

# MAGMATIC, ERUPTIVE AND TECTONIC PROCESSES IN THE ALEUTIAN ARC, ALASKA

## Introduction

The Aleutian Arc contains roughly ten percent of the world's active volcanoes. Hardly a year goes by without a major eruption from a volcano in the Aleutian Arc, and more than 170 eruptions were recorded in this area during the last 100 years (Figure 1). The volcanoes of the Aleutian Arc are the only place within the North American plate boundary system where eruptions are frequent. Only by instrumenting Aleutian volcanoes will PBO be assured of making observations that can be used to study eruption triggering and dynamics; elsewhere within the plate boundary, based on the historical record, eruptions are unlikely to occur. Individual volcanoes along the 4,000-mile long arc represent the entire spectrum in eruptive style, size, volume, and magma composition commonly found along convergent plate boundaries. Presently six volcanic centers, Augustine, Trident, Fisher, Westdahl, Akutan, and Okmok, are known to be actively deforming. The four most active volcanoes, Pavlof, Akutan, Shishaldin, and Okmok, have produced a combined total of 82 eruptions during the past century. During the 10-year period proposed for PBO instrumentation we would expect an average of one eruption from Okmok, two each from Akutan and Shishaldin, and two to three eruptions from Pavlof. More silicic volcanoes near the eastern end of the arc are also highly active. Augustine, Redoubt and Spurr have all erupted within the last 15 years, and the 1912 Katmai eruption on the Alaska Peninsula was the largest eruption on earth during the 20<sup>th</sup> century. Based on its frequent eruptive history an eruption is also expected at Augustine Volcano during the 10-year proposed PBO deployment. Presently six volcanic centers, Augustine, Trident, Fisher, Westdahl, Akutan, and Okmok, are known to be actively deforming.

This region thus forms an ideal and unique natural laboratory in the western U.S. for studying fundamental issues such as 1) the location and evolution of magma bodies, 2) eruption dynamics, 3) eruption triggering, 4) triggered seismicity, 5) relations between deformation, LP and VLP events, and 6) interaction between active faulting and volcanoes. Major earthquakes also occur frequently along this plate boundary (eg. The 1964 Great Alaskan earthquake (M 9.2), the 1965 Rat Islands earthquake (M 8.7), the 1957 earthquake (M 8.6), and numerous other events  $M > 7$ ). While there is not a clear link between major earthquakes and eruptions, observations made by the Alaska Volcano Observatory seismic monitoring networks demonstrate that seismic swarms at Aleutian Arc volcanoes have been triggered by significant earthquakes, and volcanically induced stresses interact to control deformation and perhaps other processes at these volcanoes.

Study of Alaskan volcanoes is inextricably linked to monitoring of this active plate boundary. We propose to install instrumentation at selected volcanoes along the eastern half of the Aleutian Arc comprising 21 strainmeters/seismometers [BHSM/BHS] and 62 GPS receivers. The proposed instrumentation focuses on volcanoes in three regions of Alaska: [1] Cook Inlet/Augustine, Redoubt, Spurr Volcanoes, [2] Alaska Peninsula/Katmai Group and Pavlof, and [3] Eastern Aleutians/Unimak Island, Akutan Volcano, Okmok Caldera (Figure 2). This covers eight critical volcanic centers and provides for minimal additional instrumentation

along about half of the Aleutian subduction zone. Each area contains active volcanoes of differing eruptive styles, magma composition, and chemistry. The tectonic setting and history also varies in each of these portions of the arc. Different fundamental geophysical questions can be posed in each subregion. In the following section we will outline the science goals that can be addressed with these instruments and how these will be approached in each region. All instrumentation would be tied into the backbone GPS network in Alaska.

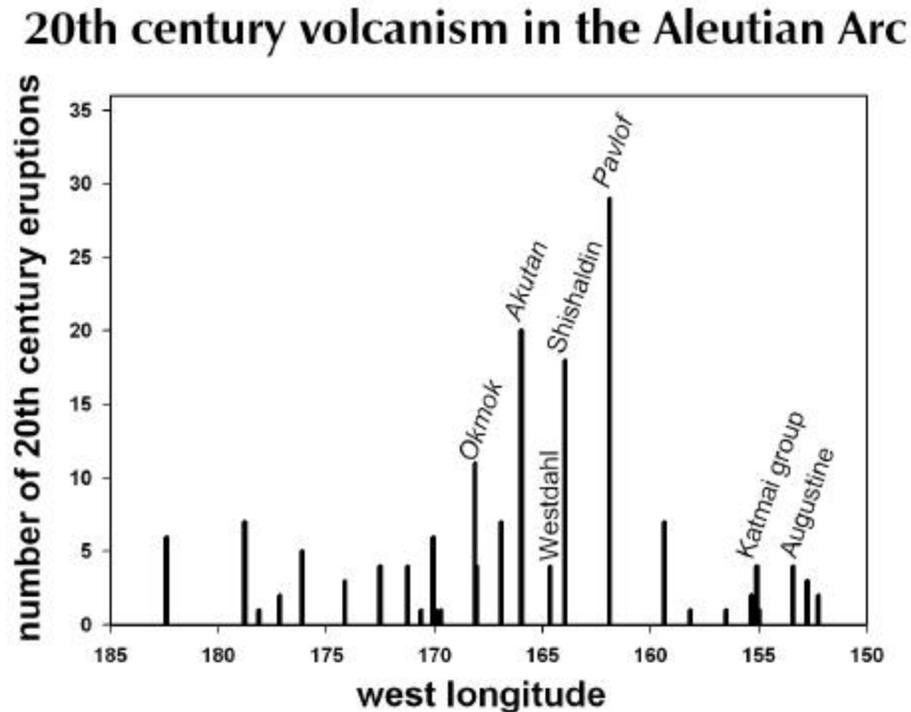


Figure 1. Recorded eruption frequency for Aleutian Arc between 1900 and 1999 plotted against west longitude (source: Tom Miller – based on CAVW – Aleutian). Labeled volcanoes are proposed for instrumentation as part of the PBO.

### Science Goals

- Obtain real-time data on the size and location of magma chambers, the dynamics of magma transport, and the geometry of intrusive bodies as they evolve before, during, and after eruptions.
- Determine the inter-relation between volcanic and tectonic deformation using GPS and BHSM.
- Develop a suite of continuous deformation measurements at a number of active volcanoes that cover the full range of eruptive style and magma chemistry.

- Combine BHSM and BHS data to isolate the mechanics, geometry and implications of long-period (LP) events, very long period (VLP) events, volcanic tremor, and other volcanic seismicity and strain transients.
- Determine the degree of remote and static triggering of volcanic intrusions and earthquake swarm activity on active volcanoes using BHSM and BHS data.
- Determine the relative frequency and importance of both static and dynamic triggered seismicity.
- Measure regional tectonic strain and its variations through each region and on a broader scale using continuous GPS.

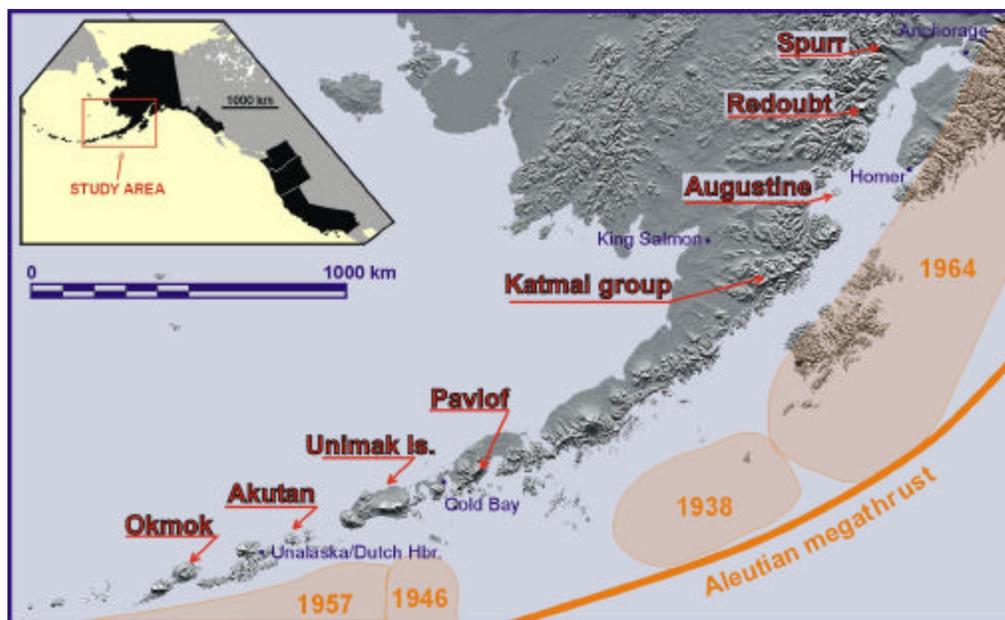


Figure 2. Volcanoes proposed for PBO instrumentation in the Aleutian Arc. Rupture zones of the 1964, 1938, 1946, and 1957 earthquakes are also shown.

### Design Philosophy

We believe the most appropriate strategy for PBO to follow at Aleutian volcanoes is to deploy smaller, yet still adequately dense networks on a number of active volcanoes that span the entire range in eruptive style and character. We propose to instrument eight volcanic centers. The basic deployment would consist of four BHSM/BHS and 8 GPS receivers. This level of instrumentation would allow us to locate 1 BHSM/BHS and 2 GPS receivers in each quadrant at five of the selected volcanoes. Because of the need to understand the relationship between volcanic and tectonic strain we have also included a few GPS receivers as far-field references for each of the volcanic centers. At some centers we have altered this instrument configuration to focus on particular scientific objective or to avoid duplication of

instrumentation proposed independently. In areas where volcanic deformation is more distributed spatially, such as Unimak Island, we would only deploy GPS instruments. Campaign surveys of GPS as well as geologic investigations would provide greater detail in areas of special interest. In areas where borehole water level data are available campaign gravity surveys would also be pursued. Clearly, the numbers of instruments are not adequate for solution of all questions posed, but tight instrumentation in a few critical places and broader coverage in others should provide a guide to future studies. Although some of these volcanoes are remote, AVO has installed and successfully operated seismic nets on most of them, and we are confident that PBO instruments can be installed and operated at all of these centers.

## **CENTERS OF FOCUS:**

### **Cook Inlet: Augustine, Redoubt, Spurr**

Request: 9 GPS, 5 strain

This region has several active volcanoes (Augustine, Redoubt, Spurr) that have erupted in the past 15 years. We plan to focus on Augustine volcano because of its frequent eruptive history, the composition of magmas, past eruptive style, and the hazard it presents to local communities. In 1991 Augustine was chosen as a focus volcano for deformation measurements by the AVO. 4-telemetered GPS receivers, 6-telemetered tiltmeters, 10 short-period seismometers, and 1 broadband seismometer presently monitor Augustine, and a network of 23 GPS monuments occupied in campaign mode. GPS measurements from Augustine indicate that a portion of the summit dome complex is unstable and has subsided 0.55 m since measurements began in 1992. Roughly 10 – 20 microearthquakes are located each month within the summit dome complex, although the aperture of the existing network precludes clear observations of the deeper ( $Z > 4$  km) magmatic system. Four borehole strain/seismic systems and four additional GPS systems would be installed on Augustine Island using the 200-m borehole casings as benchmarks. A fifth borehole system with a GPS would be installed on the western shore of Cook Inlet, 15 km west of Augustine to provide additional control on deep processes under the volcano. Two GPS would be installed on Mt. Spurr and Redoubt volcanoes; these volcanoes are less likely to erupt within the next ten years but these volcanoes with recent eruptions will allow us to study how magma may accumulate during inter-eruptive periods.

The GPS instruments in this region would be integrated into the larger-scale backbone network for Alaska and the network of instruments proposed independently to study post-seismic response effects of the 1964 Great Alaskan earthquake.

### **Alaska Peninsula: Katmai Group, Pavlof**

Request: 20 GPS, 8 strain

The volcanoes of most interest here are the Katmai group (Martin, Mageik, Trident, Novarupta, Mt Katmai, Griggs and Snowy) and Pavlof. The Katmai volcanoes are of interest as they have a high rate of volcanic seismicity, ongoing deformation near Trident, are the site of remotely triggered seismicity, and have a number of suspected shallow crustal

accumulations of magma. Pavlof is the most active volcano in North America (Figure 1) and its eruptions are significantly (> 99.9% confidence) clustered in the fall when non-tidal ocean loads are at their greatest amplitude (ocean loads are driven by forced circulation in the Gulf of Alaska). We will determine the transfer functions for tidal and non-tidal strains, and place constraints on models of magma transport and eruption. AVO seismic networks presently monitor both of these volcanic centers. Four of the BHSM/BHS systems would be installed in the Katmai region and four on Pavlof. Each center would have eight GPS within the volcanic area and the balance deployed in a regional configuration (from Kodiak to Bristol Bay which is near the southern end of the 1964 rupture zone (Figure 1) and throughout the Shumigin Islands and Shumagin seismic gap) to observe strain associated with the Aleutian subduction zone.

### **Eastern Aleutians: Unimak Island, Akutan, Okmok**

Request: 32 GPS, 8 Strain

The eastern Aleutian region is of interest both volcanically and tectonically. This region encompasses: 1) three frequently active volcanoes (Shishaldin, Akutan, and Okmok), 2) four volcanoes known to be currently deforming (Fisher Caldera, Westdahl, Akutan, and Okmok), 3) a transition from continental to oceanic crust in the overlying plate, 4) the eastern portion of the 1957 M8.6 rupture zone, and 5) the rupture zone of the 1946 M7.5 Scotch Cap earthquake. Short-period seismic networks operated by AVO currently monitor each of these volcanoes except Okmok, where a network is planned by AVO within the next few years. Elevated microseismicity continues following a 1999 eruption of Shishaldin and a major seismic swarm and magmatic intrusion at Akutan in 1996. SAR interferometry indicates that ongoing deformation is presently occurring at Fisher, Westdahl, Akutan, and Okmok. In this area four BHSM/BSS instruments would be deployed on Akutan Island and Okmok with 8 GPS units deployed on each center respectively. 16 GPS units would be deployed on Unimak Island (covering three volcanoes: Shishaldin, Fisher and Westdahl). A smaller number of GPS receivers are proposed for Unimak as the volcanoes here are tightly clustered and the instruments on the flank of one volcano can also serve to monitor the neighboring system.

The BHSM/BHS and GPS instruments in this region would be integrated into the larger-scale backbone network for Alaska and the network of instruments proposed independently to study plate coupling along the Aleutian subduction zone.

### **Total Requested Resources 61 GPS, 21 strain**

#### **PBO Working Group for Alaskan Volcanoes**

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