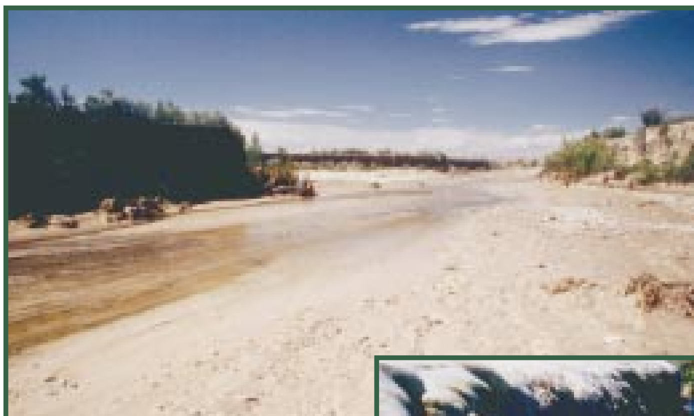
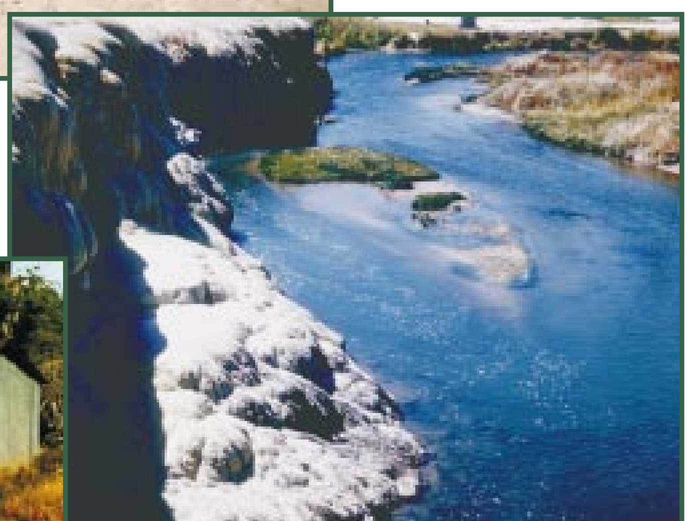
National Water-Quality Assessment — Yellowstone River Basin

Element Concentrations in Bed Sediment of the Yellowstone River Basin, Montana, North Dakota, and Wyoming—A Retrospective Analysis

Water-Resources Investigations Report 99-4185





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By David A. Peterson and Ronald B. Zelt

Water-Resources Investigations Report 99-4185

Prepared as part of the
NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

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<http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html>

FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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Multiply	by	To obtain
square kilometer (km^2)	0.3861	square mile
cubic meter per second (m^3/s)	35.31	cubic foot per second
millimeter (mm)	0.03937	inch
cubic centimeter (cm^3)	0.06102	cubic inch
kilometer (km)	0.6214	mile

Temperature can be converted to degrees Fahrenheit (°F) by using the following equations:

$$°F = 9/5\ (°C) + 32$$

ELEMENT CONCENTRATIONS IN BED SEDIMENT OF THE YELLOWSTONE RIVER BASIN, MONTANA, NORTH DAKOTA, AND WYOMING—A RETROSPECTIVE ANALYSIS

By David A. Peterson and Ronald B. Zelt

ABSTRACT

Chemical data for bed sediment were analyzed as part of the U.S. Geological Survey National Water-Quality Assessment Program investigation of the Yellowstone River Basin in parts of Montana, North Dakota, and Wyoming. The primary data set consisted of about 13,000 samples collected during 1974-79 for the National Uranium Resource Evaluation program. Data were available for 50 elements, although not all samples were analyzed for all elements.

Element concentrations varied spatially and were associated with geologic settings or ecoregions. Factor analysis indicated three groups of associated elements: factor 1 elements were strongly correlated with basaltic rocks, factor 2 elements were strongly correlated with granitic rocks, and factor 3 elements were strongly correlated with carbonate rocks. Scores for factor 1 were highest for bed-sediment samples associated with volcanic rocks of Tertiary and Cretaceous age in the Absaroka volcanic field and crystalline rocks of Precambrian age in the Beartooth Mountains. Scores for factor 2 were highest for samples associated with volcanic rocks of Quaternary age on the Yellowstone Plateau, crystalline rocks of Precambrian age, and sedimentary rocks of Tertiary age in the Wyoming Basin ecoregion. Scores for factor 3 were highest in samples associated with sedimentary rocks of Paleozoic age and volcanic rocks of Cretaceous and Tertiary age.

Descriptive statistics are presented to serve as a baseline for element concentrations in bed sediment associated with eight geologic settings or ecoregions in the study unit. Some of the concentrations of chromium, copper, lead, nickel, and zinc in bed-sediment samples from areas of crystalline rocks in the Beartooth Mountains and other formations in the western part of the study unit exceeded sediment-quality assessment values associated with toxic effects to aquatic life.

INTRODUCTION

The Yellowstone River Basin (YRB) is one of more than 50 study units in the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) program. Gilliom and others (1995, p. 2) describe the framework for NAWQA, including selection of diverse river basins that drain about one-half of the conterminous United States and reflect 60-70 percent of the national water use and population. The program is designed to describe the status and trends in the quality of the Nation's surface and ground water, and link assessment of the status and trends with an understanding of the natural and human factors that affect water quality.

The NAWQA study units were divided into three groups on a rotational schedule, with one group of studies beginning in 1991, a second set in 1994, and the third in 1997. The YRB NAWQA study began in 1997, during the third round of study-unit start-ups (Miller and Quinn, 1997). The cycle for each study unit consists of 2 years of initial planning and retrospective analysis, 3 years of intensive data collection and analysis, and 6 years of report preparation and low-level assessment activity. This report has been prepared as part of the retrospective analysis of existing data for the YRB investigation.

The NAWQA program assesses water quality of streams based on three interrelated components: water column, bed sediment and fish tissue, and ecological studies (Gilliom and others, 1995, p. 9). Analysis of the existing data for elements in bed sediment of the study unit will aid in sampling design and interpretation of the bed-sediment data to be collected by the YRB NAWQA investigation. As part of the overall YRB NAWQA retrospective effort, State, Federal, and local agencies were surveyed for water-quality data sets, including bed-sediment analyses.

The National Uranium Resource Evaluation (NURE) Program collected the only bed-sediment data set with virtually complete coverage for the study unit. The NURE program was initiated by the Atomic Energy Commission in 1973 as a nationwide, systematic study of uranium resources. The program, which later came under the auspices of the U.S. Department of Energy, had nine components, including the Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) (Information Systems Programs, Energy Resources Institute, 1985), the data from which are used in this report.

Sources of bed-sediment data, other than HSSR, include the USGS National Water Information System (NWIS) data base and site-specific investigations such as Chaffee and others (1997) and studies associated with the Cooke City Environmental Impact Statement (U.S. Department of the Interior and U.S. Department of Agriculture, 1997). Data from site-specific investigations generally were not included in this report because of concerns about comparing data collected and analyzed with differing or unknown methods, lack of ready electronic access to the data, and the limited geographic scope of the data.

Purpose and Scope

The objectives of this report are:

1. To describe the spatial distribution of element concentrations in bed sediment of streams in the YRB,
2. To provide baseline concentrations of elements in bed sediment to compare with data to be collected and analyzed by NAWQA and other investigations, and
3. To compare element concentrations in bed sediment from the study unit to published sediment-quality assessment values for the protection of aquatic life.

The scope of this report is limited to retrospective analysis of existing bed-sediment data of 50 elements from the YRB, primarily the HSSR data set. The HSSR bed-sediment data that are used in this report currently (1999) is maintained by the U.S. Geological Survey (Smith, 1999). Factor analysis is used as a statistical tool to determine relations between the element concentrations. Descriptive statistics are used to summarize the complete data set and subsets distinguished by geologic settings. Three plates are presented to show the geologic settings, an example of results from the factor analysis, and spatial distribution of a selected element.

Description of the Study Unit

The Yellowstone River is the largest tributary of the Missouri River and drains an area of approximately 182,000 square kilometers (70,000 square miles) in Montana, North Dakota, and Wyoming (fig. 1). The mean annual discharge of the Yellowstone River at gaging-station 06329500 near the mouth is 362 cubic meters per second (12,800 cubic feet per second) (Shields and others, 1999, p. 346). Major tributaries to the Yellowstone River include the Clarks Fork Yellowston, Wind/Bighorn, Tongue, and Powder Rivers.

Air masses originating in the Gulf of Mexico, the northern Pacific Ocean, and the Arctic region interact to produce the seasonal climatic regimes of the study unit. Mean annual precipitation ranges from about 150 mm (5.9 in.) in the central parts of the Bighorn and Wind River Basins to more than 1,500 mm (59 in.) at high elevations in the mountains near Yellowstone National Park (Oregon Climate Service, 1995a, 1995b). Snowfall composes a substantial part of annual precipitation in most years, with average annual snowfall ranging from less than 300 mm (12 in.) in parts of the Bighorn Basin to more than 5,200 mm (200 in.) near Yellowstone National Park (Western Regional Climate Center, digital data, 1997). In mountainous parts of the study unit, precipitation varies strongly with elevation.

The ecoregions shown on plate 1 were modified from Omernik's map (1987) of ecoregions, and are based on integrated patterns of factors including land use, morphology, potential natural vegetation, and soil. Approximately 55 percent of the study unit lies in the Northwestern Great Plains ecoregion (Zelt and others, 1999, p. 75). This ecoregion has plains with open hills of varying height and tablelands of moderate relief; predominant land cover is subhumid grasses used for graz-

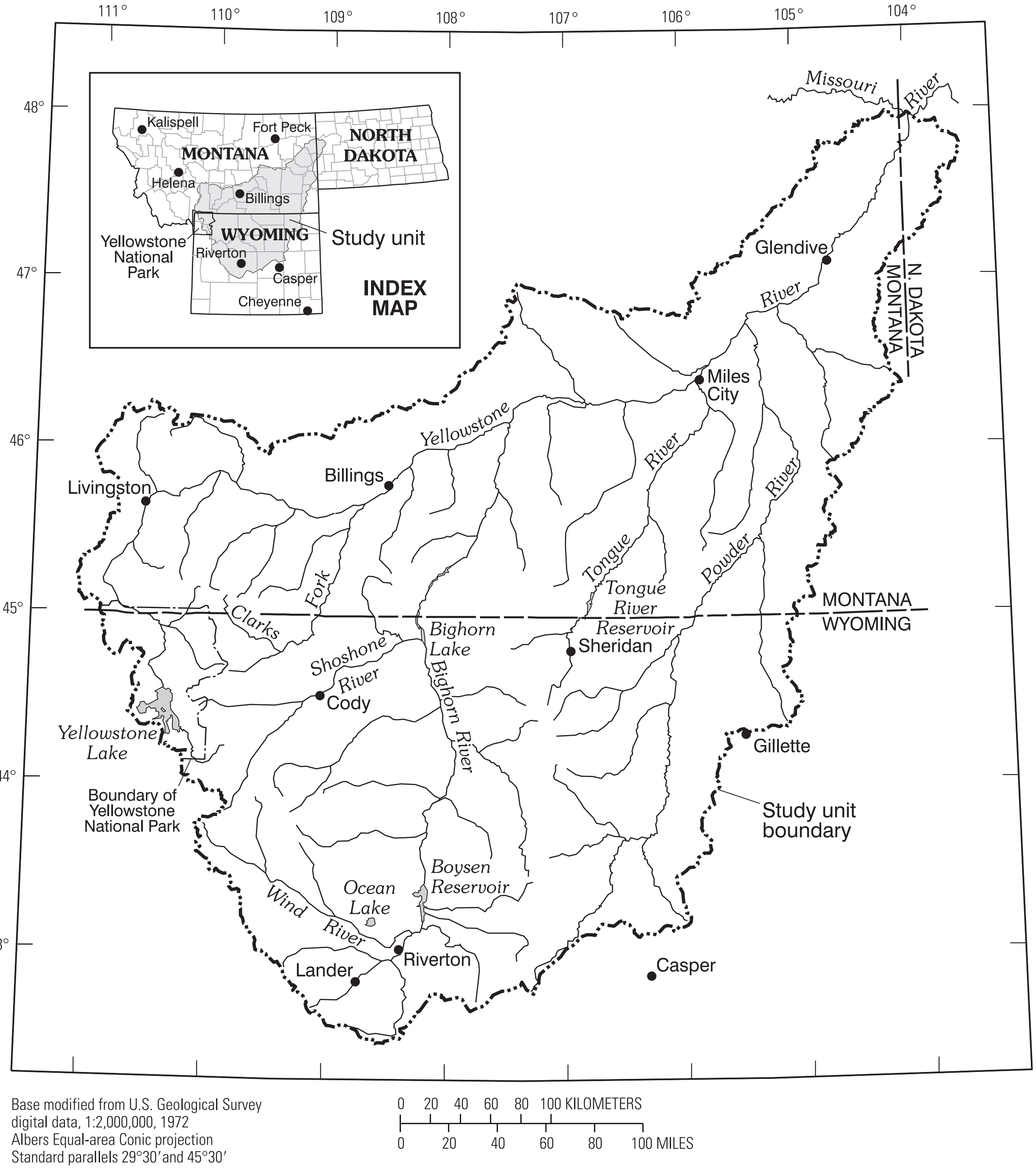

Figure 1. Location of the Yellowstone River Basin study unit, Montana, North Dakota, and Wyoming.

ing (Omernik, 1987). The Middle Rocky Mountains and Wyoming Basin ecoregions each contain about 21 percent of the study unit (Zelt and others, 1999, p. 75). The Middle Rocky Mountains ecoregion features high mountains and plateaus covered by Douglas fir, western spruce-fir forests, and alpine meadows (Omernik, 1987); land use includes grazing and silviculture. The Wyoming Basin ecoregion has plains with hills or low mountains, some irrigated agriculture, and the potential natural vegetation is shrub steppe, desert shrubland, and juniper-pinyon woodland (Omernik, 1987). The Montana Valley and Foothill Prairies ecoregion contains the remaining 3 percent of the study unit. The Montana Valley and Foothill Prairies ecoregion is characterized as subhumid grassland used for grazing, and some irrigated land (Omernik, 1987).

The ecoregions correspond in part to the structural geologic framework of uplifts and sedimentary basins in the study unit. The Beartooth Mountains, the Absaroka Range, the Wind River Range, and the Bighorn Mountains (plate 1) are the major uplifted areas that, in combination with two volcanic fields (the Yellowstone Plateau and the Absaroka field), compose most of the Middle Rocky Mountains ecoregion. The Beartooth Mountains contain a core of crystalline gneiss, granitics, and supracrustal rocks of Precambrian age (Page and Zientek, 1985), flanked primarily by rocks of Paleozoic age and younger rocks. Along the northern edge of the Beartooth Mountains, the Stillwater Complex of Precambrian age (not shown on plate 1), a layered igneous intrusion containing mineralized areas, crops out over an area about 50 km long and up to 8 km wide (Page, 1977). The Stillwater Complex contains nationally important resources of chromium and platinum-group elements, as well as substantial resources of gold, silver, copper, lead, and zinc (Hammarstrom and others, 1993). The crystalline core of Precambrian age of the Wind River Range is a high-grade metamorphic and igneous complex of migmatite, orthogneiss, and paragneiss, intruded by quartz diorite to granitic plutons (Hausel, 1989, p. 160-161). Rocks of Paleozoic age, and to a lesser extent Cretaceous age, are exposed along the eastern flank of the Wind River Range. The Bighorn Mountains represent a major structural arch with a core of crystalline granitic and gneissic rocks of Precambrian age (Hausel, 1989, p. 34-37). Throughout much of the Bighorn Mountains, the crystalline rocks of Precambrian age remain buried beneath carbonate rocks of Paleozoic age.

The Yellowstone Plateau of Quaternary age and the Absaroka volcanic field of Tertiary and Cretaceous age are recognized as distinct geologic provinces (Snoke, 1993). Rhyolites predominate among rock types in the Yellowstone Plateau, but basalts also occur. Andesite and dacite are the primary rock types in the Absaroka volcanic field (Chadwick, 1970), which encompasses the Absaroka Range and surrounding areas (plate 1). Many of the historical and recent metal-mining districts in the study unit are associated with the principal vent complexes, intrusives, and eruptive centers in the Absaroka volcanic field, as shown by Chadwick (1970). High concentrations of copper, gold, silver, zinc, lead, and other metals were deposited in the Absaroka volcanic field, the Beartooth Mountains, and surrounding areas in various types of deposits, such as porphyries, intrusions, veins, and zones of hydrothermal alteration and mineralization (Hammarstrom and others, 1993).

Structural basins in the study unit include the Bighorn Basin and Wind River Basin, which are both in the Wyoming Basin ecoregion (plate 1). The Wyoming Basin ecoregion spans the Bighorn and Wind River basins and the Owl Creek and Bridger Mountains that separate the two basins. The Powder River and Williston Basins are in the northeastern part of the study unit. The structural basins are surrounded on the flanks of the adjacent uplifts by folded and faulted rocks of Cretaceous and Paleozoic age. Rock units of Cretaceous age crop out in about 23 percent of the study unit, and usually are tilted and often beveled by erosion. Sedimentary rocks of Tertiary age unconformably overlie the eroded Cretaceous surface in most of the plains and basins of the study unit. Sedimentary rocks of Tertiary age, including sandstone, mudstone, siltstone, and shale crop out over about 43 percent of the study unit. Commercially important deposits of uranium occur in rocks of Tertiary age in the Powder River Basin and the Wind River Basin. The sedimentary rocks can be several thousand meters thick in the structural basins of the study unit (Blackstone, 1993).

A great variety of deposits of Quaternary age occur within the study unit, including eolian, fluvial, glacial, and landslide deposits. Valley-fill deposits consisting of unconsolidated gravel, sand, silt, and clay occur adjacent to most of the larger streams of the study unit (Whitehead, 1996), but are not shown on plate 1 because the sediment composition is considered to be reflective of the adjacent geologic setting.

Methods

Sample Collection

All of the HSSR bed-sediment samples from the YRB were collected under the direction of the Los Alamos Scientific Laboratory in Los Alamos, New Mexico. All 13,523 samples were collected in the YRB during 1976-79, except for two samples collected in 1974. Sampling sites were selected to represent small drainage areas of about 10 km^2 (Sharp and Aamodt, 1978, p. 9). The relatively small targeted drainages increased the likelihood that the bed sediment reflected the local geology. Downstream sediment transport undoubtedly affects element concentrations in the sediment at any given site, but the extent of the effect is unknown and beyond the scope of this report.

Each sediment sample was a composite of three grab samples from a cross section or along the margins of the stream channel. A similar procedure was followed if the stream was dry. The bed-sediment samples were dried at 100^{o}C or less and sieved in the field (Sharp and Aamodt, 1978, p. 16-19). About 25 cubic centimeters of the smaller particles (sand, silt, and clay-size) were shipped to the laboratory for elemental analysis. The sieve mesh size was 150 microns for 13,124 samples. The remaining 399 samples were sieved through 180-micron mesh and were excluded from this report because of the different mesh size. Bed-sediment samples often are sieved to minimize grain-size effects, but the mesh size used for sieving is not widely standardized. Comparing element concentrations of samples sieved with different mesh sizes is difficult because concentrations commonly are inversely related to grain size (Horowitz, 1991, p. 16-22).

Laboratory Analysis

Most of the samples were analyzed at the Los Alamos Scientific Laboratory (fig. 2). Due to program changes, some of the samples were analyzed at the Oak Ridge National Laboratory in Oak Ridge, Tennessee. The sampling and analysis efforts were subdivided into blocks corresponding to U.S. Geological Survey 1^{o} x 2^{o} quadrangle series maps. Samples from the Driggs, Ekalaka, and Sheridan quadrangles were analyzed for uranium at Los Alamos and for the other 49 elements at Oak Ridge.

The Los Alamos laboratory analyzed samples for uranium using delayed neutron counting; for arsenic, bismuth, cadmium, copper, lead, molybdenum, nickel, niobium, selenium, silver, tin, tungsten, and zirconium using energy dispersive x-ray fluorescence; for beryllium and lithium using arc-source emission spectrography; and for the remaining elements using neutron-activation (Smith, 1999). Elements typically analyzed by Los Alamos but not Oak Ridge included antimony, bismuth, cadmium, cesium, chloride, dysprosium, europium, gold, lutetium, rubidium, samarium, tantalum, terbium, tin, tungsten, and ytterbium. The Oak Ridge laboratory analyzed samples for uranium using neutron-activation and for the other elements using emission spectrochemical analysis. Elements analyzed by Oak Ridge but not Los Alamos included boron, molybdenum, phosphorus, yttrium, and zirconium. Some exceptions occurred, such as special studies of arsenic, molybdenum, selenium, and zirconium, which were analyzed only in samples collected from quadrangles on the western edge of the study unit. Quality-control samples were not available to compare results between the two laboratories.

Data Analysis

Factor analysis (Kachigan, 1986, p. 377-379) was used as a data-reduction technique to systematically summarize the large correlation matrix formed among the constituent-concentration variables. The purpose of factor analysis is to represent the variance in the concentrations through computation of a small set of derived variables called factors that commonly correspond to underlying geochemical processes (Christophersen and Hooper, 1992) or patterns of spatial variability (Lins, 1997). The first factor accounts for as much of the total variance in the data as possible, the second factor accounts for as much of the remaining variance as possible while being uncorrelated with the first factor, and so forth (Alley, 1993, p. 49). The factor analysis was performed using Statit Analysis System software (Statware, Inc., 1996). Probability plots indicated that the frequency distributions of the elements were right-skewed. Therefore, logarithms of the constituent-concentration values were used as input to factor analysis to improve the multivariate normality of the data set.

Orthogonal varimax rotation was applied to the factors to maximize the total variance explained by the factors as a whole. The purpose of rotation is to rede-

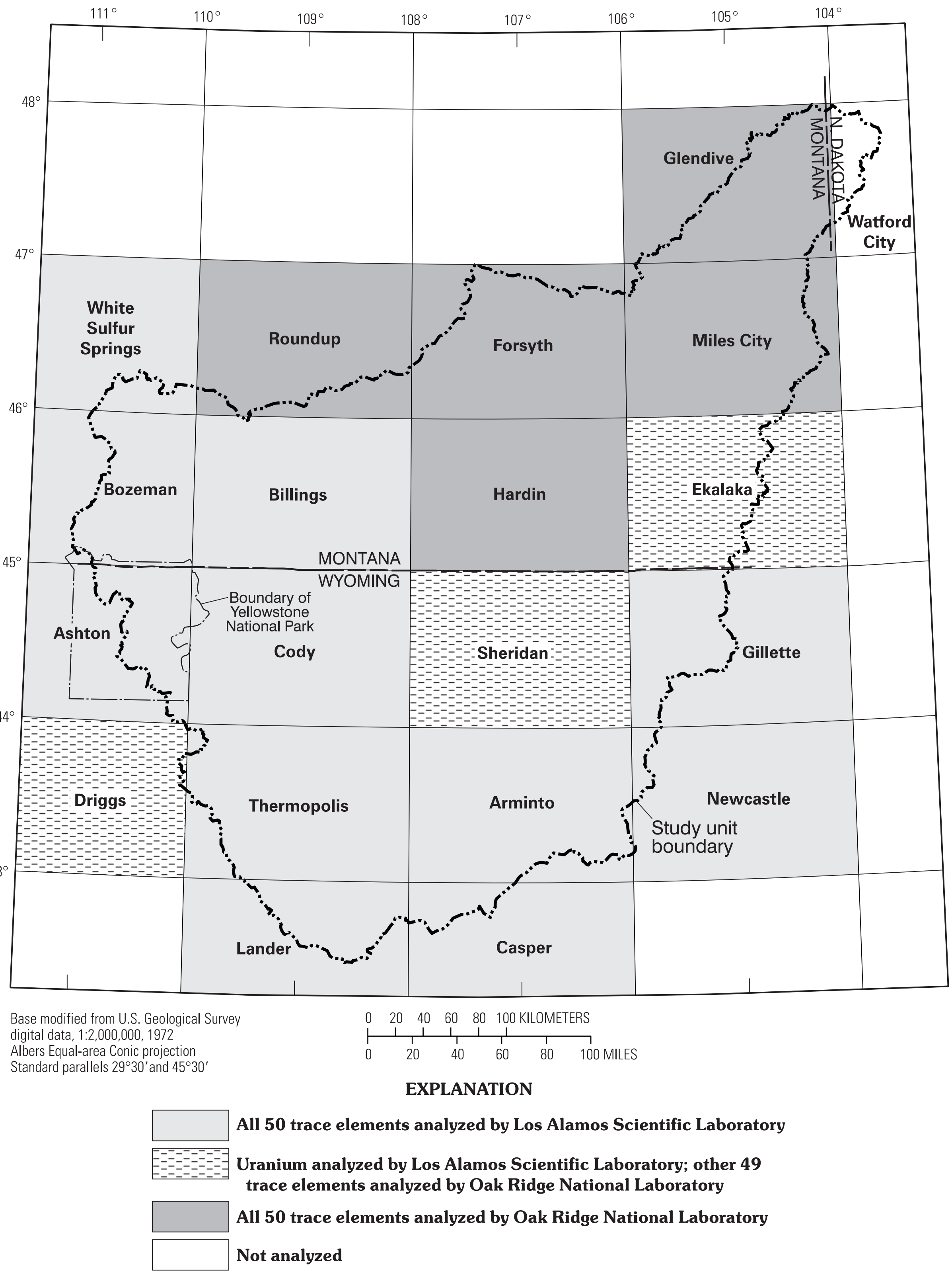

Figure 2. Location by quadrangle of bed-sediment samples analyzed by Los Alamos Scientific Laboratory and Oak Ridge National Laboratory, Yellowstone River Basin.

fine the factors in order to make sharper distinctions, because rotation does not change the number of factors or the total variance explained by the factor analysis (Kachigan, 1986, p. 389-393).

For each sample, a score was computed on each factor. These factor scores represent a weighted combination of the sample's chemical composition, as indicated by the concentrations of the elements. A sample will tend to score high on a factor only if it had large concentrations of the constituents that correlate most strongly with that factor (Kachigan, 1986, p. 385). Scores for each factor were standardized; that is, the mean score is zero with unit variance.

Acknowledgments

The authors wish to thank the USGS people that helped prepare this report and guide it through the various stages of review. Critical reviews from Ingrid Verstraeten and Robert Boyd are greatly appreciated. Steve Smith provided electronic access to the HSSR data. We also thank Melanie Clark for assisting with data retrieval, Peter Wright for assisting with data inventory, and Laura Gianakos for assisting with data compilation. Sue Roberts, Phil Bowman, Emily Sabado, and Shirley Thomas assisted with preparation of graphics, text, and tables.

ELEMENT CONCENTRATIONS

Concentrations of all 50 elements in the HSSR data set are statistically summarized in table 1. The number of sample analyses varied from one element to another because of differences in laboratory procedures and special studies, as described earlier. Uranium had the largest number of analyses (13,087), although the data set contained a total of 13,124 samples. All elements except uranium had analyses with concentrations less than the reporting limit set by the laboratory. As shown in the third column of table 1, the reporting limit was fixed for some elements, such as the reporting limit of 0.05 percent for aluminum. For other elements, such as antimony, the reporting limit listed in table 1 is given as a range because the reporting limit varied from one sample to another. Reporting limits for a given element can vary because of matrix effects or other characteristics of the individual sample or analysis.

Data sets for 36 elements in table 1 had small to moderate (less than 50 percent) amounts of censored data. Censored values are those reported as "less than" the reporting limit. For each of these 36 elements, a probability plot was generated to estimate the distribution of the data below the reporting limit (Helsel and Hirsch, 1992, p. 357-375). On the probability plot, the line through the data above the highest reporting limit was extended below the reporting limit and used to estimate the distribution of the data below the reporting limit. More than 50 percent of the data for antimony, bismuth, cadmium, chloride, gold, molybdenum, niobium, selenium, silver, tantalum, terbium, tin, and tungsten were below the reporting limit. The data for those 13 elements are not discussed further in this report because the utility of the data is limited by the censored values.

Spatial Distribution Based on Factor Analysis

The data set chosen for spatial analysis contained 25 elements that were analyzed more or less uniformly across the study unit: aluminum, barium, beryllium, calcium, cerium, chromium, cobalt, copper, hafnium, iron, lanthanum, lead, lithium, magnesium, manganese, nickel, potassium, scandium, sodium, strontium, thorium, titanium, uranium, vanadium, and zinc. There were 12,289 bed-sediment samples in the HSSR data with non-missing values for all 25 selected constituents. Results of the factor analysis were interpreted using geographic information systems technology to perform a spatial analysis that categorized each HSSR sampling site with respect to the geologic setting and ecoregion.

About 65 percent of the total variation in the chemistry of the bed sediment was explained by the first four factors (table 2). In order to determine how many factors to retain for further analysis, two objective criteria were used to compare the percentage of explained variance for each factor in the HSSR data with the percentage expected for a corresponding factor computed from a set of random data. Results for Preisendorfer and Barnett's (1977) rule N test are presented in table 2. Both the rule N test and Frontier's "broken-stick" method (Jackson, 1993) suggested that retention of 3 factors would provide the greatest amount of useful information with the fewest number of factors. The factors were then rotated as described previously in the methods section.

Table 1. *Descriptive statistics for element concentrations in bed-sediment samples collected during the National Uranium Resource Evaluation (NURE), Hydrogeochemical and Stream Sediment Reconnaissance (HSSR), Yellowstone River Basin,1974-79*

[*, concentration in percent; all other concentrations in milligrams per kilogram (mg/kg); --, percentile not calculated; <, less than]

Element	Number of analyses	Reporting limit (mg/kg)	Concentrations greater than reporting limit (percent)	Concentration (mg/kg) for selected percentiles of analyses				
				95	75	50 (median)	25	5
Aluminum (Al)	12,643	.05 *	99	7.85 *	6.37 *	5.30 *	4.36 *	3.04 *
Antimony (Sb)	7,754	1 - 17	1	--	--	<2	--	--
Arsenic (As)	957	5 -	78	44	14	9.0	5.0	3.0
Barium (Ba)	12,643	2 - 411	99	1,230	784	619	513	361
Beryllium (Be)	12,486	1	97	3.0	2.0	2.0	1.0	1.0
Bismuth (Bi)	7,778	5	15	--	--	<5.0	--	--
Boron (B)	4,844	10	98	57	37	28	21	13
Cadmium (Cd)	7,778	5	1	--	--	<5	--	--
Calcium (Ca)	12,643	.0237 - .188 *	99	5.57 *	3.42 *	2.18 *	1.31 *	0.58 *
Cerium (Ce)	12,632	7 - 15	99	101	67	56	48	36
Cesium (Cs)	7,788	.4 - 7.4	76	5.4	3.5	2.5	1.2	1.2
Chloride (Cl)	7,798	17 - 254	19	--	--	<87	--	--
Chromium (Cr)	12,635	1 - 23	99	243	77	48	36	25
Cobalt (Co)	12,632	.1 - 4.6	98	24.2	10.6	7.3	6.0	4.0
Copper (Cu)	12,622	2 - 10	98	44	27	21	16	10
Dysprosium (Dy)	7,799	1 - 4	99	6	4	4	3	2
Europium (Eu)	7,788	.2 - .9	99	2.0	1.5	1.2	0.9	0.7
Gold (Au)	7,788	.02 - .72	1	--	--	<.08	--	--
Hafnium (Hf)	12,632	.9 - 15	65	20	9.3	5.5	5.5	3.9
Iron (Fe)	12,635	.05 *	99	5.13 *	2.75 *	1.96 *	1.46 *	0.86 *
Lanthanum (La)	12,589	2 - 159	97	61	37	28	23	17
Lead (Pb)	12,622	5 - 10	84	27	17	12	7.0	3.0
Lithium (Li)	12,486	1	99	51	34	26	20	14
Lutetium (Lu)	7,788	.1 - .4	93	0.6	0.4	0.3	0.3	0.1
Magnesium (Mg)	12,643	.05 - 1.179 *	99	4.11 *	2.01 *	1.36 *	0.92 *	0.52 *
Manganese (Mn)	12,643	4	99	948	544	347	264	157
Molybdenum (Mo)	5,226	4 - 5	6	--	--	<4	--	--
Nickel (Ni)	12,622	2 - 15	74	58	26	17	8.0	8.0
Niobium (Nb)	12,622	4 - 20	39	--	--	<20	--	--

Table 1. *Descriptive statistics for element concentrations in bed-sediment samples collected during the National Uranium Resource Evaluation (NURE), Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) Yellowstone River Basin,1974-79--Continued*

Element	Number of analyses	Reporting limit (mg/kg)	Concentrations greater than reporting limit (percent)	Concentration (mg/kg) for selected percentiles of analyses				
				95	75	50 (median)	25	5
Phosphorus (P)	4,844	5	99	848	618	517	441	347
Potassium (K)	12,643	.02 - 1.084 *	99	2.13 *	1.65 *	1.42 *	1.22 *	0.96 *
Rubidium (Rb)	7,791	6 - 123	59	81	53	33	20	20
Samarium (Sm)	7,760	.3 - 9.9	97	8.9	5.5	4.5	3.6	2.0
Scandium (Sc)	12,632	1	99	16.7	8.9	6.0	5.0	3.5
Selenium (Se)	957	5	.1	--	--	<5	--	--
Silver (Ag)	12,622	2 - 5	1	--	--	<5	--	--
Sodium (Na)	12,643	.05 *	99	2.16*	1.27*	.74*	0.51*	0.25*
Strontium (Sr)	12,642	1 - 931	58	871	490	274	130	94
Tantalum (Ta)	7,436	1 - 7	2	--	--	<1	--	--
Terbium (Tb)	7,502	1 - 3	3	--	--	<1	--	--
Thorium (Th)	12,632	1.5 - 4.4	95	18.5	10.3	8.0	5.8	1.4
Tin (Sn)	7,778	10	1	--	--	<10	--	--
Titanium (Ti)	12,643	10 - 2,585	99	5,080	3,370	2,620	2,050	1,540
Tungsten (W)	7,778	15	4	--	--	<15	--	--
Uranium (U)	13,087	0.01	100	5.5	3.4	2.8	2.5	1.7
Vanadium (V)	12,643	2 - 31	99	161	92	64	50	35
Ytterbium (Yb)	7,765	.5 - 6.3	77	5.3	3.4	2.7	1.7	1.4
Yttrium (Y)	4,844	1	99	16	13	11	10	8.0
Zinc (Zn)	12,546	4 - 204	77	127	111	72	50	33
Zirconium (Zr)	5,801	2	99	214	76	60	51	42

Table 2. *Percentage of variance explained by first four unrotated factors, and comparison with percentages computed from a set of random data*

Factor	Sediment chemistry variance explained, in percent	Cumulative variance explained, in percent	Random data variance explained, in percent[1]	Result for rule N test[2]
1	38.3	38.3	7.7	p <0.05
2	12.2	50.5	7.3	p<0.05
3	8.2	58.7	7.1	p<0.05
4	6.2	64.9	6.9	p<0.05

[1]Computed for a matrix with 25 constituents.

[2]See Preisendorfer and Barnett (1977) for description of rule N tests.

The three factors identified in the factor analysis correspond to three geochemically distinct types of source rocks. Factors 1 and 2 reflect the influence of two types of igneous source rocks: basaltic (mafic) and granitic (felsic). Factor 3 reflects sedimentary rocks, carbonate rocks in particular.

Factor 1 (Basaltic Rocks)

Factor 1 largely reflects the influence of basaltic rocks, based on the correlated elements and spatial distribution of the factor scores. Factor 1 is correlated with scandium, iron, cobalt, vanadium, chromium, aluminum, nickel, manganese, copper, titanium, sodium, barium, strontium, and zinc in descending order of strength of positive correlation. Scandium, iron, cobalt, and vanadium strongly correlate ($r > 0.85$) with factor 1. Ten of the 14 elements associated with factor 1 share similar properties. Scandium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, and copper are on average at least four times more abundant in basaltic rocks than in granitic rocks, and zinc is about twice as abundant (Mason, 1966, p. 45-48). The chemical similarity of the same 10 elements can be noted from the periodic chart of the elements, where they are B-subgroup elements, atomic numbers 21-30, and are transition elements adjacent to each other in the period-4 element row. The other elements, aluminum, sodium, barium, and strontium, associated with factor 1 are present, on average, in equal or greater abundance in granite than basalt (Mason, 1966, p. 45-48), and are A-subgroup elements of the periodic table. Elements of the A subgroup have considerably lower electronegativities than elements of the B-subgroup, which has an important influence on bonding and distribution of the elements during magmatic crystallization (Mason, 1966, p. 133). The use of factor analysis, therefore, was useful in determining an association of aluminum, sodium, barium, and strontium with period-4 metals that would not be predicted from either average abundance data from Mason (1966) or from associations on the periodic chart.

Scores for factor 1 tended to be highest in the western part of the YRB (plate 2), in areas of volcanic rocks of Tertiary and Cretaceous age (Absaroka volcanic field) and crystalline rocks of Precambrian age in the Beartooth Mountains. High factor scores (greater than 1, for example) on plate 2 indicate the strongest associations of the data with factor 1. Andesite and dacite are the primary rock types in the Absaroka volcanic field (Chadwick, 1970), which corroborates the influence of basaltic rocks on factor 1. The high factor-1 scores in the Beartooth Mountains might reflect the intrusions, veins, and other geologic features within the area, rather than the host crystalline rock. Outside the Beartooth Mountains, samples from areas of crystalline rocks of Precambrian age had intermediate scores on factor 1. The lowest factor-1 scores tended to be from samples collected from sedimentary rocks of Tertiary, Cretaceous, and Paleozoic age.

The distribution of the elements is controlled in part by their chemical properties and behavior. Numerous igneous rock minerals are sources of iron, but iron concentrations can be several times larger in basaltic rocks than in granitic rocks (Mason, 1966, p. 45). Ferromagnesian minerals commonly dissolve during weathering and reprecipitate as sedimentary minerals (Hem, 1985, p. 77). Iron also is a common component in sulfide ores of other metals. Cobalt is most abundant in igneous rocks, particularly basaltic rocks (Mason, 1966, p. 45), and cobalt ions can substitute for part of the iron in ferrogmagnesian rock minerals (Hem, 1985, p. 138). Chromium is most abundant in ultramafic or basaltic rocks, and chromite (highly resistant to weathering) is common in residue overlying ultramafic rocks (Hem, 1985, p. 138). Weathering of igneous rocks commonly produces sediment enriched in aluminum; the most common of the aluminum-enriched minerals are clays (Hem, 1985, p. 73). Aluminum is about equally abundant in granitic and basaltic rocks (Mason, 1966, p. 45). Manganese is a minor constituent in many igneous and metamorphic minerals, and is most abundant in basaltic rocks (Mason, 1966, p. 45). When dissolved during weathering in an oxidizing environment, manganese generally will reprecipitate as a crust of manganese oxide in association with iron and sometimes substantial amounts of other metal ions (Hem, 1985, p. 86). Copper occurs in sulfide minerals and in ore minerals that also contain iron (Hem, 1985, p. 141). Titanium is commonly associated with iron in minerals that are highly resistant to weathering and therefore tend to persist in sediments (Hem, 1985, p. 137). Titanium forms specific minerals that are widely dispersed throughout some of the commonest rocks (Mason, 1966, p. 49), which helps explain why concentrations of titanium in bed sediment are large relative to many of the other elements (table 1). Barium, sodium, and strontium are more abundant in granitic rocks than basaltic rocks (Mason, 1966, p. 45-46). Zinc has about the same abundance in crustal rocks as copper or nickel and is fairly common (Hem, 1985, p 142).

Factor 2 (Granitic Rocks)

Factor 2 reflects the influence of granitic rocks. Factor 2 correlates with thorium, lanthanum, cerium, beryllium, hafnium, uranium, and potassium, in descending order of strength of positive correlation. Correlation coefficients ranged from 0.78 to 0.52. The average abundance of the seven elements associated with factor 2 is several times greater in granite than in basalt (Mason, 1966, p. 45-48).

Factor-2 scores were highest in samples from volcanic rocks of Quaternary age (Yellowstone Plateau). Rhyolite, which is the extrusive equivalent of granite, predominates in the volcanic rocks of the Yellowstone Plateau. Factor-2 scores were intermediate from areas of crystalline rocks of Precambrian age, both in and outside the Beartooth Mountains. The crystalline rocks of Precambrian age in the study unit are exposed at the cores of structural uplifts in the Beartooth Mountains, the Wind River Range, the Bighorn Mountains, the Owl Creek Mountains, and the Bridger Mountains (plate 1). Outcrops of granitic rocks also occur in the Granite Mountains that lie just south of the study unit and contributed basin-fill debris to the Wind River structural basin.

The lowest scores on factor 2 were associated with sedimentary rocks, with the exception of the intermediate-level scores associated with sedimentary rocks of Tertiary age in the Wyoming Basin ecoregion. Factor-2 scores for sedimentary rocks of Tertiary age were significantly different (Mann-Whitney test, probability 0.05, Iman and Conover, 1983) in the Wyoming Basin ecoregion than for the same geologic setting in the Northwestern Great Plains ecoregion. The difference in factor-2 scores between the two ecoregions might be caused by differences in environmental components or processes related to the ecoregion such as source rocks and weathering rates. Using data from two analytical laboratories probably did not cause the differences in factor-2 scores between the ecoregions, for samples from areas of rocks of Tertiary age. Testing of data from Los Alamos Scientific Laboratory in comparison with data from Oak Ridge National Laboratory on samples collected in areas of sedimentary rocks of Tertiary age indicated the concentrations were not significantly different between the laboratories (Mann-Whitney, probability 0.05). A similar test was applied to data from areas of sedimentary rocks of Cretaceous age, which indicated a small but significant difference in median test scores for samples from areas of rocks of Cretaceous age between the laboratories, but not between the two ecoregions.

Factor 3 (Carbonate Rocks)

Factor 3 is associated most strongly with carbonate rocks. Factor 3 correlates positively with magnesium and calcium ($r > 0.75$). Both of these elements are usually far more abundant in carbonate rocks than in other rock types, and in combination with carbon are the chief components of carbonate rocks, on average (Hem, 1985, p. 5). Strontium has a chemistry similar to that of calcium, is typically most abundant in carbonate rocks, and had the third strongest positive correlation with factor 3. Lead was intermediate between magnesium and calcium in correlations with factors 1 and 2, but was strongly and negatively correlated ($r = -0.64$) with factor 3.

Samples from sedimentary rocks of Paleozoic age and volcanic rocks of Tertiary and Cretaceous age had higher scores on factor 3 than did samples from other settings. The sedimentary rocks of Paleozoic age that are exposed along the flanks of the Bighorn Mountains and other structural uplifts in the study unit are primarily carbonates such as limestone and dolomite. Samples from areas of crystalline rocks of Precambrian age in and outside of the Beartooth Mountains and sedimentary rocks of Tertiary age outside the Wyoming Basin ecoregion tended to have lower factor-3 scores than those from other geologic settings.

Baseline Concentrations

Summary statistics for all 50 elements analyzed from HSSR bed sediment samples in the Yellowstone River Basin are listed in table 1. Summary statistics also are presented for the 25 elements used in the factor analysis, in eight geologic settings: table 3, volcanic rocks of Quaternary age (Yellowstone Plateau); table 4, volcanic rocks of Tertiary and Cretaceous age (Absaroka volcanic field); table 5, sedimentary rocks of Tertiary age in the Wyoming Basin ecoregion; table 6, sedimentary rocks of Tertiary age outside of the Wyoming Basin ecoregion; table 7, sedimentary rocks of Cretaceous age; table 8, sedimentary rocks of Paleozoic age; table 9, crystalline rocks of Precambrian age in the Beartooth Mountains; and table 10, crystalline rocks of Precambrian age outside the Beartooth Mountains.

Sediment-Quality Assessment Values

Smith and others (1996) summarized sediment-quality assessment values (SQAV) for the protection of aquatic life. The SQAV were developed using multiple lines of evidence, including biological and chemical data from modeling, laboratory tests, and field studies. The assessment values included a probable effect level (PEL) above which toxic effects are frequently noted, and an effects range median (ERM) (Long and others, 1995) which is the median concentration at which adverse effects were noted. Although the ERM concentrations are based on marine and estuarine sediment, Ingersoll and others (1996) considered ERMs to be as reliable as PELs for classifying freshwater sediments as either toxic or nontoxic. Kemble and others (1998) also noted that ERMs were highly reliable for classifying sediment from the upper Mississippi River as toxic or nontoxic.

The SQAV are based on bulk sediment, whereas the HSSR data are from sieved samples. The effect of sieving likely increases trace-element concentrations relative to the bulk fraction, because the trace elements generally are associated with the smaller particles (Horowitz, 1991, p. 16-22; Peterson and others, 1991). Comparison of the SQAV with the sieved data from HSSR is intended only as a point of reference and not as an absolute indication of the occurrence of toxic effects.

More than 99 percent of the copper, lead, and zinc concentrations and more than 75 percent of the chromium and nickel concentrations in the HSSR samples were less than the corresponding PEL and ERM (table 11). The highest concentrations of copper, zinc, chromium, and nickel generally occurred in samples from the western part of the study unit, as shown for copper in plate 3. Copper concentrations in bed sediment were highest in samples from crystalline rocks of Precambrian age in the Beartooth Mountains and volcanic rocks of Tertiary and Cretaceous age, as shown in the boxplots on plate 3.

Gurrieri (1998) described high concentrations of trace elements and associated adverse effects on the benthic invertebrate and periphyton communities of the Stillwater River. The headwaters of the Stillwater River, where the effects were noted, are in the Precambrian crystalline rocks of the Beartooth Mountains (plate 1). Concentrations of copper in bed-sediment samples collected where adverse effects were noted, downstream of an area affected by mining, were 5,617 and 4,820 mg/kg (Gurrieri, 1998). Lesser effects to the aquatic life were noted farther downstream, where copper concentrations ranged from 254 to 521 mg/kg (Gurrieri, 1998). The background copper concentration in bed-sediment samples (sieved through 60 micron mesh) from the upper Stillwater River basin was 353 mg/kg (Gurrieri, 1998), which is higher than both the PEL and the ERM.

Nimmo and others (1998) described toxicity to the amphipod *Hyallela azteca* (a surrogate test organism) in 7-day long toxicity tests with whole bed sediment and interstitial pore water from Soda Butte Creek in the vicinity of Yellowstone National Park (plate 3). Survival of the amphipods was nearly zero from all sites on Soda Butte Creek downstream of mine tailings and from a naturally mineralized creek where mining never occurred. The toxicity was attributed to copper (Nimmo and others, 1998, p. 924). The copper concentrations in bed sediment associated with the toxicity in Soda Butte Creek generally ranged from about 100 to 500 mg/kg (Nimmo and others, 1998, p. 923).

Table 3. *Summary statistics for element concentrations in bed-sediment samples collected from streams in areas of volcanic rocks of Quaternary age (Yellowstone Plateau), Yellowstone River Basin,1974-79*

[*, concentration in percent, all other concentrations in milligrams per kilogram (mg/kg); <, less than. Statistics calculated from 151 samples]

	Concentration (mg/kg) for selected percentiles of analyses				
Element	**95**	**75**	**50 (median)**	**25**	**5**
Aluminum (Al)	7.72 *	6.97 *	6.41 *	5.97 *	4.26 *
Barium (Ba)	1,590	939	786	629	450
Beryllium (Be)	5.5	4.0	3.0	2.0	1.0
Calcium (Ca)	4.06 *	2.66*	2.04 *	1.15 *	.43 *
Cerium (Ce)	158	120	98.0	81.5	45.0
Chromium (Cr)	299	173	114	63.5	33.0
Cobalt (Co)	23.4	14.5	9.8	5.4	0.8
Copper (Cu)	65.5	37.0	22.0	14.5	4.5
Hafnium (Hf)	22.4	12.8	10.1	7.8	4.4
Iron (Fe)	5.03 *	3.31 *	2.49 *	1.83 *	0.96 *
Lanthanum (La)	93.0	66.5	55.0	43.5	25.0
Lead (Pb)	32.5	20.5	14.0	10.0	4.0
Lithium (Li)	56.0	45.0	39.0	30.0	13.0
Magnesium (Mg)	5.00 *	2.79 *	1.98 *	1.06 *	0.11 *
Manganese (Mn)	1,180	690	518	391	161
Nickel (Ni)	59.0	33.5	22.0	8.0	8.0
Potassium (K)	2.88 *	2.33 *	1.98 *	1.63 *	1.06 *
Scandium (Sc)	18.5	11.6	8.7	6.1	4.4
Sodium (Na)	2.25 *	1.97 *	1.79 *	1.31 *	0.73 *
Strontium (Sr)	786	541	490	490	452
Thorium (Th)	21.9	16.8	13.9	11.0	5.2
Titanium (Ti)	4,890	3,840	3,270	2,750	2,060
Uranium (U)	5.67	4.16	3.31	2.72	1.61
Vanadium (V)	137	85.0	58.0	39.5	20.5
Zinc (Zn)	166	121	111	111	54.5

Table 4. *Summary statistics for element concentrations in bed-sediment samples collected from streams in areas of volcanic rocks of Tertiary and Cretaceous age (Absaroka volcanic field), Yellowstone River Basin, 1974-79*

[*, concentration in percent; all other concentrations in milligrams per kilogram (mg/kg); <, less than. Statistics calculated from 1,276 samples]

	Concentration (mg/kg) for selected percentiles of analyses				
Element	95	75	50 (median)	25	5
Aluminum (Al)	8.37 *	7.85 *	7.20 *	6.49 *	5.49 *
Barium (Ba)	1,460	1,180	968	822	620
Beryllium (Be)	3.0	2.0	2.0	2.0	0.7
Calcium (Ca)	5.48 *	4.39 *	3.55 *	2.74 *	1.69 *
Cerium (Ce)	113	83.0	69.5	60.0	48.0
Chromium (Cr)	395	230	163	117	49.0
Cobalt (Co)	33.6	24.6	18.1	14.3	9.6
Copper (Cu)	57.3	39.0	31.0	24.0	17.0
Hafnium (Hf)	18.8	9.1	5.7	3.9	2.8
Iron (Fe)	7.66 *	5.18 *	4.18 *	3.50 *	2.57 *
Lanthanum (La)	67.0	46.0	39.0	34.0	23.0
Lead (Pb)	20.0	13.0	10.0	6.0	3.0
Lithium (Li)	43.0	32.0	25.0	20.0	13.0
Magnesium (Mg)	5.87 *	4.09 *	2.45 *	1.28 *	0.84 *
Manganese (Mn)	1,170	879	726	608	473
Nickel (Ni)	91.0	52.0	35.0	21.8	8.0
Potassium (K)	2.07 *	1.72 *	1.49 *	1.27 *	0.94 *
Scandium (Sc)	26.4	16.7	12.8	10.5	7.9
Sodium (Na)	2.46 *	2.15 *	1.88 *	1.47 *	1.07 *
Strontium (Sr)	1,210	917	672	490	410
Thorium (Th)	16.5	9.8	7.8	5.9	3.9
Titanium (Ti)	6,790	4,920	4,160	3,480	2,820
Uranium (U)	3.80	2.66	2.11	1.60	1.08
Vanadium (V)	263	157	123	100	72.0
Zinc (Zn)	156	114	111	96.0	57.8

Table 5. *Summary statistics for element concentrations in bed-sediment samples collected from streams in areas of sedimentary rocks of Tertiary age, in Wyoming Basin ecoregion, Yellowstone River Basin, 1974-79*

[*, concentration in percent; all other concentrations in milligrams per kilogram (mg.kg); <, less than. Statistics calculated from 1,584 samples]

	Concentration (mg/kg) for selected percentiles of analyses				
Element	**95**	**75**	**50 (median)**	**25**	**5**
Aluminum (Al)	7.86 *	6.02 *	5.07 *	3.87 *	2.30 *
Barium (Ba)	1,310	718	609	522	410
Beryllium (Be)	3.0	2.0	2.0	2.0	1.0
Calcium (Ca)	4.53 *	2.83 *	1.98 *	1.14 *	.44 *
Cerium (Ce)	119	75.0	63.0	52.0	40.0
Chromium (Cr)	143	67.0	51.0	39.0	27.0
Cobalt (Co)	17.0	9.1	6.9	5.4	3.8
Copper (Cu)	36.0	26.0	20.0	15.0	9.0
Hafnium (Hf)	25.2	13.8	9.7	7.0	4.6
Iron (Fe)	3.66 *	2.26 *	1.61 *	1.18 *	0.74 *
Lanthanum (La)	110	45.0	35.0	28.0	20.0
Lead (Pb)	21.0	14.0	10.0	7.0	3.0
Lithium (Li)	47.0	34.2	26.0	20.0	13.0
Magnesium (Mg)	3.08 *	2.00 *	1.52 *	1.07 *	0.51 *
Manganese (Mn)	655	445	345	262	154
Nickel (Ni)	40.0	22.0	8.0	8.0	8.0
Potassium (K)	2.17 *	1.78 *	1.53 *	1.31 *	1.05 *
Scandium (Sc)	12.1	7.6	5.9	4.7	3.3
Sodium (Na)	2.10 *	1.22 *	0.80 *	0.40 *	.18 *
Strontium (Sr)	744	490	466	130	130
Thorium (Th)	28.7	13.7	10.3	8.1	5.8
Titanium (Ti)	4,870	3,460	2,900	2,460	1,880
Uranium (U)	6.27	3.78	3.13	2.70	2.10
Vanadium (V)	114	68.0	54.0	44.0	31.0
Zinc (Zn)	111	111	76.0	52.0	28.0

Table 6. *Summary statistics for element concentrations in bed-sediment samples collected from streams in areas of sedimentary rocks of Tertiary age, outside of the Wyoming Basin ecoregion, Yellowstone River Basin, 1974-79*

[*, concentration in percent; all other concentrations in milligrams per kilogram (mg/kg); <, less than. Statistics calculated from 3,451 samples]

Element	Concentration (mg/kg) for selected percentiles of analyses				
	95	75	50 (median)	25	5
Aluminum (Al)	7.05 *	5.60 *	4.80 *	4.19 *	3.44 *
Barium (Ba)	957	673	578	50	423
Beryllium (Be)	2.0	1.0	1.0	1.0	1.0
Calcium (Ca)	4.76 *	2.95 *	1.76 *	1.12 *	0.46 *
Cerium (Ce)	71.0	58.0	52.0	46.0	37.0
Chromium (Cr)	91.0	49.0	40.0	33.0	24.5
Cobalt (Co)	11.2	8.0	7.0	5.6	4.0
Copper (Cu)	35.0	24.0	19.0	15.0	10.0
Hafnium (Hf)	19.0	5.5	5.5	5.5	5.5
Iron (Fe)	2.90 *	2.18 *	1.87 *	1.56 *	1.04 *
Lanthanum (La)	40.0	28.0	24.0	21.0	17.0
Lead (Pb)	27.0	20.0	15.0	10.0	5.5
Lithium (Li)	39.0	28.0	23.0	19.0	14.0
Magnesium (Mg)	2.17 *	1.59 *	1.12 *	0.75 *	0.47 *
Manganese (Mn)	578	368	305	253	166
Nickel (Ni)	37.0	22.0	17.0	12.0	8.0
Potassium (K)	1.83 *	1.51 *	1.33 *	1.19 *	0.98 *
Scandium (Sc)	9.0	7.0	5.6	5.0	4.0
Sodium (Na)	1.16 *	0.68 *	0.55 *	0.42 *	0.20 *
Strontium (Sr)	491	219	144	111	77
Thorium (Th)	13.0	9.0	6.8	4.0	1.4
Titanium (Ti)	3,440	2,490	2,040	1,780	1,440
Uranium (U)	4.30	3.10	2.80	2.60	2.20
Vanadium (V)	99.0	70.0	57.0	48.0	38.0
Zinc (Zn)	111	70.0	54.0	45.0	33.0

Table 7. *Summary statistics for element concentrations in bed-sediment samples collected from streams in areas of sedimentary rocks of Cretaceous age, Yellowstone River Basin, 1974-79*

[*, concentration in percent; all other concentrations in milligrams per kilogram (mg/kg); <, less than. Statistics calculated from 3,698 samples]

	Concentration (mg/kg) for selected percentiles of analyses				
Element	**95**	**75**	**50 (median)**	**25**	**5**
Aluminum (Al)	7.25 *	5.96 *	5.17 *	4.41 *	3.18 *
Barium (Ba)	1,000	738	624	528	407
Beryllium (Be)	3.0	2.0	2.0	1.0	1.0
Calcium (Ca)	5.13 *	2.93 *	1.89 *	1.22 *	0.60 *
Cerium (Ce)	78.0	61.0	54.0	47.0	36.0
Chromium (Cr)	107	58.0	44.0	34.0	24.0
Cobalt (Co)	13.0	8.7	7.0	5.4	3.7
Copper (Cu)	34.0	24.0	19.0	15.0	9.0
Hafnium (Hf)	17.4	8.1	5.5	5.5	4.5
Iron (Fe)	3.28 *	2.27 *	1.79 *	1.32 *	0.84 *
Lanthanum (La)	43.0	32.0	27.0	23.0	18.0
Lead (Pb)	27.0	18.0	12.0	7.0	3.0
Lithium (Li)	58.0	38.0	28.0	22.0	15.0
Magnesium (Mg)	2.89 *	1.81 *	1.24 *	0.88 *	0.52 *
Manganese (Mn)	717	388	294	231	137
Nickel (Ni)	34.0	22.0	16.0	8.0	8.0
Potassium (K)	2.00 *	1.60 *	1.38 *	1.21 *	0.99 *
Scandium (Sc)	10.5	7.2	6.0	5.0	3.4
Sodium (Na)	1.51 *	1.00 *	0.74 *	0.55 *	0.33 *
Strontium (Sr)	503	490	207	130	106
Thorium (Th)	13.0	9.4	7.6	5.7	1.4
Titanium (Ti)	3,980	2,930	2,440	2,060	1,600
Uranium (U)	4.53	3.40	2.90	2.60	2.09
Vanadium (V)	145	92.0	68.0	52.0	38.0
Zinc (Zn)	111	103	70.0	51.0	34.0

Table 8. *Summary statistics for element concentrations in bed-sediment samples collected from streams in areas of sedimentary rocks of Paleozoic age, Yellowstone River Basin, 1974-79*

[*, concentration in percent; all other concentrations in milligrams per kilogram (mg/kg); <, less than. Statistics calculated from 1,249 samples]

Element	Concentration (mg/kg) for selected percentiles of analyses				
	95	75	50 (median)	25	5
Aluminum (Al)	7.37 *	5.64 *	4.54 *	3.65 *	2.08 *
Barium (Ba)	1,120	650	478	356	249
Beryllium (Be)	3.0	2.0	2.0	1.0	0.7
Calcium (Ca)	9.19 *	5.24 *	3.81 *	2.01 *	.71 *
Cerium (Ce)	93.0	65.0	51.0	39.0	22.4
Chromium (Cr)	180	65.0	46.0	35.0	22.0
Cobalt (Co)	22.0	9.2	7.0	5.3	3.0
Copper (Cu)	38.0	26.0	20.0	15.0	7.0
Hafnium (Hf)	17.0	10.1	7.5	5.5	3.9
Iron (Fe)	4.79 *	2.37 *	1.58 *	1.07 *	0.60 *
Lanthanum (La)	50.0	35.0	27.0	20.0	9.0
Lead (Pb)	23.0	13.0	8.0	5.0	3.0
Lithium (Li)	73.0	38.0	29.0	22.0	13.0
Magnesium (Mg)	5.35 *	3.08 *	2.06 *	1.25 *	0.62 *
Manganese (Mn)	936	550	387	283	132
Nickel (Ni)	43.0	21.0	15.0	8.0	8.0
Potassium (K)	2.59 *	1.76 *	1.51 *	1.26 *	0.86 *
Scandium (Sc)	15.4	7.8	6.0	4.5	2.7
Sodium (Na)	1.97 *	0.92 *	0.68 *	0.46 *	0.21 *
Strontium (Sr)	826	490	490	147	119
Thorium (Th)	15.8	9.7	7.4	5.6	2.8
Titanium (Ti)	4,910	3,390	2,820	2,150	1,170
Uranium (U)	4.45	2.98	2.46	2.09	1.50
Vanadium (V)	144	69.0	53.0	41.0	26.0
Zinc (Zn)	120	111	77.0	47.0	20.0

Table 9. *Summary statistics for element concentrations in bed-sediment samples collected from streams in areas of crystalline rocks of Precambrian age, in the Beartooth Mountains, Yellowstone River Basin, 1974-79*

[*, concentration in percent; all other concentrations in milligrams per kilogram (mg/kg); <, less than. Statistics calculated from 692 samples]

Element	Concentration (mg/kg) for selected percentiles of analyses				
	95	75	50 (median)	25	5
Aluminum (Al)	7.78 *	7.07 *	6.57 *	6.11 *	4.97 *
Barium (Ba)	1,400	957	680	460	246
Beryllium (Be)	3.0	2.0	2.0	1.0	0.7
Calcium (Ca)	4.18 *	3.04 *	2.20 *	1.60 *	0.98 *
Cerium (Ce)	166	93.0	73.0	58.0	37.6
Chromium (Cr)	644	232	140	89.0	53.0
Cobalt (Co)	36.2	23.3	15.9	11.4	6.4
Copper (Cu)	89.9	46.0	31.0	23.8	15.0
Hafnium (Hf)	20.8	10.3	7.1	5.2	3.5
Iron (Fe)	6.85 *	4.81 *	3.70 *	2.70 *	1.47 *
Lanthanum (La)	118	59.0	44.0	35.0	21.0
Lead (Pb)	44.5	21.0	14.0	9.0	3.0
Lithium (Li)	63.0	44.0	34.0	24.0	13.0
Magnesium (Mg)	4.72 *	2.09 *	1.53 *	1.07 *	0.61 *
Manganese (Mn)	1,240	926	729	586	334
Nickel (Ni)	180	62.0	36.0	23.0	8.0
Potassium (K)	2.28 *	1.75 *	1.39 *	1.11 *	0.69 *
Scandium (Sc)	21.9	15.6	11.8	9.4	6.5
Sodium (Na)	2.67 *	2.08 *	1.69 *	1.35 *	0.79 *
Strontium (Sr)	822	490	490	490	463
Thorium (Th)	42.9	18.0	12.4	9.2	5.8
Titanium (Ti)	5,930	4,260	3,460	2,850	1,990
Uranium (U)	44.8	12.3	4.40	2.80	1.68
Vanadium (V)	209	122	95.0	74.8	52.0
Zinc (Zn)	162	111	111	96.0	53.0

Table 10. *Summary statistics for element concentrations in bed-sediment samples collected from streams in areas of crystalline rocks of Precambrian age, outside of the Beartooth Mountains, Yellowstone River Basin, 1974-79*

[*, concentration in percent; all other concentrations in milligrams per kilogram (mg/kg); <, less than. Statistics calculated from 188 samples]

Element	Concentration (mg/kg) for selected percentiles of analyses				
	95	75	50 (median)	25	5
Aluminum (Al)	8.07 *	6.62 *	5.94 *	5.28 *	3.93 *
Barium (Ba)	1,290	758	658	514	280
Beryllium (Be)	3.0	2.0	2.0	1.0	1.0
Calcium (Ca)	5.18 *	2.76 *	1.59 *	1.14 *	0.67 *
Cerium (Ce)	143	101	77	60.0	38.0
Chromium (Cr)	225	85.0	52.5	39.0	25.0
Cobalt (Co)	20.8	12.4	9.0	7.0	4.6
Copper (Cu)	44.0	28.0	20.0	15.0	10.0
Hafnium (Hf)	24.0	13.8	6.8	5.5	4.3
Iron (Fe)	4.85 *	3.39 *	2.76 *	1.94 *	1.07 *
Lanthanum (La)	80.3	53.0	42.0	33.0	21.0
Lead (Pb)	27.0	18.2	13.0	9.0	3.0
Lithium (Li)	44.7	34.0	27.0	21.0	14.0
Magnesium (Mg)	3.72 *	1.99 *	1.30 *	0.73 *	.50 *
Manganese (Mn)	910	684	505	374	204
Nickel (Ni)	55.7	31.2	19.0	12.8	8.0
Potassium (K)	3.02 *	1.90 *	1.53 *	1.27 *	0.93 *
Scandium (Sc)	16.5	10.8	7.8	6.0	4.0
Sodium (Na)	2.21 *	1.71 *	1.21 *	0.66 *	0.30 *
Strontium (Sr)	931	490	490	200	116
Thorium (Th)	30.4	17.7	11.9	8.5	3.4
Titanium (Ti)	6,840	4,810	3,550	2,890	1,890
Uranium (U)	8.03	4.96	3.78	2.73	1.74
Vanadium (V)	146	95.5	72.0	54.0	39.4
Zinc (Zn)	122	111	74.5	52.8	32.7

Table 11. *Sediment-quality assessment values for selected elements, Yellowstone River Basin*

[HSSR, Hydrogeochemical and Stream Sediment Reconnaissance from the National Uranium Resource Evaluation (NURE); PEL, probable effect level; ERM, effects range median; mg/kg, milligrams per kilogram]

Element	Number of HSSR samples	PEL (mg/kg)	HSSR samples below PEL (percent)	ERM (mg/kg)	HSSR samples below ERM (percent)
Chromium (Cr)	12,635	90	78.5	370	98.2
Copper (Cu)	12,622	197	99.8	270	99.8
Lead (Pb)	12,622	91.3	99.8	218	99.9
Nickel (Ni)	12,622	36	85.7	51.6	93
Zinc (Zn)	12,546	315	99.7	410	99.8

SUMMARY

Retrospective analysis of element concentrations in bed-sediment samples was conducted for the Yellowstone River Basin NAWQA study unit. Element concentrations in samples collected during 1974-79 for the National Uranium Resource Evaluation (NURE) Program were statistically analyzed and summarized for 50 elements. Summary statistics, categorized by geologic setting or ecoregion, also were calculated for 25 elements used in the factor analysis. Baseline concentrations of elements were determined in bed-sediment samples from volcanic rocks of Quaternary age (Yellowstone Plateau), volcanic rocks of Cretaceous and Tertiary age (Absaroka volcanic field), sedimentary rocks of Tertiary age in the Wyoming Basin ecoregion, sedimentary rocks of Tertiary age outside of the Wyoming Basin ecoregion, sedimentary rocks of Cretaceous age, sedimentary rocks of Paleozoic age, crystalline rocks of Precambrian age in the Beartooth Mountains, and crystalline rocks of Precambrian age outside the Beartooth Mountains.

Factor analysis indicated three geochemically distinct types of source rocks: factor 1, basaltic rocks, factor 2, granitic rocks, and factor 3, carbonate rocks. Factor 1 correlated with scandium, iron, cobalt, vanadium, chromium, aluminum, nickel, manganese, copper, titanium, sodium, barium, strontium, and zinc. Scores for the basaltic-rocks factor were highest in samples collected from volcanic rocks of Cretaceous to Tertiary age (Absaroka volcanic field) and crystalline rocks of Precambrian age in the Beartooth Mountains. Factor 2 correlated with thorium, lanthanum, cerium, beryllium, hafnium, uranium, and potassium. Scores for the granitic-rocks factor were highest for volcanic rocks of Quaternary age (Yellowstone Plateau) and were intermediate for crystalline rocks of Precambrian age in and outside of the Beartooth Mountains, and sedimentary rocks of Tertiary age in the Wyoming Basin ecoregion. Factor 3 correlated positively with magnesium and calcium. Strontium had the third strongest positive correlation with the carbonate-rocks factor, and lead was negatively correlated. Scores for the carbonate-rocks factor were highest in samples collected from sedimentary rocks of Paleozoic age and volcanic rocks of Tertiary and Cretaceous age.

The use of factor analysis also revealed element associations that were not readily apparent from exploratory data analysis. For example, factor analysis indicated element concentrations in bed-sediment samples from sedimentary rocks of Tertiary age in the Wyoming Basin ecoregion are significantly different from concentrations in samples collected from the same type of rocks in the Northwestern Great Plains ecoregion. The factor analysis also indicated association of aluminum, barium, strontium, and sodium with period-4 elements in the basaltic-rocks factor that were not expected on the basis of either the concentrations of elements for rock types from the literature or from elemental properties.

A small percentage of the samples had chromium, copper, lead, nickel, or zinc concentrations that exceeded sediment-quality assessment values for the protection of aquatic life. The highest concentrations of chromium, copper, nickel, and zinc tended to be located in the western part of the study unit, in areas of crystalline rocks of Precambrian age and volcanic rocks of Tertiary and Cretaceous age.

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