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CHEMICAL COMPOSITION OF SELECTED SOLID-PHASE SAMPLES FROM THE SNAKE RIVER PLAIN AQUIFER SYSTEM AND CONTRIBUTING DRAINAGES, EASTERN IDAHO AND WESTERN WYOMING

U.S. GEOLOGICAL SURVEY
OPEN-FILE REPORT 01-36

Prepared in cooperation with the U.S. DEPARTMENT OF ENERGY

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Chemical Composition of Selected Solid-Phase Samples from the Snake River Plain Aquifer System and Contributing Drainages, Eastern Idaho and Western Wyoming

By LeRoy L. Knobel, L. DeWayne Cecil, Shenean Fisher, and Jaromy R. Green

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CONVERSION FACTORS AND ABBREVIATED UNITS

Multiply	By	To obtain
centimeter per year (cm/yr)	0.394	inch per year
gram (g)	0.035	ounce
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
milligram (mg)	0.000035	ounce
milliliter (mL)	0.000264	gallon
square meter per day (m^2/d)	10.76	square foot per day
square kilometer (km^2)	0.386	square mile
degree Celsius (°C)	[°C (9/5) + 32]	degree Fahrenheit (°F)

Other abbreviated units used in report: (n/cm^2)/s (neutrons per square centimeter per second); ppm (part per million); n (neutron).

Chemical Composition of Selected Solid-Phase Samples from the Snake River Plain Aquifer System and Contributing Drainages, Eastern Idaho and Western Wyoming

by LeRoy L. Knobel, L. DeWayne Cecil, Shenean Fisher, and Jaromy R. Green

Abstract

This report presents chemical compositions determined from 25 solid-phase samples from the eastern Snake River Plain aquifer system and contributing drainages. Seven samples were collected at selected depths from 6 coreholes located on or near the Idaho National Engineering and Environmental Laboratory, Idaho, and from 18 outcrops in the recharge areas of the Snake River Plain aquifer. This report was prepared by the U.S. Geological Survey, in cooperation with the U.S. Department of Energy, Idaho Operations Office.

Ten major elements, as many as 28 trace elements, and the amount of volatile material were determined for each sample by inductively coupled plasma-atomic emission spectroscopy, instrumental neutron activation analysis, loss on ignition, or ion-selective electrode potentiometry.

INTRODUCTION

The Idaho National Engineering and Environmental Laboratory (INEEL), which encompasses about 2,300 km^2 of the eastern Snake River Plain in southeastern Idaho (fig. 1), is operated by the U.S. Department of Energy (DOE). INEEL facilities are used in the development of peacetime atomic-energy applications, nuclear safety research, defense programs, and advanced energy concepts. Liquid radiochemical and chemical wastes generated at these facilities have been discharged to onsite infiltration ponds and disposal wells since 1952. Many of the waste constituents enter the Snake River Plain aquifer indirectly following percolation through the unsaturated zone (Pittman and others, 1988, p. 2)

In 1949, the U.S. Atomic Energy Commission—now the U.S. DOE—requested that the U.S. Geological Survey (USGS) investigate the geohydrologic conditions at the INEEL and adjacent areas before the beginning of reactor operations. Ongoing research by the USGS at the INEEL involves investigation of the migration of radioactive elements contained in low-level radioactive waste, hydrologic and geologic factors affecting waste movement, and geochemical factors that influence the chemical composition of the waste. Identification of the solid-phase chemistry of Snake River Plain aquifer and recharge-area materials is needed to aid in the study of the hydrology and geochemistry of subsurface waste disposal. This report was prepared by the USGS in cooperation with the DOE, Idaho Operations Office. Idaho State University (ISU) provided analytical services for this study.

Purpose and Scope

The purpose of this report is to provide a public record of information describing the chemical composition of geologic materials from the Snake River Plain aquifer and from its recharge areas. This report (1) presents the major- and trace-element composition of 25 solid-phase samples of basalt or rhyolite core from 6 sites and of rock samples from 18 outcrops (fig. 1), and (2) describes the methods used to analyze the samples.

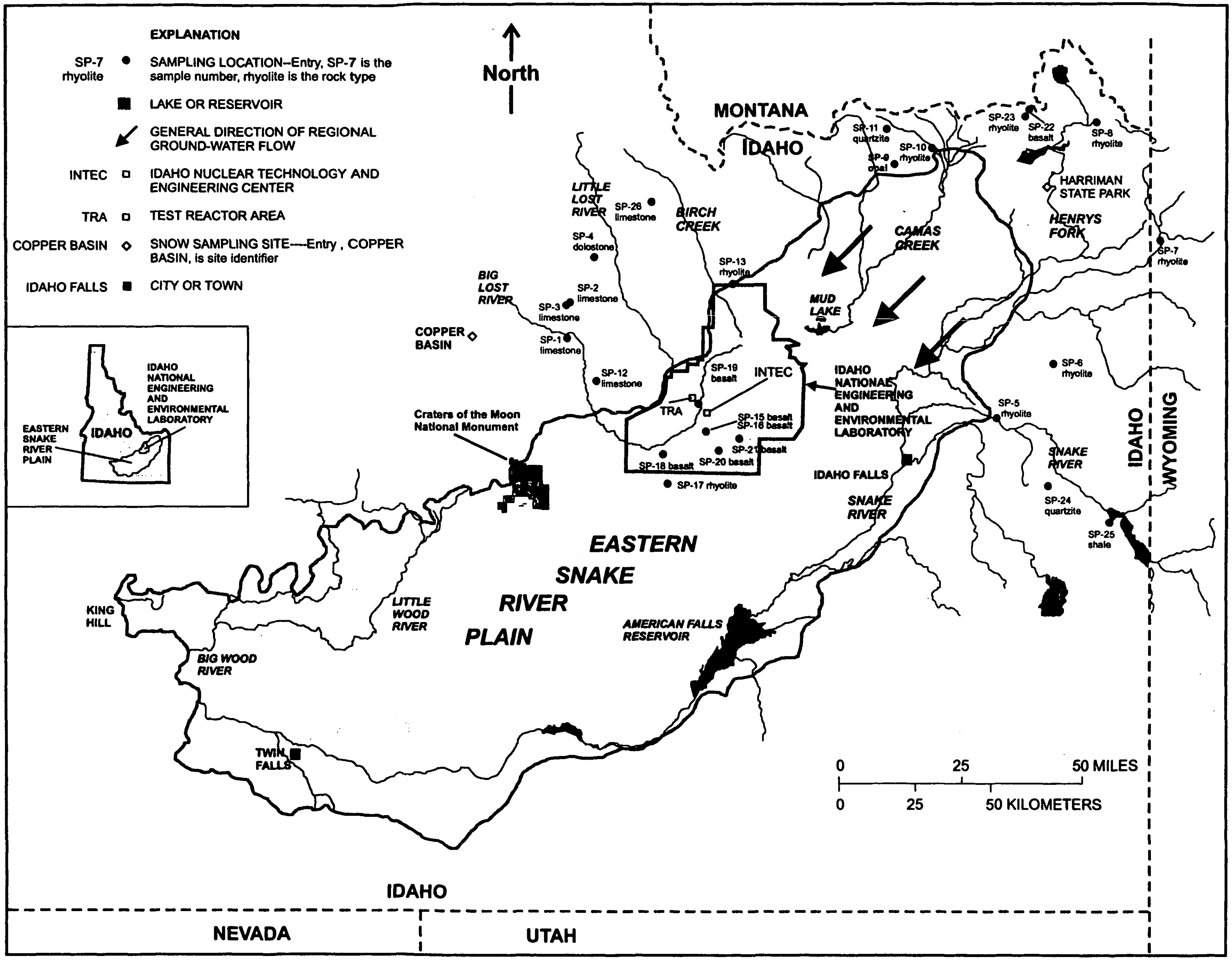

Figure 1.—Location of the eastern Snake River Plain, the Idaho National Engineering and Environmental Laboratory, and selected sampling sites

Geohydrology of the Study Area

The eastern Snake River Plain (fig. 1) is a structural downwarp (basin) filled predominantly with Quaternary basalt of the Snake River Group that is generally within 3 m of the land surface (Garabedian, 1992; Whitehead, 1992). This structural basin, defined by faulting and downwarping on the southeast and faulting on the northwest, was created by Cenozoic tectonic stresses and is a zone of transition between the Northern Rocky Mountains and Basin and Range geologic provinces to the north and east, and the Basin and Range province to the southeast. Unconsolidated sediments overlie the margins of the basin and are interbedded with the basalts and pyroclastics at depth. The basalts are several hundred to as much as 1,500 m thick and underlie most of the basin. Fractures and vesicular zones near the surfaces of the basalt flows may be highly transmissive of ground water. Reported transmissivities for the eastern Snake River Plain aquifer range from 0.1 to more than 70,000 m^2/d, a range of nearly six orders of magnitude (Ackerman, 1991). Depth to water at the INEEL varies in the basalt aquifer from about 60 m below land surface in the northern part to more than 275 m in the southern part. The hydraulic gradient at the INEEL is about 1 m/km, and horizontal linear ground-water flow velocity ranges from 1 to 6 m/day. This range is based on the distribution of chlorine-36 (^{36}Cl) through time as determined from analyses of archived samples (Cecil, Welhan, and others, 2000).

Long-term (1950–88) average precipitation in the vicinity of the INEEL is 22 cm/yr (Clawson and others, 1989, table D–1). About 40 percent of the long-term average precipitation on the eastern Snake River Plain is rainfall between April and September. However, as a result of evapotranspiration, less than 5 percent of the long-term annual average precipitation infiltrates the surface locally on the eastern Snake River Plain (Cecil and others, 1992). Recharge to the eastern Snake River Plain aquifer is from snowmelt in the mountains to the east, west, and north, and from irrigation return flow and surface water. The five watersheds that recharge the upper Snake River Plain aquifer are the Big Lost River, Little Lost River, Birch Creek, Camas Creek/Mud Lake, and the main Snake River drainage (fig. 1).

In this report, the solid-phase (rock) samples are designated SP, and their locations are shown on figure 1. In addition, sample-collection data and the geochemistry of the SP samples are described in tables 1, 2, and 3. The basalt flows that compose most of the Snake River Plain are in layers of only a few meters thick and cover areas of tens to hundreds of square kilometers. Samples SP-15, SP-16, SP-18, SP-19, SP-20, and SP-21 are representative of younger basalts on the eastern Snake River Plain (tables 2 and 3). Large-scale basalt flows, such as those in Oregon and Washington, have not been found in the Snake River Plain. The most recent volcanic eruptions on the Snake River Plain were at the Craters of the Moon National Monument (fig. 1) around 2,000 years ago (Kuntz and others, 1988). Sample SP-22 is a basalt sample that likely is related to Island Park volcanic activity.

Volcanism produced relatively thick flows of welded tuff, ash, and pumice that are exposed within and near the margins of the basin and are composed largely of rhyolite, latite, and andesite. The rhyolitic tuffs and rhyolite in this group are represented by samples SP-5, SP-6, SP-7, SP-8, SP-9 (opal contained in a rhyolitic welded tuff), SP-10, SP-13, SP-17, and SP-23 (tables 2 and 3). Subsequent basalt volcanism over the basin was limited predominantly to outpourings of pahoehoe lava (Nace and others, 1975). Some eruptions, however, such as the ones near Craters of the Moon, were violent enough to create pyroclastic rocks and significant deposits of cinders. Pre-Cretaceous sedimentary and metamorphic rocks border the basin to the northwest and east and are represented in this study by samples SP-1, SP-2, SP-3, SP-4, SP-11, SP-12, SP-24, SP-25, and SP-26 (tables 2 and 3). Of the six rock types studied, basalt and rhyolite compose most of the aquifer on the plain, and limestone and dolostone, with minor amounts of shale, quartzite, medasediments, and basalt, compose the recharge areas to the north, west, and east.

Previous Investigations

Geologic, hydrologic, and water-quality investigations have been conducted at the INEEL since it was selected as a reactor-testing station in 1949. Nace and others (1956; 1975) reported major rock-forming element and selected trace-element chemistry of a basalt sample from Craters of the Moon National Monument and a nephelite basalt sample from the Fort Hall Indian Reservation. Jones (1961) reported the average composition of major rock-forming elements in 38 basalt samples from the Snake River Plain. The data of Nace and others (1956; 1975) and Jones (1961) were republished by Bartholomay and others (1989).

Kuntz and Dalrymple (1979) determined major rock-forming element chemistry for 17 basalt samples from large volcanoes in the eastern Snake River Plain and compared the average concentrations with those of various tholeiitic basalts from other locations. Fiesinger and others (1982) analyzed 26 basaltic lava samples from an area southeast of the eastern Snake River Plain for major rock-forming elements and compared results with basaltic lava compositions of samples from the Snake River Plain.

Leeman (1982a) provided major rock-forming element chemistry of 22 representative hybrid lava samples from the Snake River Plain. Leeman (1982b) also summarized major rock-forming element and selected trace-element chemistry for basalt samples from the Snake River Plain and discussed two major variants of basaltic lavas that are present on the Snake River Plain. Honjo and Leeman (1987) reported major- and trace-element chemistry for selected samples of hybrid ferrolatite lavas from the Snake River Plain. The chemical data were selected from a more detailed report about the petrology and geochemistry of the Magic Reservoir eruptive center in south-central Idaho (Honjo, 1986).

Wood and Low (1988) reported average compositions of major rock-forming elements for groups of 152 and 15 basalt samples from the Snake River Plain. They also provided specific analytical results for 13 basalt samples from the Snake River Plain.

Shervais and others (1994) reported ranges of major-element oxide compositions and minor- and trace-element concentrations for 59 rock samples from 2 coreholes at the INEEL. The rock samples represented 14 major flow groups that are part of the eastern Snake River Plain aquifer system.

Anderson and Bartholomay (1995) used potassium oxide (K_2O) chemical data from several core samples taken from three coreholes near the Radioactive Waste Management Complex (RWMC) in conjunction with natural-gamma logs to determine stratigraphic relations of basalt and sediment at the RWMC. The K_2O values were determined by X-ray fluorescence (XRF) analysis.

Knobel and others (1995) reported the major-ion and trace-element composition of basalts from 84 samples of cores from 5 coreholes located at the INEEL. They also reported crustal abundances and descriptive statistics for the elements.

Reed and others (1997) reported major-element and trace-element chemistry data for 39 basalt samples taken from 2 coreholes near the Idaho Nuclear Technology and Engineering Center (INTEC). They used the data to make geochemical and stratigraphic correlations of basalt flows between the two boreholes beneath the INTEC.

Colello and others (1998) reported selected major-element and trace-element chemistry data for 24 basalt samples taken from 3 coreholes located on the INEEL. In related studies, Pace and others (1999) reported data for 6 basalt and 5 sediment infill samples from a corehole near INTEC, and Liszewski and others (2000) reported data for surficial samples from 20 sites located on the INEEL. The samples and chemical data were used in experiments to determine strontium distribution coefficients of basalts, sediment infill in basalts, and surficial sediments at the INEEL.

Cecil, Knobel, and others (2000) used the data presented in this report to calculate the *in situ* production of ^{36}Cl in the eastern Snake River Plain aquifer and discussed the associated implications for describing ground-water contamination near the INEEL.

Acknowledgments

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METHODS

Twenty-five rock samples were submitted to the ISU Department of Geology, Geochemical Laboratory, for analysis of elemental chemistry. The Geochemical Laboratory prepared samples for analysis by three separate analytical methods: inductively coupled plasma-atomic emission spectrometry (ICP-AES), instrumental neutron activation analysis (INAA), and loss on ignition (LOI). In addition, selected solid-phase samples were submitted to the USGS Branch of Geochemistry Laboratory to determine chloride (Cl^-) concentration by ion-selective electrode potentiometry (ISEP). An additional basalt sample (SP-14) was collected but was not processed because it duplicated a sample (ICPP 121 at 143 m) that was analyzed and reported by Reed and others (1997).

Field Methods

Although some of the whole-rock samples collected for this study were from the upper 2 to 5 m of the rock formation (in caves, open-pit mines, or mineral exploration adits) or from outcrops at land surface and may have undergone some changes as a result of weathering, the chemical data presented in tables 2 and 3 are assumed to be representative of the entire depth of the rock type, both temporally and spatially. For basalt and rhyolite samples SP-15 through SP-21 (table 1), the depth of collection was greater than 50 m in all cases; these samples were extracted from rock cores housed in the USGS Lithologic Core Library at the INEEL. All whole-rock samples were collected from fresh exposures or cores by using standard methods (Compton, 1962, p. 13–14 and p. 178–184) and powderless gloves to minimize contamination.

Analytical Methods

Sample processing for each of these analytical methods began with the preparation of a homogeneous powdered sample. Each powdered sample subsequently underwent processing according to the specific analytical method to be applied.

Inductively coupled plasma-atomic emission spectroscopy (ICP-AES)

For analyses by ICP-AES, the sample must be prepared as a solution (Lichte and others, 1987). There are a variety of methods to prepare the solution, and each method has advantages that are related to sample composition. Sequential acid dissolution by hydrofluoric acid (HF), aqua regia, perchloric acid ($HClO_4$), and nitric acid (HNO_3) is one method that has the disadvantage that silicon and boron are lost because of their volatility as fluorides. Also, several trace minerals, including chromite, are not completely dissolved by this method. Because of the silicic composition of volcanic rocks in the Snake River Plain, a fusion method of preparing sample solutions was used by the ISU laboratory as opposed to the sequential acid dissolution method.

The fusion method uses a flux to convert the sample to a glass bead, which subsequently is dissolved in dilute HNO_3 to prepare a solution for analysis. The specific method used by the ISU Geochemical Laboratory involved mixing 0.1 g of powdered sample and 0.3 g of lithium metaborate in a graphite crucible and heating in a furnace for 20 minutes at 1,050 °C. The contents of the crucible were poured immediately into 75 mL of 3.5-percent HNO_3 in a 250-mL beaker and stirred on a magnetic stirrer for 5 minutes or until the sample was clear. The contents of the beaker then were transferred to a 100-mL volumetric flask, and more dilute HNO_3 was added to bring the volume to 100 mL. The flask was capped and gently shaken to thoroughly mix the contents. A sample bottle was pretreated by rinsing with 5 mL of the sample solution that then was discarded. The pretreated sample bottle then was filled with 50 mL of the sample solution and was ready for analysis by ICP-AES. The ISU laboratory reported weight percent values for oxides of the following elements: silicon, titanium, aluminum, manganese, magnesium, calcium, potassium, and phosphorus. Using this method, the laboratory also determined strontium, zirconium, and yttrium concentrations in units of parts per million (ppm) by weight for all samples. ICP-AES analysis also was used to determine concentrations of vanadium, nickel, copper, lead, zinc, cadmium, and barium in ppm by weight for samples SP-1 through SP-13.

Instrumental neutron activation analysis (INAA)

For analyses by INAA, a precisely known amount of powdered sample must be prepared to undergo irradiation without the loss of sample (Baedecker and McKown, 1987). The laboratory placed 1 g or less, weighed to the nearest milligram, into a 0.4-dram (1 apothercaries dram equals 3.887 g), reactor-safe, laboratory-grade polyvial, which then was heat sealed. The 0.4-dram polyvial then was heat sealed into a 2-dram, reactor-safe, laboratory-grade polyvial. Preparation for neutron activation then was complete. For calibration purposes, three reference standards were included with the samples: USGS rock standards BCR-1 and BHVO-1 and the National Institute of Science and Technology (NIST) traceable coal fly ash standard reference material (SRM) 1633-A.

The prepared standards and samples were sent to the Oregon State University (OSU) Radiation Center for neutron activation in the TRIGA Reactor. Neutron activation lasted 2 hours under a neutron flux of 3×10^{12} $(n/cm^2)/s$. Once activated, the standards and samples were returned to ISU for analysis. Upon arrival at the laboratory, the inner 0.4-dram polyvials were transferred into new 2-dram polyvials for gamma counting.

Activation analysis is based on measurement of activity from radioactive nuclides produced by nuclear reactions on naturally occurring isotopes of the sample elements during the activation process. Gamma-ray spectroscopy at the ISU Geochemical Laboratory employed semiconductor detectors (high-purity germanium diodes) for gamma counting. These devices converted a gamma-ray signal from the irradiated samples to electronic pulses that could be sorted and processed by a multichannel analyzer and supporting electronics. The resulting spectra then were processed by computer software and the results were recorded. All standards and samples were counted three separate times in a sequence that optimized peak-to-background ratios for short-, intermediate-, and long-lived radionuclides, respectively. The first counts were for determining the short-lived radionuclides of sodium, samarium, lanthanum, and uranium, and took place about 5 days after irradiation. The count periods were between 2,000 and 4,000 seconds. The next counts were for the intermediate-lived radionuclides of barium (for samples SP-15 through SP-26), rubidium, neodymium, ytterbium, and lutetium, and took place about 10 to 20 days after irradiation. The count periods were 8,000 to 10,000 seconds. The final counts were for the long-lived radionuclides of iron, scandium, chromium, nickel (for samples SP-15 through SP-26), cobalt, cesium, cerium, europium, terbium, thorium, hafnium, and tantalum, and took place about 30 to 40 days after irradiation. The count periods were 20,000 to 40,000 seconds. Results were reported in ppm by weight, except for sodium and iron, which were reported as oxides of the elements in weight percent.

Loss on ignition (LOI)

For analysis by LOI at the ISU Geochemical Laboratory, precisely 2 g of powdered sample weighed to within 0.0005 of a gram was placed in a clean ceramic crucible. The weight of the crucible and powder was determined and recorded. The open crucibles were heated overnight (or for about 12 hours) at 90°C. The crucibles were removed to a desiccator, cooled for 2 to 3 minutes, and reweighed. These raw weights were recorded and subtracted from the weights of the unheated crucibles and powdered sample. The difference represented the weight of volatile components that are not actually part of the sample. The samples were returned to a desiccator and a muffle furnace was heated to 950°C. When the muffle furnace reached this temperature, lids were placed on the crucibles and they were heated for 1 hour. The crucibles were cooled 2 minutes, then the lids were removed and the crucibles were allowed to continue cooling in the desiccator until they reached room temperature (about 5 to 7 minutes). The weights of the cooled/room-temperature crucibles were determined and subtracted from the raw weight of the crucible and sample determined previously. The weight difference in grams represented the LOI component of the sample. The difference was divided by the original sample weight (2±0.0005 g) and multiplied by 100. This value was reported along with the elemental oxides as LOI in weight percent.

Ion-selective electrode potentiometry (ISEP)

For analysis of Cl^- by ISEP, 200 mg of powdered sample was weighed and placed into a confined area of the outer compartment of a Conway diffusion cell constructed of Teflon (Aruscavage, 1990). Reducing and oxidizing solutions were prepared. The reducing solution was made of 22.6 g of potassium hydroxide (KOH) dissolved in 140 mL of deionized water (H_2O) and 1.12 g of anhydrous sodium sulfite (Na_2SO_3). A 2.5-mL aliquot of reducing solution was pipetted into the inner compartment of the Conway diffusion cell. The oxidizing solution was made of 160 mL of HF added to a solution that contained 2.6 g of potassium permanganate ($KMnO_4$) dissolved in 50 mL of 15-percent sulfuric acid (H_2SO_4). A 3-mL aliquot of the oxidizing solution was added to the outer compartment of the Conway diffusion cell and digested the powdered sample by mixing overnight on an oscillating platform. The evolved chlorine was converted to Cl^- by the reducing solution contained in the inner compartment of the Conway diffusion cell. Finally, the Cl^- concentration was measured by ISEP. The applicable concentration range for Cl^- by this method was 0.01 to 2.00 percent by weight, or 100 to 20,000 ppm by weight. Results were converted directly to ppm by weight using the following equation:

$$(\text{weight percent } Cl^-/100)\times 1{,}000{,}000 \text{ g} = \text{ppm by weight } Cl^-. \quad (1)$$

For example,

$$(0.04 \text{ weight percent } Cl^-/100)\times 1{,}000{,}000 \text{ g} = 400 \text{ ppm } Cl^-.$$

Fourteen solid-phase samples were selected for determination of Cl^- concentration. The converted results are presented in table 3.

ANALYTICAL RESULTS

Major rock-forming element composition and trace element concentrations were determined by ICP/AES, INAA, and ISEP analysis for selected solid-phase samples. In addition, LOI analysis was used to determine the volatile component of the solid-phase samples.

Oxides of Major Rock-Forming Elements

Silicon, aluminum, titanium, manganese, calcium, magnesium, potassium, and phosphorus were determined by ICP-AES analysis for 25 solid-phase samples. Iron and sodium were determined by INAA. Chemical composition of the samples is reported in terms of elemental oxides in units of percent by weight. The results are reported in table 2. Also listed in table 2 is the total weight percent of the volatile component of the sample (LOI). For each sample, the 11 weight percents were summed and the totals also are listed in table 2. In the solid phase, iron occurs in both ferrous and ferric form. In this report, all iron is assumed to be ferrous iron and is reported as FeO.

Trace Elements

As many as 28 trace-element concentrations were determined for 25 solid-phase samples by ICP/AES, INAA, or ISEP analysis. The results are reported in table 3 as ppm by weight.

SUMMARY

This report presents chemical compositions determined from 25 solid-phase samples. The 25 samples were collected at 7 selected depths from 6 coreholes and 18 outcrops located in Idaho and Wyoming. This report was prepared by the USGS, in cooperation with the DOE, Idaho Operations Office. ISU provided analytical services for this study.

Ten major elements, total volatile components, and as many as 28 trace elements were determined for each solid-phase sample by ICP/AES, INAA, LOI, or ISEP analysis.

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Table 1.—Sample collection information

[Map number: location shown on figure 1. Latitude and longitude: degrees, minutes, seconds. Date sampled: month/day/year. Remarks: m, meters below land surface]

Map number	Latitude	Longitude	Date sampled	Time sampled	Locality description	Rock type	Remarks
SP-1	435050	1132640	10/21/93	1020	Leslie Butte	Limestone	Outcrop
SP-2	435722	1132618	10/21/93	1210	Hidden Mouth Cave	Limestone	Outcrop
SP-3	435712	1132641	10/21/93	1255	Blue Jay Canyon	Limestone	Outcrop
SP-4	440535	1132010	10/22/93	1356	Hawley Mountain	Dolostone	Outcrop
SP-5	433811	1114024	10/25/93	0820	Heise Rock	Rhyolite	Outcrop
SP-6	434633	1112633	10/25/93	1100	Calamity Creek	Rhyolite	Outcrop
SP-7	440838	1105950	10/25/93	1440	Cave Falls	Rhyolite	Outcrop
SP-8	445928	1111512	10/26/93	1320	Big Springs	Rhyolite	Outcrop, 10 m
SP-9	442248	1120559	10/29/93	0920	Spencer Opal Mine	Opal in rhyolite	Outcrop, 10 m
SP-10	442457	1115646	10/29/93	1050	West Camas Creek	Rhyolite	Outcrop
SP-11	442859	1120758	10/29/93	1330	Aspen Draw	Quartzite	Outcrop
SP-12	434320	1131913	12/14/93	1330	Hill Road	Limestone	Outcrop
SP-13	440105	1124635	12/17/93	1030	Reno Ditch	Rhyolite	Outcrop
SP-15	433451	1125232	08/01/94	1030	NPR WO-2	Basalt	728 m
SP-16	433449	1125231	08/01/94	1100	NPR Test	Basalt	158 m
SP-17	432402	1130132	08/01/94	1245	Big Southern Butte	Rhyolite	136 m
SP-18	433024	1130204	08/01/94	1320	RWMC C1A	Basalt	180 m
SP-19	433920	1125436	08/01/94	1350	NRF-7	Basalt	118 m
SP-20	433059	1124922	08/01/94	1430	ARA-COR-005	Basalt	193 m
SP-21	433059	1124922	08/01/94	1435	ARA-COR-005	Basalt	259 m
SP-22	443123	1113335	09/12/94	1045	Willow Creek	Basalt	Outcrop
SP-23	442923	1114007	09/12/94	1330	Howard Creek	Rhyolite	Outcrop
SP-24	432508	1112525	09/13/94	0930	Fall Creek (Adit)	Quartzite	Outcrop
SP-25	431732	1111238	09/13/94	1215	Bear Creek	Shale	Outcrop
SP-26	441540	1130625	09/14/94	1030	Meadow Canyon	Limestone	Outcrop

Table 2.—Chemical composition of major rock-forming elements (percent by weight) of selected solid-phase samples, by major rock type, eastern Snake River Plain aquifer system, Idaho and Wyoming

[Location of sample sites is shown on figure 1. Analyses by Idaho State University Geochemical Laboratory using inductively coupled plasma-atomic emission spectrometry (ICP-AES), instrumental neutron activation analysis (INAA), or loss on ignition (LOI). Percent by weight data for oxides in this report were not normalized. In this report, total iron is expressed as simple ferrous iron oxide (FeO). SiO_2 values in angle brackets indicate that the value was outside the calibration range of the instrument at the time of analysis and that the value should be adjusted if the data are normalized. Negative LOI values in parentheses indicate interference by iron and that the value should be adjusted if the data are normalized. Negative LOI values are not included in the total values. Symbols: -bd-, value is below the detection limit; <, less than]

ROCK TYPES:
A: Igneous rocks
B: Sedimentary rocks
C: Metamorphic rocks

SYMBOLS FOR CHEMICAL NOTATIONS USED IN TABLE 2

SiO_2	Silicon oxide	CaO	Calcium oxide
Al_2O_3	Aluminum oxide	MgO	Magnesium oxide
TiO_2	Titanium oxide	K_2O	Potassium oxide
FeO	Iron oxide	Na_2O	Sodium oxide
MnO	Manganese oxide	P_2O_5	Phosphorus oxide
LOI	Volatile oxide components such as H_2O and CO_2		

A: Igneous rocks

	Sample identifier and rock type					
Oxide	**SP-5 Rhyolite**	**SP-6 Rhyolite**	**SP-7 Rhyolite**	**SP-8 Rhyolite**	**SP-9 Opal in Rhyolite**	**SP-10 Rhyolite**
SiO_2	73.43	73.96	67.31	75.54	73.94	72.45
Al_2O_3	10.61	12.17	11.07	11.50	12.24	12.15
TiO_2	.12	.18	.16	.15	.24	.25
FeO	1.37	1.69	1.63	1.33	.29	1.86
MnO	.01	.13	.03	.04	<.01	.03
CaO	2.13	.77	5.13	.54	.22	.62
MgO	.92	.12	.10	.07	.02	.10
Na_2O	3.40	3.59	3.54	3.50	.13	3.75
K_2O	4.69	5.39	5.24	5.37	.87	5.36
P_2O_5	.04	.05	.03	.03	.04	.04
LOI	2.94	.74	4.34	1.35	11.51	1.16
Total	99.66	98.79	98.58	99.42	99.50	97.77

Oxide	**SP-13 Rhyolite**	**SP-15 Basalt**	**SP-16 Basalt**	**SP-17 Rhyolite**	**SP-18 Basalt**	**SP-19 Basalt**
SiO_2	74.11	45.00	45.50	<78.10>	47.70	46.10
Al_2O_3	11.73	13.20	14.70	12.50	16.20	15.80
TiO_2	.08	2.71	1.75	.16	1.77	2.18
FeO	1.10	11.70	11.00	1.66	10.50	12.50
MnO	.04	.19	.17	.05	.17	.18
CaO	1.55	10.85	10.30	.70	11.10	10.67
MgO	.13	5.52	8.22	.17	8.35	7.79
Na_2O	3.45	2.12	2.37	4.31	2.46	2.52
K_2O	5.32	1.49	.44	4.60	.45	.53
P_2O_5	.04	.85	.25	.02	.32	.44
LOI	2.24	8.45	(-.60)	.24	(-.32)	(-.56)
Total	99.79	102.08	94.70	102.51	99.02	98.71

Oxide	**SP-20 Basalt**	**SP-21 Basalt**	**SP-22 Basalt**	**SP-23 Rhyolite**
SiO_2	44.90	45.90	48.60	74.40
Al_2O_3	15.00	13.30	14.30	11.50
TiO_2	2.71	2.65	.79	.21
FeO	12.70	12.10	8.50	1.93
MnO	.19	.20	.15	.06
CaO	9.93	8.00	9.32	.48
MgO	7.24	4.98	7.51	.09
Na_2O	2.55	3.14	2.32	3.60
K_2O	.63	1.76	3.25	5.04
P_2O_5	.61	.31	.52	.03
LOI	(-.37)	(-.46)	3.56	.92
Total	96.46	92.34	98.82	98.26

B: Sedimentary rocks

Oxide	Sample identifier and rock type						
	SP-1 Limestone	SP-2 Limestone	SP-3 Limestone	SP-4 Dolostone	SP-12 Limestone	SP-25 Shale	SP-26 Limestone
SiO_2	1.70	2.26	1.83	0.66	4.27	48.40	-bd-
Al_2O_3	.26	.39	.23	.27	.33	11.80	-bd-
TiO_2	<.01	.01	<.01	<.01	.01	.58	.04
FeO	.03	.07	.03	.15	.10	3.95	.04
MnO	<.01	<.01	<.01	.02	<.01	.22	.02
CaO	53.52	53.43	53.69	30.44	51.71	8.87	54.00
MgO	.75	.45	.55	20.01	.51	6.41	.47
Na_2O	.01	.02	.01	.03	.01	.92	.02
K_2O	.05	.10	.03	.09	.11	3.22	.00
P_2O_5	.02	.03	.01	.01	.05	.28	.06
LOI	43.31	42.93	43.06	46.94	42.62	13.40	42.40
Total	99.65	99.69	99.44	98.62	99.72	98.05	97.05

C: Metamorphic rocks

Oxide	Sample identifier and rock type	
	SP-11 Quartzite	SP-24 Quartzite
SiO_2	73.24	<105.0>
Al_2O_3	3.19	-bd-
TiO_2	.12	.07
FeO	.70	.02
MnO	.08	.02
CaO	9.79	.00
MgO	.85	.03
Na_2O	.05	.02
K_2O	1.08	.32
P_2O_5	.12	.03
LOI	10.29	.33
Total	99.51	105.84

Table 3.—Chemical composition of trace elements (parts per million by weight) of selected solid-phase samples, by major rock type, eastern Snake River Plain aquifer system, Idaho and Wyoming

[Location of sample sites is shown on figure 1. Analyses by Idaho State University Geochemical Laboratory using inductively coupled plasma-atomic emission spectrometry (ICP-AES), and instrumental neutron activation analysis (INAA), except for chloride concentrations, which are by the USGS Branch of Geochemistry Laboratory using ion-selective electrode potentiometry (ISEP). Trace-element data (in ppm by weight) were not normalized in this report. Values in parentheses indicate that the value was outside the calibration range of the instrument at the time of analysis. Values in braces indicate that the data are questionable. Symbols: -bd-, value is below the detection limit; <, less than; -nd-, not determined]

ROCK TYPES

A: Igneous rocks
B: Sedimentary rocks
C: Metamorphic rocks

SYMBOLS FOR CHEMICAL NOTATIONS USED IN TABLE 3

Sc	Scandium	Ba	Barium	Yb	Ytterbium	Y	Yttrium
Cr	Chromium	La	Lanthanum	Lu	Lutetium	V	Vanadium
Co	Cobalt	Ce	Cerium	Zr	Zirconium	Cu	Copper
Ni	Nickel	Nd	Neodymium	Hf	Hafnium	Pb	Lead
Rb	Rubidium	Sm	Samarium	Ta	Tantalum	Zn	Zinc
Sr	Strontium	Eu	Europium	Th	Thorium	Cd	Cadmium
Cs	Cesium	Tb	Terbium	U	Uranium	Cl	Chloride

A: Igneous rocks

Trace element	Sample identifier and rock type					
	SP-5 Rhyolite	**SP-6 Rhyolite**	**SP-7 Rhyolite**	**SP-8 Rhyolite**	**SP-9 Opal in rhyolite**	**SP-10 Rhyolite**
Sc	1.00	2.16	1.35	1.91	2.41	3.64
Cr	4	3	{1}	{1}	{1}	3
Co	.34	1.57	.29	.49	.2	.92
Ni	4	2	2	2	3	6
Rb	153	143	163	190	3	152
Sr	25	43	51	12	36	37
Cs	3.58	1.16	2.32	3.82	.76	1.33
Ba	637	1,230	301	219	484	1,180
La	112.3	109.9	87.7	90.9	65.6	86
Ce	193	762	132	170	109	124
Nd	80	68	54	58	30	60
Sm	17.3	15.7	11.1	13.6	4.28	12.9
Eu	1.35	1.75	.80	.61	.26	1.72
Tb	2.28	2.20	1.33	1.94	.43	1.89
Yb	6.2	7.5	4.3	6.1	1.04	6.3
Lu	.82	.94	.63	.85	.25	.88
Zr	194	312	289	231	247	383
Hf	9.4	10.5	11.1	9.0	8.3	13.3
Ta	3.49	2.79	3.55	3.39	3.37	3.08
Th	25.1	25.4	28.8	27.7	20.3	24.9
U	4.9	4.4	5.1	6.2	5.3	5.3
Y	67	65	40	67	15	68
V	2	3	2	2	5	2
Cu	4	7	4	4	4	5
Pb	40	37	25	29	25	20
Zn	40	90	87	74	5	65
Cd	<.5	<.5	.8	<.5	<.5	<.5
Cl	<100	-nd-	600	700	<100	- nd-

A: Igneous rocks—Continued

Trace element	Sample identifier and rock type					
	SP-13 Rhyolite	SP-15 Basalt	SP-16 Basalt	SP-17 Rhyolite	SP-18 Basalt	SP-19 Basalt
Sc	2.7	30.0	32.7	0.2	33.1	29.0
Cr	2	266	345	2	270	219
Co	.41	43.9	49.8	.2	46.5	47.8
Ni	9	105	175	3	134	84
Rb	178	30	19	296	18	10
Sr	23	243	216	-bd-	240	267
Cs	3.03	.75	.28	3.40	.38	.24
Ba	232	585	464	834	472	612
La	45.4	28.3	16.4	72.5	17.2	22.0
Ce	93.9	53.7	34.3	139.7	33.4	39.6
Nd	38	33	17	51	16	23
Sm	9.91	7.51	4.75	15.44	4.80	5.68
Eu	.60	2.44	1.55	.52	1.60	1.80
Tb	1.57	.94	.55	4.31	.60	.75
Yb	5.2	3.21	2.69	22.8	2.52	2.79
Lu	.81	.47	.39	2.93	.38	.42
Zr	142	256	146	296	157	198
Hf	6.2	6.03	3.54	16.3	3.52	4.32
Ta	1.92	1.40	.67	19.7	.70	.90
Th	19.1	2.54	1.71	22.2	1.31	1.60
U	5.1	1.1	.8	11.5	.6	.5
Y	52	34	31	(225)	31	34
V	3	-nd-	-nd-	-nd-	-nd-	-nd-
Cu	4	-nd-	-nd-	-nd-	-nd-	-nd-
Pb	18	-nd-	-nd-	-nd-	-nd-	-nd-
Zn	29	-nd-	-nd-	-nd-	-nd-	-nd-
Cd	<.5	-nd-	-nd-	-nd-	-nd-	-nd-
Cl	-nd-	<100	100	-nd-	-nd-	100

A: Igneous rocks—Continued

	Sample identifier and rock type			
Trace element	**SP-20 Basalt**	**SP-21 Basalt**	**SP-22 Basalt**	**SP-23 Rhyolite**
Sc	29.0	23.3	28.0	3.3
Cr	188	107	418	4
Co	49.3	37.5	40.1	1.2
Ni	75	71	84	15
Rb	10	48	94	156
Sr	294	250	556	66
Cs	.29	.54	3.30	4.04
Ba	687	932	1,056	1,660
La	30.8	66.2	22.2	78.8
Ce	57.0	121.4	49.0	192.9
Nd	30	60	23	67
Sm	7.39	13.77	5.07	14.25
Eu	2.44	2.84	1.59	2.25
Tb	.96	2.22	.73	2.2
Yb	3.31	7.46	1.88	5.20
Lu	.47	1.02	.19	.71
Zr	272	62	117	338
Hf	6.07	10.8	2.85	10.9
Ta	1.26	3.20	.27	2.35
Th	2.23	6.57	5.28	23.0
U	.8	3.0	1.2	5.8
Y	43	1	17	59
V	-nd-	-nd-	-nd-	-nd-
Cu	-nd-	-nd-	-nd-	-nd-
Pb	-nd-	-nd-	-nd-	-nd-
Zn	-nd-	-nd-	-nd-	-nd-
Cd	-nd-	-nd-	-nd-	-nd-
Cl	200	200	-nd-	-nd-

B: Sedimentary rocks

	Sample identifier and rock type						
Trace element	**SP-1 Limestone**	**SP-2 Limestone**	**SP-3 Limestone**	**SP-4 Dolostone**	**SP-12 Limestone**	**SP-25 Shale**	**SP-26 Limestone**
Sc	0.12	0.35	0.16	0.21	0.21	11.4	0.1
Cr	7	8	11	3	7	55	8
Co	.19	.23	.17	.72	.19	12.7	.5
Ni	6	4	2	4	2	28	-bd-
Rb	2	2	1	2	2	99	0
Sr	701	380	439	54	467	116	576
Cs	.08	.19	.07	.1	.09	6.61	.02
Ba	27	33	38	21	34	333	24
La	1.99	3.16	4.03	.59	3.93	27.2	3.5
Ce	1.75	3.24	3.99	1.12	2.94	54.5	2.5
Nd	{1}	{2}	{2}	{.5}	{2}	21.7	2.53
Sm	.39	.69	.72	.12	.64	4.53	.72
Eu	.04	.10	.09	.02	.09	1.00	.10
Tb	.05	.09	.11	.01	.07	.66	.06
Yb	.15	.32	.27	.03	.23	2.20	.23
Lu	.03	.06	.05	.01	.04	.29	.01
Zr	4	13	2	7	11	160	31
Hf	.05	.11	.1	.05	.12	4.3	.12
Ta	.01	.02	.03	.02	.03	.74	-bd-
Th	.1	.21	.18	.14	.22	9.07	.28
U	1.9	2.5	2.9	.2	2.3	2.6	4.3
Y	3	6	6	<1	6	23	6
V	3	5	8	2	6	-nd-	-nd-
Cu	5	4	5	4	5	-nd-	-nd-
Pb	<5	<5	<5	<5	<5	-nd-	-nd-
Zn	19	25	29	7	20	-nd-	-nd-
Cd	<.5	1.3	.6	<.5	.9	-nd-	-nd-
Cl	100	200	-nd-	400	200	-nd-	-nd-

C: Metamorphic rocks

Trace element	Sample identifier and rock type	
	SP-11 Quartzite	SP-24 Quartzite
Sc	1.76	0.2
Cr	15	4
Co	1.78	.5
Ni	6	-bd-
Rb	31	7
Sr	86	8
Cs	1.19	.21
Ba	281	55
La	14.1	3.1
Ce	24.2	5.3
Nd	10	1.2
Sm	2.01	.28
Eu	.39	.07
Tb	.27	.04
Yb	.89	.15
Lu	.14	.02
Zr	68	407
Hf	1.95	1.14
Ta	.25	-bd-
Th	3.68	.55
U	1.4	.3
Y	10	(84)
V	27	-nd-
Cu	8	-nd-
Pb	7	-nd-
Zn	40	-nd-
Cd	<.5	-nd-
Cl	100	-nd-