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Analyses of Gas, Steam and Water Samples Collected in and Around Lassen Volcanic National Park, California, 1975–2002

By Cathy J. Janik and Deborah Bergfeld

Open-File Report 2010–1036

U.S. Department of the Interior
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Suggested citation:
Janik, C.J., and Bergfeld, Deborah, 2010, Analyses of gas, steam and water samples collected in and around Lassen Volcanic National Park, California, 1975-2002: U.S. Geological Survey Open-File Report, 2010-1036 [*http://pubs.usgs.gov/of/2010/1036/*].

Cover: Big Boiler. Photograph by Patrick Muffler

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8
Vertical coordinate information is referenced to the North American Vertical Datum of 1927 (NAVD 27).
Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).
Altitude, as used in this report, refers to distance above the vertical datum.
Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).
Specific conductance is given in milisiemens per centimeter at 25 degrees Celsius (mS/cm at 25 °C).

Analyses of Gas, Steam and Water Samples Collected in and Around Lassen Volcanic National Park, California, 1975–2002

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Abstract

This report contains physical and chemical data from gas, steam, and water samples collected between July 1975 and September 2002 from locations in and around Lassen Volcanic National Park, California. Data are compiled as tables in Excel spreadsheets and are organized by locale. Most data are keyed to 1 of 107 site codes that are shown on local- and regional-scale maps. Brief descriptions of terminology, sampling, and analytical methods are provided.

Introduction

A large number of gas, steam, and water samples were collected during U.S. Geological Survey (USGS) investigations in the Lassen Volcanic Center between July 1975 and September 2002. Information on sample parameters and results of bulk chemical and isotope analyses are presented in this report. Some of the stable isotope data have previously been shown in figures 2 and 3 of Janik and others (1983), and some of the water chemistry data were published by Thompson (1985). A recent publication by Janik and McLaren (2010) presents much of the gas chemistry and stable isotope data given here, but does not present location data for the samples. This report contains all available physical, chemical, and isotopic data for the samples presented in these earlier papers and includes other unpublished data.

Data in each table are organized into groups that correspond primarily to the six main areas of hydrothermal activity in and around Lassen, plus one group of "other" features. Each sample is keyed to a site code that is given in UTM coordinates that are referenced to the NAD 27 datum (table 1). Many of the samples were collected prior to the onset of handheld global positioning system (GPS) instrumentation, and the coordinates were originally estimated from topographic maps. Table 2 contains gas

chemistry data for 10 gas samples whose locations were not recorded. Those data are identified with an asterisk and a brief description.

Figure 1 shows all of the sample locations across the entire collection area. Five main collection areas are within the boundaries of Lassen Volcanic National Park and include Bumpass Hell (fig. 2), Boiling Springs Lake (fig. 3), Devils Kitchen (fig. 4), Little Hot Springs Valley (fig. 5), and Sulphur Works (fig. 6). The Boiling Springs Lake grouping includes samples collected from springs and gas vents at Boiling Springs Lake, the Drakesbad Resort, Terminal Geyser, and the Walker Well. The sixth collection area is about 3–4 km south of the park boundary and includes sample sites at Morgan and Growler hot springs along Mill Creek (fig. 7). The remaining 19 locations include sites at Cold Boiling Lake, Pilot Pinnacles, and 16 springs that are geographically scattered about the area (fig. 1). In tables 1 through 5, data for these locations are grouped under the heading of "other".

Each site code in table 1 lists all the types of features that were sampled at the site during the course of the investigation. Attempts were made to sample the same feature during each visit, but at Lassen it is common for features to change in character, and a location where a degassing spring existed in one year may have had a roiling mud pot or a dry steam vent in a different year. Sites where the sample features changed are shown with a star symbol that is labeled as "mixed" in figures 2 through 6. Fumaroles were targeted for gas collection as they typically provide gas samples with the least amount of air-contamination, however, safe access was not always possible, and at times a secondary feature was selected.

Terminology Used in Tables

The types of features sampled during this investigation include fumaroles, lakes with drowned gas vents, frying pans, pools, thermal and nonthermal springs, mud pots, and a well. We identify thermal springs (TS) as those having collection temperatures ≥17°C, applying the definition of Meinzer (1923) as thermal water having a temperature appreciably higher than the local mean annual air temperature. The mean annual air temperature at an elevation of 2,500 m on Lassen Peak for the 2005 water year was about 7°C (data from the California Department of Water Resources), and we consider 10°C as being an appreciably higher temperature. All other spring waters are herein defined as nonthermal (NTS).

Fumaroles (FM) are features where steam and gas issue from a discrete area, such as a crack or fracture, and often have sampling temperatures near or above the local boiling point. At elevations typical of the thermal areas within the park, boiling would occur at 92–93 degrees Celsius. At lower-elevation sites, such as the Morgan and Growler hot springs area, boiling would occur around 95 degrees Celsius. Many fumarole samples in table 2 have temperatures in excess of the local boiling point and are described as superheated. Gas emissions associated with superheated fumaroles at Lassen often have large, highly visible plumes of steam, and the sound of the escaping gas is very loud.

Gas from all other features was collected from the surface of a body of water. Gas from lakes (L) issues from drowned vents where the gas source is submerged under the water. Frying pans (FP) are features where gas issues from a pool of boiling water that is

no deeper than a few centimeters. Frying pans are characterized by splashing water, similar to the action of water poured onto a hot pan. Gas bubbles at pools (P) and thermal springs at Lassen rise through variable depths of water, generally less than 0.5 m. All pools in this study contained thermal water and are distinguished from thermal springs by the lack of a visible outflow channel. Mud pots (MP) are degassing features found in areas of extreme acid alteration; they contain viscous, muddy water and often have no outflow channel.

Collection Methods and Analytical Information

Details about gas-bottle preparation, sampling, and analytical methods are given in Fahlquist and Janik (1992). Gas samples were collected into evacuated glass bottles containing 4 N sodium hydroxide (caustic) by using silicone tubing to connect the collection device to the sample bottle. At fumaroles, the gas was collected using a titanium tube, and at other features gas was collected using an inverted funnel placed over the rising bubbles. At all sites, atmospheric components were purged from the collection system prior to sample collection. Steam samples from fumaroles were typically collected by cooling the sample tubing and pouring the condensed steam into a bottle. A few steam samples for isotope analyses were collected directly into evacuated bottles.

Waters collected for chemical analyses were poured into pre-rinsed plastic bottles after passing the sample through a 0.45 µm acetate-membrane filter. Other raw (nonfiltered) waters were collected in glass and plastic bottles for stable isotope and tritium analyses, respectively. For most samples, pH was determined in the field using paper indictor strips, but for some samples it was determined by using a calibrated meter in the field or in the laboratory. Samples were preserved for cation analyses by drop-wise addition of high-purity nitric acid to a pH less than 2.

Table 2 lists analytical results for 129 gas samples analyzed at the USGS Volcanic Gas Geochemistry laboratory in Menlo Park, California. Head-space gas concentrations (H_2, He, Ar, O_2, N_2, and CH_4) were measured using two gas chromatographs with He or Ar carrier gases and equipped with thermal-conductivity and flame-ionization detectors. Dissolved-gas concentrations were determined by analysis of the caustic solution. NH_3 concentrations were obtained using an ion-selective probe. Until 1987, H_2S and CO_2 concentrations were determined by gravimetry using hydrogen peroxide to oxidize the sulfur and barium chloride and strontium chloride to precipitate dissolved sulfur and carbon as $BaSO_4$ and $SrCO_3$, respectively. All sulfur in the caustic solution was assumed to be derived from H_2S. Splits of the $BaSO_4$ and $SrCO_3$ solids were used to determine the $\delta^{34}S$ and $\delta^{13}C$ composition of the gas following the methods of Thode and others (1961) and McCrea (1950). After August 1987, CO_2 concentrations were determined by direct measurement of evolved CO_2 on a vacuum-extraction line, following acidification of the caustic solution using phosphoric acid. A split of the evolved CO_2 was used for carbon isotope analysis following the standard procedure of McCrea (1950). Stable isotope analyses were preformed at USGS laboratories in Menlo Park, California, and Reston, Virginia.

Chemical analyses of 68 waters collected before 1983 were performed at USGS laboratories in Menlo Park, California, (table 3) following methods outlined in Thompson

(1985). After 1995, an additional 32 water samples were analyzed at the EES-6 laboratory at Los Alamos National Laboratory, Los Alamos, New Mexico, (table 4) following procedures outlined in Goff and others (2001). Some samples were collected solely for isotopic analyses, and these results are shown in table 5. Tritium analyses (tables 2 through 5) were performed at the University of Miami Tritium Lab, Rosenstiel School of Marine and Atmospheric Science, using the methods of Ostlund (1962).

Acknowledgments

A number of researchers produced the data that are reported here. We acknowledge the work of Dale Counce, Lynn Fahlquist, Mark Huebner, Linda Johnson, Andy Ouimette, Mike Thompson, and Doug White. Without their efforts this report would not be possible. Joel Robinson (USGS Menlo Park) produced the base maps used for the figures.

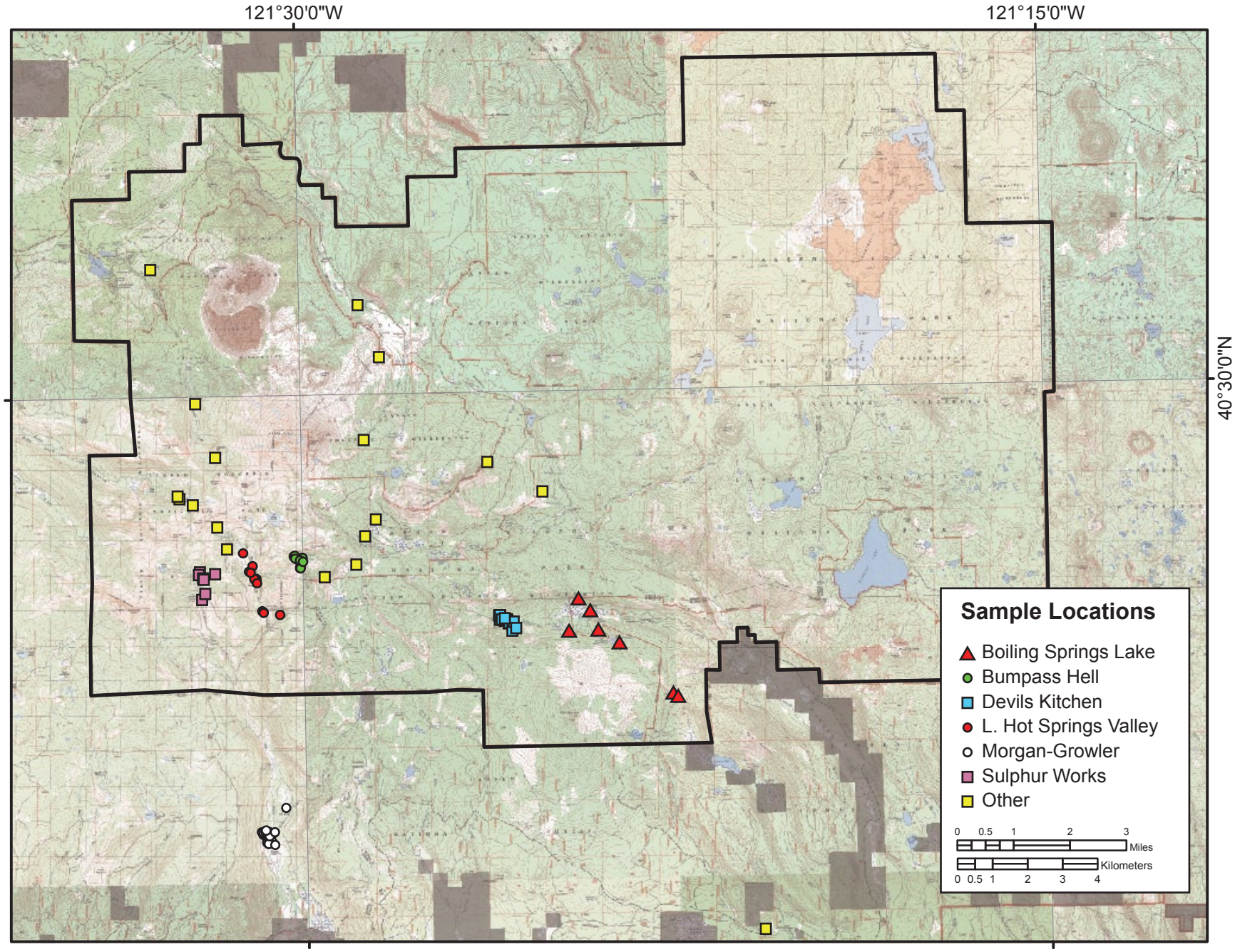

Figure 1. Topographic map showing locations for all samples collected in the Lassen region, California.

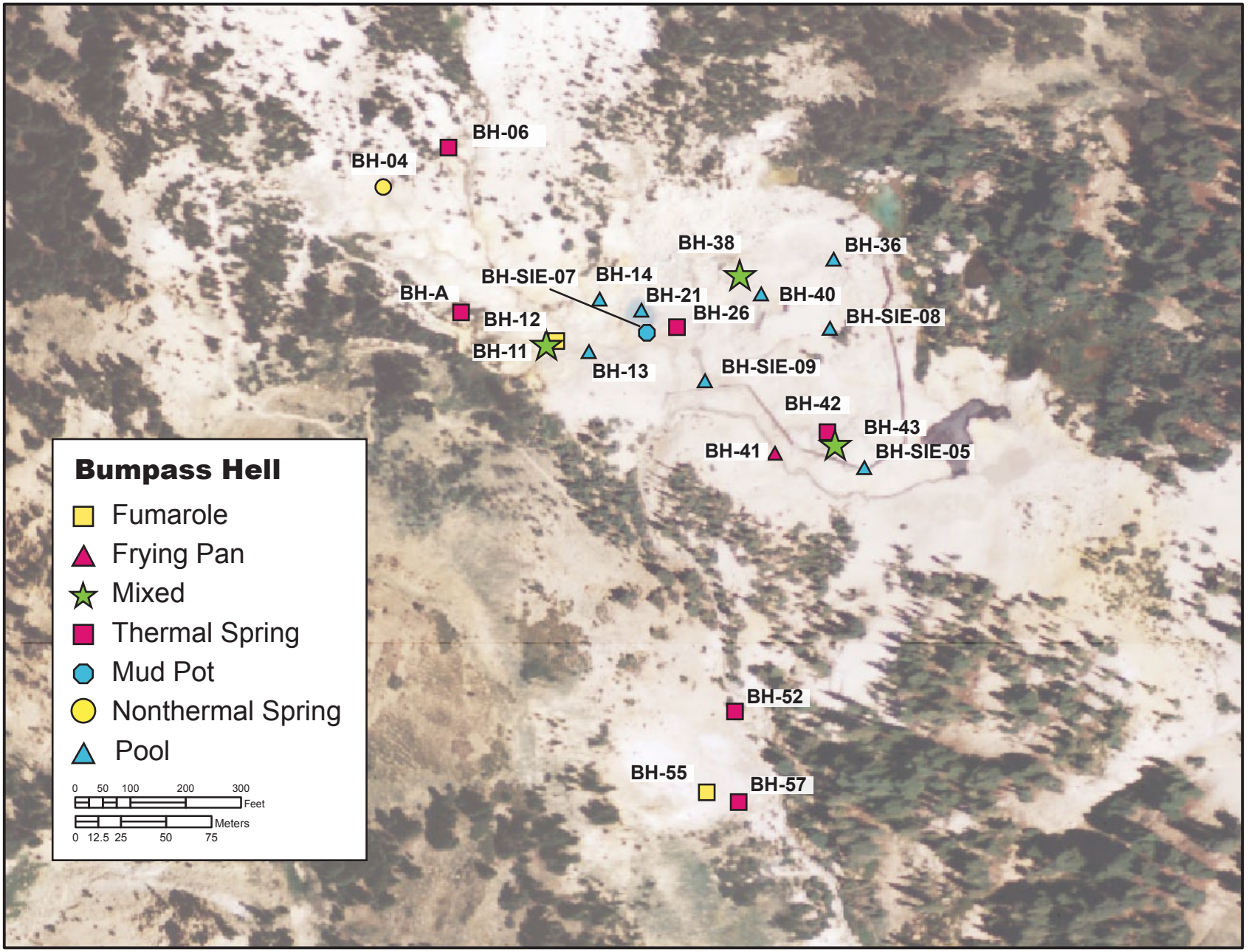

Figure 2. Locations for samples collected in the Bumpass Hell area within Lassen Volcanic National Park, California, shown on an air-photo base from the National Agriculture Imagery Program.

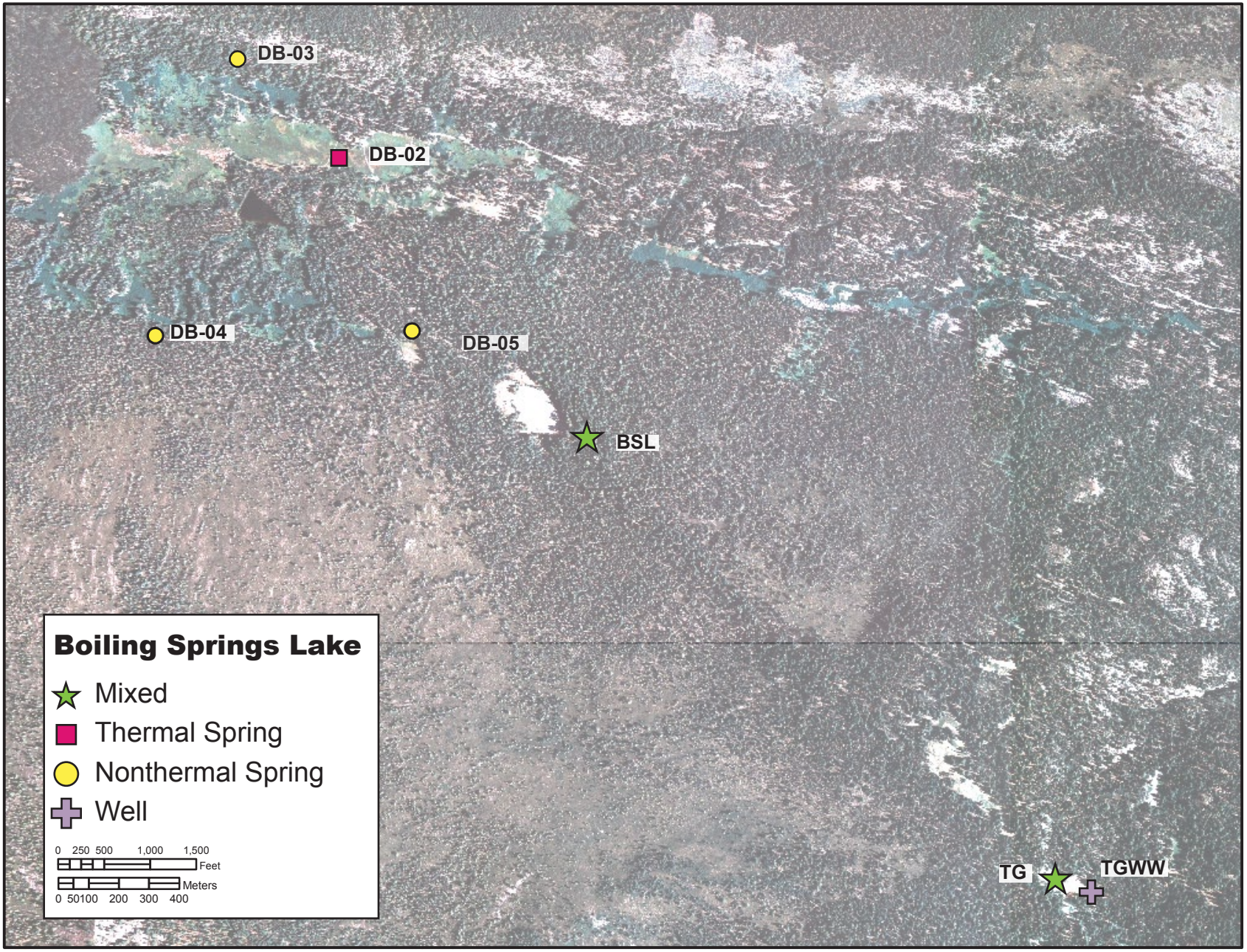

Figure 3. Locations for samples collected in the Boiling Springs Lake area within Lassen Volcanic National Park, California, shown on an air-photo base from the National Agriculture Imagery Program.

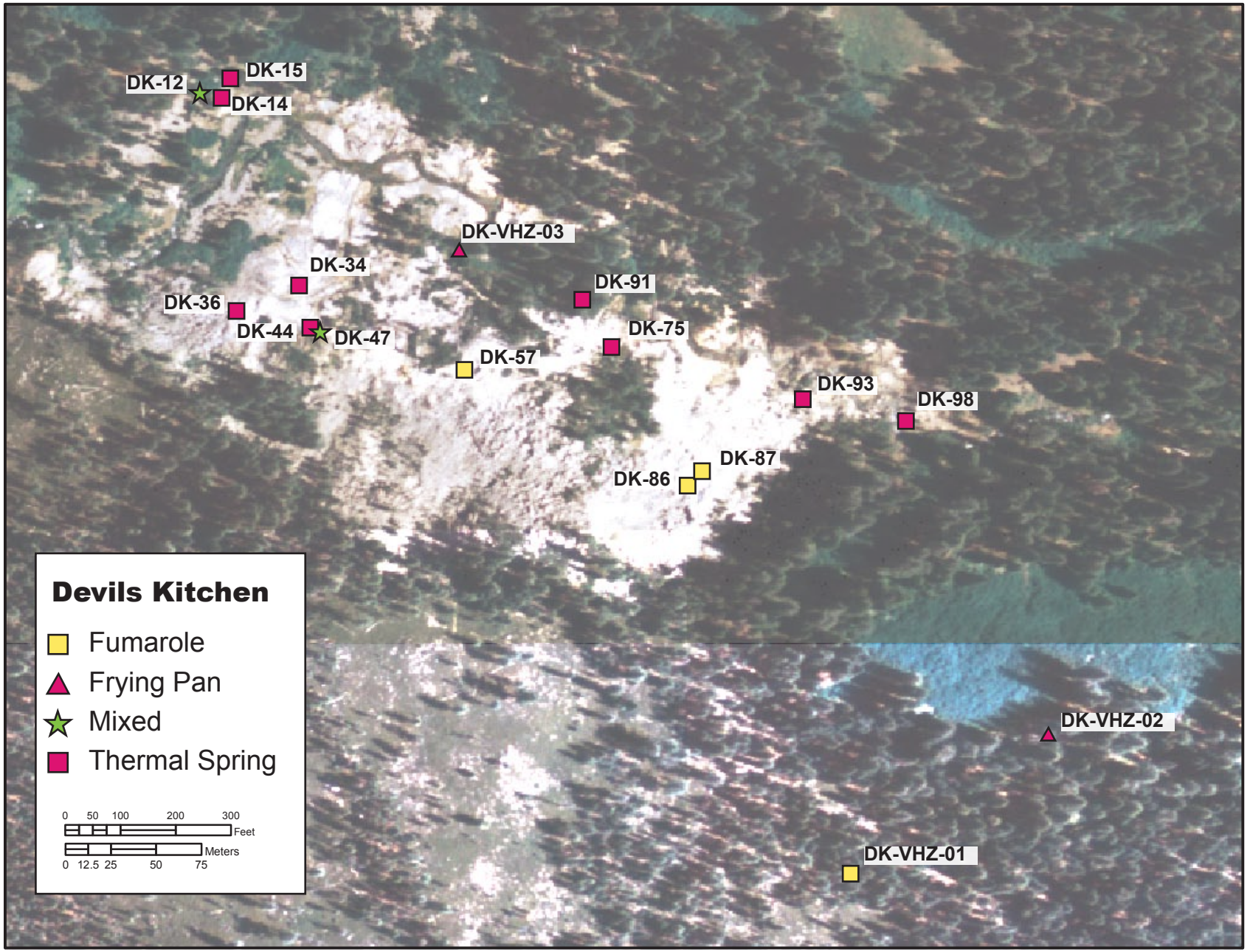

Figure 4. Locations for samples collected in the Devils Kitchen area within Lassen Volcanic National Park, California, shown on an air photo base from the National Agriculture Imagery Program.

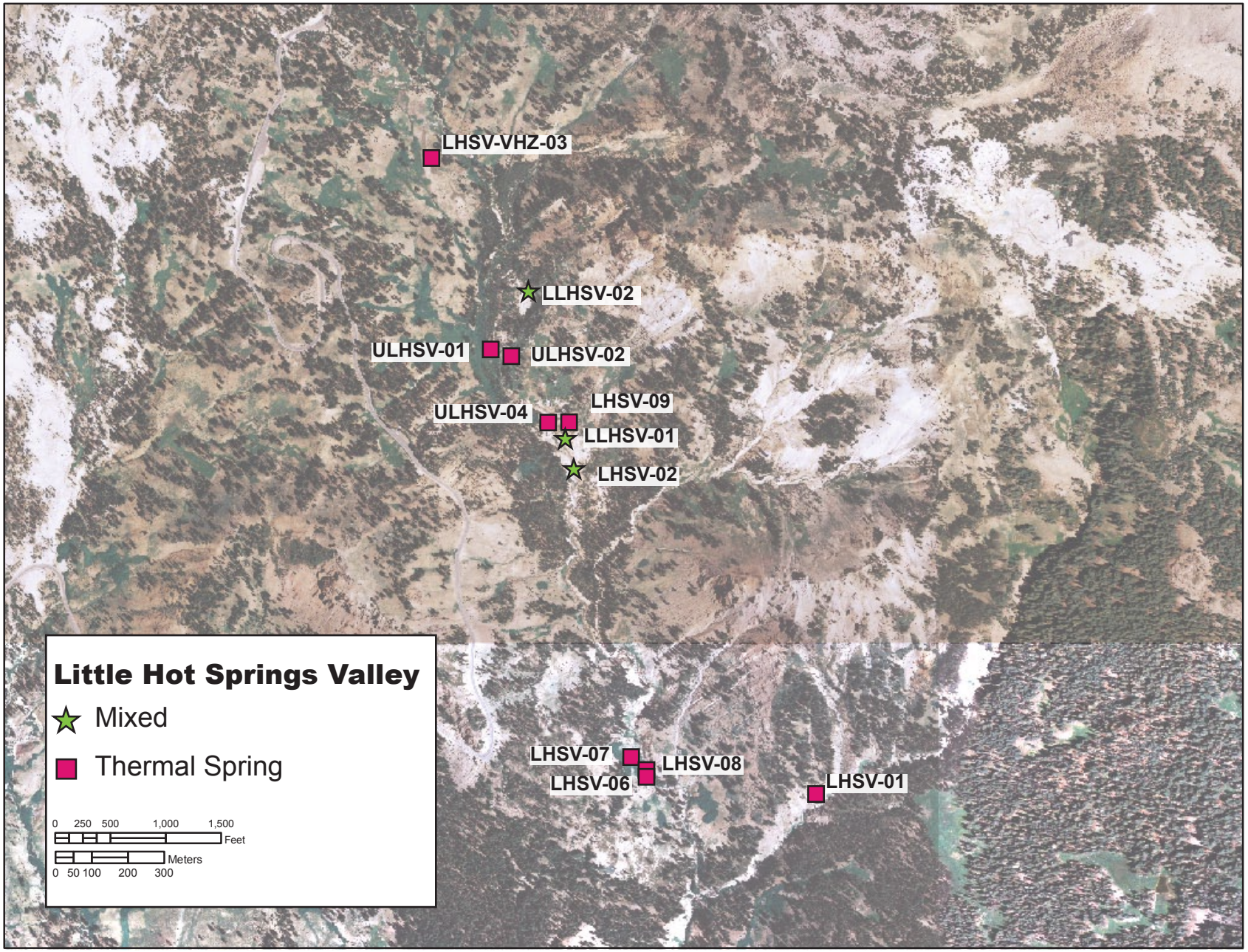

Figure 5. Locations for samples collected in the Little Hot Springs Valley area within Lassen Volcanic National Park, California, shown on an air-photo base from the National Agriculture Imagery Program.

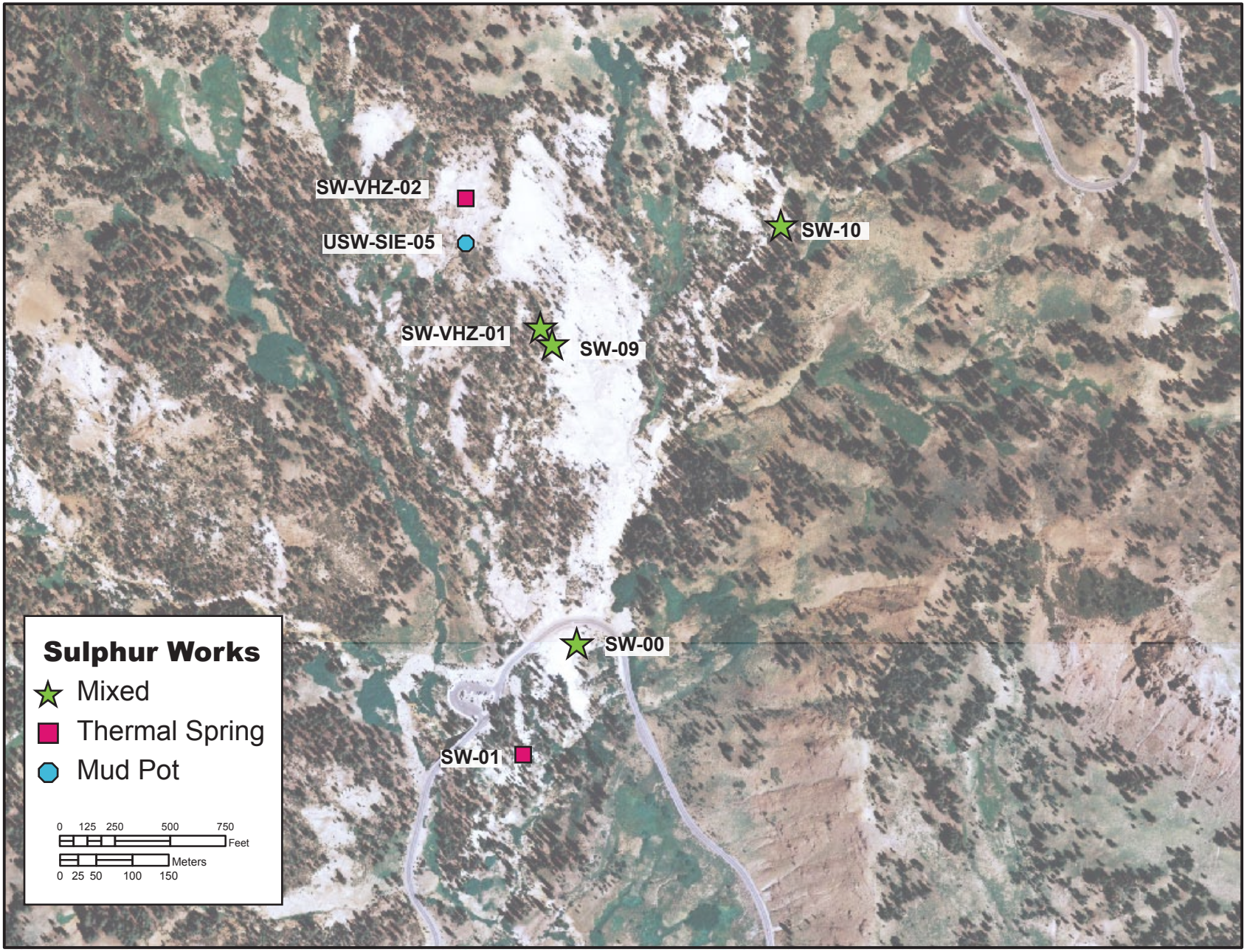

Figure 6. Locations for samples collected in the Sulphur Works area within Lassen Volcanic National Park, California, shown on an air-photo base from the National Agriculture Imagery Program.

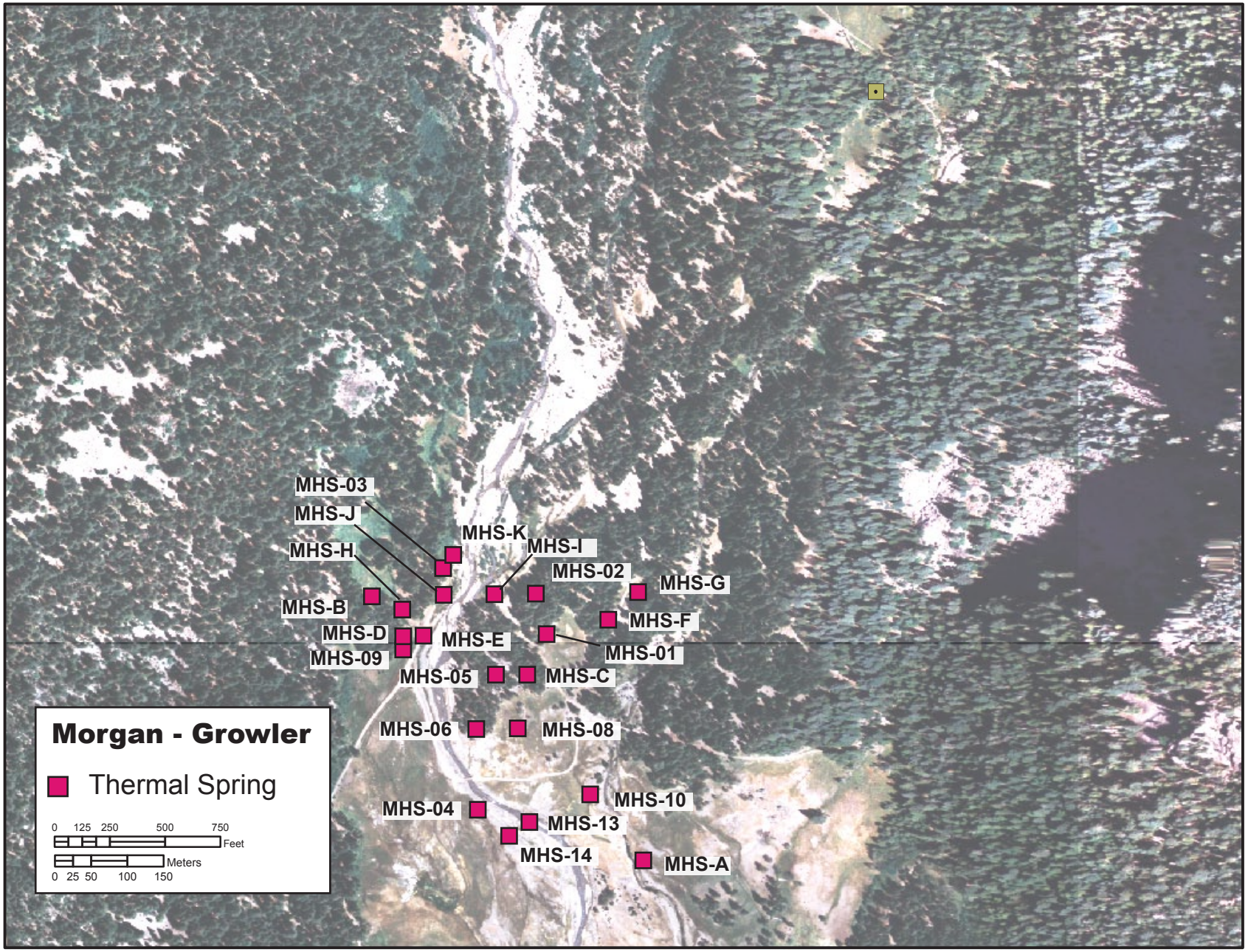

Figure 7. Locations for samples collected in the Morgan and Growler hot springs area south of Lassen Volcanic National Park, California, shown on an air-photo base from the National Agriculture Imagery Program.

Table 1. Site codes, feature types and sample location data given in UTM coordinates in relation to the NAD 27 datum, Lassen Volcanic National Park, California. Location accuracy is given as 5 m for sites located using GPS measurements and 10 m for sites located using a map. Features at some locations may no longer be active. FM, fumarole; FP, frying pan; L, lake; NTS, nonthermal spring; P, pool; TS, thermal spring. *Web link*

Table 2. Gas chemistry, tritium concentrations, and stable isotope values for gas and steam collected within and around Lassen Volcanic National Park, California. Temperature is reported in degrees Celsius (°C). Gas concentrations are reported in mol-%, and tritium concentrations are in tritium units (TU). Stable isotope values are reported in per mil (‰) relative to PDB ($\delta^{13}C$), CDT ($\delta^{34}S$) and SMOW (δD and $\delta^{18}O$). Feature abbreviations are as shown in table 1; nr, not recorded. Detection limits were not available. A blank cell indicates that a value was below the detection limit or that an analysis was not attempted. *Web link*

Table 3. Water chemistry, tritium concentrations and stable isotope values for waters collected within and around Lassen Volcanic National Park, California, between July 1975 and October 1982. Temperature is reported in degrees Celsius (°C). Analyte concentrations are in mg/kg, and tritium values are in tritium units (TU). Stable isotope values of water are reported in per-mil (‰) relative to SMOW (δD and $\delta^{18}O$). The pH was measured in the field using indicator paper (p), or in the laboratory using a meter (Lm). Feature abbreviations are as shown in table 1; nr, not recorded. Samples collected from fumaroles are condensed steam. Detection limits were not available for some samples. A blank cell indicates that a value was below the detection limit or that an analysis was not attempted. *Web link*

Table 4. Water chemistry, tritium concentrations, and stable isotope values for waters and steam collected within and around Lassen Volcanic National Park, California, between September 1996 and September 2002. Temperature is reported in degrees Celsius (°C). Analyte concentrations are in mg/kg, and tritium values are in tritium units (TU). Stable isotope values of water are reported in per-mil (‰) relative to SMOW (δD and $\delta^{18}O$). The pH was measured in the field using indicator paper (p) or a meter (mF), or in the laboratory using a meter (Lm). Feature abbreviations are as shown in table 1. Samples collected from fumaroles are condensed steam. Detection limits were not available for some samples. A blank cell indicates that a value was below the detection limit or that an analysis was not attempted. *Web link*

Table 5. Tritium concentrations and stable isotope values for steam, water, and CO_2 collected from features within and around Lassen Volcanic National Park, California. Temperature is reported in degrees Celsius (°C). Stable isotope values are reported in per-mil (‰) relative to SMOW (δD and $\delta^{18}O$) and PDB ($\delta^{13}C$). Tritium concentrations are reported as tritium units (TU). Isotope data for steam samples that are identified with an "E" were collected directly into an evacuated bottle. A blank cell indicates that an analysis was not attempted. *Web link*

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