Seismic Studies in the Mount Peulik/Becharof Lake area, Alaska

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Background:

The Mount Peulik/Becharof Lake area (MPBL) is located on the Alaska Peninsula approximately 530 km southwest of Anchorage (Figure 1). This region includes a number of important transitions in magmatic-tectonic trends: 1) A major subduction zone segment boundary defined by the western extent of the 1964 Great Alaskan Earthquake (M_w 9.2) and the eastern extent of the 1938 M_w 8.2 earthquake; 2) A dramatic change in volcano spacing and alignment between the tightly-spaced Katmai volcano group to the east and Chiginagak, Aniakchak, and Veniaminof volcanoes to the west (Figure 2) (this change is also associated with the southern terminus of contiguous mountains that make up the Alaska Range); 3) A hypothesized zone of crustal weakness, defined by the volcanic vents of Mount Peulik and the Ukinrek Maars (Figure 2), several lineaments along the southwestern shoreline of Becharof Lake, and anomalous shallow seismic swarms occurring in 1977 and 1998 near Becharof Lake (Figure 2). Each seismic swarm occurred in association with nearby magma movement; the 1977 swarm in association with the eruption of Ukinrek Maars (Estes, 1978; Kienle et al., 1980), the 1998 swarm in association with magma intrusion beneath Mount Peulik, detected via InSAR, that may have triggered the swarm (Lu et al., in press).

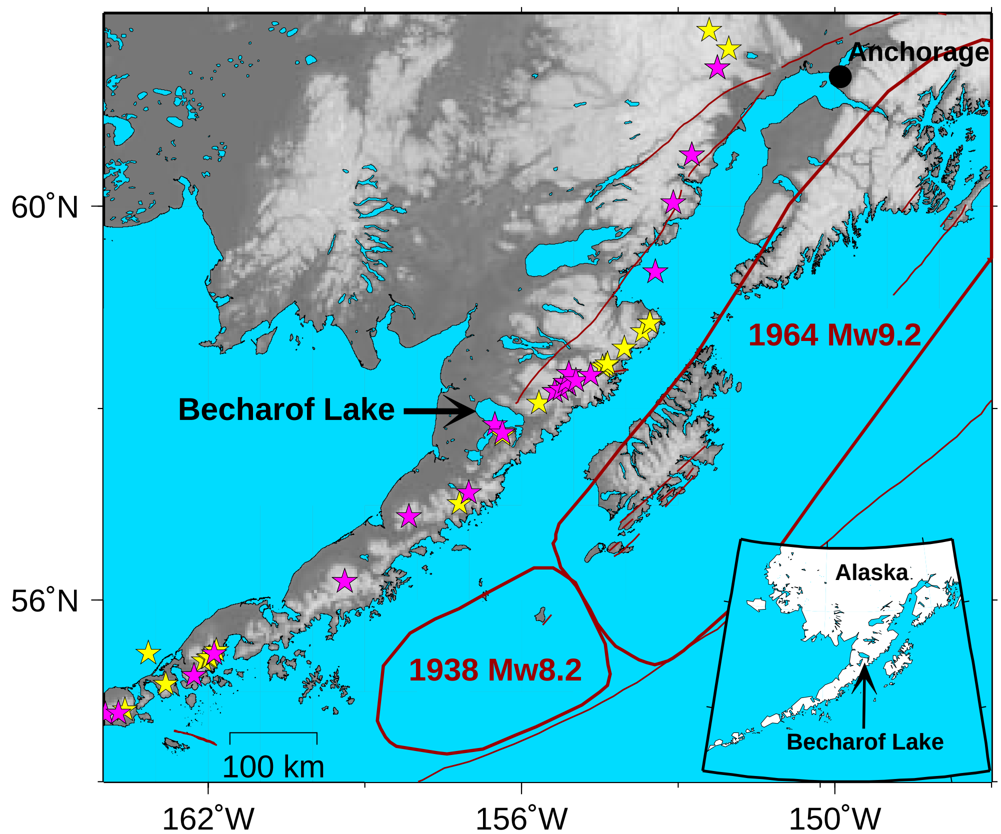

Figure 1. Map showing the location of the Mount Peulik/Becharof Lake area. Also plotted are locations of major faults (brown lines), rupture zones for the Mw9.2 and Mw8.2 earthquakes, Holocene volcanic centers (yellow stars), and historically active volcanoes (pink stars).

The spatial coincidence of these transitions suggests that there may be strong coupling between the segment boundary in the subducting slab and the overlying crust. Evidence for a well-established path to the mantle comes from the Ukinrek Maars, formed in 1977 during a 10-day-long eruption of alkali olivine basalts in a location where no volcano had previously existed. They represent one of the few examples of back-arc volcanism in Alaska (Miller et al., 1998). The olivine basalts produced by this eruption were mantle-derived (Kienle et al., 1980), as is the CO_2 that continuously issues from the nearby Gas Rocks (Barnes and McCoy, 1979).

Seismic monitoring in the MPBL has been sporadic and sparse over the last 25 years. The Alaska Volcano Observatory (AVO) currently operates networks of short-period, predominantly vertical-component, seismometers in Katmai National Park (green triangles in Figure 2) and Aniakchak National Park (145 km SW of Becharof Lake) installed in 1995-1998 and 1997, respectively. No "permanent" station has ever operated within the MPBL, although several temporary sites were located near the Ukinrek Maars in 1976-1979 and 1998 after the swarms had already begun. Thus many events in the 1977 and 1998 swarms were poorly recorded, and as a result many important characteristics of the swarms (such as epicentral lineations, fault-plane orientations, and accurate depths) are unavailable due to high location errors and detection thresholds.

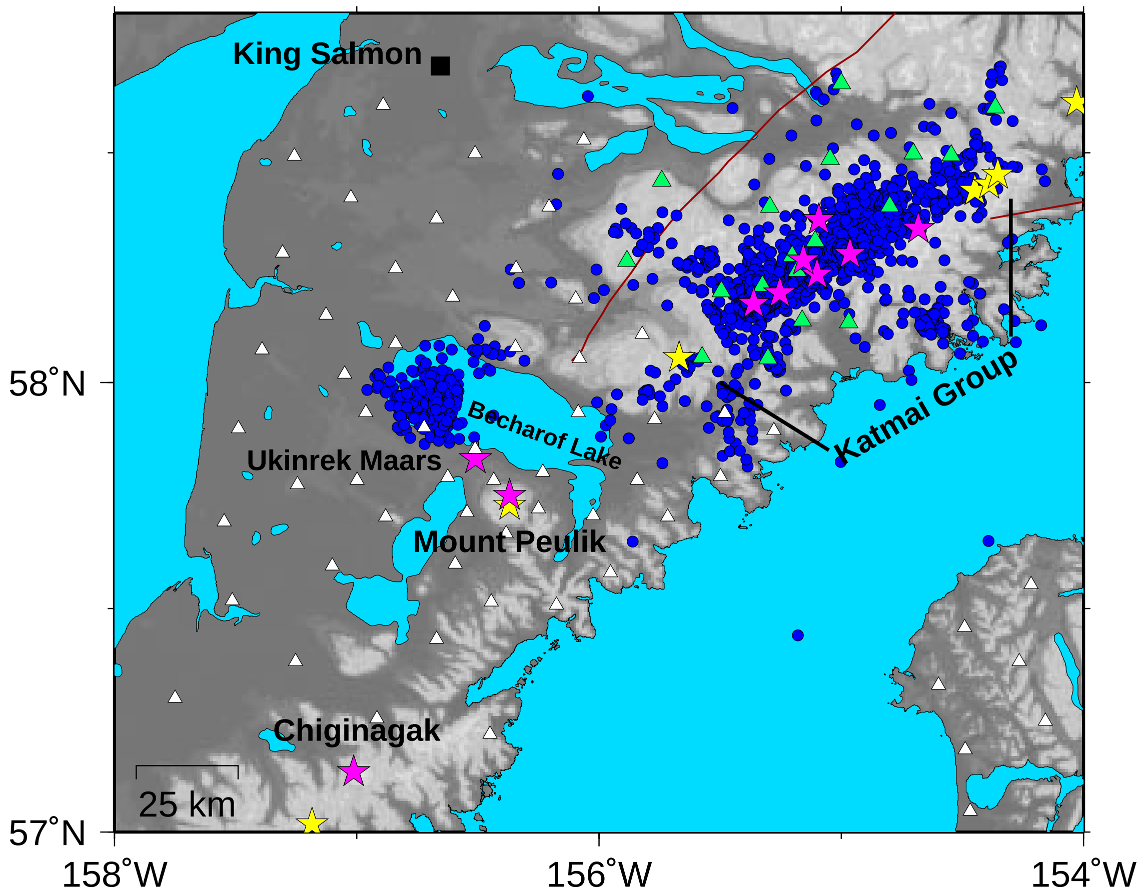

Figure 2. Map showing major faults (brown lines), volcanic centers (same symbols as in Figure 1), and 1995-2001 crustal seismicity (blue circles) in the MPBL. All earthquakes shown were located using short-period stations (green triangles) operated by AVO. White triangles represent proposed locations of 60 short-period and/or broadband AVO/ANSS/USArray seismic stations; note that seismometer spacing is densest near (currently) unmonitored volcanic centers and seismicity. The final array configuration will depend upon the number of available seismometers.

Goals:

For an area as geologically interesting as the MPBL, remarkably few geologic and geophysical studies of anything more than a reconnaissance nature have ever been performed. Thus there are many first-order questions to address in this area. Specific goals of our proposal include:

- Construct a detailed 3-D velocity image of the upper crust to a) enable first-order “mapping” of the subsurface, with the main goal of identifying significant discontinuities possibly corresponding to seismogenic faults, and b) enable much higher-precision locations of local earthquakes.
- Determine the relationship, if any, between known and/or hypothesized local faults and seismicity and volcanism in the MPBL.
- Establish the degree and nature of coupling between the segment boundary in the subducting Pacific plate and the overlying North American plate. Such coupling may manifest itself as local perturbations to the regional stress field, as structural discontinuities in the slab and/or overlying plate, as velocity, attenuation, and Vp/Vs anomalies indicative of fluid flow, and/or as shear-wave splitting anomalies associated with preferentially aligned olivine crystals.
- Attempt to constrain the source region and transport path for mantle-derived magmas that fed the 1977 Ukinrek Maars eruption of alkalic olivine basalts.
- Determine whether or not a significant body of magma lies beneath Mount Peulik that would correlate with the presumed locale of the intruded magma body detected in 1998.
- Attempt to image magma-production zones above the subducting Pacific plate. Such images would be used to address the question of whether shallow tectonic forces and structures or magma production rates are the primary factor in controlling the locus of volcanic activity.
- Investigate how “escape tectonics” associated with the southwestern extrusion of the forearc due to the collision of the Yakutat terrane with southern Alaska influences crustal stresses, seismicity, and/or structures in the greater Katmai/MPBL area.

Experiment Strategy:

The above goals would be accomplished with a combination of seismic techniques utilizing data recorded by the Bigfoot component of USArray, potential sites deployed through ANSS, nearby permanent network stations operated by AVO, and a more densely clustered array of USArray instruments placed both in the MPBL and on Kodiak Island (Figure 2). The resultant high density of 3-component stations will enable computation of high-resolution P- and S-wave velocity and attenuation tomography images using recordings of local, regional, and global passive sources (active sources may also be required to provide sufficient resolution in the uppermost several kilometers of the crust; such a project would be pursued independently, but in conjunction, with this proposal). These stations will also enable the computation of well-constrained fault-plane solutions for many more events than is possible with the present sparse permanent networks, and the 3-component instruments will enable computation of moment tensor solutions. Such solutions will enable inversions for stress tensors in different seismogenic regions of the crust (e.g. Moran, 2000) and subduction zone, and will also enable the detection of possible non-double-couple sources in the volcanic regions within and surrounding the MPBL. The 3-component recordings of large regional events and teleseisms would also be used for receiver function and shear-wave splitting studies.

As an initial step, AVO plans to install several short-period vertical-component stations near Becharof Lake and Mount Peulik within the next 1-2 years. Data from these stations will be telemetered in real-time to AVO offices in Anchorage and Fairbanks via King Salmon (Figure 2). King Salmon is an excellent staging area for this project, as it is close to the MPBL, has adequate warehouse storage, and has a fairly large year-round airport from which air-based deployment and maintenance efforts can be based. The new AVO stations will lower the detection threshold somewhat within the MPBL, and therefore enable detection of any small earthquakes that we are currently missing (the detection threshold in the MPBL is currently M_l 2.2 (Lu et al., in press)). This “new” seismicity will in turn be used to better guide placement of the USArray stations.

In order to address the more regional-scale questions raised above, we fully plan on integrating our data with that recorded by other nearby Earthscope PBO & USArray study sites in Cook Inlet & Denali (see proposal by Haeussler et al.) and in the Aleutians (see proposal by Power et al.). The combined seismic recordings from the MPBL and Cook Inlet/Denali areas, for example, may allow for a complete regional-scale 3-D tomographic image from the subducting slab to the surface, which will greatly aide in investigating, for example, magma production zones. Also, the combined stress/strain fields derived from PBO/USArray deployments from the Wrangells (see proposal by Freymueller et al.) through Cook Inlet, the MPBL, and the Aleutians will enable, for example, a more thorough assessment of the degree to which subduction influences stress and strain field orientations in the upper crust through all of southern Alaska.

Expected Results:

The combination of permanent and temporary seismometers in the MPBL will yield the following products:

- High-precision seismicity maps of crustal seismicity, to be used in studies of local and regional seismotectonics.
- High-resolution 3-D Vp & Vs velocity and attenuation models from the crust to the upper mantle, which will enable the imaging of large regions of magma storage and/or magma transport paths as well as the geophysical "mapping" of crustal and mantle structures at relatively high resolutions.
- A detailed map of the stress field across the magmatic and subduction zone segment boundaries, which will play a crucial role in establishing the nature of the relationship between volcanism, crustal seismicity, and segmentation in the subducting slab, as well as in investigations of "escape tectonics" related to the collision of the Yakutat terrane.
- A map of shear-wave splitting vectors for the mantle overlying the subducting Pacific plate, which will place constraints on the nature of mantle-plate coupling.
- A 3-D grid of receiver functions, which will help to identify and constrain the location of any significant accumulations of magma in the crust as well as other major crustal and mantle discontinuities.

These results will yield a quantum leap in our understanding of seismicity, tectonics, and magmatism in a virtually unstudied part of the Alaskan-Aleutian volcanic arc.

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