Geochemistry of the Johnson River, Lake Clark National Park and Preserve, Alaska

Water-Resources Investigations Report 03–4252

Prepared in cooperation with the
NATIONAL PARK SERVICE

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Cover photograph: View of the Johnson River upstream from the gaging station. Photograph by Tim Brabets, U.S. Geological Survey, July 1999.

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

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By Timothy P. Brabets and James R. Riehle

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U.S. DEPARTMENT OF THE INTERIOR
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Multiply	by	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

In this report, temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\ (°C) + 32$$

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute mass per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter (µS/cm) at 25°C.

VERTICAL DATUM

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—A geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

The Johnson River Basin, located in Lake Clark National Park and Preserve, drains an area of 96 square miles. A private inholding in the upper part of the basin contains a gold deposit that may be developed in the future. To establish a natural baseline to compare potential effects on water quality if development were to occur, the upper part of the Johnson River Basin was studied from 1999 to 2001 as part of a cooperative study with the National Park Service.

Two basic rock types occur within the drainage basin of the study: the Jurassic Talkeetna Formation of interbedded volcanic and volcaniclastic rocks, and the slightly younger plutonic rocks of the Aleutian-Alaska Ranges batholith. The Johnson River gold prospect reflects widespread, secondary mineralization and alteration of the Talkeetna Formation. Metals found at the prospect proper are: arsenic, cadmium, copper, gold, iron, lead, mercury, molybdenum, selenium, silver, and zinc.

The Johnson River Prospect is located in the East Fork Ore Creek Basin, a 0.5 square mile watershed that is a tributary to the Johnson River. Water quality data from this stream reflect the mineralization of the basin and the highest concentrations of several trace elements and major ions of the water column were found in this stream. Presently, pH in this stream is normal, indicating that there is sufficient buffering capacity. At the Johnson River streamgage, which drains approximately 25 mi^2 including the East Fork Ore Creek, concentrations of these constituents are significantly lower, reflecting the runoff from Johnson Glacier and Double Glacier, which account for approximately 75 percent of the total discharge.

Streambed concentrations of cadmium, lead, and zinc from East Fork Ore Creek and its receiving stream, Ore Creek, typically exceed concentrations where sediment dwelling organisms would be affected. Similar to the water column chemistry, concentrations of these elements are lower at the Johnson River streamgage, reflecting the fine sediment input from the glacier streams draining Johnson Glacier and Double Glacier. The amount of organic carbon present in the study area is relatively low and most sites indicate that some degree of toxicity is present even though these basins do not contain mineralized areas.

Acid based accounting tests on rock samples in the study area indicate a neutralizing capacity in the Talkeetna Formation rocks. These results should be used with caution because similar tests were not done on rocks from narrow veins or faults that could have acid generating potential. In addition, based on field tests during the study, carbonate-bearing rocks in streambeds are armored by a carbonate-depleted shell and would not readily neutralize acidic water.

INTRODUCTION

The Johnson River is located in Lake Clark National Park and Preserve, on the west side of Cook Inlet, Alaska (fig. 1). Like many rivers and streams in the park, the Johnson River supports resident and anadromous fish populations. Coho salmon, chum salmon, and Dolly Varden char can all be found in the river. The intertidal estuary and mud flats near the mouth of the river are important to resident and migratory birds, especially shorebirds. Bald eagle and peregrine falcon nests are found along the Johnson River and the river valley supports the largest breeding population of trumpeter swans in western Cook Inlet.

In 1975, Resource Associates of Alaska, under contract to Cook Inlet Region, Incorporated (CIRI), an Alaska Native corporation, discovered a mineral prospect in the Johnson River Basin (fig. 2) (Steefel, 1987). In 1976, CIRI selected the land, including the mineral rights underlying the Johnson River Prospect, under the Alaska Native Claims

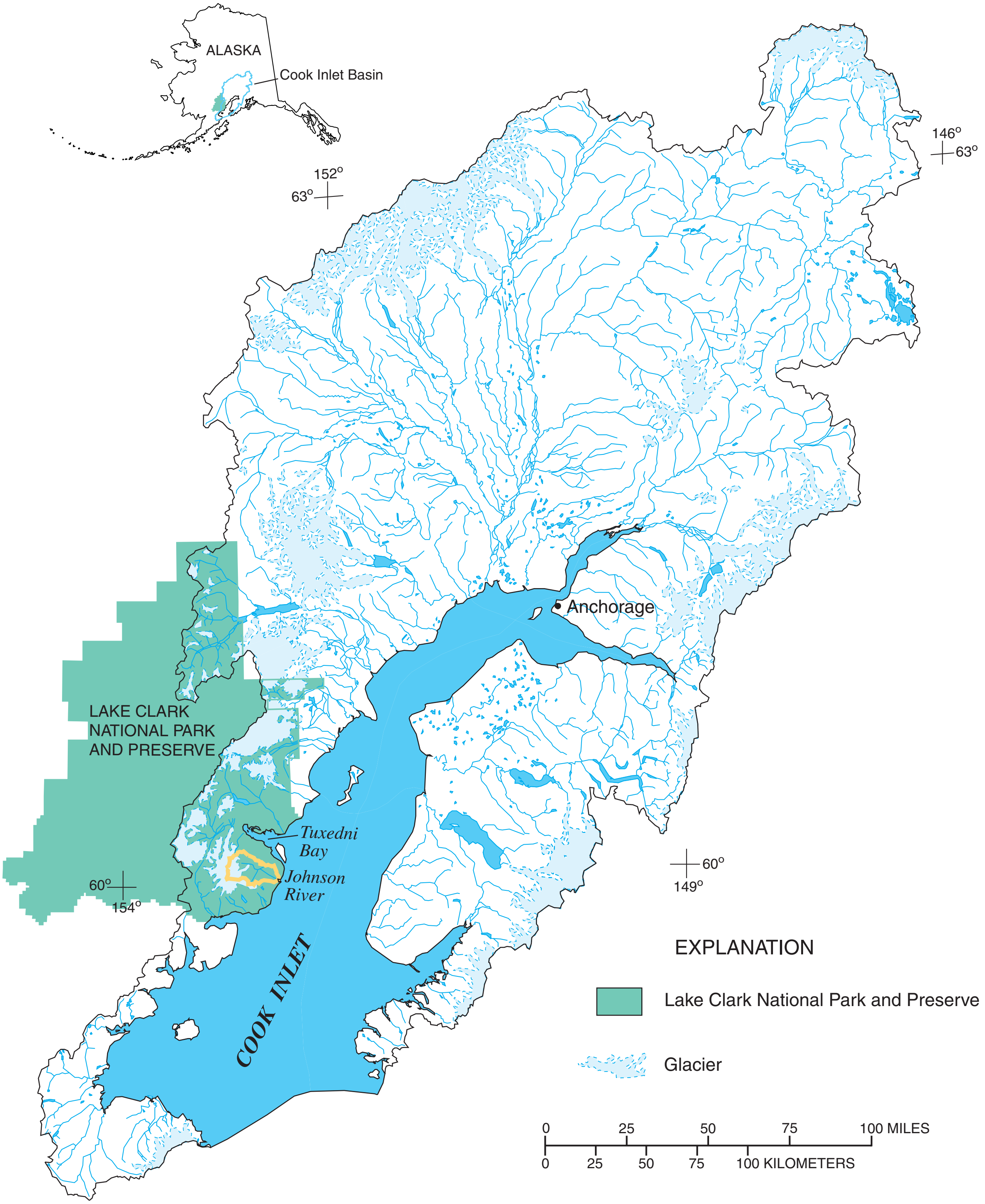


Figure 1. Location of Lake Clark National Park and Preserve, Johnson River and Cook Inlet Basin, Alaska.

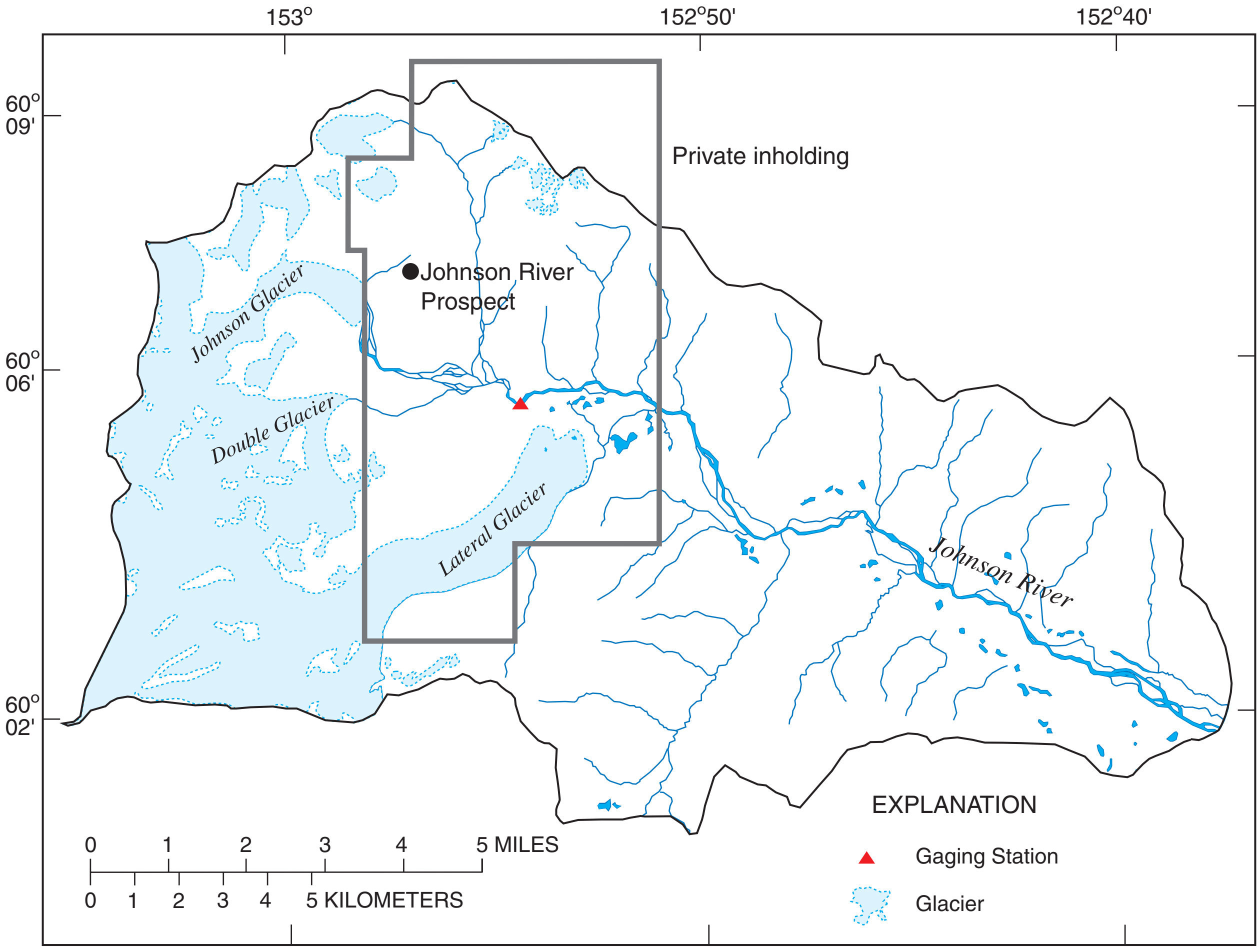


Figure 2. Location of Johnson River Prospect in the upper Johnson River Basin.

Settlement Act (ANCSA, 1971). This 33 mi^2 area of land became known as the “Johnson River Tracts.” In 1981, a joint-venture agreement was signed between CIRI and Anaconda Minerals Company to evaluate the mineral potential of the prospect. One drill hole intersected about 160 feet of ore, grading 0.59 ounces of gold per ton, 9.4 percent zinc, 2.8 percent lead, and 1.1 percent copper. Overall, Anaconda Minerals Company estimated 1-2 million tons of ore grading 0.27 ounces of gold per ton, 7 percent zinc, and lesser amounts of copper and lead (Steefel, 1987). Other metal-bearing minerals known to occur in the area have been documented by Steefel (1987) and Gray (1988) (table 1).

If the Johnson River Tracts were developed, the National Park Service is concerned about the effects of development on the water quality of the Johnson River. Weathering and breakdown of rocks in the natural environment usually takes place over an extended period of time; however, the breakdown process in physically and chemically treated tailings and wastes from mines is accelerated. If ore and waste rock

Table 1. Selected minerals present in the Johnson River Basin (modified from Steefel (1987), and Gray (1988))

Element	Symbol	Mineral associations
Arsenic	As	Possibly as arsenopyrite with iron
Cadmium	Cd	Probably dissolved in sphalerite
Copper	Cu	Chalcopyrite
Gold	Au	Native gold
Iron	Fe	Pyrite
Lead	Pb	Galena
Mercury	Hg	Several possible forms (sulfide, sulfate, chloride, or native mercury), most likely as either trace amounts of cinnabar or dissolved in sphalerite.
Molybdenum	Mo	Probably molybdenite
Selenium	Se	Typically occurs dissolved in sulfides, in gossans developed from sulfides, can also be adsorbed on surfaces of clays or iron-manganese oxides.
Silver	Ag	Possible native silver.
Zinc	Zn	Sphalerite

were kept near the mine site or near the Johnson River floodplain, the material could potentially increase the metal load and acidity of water in the Johnson River, resulting in acid mine drainage.

Purpose and Scope

This report summarizes the results of a cooperative study by the National Park Service (NPS) and the U.S. Geological Survey (USGS) during 1999 through 2001 to study the water quality of the Johnson River. The purpose of this study was to characterize the geochemistry of the Johnson River Prospect, to identify potential environmental hazards, and to determine baseline levels for selected water-quality constituents. The area of study is limited to the upper part of the Johnson River in the vicinity of the Johnson River Prospect (fig. 2).

Acknowledgements

The authors gratefully acknowledge the assistance of Cory Stephens and Peter Oswald of the U.S. Geological Survey with field work done in 2000. Additional resources were provided to the study from the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program, Cook Inlet Basin Study Unit. The authors gratefully appreciate Cook Inlet Region, Inc. for allowing access to corporation lands.

DESCRIPTION OF STUDY AREA

The Johnson River Basin, located on the west side of Cook Inlet in south central Alaska, drains an area of about 96 mi^2(fig. 2). Glaciers cover approximately 20 mi^2 of the entire basin. The topography of the watershed ranges from relatively steep in the upper part of the basin to relatively flat in the lower part of the basin. Precipitation is also variable. Mean annual precipitation is about 67 inches, but ranges from 70 inches in the headwaters to about 55 inches at the mouth at Cook Inlet. Snow accounts for about one-half the precipitation. The primary land cover is alpine tundra, and inceptisols are the primary soils. Vegetative cover and soils are generally discontinuous and thinly developed in the upper portion of the basin.

The study area, located upstream of the gaging station (site 52, fig. 3), is approximately 25 mi^2. The area includes the Johnson River Prospect, several small tributaries, and two glaciers, Johnson Glacier and Double Glacier that cover approximately 9 mi^2 of the study area. Only the small basins in the vicinity of the Johnson River Prospect, Ore Creek, and Kona Creek were studied. The Johnson River Prospect is located in the East Fork Ore Creek drainage basin (fig. 3).

METHODS OF DATA COLLECTION AND ANALYSIS

The primary factors that could affect the water quality in the Johnson River study area include the type of bedrock, occurrence of altered rock, and streamflow characteristics. For example, altered or mineralized rocks are important in geochemical studies because toxic metals and acids formed during weathering typically originate in these rocks. If metals and acids enter the stream, they may or may not be diluted, depending on the flow characteristics. Thus, efforts were made towards collecting and analyzing these types of data.

Geologic mapping of the study area was first done by Detterman and Hartsock (1966). Because the authors focused on the sedimentary rocks and their potential for hydrocarbons, the Johnson River Prospect was not studied or mapped in further detail. Additional geologic mapping and interpretation of the area was done by Detterman and Reed (1980). In addition to detailed geologic mapping, a cross section of the Johnson River Prospect was developed by Steefel (1987). The Johnson River Prospect is included in the summary work by Nokleberg and others (1994). Aerial photography obtained in 1995 provided additional information on the geology of the area for this study.

Field work was done in the summer of 2000 to enhance and build upon the previous geology studies. Thirty-eight study sites were selected to examine the geology (fig. 4). From these sites, 69 rock samples were collected and submitted for trace element analysis. Analytical procedures for trace elements are outlined in Baedecker (1987). Fourteen of the samples also were analyzed for major-element content for use in rock classification. The major-element content of the rocks was determined by x-ray fluorescence at the USGS laboratory in Lakewood, Colorado (Taggert and others, 1987).

Discharge data have been collected during open water periods (May through October) at one site located on the Johnson River since 1995 (fig. 3, site number 52, USGS station ID 15294700, Johnson River above Lateral Glacier near Tuxedni Bay, Alaska). These data provide a good overview of the flow characteristics of the Johnson River. In addition, discharge measurements were obtained at tributaries to the Johnson River located in the study area during 2000 to characterize their respective flow characteristics (table 2).

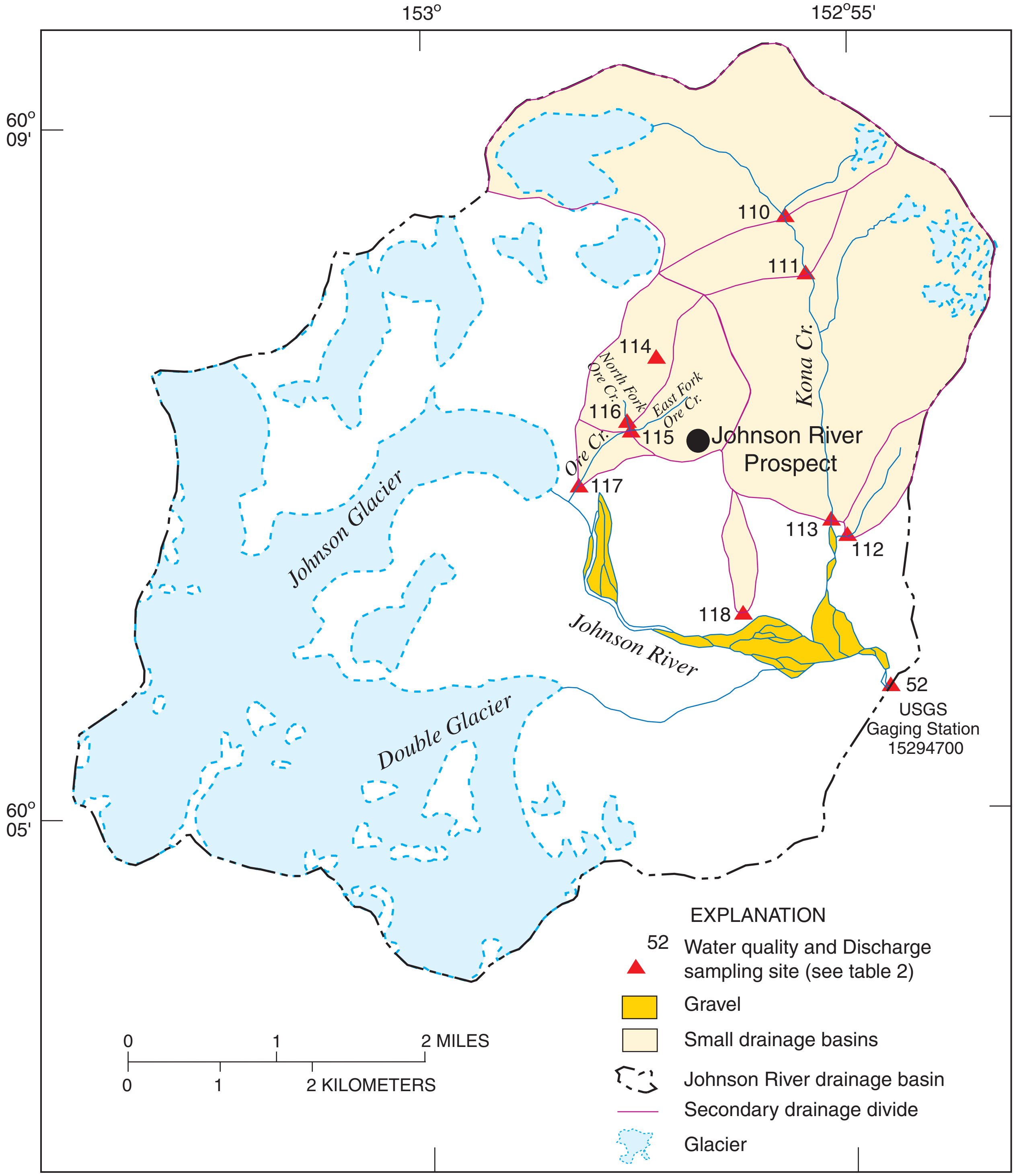


Figure 3. Locations of water quality and discharge measurement sites (see table 2 for station names).

Water samples were collected from the Johnson River at the gaging station (site number 52, fig. 3) from 1999-2001. These samples were collected over a range of discharge and provided a broad overview of the water quality of the Johnson River. Additional water samples were collected at nine sites located near the Johnson River Prospect during summer 2000 to determine the water-quality characteristics of these small streams and their relative contributions to the total discharge in the Johnson River (fig. 3, table 2).

Water samples were analyzed for major ions, dissolved solids, nutrients, trace elements, organic carbon, and sus-

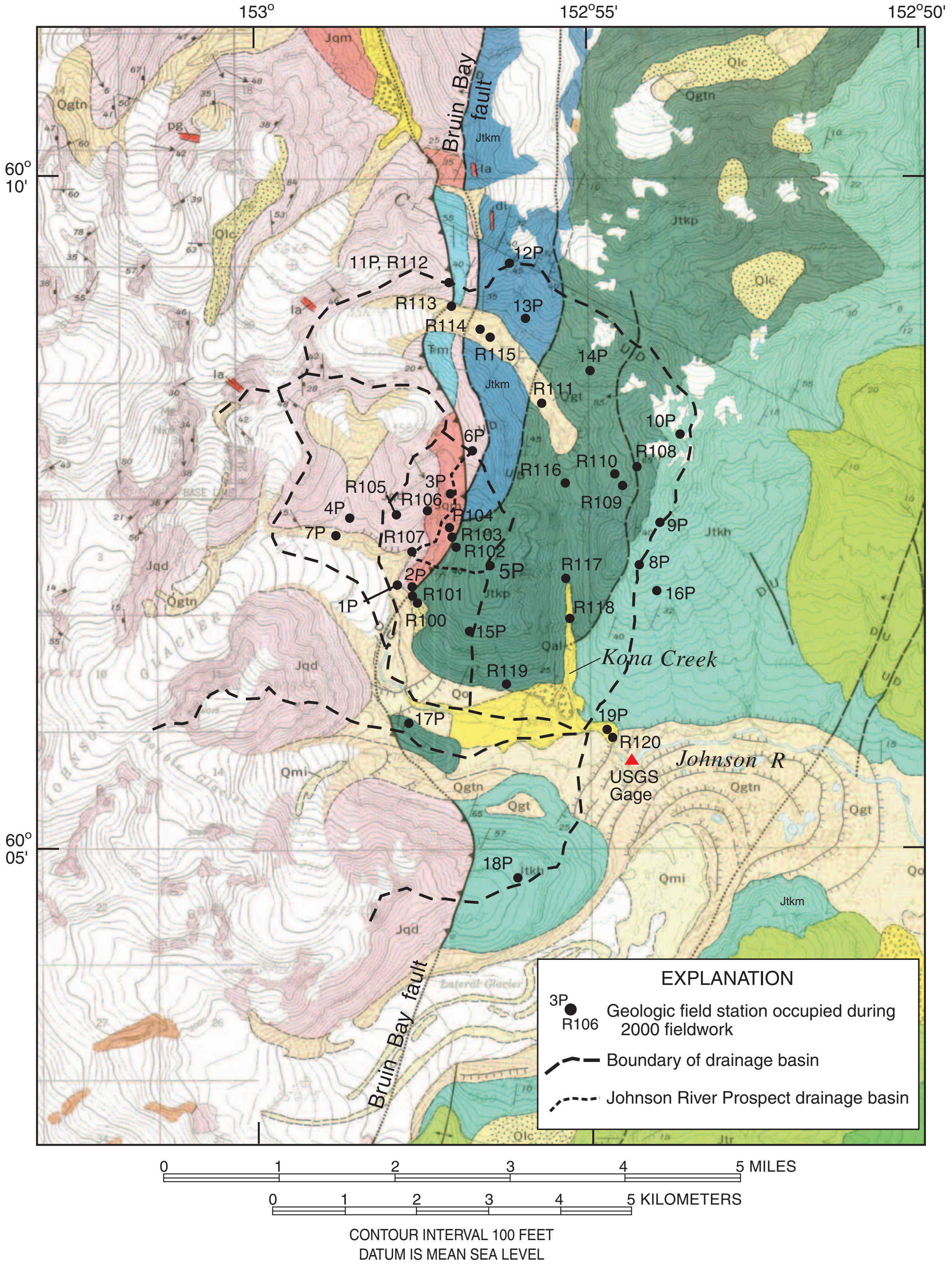
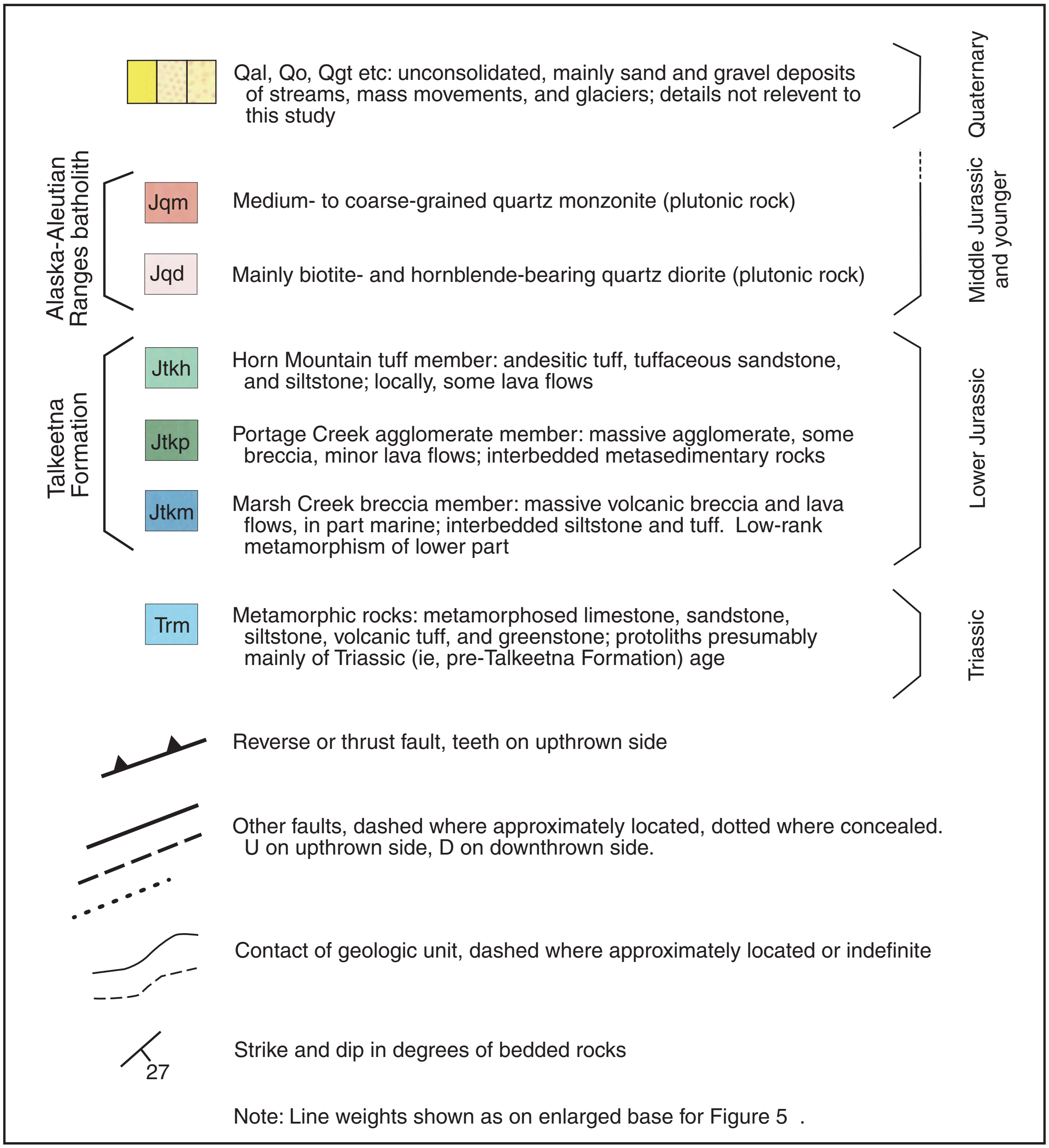


Figure 4. Locations of geologic field sites and geology map of the study area.

Explanation for the base geology map of the Johnson River area, Alaska (Detterman and Hartsock, 1966). Base used in Figures 4 and 5.



Group	Symbol	Description	Age
	🟨	Qal, Qo, Qgt etc: unconsolidated, mainly sand and gravel deposits of streams, mass movements, and glaciers; details not relevent to this study	Quaternary
Alaska-Aleutian Ranges batholith	Jqm	Medium- to coarse-grained quartz monzonite (plutonic rock)	Middle Jurassic and younger
	Jqd	Mainly biotite- and hornblende-bearing quartz diorite (plutonic rock)	
Talkeetna Formation	Jtkh	Horn Mountain tuff member: andesitic tuff, tuffaceous sandstone, and siltstone; locally, some lava flows	Lower Jurassic
	Jtkp	Portage Creek agglomerate member: massive agglomerate, some breccia, minor lava flows; interbedded metasedimentary rocks	
	Jtkm	Marsh Creek breccia member: massive volcanic breccia and lava flows, in part marine; interbedded siltstone and tuff. Low-rank metamorphism of lower part	
	Trm	Metamorphic rocks: metamorphosed limestone, sandstone, siltstone, volcanic tuff, and greenstone; protoliths presumably mainly of Triassic (ie, pre-Talkeetna Formation) age	Triassic

Reverse or thrust fault, teeth on upthrown side

Other faults, dashed where approximately located, dotted where concealed. U on upthrown side, D on downthrown side.

Contact of geologic unit, dashed where approximately located or indefinite

Strike and dip in degrees of bedded rocks

Note: Line weights shown as on enlarged base for Figure 5 .

pended-sediment. The field-collection and processing equipment used was made from Teflon, glass, or stainless steel to prevent sample contamination and to minimize analyte losses through adsorption. All sampling equipment was cleaned prior to use with a non-phosphate laboratory detergent, rinsed with distilled water, and rinsed with stream water just prior to sample collection. Depth-integrated water samples were collected across the river by using the equal-width-increment method (Edwards and Glysson, 1988) and processed onsite using methods and equipment described by Shelton (1994). Samples for organic-carbon analysis were collected separately by dipping a baked glass bottle in the centroid of flow. Samples to be analyzed for dissolved constituents were filtered either onsite or at the USGS office in Anchorage through 0.45 -*u*m capsule filters. Water samples were sent to the USGS National Water-Quality Laboratory in Lakewood, Colorado, for analysis using standard USGS analytical methods (Fishman and Friedman, 1989; Patton and Truitt, 1992; Fishman, 1993). Suspended-sediment samples were sent to the USGS Sediment Analy-

Table 2. Water-quality and discharge measurement sites in the Johnson River study area.

Site identifier[1] (figure 3)	Latitude/longitude or USGS station number	Sampling site	Drainage area (mi^2)
52	15294700	Johnson River above Lateral Glacier near Tuxedni Bay	24.8
110	60°08'26" 152°55'44"	Kona Creek 3 miles above mouth near Tuxedni Bay	2.3
111	60°08'03" 152°55'24"	Kona Creek 2.5 miles above mouth near Tuxedni Bay	2.7
112	60°06'35" 152°55'09"	Kona Creek tributary above Lateral Glacier near Tuxedni Bay	0.2
113	60°06'36" 152°55'14"	Kona Creek 0.8 miles above mouth near Tuxedni Bay	5.5
114	60°07'39" 152°57'07"	Unnamed Spring	
115	60°07'15" 152°57'28"	East Fork Ore Creek near mouth near Tuxedni Bay	0.5
116	60°07'13" 152°57'40"	North Fork Ore Creek near mouth near Tuxedni Bay	0.5
117	60°06'58" 152°58'14"	Ore Creek near mouth near Tuxedni Bay	1.1
118	60°06'09" 152°56'11"	Johnson River tributary above Lateral Glacier near Tuxedni Bay	0.1

[1] The Cook Inlet NAWQA study unit established a uniform numbering system for all surface water sites in the study basin. For a complete list of stations and numbers see http://alaska.usgs.gov/projects/Nawqa/water.sites.htm

sis Laboratory in Vancouver, Washington, for concentration and particle size analysis.

Streambed sediments were sampled at the gaging site and at the sites near the Johnson River Prospect. At each site, sediments were collected from the surface of the streambed at several depositional areas using Teflon tubes or Teflon coated spoons and composited in glass bowls (Shelton and Capel, 1994). This 'composite sample' was then sieved through a 0.063-mm Nylon sieve and analyzed for trace elements. About 250 mL of stream water was used for sieving the trace-element sample. Water included in the trace elements was decanted after very fine-grained sediments had settled. Arbogast (1990) describes laboratory procedures for processing streambed sediment samples for trace element analysis.

Since mining has yet to occur in the study area, there are no mined rock piles that could be studied to determine their neutralizing capacity or acid-generating capacity. Instead, eleven of the rock samples, representing different suites of minerals, were analyzed by acid-base accounting (ABA) techniques. ABA is a method developed in the 1960's and 1970's (Sobek and others, 1978) and is based on the assumption that drainage chemistry is a net result of reacting minerals and that the minerals that last longest and react fastest will determine long-term and overall chemistry. Samples were crushed, then soaked in strong acid to determine neutralizing capacity and analyzed for sulfur content to determine acid-generating capacity. In reality, the fastest reacting minerals often do not last long and thus affect only short-term chemistry. ABA simplifies this complexity to predict the outcome as "acidic", "near-neutral", or "alkaline" drainage based primarily on mineral balance (Morin and Hutt, 1997).

After the data were collected, checked, and compiled, data analysis was undertaken. Geologic data collected during 2000 were used to update the original Detterman and Hartsock (1966) map, and to determine the chemical composition of the Johnson River Prospect. Analyses of the rock samples were compared to the water-quality data to determine the effects of geology on water quality. Water quality changes were examined in a downstream direction from Ore Creek and Kona Creek to the Johnson River streamgage for dilution effects. Flow statistics from the Johnson River streamgage were analyzed and compared to flow values from the small tributaries near the Johnson River Prospect to determine their relative contribution to the total streamflow. ABA tests determined whether a particular rock type would be acidic or alkaline.

BEDROCK GEOLOGY OF THE JOHNSON RIVER STUDY AREA

Geologic Setting

The study area is part of the Peninsular Terrain, which is thought to have attached to mainland Alaska by the end of the Cretaceous Period 55-65 million years ago (Hillhouse and Coe, 1994). Late Paleozoic and Triassic, marine sedimentary and volcanic rocks are the oldest known rocks of the terrain. Although not well exposed in the vicinity of Johnson River (fig. 4), these Paleozoic and Triassic rocks crop out to the south of the study area where limestone, chert, and greenstone (metamorphosed oceanic basalt flows) were described by Detterman and Reed (1980).

These rocks are overlain by deposits of a major oceanic volcanic arc, the Talkeetna Formation of Lower to Middle Jurassic age (Detterman and Harstock, 1966, Detterman and Reed, 1980). Two major rocks units are exposed in the Johnson River study area: the Lower-to-Middle Jurassic Talkeetna Formation, and the Middle Jurassic and younger intrusive rocks of the Alaska-Aleutian Ranges batholith.

A major regional fault on the Alaska Peninsula, the Bruin Bay fault, trends north to south through the study area (fig. 4). The Bruin Bay fault is a thrust fault of vertical offset to the west and may also have had some left-lateral offset. The close succession of the intrusions to the volcanic-arc activity is interpreted (Reed and Lanphere, 1969 and 1973) to mean that the Jurassic part of the batholith is probably the intrusive equivalent of the Talkeetna Formation volcanic rocks, the geologically slightly younger ages reflecting slower cooling of the intrusions. Rather than a single fault, Detterman and Hartsock (1966) show multiple individual fault strands.

Modifications to the Geologic Map

Based on our 2000 field work, the Detterman and Hartsock (1966) geologic map was modified to show an intrusive body between Kona Creek and Ore Creek (fig. 5). The modified geologic map (fig. 5) shows other outlying domes that are separate from the main dome at the ground surface, but that may connect in the subsurface to the main body. Both Steefel (1987) and Gray (1988) refer to this body as “dacite” (intermediate-silica, fine-grained volcanic rock); although the two analyzed samples (R117-A and 10P-A) are low-silica dacite and low-silica rhyolite (table 3). A second modification to the Detterman and Hartsock (1966) map was the removal of the unit Trm (Triassic metamorphic rocks) that straddles Kona Creek at the Bruin Bay fault. Rocks examined at three stations (11P, R112, and R113, fig. 4) where Detterman and Hartsock (1966) mapped this unit could not be distinguished from typical Talkeetna Formation.

FLOW AND WATER-QUALITY CHARACTERISTICS OF THE JOHNSON RIVER

The following section is intended to provide background on the flow and water-quality characteristics of the Johnson River study area. Water-quality data dealing with the geochemistry of the Johnson River are provided in a later section of the report.

Discharge

Continuous discharge records for May through October are available from the streamgage at the Johnson River (station ID 15294700, site number 52, fig. 3) from 1995 through 2002 (URL: http://ak.waterdata.usgs.gov/nwis). Discharge records are not available during the winter due to logistical considerations. However, since the Johnson River is a glacial-fed river, flow is probably close to or equal to 0 ft^3/s during this period. The available flow records at the Johnson River indicate that daily discharge has ranged from 1.5 ft^3/s to 5,020 ft^3/s (fig. 6). High flows occur in late June or early July due to snowmelt. Ice melt from Johnson Glacier and Double Glacier sustain the flow during July and August. High flows may also occur during the summer due to rainfall. Based on a per unit runoff basis, runoff can ranged from 0 $ft^3/s/mi^2$ to 202 $ft^3/s/mi^2$. Monthly average discharge from May through October for 1995 to 2002 ranged from 183 ft^3/s in May to 719 ft^3/s in July (fig. 7). The highest instantaneous peak discharge for this period was 8,800 ft^3/s.

During late July 2000, measured discharge at the selected sites ranged from 0.04 ft^3/s to 123 ft^3/s (table 4). Discharges measured on July 24 at Ore Creek and Kona Creek were 24 ft^3/s and 123 ft^3/s, respectively. Based on the concurrent flow at the Johnson River streamgage, 603 ft^3/s, the flows at Ore Creek and Kona Creek represent 4 percent and 20 percent respectively, of the total flow measured at the streamgage. The remaining flow is derived from Johnson Glacier and Double Glacier. Flow conditions at this time probably represented average flow and the flows were not affected by rainfall or snowmelt. Depending on flow conditions, the relative contributions could change.

Specific Conductance

Specific conductance is determined by the type and concentration of ions in solution. It is a readily measured property that can be used to indicate the dissolved-solids or ion content in water. Values of conductance ranged from 32 to 105 µs/cm at the Johnson River streamgage (table 5). Higher values of specific conductance were measured at the lowest discharge, usually in May, reflecting contributions from groundwater or snowmelt. As discharges increase due to snow and ice melt, values of conductance were lower than the May values. In September, when there is no discharge from ice or snowmelt, values of conductance increased.

At the sites visited in 2000, conductance values showed some variation (table 4). Values measured at the two sites on Kona Creek above Kona Creek tributary ranged from 22- 26 µs/cm. The water from Kona Creek tributary (conductance

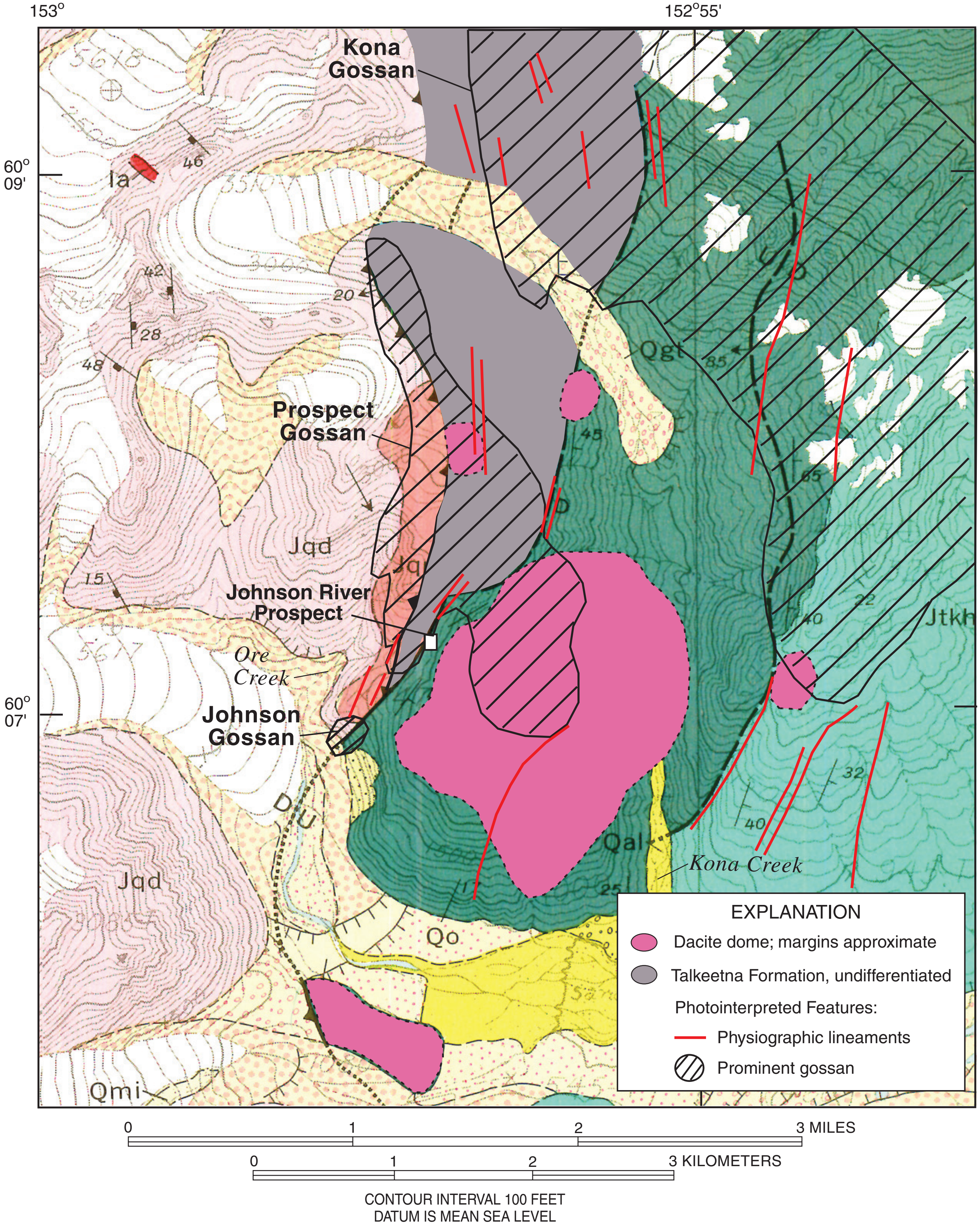


Figure 5. Geology of the study area (modified from Detterman and Hartsock, 1966).

Table 3. Major elements as oxides in percent of Johnson River rock samples.

[Analyses by USGS Denver laboratory. All by x-ray fluorescence (Taggart and others, 1987) except FeO by titration (Jackson and others, 1987), values shown are in percent]

Site identifier (figure 4)	Sample Description	Latitude	Longitude	Al_2O_3	CaO	Fe_2O_3	FeO	K_2O	MgO	MnO	Na_2O	P_2O_5	TiO_2	SiO_2	CO_2	H_2O+	H_2O-	Total	SiO_2 (normalized, volatile-free)	$K_20 + Na_2O$ (volatile-free)
R105-A	fine grained diorite or hornfels	60°07′31″	152°57′53″	19.2	9.93	6.53	6.61	0.18	4.51	0.22	2.93	0.26	1.11	48.1	0	0.9	0.1	100.58	48.3	3.12
R109	pillow lava flow	60°07′43″	152°54′27″	19.5	11.7	3.36	5.27	0.09	4.83	0.16	1.59	0.15	0.65	49.7	0.08	1.4	0.9	99.38	51.2	1.73
R111-B2	lava flow within tuff-breccia	60°08′22″	152°55′40″	17.8	5.75	3.99	5.65	0.57	5.47	0.26	4.37	0.16	0.68	48.2	2.19	4.1	0.5	99.69	51.9	5.32
R117-A	dacite plug	60°07′00″	152°55′19″	16	4.42	2.58	2.89	1.33	3.5	0.03	3.23	0.21	0.6	59.8	0.02	5.2	0.5	100.31	63.2	4.82
1P-A	granodiorite	60°07′00″	152°57′58″	12.2	2.44	0.86	0.64	1.14	0.4	0.04	3.64	0.13	0.18	77.4	0	0.5	0.1	99.67	78.1	4.83
3P-B	lava flow	60°07′42″	152°56′53″	12.2	2.11	1.49	4.75	0.39	2.02	0.19	3.37	0.16	0.6	69.2	1.4	2.6	0.1	100.58	71.7	3.90
4P-A	granodiorite w/ pyrite	60°07′30″	152°58′37″	15.4	5.26	2.38	1.99	0.29	1.19	0.08	3.22	0.2	0.42	67.9	0	0.7	0.1	99.13	69.1	3.57
4P-B	granodiorite	60°07′30″	152°58′37″	12.5	7.54	5.15	7.32	0.29	5.89	0.23	1.73	0.23	1.08	57.3	0	1.3	0.1	100.66	--	--
6P-G	mafic granodiorite	60°08′02″	152°56′48″	16.5	7.38	2.69	4.94	0.55	3.81	0.16	2.97	0.24	0.76	58	0	1.4	0.1	99.5	59.2	3.59
6P-H	felsic granodiorite	60°08′02″	152°56′48″	16.6	8.67	4.68	5.2	0.51	5.3	0.2	2.6	0.18	0.77	52.9	0	1.5	0.1	99.21	54.2	3.19
9P-J	lava flow	60°07′28″	152°54′04″	19.6	11.5	4.32	4.94	0.28	4.47	0.15	1.79	0.17	0.71	49.1	0.47	1.6	0.9	100	50.6	2.13
10P-A	dacite plug	60°08′05″	152°53′39″	13.6	1.15	3.02	0.96	3.34	2.11	0.04	3.83	0.16	0.44	68	0.46	1.8	0.3	99.21	70.4	7.42
10P-E	mafic dike	60°08′05″	152°53′57″	19.6	11	6.09	3.4	0.17	5.26	0.16	1.79	0.17	0.73	46.9	0.16	2.3	1.5	99.23	49.2	2.06
14P-D	mafic dike	60°08′34″	152°54′56″	17.6	4.08	3.79	4.49	1.32	4.56	0.16	3.56	0.2	0.69	54.4	0.55	3.5	0.4	99.3	57.4	5.14

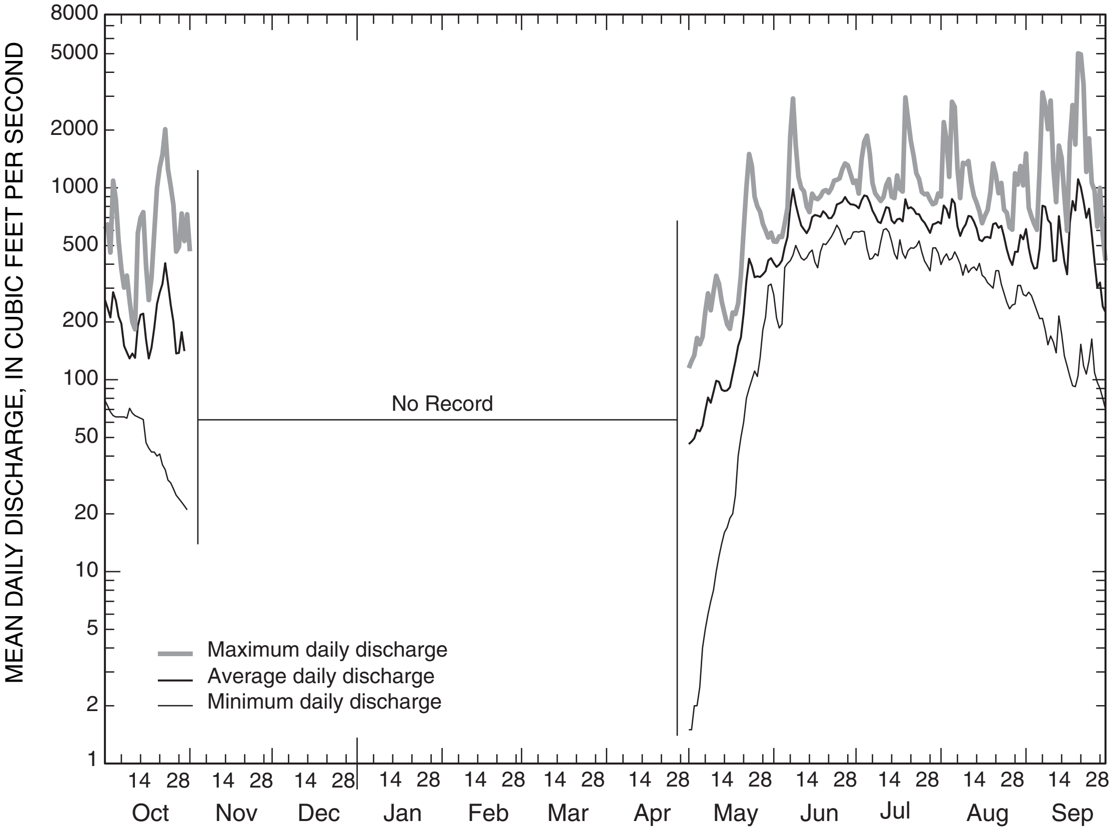


Figure 6. Discharge hydrograph of the Johnson River above Lateral Glacier near Tuxendi Bay, Alaska, 1995-2002.

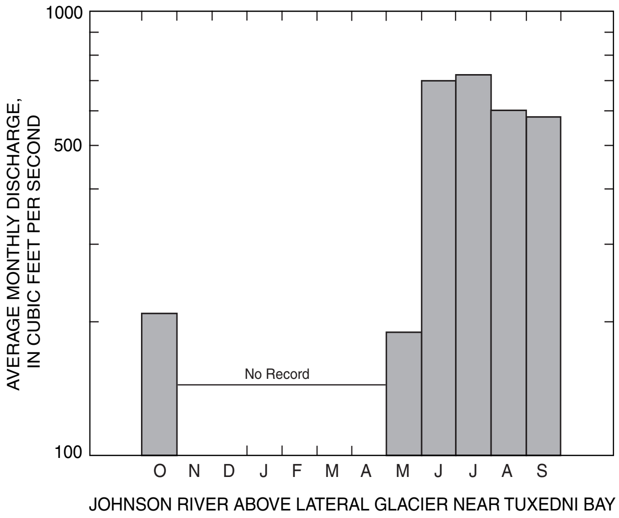


Figure 7. Average monthly discharge for the Johnson River above Lateral Glacier near Tuxedni Bay, 1995-2002.

of 111 µs/cm) elevated the conductance at the site near the mouth of Kona Creek (40 µs/cm). At the Ore Creek sites, values of conductance were consistent and ranged from 78-80 µs/cm. The highest conductance value measured was from the unnamed spring in the North Fork Ore Creek watershed (227µs/cm).

pH

The pH of water is a measure of its hydrogen-ion activity and can range from less than zero (very acidic) to 14 (very alkaline) standard units. The pH of river water not affected by contamination is typically between 6.5 and 8.0 standard units (Hem, 1985) and for fish growth and survival, the pH should remain in the 6.5 - 9.0 standard unit range. Values of pH at the Johnson River streamgage ranged from 6.9 to 7.9 for the period of sampling. Similar values were found at the other sites measured in 2000. (tables 4-5).

Water Temperature

Water temperature determines the amount of oxygen water can contain when at equilibrium with the atmosphere and it also controls the metabolic rates of fish and their rates of growth. Ranges in water temperature at the Johnson River were highly seasonal (tables 4-5). Measured water temperatures were the coldest in May (0.0 ^{o}C, 0.2 ^{o}C, and

Table 4. Discharge and physical properties measured at selected sites in the Johnson River study area.

[ft^3/s, cubic feet per second, *us*/cm, microsiemens per centimeter at 25 degrees Celsius]

Site identifier (figure 3)	Station Name	Date	Discharge (ft^3/s)	Specific Conductance (µs/cm)	Dissolved Oxygen (mg/L)	Water Temperature (°C)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)
110	Kona Creek 3 miles above mouth	7-26	56	26	13.0	2.0	6.7	5
111	Kona Creek 2.5 miles above mouth	7-26	67	22	13.0	3.4	7.4	6
112	Kona Creek tributary	7-27	2.3	111	13.0	4.5	7.2	32
113	Kona Creek 0.8 miles above mouth	7-24	123	40	12.8	3.9	7.5	9
115	East Fork Ore Creek near mouth	7-25	16	80	13.2	2.6	6.8	6
116	North Fork Ore Creek near mouth	7-25	7.8	78	13.1	3.1	7.5	29
117	Ore Creek near mouth	7-24	24	78	13.3	3.5	7.2	18
118	Johnson River tributary	7-27	0.04	46	10.0	9.8	7.3	16
114	Unnamed Spring	7-25	--	227	--	4.8	7.9	95

Table 5. Discharge, physical properties, and suspended sediment measured at Johnson River above Lateral Glacier near Tuxedni Bay, Alaska (site 52).

[ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; mg/L, milligrams per liter; °C, degree Celsius;]

Date	Discharge (ft^3/s)	Unit Discharge ($ft^3/s/mi^2$)	Specific Conductance (*us*/cm)	Dissolved Oxygen (mg/L)	Water Temperature (°C)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Suspended sediment (mg/L)
5-17-99	20.0	0.8	69	13.7	0.0	7.1	15	5
6-10-99	602	24.3	57	13.1	2.5	7.6	16	174
6-30-99	580	23.4	45	--	6.0	7.6	14	64
7-21-99	627	25.3	37	13.2	5.0	7.8	--	72
8-6-99	2460	99.2	32	12.0	3.0	7.9	12	882
8-24-99	521	21.0	41	11.9	6.7	7.0	12	33
9-16-99	451	18.2	55	14.2	2.8	7.1	15	13
10-7-99	200	8.1	78	12.7	4.3	7.5	21	2
5-9-00	45.0	1.8	105	15.2	0.2	7.2	15	13
6-15-00	497	20.0	64	15.3	2.1	7.0	14	22
7-26-00	603	24.3	42	13.2	3.0	7.1	12	47
8-16-00	439	17.7	42	13.6	3.8	7.2	13	60
9-18-00	89.0	3.6	87	12.4	2.2	7.5	19	4
5-23-01	174	7.0	93	14.2	1.2	7.2	18	25
6-26-01	1220	49.2	45	12.8	2.5	7.2	12	118
8-1-01	827	33.3	38	12.9	5.8	7.1	10	75
9-3-01	693	27.9	46	11.5	4.3	7.2	12	16
9-27-01	280	11.3	58	13.3	3.3	6.9	14	5

1.2 °C), reflecting the beginning of snowmelt. By June, water temperatures had risen to 2.0 °C or higher. From June, temperatures varied, ranging from 3.0 °C to 6.7 °C. By mid-to-late September, water temperatures had cooled to 3.3 °C or lower.

At other sites visited in the summer of 2000, water temperatures ranged from 2.0 to 9.8 °C (table 4). The highest water temperatures were found at the unnamed spring, and at tributaries to Kona Creek and the Johnson River (site numbers 112 and 118). Since discharge was relatively low at these two sites, water temperature was likely influenced by air temperature. Water temperature at the sites on Kona Creek and Ore Creek was similar to the water temperature at the Johnson River gage.

Dissolved Oxygen

The dissolved-oxygen concentration in a stream is controlled by several factors, including water temperature, air temperature and pressure, hydraulic characteristics of the stream, photosynthetic or respiratory activity of stream biota, and the quantity of organic matter present. Salmon and other fish require well-oxygenated water at every stage in their life, but young fish are more susceptible to oxygen deficiencies than adult fish. Dissolved oxygen concentrations at the Johnson River ranged from 11.9 to 15.3 mg/L. and from 10.0 to 13.3 mg/L at other sites visited in the summer of 2000 (tables 4-5). Measured concentrations of dissolved oxygen were sufficient to support fish.

Alkalinity

Alkalinity is a measure of the capacity of the substances dissolved in water to neutralize acid. In most natural waters, alkalinity is produced mainly by bicarbonate and carbonate (Hem, 1985), which are ions formed when carbon dioxide or carbonate rocks dissolve in water. Alkalinity concentrations (reported as equivalent concentrations of calcium carbonate ($CaCO_3$)) for the Johnson River ranged from 12 to 21 mg/L (table 5). These alkalinity concentrations indicate that water in the Johnson River has a low buffering capacity and limited availability of inorganic carbon (Hem, 1985). Also, given the range of pH values of the Johnson River, all of the alkalinity can be assigned to dissolved bicarbonate (Hem, 1985).

At the sites visited in the summer of 2000, alkalinity concentrations ranged from 5 mg/L to 95 mg/L (table 4). Sites in the Kona Creek Basin had relatively low alkalinity (less than 10 mg/L) while the small tributary to Kona Creek, North Fork Ore Creek, and the unnamed spring had relatively high values of alkalinity (29 mg/L).

Nutrients

In aquatic ecosystems, nitrogen commonly occurs in the following forms: nitrate (NO_3), nitrite (NO_2), and ammonium (NH_4). In the laboratory, ammonium is analyzed as ammonia (NH_3); thus nitrogen concentrations are reported as total and dissolved ammonia plus organic nitrogen (often called Kjeldahl nitrogen), dissolved ammonia, dissolved nitrite plus nitrate, and dissolved nitrite. Nitrite readily oxidizes to nitrate in natural water; therefore nitrate is generally more abundant than nitrite in water bodies. Total ammonia plus organic nitrogen concentrations represent the ammonium and organic nitrogen compounds in solution and associated with colloidal material. Nitrite and nitrate are oxidized forms of inorganic nitrogen that together make up most of the dissolved nitrogen in well-aerated streams.

All concentrations of the various nitrogen forms were less than 1.0 mg/L (table 6). Due to its toxicity to freshwater aquatic life, the U.S. Environmental Protection Agency (USEPA, 1976) suggests a limitation of 0.02 mg/L of ammonia (as un-ionized ammonia, NH_3) for waters to be suitable for fish propagation. Based on the values of pH, water temperature, and ammonia in the Johnson River (table 5) the un-ionized ammonia, was calculated as 0.2 percent of dissolved ammonia (interpolated from table 3, United States Environmental Protection Agency, 1976, p. 11). Thus, even at the maximum concentration of dissolved ammonia (0.056 mg/L), the concentration of un-ionized ammonia is well below the recommended criteria for fish propagation.

Phosphorus is an essential element in the growth of plants and animals. It occurs as organically bound phosphorus or as phosphate. High concentrations of phosphorus in water are not considered to be toxic to human or aquatic life. However, its presence can stimulate the growth of algae in lakes and streams. It was first noted by Sawyer (1947) that nuisance algal conditions could be expected in lakes when concentrations of inorganic nitrogen ($NH_3 + NO_2 + NO_3$ as N) as low as 0.3 mg/L are present in conjunction with as much as 0.01 mg/L of phosphorus.

Phosphorus concentrations are reported as total phosphorus, dissolved phosphorus, and dissolved orthophosphate. The orthophosphate ion, PO_4, is the most important form of phosphorus because it is directly available for metabolic use by aquatic plants. Concentrations of total phosphorus and dissolved phosphorus were less than 0.6 mg/L for all samples collected at the Johnson River (table 6).

Table 6. Nutrient and organic carbon concentrations measured in 18 water samples collected from Johnson River above Lateral Glacier near Tuxedni Bay, Alaska (site 52).

[all values in mg/L; $NO_2 + NO_3$, nitrite plus nitrate, E, estimated, <, less than].

Date	Nitrogen nitrite, dissolved	Nitrogen $NO_2 + NO_3$, dissolved	Nitrogen ammonia, dissolved	Nitrogen ammonia + organic, total	Nitrogen ammonia + organic, dissolved	Phosphorus, total	Phosphorus, dissolved	Phosphorus ortho, dissolved	Organic carbon, dissolved	Organic carbon, particulate
5-17-99	0.001	0.300	0.004	E0.09	<0.10	0.006	<0.004	0.002	0.30	<0.20
6-10-99	0.001	0.130	0.003	<0.10	<0.10	0.089	<0.004	0.001	0.20	<0.20
6-30-99	0.001	0.048	0.003	<0.10	E0.06	0.045	<0.004	0.003	<0.10	<0.20
7-21-99	0.001	0.014	<0.002	0.11	0.15	0.058	<0.004	0.001	0.30	0.20
8-6-99	0.001	0.031	0.002	0.11	E0.05	0.594	<0.004	0.001	0.20	<0.20
8-24-99	<0.001	0.023	0.005	0.12	E0.05	0.021	<0.004	<0.001	0.20	<0.20
9-16-99	<0.001	0.030	0.007	<0.10	<0.10	0.016	<0.004	<0.001	0.39	<0.20
10-7-99	<0.001	0.076	<0.002	E0.07	E0.05	E0.004	<0.006	0.008	0.36	<0.20
5-9-00	0.001	0.302	<0.002	E0.09	<0.10	0.038	<0.006	<0.001	0.90	<0.20
6-15-00	<0.001	0.160	0.056	<0.10	E0.05	0.013	<0.006	<0.001	<0.33	<0.20
7-26-00	0.001	0.032	<0.002	<0.10	<0.10	0.032	<0.006	0.002	<0.33	<0.20
8-16-00	0.001	0.047	0.011	<0.10	<0.10	0.029	<0.006	0.003	<0.33	<0.20
9-18-00	<0.001	0.030	0.004	<0.10	<0.10	<0.008	E0.003	<0.001	E0.24	<0.20
5-23-01	<0.001	0.181	<0.002	<0.08	<0.10	0.017	<0.006	<0.007	E0.19	0.10
6-26-01	<0.001	0.079	0.002	E0.06	<0.10	0.059	<0.006	<0.007	<0.30	0.30
8-1-01	<0.001	0.025	<0.002	<0.08	<0.10	0.042	<0.006	<0.007	<0.30	0.40
9-3-01	<0.001	E0.023	E0.005	<0.08	E0.06	0.012	<0.006	<0.007	<0.30	0.10
9-27-01	0.001	0.024	0.002	<0.08	<0.10	0.006	<0.006	<0.007	<0.30	<0.10

Organic Carbon

Dissolved organic carbon (DOC) is commonly a major pool of organic matter in ecosystems. DOC is defined as organic carbon in the filtrate (dissolved and colloidal phases) that has passed through a 0.45 -µm pore-size filter. Generally, DOC is in greater abundance than particulate organic carbon (POC), accounting for approximately 90 percent of the total organic carbon of most waters (Aiken and Cotsaris, 1995). In the aquatic system, the sources of DOC can be categorized as (1) allochthonous - entering the system from a terrestrial source, and (2) autochthonous - being derived from biota (algae, bacteria, macrophytes) growing in the water body.

At the Johnson River, concentrations of DOC ranged from less than 0.10 mg/L to 0.90 mg/L. All POC concentrations were less than 1.0 mg/L (table 6). The relatively low concentrations of DOC are likely related to the lack of well developed soil within the study area.

Suspended sediment

Suspended-sediment concentrations of the Johnson River ranged from 2 mg/L to 882 mg/L (table 5). Low concentrations of suspended sediment were usually noted at low flow or before snow melt begins. The Johnson River is relatively clear during these times. Greater suspended sediment concentrations are present in the river during high flows. Suspended sediment concentrations show a good correlation (R = 0.74) with discharges greater than 200 ft^3/s (fig. 8).

GEOCHEMISTRY AND WATER QUALITY OF THE STUDY AREA

Chemical Compositions and Classification of Rocks

Only one of the analyzed rock samples of the Talkeetna Formation is true andesite (fig. 9); most fall near the basalt-basaltic andesite boundary. The dome and its related tuffs and lava flows are low-silica dacite or low-silica rhyolite. Rock samples from the batholith range in silica content from basalt to rhyolite (fig. 9) and only two samples would be considered andesites. The older lava flows and tuffs are mafic (basaltic andesite) while the dome and equivalent tuffs--the youngest rocks and deposits of the Talkeetna arc—are the most silicic.

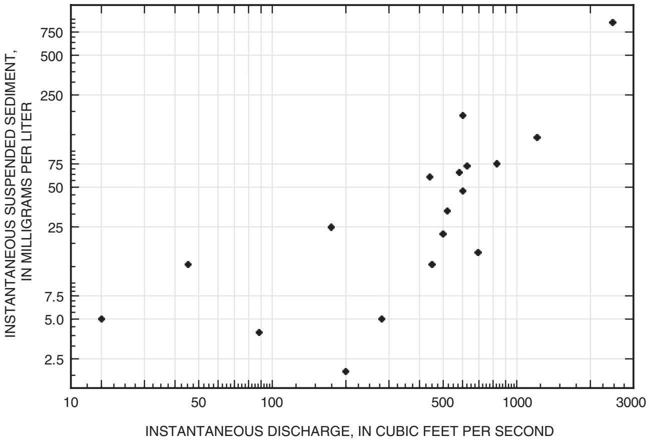


Figure 8. Relation between instantaneous discharge and instantaneous suspended sediment for the Johnson River above Lateral Glacier near Tuxedni Bay, Alaska, 1999-2001.

Mineralization at the Johnson River Prospect

The Johnson River Prospect is located within several square miles of orange-stained rocks, referred to as the Prospect and Kona gossans (fig. 5), developed in the Talkeetna Formation adjacent to and up to 2 mi east of the Bruin Bay

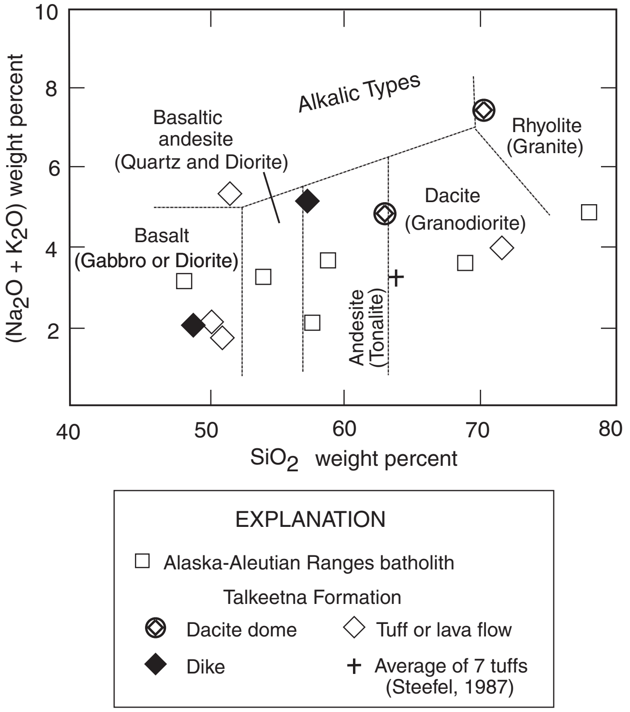


Figure 9. Classification of chemically analyzed samples of the Talkeetna Formation and of the Alaska-Aleutian Ranges batholith (Names of coarse-grained equivalents given in parenthesis).

fault (fig. 5). Upper-plate plutonic rocks of the batholith immediately west of the Bruin Bay fault also show gossan colors (fig. 10). “Gossan” is iron oxide formed during weathering oxidation of pyrite (iron sulfide). Oxidation of sulfur forms acid, which in turn increases the solubility of metals in surface waters. The major implication of gossans to geologists is that gossan rock has undergone enrichment of sulfur and also metals. Mineralization is divided by Steefel (1987) into two stages: an early anhydrite-pyrite-sericite-chlorite-calcite stage, and a later stage during which quartz, gold, barite, and sulfides were added. Metal minerals of the later stage--native gold, sphalerite, chalcopyrite, silver, and galena—are zoned with zinc and silver occurring near the top, followed next by a copper, gold, lead zone, and finally by a copper and pyrite zone.

Alteration at the Johnson River Prospect and Elsewhere in the Study Area

Alteration associated with the Johnson River Prospect mineralization and with the more extensive Prospect gossan is not easily identified in detail. Alteration minerals are typically very fine, occur in trace amounts, and comprise several mineral groups that each vary widely in chemical composition and environmental implications. Sericitic alteration is characterized by quartz, pyrite, and sericite (a potassium mica) and typically occurs at veins which were pathways (fractures) for acidic fluids that added sulfur and removed alkalis from the altered rock (table 7).

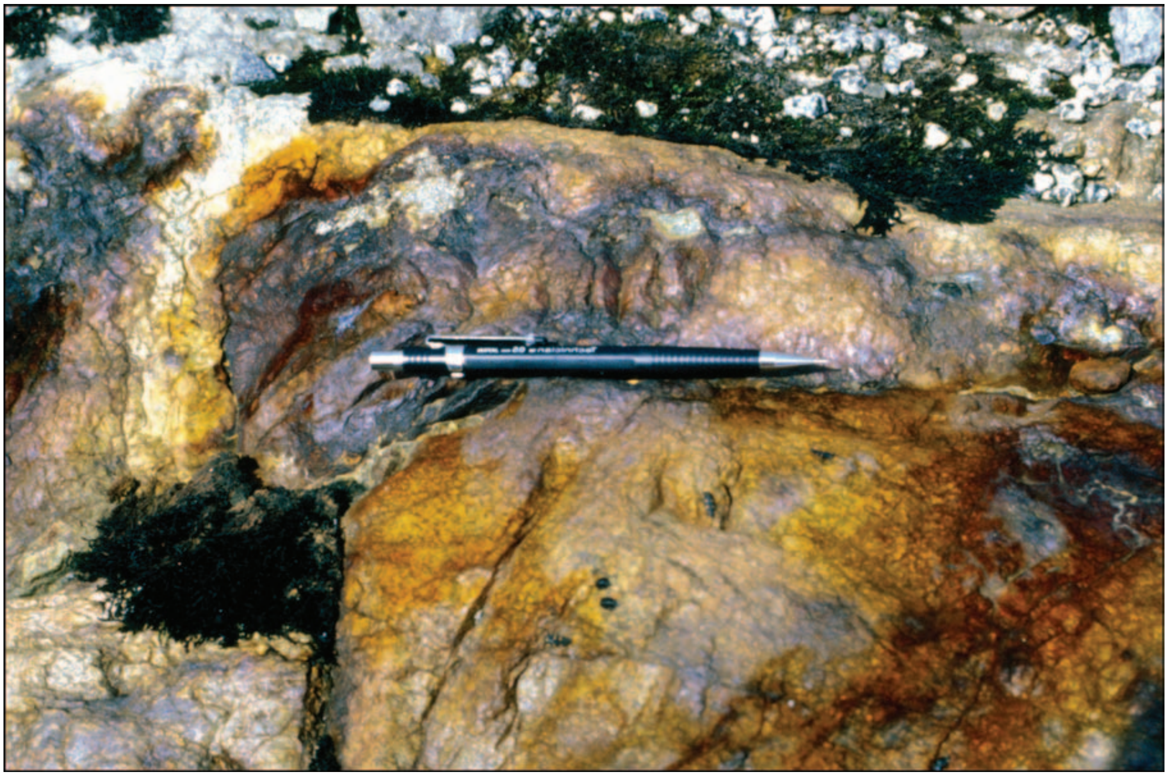
Pyrite is a common crustal mineral and its significance is dependent on the other minerals present with it. At the Johnson River Prospect, pyrite provided the iron that was later oxidized to create the striking color gossan on both sides of the Bruin Bay fault. A gossan typically involves secondary permeability (fractures and faults), which allows for later incursion of oxygenated ground water. In the case of intensive gossans, iron was probably added to the original rock, potentially along with other metals of economic interest. The orange color means that much of the pyrite has already been oxidized and cannot further contribute to acidity. The uncertainty, however, is how much unoxidized pyrite remains beneath the oxidized rock surface, awaiting exposure by landslides or human activity. Sulfur content of the rocks is one measure of this potential. A number of analyzed samples of the Talkeetna Formation were high in sulfur (analyses available at USGS office). This supports the likelihood that unoxidized Talkeetna Formation rocks in the subsurface have moderate to high pyrite contents.

Discussion of Geochemical Data

Major-element analyses (table 3) provide a basis for classification of igneous rocks and have been previously discussed. Rock samples analyzed for minor elements were grouped according to rock type and the averages for each rock category were calculated (data available at USGS office). Rock samples from the fault-fracture-controlled mineralization at the Johnson River Prospect contained high amounts of gold, mercury, silver, arsenic, cadmium, copper, molybdenum, lead, zinc, and selenium. These include the same metals (gold, silver, copper, lead and zinc) noted by Steefel (1987) and Gray (1988). Molybdenum is not mentioned by Steefel, and it does not occur in significant concentrations in our samples. Mercury and arsenic are associated worldwide in shallow hot-springs deposits or commonly occur in trace amounts together with cadmium and selenium in a variety of precious- and base-metal deposits, especially those formed as veins with quartz or calcite (Rose and others, 1979; Levinson, 1974). Johnson River Prospect samples are also elevated in carbon dioxide and sulfur, indicative of calcite, sulfides, or anhydrite dissolution.

Non-mineralized samples from the Talkeetna Formation were compared with those from the Prospect and Kona gossans. Gossan samples are generally much higher in mercury, arsenic, cadmium, and zinc, and slightly higher in copper, manganese, molybdenum, lead (one sample), and selenium. The gossan Talkeetna Formation is also higher in carbon dioxide and sulfur. This suite of elevated elements is essentially identical to that of the Johnson River Prospect, suggesting that the broad areas of the Kona gossan in the Talkeetna Formation to the north and east of the Prospect drainage were formed by similar processes, such as, a combination of magmatic heat, sulfur, and seawater convecting through permeable deposits above and adjacent to intrusives.

Sulfur content of gossan samples varies widely, reflecting both variable sulfur addition during mineralization as well as variable degree of oxidation of pyrite during subsequent weathering and consequent loss of sulfur from the rock. In general, sulfur in the rock samples is not extremely high, and the highest values are found in rock samples immediately adjacent to the Johnson River Prospect (Prospect Gossan). Sulfur in this area may not occur as pyrite, but as anhydrite, in which sulfur is already in its most oxidized state. However, future disturbance of gossan areas such as natural landslides, faulting in earthquakes, or human activity could expose higher levels of sulfur assuming that unoxidized pyrite is more abundant beneath the present weathering zone.



A section of the vein system at the Johnson River Prospect, that has much greater abundance of oxidized metals, which yield the bright orange stain (rust and other hydrated iron oxides). The entire region of the prospect shows such orange staining (a "gossan"), indicating pervasive enrichment, though at lower levels than the prospect proper, in iron, sulfur, and other metals.

Secondary veins (white) can be seen clearly cutting fault-breccia pieces of Talkeetna Formation (dark gray) at the Johnson River Prospect. Very little oxidation of sulfides has occurred as indicated by the lack of orange staining. This may be because the rock surface was only recently exposed and has not yet weathered, or because the secondary vein minerals are chiefly carbonates and silicates and do not include many sulfides.

Figure 10. Photographs of the Johnson River Prospect gossan and secondary veins.

Table 7. Alteration minerals of the Johnson River Prospect and associated gossans in the nearby Talkeetna Formation and batholith (identified by Gray, 1988).

Subtype	Occurrence
	Sericitic alteration: acidic fluids, addition of sulfur
Pyrite	Low levels in Talkeetna Formation, including dacite dome; responsible for gossan
Quartz-sericitic-pyrite	Veins/fractures in gossan areas of Talkeetna Formation; intensive at Johnson River Prospect where fault controlled
Anhydrite-chlorite-pyrite	Intensive at Johnson River Prospect where fault controlled
	Propylitic alteration: breakdown of plagioclase, addition of water and carbon dioxide
Chlorite-calcite (epidote)	Pervasive and low levels throughout Talkeetna Formation
Zeolite	Low levels, especially in porous silica-rich tuffs of Talkeetna Formation

Carbonate in the rocks provides the neutralizing capacity to affect the potential acidity generated by pyrite and sulfur. Calcite is the most soluble of the common carbonate minerals and was detected frequently during the fieldwork by applying hydrochloric acid to rocks. Calcite found in batholith rocks is confined to minor fractures and is not abundant. Carbonate xenoliths in batholith rocks derived from Triassic or Permian limestones are known to occur in the geologic column elsewhere on the Alaska Peninsula, but none were identified during this study nor reported by Detterman and Hartsock (1966). There is, however, an abundant amount of calcite in both lavas and volcaniclastic rocks of the Talkeetna Formation from the analyses of thin sections from the rock samples (analyses available at USGS office).

Discussion of Water-Quality Data

The water samples collected for this study have approximately the same anion and cation content (tables 8 and 9). At the Johnson River gage, calcium is the dominant cation while bicarbonate is the dominant anion (fig. 11). Samples from Kona Creek and Kona Creek tributary indicate the same type of cation/anion relation. In the Ore Creek Basin, there are differences that reflect the geology of the watershed. Calcium is the dominant cation and sulfate is the dominant anion in East Fork Ore Creek, which drains the Johnson River Prospect (fig. 11). The high sulfate reflects the elevated amounts of sulfur found in the Johnson River Prospect. North Fork Ore Creek and the unnamed spring adjacent to the Johnson River Prospect, however, have characteristics similar to the Kona Creek and Johnson River gage sites - calcium is the dominant cation and bicarbonate the dominant anion (fig. 11), reflecting the relatively low amounts of sulfur found in rock samples from these areas. Water from the North Fork Ore Creek has a dilution affect on the water of East Fork Ore Creek, which is indicated by the approximately equal percentage of the anions sulfate and bicarbonate found at the mouth of Ore Creek.

Water samples from the Johnson River gage site were analyzed for 23 trace elements, both in the dissolved phase and total content (appendix 1). These samples cover a range of discharge (20 ft^3/s to 2,460 ft^3/s) for 1999-2001. Most of these same elements, though only in the dissolved phase, were analyzed from water samples collected from the sites visited during summer 2000 (table 10).

At the Johnson River gage site, concentrations of about one-half the trace elements analyzed were less than 5.0 µg/L (appendix 1). At the other sites sampled in 2000, concentrations of 9 trace elements were less than 1.0 µg/L (table 10). In comparing the concentrations of the trace elements to published or known values and with standards that have been established for the protection of aquatic life, concentrations of all trace elements were within the normal ranges and did not exceed standards for protection of aquatic life (Smith and Huyck, 1999).

There were some notable characteristics of the trace element data from the water samples. The highest concentrations of several dissolved trace elements (aluminum, cadmium, copper, lead, manganese, and zinc) were found at East Fork Ore Creek, which drains the Johnson River Prospect, reflecting the mineralization of the basin. At Ore Creek, concentrations of these elements were lower, due to the dilution effect from North Fork Ore Creek. At the Johnson River gage site, concentrations of these elements were further diluted, reflecting the additional runoff from Johnson Glacier, Double Glacier, and Kona Creek. In addition, three trace elements (total aluminum, total iron, and total manganese) showed a strong correlation with suspended sediment that suggest these three elements are adsorbed onto the sediment (fig. 12).

Streambed sediments of the Johnson River at the gage site and at seven other sites in the study area were collected and analyzed for 39 trace elements (appendix 2). The highest concentrations of several trace elements (arsenic,

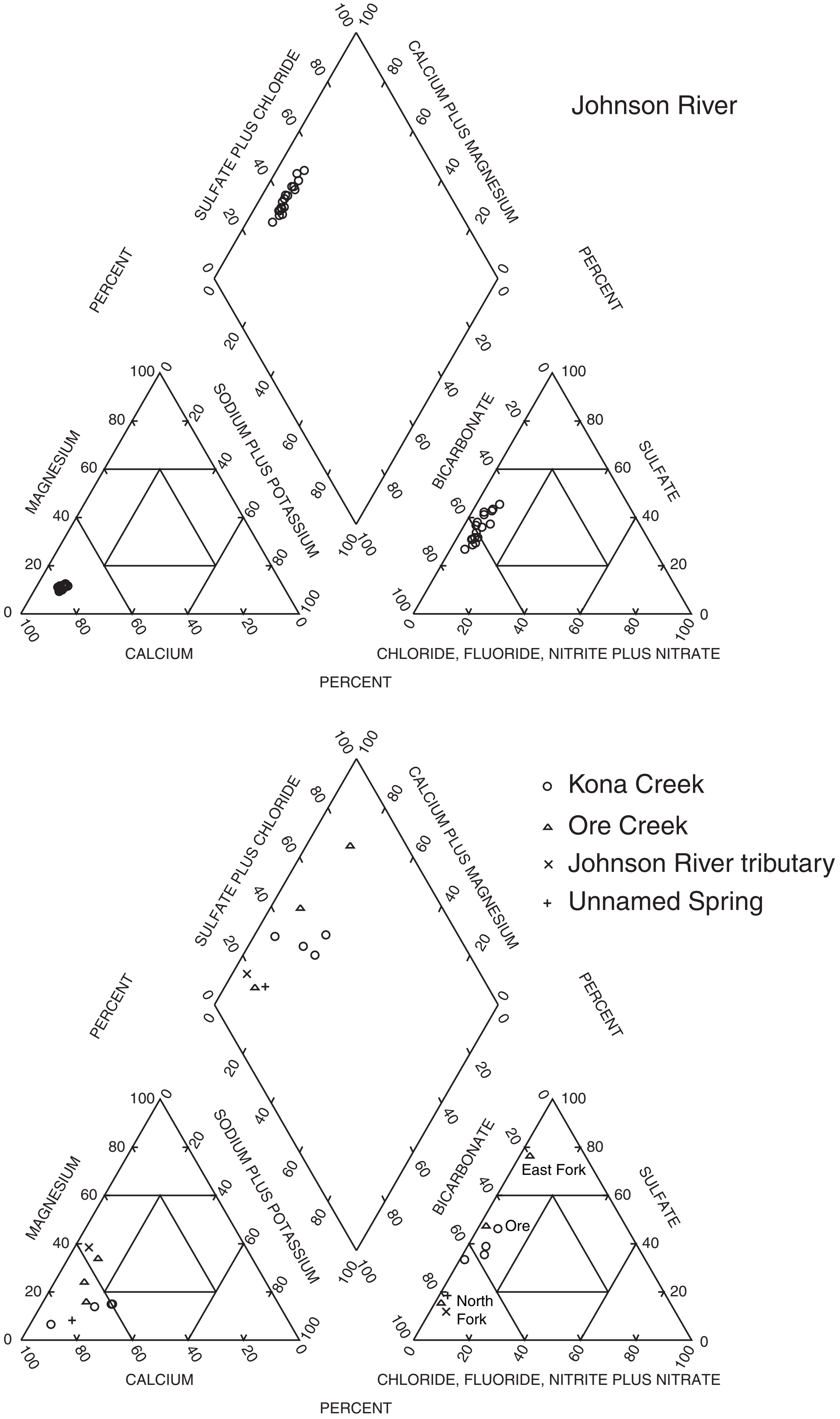


Figure 11. Trilinear diagrams of water samples from the Johnson River Basin.

Table 8. Major dissolved inorganic constituents measured in 18 water samples collected from Johnson River above Lateral Glacier near Tuxedni Bay, Alaska (site 52).

[all values in mg/L, E, estimated]

Date	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Silica	Dissolved Solids
5-17-99	9.5	0.92	1.3	0.18	18	12.0	1.0	4.2	42
6-10-99	8.1	0.73	0.9	0.27	17	8.4	0.7	3.2	41
6-30-99	6.8	0.62	0.8	0.30	16	6.4	0.5	2.6	51
7-21-99	5.3	0.43	0.6	0.22	--	5.2	0.3	1.8	27
8-6-99	5.4	0.37	0.5	0.35	12	3.7	<0.1	1.8	26
8-24-99	6.6	0.52	0.7	0.29	15	5.8	0.3	2.3	23
9-16-99	7.8	0.64	0.8	0.28	18	8.8	<0.3	2.7	34
10-7-99	11.2	0.98	1.1	0.35	26	13.5	0.6	4.4	46
5-9-00	15.0	1.24	2.5	E0.20	26	17.9	1.7	5.6	68
6-15-00	8.6	0.80	1.1	0.32	18	9.9	1.4	3.5	36
7-26-00	5.9	0.52	0.7	0.27	16	5.6	0.6	2.3	24
8-16-00	6.5	1.23	0.7	0.40	17	6.6	0.5	2.0	28
9-18-00	12.0	0.90	1.3	0.46	25	15.6	0.8	3.8	50
5-23-01	13.8	1.04	1.8	0.31	23	17.8	2.0	4.7	44
6-26-01	6.4	0.58	0.9	0.27	16	5.9	0.7	2.7	23
8-01-01	5.3	0.45	0.6	0.40	13	5.3	0.5	2.0	20
9-3-01	6.7	0.54	0.7	0.21	16	7.0	0.5	2.4	20
9-27-01	8.7	0.72	0.9	0.24	18	10.8	0.5	3.2	34

Table 9. Major dissolved inorganic constituents measured in water samples collected from sites in the Johnson River study area, July 2000.

[all values in mg/L; E, estimated]

Site identifier (figure 3)	Sampling site	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Silica
115	East Fork Ore Creek	9.4	1.3	0.9	<0.2	8	24	0.8	3.5
114	Unnamed Spring	29	12	1.6	0.3	124	14	5.0	5.1
116	North Fork Ore Creek	8.7	3.2	1.0	<0.2	38	5.5	0.5	3.7
117	Ore Creek	9.9	2.2	1.0	<0.2	23	17	0.6	3.9
118	Johnson River tributary	6.7	0.4	0.6	<0.2	21	3.9	0.4	2.9
110	Kona Creek 3 miles above mouth	2.8	0.4	0.6	<0.2	6	4.7	0.4	2.1
111	Kona Creek 2.5 miles above mouth	2.9	0.4	1.8	<0.2	8	4.5	0.5	2.2
112	Kona Creek tributary	19	0.9	1.0	0.4	42	17	0.6	4.6
113	Kona Creek 0.8 miles above mouth	4.9	0.6	0.8	<0.2	12	5.9	0.8	2.8

Table 10. Dissolved trace element concentrations measured in water samples collected from sites in the Johnson River study area, July 2000.

[all values in *ug*/L; E, estimated; M, presence verified, but not qantified]

Site identifier (figure 3)	Sampling site	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium
115	East Fork Ore Creek	40	<1.0	<1	13	<1.0	<12	3.4
114	Unnamed Spring	25	<1.0	3	45	<1.0	57	<1.0
116	North Fork Ore Creek	24	<1.0	1	23	<1.0	32	<1.0
117	Ore Creek	47	<1.0	E1	20	<1.0	24	1.5
118	Johnson River tributary	27	<1.0	<1	1.8	<1.0	E7.3	<1.0
110	Kona Creek 3 miles above mouth	28	<1.0	<1	7.9	<1.0	E8.6	<1.0
111	Kona Creek 2.5 miles above mouth	24	<1.0	<1	9.1	<1.0	E9.0	<1.0
112	Kona Creek tributary	5.3	<1.0	<1	1.0	<1.0	22	<1.0
113	Kona Creek 0.8 miles above mouth	31	<1.0	<1	7.3	<1.0	E8.7	<1.0

Site identifier (figure 3)	Sampling site	Chromium	Cobalt	Copper	Iron	Lead	Lithium	Manganese
115	East Fork Ore Creek	<0.8	<1.0	1.6	<10	1.6	M	28
114	Unnamed Spring	<0.8	<1.0	<1.0	<10	<1.0	4	<1.0
116	North Fork Ore Creek	<0.8	<1.0	<1.0	<10	<1.0	1	<1.0
117	Ore Creek	<0.8	<1.0	<1.0	E6.7	<1.0	1	14
118	Johnson River tributary	<0.8	<1.0	<1.0	<10	<1.0	M	<1.0
110	Kona Creek 3 miles above mouth	<0.8	<1.0	<1.0	<10	<1.0	<1	1.6
111	Kona Creek 2.5 miles above mouth	<0.8	<1.0	<1.0	<10	<1.0	<1	1.3
112	Kona Creek tributary	<0.8	<1.0	<1.0	<10	<1.0	M	<1.0
113	Kona Creek 0.8 miles above mouth	<0.8	<1.0	<1.0	<10	<1.0	<1	2.0

Site identifier (figure 3)	Sampling site	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Vanadium	Zinc
115	East Fork Ore Creek	<1.0	<1.0	<1	<1.0	39	<0.9	<1	687
114	Unnamed Spring	1.7	<1.0	<1	<1.0	72	<0.9	<1	6.5
116	North Fork Ore Creek	<1.0	<1.0	<1	<1.0	18	<0.9	<1	5.2
117	Ore Creek	<1.0	<1.0	<1	<1.0	33	<0.9	<1	303
118	Johnson River tributary	<1.0	<1.0	<1	<1.0	7.8	<0.9	<1	4.1
110	Kona Creek 3 miles above mouth	<1.0	<1.0	<1	<1.0	8.5	<0.9	<1	6.1
111	Kona Creek 2.5 miles above mouth	<1.0	<1.0	<1	<1.0	9.1	<0.9	<1	6.1
112	Kona Creek tributary	<1.0	<1.0	<1	<1.0	16	<0.9	<1	<1.0
113	Kona Creek 0.8 miles above mouth	<1.0	<1.0	<1	<1.0	10	<0.9	<1	9.0

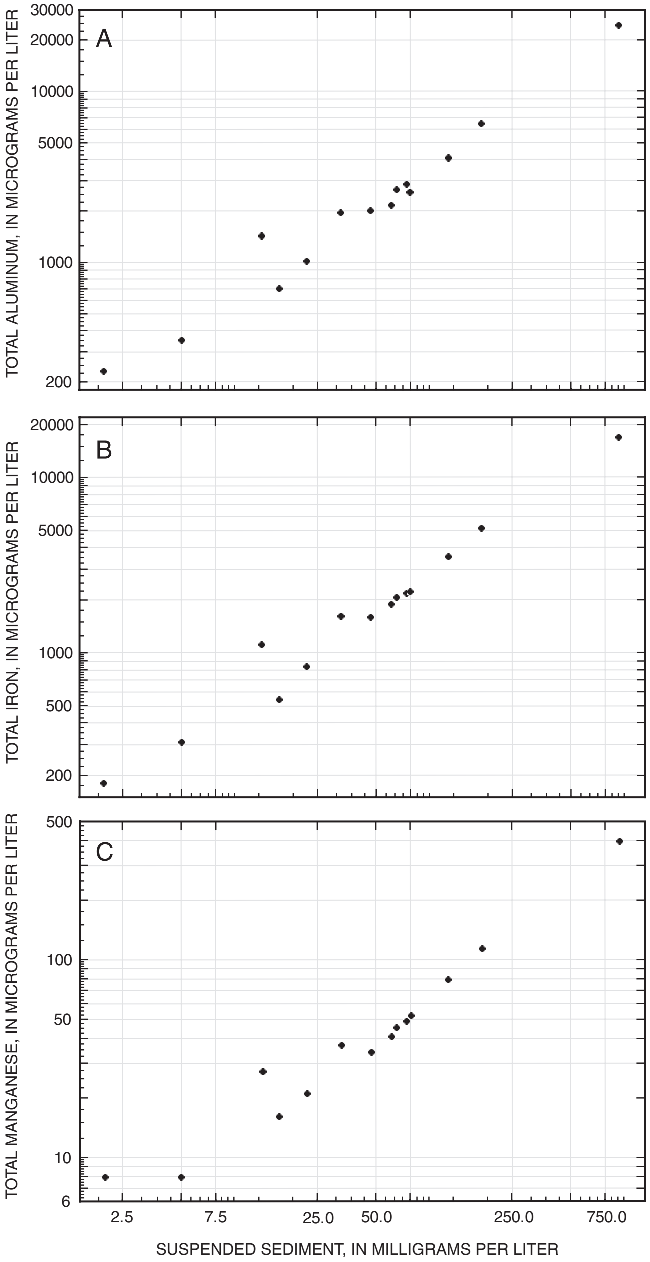


Figure 12. Relation between (A) total aluminum, (B) total iron, and (C) total magnesium and suspended sediment at Johnson River above Lateral Glacier near Tuxedni Bay, Alaska.

barium, cadmium, copper, lead, selenium, and zinc) were found in East Ore Creek and to a lesser extent, Ore Creek, reflecting the mineralization of the Johnson River Prospect. Concentrations of these trace elements were substantially lower at the most downstream site of the study area, the Johnson River gage. This suggests that discharge from Kona Creek, Johnson Glacier, and Double Glacier transport fine sediment that mixes with the sediment from Ore Creek.

The focus in the literature on criteria for streambed sediments has been limited to nine trace elements: arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc. Trace-element concentrations in the streambed sediments were compared with those of previous studies (table 11). Gilliom and others (1998) determined national median concentrations (in micrograms per gram, dry weight) for these elements. As part of the NAWQA program, a NAWQA data base has been established where users may retrieve water-quality data from other NAWQA study units based on criteria such as land use. From this data base, trace element data for basins listed as “mined” were retrieved and the median concentration values determined. The Canadian Council of Ministers of the Environment (1999) has established guidelines for some trace elements in unsieved streambed sediment. These guidelines use two assessment values: a lower value, called the “interim freshwater sediment quality guideline” (ISQG), is the concentration below which adverse effects are expected to occur rarely and the upper value, called the “probable effect level” (PEL), is the concentration above which adverse effects are expected to occur frequently. Because trace-element samples for the NAWQA program are from sediments finer than 0.063 mm where concentrations tend to be greatest, comparisons with the Canadian guidelines may overestimate the effects on aquatic organisms (Deacon and Stephens, 1998). However, it was felt that the PEL would be useful for comparative purposes when applied to the finer than 0.063 mm size fraction sediment samples analyzed for this study.

MacDonald and others (2000) established sediment quality guidelines (SQGs) for seven trace elements and Van Derveer and Canton (1997) established guidelines for selenium. These guidelines use the following two concentrations for a given trace element: the threshold effect concentration (TEC) and the probable effect concentration (PEC) and assume a one-percent organic carbon concentration. The TEC is the concentration below which sediment-dwelling organisms are unlikely to be adversely affected, and the PEC is the concentration above which toxicity is likely. In addition, MacDonald and others (2000) developed a Mean PEC Quotient (table 12) which is the toxicity of the combined trace element concentrations. This value is determined by summing the concentrations of all the trace elements analyzed and dividing by the number of elements. MacDonald and others found that sediments with mean PEC quotients of less than 0.5 accurately predicted the absence of toxicity in 83 percent of the samples they examined. Mean PEC quotients greater than 0.5 accurately predicted toxicity in 85 percent of the samples.

Comparison of the concentrations of the bed sediments of the nine trace elements with median values from Gilliom and others (1998) and the NAWQA data base

Table 11. Concentrations of selected trace elements in streambed sediments from various studies.

[values in micrograms per gram; --; no data]

Trace element	Gilliom and others (1998)[1]	NAWQA database[2]	Interim Freshwater Sediment Quality Guideline (ISQG)[3]	Probable Effect Level[3] (PEL)	Threshold Effect Concentration (TEC)[4]	Probable Effect Concentration (PEC)[4]	East Fork Ore Creek	Ore Creek
Arsenic	6.4	13.0	5.9	17.0	9.8	33.0	64	44
Cadmium	0.4	0.9	0.6	3.5	0.99	5.0	4.3	4.6
Chromium	62	68.5	37.3	90	43.4	111	14	23
Copper	26	36	35.7	197	31.6	149	76	92
Lead	24	41.5	35.0	91.3	35.8	128	230	180
Mercury	0.06	0.08	0.17	0.49	0.18	1.06	0.93	0.28
Nickel	25	38	--	--	22.7	48.6	4.0	8.0
Selenium	0.7	0.8	--	--	[5]2.5	[5]4.0	2.6	1.2
Zinc	110	235	123	315	121	459	1000	1800

[1] Median values

[2] Median values among mined sites

[3] Canadian Council of Ministers of the Environment (1995)

[4] MacDonald and others (2000)

[5] VanDerveer and Canton (1997)

(http://water.usgs.gov/nawqa/data, accessed July, 2002) indicated that with the exception of chromium and nickel, concentrations of trace elements at East Fork Ore Creek and Ore Creek exceeded the median values (table 11). Concentrations of arsenic, copper, and mercury from the Kona Creek sites and the Johnson River gage sites also exceeded these median values (tables 11). Concentrations of cadmium, lead, and zinc from East Fork Ore Creek and Ore Creek exceeded the ISQG limits. PEL concentrations of arsenic, cadmium, lead, mercury, and zinc were exceeded only at East Fork Ore Creek and Ore Creek. There was some variation in TEC levels. TEC levels of arsenic and copper were exceeded at all sites and TEC levels of cadmium, lead, selenium, and zinc were exceeded only at East Fork Ore Creek and Ore Creek. Finally, only concentrations of arsenic, lead, and zinc at East Fork Ore Creek and Ore Creek exceeded the PEC (table 11).

Comparison of the concentrations of the trace elements with the percent organic carbon and PEC quotient offer some insights about the bioavailability of these elements (table 12). The highest concentration of organic carbon (1.30 percent) and the lowest PEC quotient (0.23) was found at Kona Creek Tributary. All other sites had organic carbon concentrations from 0.05 percent to 1.00 percent and PEC quotient values greater than 0.5, which would indicate some level of potential toxicity (table 12). As MacDonald and others (2000) noted, sites containing relatively low concentrations of organic carbon have higher potential toxicity.

As a preliminary survey of the neutralizing potential of Johnson River bedrock, 11 samples were submitted to an acid-base accounting (ABA) test. The samples (table 13) have low sulfur contents: 0.50 percent in a gossaned, sheared granodiorite and 0.58 percent in limey volcaniclastic sandstone from the upper part of the Talkeetna Formation were the only detectable abundances. Neutralizing potential ranged by two orders of magnitude, from 4 to 590. The highest values were three tuff-breccia samples and a volcaniclastic sandstone (Talkeetna Formation) and the gossaned granodiorite sample that also had 0.58 percent sulfur. Such high values in Talkeetna Formation volcaniclastic rocks reflect secondary veins and vesicles of calcite (propylitic alteration) as well as clasts of limestone that were probably eroded from reefs growing in the vicinity of the volcanic arc.

As noted previously, ABA maximizes the reported neutralizing potential by crushing the sample so that the entire volume is exposed to the test acid. Field tests for this study indicated that stream cobbles had lost most of the calcite originally in the outer shell, and, unless broken open, had little or no reaction to acid. Thus, in the case of a natural or manmade exposure of unweathered sulfide-bearing rock, the effect on downstream acidity will depend on how much calcite is also exposed or if the existing calcite is crushed. If sulfide significantly outweighs calcite, then bed sediments in the adjacent drainage may not be effective in buffering the resulting acidity because they are now armored by a calcite-depleted shell.

Table 12. Concentrations of trace elements, percent organic carbon, and mean PEC quotient for streambed sediment at sites located in the Johnson River study area.

[values in micrograms per gram; bold indicates values exceeds TEC or PEC when normalized for organic carbon content or value exceeds 0.5 for PEC quotient]

Site identifier (figure 3)	Sampling site	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Zinc	Organic Carbon (percent)	Mean PEC quotient
52	Johnson River above Lateral Glacier	**16**	0.2	66	**75**	4	**0.13**	**17**	0.3	**130**	0.05	**6.02**
110	Kona Creek 3 miles above mouth	**19**	<0.1	38	**56**	6	**0.75**	11	0.6	**120**	0.25	**1.27**
111	Kona Creek 2.5 miles above mouth	**18**	0.1	42	**57**	5	0.16	11	0.6	**140**	0.26	**0.98**
112	Kona Creek tributary	18	<0.1	77	47	4	0.10	25	0.2	85	1.30	0.23
113	Kona Creek 0.8 miles above mouth	**16**	0.4	48	63	17	0.28	14	0.7	150	0.49	**0.62**
115	East Fork Ore Creek	**64**	**4.3**	14	76	230	0.93	4	2.6	**1,000**	1.00	**0.72**
116	North Fork Ore Creek	**34**	<0.1	41	**54**	<1	**0.53**	15	0.2	**120**	0.16	**2.21**
117	Ore Creek	**44**	**4.6**	23	**92**	**180**	**0.28**	8	1.2	**1,800**	0.24	**4.60**

Table 13. Results of acid based accounting tests on 11 rock samples from the Johnson River study area.

[units for MPA, NP, and NNP are kilograms $CaCO_3$ per metric ton]

Site location (figure 4)	Sample identifier	Sample type	Sulfate (percent S)	Sulfur (percent)	Sulfur (percent total)	Carbon dioxide (percent)	Maximum potential acidity (MPA)[1]	Neutralizing potential (NP)[2]	Net neutralizing potential (NNP)[3]	Ratio (NP/MPA)
R107	B	Lava	<0.01	<0.01	<0.01	0.8	1	44	43	44
R112	A	Lava flow	<0.01	<0.01	<0.01	0.2	1	4	3	4
R113	A	Tuff	<0.01	<0.01	<0.01	1.6	1	94	93	94
R117	A	Dacite plug	<0.01	<0.01	<0.01	0.6	1	13	12	13
R107	C	Granodiorite	<0.01	<0.01	0.01	16.2	1	355	354	355
R110	A	Tuff	<0.01	<0.01	<0.01	3.8	1	218	217	218
3P	C	Lava flow	<0.01	0.50	0.50	0.8	16	27	11	1.7
4P	CA	Granodiorite	<0.01	0.07	0.07	0.4	2	7	5	3.5
5P	C	Dacite plug	<0.01	<0.01	<0.01	<0.2	1	9	8	9.0
9P	CB	Lava flow	0.04	0.04	0.58	21.4	18	525	507	29
12P	CA	Tuff	<0.01	<0.01	<0.01	24.6	1	591	590	[1]591

[1] MPA is determined by multiplying the percent total sulfur by 31.25

[2] NP is the capacity to neutralize acidity to pH 6.0

[3] NNP equals NP - MPA

SUMMARY AND CONCLUSIONS

The Johnson River Basin, located on the west side of Cook Inlet in south-central Alaska, drains an area of about 96 mi^2. In the upper part of the basin, a mineral deposit is located on a private inholding. Due to the possibility of developing the mineral prospect, the upper part of the Johnson River Basin was studied from 1999 through 2001 as part of a cooperative study with the National Park Service. The purpose of this study was to characterize the geochemistry of the Johnson River Prospect, to identify potential environmental hazards, and to determine baseline levels for selected water-quality constituents. Major findings are:

The two main rock units that occur in the study area are the Early Jurassic Talkeetna Formation and the Middle and Late Jurassic plutonic rocks of the Alaska-Aleutian Ranges batholith. Both show extensive areas of oxidation of previously mineralized, sulfide-rich rocks (gossans). The main structural feature of the study area is the Bruin Bay fault.

The widespread gossans in the volcanic Talkeetna Formation have a similar metal signature to the Johnson River Prospect (lead, zinc, cadmium, arsenic, copper, mercury, gold, and sulfur).

The average monthly discharge for the Johnson River during the open water period (May through October) ranges from 183 ft^3/s in May to 719 ft^3/s in July. Most of the flow originates from Johnson Glacier and Double Glacier. Physical and chemical parameters (specific conductance, pH, water temperature, and dissolved oxygen) and concentrations of basic water-quality constituents indicate good water quality. Water type of the Johnson River is classified as calcium bicarbonate.

Water quality samples from various sites in the study area indicate that most trace metals occur at low concentrations in the dissolved phase. The low dissolved metal contents are most likely the result of a combination of natural buffering by available carbonate and current level of weathering of previously sulfur-bearing rocks. Concentrations of total aluminum, total iron, and total manganese collected at the Johnson River gage correlate with suspended-sediment concentration.

The highest concentrations of several trace elements from streambed sediments (arsenic, barium, cadmium, copper, lead, selenium, and zinc) were found at East Fork Ore Creek, which drains the Johnson River Prospect, and Ore Creek. Concentrations of these elements substantially decrease downstream, indicating the introduction of additional fine sediment from streams draining Johnson Glacier and Double Glacier.

Concentrations of several trace elements from streambed sediments of East Fork Ore Creek and Ore Creek exceed the Interim Freshwater Sediment Quality Guidelines, probable effect levels, threshold effect concentrations, and probable effect concentrations. Most sites sampled in the study area have low amounts of organic carbon and mean PEC quotients greater than 0.5, which indicates the presence of toxicity.

Acid-Base Accounting (ABA) tests on 11 rock samples indicated low acid-generating potential and high acidity-neutralizing potential of most samples. ABA maximizes the reported neutralizing potential by crushing the sample so that the entire volume is exposed to the test acid. Conversely, field tests show that stream cobbles have lost most of the calcite originally in the outer shell and unless broken open, have little further reaction to acid. Thus, in the case of a natural or manmade exposure of unweathered sulfide-bearing rock, the effect on downstream acidity will depend on how much calcite is newly exposed along with unweathered sulfide. If sulfide significantly outweighs calcite, then bed sediments in the adjacent drainage may be ineffective in buffering the resulting surge of acidity because they are now armored by a calcite-depleted shell.

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APPENDIX

Appendix 1. Trace element concentrations measured in 18 water samples collected from Johnson River above Lateral Glacier near Tuxedni Bay, Alaska (site 52).

[all values in ug/L; E, estimated, <, less than, --, no data; M, presence verified, but not quantified]

Date	Aluminum, dissolved	Aluminum, total	Antimony, dissolved	Antimony, total	Arsenic, dissolved	Arsenic, total	Barium, dissolved	Barium, total	Beryllium, dissolved	Beryllium, total	Boron, dissolved	Cadmium, dissolved
5-17-99	10	--	<1.0	--	<1.0	--	9.1	--	<1.0	--	--	<1.0
6-10-99	18	6,460	<1.0	<1.0	<1.0	3	9.1	42.6	<1.0	<4.0	--	<1.0
6-30-99	28	2,670	<1.0	<1.0	<1.0	1	8.6	16.4	<1.0	<4.0	--	<1.0
7-21-99	22	2,870	<1.0	<1.0	<1.0	2	6.1	16.4	<1.0	<4.0	--	<1.0
8-6-99	24	24,400	<1.0	<1.0	<1.0	7	3.7	76.3	<1.0	<4.0	--	<1.0
8-24-99	21	1,940	<1.0	<1.0	<1.0	1	7.0	15.3	<1.0	<4.0	--	<1.0
9-16-99	19	1,420	<1.0	<1.0	<1.0	E1	8.8	14.0	<1.0	<5.0	--	<1.0
10-7-99	18	232	<1.0	<1.0	<2.0	<3	13.0	13.8	<1.0	<5.0	--	<1.0
5-9-00	<16	--	<1.0	--	<0.9	--	14.0	--	<1.0	--	23	<1.0
6-15-00	14	1,020	<1.0	<1.0	E0.6	<3	11.5	15.2	<1.0	<5.0	25	<1.0
7-26-00	70	2,010	<1.0	<1.0	E0.7	E1	6.5	13.0	<1.0	<5.0	17	<1.0
8-16-00	13	2,160	<1.0	<1.0	E0.8	E2	7.3	15.7	<1.0	<5.0	20	<1.0
9-18-00	22	--	<1.0	--	1.2	--	14.1	--	<1.0	--	43	<1.0
5-23-01	11	--	0.08	--	0.4	--	14.9	--	<0.06	--	54	E0.03
6-26-01	33	4,070	0.07	--	0.5	E1	8.8	27.0	<0.06	<2.5	17	E0.03
8-1-01	21	2,570	0.07	--	0.7	E1	6.3	15.7	<0.06	<2.5	16	<0.04
9-3-01	20	706	0.06	--	0.8	M	6.9	10.0	<0.06	<2.5	19	E0.02
9-27-01	19	353	0.10	--	0.8	E1	8.7	10.1	<0.06	<2.5	33	0.04

Date	Cadmium, total	Chromium, dissolved	Chromium, total	Cobalt, dissolved	Cobalt, total	Copper, dissolved	Copper, total	Iron, dissolved	Iron, total	Lead, dissolved	Lead, total	Lithium, dissolved	Lithium, total
5-17-99	--	<1.0	--	<1.0	--	2.1	--	<10.0	--	<1.0	--	--	--
6-10-99	<1.0	<1.0	1.0	<1.0	2.0	<1.0	E11.7	<10.0	5,120	<1.0	<1.0	--	<12.0
6-30-99	<1.0	<1.0	<1.0	<1.0	1.0	<1.0	E6.5	M	2,060	<1.0	<1.0	--	<12.0
7-21-99	<1.0	<1.0	<1.0	<1.0	1.0	<1.0	<12.0	<10.0	2,180	<1.0	<1.0	--	<12.0
8-6-99	<1.0	--	5.0	<1.0	10	<1.0	38.7	<10.0	16,900	<1.0	2.0	--	E6.1
8-24-99	<1.0	<1.0	<1.0	<1.0	1.0	<1.0	<12.0	<10.0	1,610	<1.0	<1.0	--	<12.0
9-16-99	<0.11	<1.0	<1.0	<1.0	E1.0	<1.0	<20.0	<10.0	1,120	<1.0	<1.0	--	<7.0
10-7-99	<0.11	<0.8	<1.0	<1.0	<2.0	<1.0	<20.0	<10.0	180	<1.0	1	--	<7.0
5-9-00	--	--	--	<1.0	--	<1.0	--	<10	--	<1.0	--	E0.1	--
6-15-00	<0.11	<0.8	<1.0	<1.0	<2.0	<1.0	<20.0	<10.0	840	<1.0	<1.0	0.4	<7.0
7-26-00	<0.11	<0.8	M	<1.0	<2.0	<1.0	<20.0	30	1,590	<1.0	<1.0	0.5	<7.0
8-16-00	<0.11	E0.8	M	<1.0	E1.0	<1.0	<20.0	<10.0	1,900	<1.0	<1.0	0.3	<7.0
9-18-00	--	E0.5	--	<1.0	--	<1.0	--	<10.0	--	<1.0	--	0.9	--
5-23-01	--	E0.4	--	0.12	--	0.6	--	<10.0	--	<0.08	--	1.4	--
6-26-01	E0.07	<0.8	M	0.07	E2.0	0.6	<20.0	10.0	3,510	E0.06	<1.0	E0.2	<7.0
8-01-01	<0.10	<0.8	<1.0	0.04	E1.0	0.5	<20.0	<10.0	2,240	<0.08	<1.0	E0.2	<7.0
9-3-01	E0.05	<0.8	<1.0	0.04	<2.0	<0.2	<20.0	M	540	<0.08	<1.0	E0.2	<7.0
9-27-01	<0.10	<0.8	<1.0	0.07	<2.0	0.4	<20.0	<10.0	310	<0.08	<1.0	0.4	<7.0

Appendix 1. Trace element concentrations measured in 18 water samples collected from Johnson River above Lateral Glacier near Tuxedni Bay, Alaska (site 52)—Continued.

Date	Manganese, dissolved	Manganese, total	Mercury, total	Molybdenum, dissolved	Molybdenum, total	Nickel, dissolved	Nickel, total	Selenium, dissolved	Selenium, total	Silver, dissolved	Silver, total
5-17-99	3.6	--	--	<1.0	--	<1.0	--	<1.0	--	<1.0	--
6-10-99	4.8	114	--	<1.0	<1.0	<1.0	1.0	<1.0	<1.0	<1.0	<1.0
6-30-99	4.2	45	--	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
7-21-99	3.4	49	--	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
8-6-99	8.7	395	--	<1.0	<1.0	<1.0	5.0	<1.0	<1.0	<1.0	<1.0
8-24-99	4.0	37	--	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
9-16-99	3.9	27	--	<1.0	1.3	<1.0	<2.0	<1.0	<2.6	<1.0	<1.0
10-7-99	3.4	8.0	--	<1.0	<1.0	<1.0	<2.0	<2.4	<2.6	<1.0	<1.0
5-9-00	4.2	--	--	<1.0	--	1.33	--	<0.7	--	<1.0	--
6-15-00	2.9	21	<0.30	<1.0	<1.0	<1.0	<2.0	<0.7	<2.6	<1.0	<1.0
7-26-00	3.5	34	<0.30	<1.0	1.3	<1.0	<2.0	<0.7	<2.6	<1.0	<1.0
8-16-00	4.2	41	<0.30	<1.0	<1.0	<1.0	<2.0	<0.7	<2.6	<1.0	<1.0
9-18-00	3.6	--	--	<1.0	--	<1.0	--	E0.4	--	<1.0	--
5-23-01	3.1	--	--	0.4	--	0.18	--	<0.3	--	<1.0	--
6-26-01	4.9	79	0.03	0.3	<1.5	0.15	<2.0	<0.3	<3.0	<1.0	<0.40
8-1-01	4.8	52	<0.01	0.4	E0.8	<0.06	<2.0	<0.3	E0.2	<1.0	<0.40
9-3-01	2.6	16	<0.01	0.4	<1.5	<0.06	<2.0	E0.2	<3.0	<1.0	<0.40
9-27-01	2.2	8.0	<0.01	0.6	E1.1	<0.06	<2.0	<0.3	<3.0	<1.0	<0.40

Date	Strontium, dissolved	Strontium, total	Thallium, dissolved	Vanadium, dissolved	Zinc, dissolved	Zinc, total
5-17-99	--	--	--	--	3.0	--
6-10-99	--	29.0	--	--	4.0	E32
6-30-99	--	18.9	--	--	7.0	E22
7-21-99	--	15.4	--	--	3.0	<40
8-6-99	--	65.2	--	--	<1.0	E40
8-24-99	--	15.4	--	--	3.0	<40
9-16-99	--	17.0	--	--	7.0	E15
10-7-99	--	22.3	--	--	11	E17
5-9-00	24.5	--	<0.90	<1.0	<5.0	--
6-15-00	19.4	19.0	<0.90	<1.0	7.0	E20
7-26-00	11.9	14.9	<0.90	<1.0	4.0	<31
8-16-00	12.5	15.6	<0.90	<1.0	2.0	<31
9-18-00	24.0	--	<0.90	<1.0	3.0	--
5-23-01	26.3	--	<0.04	E0.2	4.0	--
6-26-01	12.5	18.9	<0.04	0.5	3.0	E23
8-1-01	10.6	14.5	<0.04	0.5	3.0	E17
9-3-01	12.5	13.2	<0.04	0.6	4.0	<31
9-27-01	16.9	17.4	<0.04	0.6	8.0	<31

Appendix 2. Trace element concentrations measured in streambed sediment samples collected from sites located in the Johnson River Basin, Alaska.

[all values in micrograms per gram, dry weight; <, less than; M, presence verified, but not quantified]

Site identifier (figure 3)	Sampling site	Aluminum	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cadmium	Cerium
52	Johnson River above Lateral Glacier near Tuxedni Bay	8.1	2.8	16	210	0.2	<0.1	0.2	21
110	Kona Creek 3 miles above mouth above Lateral Glacier near Tuxedni Bay	8.5	1.4	19	250	M	<1.0	<0.1	30
111	Kona Creek 2.5 miles above Lateral Glacier near Tuxedni Bay	8.3	1.5	18	260	M	<1.0	0.1	29
112	Kona Creek tributary above Lateral Glacier near Tuxedni Bay	9.0	0.4	18	250	1.0	<1.0	<0.1	27
113	Kona Creek 0.8 miles above mouth above Lateral Glacier near Tuxedni Bay	8.8	1.7	16	340	1.0	<1.0	0.4	25
115	East Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	10	5.8	64	1100	1.0	<1.0	4.3	36
116	North Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	8.0	10	34	200	1.0	<1.0	<0.1	22
117	Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	9.0	5.9	44	860	1.0	<1.0	4.6	27

Site identifier (figure 3)	Sampling site	Chromium	Cobalt	Copper	Europium	Gallium	Gold	Holmium	Iron
52	Johnson River above Lateral Glacier near Tuxedni Bay	66	33	75	1.0	16	<1.0	2.0	13
110	Kona Creek 3 miles above mouth above Lateral Glacier near Tuxedni Bay	38	26	56	1.0	16	<1.0	2.0	8.2
111	Kona Creek 2.5 miles above Lateral Glacier near Tuxedni Bay	42	27	57	1.0	16	<1.0	2.0	8.9
112	Kona Creek tributary above Lateral Glacier near Tuxedni Bay	77	24	47	1.0	15	<1.0	1.0	4.8
113	Kona Creek 0.8 miles above mouth above Lateral Glacier near Tuxedni Bay	48	23	63	1.0	16	<1.0	1.0	6.5
115	East Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	14	18	76	2.0	20	<1.0	1.0	5.8
116	North Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	41	44	54	1.0	18	<1.0	1.0	11
117	Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	23	24	92	1.0	18	<1.0	1.0	6.6

Site identifier (figure 3)	Sampling site	Lanthanum	Lead	Lithium	Manganese	Mercury	Molybdenum	Neodymium
52	Johnson River above Lateral Glacier near Tuxedni Bay	9.0	4.0	10	1800	0.13	0.5	16
110	Kona Creek 3 miles above mouth above Lateral Glacier near Tuxedni Bay	12	6.0	9.0	1600	0.75	2.0	20
111	Kona Creek 2.5 miles above Lateral Glacier near Tuxedni Bay	12	5.0	9.0	1600	0.16	2.0	22
112	Kona Creek tributary above Lateral Glacier near Tuxedni Bay	11	4.0	20	1200	0.10	3.0	16
113	Kona Creek 0.8 miles above mouth above Lateral Glacier near Tuxedni Bay	10	17	12	1400	0.28	1.0	16
115	East Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	15	230	17	1600	0.93	4.0	22
116	North Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	8.0	<1.0	19	2000	0.53	<1.0	15
117	Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	12	180	16	1600	0.28	3.0	18

Appendix 2. Trace element concentrations measured in streambed sediment samples collected from sites located in the Johnson River Basin, Alaska—Continued.

Site identifier (figure 3)	Sampling site	Nickel	Niobium	Scandium	Selenium	Silver	Strontium	Tantalum	Thallium
52	Johnson River above Lateral Glacier near Tuxedni Bay	17	<4.0	44	0.3	0.5	200	<1.0	<1.0
110	Kona Creek 3 miles above mouth above Lateral Glacier near Tuxedni Bay	11	<4.0	49	0.6	<0.1	8.5	<1.0	<1.0
111	Kona Creek 2.5 miles above Lateral Glacier near Tuxedni Bay	11	<4.0	49	0.6	<0.1	200	<1.0	<1.0
112	Kona Creek tributary above Lateral Glacier near Tuxedni Bay	25	<4.0	29	0.2	<1.0	200	<1.0	<1.0
113	Kona Creek 0.8 miles above mouth above Lateral Glacier near Tuxedni Bay	14	<4.0	36	0.7	0.1	190	<1.0	<1.0
115	East Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	4	<4.0	31	2.6	0.8	74	<1.0	1.3
116	North Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	15	<4.0	56	0.2	<0.1	140	<1.0	<1.0
117	Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	8	<4.0	36	1.2	0.2	110	<1.0	<1.0

Site identifier (figure 3)	Sampling site	Thorium	Tin	Titanium	Uranium	Vanadium	Ytterbium	Yttrium	Zinc
52	Johnson River above Lateral Glacier near Tuxedni Bay	2.0	1.0	0.7	1.1	550	4.0	36	130
110	Kona Creek 3 miles above mouth above Lateral Glacier near Tuxedni Bay	2.0	1.0	0.7	<1.0	300	4.0	42	120
111	Kona Creek 2.5 miles above Lateral Glacier near Tuxedni Bay	2.0	1.0	0.8	<1.0	340	4.0	43	140
112	Kona Creek tributary above Lateral Glacier near Tuxedni Bay	<1.0	1.0	0.5	0.8	150	3.0	27	85
113	Kona Creek 0.8 miles above mouth above Lateral Glacier near Tuxedni Bay	1.0	1.0	0.6	<1.0	220	3.0	31	150
115	East Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	2.0	2.0	0.5	<1.0	140	4.0	34	1000
116	North Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	<1.0	1.0	0.8	<1.0	420	4.0	38	120
117	Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	1.0	1.0	0.5	1.0	220	4.0	33	1800