Volcanism and Subduction
The Kamchatka Region

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Editors

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PREFACE

Long before introduction of the subduction paradigm, it was recognized that there was a “Pacific Ring of Fire” characterized by explosive eruptions, devastating earthquakes, and far-reaching tsunamis. This belt of closely coupled tectonism and volcanism girdles a hemispheric ocean. We chose a segment of this ring as the subject of this volume, a choice that deserves some explanation. An astronaut arriving here, had Earth’s oceans gone the way of Mars’ oceans, would certainly be drawn to this deep kinked furrow in the planet’s skin, but there are more reasons than topography.

One reason is the high level of activity. Five of Earth’s ten largest earthquakes of the 20th century occurred in this segment, and over a span of only 12 years. Volcanism is likewise robust. Exceptional volcanic events include the great Katmai/Novarupta eruption of 1912, by far the largest on Earth in the last hundred years; the Bezymianny and Shiveluch collapse/Plinian events of 1956 and 1964, respectively; and the Great Tolbachik Fissure Eruption of 1975 with a vent span of 30 km. At this writing, 5 volcanoes of the Kurile-Kamchatka system and 3 of Aleutian-Alaska are in continuous to frequent intermittent low-level eruption. Tsunamis of the past century have obliterated whole villages, Severo-Kurilsk in 1952 and Valdez, Alaska in 1964. Here is a place where Earth’s interior dynamics are illuminated dramatically and sometimes tragically by earthquakes, deformation, and melting.

Obviously the activity does not end at the geographic limits of this volume. Vigorous subduction continues uninterrupted south of the Kuriles into Japan. At the other end, volcanism but not seismicity diminishes in southeastern Alaska where the plate boundary becomes the Queen Charlotte transform fault of western Canada. The chosen segment does, however, coincide with relative lack of visibility within the global geoscience community. This is somewhat ironic, because the Aleutian arc is a place where important aspects of the subduction paradigm were first introduced.

One impediment to science in this region is the harsh environment. The weather is often cold and stormy, and supply points are few and far. In most cases, a helicopter or ship or both are required. The high cost of transportation and support are exacerbated by the need for budgeting weather days. Scientists stuck in bad weather and unaccustomed to this fact of northern life have been known to contact their embassies for help in improving flying conditions. Field seasons are generally limited to mid June to mid September, and maintaining operation of geophysical instruments through the long winter is difficult. A team or expedition approach to field work is often needed, though happily this has benefits in encouraging cross-discipline collaboration and cross-culture understanding.

The new driving force toward scientific understanding of this part of the world is the concern shared by all governments about natural hazards. Significant local populations are at risk to earthquakes and eruptions, and the entire northern Pacific basin is at risk to tsunamis generated here. For volcanology, the risk for jet aircraft encountering ash clouds from explosive eruptions has motivated rapid growth of volcano observatories in Alaska, Kamchatka, and in Sakhalin for the Kuriles. Some 25,000 passengers and equally impressive amounts of cargo are carried by roughly 200 large aircraft per day along the Kurile-Kamchatka-Aleutian volcanic line en route between eastern Asia and North America. Approximately one hundred volcanoes in this subduction segment are capable of erupting ash clouds to flight levels.

Before the growth in volcano monitoring, for which a triggering event was the near-disastrous encounter of a wide-body passenger jet with an ash cloud from Redoubt volcano over southcentral Alaska in 1989, only the Soviet Union maintained volcano observatories in the region. Alaska Volcano Observatory (AVO) now employs dense seismic networks on 30 volcanoes, as well as continuously recording, telemetered GPS networks on four of them. The Kamchatka Volcanic Eruption Response Team (KVERT) monitors 10 Kamchatka and northern Kurile volcanoes seismically in real time. Both in Kamchatka and Alaska, a great deal of work has gone into developing stand-alone telemetered geophysical stations that can withstand the rigors of the environment for long periods without expensive helicopter visits.

An important parallel development was the use of satellite-based remote sensing observations to detect and warn of volcano unrest and eruption. Nowhere in the world is satellite data used so intensively for volcano hazard mitigation as at the observatories of Alaska, Kamchatka, and Sakhalin. Rapidly advancing technology has changed not just the resolution of satellite systems but also the kinds of data that can be acquired, including volcano deformation, eruption cloud composition, and estimation of effusion rate. Although seismic data from dense proximal networks remains the preferred means of detecting activity precursory to eruptions, satellite remote sensing makes possible monitoring of volcanoes for which ground installations are prohibitively expensive and provides essential confirmation of explosive ash production where ground stations are present.

Another societal imperative motivating geoscience investigations of active processes is the need for economical, clean, reliable energy for isolated communities. Important use of geothermal energy has been a reality in Kamchatka and the Kurile Islands for some time, and is under serious consideration in Alaska. With concern about oil spills in rich fisheries and rising oil prices, geothermal will likely grow so that northern coastal communities can remain viable.

In order to view the geophysics of this region as a whole and to encourage development of international and interdisciplinary investigations, workers from Hokkaido, Kamchatka and Alaska formed the Japan-Kamchatka-Alaska Subduction Processes Consortium (JKASP). Five biennial meetings, each attracting 100 to 200 scientists and students, have taken place to date: 1998 in Petropavlovsk-Kamchatsky, 2000 in Sapporo, 2002 in Fairbanks, 2004 in Petropavlovsk-Kamchatsky, and 2006 in Sapporo. The present volume is an outgrowth of the birth of this geoscience community.

The contents of the volume span a broad range of disciplines within the general theme of subduction processes. Students will rapidly appreciate that this classic subduction zone lacks the classic simplicity of textbook cartoons, wonder at the relationship of present-day topography to tectonic history, and find that the crowning volcano at Earth’s sharpest subduction corner is not andesite but basalt. For scientists of more southern experience, we hope that the book will serve as a stimulating and useful introduction to the research and the researchers of the far north Pacific. For those who have worked here, we hope that the papers herein will point the way to new connections, collaborations, and directions. Most of all, we hope that through these and other efforts the window of opportunity for collaboration that has opened among Japan, Russia, and the US will remain open; that the Kurile-Kamchatka-Aleutian-Alaska subduction system will be a shared natural geodynamic laboratory of our countries, and indeed of the world.

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Introduction: Subduction's Sharpest Arrow

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In the center of the 6000-km reach of Kurile-Kamchatka-Aleutian-Alaska subduction is arguably Earth's most remarkable subduction cusp. The Kamchatka-Aleutian junction is a sharp arrowhead mounted on the shaft of the Emperor Seamount Chain. This collection of papers provides context, definition, and suggestions for the origin of the junction, but a comprehensive understanding remains elusive, in part because of the newness of international collaborations. Necessary cross-border syntheses have been impeded by the adversarial international relations that characterized the 20th century. For much of this period, Kamchatka and the Kurile Islands were part of the Soviet Union, a mostly closed country. The entire region was swept by World War II, abundant remnants of which are wrecked ships and planes, unexploded ordnance, and Rommel stakes.

Of the three countries with a direct interest in this region, Russia has the longest presence. Russia established settlements in Kamchatka beginning in the early 18th century, then colonized the Aleutians, Kodiak, and southeast Alaska following A. Chirikov's and V. Bering's discovery voyage from Petropavlovsk-Kamchatsky in 1741. Hokkaido was the last territory area added permanently to Japan, during the latter half of the 19^{th} century. Similarly, the United States purchased the Aleutians and Alaska from Russia in 1867 in the interest of territorial expansion, whaling, and harvesting of fur.

The strategic importance of the region to the US and Russia increased dramatically with World War II, when Japan began launching military operations from the northern Kuriles and occupied the American Near Islands (so named because they are close to Kamchatka) of the Aleutians. At the same time, Alaska and Kamchatka airfields were needed to ferry materiel in support of the Soviet Union's war effort against Nazi Germany. An immediate American response to these events was to build a road through Canada to Fairbanks, providing what is still Alaska's only land link to the rest of the United States. In contrast to Alaska, Kamchatka is geographically continuous with Russia but still lacks a land transportation connection. During the war, American soldiers wrote of the Aleutian Islands as a sort of cold, damp hell, while American school teachers more often described them as a flower garden with an advanced native culture. In any case, they were a remote and exotic place to those Americans who even knew they existed. This is still the largely true, and few Americans are aware of the hardships the Aleuts endured during the war, nor of the rich legacy of Russian culture that persists in Alaska among Native people.

Hardly better for science than World War II was the Cold War. The situation changed from the US and Soviet Union allied against Japan to the US and Japan allied against the Soviet Union. Kamchatka and Alaska became armed camps, with the US testing its largest nuclear weapons on Kamchatka's doorstep in the western Aleutians and with Kamchatka off-limits even to most Russians. The Soviet Union did, however, maintain a robust geoscience effort in Kamchatka. Likewise, the United States, in part in support of defense activities, conducted extensive geological and geophysical work in the Aleutians.

The end of the Cold War brought an end to most travel prohibitions. A lingering border dispute over the southern Kuriles is now being addressed in a positive way by Russia and Japan in terms of access for hazard monitoring and science. But easing of tensions did not make travel easy, only possible. Issues of expense, language, culture, and cumbersome visa procedures remain. Air routes are inconvenient and expensive.

For Russians, the Kurile-Kamchatka-Aleutian-Alaska region is a fabled part of their history, and Kamchatka is the one place in their vast country where spectacular volcanism and the greatest earthquakes can be studied firsthand. It is perhaps not surprising, then, that only recently did the state of knowledge of Aleutian/Alaska volcanoes reach the level of knowledge about Kamchatka volcanoes. The record of eruption from historical documents and careful tephrochronology in Kamchatka, some of which is presented here in the overview paper on volcanism by V. Ponomereva and coauthors, still surpasses that of Aleutia/Alaska. The Kurile Islands, posing transportation and telemetry difficulties in their central portion and lingering international tension in the south, remain the least known.

The positioning of the Emperor seamount chain as the shaft at the Kamchatka-Aleutian arrowhead may or may not be a coincidence, but what seems not a coincidence is the prodigious rate of magma production inboard of this junction, represented by the largely mafic Kliuchevskaya group and its more silicic northern neighbor, Shiveluch. In this volume, M. Portyangin and coauthors suggest an answer in large-scale slab melting, as the Pacific slab, torn open under the western Aleutians, dives into hot mantle under Kamchatka. In tectonic overview papers, G. Avdieko and coauthors and D. Scholl wrestle with the meaning of the cusp from vantage points from the west and east of it, respectively. A. Lander and M. Shapiro focus on constraining the onset of the modern volcanic and subduction regime of Kamchatka with seismic data. Intriguing related problems are the welding of arc fragments to Kamchatka as the eastern capes, the origin and behavior of neighboring microplates, and the apparent double arcs of Kamchatka, one young and robust and the other old and dying.

On either side of the arrow's point are two almost matching arc pairs: continental Kamchatka Peninsula with oceanic Kurile Islands, and continental Alaska Peninsula with oceanic Aleutian Islands. We use the term "arc" for the volcanic expression of subduction in deference to history and to economy of letters, but the volcanoes more properly comprise "supra-subduction zone volcanism". Much of the segment of interest is not an island arc because, except for the Aleutians, the arrangement is not arcuate and, except for the Aleutians and Kuriles, the volcanoes are not islands. The arcuate shape seems irrelevant and to call continent-sited volcanoes "islands" is even worse. Continental margin subduction faithfully follows the shape of the unsubductable continental margin, as is clear along Kamchatka and Alaska. Kurile subduction is a straight line pinned to continental margins at both ends, Hokkaido and Kamchatka. D. Scholl suggests that the Aleutians, a true arc and perhaps an inspiration for the term, "budded" off continental margin subduction of the Alaska Peninsula and progressed westward, turning to the right as it went until it was parallel to Pacific Plate motion and became a transform fault. We should perhaps view the western end as "free", unconstrained by a continental margin because it is perpendicular to it, and hence able to migrate in either direction. Confusingly, arguments can be made for migration in either direction: southward because older "supra-subduction zone volcanism" extends north of the current junction and northward if the east coast capes of the Kamchatka Peninsula represent prior positions of the junction. Indeed, the current plate boundary, the “corner” representing the northern limit of the subducting Pacific plate, is not where the Aleutian arc/trench pair meets Kamchatka but north of this at a back-arc shear zone. Bering Island seems destined to become another cape on the east coast of Kamchatka.

Scholl argues that the Aleutians, and Avdeiko and coauthors and Lander and Shapiro argue that the eastern volcanic front of Kamchatka, record a large forward jump in volcanism due to jamming of subduction by arc fragments. For the Aleutians, this resulted in capture by North America of the Bering microplate. But now the western Aleutians are being fritted and torn from the North American/Bering plate. For Kamchatka, the postulated jump caused the death of Sredinny Range volcanoes and rise of the prolific and caldera-rich volcanism of the eastern Kamchatka Peninsula. It would seem then that the only steady state subduction regimes are the Kuriles and the Alaska Peninsula, though the latter has a relative dearth of older volcanic rocks on its Mesozoic basement, giving the impression of a very recent start to volcanic growth. These interpretations remain speculative. For example, Scholl observes that the age of Bering microplate crust is poorly known and Ponomareva and coauthors show that the Sredinny Range can be viewed as back-arc volcanism arising from the modern subduction configuration.

The volume is divided into three themes: tectonics, earthquakes, and volcanism. Each section begins with one or more overview papers that not only provide background and context, but also new ideas. They are followed by topical studies focusing on specific features or processes. Of course, the ultimate goal should be a holistic view that encompasses all these manifestations of subduction. It is clear that we are far from that. But although the discussions of tectonics are highly speculative, they pose hypotheses that are clearly testable with more data on age and origin of terranes and on current rates of deformation. Perhaps the greatest progress is evident in seismology, with an understanding of earthquake distribution in time and space based on slab age, convergence rate, stress distribution, and formation of asperities. The diversity of volcanic expression of subduction, in contrast to all other tectonic domains, seems most resistive to solution, though increasingly under attack by new sophisticated geochemical techniques and synthesis with geophysical results. An accompanying DVD provides a view of eruptions in Kamchatka and of the style of field work conducted there not previously available outside Russia.

If there is one place where tectonic, seismic, and volcanic interpretations seem to be converging, it is the arrow itself. The subduction of the torn Pacific plate corner, the seismically inferred rounding of its leading edge, and geochemical inference of a large slab component in resultant eruption products are internally consistent. It is towards such a synthesis of geological, geophysical, and geochemical techniques at the micro and macro scales that this volume strives.

Section I: Tectonics and Subduction Zone Structure

Viewing the Tectonic Evolution of The Kamchatka-Aleutian (KAT) Connection With an Alaska Crustal Extrusion Perspective

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The Kamchatka and Aleutian (KAT) arc-trench systems meet orthogonally at Cape Kamchatka Peninsula. The KAT connection is the intersection of the NE-striking Kamchatka subduction zone and the NW-striking, transform setting of the western, Komandorsky sector of the Aleutian Ridge. Deciphering the origin and evolution of the KAT connection is challenging because of the paucity of constraining information about the age and latitude of formation of major crustal blocks of the deep water Bering Sea Basin.

It is proposed that in the late early Eocene (~50 Ma) the combined tectonic machinery of subduction zone obstruction and continental margin extrusion created the tectonic and rock architecture of the Aleutian-Bering Sea region. Accretion of the Olyutorsky arc to the north Kamchatka-Koryak subduction zone forced the offshore formation of the Aleutian subduction zone (SZ), added a sector of Pacific crust—Aleutia—to the North America plate, and established the KAT connection. Subsequently, but also