Kamchatka: Edge of the Plate

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Photo: Katrin Batereau

Installing a PASSCAL seismo-acoustic station at Karymsky Volcano, August, 1997. Jeff Johnson, a student from the University of Washington is connecting a 3 component Guralp 40T. The experiment included infra-sonic accoustic recordings of the explosion events that occured every 5-15 minutes on average.

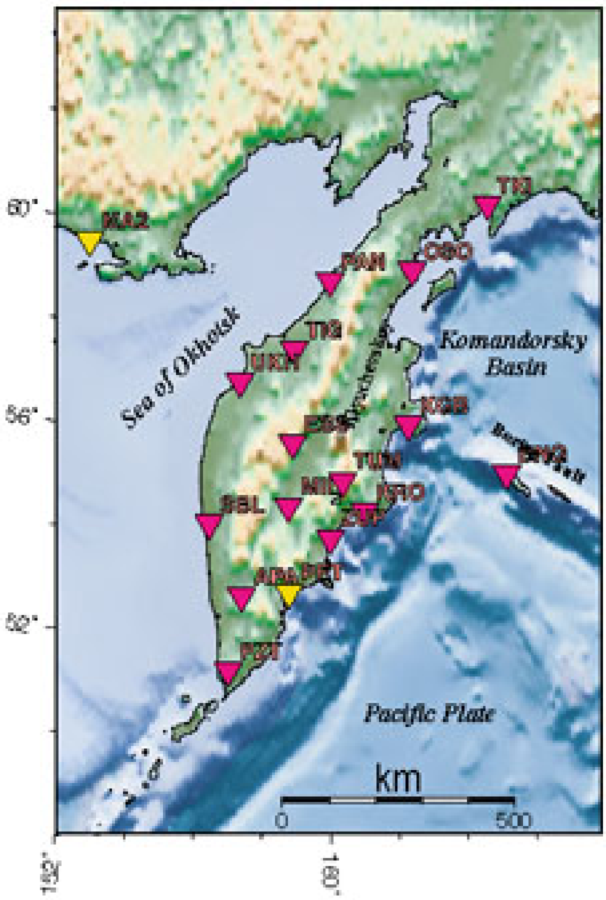
New PASSCAL data have been acquired along the extent of the Kamchatka Peninsula to examine the interaction of the Pacific Plate and the mantle in the corner junction of the Aleutian and Kamchatka trenches. The project, called the Side Edge of Kamchatka Slab, is a collaborative effort between researchers at Yale University and the Russian Academy of Sciences Institutes in Petropavlovsk-Kamchatski, in particular the Institute of Volcanology (Alexey Ozerov) and KOMSP (Evgenii Gordeev). In Russia, Kamchatka is known as the caboose, the last car on the train. It is practically the farthest one can get from Moscow, the center of cultural life in Russia. Being nine time zones away from the financial centers creates a sense of isolation and liberation. For Russians, Kamchatka is a land of dreams and possibilities, much as Alaska is the last frontier for Americans. This gives one the sense that being in Kamchatka is like being on the edge of the world. The majestic volcanoes, the continuous seismicity and the incredible geology are omnipresent reminders that this is a special place. The relentless subduction of the Pacific plate plunges beneath Kamchatka, 70mm per year. Kamchatka is home to 29 active volcanoes, and neighbor to the Bering strike-slip fault, marking the western end of the Aleutian-Komandorsky Islands. This land mass provides an exceptional platform for investigating the interactions of volcanism, tectonics, and mantle dynamics.

We installed 15 broadband PASSCAL instruments along the length of the Kamchatka Peninsula. Each station included a Guralp 3T sensor, housed in an established short-period seismic station or other existing structures to protect against the harsh environment. Nearly all stations had backup power systems, including dry cell batteries, solar panels and local, though intermittent, electricity outlets. During the duration of this installation, Russia suffered significant financial crises, which translated into erratic fuel supply to power stations and considerable chaos in heating and power to individuals and institutions alike. In spite of these

difficulties, we are fortunate to announce at least an 80% return on the seismic signals for most of the duration of the experiment. The high level of technical expertise in the Russian Institutes was critical to the success of our experiment.

Description of the SEKS Experiment

In this PASSCAL experiment we address issues related to the transform-trench double junction in Kamchatka: What are the implications for the crust and upper mantle? The surficial manifestation of the connection is the massive Bering strike slip fault, extending from Attu Island westward towards Kamchatka. In Kamchatka, the margin between the Pacific Plate and North America takes a sharp turn south, towards the Kurile trench and Japan. How does the Pacific plate accommodate this sharp apparent bend? We have proposed a new model for the northern extent of the subducting Pacific Plate and outline the implications for flow in the upper mantle.



Plan view of the SEKS array. The target was to straddle the intersection of the Aleutian Arc (Bering Fault) with the Kamchatka Arc. GSN stations PET and

There are two possibilities to explain the Aleutian/Kamchatka connection. The first employs a laterally continuous slab, the Pacific plate, which subducts uninterrupted below both the Aleutians and Kamchatka. This model requires the Pacific Plate north of Bering fault to move laterally through the mantle and bend around the Kamchatka corner. It predicts the presence of a large body of cold slab in the upper mantle, northwest of the Kamchatka/ Bering intersection. A second, alternative, model is that subduction in Kamchatka is parallel to subduction in the Aleutians, and there is no connection between the slab below the Bering Sea and the slab in the Kamchatka region. In this model a tear between Kamchatka and the Aleutian subduction zones isolates and separates these bodies. Furthermore, the upper mantle would be open to flow through the tear beneath the Komandorsky Basin. It is primarily the secondthe tear-modelthat we consider in this paper. The purpose of our study is to test these alternative models.

MA2 are shown in gold.

The main surface observation connecting the Aleutians and Kamchatka is a very long strike slip fault that starts in the Aleutians and ends in central Kamchatka, slightly north of the Kliuchevskoy group of volcanoes. The Bering fault is over 1,000 km long and has been studied in some detail by Russian and western researchers. Nearly all earlier studies suggest that the Bering fault is strike slip, with relatively shallow seismicity. The Bering fault separates the Komandorsky part of the North American plate from the Pacific plate. Young Komandorsky basin is juxtaposed against much older Pacific slab. The Komandorsky basin contains an older spreading center, which ceased approximately 10 million years ago. There is very high heat flow in the Komandorsky basin, as opposed to heat flow in the adjacent Pacific slab. Gravity studies show that the Komandorsky basin is relatively thin compared to the much thicker, older Pacific plate.

Mantle Dynamics

The implications for a tear in the subducting Pacific plate are numerous and essential for our understanding of mantle dynamics. In the past, researchers have primarily concentrated on two-dimensional models of the flow in the mantle, where slabs are typically represented as infinite planes in a half space. The introduction of a tear, however, forces us to consider the three-dimensional nature of flow in the mantle. What happens near the edge of the exposed end of a subducting plate? How is flow near the edge modified by the more complicated boundary conditions and how do these affect the very nature of the slab itself? Our initial studies have focused on heating of slab by conduction and convective ablation. The shallowing of the seismicity in the northern part of the Kamchatka Arc suggests parts of the slab are potentially missing or have thinned considerably.

Anisotropy

If slab rollback and trench-parallel asthenospheric flow are important, then a northward pattern of mantle flow should be clearly apparent in observations of velocity anisotropy. Initial results from studies of shear wave splitting in the mantle below Kamchatka suggest that there observable trench parallel anisotropy is small below the broadband array or offshore. Several observations in our northernmost stations, however, show significant anisotropy trending northwest-southeast, nearly parallel to the direction of the Pacific Plate. These observations seem to agree with the model that mantle is

Photo: Jeff Johnson

Katrin Batereau and Jonathan Lees install a station on the flanks of Klyuchevskoy Volcano.

In the background are extinct volcano Kamen

straining past the edge of the exposed slab north of the Aleutian-Kamchatka juncture.

and extremely active Bezymianni, the great lateral blast volcano from 1956.

Volcano Geochemistry

Most melts at volcanic arcs are formed in the mantle wedge, but experimental and geochemical research has identified subduction zones where the crust of the slab has apparently melted. Oceanic crust, however, is refractory and much higher temperatures are required to melt it relative to the more liable mantle. These crustal melts, or slab melts, were first described in the Aleutians where they are now called adakites. Their distinctive geochemical signature has been recognized in many places, including the Kamchatka arc. Factors favoring slab melts include subduction of a young (hot) plate, slow subduction allowing heating at shallow levels, and slab edges where asthenospheric heating can produce sufficient temperatures for crustal melting. Volcanoes above the Kamchatka corner show evidence of slab melts. Seismic data provide an opportunity to study the slab for evidence of hot spots where crustal melting might be occurring.

Photo: Jonathan Lees

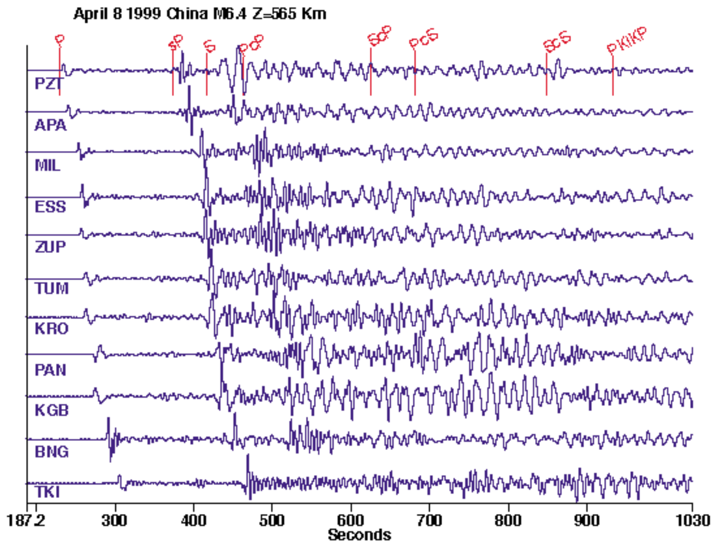
Installation at Zupanova, a station on the coast. A small shelter was used to protect instrumentation from extreme weather conditions. Russian M-8 helicopters were used for transportation to many of the stations in the SEKS array.

Karymsky Volcano

Opportunities for exploring various aspects of geophysics abound in Kamchatka. During the SEKS experiment, we were fortunate to witness the ongoing explosive activity of Karymsky Volcano. Karymsky is located in a vast caldera complex, comparable in size and activity to Long Valley Caldera in California. On January 1, 1996, a M7.0 earthquake triggered massive eruptions of Karymsky Volcano and nearby Karymsky Lake. Since the initial eruptions, Karymsky has continuously erupted in Strombolean mode, exploding every 5 to 15 minutes for nearly 4 years. The numerous, repetitive small explosions provide excellent multiplicity of volcanic events, recorded annually by the members of the SEKS working group and students. In addition, observations of infrasonic acoustic (Jeff Johnson, University of Washington), COSPEC (Phil Kyle, New Mexico Inst. Tech; Toby Fischer, Berkeley), gravity (Emily Brodsky, Caltech), GPS (Dan Johnson, Central Washington University) and petrologic analyses (Alexei Ozerov, Institute of Volcanology, RAS) are being combined to distinguish models of conduit dynamics that control explosive activity. Our efforts in Kamchatka thus span several orders of magnitude in scale, from mantle to volcano conduit dynamics.

Conclusion

While the challenges were daunting, we found the overall experience of working in this remote part of the world rewarding and exhilarating. Initial inspection of the data suggests we have a unique data set illuminating the subduction zone, the volcanic front and the tectonic relations between the active Kamchatka arc and the Bering-Aleutian transform.



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Event recorded on SEKS array on April 8, 1999, from a M6.4, 565 km depth earthquake in southeast China. Several predicted phase arrival are shown for reference. The data was filtered with a lowpass cutoff at 5 Hz. Only vertical components are shown.

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