Effects of 1980s Uranium Mining in the Kanab Creek Area of Northern Arizona

By James K. Otton, Tanya J. Gallegos, Bradley S. Van Gosen, Raymond H. Johnson, Robert A. Zielinski, Susan M. Hall, L. Rick Arnold, and Douglas B. Yager

Chapter B of

Hydrological, Geological, and Biological Site Characterization of Breccia Pipe Uranium Deposits in Northern Arizona

Edited by Andrea E. Alpine

Scientific Investigations Report 2010–5025

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

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
	Concentration	
Part per billion (ppb)	1.0	microgram per liter (µg/L)
part per million (ppm)	1.0	milligram per liter (mg/L)
ton per year (ton/yr)	0.9072	metric ton per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

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

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

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

Abbreviations Used in This Report

<	less than
>	greater than
°C	degree Celsius
µR/h	microrad per hour (a rad is a unit of absorbed radiation dose causing 0.01 joule of energy to be absorbed per kilogram of matter)
µg/L	microgram per liter
µm	micrometer
cfs	cubic foot per second
cm	centimeter
ft	foot
g	gram
h	hour
in.	inch
kg	kilogram
lb	pound
m/s	meter per second
mg/L	milligram per liter
mi	mile
mm	millimeter
ppb	parts per billion
ppm	parts per million
DI	deionized water
GFAA	graphite furnace atomic absorption spectrophotometry
GPS	global positioning system
HSSR	Hydrogeochemical and Stream Sediment Reconnaissance
ICP–AES	inductively coupled plasma-atomic emission spectrometry
ICP–MS	inductively coupled plasma-mass spectrometry
INAA	instrumental neutron activation analysis
N	north
NURE	National Uranium Resource Evaluation
USBM	U.S. Bureau of Mines
USGS	U.S. Geological Survey
W	west

Chapter B

Effects of 1980s Uranium Mining in the Kanab Creek Area of Northern Arizona

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Abstract

In August and October of 2009, the U.S. Geological Survey conducted a field assessment of the geochemistry of surface soils, waste rock, and sediments in and around several reclaimed or inactive breccia-pipe uranium mines; these mines are located on Bureau of Land Management lands in the Kanab Creek area north of Grand Canyon National Park. Surface soil, stream sediment, and mined waste-rock samples were collected at six sites that represent various stages of mining: mined and reclaimed (Hermit, Pigeon, and the Hack mine complex); partially mined and on hold (Kanab North); and mineralized and explored by drilling, but not mined (Kanab South). Previous studies on undisturbed sites in the study area suggest that soil and sediment can naturally contain as much as 5.6 parts per million uranium and 39 parts per million arsenic. The average soil uranium concentration in a region bounded by the surrounding twelve 7.5 minute quadrangles is 2.4 parts per million. Stream sediments were also collected in a canyon with no mining history or known uranium deposits—Jumpup Canyon—to provide geochemical data for comparison with data in the mined areas. Samples at breccia-pipe mine sites were analyzed to determine historic dispersion (by wind and water) of uranium and trace elements. Some samples were leached to simulate the potential mobility of uranium and other trace elements during weathering. Radioactivity was measured with a microR meter to determine the degree of exposure to radioactivity at each site. Findings show the following:

- Uranium and arsenic: These two elements were consistently the most abundant trace elements of concern at mined sites.
- Jumpup Canyon: Concentrations of uranium and other trace elements in stream sediments in this background area were lower than in regional soil levels. The Jumpup Canyon sediment samples (n=9) had average concentrations of 1.7 parts per million uranium and 4.6 parts per million arsenic.
- Pigeon Mine: Fewer than 10 weathered uranium ore and waste-rock fragments were found at Pigeon reclaimed sites. Wind dispersed some wastes offsite. Soils collected inside the disturbed and reclaimed mine area (n=26) had median concentrations of 4.4 parts per million uranium and 41 parts per million arsenic, reflecting the geochemistry of the cover materials used to reclaim the site. Soils collected outside of the disturbed area (n=16) had median concentrations of 6.3 parts per million uranium and 25 parts per million arsenic. Stream sediments below the mine contained elevated uranium and arsenic concentrations, but dispersion from the mine site and weakly mineralized rock outside the mine site may both be responsible.
- Kanab North Mine: Mined waste rock, uranium ore, pond sludge, and local wind- and water-dispersed fine particles on the unreclaimed mine site (all of which contained high concentrations of uranium and other trace element constituents such as arsenic) were exposed to the ambient environment for about 20 years at the Kanab North partially mined site. Offsite, only one soil sample approximated background uranium concentrations, suggesting that dispersion extends beyond the limit of sampling, about 420 feet. Soil samples (n=20) collected within about 420 feet outside of the fenced mine site had an average uranium concentration of 27.8 parts per million (more than 10 times background concentration) and arsenic concentration of 12 parts per million. Wind appears to be the dominant process dispersing material offsite.
- Kanab South drill site: Although uranium has not been mined at this breccia pipe site (only exploratory drilling has taken place), elevated concentrations of uranium and other trace elements are found at this site and in its vicinity as compared with concentrations in Jumpup Canyon and with regional concentrations in soils of the western United States. In six soils sampled around the drilled area, uranium concentrations ranged from 1.3 to 2.7 parts per million and arsenic concentrations ranged from 5 to 23 parts per million. In six stream sediments from the Kanab South area, uranium concentrations ranged from 1.5 to 3.6 parts per million and arsenic concentrations ranged from 4 to 20 parts per million. Several trace elements in stream sediment samples collected downstream from the pipe location were anomalously high by a small amount.

- Hermit Mine: The reclaimed Hermit Mine site, active for less than one year, contains very little evidence of elevated concentrations of uranium either onsite or offsite. The 22 soils sampled inside of the disturbed area averaged 4.6 parts per million uranium (median, 3.1 parts per million) and 7.5 parts per million arsenic (median 6.0 parts per million); 35 soils and stream sediments collected outside of the disturbed area averaged 1.9 parts per million uranium (less than the regional background average of 2.4 ppm) (median 1.6 parts per million), and 4.6 parts per million arsenic (median 4.0 parts per million).
- Hack 1 Mine: During mining, ore and waste-rock piles were eroded by a flash flood. Since the cessation of mining and completion of reclamation, reclaimed mined waste rock were eroded by floods that exposed covered uranium-enriched mined waste-rock and ore fragments in a terrace adjacent to the stream channel that runs through Hack Canyon. Fragments of material from these floods were found in the channel and on the floodplain for as much as a half mile downstream from the reclaimed site. Downstream from Hack 1, concentrations of uranium and arsenic in stream sediments ranged from 2.4 to 10.2 parts per million for uranium and from 9 to 17 parts per million for arsenic. The highest concentrations were found about a half mile downstream near the low end of the eroded terrace. Most trace elements in stream sediments were at background concentrations at a sample site about 1.7 mi east of the Hack 1 reclaimed mine site.
- Hack 2 and 3 Mines: In a reconnaissance radiometric survey, two anomalously radioactive areas (of less than 1 square foot) and one uranium waste-rock or ore fragment were found downstream of the reclaimed Hack 2 and 3 Mine area but above the location of the Hack 1 Mine. A single stream-sediment sample downstream from the Hack 2 and 3 Mine area had concentrations of 5 parts per million uranium and 10 parts per million arsenic. However, the waste-rock fragment along the channel contained 7,760 parts per million uranium.
- Elevated radioactivity is evident at all sites (except the Jumpup Canyon background area). The highest microR measurements were found at the Kanab North Mine (a partially mined site with abundant mined waste rock at the surface inside a fenced site perimeter), followed by the Pigeon site and then the Hack Mine complex (within a half mile downstream of Hack 1 Mine). Much lower microR measurements were recorded at the Hermit site. Very little radiation above background concentrations was found at the unmined Kanab South site, except at a weakly uraniferous limonite-stained outcrop. Radioactivity rapidly decreases within 400 feet outside of the fenced area of the Kanab North site. Similarly, radioactivity notably decreased within a few feet of anomalous point sources (ore and waste-rock fragments) at reclaimed Pigeon, and Hack 1, 2, and 3 sites.
- Uranium in mine wastes that were leached with synthetic rainwater and simulated river water increased in solubility with increased weathering. This increased solubility was reflected in the percentages of uranium leached from solids during 24-hour contact with the synthetic rainwater: unweathered ore (0.2–0.33 percent), wind-transported fines (0.5–1.66 percent), weathered ore and waste rock (0.89–2.76 percent), and chemically redistributed uranium redeposited on waste (0.57–17.06 percent); background-area samples leached 0.16–0.19 percent.
- Although experimental data indicate that concentrations of leached trace-elements derived from waste rock or ore under experimental conditions can be very high, the dilution factors during floods are also very high. The resultant contribution to trace element concentrations in the passing water is less than one part per billion. Projection of site-specific future mobilization of uranium and trace elements contained in contaminated soils and mined waste rock and the efficiency of natural attenuation processes cannot be determined from these results and should be considered for future study.

Introduction

Lands containing substantial uranium resources in northern Arizona region (Finch and others, 1990; Otton and Van Gosen, this report) have been proposed for withdrawal from mineral entry. Previous uranium mining in northern Arizona began in the early 1950s, although most uranium mining occurred in the 1980s in the Kanab Creek drainage on Bureau of Land Management lands north of Grand Canyon National Park. The effect of past mining is here evaluated to provide a factual basis for understanding possible future effects and for suggesting new remedial approaches. This report reviews existing information and presents new data that examines the remnant effects of uranium mining and reclamation on soils and stream sediments in and near selected mine sites, and it evaluates the effects of long-term exposure of materials exposed at a standby mine site to environmental conditions. Companion reports in this volume discuss potential effects on water and ecosystems.

Sites of this investigation represent the variety of geologic and topographic settings of uranium mines in the Kanab Creek area (North Segregation Area). The sites selected are the reclaimed Pigeon, Hermit, and Hack (1, 2, and 3) Mines and the Kanab North Mine, currently on standby status (fig. 1). The Kanab South pipe, drilled but not developed, and Jumpup Creek, a drainage in the North Kaibab National Forest that is remote from mining, were also studied.

This report summarizes previous investigations whose results can be compared with geochemical data gathered during this study and provides background information for the sites, and it describes the site geochemical and radiometric investigations conducted during this study, leaching experiments conducted on ore and waste-rock samples, and the results of these investigations.

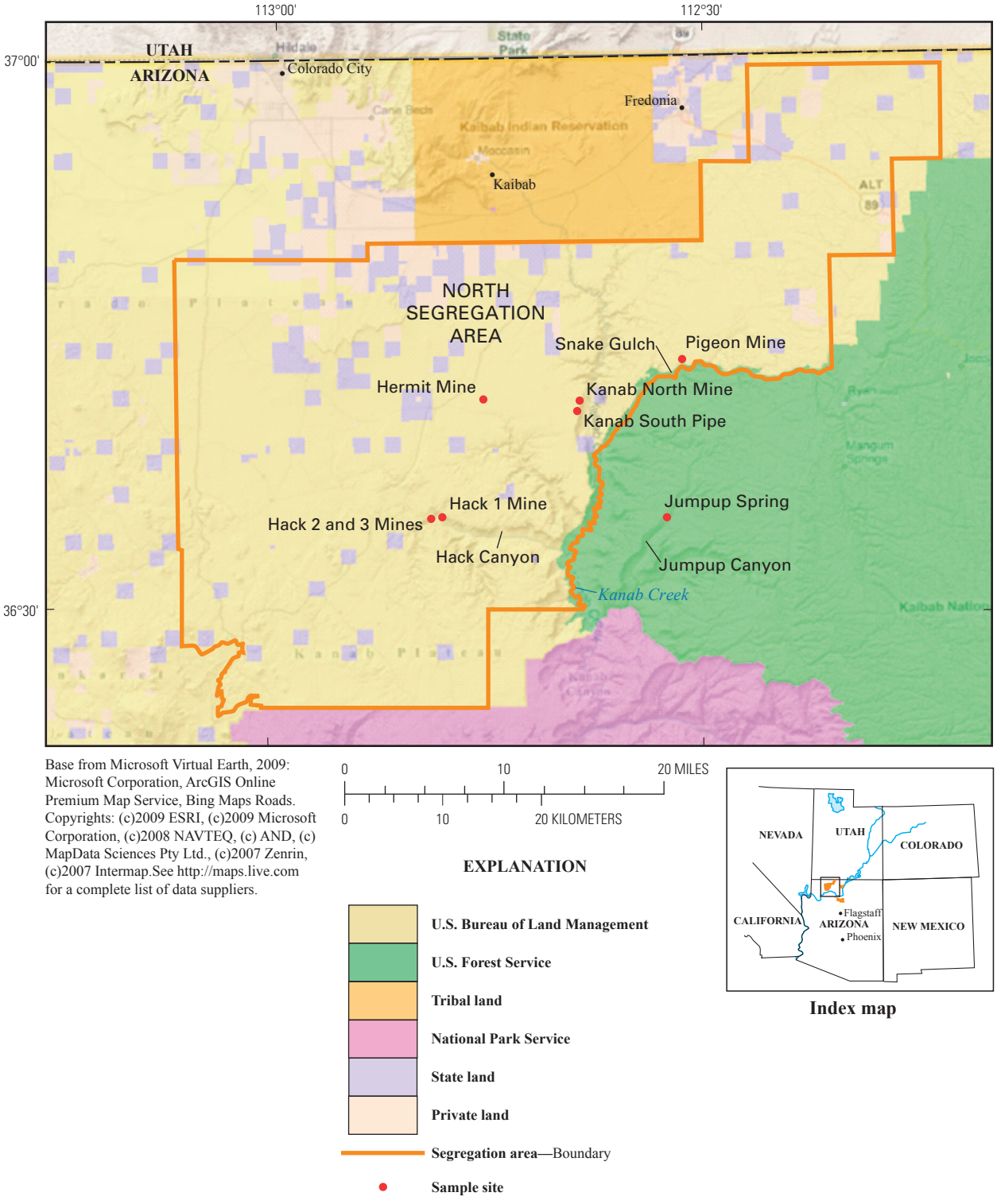


Figure 1. Location of sites (mines and stream segments) studied for this report in North Segregation Area (Kanab Creek area), northern Arizona.

Previous Investigations

Premining Geochemistry Studies

Geochemical results of analyses of soil and stream sediment samples collected as part of this study are compared with the results of previous studies. Defining premining trace-element geochemistry is important for distinguishing concentrations that are due to natural processes from those related to uranium mining. This section summarizes previous studies that will be used in later sections to aid in establishing natural background concentrations in the study area. Previous investigations of the geochemistry of soils, stream sediments, and rocks of the Kanab Creek and the South Rim areas (fig. 2) include (1) soil samples collected during the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) program of the 1970s (Smith, 1997), (2) stream sediments and soils collected during study of the geochemistry of the Snake Gulch area near the Pigeon Mine (Hopkins and others, 1984), and (3) geochemistry of soils formed on two solution-collapse features (breccia pipes) in the South Rim of the Grand Canyon area (Van Gosen and Wenrich, 1991). These three studies are discussed below.

National Uranium Resource Evaluation Soil Sampling

The NURE Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) program sampled and chemically analyzed surface waters and groundwaters from streams, springs, wells and ponds, and stream sediments, soils, and rocks across the United States. Resulting data were released in a series of reports. In 1984, under an agreement with the Department of Energy, the U.S. Geological Survey (USGS) took over management of the HSSR dataset and prepared the data for release online (Smith, 1997). In the NURE regional geochemical survey of the western United States (conducted by Savannah River Laboratory), samples were taken as close to random grid points as possible (Price and Jones, 1981). The sample medium depended on regional conditions that would allow uniform collection throughout a broad area. In the northern Grand Canyon area, soil was the primary medium sampled, and soil sample sites were located on plateau surfaces probably because of ease of access. Samples were taken without regard to the location of the many solution-collapse features in the area. No waters, stream sediments, or rocks were sampled in the northern Grand Canyon area. Delayed neutron activation and instrumental neutron activation analysis were used to analyze the soil samples for uranium and for other trace elements commonly associated with uranium-bearing minerals in some geologic settings. The fraction passing a 100-mesh sieve (0.149 millimeter (mm) opening) was analyzed. At each site, 10 or more samples collected within a 25-yard radius were composited. Plastic scoops or stainless steel "bag" samplers were used and samples were collected in either cloth or paper bags. Detailed location and data sheets were filled out for each site (appendix C of Price and Jones, 1981).

An area in northern Arizona extending through twelve 7.5 minute quadrangles was selected for soil geochemistry characterization from the larger HSSR dataset (fig. 2). This area contains the southern Kanab Creek drainage basin from just north of the Kanab North Mine to its confluence with the Colorado River. Of the 120 HSSR samples in this area, all but 17 were collected in mid-May 1979 and those 17 were collected in late October 1979. This sampling thus predated uranium mining in the area, with the exception of minor production (about 5,000 pounds (lb) U_3O_8) at the Hack Canyon Mine (adjacent to Hack 1 Mine). Concentrations of uranium, aluminum, cerium, dysprosium, europium, iron, hafnium, lanthanum, lutetium, manganese, samarium, scandium, sodium, thorium, titanium, vanadium, and ytterbium were reported. In this analytical suite, only uranium and vanadium are noted as markedly anomalous in the breccia-pipe ores of the Grand Canyon region (Wenrich and others, 1995). Therefore, comparisons of our current data with HSSR data are limited to these two elements.

Most of the 120 samples were taken from soils on upland surfaces formed on sandstone or carbonate rocks or alluvium derived from them. However, 14 soil sample sites were located on mafic volcanic rocks (basalt). Because basalt does not host breccia-pipe uranium deposits nor does it occur in mined areas, these samples would not provide background soil geochemical data suitable for this study; thus they were excluded. Uranium concentrations in the remaining 106 soil samples ranged from 1.4 to 3.4 parts per million (ppm). The average and median of the 106 samples is 2.4 ppm uranium and the mode is 2.3 ppm uranium. The value of 2.4 ppm uranium is considered the background concentration for soils on the upland surfaces in the Kanab Creek area. Vanadium concentrations ranged from 9 to 75 ppm with 6 nondetect concentrations (the lower reporting limit for these samples ranged from 7 to 13 ppm). The average of the reported and censored concentrations (using one half of the lower reporting limit for the censored data) is 37 ppm vanadium. The median was 35.5 ppm vanadium and the mode 35 ppm vanadium. The background for vanadium in soils in the study area is defined as 37 ppm.

Snake Gulch Area

In the early 1980s, the USGS and the U.S. Bureau of Mines assessed the mineral resource potential of the northern Kanab Creek and Snake Gulch area (Billingsley and others, 1983). This work was performed as part of the evaluation and planning process for the Kanab Creek Roadless Area. A reconnaissance geochemical survey collected and analyzed bulk stream sediment; panned concentrate of stream sediment; and rock, soil, and clay samples. Samples were collected in March 1982 (Billingsley and others, 1983; Hopkins and others, 1984). The stream sediment and soil sample data are relevant to this study. In addition to providing stream sediment geochemical data, the March 1982 date of sampling provides premining soil-sample data for the Pigeon Mine site. Billingsley and others (1983) note that in March 1982 the

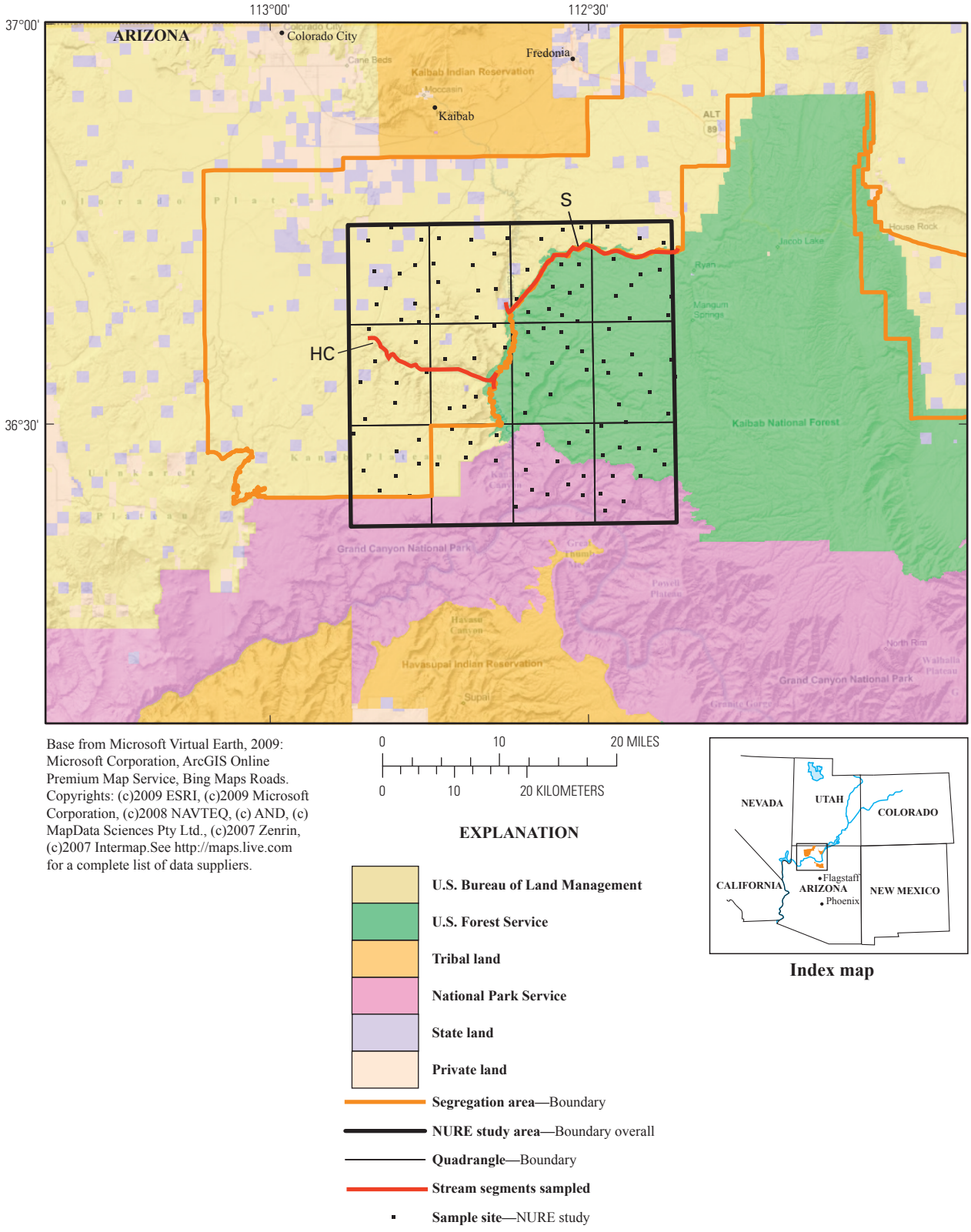


Figure 2. Location of sites in the North Segregation Area (Kanab Creek area) studied during previous investigations. NURE, National Uranium Resource Evaluation, Hydrogeochemical Stream-Sediment Reconnaissance soil sample locations (Smith, 1997); S, Snake Gulch–Kanab Creek area; red line, stream segments sampled (Hopkins and others, 1984); HC, Hack Canyon–Kanab Creek area, red line, stream segments studied (Carver, 1999).

Pigeon Mine site was being cleared by Energy Fuels Nuclear, Inc., but mining did not begin until 1984. Eighteen miles to the southwest, mines in Hack Canyon were actively producing uranium ore during the early 1980s.

Features that could influence the stream-sediment geochemistry in the Snake Gulch–Kanab Creek drainage basins include 19 mapped solution-collapse features (fig. 3) and stratabound copper deposits of the historic Jacob Lake–Warm Springs mining district, which lies east of a roadless area near Jacob Lake. This district contains thinly layered copper-gold-silver-lead deposits, which were mined on a small scale between the early 1900s and about 1942 (Tainter, 1947). The copper deposit closest to the roadless area lies 4 miles (mi) to the east of the head of Snake Gulch. Mills that processed the ores were built in 1901 and 1928 at Ryan, about 2.5 mi southeast of the head of Snake Gulch (Tainter, 1947).

Analytical results from the March 1982 geochemical survey are tabulated in Hopkins and others (1984). This tabulation contains analyses of 31 composite stream sediment samples, 2 of which were collected at sites near the confluence of Kanab Creek and Snake Gulch and 29 of which were from sites within Snake Gulch and canyons tributary to Snake Gulch (fig. 3). These samples provide a snapshot of the composition of sediments carried by Snake Gulch and northern Kanab Creek. Uranium-mineralized breccia pipes of northern Arizona (Wenrich, 1985, 1986) typically are enriched in certain metals; analysis of these stream sediments focused on those metals (table 1).

The highest base metal concentrations in stream sediment from Snake Gulch were measured in samples located downstream of the Pigeon pipe. Specifically, sample site 10S (fig. 3) had the highest concentration of nickel (30 ppm), lead (44 ppm), and vanadium (100 ppm); sample site 11S had the highest concentration of barium (700 ppm) and chromium (100 ppm) and high concentrations of nickel (30 ppm) and vanadium (100 ppm).

All 31 stream sediment samples contain less than 2 ppm uranium. The low uranium and generally low base metal concentrations may indicate that the dispersed metals are diluted by much larger volumes of sediment derived from the unmineralized rock that also is carried downstream by the braided stream systems of Snake Gulch and northern Kanab Creek.

Billingsley and others (1983) note slight enrichments in arsenic, barium, copper, and molybdenum in stream sediments in the eastern reaches of Snake Gulch. They attribute these geochemical anomalies to the mining of the Jacob Lake–Warm Springs copper deposits and to ore processing in the mills at Ryan.

Through the courtesy of Energy Fuels Nuclear, Inc., the USGS was able to collect three samples of fresh-cut soil from the surface of the Pigeon pipe during the mining company's surface excavation in March 1982. Analytical results of these soils are summarized in table 2. The three soils have uranium concentrations of 2.2, 2.2, and 5.6 ppm and modest enrichments in base metals (Hopkins and others, 1984, their fig. 3).

Soils over Grand Canyon Breccia Pipes

Van Gosen and Wenrich (1991) sampled the soils on 50 solution-collapse features exposed on the Coconino Plateau, which is the extensive plateau surface south of the central Grand Canyon (fig. 4). The subsurface character of the majority of these 50 collapse features is unknown, because most have not been drilled. Two of the sampled solution-collapse features are breccia pipes that host uranium orebodies—the SBF pipe and the Canyon pipe. The soil composition overlying these breccia pipes is thus useful in evaluating the results of the current study.

The soil samples of Van Gosen and Wenrich (1991) were collected from 3 to 4 inches (in.) depth. A pilot sampling study during 1984 compared the analyses of soils collected at 3–4 in. depth with those of soils collected at 7–8 in. depth. No difference in metal concentrations was found at the two depths. Thus, the 3–4 in. depth was used in the subsequent larger soil sampling program. A shallower 0–2 in. (0–5 centimeter (cm)) depth was used in the current study. The soil samples in the study of Van Gosen and Wenrich (1991) were sieved through an 80 mesh screen opening (0.0067 in. or 177 micrometers (μm)). The <80 mesh material was then pulverized to <100 mesh, and this <100 mesh material was submitted for geochemical analysis. The same sieving and processing method was used in the current study.

SBF Pipe

The SBF breccia pipe is located just southeast of the Hualapai Indian Reservation (fig. 4). It is exposed on the surface of the Coconino Plateau (fig. 4) as a 7-foot (ft)-high raised rim composed of Harrisburg Member of the Kaibab Formation (Wenrich and Aumente-Modreski, 1994). This rim encloses a soil-covered, circular basin filled with Moenkopi Formation sandstone and siltstone. Intermittent drilling by Union Pacific Resources from 1984 to 1987 confirmed a breccia pipe structure at depth that contains a uranium deposit. The soil survey of Van Gosen and Wenrich (1991, their fig. 32) collected 20 soil samples within the structural basin and 16 background soil samples outside of the basin.

Canyon Pipe

The surface expression of the Canyon breccia pipe is a sage-covered, elliptical clearing in a ponderosa pine forest, located about 6.5 mi southeast of Tusayan (fig. 4). The bounds of the clearing define a shallow basin that overlies the collapse structure; the clearing is about 2,000 ft long (north-south) by 1,600 ft wide (east-west) (Wenrich, 1992, her fig. 2; Wenrich and Aumente-Modreski, 1994, their fig. 3). The underlying breccia pipe averages less than 200 ft in diameter

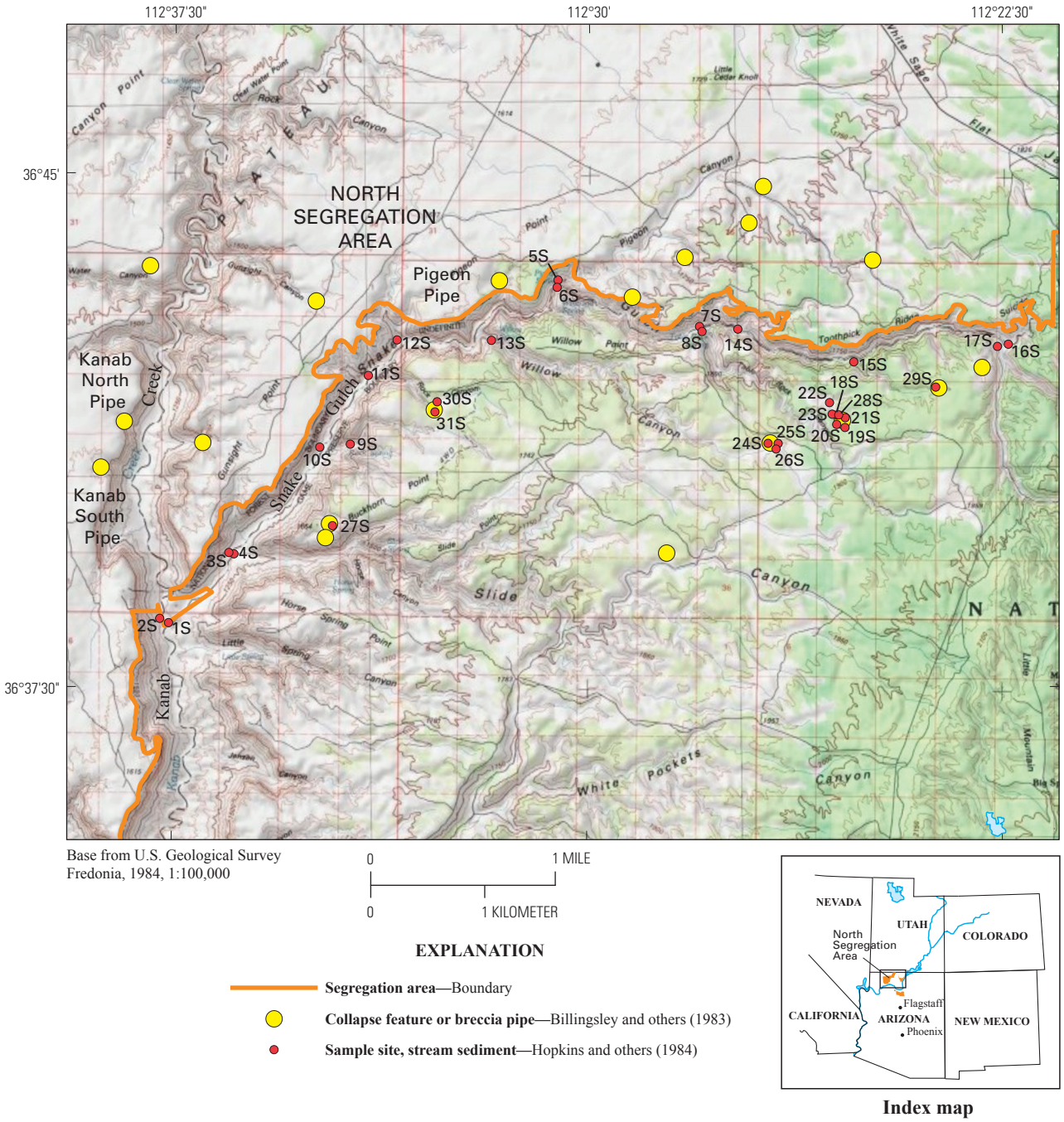


Figure 3. Snake Gulch–Kanab Creek area, showing locations of 31 sites where composite stream sediment samples were collected by the U.S. Geological Survey in March 1982 (Hopkins and others, 1984) and of 19 solution-collapse features and breccia pipes (Billinglsey and others, 1983, sheet 1).

Table 1. Summary of geochemical analyses of 31 stream sediment samples collected in March 1982, northern Kanab Creek and Snake Gulch area, northern Arizona.

[Data from Hopkins and others (1984); sample site locations shown in figure 3; ppm, parts per million; <, less than; --, not available]

Element	Range in values (ppm)	Sample site with highest concentration
Silver	<0.5	--
Arsenic	<200	--
Barium	300–700	2, 11, 15, 18
Cadmium	<20	--
Cobalt	5–7	numerous sites
Chromium	20–100	3, 5, 7, 8, 11, 14, 15, 16
Copper	3–11	31
Molybdenum	<5	--
Nickel	10–30	10, 11
Lead	5–44	10
Antimony	<100	--
Strontium	<100–1,500	9
Uranium	0.2–2.0	9
Vanadium	30–100	4, 10, 11, 15
Zinc	11–29	24

Table 2. Summary of analyses of three soil samples collected in March 1982 (prior to mining) from the surface of the Pigeon breccia pipe.

[Data from Hopkins and others, 1984; <, less than; ppm, parts per million]

Element	Range in concentration, (ppm)
Silver	<0.5
Arsenic	<200
Barium	1,000–3,000
Cadmium	<20
Cobalt	7–20
Chromium	100–100
Copper	11–29
Molybdenum	<5–7
Nickel	30–50
Lead	13–20
Antimony	<100
Strontium	19–300
Uranium	2.2–5.6
Vanadium	100–150
Zinc	17–85

and it narrows within Coconino Sandstone and Hermit Formation horizons (Casadevall, 1989). Drilling by Energy Fuels Nuclear, Inc., passed through a zone of abundant sulfide minerals near the contact of the Coconino Sandstone and Toroweap Formation (Casadevall, 1989). The drilling showed that uranium minerals extend for more than 1,600 ft vertically through the breccia pipe, from the lower Toroweap Formation to the upper Redwall Limestone. Uranium ore averages 0.74 percent U_3O_8 and occurs mainly in the Coconino, Hermit, and Esplanade horizons of the pipe (Casadevall, 1989). The soil survey of Van Gosen and Wenrich (1991, their fig. 58) collected 18 soil samples inside the structural basin and 14 background soil samples outside of the basin. After the 1986 soil sampling survey, a head frame was built on the site in preparation for underground mining (Wenrich, 1992, her fig. 2). However, owing to a subsequent steep drop in uranium prices, the mine was never developed.

Soil Survey Results

Wenrich (1985) indicated that breccia pipe orebodies typically are enriched in silver (Ag), arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb), strontium (Sr), uranium (U), vanadium (V), and zinc (Zn). See table 3 for average concentrations of these elements in soils collected over the SBF and Canyon breccia pipes (Van Gosen and Wenrich, 1991). These data are considered representative (average) concentrations in soils that formed above undisturbed breccia pipes that contain uranium deposits at depth. Soil samples that were collected outside of the collapse features provide additional information about metal concentrations typical of soils of the Kaibab Limestone ("background concentrations"). The concentrations over and outside of the breccia pipes are similar, which suggests that uranium deposits at depth has only limited effects on the surface soil geochemistry. In soils inside the projected boundary of the SBF pipe, only arsenic concentrations appear to be elevated with respect to soils outside the projected boundary of the pipe (average 33 ppm as compared with <10 ppm).

The results of these three studies and additional crustal abundance data and composition of average western U.S. soils are summarized in table 4.

Postmining Geochemistry Study

Hack Canyon and Kanab Creek

Carver (1999) examined the concentration of trace elements in stream sediments in Hack Canyon. Carver collected stream sediments at 10 locations on the floor of Hack Canyon Wash—at 5 sites each upstream and downstream of the Hack Mine complex (Hack Mine 1, 2, and 3) (fig. 1). Water and stream-sediment samples were also collected at 3 sites in Kanab Creek: 1 site above, 1 site below, and 1 site at the confluence of Hack Canyon and Kanab Creek. The intent of Carver's study was to evaluate whether trace elements had migrated within Hack Canyon Wash downstream from the former Hack Mine complex toward Kanab Creek. In addition to the bulk sediment sampling, Carver (1999) sieved the sediment samples into gravel (>2 mm), sand (2 mm to 63 μm), silt (63 μm to 53 μm),

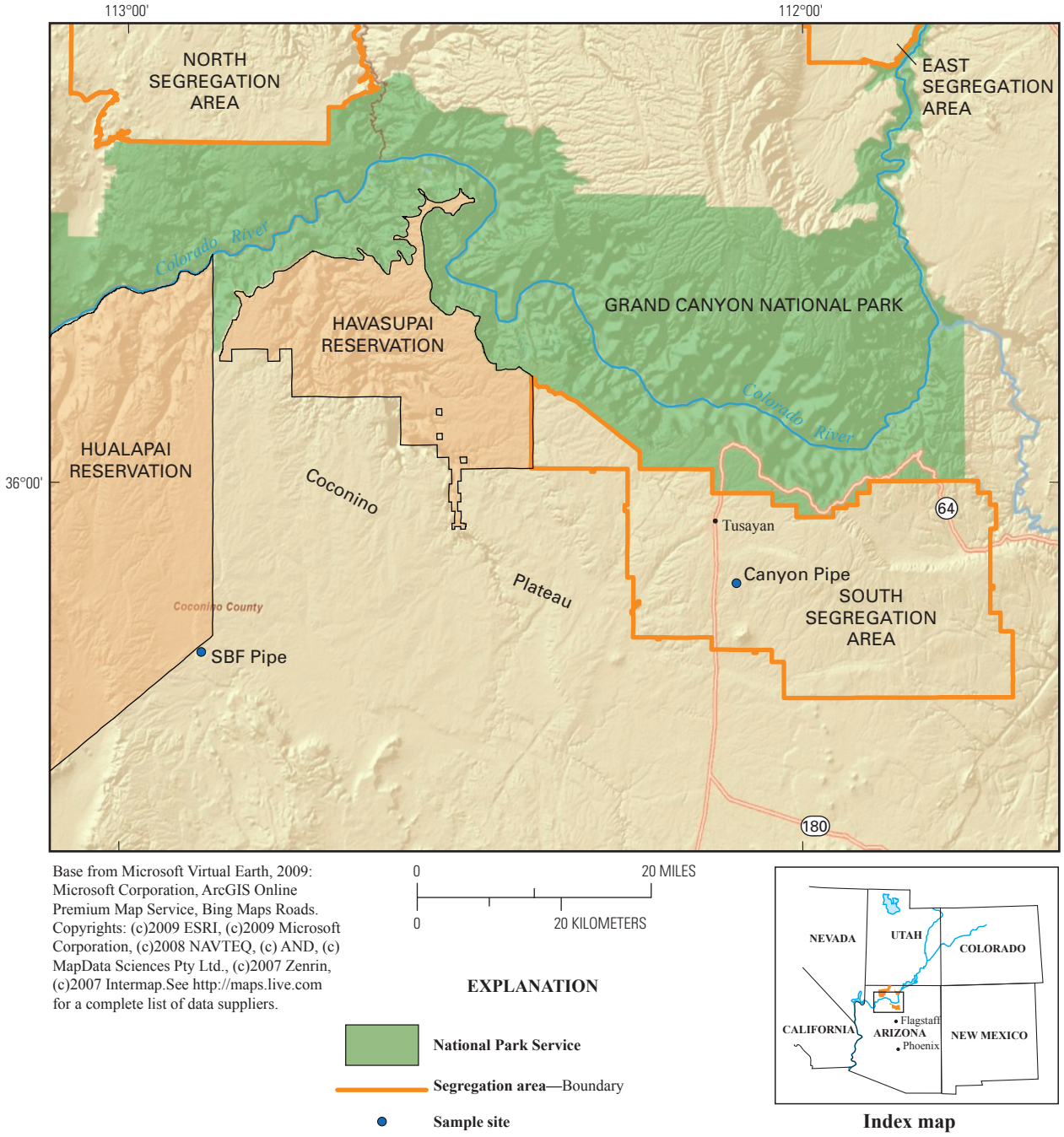


Figure 4. Location of SBF (breccia) pipe and Canyon (breccia) pipe, solution-collapse features whose soil geochemistry is discussed in this report.

Table 3. Average trace-element concentrations in soil samples collected in and near the surface expression of two uranium-ore-bearing breccia pipes exposed on the surface of the Coconino Plateau, northern Arizona.

[Sample site locations shown in figure 4; values shown here averaged from data reported by Van Gosen and Wenrich (1991); inside soil, near-surface soil samples collected inside the surface expression that overlies the collapse feature; outside soils, near-surface background soil samples collected outside the surface expression; <, less than; ppm, parts per million]

Soil sample site relative to collapse feature	Concentration (ppm)													
	Silver	Arsenic	Barium	Cadmium	Cobalt	Chromium	Copper	Molybdenum	Nickel	Lead	Strontium	Uranium	Vanadium	Zinc
Unmined breccia pipes with known uranium ore bodies at depth														
SBF breccia pipe														
Inside soil (n=20)	<2	33	470	<2	8	49	24	<2	21	17	150	3	50	63
Outside soil (n=16)	<2	<10	410	<2	8	48	22	<2	20	15	210	3	44	53
Canyon breccia pipe														
Inside soil (n=18)	<2	<10	540	<2	10	52	20	<2	24	17	130	3	54	57
Outside soil (n=14)	<2	11	480	<2	10	60	19	<2	23	16	110	3	54	54

Table 4. Summary of element concentrations reported in premining and other previous studies.

[<, less than; na, not analyzed; ppm, parts per million; NURE HSSR, National Uranium Resource Evaluation, Hydrochemical and Stream Sediment Reconnaissance]

Study	Concentration (ppm)											
	Arsenic	Cadmium	Cobalt	Copper	Molybdenum	Nickel	Lead	Antimony	Thallium	Uranium	Vanadium	Zinc
Premining studies												
NURE HSSR soils (average of 106 samples)[1]	na	na	na	na	na	na	na	na	na	2.4	37	na
Pigeon pipe soils (range of 3 samples)[2]	<200	<20	5–7	3–11	<5	10–30	5–44	<100	na	0.2–2	30–100	11–29
Snake Gulch stream sediments (range of 31 samples)[3]	<200	<20	7–20	11–29	<5–7	30–50	13–20	<100	na	2.2–5.6	100–150	17–85
Premining mineralized breccia pipe (range of averages)[4]	<10–33	<2	8–10	19–24	<2	20–24	15–17	na	na	3	44–54	53–63
Other studies												
Crustal abundance (average)[5]	2	0.18	25	60	2	80	16	0.2	1	3	150	70
Average soil concentrations in western United States[6]	5.5	0.06	7.1	21	0.85	15	17	0.47	1	2.5	150	55

[1]NURE HSSR: Smith (1997).

[2]Pigeon pipe (Snake Gulch study) soils: Hopkins and others, 1984.

[3]Snake Gulch stream sediments: Hopkins and others, 1984.

[4]Breccia pipe soils range reported for uranium mineralized features: Van Gosen and Wenrich, 1991.

[5]Crustal abundance: summarized in Smith and Logsdon (1999).

[6]Average soil concentrations: summarized in Smith and Logsdon (1999).

and clay (<53 μm) size particles and then separately analyzed each fraction. Concentrations of arsenic, cadmium, chromium, cobalt, copper, iron, manganese, molybdenum, lead, nickel, silver, thorium, tungsten, uranium, vanadium, and zinc were measured in sediment and water samples by using graphite furnace atomic absorption spectrophotometry (GFAA), flame atomic absorption spectrophotometry, and inductively coupled plasma–mass spectrometry (ICP–MS). Carver (1999) then applied statistical tests to the geochemical results in order to test the normality of the data distribution and to compare the element concentrations in stream sediments above and below the Hack Canyon Mine. Carver concluded (1999, p. 51) that "mean concentrations above the mine are equal to the mean concentrations below the mine" in the elements in which the mineralized breccia pipes of this region are typically enriched (table 5).

Some stream sediments collected upstream of the Hack Canyon Mine have copper, nickel, and zinc concentrations that exceed those in sediments sampled below the mine (table 5) and in sediments from Snake Gulch. In particular, high copper concentrations were found in some stream sediments several miles upstream of the mine. These anomalies may indicate that undiscovered, mineralized breccia pipes or stratabound copper deposits lie in the western, upper reaches of Hack Canyon. The lack of corresponding high uranium values may indicate a source other than a breccia pipe.

Two sediment samples collected at one site in the wash just below the Hack 1 Mine contained consistently elevated amounts of the elements in which the ore-bearing Grand Canyon breccia pipes are typically enriched (table 5). For example, these sediments contain as much as 2,000 ppm arsenic, 5,300 ppm copper, 276 ppm molybdenum, 1,200 ppm lead, 154 ppm uranium, and 89 ppm zinc. These high element concentrations are consistent with the geochemistry of ore and waste rock from Hack Mine operations. In contrast, stream sediments collected less than a quarter of a mile downstream from the mine contain much lower concentrations: 20.8 ppm arsenic, 43 ppm copper, <1 ppm molybdenum, 10.1 ppm lead, 3.6 ppm uranium, and 66.5 ppm zinc. The lower concentrations are interpreted to be due to dilution by detritus derived from unmineralized rock within the drainage.

Carver (1999, p. iv) noted that "trace metal concentrations were found to increase with decreasing particle size for chromium, cobalt, copper, iron, lead, manganese, thorium, vanadium, and zinc." She noted that a large fraction of the clay particles are likely to remain suspended in water during floods. Carver (1999, p. 54) further concluded that: "Clays and sediments, as opposed to dissolved species, are therefore the primary carriers for moving trace metals downstream to the Colorado River." Carver (1999, p. 49) also tested the ability of microbial organisms to capture trace elements and concluded that "the results of this experiment suggest a physical-chemical transport of trace metals rather than a biological mechanism."

The precise location of sediment samples collected from Kanab Creek does not appear to be provided in Carver (1999). A summary of Carver's results is presented in table 6. The trace element concentrations in these sediments are similar to the concentrations found both in the upper reaches of Hack Canyon and at sites several miles downstream of the Hack Mines, except for the highest concentrations of copper, nickel, and zinc above the mines.

Table 5. Summary of trace element concentrations in bulk stream sediment samples from 10 sites in Hack Canyon.

[Samples collected and analyzed by Carver (1999); sediments collected at 5 sites upstream of Hack Canyon mine complex, 4 sites downstream of the mine, and 1 site in the wash just below the mine; <, less than; ppm, parts per million; GFAA, graphite furnace atomic absorption; ICP–MS, inductively coupled plasma mass spectrometry]

Element	Analytical method	Upstream[1] (ppm)	Downstream[2] (ppm)	Wash just below Hack 1 Mine[3] (ppm)
Arsenic	GFAA	0.8–19.5	2.1–20.8	1,400 and 1,780
Arsenic	ICP–MS	1.2–11.5	0.97–8.9	1,460 and 2,000
Cobalt	ICP–MS	1.7–8.9	2.0–7.7	5.7 and 4.4
Copper	GFAA	3.8–534	0.85–97.6	162 and 24.6
Copper	ICP–MS	4.5–234	<19.5–87.9	166 and 5,320
Molybdenum	ICP–MS	<1–1.1	all <1	276 and 22.8
Nickel	ICP–MS	23.1–79.5	19.6–38.7	17.0 and 20.9
Lead	GFAA	<6.7–9.9	1.3–10.1	1,200 and 670
Uranium	ICP–MS	0.6–1.5	0.6–3.6	11.3 and 154
Vanadium	ICP–MS	3.8–35.1	6.1–24.9	10.6 and 6.8
Zinc	ICP–MS	0.5–86.8	13.7–82.8	64.6 and 89

[1]Five sites, many samples.

[2]Four sites, many samples.

[3]One site, two samples.

Table 6. Summary of Carver (1999) concentration ranges in trace elements in stream-sediment and water samples, collected at three sites near the confluence of Hack Canyon and Kanab Creek.

[ppm, parts per million; µg/L, micrograms per liter; GFAA, graphite furnace atomic absorption; ICP–MS, inductively coupled plasma mass spectrometry; n.d., element not detected (below detection limit)]

Element	Analytical method	Stream sediment concentrations[1] (ppm)	Kanab Creek water concentrations[2] (µg/L)
Arsenic	GFAA	7.2–20.8	n.d.
Arsenic	ICP–MS	4.3–7.1	n.d.–1.0
Cobalt	ICP–MS	4.8–8.9	1.65–1.8
Copper	GFAA	7.9–22.6	n.d.
Copper	ICP–MS	8.6–19.6	n.d.
Molybdenum	ICP–MS	0.3–0.4	n.d.
Nickel	ICP–MS	30.2–37.5	32.5–37.5
Lead	GFAA	7.0–16.9	n.d.
Uranium	ICP–MS	1.1–1.8	6.25–7.2
Vanadium	ICP–MS	13.2–30.2	n.d.
Zinc	ICP–MS	38.3–81.3	n.d.

[1]Six samples.

[2]Three samples.

Kanab Creek Water Samples

Three samples of Kanab Creek water showed low trace-element concentrations, and concentrations of most elements were below the detection limits of the analytical methods used (table 6). The waters had measurable concentrations of cobalt, nickel, and uranium. Uranium concentrations of the Kanab Creek water samples ranged narrowly from 6.25 to 7.2 ppm. Concentration of these elements differed little among the sampled sites (table 6).

Sampling, Sample Processing, and Analytical Methods

Soil, Stream Sediment, and Mine Waste Sampling

Between August 24 and October 7, 2009, soil, stream sediment, mined-rock waste, and rock samples were collected at six sites within the North Segregation Area, an area proposed for withdrawal in the Kanab Creek area north of Grand Canyon National Park (fig. 1). Stream sediment samples were also collected along Jumpup Canyon near Jumpup Spring (fig. 1). Procedures for collecting each of these media are described below.

Sample locations were selected before we arrived at each site on the basis of topographic maps and aerial images. The sampling plan was designed to characterize (1) compositions of material unaffected by mining (background); (2) mined rock presently on the ground surface that contains concentrations of trace elements substantially above background concentrations; (3) trace-element-enriched materials derived from mined rock that were transported by wind or water subsequent to the onset of uranium mining or reclamation. Soil samples were collected from 0–2 in. (0–5 cm) depth along traverses that crossed each site and continued beyond the extent of mining disturbance into areas that are presumed to contain materials that show background trace-element concentrations. At the time of sampling, all stream drainages crossing the mine sites were dry. Alluvial sediments from channels in these dry streams constituted the stream-sediment samples. The Pigeon Mine, Hack Mine complex, and Kanab North Mine sites contained additional surface features such as waste-rock piles, former waste-rock-pile sites identified by scattered waste rock at the surface, and current or former wastewater-pond sites. These features required additional description, mapping, and sampling beyond that employed for the background and undeveloped-mine sites.

At each soil and stream sediment sampling location, any surface litter of structured organic matter (such as leaves, needles, or twigs) or of pebbles or cobbles larger than about 1 in. (2.5 cm) in diameter were carefully removed so that the uppermost surface contained only mineral matter and sparse organic matter. Stainless steel sampling tools and sieve were "conditioned" by digging and sieving adjacent soil before collecting the samples of interest. A stainless steel trowel was used to carefully excavate the 0–5 cm depth interval and collect a composite sample of 1–2 kg in a plastic 1-gallon bucket. Stream sediments were sampled from a locality that generally included a stream reach of 50–100 ft, depending on an onsite evaluation of the availability of about 5–10 sites of sediment accumulation suitable for sampling. As we moved from site to site, subequal amounts of sediment from each site were passed through the 2 mm stainless steel sieve (after conditioning the sieve) until a sample containing at least 1 kg of <2 mm material was obtained. A second pass through each sample site was necessary at some localities to accumulate sufficient material. At mine sites, composite samples (consisting of no less than five subsamples) of near-surface (0–5 cm depth) materials from some mined waste-rock piles and from pond sediments were also collected; these composite samples were not sieved.

Each soil and stream sediment sample was placed into a clean plastic sample bag, labeled with a permanent marker, and sealed with duct tape. Dry rags and a plastic brush were used to clean sampling tools. At each sampling location, all required site and material characterization data were recorded on a sampling sheet. Careful notes, such as sketches of the sampled areas and photographs, were made to thoroughly document the area around each sample collected. An entire duplicate sample at about 1 sampling location in 10 was collected to check the reproducibility of the sampling procedure. At soil sampling sites, duplicate samples were collected from contiguous 2-in. (5-cm) -deep excavations. Duplicates at stream sediment sampling localities were collected by revisiting each of the 5–10 sampling sites and collecting materials adjacent to previous sampling points. Because mine-site material was expected to contain, relative to background materials, high concentrations of uranium and other ore-signature trace elements, mine site materials were collected separately from other less-contaminated samples. When we sampled along traverses, less-contaminated outlying areas were sampled first. All equipment was cleaned between sites that were likely to have very different concentrations of trace elements.

Sample Processing

Soil, stream sediment, and rock samples were prepared for analysis according to procedures outlined in chapter A3 (Peacock, 2002), chapter A2 (Peacock, Taylor, and Theodorakos, 2002), and chapter A1 (Taylor and Theodorakos, 2002) in "Analytical methods for chemical analysis of geologic and other materials, U.S. Geological Survey" (Taggert, 2002). Upon reaching the laboratory, the samples (as received) were air dried at 40°C, as needed. Subsequent preparation procedures took place inside a dust hood to minimize dispersion of dusts. Stream sediment samples were sieved through an 80-mesh sieve (opening equal to 177 μm). The fraction that passed through the 80-mesh sieve was split into two parts. One part was preserved for archiving and the other was pulverized to <100-mesh (<150 μm) and mixed to insure homogeneity for subsequent analysis. Soil samples, as received, were immediately split and pulverized to <100-mesh. The mine wastes and rock samples were crushed to reduce the particle size and split into two parts; one part was preserved for reference or future use, and the other was pulverized to <100-mesh. The <100-mesh fractions of soils, stream sediments, mined-rock waste, and rock were further split into two parts, one of which was archived. The other split was sent to a contract laboratory for whole-rock analysis to determine total elemental composition.

Bulk Chemical Analysis

All solid samples were analyzed by inductively coupled plasma–atomic emission spectrometry (ICP–AES) and inductively coupled plasma–mass spectrometry (ICP–MS) after acid digestion. This method is described at *http://minerals.cr.usgs.gov/projects/analytical_chem/references.html#M19* and is summarized here. Forty-two major, minor, and trace elements (reporting limits listed on the website shown above) are determined in geological materials. Each sample is digested using a mixture of hydrochloric, nitric, perchloric, and hydrofluoric acids, heated to 110°C to dryness and redissolved in nitric acid. Aliquots of the resulting solution were aspirated into the ICP–AES and the ICP–MS spectrometers. The ICP–AES is calibrated by standardizing with digested rock reference materials and a series of multi-element solution standards. The ICP–MS was calibrated with aqueous standards, and internal standards were used to compensate for matrix affects and internal drift. Data are deemed acceptable if measured concentrations of all 42 elements are within ±15 percent at five times the lower limits of determination (LOD), and the calculated relative standard deviation of duplicate samples is no greater than 15 percent.

Chain of Custody

Chain-of-custody procedures were followed for sample collection, transport, processing, and analysis. After collection, individual plastic bags containing each sample, previously sealed with duct tape, were placed into shipping containers. Shipping containers were locked and placed inside a secured vehicle or locked room that could be accessed only by USGS field personnel. Once shipping containers were filled to capacity, they were locked and prepared for transport, either by a vehicle driven by USGS field personnel or by commercial overnight delivery service. For each shipment, a chain-of-custody form was filled out that summarized the total number of samples collected of each sample medium (such as soil, surface sediment, or rock) in each shipment. Accompanying this form was a sample inventory. The individuals who shipped and received the samples signed the form as a designation of responsibility for the samples. Before shipment by the commercial overnight delivery service, boxes containing the samples were sealed with evidence tape to assure that the containers remained secure during shipment. Samples transported by the commercial overnight delivery service were hand-delivered directly to project personnel at USGS offices on the Denver Federal Center, who then verified that they received all samples listed on the inventory and then signed for the receipt of those samples. Subsequently, of all samples were processed in a secure area. Each sample was photographed as received. Processed samples were shipped to various analytical laboratories using a similar chain-of-custody shipping procedure for transport and receipt by the laboratory.

Radioactivity Surveys

Virtually all sample sites were measured with one of two Ludlum Model 19 MicroR exposure meters. Additional parts of some mine sites were surveyed without sampling. These extremely sensitive NaI scintilometers are used by health physicists to assess radiation exposure and absorbed dose (in rads) from gamma-ray and x-ray emissions. Reported gamma-ray activities in microrads (μR)/hour (h) can be

compared with the average gamma-ray dose from terrestrial sources of radioactivity (rocks or soil) of approximately 3.2 μR/h, or 28,000 μR/year (National Council on Radiation Protection Measurements, 1987). These instruments were calibrated at the U.S. Geological Survey reactor facility at the Denver Federal Center approximately one week prior to the start of field studies on August 24, 2009.

In the natural environment, these instruments measure total gamma-ray activities derived from radioactive decay products of the uranium and thorium series and of potassium-40 (^{40}K). In most natural environments, variations in the total activity can be attributed, for the most part, to variations in the uranium, thorium, and potassium content of soils and rocks. In the vicinity of uranium ore deposits, total gamma-ray activity is predominantly attributed to emissions from uranium and its decay products.

The radioactivity of the immediate vicinity (within a 1–3 m radius) was measured around each soil, stream sediment, and rock sampling site by using a microR meter placed on the ground surface at the sampled point. Additional walking surveys with continuous scans measured radioactivity along stream beds between the sampled stream reaches. Measurements were observed at waist height or, in a few instances, by placing the instrument on the ground. Similar walking radioactivity surveys along linear soil sample traverses radiating outward from sampled mine site perimeters were also performed. These walking surveys provided some estimates of the expected microR readings at measured and recorded sites and aided in the search for ore or waste rock exposed at the surface. Detailed microR surveys (without collection of soil samples) were conducted at the Pigeon and Kanab North sites. For each measurement site with or without media sampling, global positioning system (GPS) latitude, longitude, and elevation readings were recorded along with the microR measurements. Traverse lines and specific sites for soil sampling were selected using aerial photographs to avoid being influenced by soil features or changes in microR readings.

Batch Leaching

A few samples were selected for batch leaching experiments. Samples selected for leaching included unprocessed uranium ore, mined waste-rock, surface sediments thought to contain fines or salts transported by runoff from a waste pile, and background samples. The purpose of the leaching experiments was to evaluate the solubility of trace elements in these sources. In this method, two leaching solutions were used: deionized (DI) water equilibrated with the atmosphere to produce a simulated-rainwater solution (pH = 5.6, $-\log pCO_3^{2-} = 3.5$), and water containing 300 milligrams per liter (mg/L) [HCO_3^-], which is consistent with the bicarbonate concentration of the Colorado River and other surface waters and groundwaters. Two time periods (1 h and 24 h) were used in the rainwater experiments to determine the differences in trace element solubility during a short and a long rain event and to determine the soluble components of weathered mine waste.

Samples were processed by grinding and crushing, as necessary, to a size less than 2 mm; they then were mixed and split using a stainless-steel splitter to obtain a homogenous 50 g sample. Samples were then processed according to the Hageman and Briggs Field Leach Test (Hageman and Briggs, 2000), which is a modification of Environmental Protection Agency Method 1312 (Synthetic Precipitation Leaching Procedure). In summary, 50 g of a solid sample were extracted in 1,000 milliliters (mL) of deionized (18 MΩcm) water (20:1 liquid/solid ratio). New extraction vessels (Nalgene high density polyethylene 1 L bottles) were rinsed with DI water. Fifty grams of each sample was weighed and placed into the extraction vessel. One liter of DI water was slowly added to the vessel, and each vessel was capped. The extractor vessels were secured in an Analytical Testing Rotary Agitator (Model DC-20B) and rotated end-over-end at 28 revolutions per minute (rpm) for 1 h and 24 h. One replicate sample and a blank sample containing only DI water were processed with every 10 samples. At the end of the initial 24-h agitation period, a 250 mL aliquot of the mixture was poured into a centrifuge bottle and centrifuged at 5,000 rpm for 30 minutes (min) to remove mineral particles larger than approximately 0.4 micrometers (μm) from suspension. This mixture was then processed as described for the 24-h extraction with DI water.

After centrifugation, an aliquot of the supernatant liquid was taken for measurement of pH, alkalinity, and specific conductivity. The remainder of the 250-mL aliquot of sample was filtered through a 0.7-μm glass-fiber syringe filter (Nalgene PN 189-2000) in series with a 0.45-μm surfactant-free cellulose acetate syringe filter (Cameo DDE04025S0) pressurized through a 60-mL plastic sterile Luer-Lok syringe (BD P/N 309653). Filtrates were split into four 50-mL samples for chemical analysis. The 50-mL aliquot was acidified to pH 1.5 with Ultrex II Ultrapure nitric acid. One of the samples was submitted for trace element analysis using ICP–MS (Lamothe and others, 2002).

Site Investigations

Five sites were selected for study (fig. 1): Pigeon Mine, Kanab North Mine, Kanab South drill site, Hermit Mine, and Hack Mine complex (Hack Canyon and Hack 1, 2, 3 Mines). A stream-sediment survey was conducted along Jumpup Canyon near Jumpup Spring in an unmined area of the North Kaibab Ranger District to estimate background concentrations of trace elements in stream sediments. The Pigeon Mine is a fully reclaimed site in a small unnamed canyon that is a tributary of Snake Gulch. The Kanab North Mine is a mine site on standby with substantial quantities of mined waste rock stored on the ground surface. The site lies on a plateau within a few hundred feet of the cliff on the west side of Kanab Creek. The Kanab South pipe is located along a drainage tributary to Kanab Creek and is a few hundred yards from the cliff on the west side of Kanab Creek. The amount of ore identified by drilling the deposit was insufficient to support mine development. The drilling roads and pads were reclaimed. The Hermit

Mine is a completely reclaimed site on a gently rolling plateau surface. The Hack Mine complex is in the upper part of Hack Canyon 8 to 9 mi west of Kanab Creek. Each of these sites is distinct and has different exposure to wind and floods, volume and grade of mined ore, and length of time that ore and waste materials have been exposed at the surface.

The trace elements considered during this study are arsenic (As), cadmium (Ca), cobalt (Co), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), thallium (Tl), uranium (U), vanadium (V), and zinc (Zn). These elements include those of significant environmental concern and elements known to be present in breccia-pipe uranium ores at concentrations substantially greater than in the surrounding rock.

Jumpup Canyon

Jumpup Canyon is a major eastern tributary to Kanab Creek (fig. 1). It drains much of the west-central part of the Forest Service land in which it is located. This area was withdrawn as a wildlife refuge in the early 1900s and, although early prospectors likely investigated the area, there has been no reported exploration and mineral development for 100 years. Billingsley and others (2008) mapped a few collapse structures and one breccia pipe in areas around the lower part of Jumpup Canyon.

The geology along the sampled part of the canyon consists of a flat-lying Permian section with the plateau capped by the Harrisburg Member of the Kaibab Formation. Exposed in the canyon wall below the Harrisburg Member are, in order, the Fossil Mountain Member of the Kaibab Formation; the Woods Ranch, Brady Canyon, and Seligman Members of the Toroweap Formation; and the Hermit Formation. Above the Hermit Formation, the Coconino Sandstone is mostly absent, but it is found as a thin unit in a few locations along the canyon wall. The Hermit Formation is mostly covered by talus and colluvium on the canyon slopes. The Coconino Sandstone and Hermit Formation are common hosts for uranium in breccia pipes (Billingsley and others, 2008). Above and near Jumpup Spring, terrace gravels are deposited along the east canyon wall.

Nine stream sediments were sampled along Jumpup Canyon from a point about 5,800 ft upstream from Jumpup Spring to a point about 6,300 ft downstream (fig. 1). A tenth sample was taken in the lower part of Pine Hollow, which joins Jumpup Canyon at the spring. Water from Jumpup Spring was sampled during the companion study led by Don Bills and others (this volume). One sediment sample, taken just downstream from Jumpup Spring, consists of black, organic muck from the downstream end of a small pool of water fed by Jumpup Spring. The uranium concentration in stream sediment samples along Jumpup Canyon and its tributary ranged from 1.6 to 1.9 ppm, and the uranium concentration in the black organic-muck sample was 2.9 ppm.

The average, median, and range for trace element concentrations in 9 of the 10 Jumpup Canyon stream sediment samples (excluding the muck sample) are given in table 7. The median concentrations are considered background concentrations for stream sediments in this study. The tenth sample, the organic muck below Jumpup Spring, was slightly enriched in uranium (2.9 ppm) and contained anomalously high concentrations of copper (66.6 ppm), nickel (23 ppm), and zinc (362 ppm). MicroR measurements for all sample sites along Jumpup Canyon ranged narrowly from 4 to 5 μR/h.

Pigeon Mine

Pigeon Mine lies in a small wash north of Snake Gulch, an eastern tributary to Kanab Creek (figs. 1, 5). The center of the mine site is located at 36°43'27.35" N. latitude and 112°31'40.80" W. longitude at an altitude of 5,210 ft above sea level (asl). The center is about 165–200 ft below the adjacent plateau surface to the west, north, and south. Gullies feed radially towards the center of the collapse feature from three sides, and a narrow ridge to the southeast separates the pipe from an adjacent wash. A wash exits the pipe area to the south then turns sharply east to join the adjacent wash (fig. 5). The geologic unit at the surface is the Harrisburg Member of the Kaibab Formation (Billingsley and others, 2008).

The pipe was discovered in 1980. The site was prepared and developed from 1982 to 1984, and mining began in December 1984. The pipe was mined out in late 1989 and reclamation begun. Production totaled 5.7 million pounds U_3O_8 at an average grade of 0.65 percent from 439,400 tons of ore (Pool and Ross, 2007). During mining operations a shaft was dug into the pipe (fig. 6) on the slopes of the small wash, and a mine-site pad was established adjacent to the shaft. Two areas were cleared for site operations on the plateau to the north (fig. 6). One, centered at 36°43'43.82" N. latitude and 112°31'47.90" W. longitude, was the location of mine operation buildings and ore and mined waste-rock piles. This area, here referred to as the operations site, is about 480 × 340 ft; the long dimension is oriented northeast. Waste-rock and ore piles were at the surface of the operations site for a maximum of 5 years. The second area, centered at 36°43'52.21" N. latitude and 112°31'45.07" W. longitude, is a 400 × 400 ft square that contained wastewater ponds.

Table 7. Range, average, and median concentrations of trace elements in stream sediment from Jumpup Canyon.

[ppm, parts per million]

Element	Range (ppm)	Average (ppm)	Median (ppm)
Arsenic	4–5	4.6	5
Cadmium	0.2–0.4	0.3	0.3
Cobalt	3.3–5.0	4.2	4.4
Copper	9.3–18.7	12.9	12.5
Molybdenum	0.61–1.0	0.78	0.74
Nickel	7.9–12.5	10.3	10.9
Lead	10.1–14.6	12.4	12.5
Antimony	0.38–0.56	0.47	0.47
Thallium	0.3–0.4	0.31	0.3
Uranium	1.6–1.9	1.7	1.7
Vanadium	23–32	29	29
Zinc	32–53	42	41



Figure 5. Pigeon Mine site (in small wash); view to northeast. Surface of Pigeon breccia pipe is pale reddish-brown, a color derived from material used to cover mined waste rock throughout the site. Boulders mantle reconstructed drainages in the pipe. (Photograph courtesy of Don Bills, U.S. Geological Survey, Flagstaff, Arizona. Taken August 25, 2009.)

Reclamation has been completed. Within the wash, land surface that was altered during mining was recontoured and is covered with a mix of local soil and rock and gravel from the local county gravel pit (fig. 7). The surface was revegetated, but a few areas support little new growth. Breccia crops out in the covered area. A small gully has eroded the surface of the covered area, but it does not appear to have penetrated buried waste rock (if any is present). The principal gullies draining the site were reconstructed, and large boulders were placed along the channels to control erosion. The haul road was regraded within the wash; it is covered with boulders, here and on the adjacent plateau, to discourage travel. The operations and wastewater pond sites on the nearby plateau were cleared, regraded, and revegetated (fig. 8).

Pigeon Mine was the site of the following USGS studies:

- Soil and mined waste-rock sampling of the cover area within the mine site;
- Soil sampling on the adjacent plateau and hillslope areas;
- Stream sediment sampling within the pipe area and along the wash immediately to the east;
- Soil and waste-rock sampling along two traverses across the former mine operations and mined waste-rock storage pile site;
- MicroR readings at each of the soil and stream sediment sites listed above;
- MicroR readings across the site of the former wastewater ponds; and
- Detailed microR readings and sampling on the east slope of the narrow ridge separating the mine site from the adjacent wash. This area contains exposed, mined waste rock that has been transported downslope (fig. 7).

Geochemical data for soil, stream sediment, rock, and mined waste-rock samples are shown on separate map series for the mine site and for the operations site; data for uranium, arsenic, cadmium, antimony, cobalt, copper, lead, molybdenum, nickel, vanadium, zinc, and thallium is presented (figs. 9*A*–*X*). No samples were collected across the waste pond site, but radioactivity was measured in that area.

Soil samples collected across the surface of the reclaimed area of the pipe have uranium concentrations that range from 2.2 to 8.1 ppm, except for two samples that contain 68 and 79.1 ppm uranium (fig. 9*A*, n=26; samples GC09PS50–75a). The average and median concentrations of 9.6 and 4.4 ppm uranium, respectively, show the effect of two high-concentration samples. These latter samples likely represent soil contaminated by partly exposed waste material. The uranium content of the cover material is thus about 4.4 ppm. Along the reclaimed area's southeast margin, the edge of the gravel cover allows underlying mined waste rock to be exposed along a short section of the crest of the ridge (fig. 7). Owing to distinctive reddish to yellowish colors of slope wash derived from the mined waste rock, which are distinct from the pale reddish-brown



Figure 6. Pigeon Mine during operation; waste-rock piles and wastewater ponds placed on plateau surface. Operations offices were to the left of waste-rock pile. (Photograph courtesy of Denison Mines, Fredonia, Arizona.)

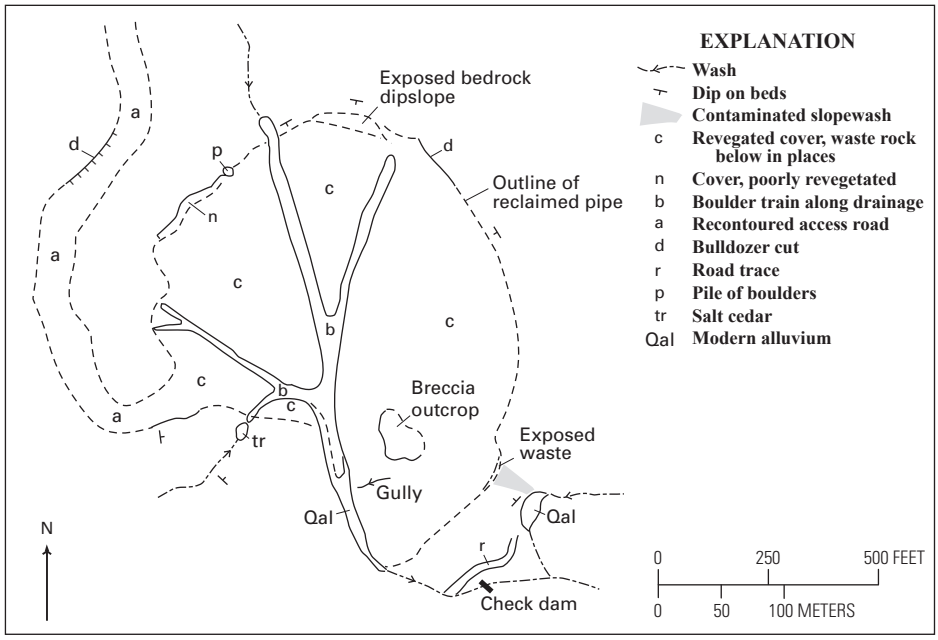


Figure 7. Pigeon pipe showing reclaimed pipe area and related features.

color of the natural soils, this material can be traced downslope from the ridge crest to the edge of the stream channel. One sample of the slope wash contained 20.4 ppm uranium, and a sample of the exposed waste rock contained 171 ppm uranium (fig. 9*A*, table 8).

Concentrations of uranium in soil samples on adjacent hilltops and slopes outside of the reclaimed pipe area range from 3.2 to 36.6 ppm and average 9.5 ppm (median, 6.3 ppm) (fig. 9*A*, n=16; table 8, samples GC09PS01–16). All soil samples that contained uranium concentrations exceeding 7 ppm were collected on the east side of the pipe. The two highest uranium concentrations (26.5 and 36.6 ppm) (fig. 9*A*; table 8, samples GC09PS06–7) were found on the hillslope close to the eastern edge of the pipe. These two sites are downslope from the ridge crest where it is several tens of feet to the east of the bedrock contact with the pipe and the reclaimed area. Slope wash derived from mined waste rock could not have contributed to the uranium content of these soils because of their physical location relative to mine operations. These concentrations are clearly anomalous when compared with regional soil samples from the 12-quadrangle part of the NURE HSSR study (mean 2.4 ppm uranium) and the median concentration of the present-day soil cover (4.4 ppm). These data suggest that windblown dusts from the site may have contributed uranium to soils during mine operations. The ratio of arsenic to uranium in these two soil samples is about 2:1, similar to the average ratio of arsenic to uranium in mine waste samples collected from the site (table 8, samples GC09PW01, -W02, -W03, -W101, -R75 and -R76). A single soil sample taken from a hillslope across the stream to the east contained 11.1 ppm uranium (fig. 9*A*; table 8, sample GC09PS08,). This sample may also be contaminated by windblown dust, but other highly anomalous trace elements are present in this sample—arsenic (393 ppm), silver (2 ppm), molybdenum (96.7 ppm), and zinc (254 ppm). The arsenic/uranium ratio is much higher in this soil sample (35:1) than in the two samples discussed previously. This soil sample also contained 3.62 percent iron, three times the average of the other 15 soil samples (1.21 percent). Examination of bedrock exposed in the small drainage revealed several irregularly shaped, crosscutting zones of resistant, limonite-cemented sandstone, some of which have radioactivity levels above background. Similar limonite-cemented sandstone occurs near the Kanab South pipe. These zones may have been formed by fluids circulating near the pipe during ore formation; they occur along the ridge where this soil sample was collected and are the most likely source of iron.

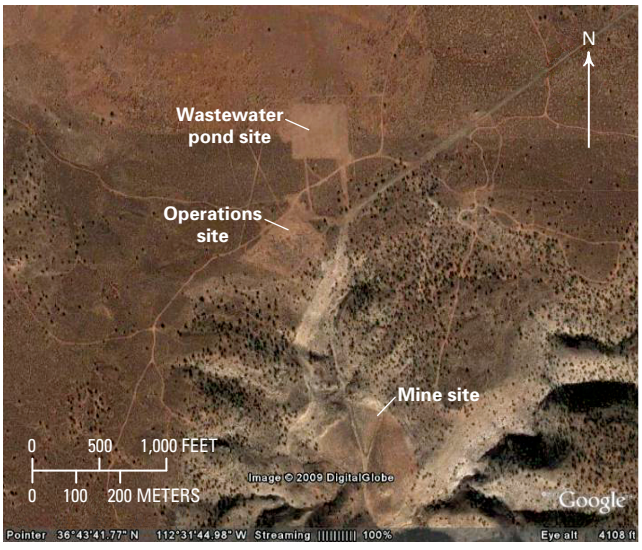


Figure 8. Former Pigeon Mine site, showing reclaimed operations area, waste-water ponds, and mine area.

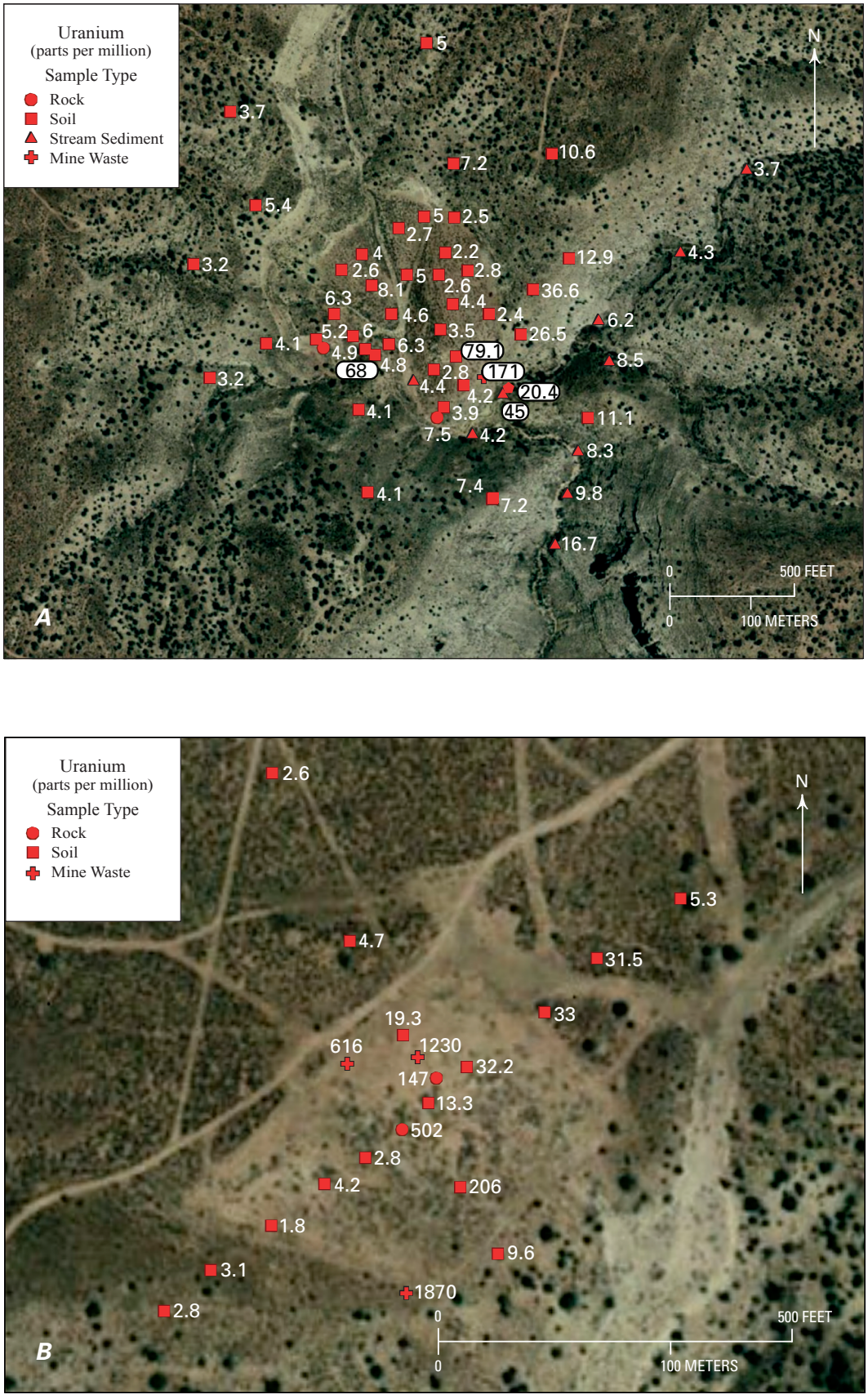


Figure 9. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Uranium concentration at mine site (*A*) and operations site (*B*).

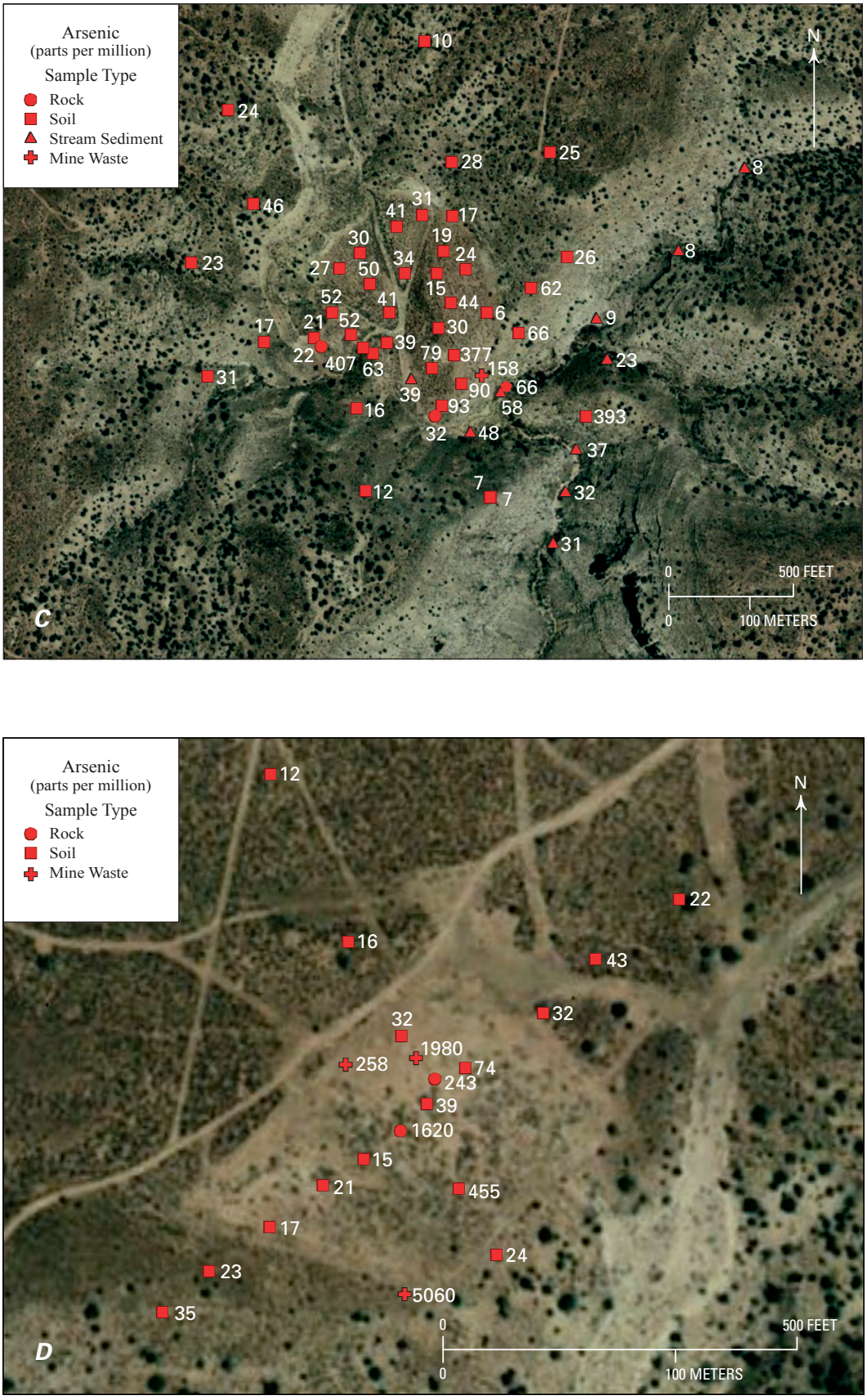
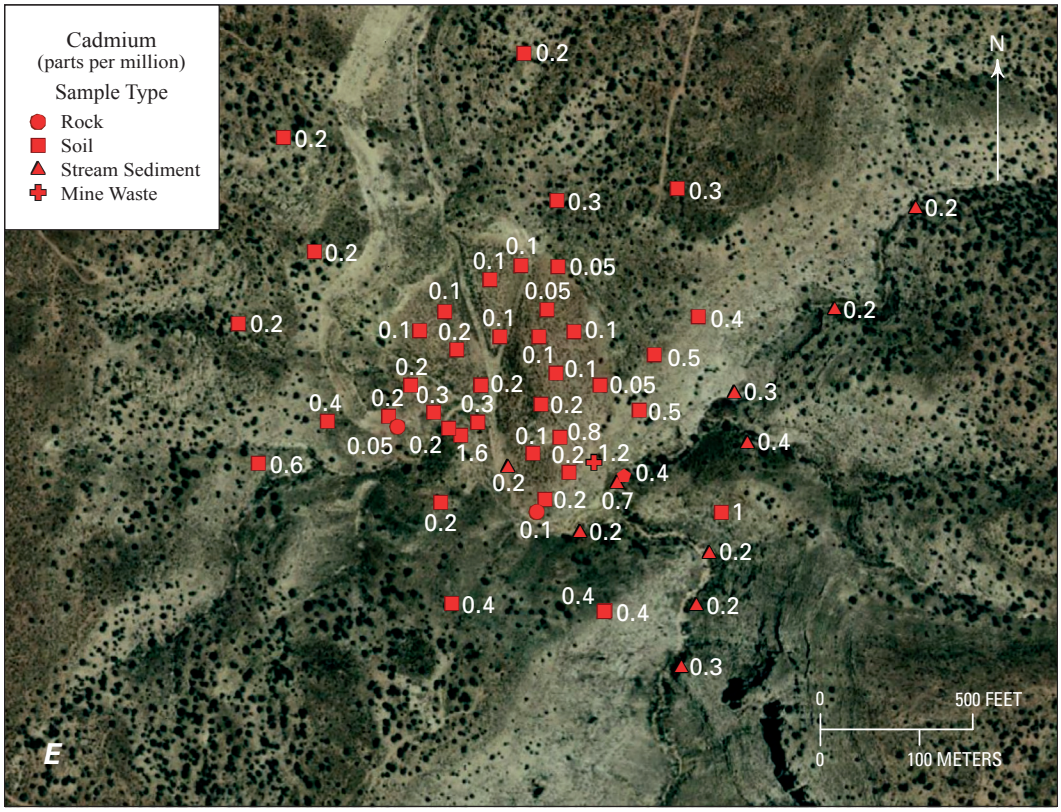


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Arsenic concentration at mine site (*C*) and operations site (*D*).



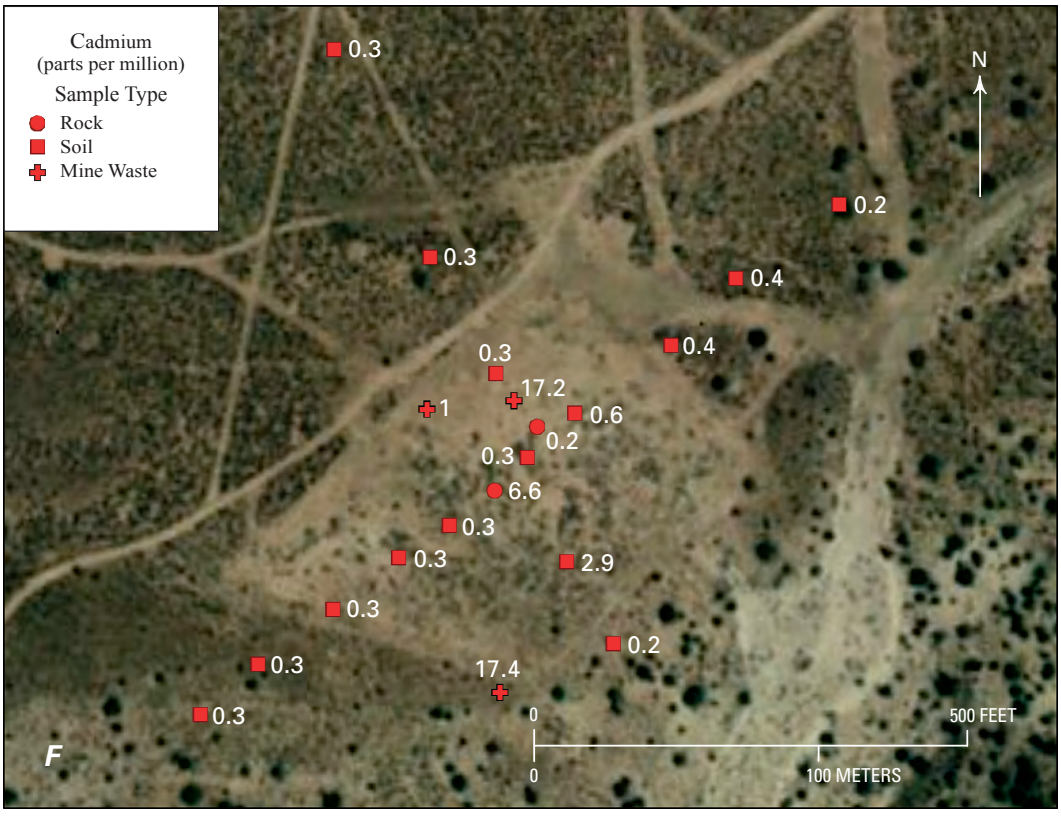
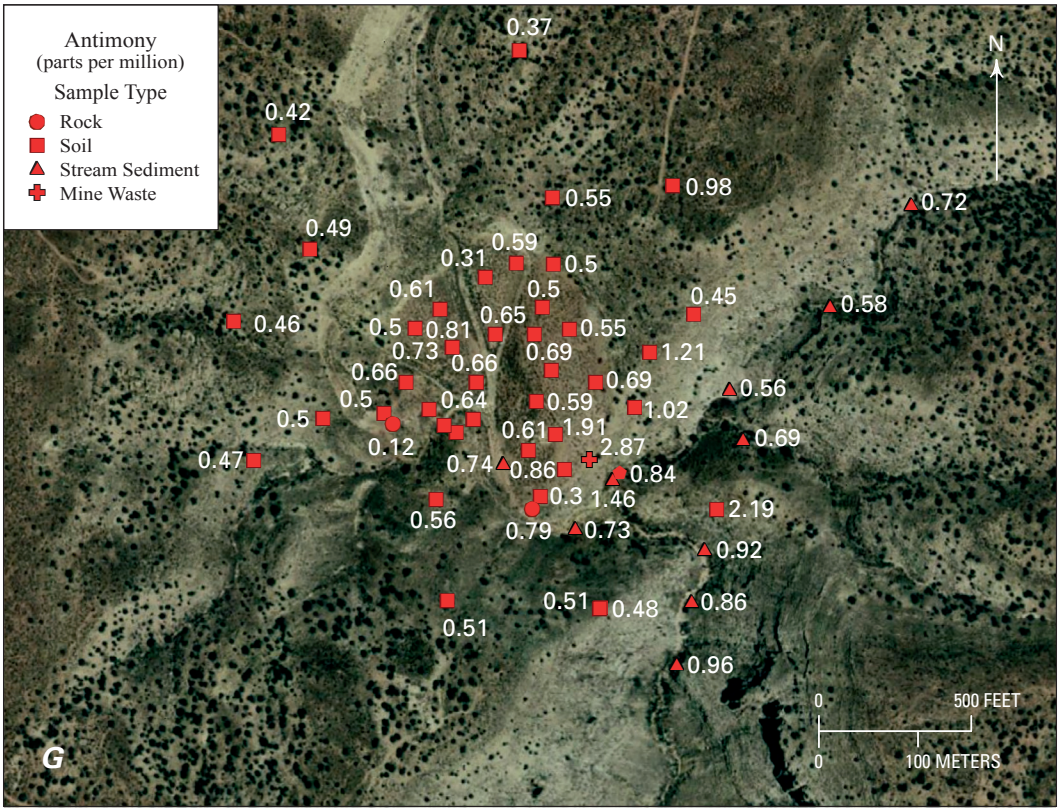


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Cadmium concentration at mine site (*E*) and operations site (*F*).



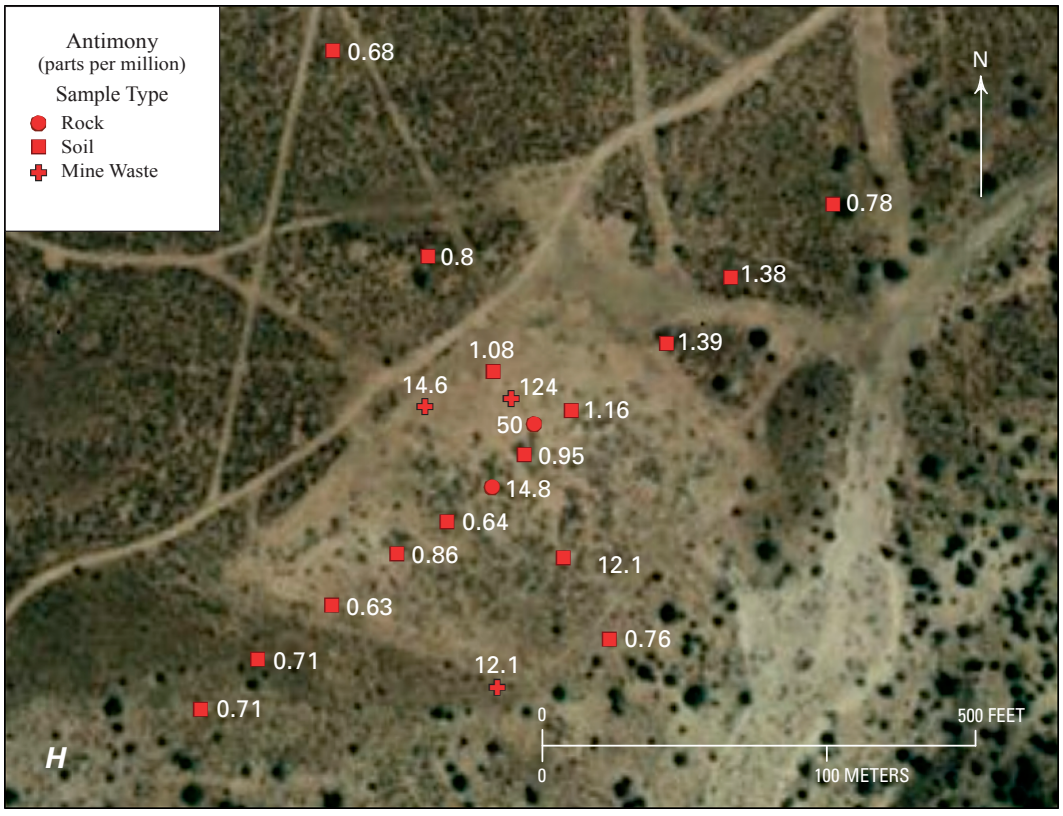
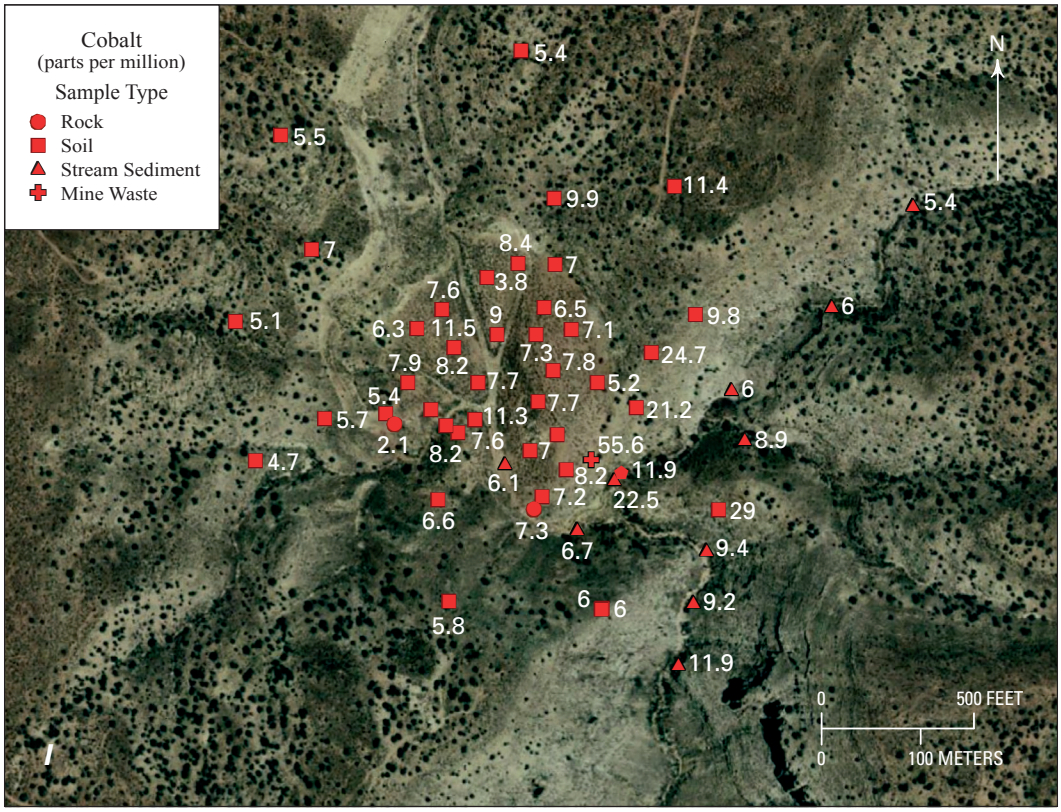


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Antimony concentration at mine site (*G*) and operations site (*H*).



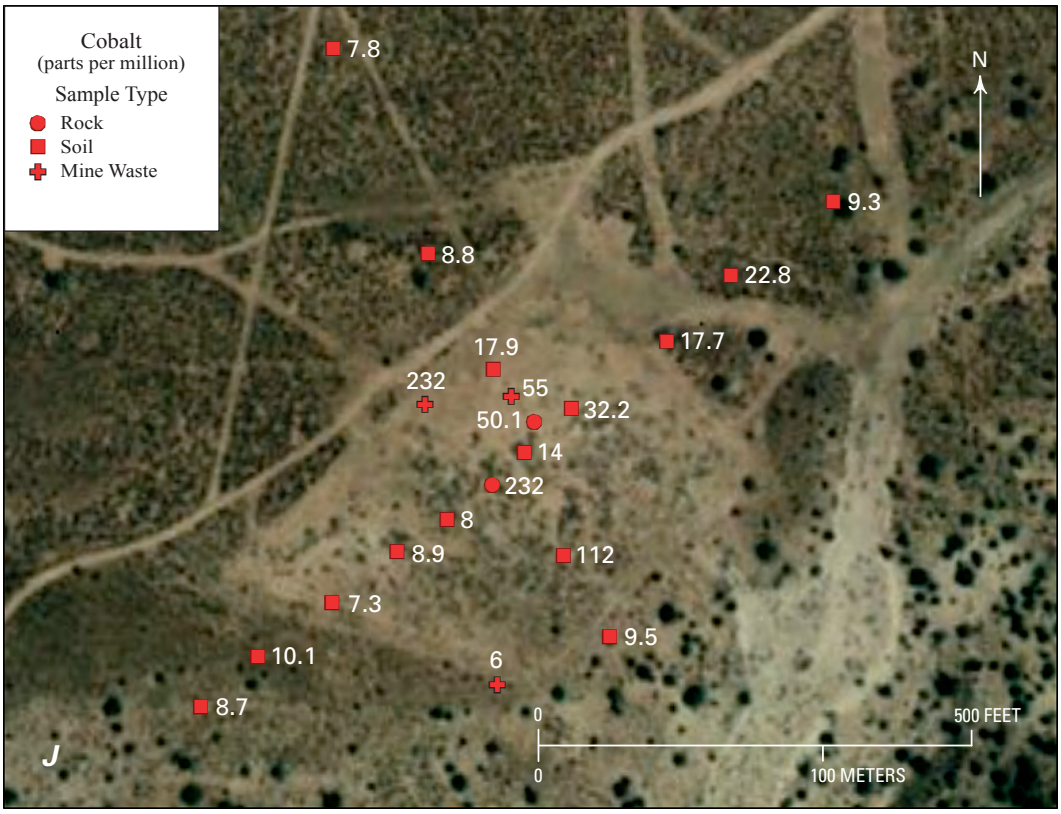
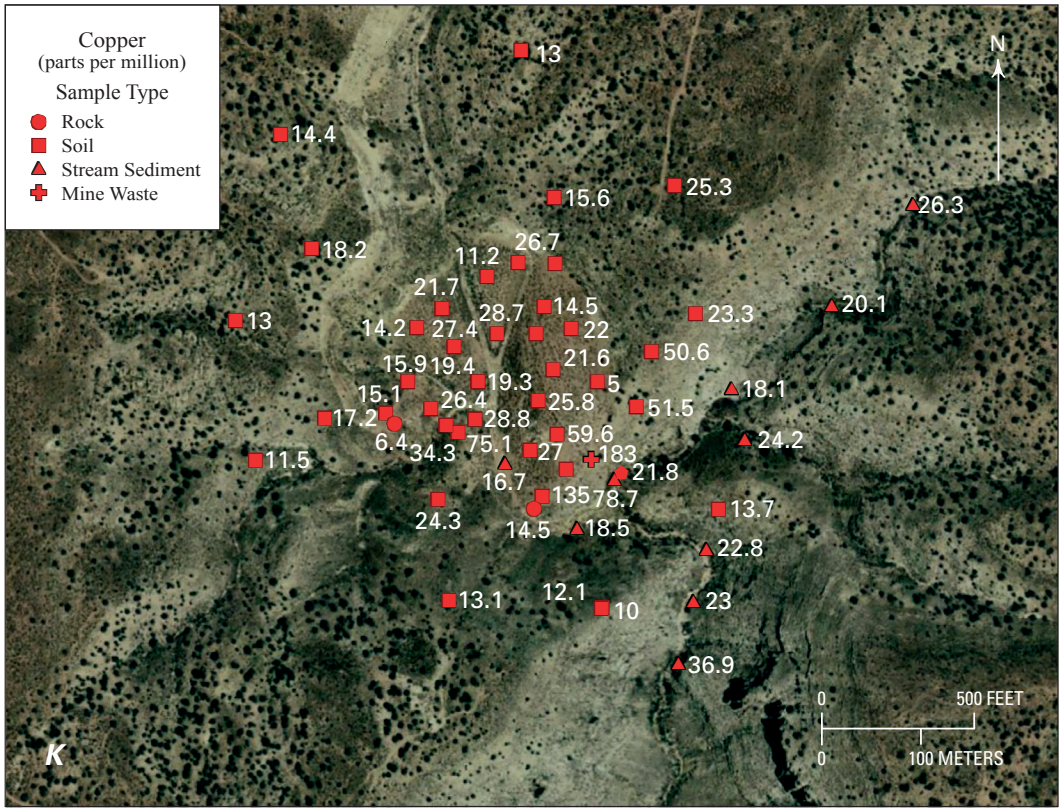


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Cobalt concentration at mine site (*I*) and operations site (*J*).



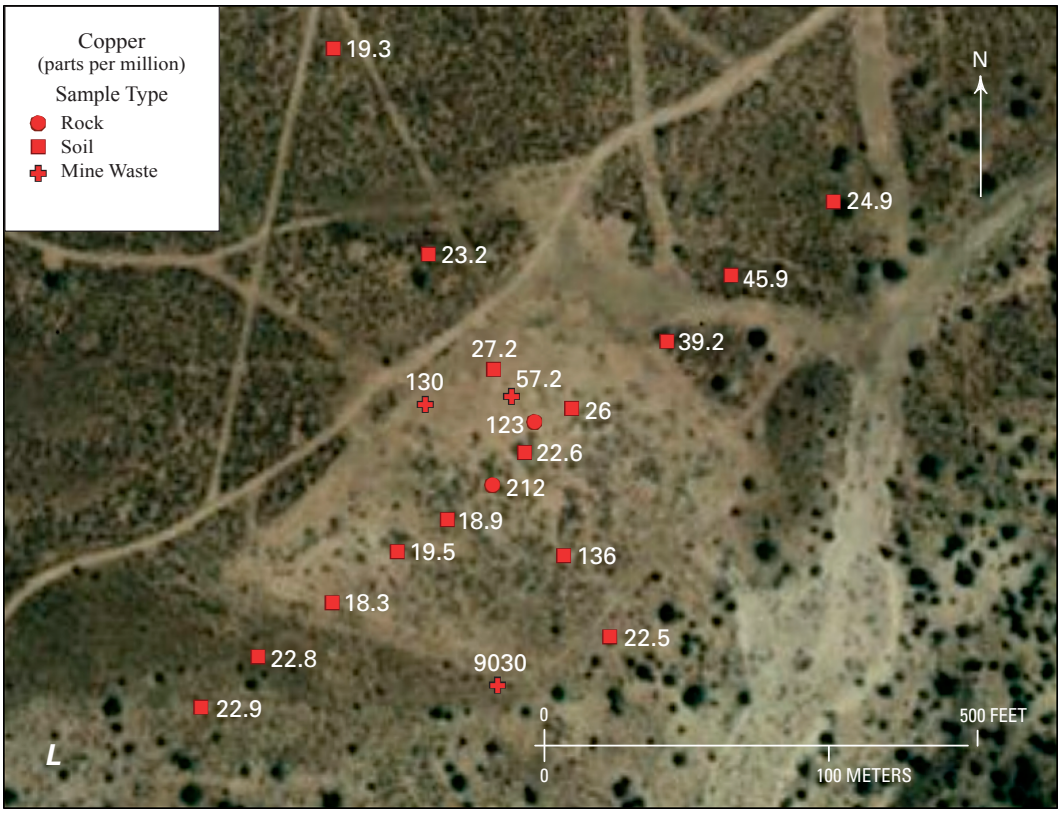


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Copper concentration at mine site (*K*) and operations site (*L*).

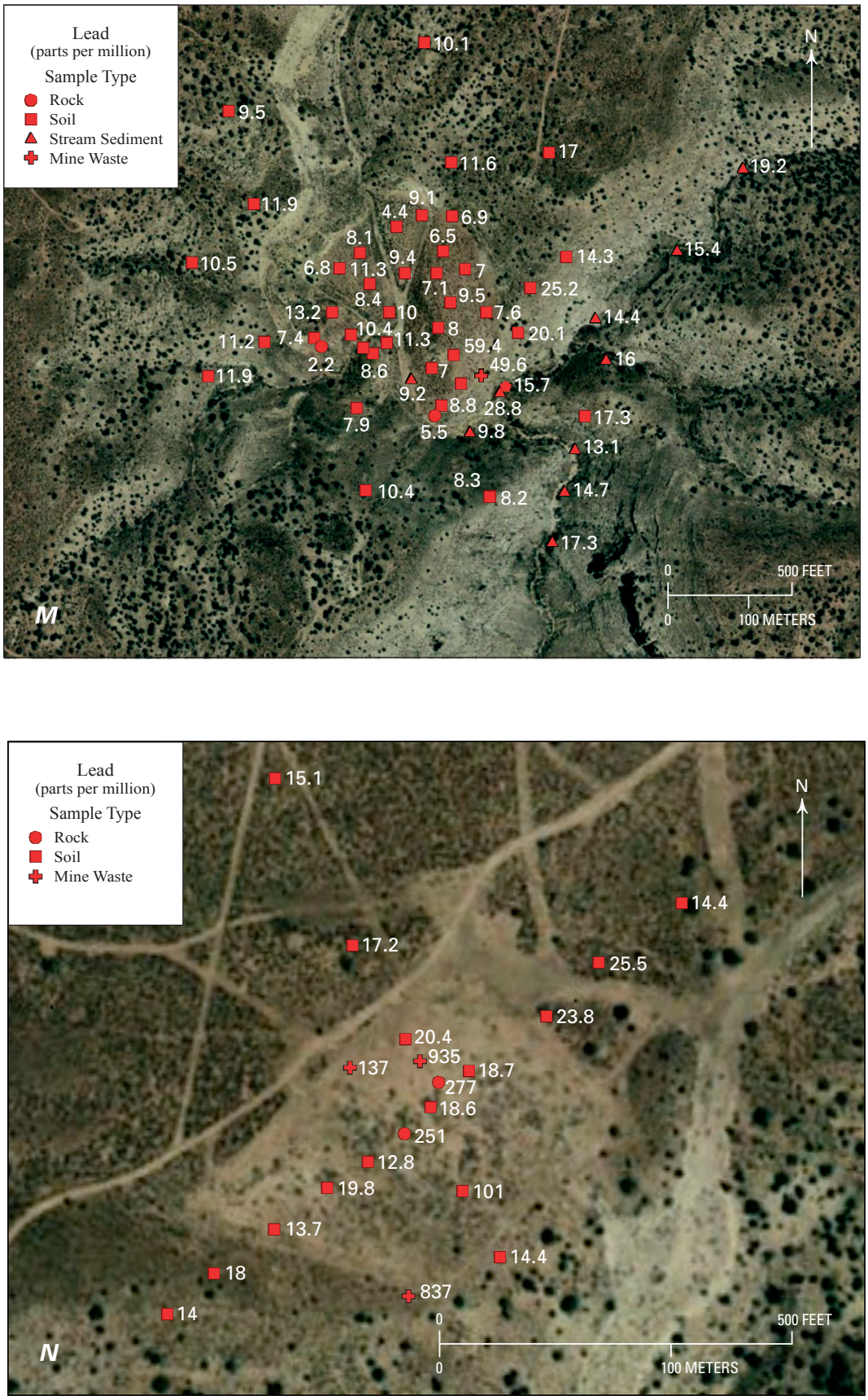
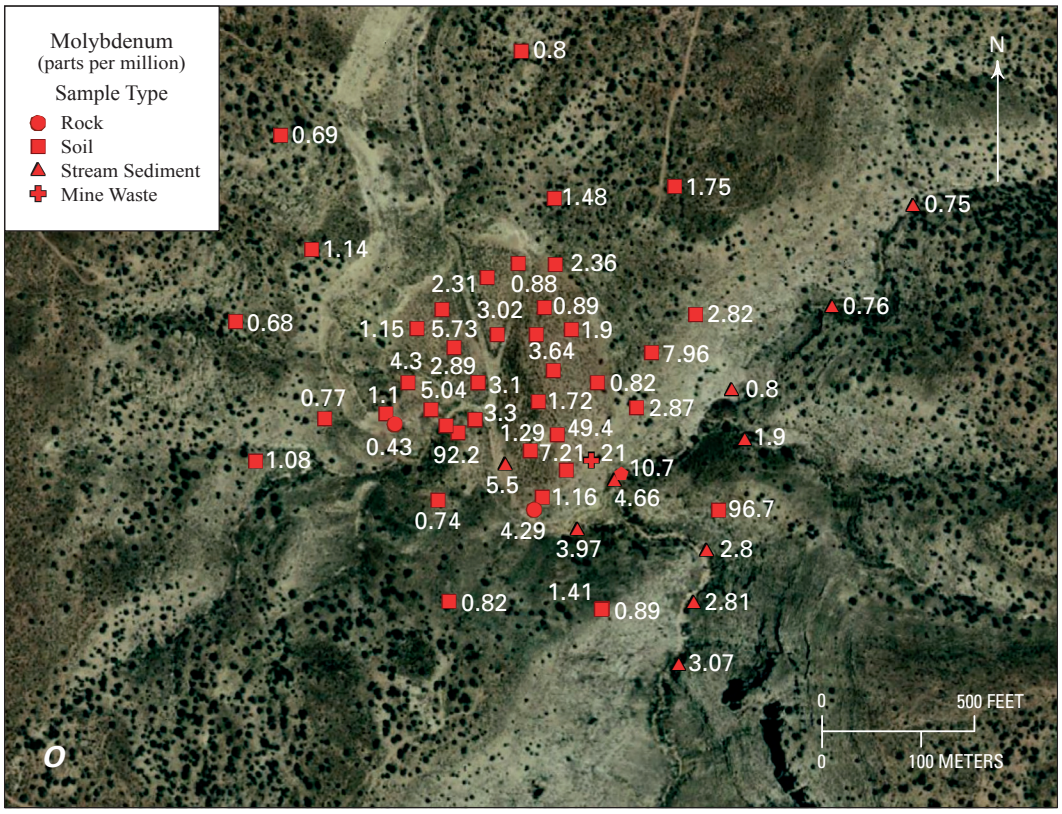


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Lead concentration at mine site (*M*) and operations site (*N*).



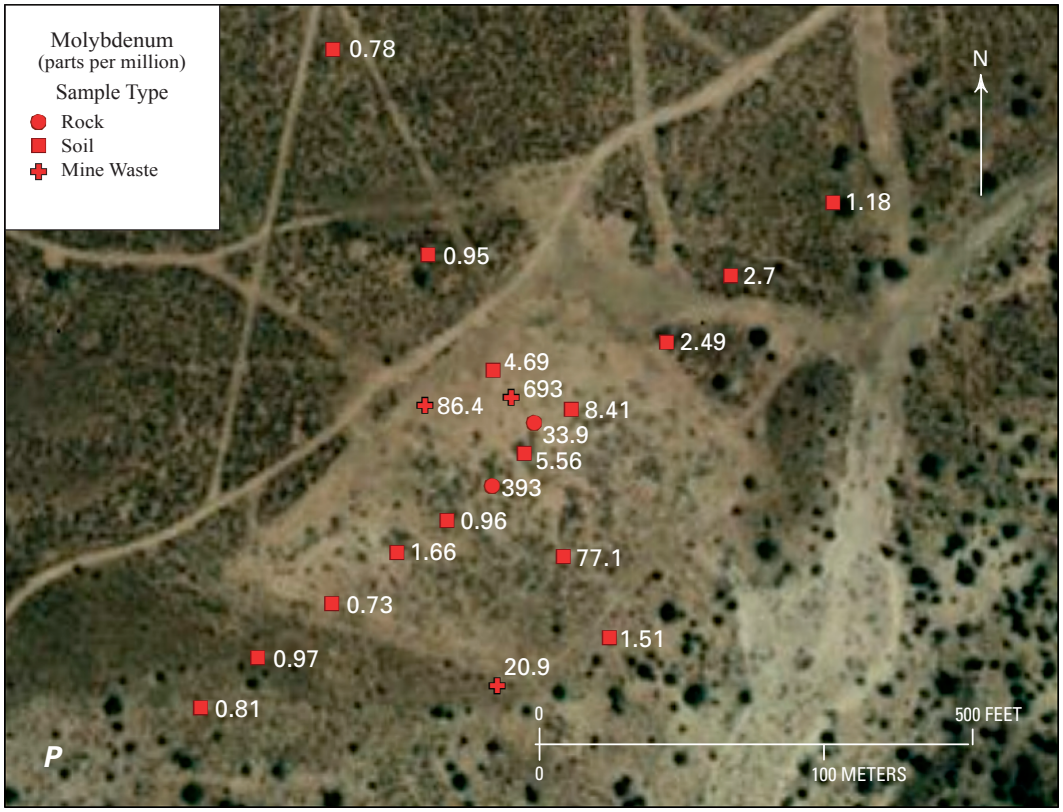
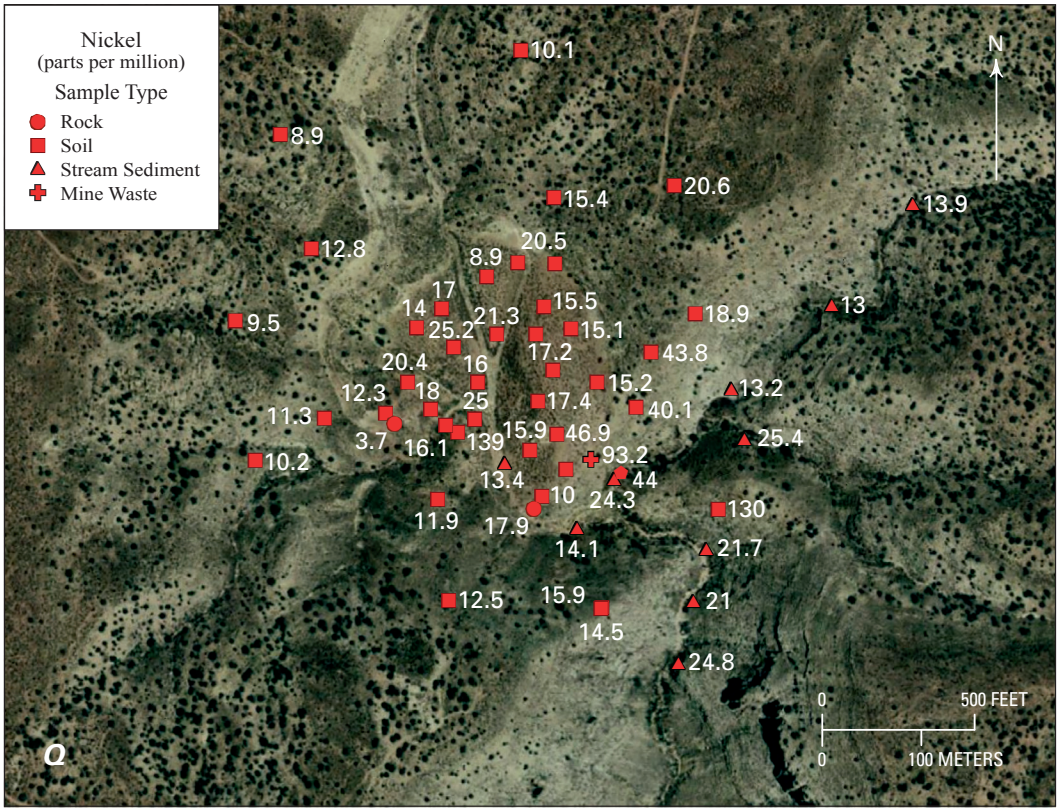


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Molybdenum concentration at mine site (*O*) and operations site (*P*).



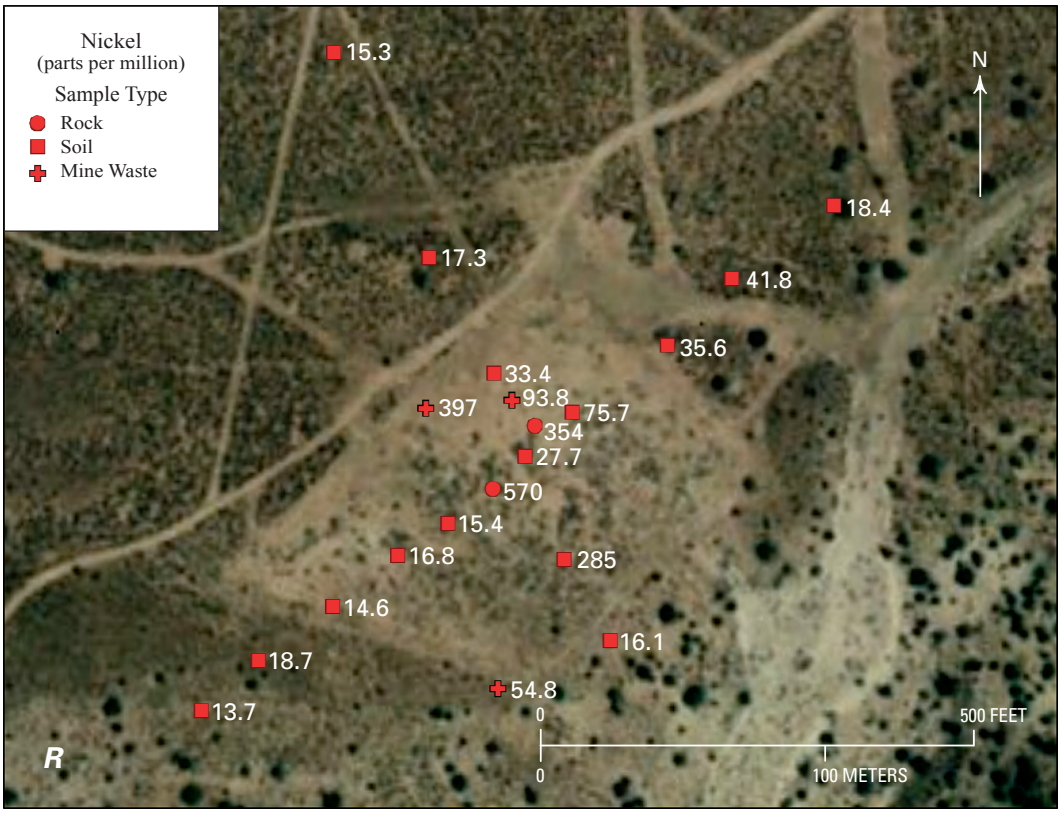
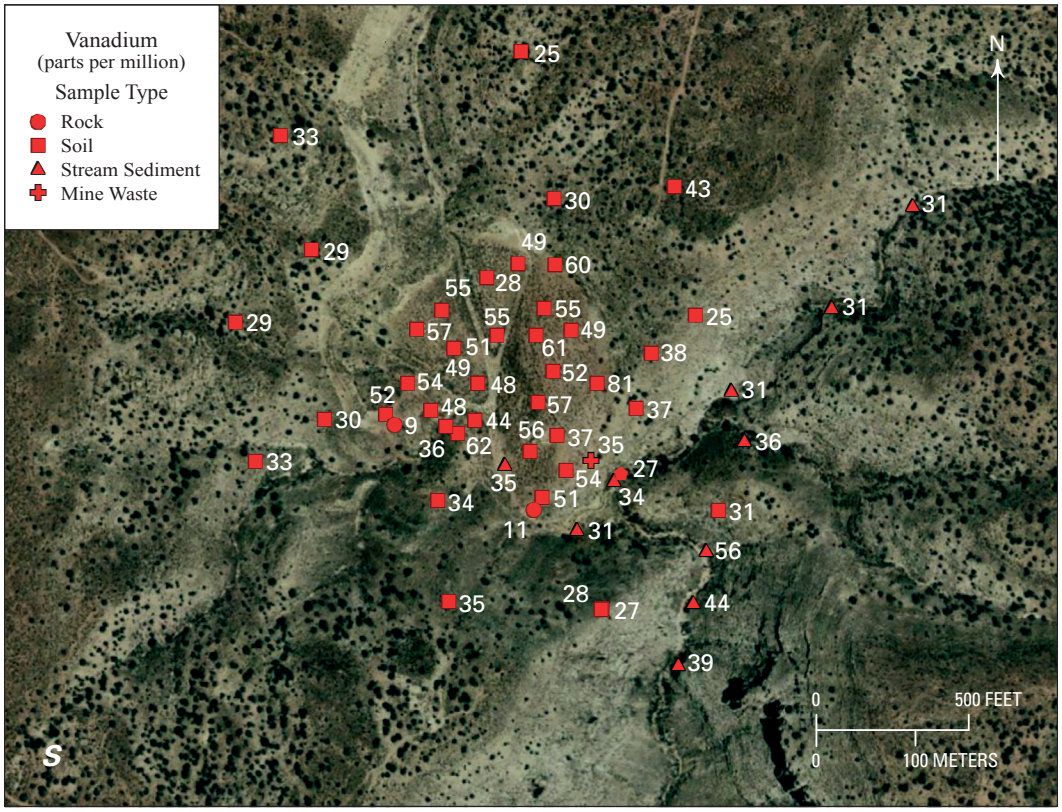


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Nickel concentration at mine site (*Q*) and operations site (*R*).



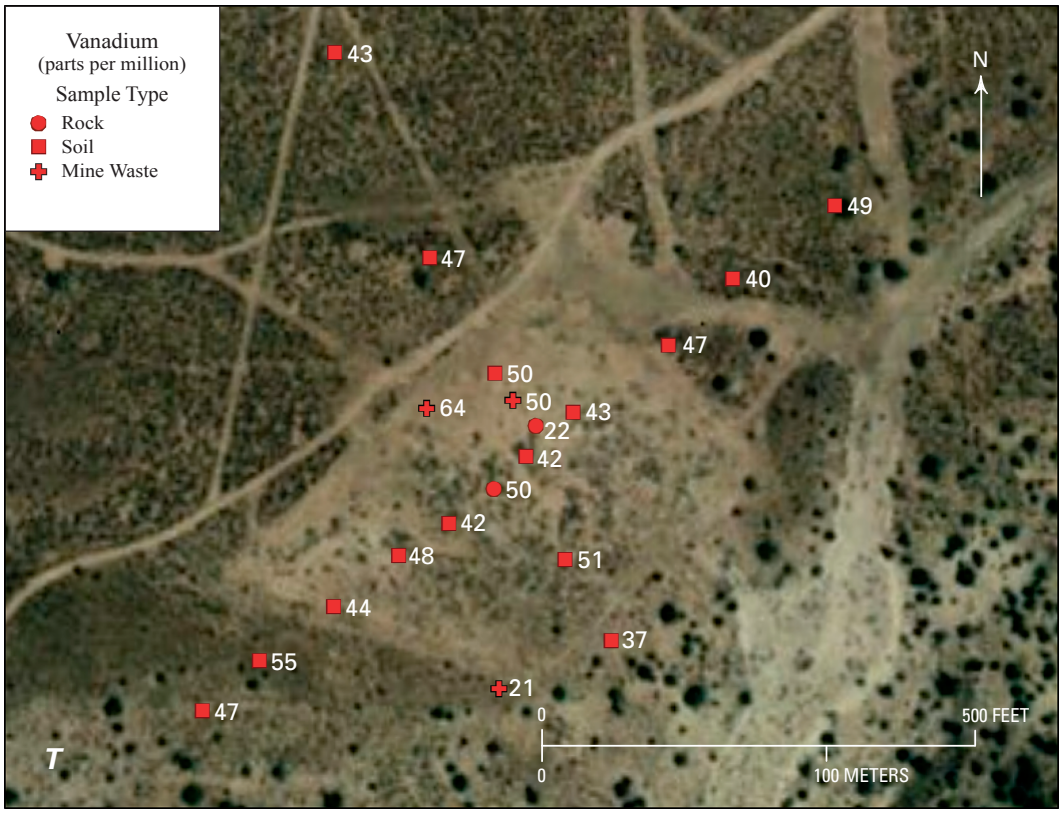
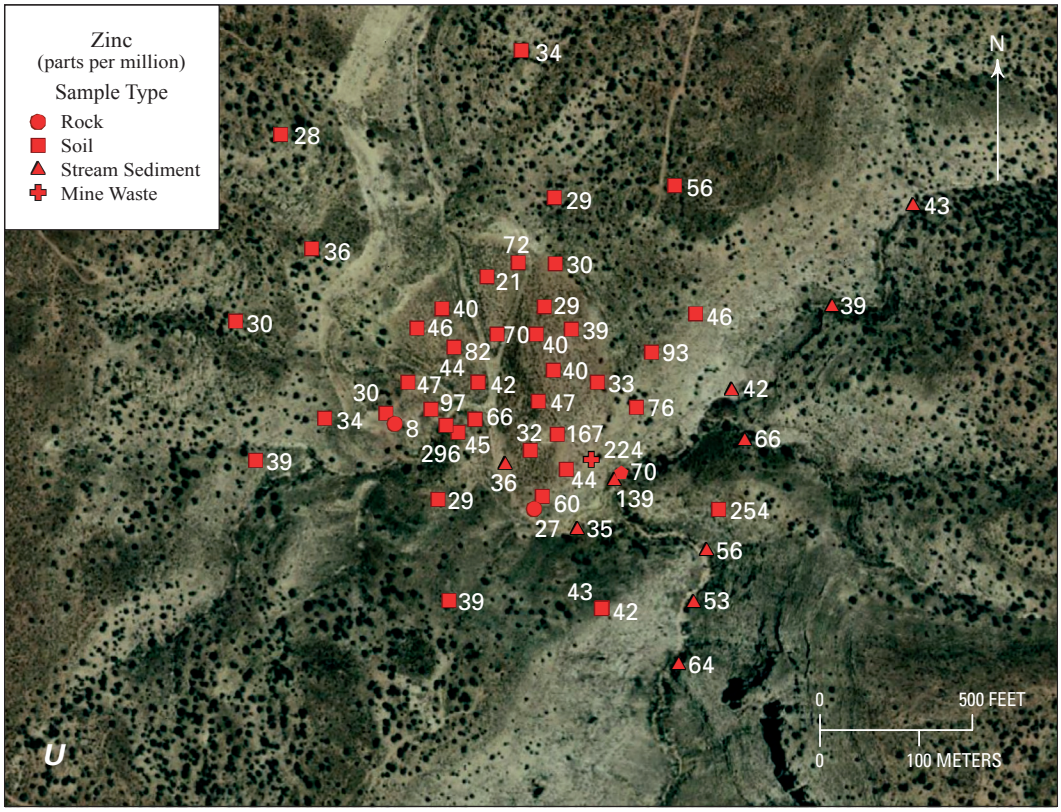


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Vanadium concentration at mine site (*S*) and operations site (*T*).



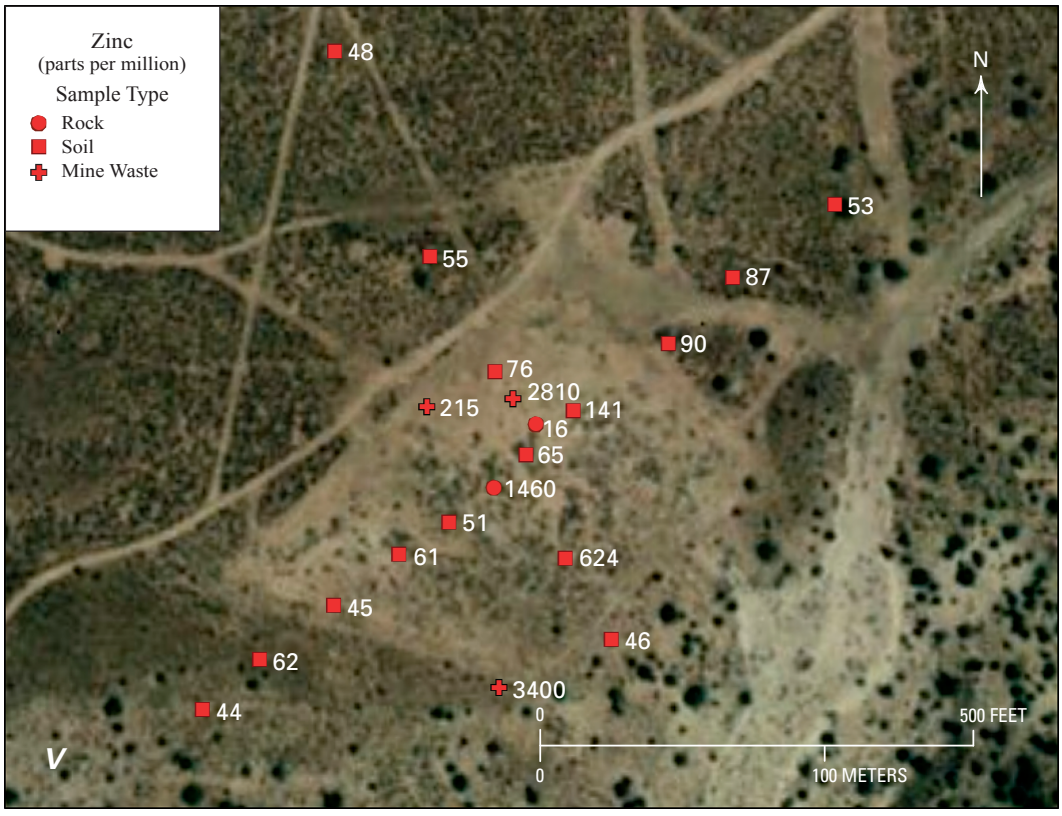
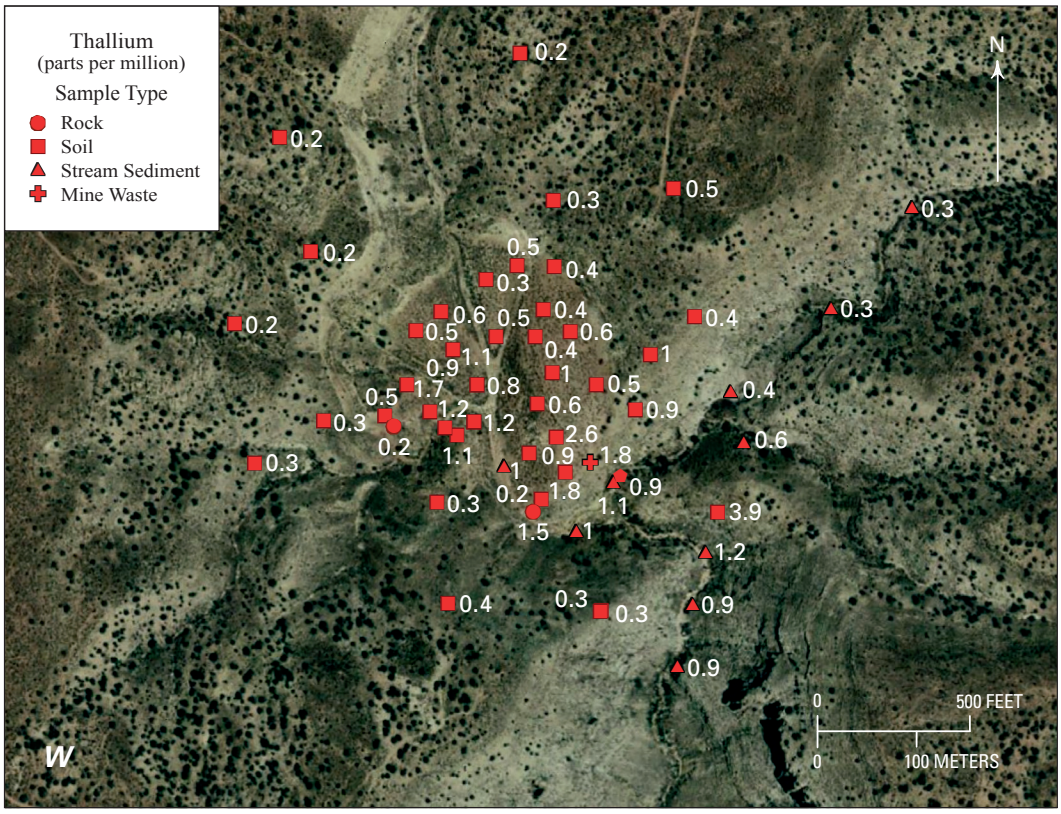


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Zinc concentration at mine site (*U*) and operations site (*V*).



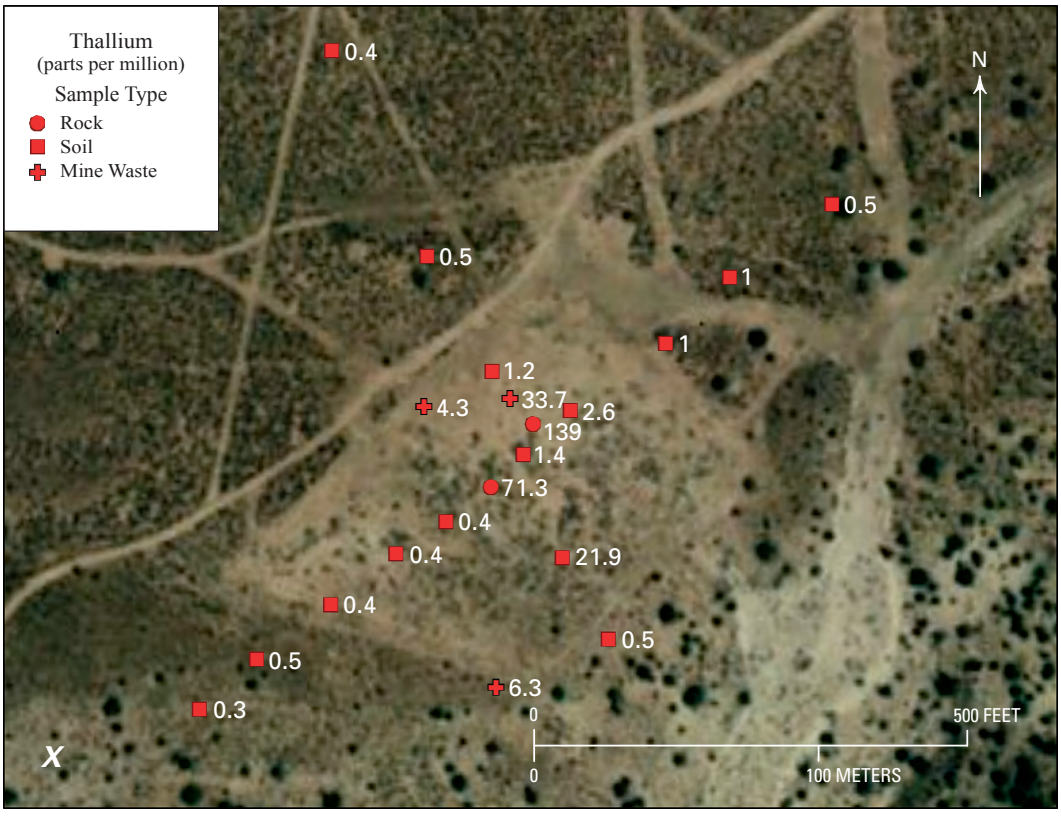


Figure 9—Continued. Concentration of selected elements in soils, stream sediments, waste rock, and rock samples at Pigeon Mine site. Thallium concentration at mine site (*W*) and operations site (*X*).

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study. Description of major, minor, and trace element data from samples collected at Jumpup Canyon, Pigeon, Kanab North, Kanab South, Hermit, and Hack Canyon sample sites.

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Sample medium	Latitude	Longitude	Description of sample site	Sample site
GC09JSS50	Sediment	36.59117	–112.53754	Stream sediment upgradient from Jumpup Spring	Jumpup Canyon
GC09JSS51	Sediment	36.58704	–112.54138	Stream sediment upgradient from Jumpup Spring	Jumpup Canyon
GC09JSS52	Sediment	36.58256	–112.54688	Stream sediment upgradient from Jumpup Spring	Jumpup Canyon
GC09JSS53	Sediment	36.58005	–112.54400	Stream sediment upgradient from Jumpup Spring	Jumpup Canyon
GC09JSS54	Sediment	36.58102	–112.54704	Stream sediment upgradient from Jumpup Spring	Jumpup Canyon
GC09JSS05	Sediment	36.58089	–112.54758	Organic muck in pond just downgradient from Jumpup Spring	Jumpup Canyon
GC09JSS01	Sediment	36.56663	–112.56202	Stream sediment downgradient from Jumpup Spring	Jumpup Canyon
GC09JSS02	Sediment	36.56976	–112.55717	Stream sediment downgradient from Jumpup Spring	Jumpup Canyon
GC09JSS03	Sediment	36.57292	–112.55304	Stream sediment downgradient from Jumpup Spring	Jumpup Canyon
GC09JSS04	Sediment	36.57605	–112.55054	Stream sediment downgradient from Jumpup Spring	Jumpup Canyon
GC09PS50	Soil	36.72530	–112.52762	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS51	Soil	36.72491	–112.52775	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS52	Soil	36.72467	–112.52784	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS53	Soil	36.72434	–112.52765	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS54	Soil	36.72406	–112.52783	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS55	Soil	36.72423	–112.52716	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS56	Soil	36.72320	–112.52780	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS57	Soil	36.72344	–112.52752	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS58	Soil	36.72362	–112.52792	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS59	Soil	36.72376	–112.52762	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS60	Soil	36.72471	–112.52745	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS61	Soil	36.72391	–112.52854	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS62	Soil	36.72391	–112.52854	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS63	Soil	36.72379	–112.52873	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS64	Soil	36.72386	–112.52886	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS65	Soil	36.72400	–112.52903	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS66	Soil	36.72397	–112.52954	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS67	Soil	36.72425	–112.52928	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS68	Soil	36.72474	–112.52918	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS69	Soil	36.72491	–112.52889	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS70	Soil	36.72456	–112.52876	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS71	Soil	36.72424	–112.52850	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS72	Soil	36.72424	–112.52850	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS73	Soil	36.72467	–112.52828	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS74	Soil	36.72519	–112.52838	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS75a	Soil	36.72531	–112.52803	Surface soil in Pigeon Mine reclaimed area	Pigeon
GC09PS01	Soil	36.72599	–112.52627	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS02	Soil	36.72723	–112.52797	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS03	Soil	36.72590	–112.52762	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS04	Soil	36.72650	–112.53068	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS05	Soil	36.72483	–112.52605	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS06	Soil	36.72449	–112.52655	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS07	Soil	36.72400	–112.52673	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS08	Soil	36.72306	–112.52582	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS09	Soil	36.72219	–112.52714	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS10	Soil	36.72218	–112.52715	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS11	Soil	36.72546	–112.53035	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS12	Soil	36.72482	–112.53121	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS13	Soil	36.72393	–112.53022	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS14	Soil	36.72356	–112.53101	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PS15	Soil	36.72319	–112.52896	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study. Description of major, minor, and trace element data from samples collected at Jumpup Canyon, Pigeon, Kanab North, Kanab South, Hermit, and Hack Canyon sample sites.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Sample medium	Latitude	Longitude	Description of sample site	Sample site
GC09PS16	Soil	36.72227	–112.52886	Surface soil on hillslopes outside of Pigeon Mine reclaimed area	Pigeon
GC09PSS03	Sediment	36.72351	–112.52820	Stream sediment below boulder train in Pigeon Mine reclaimed area	Pigeon
GC09PSS04	Sediment	36.72292	–112.52741	Stream sediment just downgradient from Pigeon Mine reclaimed area	Pigeon
GC09PSS01	Sediment	36.72580	–112.52359	Stream sediment from wash to east-upgradient from Pigeon Mine	Pigeon
GC09PSS02	Sediment	36.72490	–112.52452	Stream sediment from wash to east-upgradient from Pigeon Mine	Pigeon
GC09PSS10	Sediment	36.72416	–112.52565	Stream sediment from wash to east-upgradient from Pigeon Mine	Pigeon
GC09PSS09	Sediment	36.72370	–112.52551	Stream sediment from wash to east-upgradient from Pigeon Mine	Pigeon
GC09PSS08	Sediment	36.72336	–112.52698	Stream sediment from wash to east-downgradient from Pigeon Mine	Pigeon
GC09PSS05	Sediment	36.72271	–112.52596	Stream sediment from wash to east-downgradient from Pigeon Mine	Pigeon
GC09PSS06	Sediment	36.72224	–112.52611	Stream sediment from wash to east-downgradient from Pigeon Mine	Pigeon
GC09PSS07	Sediment	36.72168	–112.52629	Stream sediment from wash to east-downgradient from Pigeon Mine	Pigeon
GC09PR01	Rock outcrop	36.72309	–112.52789	Cherty limestone at south edge of Pigeon Mine reclaimed site	Pigeon
GC09PR02	Rock outcrop	36.72388	–112.52944	Surface rock at border of Pigeon Mine reclaimed iste	Pigeon
GC09PW101	Mine waste	36.72353	–112.52724	Exposed waste rock layer at east edge of Pigeon mine reclaimed site	Pigeon
GC09PR101	Slope wash	36.72342	–112.52690	Slope wash- on hillslope below east edge of Pigeon mine reclaimed site	Pigeon
GC09PS75	Soil	36.72974	–112.52896	E-W soil transect across mine operations area (east of reclaimed area)	Pigeon
GC09PS76	Soil	36.72951	–112.52937	E-W soil transect across mine operations area (east of reclaimed area)	Pigeon
GC09PS77	Soil	36.72930	–112.52963	E-W soil transect across mine operations area (east of reclaimed area)	Pigeon
GC09PS78	Soil	36.72909	–112.53001	E-W soil transect across mine operations area (former waste rock pile)	Pigeon
GC09PS79	Soil	36.72895	–112.53020	E-W soil transect across mine operations area (former waste rock pile)	Pigeon
GC09PS80	Soil	36.72874	–112.53051	E-W soil transect across mine operations area (reclaimed building site)	Pigeon
GC09PS81	Soil	36.72864	–112.53071	E-W soil transect across mine operations area (reclaimed building site)	Pigeon
GC09PS82	Soil	36.72848	–112.53097	E-W soil transect across mine operations area (reclaimed building site)	Pigeon
GC09PS83	Soil	36.72831	–112.53127	E-W soil transect across mine operations area, west of reclaimed site	Pigeon
GC09PS84	Soil	36.72815	–112.53150	E-W soil transect across mine operations area, west of reclaimed site	Pigeon
GC09PS85	Soil	36.73025	–112.53094	N-S soil transect across mine operations area, north of reclaimed site	Pigeon
GC09PS86	Soil	36.72959	–112.53057	N-S soil transect across mine operations area, north of reclaimed site	Pigeon
GC09PS87	Soil	36.72922	–112.53032	N-S soil transect across mine operations area (former waste rock pile)	Pigeon
GC09PS88	Soil	36.72862	–112.53005	N-S soil transect across mine operations area (former waste rock pile)	Pigeon
GC09PS89	Soil	36.72836	–112.52987	N-S soil transect across mine operations area, south of reclaimed site	Pigeon
GC09PW01	Mine waste	36.72913	–112.53025	Waste rock, reclaimed mine operations area, former mine waste pile	Pigeon
GC09PW02	Mine waste	36.72911	–112.53059	Grey mud on soil, mine operations area, former waste rock pile	Pigeon
GC09PW03	Mine waste	36.72821	–112.53032	Waste rock at south edge of reclaimed mine operations area	Pigeon
GC09PR75	Rock	36.72905	–112.53016	Waste rock, reclaimed mine operations area, former mine waste pile	Pigeon
GC09PR76	Rock	36.72885	–112.53033	Waste rock, reclaimed mine operations area, former mine waste pile	Pigeon
GC09KNW01	Mine waste	36.68622	–112.64315	Composite sample of east face of waste rock pile at Kanab North Mine	Kanab North
GC09KNW12	Mine waste	36.68674	–112.64366	Runoff from waste rock pile at Kanab North Mine site	Kanab North
GC09KNW08	Mine waste	36.68831	–112.64373	Sludge at bottom of waste-water pond at Kanab North Mine site	Kanab North
GC09KNW03	Mine waste	36.68581	–112.64344	Disturbed soil at south end of Kanab North Mine site	Kanab North
GC09KNW04	Mine waste	36.68664	–112.64319	Surface material on waste rock pile at Kanab North Mine site	Kanab North
GC09KNW05	Mine waste	36.68660	–112.64439	Surface material at Kanab North Mine site	Kanab North
GC09KNW06	Mine waste	36.68692	–112.64452	Surface material at Kanab North Mine site	Kanab North
GC09KNW07	Mine waste	36.68809	–112.64428	Surface material at Kanab North Mine site	Kanab North
GC09KNW09	Mine waste	36.68805	–112.64347	Surface material at Kanab North Mine site	Kanab North
GC09KNW10	Mine waste	36.68756	–112.64317	Surface material at Kanab North Mine site	Kanab North
GC09KNW11	Mine waste	36.68729	–112.64261	Surface material at Kanab North Mine site	Kanab North
GC09KNW13	Mine waste	36.68632	–112.64364	Waste rock at Kanab North Mine area	Kanab North
GS09KNS50	Soil	36.68755	–112.64484	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North
GS09KNS51	Soil	36.68823	–112.64449	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North
GS09KNS52	Soil	36.68865	–112.64371	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North
GS09KNS53	Soil	36.68872	–112.64309	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study. Description of major, minor, and trace element data from samples collected at Jumpup Canyon, Pigeon, Kanab North, Kanab South, Hermit, and Hack Canyon sample sites.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Sample medium	Latitude	Longitude	Description of sample site	Sample site
GS09KNS54	Soil	36.68796	–112.64242	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North
GS09KNS55	Soil	36.68719	–112.64238	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North
GS09KNS56	Soil	36.68647	–112.64278	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North
GS09KNS57	Soil	36.68592	–112.64325	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North
GS09KNS58	Soil	36.68602	–112.64407	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North
GS09KNS59	Soil	36.68658	–112.64479	Surface soil-near perimeter fence outside of Kanab North mine site	Kanab North
GC09KNS01	Soil	36.68772	–112.64607	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS02	Soil	36.68819	–112.64552	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS03	Soil	36.68895	–112.64468	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS04	Soil	36.68905	–112.64390	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS05	Soil	36.68898	–112.64291	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS06	Soil	36.68819	–112.64228	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS07	Soil	36.68799	–112.64211	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS08	Soil	36.68701	–112.64207	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS09	Soil	36.68603	–112.64221	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS10	Soil	36.68525	–112.64280	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS11	Soil	36.68524	–112.64388	Surface soil-distant from fence, outside of Kanab North mine site	Kanab North
GC09KNS12	Soil	36.68614	–112.64505	Surface soil- distant from fence, outside of Kanab North mine site	Kanab North
GC09KSSS03	Sediment	36.67739	–112.64738	Stream sediment just west of breccia pipe at Kanab South Pipe	Kanab South
GC09KSSS02	Sediment	36.67771	–112.64669	Stream sediment at lower edge of breccia pipe at Kanab South Pipe	Kanab South
GC09KSSS01	Sediment	36.67805	–112.64619	Stream sediment east downstream of Kanab South Pipe	Kanab South
GC09KSSS04	Sediment	36.67733	–112.64715	Stream sediment south of Kanab South Pipe	Kanab South
GC09KSSS05	Sediment	36.67639	–112.64700	Stream sediment south of Kanab South Pipe	Kanab South
GC09KSSS06	Sediment	36.67528	–112.64737	Stream sediment south of Kanab South Pipe	Kanab South
GC09KSS01	Soil	36.67906	–112.64777	Surface soil on hills- Kanab South Pipe	Kanab South
GC09KSS02	Soil	36.67906	–112.64777	Surface soil on hills- Kanab South Pipe- duplicate	Kanab South
GC09KSS03	Soil	36.67809	–112.64903	Surface soil on hills- Kanab South Pipe	Kanab South
GC09KSS04	Soil	36.67732	–112.64964	Surface soil on hills- Kanab South Pipe	Kanab South
GC09KSS05	Soil	36.67632	–112.64773	Surface soil on hills- Kanab South Pipe	Kanab South
GC09KSS06	Soil	36.67698	–112.64570	Surface soil on hills- Kanab South Pipe	Kanab South
GC09KSR01	Rock outcrop	36.67733	–112.64715	Surface outcrop of limonite-cemented sandstone at Kanab South Pipe	Kanab South
GC09HS01	Soil	36.69138	–112.75299	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS02	Soil	36.68967	–112.75378	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS03	Soil	36.68936	–112.75317	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS04	Soil	36.68915	–112.75256	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS05	Soil	36.68892	–112.75142	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS06	Soil	36.68939	–112.75056	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS07	Soil	36.69014	–112.75071	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS08	Soil	36.69022	–112.75162	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS09	Soil	36.69097	–112.75259	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS10	Soil	36.69051	–112.75274	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS11	Soil	36.69038	–112.75361	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS12	Soil	36.69001	–112.75300	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS13	Soil	36.68962	–112.75208	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS14	Soil	36.68966	–112.75131	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS15	Soil	36.68965	–112.75135	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS16	Soil	36.69003	–112.75020	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS17	Soil	36.69095	–112.75097	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS18	Soil	36.69077	–112.75179	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS19	Soil	36.69142	–112.75178	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS20	Soil	36.69187	–112.75231	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS21	Soil	36.69139	–112.75072	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS22	Soil	36.69078	–112.75022	Samples of surface soil inside of Hermit Mine disturbed area	Hermit
GC09HS58	Soil	36.69044	–112.74982	Surface soil along E-W transect east of Hermit Mine	Hermit

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study. Description of major, minor, and trace element data from samples collected at Jumpup Canyon, Pigeon, Kanab North, Kanab South, Hermit, and Hack Canyon sample sites.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Sample medium	Latitude	Longitude	Description of sample site	Sample site
GC09HS59	Soil	36.69032	–112.74866	Surface soil along E-W transect east of Hermit Mine	Hermit
GC09HS60	Soil	36.69000	–112.74759	Surface soil along E-W transect east of Hermit Mine	Hermit
GC09HS61	Soil	36.69002	–112.74649	Surface soil along E-W transect east of Hermit Mine	Hermit
GC09HS62	Soil	36.68988	–112.74539	Surface soil along E-W transect east of Hermit Mine	Hermit
GC09HS63	Soil	36.68977	–112.74416	Surface soil along E-W transect east of Hermit Mine	Hermit
GC09HS64	Soil	36.68973	–112.74311	Surface soil along E-W transect east of Hermit Mine	Hermit
GC09HS65	Soil	36.68827	–112.75201	Surface soil along N-S transect south of Hermit Mine	Hermit
GC09HS66	Soil	36.68747	–112.75234	Surface soil along N-S transect south of Hermit Mine	Hermit
GC09HS67	Soil	36.68747	–112.75234	Surface soil along N-S transect south of Hermit Mine	Hermit
GC09HS68	Soil	36.68665	–112.75265	Surface soil along N-S transect south of Hermit Mine	Hermit
GC09HS69	Soil	36.68578	–112.75303	Surface soil along N-S transect south of Hermit Mine	Hermit
GC09HS70	Soil	36.68492	–112.75335	Surface soil along N-S transect south of Hermit Mine	Hermit
GC09HS71	Soil	36.68405	–112.75365	Surface soil along N-S transect south of Hermit Mine	Hermit
GC09HS50	Soil	36.69033	–112.76189	Surface soil along E-W transect west of Hermit Mine	Hermit
GC09HS51	Soil	36.69012	–112.76081	Surface soil along E-W transect west of Hermit Mine	Hermit
GC09HS52	Soil	36.69000	–112.75966	Surface soil along E-W transect west of Hermit Mine	Hermit
GC09HS53	Soil	36.68967	–112.75837	Surface soil along E-W transect west of Hermit Mine	Hermit
GC09HS54	Soil	36.68954	–112.75744	Surface soil along E-W transect west of Hermit Mine	Hermit
GC09HS55	Soil	36.68940	–112.75633	Surface soil along E-W transect west of Hermit Mine	Hermit
GC09HS56	Soil	36.68923	–112.75514	Surface soil along E-W transect west of Hermit Mine	Hermit
GC09HS57	Soil	36.68915	–112.75404	Surface soil along E-W transect west of Hermit Mine	Hermit
GC09HS76	Soil	36.69260	–112.75355	Surface soil along road transect NW of Hermit Mine	Hermit
GC09HS77	Soil	36.69260	–112.75355	Surface soil along road transect NW of Hermit Mine	Hermit
GC09HS78	Soil	36.69332	–112.75419	Surface soil along road transect NW of Hermit Mine	Hermit
GC09HS79	Soil	36.69407	–112.75485	Surface soil along road transect NW of Hermit Mine	Hermit
GC09HS80	Soil	36.69480	–112.75551	Surface soil along road transect NW of Hermit Mine	Hermit
GC09HS81	Soil	36.69560	–112.75618	Surface soil along road transect NW of Hermit Mine	Hermit
GC09HS75	Soil	36.69182	–112.75292	Surface soil along road transect NW of Hermit Mine	Hermit
GC09HS105	Soil	36.70274	–112.74909	Surface soil in drainage downgradient north from Hermit Mine	Hermit
GC09HS106	Soil	36.70029	–112.75101	Surface soil in drainage downgradient north from Hermit Mine	Hermit
GC09HS107	Soil	36.69944	–112.75209	Surface soil in drainage downgradient north from Hermit Mine	Hermit
GC09HS108	Soil	36.69677	–112.75177	Surface soil in drainage downgradient north from Hermit Mine	Hermit
GC09HS109	Soil	36.69428	–112.75152	Surface soil in drainage downgradient north from Hermit Mine	Hermit
GC09HS110	Soil	36.69316	–112.75106	Surface soil in drainage downgradient north from Hermit Mine	Hermit
GC09HSS100	Sediment	36.70485	–112.74705	Sediment @ 0–2" depth in stock tank downgradient from Hermit Mine	Hermit
GC09HSS101	Sediment	36.70485	–112.74705	Sediment @ 6–9" depth in stock tank downgradient from Hermit Mine	Hermit
GC09HSS102	Sediment	36.70485	–112.74705	Sediment @ 9–12" depth in stock tank downgradient from Hermit Mine	Hermit
GC09HSS103	Sediment	36.70485	–112.74705	Sediment @ 16–19" depth in stock tank downgradient from Hermit Mine	Hermit
GC09HSS104	Sediment	36.70450	–112.74723	Stream sediment at mouth of stock tank downgradient from Hermit Mine	Hermit
GC09HKSS01	Sediment	36.58881	–112.81559	Hack Canyon upstream from mines	Hack Canyon
GC09HKSS02	Sediment	36.57991	–112.81502	Robinson Canyon upstream from mines	Hack Canyon
GC09HKSS04	Sediment	36.58588	–112.79572	Tributary canyon upstream from Hack 1 mine	Hack Canyon
GC09HKSS05	Sediment	36.58615	–112.79644	Tributary canyon upstream from Hack 1 mine	Hack Canyon
GC09HKSS03	Sediment	36.58423	–112.80953	Hack Canyon downstream from Hack 2&3 mines	Hack Canyon
GC09HKSS06	Sediment	36.58224	–112.79949	Hack Canyon downstream from Hack 1 mine	Hack Canyon
GC09HKSS07	Sediment	36.57947	–112.79886	Hack Canyon downstream from mines	Hack Canyon
GC09HKSS08	Sediment	36.57842	–112.79243	Hack Canyon downstream from mines	Hack Canyon
GC09HKSS09	Sediment	36.57306	–112.78210	Hack Canyon downstream from mines	Hack Canyon
GC09HKSS10	Sediment	36.56619	–112.74516	Hack Canyon downstream from mines	Hack Canyon
GC09HKRK01	Mine waste	36.58534	–112.80902	Waste on alluvial surface—Hack Canyon downstream from mines	Hack Canyon
GC09HKRK02	Mine waste	36.58297	–112.79952	Waste on alluvial surface—Hack Canyon downstream from mines	Hack Canyon
GC09HKRK03	Mine waste	36.58120	–112.79947	Waste on alluvial surface—Hack Canyon downstream from mines	Hack Canyon
GC09HKRK04	Mine waste	36.58120	–112.79947	Waste on alluvial surface—Hack Canyon downstream from mines	Hack Canyon
GC09HKRK05	Mine waste	36.57924	–112.79874	Waste on alluvial surface—Hack Canyon downstream from mines	Hack Canyon

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Aluminun wt. %	Calcium wt. %	Iron wt. %	Potassium wt. %	Magnesium wt. %	Sodium wt. %	Sulfur wt. %	Titanium wt. %	Silver ppm
GC09JSS50	2.82	4.22	1.26	1.29	1.19	0.25	0.03	0.16	<1
GC09JSS51	2.77	4.73	1.22	1.08	1.26	0.26	0.03	0.15	<1
GC09JSS52	2.81	4.38	1.19	1.18	1.19	0.27	0.03	0.16	<1
GC09JSS53	2.72	6.67	1.09	1.17	1.24	0.28	0.23	0.15	<1
GC09JSS54	2.92	5.73	1.21	1.1	1.35	0.26	0.08	0.15	<1
GC09JSS05	1.29	6.63	0.87	0.59	0.99	0.13	0.27	0.07	<1
GC09JSS01	2.45	5.57	1.02	1.24	1.32	0.25	0.02	0.14	<1
GC09JSS02	2.55	5.4	1.13	1.12	1.35	0.25	0.03	0.14	<1
GC09JSS03	2.1	5.58	0.9	1.15	1.27	0.18	0.02	0.12	<1
GC09JSS04	2.24	5.02	0.94	1.29	1.2	0.2	0.02	0.12	<1
GC09PS50	4.53	8.04	1.79	2.19	4.9	0.06	0.04	0.23	<1
GC09PS51	4.29	8.05	1.74	1.9	4.86	0.06	0.04	0.22	<1
GC09PS52	4.79	7.51	2.02	2.56	4.57	0.06	0.04	0.23	<1
GC09PS53	4.07	6.98	1.8	2	4.1	0.06	0.17	0.21	<1
GC09PS54	4.22	7.08	1.79	2.26	4.26	0.06	0.07	0.21	<1
GC09PS55	6.32	6.61	2.9	3.24	4.4	0.08	0.03	0.3	<1
GC09PS56	4.08	7.58	1.77	1.95	4.11	0.07	0.19	0.21	<1
GC09PS57	4.29	7.01	1.85	2.27	4.13	0.06	0.28	0.22	<1
GC09PS58	4.13	8.1	1.7	1.89	4.94	0.06	0.07	0.21	<1
GC09PS59	2.8	4.91	2.88	1.58	2.79	0.04	1.43	0.14	<1
GC09PS60	3.73	7.8	1.68	1.74	4.5	0.06	0.09	0.2	<1
GC09PS61	3.85	7.49	1.69	2.09	4.05	0.07	0.15	0.2	<1
GC09PS62	3.56	7.26	1.58	1.97	3.96	0.06	0.15	0.18	<1
GC09PS63	2.71	8.79	1.46	1.44	3.61	0.08	0.15	0.14	<1
GC09PS64	3.71	3.71	2.43	1.86	1.92	0.05	1.38	0.2	<1
GC09PS65	3.43	8.36	1.59	1.84	4.56	0.09	0.15	0.18	<1
GC09PS66	4.01	8.84	1.6	2.28	4.45	0.07	0.05	0.19	<1
GC09PS67	4.1	8.7	1.83	2.3	5.29	0.06	0.15	0.2	<1
GC09PS68	4.3	8.56	1.72	2.39	5.16	0.06	0.04	0.22	<1
GC09PS69	4.28	8.84	1.77	2.35	5.09	0.06	0.07	0.22	<1
GC09PS70	3.87	8.9	1.73	2.04	5.03	0.06	0.19	0.2	<1
GC09PS71	3.77	8.61	1.62	2.03	4.58	0.07	0.14	0.2	<1
GC09PS72	3.67	8.94	1.54	1.96	4.55	0.07	0.12	0.19	<1
GC09PS73	4.4	8.92	1.79	2.28	5.3	0.06	0.05	0.21	<1
GC09PS74	1.89	6.56	0.92	0.91	3.43	0.03	0.03	0.1	<1
GC09PS75a	3.77	9.15	1.57	1.97	5.49	0.05	0.04	0.19	<1
GC09PS01	3.61	7.4	1.8	1.48	1.27	0.32	0.04	0.2	<1
GC09PS02	1.97	4.73	0.93	0.64	1.76	0.16	0.04	0.12	<1
GC09PS03	2.27	9.15	1.02	1.04	2.54	0.07	0.04	0.12	<1
GC09PS04	2.37	4.85	1.16	0.88	2.05	0.14	0.03	0.16	<1
GC09PS05	1.97	4.86	0.95	0.88	2.17	0.14	0.04	0.1	<1
GC09PS06	3.08	7.87	1.8	1.3	2.02	0.23	0.08	0.16	<1
GC09PS07	3.19	6.88	1.16	1.64	3.86	0.08	0.07	0.17	<1
GC09PS08	1.94	11.1	3.62	0.87	3.78	0.19	0.11	0.11	2
GC09PS09	1.78	14.9	0.91	0.82	7.31	0.19	0.05	0.1	<1
GC09PS10	1.68	>15	0.89	0.8	7.51	0.17	0.04	0.1	<1
GC09PS11	1.82	4.14	1.28	0.73	1.71	0.13	0.03	0.11	<1
GC09PS12	2.2	3.7	1.27	0.92	1.49	0.17	0.03	0.13	<1
GC09PS13	2.67	7.69	1.13	1.39	1.76	0.17	0.03	0.14	<1
GC09PS14	2.9	5.18	1.22	1.72	2.36	0.15	0.02	0.14	<1
GC09PS15	2.72	12	1.31	1.52	4.53	0.15	0.03	0.15	<1
GC09PS16	3.24	5.99	1.32	1.4	2.4	0.23	0.03	0.18	<1
GC09PSS03	2.64	6.79	1.26	1.23	3.86	0.05	0.19	0.16	<1

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Aluminun wt. %	Calcium wt. %	Iron wt. %	Potassium wt. %	Magnesium wt. %	Sodium wt. %	Sulfur wt. %	Titanium wt. %	Silver ppm
GC09PSS04	2.64	6.76	1.2	1.46	3.72	0.07	0.17	0.17	<1
GC09PSS01	2.73	4.92	1.19	1.27	1.81	0.2	0.04	0.15	<1
GC09PSS02	2.8	4.82	1.22	1.32	1.7	0.21	0.04	0.15	<1
GC09PSS10	3.01	5.17	1.3	1.55	1.83	0.24	0.03	0.17	<1
GC09PSS09	3.16	6.13	1.39	1.53	2.45	0.24	0.05	0.17	<1
GC09PSS08	2.91	6.51	1.26	1.55	3.33	0.12	0.14	0.17	<1
GC09PSS05	4.72	6.62	1.82	2.18	3.62	0.13	0.1	0.25	<1
GC09PSS06	3.91	6.61	1.57	1.86	3.28	0.17	0.09	0.21	<1
GC09PSS07	3.31	6.05	1.4	1.64	2.83	0.18	0.12	0.18	<1
GC09PR01	0.47	13	0.43	0.2	7.82	0.02	0.07	0.03	<1
GC09PR02	0.57	2.56	0.23	0.27	0.89	0.01	0.06	0.03	<1
GC09PW101	2.87	6.29	1.14	1.23	3.66	0.04	0.19	0.15	<1
GC09PR101	0.97	13.9	0.82	0.52	7.32	0.03	0.09	0.05	<1
GC09PS75	3.88	4.31	2	2.04	1.4	0.34	0.03	0.21	<1
GC09PS76	3.56	5.45	1.88	2	1.28	0.3	0.1	0.19	<1
GC09PS77	4.5	3.29	2.13	2.42	1.12	0.44	0.1	0.26	<1
GC09PS78	3.85	6.91	2.12	2.01	1.77	0.34	0.18	0.22	<1
GC09PS79	3.67	8.15	1.84	1.98	2	0.32	0.11	0.2	<1
GC09PS80	3.89	8.09	1.88	2.14	1.86	0.32	0.03	0.21	<1
GC09PS81	4.16	8.7	2	2.12	1.75	0.32	0.04	0.21	<1
GC09PS82	4.03	8.22	1.93	2.21	1.56	0.36	0.03	0.21	<1
GC09PS83	4.9	3.76	2.45	2.47	2.16	0.5	0.03	0.28	<1
GC09PS84	3.46	10	2.01	1.68	5.01	0.3	0.03	0.19	<1
GC09PS85	3.97	7.79	1.79	2.21	1.58	0.39	0.03	0.23	<1
GC09PS86	4.35	3.67	2.09	2.33	0.9	0.41	0.03	0.25	<1
GC09PS87	4.28	5.45	2.1	2.19	1.52	0.39	0.09	0.23	<1
GC09PS88	3.53	5.28	3.09	1.78	1.89	0.29	1.63	0.19	<1
GC09PS89	2.89	10.8	1.52	1.5	4.58	0.25	0.05	0.17	<1
GC09PW01	1.52	1.57	3.29	0.68	0.41	0.07	3	0.1	4
GC09PW02	4.05	8.45	1.94	1.54	2.07	0.29	0.29	0.21	1
GC09PW03	0.85	1.98	2.19	0.49	0.1	0.01	3.98	0.05	>10
GC09PR75	0.59	0.26	>15	0.3	0.03	<0.01	>5	0.07	7
GC09PR76	1.91	6.87	5.95	0.87	2.72	0.07	>5	0.1	2
GC09KNW01	3.65	3.92	2.41	2	2.27	0.06	1.94	0.22	3
GC09KNW12	1.94	5.29	3.92	1.11	2.99	0.07	4.12	0.11	5
GC09KNW08	2.43	3.83	0.75	1.87	1.7	0.39	1.98	0.12	<1
GC09KNW03	2.2	>15	1.08	1.08	0.82	0.18	0.04	0.12	<1
GC09KNW04	2.15	3.51	2.47	1.24	1.93	0.04	2.8	0.11	3
GC09KNW05	3.65	4.34	1.56	2.03	2.14	0.06	0.91	0.2	2
GC09KNW06	3.44	4.17	1.56	1.91	2.41	0.06	1.33	0.2	3
GC09KNW07	1.96	>15	0.69	0.92	2.01	0.07	0.15	0.1	<1
GC09KNW09	2.85	6.42	1.53	1.48	3.39	0.16	1.04	0.15	1
GC09KNW10	2.75	5	2.36	1.59	2.41	0.06	2.08	0.15	2
GC09KNW11	3.3	4.33	1.43	1.94	2.41	0.05	0.65	0.18	2
GC09KNW13	1.45	6.33	12	0.86	2.84	0.09	>5	0.06	>10
GS09KNS50	2.18	15	1.04	0.81	3.16	0.1	0.08	0.13	<1
GS09KNS51	3.08	11.5	1.25	1.29	2.06	0.2	0.07	0.16	<1
GS09KNS52	2.99	6.94	1.3	1.55	1.17	0.17	0.06	0.15	<1
GS09KNS53	1.93	9.67	0.86	0.97	1.25	0.07	0.05	0.09	<1
GS09KNS54	2.45	5.68	1.23	1.3	1.05	0.15	0.1	0.13	<1
GS09KNS55	3	5.64	1.41	1.66	1.04	0.22	0.09	0.16	<1
GS09KNS56	2.97	4.77	1.42	1.75	0.77	0.25	0.07	0.17	<1
GS09KNS57	3.03	8.1	1.36	1.71	0.77	0.25	0.03	0.17	<1

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Aluminun wt. %	Calcium wt. %	Iron wt. %	Potassium wt. %	Magnesium wt. %	Sodium wt. %	Sulfur wt. %	Titanium wt. %	Silver ppm
GS09KNS58	3.17	3.63	1.48	1.77	0.72	0.27	0.04	0.18	<1
GS09KNS59	3.22	6.44	1.61	1.7	1.13	0.3	0.07	0.18	<1
GC09KNS01	3.96	4.49	1.78	1.9	1.03	0.34	0.03	0.21	<1
GC09KNS02	3.07	3.24	1.58	1.68	1.31	0.3	0.03	0.19	<1
GC09KNS03	2.82	10.1	1.2	1.34	1.31	0.13	0.03	0.14	<1
GC09KNS04	3.42	5.08	1.51	1.82	0.92	0.25	0.03	0.18	<1
GC09KNS05	3.2	9.32	1.69	1.33	3.73	0.09	0.04	0.18	<1
GC09KNS06	2.87	3.88	1.39	1.49	1.14	0.2	0.08	0.15	<1
GC09KNS07	2.74	6.42	1.33	1.18	2.2	0.14	0.11	0.15	<1
GC09KNS08	2.6	8.55	1.4	1.42	2.22	0.18	0.06	0.16	<1
GC09KNS09	2.98	8.4	1.53	1.64	2.08	0.26	0.03	0.19	<1
GC09KNS10	3.07	7.87	1.72	1.41	2.76	0.14	0.03	0.18	<1
GC09KNS11	3.71	7.93	1.78	1.92	1.81	0.35	0.03	0.21	<1
GC09KNS12	3.2	7.15	1.64	1.76	1.53	0.31	0.04	0.19	<1
GC09KSSS03	3.26	5.13	1.76	1.45	1.85	0.25	0.03	0.18	<1
GC09KSSS02	4.1	5.03	1.74	1.64	2.22	0.18	0.03	0.2	<1
GC09KSSS01	3.42	5.16	1.63	1.53	2.24	0.17	0.09	0.17	<1
GC09KSSS04	3.13	2.86	1.68	1.4	1.3	0.28	0.03	0.18	<1
GC09KSSS05	3.52	3	1.85	1.41	1.35	0.34	0.03	0.2	<1
GC09KSSS06	3.21	2.67	1.7	1.39	1.28	0.31	0.03	0.19	<1
GC09KSS01	3.38	3.89	1.85	1.49	1.08	0.34	0.03	0.22	<1
GC09KSS02	3.24	2.88	1.75	1.52	1	0.32	0.02	0.2	<1
GC09KSS03	2.85	3.18	2.05	1.19	1.61	0.24	0.02	0.18	<1
GC09KSS04	1.89	7.82	1.43	0.85	2.92	0.15	0.03	0.12	<1
GC09KSS05	2.79	0.75	1.92	1.28	0.64	0.27	0.03	0.18	<1
GC09KSS06	3.01	1.88	2.4	1.21	1.14	0.27	0.02	0.19	<1
GC09KSR01	1.81	0.99	>15	0.39	0.23	0.05	0.77	0.02	1
GC09HS01	4.87	6.3	2.06	2.9	1.43	0.2	0.02	0.19	<1
GC09HS02	5.31	7.24	2.2	3.05	2.17	0.18	0.58	0.2	<1
GC09HS03	5.29	7.03	2.14	2.85	2.02	0.17	0.49	0.2	<1
GC09HS04	4.28	4.79	1.8	2.55	0.86	0.2	0.02	0.17	<1
GC09HS05	5.48	7.87	2.29	3.23	3.01	0.11	0.96	0.21	<1
GC09HS06	5.52	7.03	2.19	2.84	2.93	0.07	1.67	0.22	<1
GC09HS07	4.87	8.28	1.98	2.83	2.25	0.14	1.75	0.18	<1
GC09HS08	5.62	8.84	2.5	3.35	3	0.09	1.48	0.22	<1
GC09HS09	5.25	5.66	2.19	2.93	1.8	0.17	0.04	0.21	<1
GC09HS10	5.34	6.44	2.25	3.15	2.18	0.17	0.31	0.21	<1
GC09HS11	4.98	6.25	2.06	2.97	1.13	0.23	0.03	0.19	<1
GC09HS12	6.25	2.64	2.6	2.77	1.23	0.28	0.03	0.28	<1
GC09HS13	5.56	7.61	2.46	2.74	3.11	0.09	0.97	0.22	<1
GC09HS14	5.68	8.06	2.59	2.9	3.14	0.09	0.97	0.24	<1
GC09HS15	5.71	8.29	2.62	2.92	3.09	0.09	1.12	0.24	<1
GC09HS16	6.09	7.35	2.67	3.04	3.47	0.09	0.11	0.26	<1
GC09HS17	5.11	8.4	2.21	2.6	2.7	0.1	1.46	0.19	<1
GC09HS18	5.38	8.07	2.4	2.64	2.93	0.11	1.24	0.21	<1
GC09HS19	5.28	7.1	2.29	2.64	2.28	0.15	0.7	0.21	<1
GC09HS20	6.04	7.25	2.77	3	3.35	0.08	0.45	0.26	<1
GC09HS21	5.31	8.36	2.44	2.73	2.8	0.09	1.33	0.21	<1
GC09HS22	5.17	8.4	2.29	2.29	3.2	0.09	1.38	0.2	<1
GC09HS58	5.47	2.78	2.33	2.49	1.04	0.28	0.03	0.25	<1
GC09HS59	4.75	2.01	1.85	2.47	0.79	0.2	0.02	0.19	<1
GC09HS60	5.35	2.88	2.17	2.71	1.13	0.25	0.02	0.24	<1

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Aluminun wt. %	Calcium wt. %	Iron wt. %	Potassium wt. %	Magnesium wt. %	Sodium wt. %	Sulfur wt. %	Titanium wt. %	Silver ppm
GC09HS61	4.84	3.39	1.65	2.62	1.05	0.17	0.02	0.18	<1
GC09HS62	5.71	4.36	2.21	2.54	1.42	0.12	0.03	0.16	<1
GC09HS63	4.8	3.37	1.95	2.45	1.14	0.2	0.02	0.19	<1
GC09HS64	4.16	4.33	1.78	2.16	1.25	0.17	0.02	0.17	<1
GC09HS65	5.97	4.33	2.3	2.85	1.51	0.2	0.02	0.23	<1
GC09HS66	5.3	4.53	1.84	2.84	1.36	0.18	0.02	0.19	<1
GC09HS67	5.24	4.49	1.79	2.83	1.33	0.16	0.02	0.18	<1
GC09HS68	6.11	5.07	2.33	2.47	1.09	0.13	0.02	0.19	<1
GC09HS69	6.27	5.96	2.62	2.26	1.98	0.08	0.02	0.21	<1
GC09HS70	5.02	4.88	2.11	2.33	1.48	0.16	0.02	0.2	<1
GC09HS71	4.79	5.06	1.99	2.11	1.25	0.19	0.02	0.19	<1
GC09HS50	4.12	7.72	1.35	1.8	2.14	0.16	0.03	0.13	<1
GC09HS51	4.18	7.99	1.77	2.14	0.91	0.27	0.02	0.18	<1
GC09HS52	4.73	4.38	1.71	2.56	0.95	0.25	0.02	0.2	<1
GC09HS53	4.6	5.91	1.64	2.52	1.4	0.18	0.02	0.16	<1
GC09HS54	4.67	4.05	1.74	2.7	1.02	0.18	0.02	0.16	1
GC09HS55	4.44	5.54	1.82	1.74	0.98	0.18	0.02	0.17	<1
GC09HS56	5.47	2.96	2.27	2.65	1.1	0.26	0.02	0.25	<1
GC09HS57	4.74	7.04	1.97	1.96	1.45	0.22	0.02	0.19	<1
GC09HS76	5.56	3.99	2.29	2.38	1.54	0.28	0.04	0.26	<1
GC09HS77	5.46	3.65	2.23	1.4	1.4	0.27	0.03	0.25	<1
GC09HS78	5.12	4.09	1.98	2.38	1.07	0.24	0.02	0.21	<1
GC09HS79	4.34	6.19	1.88	2.05	1.68	0.15	0.02	0.16	<1
GC09HS80	4.24	7.86	1.85	2.32	1.47	0.18	0.02	0.16	<1
GC09HS81	4.41	5.6	1.95	1.93	1.45	0.3	0.03	0.21	<1
GC09HS75	4.29	7.14	1.82	1.94	1.42	0.18	0.02	0.17	<1
GC09HS105	5	5.08	1.97	2.3	1.87	0.23	0.02	0.21	<1
GC09HS106	5.84	4.67	2.43	2.43	1.62	0.26	0.02	0.25	<1
GC09HS107	5.47	8.11	2.22	1.74	2.12	0.16	0.03	0.21	<1
GC09HS108	5.78	7.16	2.29	2.03	2.1	0.22	0.03	0.24	<1
GC09HS109	6.2	2.77	2.62	2.54	1.24	0.31	0.02	0.27	<1
GC09HS110	5.75	3.06	2.36	2.25	1.09	0.24	0.02	0.24	<1
GC09HSS100	7.24	4.1	3.09	2.48	1.66	0.26	0.05	0.31	<1
GC09HSS101	8.07	4.29	3.39	2.7	1.76	0.24	0.04	0.33	<1
GC09HSS102	7.91	4.35	3.33	2.41	1.74	0.23	0.04	0.33	<1
GC09HSS103	7.14	4.43	2.97	2.64	1.75	0.28	0.03	0.3	<1
GC09HSS104	5.56	4.48	2.26	1.83	1.88	0.24	0.03	0.23	<1
GC09HKSS01	2.22	9.24	1.1	1.12	2.95	0.14	0.05	0.12	<1
GC09HKSS02	2.92	8.57	1.37	1.31	2.91	0.2	0.07	0.15	<1
GC09HKSS04	2.06	10.3	0.89	1.08	3.36	0.13	1.25	0.11	<1
GC09HKSS05	2.18	7.91	1.07	1.17	2.93	0.12	0.05	0.12	<1
GC09HKSS03	3.04	8.15	1.36	1.44	2.77	0.23	0.06	0.16	<1
GC09HKSS06	2.55	8.87	1.18	1.23	2.85	0.17	0.07	0.14	<1
GC09HKSS07	3.31	8.07	1.46	1.51	2.7	0.23	0.07	0.17	<1
GC09HKSS08	2.52	8.39	1.13	1.25	2.81	0.17	0.06	0.13	<1
GC09HKSS09	2.4	7.56	1.04	1.33	2.56	0.14	0.06	0.12	<1
GC09HKSS10	1.75	7	0.85	1.08	2.26	0.09	0.13	0.09	<1
GC09HKRK01	2.84	0.34	1.03	1.25	0.16	0.03	1.18	0.16	>10
GC09HKRK02	0.32	0.3	>15	0.09	0.07	<0.01	>5	0.01	>10
GC09HKRK03	2.54	1.14	2.71	1	0.28	0.02	1.58	0.13	3
GC09HKRK04	0.36	0.17	1.04	0.08	0.03	<0.01	0.82	<0.01	2
GC09HKRK05	0.38	2.49	>15	0.22	0.36	<0.01	>5	0.04	>10

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Arsenic ppm	Barium ppm	Beryllium ppm	Bismuth ppm	Cadmium ppm	Cerium ppm	Cobalt ppm	Chromium ppm	Cesium ppm	Copper ppm
GC09JSS50	5	333	0.8	0.12	0.3	30.5	4.7	35	<5	12.5
GC09JSS51	5	325	0.7	0.12	0.3	31.2	4.6	37	<5	18.7
GC09JSS52	4	338	0.7	0.12	0.2	31	4.6	33	<5	15
GC09JSS53	4	309	0.7	0.11	0.4	25.2	4.4	36	<5	16.4
GC09JSS54	5	310	0.8	0.12	0.4	28.3	5	38	<5	13.4
GC09JSS05	3	112	1	0.09	0.6	13.4	3.2	58	<5	66.6
GC09JSS01	4	308	0.6	0.1	0.3	25.2	3.7	28	<5	10.2
GC09JSS02	5	308	0.7	0.12	0.3	27.7	4.2	33	<5	11.4
GC09JSS03	5	266	0.5	0.09	0.3	24.6	3.3	29	<5	9.3
GC09JSS04	4	288	0.6	0.1	0.2	23.5	3.5	28	<5	9.4
GC09PS50	17	406	1.4	0.15	<0.1	41.9	7	36	9	15.5
GC09PS51	19	391	1.6	0.13	<0.1	39.3	6.5	34	9	14.5
GC09PS52	15	389	1.5	0.15	<0.1	43.3	7.3	37	10	21.2
GC09PS53	44	404	1.3	0.13	0.1	37.7	7.8	36	7	21.6
GC09PS54	30	444	1.4	0.14	0.2	39.3	7.7	42	8	25.8
GC09PS55	6	343	2.1	0.19	<0.1	52.5	5.2	51	14	5
GC09PS56	93	371	1.2	0.13	0.2	36.3	7.2	47	7	14.5
GC09PS57	90	398	1.3	0.13	0.2	37.6	8.2	44	7	13.8
GC09PS58	79	473	1.4	0.14	0.1	40.1	7	32	8	27
GC09PS59	377	440	0.8	0.09	0.8	29.8	20.8	31	<5	59.6
GC09PS60	24	385	1.2	0.15	0.1	35.4	7.1	30	7	22
GC09PS61	44	430	1.2	0.11	0.4	35.2	11.6	38	7	30.3
GC09PS62	39	428	1.1	0.11	0.3	33.2	11.3	26	6	28.8
GC09PS63	63	342	0.8	0.1	0.2	28.6	7.6	23	<5	34.3
GC09PS64	407	131	1	0.11	1.6	33.9	37.7	40	<5	75.1
GC09PS65	52	427	1.1	0.11	0.3	32.3	8.2	28	7	26.4
GC09PS66	21	395	1.3	0.14	0.2	37.6	5.4	27	8	15.1
GC09PS67	52	511	1.4	0.13	0.2	36.9	7.9	31	9	15.9
GC09PS68	27	458	1.5	0.14	0.1	39.9	6.3	30	10	14.2
GC09PS69	30	443	1.4	0.14	0.1	39.7	7.6	31	9	21.7
GC09PS70	50	428	1.2	0.12	0.2	35.5	11.5	41	8	27.4
GC09PS71	45	443	1.2	0.12	0.2	34.5	8.2	27	8	19.4
GC09PS72	41	442	1.2	0.12	0.2	33.9	7.7	30	7	19.3
GC09PS73	34	406	1.3	0.13	0.1	38.8	9	45	8	28.7
GC09PS74	41	377	0.7	0.06	0.1	21.5	3.8	16	<5	11.2
GC09PS75a	31	402	1.2	0.11	0.1	33.8	8.4	38	7	26.7
GC09PS01	25	461	0.9	0.18	0.3	42	11.4	34	<5	25.3
GC09PS02	10	320	0.5	0.12	0.2	28.4	5.4	18	<5	13
GC09PS03	28	261	0.6	0.1	0.3	25.2	9.9	24	<5	15.6
GC09PS04	24	350	0.5	0.11	0.2	33.4	5.5	18	<5	14.4
GC09PS05	26	231	0.5	0.1	0.4	21.6	9.8	31	<5	23.3
GC09PS06	62	343	0.8	0.14	0.5	34.3	24.7	45	<5	50.6
GC09PS07	66	302	0.9	0.11	0.5	35.6	21.2	37	<5	51.5
GC09PS08	393	217	0.7	0.09	1	21.7	29	49	<5	13.7
GC09PS09	7	170	0.5	0.08	0.4	18.4	6	53	<5	12.1
GC09PS10	7	163	0.4	0.08	0.4	17.1	6	53	<5	10
GC09PS11	46	275	0.5	0.11	0.2	24.1	7	17	<5	18.2
GC09PS12	23	314	0.6	0.13	0.2	27.5	5.1	17	<5	13
GC09PS13	17	301	0.7	0.12	0.4	30.1	5.7	25	<5	17.2
GC09PS14	31	318	0.8	0.14	0.6	29.7	4.7	26	<5	11.5
GC09PS15	16	264	0.8	0.12	0.2	30.5	6.6	32	<5	24.3
GC09PS16	12	320	0.9	0.12	0.4	34.5	5.8	38	<5	13.1
GC09PSS03	39	356	0.8	0.09	0.2	27.8	6.1	32	<5	16.7

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Arsenic ppm	Barium ppm	Beryllium ppm	Bismuth ppm	Cadmium ppm	Cerium ppm	Cobalt ppm	Chromium ppm	Cesium ppm	Copper ppm
GC09PSS04	48	368	0.8	0.1	0.2	27.6	6.7	28	<5	18.5
GC09PSS01	8	320	0.7	0.16	0.2	29.8	5.4	33	<5	26.3
GC09PSS02	8	326	0.7	0.14	0.2	30.7	6	28	<5	20.1
GC09PSS10	9	342	0.8	0.15	0.3	33.1	6	26	<5	18.1
GC09PSS09	23	313	1	0.16	0.4	30.5	8.9	40	<5	24.2
GC09PSS08	58	461	0.8	0.12	0.7	29	22.5	31	<5	78.7
GC09PSS05	37	380	1.4	0.15	0.2	40.7	9.4	47	9	22.8
GC09PSS06	32	388	1.1	0.15	0.2	34.9	9.2	39	7	23
GC09PSS07	31	389	0.9	0.13	0.3	33.7	11.9	37	<5	36.9
GC09PR01	32	370	<0.1	<0.04	0.1	5.61	7.3	9	<5	135
GC09PR02	22	270	0.2	<0.04	<0.1	11.8	2.1	9	<5	6.4
GC09PW101	158	509	0.8	0.08	1.2	29.8	55.6	34	<5	183
GC09PR101	66	125	0.4	<0.04	0.4	12.3	11.9	93	<5	21.8
GC09PS75	22	444	1.1	0.17	0.2	45.3	9.3	34	<5	24.9
GC09PS76	43	494	1	0.17	0.4	41.2	22.8	24	<5	45.9
GC09PS77	32	563	1.3	0.22	0.4	48.7	17.7	32	<5	39.2
GC09PS78	74	498	1.1	0.16	0.6	45.5	32.3	31	<5	26
GC09PS79	39	448	1	0.16	0.3	42.2	14	29	<5	22.6
GC09PS80	15	405	1.1	0.15	0.3	43.1	8	28	<5	18.9
GC09PS81	21	425	1.1	0.15	0.3	45.1	8.9	33	<5	19.5
GC09PS82	17	423	1.1	0.16	0.3	46.8	7.3	28	<5	18.3
GC09PS83	23	491	1.5	0.21	0.3	56.6	10.1	35	5	22.8
GC09PS84	35	340	1.2	0.17	0.3	46	8.7	28	<5	22.9
GC09PS85	12	447	1.1	0.18	0.3	44.7	7.8	29	<5	19.3
GC09PS86	16	471	1.2	0.2	0.3	49.4	8.8	32	<5	23.2
GC09PS87	32	538	1.2	0.17	0.3	45.4	17.9	34	<5	27.2
GC09PS88	455	125	1	0.14	2.9	37.2	112	38	<5	136
GC09PS89	24	307	0.9	0.14	0.2	35.7	9.5	22	<5	22.5
GC09PW01	1,980	59	0.5	0.05	17.2	13.6	55	38	<5	57.2
GC09PW02	258	909	1.3	0.14	1	48.8	232	41	<5	130
GC09PW03	5,060	36	<0.1	<0.04	17.4	12.5	6	8	<5	9,030
GC09PR75	243	71	0.3	<0.04	0.2	16.4	50.1	18	<5	123
GC09PR76	1,620	34	0.6	0.06	6.6	18.3	232	38	<5	212
GC09KNW01	280	458	1.3	0.1	2.5	32.7	96.3	38	<5	173
GC09KNW12	803	484	0.6	0.04	8.4	22	175	20	<5	516
GC09KNW08	44	330	0.4	0.06	0.7	22.4	48.5	13	<5	41.3
GC09KNW03	4	416	0.6	0.11	0.4	29.1	5.3	20	<5	12.2
GC09KNW04	283	605	0.7	0.05	3.8	19.1	59.5	29	<5	113
GC09KNW05	169	533	1.2	0.1	2.3	34.9	67.8	21	<5	216
GC09KNW06	210	341	1.3	0.08	3	30.6	87.7	21	<5	243
GC09KNW07	24	1150	0.6	0.07	0.3	21.2	9.3	16	<5	23.9
GC09KNW09	128	504	0.7	0.07	1.6	31.9	59.3	27	<5	129
GC09KNW10	388	516	0.7	0.06	6.2	28.4	111	28	<5	172
GC09KNW11	145	417	1	0.07	2.4	32	59.8	20	<5	178
GC09KNW13	1,980	111	1.2	<0.04	10.4	25.4	57.3	14	<5	107
GS09KNS50	25	634	0.6	0.08	0.3	26	8.6	19	<5	17.6
GS09KNS51	14	703	0.8	0.11	0.2	32	8.6	21	<5	17.1
GS09KNS52	14	482	0.8	0.11	0.3	32.8	8.5	19	<5	18.2
GS09KNS53	11	400	0.5	0.08	0.3	28.9	6.6	16	<5	10.7
GS09KNS54	27	455	0.7	0.11	0.4	31.7	14.4	17	<5	29.4
GS09KNS55	18	469	0.8	0.14	0.4	37.4	15.3	21	<5	24.2
GS09KNS56	14	436	0.8	0.14	0.3	35.6	12.6	23	<5	23.3
GS09KNS57	6	441	0.8	0.12	0.2	33.8	6.6	20	<5	13.7

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Arsenic ppm	Barium ppm	Beryllium ppm	Bismuth ppm	Cadmium ppm	Cerium ppm	Cobalt ppm	Chromium ppm	Cesium ppm	Copper ppm
GS09KNS58	8	440	0.9	0.15	0.2	35.3	8.2	22	<5	17.5
GS09KNS59	18	485	0.8	0.14	0.3	38.3	10	21	<5	21
GC09KNS01	8	482	1	0.16	0.2	41.2	6.6	28	<5	16.3
GC09KNS02	9	440	0.8	0.17	0.2	39.8	6.4	22	<5	15.2
GC09KNS03	6	510	0.8	0.11	0.2	32.9	5.1	20	<5	15
GC09KNS04	7	517	0.9	0.14	0.2	37.3	6.7	19	<5	15.4
GC09KNS05	8	466	0.8	0.12	0.2	40.7	6.8	24	<5	11.4
GC09KNS06	25	489	0.8	0.13	0.3	36	14.8	22	<5	30.6
GC09KNS07	20	429	0.7	0.12	0.4	32.9	19.3	22	<5	30.2
GC09KNS08	9	419	0.7	0.12	0.3	32.6	9.3	22	<5	16.8
GC09KNS09	6	463	0.8	0.14	0.2	38.5	6.4	25	<5	12.5
GC09KNS10	3	399	0.8	0.13	0.2	35.2	4.9	22	<5	8.9
GC09KNS11	5	487	0.9	0.16	0.2	41.7	6.5	26	<5	13.5
GC09KNS12	7	477	1	0.15	0.2	40.4	7.6	26	<5	15
GC09KSSS03	4	437	0.8	0.14	0.1	34.3	5.6	26	<5	15.7
GC09KSSS02	13	464	1.1	0.2	0.1	36.5	8.8	31	6	18.6
GC09KSSS01	20	421	0.9	0.16	0.6	34	8.7	28	<5	23
GC09KSSS04	10	412	0.8	0.16	0.2	36.7	6.2	26	<5	16.7
GC09KSSS05	9	439	1	0.17	0.2	39.6	6.7	30	<5	17.5
GC09KSSS06	8	407	0.9	0.16	0.2	38.3	5.8	26	<5	16.1
GC09KSS01	5	439	0.9	0.17	0.2	44.5	6.5	33	<5	14.5
GC09KSS02	5	409	0.9	0.17	0.2	42.8	5.8	28	<5	13.9
GC09KSS03	5	335	0.9	0.15	0.2	42.7	6	28	<5	11.6
GC09KSS04	3	315	0.5	0.11	0.2	32.9	4.9	20	<5	8.8
GC09KSS05	23	357	0.8	0.19	0.2	41.5	6.8	26	<5	17.8
GC09KSS06	16	373	0.9	0.17	0.2	44	6.6	26	<5	16.7
GC09KSR01	896	978	0.4	<0.04	0.9	12	140	20	<5	1,010
GC09HS01	5	531	1.4	0.15	0.1	39.7	7.6	22	<5	18.2
GC09HS02	13	603	1.3	0.15	0.2	38.5	9.6	25	6	25.9
GC09HS03	7	568	1.3	0.15	0.1	38.5	8.7	24	6	19.4
GC09HS04	4	539	1	0.14	0.1	34.5	6.9	19	<5	15.6
GC09HS05	5	531	1.4	0.17	<0.1	39.1	9	27	8	16.3
GC09HS06	27	369	1.3	0.18	0.3	39.8	10.9	30	7	31
GC09HS07	4	367	1.1	0.14	<0.1	34.5	7.4	24	6	17.9
GC09HS08	6	445	1.6	0.18	<0.1	41.1	9.8	28	8	16.5
GC09HS09	18	571	1.3	0.16	0.2	39.7	12.9	25	6	30.1
GC09HS10	7	560	1.4	0.17	<0.1	39.4	8.2	18	6	18.4
GC09HS11	7	561	1.1	0.14	0.1	37.2	7.4	23	<5	21.6
GC09HS12	6	590	1.6	0.23	0.2	57	10	22	7	31.1
GC09HS13	6	477	1.5	0.19	<0.1	43.6	9.8	20	8	17
GC09HS14	5	456	1.6	0.2	<0.1	44.1	9.9	20	8	17.6
GC09HS15	5	462	1.6	0.2	<0.1	43.7	10.2	20	9	17.8
GC09HS16	6	530	1.7	0.2	<0.1	46.4	10.1	32	9	17.9
GC09HS17	6	454	1.3	0.16	<0.1	38.3	8.7	20	6	17.7
GC09HS18	5	498	1.4	0.18	<0.1	43.2	9.5	22	7	17.9
GC09HS19	6	512	1.3	0.17	<0.1	43.3	9.3	22	7	19.4
GC09HS20	5	493	1.8	0.21	<0.1	47.7	10.7	23	9	16.7
GC09HS21	6	467	1.5	0.19	<0.1	42.3	10.2	19	8	16.8
GC09HS22	5	490	1.4	0.18	<0.1	40.7	9.3	19	8	15.8
GC09HS58	8	559	1.4	0.2	0.2	39.8	10.9	24	5	29
GC09HS59	4	578	1.1	0.18	0.2	39.9	8.3	19	<5	19.6
GC09HS60	4	573	1.3	0.18	0.2	44.4	9.5	27	5	26
GC09HS61	4	583	0.9	0.14	0.2	40.6	10.1	18	<5	61

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Arsenic ppm	Barium ppm	Beryllium ppm	Bismuth ppm	Cadmium ppm	Cerium ppm	Cobalt ppm	Chromium ppm	Cesium ppm	Copper ppm
GC09HS62	3	848	0.8	0.13	0.1	35.5	6.7	16	<5	11.7
GC09HS63	3	532	0.9	0.16	0.2	40.9	7	21	<5	13.7
GC09HS64	3	502	0.9	0.14	0.1	39.3	6.5	17	<5	11.3
GC09HS65	5	595	1.4	0.18	0.2	48.5	13.1	25	6	54.2
GC09HS66	4	552	1.1	0.15	0.1	37.6	13.3	21	<5	84
GC09HS67	4	546	1.1	0.14	0.1	35.7	13.6	19	<5	82.3
GC09HS68	5	590	1.1	0.14	0.1	33.8	8.1	21	<5	19.6
GC09HS69	5	719	1.6	0.16	0.1	48.3	9.3	23	6	17.3
GC09HS70	4	533	1.1	0.14	0.1	46.9	7.3	18	<5	12.3
GC09HS71	4	528	1	0.14	0.1	39.9	6.9	19	<5	11.8
GC09HS50	4	582	0.7	0.1	0.1	30.2	6	16	<5	23.8
GC09HS51	4	535	0.9	0.14	0.2	39.6	6.6	21	<5	26.2
GC09HS52	4	612	0.9	0.14	0.2	32.7	7.5	18	<5	32.4
GC09HS53	3	603	1	0.13	0.2	36.8	7.7	15	<5	26.2
GC09HS54	3	600	0.8	0.14	0.1	36.3	6.5	11	<5	19.9
GC09HS55	3	565	0.8	0.14	0.1	37.7	6.6	15	<5	14.4
GC09HS56	4	595	1.3	0.2	0.2	48.3	9	21	5	24.2
GC09HS57	4	594	1.1	0.16	0.2	43	8.5	22	<5	28.2
GC09HS76	10	603	1.4	0.21	0.2	41.8	10.3	28	6	44
GC09HS77	9	594	1.3	0.21	0.2	39.8	10.5	28	5	44.1
GC09HS78	5	568	1.1	0.17	0.2	41.1	8.3	20	<5	34.2
GC09HS79	4	538	0.8	0.13	0.2	37.4	7.5	15	<5	12.6
GC09HS80	4	552	0.8	0.13	0.2	33.5	6.5	17	<5	13.6
GC09HS81	5	617	0.9	0.16	0.2	38.2	7.2	23	<5	23.3
GC09HS75	5	524	0.9	0.14	0.1	36.7	7.4	19	<5	16.2
GC09HS105	4	602	1.2	0.16	0.1	41.3	7.3	23	<5	20.6
GC09HS106	5	584	1.5	0.19	0.2	39.7	9.6	30	6	31.6
GC09HS107	5	592	1.3	0.16	0.2	44.3	9.6	26	6	27.9
GC09HS108	5	597	1.4	0.16	0.2	45.6	9.3	29	6	30
GC09HS109	5	629	1.6	0.21	0.2	55.9	10.5	32	7	35.6
GC09HS110	5	593	1.4	0.17	0.2	45	10.1	27	6	35.1
GC09HSS100	6	567	2	0.25	0.3	36.1	10.5	44	6	32.9
GC09HSS101	7	579	2.2	0.26	0.3	38.7	11	45	7	33
GC09HSS102	7	582	2.2	0.25	0.3	38.9	11.3	48	7	32.1
GC09HSS103	6	583	1.9	0.23	0.3	42.4	9.8	38	8	28.8
GC09HSS104	4	585	1.3	0.16	0.2	40.8	7.4	27	6	18.9
GC09HKSS01	12	273	0.6	0.16	0.3	26.2	4.3	16	<5	12.2
GC09HKSS02	12	314	0.8	0.19	0.3	33.9	5.2	24	<5	16
GC09HKSS04	14	264	0.5	0.17	0.4	25.3	3.7	20	<5	9.9
GC09HKSS05	10	345	0.6	0.17	0.3	31.5	3.8	14	<5	11.8
GC09HKSS03	10	349	1.1	0.18	0.3	35.5	6.2	24	<5	17.8
GC09HKSS06	14	288	0.6	0.17	0.4	30.3	5.5	17	<5	22.9
GC09HKSS07	17	355	0.8	0.18	0.4	37.8	6.7	20	<5	37.5
GC09HKSS08	11	300	0.7	0.17	0.5	28.5	4.8	19	<5	22.4
GC09HKSS09	11	272	0.7	0.19	0.3	26.1	3.9	16	<5	17.9
GC09HKSS10	9	223	0.6	0.15	0.3	19.6	3.2	11	<5	9.5
GC09HKRK01	547	406	1.8	0.23	5.6	37.6	3.8	11	<5	928
GC09HKRK02	>10,000	184	0.2	0.13	53.5	7.77	581	8	<5	1,670
GC09HKRK03	2,040	947	0.5	0.11	0.6	18.6	4	11	<5	1,740
GC09HKRK04	1,690	3150	<0.1	0.2	21.6	2.37	12.2	5	<5	306
GC09HKRK05	>10,000	67	0.5	0.21	1	18	908	12	<5	7,480

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Gallium ppm	In ppm	Lanthanum ppm	Lithium ppm	Manganese ppm	Molybdenum ppm	Niobium ppm	Nickel ppm	Phosphorus ppm	Lead ppm	Rubidium ppm
GC09JSS50	6.57	0.02	18.1	17	290	0.74	5.5	10.9	1,630	12.5	51.1
GC09JSS51	6.46	0.02	18.2	17	275	0.72	5.2	12.4	1,560	14.6	42.2
GC09JSS52	6.4	0.02	18	17	280	0.76	5.7	11	1,530	13.9	47.5
GC09JSS53	6.22	0.02	14.3	21	230	0.89	5.2	12.5	970	13.9	44.4
GC09JSS54	6.81	0.02	16.7	22	273	1	5.6	12.1	1,240	13	45.2
GC09JSS05	3.11	<0.02	7.4	9	150	1.14	2.4	23	1,670	9.7	24.9
GC09JSS01	5.57	<0.02	15	14	231	0.69	4.9	8.6	1,380	11	47.4
GC09JSS02	5.87	0.02	16.4	16	254	0.87	5.1	9.7	1,410	11.9	44
GC09JSS03	4.82	<0.02	14.6	14	205	0.72	4.1	7.9	1,430	10.3	45
GC09JSS04	5.12	<0.02	14.2	15	216	0.61	4.3	8	1,380	10.1	48.8
GC09PS50	10.9	0.04	22.7	24	342	0.88	7.2	15.8	840	6.9	65.1
GC09PS51	10.4	0.04	20.8	23	337	0.89	6.8	15.5	820	6.5	59.9
GC09PS52	11.6	0.04	23	25	351	0.95	7	16.4	870	7.1	67.8
GC09PS53	9.71	0.03	19.9	22	314	3.64	6.1	17.2	810	9.5	59.9
GC09PS54	10.3	0.03	21.1	22	333	1.72	6.4	17.4	850	8	71.4
GC09PS55	15.4	0.05	27.3	29	327	0.82	10	15.2	870	7.6	109
GC09PS56	9.72	0.03	20	21	298	4.29	6.2	17.9	1,200	8.8	62.2
GC09PS57	10.1	0.03	19.8	23	307	7.21	6.6	18.8	890	14.7	66
GC09PS58	9.99	0.03	21.4	22	346	1.29	6.4	15.9	930	7	61.5
GC09PS59	6.46	0.02	16.5	17	219	49.4	4.3	46.9	990	59.4	54.3
GC09PS60	8.7	0.03	19	21	340	1.9	5.9	15.1	880	7	60.5
GC09PS61	8.56	0.03	19.7	21	331	4.28	5.6	25.7	980	21.4	55.8
GC09PS62	7.88	0.03	18.5	20	325	3.3	5.3	25	930	11.3	50.7
GC09PS63	5.89	0.02	16.5	17	306	2.58	4	16.1	1,160	8.6	48.9
GC09PS64	8.21	0.03	19.2	19	185	92.2	5.6	139	1,030	68.6	60.7
GC09PS65	7.63	0.03	18	20	375	5.04	5.1	18	910	10	58.6
GC09PS66	8.91	0.03	20.4	22	276	1.1	5.6	12.3	820	7.4	52
GC09PS67	9.3	0.03	20.7	23	355	4.3	5.9	20.4	1,000	13.2	50.6
GC09PS68	9.89	0.04	21.9	23	350	1.15	6.2	14	960	6.8	56.3
GC09PS69	9.52	0.03	21.3	23	359	2.31	6.2	17	960	8.1	66.9
GC09PS70	8.62	0.03	20	22	383	5.73	5.8	25.2	950	11.3	50.1
GC09PS71	8.43	0.03	19.4	21	317	3.1	5.7	17.2	970	10	55.8
GC09PS72	8.28	0.03	19	21	314	2.89	5.5	16	1,010	8.4	59
GC09PS73	9.86	0.03	21.1	23	407	3.02	6.3	21.3	850	9.4	60
GC09PS74	4.35	<0.02	13.4	16	204	0.88	2.8	8.9	930	4.4	31
GC09PS75a	8.13	0.03	18.9	21	416	2.36	5.6	20.5	830	9.1	49.9
GC09PS01	8.82	0.03	22.5	22	496	1.75	6.9	20.6	1,170	17	60.9
GC09PS02	5.04	<0.02	17.2	15	251	0.8	3.5	10.1	1,400	10.1	27.4
GC09PS03	5.27	<0.02	14.9	16	283	1.48	3.7	15.4	870	11.6	35
GC09PS04	5.76	0.02	18.2	19	234	0.69	3	8.9	1,000	9.5	36.5
GC09PS05	4.64	<0.02	14.9	14	216	2.82	2.8	18.9	2,360	14.3	33.9
GC09PS06	7.17	0.02	21.4	21	331	7.96	5.2	43.8	2,370	25.2	51.8
GC09PS07	7.31	0.03	19.7	20	250	2.87	4.9	40.1	1,310	20.1	51
GC09PS08	4.79	<0.02	18.9	17	226	96.7	3.6	130	2,720	17.3	34.1
GC09PS09	4.35	<0.02	12.4	13	224	1.41	3.5	15.9	3,360	8.3	33.4
GC09PS10	4.07	<0.02	11.7	14	217	0.89	3.2	14.5	3,280	8.2	32.8
GC09PS11	4.57	<0.02	13.6	15	289	1.14	3.2	12.8	830	11.9	30
GC09PS12	5.69	0.02	16.3	17	297	0.68	3.9	9.5	880	10.5	38.9
GC09PS13	6.36	0.02	17.1	17	270	0.77	4.4	11.3	800	11.2	49.4
GC09PS14	6.87	0.02	16.7	17	227	1.08	4.2	10.2	680	11.9	58.1
GC09PS15	6.64	0.02	16.9	15	417	0.74	4.9	11.9	760	7.9	55.3
GC09PS16	7.64	0.02	19.2	20	331	0.82	5.6	12.5	870	10.4	52
GC09PSS03	6.15	0.03	14.4	14	293	5.5	5	13.4	880	9.2	46

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Gallium ppm	In ppm	Lanthanum ppm	Lithium ppm	Manganese ppm	Molybdenum ppm	Niobium ppm	Nickel ppm	Phosphorus ppm	Lead ppm	Rubidium ppm
GC09PSS04	5.94	0.03	14.9	15	278	3.97	5.1	14.1	1,060	9.8	53.3
GC09PSS01	6.35	0.03	16.5	16	269	0.75	5.4	13.9	1,140	19.2	50.7
GC09PSS02	6.43	0.02	16.5	16	270	0.76	5.2	13	1,100	15.4	50.2
GC09PSS10	6.68	0.03	17.7	17	270	0.8	5.4	13.2	1,140	14.4	59.3
GC09PSS09	7.23	0.03	17.5	18	282	1.9	5.8	25.4	1,650	16	60.3
GC09PSS08	6.5	0.03	16	16	282	4.66	5.2	44	1,290	28.8	56.9
GC09PSS05	10.8	0.04	21.8	24	304	2.8	8.3	21.7	1,210	13.1	84.5
GC09PSS06	8.81	0.03	19.1	21	303	2.81	6.9	21	1,170	14.7	72.9
GC09PSS07	7.49	0.03	18.2	18	292	3.07	6.1	24.8	1300	17.3	62.3
GC09PR01	1.31	<0.02	5.1	5	478	1.16	0.9	10	570	5.5	6.7
GC09PR02	1.71	<0.02	7	10	74	0.43	0.7	3.7	950	2.2	8.8
GC09PW101	6.56	0.02	15.3	14	185	21	4.5	93.2	860	49.6	40.5
GC09PR101	2.51	<0.02	11.6	9	235	10.7	1.2	24.3	7540	15.7	16.7
GC09PS75	9.2	0.03	23.9	22	642	1.18	6.7	18.4	820	14.4	77.7
GC09PS76	8.12	0.03	21.7	22	575	2.7	6	41.8	800	25.5	51.1
GC09PS77	10.2	0.04	25.4	26	601	2.49	7.9	35.6	880	23.8	84.5
GC09PS78	8.78	0.03	23.4	22	597	8.41	6.8	75.7	790	18.7	72.9
GC09PS79	8.13	0.03	21.7	21	552	5.56	6.2	27.7	690	18.6	70.5
GC09PS80	8.74	0.03	22.2	22	553	0.96	6.4	15.4	750	12.8	64.4
GC09PS81	9.29	0.03	22.9	24	542	1.66	6.7	16.8	660	19.8	54.1
GC09PS82	8.95	0.03	24.6	23	567	0.73	6.6	14.6	760	13.7	53.9
GC09PS83	11.1	0.04	27.1	28	976	0.97	8.7	18.7	750	18	69.7
GC09PS84	7.8	0.03	22.3	20	991	0.81	5.9	13.7	710	14	61.2
GC09PS85	8.64	0.03	24	22	515	0.78	7.2	15.3	770	15.1	64.7
GC09PS86	9.73	0.04	25.9	25	464	0.95	7.7	17.3	720	17.2	84.7
GC09PS87	9.48	0.03	23.1	25	600	4.69	7.3	33.4	710	20.4	78
GC09PS88	7.9	0.03	19.9	20	501	77.1	6	285	1040	101	63.4
GC09PS89	6.39	0.02	18.7	17	712	1.51	5.2	16.1	560	14.4	51
GC09PW01	4.72	<0.02	9.1	11	86	693	3.2	93.8	1380	935	25.5
GC09PW02	10.1	0.03	27.4	23	520	86.4	7.2	397	1470	137	67
GC09PW03	2.42	<0.02	2.7	6	18	20.9	1.5	54.8	230	837	13.6
GC09PR75	1.57	<0.02	12.8	4	11	33.9	1.8	354	960	277	11
GC09PR76	5.04	<0.02	10.5	11	271	393	3.1	570	1470	251	31.1
GC09KNW01	8.2	0.03	19	21	187	173	6.1	115	1060	154	61.2
GC09KNW12	4.48	<0.02	12.8	13	182	328	3.1	180	1460	220	30.4
GC09KNW08	5.12	<0.02	11.6	16	162	230	3.3	48.1	380	32.2	53.8
GC09KNW03	4.98	<0.02	16.3	14	329	1.63	4.5	9	770	11.2	41.5
GC09KNW04	4.79	<0.02	13	14	123	401	2.9	68.5	1610	64.3	34.8
GC09KNW05	8.12	0.03	17.5	22	199	44.8	5.1	105	530	146	64.7
GC09KNW06	7.24	0.02	15.4	23	188	75	5.5	95	600	196	55
GC09KNW07	5.25	<0.02	11.4	14	103	11.4	3.2	12.8	490	17.1	31.4
GC09KNW09	6.41	<0.02	16.6	19	303	118	4	64	840	79.6	43.9
GC09KNW10	6.31	<0.02	14.9	18	209	164	4.3	129	830	215	44.6
GC09KNW11	7.42	0.02	16.1	19	213	37	4.7	78.5	510	152	58.9
GC09KNW13	3.22	<0.02	10.5	9	218	102	2.2	123	970	1790	24.7
GS09KNS50	5.27	<0.02	14.8	18	251	2.82	4	12.5	590	9.8	29.1
GS09KNS51	7.15	0.02	18.1	20	283	2	5	13.4	600	10.8	46.8
GS09KNS52	7.03	0.02	18.5	21	346	2.62	4.6	13.3	560	12.2	57
GS09KNS53	4.67	<0.02	17.4	17	343	2.22	2.9	9.3	650	9.4	35.7
GS09KNS54	5.85	<0.02	17.3	19	338	4.01	3.9	21.1	530	25.4	48.3
GS09KNS55	7.05	0.02	19.8	19	363	3.86	5	20.6	580	19.1	56.9
GS09KNS56	6.96	0.02	19.7	19	311	4.1	5.2	18.9	530	18.5	58.6
GS09KNS57	7.06	0.02	19.1	20	310	1.13	5.3	11.6	520	11.1	60.7

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Gallium ppm	In ppm	Lanthanum ppm	Lithium ppm	Manganese ppm	Molybdenum ppm	Niobium ppm	Nickel ppm	Phosphorus ppm	Lead ppm	Rubidium ppm
GS09KNS58	7.48	0.02	19.4	20	339	1.56	5.5	14.2	520	14.6	65.2
GS09KNS59	7.44	0.03	20.8	20	370	1.89	5.8	16.3	610	15.9	60.9
GC09KNS01	9.27	0.03	22	24	404	0.97	6.9	12.3	660	13.6	71.4
GC09KNS02	7.2	0.02	20.7	20	484	1.16	5.7	11.7	600	14.8	61.4
GC09KNS03	6.97	<0.02	18.9	20	257	0.73	4.4	8.5	500	9.3	49.5
GC09KNS04	8.12	0.02	20.7	22	356	1.08	5.5	12.1	590	12.7	65.5
GC09KNS05	7.7	0.03	21.8	22	469	1.07	5	10.2	860	9.1	45.8
GC09KNS06	6.88	0.02	19.1	21	388	3.31	4.5	23.6	590	24.2	54.5
GC09KNS07	6.5	0.02	18.6	18	363	5.09	4.7	25	640	23.2	42.9
GC09KNS08	6.24	0.02	18	18	424	1.87	4.8	13.2	630	15.3	51.7
GC09KNS09	6.81	0.02	20.2	19	464	0.91	5.6	10.5	680	12.7	56.1
GC09KNS10	7.02	0.02	18.8	21	416	0.61	5	7.1	900	9.3	48.3
GC09KNS11	8.62	0.03	21.7	21	433	0.87	6.5	11.9	750	13.4	69
GC09KNS12	7.32	0.02	21.4	20	472	1.19	5.8	12.5	670	14.2	61.5
GC09KSSS03	7.81	0.03	17.6	19	430	0.63	6.1	10.9	720	12.7	59.2
GC09KSSS02	9.73	0.04	18.6	22	510	1.22	6.8	15.6	670	16.5	67.6
GC09KSSS01	8.09	0.03	17.6	18	423	0.63	6	15.4	870	20.7	60
GC09KSSS04	7.47	0.03	18.7	19	427	0.9	6.3	12.1	710	15	58.1
GC09KSSS05	8.34	0.03	19.9	20	472	0.75	7.3	13.1	770	14.8	59.5
GC09KSSS06	7.66	0.03	19.1	18	430	0.74	6.6	11.4	660	13.8	55.7
GC09KSS01	8.35	0.03	22.8	19	477	0.67	7.8	11.9	670	14.2	62.7
GC09KSS02	7.83	0.03	21.4	19	466	0.69	6.8	11.2	650	15	61.8
GC09KSS03	7.29	0.03	21.7	18	544	0.72	6.4	11.2	790	12	54.2
GC09KSS04	4.87	0.02	16.7	13	503	0.45	4	7.6	790	9.4	36.8
GC09KSS05	6.77	0.03	19.2	17	538	0.95	5.7	11.4	610	17.7	55.7
GC09KSS06	7.56	0.03	22.2	20	495	0.97	6.4	12	650	16	55.6
GC09KSR01	3.38	0.02	7.4	7	195	32.3	0.6	365	850	415	4.3
GC09HS01	10.2	0.03	21.2	29	504	0.72	5.9	12.4	610	12.2	70.5
GC09HS02	11.2	0.04	20.2	31	540	11	6.4	15.9	700	14.1	74.4
GC09HS03	11.3	0.04	20.6	31	531	7.45	6.4	13.8	640	11.5	64.5
GC09HS04	8.62	0.03	18.4	26	514	0.63	5.1	10.3	520	12.3	58.9
GC09HS05	12.1	0.04	20.6	31	578	1.02	6.7	14	670	10.8	75.6
GC09HS06	12.5	0.04	21.6	28	502	3.82	6.5	18.4	880	14.7	94.3
GC09HS07	10.1	0.03	18.1	29	493	3.04	5.5	10.7	570	9.4	88.8
GC09HS08	12.5	0.05	20.8	32	576	1.36	6.8	15.7	680	10.7	88.5
GC09HS09	11.1	0.04	20.6	31	511	2.17	6.3	20.2	690	15.2	68
GC09HS10	11.4	0.04	21.4	32	548	0.88	6.4	12.7	600	11.2	97.9
GC09HS11	10.2	0.04	20.4	29	457	0.85	6.1	12.4	530	11.2	85.2
GC09HS12	15.9	0.05	29.7	32	819	1.62	10.1	15.6	1,010	17	109
GC09HS13	14.1	0.05	22.2	30	557	1.29	8	15	680	11.6	96.2
GC09HS14	14.2	0.05	22.6	31	580	1.14	8.1	15.8	670	11.9	106
GC09HS15	14.5	0.05	22.1	30	584	1.25	8.4	15.8	690	11.5	107
GC09HS16	15.5	0.05	24.1	32	607	1.26	9.1	15.5	750	12.6	106
GC09HS17	12.5	0.04	19.8	28	502	1.84	6.6	12.7	640	10.6	92.3
GC09HS18	13.6	0.04	22.3	30	545	1.53	7.6	14.6	660	11.5	96.2
GC09HS19	13.5	0.04	22.6	30	529	1.67	7.4	14.2	670	11.9	95
GC09HS20	15.7	0.05	24	32	606	1.42	8.9	16.8	750	12.6	99.7
GC09HS21	14	0.05	21.3	29	546	1.16	7.4	15.3	680	11.6	101
GC09HS22	13.2	0.04	21	28	514	0.96	7.1	13.6	630	10.8	82.3
GC09HS58	14.2	0.04	18.7	30	829	1.38	9.4	16.4	860	18.3	68.4
GC09HS59	10.8	0.03	19.1	28	843	0.71	7	10.8	760	14.9	89
GC09HS60	13.4	0.04	21.2	30	842	0.79	8.4	12.8	940	16	94.8

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Gallium ppm	In ppm	Lanthanum ppm	Lithium ppm	Manganese ppm	Molybdenum ppm	Niobium ppm	Nickel ppm	Phosphorus ppm	Lead ppm	Rubidium ppm
GC09HS61	10.9	0.03	20.7	26	752	0.63	6.4	9.5	790	14.9	88.3
GC09HS62	12.2	0.03	19.2	27	599	0.58	5.6	9.5	680	12.3	88.7
GC09HS63	11.3	0.03	21.6	26	620	0.62	6.9	9.8	740	14.1	87.1
GC09HS64	9.69	0.03	19.9	25	603	0.53	6	9	670	12.4	79
GC09HS65	14.6	0.04	24	31	825	0.92	8.2	14.8	890	15.7	100
GC09HS66	12.1	0.03	18.4	29	628	0.79	6.8	10.8	790	15	98.4
GC09HS67	11.9	0.03	17.4	28	630	0.76	6.6	10.6	770	14.6	81.6
GC09HS68	14.7	0.04	16.9	30	584	0.68	6.7	11.8	530	11.6	68.2
GC09HS69	16.3	0.05	24	32	696	0.63	7.6	13.7	920	13.4	74.3
GC09HS70	12.2	0.03	24.3	26	648	0.57	7.2	10.2	790	12.6	85
GC09HS71	11	0.03	21.1	25	534	0.57	6.9	9.6	700	13.1	75.8
GC09HS50	8.79	0.03	16.4	24	434	0.44	4.7	7	580	9.1	60.6
GC09HS51	9.73	0.03	21.2	23	428	0.66	6.6	10.6	530	12.8	79.4
GC09HS52	11.1	0.03	16.1	26	546	0.59	7.1	9.8	650	12.1	74.8
GC09HS53	10	0.03	19.6	26	560	0.62	5.7	8.5	660	12.3	84.7
GC09HS54	10	0.03	19.5	25	524	0.58	5.5	7.5	540	12.7	93.1
GC09HS55	10.1	0.03	20	24	534	0.61	6.2	8.2	610	12.6	64.2
GC09HS56	13.9	0.04	25.4	30	807	0.87	9.1	13.2	980	17.1	95.6
GC09HS57	11.2	0.03	22.3	26	562	0.76	6.7	11.1	780	13.5	73.2
GC09HS76	14	0.05	20.3	30	767	1.13	9.3	16.2	1,060	17.5	65.8
GC09HS77	13.8	0.04	19.3	31	800	1.19	8.9	15.6	1,010	16.9	39
GC09HS78	11.8	0.03	20.6	29	613	0.66	7.4	11.6	760	15.2	77.1
GC09HS79	9.58	0.03	20	23	640	0.61	5.5	8.2	730	12.7	73.2
GC09HS80	9.29	0.03	17.9	22	488	0.64	5.2	8.1	610	12.3	80.3
GC09HS81	10	0.03	19.7	26	515	0.84	7.2	11.3	670	12.4	69.9
GC09HS75	9.73	0.03	19.2	25	484	0.75	6	10.1	570	11.9	69.9
GC09HS105	11.7	0.04	21.6	29	504	0.63	7.6	11.4	620	12.3	82.3
GC09HS106	14.9	0.05	19.7	32	767	0.74	9.2	15.5	760	15	67.3
GC09HS107	12.8	0.04	23.3	30	691	0.72	7.5	13.9	790	12.5	69.5
GC09HS108	13.4	0.04	23.3	32	662	0.74	8.6	13.8	780	13.1	81.6
GC09HS109	14.6	0.05	28	32	954	0.96	9.6	16.7	950	17.2	100
GC09HS110	14	0.04	22.2	31	897	0.81	8.7	15	740	15.2	82.5
GC09HSS100	18.6	0.06	16.7	40	676	1.05	11.4	21.5	1,120	18.4	40.3
GC09HSS101	20.5	0.07	17.4	43	685	0.98	12	21.1	1,180	19	42.2
GC09HSS102	20.4	0.07	17.9	42	665	1.07	12	22.7	1,160	18.2	42.2
GC09HSS103	18	0.06	20.8	38	607	1.01	11.1	18.1	1,060	19.7	68.9
GC09HSS104	12.7	0.04	21.3	30	590	9.71	8.1	11.9	830	13.5	66.5
GC09HKSS01	5.38	0.02	16.3	14	339	1.16	3.3	13	1,260	8.9	41.7
GC09HKSS02	7.57	0.03	19.5	16	381	1.14	5.3	11	1,430	11.6	51.6
GC09HKSS04	5.15	0.02	15.9	14	251	1.1	3.9	8.5	2,220	11	38.5
GC09HKSS05	5.31	0.02	18	12	305	1.03	3.4	7.9	1,220	11.6	41.9
GC09HKSS03	7.91	0.03	20.9	17	366	2.02	6.1	14.2	1,490	12.7	58.5
GC09HKSS06	6.4	0.03	17.8	15	336	1.94	4.5	13.6	1,360	12.5	46.1
GC09HKSS07	8.49	0.04	20.8	18	376	2.91	5.5	15.9	1,390	22.9	57.9
GC09HKSS08	6.45	0.03	17.6	15	324	1.7	4.4	12.1	1,300	12.2	48.5
GC09HKSS09	5.78	0.03	15.2	13	283	1.26	3.8	10.7	1,160	9.7	45.7
GC09HKSS10	4.34	0.02	11.9	11	204	1.19	2.6	8.8	900	9.2	36.7
GC09HKRK01	7.36	0.04	13	29	14	476	5	67.1	280	290	38.1
GC09HKRK02	2.99	0.03	1.4	2	11	104	0.5	1,260	280	324	3.5
GC09HKRK03	5.52	0.03	9.9	13	21	14.3	4.4	12.2	310	212	32.7
GC09HKRK04	2.51	<0.02	1.9	3	13	78.1	0.3	22.9	960	127	2.6
GC09HKRK05	1.91	0.05	5.8	5	41	4,450	1.7	622	760	939	7.5

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Antimony ppm	Scandium ppm	Tin ppm	Strontium ppm	Tellurium ppm	Thorium ppm	Thallium ppm	Uranium ppm	Vanadium ppm	Tungsten ppm	Yttrium ppm	Zinc ppm
GC09JSS50	0.47	4.8	1	101	<0.1	5.1	0.3	1.7	31	0.7	15.7	41
GC09JSS51	0.56	4.8	1.1	98.8	<0.1	5.7	0.3	1.7	31	0.6	15.3	46
GC09JSS52	0.55	4.8	1.1	94.8	<0.1	5.3	0.3	1.6	31	0.7	15.5	41
GC09JSS53	0.56	4.6	1	174	<0.1	4.6	0.3	1.6	29	0.6	12.1	50
GC09JSS54	0.5	5.2	1	133	<0.1	4.9	0.4	1.9	32	0.7	15.2	53
GC09JSS05	0.25	2.4	3.2	221	<0.1	2.3	0.5	2.9	13	0.3	6.5	362
GC09JSS01	0.4	4	0.8	94.3	<0.1	5.1	0.3	1.7	26	0.5	14.4	36
GC09JSS02	0.44	4.4	0.8	94.9	<0.1	5.6	0.3	1.8	29	0.6	14.3	42
GC09JSS03	0.38	3.5	0.8	80.8	<0.1	4.1	0.3	1.6	23	0.5	13.5	32
GC09JSS04	0.38	3.8	0.8	86.2	<0.1	4.4	0.3	1.6	25	0.5	13.5	35
GC09PS50	0.5	7	1.5	174	<0.1	7.4	0.4	2.5	60	1.1	15.5	30
GC09PS51	0.5	7	1.4	162	<0.1	6.9	0.4	2.2	55	1	15	29
GC09PS52	0.54	7.6	1.6	167	<0.1	7.5	0.4	2.6	61	1.1	15.3	40
GC09PS53	0.69	6.3	1.3	140	<0.1	6.7	1	4.4	52	1.6	14.7	40
GC09PS54	0.59	6.9	1.4	152	<0.1	7.3	0.6	3.5	57	1.2	15.4	47
GC09PS55	0.69	10.1	2.2	234	<0.1	8.8	0.5	2.4	81	1.3	17	33
GC09PS56	0.79	6.2	1.4	141	<0.1	6.3	1.5	3.9	51	2.6	15.5	60
GC09PS57	0.89	6.4	1.4	147	<0.1	6.4	1.8	4.2	54	2.4	14.5	44
GC09PS58	0.61	6.7	1.4	167	<0.1	6.8	0.9	2.8	56	2.1	15.2	32
GC09PS59	1.91	4.3	0.9	94.3	<0.1	5.4	2.6	79.1	37	4.3	13.2	167
GC09PS60	0.55	6.2	1.2	139	<0.1	6.5	0.6	2.8	49	1.1	14.7	39
GC09PS61	0.96	5.9	1.2	143	<0.1	6.1	1.2	6.3	50	1.4	14.2	86
GC09PS62	0.83	5.5	1.2	133	<0.1	5.7	1.2	6	44	1.2	13.8	66
GC09PS63	0.74	4	0.9	128	<0.1	4.7	1.1	4.8	36	1.4	13.3	45
GC09PS64	6.4	4.5	1.1	119	<0.1	5.6	11.5	68	62	3.1	14.6	296
GC09PS65	0.75	5.3	1.1	150	<0.1	5.5	1.2	6	48	1.2	12.8	97
GC09PS66	0.5	6.3	1.3	215	<0.1	6.3	0.5	5.2	52	1	13.6	30
GC09PS67	0.66	6.5	1.3	171	<0.1	6.2	1.7	6.3	54	1.1	14.2	47
GC09PS68	0.5	6.8	1.4	177	<0.1	6.8	0.5	2.6	57	1.1	14.8	46
GC09PS69	0.61	6.7	1.4	167	<0.1	6.5	0.6	4	55	1.1	14.8	40
GC09PS70	0.81	5.8	1.2	153	<0.1	6	1.1	8.1	51	1.1	13.6	82
GC09PS71	0.73	5.8	1.2	164	<0.1	5.9	0.9	4.6	49	1.1	13.8	44
GC09PS72	0.66	5.7	1.2	168	<0.1	5.8	0.8	4.3	48	1.2	13.6	42
GC09PS73	0.65	6.5	1.4	160	<0.1	6.5	0.5	5	55	1.1	14.2	70
GC09PS74	0.31	2.8	0.6	99.6	<0.1	3.5	0.3	2.7	28	0.6	10.6	21
GC09PS75a	0.59	5.6	1.2	136	<0.1	5.8	0.5	5	49	0.9	13.1	72
GC09PS01	0.98	5	1.4	149	<0.1	7.3	0.5	10.6	43	1	19.4	56
GC09PS02	0.37	2.8	0.8	79.5	<0.1	4.5	0.2	5	25	0.7	14.4	34
GC09PS03	0.55	3.2	0.9	170	<0.1	4.2	0.3	7.2	30	0.8	13.9	29
GC09PS04	0.42	3.4	0.9	107	<0.1	6.7	0.2	3.7	33	0.8	15.6	28
GC09PS05	0.45	2.7	0.7	81.5	<0.1	3.8	0.4	12.9	25	0.6	14.5	46
GC09PS06	1.21	4.6	1	102	<0.1	7.3	1	36.6	38	1	21	93
GC09PS07	1.02	4.5	1	144	<0.1	5.9	0.9	26.5	37	1.3	15.5	76
GC09PS08	2.19	2.9	0.7	113	<0.1	3.6	3.9	11.1	31	0.6	19.6	254
GC09PS09	0.51	2.6	0.8	93.8	<0.1	3.1	0.3	7.4	28	0.5	13.4	43
GC09PS10	0.48	2.5	0.6	87.7	<0.1	2.9	0.3	7.2	27	0.5	13.1	42
GC09PS11	0.49	2.6	0.7	69.6	<0.1	4.3	0.2	5.4	29	0.8	12.1	36
GC09PS12	0.46	3.3	1	76.1	<0.1	4.7	0.2	3.2	29	0.7	13.6	30
GC09PS13	0.5	3.7	0.9	121	<0.1	5.1	0.3	4.1	30	0.6	13.8	34
GC09PS14	0.47	4	1	128	<0.1	5.6	0.3	3.2	33	0.7	12.6	39
GC09PS15	0.56	4.2	1.1	122	<0.1	5.1	0.3	4.1	34	1	13.2	29
GC09PS16	0.51	4.4	1.3	116	<0.1	6.2	0.4	4.1	35	0.8	14.9	39

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Antimony ppm	Scandium ppm	Tin ppm	Strontium ppm	Tellurium ppm	Thorium ppm	Thallium ppm	Uranium ppm	Vanadium ppm	Tungsten ppm	Yttrium ppm	Zinc ppm
GC09PSS03	0.86	5.7	1.8	102	<0.1	5.2	1	4.4	35	1.8	13.2	36
GC09PSS04	0.73	5.9	1	103	<0.1	5.3	1	4.2	31	1.7	14.2	35
GC09PSS01	0.72	4.7	1.1	113	<0.1	5.3	0.3	3.7	31	0.8	13.2	43
GC09PSS02	0.58	4.8	1.1	111	<0.1	5.5	0.3	4.3	31	0.8	12.6	39
GC09PSS10	0.56	5.1	1.2	117	<0.1	5.6	0.4	6.2	31	0.8	13.5	42
GC09PSS09	0.69	5.8	1.3	129	<0.1	5.2	0.6	8.5	36	0.8	14.8	66
GC09PSS08	1.46	5.8	1	126	<0.1	5.4	1.1	45	34	1.4	14.9	139
GC09PSS05	0.92	8.7	2.1	173	<0.1	6.7	1.2	8.3	56	2.3	15.8	56
GC09PSS06	0.86	7.4	1.5	148	<0.1	5.9	0.9	9.8	44	1.8	14.8	53
GC09PSS07	0.96	6.1	1.2	131	<0.1	5.7	0.9	16.7	39	1.4	14.7	64
GC09PR01	0.3	0.9	0.2	58.3	<0.1	1	0.2	7.5	11	<0.1	5.7	27
GC09PR02	0.12	0.7	0.1	53.7	<0.1	1.6	0.2	4.9	9	<0.1	8.6	8
GC09PW101	2.87	4.2	1	122	<0.1	5	1.8	171	35	1.7	12.1	224
GC09PR101	0.84	2.2	0.6	77.6	<0.1	1.7	0.9	20.4	27	0.2	19	70
GC09PS75	0.78	5.4	1.4	96.3	<0.1	7.9	0.5	5.3	49	1	16.3	53
GC09PS76	1.38	4.8	1.2	113	<0.1	6.9	1	31.5	40	1.2	15.8	87
GC09PS77	1.39	6.1	1.5	120	<0.1	8.2	1	33	47	1.3	16.6	90
GC09PS78	1.16	5.3	1.2	134	<0.1	7.8	2.6	32.2	43	1.1	17.2	141
GC09PS79	0.95	5	1.1	145	<0.1	7.4	1.4	13.3	42	1	15.2	65
GC09PS80	0.64	5.3	1.1	139	<0.1	7.3	0.4	2.8	42	1	16.4	51
GC09PS81	0.86	5.7	1.3	165	<0.1	7.8	0.4	4.2	48	1.1	16	61
GC09PS82	0.63	5.5	1.2	155	<0.1	8.1	0.4	1.8	44	1	16	45
GC09PS83	0.84	6.9	1.4	126	<0.1	9.3	0.5	3.1	55	1.2	17.5	62
GC09PS84	0.71	5	1.2	136	<0.1	7.3	0.3	2.8	47	1.1	15	44
GC09PS85	0.68	5.4	1.3	148	<0.1	7.7	0.4	2.6	43	0.9	18.3	48
GC09PS86	0.8	5.9	1.4	107	<0.1	8.7	0.5	4.7	47	1	16.7	55
GC09PS87	1.08	5.9	1.3	131	<0.1	8	1.2	19.3	50	1.2	16.1	76
GC09PS88	6.2	4.8	1.1	152	<0.1	6	21.9	206	51	2.2	16.9	624
GC09PS89	0.76	4.1	1	113	<0.1	6	0.5	9.6	37	1.2	13.6	46
GC09PW01	124	3.7	0.6	155	<0.1	2.2	33.7	1,230	50	19.4	6.2	2,810
GC09PW02	14.6	5.8	1.2	210	<0.1	7.6	4.3	616	64	4.6	23	215
GC09PW03	12.1	0.8	0.3	436	<0.1	0.3	6.3	1,870	21	9.9	3.3	3,400
GC09PR75	50	0.9	0.2	109	<0.1	2.5	139	147	22	1.3	9.1	16
GC09PR76	14.8	2.3	0.6	148	<0.1	2.3	71.3	502	50	2.9	14.5	1,460
GC09KNW01	1.31	5.9	1.2	107	<0.1	5.7	12.4	679	66	0.8	16.9	458
GC09KNW12	2.3	2.4	0.5	115	<0.1	3.1	20.4	1,720	66	0.4	16.1	1,590
GC09KNW08	0.66	2.7	2.5	250	<0.1	3.4	1.8	1,800	24	0.3	7.8	165
GC09KNW03	0.45	3.7	0.7	210	<0.1	4.6	0.3	6.4	24	0.6	14.8	33
GC09KNW04	0.97	3.3	0.6	99.5	<0.1	2.9	9.5	295	50	0.5	14.8	528
GC09KNW05	1.28	5.8	1.1	101	<0.1	5.7	3.2	1,350	50	0.9	16.7	503
GC09KNW06	1.59	5.3	1.1	96.9	<0.1	5.2	4	2,190	49	0.9	17.5	621
GC09KNW07	0.45	3.1	0.8	626	<0.1	3.3	0.7	50.2	30	0.9	6.8	51
GC09KNW09	1.16	3.6	0.9	149	<0.1	5	2.7	700	49	0.7	13.9	429
GC09KNW10	1.62	3.5	0.8	112	<0.1	4.1	10.7	2,840	47	0.8	16	1,350
GC09KNW11	1.12	4.2	0.9	87.6	<0.1	4.9	2.8	1,050	44	0.5	13.6	600
GC09KNW13	3.07	1	0.4	64.7	<0.1	1.7	30.2	488	51	1.4	28.4	1,400
GS09KNS50	0.45	3	0.7	379	<0.1	4.1	0.4	27	36	1	10	54
GS09KNS51	0.52	4	1	284	<0.1	5.2	0.4	23.5	39	0.9	11.9	53
GS09KNS52	0.5	3.9	1.8	160	<0.1	5.1	0.5	29.1	35	0.8	13.8	54
GS09KNS53	0.36	2.5	0.6	161	<0.1	3.8	0.3	22.6	24	0.6	15.7	36
GS09KNS54	0.63	3.1	0.8	115	<0.1	4.8	0.6	69.5	33	0.7	13.3	86
GS09KNS55	0.58	3.9	1	121	<0.1	6.3	0.7	69.5	36	0.7	14.9	89

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Antimony ppm	Scandium ppm	Tin ppm	Strontium ppm	Tellurium ppm	Thorium ppm	Thallium ppm	Uranium ppm	Vanadium ppm	Tungsten ppm	Yttrium ppm	Zinc ppm
GS09KNS56	0.55	3.9	0.9	106	<0.1	6.3	0.7	47	35	0.7	14	75
GS09KNS57	0.49	4	0.9	131	<0.1	5.8	0.3	7.4	34	0.7	13.7	41
GS09KNS58	0.57	4.2	0.9	95.9	<0.1	5.9	0.5	20.4	35	0.7	13.8	52
GS09KNS59	0.61	4.3	1	133	<0.1	6.3	0.5	30.7	39	0.9	14.7	62
GC09KNS01	0.64	5.1	1.1	127	<0.1	7	0.4	6.9	41	0.9	15.3	46
GC09KNS02	0.55	4	0.9	97.3	<0.1	6.9	0.4	10.3	37	0.9	14	42
GC09KNS03	0.46	3.6	1.2	211	<0.1	5.3	0.3	9	33	0.9	12.4	28
GC09KNS04	0.54	4.3	1.1	124	<0.1	6.3	0.4	14.9	36	0.8	14.6	45
GC09KNS05	0.49	4.5	1	199	<0.1	7.4	0.3	14.2	44	0.8	15.5	38
GC09KNS06	0.68	3.8	0.9	98.8	<0.1	5.6	0.6	64.5	36	0.7	13.9	82
GC09KNS07	0.56	3.7	0.8	126	<0.1	5.6	0.8	80.2	38	0.7	14	109
GC09KNS08	0.52	3.5	0.8	161	<0.1	5.6	0.4	33	34	0.7	14.8	52
GC09KNS09	0.52	4.2	0.9	172	<0.1	6.8	0.3	9.8	37	0.8	15.9	38
GC09KNS10	0.48	4.2	1	190	<0.1	6.7	0.2	2.9	42	0.8	15	30
GC09KNS11	0.61	5	1.1	173	<0.1	7.8	0.3	6.2	41	0.9	15	46
GC09KNS12	0.53	4.5	1	127	<0.1	7.1	0.4	13.9	38	0.8	15.5	47
GC09KSSS03	0.58	5.5	1.5	122	<0.1	6	0.3	1.5	41	0.9	12.7	38
GC09KSSS02	0.63	7.7	1.5	136	<0.1	6.7	0.4	2	55	1.2	13.3	40
GC09KSSS01	0.65	6.2	1.5	121	<0.1	5.7	0.6	3.6	46	2.1	13	67
GC09KSSS04	0.63	5.3	1.2	94.1	<0.1	6.2	0.4	1.8	39	0.9	12.7	41
GC09KSSS05	0.67	6	1.3	103	<0.1	6.9	0.4	1.9	43	1.1	14.2	46
GC09KSSS06	0.63	5.5	1.2	94.2	<0.1	7	0.4	2	40	0.9	13.6	41
GC09KSS01	0.68	5.9	1.2	114	<0.1	8.1	0.4	2	44	1.1	16.4	44
GC09KSS02	0.61	5.5	1.2	98.9	<0.1	7.7	0.3	1.9	41	1.3	14.6	42
GC09KSS03	0.63	5.4	1.1	89.9	<0.1	6.8	0.3	1.6	44	1	15.6	44
GC09KSS04	0.47	3.7	0.7	114	<0.1	5.4	0.2	1.3	30	0.7	13.5	29
GC09KSS05	0.76	5	1.2	71.1	<0.1	7.4	0.3	2.7	42	1	12.9	42
GC09KSS06	0.84	5.4	1.1	80.9	<0.1	7.6	0.3	2.5	48	1.2	14.9	45
GC09KSR01	3.48	1.8	<0.1	365	<0.1	1.6	0.8	54.9	69	0.3	8.8	1,720
GC09HS01	0.74	5.9	1.2	181	<0.1	6.5	0.4	3.1	50	1	13.1	46
GC09HS02	0.84	6.4	1.2	248	<0.1	6.6	0.5	5.6	59	1.2	13.8	57
GC09HS03	0.83	6.5	1.3	221	<0.1	6.7	0.4	3	56	1.2	13.8	51
GC09HS04	0.63	4.5	1	136	<0.1	5.7	0.4	2.6	42	0.8	11.7	36
GC09HS05	0.86	7.4	1.4	337	<0.1	6.5	0.4	2.9	60	1.3	14.1	43
GC09HS06	0.79	7.8	1.5	240	<0.1	6.8	0.6	11.3	65	1.8	14.8	94
GC09HS07	0.64	5.8	1.1	323	<0.1	6	0.4	7.2	50	1	12.8	38
GC09HS08	0.9	7.9	1.5	371	<0.1	7	0.4	3.3	58	1.4	14.1	46
GC09HS09	0.92	6.2	1.3	192	<0.1	6.8	0.5	19.9	58	1.2	14.1	56
GC09HS10	0.76	6.6	1.3	234	<0.1	6.7	0.4	2.3	56	1.2	13.9	42
GC09HS11	0.65	5.6	1.2	173	<0.1	6.4	0.4	1.6	51	0.9	12.9	41
GC09HS12	0.88	9.1	1.7	140	<0.1	9.6	0.5	3.7	61	1.4	19.3	65
GC09HS13	0.9	9.1	1.5	387	<0.1	7.3	0.4	3.1	64	1.5	15.3	48
GC09HS14	0.92	9.6	1.6	322	<0.1	7.4	0.4	3.1	63	1.5	15.7	48
GC09HS15	0.93	9.8	1.6	364	<0.1	7.4	0.4	3.1	62	1.5	15.9	49
GC09HS16	0.94	9.8	1.7	268	<0.1	7.8	0.5	2.8	76	1.7	16.7	50
GC09HS17	0.76	7.8	1.3	306	<0.1	6.4	0.4	4.3	58	1.2	14.5	42
GC09HS18	0.87	8.6	1.5	358	<0.1	7.2	0.4	3.6	59	1.3	15.4	46
GC09HS19	0.81	8.1	1.3	283	<0.1	7	0.4	4.7	61	1.3	15.6	45
GC09HS20	0.97	10	1.7	273	<0.1	7.6	0.5	2.8	72	1.8	16.3	52
GC09HS21	0.91	9.3	1.5	390	<0.1	7	0.4	3.7	60	1.6	14.9	52
GC09HS22	0.86	8.6	1.4	351	<0.1	6.8	0.4	2.7	60	1.3	14.3	43
GC09HS58	0.84	7.7	1.4	138	<0.1	6.6	0.5	5.9	58	1.3	14.7	63
GC09HS59	0.69	6.2	1.2	117	0.1	6.7	0.4	2.1	43	1.1	13.9	41

Table 8. Chemical analyses of soil, sediment, rock, and mine waste samples collected by this study.—Continued

[Datum for all latitude and longitude values is WGS 1984; ppm, parts per million; wt. %, weight percent; see text for description of sample processing and analytical procedures; no., number]

Field no.	Antimony ppm	Scandium ppm	Tin ppm	Strontium ppm	Tellurium ppm	Thorium ppm	Thallium ppm	Uranium ppm	Vanadium ppm	Tungsten ppm	Yttrium ppm	Zinc ppm
GC09HS60	0.75	7.2	1.4	122	<0.1	7.6	0.5	2.2	52	1.2	16.3	51
GC09HS61	0.59	5.5	1	130	<0.1	6.2	0.4	1.8	43	0.9	14.8	39
GC09HS62	0.59	5.7	1	121	<0.1	6.4	0.4	1.7	48	0.8	13.6	47
GC09HS63	0.63	5.9	1.2	125	<0.1	6.7	0.4	1.5	47	0.9	14.9	42
GC09HS64	0.56	5.3	1	126	<0.1	5.9	0.4	1.4	42	0.8	14.1	38
GC09HS65	0.8	8	1.4	156	<0.1	7.8	0.5	1.9	57	1.3	17.1	53
GC09HS66	0.66	6.1	1.1	144	<0.1	6	0.4	1.4	49	1	13.7	41
GC09HS67	0.65	5.8	1.1	142	<0.1	5.7	0.4	1.4	47	1	13.4	39
GC09HS68	0.63	6.9	1.2	125	<0.1	6.3	0.4	1.2	58	0.9	13.1	50
GC09HS69	0.68	8.3	1.5	133	<0.1	8	0.4	1.5	62	1.1	17.2	61
GC09HS70	0.64	6.5	1.2	133	<0.1	7.2	0.4	1.6	50	1	16.3	42
GC09HS71	0.62	6.2	1.2	131	<0.1	6.6	0.4	1.4	48	0.9	15	41
GC09HS50	0.47	5	1.3	297	<0.1	4.9	0.3	1.2	38	0.7	12.1	30
GC09HS51	0.6	5.5	1.2	193	<0.1	6.9	0.4	1.5	41	0.9	15.5	38
GC09HS52	0.61	5.3	1.1	156	<0.1	5.6	0.4	1.1	44	0.9	13	40
GC09HS53	0.52	5.2	0.9	171	<0.1	6.3	0.4	1.4	42	0.8	13.9	37
GC09HS54	0.58	4.5	0.9	146	<0.1	5.8	0.4	1.3	42	0.8	12.5	34
GC09HS55	0.63	5.3	1	157	<0.1	6.2	0.4	1.3	43	0.9	14	36
GC09HS56	0.77	7.1	1.4	133	<0.1	7.2	0.5	1.5	55	1.2	14.8	55
GC09HS57	0.68	6.4	1.3	191	<0.1	7	0.4	2	47	1.1	15.2	42
GC09HS76	0.8	8.2	1.6	156	<0.1	7.3	0.5	3.8	61	1.5	16.2	61
GC09HS77	0.79	7.9	1.6	154	<0.1	7	0.5	3.1	58	1.4	15.4	60
GC09HS78	0.72	6.7	1.2	151	<0.1	7.2	0.4	1.6	48	1.1	14.9	44
GC09HS79	0.61	5.9	1.1	162	<0.1	6.2	0.4	1.5	43	0.8	15.1	37
GC09HS80	0.6	5.3	1.1	217	<0.1	5.8	0.4	1.6	44	0.8	13.8	34
GC09HS81	0.66	6.3	1.2	220	<0.1	6.6	0.4	1.9	51	1	14.7	42
GC09HS75	0.69	6.1	1.1	193	<0.1	6.5	0.4	3.1	45	1	13.3	36
GC09HS105	0.66	7.1	1.3	199	<0.1	7.4	0.4	1.7	50	1.1	15.1	45
GC09HS106	0.8	8.6	1.7	177	<0.1	6.8	0.5	1.4	57	1.3	16.2	60
GC09HS107	0.69	8	1.4	258	<0.1	7.6	0.4	2	55	1.1	17.1	51
GC09HS108	0.74	8.8	1.5	256	<0.1	7.9	0.4	2	57	1.3	17.8	53
GC09HS109	0.88	9.2	1.8	149	<0.1	9.4	0.5	2.9	63	1.5	18.7	65
GC09HS110	0.83	8.5	1.6	140	<0.1	7.5	0.5	2.2	55	1.3	16.8	57
GC09HSS100	0.98	9.2	6.6	167	<0.1	6	0.6	1.7	78	1.7	15.2	82
GC09HSS101	1.06	10.6	2.8	177	<0.1	6.7	0.6	1.9	82	1.8	16.5	88
GC09HSS102	1.06	10.7	2.9	174	<0.1	6.6	0.6	1.9	81	1.8	16.7	87
GC09HSS103	0.95	10.6	2.6	176	<0.1	7.5	0.5	1.9	71	1.6	18.1	73
GC09HSS104	0.69	7.7	1.5	176	<0.1	6.9	0.5	1.6	53	1.1	15.6	50
GC09HKSS01	0.34	3.2	1.2	110	<0.1	4.3	0.3	3.9	26	0.5	12.5	34
GC09HKSS02	0.46	4.4	1.9	129	<0.1	5.8	0.4	2.1	33	0.8	14.7	39
GC09HKSS04	0.36	3.2	0.8	194	<0.1	4.2	0.3	2.9	25	0.7	14.5	42
GC09HKSS05	0.33	3.2	0.9	101	<0.1	5.7	0.3	2.8	26	1	12.8	32
GC09HKSS03	0.5	4.8	1.2	126	<0.1	6.4	0.4	5	34	0.9	16.3	46
GC09HKSS06	0.39	3.8	0.9	114	<0.1	5.4	0.4	6.5	29	0.7	13.2	43
GC09HKSS07	0.5	4.8	1.3	134	<0.1	6	0.4	10.2	37	0.8	14.8	52
GC09HKSS08	0.41	4.1	1	111	<0.1	4.9	0.3	4.8	28	0.6	13.7	53
GC09HKSS09	0.34	3.3	0.8	102	<0.1	4.4	0.3	3.2	26	0.5	11.3	37
GC09HKSS10	0.29	2.6	0.9	88.5	<0.1	3.2	0.3	2.4	19	0.4	9	28
GC09HKRK01	8.7	3.8	0.8	101	0.3	6.1	4.8	7,760	29	20.4	25.7	797
GC09HKRK02	8.55	0.9	0.3	400	0.1	<0.2	349	3,630	8	12.4	4	>10,000
GC09HKRK03	12.4	2.2	0.6	81.5	<0.1	3.7	1.7	825	32	3.5	8.1	92
GC09HKRK04	1.99	0.3	0.3	143	<0.1	0.6	3.2	122	7	0.4	0.9	5,270
GC09HKRK05	12.9	2.9	0.5	128	0.4	1.4	129	>10,000	273	22.3	17.9	111

Soil samples and a few rock samples were collected along and near two traverses across the reclaimed operations area that was the site of mine buildings and a waste-rock pile (fig. 9*B*). One soil traverse started east of the reclaimed zone and went southwest across the trace of the waste pile and the building location to undisturbed soils on the west side (table 8, samples GC09PS75–84). The second traverse started north-northwest of the site and went south-southeast across it (table 8, samples GC09PS85–89). Along the east-to-west traverse, the first five soil samples contained 5.3–33 ppm uranium whereas the next five samples contained 1.8–4.2 ppm uranium. The second group of samples averaged 2.7 ppm, slightly above the regional soil concentration. The break in concentrations between the two sample sets corresponds with the west edge of the before-restoration location of the mined waste-rock pile. Dispersion of material from the waste-rock pile to the east is indicated by concentrations above background in the two easternmost samples on this traverse. The proximity of these two samples to traces of roads indicates that dust from trucks may contribute to these elevated uranium concentrations. The north-to-south traverse crossed two sites that yielded modest uranium concentrations (2.6 and 4.7 ppm) north of the disturbed zone, substantially elevated uranium concentrations (19.3 and 206 ppm) in disturbed soils of the former mined waste-rock pile, and an elevated uranium concentration (9.6 ppm) south and down slope of the disturbed zone. Five mined waste-rock samples collected from the surface of this area contained from 147 ppm to 1,870 ppm uranium (table 8, samples GC09PR75–76 and GC09PW01–03). Four of these samples were in the area of the mined waste-rock pile, and one (1,870 ppm uranium) was at the southwest edge of the site.

Stream sediments were collected from two segments of the stream drainage at the reclaimed mine site (fig. 9*A*). Two samples were taken along the wash that directly drains the site, but below the zone where boulders were placed along the drainage. These samples contain 4.4 and 4.2 ppm uranium, very similar to the median value of soil samples from the reclaimed site, indicating that this sediment is composed of eroded cover and is little affected by local waste (enriched in uranium) that underlies cover within the reclaimed area. The remainder of the samples was collected from the stream drainage east of the site. Samples upstream of the mine site range from 3.7 to 8.5 ppm uranium; highest concentrations are found closest to the site. Sediment sample GC09SS08 was collected where the western side of the stream channel is contaminated with uranium in slope wash derived from exposed waste rock near the top of the slope. It is a composite of sediment from three locations across the wash bottom. This composite contained 45 ppm uranium. The western location measured 54 μR/h whereas the other two locations measured 13 and 14 μR/h. Three samples taken downstream from GC09SS08 contain 8.3, 9.8, and 16.7 ppm uranium; concentrations increased downstream. These data indicate that uranium concentrations in stream sediments in this small wash proximal to and below mine operations are greater than background values at Jumpup Canyon (1.9 ppm) and the stream sediments draining the reclaimed site (4.4 and 4.2 ppm). Stream sediment samples below the mine site contain higher uranium concentrations than the three upstream. The distribution of these increased concentrations is consistent with dispersion by wind and water from materials redistributed by mining operations and restoration activities. However, uranium derived from the abundant limonite-cemented sandstone outcrops in this part of the wash cannot be eliminated as a possible source of elevated uranium.

Arsenic concentration patterns are similar to those of uranium, but concentrations are generally higher (fig. 9*C*). Soils within the interior of the pipe contain 6–407 ppm arsenic and have average and median concentrations of 68 ppm and 41 ppm, respectively. Two samples that contain 68 and 79.1 ppm uranium also have high arsenic concentrations (407 and 377 ppm). As noted in the uranium discussion, these samples are soils probably contaminated by mined waste rock. Outside of the pipe, arsenic concentrations for the 16 samples range from 7 to 393 ppm and average 50 ppm (median, 25 ppm). Without the single high value from the anomalous iron-rich soil sample (table 8, GC09PS08), the average and median are essentially identical. Other samples from the east slope that contain high arsenic concentrations (62 and 66 ppm arsenic) are the same as samples with high uranium concentrations (26.5 and 36.6 ppm). Stream sediments above the site contain modest arsenic concentrations (8–23 ppm), whereas stream sediment from site SS08 contained 58 ppm arsenic, and samples downstream range decrease in concentration from 37 to 31 ppm. All arsenic concentrations in stream sediments exceed that of the Jumpup Canyon (median, 5 ppm). Arsenic in the exposed waste rock and the slope wash at the east edge of the reclaimed mine site is elevated similar to uranium concentrations.

In the operations area (fig. 9*D*), soil arsenic concentrations range from 12 to 455 ppm, whereas rock and mine waste samples range from 243 to 5,060 ppm. Highest concentrations for soil, rock, and mine waste are within the area once occupied by the mine-waste pile, except for the anomalous rock sample along the southwest edge of the reclaimed area.

The concentration of cadmium in soil within the reclaimed mine site has a narrow range of 0.05–1.6 ppm and has identical average and median concentrations (0.4 ppm). Highest concentrations occur in samples that are enriched in uranium and arsenic, such as the two samples from within the site, the sample of exposed mined waste rock (1.2 ppm), and the sample on the ridge east of the stream (1 ppm, fig. 9*E*). Stream sediments above (0.2–0.4 ppm) and below (0.2–0.3 ppm) the site do not differ in cadmium concentrations. In the operations area (fig. 9*F*), most soils fall in the narrow range of 0.2–0.4 ppm, but one soil sample (2.9 ppm) and the rock and mined waste-rock samples just described remain the highest for the site (1–17.4 ppm).

Antimony concentration follows a pattern similar to that of cadmium at the mine site (fig. 9*G*), but it has a slightly broader range of concentrations (0.37–2.87 ppm). Stream sediments below the site contain greater amounts of antimony than do samples from above the mine. Concentrations of antimony in soil, rock, and mine waste at the operations site also follow a pattern similar to that of cadmium, except for one remarkably high antimony concentration (124 ppm) in a mined waste-rock sample (fig. 9*H*).

Cobalt concentrations in soils sampled from the reclaimed mine area averaged 9.4 ppm (median, 7.7 ppm), whereas soils outside of the reclaimed area averaged 10.2 ppm (median, 6.3 ppm) (fig. 9*I*, table 8). Soils along the traverses across the operations site contained 7.3–112 ppm cobalt (fig. 9*J*). Rock and mine waste samples from the same site contained 6–232 ppm cobalt. All samples greater than 25 ppm cobalt were found where the waste-rock pile had been located.

Copper concentrations in soils sampled from the reclaimed mine area ranged from 5.0 to 75.1 ppm, averaged 24.4 ppm, and had a median value of 21.7 ppm. Soils adjacent to the reclaimed area contained 10.0–51.5 ppm copper and averaged 20.4 ppm (fig. 9*K*). The median concentration was lower, 15.0 ppm. Soils along the traverses across the operations site contained 19.3–136 ppm copper (fig. 9*L*). Rock and mine waste samples from the same site contained 57–9,030 ppm copper. The very high copper concentration was measured in the same isolated waste-rock sample that also contained 1,870 ppm uranium and 5,060 ppm arsenic.

Lead concentrations in soils sampled from the mine reclaimed area averaged 13.5 ppm (median, 8.7 ppm), whereas soils adjacent to the reclaimed area averaged 12.8 ppm (median, 11.4 ppm) (fig. 9*M*, table 8). Lead concentrations in stream sediments above and below the mine site had a narrow range of 13.1 to 19.2 ppm. Narrow concentration ranges were also measured for molybdenum (average 8.0 ppm, reclaimed; 7.7 ppm, adjacent) (fig. 9*O*, table 8); nickel (average 23.4 ppm, reclaimed; 24.2 ppm, adjacent) (fig. 9*Q*, table 8); zinc (average 63 ppm, reclaimed; 57 ppm, adjacent) (fig. 9*U*, table 8); and thallium (average 1.3 ppm, reclaimed; 0.6 ppm, adjacent) (fig. 9*W*, table 8). In the case of molybdenum, the average value exceeds the median value because of two anomalous soil samples within the reclaimed mine site (median, 2.74 ppm).

Lead concentrations in soils in the operations area range from 14 to 101 ppm (fig. 9*N*, table 8). Rocks and mine waste range from 137 to 935 ppm; most high concentrations were found in the mine waste-pile area. Molybdenum concentrations in most soils in the operations area are low to moderate (0.81–5.56 ppm) (fig. 9*P*, table 8), and they strongly contrast with a contaminated soil (table 8, 77.1 ppm molybdenum, and elevated concentrations of uranium and arsenic) and with rock and mine-waste samples (20.9–693 ppm molybdenum). Zinc concentrations have a similar contrast (fig. 9*V*, table 8), as do nickel (fig. 9*R*, table 8) and thallium (fig. 9*X*, table 8), but in a less pronounced manner.

Vanadium concentrations in soils sampled from the mine reclaimed area averaged 52 ppm (median, 52 ppm), whereas soils adjacent to the reclaimed area averaged 32 ppm (median, 31 ppm) (fig. 9*S*, table 8). Vanadium concentrations are somewhat higher in stream sediments below the mine. Concentrations decrease with increasing distance downstream. Mined waste rock and soils at the operations site do not contain high vanadium concentrations; vanadium in all soils and rock ranged from 21 to 64 ppm.

MicroR measurements were made at the mine site (fig. 10*A*) and the operations area, including the former position of the mined waste-rock pile (fig. 10*B*). In addition, measurements were taken across the former site of the wastewater ponds (fig. 10*B*, top). MicroR readings across the surface of the reclaimed pipe range from 5 to 20 μR/h, except for one location which measured 55 μR/h (fig. 10*A*). Outside of the pipe on undisturbed soils, readings ranged from 5 to 15 μR/h, except at the exposed waste-rock and slope-wash sites where measurements were 65 μR/h and 19 μR/h (fig. 10*A*). Stream sediment sites measured 5–7 μR/h above the mine site, 13 μR/h at site SS08, and 6.5–8.5 μR/h below the site; this trend is consistent with an increase in uranium concentration downstream from the site. A detailed microrad-per-hour survey on the hillslope along a traverse line between the stream at the check dam and the crest of the ridge to the north (see unlabeled line of locations, fig. 10*A*) measured 10 to 85 μR/h. Bedrock outcrops produced the lowest part of the range (10–13 μR/h), and local accumulations of fine-grained sediment produced the highest part of the range.

Within the reclaimed operations site, 5–7 μR/h was measured in the southwestern third of the area, where buildings were located, except for a single locality where the uranium-rich waste-rock was found (fig. 10*B*, 600 μR/h; fig. 9*B*, 1,870 ppm uranium). Throughout the rest of the reclaimed area, radioactivity measurements were highly variable and ranged from 7 to 400 μR/h. Measurements greater than 50 μR/h are highlighted in fig. 10*B*. These areas of increased radioactivity occupy the position of the former mined waste-rock pile. Around the perimeter of the operations area, concentrations range from 4.5–6 μR/h on the southwest side to 6–17 μR/h on the northeast side. These data support the eastward dispersion of radioactive materials that is indicated by the soil samples enriched in uranium east of the former mined waste-rock pile. Most readings were taken near the trace of roads, and thus both windblown dust from the pile and dust from trucks transporting ore may have contributed. The area formerly occupied by the wastewater ponds registered 4.5–6 μR/h, whereas the surrounding area registered 5–7.5 μR/h. The lower radioactivity measurements in the reclaimed area may reflect permanent removal of a slightly more radioactive surface layer during pond construction, or it may represent differences between native soils and nonnative cover materials. Both sets of measurements are within the range of background.

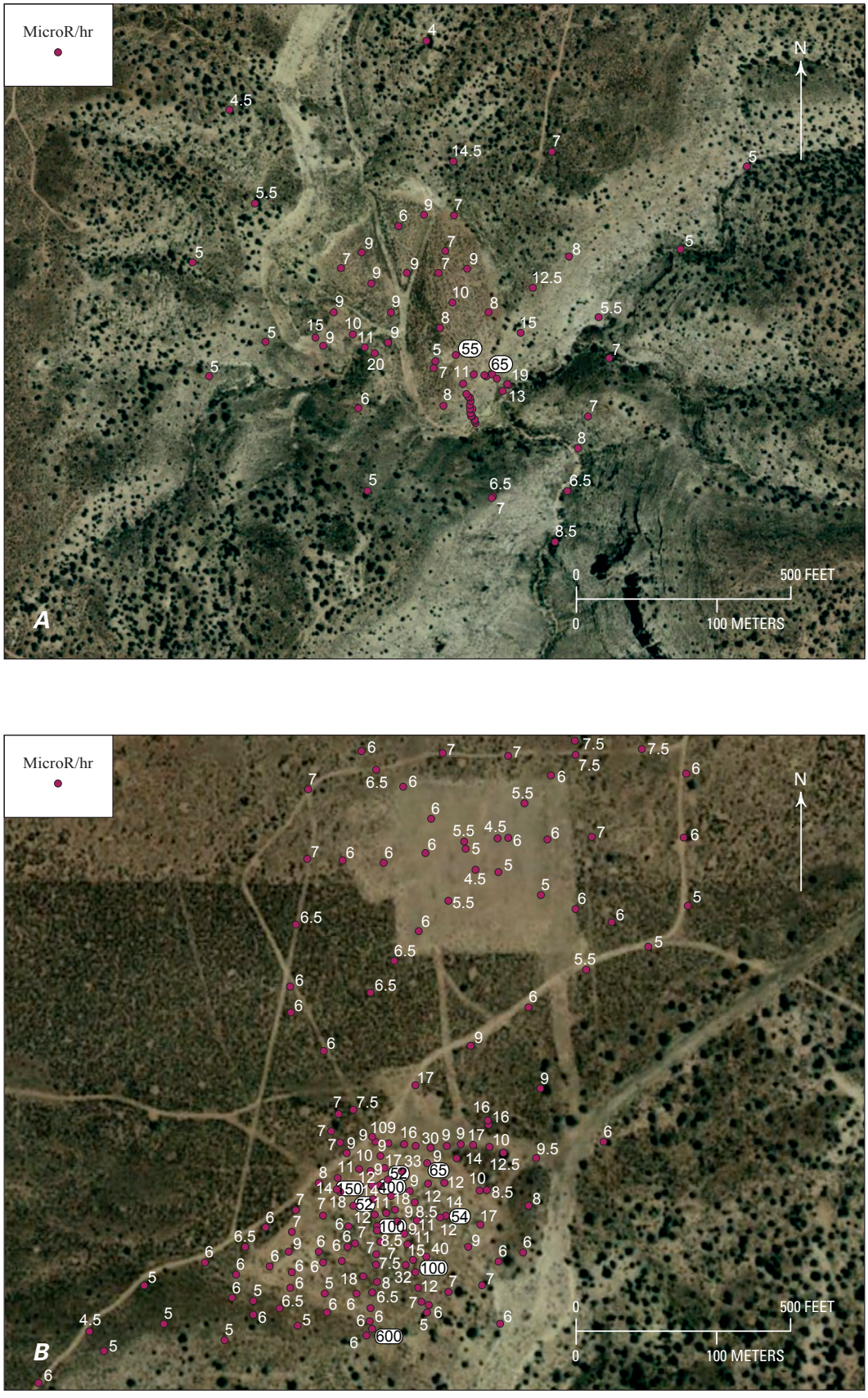


Figure 10. Radioactivity measurements (in µR/h) at Pigeon Mine. *A*, mine area; *B*, operations and wastewater-pond site. See also figure 6; circled readings, greater than 50 µR/h.

Kanab North Mine

The Kanab North Mine site lies on the plateau surface on the western side of Kanab Creek at 36°41'14.42" N. latitude and 112°38'36.98" W. longitude (fig. 1). The altitude of the mine site is about 5,020 ft asl, whereas the adjacent section of Kanab Creek is at an altitude of about 3,850 ft asl. The surface lithologic unit at the mine site is the Timpoweap Member of the Triassic Moenkopi Formation (Billingsley and others, 2008). A cliff edge lies about 150 ft east of the east fence at its closest point (fig. 11). The breccia pipe is located on the steep west wall of Kanab Creek just northwest of the mine site, where it is exposed in the Woods Ranch Member of the Toroweap Formation (arrow, fig. 11*B*). The pipe is accessed by a shaft and drifts from the mine site. A small drainage passes through the mine site from the southwest; it leaves the site as a low swale just north of the fence that turns sharply eastward towards the cliffs just to the east (figs. 11*B*, 12).

The pipe was discovered in 1981. Development was delayed until 1984 because of the uncertain wilderness land status of the area. It was mined from 1988 to December 1990 and went on standby and maintenance in 1992. Production was 2.77 million pounds U_3O_8 at an average grade of 0.53 percent from 260,800 tons of ore (Pool and Ross, 2007). No reclamation work has taken place as of December 2009.

A fenced and bermed perimeter surrounds the site (fig. 12). Within the site, water drains towards a lined wastewater pond (location lp, fig. 12*A*) located along the trace of the small drainage noted previously. A mined waste-rock pile about 340 ft (100 m) long occupies the southern part of the site (location wr, fig. 12*A*).

Kanab North Mine was the site of the following USGS studies:

- Mapping of site features;
- Composite sampling of the east face of the waste-rock pile at the site;
- Sampling of soils within a few feet of fenced perimeter;
- Sampling of soils more distant from the fence line;
- MicroR measurements at each of the sites noted above;
- MicroR measurements of the mine site within the berm;
- MicroR surveys of the perimeter of the site; and
- Sampling of rock at selected microR measurement locations within the fenced perimeter.

Erosion within the site has moved sediment into the lined pond (fig. 13). In a few low spots on the site adjacent to berms, water ponds and allows very fine-grained silt and clay to accumulate. The largest two of these features are indicated on the map (location ps, fig. 12*A*).

A berm completely surrounds the Kanab North Mine site except at the entry gate on the west side. This berm was examined for evidence of damage and repair. The berm appears intact around the entire perimeter with no evidence of repair. However, at one location along the east side it appears that wet, fine-grained material, possibly water and fine-grained sediment that had accumulated in a low spot or other waste of unknown origin, was pushed over the top of the berm. At this location, the crest of the berm is slightly lower and discolored with fine-grained, medium-gray to very light reddish-gray sediment in contrast to the moderately red-brown rocky material along the berm crest to the south and the mostly off-white rocky material along the berm crest to the north. This location is further marked by brush piled on the berm slope (arrow, fig. 11*A*). At the outside toe of the berm below the brush cover, mud-cracked, fine-grained sediment of similar medium-gray to very light reddish-gray has accumulated. It does not appear that this material has moved outside of the fence or into the adjacent low wash, because the adjacent pale-reddish-brown soil is not discolored. A flat bedrock outcrop occurs along the fence at this location.

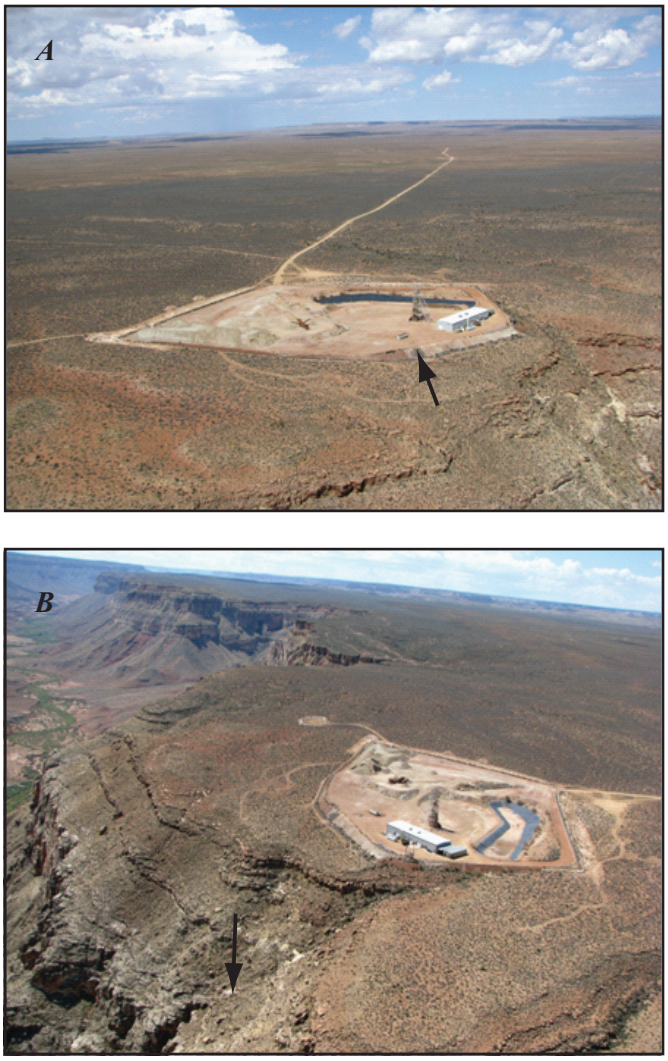


Figure 11. Kanab North Mine site. *A*, View to northwest showing berms (northern and eastern part of site) and trench (south side of site; to the left). Arrow points to brush piled on the berm slope where fine-grained sediment was pushed over the berm. *B*, View to south showing berms (northern and eastern parts of site), trench (west side of site to the right), and sediment in lined pond. Arrow points to approximate location of exposed breccia pipe in a deep gully that drains the site. (Photographs courtesy of Don Bills, U.S. Geological Survey, Flagstaff, Arizona. Taken August 25, 2009.)

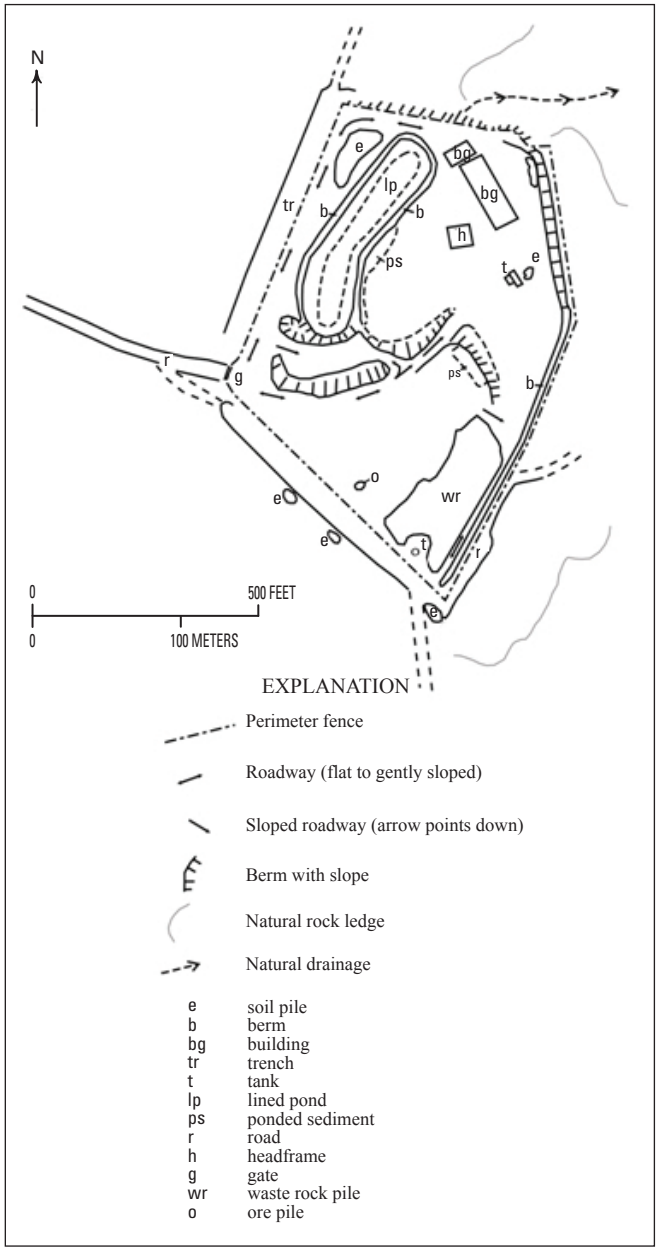




Figure 12. Two views of Kanab North Mine site. *A*, Diagrammatic map. *B*, Photograph from which map 12*A* was drawn.

Within the interior of the fenced and bermed mine site, uranium concentrations in samples of surface material (disturbed soils, graded mine operation surfaces, sediment in the pit bottom; n=13) range from 6.4 to 2,840 ppm and average 1,135 ppm (median, 1,050 ppm) (fig. 14*A*; table 8, samples GC09KNW02–13,). A composite of 10 samples collected on the east face of the waste-rock pile contained 679 ppm uranium (sample GC09KNW01, excluded from the reported average; approximate location of midpoint for this composite is shown in fig. 14*A*). A disturbed soil near the south end of the mined waste-rock pile contained 6.4 ppm uranium. Sludge from the bottom of the pond contained 1,800 ppm uranium. Fine-grained sediment that had washed off the waste pile and accumulated in a low point contained 1,720 ppm uranium. Other samples from the mine operations surface contained 50.2–2,840 ppm uranium.

Soil samples beyond the fenced perimeter contained 2.9–80.2 ppm uranium and averaged 27.8 ppm (median, 21.5 ppm) (fig. 14*A*; table 8, samples GC09KNS01–12 and 50–59). No concentrations in the sampled soils were as low as the average uranium concentrations in area soils, 2.4 ppm. All uranium concentrations above 31 ppm (33–80.2 ppm) are in samples collected on the east side of the site between the perimeter fence and the edge of the cliff overlooking Kanab Creek. On the west side of the mine site, concentrations ranged from 6 to 31 ppm. No evidence suggests that water moved material offsite. During our mine site visits on two hot days in August, the authors observed wind gusts pick up fine sediment from the surface of the mine site and carry it eastward offsite. Therefore, one explanation of the elevated soil uranium concentrations is windblown dust from the site. An alternative suggested by radioactive limonite-cemented sandstone in exposures east of the Pigeon Mine site is that site-wide, anomalously high uranium concentrations are derived from such cemented sandstone present at the Kanab North site. However, such limonite-cemented sandstones were not observed in the sandstone bedrock along the rim of the cliff or in other low outcrops at the site, as would be expected because they are typically more resistant to weathering. In addition, iron concentration in soils beyond the fenced perimeter ranges from 0.86 to 1.78 percent and average 1.43 percent iron (median, 1.42 percent), well below that of iron in the soil formed on iron-cemented sandstone at the Pigeon Mine site. Long-term wind data do not exist for the Kanab North Mine site. However, from March 1983 to March 1984, Energy Fuels Nuclear, Inc., gathered data from a meteorological station on the plateau about 10 mi to the southwest (EnecoTech, Inc., 1987) Although local conditions adjacent to Kanab Creek Canyon likely differ from

conditions at this station, a wind rose (fig. 1 of EnecoTech, Inc., 1987) shows variable winds dominated by the south-southeast to southwest and west to northwest directions. Highest mean speeds of winds at the station (table 2 of EnecoTech, Inc., 1987) during the reporting period were 4.0 meters per second (m/s) from the southwest), 4.0 m/s from the east-northeast, and 3.7 m/s from the west-southwest, but mean wind speeds varied over a narrow range of 3.0 to 4.0 m/s for 13 of the 16 directions. Winds from the east, east-southeast, and southeast were the least frequent and had lowest mean speeds (2.2–2.7 m/s).

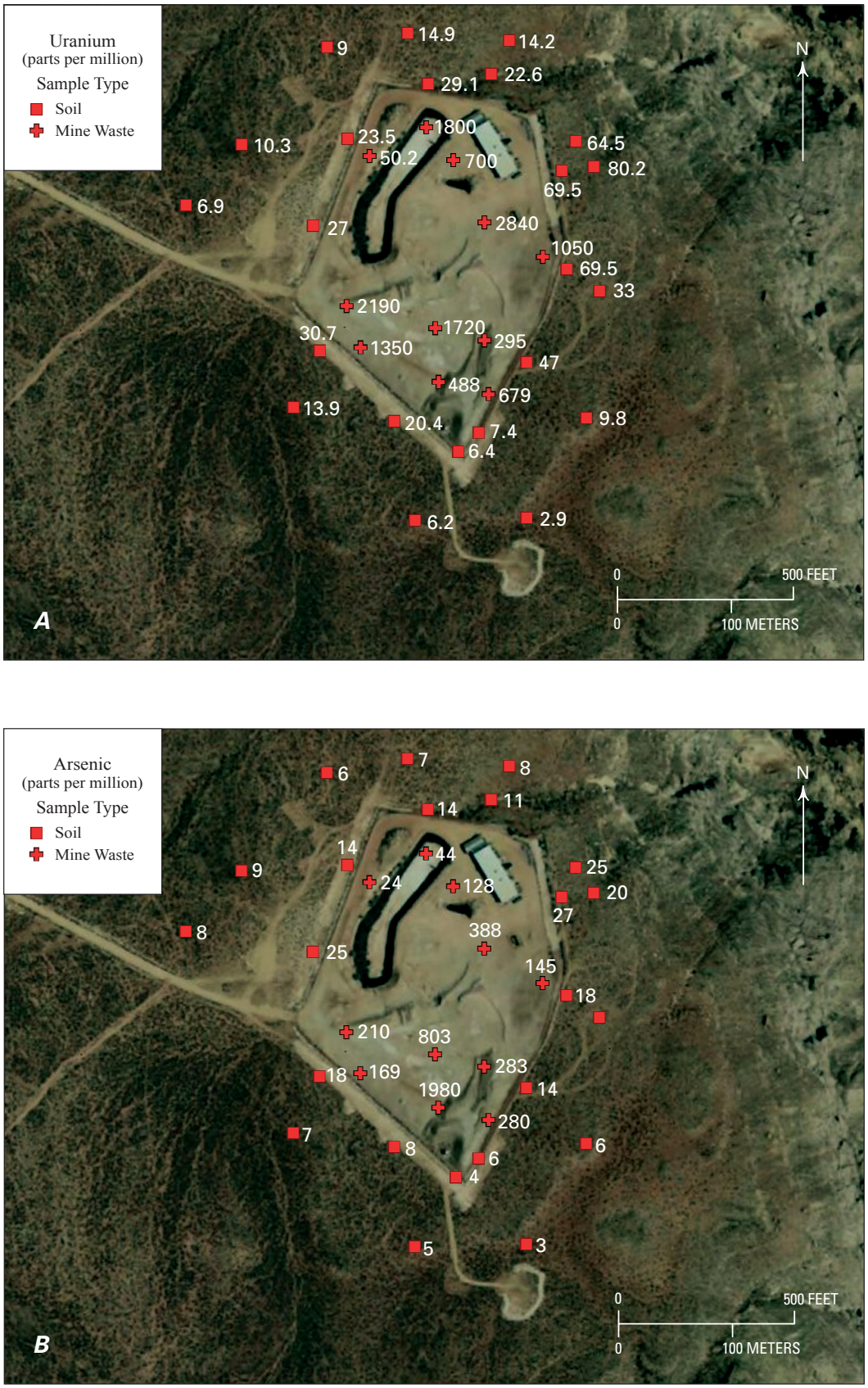
Wind erosion of mill tailings and mine waste has been studied for the past 40 years. A reported threshold speed for dust to move from mine tailings in the southwestern United States is 5.1 m/s (table 2.1 of Goudie and Middleton, 2006, citing other sources). Till and Grogan (2008) in summarizing modeling studies of wind suspension from dry, bare surfaces noted that the MILDOS model of Strenge and Bander (1981) yielded fugitive dust emissions (suspension fluxes) at wind speeds of 4.5 m/s and greater. The nearby meteorological station showed that wind speeds exceeded 5 m/s 19.2 percent of the time from all directions, and winds from south-southwest to north-northwest exceeded 5 m/s 12.6 percent of the time. The soil geochemical data, wind speed data, our own observations, and the reported wind speed thresholds for dust emissions all indicate that wind is likely to disperse dust from the site frequently, and wind dispersion to the east is favored. Mine-site-specific data, especially chemical analysis of dust collected in traps, could provide additional evidence.

Other trace elements are present in high concentrations that are similar in the degree of soil enrichment and range of variation shown by uranium (n=11). Within the fenced perimeter, arsenic ranges from 4 to 1,980 ppm and averages 380 ppm (median, 169 ppm) (fig. 14*B*, table 8); lead ranges from 11 to 1,790 ppm and averages 266 ppm (median, 146 ppm) (fig. 14*G*, table 8); and zinc ranges from 33 to 1,590 ppm and averages 661 ppm (median, 528 ppm) (fig. 14*K*, table 8). Some trace elements have lower to much lower maximum concentrations and more limited ranges: cadmium ranges from 0.3 to 10.4 ppm and averages 3.6 ppm (median, 2.4 ppm) (fig. 14*C*, table 8); cobalt ranges from 5.3 to 175 ppm and averages 67 ppm (median, 59.5 ppm) (fig. 14*E*, table 8); copper ranges from 12.2 to 516 ppm and averages 159 ppm (median, 129 ppm) (fig. 14*F*, table 8); molybdenum ranges from 1.63 to 401 ppm and averages 138 ppm (median, 102 ppm) (fig. 14*H*, table 8); nickel ranges from 9 to 180 ppm and averages 83 ppm (median, 78.5 ppm) (fig. 14*I*, table 8); thallium ranges from 0.3 to 30.2 ppm and averages 7.8 ppm (median, 3.2 ppm) (fig. 14*L*, table 8); and antimony ranges from 0.45 to 3.07 ppm and averages 1.3 ppm (median, 1.16 ppm) (fig. 14*D*, table 8). Vanadium has a very narrow range (24–66 ppm, average 44, median 49 ppm; fig. 14*J*, table 8). Soils samples from outside the fenced perimeter (n=22) show lower averages and medians for the other trace elements (arsenic, 12 ppm and 9 ppm; cadmium, 0.26 ppm and 0.2 ppm; cobalt, 9.1 ppm and 7.9 ppm; copper, 17.9 ppm and 16.6 ppm; molybdenum, 2.05 ppm and 1.72 ppm; nickel, 14.5 ppm and 12.5 ppm; lead, 14.5 ppm and 13.5 ppm; antimony, 0.54 ppm and 0.54 ppm; thallium, 0.44 ppm and 0.4 ppm; vanadium, 37 ppm and 36 ppm; and zinc, 55 ppm and 50 ppm, respectively).

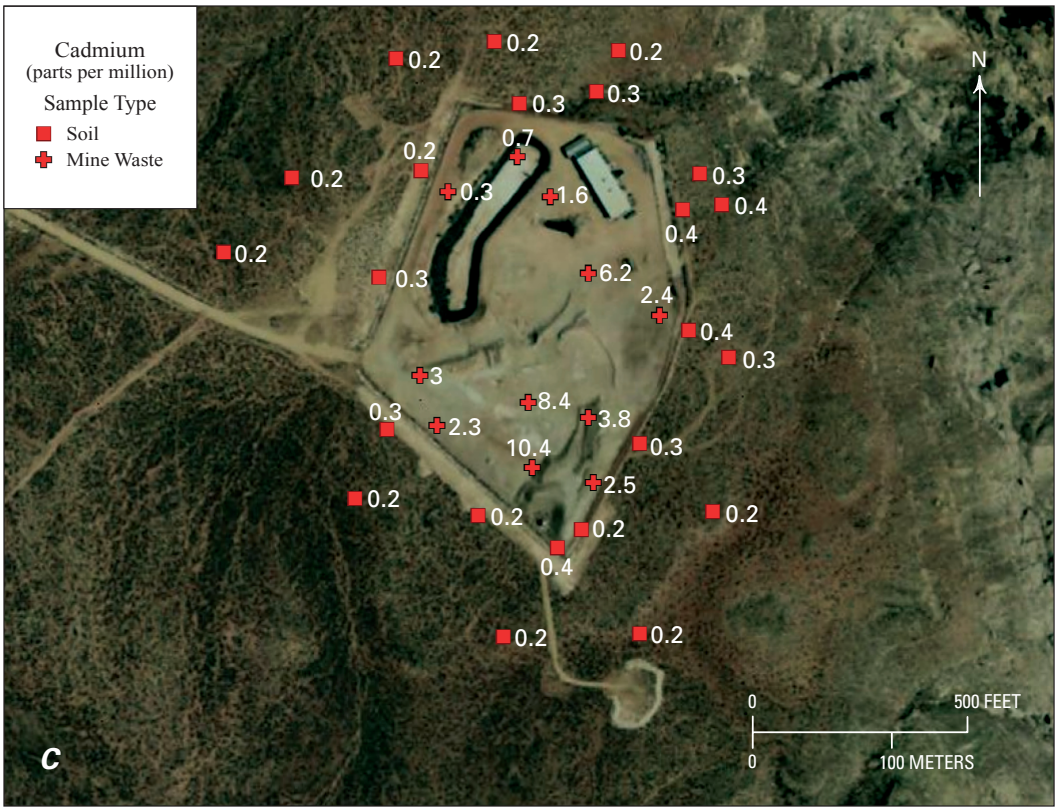
MicroR data for the Kanab North Mine site show that radioactivity within the fenced perimeter ranges from 40 to 1,000 µR/h; only three measurements were less than 50 µR/h and the average was 361 µR/h (fig. 15). Outside the fence, measurements range from 5 µR/h in the western edge of the study area to 75 µR/h near the fence along the eastern side of the site. The overall average is 19 µR/h. Data are insufficient to establish the local background, because the measurements apparently did not extend westward beyond the local effects of mine operations. Although the east side of the site has the highest individual readings, the east-side average of 20.6 µR/h is only slightly higher than the west-side average of 17.7 µR/h.

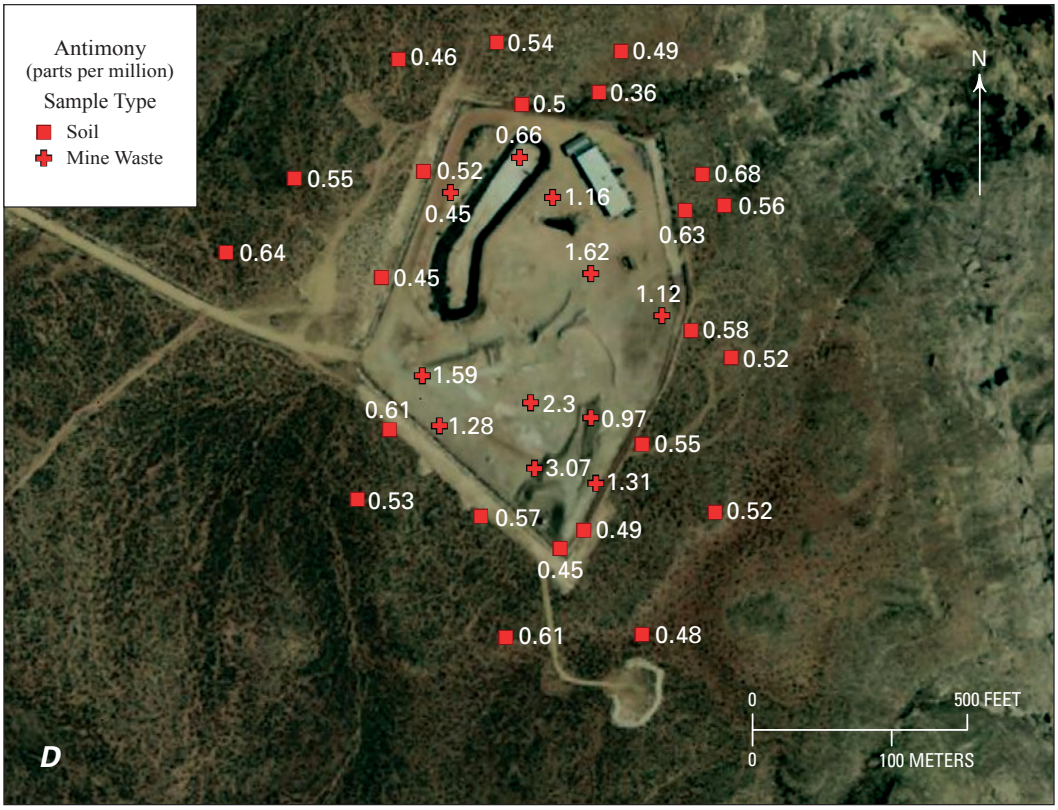


Figure 13. Wastewater pond at Kanab North Mine site showing sediment accumulated in bottom.

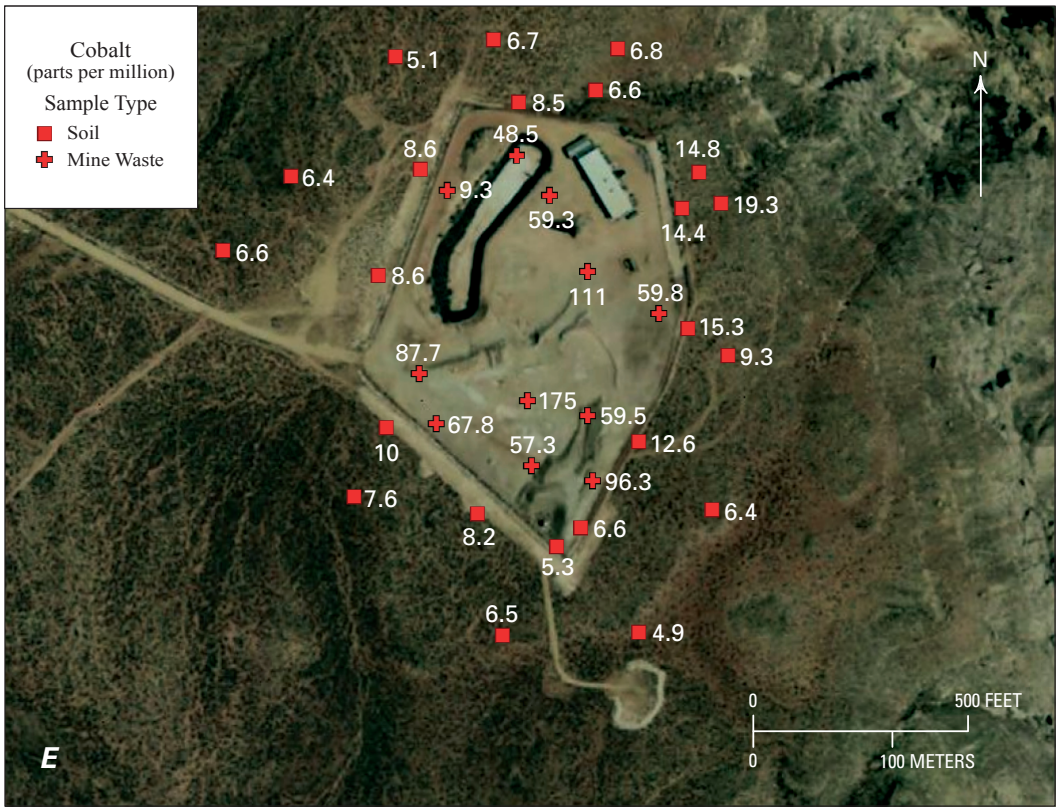


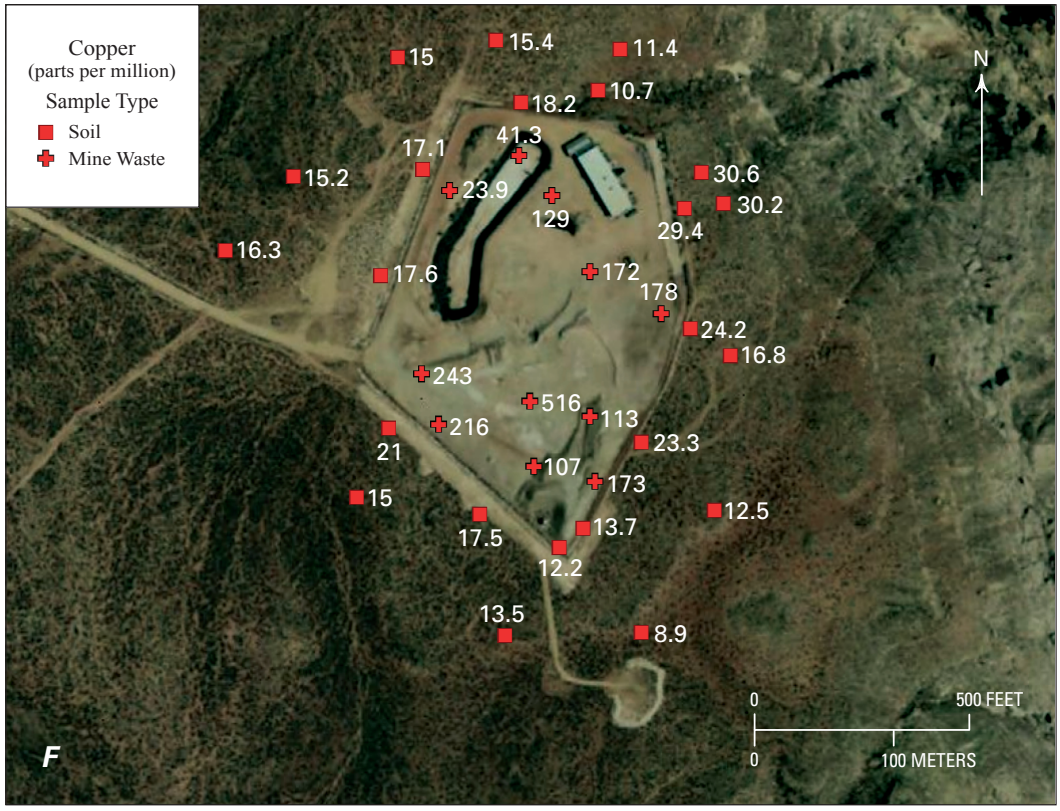
Figures 14. Concentrations of 12 elements at Kanab North Mine site and vicinity. *A*, Uranium; *B*, Arsenic.



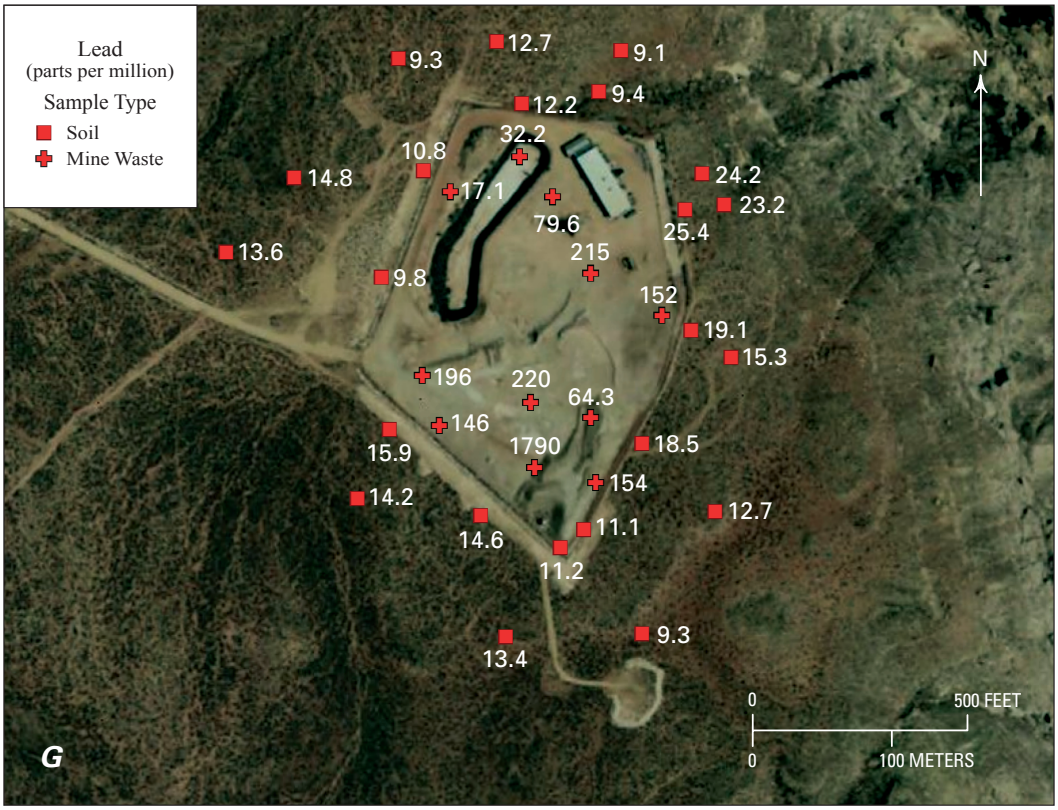


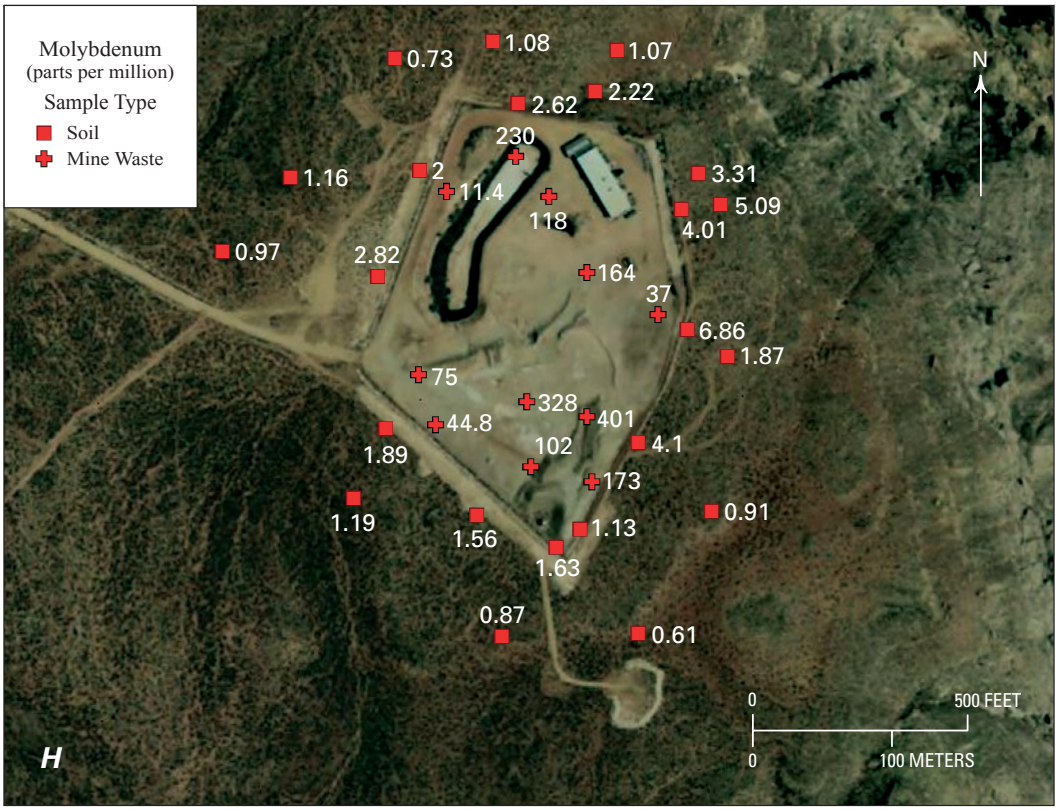
Figures 14—Continued. Concentrations of 12 elements at Kanab North Mine site and vicinity. *C*, Cadmium ; *D*, Antimony.



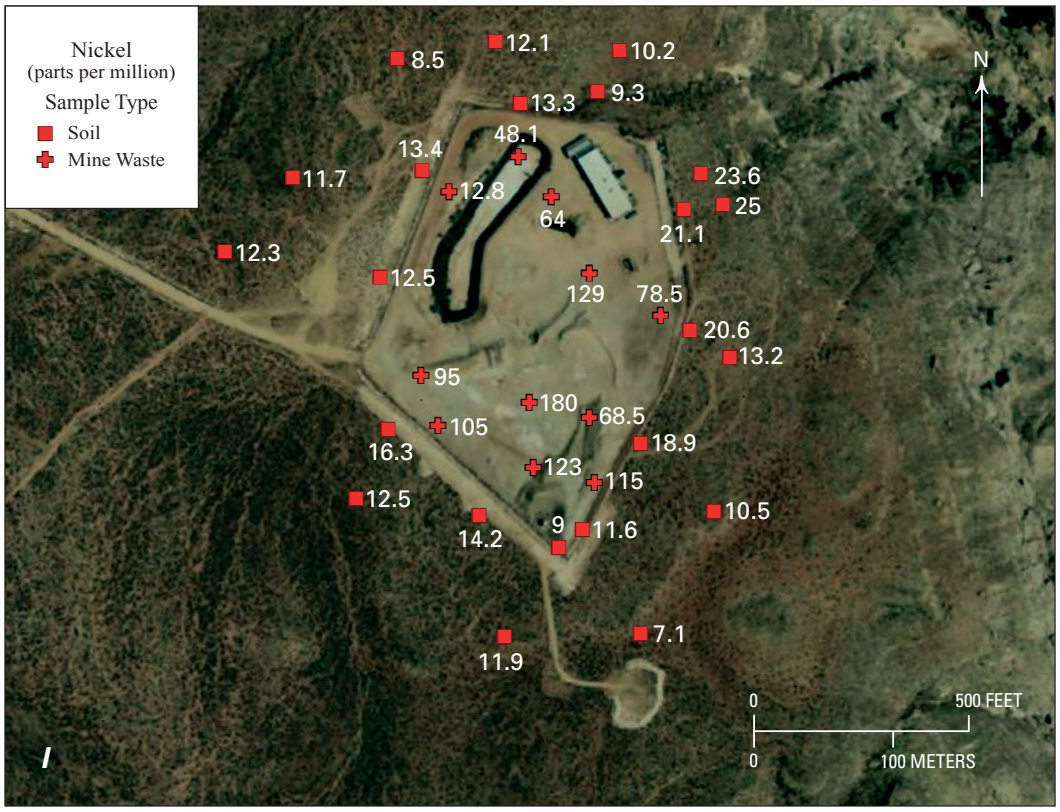


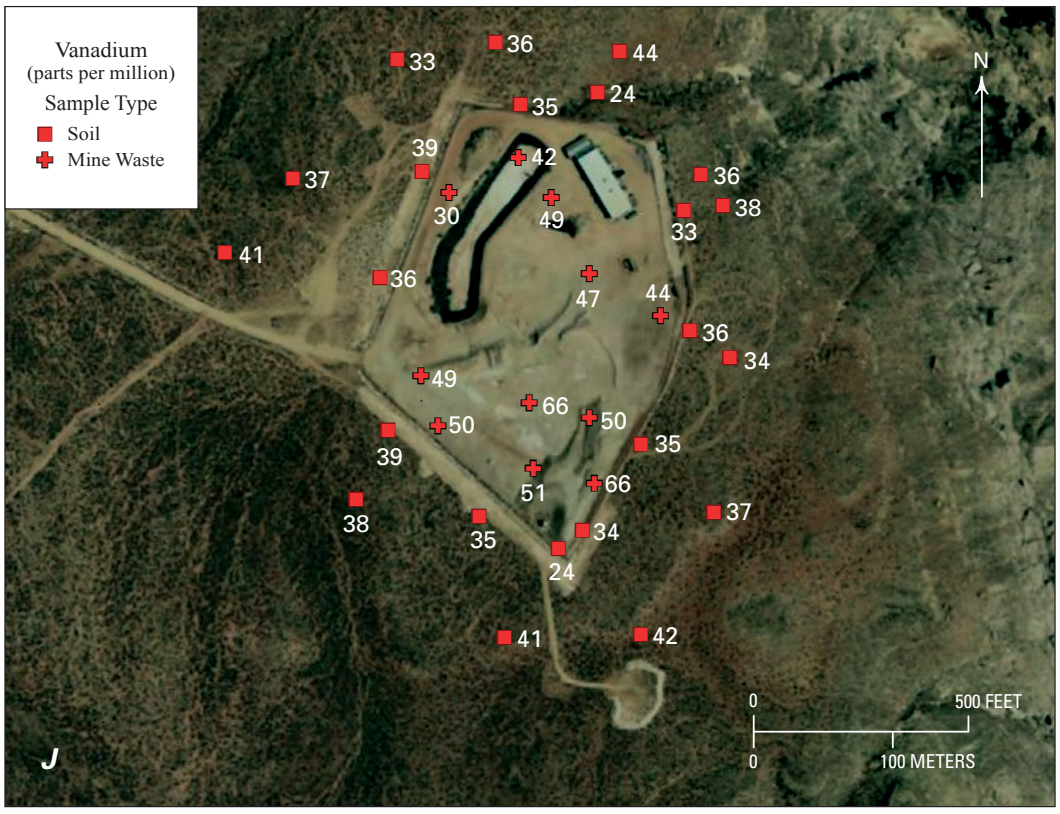
Figures 14—Continued. Concentrations of 12 elements at Kanab North Mine site and vicinity. *E*, Cobalt; *F*, Copper.



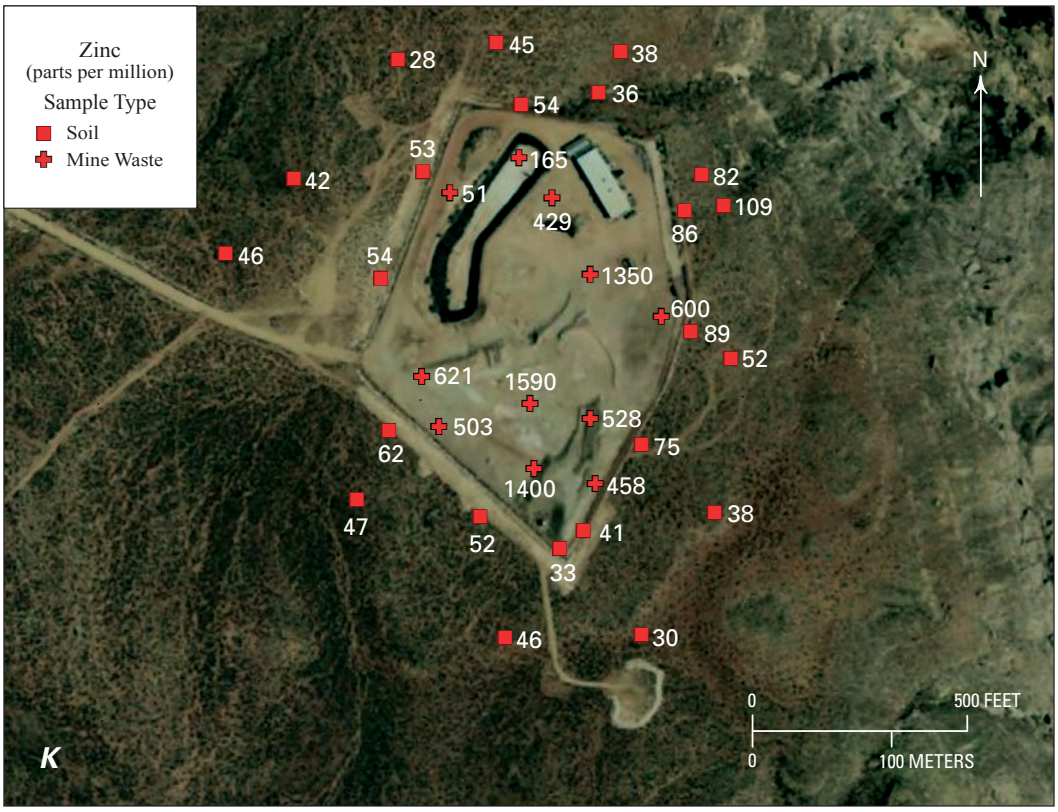


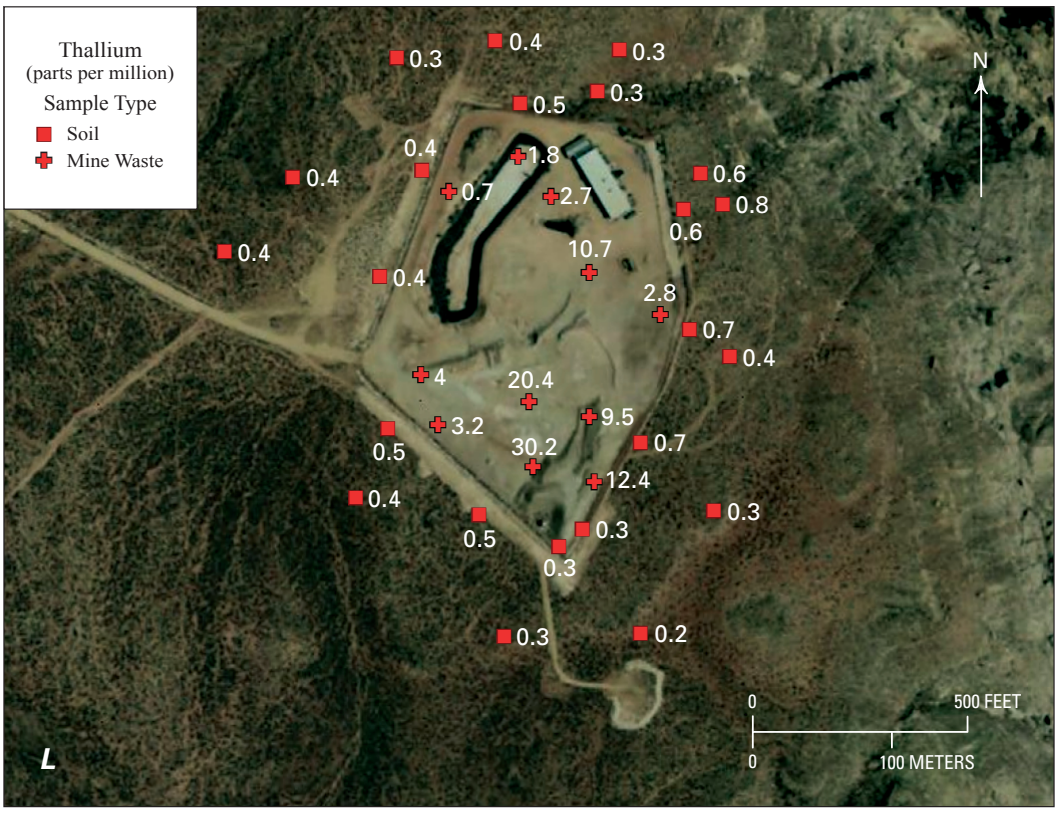
Figures 14—Continued. Concentrations of 12 elements at Kanab North Mine site and vicinity. *G*, Lead; *H*, Molybdenum.





Figures 14—Continued. Concentrations of 12 elements at Kanab North Mine site and vicinity. *I*, Nickel; *J*, Vanadium.





Figures 14—Continued. Concentrations of 12 elements at Kanab North Mine site and vicinity. *K*, Zinc; *L*, Thallium.

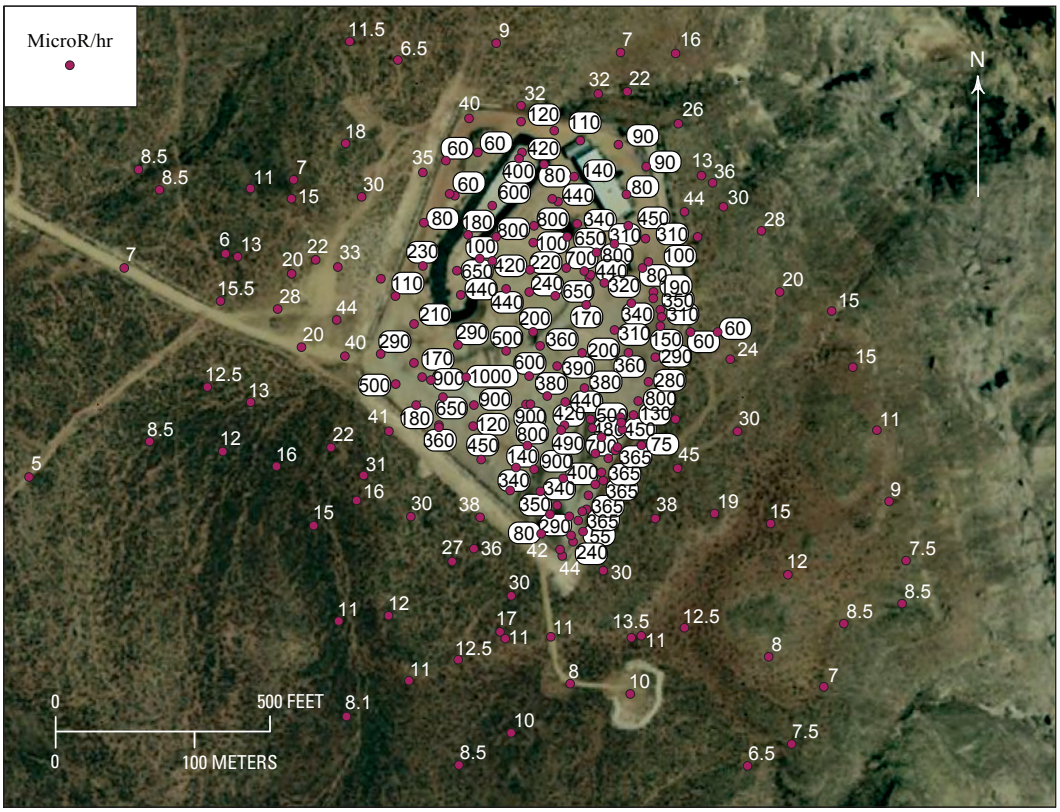


Figure 15. Radioactivity measurements at the Kanab North Mine site. Measurements exceeding 50 µR/h are circled.

Kanab South Pipe

The approximate center of the Kanab South pipe is at 36°4'39.81" N. latitude and 112°38'48.47" W. longitude (fig. 1). The altitude of the center is about 5,035 ft asl. Similar to the Kanab North Mine site, which is located about 3,700 ft to the north, the surface lithologic unit at the pipe is the Timpoweap Member of the Triassic Moenkopi Formation (Billingsley and others, 2008). Erosion of the pipe created an opening in the small wash that passes through it (fig. 16). About 500 ft northeast of the center of the pipe, the wash drops steeply into the valley of Kanab Creek. Variably dipping beds exposed in the low cliffs along the small wash indicate the presence of a collapse feature, as do the reddish sandstone beds in the center of the pipe that appear to be stratigraphically lower than expected for the surrounding units. Several roads were built to facilitate drilling at the site (fig. 16). The road traces have been recontoured to reestablish the original slopes. Disturbed ground marked by large boulders shows where the roads were located.

The USGS conducted the following studies at this site:

- Stream sediment sampling along the small drainage that passes through the site;
- Soil sampling on the adjacent low hills next to the wash; and
- MicroR measurements at each of the sample sites.

A few irregular, crosscutting masses and layers of limonite-cemented sandstone were observed in the low cliffs along the wash south of the pipe. These features showed variable degrees of anomalous radioactivity that ranged from background to several times background and suggested a relation between these features and the mineralization deeper in the adjacent pipe. One of these layers was sampled and analyzed. It (fig. 17; table 8, sample GC09KSR01) contains 54.9 ppm uranium, 896 ppm arsenic, 0.9 ppm cadmium, 3.48 ppm antimony, 140 ppm molybdenum, 140 ppm cobalt, 1,010 ppm copper, 365 ppm nickel, 69 ppm vanadium, 1,720 ppm zinc, and 0.8 ppm thallium. The high concentrations of several elements support a relation with the nearby uranium mineralization.

Concentrations of uranium in stream sediments in the wash as it crosses the pipe range from 1.5 to 3.6 ppm uranium and average 2.1 ppm (fig. 17; table 8, sample GC09KSSS01–06), slightly greater than the Jumpup Creek average of 1.9 ppm. The highest concentration was in a sample below the pipe in the area of the drill sites. However, information is insufficient to determine whether the pipe mineralization or drilling disturbances contributed to the higher uranium. Uranium concentration in soils on the adjacent low hills ranged from 1.3 to 2.7 ppm and averaged 2.0 ppm uranium (fig. 17; table 8, sample GC09KSS01–06), a little lower than the regional average of 2.4 ppm.

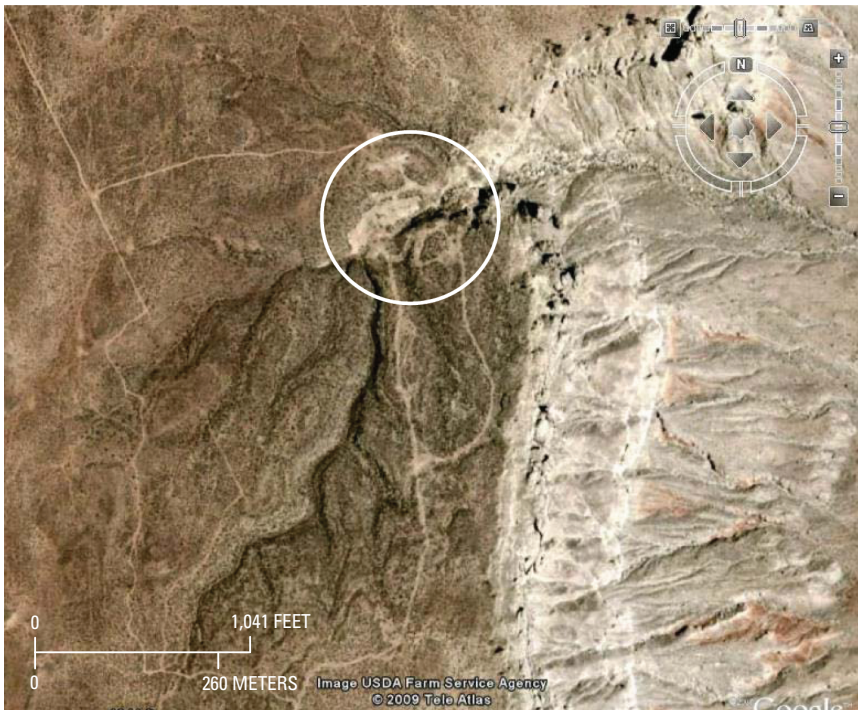


Figure 16. Kanab South pipe (inside white circle) showing drilling roads, small wash that passes through the site, and edge of cliffs on west side of Kanab Creek.

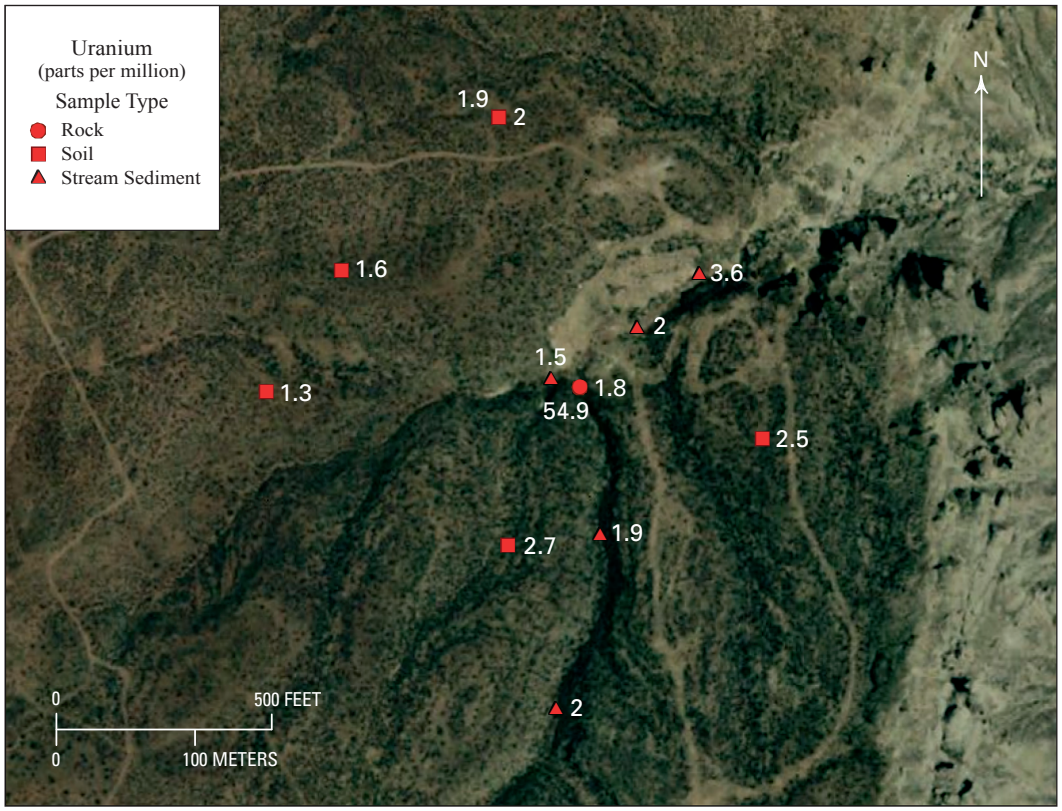


Figure 17. Uranium concentrations at Kanab South pipe site. Duplicate analytical concentrations shown for northernmost sample. A rock sample and a stream-sediment sample were collected at one site (stream sediment, 1.8 ppm uranium; rock, 54.9 ppm uranium).

Arsenic concentrations in soil samples differed with location. Two samples collected west of the pipe contained 3 and 5 ppm arsenic, whereas samples to the south and east contained 23 and 16 ppm, respectively. Stream sediments contained 4–20 ppm arsenic; the lowest concentration was in the stream draining the area that had low soil concentrations, and the highest concentration was just downstream from the pipe.

Other trace elements in soils and stream sediments showed limited variability, although the pipe may have influenced some stream sediment analyses. Cadmium in both soils and stream sediments was low, 0.1 or 0.2 ppm, except for the sample downstream from the position of the pipe, which contained 0.6 ppm. Antimony was also low in soils and stream sediments (0.47–0.84 ppm) but with no apparent downstream anomaly. Cobalt concentrations in soils and stream sediments ranged narrowly from 4.9 to 8.8 ppm; the two highest concentrations were in stream sediment samples at and below the position of the pipe. Copper concentrations in soils and stream sediments ranged narrowly from 8.8 to 23 ppm; the two highest concentrations were at and below the position of the pipe. Lead concentrations in soils and stream sediments ranged narrowly from 9.4 to 20.7 ppm; the highest concentration was below the position of the pipe. Molybdenum in soils and stream sediments had a narrow range of 4.9 to 8.8 ppm; the two highest concentrations were at or below the position of the pipe. Nickel concentrations also had a narrow range of 7.6 to 15.6 ppm, highest at or below the pipe. Vanadium concentration in soils and stream sediments ranged from 30 to 55 ppm; the highest concentration was over the pipe. Soil samples averaged 41 ppm vanadium, a little greater than the regional soil average in the NURE geochemical data (37 ppm). Zinc in soils and stream sediments ranged from 29 to 67 ppm; the highest concentration was at the downstream site. Thallium concentrations ranged from 0.2 to 0.6 ppm, and again the highest concentration was downstream. These data consistently suggest that modest geochemical anomalies are measured in the immediate vicinity of the pipe. MicroR measurements show modest levels of radioactivity (3–7 μR/h) associated with the stream sediment and soils at the site. Highest values occur near the pipe and downstream (5–7 μR/h). Because the geologic and physiographic setting of the Kanab South drill site is very similar to that of the Kanab North Mine site, soil and stream sediment geochemical data and the microR measurements for the Kanab South site may approximate local background levels for the Kanab North site.

Hermit Mine

The Hermit Mine is a reclaimed site centered at 36°41'24.81" N. latitude and 112°45'06.57" W. longitude (fig. 1). The surface at the site is part of a gently rolling plateau (fig. 18). It drains towards a stock tank that is located about 5,500 ft to the north-northeast. Aerial photographs show concentric inward-dipping beds that aided discovery of the deposit. The surface lithologic unit at the mine site is the lower red member of the Triassic Moenkopi Formation (Billingsley and others, 2008). The reclaimed area is an irregular shape that extends about 1,300 ft north to south and 1,300 ft east to west. The pipe was drilled in October 1982 and the uranium discovery was announced in August 1986. Production began in January 1989 and the pipe was mined out at the end of 1989 and reclamation begun. Production was 550 thousand pounds U_3O_8 at average grade of 0.76 percent from 36,339 tons of ore (Pool and Ross, 2007). No historic photos are available to define where mine operation features were located on the site; however, a mine plan map shows the proposed site operations (fig. 19). A concrete pad remains on the south edge of the site, and a power line leading to the Kanab North Mine site crosses the south part of the site (power poles visible in fig. 18).

The USGS conducted the following studies at this site:

- Soil sampling within the disturbed area of the site;
- Soil sampling along four transects away from the disturbed area;
- Soil and stream sediment sampling along the small drainage that leads to the stock tank north of the site plus three vertical auger samples of the stock tank sediment; and
- MicroR measurements at each of the sample sites.

Soil and stream sediment samples are difficult to distinguish from one another at the Hermit Mine, because the drainage that extends from north of the site to the stock tank has a very poorly developed channel. Soil samples (n=22) within the reclaimed area contained 1.6–19.9 ppm uranium and averaged 4.6 ppm (median, 3.1 ppm) (table 8, samples GC09HS01–22; fig. 20*A*). Four samples contained 5 ppm uranium or greater. The four samples are highlighted in figure 20*A* (inset). Soil samples (n=25) along four transects that extend radially from the site contained 1–5.9 ppm uranium; only two concentrations exceeded 3 ppm uranium (table 8, samples GC09HS50–71, 01–22). The soil sample containing 5.9 ppm uranium was



Figure 18. Reclaimed Hermit Mine site; view to northeast. Entry road to north-northwest (left). (Photograph courtesy of Don Bills, U.S. Geological Survey, Flagstaff, Arizona. Taken August 25, 2009.)

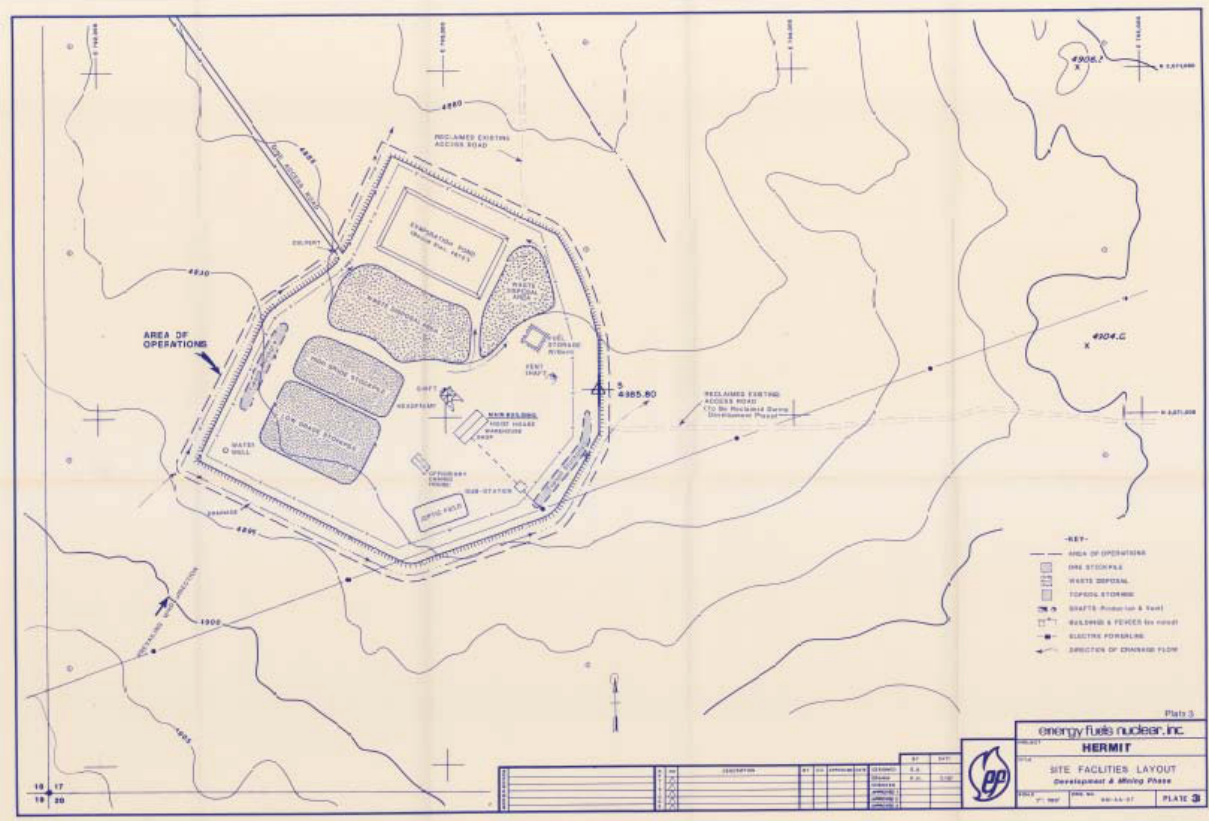


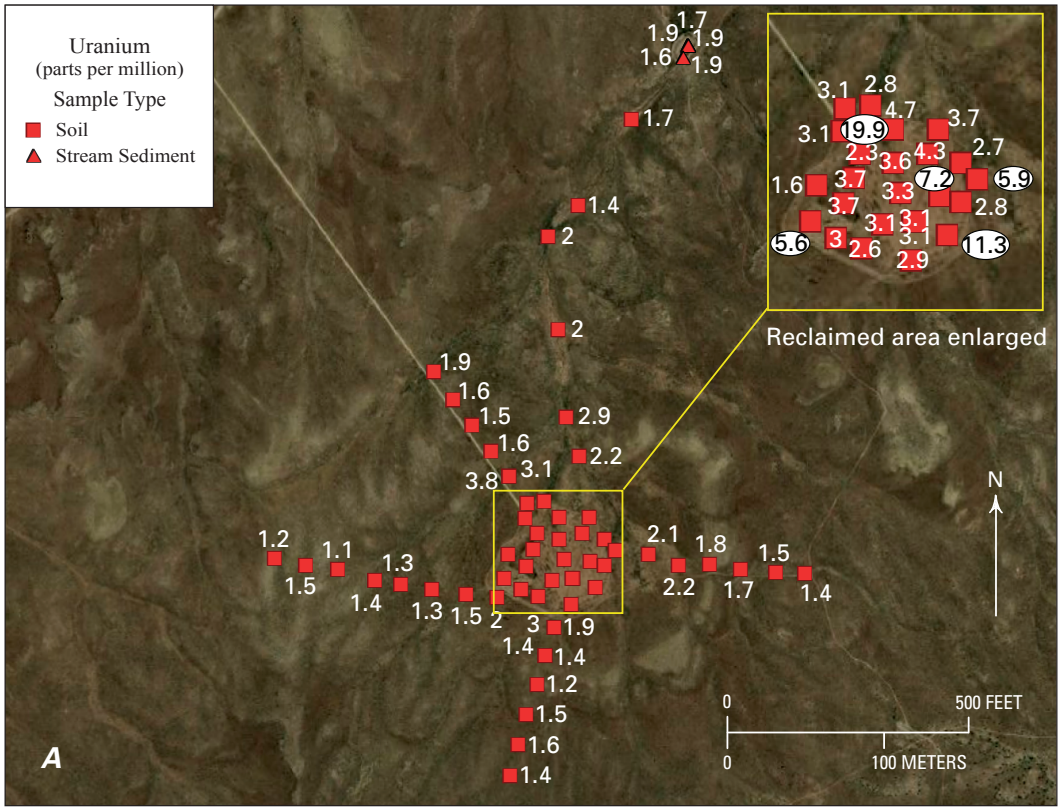
Figure 19. Hermit Mine plan map (EnecoTech Inc., 1987).

collected about 70 ft east of the disturbed area. Along the access road to the northwest of the reclaimed site, samples nearest to the site contained 3.1 and 3.8 ppm uranium. To the west and the south, soil uranium concentrations drop to concentrations below the regional average of 2.4 ppm uranium about 40 ft from the site margin. Samples collected near the ends of the three transects distant from the roads contain 1.1–1.6 ppm uranium. Soils along the drainageway to the north of the site (n=6) contained 1.4–2.9 ppm uranium; higher concentrations came from samples closer to the former mine site. Five samples were collected at the stock tank, two from the surface and three from a vertical profile hand augered to 19 in. depth in sediment accumulated in the stock tank sample (GC09HSS100–104, fig. 20*A*). The five samples contained 1.6–1.9 ppm uranium, a little less than in samples along the drainage closer to the site.

Other trace elements show similar modest variations. Arsenic in all soil and stream sediment samples ranged from 3 to 27 ppm; concentrations greater than 6 ppm are restricted to the reclaimed area (maximum 27 ppm, fig. 20*B*), at sites along the access road closest to the reclaimed area (9 and 10 ppm, fig. 20*B*) and at the stock tank (7 ppm, fig. 20*B*). Copper in soils and stream sediment samples ranged from 11.8 to 84 ppm; highest concentrations are at two sites along the south transect immediately adjacent to the site (fig. 20*C*). Neither uranium nor arsenic is anomalously high at these two sites (fig. 20*A,B*). Thus, these elevated levels may be related not to mine waste but to a natural feature or perhaps some other site disturbance such as power-line installation. Cobalt was also highest at these two sites (table 8, 13–14 ppm). Molybdenum was consistently highest in the reclaimed part of the site, ranging there from 0.75 to 11 ppm, and all external sites contained less than 1 ppm except for two sites along the road (fig. 20*D*). A surface sample at the stock tank contained 9.71 ppm molybdenum.

All soil and stream sediment concentrations ranged narrowly for other elements: antimony, 0.47–1.06 ppm; cadmium, 0.05–0.3 ppm; cobalt, 6.0–13.6 ppm; lead, 9.1–19.7 ppm; nickel, 7–22.7 ppm; thallium, 0.3–0.6 ppm; vanadium, 38–81 ppm; and zinc, 30–87 ppm. Except for cobalt, highest concentrations were either in the reclaimed area or in the stock tank. The stock tank seemed to accumulate most of these elements, possibly because its fine-grained sediment tends to accumulate many trace elements (Carver, 1999). Table 9 compares trace element concentrations inside and outside of the reclaimed area.

MicroR measurements at soil-sample sites within the reclaimed area ranged from 4 to 44 µR/h (fig. 21). On the four soil traverses beyond the perimeter of the disturbed zone most readings were in the 6–7 µR/h range. Some measurements for closer sites ranged from 8 to 10 µR/h. Slightly elevated results were obtained for sediments along the wash to the stock tank (7–9.5 µR/h); highest values are closer to the site. At the stock tank, measurements of 7.5 and 10 µR/h were recorded. On the basis of these readings, background for the Hermit Mine site is 6–7 µR/h, higher than the background measurements in the Jumpup Canyon stream sediment sites (4–5 µR/h).



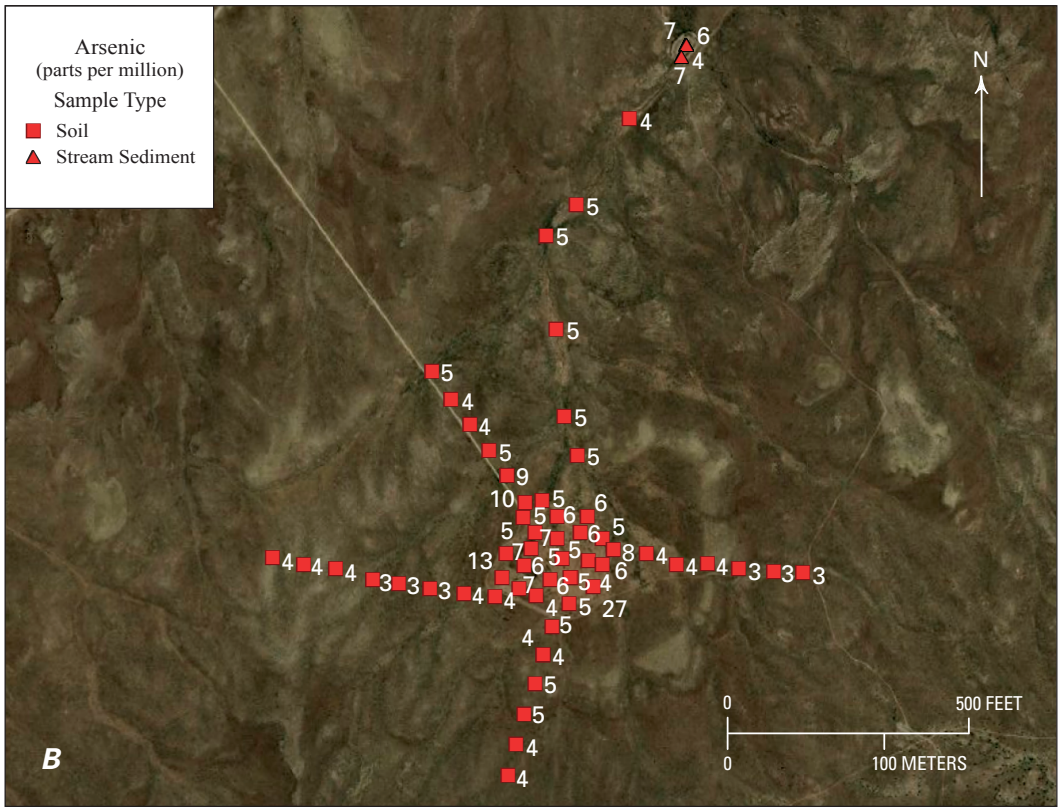
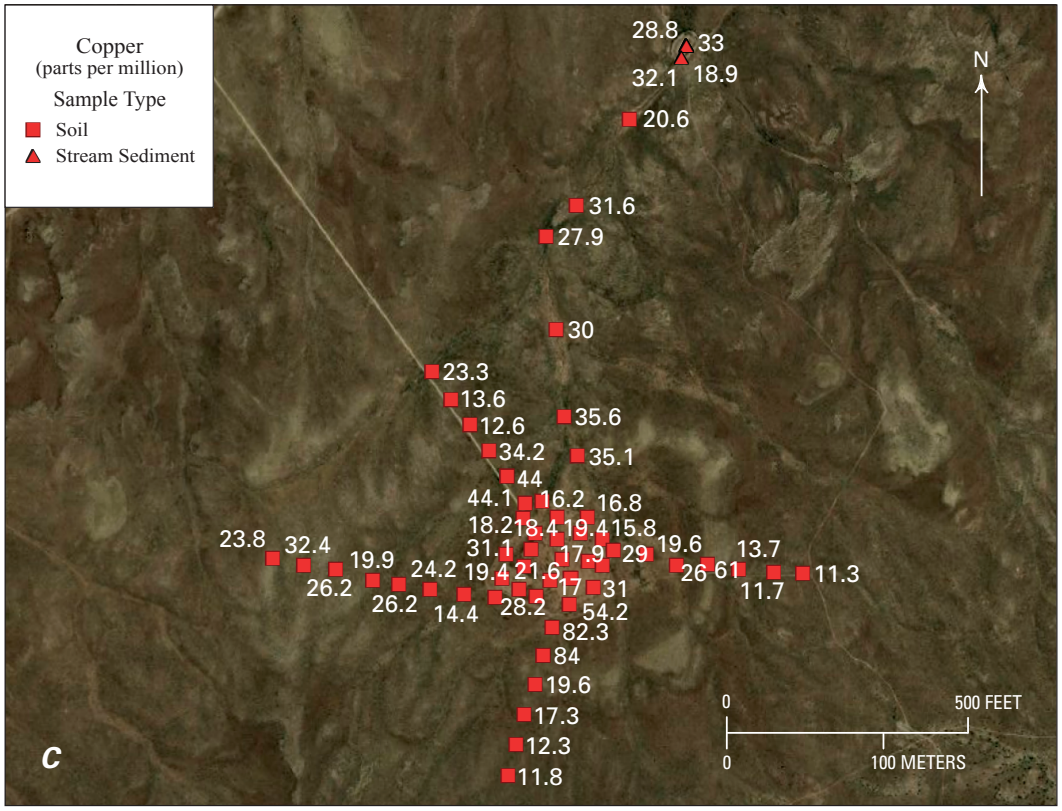


Figure 20. Concentrations of four elements at Hermit Mine. *A*, Uranium; concentrations exceeding 5 mg/L circled; *B*, Arsenic.



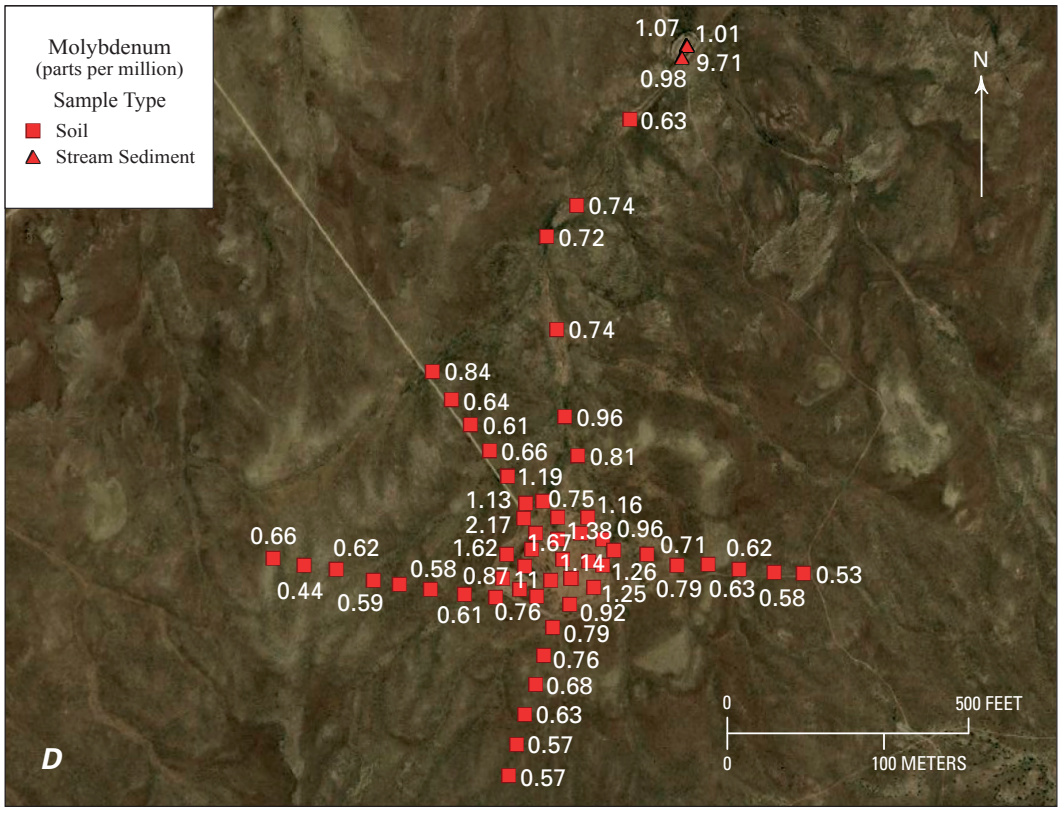


Figure 20—Continued. Concentrations of four elements at Hermit Mine. *C*, Copper; *D*, Molybdenum.

Table 9. Trace element concentrations in soil samples inside and outside the Hermit Mine reclaimed area.

[Samples inside reclaimed area, n=22; samples outside reclaimed area, n=35; ppm, parts per million]

Trace element	Concentration inside (ppm)			Concentration outside (ppm)		
	Range	Average	Median	Range	Average	Median
Arsenic	4–27	7.5	6.0	3–10	4.6	4.0
Cadmium	0.05–0.3	0.09	0.05	0.1–0.2	0.2	0.2
Cobalt	6.9–12.9	9.4	9.6	6.0–13.6	8.7	8.3
Copper	15.6–31.1	19.8	17.9	11.3–84	29.1	26.0
Molybdenum	0.63–11.0	2.19	1.33	0.44–1.38	0.73	0.68
Nickel	10.3–20.2	14.6	14.8	7.0–16.7	11.5	10.8
Lead	9.4–17.0	12.1	11.6	9.1–18.3	13.9	13.1
Antimony	0.63–0.97	0.83	0.86	0.47–0.88	0.68	0.66
Thallium	0.4–0.6	0.43	0.4	0.3–0.5	0.42	0.40
Uranium	1.6–19.9	4.6	3.1	1.1–5.9	1.9	1.6
Vanadium	42–76	59	60	38–63	50	48
Zinc	36–94	50	47	30–65	46	42

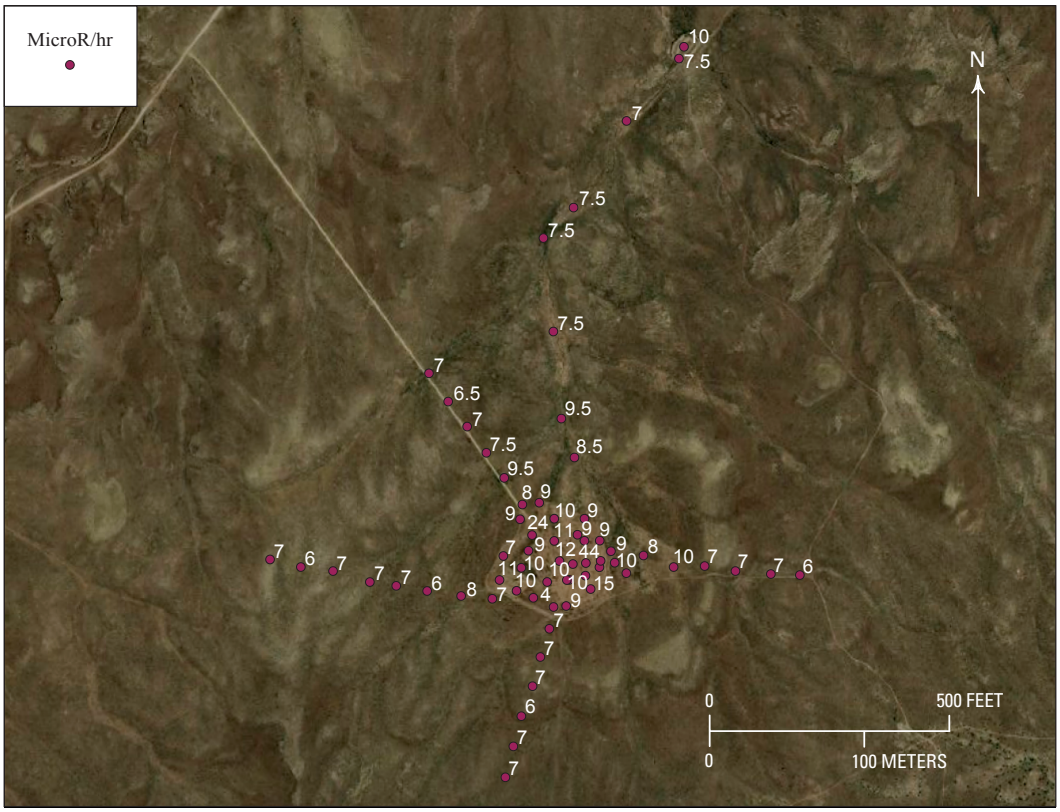


Figure 21. Radioactivity measurements at Hermit Mine site.

A comparison of the uranium and arsenic data and the microR measurements with the mine plan map (fig. 19) shows a few elevated concentrations of uranium in soils and some higher microrad-per-hour measurements at the planned locations of ore and waste-rock piles. However, higher values for both (including the highest radioactivity measurement, 44 µR/h) also were found on the east side. It cannot be determined if some ore or mine waste piles were located on the east side or if some radioactive material was redistributed to that side during mine operations or reclamation.

Hack Mines

Four breccia pipes were mined along Hack Canyon near the intersections of Robinson Canyon and Hack Canyon (Hack 2 and 3, fig. 22), and a small unnamed tributary canyon and Hack Canyon (Hack Canyon and Hack 1, fig. 22). The Hack Canyon Mine was discovered in the early 1900s and mined intermittently for copper and silver until about 1945. From 1950 to 1954 and in 1964 about 5,000 pounds of U_3O_8 were produced (Chenoweth, 1988). In the middle 1970s, the Hack 1 pipe was found near the



Figure 22. Features near Hack Canyon. H, Hack Canyon; R, Robinson Canyon; T, unnamed tributary canyon. Hack 1 (arrow 1), Hack Canyon (HC), Hack 2 (arrow 2), and Hack 3 (arrow 3) Mines; location of mines approximate.

original mine; mining began in 1981 and ceased in 1987. In the late 1970s the Hack 2 was opened on the opposite side of and farther upstream in Hack Canyon. Mining started in 1981 and ceased in May 1987. Hack 3 was discovered adjacent to Hack 2; development started about 1982 and mining ceased in June 1987. Reclamation of all three Hack Mines plus the older Hack Canyon Mine site was planned and completed from March 1987 to April 1988. On August 19, 1984, a flash flood in the tributary drainage where the Hack 1 Mine was operating (location T, fig. 22) eroded ore and mined waste-rock piles and washed these materials downstream. Energy Fuels Nuclear, Inc., recovered radioactive rock from the stream bed as far downstream as the wilderness boundary fence, which was then about 1 mi down the wash (Roger Smith, formerly with Energy Fuels Nuclear, Inc., oral commun., 2009).

During mining of the three pipes, 9.5 million pounds of U_3O_8 were produced from 742,200 tons of ore (fig. 4) (Pool and Ross, 2007). The average grade ranged from 0.50 to 0.70 percent U_3O_8. The period of time during which uranium ore and waste-rock piles were at the surface can be estimated at about 6 or 7 years (about 1981 to about December 1987, Energy Fuels Nuclear, Inc., undated). For the Hack Mines reclamation, alluvium from a gravel pit adjacent to the Hack 2 and 3 Mines was used to cover the recontoured ore and waste-rock pile areas (Energy Fuels Nuclear, Inc., undated).

The USGS conducted the following studies at Hack Mine sites:

- Stream sediment sampling at 10 sites along Hack Canyon, Robinson Canyon, and unnamed Hack 1 tributary canyon down to the current wilderness boundary fence;
- Rock sampling and photodocumentation of selected ore or waste-rock fragments in the channel and on the flood plain; and
- MicroR measurements at each of the sample sites listed above and other sites.

Stream sediment samples were taken from four sites above the mining operations: one upstream from the Hack 2 and 3 Mines along Hack Canyon (table 8, sample GC09HKSS01); one upstream from the same mines along Robinson Canyon (table 8, sample GC09HKSS02); and two samples upstream from the Hack 1 and old Hack Canyon Mines on an unnamed tributary canyon to Hack Canyon (table 8, sample GC09HKSS04 and SS05). Six stream sediment samples were taken along Hack Canyon: one between the Hack 2 and 3 Mines and the tributary canyon where Hack 1 Mine was located (table 8, sample GC09HKSS03), and five downstream from all mining operations (table 8, sample GC09HKSS06–SS10).

During sampling in Hack Canyon, the field party noticed mineralized rock along the wash bottom. Two locations were documented below the Hack 2 and 3 Mines, and multiple sites extended below the Hack 1 Mine tributary canyon for a few hundred feet down valley from the SS07 stream-sediment sample location. Five mineralized rock samples were collected and submitted for analysis (table 8, samples GC09HKRK01–05). The radioactivity of some additional mineralized rock was measured with the microR meter and their locations were determined using a GPS unit.

All stream sediment samples, including those collected upstream of Hack 2 and 3 (samples GC09HKSS01–02) and upstream of Hack 1 (samples GC09HKSS04–05) have high concentrations of trace elements relative to the average Jumpup Canyon concentrations. The relatively high concentrations are apparent for uranium (2.1–10.2 ppm, Jumpup average 1.7 ppm); arsenic (9–17 ppm; Jumpup average 4.6 ppm), and molybdenum (1.1–1.9 ppm, Jumpup average 0.78 ppm). However, other elements are present in concentrations that are at or only slightly above background values: cadmium (0.3–0.5 ppm; Jumpup average 0.3 ppm); cobalt (3.2–6.7 ppm, Jumpup average 4.2 ppm); copper (9.5–37.5 ppm; Jumpup average 12.9 ppm); antimony (0.29–0.5 ppm; Jumpup average 0.47 ppm); lead (8.9–22.9 ppm; Jumpup average 12.4 ppm); nickel (7.9–15.9 ppm, Jumpup average 10.3 ppm); thallium (0.3–0.4 ppm; Jumpup average 0.31 ppm); vanadium (19–37 ppm; Jumpup average 29 ppm); and zinc (32–53 ppm; Jumpup average 42 ppm).

Uranium concentrations in stream sediments and mineralized rock are summarized in an aerial image of the Hack Canyon site (fig. 23). The four background stream sediment samples range in uranium concentration from 2.1 to 3.9 ppm. Concentrations in two samples below the confluence of the tributary canyon with Hack Canyon, which contain 6.5 ppm and 10.2 ppm, are higher than these background concentrations. However, these concentrations drop to 4.8 and 3.2 ppm farther downstream (fig. 23) and to 2.4 ppm farther yet downstream near Willow Spring (east of the area of fig. 23). A similar pattern in all trace element concentrations in stream sediment samples is apparent. Figure 24 shows the ratio of stream sediment trace element concentrations to background concentrations as compared with stream channel distance below the Hack 1 Mine location. Sample site SS07, at the lower end of an eroded waste-rock terrace (see following discussion), consistently contained concentrations of trace elements that are higher than concentrations at upstream site SS06. At sample site SS09, most trace elements have dropped to background concentrations or below (a ratio of 1 or less). At sample site SS10, only molybdenum is slightly

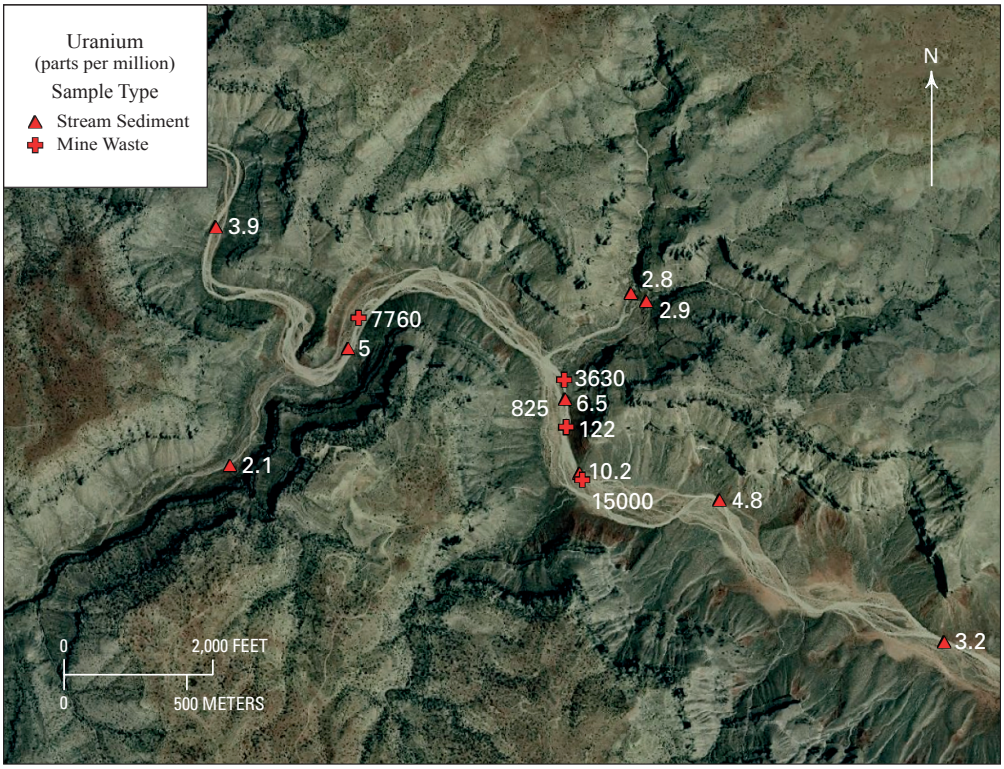


Figure 23. Uranium concentrations in stream sediment and in ore and waste-rock samples. One mine-waste sample (825 ppm uranium) and one stream-sediment sample (6.5 ppm uranium) are from same site. Site for sample GC09HKSS10 (2.4 ppm uranium) lies east of photograph boundary. One mine-waste sample exceeded the 10,000 ppm upper detection limit for the analytical method, and the concentration given here (15,000 ppm uranium) is an estimate.

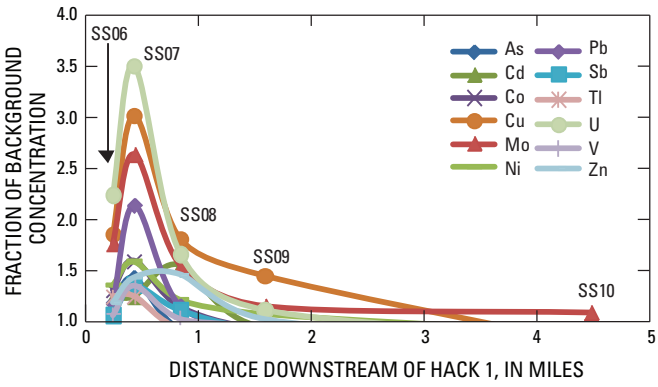


Figure 24. Ratio of concentrations of Arsenic (As), Cadmium (Cd), Cobalt (Co), Copper (Cu), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Antimony (Sb), Thallium (Tl), Uranium (U), Vanadium (V), and Zinc (Zn) in stream sediments to their concentrations in background stream sediments as a function of distance downstream from the Hack 1 Mine. Background data are the average of the trace element concentrations in four samples upstream from mining operations. SS06 to SS10, samples GC09HKSS06–10 (see table 8).

above background concentration. The results of the stream sediment geochemistry in this study are consistent with those of Carver (1999).

Scattered fragments of ore or waste rock, generally 2 to 18 in. in diameter, are found on the wash bottom. MicroR measurements for these samples were quite variable and ranged from 18 to 900 µR/h. The mineralized rock samples collected from the wash contained 122 ppm to >10,000 ppm uranium (the upper detection limit for the analytical method, shown as 15,000 ppm in fig. 23) and are similarly high in several associated trace elements (table 8, samples GC09HKRK01–05). The appearance of these fragments is varied, but commonly they are yellowish orange, dark gray, greenish gray, or reddish brown (fig. 25*A*–*H*). The uranium-mineralized rock fragments along the floor of Hack Canyon may be derived from the flood of August 19, 1984, from undocumented floods before or after 1984 during the period of mining, or from one or more post-reclamation floods that eroded the edge of the terrace adjacent to the channel.

Adjacent to the stream channel just downstream of the reclaimed Hack 1 Mine and upstream of sample GC09HKSS08 is a terrace which has been eroded by floods, revealing a cross section of uranium-mine waste rock covered by gravel. Figure 26*A* shows the location of this terrace. Figure 26*B* shows mining operations on this terrace in June 1985. During reclamation, waste rock from mine operations was spread on the terrace surface, contoured, and then covered with gravel. Four to 10 ft of buried uranium mineralized waste rock and 2 to 3 ft of cover material are now exposed where the edge of the terrace has been eroded by flow down the channel. The microR measurements for the lower, northern length of this terrace range from 200 to 1,900 µR/h; radioactivity decreases along the higher, southern length (20–100 µR/h). Images of this eroded terrace edge are shown in figure 27. Waste-rock sample GC09HKRK02 (table 8) was collected from the terrace wall. A few large rocks from this terrace edge have been eroded into the channel (fig. 28). In the stream reach from downstream of the reclaimed Hack 1 Mine to just downstream of the old wilderness boundary fence at sample site GC09HKSS07, microR measurements at stream sediment sites ranged from 7 to 9 µR/h. At sample location GC09HKSS08, microR readings were at background (4–5 µR/h), which correlates well with background uranium concentrations measured in the stream sediments. MicroR measurements at sites along Jumpup Canyon are in the same range, although the average uranium concentrations in the Jumpup Canyon stream sediments are smaller (average 1.9 ppm).

Leaching of Waste Samples

During and after mining operations, ore and uraniferous waste rock are exposed to surface conditions that include episodic wetting events. Wetting is of concern because of the potential dissolution and transport of environmentally sensitive trace elements. Ore and waste rock can be wetted (1) while exposed on the ground surface at mine sites during active operations and standby conditions, (2) while buried in alluvial soils along a drainage where they were covered by clean fill during reclamation, (3) while buried in alluvium after floods have washed them downstream, and (4) in underground mine openings when used as backfill. As part of the USGS investigation of possible effects of mining , samples of ore and waste rock were leached by simulated rainfall for materials left at the surface and by more carbonate-rich solutions that might form as water percolates downward through unsaturated zones towards the saturated zone in stream beds or in backfilled underground mine workings.

Waste materials found at active or standby mine sites differ from site to site but can include (fig. 29) lower grade uranium ore or mineralized waste rock stored in piles or left on the surface of the mine site during storage, transport, site grading, or similar processes (location O, fig. 29); particles displaced from ore or waste rock that were physically transported by gravity, wind or water (location P); particles that were formed by mechanical weathering of rock fragments on surfaces and enriched in trace elements (location M); surface sediments ponded in low places and enriched by trace elements in salts derived from dissolution of nearby ore or waste (location C); and leached trace elements sequestered in the unsaturated zone (location V). In this area, groundwater is not generally a receptor for dispersed trace elements, except where shallow, perched water may be present. Wind disperses dust offsite. The origin and character of these waste sources is important for understanding the potential for future dispersion, bioavailability, and mobility of uranium and other trace element contaminants of concern.



Figure 25. Ore and waste rock on the wash bottom of Hack Canyon. *A*, Sample GC09HKRK03 (weathered, 18 in. across); radioactivity measurement, 900 µR/h. *B*, Sample GC09HKRK04 (weathered, 5 in. diameter); radioactivity measurement, 125 µR/h. Sites of samples GC09HKRK03 and GC09HKRK04 are within 5 ft of each other. *C*, *D*, Waste rock and ore between GC09HKSS06 and GC09HKSS07 (microR meter for scale; radioactivity measurement on less weathered rock, 60 µR/h).

Because these sites are located in an arid region, the mobilization of contaminants from sources at the mine sites is largely limited to (1) physical dispersion of fines by wind, (2) low-intensity rainfall that locally could mobilize dissolved species by dissolution or desorption processes, and (3) high-intensity rainfall that could promote infiltration of dissolved species into the unsaturated zone or cause physical and chemical transport through sheet flow and channel erosion during flooding. In the event of physical dispersion or transport of solids (dust, waste rock, or uranium ore) to a surface water body such as a stream channel with perennial flow (for example, the lower part of Kanab Creek), dissolution of uranium is expected to increase through interaction with bicarbonate dissolved in water (Langmuir, 1978). The study reported here study investigated the potential for low- and high-intensity rainfall to mobilize uranium and other trace element contaminants by leaching representative waste sources present at the Hack, Pigeon, and Kanab North Mines. Background samples from Kanab South and Jumpup Canyon were also leached for comparison. Table 10 describes the whole-rock composition of these samples with respect to the crustal abundance of trace elements of concern that are typically associated with uranium breccia pipes in Arizona.

The whole-rock composition of the samples selected for leaching (n=11; table 10) are generally above crustal abundances for uranium and a number of other elements of environmental concern such as arsenic, barium, cadmium, cobalt, copper, molybdenum, nickel, lead, antimony, thallium, uranium, and zinc (table 10, highlighted in red). However, during leaching with simulated rainwater and groundwater or surface water, not all of these elements are leached into solution. Generally, in these samples synthetic rainwater extracted substantial amounts of uranium, arsenic, and molybdenum, and



Figure 25—Continued. Ore and waste rock on the wash bottom of Hack Canyon. *E*, *F*, Weathered waste rock and ore between GC09HKSS06 and GC09HKSS07 (microR meter for scale; radioactivity measurement, 25 µR/h). *G*, Waste rock and ore in overbank area (to lower right) adjacent to locality of GC09HKSS07 stream-sediment sample. *H*, Closeup of waste rock and ore (microR meter for scale; radioactivity measurement, 400 µR/h).

concentrations increased as the duration of leaching increased (see following sections). Likewise, the addition of bicarbonate to the leaching solution also increased the concentrations of uranium in solution owing to the formation of uranyl-carbonate aqueous complexes, which promote the dissolution of uranium minerals (Langmuir, 1978). As extracted uranium concentrations increase, more arsenic and molybdenum are also released. These relationships, as well as site-specific elements, are briefly discussed below.

Pigeon Mine Samples

At the Pigeon reclaimed mine site and mine operations area, several samples enriched in uranium were identified (n<10) by anomalously high microR measurements. The representative samples collected and selected for leaching (table 10) included weathered uranium ore from the operations area (600 µR/h, sample GC09PW–03), and soil samples enriched in uranium possibly by the addition of salts derived from waste (150 µR/h, sample GC09PW–02) or from fine-grained sediments derived from waste (sample GC09PS–88) at the reclaimed mine site. These samples were leached for 1 h and for 24 h with synthetic rainwater. Leaching results for the Pigeon Mine samples are summarized in table 11.

During the first hour of leaching with the synthetic rainwater, solutions contained 18.2–489 ppb arsenic, 60–401 ppb uranium, and 2.5–106 ppb molybdenum. Leachate from sample GC09PW–02 (which contains readily leachable salts) contained the highest concentrations of all three elements. The weathered ore sample (GC09PW–03) leached higher concentrations of copper (3,870 ppb), manganese (108 ppb), nickel (96 ppb), and zinc (1,220 ppb). After a 24-h leaching period in simulated rainwater, concentrations in solution were higher: 29.7–799 ppb



Figure 26. *A*, Tributary canyon and Hack Canyon bottom showing location of waste-rock terrace (upper and lower extent of terrace marked by arrows). Upstream part of terrace is substantially lower than downstream part. (Photograph courtesy of Don Bills, U.S. Geological Survey, Flagstaff, Arizona. Taken August 25, 2009.) *B*, Tributary canyon and Hack Canyon during mining operations (upper and lower extent of terrace marked by arrows). (Photograph courtesy of Pam Hill, American Clean Energy Resources Trust. Taken June 1985.)

arsenic, 171–1,270 ppb uranium, and 9.3 to 503 ppb molybdenum. Once again, leachate from sample GC09PW–02 contained the highest concentrations of uranium, arsenic, and molybdenum. This result suggests that sample GC09PW–02 is a contaminated soil that contains redistributed secondary salt or a sorbed phase and thus has the most readily leachable uranium, arsenic, and molybdenum. Uranium leached from the weathered ore sample (GC09PW–03) increased substantially to 1,020 ppb, and the sample yielded additional trace-element constituents such as 16.3 ppb cadmium, 3,270 ppb copper, and 186 ppb manganese, 182 ppb nickel, in addition to 1,600 ppm sulfate.

Kanab North Mine Samples

Because the Kanab North site is partially mined and not yet reclaimed, the mine site contained the most obvious sources of uranium waste material, weathered ore fragments, and ponded sediment. Sample leach data reported here include samples from a low-grade ore stock pile (sample GC09KNW–13), surface ponded sediment enriched in uranium (sample GC09KNW–12), weathered ore and waste rock from a large waste-rock pile (sample GC09KNW–01), sludge from the wastewater pond (sample GC09KNW–08), and physically transported waste (sample GC09KNW–10). These samples were leached for 1 h and for 24 h with simulated rainwater. Leaching results for Kanab North samples are summarized in table 12.

During the 1-h leaching with simulated rainwater, more uranium was released from the pond sludge (sample GC09KNW–08) than from the weathered uranium ore (sample GC09KNW–13)—19,600 ppb as compared with 924 ppb uranium in solution. The pond sludge also yielded 8,820 ppb molybdenum, 4,930 ppb strontium and 2,720 ppm sulfate. These concentrations suggest that the pond sludge contains readily leachable phases that may be mobilized during short rain events. Because the pond is lined, infiltration of dissolved uranium into the unsaturated zone is limited; however, rainwater in the pond may contain very high trace-element concentrations until evaporation to dryness causes them to precipitate into the sludge again. After a 24-h leaching period, uranium in the leachate increased substantially in the remainder of the samples: GC09KNW–13 (21,200 ppb uranium and 347 ppb molybdenum), GC09KNW–12 (487 ppb uranium and 998 ppb molybdenum), GC09KNW–01 (301 ppb uranium and 695 ppb molybdenum), GC09KNW–08 (27,600 ppb uranium and 10,900 ppb molybdenum), and GC09KNW–10 (708 ppb uranium and 592 ppb molybdenum). Unlike leaching of Pigeon Mine samples, leaching of Kanab North Mine waste samples produced very little arsenic (3.8–114 ppb) in solution.

Hack Canyon Mines Samples

Although a number of uranium-mineralized rock samples were found along Hack Canyon downstream from the Hack 1, 2, and 3 reclaimed mine sites and from the buried waste rock exposed in the terrace just downstream from Hack 1, these specimens were collected after the leaching experiments so they were not included. A sample of Hack Ore (01-Hack Ore) previously collected and archived by the USGS was used in the leaching study as a representative analog to determine leachability of uranium and other trace elements from ore at this site. Whole-rock compositions of the archived analog sample (01-Hack Ore, analyzed by instrumental neutron activation analysis [INAA]) are compared with the fragments of waste rock and weathered ore collected from the Hack Canyon



Figure 27. Terrace downstream of the former Hack 1 Mine (see also fig. 26) at confluence of tributary canyon and Hack Canyon. *A*, View upstream (north) along eroded low terrace edge. Person provides scale. *B*, View downstream (south) along low, eroded terrace edge toward higher terrace. *C*, Low part of terrace; view east toward reclaimed Hack 1 Mine at wall of terrace. Radioactivity measurements here, 200–1,900 µR/h. *D*, High downstream end of terrace. Radioactivity measurements here, 100–250 µR/h.

Mine (sample GC09HKR01–05, not used in this leaching study, analyzed by ICP–MS and ICP–AES); results are shown in table 13a. Concentration of trace elements commonly associated with breccia pipe ores differ widely (table 13a).

Hack ore and waste rock could migrate in a flash flood to a saturated perennial stream environment. This scenario would involve high-intensity rain followed by burial in the stream bed below the water table. In order to simulate this situation, the Hack Ore sample was leached in synthetic rainwater for a 1-h period and a 24-h period followed by leaching in a solution containing 300 mg/L bicarbonate. Concentrations of bicarbonate in Colorado River water averaged 162 ppm during the interval 1980 to 2009; its maximum concentration was 186 ppm. Data are available through the USGS National Water Information System at *http://waterdata.usgs.gov/nwis/qw*. A factor of approximately two times this average value was used to account for any higher values that may be present in stream flow at various times and to estimate effects of shallow alluvial groundwater (which can have higher bicarbonate concentrations—at times greater than 300 mg/L). Leaching results for the Hack waste-ore analog sample are summarized in table 13b–d.

Figure 30 shows the concentration of trace elements as a function of leaching solution for the Hack Ore sample, first with simulated rainwater at various time intervals for the first 24 h, then after 24 h equilibration with simulated river water. After the first hour (table 13b), trace element concentrations increase in solution for arsenic (2,020 ppb), cadmium (6.9 ppb), cobalt (334 ppb), molybdenum (4,960 ppb), nickel (782 ppb), antimony (12.1 ppb) and uranium (590 ppb). After a 24-h equilibration period, the same elements substantially increased and appeared to be approaching a steady-state



Figure 28. Large waste-rock boulder in streambed approximately 10 ft west of low terrace. *A*, View upstream of terrace and waste-rock boulder. *B*, View east toward eroded terrace wall from waste-rock boulder in streambed (Hack 1 Mine site is beyond terrace). Terrace gravel cover is pale reddish-brown. Radioactivity measurement on waste-rock boulder, 300 µR/h.

concentration in solution at 13,800 ppb arsenic, 26.8 ppb cadmium, 1,190 ppb cobalt, 17,400 ppb molybdenum, 3,480 ppb nickel, 75.7 ppb antimony and 4,410 ppb uranium. A major rain event at Hack Canyon that leaches 1 metric ton (1,000 kg) of ore and waste rock at a liquid/solid weight ratio of 20:1 will produce 20,000 liters of metal-rich leachate solution. In the worst case, all this solution would enter the stream channel as runoff and seepage during the event. Compare this 20,000 liter volume with the 10,477 liters per second (L/s) average flow past the mine site during the 1984 flood in Hack Canyon (370 cubic feet per second (cfs) (Energy Fuels Nuclear, Inc., undated) × 28.316 liters per cubic foot (L/ft^3). Clearly, the total volume of floodwater available during the entire duration (9.05×10^8 liters in 24 h) of a flood event allows for extreme dilution of mine-derived leachates of ore and waste rock to concentrations below 1 ppb for all constituents.

After 24-h contact between the Hack Ore and the 300 mg/L bicarbonate solution (table 13d), dissolved concentrations increased further to 36,400 ppb arsenic, 63,000 ppb uranium, 34.7 ppb cadmium, 1,890 ppb cobalt, 6,380 ppb nickel, 23,800 ppb molybdenum, and 114 ppb antimony. Even if such a solution generated by an assumed 1 metric ton of uranium ore and waste material buried in the stream bed did reach a surface water, such as the Colorado River with a flow rate of 10,780 cfs, then trace element concentrations in the flow would be below 1 ppb. (See summary data for USGS streamgage 09402500 on the Colorado River just northeast of Grand Canyon Village at *http://waterwatch.usgs.gov/?m=mv01d&r=az&w=map*.)

Mobility of Contaminants

The leaching experiments demonstrate that all samples appear to have a small component of uranium in readily water-soluble form. Percentages of uranium leached during 24-h contact with synthetic rainwater were as follows: unweathered ore (0.2–0.33 percent), wind transported fines (0.5–1.66 percent), weathered ore and waste rock (0.89–2.76 percent), chemically redistributed uranium waste in some soils and pond sediments (0.57–17.06 percent), and background samples (0.16–0.19 percent). Readily soluble uranium is probably desorbed or derived from surface coatings of sparingly soluble secondary minerals (in weathered waste rocks and ore specimens). The liquid/solid weight ratio of 20:1 used in the batch-leaching experiments simulated water saturation within intergranular pore spaces and excess pore water draining from a saturated ore or waste-rock pile. A liquid/solid weight ratio of 20:1 does not simulate the additional dilution

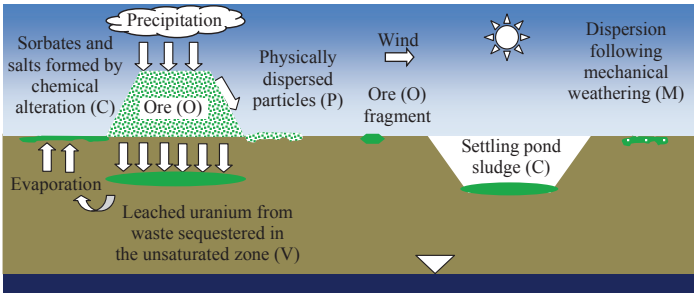


Figure 29. Processes expected to disperse trace elements contained in stored ore and mined waste rock at mine sites within study area. In this area, groundwater is generally not a receptor for dispersed trace elements from mine sites, except where shallow perched water is present.

Table 10. Elements in whole rock composition of samples selected for leaching compared with crustal abundance of those elements.

[Crustal abundance data from Smith and Logsdon (1999); red, concentration exceeds crustal abundance of element; ppm, parts per million; na, not analyzed]

Sample	Concentration (ppm)								
	Arsenic	Barium	Cadmium	Cobalt	Chromium	Copper	Manganese	Molybdenum	Nickel
Hack									
01-Hack Ore	3,210	6,320		205	33	na	na	na	1,600
Pigeon									
GC09PW03	5,060	36	17.40	6	8	9,030	18	20.9	55
GC09PS88	455	125	2.90	112	38	136	501	77.1	285
GC09PW02	258	909	1.00	232	41	130	520	86.4	397
GC09PS08	393	217	1.00	29	49	14	226	96.7	130
Kanab North									
GC09KNW01	280	458	2.50	96	38	173	187	173.0	115
GC09KNW08	44	330	0.70	49	13	41	162	230.0	48
GC09KNW10	388	516	6.20	111	28	172	209	164.0	129
GC09KNW13	1,980	111	10.40	57	14	107	218	102.0	123
GC09KNW12	803	484	8.40	175	20	516	182	328.0	180
GC09KNS12	7	477	0.20	8	26	15	472	1.2	13
Crustal abundance	**2**	**430**	**0.18**	**25**	**200**	**60**	**900**	**2**	**80**

Sample	Concentration (ppm)							
	Lead	Antimony	Strontium	Thorium	Thallium	Uranium	Vanadium	Zinc
Hack								
01-Hack Ore	na	9.2	713	2.5	na	26,800	na	4,100
Pigeon								
GC09PW03	837	12.1	436	0.3	6.30	1,870	21	3,400
GC09PS88	101	6.2	152	6.0	21.90	206	51	624
GC09PW02	137	14.6	210	7.6	4.30	616	64	215
GC09PS08	17	2.2	113	3.6	3.90	11	31	254
Kanab North								
GC09KNW01	154	1.3	107	5.7	12.40	679	66	458
GC09KNW08	32	0.7	250	3.4	1.80	3,236	24	165
GC09KNW10	215	1.6	112	4.1	10.70	2,840	47	1,350
GC09KNW13	1,790	3.1	65	1.7	30.20	15,380	51	1,400
GC09KNW12	220	2.3	115	3.1	20.40	1,720	66	1,590
GC09KNS12	14	0.5	127	7.1	0.40	13.9	38	47
Crustal abundance	**16**	**0.2**	**350**	**10**	**1**	**3**	**150**	**70**

Table 11. Concentrations of uranium and other trace elements in 1- and 24-hour leachates of Pigeon Mine samples.

[µg/L, microgram per liter; mg/L, milligram per liter]

Sample	Final pH	Trace element concentrations (µg/L)									
		Arsenic	Barium	Cadmium	Cobalt	Chromium	Copper	Manganese	Molybdenum	Nickel	Lead
1-hour simulated rainwater leachates[1]											
PW-03	6.1	18.2	25.9	14.6	7.72	<1	3,870	108	2.5	96	13
PS-88	8.06	50.5	140	0.09	0.74	<1	9.6	1.2	28.5	7	0.4
PW-02	9.15	489	166	0.19	4.71	1	16.8	2.8	106	19	3.8
24-hour simulated rainwater leachates[2]											
PW-03	6.85	29.7	61.5	16.3	13.6	<1	3,270	186	9.3	182	2.1
PS-88	8.75	88.6	165	0.21	3.26	<1	11.8	4.7	122	18	2.1
PW-02	9.3	799	133	0.74	12	1.4	19.6	7.6	503	40.1	4.5

Sample	Trace element concentrations (µg/L)								Major ions (mg/L)			
	Antimony	Selenium	Strontium	Thorium	Thallium	Uranium	Vanadium	Zinc	Sulfate	Pottasium	Calcium	Phosphorus
1-hour simulated rainwater leachates[1]												
PW-03	1.08	8.6	567	<0.2	<0.1	167	<0.5	1,220	1,050	0.2	409	<0.01
PS-88	1.96	1	20.1	<0.2	<0.1	60	1	6.7	30	0.91	13.9	0.1
PW-02	7.25	2.5	20.3	<0.2	0.1	401	7.2	8.5	10	1.17	7.96	0.3
24-hour simulated rainwater leachates[2]												
PW-03	1.92	16.7	850	<0.2	<0.1	1,020	<0.5	1,520	1,600	0.2	599	0.02
PS-88	3.35	1.2	30	<0.2	0.2	171	1.4	17	38	1.55	19.9	0.1
PW-02	13.3	2.9	30.7	<0.2	0.2	1,270	9.8	18.3	6	3.03	14	0.2

[1]Initial pH of two blank samples, 5.52 and 5.65.

[2]Initial pH of two blank samples, 5.7 and 5.6.

Table 12. Concentrations of uranium and other trace elements in 1- and 24-hour simulated-rainwater leachates of Kanab North samples (see also table 8).

Sample	Final pH	Trace metal concentrations (µg/L)									
		Arsenic	Barium	Cadmium	Cobalt	Chromium	Copper	Manganese	Molybdenum	Nickel	Lead
1-hour simulated rainwater leachates[1]											
KNW-13	7.38	3.8	21	0.58	14	<1	<0.5	47.7	47.4	26.4	0.1
KNW-12	8.1	6.9	19.4	1.06	32.4	<1	2.7	36.4	340	21.1	0.07
KNW-01	8.2	15.1	45.4	0.49	5.08	1.2	1.2	5.9	264	4.4	0.07
KNW-08	9.05	30.9	27.2	11.9	2.14	<1	20	25	8,820	4.8	<0.05
KNW-10	7.56	51.5	40.5	0.29	0.62	<1	1.7	0.5	135	0.9	0.2
24-hour simulated rainwater leachates[2]											
KNW-13	7.82	14.7	122	0.86	5.71	<1	0.83	27.6	347	23	<0.05
KNW-12	8.1	24.4	97.6	1.9	27	<1	3	4.4	998	19.7	<0.05
KNW-01	8.44	35.3	82.9	1.13	3.31	<1	1.2	3.2	695	3.5	<0.05
KNW-08	9.12	39.4	42.2	16	2.92	<1	55	33.3	10,900	6.2	<0.05
KNW-10	9.00	114	49.3	0.91	0.95	<1	1.5	0.4	592	1.3	<0.05

Sample	Trace metal concentrations (µg/L)								Major ions (mg/L)			
	Antimony	Selenium	Strontium	Thorium	Thallium	Uranium	Vanadium	Zinc	Sulfate	Potassium	Calcium	Phosphorus
1-hour simulated rainwater leachates[1]												
KNW-13	0.68	1.8	49.6	<0.2	<0.1	924	<0.5	48.4	155	0.51	60.2	<0.01
KNW-12	0.59	66.4	165	<0.2	0.63	10.4	<0.5	39.1	770	1.82	127	0.01
KNW-01	0.89	9.8	34.4	<0.2	<0.1	13.9	<0.5	12.5	168	1.29	38.3	0.02
KNW-08	1.16	17.8	4,930	<0.2	13	19,600	<0.5	6.1	2,720	51.9	364	0.05
KNW-10	1.08	5.3	300	<0.2	0.1	354	0.6	5.4	305	2.27	108	0.07
24-hour simulated rainwater leachates[2]												
KNW-13	2.68	4.2	126	<0.2	<0.1	21,200	<0.5	72	425	0.9	158	0.01
KNW-12	1.04	71.2	192	<0.2	0.4	487	<0.5	52.7	890	2.16	152	0.03
KNW-01	0.88	11	44	<0.2	<0.1	301	0.5	17.4	196	1.27	46.2	0.04
KNW-08	1.72	24.3	6,340	<0.2	23.4	27,600	<0.5	9	3,520	59.8	488	0.06
KNW-10	1.43	6.6	370	<0.2	0.68	708	1.1	5.2	386	3.32	124	0.02

[1]Intial pH values for two blanks, 5.52 and 5.65.

[2]Initial pH values for two blanks, 5.7 and 5.6.

Table 13. Whole-rock composition of ore and rock from Hack Canyon and concentrations of uranium and trace elements in 1- and 24-hour leachates of ore collected in Hack Canyon.

Table 13a. Whole-rock composition of the Hack Ore archived sample (01-Hack Ore) with data from table 8 for other uranium-bearing rock samples from the Hack Canyon wash for comparison. Crustal abundance data are shown for comparison (Smith and Logsdon, 1999). Analyses exceeding crustal abundance are highlighted in red. N/A, not analyzed. The 01-Hack Ore was an archived sample analyzed by INAA. The other samples were analyzed by ICP–MS and ICP–AES.

Sample	Concentration (ppm)																
	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Sr	Th	Tl	U	V	Zn
01-Hack Ore	3,210	6,320	N/A	205	33	N/A	N/A	N/A	1,600	N/A	9.2	713	2.5	N/A	26,800	N/A	4,100
GC09HKRK01	547	406	5.6	3.8	11	928	14	476	67.1	290	8.7	101	6.1	4.8	7,760	29	797
GC09HKRK02	>10,000	184	53.5	581	8	1,670	11	104	1,260	324	8.55	400	<0.2	349	3,630	8	>10,000
GC09HKRK03	2,040	947	0.6	4	11	1,740	21	14.3	12.2	212	12.4	81.5	3.7	1.7	825	32	92
GC09HKRK04	1,690	3,150	21.6	12.2	5	306	13	78.1	22.9	127	1.99	143	0.6	3.2	122	7	5,270
GC09HKRK05	>10,000	67	1	908	12	7,480	41	4,450	622	939	12.9	128	1.4	129	>10,000	273	111
Crustal abundance	2	390	0.16	29	122	68	1060	1.2	99	13	0.2	384	10	1	3	136	76

Table 13b. Concentrations of uranium and other trace metals in 1-hour simulated rainwater leachate of the 01-Hack Ore analog. Initial pH values for two blanks were 5.52 and 5.65.

Sample	Final pH	Trace metal concentrations (µg/L)																		Major ions (mg/L)			
		As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Se	Sr	Th	Tl	U	V	Zn	SO_4	K	Ca	P
Hack Ore	8.01	2,020	75.5	6.9	334	<1	1.3	17.7	4,960	782	1.1	12.1	2.9	112	<0.2	<0.1	590	10.8	15.4	85	0.76	39.5	0.03

Table 13c. Concentrations of uranium and other trace metals in 24-hour simulated rainwater leachate of the 01-Hack Ore analog. Initial pH values for two blanks were 5.7 and 5.6.

Sample	Final pH	Trace metal concentrations (µg/L)																		Major ions (mg/L)			
		As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Se	Sr	Th	Tl	U	V	Zn	SO_4	K	Ca	P
Hack Ore	7.78	13,800	171	26.8	1,190	<1	1.6	30.2	17,400	3,480	0.1	75.7	6.9	324	<0.2	<0.1	4,410	30.4	82.4	222	0.92	105	0.08

Table 13d. Concentrations of uranium and other trace metals in 24-hour simulated river water leachates from the 01-Hack Ore analog. Initial pH values for two blanks were 8.80 and 8.87.

Sample	Final pH	Trace metal concentrations (µg/L)													Major ions (mg/L)								
		As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Se	Sr	Th	Tl	U	V	Zn	SO_4	K	Ca	P
Hack Ore	7.7	36,400	248	34.7	1,890	13.9	3.8	32	23,800	6,380	0.73	114	17.3	463	<0.2	2.1	63,000	165	110	251	3.2	123	0.5

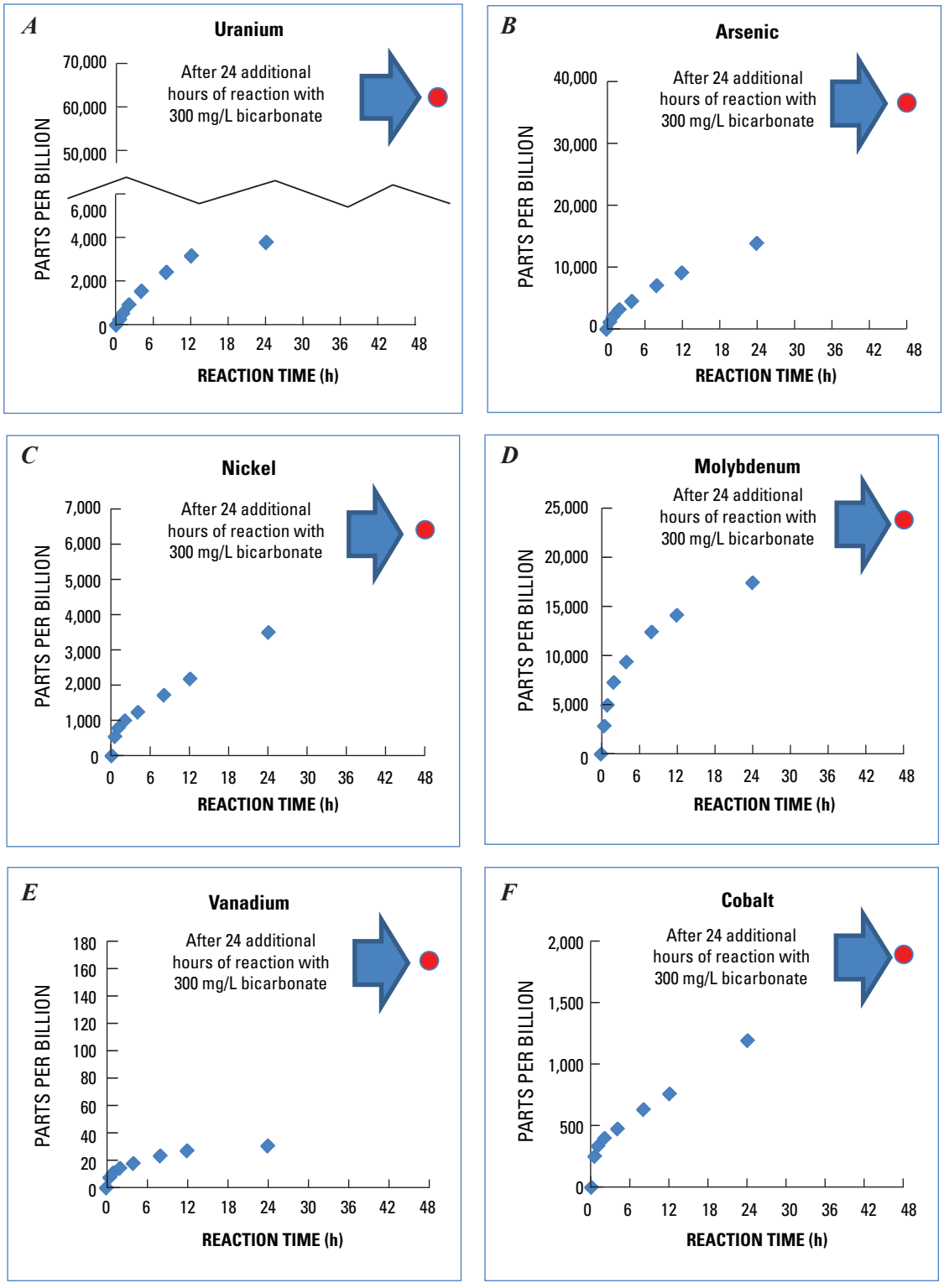


Figure 30. Concentration of seven elements in ore from Hack Mine leached into simulated rainwater during a 24-hour period (blue diamond) followed by equilibration in a 300 mg/L bicarbonate solution for 24 hours (large red dot). *A*, Uranium; *B*, Arsenic; *C*, Nickel; *D*, Molybdenum; *E*, Vanadium; *F*, Cobalt; *G*, Antimony. Leaching solutions were simulated rainwater (deionized water equilibrated with air, pH=5.6) and simulated carbonate-enriched river water (deionized water containing 300 mg/L dissolved sodium bicarbonate, pH=8.3).

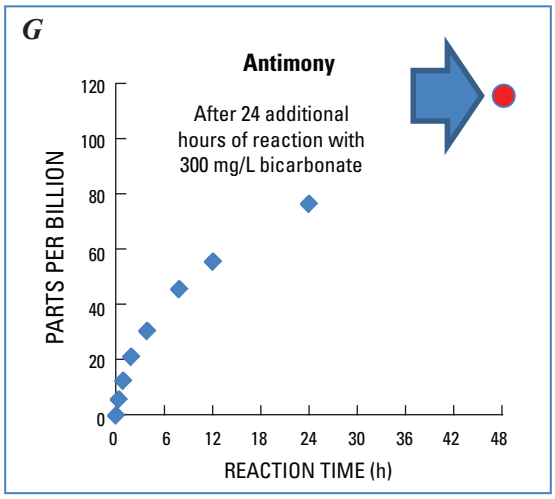


Figure 30—Continued. Concentration of seven elements in ore from Hack Mine leached into simulated rainwater during a 24-hour period (blue diamond) followed by equilibration in a 300 mg/L bicarbonate solution for 24 hours (large red dot). *A*, Uranium; *B*, Arsenic; *C*, Nickel; *D*, Molybdenum; *E*, Vanadium; *F*, Cobalt; *G*, Antimony. Leaching solutions were simulated rainwater (deionized water equilibrated with air, pH=5.6) and simulated carbonate-enriched river water (deionized water containing 300 mg/L dissolved sodium bicarbonate, pH=8.3).

that such waters experience when entering the larger surrounding environment. Projected dilution factors should be defined for specific environments and depend on duration and intensity of rainfall and the extent of mixing of mine-derived runoff with water from other sources.

Carbonate-based leaching, designed to simulate prolonged interaction of rock with surface water or groundwater in an area where carbonate rocks are common, mobilized greater amounts of uranium in unweathered ore (3–5 percent), wind-transported fines (7–13 percent), weathered ore and waste rock (14–20 percent), chemically redistributed uranium on waste (18–91 percent), and background soils (1–2 percent). The most leachable materials were again soil samples and pond sludges previously enriched in uranium and other trace elements through evaporative concentration or sorption. Interestingly, a greater percentage of uranium is leached from weathered waste-rock samples compared with the unweathered high-grade ore specimens (01-Pigeon Ore and 01-Hack Ore). These results are summarized in figure 31. Although measured concentrations are high at the 20:1 liquid/solid ratio used in the experiments, the extreme dilution in flood waters or after transport into large flowing water bodies will produce much lower concentrations in those waters. (The specific dilution will depend on water volume and flow rate.)

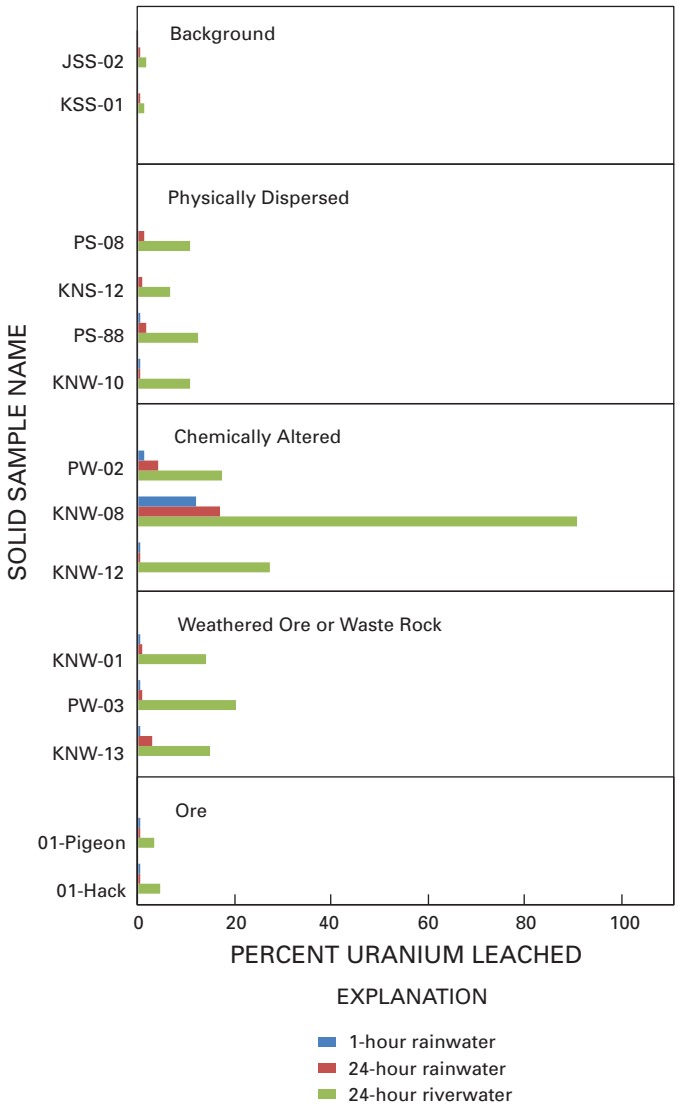


Figure 31. Percentage of uranium leached from five types of material during three experiments.

Summary

Uranium mining in the Kanab Creek area produced a varied legacy of contamination depending on the physiographic setting of the mining operations, the length of time that mined rock was exposed at the surface, and the effectiveness of reclamation at the site. Our study was designed to examine these effects through collection and geochemical analyses of a limited number of soils, stream sediments, and mine wastes located inside and outside of reclaimed and unreclaimed breccia pipe uranium mine sites. These mine sites were the Pigeon Mine, the Kanab North Mine, the Hermit Mine and the Hack Mine complex (Hack 1, 2, 3).

At the Pigeon Mine site, scattered fragments of uraniferous waste rock remain at the surface after reclamation in the small drainage where the mine was located and in the operations

area in and near the former waste-rock pile site. Some waste rock remained uncovered after reclamation in the mine area, and slope wash has dispersed uranium and trace elements to the stream channel edge downslope. Dust dispersed contaminants downwind to soils adjacent to the mine and operations sites. In some cases, anomalous soils offsite may be due to soils formed over limonite-cemented sandstone that had been altered by ore-forming solutions related to nearby mineralization. In the bed of a small intermittent stream, concentrations of uranium and several trace elements increased down valley towards Snake Gulch, but it is unclear how much of this increase is related to mine operations and how much is derived from the weakly mineralized rock outside of the pipe.

At the Kanab North Mine site, where ore and waste rock have been present at the surface for more than 20 years, wind dispersion of dust has carried contaminants to nearby soils and especially to soils downslope and downwind to the east. Soils outside of the fenced perimeter average 28 ppm uranium compared with the average of 2.4 ppm uranium estimated from NURE data. Although uraniferous sediment has moved within the site during rain events, no waterborne sediment has moved offsite, because a berm surrounding the site has remained intact during the standby period. Ponding of fine-grained sediment within and adjacent to onsite berms may contribute to offsite dispersion by wind.

The Hermit Mine was operational for less than 1 year. The relatively flat reclaimed mine site shows little radioactivity in excess of background levels and minor waste-rock debris. Very limited dispersion of trace elements was found offsite. Uranium and trace element concentrations in soils drop to background concentrations within a few hundred feet outside the reclaimed edge. No stream channel crosses the site, thus limiting the likelihood of flood-related effects.

The Hack Mine complex, operational for about 7 years, has been flooded owing to its deep canyon setting (about 230 m of local relief). Two or more floods carried ore and waste rock offsite during mining operations and during erosion of a reclaimed terrace area underlain by waste rock adjacent to the main channel of Hack Canyon. Ore and waste-rock fragments are found in the active channel and scattered on the floodplain of the wash for about a half mile downstream from the Hack 1 Mine. Associated finer grained stream sediments show limited dispersion of contaminants downstream. Mine-derived particulates in stream sediments are diluted by the vast quantities of native fine-grained sediment that are incorporated into a flow during a flood, likely limiting the effects of such contaminants.

Ore and waste-rock samples from a variety of mine site settings were leached using simulated rainwater and a simulated surface or shallow ground water rich in dissolved bicarbonate. Results of both studies show varied leaching of uranium and other trace elements. In some instances, uranium concentrations in the experimental leachates were very high—several hundred to several thousand parts per billion—but in natural settings such element-rich waters leached from mine sites are subject to very large dilutions as they mix with runoff. Mine wastes that are covered by fill such as at the Pigeon and Hack Mine sites may have relatively high concentrations of uranium and related trace elements in pore waters during rainfall events.

Future Studies

Listed below are studies that would improve our understanding of mine-related effects.

1. Studies of the dispersion of mercury, selenium, and radium at the mine sites;
2. Studies of the vertical distribution of trace elements in wind-contaminated soils and biogeochemical uptake by plants;
3. Documentation of the local background geochemistry of soils and stream sediments due to differences in geology and weak mineralization in outcrops outside of pipes;
4. New sampling of stream sediments in Snake Gulch to document changes that may exist owing to the mining of the Pigeon pipe;
5. Detailed mapping of dispersed fragments of ore and waste rock along Hack Canyon and the relation to the braided, aggrading stream;
6. Evaluation of radon emissions in the natural background and at reclaimed mine sites;
7. Evaluation, in greater detail, of the mobilization of dissolved trace elements from ore or waste rock during flood events; and
8. Development of geochemical and aqueous transport models for transport to deep groundwater of any contaminants mobilized from mined waste rock located in back-filled mine openings.

Acknowledgments

We thank Laura Biewick (USGS) for creating maps from GIS databases to display location information and geochemical data. Rody Cox (USBLM), Roger Smith (formerly with Energy Fuels Nuclear, Inc.), and Cindy Woodward (Denison Mines) provided useful discussion and copies of documents related to mine reclamation. Denison Mines (Fredonia, Arizona) provided access to the Kanab North Mine site. Papillon Grand Canyon Helicopters provided access to reclaimed mine sites in Hack Canyon. We thank George Breit (USGS) and Jon Spencer (Arizona Bureau of Geology and Mineral Technology) for reviewing early versions of this paper.

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Glossary

M

Mineral entry The filing of a claim for public land to obtain the right to any minerals it may contain (U.S. Bureau of Mines, 1996).

Mineralization The process or processes by which a mineral or minerals are introduced into a rock, resulting in a valuable or potentially valuable deposit (U.S. Bureau of Mines, 1996).

O

Ore The naturally occurring material from which a mineral or minerals of economic value can be extracted profitably (U.S. Bureau of Mines, 1996).

Orebody A continuous, well-defined mass of material of sufficient ore content to make extraction economically feasible (U.S. Bureau of Mines, 1996).

Ore deposit A mineral deposit that has been tested and is known to be of sufficient size, grade, and accessibility to be producible to yield a profit (U.S. Bureau of Mines, 1996).

R

Resource "Resource" or "uranium resource" as used in this report closely follows the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) definition:

> A Mineral Resource is a concentration or occurrence of…natural solid inorganic material…in or on the Earth's crust in such form and quantity and of such a grade or quality that it has reasonable prospects for economic extraction. The location, quantity, grade, geological characteristics and continuity of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge (CIM Standing Committee on Reserve Definitions, 2005).

W

Waste rock Barren or submarginal rock or ore that has been mined, but is not of sufficient value to warrant treatment and is therefore removed ahead of the milling processes (U.S. Bureau of Mines, 1996).