>90th percentile) are present in stream-sediment samples throughout much of the Colorado Mineral Belt and are highest (>97.5th percentile) at the northern end of the mineral belt (figs. 86 and 87). The highest concentrations (six samples, ranging from 170 to 970 parts per million (ppm) W) all represent sediments near the tungsten vein deposits in the Boulder-Tungsten district, where ferberite (the iron-rich end member of the wolframite mineral series) is common. Samples with lower tungsten concentrations (90th to 97.5th percentile) surround the Boulder-Tungsten district and extend into the Gold Hill, Jamestown, North Gilpin, and Ward districts. High tungsten concentrations (>90th percentile) are also found in samples from the Blackhawk, Central City–Idaho Springs, Chicago Creek–Freeland, Dumont, Henderson, and Silver Plume–Georgetown districts. A dispersion train is evident along Clear Creek from the Henderson district eastward to the range front. Within the mineral belt, scattered samples containing high tungsten concentrations (>90th percentile) were obtained in the Alma, Argentine, Bonanza, Breckenridge, Browns Canyon, Consolidated Montgomery, Eldora, Gold Brick, Holy Cross, Monarch, Twin Lakes, Upper Blue River, and Winfield districts. Scattered sample locations containing high tungsten concentrations (>90th percentile) lie north and south of the mineral belt, including the greisen deposit from the Redskin stock in the Lake George district. Many samples with high tungsten concentrations (>90th percentile) are scattered throughout the study area and may be related to trace amounts of disseminated scheelite in Proterozoic gneisses, particularly calc-silicate gneisses, in Colorado (Tweto, 1960).







Central Colorado Stream-Sediment  
Geochemistry—Uranium

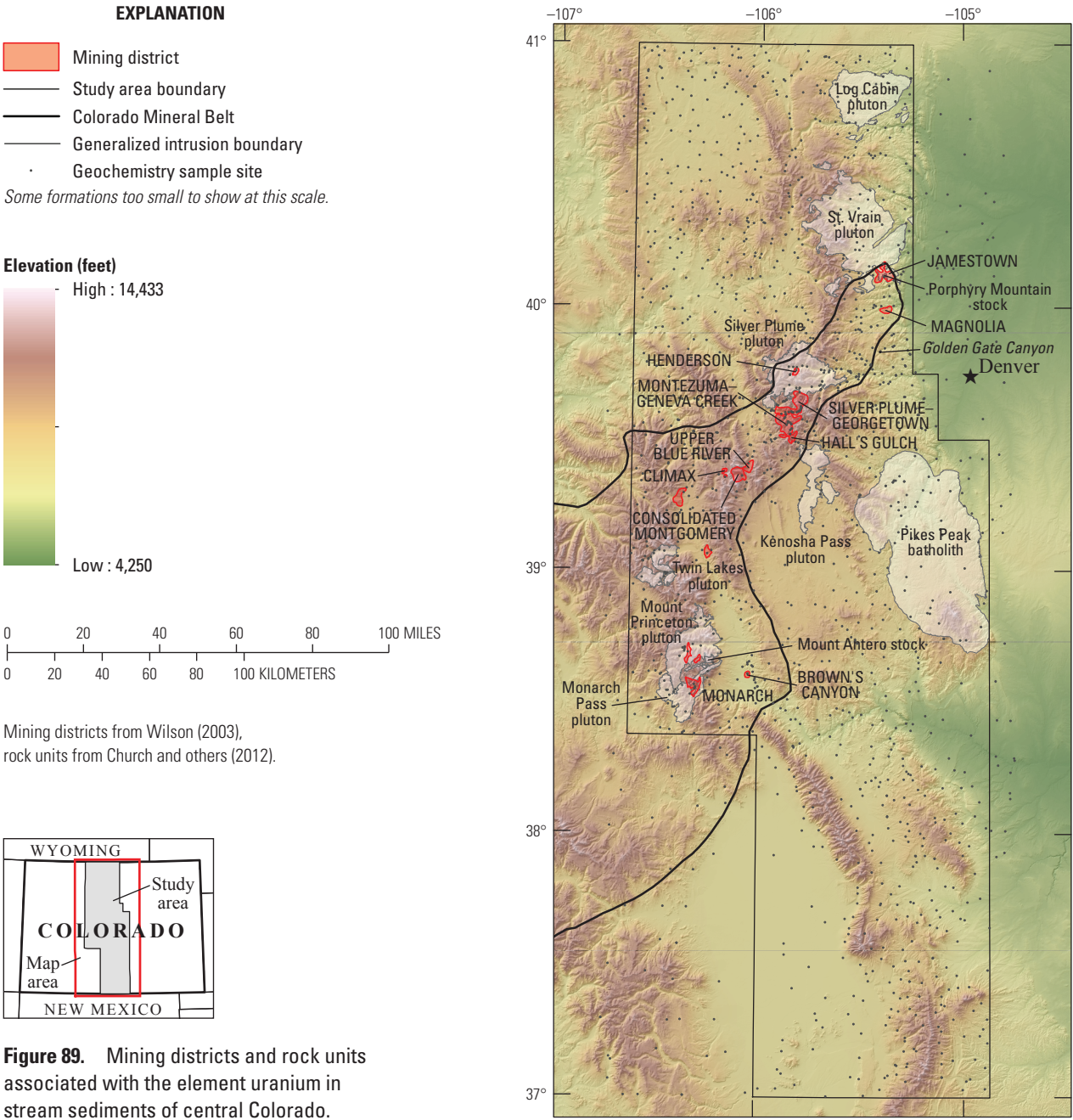


**Figure 88.** Maps of central Colorado stream-sediment geochemistry—uranium (U). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Uranium (U) is a lithophile element concentrated in felsic igneous rocks and igneous rocks and residing in trace and accessory minerals such as zircon, xenotime, monazite, allanite, sphene and apatite. In sedimentary rocks, uranium concentrations are greatest in organic-rich shales, phosphorite, and immature clastic rocks derived from granitic and felsic-volcanic sources. Uranium deposits typically occur in sedimentary rocks, basin-fill deposits, fracture and fault zones, and in some tuffaceous volcanic rocks where groundwater or hydrothermal solutions encountered reducing conditions that caused uranium to precipitate.

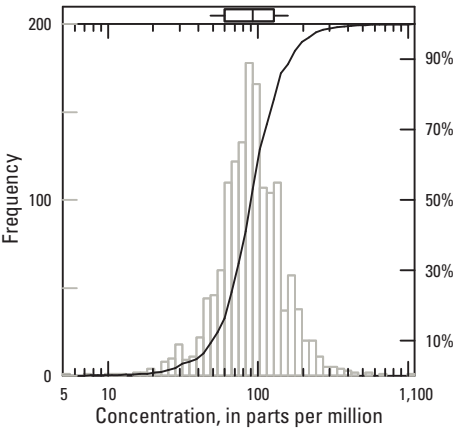
High uranium concentrations (>97.5th percentile) are found in stream-sediment samples from many Mesoproterozoic granitic plutons (figs. 88 and 89). These deposits include some phases of the Pikes Peak batholith and the Kenosha Pass, Log Cabin, Monarch Pass, St. Vrain, and Silver Plume plutons. Sample locations over several Late Cretaceous to Oligocene plutons and stocks contain similar high concentrations, such as the Mount Antero stock, the Mount Princeton pluton, the felsic phase of the Twin Lakes pluton, and the Climax, Henderson, and Porphyry Mountain stocks. Several samples with high U concentrations (>90th percentile) also are associated with rhyolitic welded tuff units in the central part of the study area. Within the Colorado Mineral Belt, high uranium concentrations (>97.5th percentile) are found in samples from the Browns Canyon, Climax, Consolidated Montgomery, Halls Gulch, Henderson, Jamestown, Magnolia, Monarch, Montezuma–Geneva Creek, Silver Plume–Georgetown, and Upper Blue River districts, as well as very close to the range front from the Golden Gate Canyon area in the vicinity of the Schwarzwald uranium mine.







Central Colorado Stream-Sediment  
Geochemistry—Vanadium



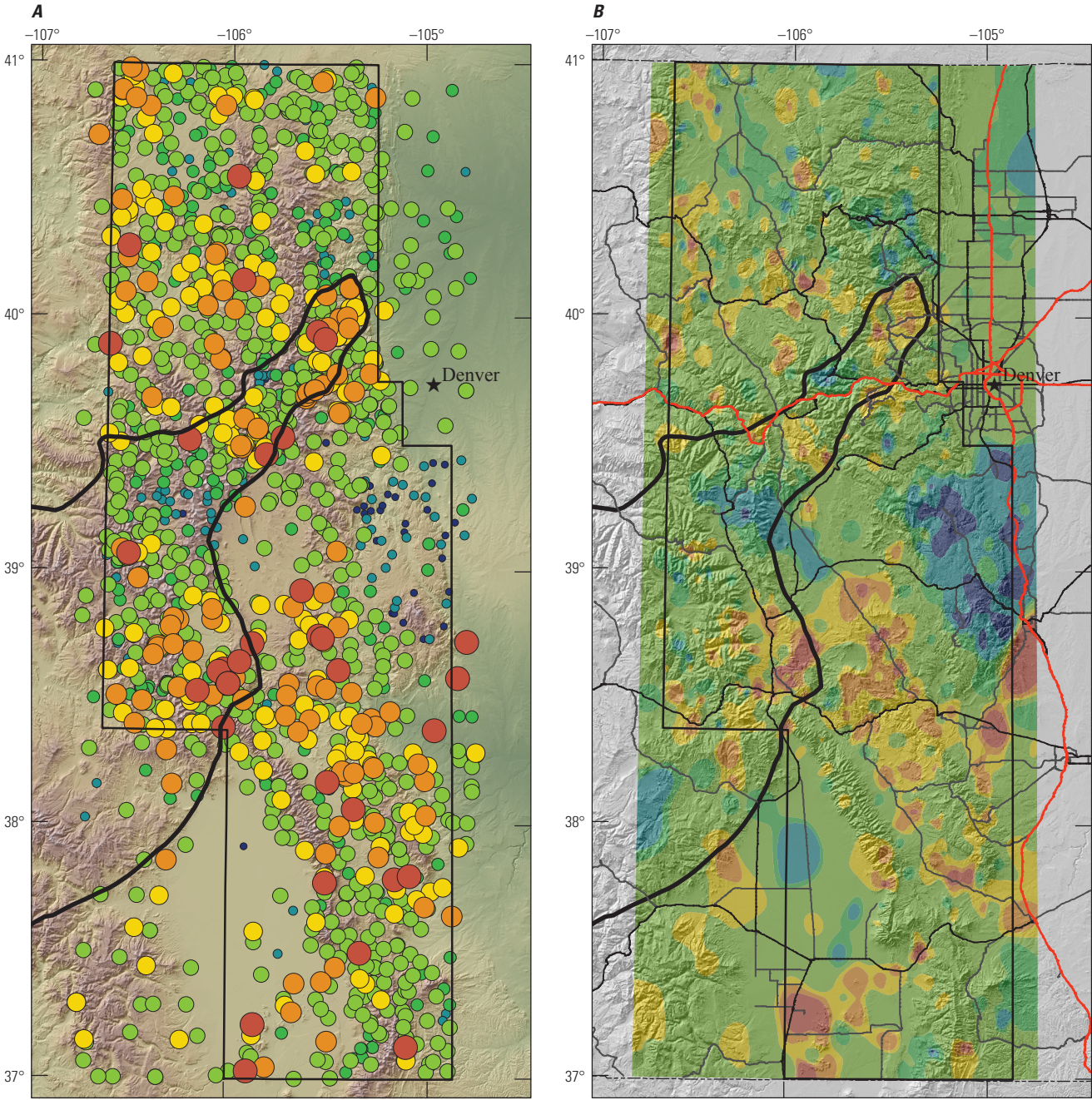
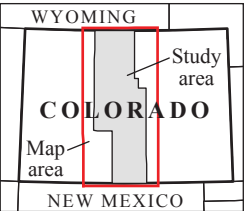
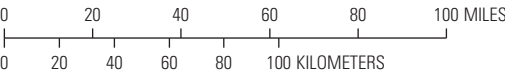
V parts per million (ppm)	
Samples:	1479
Minimum:	5.0000
Maximum:	1000.0000
Mean:	101.4408
Geometric mean:	89.2303
Median:	90.0000
Mode:	110.0000
Standard deviation:	60.96
Standard error:	1.585
Skew:	4.51
Kurtosis:	44.38

**Vanadium** (parts per million)  
Crustal abundance = 136 ppm  
Limit of detection = not applicable

- 5.0–29 ppm (<2.5th percentile)
- 30–50 ppm (2.5–10th percentile)
- 51–68 ppm (10–25th percentile)
- 69–120 ppm (25–75th percentile)
- 130–160 ppm (75–90th percentile)
- 170–240 ppm (90–97.5th percentile)
- 250–1,000 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

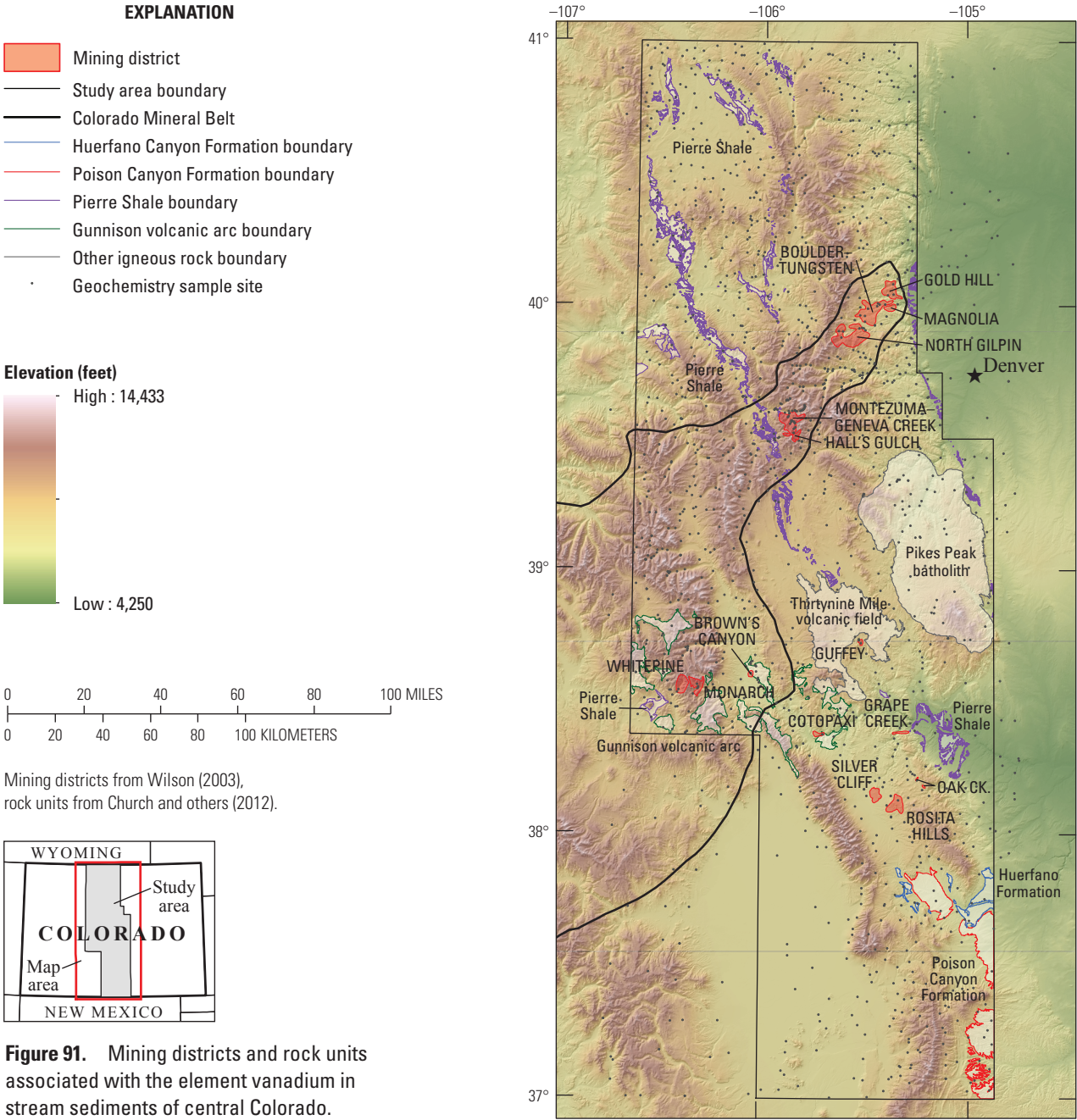


**Figure 90.** Maps of central Colorado stream-sediment geochemistry—vanadium (V). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Vanadium (V) concentration in igneous rocks is related directly to abundance of the Fe-Ti minerals magnetite, ilmenite, and rutile and thus tends to be highest in mafic igneous rocks. Clay-rich sedimentary rocks also may show relatively high vanadium concentrations. Granites generally have low concentrations, as do mature clastic sedimentary rocks and carbonates. Vanadium, with its multiple oxidation states, characteristically is controlled by oxidation-reduction reactions in low-temperature aqueous solutions in the near-surface environment.

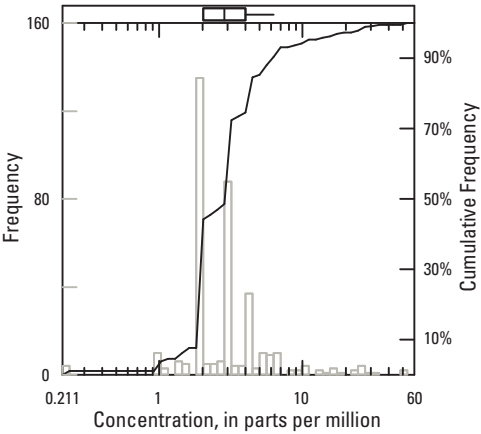
In the study area, most of the high vanadium concentrations probably are related to rock type. Stream-sediment samples with high vanadium concentrations in the >90th percentile range are scattered widely and associated with a variety of rock units (figs. 90 and 91). High concentrations are associated with mafic and ultramafic igneous rocks (such as those of the Thirtynine Mile volcanic field and the Gunnison volcanic arc), organic-rich shales such as the Pierre Shale, and with some basin-fill sedimentary units such as the Huerfano and northern Poison Canyon Formations in the southern part of the study area, where they may be related to small stratabound uranium-vanadium deposits (Vanderwilt, 1947). Similar to the distribution of samples containing cobalt, samples showing high (>90th percentile) vanadium concentrations south of the Colorado Mineral Belt may be related to Mesoproterozoic stratabound base-metal deposits in the Cotopaxi, Grape Creek, Guffey, Oak Creek, Rosita Hills, and Silver Cliff districts. Within the mineral belt, clusters of sample locations containing abundant vanadium are found in the Gold Hill, Magnolia, Boulder-Tungsten, and North Gilpin districts at the northeastern end, in the Halls Gulch and Montezuma–Geneva Creek districts, and at the southern end in the Browns Canyon, Whitepine, and Monarch districts. Concentrations of common accessory heavy minerals (such as magnetite, ilmenite, and rutile) in alluvial placers also may result in scattered, isolated samples showing high vanadium concentrations. The Mesoproterozoic Pikes Peak batholith is depleted noticeably in vanadium, reflecting that batholith’s strongly granitic composition.







Central Colorado Stream-Sediment  
Geochemistry—Ytterbium



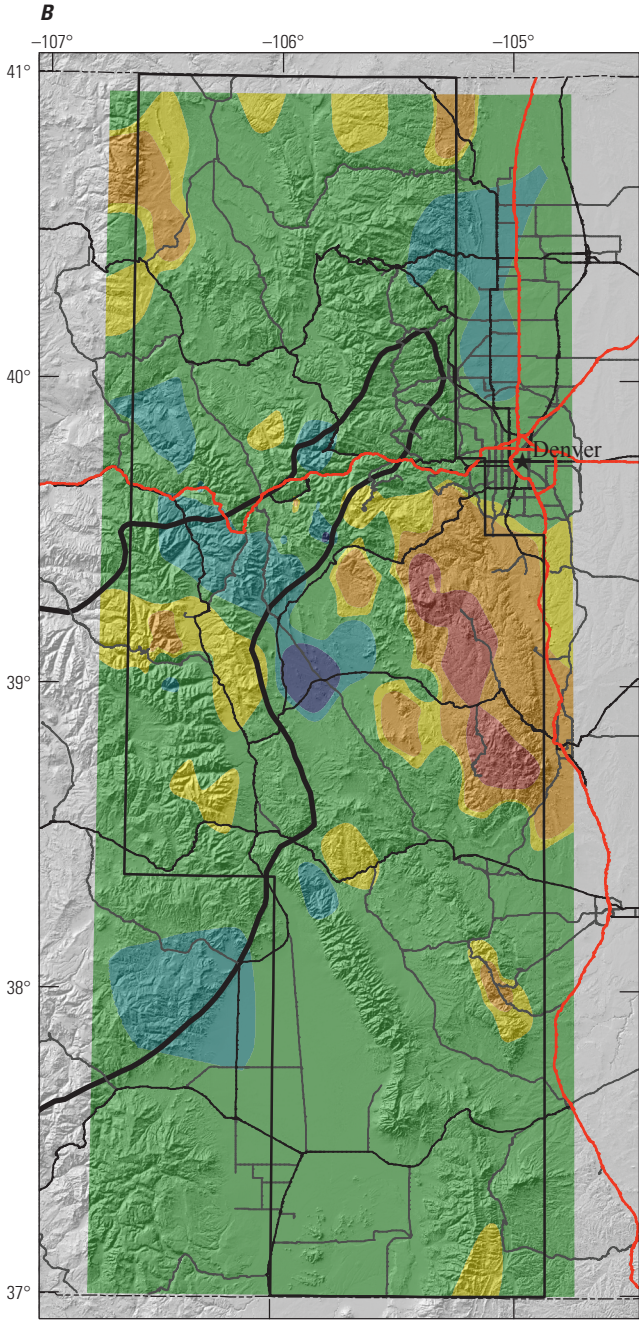
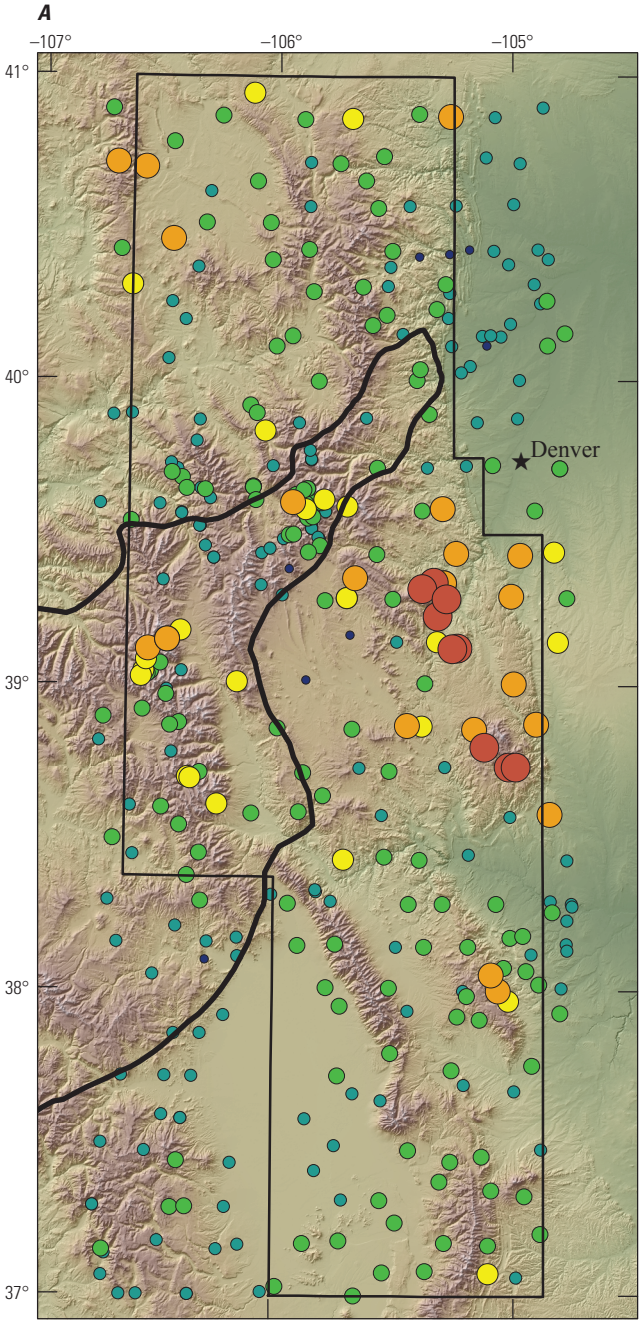
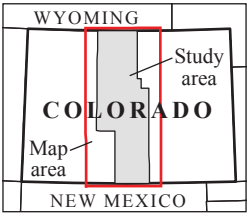
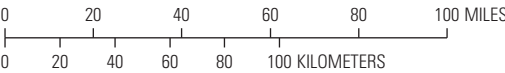
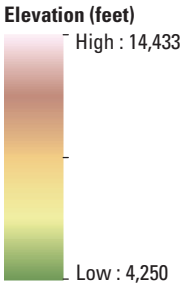
Yb parts per million (ppm)	
Samples:	369
Minimum:	<1
Maximum:	51.0000
Mean:	3.9695
Geometric mean:	2.8891
Median:	3.0000
Mode:	2.0000
Standard deviation:	5.406
Standard error:	0.2814
Skew:	5.381
Kurtosis:	35.12

**Ytterbium** (parts per million)  
Crustal abundance = 3.10 ppm  
Limit of detection = 1 ppm

- <1.0 ppm (<2.5th percentile)
- 1.1–2.0 ppm (2.5–25th percentile)
- 2.1–4.0 ppm (25–75th percentile)
- 4.1–6.0 ppm (75–90th percentile)
- 6.1–22 ppm (90–97.5th percentile)
- 23–51 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

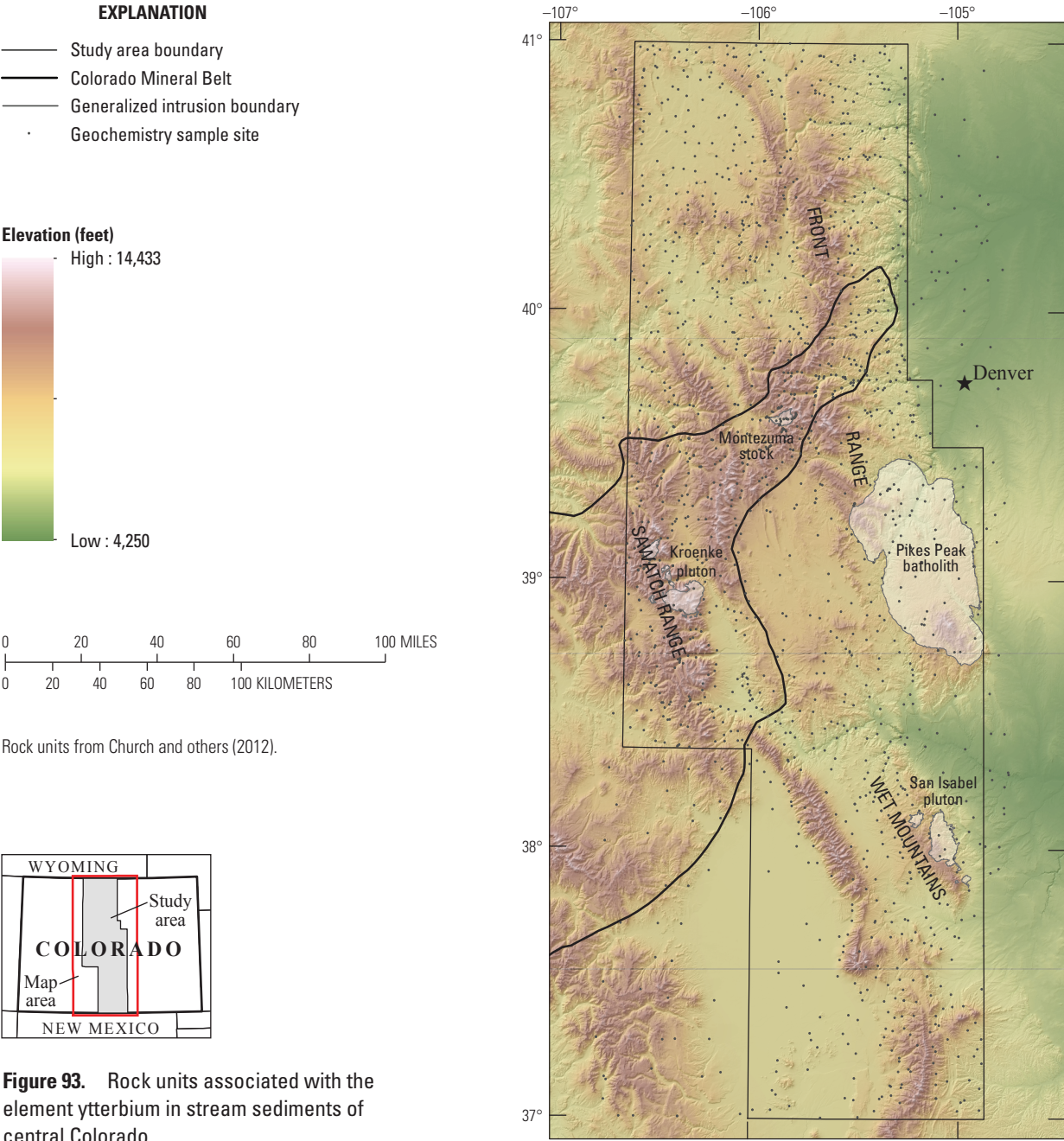


**Figure 92.** Maps of central Colorado stream-sediment geochemistry—ytterbium (Yb). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Ytterbium (Yb) is one of 15 metallic elements called rare earth elements (REEs). The REEs, including ytterbium, are strongly lithophile in igneous rocks. See the cerium map (fig. 19) for further discussion of the geochemical behavior of the REEs.

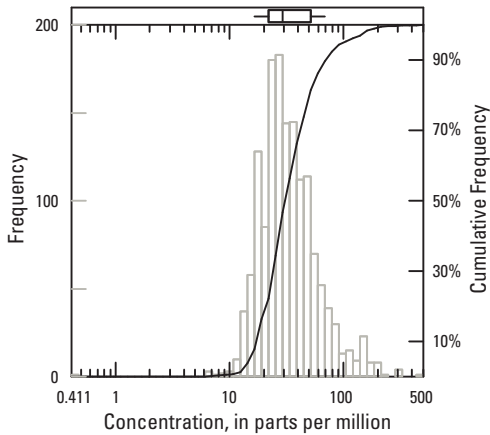
In this study, only a small subset of samples (369 out of 1,479) from the Church and others (2012) and Grossman (1998) studies were analyzed for ytterbium (fig. 92). The highest concentrations of ytterbium (>90th percentile) were found in stream-sediment samples overlying the main phase of the Mesoproterozoic Pikes Peak batholith and from sample locations underlain by the San Isabel pluton in the Wet Mountains and the Kroenke pluton in the Sawatch Range, and in one sample downstream from the Tertiary Montezuma stock in the west-central Front Range (figs. 92 and 93). Several other REEs (Ce, Eu, Ho, La, and Nd) show spatial associations with felsic rocks in mining districts within the Colorado Mineral Belt (see respective pages, this report). The lack of this spatial association for ytterbium (and for yttrium as well) likely reflects the fact that the granitic rocks within the mineral belt are more enriched in light (La, Ce, Nd) and middle (Eu, Ho) REEs than in heavy REEs (Y, Yb). The overall map patterns for ytterbium mimic fairly well the patterns for yttrium, where many more samples ( $n = 1,479$ ) were analyzed.







Central Colorado Stream-Sediment  
Geochemistry—Yttrium



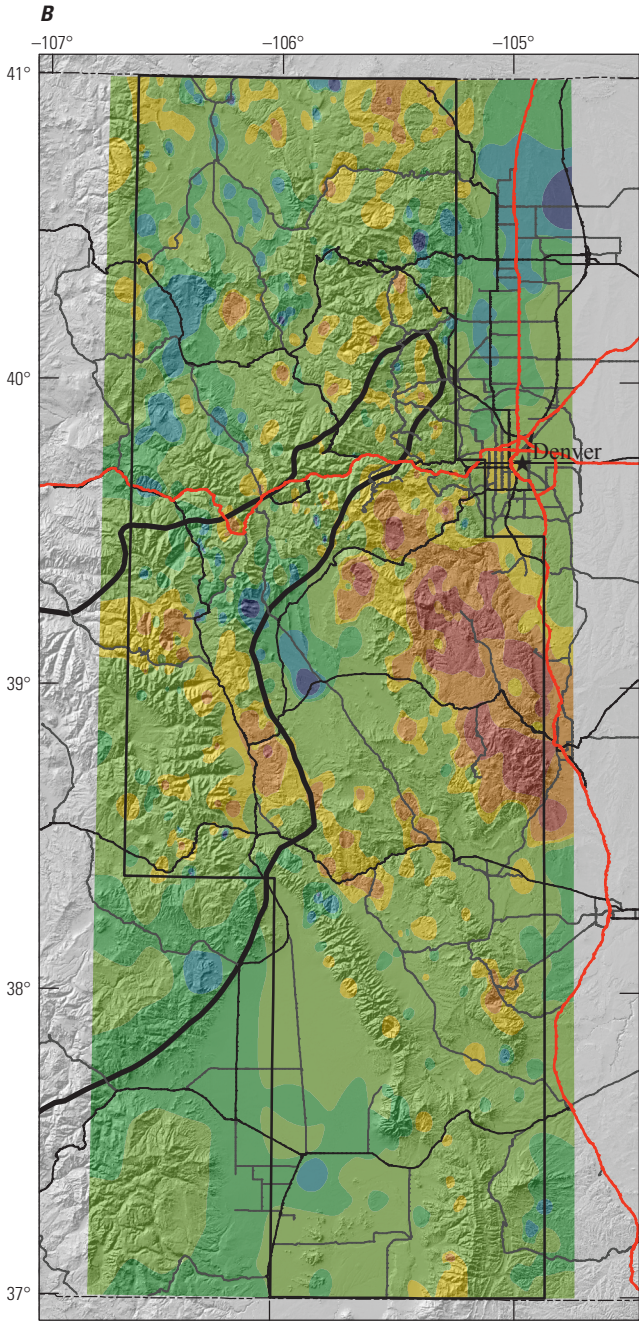
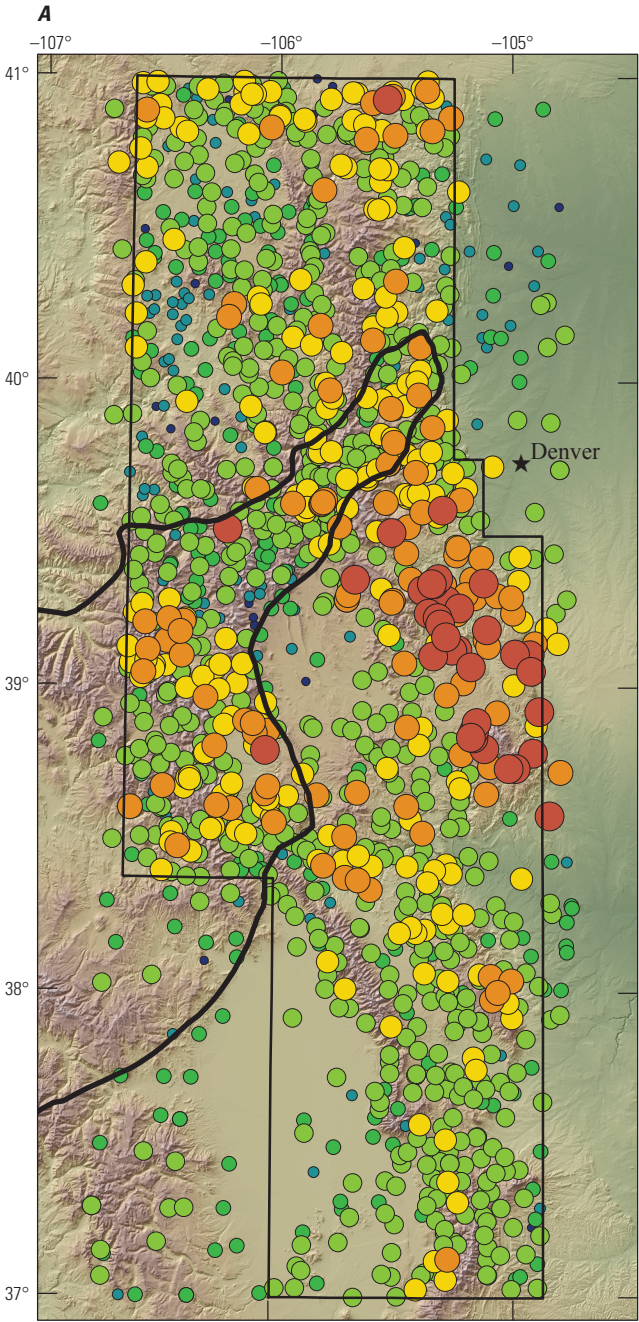
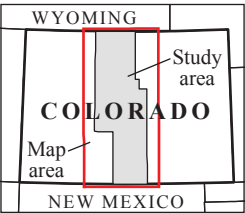
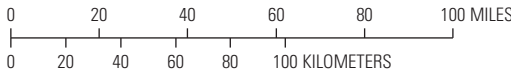
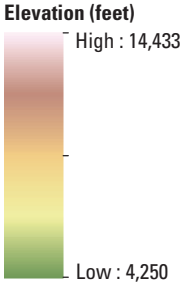
Y parts per million (ppm)	
Samples:	1479
Minimum:	<2
Maximum:	453.0000
Mean:	40.2749
Geo.Mean:	33.0884
Median:	31.0000
Mode:	19.0000
Std.Dev.:	33.95
Std.Err.:	0.8827
Skew:	4.184
Kurtosis:	28.06

**Yttrium** (parts per million)  
Crustal abundance = 31.0 ppm  
Limit of detection = 2 ppm

- <13.1 ppm (<2.5th percentile)
- 13.1–17.0 ppm (2.5–10th percentile)
- 17.1–22.0 ppm (10–25th percentile)
- 22.1–45.3 ppm (25–75th percentile)
- 45.4–69.0 ppm (75–90th percentile)
- 69.1–145 ppm (90–97.5th percentile)
- 146–453 ppm (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

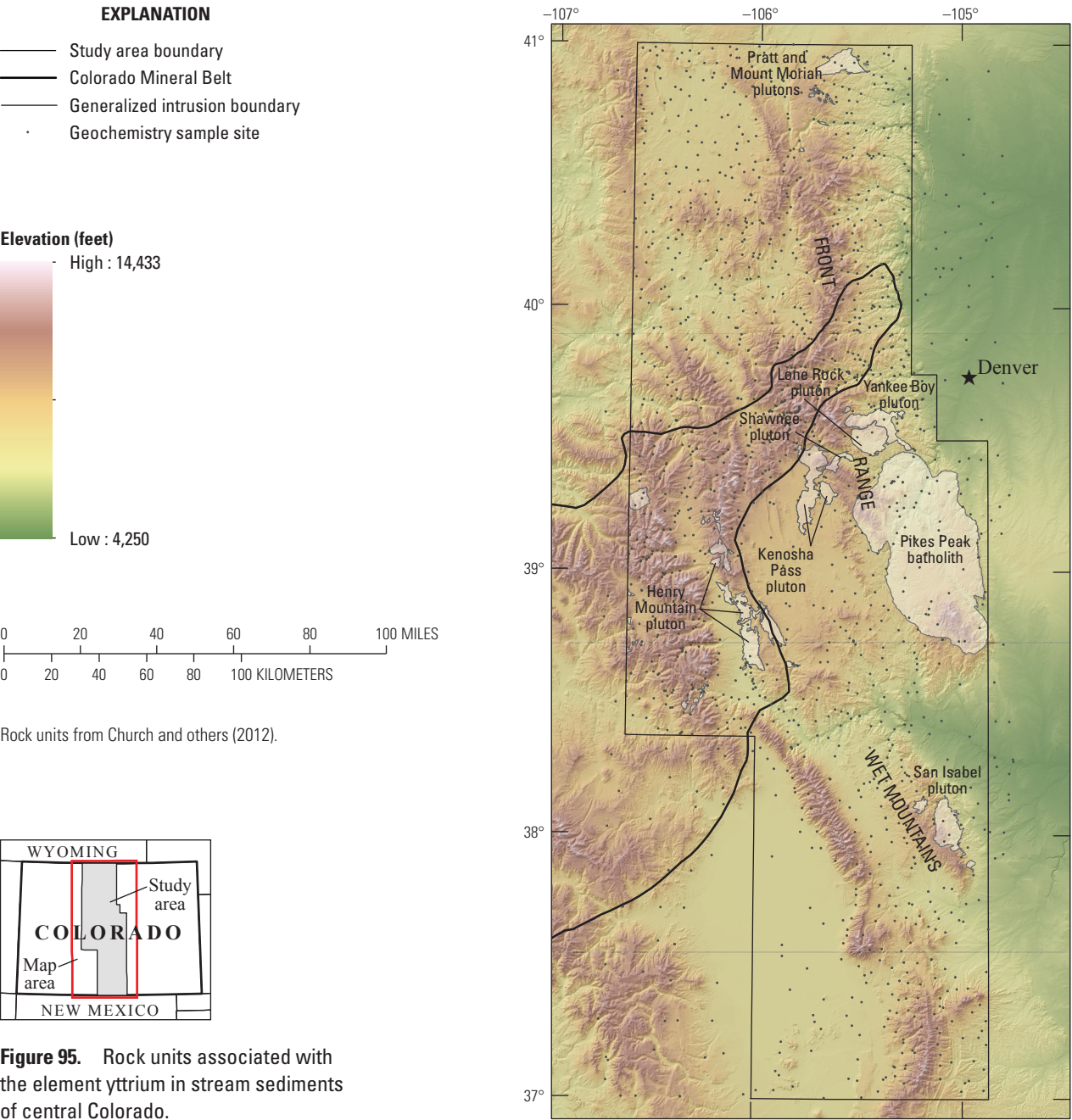


**Figure 94.** Maps of central Colorado stream-sediment geochemistry—yttrium (Y).  
(A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Yttrium (Y) is one of 15 metallic elements called rare earth elements (REEs). The REEs, including yttrium, are strongly lithophile in igneous rocks. See the cerium map (fig. 19) for further discussion of the geochemical behavior of the REEs.

The highest concentrations of yttrium (>90th percentile) are found in stream-sediment samples obtained over and near the main phase of the Mesoproterozoic Pikes Peak batholith, with scattered lower concentrations (>90th to 97.5th percentile) from samples overlying several other, mainly Mesoproterozoic, granitic plutons in the study area (figs. 94 and 95). Plutons associated with high yttrium include the Kenosha Pass, Lone Rock, Shawnee, and Yankee Boy plutons in the Front Range, the southern portion of the Henry Mountain pluton, the Pratt and tectonized Mount Moriah plutons near the Wyoming border, and the Mesoproterozoic San Isabel pluton in the southern Wet Mountains. Other REEs (Ce, Eu, Ho, La, and Nd) show spatial associations with felsic rocks in mining districts within the Colorado Mineral Belt. The lack of this spatial association for yttrium (and for ytterbium, as well) likely reflects the fact that the granitic rocks within the mineral belt are more enriched in light (La, Ce, Nd) and middle (Eu, Ho) REEs than in heavy REEs (Y, Yb).

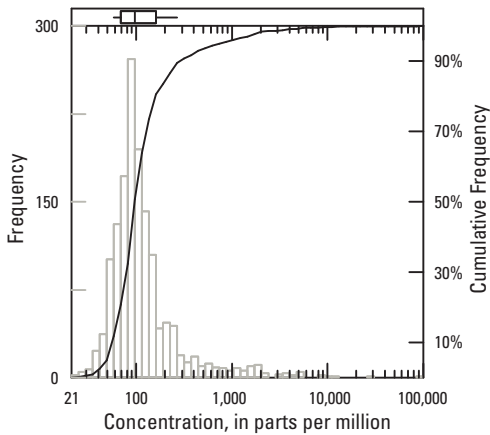


**Figure 95.** Rock units associated with the element yttrium in stream sediments of central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Zinc



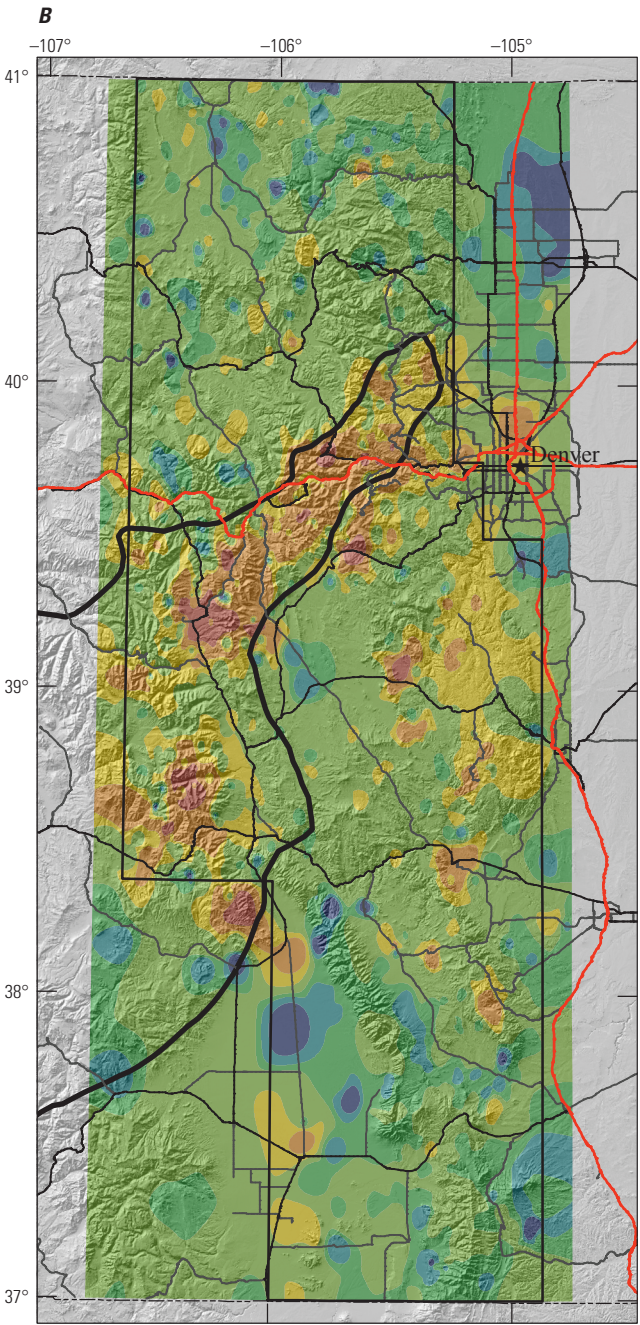
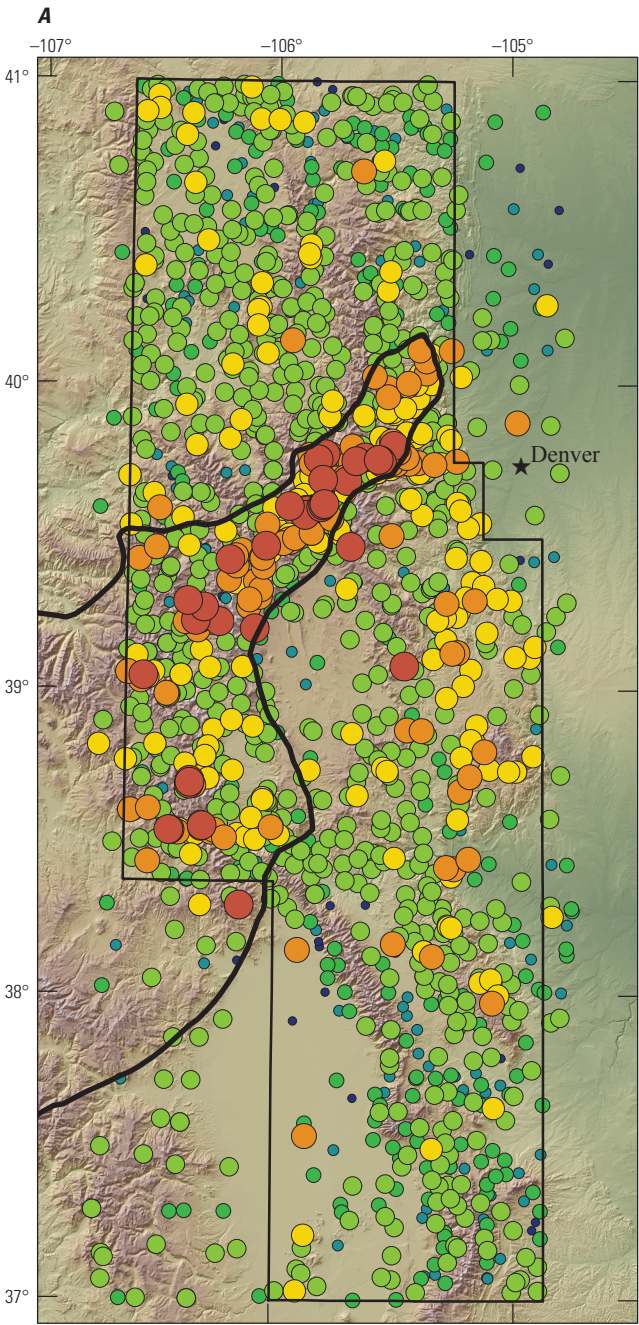
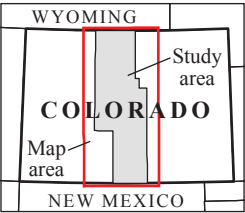
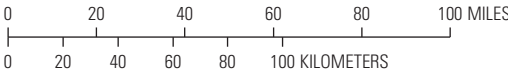
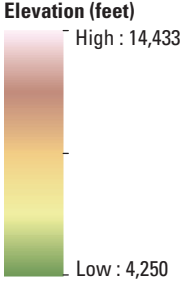
Zn parts per million (ppm)	
Samples:	1479
Minimum:	21.0000
Maximum:	96000.0000
Mean:	316.1394
Geometric mean:	117.4226
Median:	96.0000
Mode:	110.0000
Standard deviation:	2677
Standard error:	69.6
Skew:	31.67
Kurtosis:	1108

EXPLANATION

**Zinc (parts per million)**  
Crustal abundance = 76.0 ppm  
Limit of detection = not applicable

- 21.0–41.0 ppm (<2.5th percentile)
- 41.1–55.0 ppm (2.5–10th percentile)
- 55.1–73.0 ppm (10–25th percentile)
- 73.1–140 ppm (25–75th percentile)
- 141–280 ppm (75–90th percentile)
- 281–1,700 ppm (90–97.5th percentile)
- 1,710–96,000 ppm (>97.5th percentile)

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

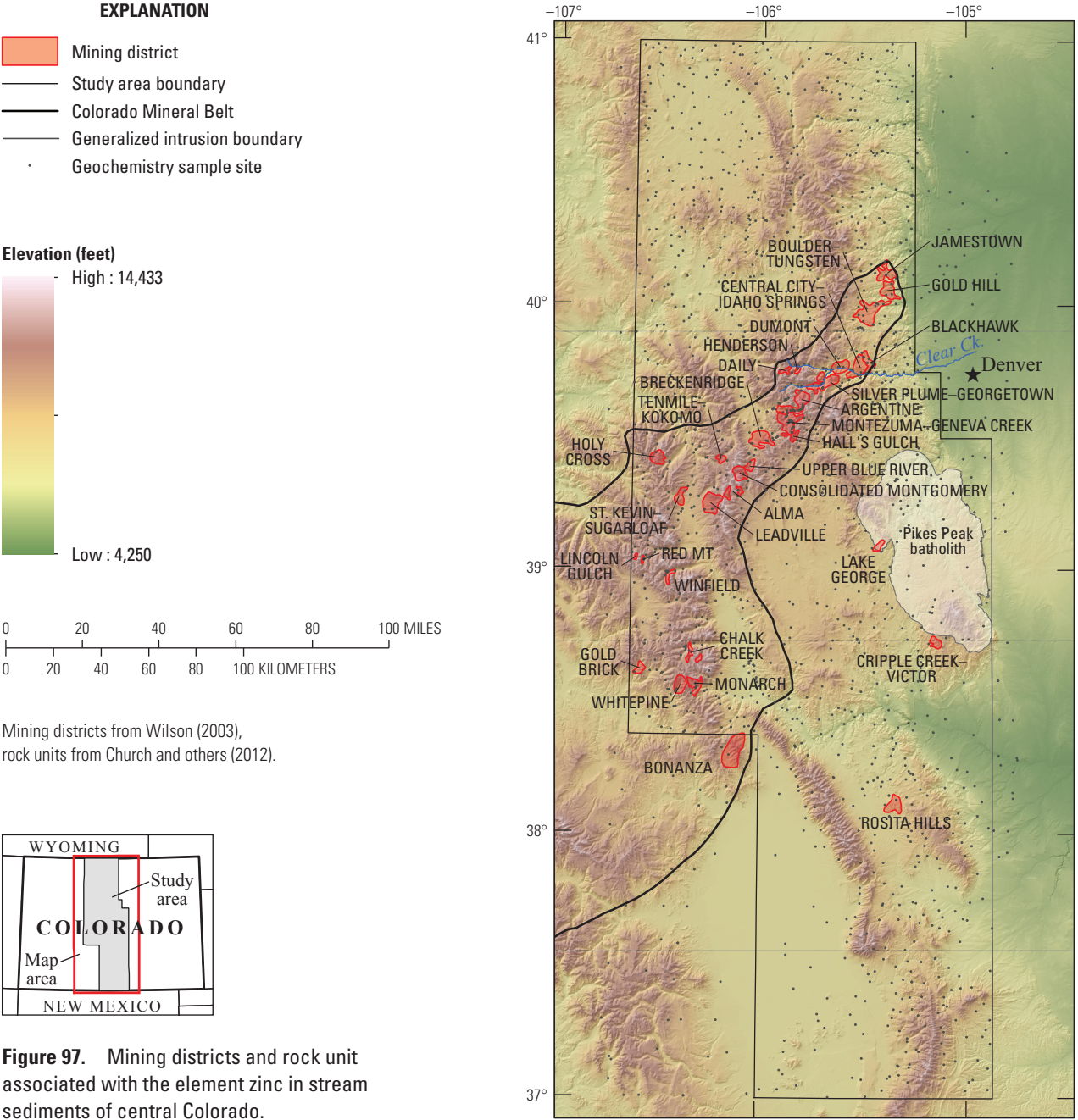


**Figure 96.** Maps of central Colorado stream-sediment geochemistry—zinc (Zn).  
(A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Zinc (Zn) is strongly chalcophile in its geochemistry, although it is locally present in some silicate minerals such as biotite. Zinc is commonly found in sphalerite and in other more complex sulfide minerals. It is relatively mobile during weathering and may be concentrated on manganese- and iron-hydroxide precipitates and on organic matter. Organic-rich shales are commonly enriched in zinc.

The distribution of zinc in stream sediments is similar to that of cadmium and bismuth. Almost all concentrations are in the >97.5th percentile range; they occur in and help define the entire Colorado Mineral Belt (figs. 96 and 97). The single highest zinc concentration (96,000 parts per million, ppm) is from a sample obtained downstream of the Leadville district. Extremely high zinc concentrations (11,000 and 26,000 ppm, respectively) are found in two samples taken near the Chalk Creek district. Another sample with an extremely high zinc concentration of 13,000 ppm is from the Montezuma–Geneva Creek district. Elsewhere in the mineral belt, high zinc concentrations (>90th percentile) are found in numerous samples from many districts, including the Alma, Argentine, Blackhawk, Bonanza, Boulder-Tungsten, Breckenridge, Central City–Idaho Springs, Consolidated Montgomery, Daily, Dumont, Gold Brick, Gold Hill, Halls Gulch, Henderson, Holy Cross, Jamestown, Lincoln Gulch, Monarch, Red Mountain, Silver Plume–Georgetown, St. Kevin–Sugarloaf, Tenmile-Kokomo, Upper Blue River, Whitepine, and Winfield districts. A zinc dispersion train is evident along Clear Creek from the Henderson district eastward to the range front. South of the mineral belt, high zinc concentrations (>90th percentile) are found in samples from the Cripple Creek–Victor, Lake George, and Rosita Hills districts and from scattered locations within the Mesoproterozoic Pikes Peak batholith.

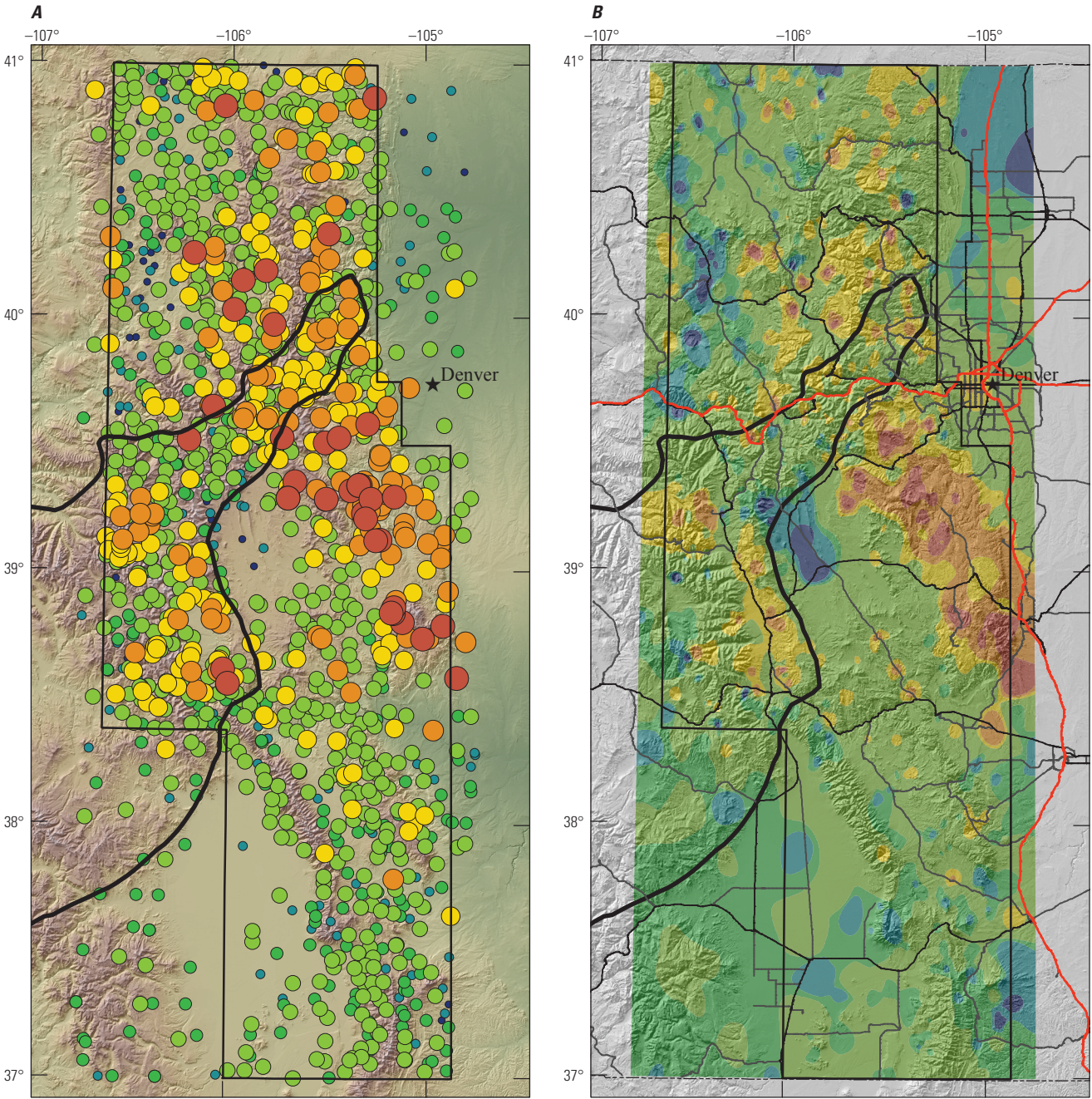
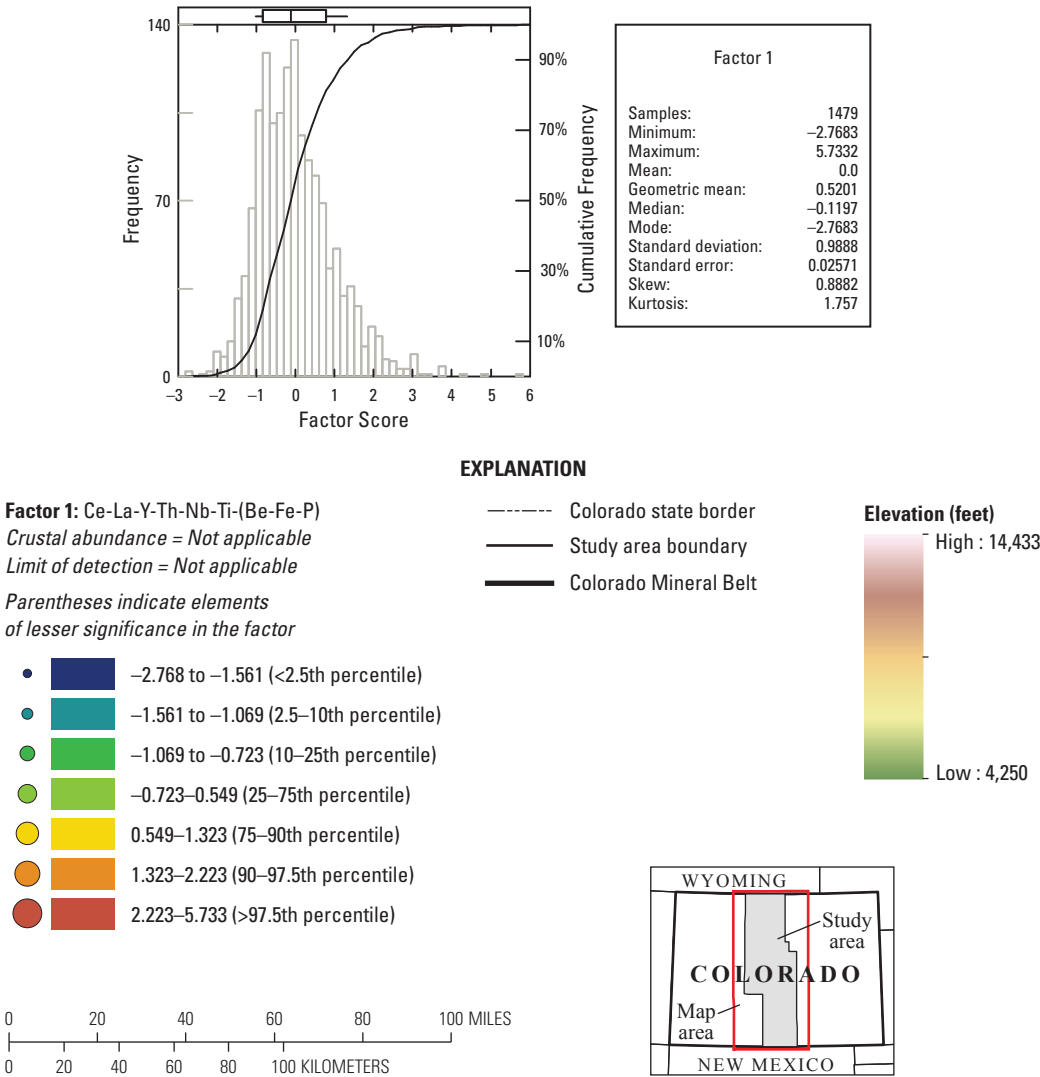


**Figure 97.** Mining districts and rock unit associated with the element zinc in stream sediments of central Colorado.





Central Colorado  
Stream-Sediment Geochemistry—  
Factor 1: Ce-La-Y-Th-Nb-Ti-(Be-Fe-P)



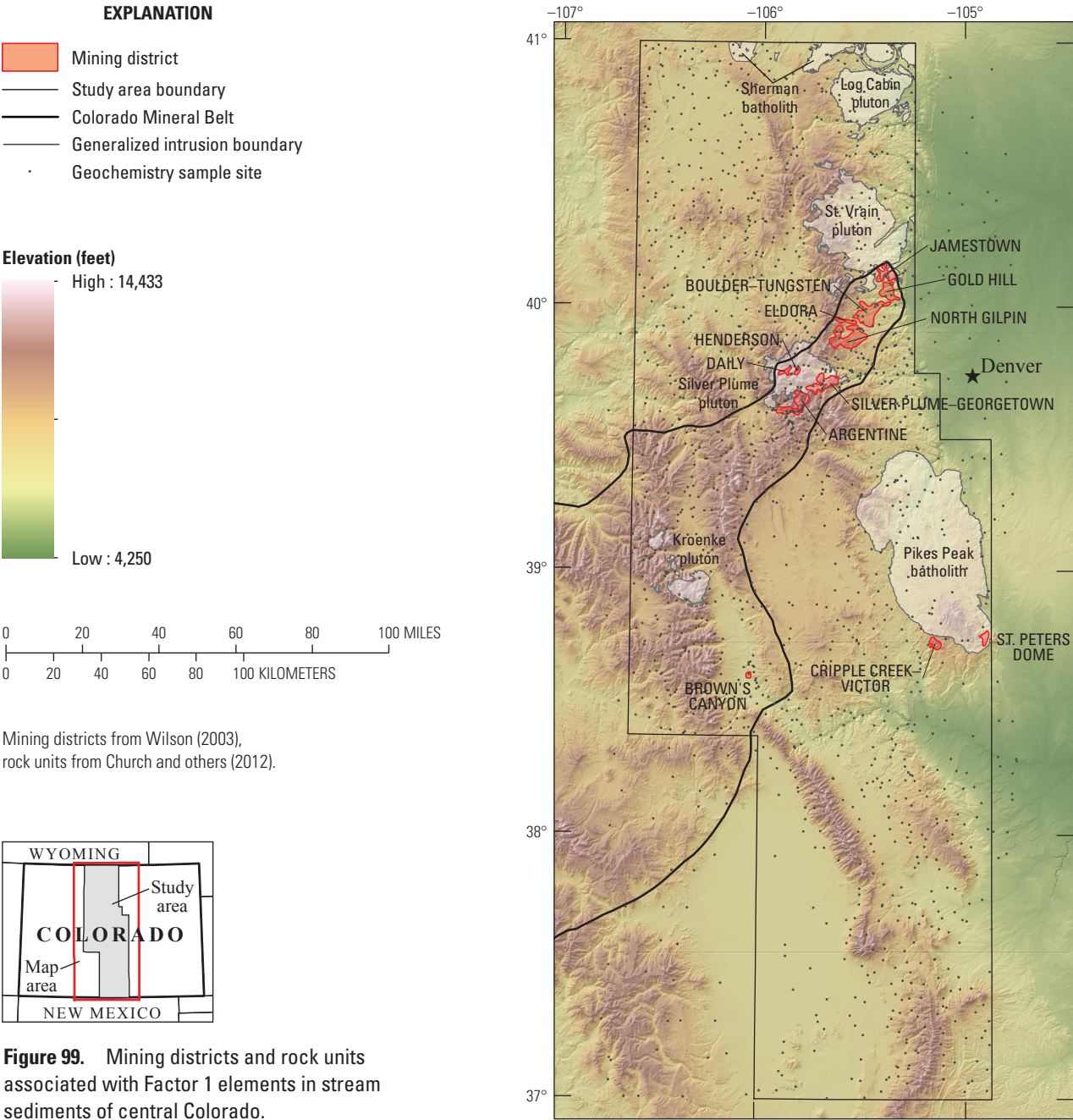
**Figure 98.** Maps of central Colorado stream-sediment geochemistry—Factor 1: Ce-La-Y-Th-Nb-Ti-(Be-Fe-P). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



The factor analysis maps presented in this report represent factor scores for a five-factor model generated using R-mode factor analysis, a multivariate statistical procedure.

Details on the factor analysis procedures used in this report are provided in the Methods section; elements within a given factor behave similarly in their gross distributions.

Factor 1, containing elements Ce-La-Y-Th-Nb-Ti-(Be-Fe-P), explains the most variance for elements within the dataset. It is a lithologic factor related to high concentrations of rare earth elements (REEs) and several other lithophile elements (that is, Be, Nb, and Th) in stream-sediment samples from certain granitic rocks. Here and in subsequent factor suites, elements in parentheses are weaker components of the respective factor. Titanium in this factor likely represents the presence of sphene (which also commonly contains REEs), rutile, or ilmenite (with iron) in sediments derived from granitic rocks. Phosphorus probably is incorporated into the REE-rich phosphate monazite. Factor 1 highlights many of the lithophile-element-rich granitic batholiths and plutons (mostly Mesoproterozoic) in the northern two-thirds of the study area. Those intrusions include the Pikes Peak and Sherman batholiths, and the Kroenke, Log Cabin, St. Vrain, and Silver Plume plutons (figs. 98 and 99). Mining districts indicated most strongly by Factor 1 (that is, falling above the 97.5th percentile) include the Browns Canyon, Cripple Creek–Victor, and St. Peters Dome districts. Mining districts indicated by Factor 1 at the 90th to 97.5th percentile include the Argentine, Boulder-Tungsten, Daily, Eldora, Gold Hill, Henderson, Jamestown, North Gilpin, and Silver Plume–Georgetown districts.

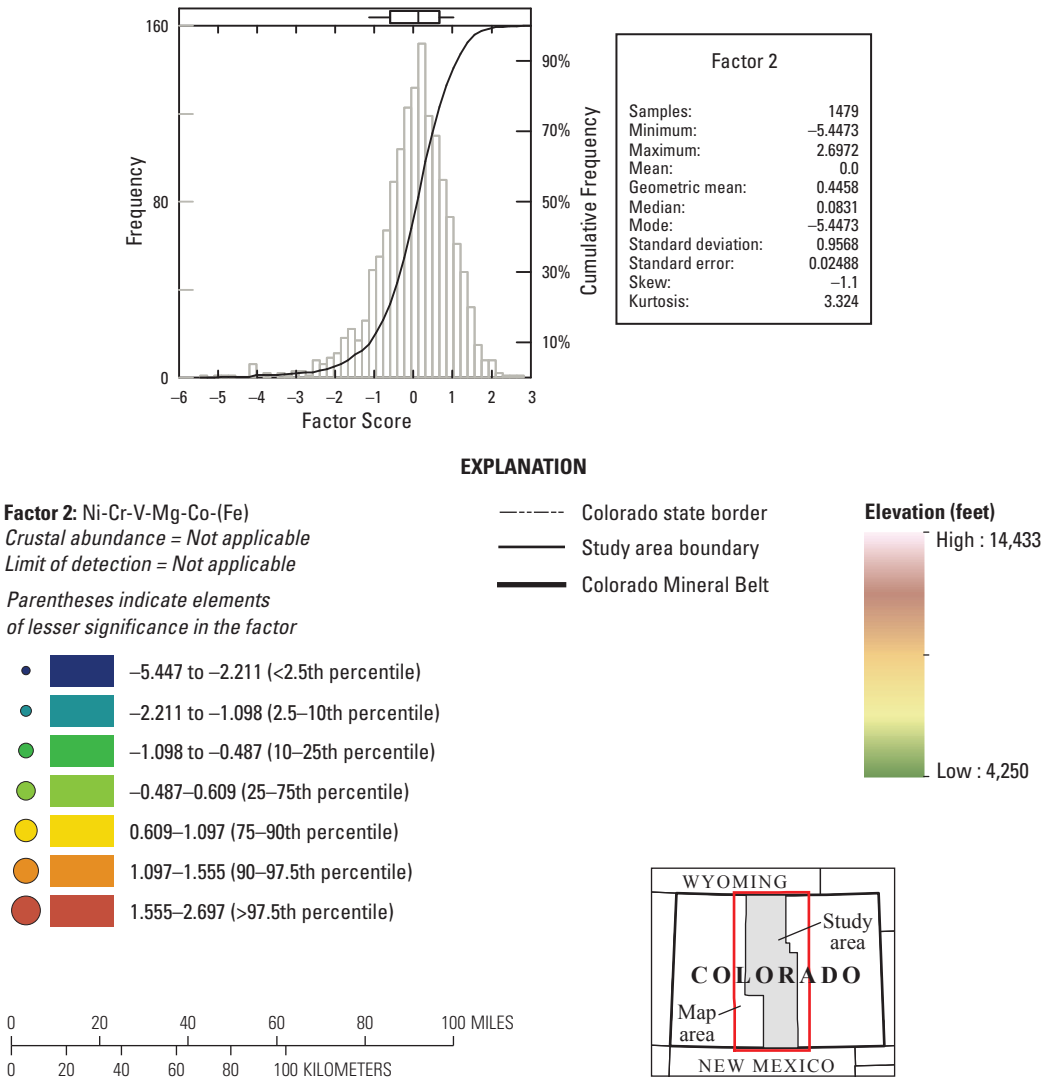


**Figure 99.** Mining districts and rock units associated with Factor 1 elements in stream sediments of central Colorado.

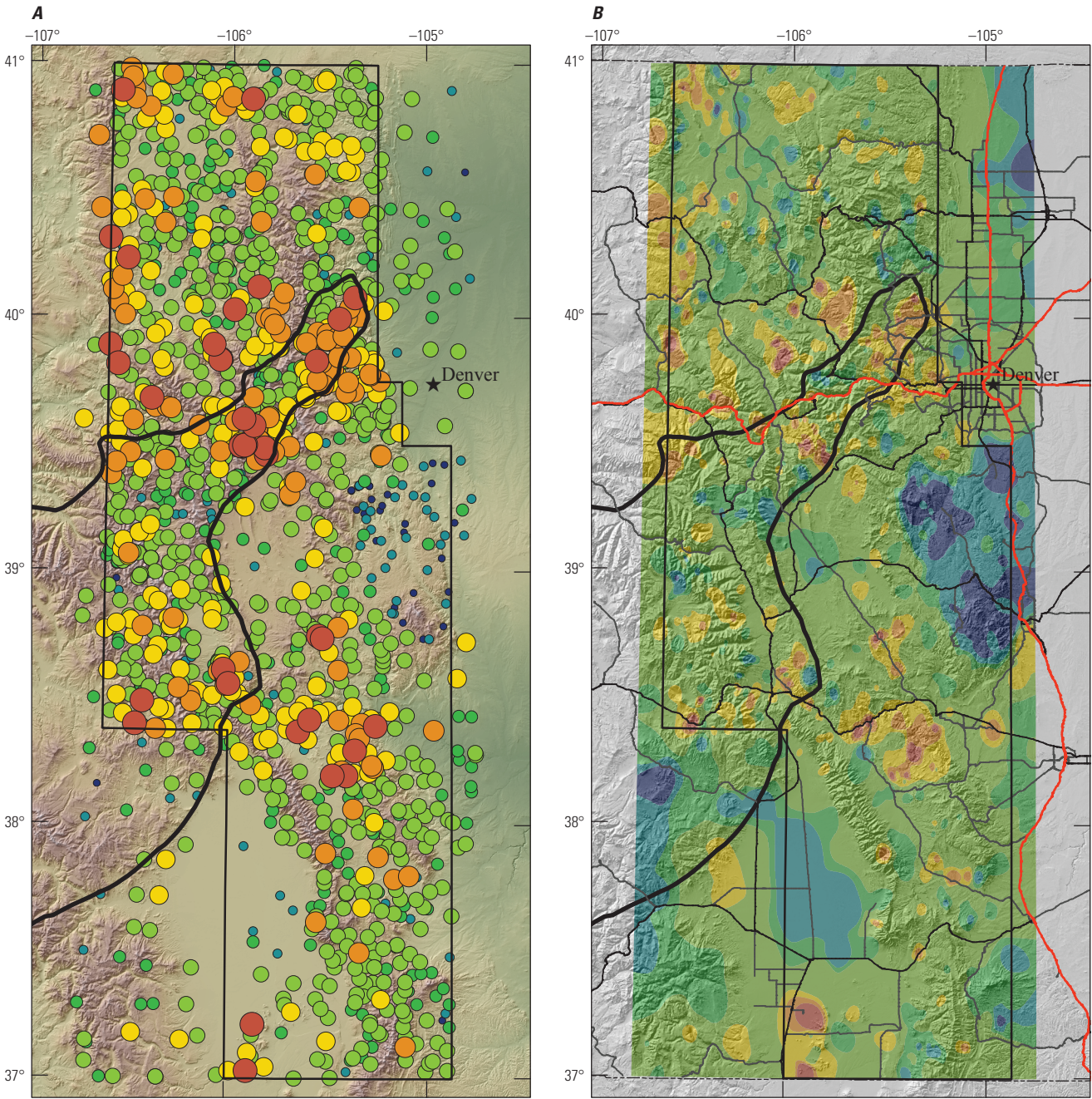




Central Colorado Stream-Sediment  
Geochemistry—Factor 2: Ni-Cr-V-Mg-Co-(Fe)



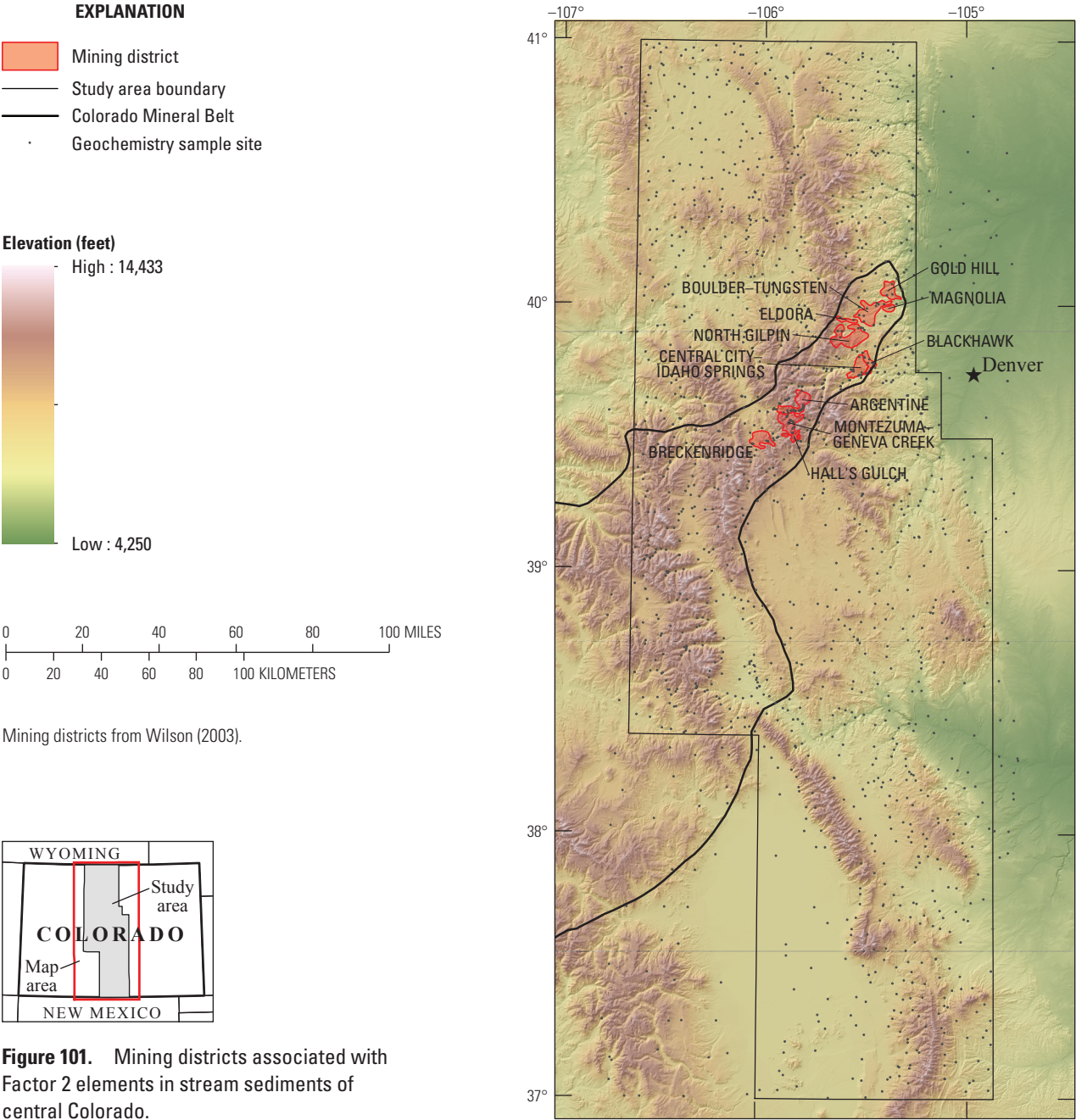
**Figure 100.** Maps of central Colorado stream-sediment geochemistry—Factor 2: Ni-Cr-V-Mg-Co-(Fe). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



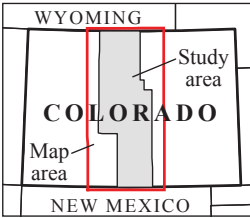


Details on the factor analysis procedures used in this report are provided in the Methods section; elements within a given factor behave similarly in their gross spatial distributions.

Factor 2, containing elements Ni-Cr-V-Mg-Co-(Fe), explains the second-greatest variability for elements within the dataset and is a lithologic factor that indicates association with mafic rocks. Wide distribution of Factor 2 elements throughout the study area likely reflects sediments derived in part from mafic dikes, amphibolites, and other mafic igneous bodies of various ages present throughout the area (figs. 100 and 101). Although numerous stream-sediment samples with high values (above the 90th percentile) for Factor 2 were obtained in and around mining districts in the Colorado Mineral Belt, it is unlikely that such mineralization is related genetically to this factor. Mineral deposits containing high concentrations of this suite of mafic elements (Ni, Cr, V, Mg, and Co) are not present within the study area, although some deposits show enrichment in Co and V. The various rock and deposit types that might be indicated by the elements Co, Cr, Mg, Ni, and V are provided in more detail in individual element discussions associated with figures 23, 25, 45, 55, and 91, respectively.



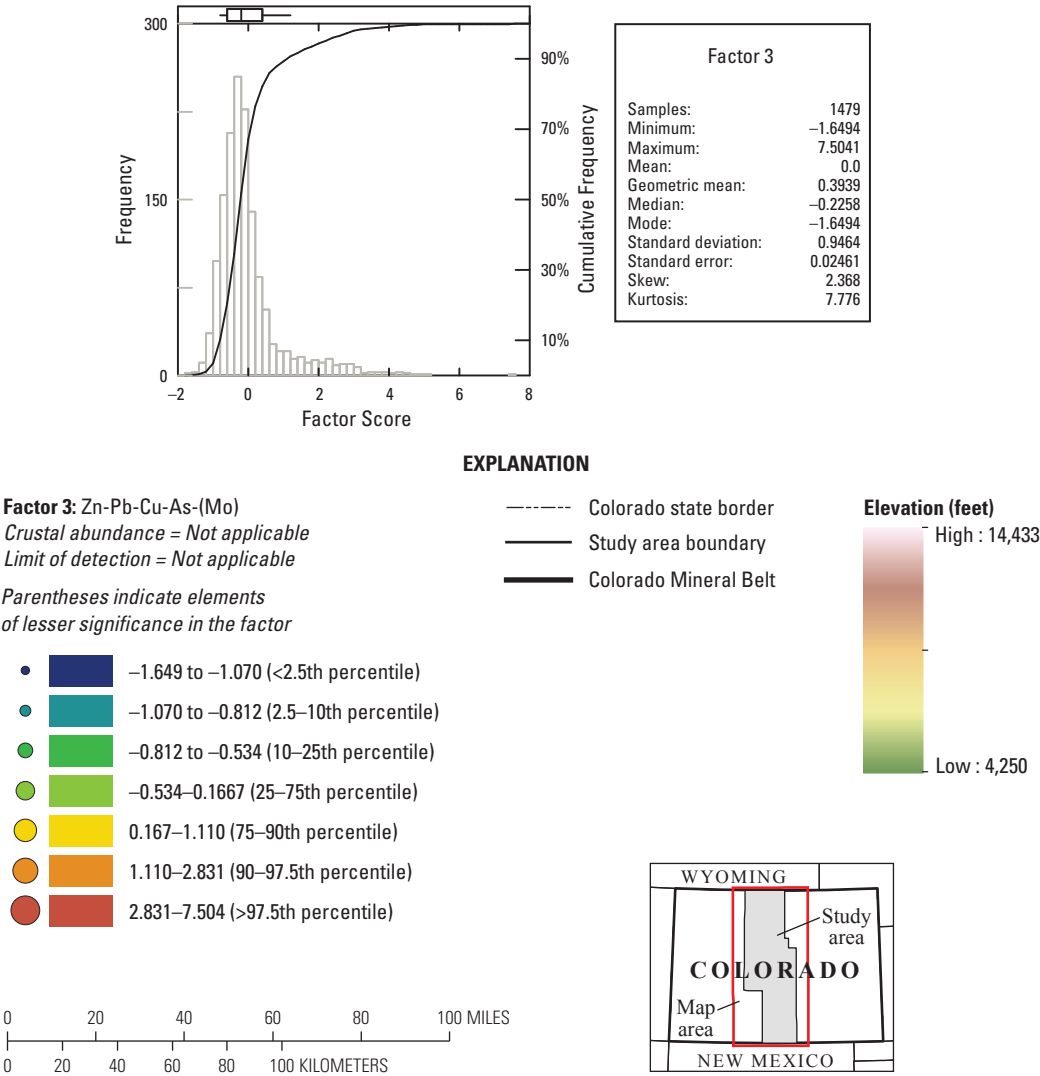
**Figure 101.** Mining districts associated with Factor 2 elements in stream sediments of central Colorado.



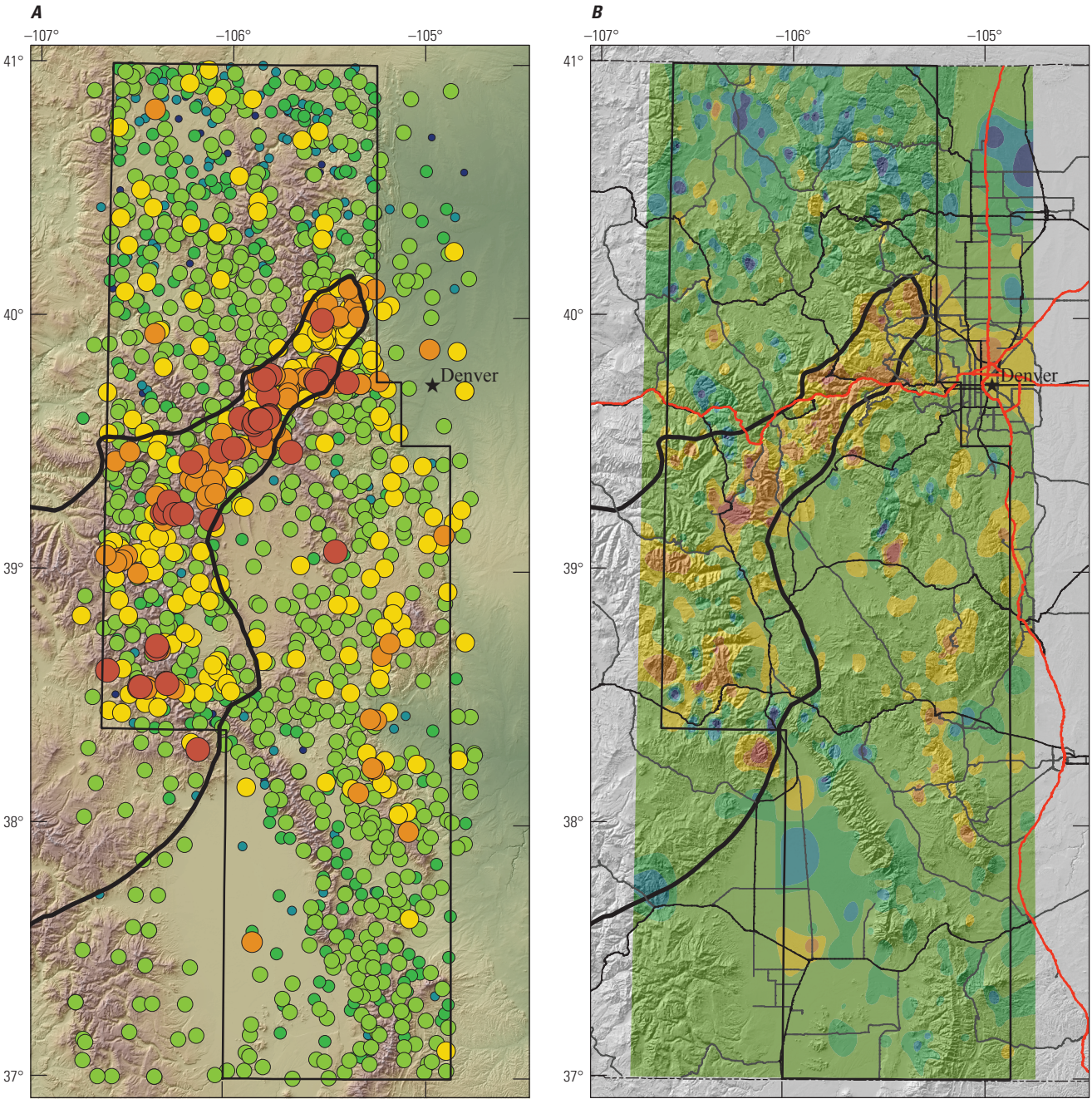




Central Colorado Stream-Sediment  
Geochemistry—Factor 3: Zn-Pb-Cu-As-(Mo)



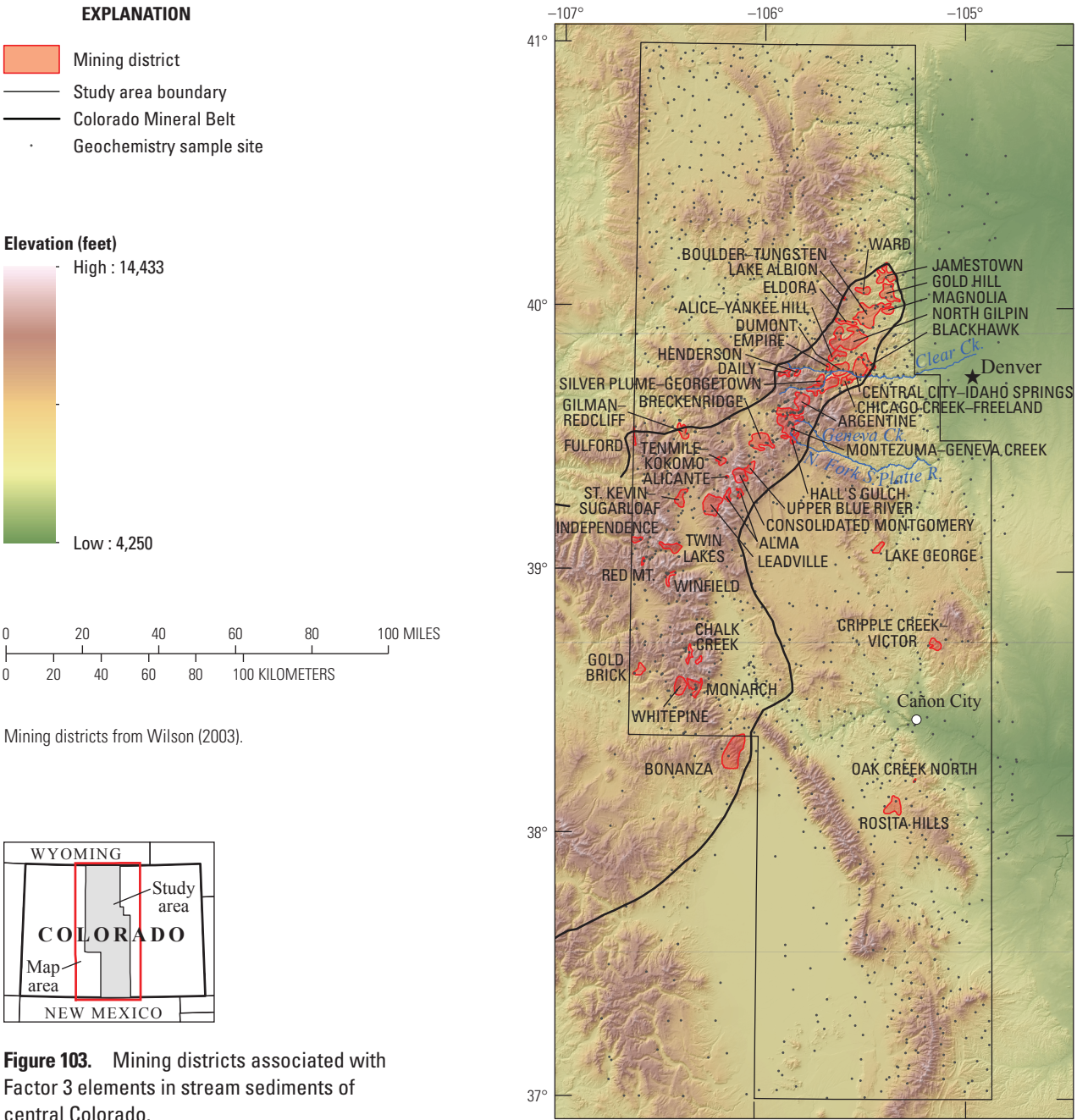
**Figure 102.** Maps of central Colorado stream-sediment geochemistry—Factor 3: Zn-Pb-Cu-As-(Mo). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Details on the factor analysis procedures used in this report are provided in the Methods section; elements within a given factor behave similarly in their gross spatial distributions.

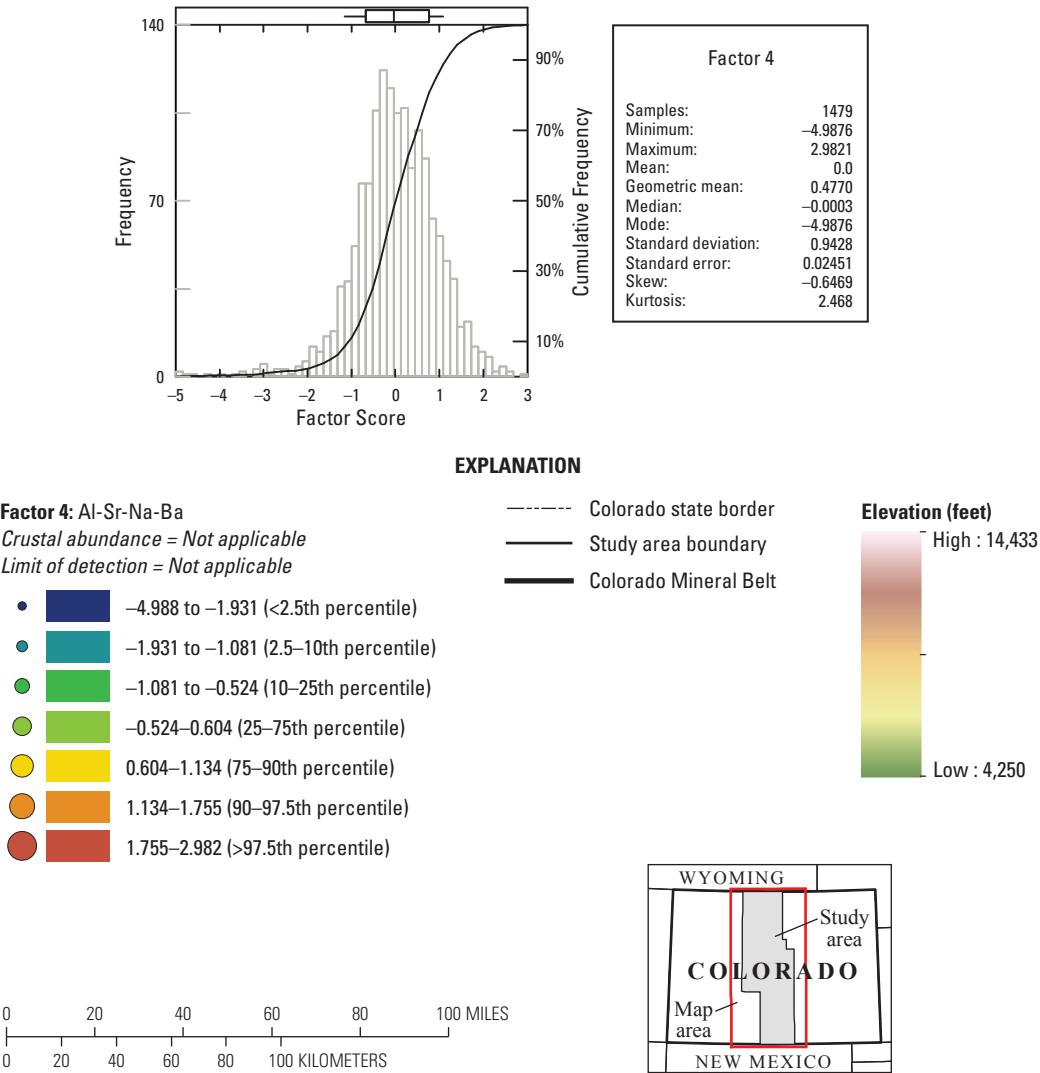
Factor 3, containing elements Zn-Pb-Cu-As-(Mo), explains the third-largest variability for elements within the dataset and reflects strong mineralization. The factor indicates areas of polymetallic and porphyry hydrothermal mineralization and related historical mining activity. Scores for this factor strongly highlight most metal-mining districts within and outside the Colorado Mineral Belt (figs. 102 and 103), such as the Alicante, Alice–Yankee Hill, Alma, Argentine, Blackhawk, Boulder-Tungsten, Breckenridge, Central City–Idaho Springs, Chalk Creek, Chicago Creek–Freeland, Consolidated Montgomery, Cripple Creek–Victor, Daily, Dumont, Eldora, Empire, Fulford, Gilman-Redcliff, Gold Hill, Henderson, Independence, Jamestown, Lake Albion, Lake George, Leadville, Magnolia, Monarch, Montezuma–Geneva Creek, North Gilpin, Oak Creek North, Red Mountain, Rosita Hills, Silver Plume–Georgetown, St. Kevin–Sugarloaf, Tenmile-Kokomo, Twin Lakes, Upper Blue River, Ward, Whitepine, and Winfield districts. The factor effectively synthesizes geochemical patterns shown in single-element maps for the ore-related metals Zn, Pb, Cu, As, and Mo (figs. 96, 40, 26, 6, and 50, respectively). An apparent dispersion train is present in Clear Creek from the Henderson and Daily districts eastward, downstream to the range front. Additional dispersion is seen in the Montezuma–Geneva Creek district eastward along Geneva Creek to the North Fork of the South Platte River. Historical mining and mineral processing activities around Denver and Cañon City (described in more detail in discussions of copper and arsenic, figs. 27 and 7, respectively) also are indicated by anomalous samples, although not as strongly as observed at sites within the mineral belt.



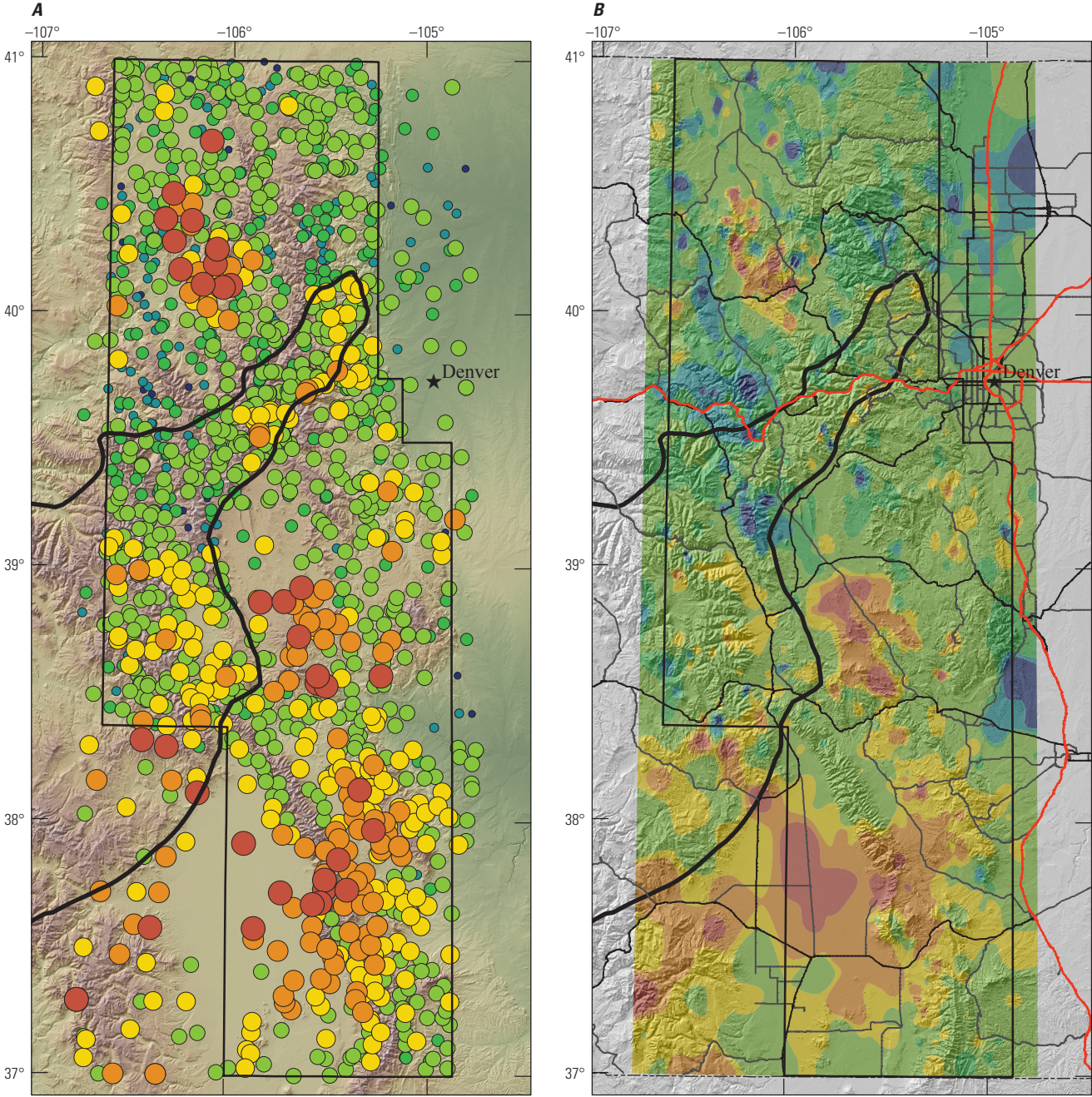




Central Colorado Stream-Sediment  
Geochemistry—Factor 4: Al-Sr-Na-Ba



**Figure 104.** Maps of central Colorado stream-sediment geochemistry—Factor 4: Al-Sr-Na-Ba. (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



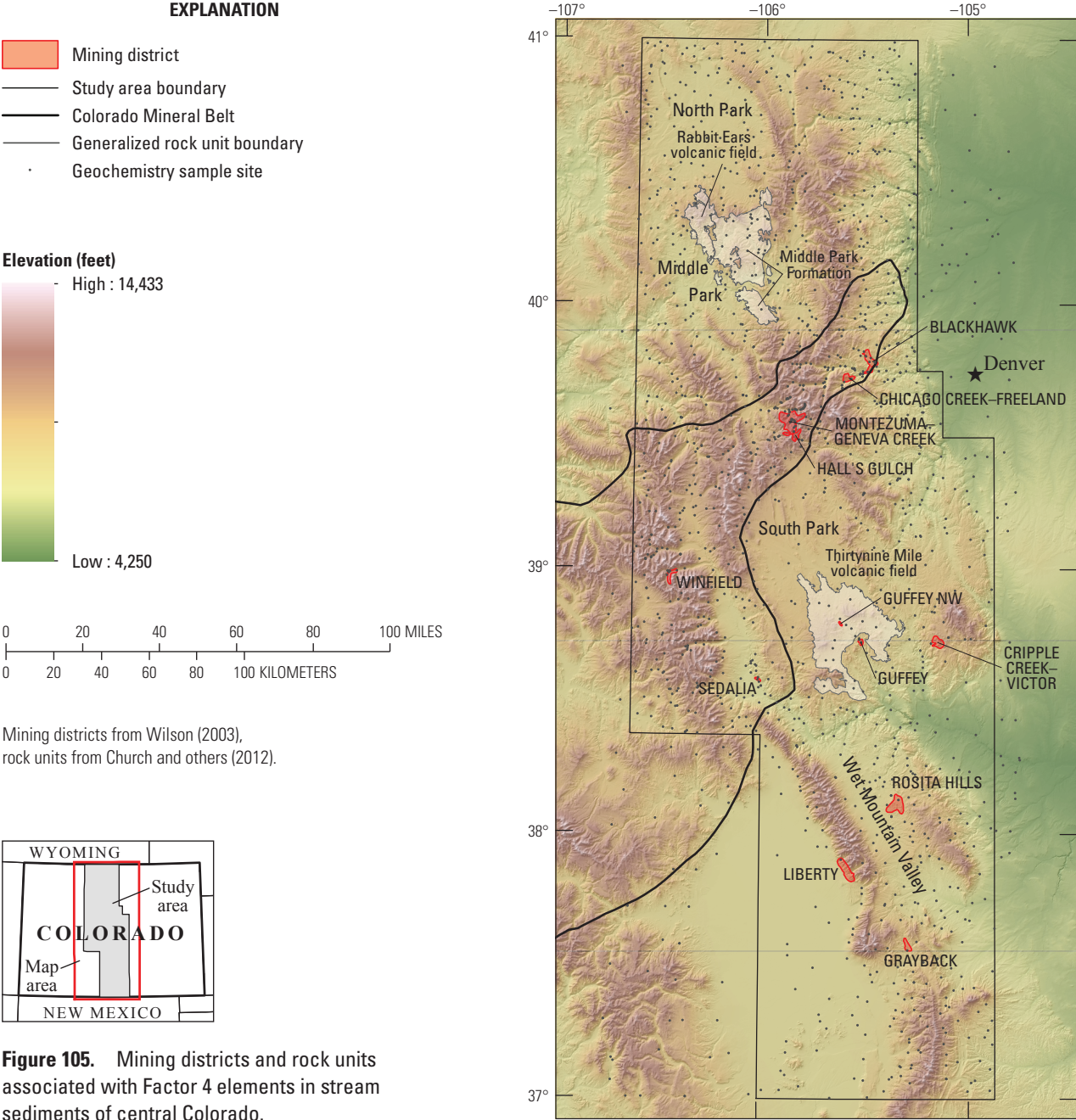


Details on the factor analysis procedures used in this report are provided in the Methods section; elements within a given factor behave similarly in their gross distributions.

Factor 4, consisting of elements Al-Sr-Na-Ba, explains the fourth-greatest variability for elements within the dataset, is most likely due to rock type, and perhaps reflects evaporative processes in basinal areas. The factor indicates the presence of plagioclase, a mineral highly abundant in intermediate-composition alkalic-calcic igneous rocks. Factor 4 highlights the Thirtynine Mile volcanic field and extrusive volcanic and plutonic rocks in much of the southern third of the study area, as well as the Rabbit Ears volcanic complex and the Middle Park Formation, which commonly contains volcanic debris (figs. 104 and 105). Even though stream-sediment samples showing high Factor 4 scores (above the 90th percentile) were obtained near mining districts, Factor 4 probably is unrelated to mineralization.

Potassium feldspar is more abundant than plagioclase in granitic rocks within the Colorado Mineral Belt. A comparison of Factor 4 distribution and barium distribution (fig. 8), shows the general absence of anomalous samples within the northern end of the mineral belt on the Factor 4 map. That absence probably indicates that the barium contribution to Factor 4 is due to plagioclase, whereas high barium concentrations within the mineral belt (fig. 8) are due to barium’s substitution into potassium feldspar.

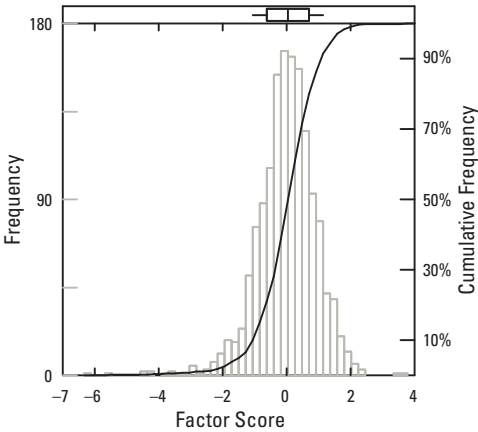
Factor 4 distributions are very similar to those of sodium and strontium alone (figs. 70 and 72, respectively). Anomalous samples in basins such as North Park, Middle Park, South Park, and the Wet Mountain Valley may reflect sediments affected by surface-water evaporation (Na and Sr) and containing associated fine clay minerals (Al and Ba).







Central Colorado  
Stream-Sediment Geochemistry—  
Factor 5: K-Li-Al-(Be)-(-Ca)-(-Fe)-(-V)



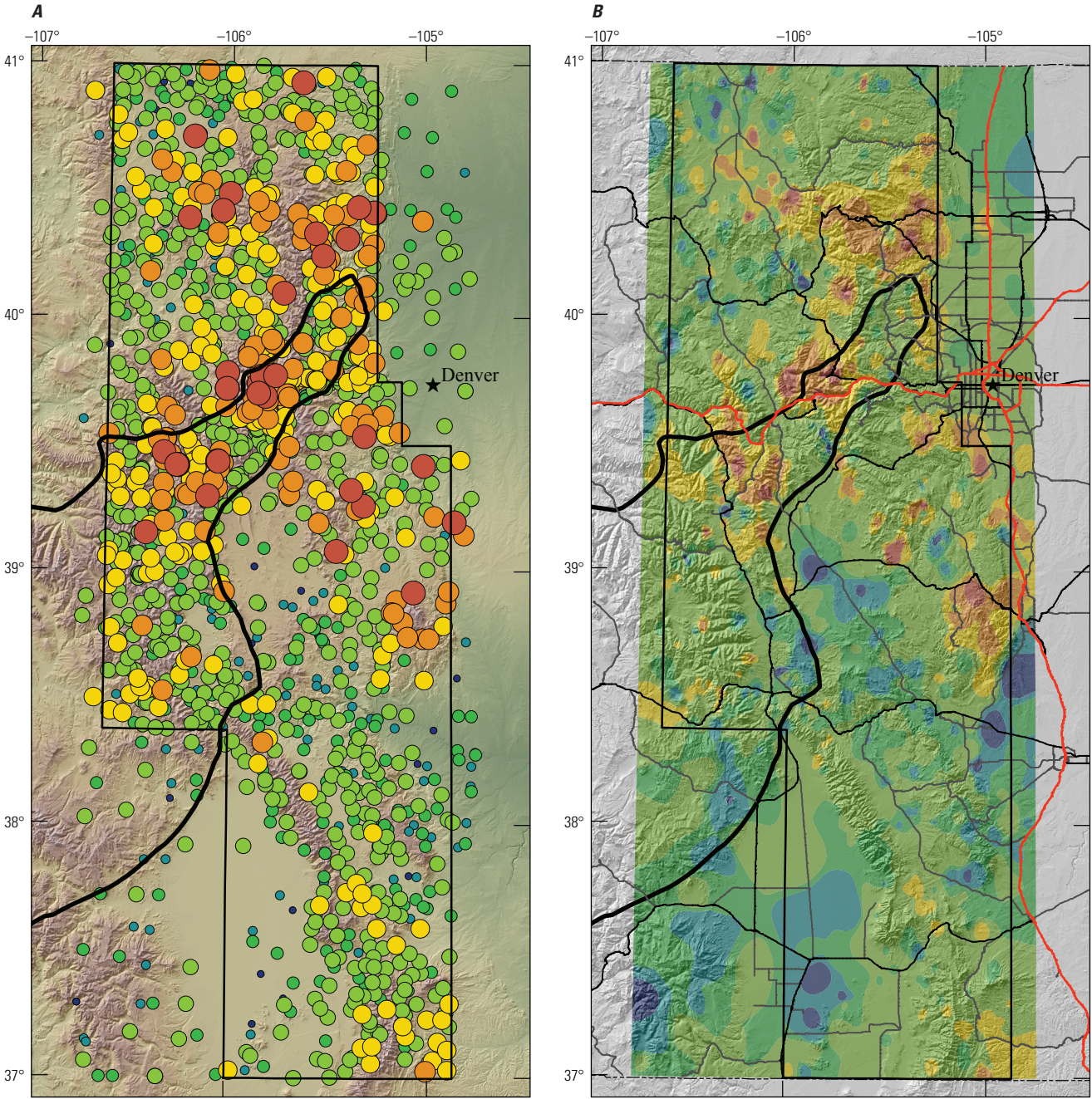
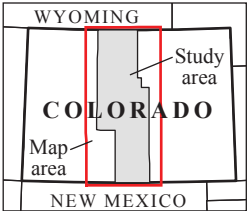
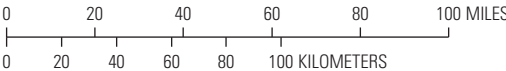
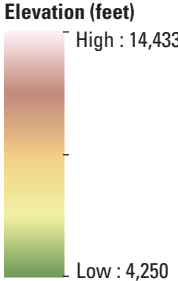
Factor 5	
Samples:	1479
Minimum:	-6.1261
Maximum:	3.7154
Mean:	0.0
Geometric mean:	0.4281
Median:	0.0441
Mode:	-6.1261
Standard deviation:	0.9237
Standard error:	0.02402
Skew:	-0.8652
Kurtosis:	3.845

**Factor 5: K-Li-Al-(Be)-(-Ca)-(-Fe)-(-V)**  
*Crustal abundance = Not applicable*  
*Limit of detection = Not applicable*  
*Parentheses indicate elements of lesser significance in the factor*

- -6.126 to -1.983 (<2.5th percentile)
- -1.983 to -1.066 (2.5–10th percentile)
- -1.066 to -0.497 (10–25th percentile)
- -0.497–0.515 (25–75th percentile)
- 0.515–1.078 (75–90th percentile)
- 1.078–1.623 (90–97.5th percentile)
- 1.623–3.715 (>97.5th percentile)

EXPLANATION

- Colorado state border
- Study area boundary
- Colorado Mineral Belt



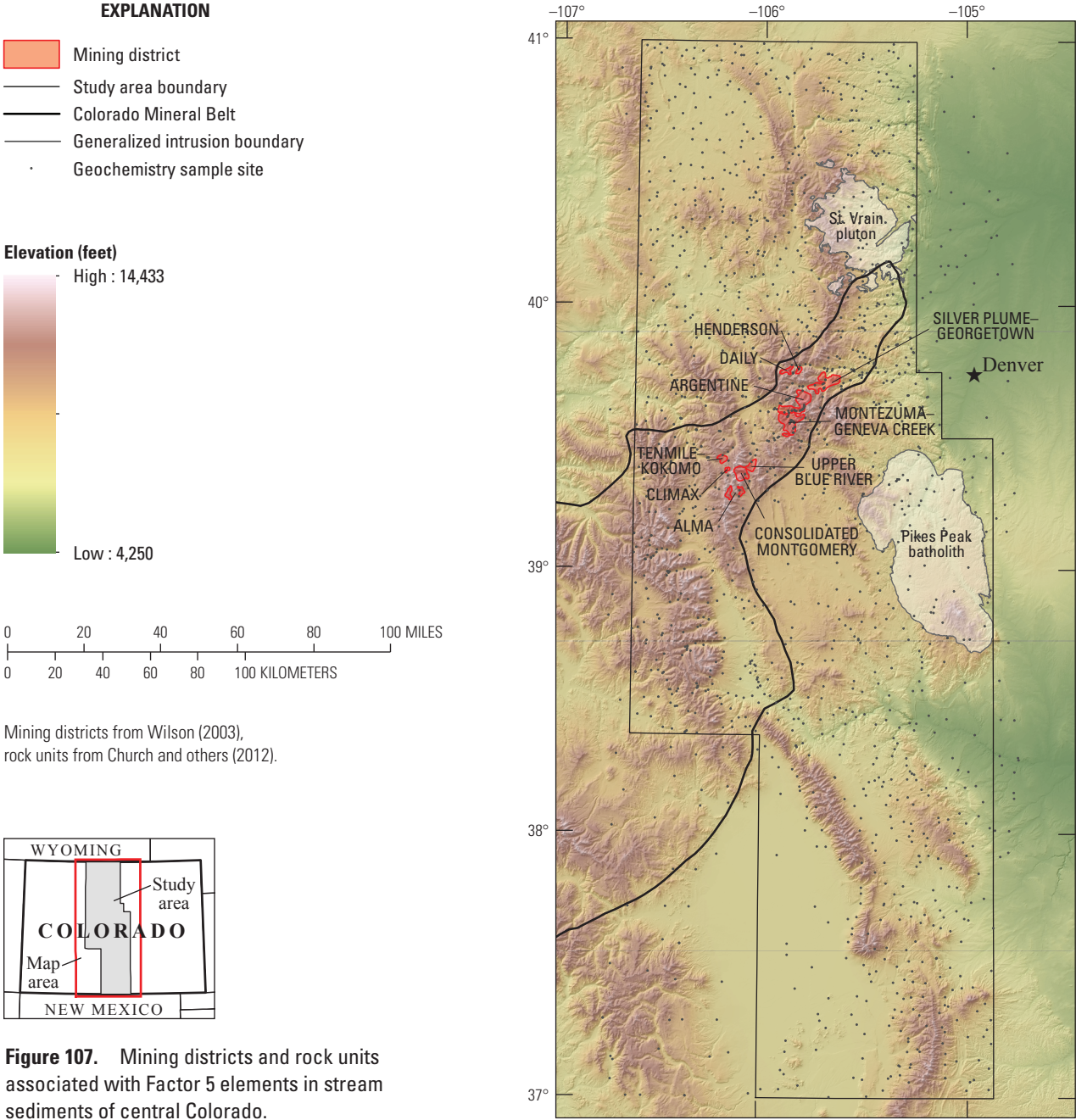
**Figure 106.** Maps of central Colorado stream-sediment geochemistry—Factor 5: K-Li-Al-(Be)-(-Ca)-(-Fe)-(-V). (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



Details on the factor analysis procedures used in this report are provided in the Methods section; elements within a given factor behave similarly in their gross spatial distributions.

The group of elements in Factor 5, K-Li-Al-(Be)-(-Ca)-(-Fe)-(-V), explains the smallest variability for elements in the dataset. This factor likely reflects potassium feldspar or muscovite (or both) either in magmatically evolved igneous rocks of granitic composition or in altered rocks around porphyry systems. Potassium and aluminum, along with silicon, are the principal components in both minerals. Lithium may substitute for aluminum in micas, suggesting that this factor may be linked to lithium-bearing mica in highly evolved granitic rocks. Beryllium also is concentrated in similar granitic rocks. The negative loading of calcium, vanadium, and iron (indicated by the attached minus signs in the element list above) agrees with Factor 5 indicating evolved granites, as stream-sediment samples from such granites typically have low concentrations of those elements.

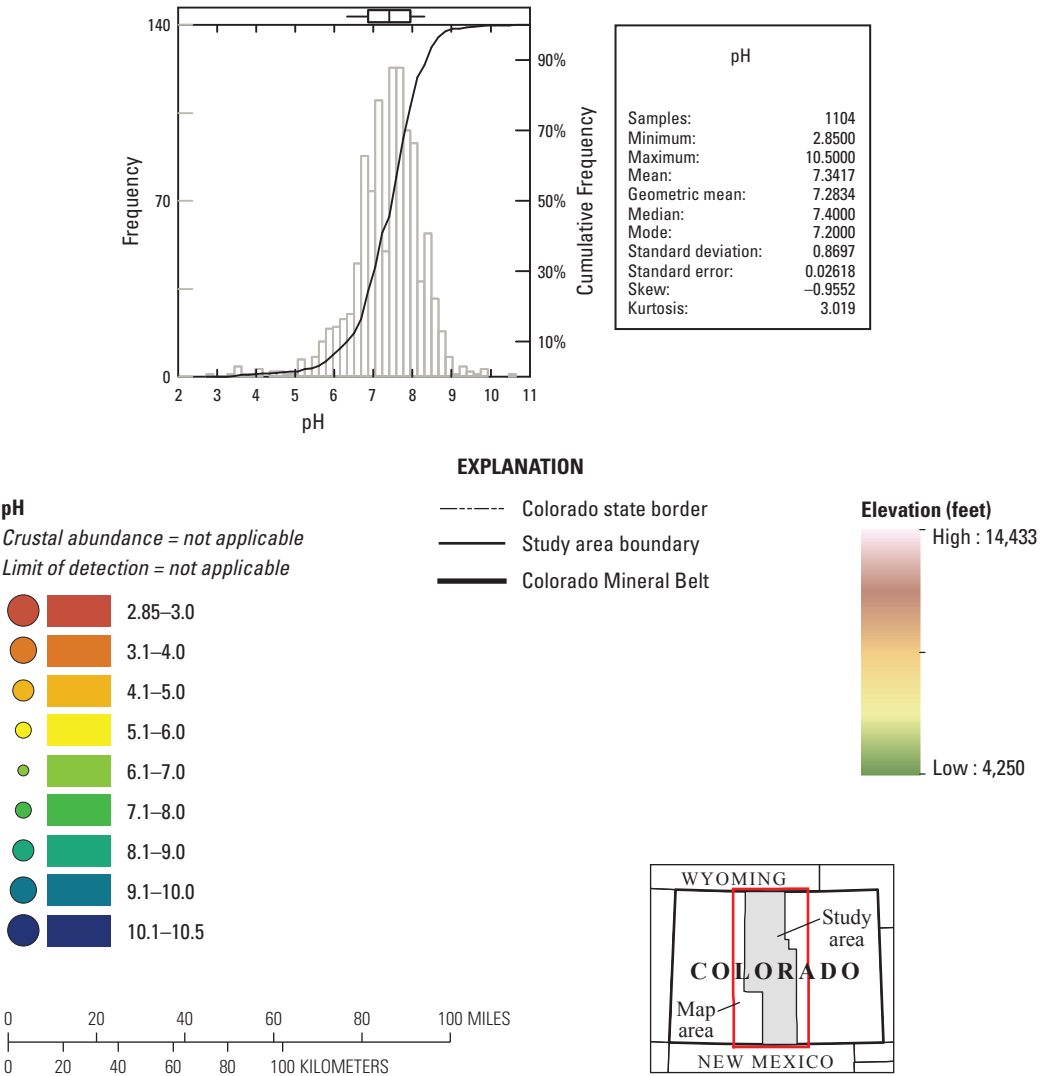
Factor 5 identifies various rocks within and outside of the Colorado Mineral Belt (figs. 106 and 107). Clusters with high Factor 5 scores within the mineral belt are associated with two districts: the Argentine, Daily, Henderson, Montezuma–Geneva Creek, and Silver Plume–Georgetown districts; and the Alma, Climax, Consolidated Montgomery, Tenmile-Kokomo, and Upper Blue River districts. The anomalies centered on the Climax and Henderson districts (and perhaps others as well) may indicate potassically altered granitic rocks surrounding those porphyry centers. North and south of the mineral belt, two large clusters identify the Mesoproterozoic St. Vrain pluton and the Pikes Peak batholith, respectively.



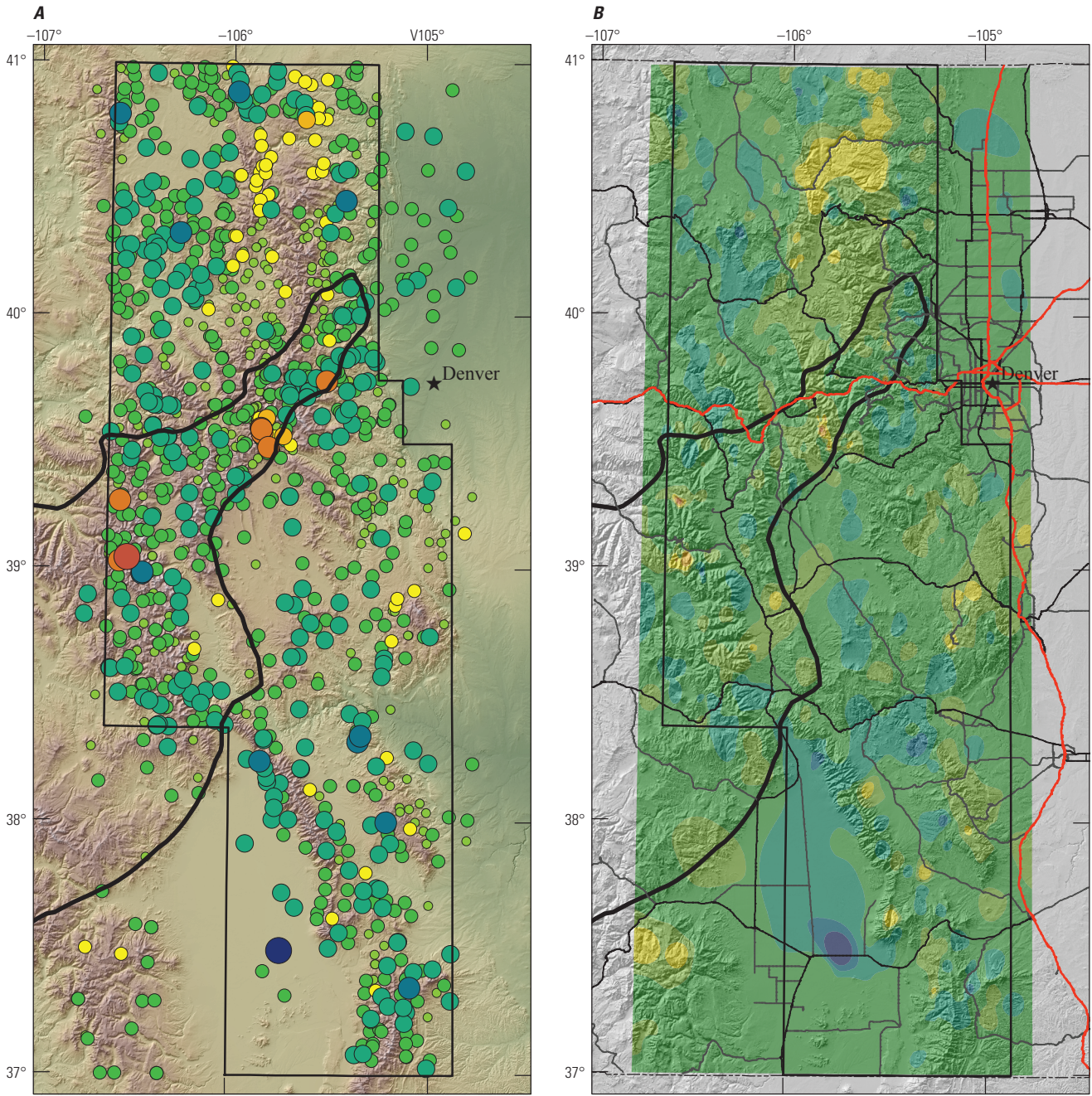




Central Colorado Stream Water  
Geochemistry—pH



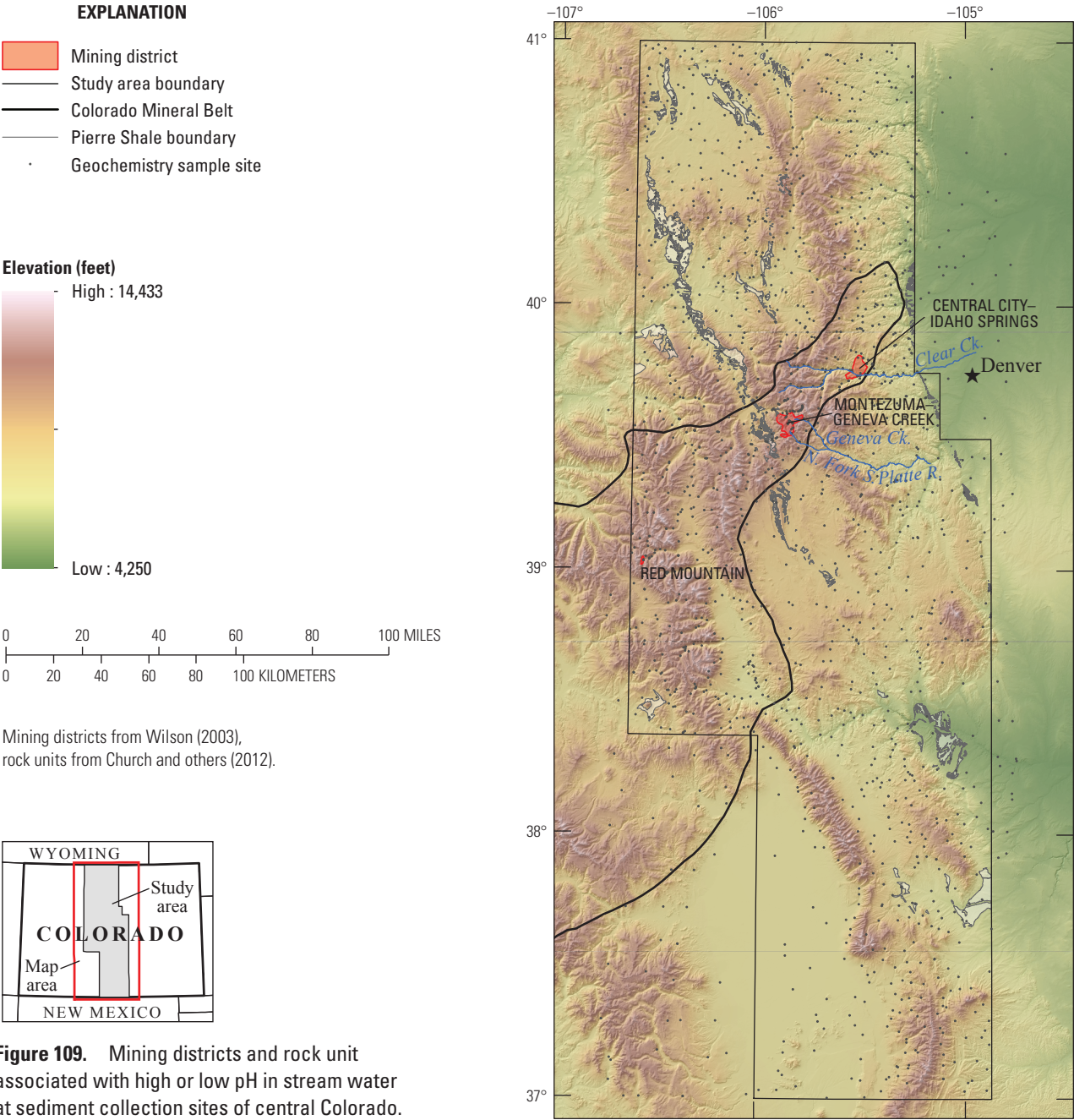
**Figure 108.** Maps of central Colorado stream water geochemistry—pH.  
(A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





The pH and specific conductance were measured on waters at stream-sediment collection sites. Resulting pH data mostly reflect waters analyzed in the late 1970s under the National Uranium Resource Evaluation (NURE) study, but the data also include a smaller set of waters whose pH was measured during a more recent study by Church and others (2012). The pH measures the hydronium ion ( $\text{H}_3\text{O}^+$ ) content of water; the higher the hydronium-ion content, the lower the pH and the more acidic the water. Within the study area, many mining-affected riparian areas have been remediated since these water samples in the 1970s, and these areas now have less-acidic waters.

Data compiled in this study show that waters with pH values below 4.5 occur almost exclusively within the Colorado Mineral Belt and probably reflect historical acid-mine drainage and acid generated during weathering of exposed hydrothermal sulfide deposits (figs. 108 and 109). The lowest measured pH (2.85) is from a site downstream of the Red Mountain district along the western edge of the study area within the mineral belt. Other low-pH sites within the mineral belt (below 4.0) are from waters draining the Montezuma–Geneva Creek and the Central City–Idaho Springs districts. At the northern end of the study area is a large, diffuse cluster of sites with pH values of 5.1 to 6.0, all recorded by the 1970s NURE data (Smith, 2006). It is unclear whether that cluster is valid or is due to a meter-calibration error. Similarly, high pH values (above 9.1) from sites scattered throughout the study area also came from the 1970s NURE data and are poorly constrained. North and south of the mineral belt, sites with pH values of 8.1 and above are from areas commonly underlain by locally calcareous Cretaceous and younger sedimentary units such as the Pierre Shale.

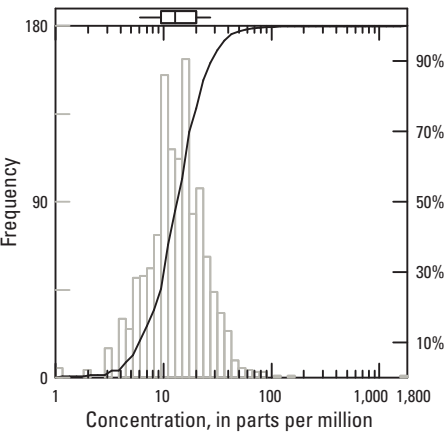


**Figure 109.** Mining districts and rock unit associated with high or low pH in stream water at sediment collection sites of central Colorado.





Central Colorado Stream-Sediment  
Geochemistry—Scintillometry



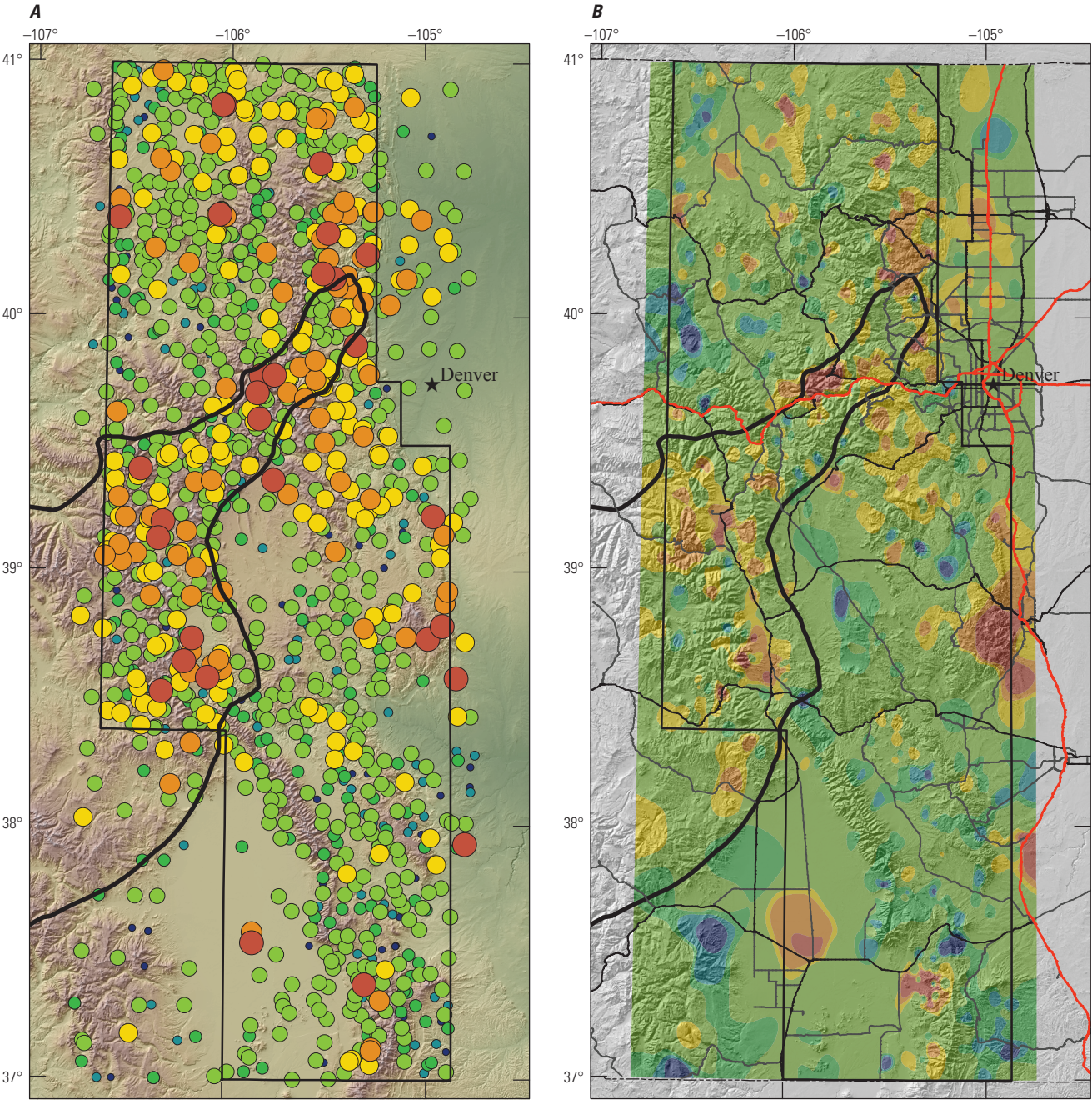
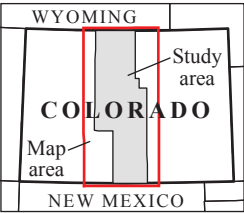
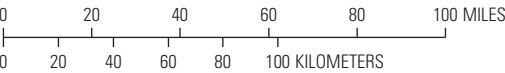
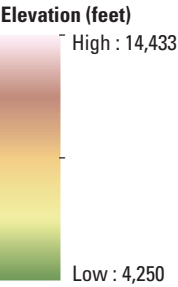
Scintillometry parts per million (ppm)	
Samples:	1235
Minimum:	1.0000
Maximum:	1759.0000
Mean:	17.1822
Geometric mean:	13.2966
Median:	13.0000
Mode:	12.0000
Standard deviation:	50.81
Standard error:	1.446
Skew:	32.66
Kurtosis:	1115

EXPLANATION

**Scintillometry** (equivalent uranium (eq U) in parts per million)  
*Crustal abundance = not applicable*  
*Limit of detection = not applicable*

- 1.0–4.0 eq U (<2.5th percentile)
- 4.1–6.0 eq U (2.5–10th percentile)
- 6.1–9.0 eq U (10–25th percentile)
- 9.1–20 eq U (25–75th percentile)
- 21–28 eq U (75–90th percentile)
- 29–41 eq U (90–97.5th percentile)
- 42–1,759 eq U (>97.5th percentile)

- Colorado state border
- Study area boundary
- Colorado Mineral Belt

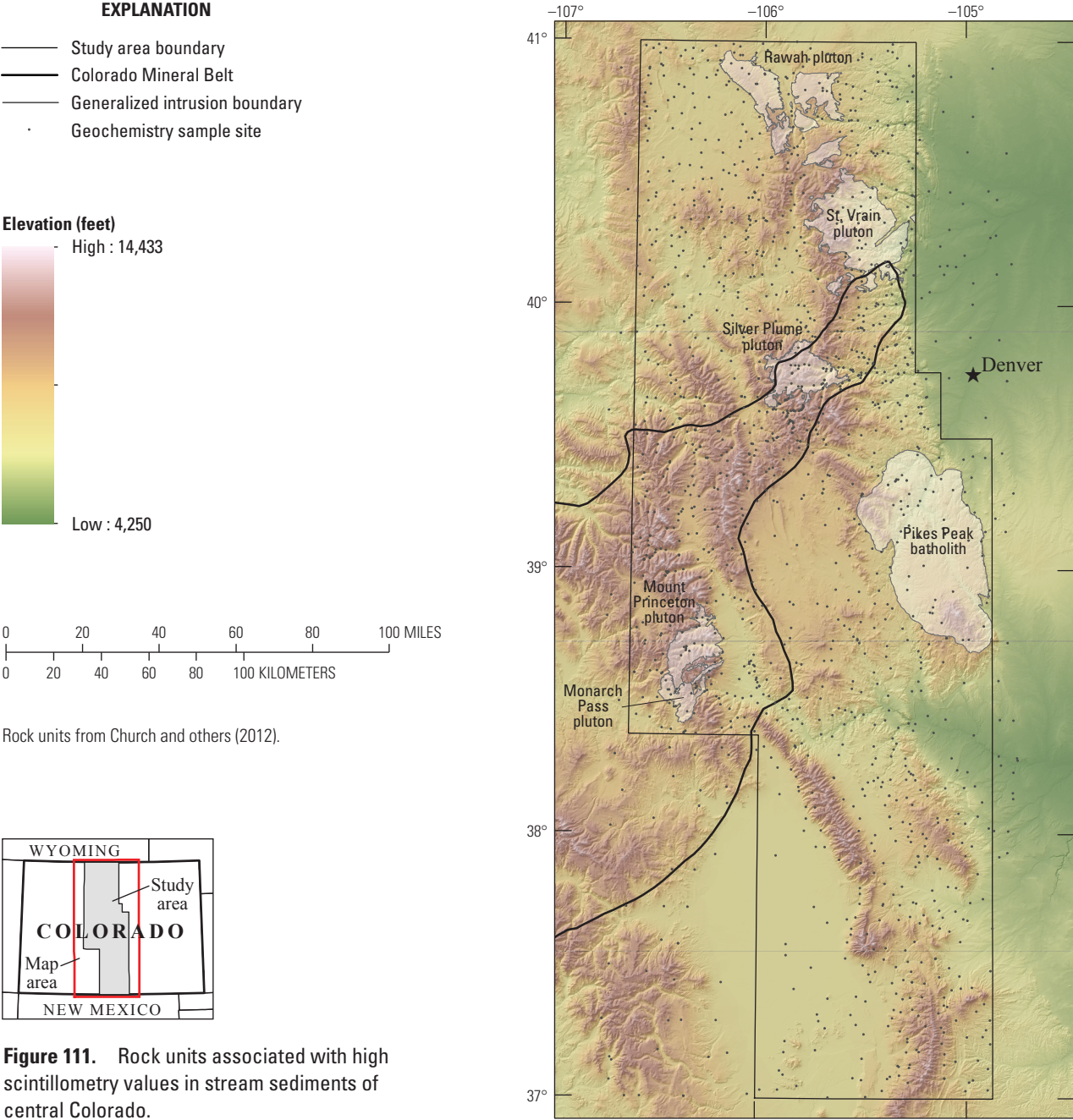


**Figure 110.** Maps of central Colorado stream-sediment geochemistry—Scintillometry. (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.



A scintillometer measurement was taken onsite at stream-sediment sample locations during the 1970s National Uranium Resource Evaluation (NURE) program. Scintillometry measures the total radiation (primarily gamma radiation) emitted by the decay of radioactive elements in minerals at the location of the sensor. Source minerals commonly are heavy resistate minerals such as zircon, monazite, sphene, thorite, and xenotime. The highest readings commonly occur at sites near granitic source rocks.

High scintillometry readings probably reflect rock type, rather than mineralization or relation to mineral deposits. The generally scattered high concentrations (>97.5th percentile) likely illustrate radioactive-element concentrations in felsic igneous rocks of various ages, such as the Pikes Peak batholith and the Monarch Pass, Mount Princeton, Rawah, St. Vrain, and Silver Plume plutons (figs. 110 and 111).

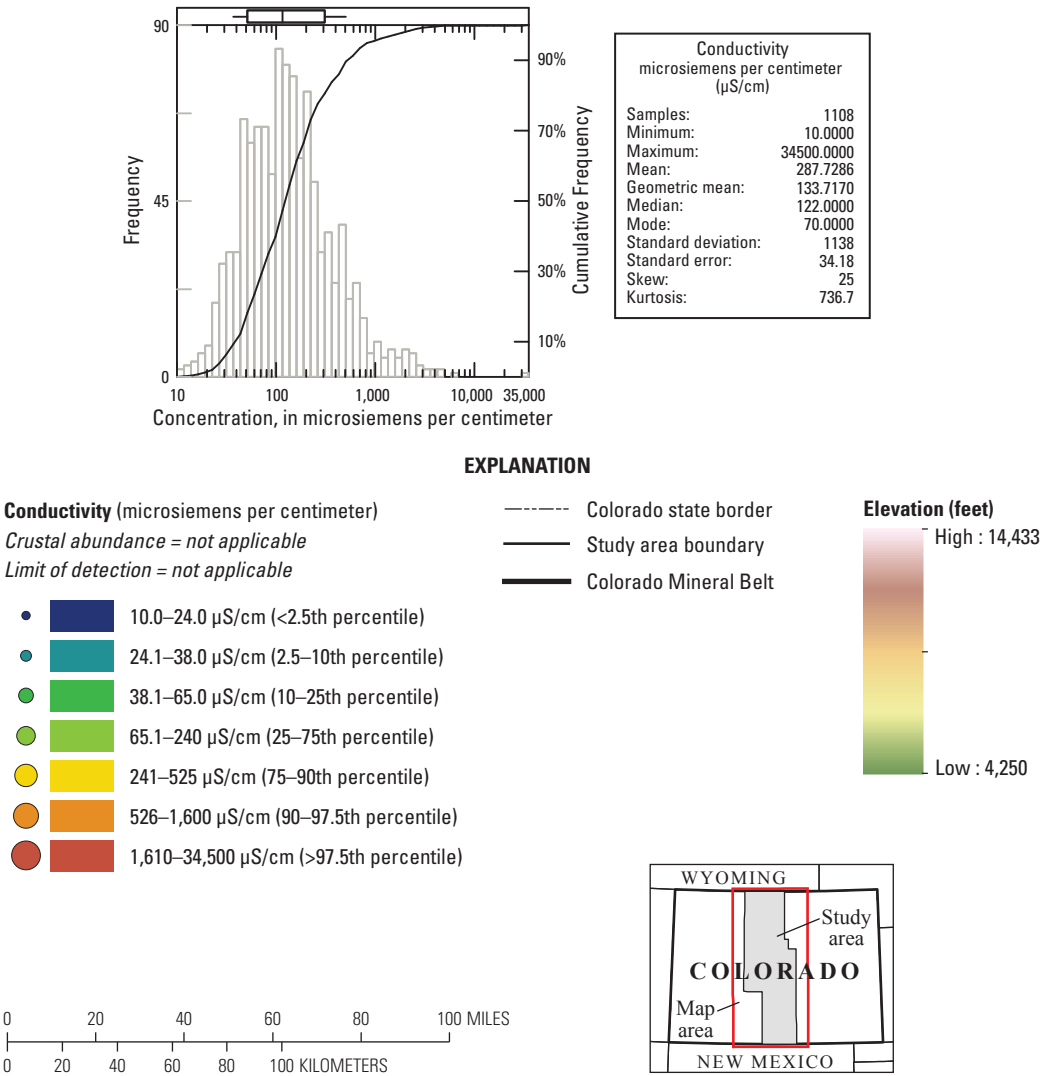


**Figure 111.** Rock units associated with high scintillometry values in stream sediments of central Colorado.

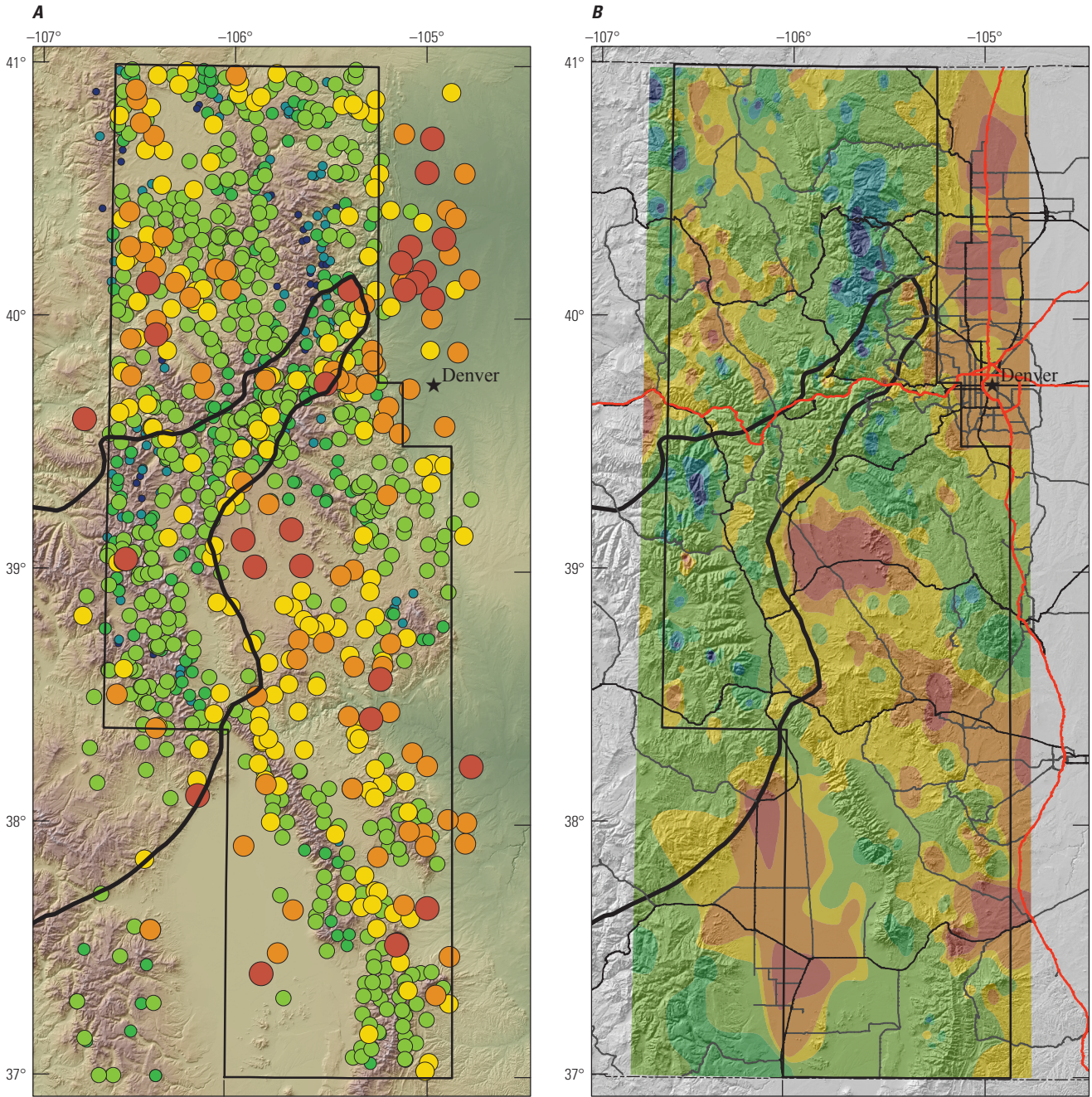




Central Colorado Water Geochemistry—  
Specific Conductance



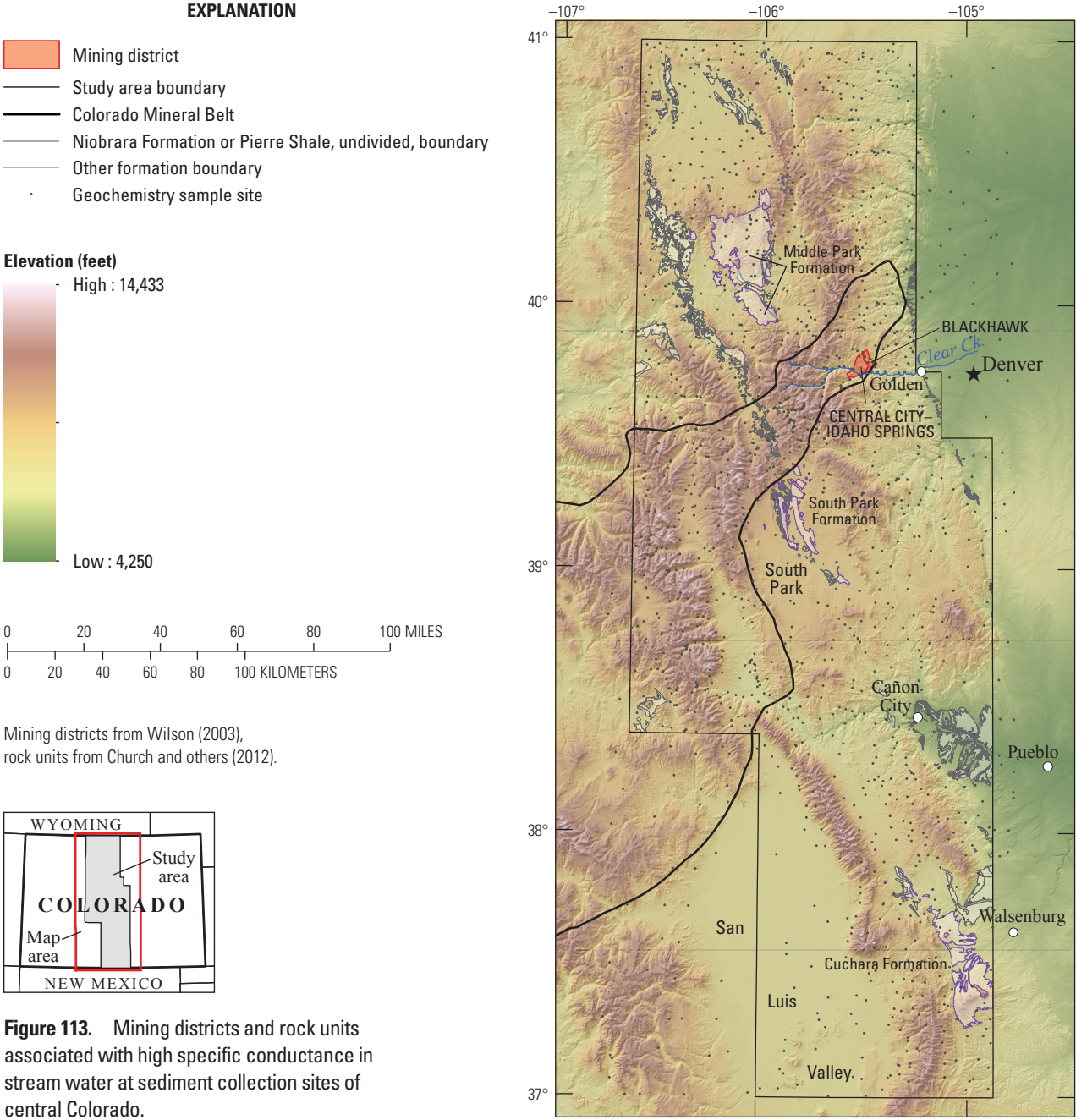
**Figure 112.** Maps of central Colorado stream water geochemistry—Specific Conductance. (A) Sample site values as graduated symbols; (B) Filled-contour prediction surface.





Specific conductance (conductivity) and pH were measured on waters at stream-sediment collection sites. Those data largely reflect waters measured in the late 1970s under the National Uranium Resource Evaluation (NURE) study and on a smaller number of waters measured during a more recent study by Church and others (2012). Specific conductance is the ability of a substance to conduct an electrical current. For water, it is a measure of dissolved ion content: the more ions in solution, the higher the conductivity. Marine and lacustrine shales and evaporitic rocks commonly produce waters with high specific conductance.

Within the study area, waters with higher specific conductance concentrations (>90th percentile) commonly are underlain by fine-grained Cretaceous sedimentary rocks (such as the Niobrara Formation and the Pierre Shale), and by younger unconsolidated or poorly consolidated basin-fill sedimentary units such as the Middle Park, South Park, and Cuchara Formations (figs. 112 and 113). The large regional cluster of sites with high specific conductance to the northeast of the study-area boundary (north of Denver) may reflect dissolved fertilizer loads in agricultural runoff. Similar, but less pronounced, anomalous clusters of sites also are present in lowland basin areas south of Pueblo, east of Cañon City, west of Walsenburg, in South Park, and in the San Luis Valley. Although some of those might be related to anthropogenic activities, natural causes, such as concentration of dissolved constituents by evaporation, also are possible. Along Clear Creek west of Golden, elevated specific conductance values might reflect higher dissolved-metal loads related to historical acid-mine drainage below mines of the Central City–Idaho Springs and Blackhawk districts, because those measurements were taken before clean-up efforts undertaken since the early 1990s.



**Figure 113.** Mining districts and rock units associated with high specific conductance in stream water at sediment collection sites of central Colorado.



## References Cited

- Anderson, J.L., 1983, Proterozoic anorogenic granite plutonism of North America, *in* Medaris, L.G., Byers, C.W., Mickelson, D.M., and Shanks, W.C., eds., Proterozoic geology—Selected papers from an international Proterozoic symposium: Geological Society of America Memoir 161, p. 133–154.
- Armbrustmacher, T.J., 1984, Alkaline rock complexes in the Wet Mountains area, Custer and Fremont Counties, Colorado: U.S. Geological Survey Professional Paper 1269, 33 p.
- Barker, Fred, Wones, D.R., Sharp, W.N., and Desborough, G.A., 1975, The Pikes Peak batholith, Colorado Front Range, and a model for the origin of the gabbro-anorthosite-syenite-potassic granite suite: Precambrian Research, v. 2, p. 97–160.
- Bickford, M.E., Cullers, R.L., Shuster, R.D., Premo, W.R., and Van Schmus, W.R., 1989a, U-Pb zircon geochronology of Proterozoic and Cambrian plutons in the Wet Mountains and southern Front Range, Colorado, *in* Grambling, J.A., and Tewksbury, B.J., eds., Proterozoic geology of the southern Rocky Mountains: Geological Society of America Special Paper 235, p. 49–64.
- Bickford, M.E., Shuster, R.D., and Boardman, S.J., 1989b, U-Pb geochronology of the Proterozoic volcano-plutonic terrane in the Gunnison and Salida areas, Colorado, *in* Grambling, J.A., and Tewksbury, B.J., eds., Proterozoic geology of the southern Rocky Mountains: Geological Society of America Special Paper 235, p. 33–48.
- Bookstrom, A.A., Naeser, C.W., and Shannon, J.R., 1987, Isotopic age determinations, unaltered and hydrothermally altered igneous rocks, north-central Colorado Mineral Belt: Isochron West, v. 49, p. 13–20.
- Church, S.E., San Juan, C.A., Fey, D.L., Schmidt, T.S., Klein, T.L., DeWitt, E.H., Wanty, R.B., Verplanck, P.L., Mitchell, K.A., Adams, M.G., Choate, L.M., Todorov, T.I., Rockwell, B.W., McEachron, Luke, and Anthony, M.W., 2012, Geospatial database for regional environmental assessment of central Colorado: U.S. Geological Survey Data Series 614, 76 p.
- Cox, D.P., 1986a, Descriptive model of polymetallic veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 125.
- Cox, D.P., 1986b, Descriptive model of porphyry Cu, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76.
- Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p.
- Cunningham, C.G., Naeser, C.W., Marvin, R.F., Luedke, R.G., and Wallace, A.R., 1994, Ages of selected intrusive rocks and associated ore deposits in the Colorado Mineral Belt: U.S. Geological Survey Bulletin 2109, 31 p.
- DeVoto, R.H., 1990, Paleozoic stratigraphy, tectonism, thermal history, and basin evolution of central Colorado, *in* Beaty, D.W., Landis, G.P., Thompson, T.B., eds., Carbonate-hosted sulfide deposits of the central Colorado Mineral Belt: Economic Geology Monograph, v. 7, p. 29–44.
- Dickinson, W.R., and Snyder, W.S., 1978, Plate tectonics of the Laramide orogeny, *in* Mathews, Vincent, III, ed., Laramide folding associated with basement block faulting in the western United States: Geological Society of America Memoir 151, p. 355–366.
- Grossman, J.N., 1998, National geochemical atlas—The geochemical landscape of the conterminous United States derived from stream sediment and other solid sample media analyzed by the National Uranium Resource Evaluation (NURE) Program: U.S. Geological Survey Open-File Report 98–622. Available at: <http://pubs.er.usgs.gov/publication/ofr98622/>.
- Henderson, C.W., 1926, Mining in Colorado, a history of discovery, development and production: U.S. Geological Survey Professional Paper 138, 263 p.
- Howarth, R.J., and Sinding-Larsen, R., 1983, Multivariate analysis, *in* Govett, G.J.S., ed., Handbook of exploration geochemistry: Amsterdam, The Netherlands, Elsevier, v. 2, p. 207–289.
- Kelley, K.D., and Ludington, S.E., 2002, Cripple Creek and other alkaline-related gold deposits in the southern Rocky Mountains, USA—Influence of regional tectonics: Mineralium Deposita, v. 37, p. 38–60.
- Knepper, D.H., and Marrs, R.W., 1971, Geological development of the Bonanza–San Luis Valley–Sangre De Cristo Range area, south-central Colorado, *in* James, H.L., ed., San Luis Basin field conference, Colorado, 22nd, Guidebook: Socorro, New Mexico Geological Society, p. 249–264.
- Levinson, A.A., 1980, Introduction to exploration geochemistry (2d ed.): Wilmette, Ill., Applied Publishing Ltd., 924 p.
- Lovering, T.S., and Goddard, E.N., 1950, Geology and ore deposits of the Front Range, Colorado: U.S. Geological Survey Professional Paper 223, 319 p.
- Lindgren, Waldemar, and Ransome, F.L., 1906, Geology and gold deposits of the Cripple Creek District, Colorado: U.S. Geological Survey Professional Paper 54, 516 p.
- Lindsey, D.A., Clark, R.F., and Soulliere, S.J., 1986, Minturn and Sangre de Cristo Formations of southern Colorado—A prograding fan delta and alluvial fan sequence shed from the ancestral Rocky Mountains, *in* Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 541–561.
- Ludington, S.D., 1986, Descriptive model of Climax Mo deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 73.
- Mutschler, F.E., Wright, E.G., Ludington, S.D., and Abbott, J.T., 1981, Granite molybdenite systems: Economic Geology, v. 76, p. 874–897.
- Pearson, R.C., 1980, Mineral resources of the Indian Peaks study area, Boulder and Grand Counties, Colorado: U.S. Geological Survey Bulletin 1463, 109 p.
- Rankama, K., and Sahama, T.G., 1950, Geochemistry: Chicago, Ill., University of Chicago Press, 912 p.
- Reed, J.C., Jr., Bickford, M.E., Premo, W.R., Aleinikoff, J.N., and Pallister, J.S., 1987, Evolution of the Early Proterozoic Colorado province—Constraints from U-Pb geochronology: Geology, v. 15, p. 861–865.
- Reimann, C., and de Caritat, P., 1998, Chemical elements in the environment: Berlin, Springer, 398 p.



Rice, C.M., Harmon, R.S., and Shepherd, T.J., 1985, Central City, Colorado—The upper part of an alkaline porphyry molybdenum system: *Economic Geology*, v. 80, p. 1769–1796.

Rose, A.W., Hawkes, H.E., and Webb, J.S., 1979, *Geochemistry in mineral exploration* (2d ed.): New York, Academic Press, 657 p.

Sims, P.K., Drake, A.A., Jr., and Tooker, E.W., 1963, Economic geology of the Central City district, Gilpin County, Colorado: U.S. Geological Survey Professional Paper 359, 251 p.

Simmons, E.C., and Hedge, C.E., 1978, Minor-element and Sr-isotope geochemistry of Tertiary stocks, Colorado mineral belt: *Contributions to Mineralogy and Petrology*, v. 67, p. 379–396.

Smith, D.B., Garrett, R.G., Closs, L.G., Ellefsen, K.J., Kilburn, J.E., Horton, J.D., and Smith, S.M., 2011, Geochemical mapping of the Denver, Colorado (USA) urban area—A comparison of studies in 1972 and 2005, *in* Johnson, C.C., Demetriades, A., Locutura, J., and Ottesen, R.T., eds., *Mapping the chemical environment of urban areas*: Oxford, John Wiley, p. 521–546.

Smith, D.R., Noblett, J., Wobus, R., Unruh, D., and Chamberlain, K.R., 1999, A review of the Pikes Peak batholith, Front Range, central Colorado—A “type example” of A-type granitic magmatism: *Rocky Mountain Geology*, v. 34, no. 2, p. 289–312.

Smith, S.M., 2006, National geochemical database—Reformatted data from the National Uranium Resource Evaluation (NURE) Hydrogeochemical and Stream Sediment (HSSR) program: U.S. Geological Survey Open-File Report 97–492, unpaginated. Available at: <http://pubs.usgs.gov/of/1997/ofr-97-0492/index.html>.

Steven, T.A., and Lipman, P.W., 1976, Calderas of the San Juan volcanic field, southwestern Colorado: U.S. Geological Survey Professional Paper 958, 35 p.

Tabachnick, B.G., and Fidell, L.S., 2007, *Using multivariate statistics*, (5th ed.): Boston, New York, Pearson Education Inc., 978 p.

Taggart, J.E., 2002, Analytical methods for chemical analysis of geologic and other materials, U.S. Geological Survey: U.S. Geological Survey Open-File Report 02–223, variously paginated. Available at: <http://pubs.usgs.gov/of/2002/ofr-02-0223/>.

Tweto, Ogden, 1960, Scheelite in the Precambrian gneisses of Colorado: *Economic Geology*, v. 55, p. 1406–1428.

Tweto, Ogden, and Sims, P.K., 1963, Precambrian ancestry of the Colorado Mineral Belt: *Geological Society of America Bulletin*, v. 74, p. 991–1014.

Van Schmus, W.R., Bickford, M.E., Anderson, J.L., Bender, E.E., Anderson, R.R., Bauer, P.W., Robertson, J.M., Bowring, S.A., Condie, K.C., Denison, R.E., Gilbert, M.C., Grambling, J.A., Mawer, C.K., Shearer, C.K., Hinze, W.J., Karlstrom, K.E., Kisvarsanyi, E.B., Lidiak, E.G., Reed, J.C., Jr., Sims, P.K., Tweto, O., Silver, L.T., Treves, S.B., Williams, M.L., and Wooden, J.L., 1993, Transcontinental Proterozoic provinces, *in* Reed, J.C., Jr., Bickford, M.E., Houston, R.S., Link, P.K., Rankin, D.W., Sims, P.K., and Van Schmus, W.R., eds., *Precambrian; Conterminous U.S.—The geology of North America*: Geological Society of America, p. 171–334.

Vanderwilt, J.W., 1947, Mineral resources of Colorado: Denver, Colo., Colorado Mineral Resources Board, 547 p. text and 61 p. plates.

Wedepohl, K.H., ed., 1969–78, *Handbook of geochemistry*: Berlin, Springer-Verlag, v. 1–4, variously paginated.

Wilson, A.B., and Sims, P.K., 2003, The Colorado mineral belt revisited—An analysis of new data: U.S. Geological Survey Open-File Report 03–046, 7 p. Available at: <http://pubs.usgs.gov/of/2003/ofr-03-046/>.

Wilson, A.B., 2003, Databases and simplified geology for mineralized areas, claims, mines and prospects in Colorado: U.S. Geological Survey Open-File Report 03–090, unpaginated. Available at: <http://pubs.usgs.gov/of/2003/ofr-03-090/>

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