Chemical Composition of Samples Collected from Waste Rock Dumps and Other Mining-Related Features at Selected Phosphate Mines in Southeastern Idaho, Western Wyoming, and Northern Utah

By

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ABSTRACT

This report provides chemical analyses for 31 samples collected from various phosphate mine sites in southeastern Idaho (25), northern Utah (2), and western Wyoming (4). The sampling effort was undertaken as a reconnaissance and does not constitute a characterization of mine wastes. Twenty-five samples were collected from waste rock dumps, 2 from stockpiles, and 1 each from slag, tailings, mill shale, and an outcrop. All samples were analyzed for a suite of major, minor, and trace elements. Although the analytical data set for the 31 samples is too small for detailed statistical analysis, a summary of general observations is made.

Element concentrations vary considerably because of the differing rock types collected over a wide geographic area. For the 25 waste rock dump samples, concentrations of arsenic, antimony, thallium, chromium, copper, nickel, and vanadium are moderately elevated, ranging from 1.5 to 5.6 times those of average world-wide shale, the average concentrations of four elements are significantly elevated compared to their average abundance in average world-wide shale – selenium (x 77), cadmium (x 172), molybdenum (x 19), and zinc (x 12). A sample of slag, a product of high-temperature processing, collected from an inactive elemental phosphorus plant at the Georgetown Canyon mine contains the highest concentrations for 17 elements - silver, cobalt, chromium, copper, europium, iron, gallium, manganese, molybdenum, niobium, nickel, phosphorus, thorium, titanium, vanadium, ytterbium, and zirconium – and the lowest concentrations for 17 others - aluminum, carbon, calcium, cadmium, mercury, potassium, lanthanum, lithium, magnesium, sodium, sulfur, scandium, selenium, strontium, thallium, yttrium, and zinc. Highly contrasting geochemical signatures occur for two samples collected from the same waste-rock dump at the Waterloo mine near Montpelier, ID illustrating the heterogeneous nature waste dump rocks.

INTRODUCTION

Location, Background, and Purpose

The U.S. Geological Survey (USGS) has studied the Permian Phosphoria Formation and related rock units in southeastern Idaho and the Western Phosphate Field throughout much of the twentieth century. In response to a request by the Bureau of Land Management (BLM), a new series of resource, geological, and geoenvironmental studies were initiated by the USGS in 1998. Present studies consist of integrated, multidisciplinary research directed toward (1) resource and reserve estimation of phosphate in selected 7.5-minute quadrangles; (2) element residence, mineralogical, and petrochemical characteristics; (3) mobilization and reaction pathways, transport, and fate of potentially toxic elements associated with the occurrence, development, and societal use of phosphate; (4) geophysical signatures; and (5) improving understanding of depositional environments. To carry out these studies, the USGS is conducting collaborative research with the BLM and the U.S. Forest Service (FS), which are responsible for land management and resource conservation on public lands, and with five companies currently leasing or developing phosphate resources in southeast Idaho: Agrium U.S. Inc. (Rasmussen Ridge mine), Astaris LLC (Dry Valley mine), J.R. Simplot Company (Smoky Canyon mine), Rhodia Inc. (Wooley Valley mine – inactive), and Monsanto (Enoch Valley mine). Because raw data acquired during the project require time to interpret, the data are released in open-file reports for prompt availability to other scientists. Open-file reports associated with this series of resource and geoenvironmental studies are submitted to the Federal and industry collaborators for comment; however, the USGS is solely responsible for the content of the reports.

Limited sampling of phosphate mine wastes and other deposits at selected active and historic phosphate mines in southeastern Idaho, western Wyoming, and northern Utah was completed in support of on-going geologic mapping, remote sensing, and phosphate resource studies. These data, together with related sampling and chemical analyses of rock outcrops, exposed sections at active mines, and archived samples from previous studies, will contribute to an overall effort to characterize the spatial distribution of selenium and other trace elements throughout the Western Phosphate Field, both in situ and in waste piles. Analyses of samples of outcrops and exposed sections will contribute to developing a model of trace element distribution either associated with original deposition or as a result of post-depositional diagenetic or weathering processes. Analyses of mine wastes will contribute to understanding the source characteristics and mobilization of trace elements. The samples and analyses described in this report are a reconnaissance and do not constitute a characterization of mine wastes.

Previous Studies

A considerable body of knowledge on the Phosphoria Formation and related rock units in the Western Phosphate Field has been published by scientists of the USGS as well as from others. The historic literature is too large to list; however, mention of selected references is warranted. Pioneering workers such as Mansfield (1918, 1920, 1927, 1933), McKelvey and others (1953a, 1953b, 1959, 1967), Sheldon (1963, 1989), Service and Popoff (1964), Service (1966, 1967), and Gulbrandsen and Krier (1980), concentrated predominantly on delineation and evaluation of phosphate resources and on deposit origin. Research in recent decades has produced significant literature by Gulbrandsen (1966), Piper (1974), Desborough (1977), Altschuler (1980) and others on the unusual chemistry of the Meade Peak Phosphatic Shale Member, the primary source of phosphate ore. Phosphate deposit origin, demand, and commodity studies are reported in Herring (1995), Herring and Fantel (1993), and Herring and Stowasser (1991).

Current studies by the USGS have produced numerous reports relevant to the geochemistry of the Phosphoria Formation, particularly the Meade Peak Phosphate Shale Member in southeastern Idaho (Desborough and others, 1999; 2000; Herring and others, 1999a, b, c; 2000a, b, c; Grauch and others, 1999, 2000a, b; and Piper, 1999a, b. A detailed history of phosphate mining in southeastern Idaho was recently completed by Lee (2001). In addition, a spatially registered description of selected phosphate mines in southeastern Idaho, showing mine pits, waste dumps, tailings and other phosphate-mining-related features, has been prepared (Causey and Moyle, 2001). Mine waste samples described in this report were collected during field reconnaissance at several of the mines included in the geospatial database.

METHODOLOGY

Field Sampling

Thirty-one samples collected for geochemical analysis were obtained from waste rock dumps (25), stockpiles or mill shale piles (3), tailings (1), slag (1), and outcrop (1) from 20 mines and prospects. Waste rock dump, stockpiles or mill shales, and tailings samples were collected as composite grab samples. Composite grab samples consist of rock material collected from two or more 0.3- to 0.6 –m-deep holes excavated into the waste rock dump, stockpile, or tailings impoundment and combined into a single composite sample. A sample of slag was "selected" from a heterogeneous mix of mine wastes, processing byproducts and alluvium at a mine-plant complex, and a continuous "chip channel" sample was obtained from an outcrop of Meade Peak member at one inactive mine site. Approximately 2.5 to 5 kg of rock was collected at each sample locality. Samples were shipped to the laboratory of the USGS in Denver, Colorado for sample preparation.

Rock Sample Preparation and Geochemical Analyses[3]

Rock samples were air-dried followed by disaggregation in a mechanical jaw crusher. A split was ground to <100 mesh (0.15 mm) in a ceramic plate grinder. A riffle splitter was used to obtain splits to ensure similarity with the whole sample. One set of splits for all samples was archived, and approximately 50-g splits of ground material was shipped to the contract laboratory for analysis.

Forty major, minor, and trace elements were determined for all 31 samples by inductively coupled plasma-atomic emission spectrometry (ICP-AES), also referred to as the ICP-40

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[3] Aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), bismuth (Bi), cadmium (Cd), calcium (Ca), carbon (C),cerium (Ce), chromium (Cr), cobalt (Co), copper (Cu), europium (Eu), gallium (Ga), gold (Au), holmium (Ho), iron (Fe), lanthanum (La), lead (Pb), lithium (Li), magnesium (Mg), manganese (Mn), mercury (Hg), molybdenum (Mo), neodymium (Nd), niobium (Nb), nickel (Ni), phosphorus (P), potassium (K), scandium (Sc), selenium (Se), silicon (Si), silver (Ag), sodium (Na), strontium (Sr), sulfur (S), tantalum (Ta), tellurium (Te), tin (Sn), thallium (Tl), thorium (Th), titanium (Ti), uranium (U), vanadium (V), ytterbium (Yb), yttrium (Y), zinc (Zn), zirconium (Zr).

package, after low-temperature (<150^{o}C) digestion using concentrated hydrochloric, hydrofluoric, nitric, and perchloric acids (Crock and others, 1983). Splits of all samples were also submitted to the contract laboratory for analysis of 16 major, minor, and trace elements (Al, Ba, Ca, Cr, Fe, Mg, Mn, Nb, P, K, Si, Na, Sr, Ti, Y, Zr) by ICP-AES using a lithium metaborate fusion. This technique is also referred to as the ICP-16 package. The samples were fused with lithium metaborate in a graphite crucible. In-house standards were run to monitor the proper digestion procedure, and synthetic standards were used to calibrate the instrument. Sample solutions were aspirated into the ICP through a high-solids nebulizer, and metal concentrations were measured simultaneously. Eight samples were also submitted for a 10-element ICP-AES technique, also referred to as ICP-10, for determination of Ag, As, Au, Bi, Cd, Cu, Mo, Pb, Sb, and Zn. Hydrochloric acid and hydrogen peroxide were used to solubilize metals not tightly bound in the silicate lattice of rocks. Metals are extracted as organic halides. Concentrations of the extracted metals were determined simultaneously after aspiration into a multichannel ICP instrument. This procedure is a partial digestion and results may be biased low when compared to procedures involving complete dissolution of the sample.

Sample splits were also submitted for individual analysis of ten elements or compounds by specific methods. Arsenic, Sb, Se, Tl and Te analyses were performed by hydride generation-atomic absorption spectrometry. Hg was analyzed by cold vapor-atomic absorption spectrometry. Total S and total C were analyzed by combustion in an oxygen atmosphere followed by infrared measurement of evolved CO_2 and SO_2. Carbonate (inorganic) C was determined by coulometric titration after acidification. An interim value for CO_2 is also reported. Organic C may be calculated as the difference between total and carbonate carbon.

SAMPLING

Waste Rock Dumps and Other Deposits Sampled

Generally located close to the mine to reduce haulage costs, a waste rock dump is composed of heterogeneous mine waste materials excavated from underground or surface workings for the purpose of exposing and excavating ore. The Bureau of Mines (1968) dictionary defines ***waste rock*** as “barren or submarginal rock or ore which has been mined but is not of sufficient value to warrant treatment and is therefore removed ahead of the milling process” and a ***waste dump*** as “the area where mine waste or spoil materials are disposed of or piled.” Typically, waste rock may be placed on hillsides, in valleys or ravines, or on any convenient surface that provides long-term stability. Modern open-pit operations often backfill waste rock into the mine pit to return the surface as close as possible to the original landform and to minimize exposure of waste rock to surface weathering processes (figure 1). Waste rock dumps range in size (volume) from a few hundred to a thousand cubic meters, typical of smaller underground mines, to tens of millions of cubic meters at large, open-pit mines. Ore is often placed into temporary piles or impoundments called stockpiles until it is ready for transport or processing. Mill shales consist of subeconomic phosphatic rock, generally 14 to <18 percent P_2O_5, stockpiled for possible future use. Tailings are fine-grained waste materials from milling (crushing and grinding) and other processes. Tailings have generally been subjected to both mechanical and chemical processes that result in fundamental changes in their chemical and physical characteristics. Slag is the waste product of a process that subjects ore to high temperatures to recover a desirable product such as phosphorus. Molten slag is periodically removed, tapped, from electric arc furnaces at temperatures ranging from 1450° to 1550° C (Van Wazer, 1961). Slag is typically fused and is also altered chemically from the original rock composition.

Phosphate mine waste rock dumps may consist of a range of materials or lithologies including overburden (unconsolidated surficial material), overlying strata such as Rex Chert, low-grade material from portions of the Meade Peak member, such as center waste shale, underlying strata such as the Wells Formation, or any other materials associated with the mine site (figure 2). At large, open-pit phosphate mines typical of modern operations, a single mine may have several waste rock dumps, each composed of a unique assemblage of rock types (figure 3).

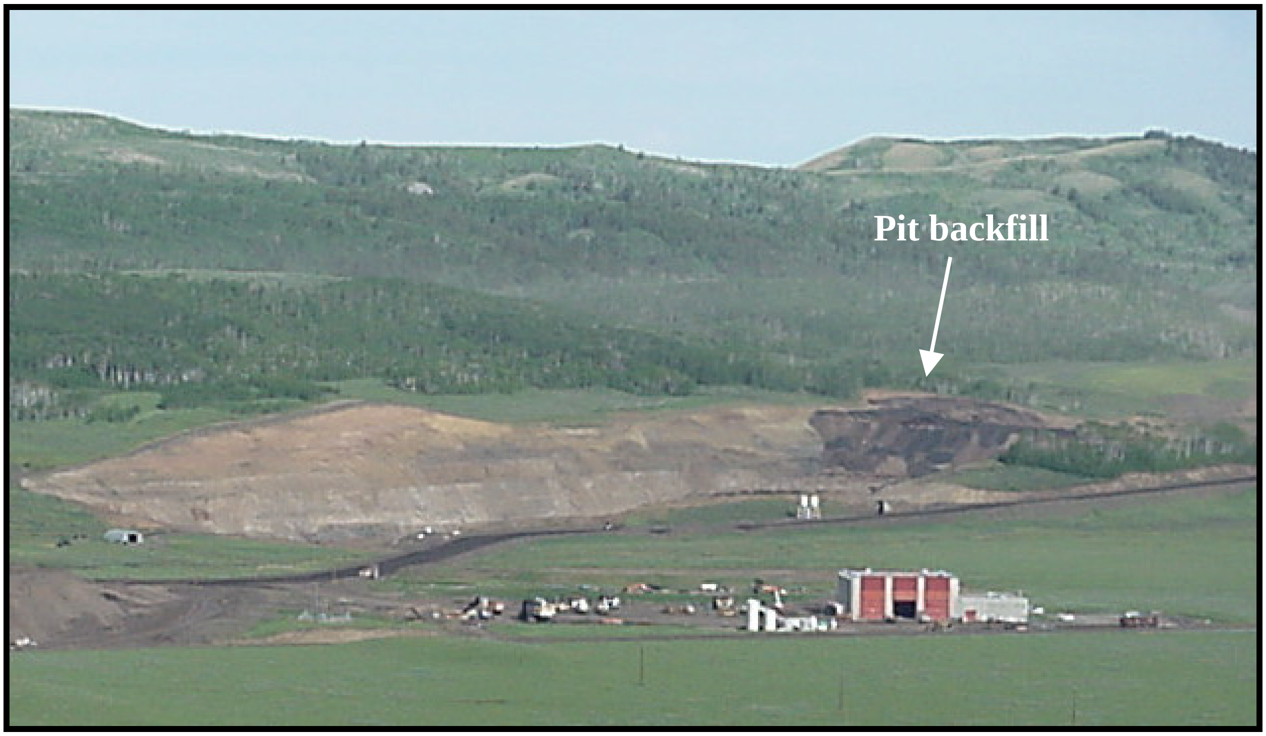

Figure 1. View west of Dry Valley mine showing waste rock backfill into open pit on right.

Waste rock dumps are heterogeneous in both grain size and structure. The rock fragments in a dump are a product of mechanical processes, such as drilling, blasting, and ripping, designed to disaggregate a massive body of in-place rock in order to excavate and transport the materials. Consequently, dump rock may range in size from clay particles to boulders (e.g. less than 0.1 mm to greater than 1 m in diameter). Natural gravity sorting of rock poured from a haulage truck onto a waste dump face may result in a vertical size distribution, finer materials tend to remain near the top and coarse materials tend to roll down the face toward the toe of the dump (figure 2).

Figure 2. Various colors and sizes of rock in a complex of waste rock dumps at an active phosphate mine in southeastern Idaho illustrate the heterogeneous lithology and grain size characteristics of dumps. Note the high incidence of coarse rock near the toe of the dumps.

The manner in which a waste rock dump is designed and constructed can also result in significant differences in structure. Commonly, construction of a dump progresses by addition of material to the top of the dump at the face, allowing waste rock to form a continuously renewed veneer on the face. The dump progresses outward horizontally as successive layers are added to the face. However, some dumps are engineered in other ways, resulting in significantly different internal structures. For instance, in order to enhance dump stability and to minimize the release of fine sediment into the down-stream environment, some dumps have been designed with a French drain, a layer of coarse, durable rock, such as chert, placed at the base to allow unrestricted flow of a stream through the base of the dump. At other locations, waste rock dumps have been constructed in layers or raises resulting in a sequence or stack of dumps.

Figure 3. View north of several waste rock dumps at the Waterloo mine near Montpelier, ID.

Limitation of Data

As noted in the introduction, studies of mine wastes may contribute to understanding the source characteristics, mobilization, and transport of trace elements of concern; however, the sampling and analyses described here are reconnaissance in nature. Clearly, every dump constitutes a unique set of physical and chemical conditions, and one or two samples collected from the surface, or near surface, are not representative. Consequently, the data presented here do not constitute a characterization of mine wastes nor are the data considered to be representative of any of the mine sites investigated.

Sample Sites and Data

The region studied includes portions of Idaho, Utah, and Wyoming (figure 4 and table 1) where 31 samples were collected from 20 mines and prospects. Twenty-five samples were collected in southeastern Idaho (figures 5-18), two in northern Utah (figures 4 and 19), and four in western Wyoming (figures 4 and 20-22). Of the samples, 25 were collected from waste rock dumps, 2 from stockpiles, and one each of a mill shale pile, tailings (figure 16), slag (figure 15), and an outcrop (figure 18). Mine names, sample locations, sample types and methods, and brief lithologic descriptions are listed in Table 1, and detailed sample information and geochemical analyses for the 31 samples collected are presented in Appendix tables A-1, A-2, A-3, and A-4. Federal Geographic Data Committee compliant metadata are listed in Appendix B.

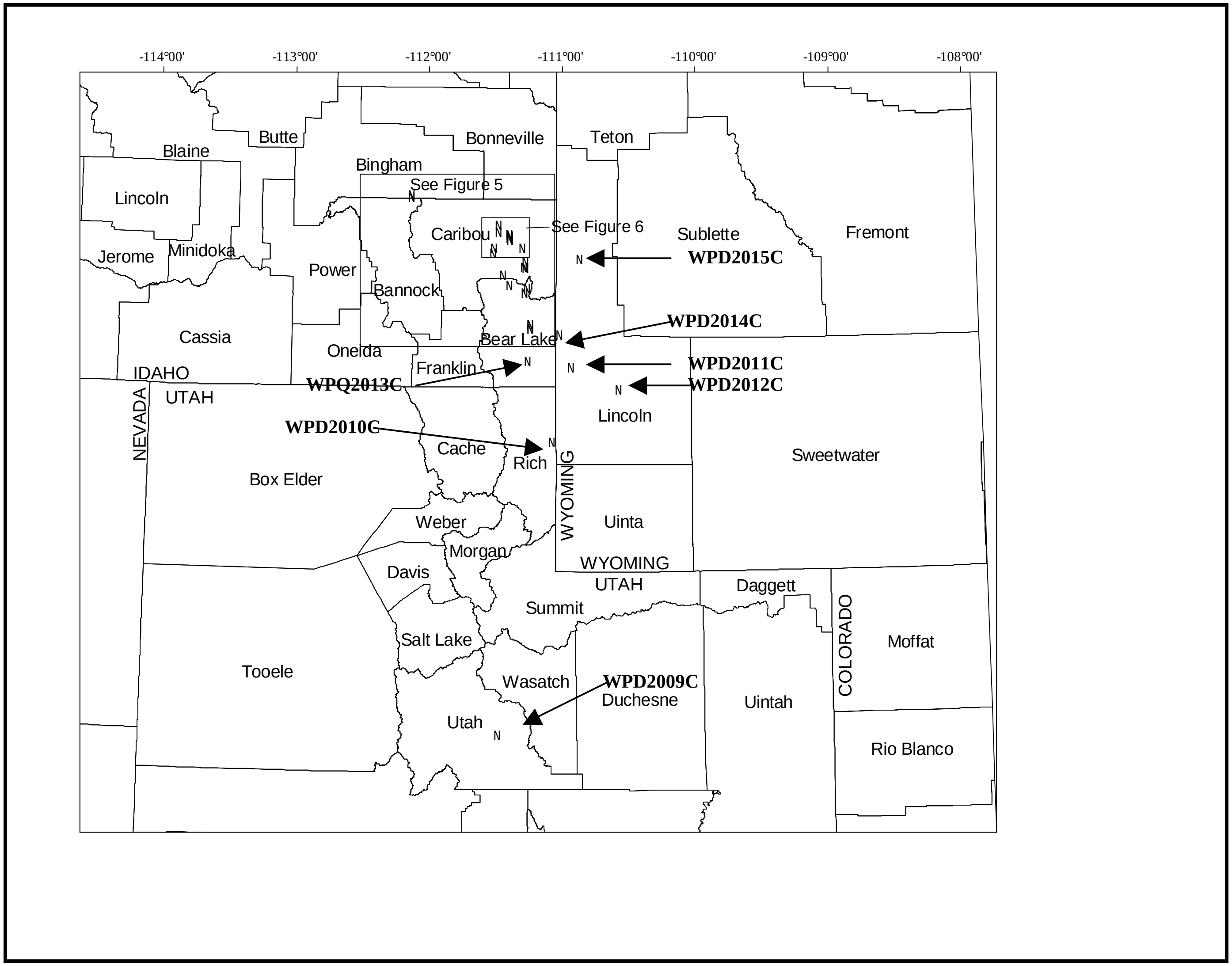

Figure 4. Generalized map of southeast Idaho, western Wyoming, and northern Utah showing phosphate sample sites, selected sample numbers, and locations of figures 5 and 6.

Table 1. List of phosphate mine sites sampled showing mine type, feature sampled, lithology, and sample type.

SITE NAME	COUNTY	MINE TYPE	FEATURE SAMPLED	LITHOLOGY	SAMPLE NUMBER	SAMPLE TYPE	QUADRANGLE MAP
IDAHO							
Ballard Mine	Caribou	open pit	waste dump	shale	WPD2005C	composite	Lower Valley
Champ Mine	Caribou	open pit	waste dump	black shale & limestone	WPD2001C	composite	Dry Valley
Conda/Woodall Mountain Mine	Caribou	open pit & UG	waste dump	gray-black shale	WPD2024C	composite	Soda Springs
Conda/Woodall Mountain Mine	Caribou	open pit & UG	waste dump	tan-brown shale, limestone, & pelletal phosphorite	WPD2025C	composite	Soda Springs
Diamond Gulch Mine	Caribou	open pit	waste dump	black shale & limestone	WPD2004C	composite	Fossil Canyon
Gay Mine	Bannock	open pit	mill shale pile	gray-black shale	WPQ2026C	composite	Yandell Springs
Gay Mine	Bingham	open pit	waste dump	brown-gray shale & limestone	WPD2027C	composite	Yandell Springs
Georgetown Mine - plant	Bear Lake	open pit	slag pile	gray, metallic	WPQ2028C	select	Harrington Peak
Georgetown Canyon - Church Hollow	Bear Lake	open pit	tailings	brownish-gray, fine-grained, phosphatic shale w/ pea-sized gravel	WPD2029C	composite	Harrington Peak
Henry Mine, central	Caribou	open pit	waste dump	gray-black shale	WPD2018C	composite	Lower Valley
Home Canyon Mine	Bear Lake	UG	waste dump	black shale	WPD2007C	composite	Montpelier Canyon
Home Canyon Mine	Bear Lake	UG	stockpile	phosphorite	WPD2008C	composite	Montpelier Canyon
Hot Springs Mine	Bear Lake	Prospect Pit	outcrop	flat-lying organic-rich shale & phosphorite	WPQ2013C	chip (4.5')	Bear Lake North
Maybe Canyon adit	Caribou	UG	waste dump	black shale	WPD2006C	composite	Dry Valley
Mountain Fuel Mine	Caribou	open pit	waste dump	black shale & limestone	WPD2002C	composite	Dry Valley
Mountain Fuel Mine	Caribou	open pit	waste dump	black shale & limestone	WPD2003C	composite	Dry Valley
Rattlesnake Canyon Mine	Bear Lake	UG	waste dump	brown-black shale	WPD2016C	composite	Fossil Canyon

UG = underground workings

Table 1. List of phosphate mine sites sampled showing mine type, feature sampled, lithology, and sample type. – continued

SITE NAME	COUNTY	MINE TYPE	FEATURE SAMPLED	LITHOLOGY	SAMPLE NUMBER	SAMPLE TYPE	QUADRANGLE MAP
IDAHO (continued)							
Waterloo Mine	Bear Lake	open pit & UG	waste dump	dark gray to black phosphatic shale	WPD2030C	composite	Montpelier Canyon
Waterloo Mine	Bear Lake	open pit & UG	waste dump	beige-tan fissile sandy shale and limestone w/ brown-orange iron oxide stains	WPD2031C	composite	Montpelier Canyon
Wooley Valley Mine, Unit 1	Caribou	open pit	waste dump	brown-black shale	WPD2017C	composite	Lower Valley
Wooley Valley Mine, Unit 4, face level 5	Caribou	open pit	waste dump	dark brown shale	WPD2019C	composite	Lower Valley
Wooley Valley Mine, Unit 4, face level 4	Caribou	open pit	waste dump	brown-black shale & chert	WPD2020C	composite	Lower Valley
Wooley Valley Mine, Unit 4, face level 3	Caribou	open pit	waste dump	brown-black shale & chert	WPD2021C	composite	Lower Valley
Wooley Valley Mine, Unit 4, face level 2	Caribou	open pit	waste dump	brown shale, chert, limestone, & siltstone	WPD2022C	composite	Lower Valley
Wooley Valley Mine, Unit 4, face level 1	Caribou	open pit	waste dump	gray-brown shale, chert, siltstone, & limestone	WPD2023C	composite	Lower Valley
UTAH							
Benjamin Mine	Rich	UG	waste dump	black shale & phosphorite	WPD2010C	composite	Rex Peak
Little Diamond	Utah	UG	waste dump	black shale & phosphorite	WPD2009C	composite	Billies Mountain
WYOMING							
Cokeville Mine	Lincoln	UG	stockpile	shale & oolitic phosphorite	WPD2011C	composite	Cokeville
Dry Creek - USBM adit	Lincoln	UG	waste dump	black shale	WPD2015C	composite	Red Top Mountain
Raymond Creek	Lincoln	UG	waste dump	black shale	WPD2014C	composite	Geneva
South Mountain Mine	Lincoln	Open Pit	waste dump	black oolitic phosphorite	WPD2012C	composite	Sublet

UG = underground workings

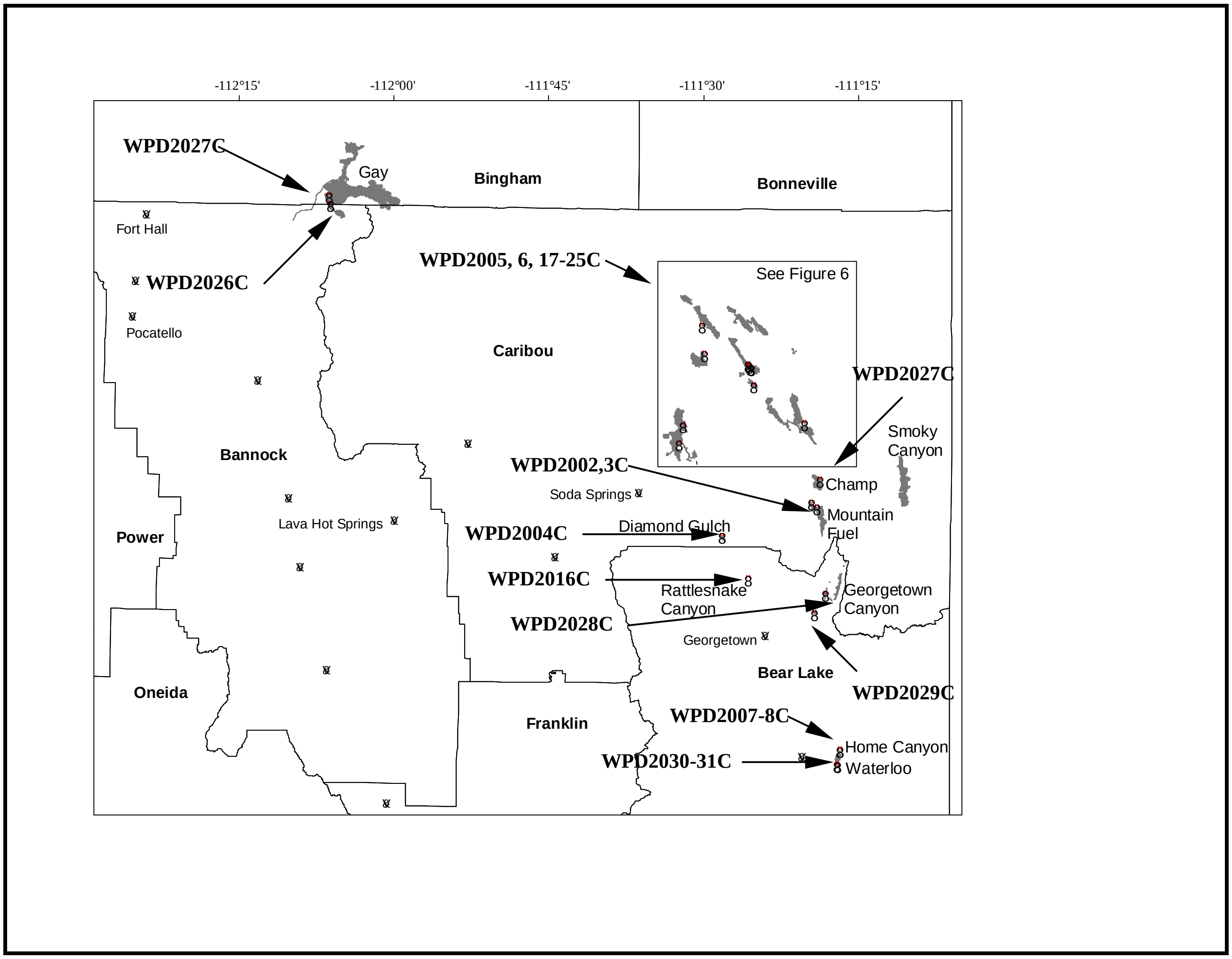

Figure 5. Generalized map of phosphate mines in southeastern Idaho showing selected sample sites and location of figure 6.

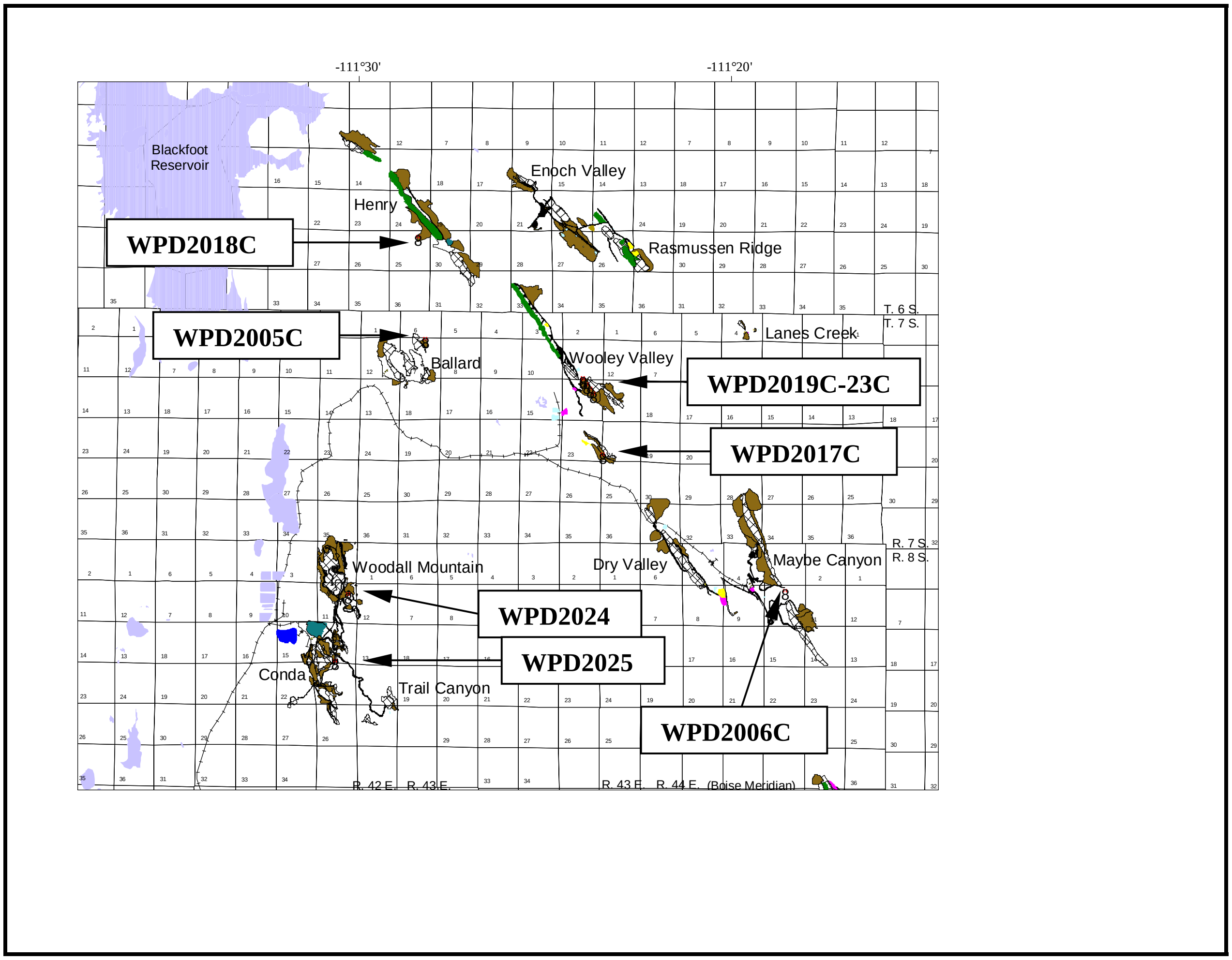

Figure 6. Map of selected phosphate mines in the Blackfoot River watershed, Caribou County, Idaho, showing sample sites.

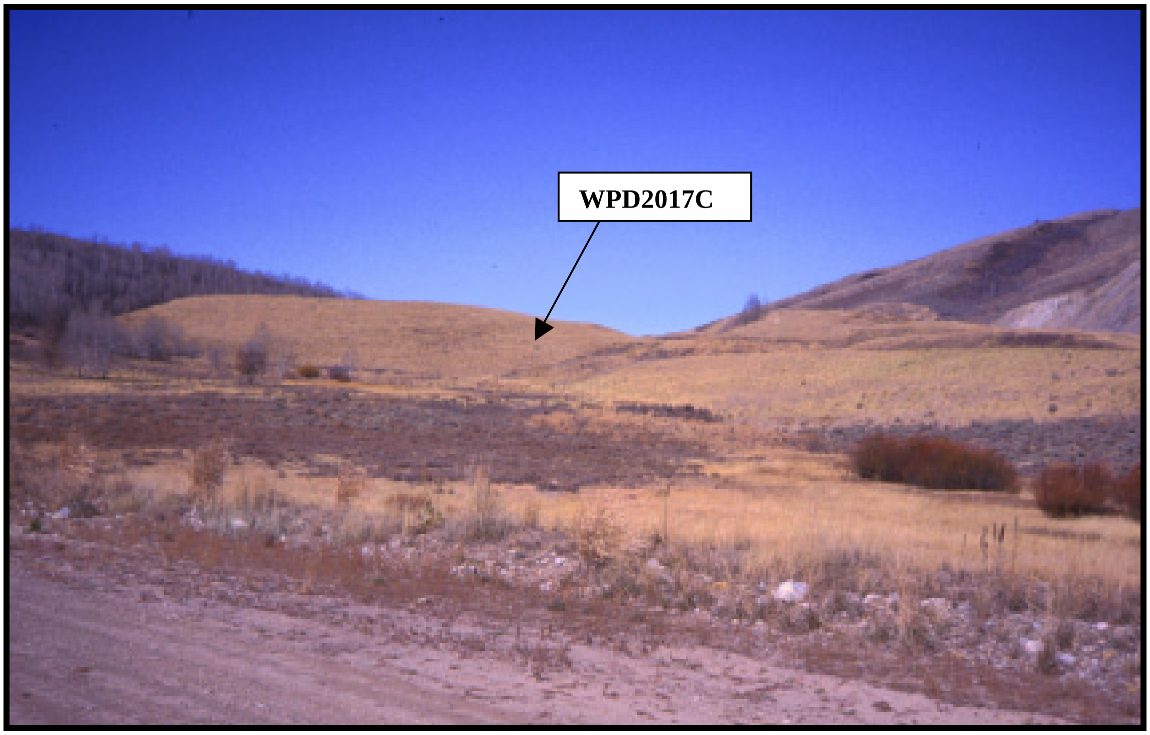

Figure 7. View north of the Wooley Valley mine waste rock dump at Unit I, Caribou County, Idaho, showing sample site WPD2017C.

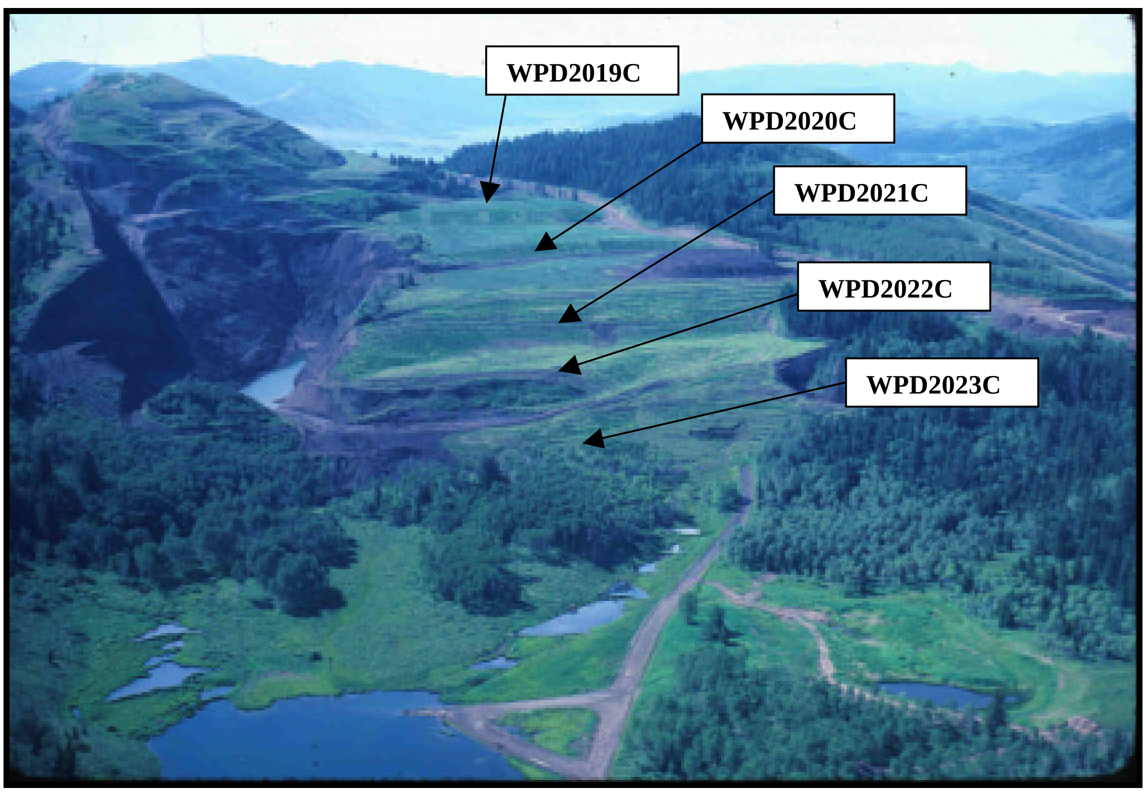

Figure 8. View south of the Wooley Valley mine waste rock dump at Unit IV, Caribou County, Idaho, showing sample sites WPD2019C-23C.

Figure 9. View west of the Ballard mine and waste rock dumps, Caribou County, Idaho, showing sample site WPD2005C.

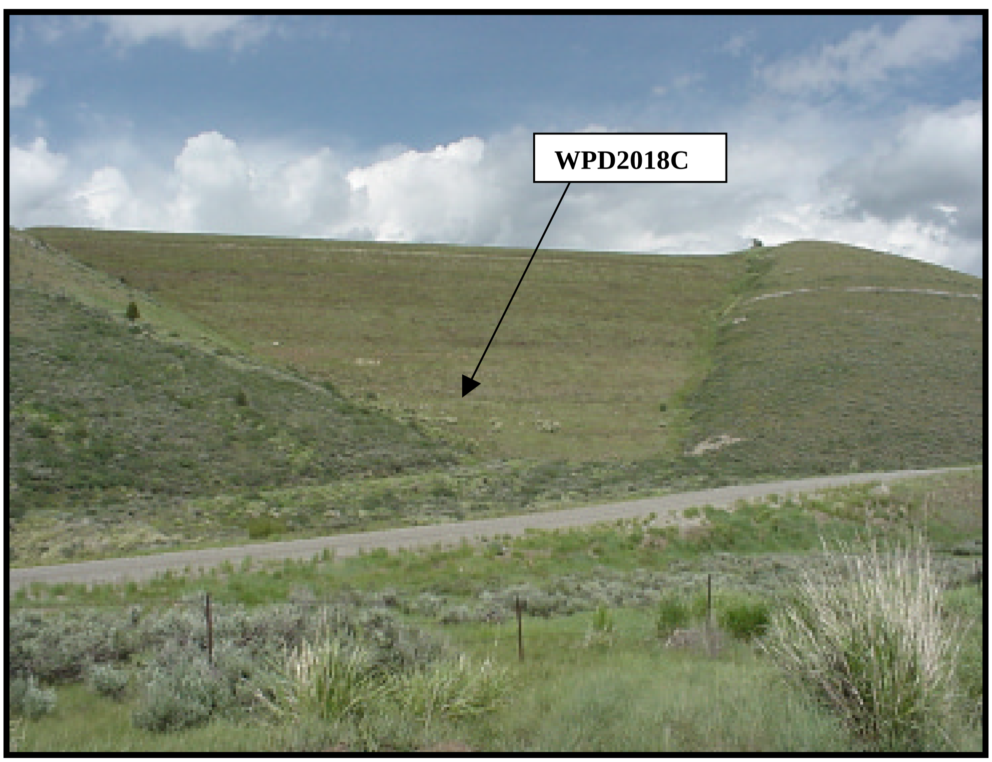

Figure10. View northeast of a waste rock dump at the Henry mine, central, Caribou County, Idaho, showing sample site WPD2018C.

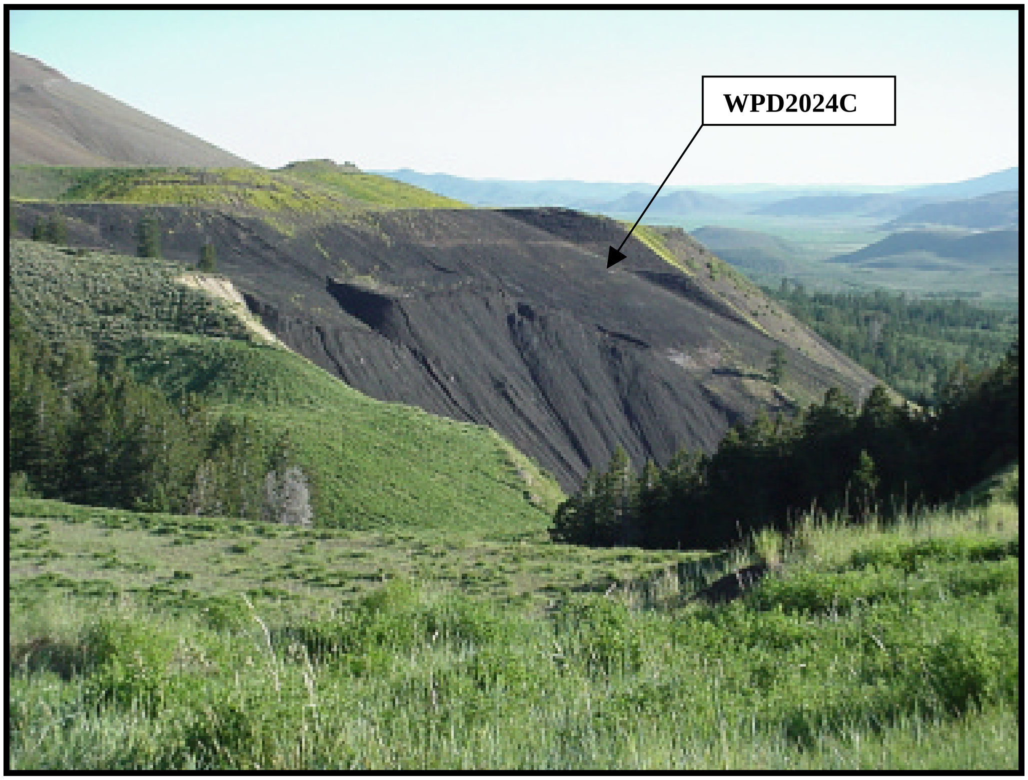

Figure 11. View north of a waste rock dump at the Woodall Mountain mine, Caribou County, Idaho, showing sample site WPD2024C.

Figure 12. View south of the Champ-Champ Extension mine, Caribou County, Idaho, showing sample site WPD2001C.

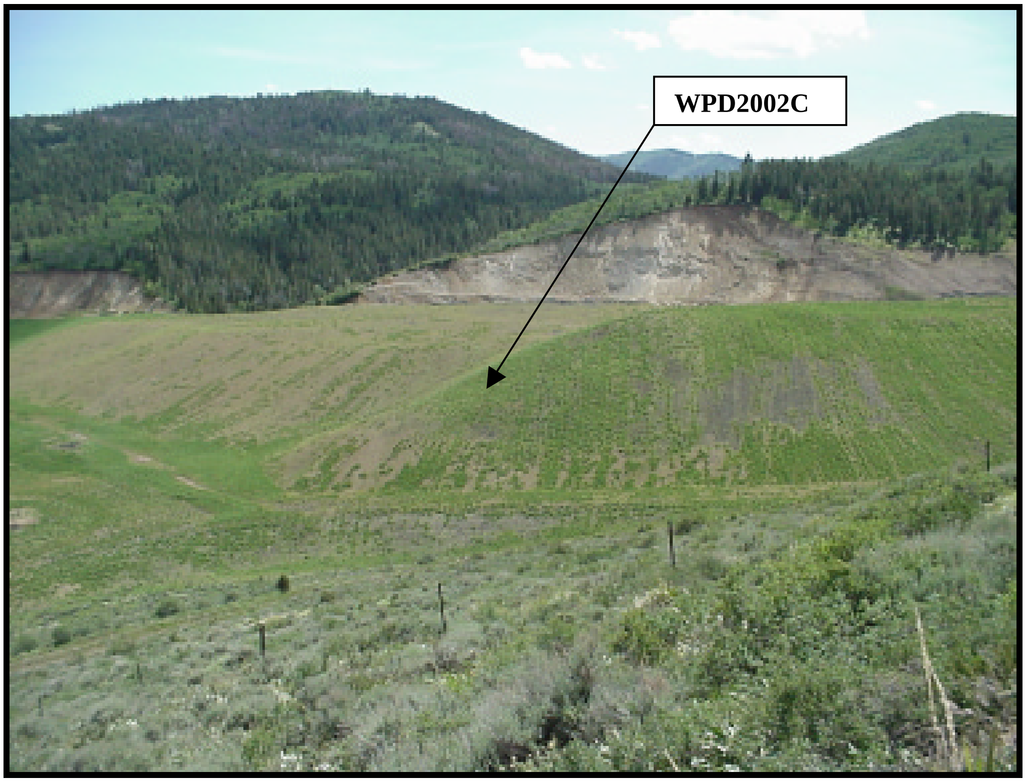

Figure 13. View west of reclaimed waste rock dump at the middle part of Mountain Fuel mine, Caribou County, Idaho, showing sample site WPD2002C.

Figure 14. View southwest of partially-reclaimed waste rock dump on the west side of the Mountain Fuel mine, Caribou County, Idaho, showing sample site WPD2003C.

Figure 15. View south of Georgetown mine, Bear Lake County, Idaho, processing plant near sample site WPQ2028C.

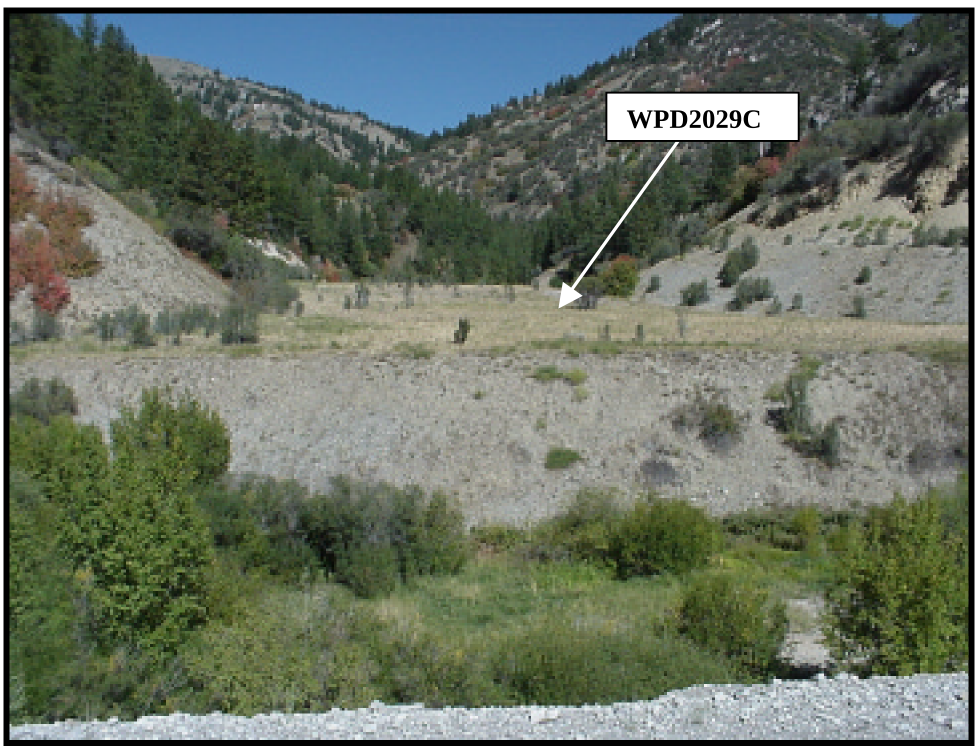

Figure 16. View north of Church Hollow tailings near Georgetown Canyon mine, Bear Lake County, Idaho, showing sample site WPD2029C.

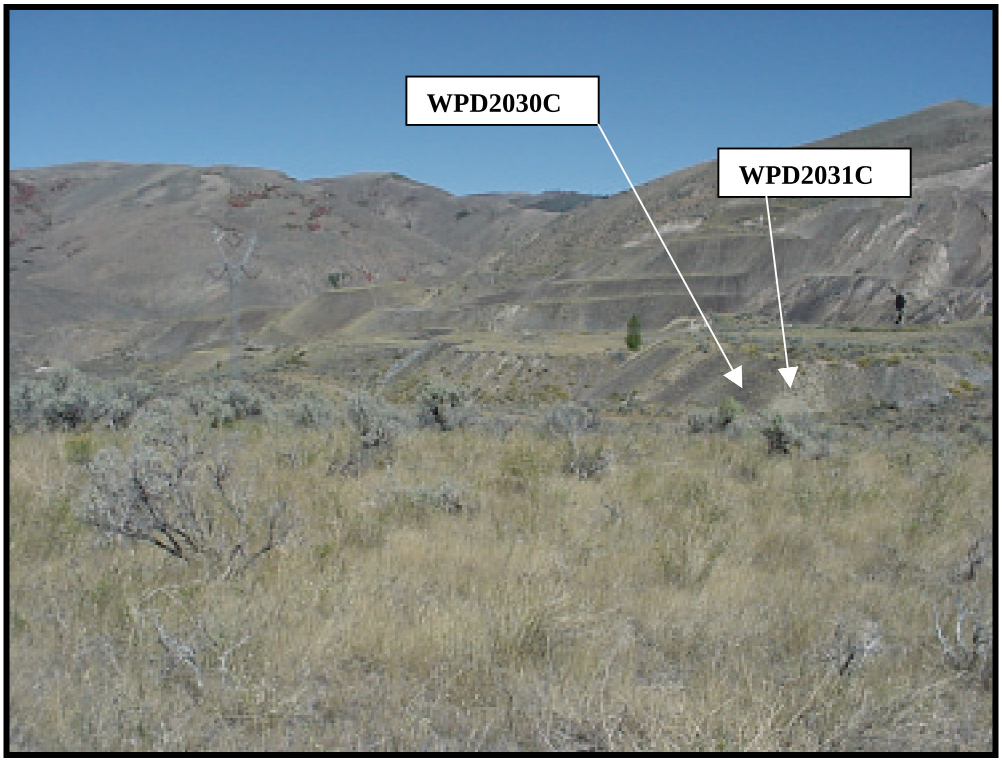

Figure 17. View north of waste rock dumps at the Waterloo mine, Bear Lake County, Idaho, showing sample sites WPD2030C (dark rock) and WPD2031C (light rock).

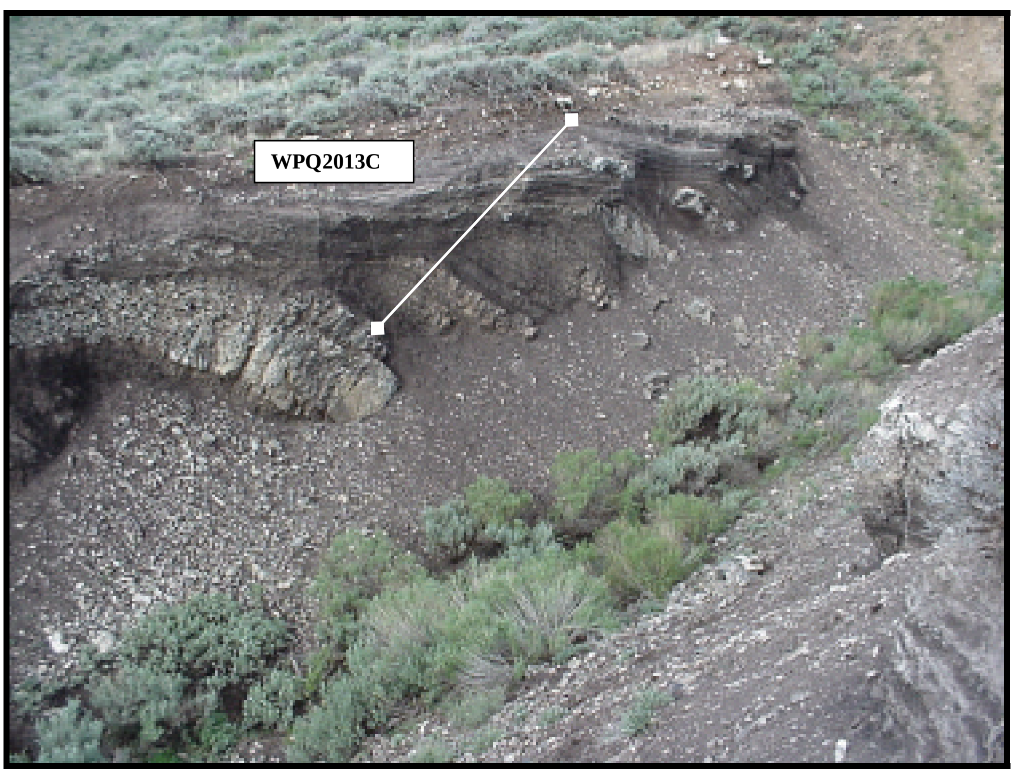

Figure 18. View southwest of sample site at Hot Springs mine, Bear Lake County, Idaho; showing sample WPQ2013C cut along line.

Figure 19. View northwest of waste rock dump at Little Diamond Creek mine, Utah County, Utah, showing sample site WPD2009C.

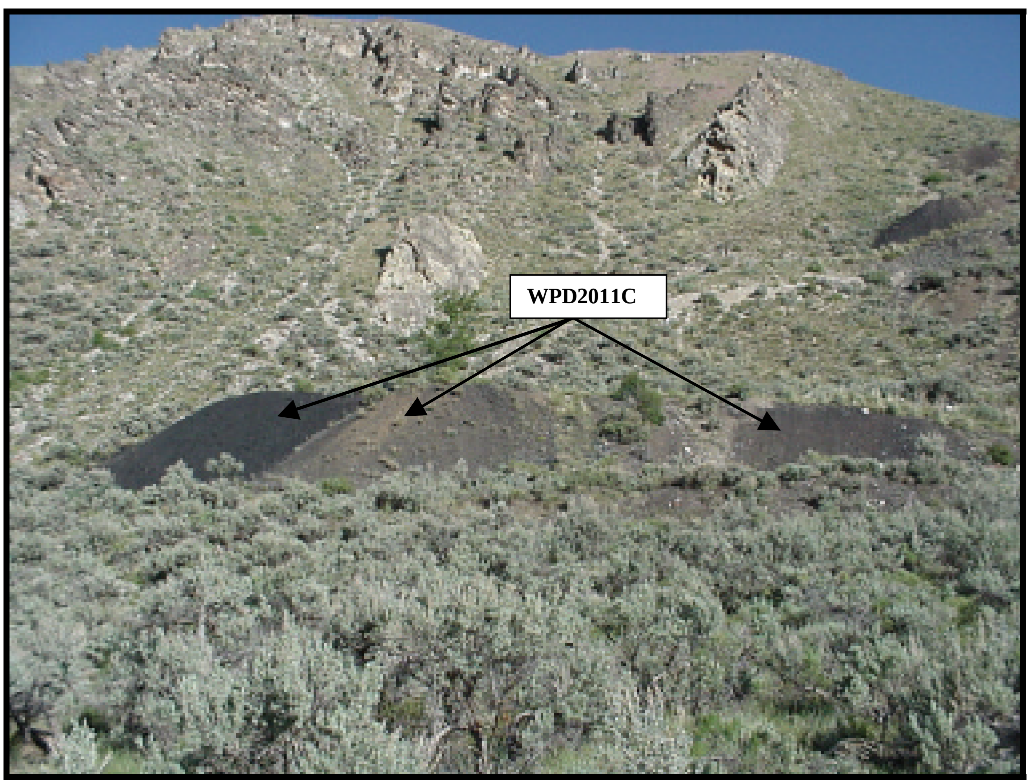

Figure 20. View north of waste rock dumps at Cokeville mine, Lincoln County, Wyoming, showing sample site WPD2011C.

Figure 21. View north of adits and dumps at Raymond Creek mine, Lincoln County, Wyoming. Sample WPD2014C collected from waste rock dump in area from which photograph is taken.

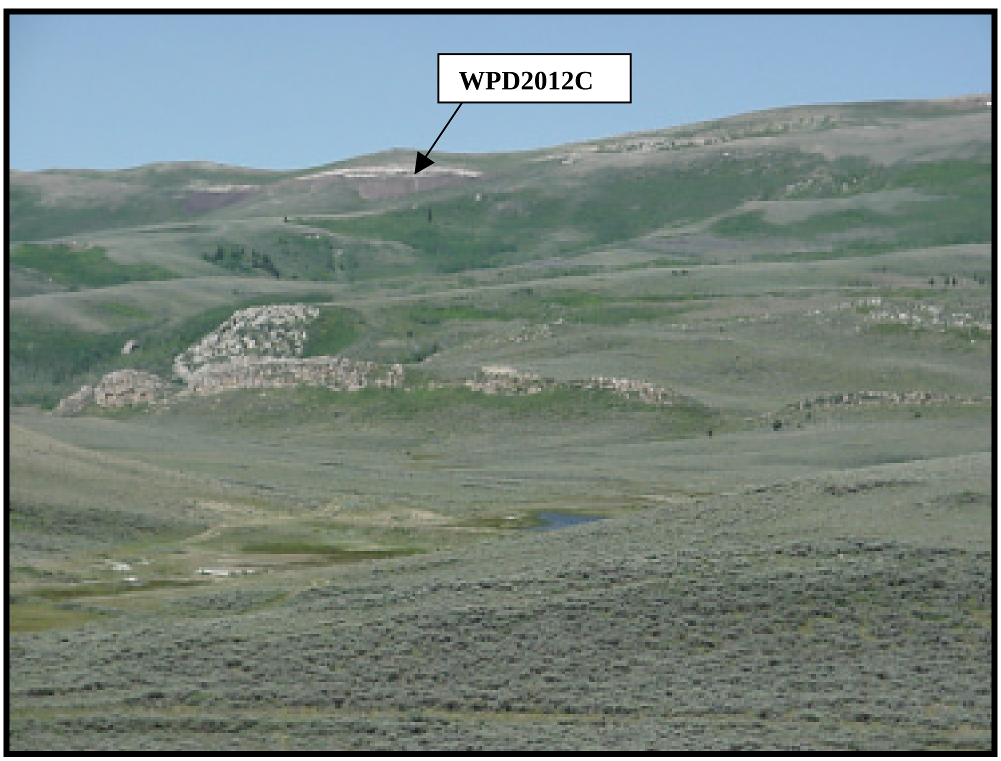

Figure 22. View west toward waste rock dump sampled at South Mountain mine, Lincoln County, Wyoming, showing sample site WPD2012C.

DISCUSSION

The analytical results for waste rock dump and other samples exhibit a wide range of element concentrations. Although the data set of 31 samples (tables A-1, A-2, A-3, and A-4) is too small for detailed statistical analysis, a summary of general observations of the chemical analyses is warranted. Several elements occur in concentrations at or below the detection limit of the analytical method. In all samples analyzed, Au, Sn, and Ta are below detection, Bi and U were detected only in one sample each, and Be is at or near detection limit (2 ppm) in all but two samples. Be was detected in the tailings (WPD2029C) and slag (WPQ2028C) samples, both of which were collected from the Georgetown Canyon mine area.

Table 2 lists reported maximum and minimum concentrations and calculated average concentrations for a suite of selected analytes for all 31 samples. Because this reconnaissance was primarily focused on waste rock dumps, table 2 lists similar data for the subset of 25 samples collected only from dumps. For comparison, the average abundance for each element in shale (Carmichael, 1989) is also included in table 2. Maximum and minimum ranges and average concentration for fourteen of the analytes from the two data sets listed in table 2 are illustrated graphically in figures 23a and 23b. The graph in figure 24 plots the average concentration of the fourteen selected analytes in the 25 waste rock dump samples normalized to that of the average abundance of each element in shale. In the 25 waste rock dump samples, only Co is significantly lower while Ce and Pb concentrations are essentially the same as that of average shale. Several elements – As, Sb, Tl, Cr, Cu, Ni, and V – are moderately elevated, ranging from 1.5 to 5.6 times those in shale. However, the average concentration of four elements in the waste rock dump samples are significantly elevated compared to their average abundance in shale – Se (x 77), Cd (x 172), Mo (x 19), and Zn (x 12).

The effect of heterogeneous lithology on the chemistry of a waste rock dump is illustrated by the analyses of two samples (WPD2030-31C) from the Waterloo mine near Montpelier, ID (figures 5 and 17). Sample WPD2030C was collected from an exposure of dark gray to black phosphatic shale whereas sample WPD2031C was collected from an exposure of iron-oxide-stained sandy shale and limestone about 15-ft away on the face of the same dump. The sandy shale and limestone sample exhibits low concentrations of As, Cd, Cr, Cu, Mo, Ni, Se, Sb, and V, and the highest concentration of Ba - distinctly different than the black shale, which contains much higher concentrations of As, Cd, Cr, Cu, Mo, Ni, Se, Sb, and V and lower Ba.

The full data set of 31 samples (figure 23a) shows a wider concentration range of certain elements compared to the 25 collected only from waste rock dumps (figure 23b). The sample of slag (WPQ2028C) exhibits a chemical composition radically different than that of unprocessed rock. The slag sample contains the highest concentration for 17 of the elements determined - Ag, Co, Cr, Cu, Eu, Fe, Ga, Mn, Mo, Nb, Ni, P, Th, Ti, V, Yb, and Zr – and the lowest concentration for 17 others - Al, C, Ca, Cd, Hg, K, La, Li, Mg, Na, S, Sc, Se, Sr, Tl, Y, and Zn. However, the extremely high temperature conditions associated with elemental phosphorus production are not typical of the natural processes that operate at the Earth’s surface, including waste rock dumps or other impoundments.

Element concentrations vary considerably because of the differing rock types and wide geographic distribution. That samples from the same waste rock dump exhibit very different chemical compositions calls attention to the caution that must be exercised when attempting to characterize a waste-rock dump.

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Table 2. Average, maximum, and minimum concentrations for selected individual and ICP-40 analytes for the 25 samples from waste-rock dumps and for all 31 samples, and average abundance of elements in shale (ppm, parts per million; %, percent; NR, not reported).

	ANALYTE, Unit of Measure	AVERAGE ABUNDANCE IN SHALE[1]	WASTE DUMP SAMPLES			ALL SAMPLES		
			AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM
INDIVIDUAL ANALYSES	**As, ppm**	6.6	**28.0**	92.8	5.6	**27.1**	92.8	5.6
	Hg, ppm	0.4	**0.4**	0.78	0.02	**0.4**	0.92	0.01
	Se, ppm	0.6	**46**	285	1.3	**42**	285	1.3
	Sb, ppm	1.5	**6.0**	24.3	0.8	**6.2**	24.3	0.8
	Tl, ppm	1	**3.0**	13.7	0.3	**3.1**	13.7	0.05
	C, %	0.1	**5.2**	10.2	1.77	**4.8**	10.2	0.47
	CO2, %	NR	**6.5**	30.2	0.36	**5.7**	30.2	0.36
	CRBNT_C, %	NR	**1.8**	8.24	0.1	**1.6**	8.24	0.1
	S, %	0.022	**0.74**	2.17	0.025	**0.74**	2.17	0.025
ICP-40 PACKAGE	**Al, %**	8	**3.33**	5.23	0.405	**3.04**	5.23	0.405
	Ca, %	2.5	**13.4**	31.7	4.16	**14.7**	31.7	1.27
	Fe, %	4.7	**1.5**	2.6	0.36	**2.4**	31.6	0.36
	K, %	2.3	**1.4**	2.04	0.25	**1.3**	2.04	0.2
	Mg, %	1.34	**1.4**	8.365	0.16	**1.1**	8.365	0.125
	Na, %	0.66	**0.5**	0.99	0.245	**0.5**	0.99	0.067
	P, %	0.077	**4.7**	12.0	0.395	**6.1**	18.5	0.395
	Ti, %	0.45	**0.1**	0.27	0.017	**0.1**	0.337	0.017
	Ag, ppm	0.1	**6**	12	1	**7**	27	1
	Ba, ppm	580	**221**	433	64	**207**	433	64
	Cd, ppm	0.3	**52**	225	3	**59**	225	1
	Ce, ppm	50	**48**	70	14	**46**	70	14
	Co, ppm	20	**4**	8	1	**7**	111	1
	Cr, ppm	100	**564**	1880	8	**1617**	30800	8
	Cu, ppm	57	**83**	230	23	**227**	4330	23
	Eu, ppm	1	**2**	8	1	**3**	9	1
	Ga, ppm	19	**15**	45	4	**19**	164	4
	Ho, ppm	1	**5**	14	2	**4**	14	2
	La, ppm	40	**115**	420	21	**125**	420	10
	Li, ppm	60	**22**	47	7	**21**	47	3
	Mn, ppm	850	**195**	1240	20	**262**	2200	20
	Mo, ppm	2	**39**	225	3	**75**	1150	3
	Nb, ppm	20	**6**	14	2	**6**	35	2
	Nd, ppm	23	**76**	249	4.5	**82**	249	4.5
	Ni, ppm	95	**180**	486	19	**408**	7280	19
	Pb, ppm	20	**14**	27	6	**15**	35	6
	Sc, ppm	10	**7**	11	1	**6**	11	1
	Sr, ppm	450	**518**	1150	175	**558**	1150	53
	Th, ppm	11	**7**	12	3	**7**	28	3
	V, ppm	130	**628**	3200	74	**1852**	35840	74
	Y, ppm	30	**155**	511	20	**170**	511	14
	Yb, ppm	3	**7**	18	2	**9**	39	2
	Zn, ppm	80	**992**	3570	118	**1030**	3570	56

(1/ Carmichael, 1989, table 71)

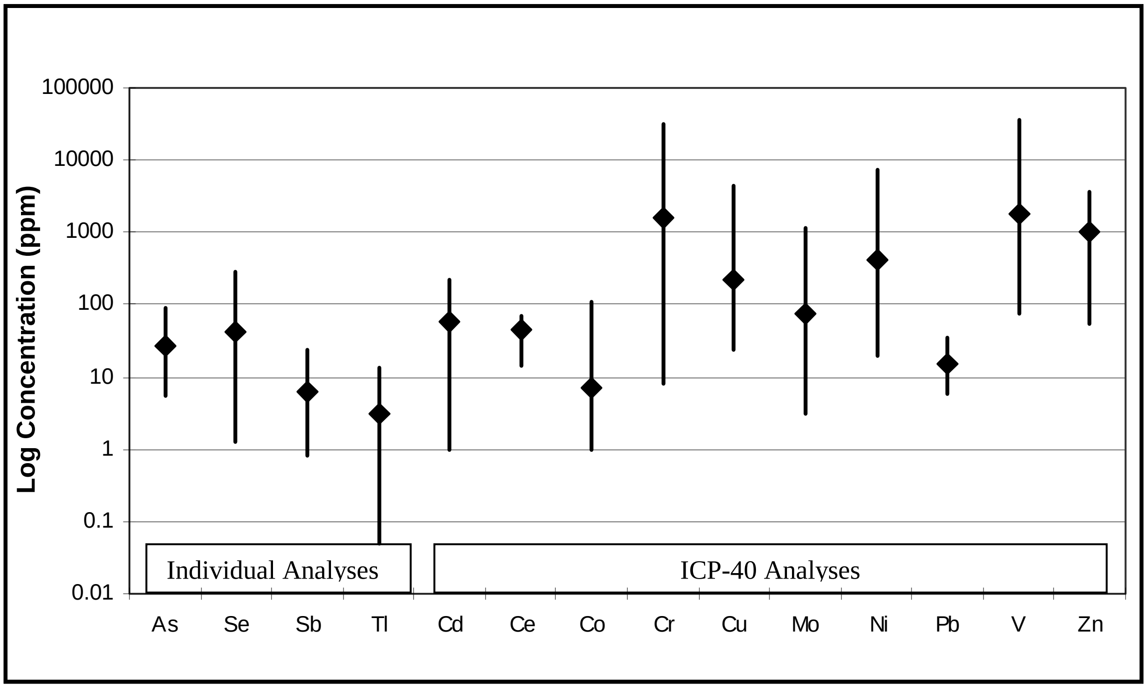

Figure 23a. Range and average concentrations of selected elements for all 31 samples analyzed (ppm = parts per million).

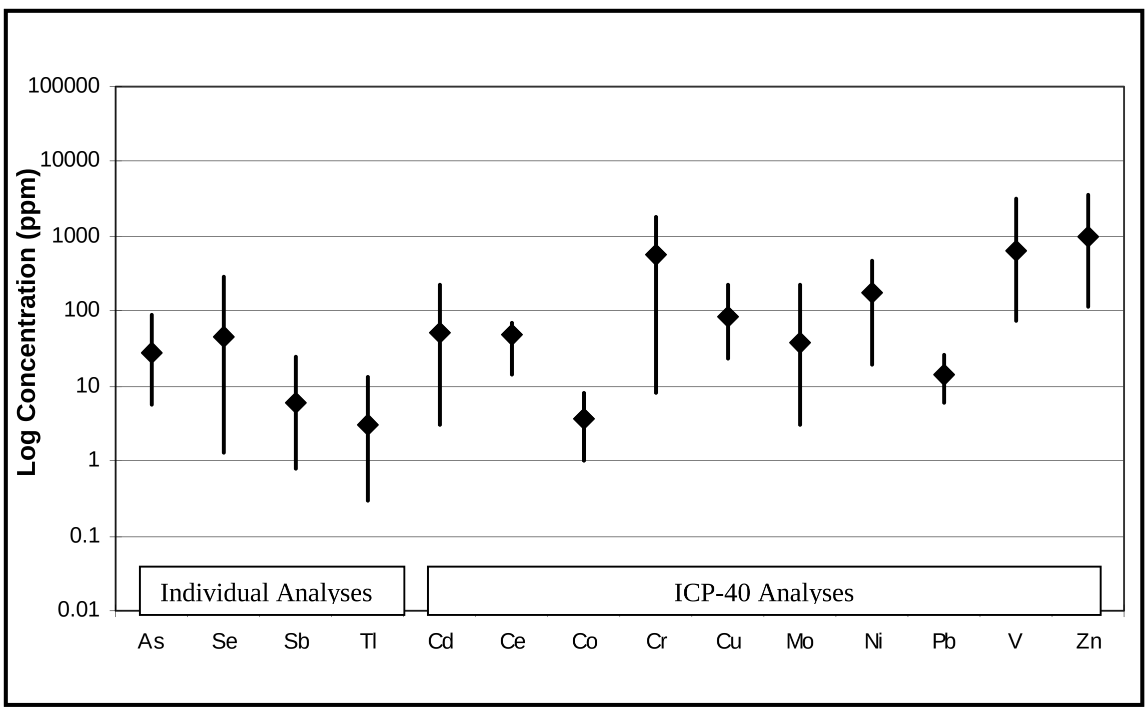

Figure 23b. Range and average concentrations of selected elements for 25 waste rock dump samples analyzed (ppm = parts per million).

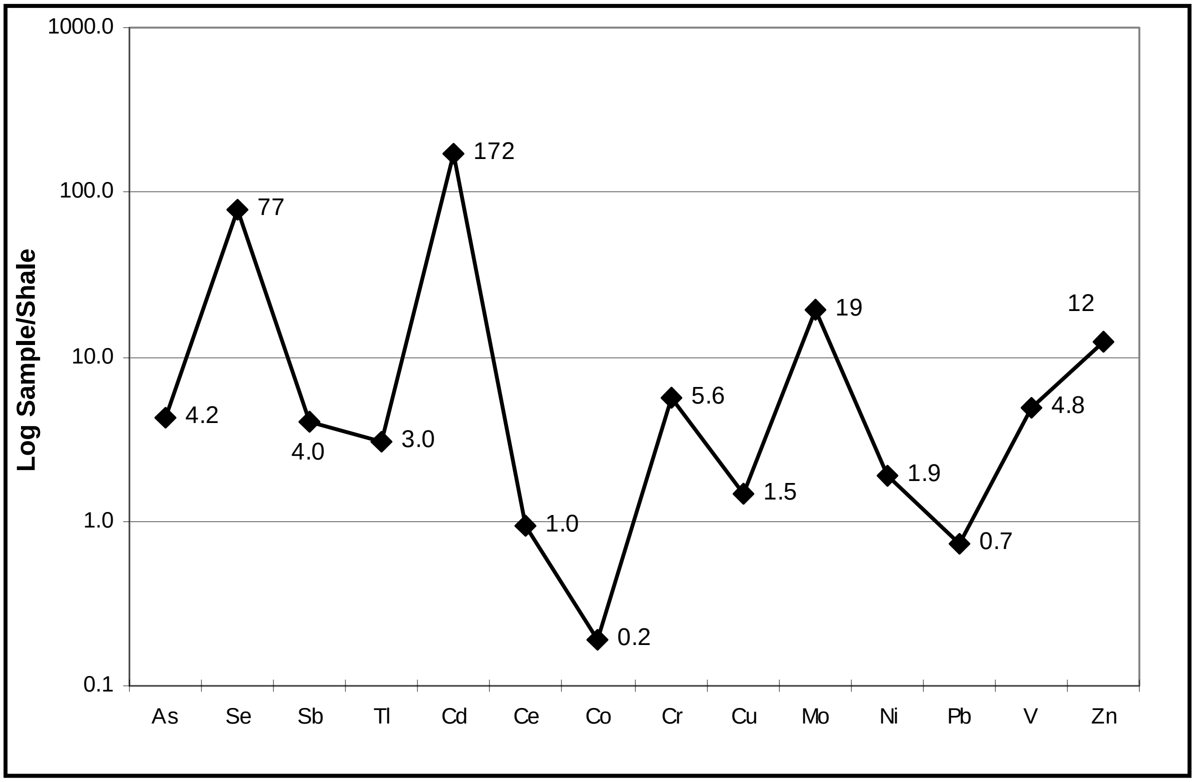

Figure 24. Graph of average concentration of selected elements for 25 waste-rock dump samples normalized to the average abundance of the elements in average world-wide shales (Carmichael, 1989, table 71).

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APPENDIX A. Data Tables

Table A-1. Sample descriptions and locations.

SAMPLE INFORMATION							LOCATION								
FIELD NUMBER	LAB NUMBER	SITE NAME	FEATURE	TYPE	LITHOLOGY	DATE	QUADRANGLE MAP	COUNTY	STATE	LON_dec	LAT_dec	TWSP	RANGE	SECTION	PARCEL
WPD2001C	C-136960	Champ Mine	waste dump	composite	black shale & limestone	06/19/99	Dry Valley	Caribou	ID	-111.2712	42.6752	9 S	44 E	2	NNE
WPD2002C	C-136961	Mountain Fuel Mine	waste dump	composite	black shale & limestone	06/19/99	Dry Valley	Caribou	ID	-111.2758	42.6399	9 S	44 E	14	NSE
WPD2003C	C-136962	Mountain Fuel Mine	waste dump	composite	black shale & limestone	06/19/99	Dry Valley	Caribou	ID	-111.2859	42.6465	9 S	44 E	14	NWNW
WPD2004C	C-136963	Diamond Gulch Mine	waste dump	composite	black shale & limestone	06/20/99	Fossil Canyon	Caribou	ID	-111.4401	42.6031	9 S	43 E	33	NENW
WPD2005C	C-136964	Ballard Mine	waste dump	composite	shale	06/21/99	Lower Valley	Caribou	ID	-111.4730	42.8359	7 S	43 E	7	NWNE
WPD2006C	C-136965	Maybe Canyon adit	waste dump	composite	black shale	06/24/99	Dry Valley	Caribou	ID	-111.2982	42.7472	8 S	44 E	10	WNE
WPD2007C	C-136966	Home Canyon Mine	waste dump	composite	black shale	06/25/99	Montpelier Canyon	Bear Lake	ID	-111.2353	42.3309	12 S	45 E	31	SWSE
WPD2008C	C-136967	Home Canyon Mine	stockpile	composite	phosphorite	06/25/99	Montpelier Canyon	Bear Lake	ID	-111.2350	42.3311	12 S	45 E	31	SWSW
WPD2009C	C-175612	Little Diamond	waste dump	composite	black shale & phosphorite	06/08/00	Billies Mountain	Utah	UT	-111.4654	40.1008	8 S	4 E	22	SE
WPD2010C	C-175613	Benjamin Mine	waste dump	composite	black shale & phosphorite	06/09/00	Rex Peak	Rich	UT	-111.0791	41.6926	11 N	8 E	18	NWSE
WPD2011C	C-175614	Cokeville Mine	stockpile	composite	shale & oolitic phosphorite	06/11/00	Cokeville	Lincoln	WY	-110.9374	42.0992	24 N	119 W	4	NENW
WPD2012C	C-175615	South Mountain Mine	waste dump	composite	black oolitic phosphorite	06/11/00	Sublet	Lincoln	WY	-110.5823	41.9813	23 N	116 W	9	SE
WPQ2013C	C-175616	Hot Springs Mine	outcrop	chip (4.5')	flat-lying organic-rich shale & phosphorite	06/13/00	Bear Lake North	Bear Lake	ID	-111.2528	42.1322	15 S	44 E	12	NWSE
WPD2014C	C-175617	Raymond Creek	waste dump	composite	black shale	06/13/00	Geneva	Lincoln	WY	-111.0217	42.2772	26 N	119 W	6	NWNE
WPD2015C	C-175618	Dry Creek - USBM adit	waste dump	composite	black shale	06/14/00	Red Top Mountain	Lincoln	WY	-110.8729	42.6886	31 N	118 W	10	NW
WPD2016C	C-175619	Rattle Snake Mine	waste dump	composite	brown-black shale	06/21/00	Fossil Canyon	Bear Lake	ID	-111.3948	42.5497	10 S	43 E	14	SWSE
WPD2017C	C-175620	Wooley Valley Mine, Unit 1	waste dump	composite	brown-black shale	06/23/00	Lower Valley	Caribou	ID	-111.3866	42.7951	7	43	24	SWSW
WPD2018C	C-175621	Henry Mine, central	waste dump	composite	gray-black shale	06/23/00	Lower Valley	Caribou	ID	-111.4764	42.8721	6	42	25	NE
WPD2019C	C-175622	Wooley Valley Mine, Unit 4, face level 5	waste dump	composite	dark brown shale	06/23/00	Lower Valley	Caribou	ID	-111.3913	42.8168	7	43	14	NE
WPD2020C	C-175623	Wooley Valley Mine, Unit 4, face level 4	waste dump	composite	brown-black shale & chert	06/23/00	Lower Valley	Caribou	ID	-111.3927	42.8183	7	43	14	NE
WPD2021C	C-175624	Wooley Valley Mine, Unit 4, face level 3	waste dump	composite	brown-black shale & chert	06/23/00	Lower Valley	Caribou	ID	-111.3945	42.8201	7	43	14	NE
WPD2022C	C-175625	Wooley Valley Mine, Unit 4, face level 2	waste dump	composite	brown shale, chert, limestone, & siltstone	06/23/00	Lower Valley	Caribou	ID	-111.3960	42.8217	7	43	14	NE

Table A-1. Sample descriptions and locations. - continued

SAMPLE INFORMATION							LOCATION								
FIELD NUMBER	LAB NUMBER	SITE NAME	FEATURE	TYPE	LITHOLOGY	DATE	QUADRANGLE MAP	COUNTY	STATE	LON_dec	LAT_dec	TWSP	RANGE	SECTION	PARCEL
WPD2023C	C-175626	Wooley Valley Mine, Unit 4, face level 1	waste dump	composite	gray-brown shale, chert, siltstone, & limestone	06/23/00	Lower Valley	Caribou	ID	-111.3966	42.8223	7	43	14	NE
WPD2024C	C-175627	Woodall Mountain Mine	waste dump	composite	gray-black shale	06/26/00	Soda Springs	Caribou	ID	-111.5094	42.7451	8	42	11	NE
WPD2025C	C-175628	Conda Mine	waste dump	composite	tan-brown shale, limestone, & pelletal phosphorite	06/26/00	Soda Springs	Caribou	ID	-111.5156	42.7214	8	42	14	SWSWSW
WPQ2026C	C-175629	Gay Mine	mill shale pile	composite	gray-black shale	06/26/00	Yandell Springs	Bannock	ID	-112.1264	43.0222	5	37	4	NWNE
WPD2027C	C-175630	Gay Mine	waste dump	composite	brown-gray shale & limestone	06/26/00	Yandell Springs	Bingham	ID	-112.1294	43.0326	4	37	33	E NW
WPQ2028C	C-175631	Georgetown Mine - plant	slag pile	select	gray, metallic	06/26/99	Harrington Peak	Bear Lake	ID	-111.2617	42.5297	10	44	25	NENW
WPD2029C	C-185794	Georgetown Canyon - Church Hollow	tailings	composite	brownish-gray, fine-grained, phosphatic shale w/ pea-sized gravel	09/12/00	Harrington Peak	Bear Lake	ID	-111.2792	42.5056	10 S	44 E	35	NESESW
WPD2030C	C-185795	Waterloo Mine	waste dump	composite	dark gray to black phosphatic shale	09/12/00	Montpelier Canyon	Bear Lake	ID	-111.2400	42.3119	13 S	45 E	7	NENW
WPD2031C	C-185796	Waterloo Mine	waste dump	composite	beige-tan fissile sandy shale and limestone w/ brown-orange iron oxide stains	09/12/00	Montpelier Canyon	Bear Lake	ID	-111.2397	42.3117	13 S	45 E	7	NENW

Table A-2. Individual and ICP-10 analyses. (C_Tot, total carbon; C_Crbt, carbonate C; ppm, parts per million; %, percent; NA = not analyzed; < = less than).

SAMPLE FIELD NUMBER	INDIVIDUAL ANALYSES										ICP-10 PACKAGE ANALYSES									
	As, ppm	Hg, ppm	Se, ppm	Sb, ppm	Te, ppm	Tl, ppm	C_Tot, %	CO2, %	C_Crbt, %	S, %	Ag, ppm	As, ppm	Au, ppm	Bi, ppm	Cd, ppm	Cu, ppm	Mo, ppm	Pb, ppm	Sb, ppm	Zn, ppm
WPD2001C	30.4	0.49	33.1	5.1	<0.1	1.7	4.16	3.33	0.91	0.50	4.2	20	0.2	3	38.3	116.0	31.3	9	5	1169.6
WPD2002C	16.2	0.20	20.6	6.3	<0.1	1.0	1.77	2.14	0.58	0.17	1.7	12	<0.1	1	21.0	62.9	7.0	11	7	435.0
WPD2003C	38.1	0.68	20.5	6.3	0.1	1.7	2.08	0.43	0.12	0.31	5.7	33	0.3	3	15.5	117.0	42.4	11	6	997.0
WPD2004C	17.6	0.33	9.4	4.5	0.1	1.5	2.83	2.93	0.80	0.43	3.3	10	0.2	3	65.7	69.0	15.2	10	4	683.0
WPD2005C	33.2	0.78	33.2	9.8	0.2	1.0	4.31	5.09	1.39	0.37	9.4	27	0.2	3	25.5	132.0	36.1	11	8	1149.0
WPD2006C	17.2	0.35	84.0	7.2	<0.1	13.7	7.81	5.73	1.56	1.70	4.3	14	0.5	9	231.0	85.7	108.0	14	7	3418.7
WPD2007C	18.3	0.25	35.8	4.3	<0.1	3.6	5.87	8.35	2.28	1.59	4.4	15	0.4	6	101.0	55.0	69.5	11	3	1768.0
WPD2008C	17.2	0.25	37.5	4.6	<0.1	4.0	5.98	7.22	1.97	1.33	4.5	14	0.4	5	99.6	54.5	57.3	10	4	1824.0
WPD2009C	28.4	0.25	3.6	5.3	NA	0.3	2.12	6.37	1.74	0.92	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2010C	13.4	0.11	32.7	2.9	NA	3.7	3.48	5.20	1.42	1.49	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2011C	42.6	0.36	77.9	6.1	NA	3.3	6.63	5.49	1.50	1.48	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2012C	36.0	0.44	51.2	11.6	NA	12.0	5.79	4.73	1.29	0.94	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPQ2013C	38.4	0.92	71.7	11.1	NA	2.1	6.98	5.39	1.47	0.79	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2014C	92.8	0.36	66.9	10.7	NA	3.4	8.13	7.52	2.05	1.49	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2015C	45.1	0.46	285.0	24.3	NA	13.6	9.35	2.90	0.79	2.07	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2016C	40.6	0.47	16.9	8.1	NA	4.0	4.81	6.84	1.87	0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2017C	32.6	0.55	147.0	8.1	NA	1.7	10.20	1.44	0.39	1.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2018C	23.6	0.31	23.5	3.2	NA	1.6	2.05	0.87	0.24	0.13	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2019C	26.5	0.36	23.2	3.3	NA	1.1	3.00	4.26	1.16	0.29	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2020C	22.2	0.36	20.7	3.9	NA	1.8	2.58	1.07	0.29	0.26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2021C	9.9	0.15	14.3	1.6	NA	1.7	9.57	30.20	8.24	0.20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2022C	24.1	0.39	19.2	4.7	NA	4.6	3.06	2.42	0.66	0.30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2023C	26.2	0.49	16.9	4.5	NA	1.5	3.35	0.36	0.10	0.31	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2024C	34.2	0.48	80.8	5.0	NA	1.7	8.32	2.56	0.70	2.17	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2025C	10.8	0.30	8.5	2.3	NA	0.8	5.78	14.30	3.90	0.59	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPQ2026C	30.0	0.75	9.0	10.3	NA	5.5	1.55	0.84	0.23	0.29	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2027C	15.8	0.13	9.1	1.8	NA	1.2	2.28	4.78	1.30	0.10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPQ2028C	14.4	<0.02	1.3	3.5	NA	<0.1	0.47	0.45	0.12	<0.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2029C	13.3	0.22	13.2	4.0	NA	1.2	3.05	4.05	1.11	0.23	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2030C	26.4	0.29	33.1	6.5	NA	0.9	6.86	15.40	4.20	0.73	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WPD2031C	5.6	0.02	1.3	0.8	NA	0.4	3.89	13.80	3.77	<0.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table A-3. ICP-16 analyses (ppm, parts per million; %, percent; < = less than; > = greater than).

SAMPLE FIELD NUMBER	ICP-16 PACKAGE ANALYSES															
	Al, %	Ca, %	Fe, %	K, %	Mg, %	Na, %	P, %	Si, %	Ti, %	Ba, ppm	Cr, ppm	Mn, ppm	Nb, ppm	Sr, ppm	Y, ppm	Zr, ppm
WPD2001C	3.37	12.90	1.62	1.43	0.56	0.60	5.05	19.80	0.23	195	1030	213	<10	537	172	170
WPD2002C	4.80	5.64	2.55	1.83	1.02	0.72	2.09	26.00	0.29	319	440	1280	<10	216	89	195
WPD2003C	4.51	9.09	2.30	1.88	0.18	0.92	3.76	23.00	0.33	242	1630	281	<10	482	193	239
WPD2004C	2.40	20.50	1.15	0.92	0.39	0.63	8.15	13.90	0.15	181	666	168	<10	560	126	66
WPD2005C	4.02	11.30	1.98	1.83	0.50	0.59	3.29	20.40	0.26	235	1900	212	14	572	138	159
WPD2006C	1.10	25.80	0.60	0.55	0.95	0.77	10.50	6.26	0.08	102	614	<100	<10	843	102	96
WPD2007C	2.18	22.30	0.99	0.73	0.62	0.42	7.32	11.00	0.16	151	648	116	<10	682	119	141
WPD2008C	1.46	26.80	0.69	0.50	0.35	0.30	9.37	7.12	0.10	93	635	146	14	863	132	89
WPD2009C	0.41	33.70	0.50	0.23	0.17	0.97	11.80	4.62	0.03	95	447	<100	<10	1130	485	72
WPD2010C	0.98	29.90	0.55	0.48	0.58	0.82	11.10	6.82	0.08	104	563	<100	<10	963	173	102
WPD2011C	1.51	25.20	0.76	0.82	0.86	0.52	9.38	7.79	0.10	96	1010	<100	<10	884	321	105
WPD2012C	4.51	7.02	1.99	1.81	1.61	0.46	1.88	23.60	0.31	339	1180	119	<10	179	119	266
WPQ2013C	2.49	20.10	1.34	1.11	0.49	0.17	7.09	11.10	0.14	179	2050	<100	<10	778	278	99
WPD2014C	3.85	11.60	1.69	1.90	1.22	0.76	2.59	19.20	0.26	223	833	256	<10	472	117	229
WPD2015C	4.78	6.73	2.21	1.94	1.00	0.51	2.05	22.20	0.33	222	1180	144	<10	197	129	268
WPD2016C	1.39	27.40	0.70	0.78	1.01	0.33	9.64	7.63	0.08	129	699	<100	<10	624	146	81
WPD2017C	3.55	11.90	1.74	1.34	0.45	0.51	4.94	18.60	0.22	195	1950	118	<10	646	248	196
WPD2018C	5.22	4.34	2.40	1.69	0.61	0.50	1.59	29.10	0.31	280	1090	311	13	240	117	247
WPD2019C	3.33	10.20	1.68	1.24	1.11	0.65	3.41	24.10	0.23	203	798	186	<10	526	143	217
WPD2020C	4.20	10.80	1.88	1.40	0.50	0.62	4.34	23.40	0.27	273	986	297	<10	482	173	252
WPD2021C	1.21	17.60	0.57	0.53	8.31	0.24	1.44	9.89	0.08	63	405	124	<10	246	56	71
WPD2022C	4.18	9.70	1.82	1.44	0.85	0.46	3.68	24.10	0.26	200	1110	255	10	468	157	221
WPD2023C	4.41	7.78	1.83	1.55	0.24	0.70	3.85	24.90	0.30	244	1370	<100	<10	766	187	301
WPD2024C	3.57	13.40	1.93	1.66	0.73	0.45	5.22	17.50	0.22	198	1270	<100	12	625	176	169
WPD2025C	1.27	24.60	0.36	0.68	3.77	0.32	7.68	6.87	0.08	84	685	<100	<10	779	143	77
WPQ2026C	3.15	19.00	1.45	1.29	0.28	0.24	7.90	16.80	0.19	243	1620	<100	12	590	298	176
WPD2027C	4.03	8.43	1.69	1.49	1.22	0.59	2.12	26.90	0.24	380	387	326	<10	281	81	282
WPQ2028C	0.50	1.36	>30	0.20	0.14	0.07	18.00	6.08	1.50	134	39630	2430	138	50	15	431
WPD2029C	3.03	14.80	1.54	1.24	0.95	0.38	4.66	18.40	0.19	200	650	569	10	533	118	142
WPD2030C	2.52	15.00	1.03	1.31	3.44	0.31	3.00	12.80	0.15	140	573	128	<10	400	126	100
WPD2031C	3.11	12.00	1.39	1.17	0.69	0.45	0.37	20.80	0.21	416	65	394	<10	193	21	102

Table A-4. ICP-40 analyses (ppm, parts per million; %, percent; < = less than).

SAMPLE FIELD NUMBER	ICP-40 PACKAGE ANALYSES																			
	Al, %	Ca, %	Fe, %	K, %	Mg, %	Na, %	P, %	Ti, %	Ag, ppm	As, ppm	Au, ppm	Ba, ppm	Be, ppm	Bi, ppm	Cd, ppm	Ce, ppm	Co, ppm	Cr, ppm	Cu, ppm	Eu, ppm
WPD2001C	3.558	12.000	1.60	1.48	0.513	0.420	4.895	0.127	5	20	<8	207	<1	<50	35	49	5	780	100	3
WPD2002C	5.067	5.834	2.60	1.91	1.002	0.575	2.195	0.222	<2	17	<8	340	<1	<50	19	51	7	290	65	2
WPD2003C	4.686	9.516	2.29	1.92	0.166	0.801	4.180	0.152	8	26	<8	275	<1	<50	15	63	8	1600	117	4
WPD2004C	2.519	20.200	1.13	1.06	0.385	0.438	8.945	0.114	4	10	<8	208	<1	<50	62	48	5	334	78	2
WPD2005C	4.239	11.300	2.01	1.89	0.499	0.447	3.700	0.152	12	19	<8	235	<1	<50	25	52	5	1880	130	3
WPD2006C	1.208	25.100	0.72	0.62	0.964	0.651	11.500	0.070	3	13	<8	122	<1	<50	225	24	3	690	102	<2
WPD2007C	2.298	22.200	0.97	0.83	0.618	0.310	8.310	0.102	3	13	<8	178	<1	<50	90	31	4	720	63	<2
WPD2008C	1.546	25.900	0.64	0.59	0.361	0.226	10.600	0.070	3	11	<8	103	<1	<50	97	25	3	738	69	<2
WPD2009C	0.405	31.700	0.46	0.25	0.160	0.990	11.900	0.017	2	11	<8	88	<1	<50	51	65	<2	304	57	8
WPD2010C	1.080	27.200	0.57	0.53	0.585	0.860	12.000	0.050	<2	18	<8	110	<1	<50	77	14	<2	370	38	2
WPD2011C	1.590	24.000	0.76	0.89	0.840	0.550	10.100	0.050	5	39	<8	103	<1	<50	94	51	<2	448	102	4
WPD2012C	4.635	6.625	1.98	1.97	1.540	0.490	1.915	0.209	7	29	<8	334	<1	<50	79	69	2	716	80	2
WPQ2013C	2.500	18.600	1.23	1.17	0.455	0.185	7.270	0.055	14	26	<8	181	<1	<50	85	43	<2	1470	221	5
WPD2014C	4.125	11.300	1.79	2.03	1.185	0.810	2.855	0.182	5	85	<8	237	<1	<50	64	51	4	942	71	2
WPD2015C	4.975	6.285	2.26	2.04	0.950	0.555	2.125	0.270	11	39	<8	242	<1	<50	186	61	3	1340	94	2
WPD2016C	1.445	24.900	0.69	0.82	1.035	0.335	10.200	0.050	5	42	<8	137	<1	<50	65	31	3	340	69	<2
WPD2017C	3.385	11.400	1.64	1.38	0.410	0.530	5.130	0.094	11	25	<8	189	<1	<50	43	61	3	555	230	4
WPD2018C	5.230	4.160	2.39	1.78	0.590	0.530	1.680	0.226	4	25	<8	287	1	<50	13	50	7	690	85	3
WPD2019C	3.380	9.760	1.75	1.33	1.045	0.685	3.745	0.121	5	21	<8	201	<1	<50	23	64	4	536	62	3
WPD2020C	4.220	10.100	1.85	1.47	0.465	0.650	4.545	0.121	7	18	<8	269	<1	<50	36	58	6	510	89	3
WPD2021C	1.325	16.700	0.56	0.57	8.365	0.245	1.570	0.044	<2	<10	<8	64	<1	<50	40	16	<2	180	34	<2
WPD2022C	4.135	9.345	1.81	1.53	0.830	0.470	3.890	0.116	8	23	<8	211	<1	<50	61	54	6	644	104	3
WPD2023C	4.445	7.285	1.80	1.60	0.220	0.715	3.955	0.138	9	18	<8	255	<1	<50	28	70	<2	677	123	3
WPD2024C	3.715	12.800	1.83	1.82	0.695	0.485	5.435	0.116	6	26	<8	208	<1	<50	17	62	4	340	93	3
WPD2025C	1.290	23.300	0.36	0.72	3.740	0.345	8.165	0.044	6	<10	<8	89	<1	<50	71	24	<2	361	72	<2
WPQ2026C	3.215	18.200	1.40	1.40	0.275	0.245	8.485	0.083	21	23	<8	255	<1	<50	145	58	<2	1210	183	5
WPD2027C	4.135	7.870	1.73	1.55	1.185	0.610	2.260	0.187	3	18	<8	388	<1	<50	17	61	6	122	40	<2
WPQ2028C	0.490	1.270	31.60	0.20	0.125	0.067	18.500	0.337	27	20	<8	121	2	52	<2	26	111	30800	4330	9
WPD2029C	3.215	14.500	1.62	1.34	0.914	0.385	5.095	0.100	3	11	<8	199	2	<50	26	43	5	330	70	<2
WPD2030C	2.720	14.800	1.12	1.43	3.444	0.325	3.280	0.095	5	29	<8	154	1	<50	26	33	<2	198	49	2
WPD2031C	3.315	11.800	1.44	1.28	0.683	0.480	0.395	0.131	<2	<10	<8	433	1	<50	3	23	5	8	23	<2

Table A-4. ICP-40 analyses (ppm, parts per million; %, percent; < = less than). - continued

SAMPLE FIELD NUMBER	ICP-40 PACKAGE ANALYSES																			
	Ga, ppm	Ho, ppm	La, ppm	Li, ppm	Mn, ppm	Mo, ppm	Nb, ppm	Nd, ppm	Ni, ppm	Pb, ppm	Sc, ppm	Sn, ppm	Sr, ppm	Ta, ppm	Th, ppm	U, ppm	V, ppm	Y, ppm	Yb, ppm	Zn, ppm
WPD2001C	13	<4	122	21	202	28	<4	77	238	7	9	<50	490	<40	9	<100	406	170	9	1150
WPD2002C	19	<4	77	32	1240	8	<4	55	88	15	10	<50	211	<40	9	<100	295	97	6	427
WPD2003C	18	<4	191	27	304	39	<4	112	297	17	11	<50	488	<40	12	<100	209	218	10	989
WPD2004C	10	<4	114	18	164	15	<4	60	118	9	5	<50	558	<40	9	<100	860	145	7	676
WPD2005C	17	<4	136	27	240	33	<4	78	334	14	11	<50	565	<40	9	<100	300	158	8	1210
WPD2006C	4	<4	91	11	37	116	<4	45	302	14	3	<50	857	<40	8	154	2590	120	6	3570
WPD2007C	10	<4	89	13	112	62	<4	45	155	10	4	<50	703	<40	<6	<100	873	143	7	1540
WPD2008C	8	<4	96	11	81	57	<4	49	151	8	<2	<50	841	<40	6	<100	1070	155	7	1650
WPD2009C	<4	14	420	7	20	7	<4	249	32	16	<2	<50	1150	<40	<6	<100	96	511	18	404
WPD2010C	6	7	105	17	31	17	<4	77	61	16	2	<50	1020	<40	<6	<100	431	188	7	907
WPD2011C	9	4	226	18	57	41	<4	137	185	17	5	<50	966	<40	<6	<100	684	344	13	1620
WPD2012C	45	5	92	29	109	101	9	69	263	21	10	<50	180	<40	9	<100	2420	127	8	1330
WPQ2013C	13	6	211	23	51	59	<4	135	289	16	8	<50	829	<40	<6	<100	891	291	13	1250
WPD2014C	25	<4	101	26	242	68	7	77	217	19	8	<50	521	<40	6	<100	891	124	6	1150
WPD2015C	27	5	115	47	139	225	11	78	486	27	10	<50	205	<40	10	<100	3200	142	9	2960
WPD2016C	9	6	118	13	81	33	<4	81	150	12	3	<50	656	<40	<6	<100	682	156	7	1110
WPD2017C	12	5	184	26	98	47	5	125	243	15	8	<50	652	<40	7	<100	353	261	11	926
WPD2018C	16	5	90	34	292	14	14	67	192	14	10	<50	250	<40	8	<100	200	124	7	646
WPD2019C	12	5	117	13	175	22	6	83	161	12	7	<50	564	<40	7	<100	198	154	7	771
WPD2020C	15	9	114	24	280	21	9	86	187	17	9	<50	509	<40	6	<100	329	181	9	816
WPD2021C	20	<4	42	8	121	9	<4	41	117	6	2	<50	258	<40	<6	<100	194	61	3	714
WPD2022C	16	6	104	26	266	25	9	75	257	16	9	<50	505	<40	7	<100	633	171	8	1580
WPD2023C	16	5	133	19	28	12	10	82	107	18	10	<50	794	<40	7	<100	282	204	9	440
WPD2024C	15	6	146	23	61	41	8	94	214	15	10	<50	667	<40	<6	<100	243	188	9	816
WPD2025C	12	5	114	11	79	7	<4	86	97	11	3	<50	815	<40	<6	<100	542	153	7	612
WPQ2026C	16	7	231	26	81	14	<4	148	129	20	7	<50	642	<40	<6	<100	1620	317	15	986
WPD2027C	15	6	77	22	309	6	10	54	66	18	6	<50	300	<40	10	<100	207	86	5	351
WPQ2028C	164	<4	10	3	2200	1150	35	88	7280	10	<2	<50	53	<40	28	<100	35840	14	39	56
WPD2029C	9	<4	90	32	536	15	<4	41	94	35	6	<50	491	<40	9	<100	516	122	7	403
WPD2030C	6	<4	101	15	119	28	<4	44	133	7	5	<50	372	<40	11	<100	289	127	7	737
WPD2031C	7	<4	21	24	371	3	4	<9	19	13	5	<50	175	<40	8	<100	74	20	2	118

APPENDIX B. Metadata

Identification_Information:
  Citation:
    Citation_Information:
      Originator: Phillip R. Moyle and J. Douglas Causey
      Publication_Date: 2001
      Title: Chemical Composition of Samples Collected from Waste Rock Dumps and Other Mining-Related Features at Selected Phosphate Mines in Southeastern Idaho, Western Wyoming, and Northern Utah
      Edition: 1
      Geospatial_Data_Presentation_Form: map
      Series_Information:
        Series_Name: Open File Report
        Issue_Identification: OF 01-411
      Publication_Information:
        Publication_Place: Menlo Park, CA
        Publisher: U. S. Geological Survey
      Online_Linkage: http://geopubs.wr.usgs.gov/open-file/of01-411
  Description:
    Abstract:
      This text file contains chemical analyses for 31 samples collected from various phosphate mine
      sites in southeastern Idaho (25), northern Utah (2), and western Wyoming (4).
    Purpose:
      The sampling effort was undertaken as a reconnaissance and does not constitute a characterization of mine
      wastes. Twenty-five samples were collected from waste rock dumps, 2 from stockpiles, and 1 each from slag, tailings, mill shale, and an outcrop. All samples were analyzed for a suite of major, minor, and trace elements.
  Time_Period_of_Content:
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 2001
    Currentness_Reference: publication date
  Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: None planned
  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -112.1294
      East_Bounding_Coordinate: -110.5823
      North_Bounding_Coordinate: 43.0326
      South_Bounding_Coordinate: 40.1008
  Keywords:

Theme:
Theme_Keyword_Thesaurus: None.
Theme_Keyword: chemical analysis
Theme_Keyword: ICP
Theme_Keyword: Phosphate
Theme_Keyword: Sample
Theme_Keyword: mine waste
Place:
Place_Keyword_Thesaurus: None
Place_Keyword: Idaho
Place_Keyword: Utah
Place_Keyword: Wyoming
Place_Keyword: Rich County
Place_Keyword: Caribou County
Place_Keyword: Bear Lake County
Place_Keyword: Bingham County
Place_Keyword: Bannock County
Place_Keyword: Lincoln County
Place_Keyword: Utah County
Access_Constraints: None
Use_Constraints:
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Country: USA
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Contact_Electronic_Mail_Address: pmoyle@usgs.gov
Native_Data_Set_Environment: Microsoft Windows 2000 Version 5.0 (Build 2195) Service Pack 2; ESRI ArcCatalog 8.1.1.649

Data_Quality_Information:
  Attribute_Accuracy:
    Attribute_Accuracy_Report:
      Attribute accuracy was verified by manual comparison of the
          source with topographic maps
  Logical_Consistency_Report: Longitude and latitude information is unique location for each point
  Completeness_Report: All data created by this project
  Positional_Accuracy:
    Horizontal_Positional_Accuracy:
      Horizontal_Positional_Accuracy_Report: +- 10 meters
  Lineage:
    Process_Step:
      Process_Description: Data reported on spreadsheet was copied and pasted to text file.
      Process_Date: 2001
      Process_Contact:
        Contact_Information:
          Contact_Person_Primary:
            Contact_Person: J. Douglas Causey
            Contact_Organization: U.S. Geological Survey
          Contact_Position: Geologist
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            Address_Type: mailing and physical address
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            City: Spokane
            State_or_Province: WA
            Postal_Code: 99201-1087
            Country: USA
          Contact_Voice_Telephone: 509.368.3116
          Contact_Facsimile_Telephone: 509.368.3199
          Contact_Electronic_Mail_Address: dcausey@usgs.gov
          Hours_of_Service: 8-4 PST
Spatial_Reference_Information:
  Horizontal_Coordinate_System_Definition:
    Geodetic_Model:
      Horizontal_Datum_Name: North American Datum of 1927
Entity_and_Attribute_Information:
  Overview_Description:
    Entity_and_Attribute_Overview:
      The columns and their definitions are listed below. All values that were less than (<) were converted to minus (-).
Samples were processed by several methods. As a result, there was duplication of analyses for some elements.

Rock samples were air dried followed by disaggregation in a mechanical jaw crusher. A split was ground to <100 mesh (0.15 mm) in a ceramic plate grinder. A riffle splitter was used to obtain splits to ensure similarity with the whole sample. One set of splits for all samples was archived, and approximately 50-g splits of ground material was shipped to the contract laboratory for analysis.

Forty major, minor, and trace elements were determined for all 31 samples by inductively coupled
plasma-atomic emission spectrometry (ICP-AES), also referred to as the ICP-40 package, after low-temperature (<150oC) digestion using concentrated hydrochloric, hydrofluoric, nitric, and perchloric acids (Crock and others, 1983).

Splits of all samples were also submitted to a contract laboratory for analysis of 16 major, minor, and trace elements (Al, Ba, Ca, Cr, Fe, Mg, Mn, Nb, P, K, Si, Na, Sr, Ti, Y, Zr) by ICP-AES
using a lithium metaborate fusion. This technique, also referred to as the ICP-16 package, was used especially to provide analysis of silicon (Si) for these siliceous, phosphatic shale samples. The samples were fused with lithium metaborate in a graphite crucible. In-house standards, and synthetic standards were used to calibrate the instrument. Sample solutions were aspirated into the ICP through a high-solids nebulizer, and metal concentrations were measured simultaneously. Selenium, arsenic, and antimony analyses were accomplished using hydride generation followed by atomic absorption (AA) spectroscopy. Tellurium and thallium were determined using AA graphite furnace spectroscopy. Total sulfur and the various forms of carbon were determined using a LECO furnace followed by gas chromatographic measurement.

Eight samples were also submitted for a 10- element ICP-AES technique, also referred to as ICP-10, for determination of Ag, As, Au, Bi, Cd, Cu, Mo, Pb, Sb, and Zn. Hydrochloric acidhydrogen peroxide were used to solubilize metals not tightly bound in the silicate lattice of rocks, and metals are extracted as organic halides. Concentrations of the extracted metals were determined simultaneously after aspiration into a multichannel ICP instrument. This procedure is a partial digestion and results may be biased low when compared to procedures involving complete dissolution of the sample.

SEQ_NO -Unique sequence number
LAB_NO -Laboratory number
SAMPLE_NO -Field sample number
DATE_COLL -Date sample collected
SAMP_TYPE -Type of sample taken
FEAT_SAMP -Mine feature sampled
LITHOLOGY -Rock type sampled
SITE_NAME -Name of mine or property where sample collected
QUAD_MAP -U.S. Geological Survey 7.5' Topographic map upon which site is located
COUNTY -County
STATE -State
LONGITUDE -Longitude of sample taken with GPS
LATITUDE -Latitude of sample taken with GPS
MERIDIAN -Meridian
TWSP -Township

RANGE -Range
SECTION -Section
PARCEL -Fractional part of section
As_Hyd_ppm -Arsenic in parts per million analyzed by hydride generation-atomic absorption spectrometry
Hg_CVA_ppm -Mercury in parts per million analyzed by cold vapor atomic absorption
Se_Hyd_ppm -Selenium in parts per million analyzed by hydride generation-atomic absorption spectrometry
Sb_Hyd_ppm -Antimony in parts per million analyzed by hydride generation-atomic absorption spectrometry
Te_Hyd_ppm -Tellurium in parts per million analyzed by hydride generation-atomic absorption spectrometry
Tl_Hyd_ppm -Thallium in parts per million analyzed by hydride generation-atomic absorption spectrometry
C_Tot_pct -Carbon in percent analyzed by combustion in an oxygen atmosphere followed by infrared measurement of evolved CO2
CO2_Ac_pct -Carbon dioxide in percent evolved after acidification
C_Crbt_pct -Carbonate (inorganic) carbon in percent analyzed by coulometric titration after acidification
S_Tot_pct -Sulfur in percent analyzed by combustion in an oxygen atmosphere followed by infrared measurement of evolved SO2
Ag_10_ppm -Silver in parts per million analyzed by 10 element method
As_10_ppm -Arsenic in parts per million analyzed by 10 element method
Au_10_ppm -Gold in parts per million analyzed by 10 element method
Bi_10_ppm -Bismuth in parts per million analyzed by 10 element method
Cd_10_ppm -Cadmium in parts per million analyzed by 10 element method
Cu_10_ppm -Copper in parts per million analyzed by 10 element method
Mo_10_ppm -Molybdenum in parts per million analyzed by 10 element method
Pb_10_ppm -Lead in parts per million analyzed by 10 element method
Sb_10_ppm -Antimony in parts per million analyzed by 10 element method
Zn_10_ppm -Zinc in parts per million analyzed by 10 element method
Al_16_pct -Aluminum in percent analyzed by 16 element method
Ca_16_pct -Calcium in percent analyzed by 16 element method
Fe_16_pct -Iron in percent analyzed by 16 element method
K_16_pct -Potassium in percent analyzed by 16 element method
Mg_16_pct -Magnesium in percent analyzed by 16 element method
Na_16_pct -Sodium in percent analyzed by 16 element method
P_16_pct -Phosphorous in percent analyzed by 16 element method
Si_16_pct -Silicon in percent analyzed by 16 element method
Ti_16_pct -Titanium in percent analyzed by 16 element method
Ba_16_ppm -Barium in parts per million analyzed by 16 element method
Cr_16_ppm -Chromium in parts per million analyzed by 16 element method
Mn_16_ppm -Manganese in parts per million analyzed by 16 element method
Nb_16_ppm -Niobium in parts per million analyzed by 16 element method
Sr_16_ppm -Strontium in parts per million analyzed by 16 element method
Y_16_ppm -Yittrium in parts per million analyzed by 16 element method

Zr_16_ppm -Zirconium in parts per million analyzed by 16 element method
Al_40_pct -Aluminum in percent analyzed by 40 element method
Ca_40_PCT -Calcium in percent analyzed by 40 element method
Fe_40_pct -Iron in percent analyzed by 40 element method
K_40_pct -Potassium in percent analyzed by 40 element method
Mg_40_pct -Magnesium in percent analyzed by 40 element method
Na_40_pct -Sodium in percent analyzed by 40 element method
P_40_pct -Phosphorous in percent analyzed by 40 element method
Ti_40_pct -Titanium in percent analyzed by 40 element method
Ag_40_ppm -Silver in parts per million analyzed by 40 element method
As_40_ppm -Arsenic in parts per million analyzed by 40 element method
Au_40_ppm -Gold in parts per million analyzed by 40 element method
Ba_40_ppm -Barium in parts per million analyzed by 40 element method
Be_40_ppm -Beryllium in parts per million analyzed by 40 element method
Bi_40_ppm -Bismuth in parts per million analyzed by 40 element method
Cd_40_ppm -Cadmium in parts per million analyzed by 40 element method
Ce_40_ppm -Cerium in parts per million analyzed by 40 element method
Co_40_ppm -Cobalt in parts per million analyzed by 40 element method
Cr_40_ppm -Chromium in parts per million analyzed by 40 element method
Cu_40_ppm -Copper in parts per million analyzed by 40 element method
Eu_40_ppm -Europium in parts per million analyzed by 40 element method
Ga_40_ppm -Gallium in parts per million analyzed by 40 element method
Ho_40_ppm -Holmium in parts per million analyzed by 40 element method
La_40_ppm -Lanthanium in parts per million analyzed by 40 element method
Li_40_ppm -Lithium in parts per million analyzed by 40 element method
Mn_40_ppm -Manganese in parts per million analyzed by 40 element method
Mo_40_ppm -Molybdenum in parts per million analyzed by 40 element method
Nb_40_ppm -Niobium in parts per million analyzed by 40 element method
Nd_40_ppm -Neodymium in parts per million analyzed by 40 element method
Ni_40_ppm -Nickel in parts per million analyzed by 40 element method
Pb_40_ppm -Lead in parts per million analyzed by 40 element method
Sc_40_ppm -Scandium in parts per million analyzed by 40 element method
Sn_40_ppm -Tin in parts per million analyzed by 40 element method
Sr_40_ppm -Strontium in parts per million analyzed by 40 element method
Ta_40_ppm -Tantalum in parts per million analyzed by 40 element method
Th_40_ppm -Thorium in parts per million analyzed by 40 element method
U_40_ppm -Uranium in parts per million analyzed by 40 element method
V_40_ppm -Vanadium in parts per million analyzed by 40 element method
Y_40_ppm -Yittrium in parts per million analyzed by 40 element method
Yb_40_ppm -Ytterbium in parts per million analyzed by 40 element method
Zn_40_ppm -Zirconium in parts per million analyzed by 40 element method

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Digital_Form:
Digital_Transfer_Information:
Format_Name: ASCII
Format_Version_Number: 1
File_Decompression_Technique: no compression applied
Digital_Transfer_Option:
Online_Option:
Computer_Contact_Information:
Network_Address:
Network_Resource_Name: http://geopubs.wr.usgs.gov/open-file/of01-411
Fees: None
Ordering_Instructions: Web only publication
Metadata_Reference_Information:
Metadata_Date: 20020103
Metadata_Future_Review_Date: None
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: U.S. Geological Survey

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Contact_Facsimile_Telephone: 509.368.3199
Contact_Electronic_Mail_Address: dcausey@usgs.gov
Hours_of_Service: 8-4 PST
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Access_Constraints: None
Metadata_Use_Constraints: None