REDOUBT VOLCANO: GEOLOGIC INVESTIGATIONS

In 2008 the Alaska Volcano Observatory (AVO), led by the Division of Geological & Geophysical Surveys (DGGS), initiated efforts to produce an updated geologic map and hazard assessment of Redoubt Volcano. Those efforts were interrupted by the onset of Redoubt's eruption on March 15, 2009, following 19 years of repose. The eruption ceased by July 1, 2009. Fieldwork since that time has concentrated in decreasing measure on mapping and sampling of 2009 deposits and increasingly back to completion of the geologic map and hazard assessment report.

Activities and Results: The primary goal of the 2011 field season on Redoubt Volcano was to increase our sample density of lava flows on the edifice and finalize placement of geologic contacts. The purpose of the sampling was to complement the dataset of surprisingly variable Holocene lava ages already analyzed by U.S. Geological Survey (USGS) collaborators, and help define units. A secondary goal for the 2011 season was to increase the sample density over the surface of the 2009 lava dome. Vesicularity studies and geochemical analyses completed earlier in the year indicate that a lava, which was more (and highly) vesicular and slightly different chemically than the initially extruded lava, began to effuse from the top of the final 2009 lava dome one month into its growth. Unfortunately, field efforts by AVO–DGGS geologists this season were hampered by persistently poor weather. Almost two weeks of planned mapping and sampling were reduced to fewer than four days. The sampling goal was nonetheless adequately accomplished over three days of intense sampling, but little to no time was left for detailed mapping; the dome was inaccessible.

Products: AVO–DGGS geologist Kate Bull is lead author on two manuscripts in review as part of a 2012 special issue on the 2009 eruption of Redoubt Volcano to be published in the *Journal of Volcanology and Geothermal Research.* One paper provides an overview of the eruption and summarizes the contributions of the papers in the special issue, the second describes the morphologic and vesicularity changes that occurred during growth of the final 2009 lava dome. Co-authors include collaborators from the USGS Volcano Hazards Program at AVO, the Cascades Volcano Observatory, and Menlo Park, and researchers from the University of Alaska Fairbanks and the University of Northern Colorado. Completion of the geologic map of Redoubt Volcano is expected in 2012.

Figure 1. AVO–USGS geologist Heather Bleick sampling lava flows on Redoubt Volcano's edifice (Photo by Kate Bull, DGGS–AVO).

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CHIGINAGAK VOLCANO: GEOLOGIC MAPPING AND HAZARD ASSESSMENT

Mount Chiginagak is a hydrothermally active volcano on the Alaska Peninsula, approximately 170 kilometers (100 miles) south–southwest of King Salmon. This small stratovolcano, approximately 8 km in diameter, has erupted through Tertiary to Permian sedimentary and igneous rocks. The DGGS-led geologic mapping and hazard assessment work that began in 2004 was curtailed by the 2005 acid crater lake drainage (see p. 64). However, intermittent geologic fieldwork since 2005 has consisted of lava sample collection for age dating and geochemical analysis, mapping of Holocene lava flows, lahars, and debris avalanches, and the collection and stratigraphic description of tephra deposits.

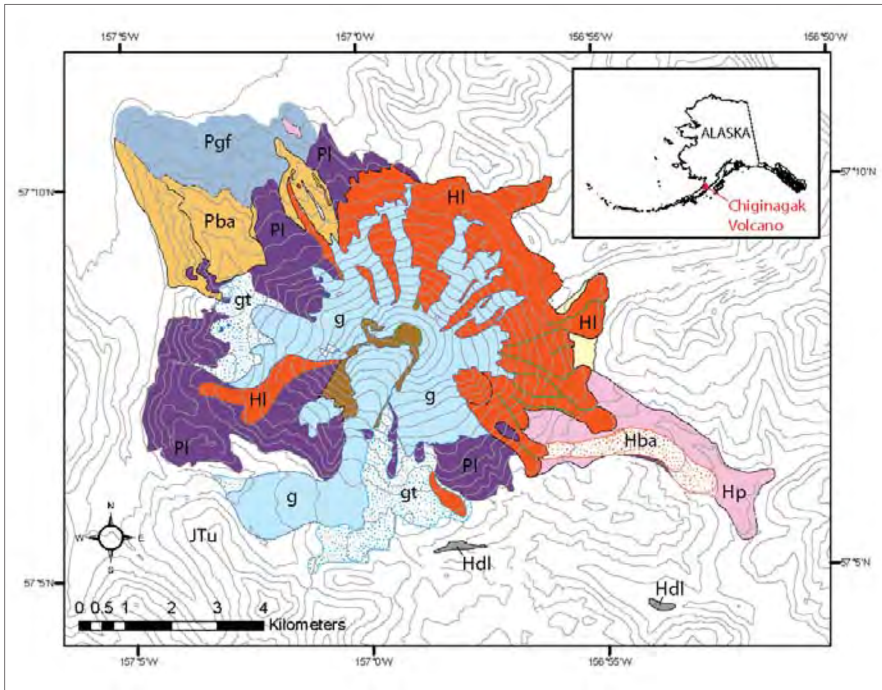

Figure 1. Generalized geologic map of Chiginagak volcano showing major undifferentiated deposits of Pleistocene lavas (Pl), Pleistocene block-and-ash flow deposits interlayered with andesite lavas (Pba), undifferentiated glaciofluvial and glaciolacustrine deposits (Pgf), Holocene lavas (Hl), Holocene block-and-ash flow deposits (Hba), Holocene pyroclastic flow deposits (Hp), Holocene debris avalanche and lahar deposits (Hdl), glaciers and perennial snow fields (g), and glacial till (gt). Pending $^{40}Ar/^{39}Ar$ age determinations and geochemical analyses will help differentiate these major depositional units. Unit JTu refers to undifferentiated bedrock (Tertiary to Permian rocks mapped by Detterman and others, 1987).

Pleistocene pyroclastic flows and block-and-ash flows, interlayered with andesitic lava flows, dominate the edifice rocks on the northern and western flanks (fig. 1, Unit Pba). The oldest rocks dated (~250 thousand years old) are lava bombs found in a cliff-forming pyroclastic flow deposit on the northwestern flank. Pleistocene porphyritic lava flows range in composition from 54.2 to 62.7 weight percent silica (SiO_2) and contain variable proportions of plagioclase, hypersthene, and augite.

Figure 2. Janet Schaefer (DGGS) collecting a sample of a prismatically jointed andesite lava block atop a block-and-ash flow deposit on the southeastern flank of Chiginagak volcano. Photo by Willie Scott (USGS), August 21, 2004.

Our mapping indicates that Holocene activity consists primarily of debris avalanches, lahars, and lava flows. Terrace deposits of lahars and debris avalanches appear along a creek draining the southeastern flank toward the Pacific Ocean (fig. 1, Unit Hdl) and in upper Indecision Creek below the toe of the south flank glacier. Holocene lava flows (Unit Hl, fig. 1) cover Pleistocene lavas on the northeastern flank and range in composition between 55.9 and 57.5 weight percent SiO_2. Holocene block-and-ash flow and pyroclastic flow deposits extend almost 8 km from the summit, down a valley on the southeastern flank (fig. 1, Units Hba and Hp; and fig. 2). Proximal tephra collected during recent fieldwork suggests there may have been limited Holocene explosive activity that resulted in localized ash fall.

A geologic map is scheduled to be published in 2012, followed by a hazard assessment in 2013.

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CHIGINAGAK VOLCANO: MONITORING THE PERSISTENT ENVIRONMENTAL DAMAGE FROM THE 2005 ACID CRATER LAKE DRAINAGE

Mount Chiginagak is a hydrothermally active volcano on the Alaska Peninsula, approximately 170 kilometers (100 miles) south–southwest of King Salmon. Sometime between November 2004 and May 2005, a 400-meter-wide (~1,300-foot-wide), 100-meter-deep (~330-foot-deep) lake developed in the formerly snow-and-ice-filled crater of the volcano. In early May 2005, an estimated 3 million cubic meters (106 million cubic feet) of sulfurous, clay-rich debris and acidic water exited the crater through tunnels in the base of a glacier that breaches the south crater rim. More than 27 kilometers (17 miles) downstream, the acidic waters of the flood reached approximately 1.3 meters (4 feet) above normal stream levels and inundated an important salmon spawning drainage, acidifying Mother Goose Lake from its surface to its maximum depth of 45 meters (~148 feet; resulting pH ~2.9) and preventing the annual salmon run in the King Salmon River. A simultaneous release of gas and acidic aerosols from the crater caused widespread vegetation damage along the flow path.

Since 2005, a DGGS-led interdisciplinary science team has been monitoring the crater lake water that continues to flow into Mother Goose Lake by collecting surface water samples for major cation and anion analysis, measuring surface-water pH of affected drainages, and photo-documenting the condition of the summit crater lake. Results of this work have been published as DGGS Report of Investigations 2011-6. The report describes water sampling locations, provides a table of chemistry and pH measurements, and documents the condition of the summit crater between 2004 and 2011.

Beginning in 2009, 4 years after the flood event, an ice layer began to form again in the crater lake, indicating a cessation in the crater's fumarolic heat source. By 2011, the water level in the crater had decreased significantly (fig. 1). Although the crater lake surface is freezing, some water likely remains under the ice, draining beneath the south flank glacier into Indecision Creek, continuing to supply acidic water to Mother Goose Lake. Despite this acid input, acidity in Mother Goose Lake is decreasing, fish are returning, and time-series trends show decreasing concentrations of pollutants such as copper (Cu) and cadmium (Cd). We expect these trends to continue as input of acidic water from the crater lake declines.

This work was made possible with funding from the U.S. Geological Survey's Volcano Hazard Program as well as the U.S. Department of Interior, Fish & Wildlife Service (USFWS). The DGGS-led geologic mapping and hazard assessment fieldwork that began in 2004 is described separately (p. 63).

Figure 1. Crater lake images showing the change from 2004 through 2011. (A) A pre-flood, ice-filled crater in August 2004 (Mother Goose Lake in background), to (B) a partially drained crater lake in August 2005, 3½ months after the flood, and (C) a mostly drained crater lake and the accumulation of snow and ice in August 2011. Photos by J. Schaefer.

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OKMOK VOLCANO: GEOMORPHOLOGY AND HYDROGEOLOGY OF THE 2008 PHREATOMAGMATIC ERUPTION

On July 12, 2008, with less than 5 hours of precursory seismic activity, the central Aleutian volcano Okmok erupted explosively, marking the beginning of a 5-week-long eruption that dramatically changed the morphology and groundwater system within the 8-km-wide caldera. The initial explosion sent an ash- and gas-rich column to 15 km above sea level. Early in the eruption, heavy rain mixed with new tephra on the flanks of the volcano, generating lahars (volcanic mudflows) that traveled across the upper slopes of the volcano and down all major drainages, creating large new deltas along the shoreline. For the next 5 weeks, eruption intensity waxed and waned with explosions occurring from multiple vents on the caldera floor as rising magma interacted with shallow groundwater. One crater formed next to, and eventually captured and drained, the largest pre-existing caldera lake (total volume drained was 13.6 million cubic meters). As the eruption subsided, coalescing maar and collapse craters eventually filled with water, forming a new lake to the west of cone D and dramatically changing the morphology and volume of the old lake. The longest-lived vent formed a 250–300-m-high, ~1.5-km-wide tuff cone on the western flank of pre-existing cone D. This new tuff cone, the new lakes and collapse pits, and the accumulation of many tens of meters of fine-grained tephra have significantly altered the Okmok landscape. This eruption was substantially larger than any Okmok eruption since that of 1817 (which destroyed the then-unoccupied village of Egorkovskoe on the north coast of Umnak) and far larger than the eruptions of 1945, 1958, or 1997.

Division of Geological & Geophysical Surveys (DGGS) geologist Janet Schaefer, along with Alaska Volcano Observatory (AVO) colleagues Jessica Larsen (University of Alaska Fairbanks Geophysical Institute) and Tina Neal (U.S. Geological Survey), are writing a DGGS Report of Investigations documenting this fascinating eruption. Fieldwork focused on the stratigraphy and sedimentology of the tephra deposits from the 2008 eruption, documentation and description of vent evolution, a revision of the hazard assessment, creation of a post-eruptive geologic map, and acquisition of surveyed GPS points for digital elevation model (DEM) creation. The new post-eruption DEM of the caldera will aid significantly in quantifying the geomorphic changes in the caldera (fig. 1). Anticipated release of the Report of Investigations is fall 2012.

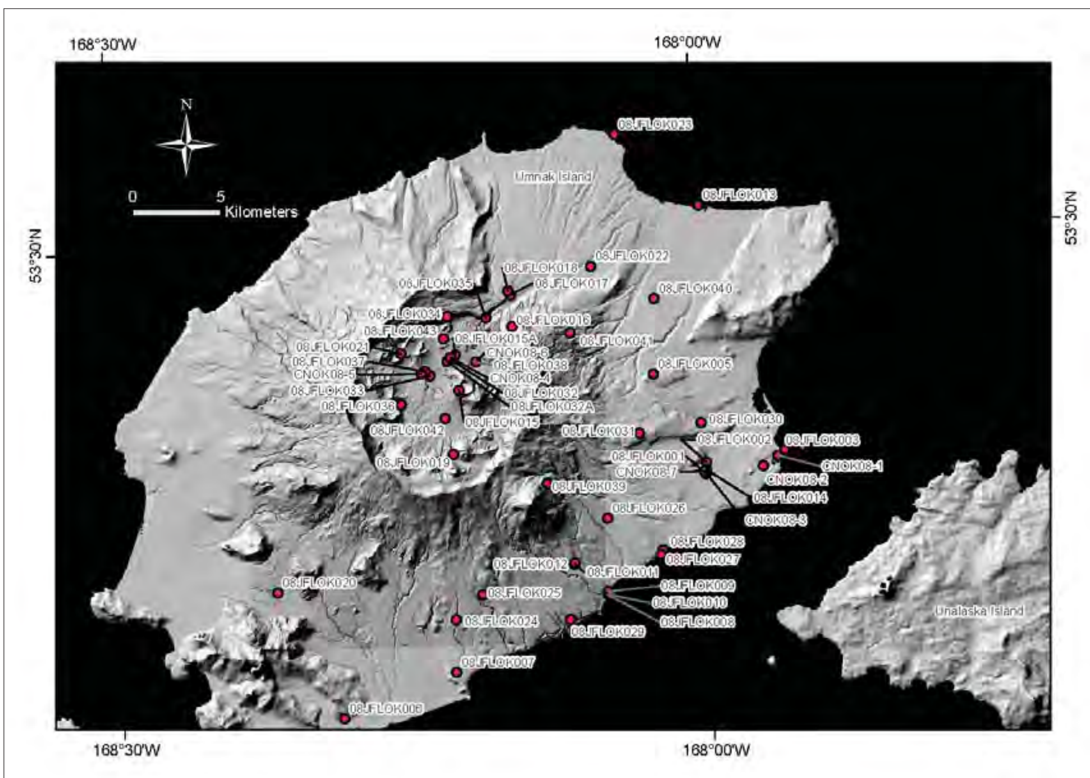

Figure 1. Field stations around Okmok volcano from August and September 2008. The shaded-relief basemap combines DEM data from 2000 with an overlay of a more detailed shaded relief image in the caldera derived from a DEM created from January 21, 2010, Worldview imagery.

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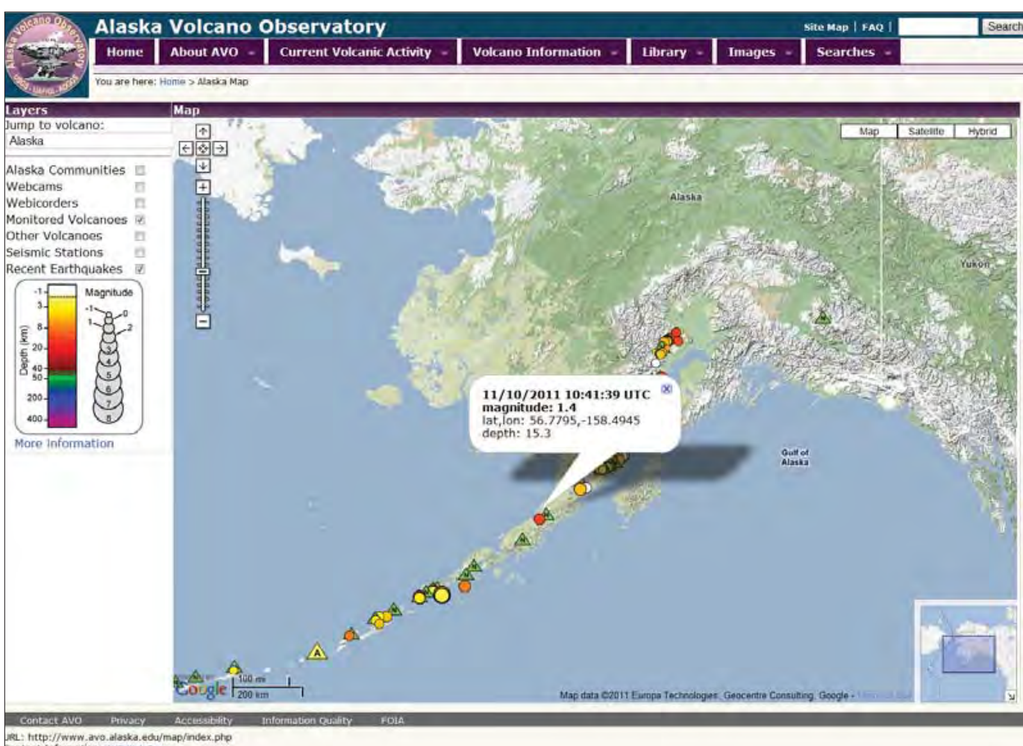
ALASKA VOLCANO OBSERVATORY WEBSITE AND DATABASE

The Alaska Volcano Observatory (AVO) public website (http://www.avo.alaska.edu) serves about 6 million pages and approximately 300 gigabytes of data to well over 100,000 unique visitors per month, and is among the top ten U.S. Geological Survey (USGS) and USGS-affiliated websites in the country. It continues to be the most complete single resource on Quaternary volcanism in Alaska. DGGS was the original creator of the AVO website in 1994, and continues to be the site designer, builder, and manager.

AVO's website content is dynamically queried from a combination of MySQL and PostgreSQL databases named GeoDIVA (Geologic Database of Information on Volcanoes in Alaska). GeoDIVA maintains complete, flexible, timely, and accurate geologic and geographic information on Pleistocene and younger Alaska volcanoes to assist scientific investigations, crisis response, and public information. GeoDIVA is currently the most comprehensive and up-to-date authoritative source for information on Alaska volcanoes. It is still under construction, in a modular format. As modules are completed, they undergo continual maintenance so that they remain timely and useful. Current modules in maintenance mode include: bibliography (4,650+ references); basic volcano information (~140 major and ~200 minor volcanic features, 52 "historically active" volcanoes); eruption history information (information, text, and references for more than 430 historical eruptions); images (19,300+); sample information (~9,300); hand-sample storage (15,000+); and vent count (~1,200 vents). Modules in continuing development and initial data-load stages include geochemistry (~3,650 analyses); petrology (~130 1,000-point point-count analyses); GIS data; geochronology; and tephra chronology/tephra impacts.

The website employs several map interfaces to display spatial information to the public. As the Department of the Interior moves toward a restrictive contract with Google for use of Google's map interface, AVO is starting to move toward a more open interface to display maps on the website. In addition to being less restrictive, the other map interfaces AVO is investigating will allow AVO to display much more spatial data on the website than before.

AVO is on the leading edge of web and database development for volcano observatories, and is actively sharing its expertise with other observatories in the U.S. DGGS is following new and emerging technologies that will allow staff to further enhance AVO's web presence and data dissemination abilities. DGGS refines and enhances the applications that AVO and other observatories use on a regular basis. We will focus on continual incremental improvements to the site, and serving new database modules as they become available.



The map display of recent earthquakes (among other items) uses Google maps as its mapping interface. AVO is moving toward using alternate interfaces such as ESRI's API or the OpenLayers API.

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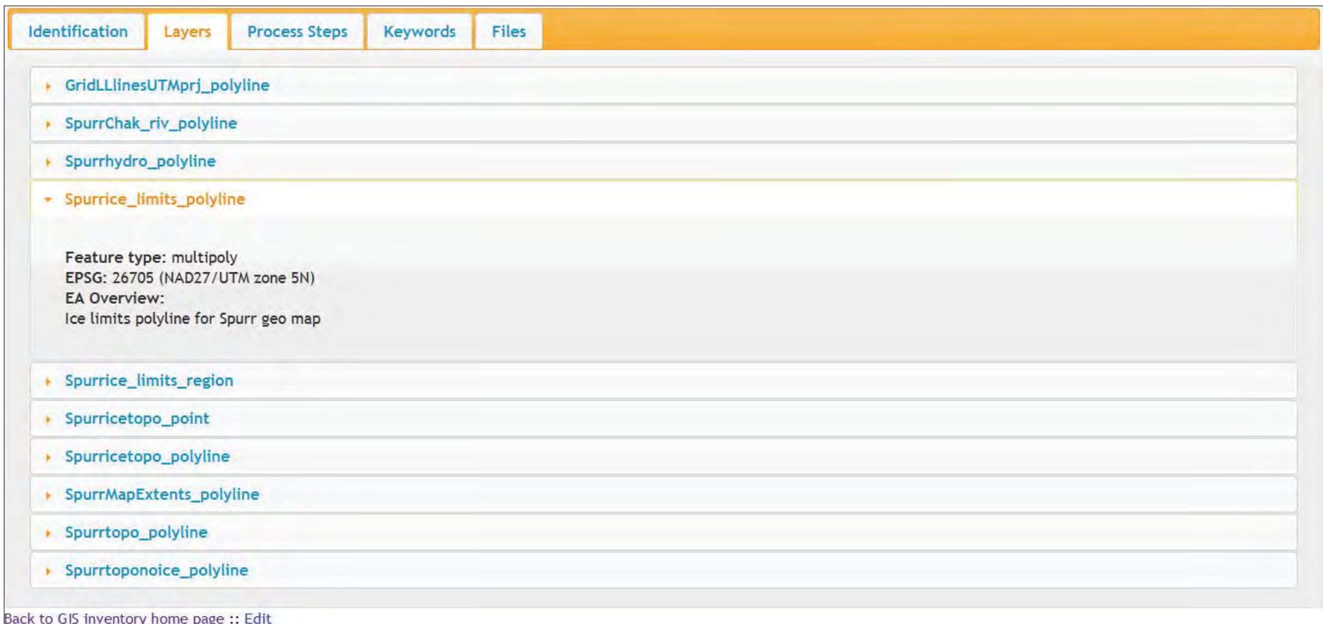
ALASKA VOLCANO OBSERVATORY GIS INVENTORY DATABASE

Nearly every Alaska Volcano Observatory (AVO) geoscientist now uses geographic information system (GIS) software for some of their tasks. AVO also collects georeferenced imagery for use in volcano monitoring and mapping. These data traditionally have been stored on individual users' desktop computers, leading to data inconsistencies, inaccessible data, and lack of standard metadata. As an initial goal toward implementing an enterprise GIS system for AVO, DGGS has created a utility to inventory, organize, and store AVO's existing GIS files. Staff are currently uploading data to the catalog, and making improvements to the user interface and export options.

Users of this database can upload their spatial data to a server, along with associated metadata. Other users (currently internal to AVO) can search within the metadata, and download the spatial files for their own use.



A list of layers associated with the Spurr geology map as stored in the AVO GIS inventory database.

The data and metadata upload routine is a multipart procedure during which the user can save their progress at any point and return to finish the process at a later time. Because not all collected data will be immediately published, only a subsection of the Federal Geographic Data Committee (FGDC) metadata standard is required at the time of data upload. For data that will be published in the future, metadata stored in the database can be exported to a standard xml file, where it can then be imported into the metadata editor of choice.

This GIS catalog (all of our most critical GIS data on one server, with appropriate metadata and use restrictions) is a stepping stone toward implementation of a more robust web GIS application of viewing/selecting the data files within a web browser, via a larger geospatial database.

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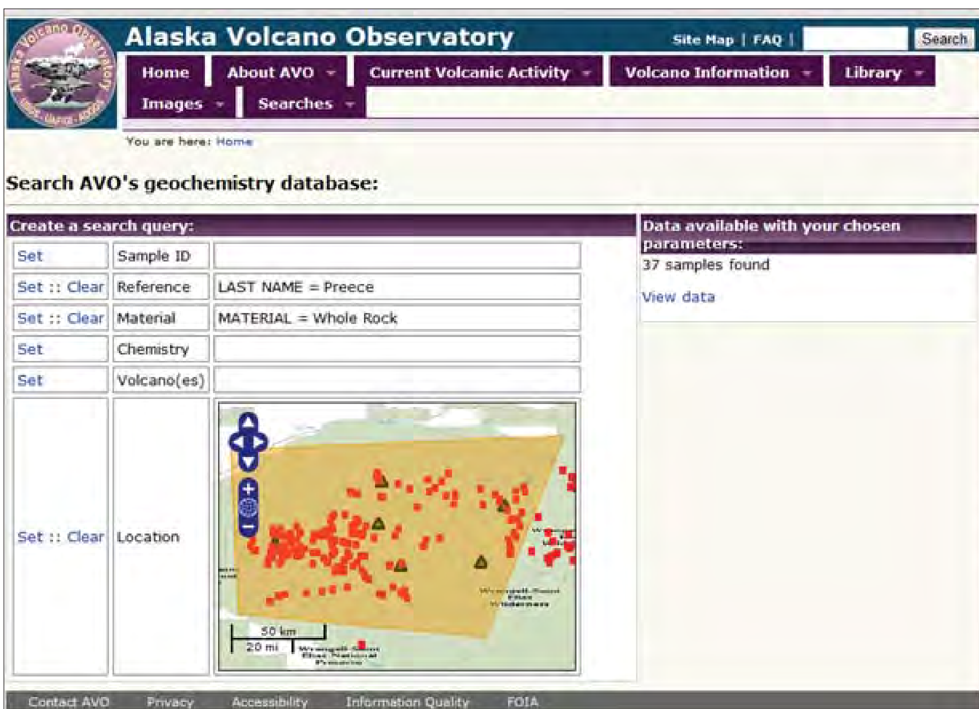
ALASKA VOLCANO OBSERVATORY GEOCHEMICAL DATABASE

As part of DGGS's ongoing efforts with the Geological Database of Information on Volcanoes in Alaska (GeoDIVA), DGGS/AVO staff have created a database structure to hold geochemical data on Quaternary volcanic rocks in Alaska. Published data will be available to the public through AVO's website, and searchable by map, volcano, sample metadata information, or specific geochemical values or analysis types. Unpublished data will also be available internally to AVO users, if the data owner has granted explicit permission.

Currently, only whole-rock major and trace element values and metadata are being uploaded to the database, although the system is designed to accommodate other types of geochemical data, and is intended to be compatible with other major geochemical database efforts such as EarthChem. We are making every effort to provide the best data possible for each sample and analysis, which often entails additional actions such as tracking down obscure references and untangling sample nomenclatures through the decades. In addition, we have adjusted the results for some samples analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at Washington State University prior to 2007 to correct calibration errors in the original report; we retain the best known value for each analysis, and do not keep the erroneous values.

This database will be a valuable research tool for geoscientists, with interests ranging from volcano-specific processes to whole-arc data synthesis. Because the database is an intrinsic part of GeoDIVA, it will also help consolidate all of Alaska's volcano information in one place. The database currently holds about 9,300 samples, and nearly half of those (4,674) have geochemical data entered. We estimate that fewer than 1,000 published analyses remain to be entered. We estimate the geochemical database will be ready for release and on-line public query in the fall of 2012 and will continue to grow as new geochemistry is published and added to the system.



View of prototype geochemical web-based search: in this example 37 sample analyses published by Shari Preece are located in the user-created polygon.

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ALASKA VOLCANO OBSERVATORY — VOLCANO NOTIFICATION SERVICE (VNS)

AVO/DGGS developed the Volcano Notification Service (VNS), allowing the public to customize the information products they receive from all U.S. volcano observatories about any U.S.-monitored volcano. Previously, information releases were sent on an all-or-nothing basis per observatory—if an email address was on a list, that address was sent all information about all volcanoes by that observatory.

Anyone can subscribe to the VNS with an email address, and can create their own username and password for the VNS. Users can add as many email addresses as they need: a confirmation code is sent to each address to ensure the address was entered correctly and the user owns the address in question. The service can be accessed at http://volcanoes.usgs.gov/vns/.

Once a user is registered, he/she can select any or all volcanoes from each region—Alaska, Cascades, Hawaii, Long Valley, Yellowstone, and the Northern Marianas Islands. Volcanoes can be selected through a map view (fig. 1), or via a text-based list, sorted by region. Once selected, users can choose volcano-specific alert levels and color codes for their notifications. For example, an airline user may only be interested in Cook Inlet volcanoes when they are at elevated color codes, so the user might select Redoubt, Spurr, and Augustine, and elect to receive updates about those volcanoes when they are at color code Yellow or higher.

After a user selects volcanoes and alert levels/color codes, he/ she can then choose which information products to receive. Information products are observatory-specific and range from general information statements that include background commentary about volcanoes, to daily status reports on volcanic activity, to urgent notifications of significant activity.

The notification service checks for new volcano updates every five minutes, so users can expect to receive their emails between five and ten minutes after a new notification has been posted. Traditional notifications such as faxes and phone calls to emergency managers and airline coordinators will also continue.

Figure 1. The volcano selection interface uses a Google map to display monitored US monitored volcanoes. Users can zoom to specific regions by clicking the regional links to the left of the map.

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