PENROSE CONFERENCE REPORT

Arc Crustal Genesis and Evolution

Valdez, Alaska, USA

9–15 July 2006

Conveners:

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The Penrose Conference on arc crustal genesis and evolution was convened in Valdez, south-central Alaska on 9–15 July 2006 near the accreted Jurassic Talkeetna arc. In general, presentations integrated recent results on well-exposed arc crustal sections—in the Jurassic Talkeetna arc in south-central Alaska and in the Cretaceous Ladakh-Kohistan arc in northern Pakistan and India—with important new developments in active-arc geochemistry, petrology, and geophysics. The Talkeetna and Ladakh-Kohistan arcs provide exposures of relatively complete sections from Moho depth (30–40 km in both cases), to volcanic rocks and volcaniclastic sediments, and depth sections and temporal progressions that are not accessible in active oceanic arcs. Both areas have been the subject of large, multidisciplinary projects over the past decade, including the Talkeetna Continental Dynamics Project funded by the U.S. National Science Foundation.

Recent intensive investigations of arc plutonic suites elsewhere complement these projects. New data from the MARGINS Initiative, Sierra Nevada Continental Dynamics Projects, Aleutian studies, and similar international initiatives provide constraints on crustal thickness and volcanic fluxes in active arcs. Studies of ultrahigh-pressure metamorphic rocks and new experimental methods have yielded insights into mantle-wedge melt generation and subduction-zone dehydration and anatexis. This conference provided an opportunity to synthesize these results, with a focus on direct observations of arc crustal sections, from the uppermost mantle to the volcanics, that constrain arc processes and their role in the genesis and evolution of continental crust.

Fifty-five participants engaged in discussions of new developments in arc geochemistry, petrology, tectonics, and geophysics while overlooking the waters of Prince William Sound. The Talkeetna arc was showcased by day-long field trips to the volcanic carapace (led by Peter Clift and Amy Draut) and Moho (led by Luc Mehl) in the Chugach Mountains, and to the Red Mountain mantle tectonite south of Homer, Alaska.

Peter Kelemen kicked off the conference with an overview of the Talkeetna arc and implications of recent discoveries for arc crustal genesis. Matt Rioux followed with a description of the geochronology and the Talkeetna section in the Chugach and Talkeetna Mountains. In their papers and presentations at the meeting, Matt Rioux and Andrew Greene provided comprehensive summaries of arc geochemistry in the Chugach and Talkeetna Mountains. Mike Johnsen presented complementary data for the Alaska Peninsula section of the arc. Brad Hacker reported on thermobarometry and thermochronology of the Talkeetna arc and concluded with a discussion of the effects of ultrahigh-pressure and ultrahigh-temperature reworking on the continental crust.

Placing the Talkeetna arc section in a regional context, Sarah Roeske provided an introduction to the tectonics of Alaska, including the Cenozoic history of the Talkeetna arc and related structures. Chris Nye presented detailed geophysical and geochemical data from Recent volcanoes of Alaska. Jeff Freymueller showed GPS data indicating that the locked and creeping segments of the Aleutian subduction zone may control the first-order segmentation of the arc. Brian Jicha presented new $^{40}Ar/^{39}Ar$ ages from the Aleutians that show episodic plutonism and volcanism along the entire arc, with peak periods of activity from 38–29, 16–11, and 6–0 Ma. David Farris used structural relationships in the Kodiak portion of the Talkeetna arc to propose that the arc was exhumed following an episode of subduction erosion during which blueschist units were underplated directly beneath the former arc crust.

As noted, observations of the Talkeetna arc section are complemented by work on the very similar Kohistan arc section in the northwestern Himalaya. Oliver Jagoutz began a series of talks on the Kohistan arc section by discussing Sr-Nd-Pb systematics. Othmar Müntener discoursed on the genesis of garnet in Kohistan, concluding that some of the garnets crystallized during cooling of a melt based on petrography, phase relations, and thermometry. Carlos Garrido offered an alternative interpretation, based on rock textures, that some of the garnet-bearing lower crustal rocks are restites from dehydration melting of amphibole-bearing gabbro. Bruno Dhuime discussed the evolution of the mafic–ultramafic rocks of Kohistan. Pierre Bouilhol talked about the effects of melt infiltration in the lower crust of Kohistan.

Several presentations focused on development of arc batholiths. Linc Hollister described the magmatic, structural, and metamorphic evolution of the Coast Mountains Batholith of Canada. Mihai Ducea described the temporal variations in magma flux through the arcs of western North America. Cin-Ty Lee used observations from the Sierra Nevada and Peninsular Ranges batholiths, and lower crustal xenoliths in the same regions, to conclude that delamination of the lower crust of island arcs is important in the formation of continental crust. Allen Glazner reported on the importance of subsolidus-metamorphic

processes in plutonic rocks, highlighting the long emplacement time scales of some plutonic suites. Dave Kimbrough spoke on the distinct spatial, temporal, and compositional patterns in the Peninsular Ranges batholith, with particular attention to the role of underplating of isotopically primitive accretionary wedge material. Marty Grove presented a compelling story that emplacement of the massive La Posta tonalite-trondhjemite-granodiorite suite of the Peninsular Ranges batholith was triggered by subduction-accretion of the Catalina Schist.

Ongoing studies of active arcs, particularly intra-oceanic arcs in the western Pacific, complement work on Mesozoic crustal sections. Donna Shillington contrasted Aleutian seismological data with velocities calculated for rocks from the Aleutians and Talkeetna. Simon Klemperer gave a tutorial on constraining uncertainties in geophysical models, compared various ways of modeling geophysical data, and presented new P-wave velocity data for the Izu-Bonin-Mariana arc. Patricia Fryer noted that the unusually silicic character of the Mariana arc crust may be due to tectonic erosion exposing crust as old as Cretaceous. James Hawkins documented marked similarities between the Zambales Range ophiolite and rocks from the Mariana Trench, concluding that a supra-subduction zone origin is likely for both. Richard Arculus presented a panoply of recently acquired images, including 70 new volcanoes, from the Tonga-Kermadec arc. Katy Kelley discussed the implications of new measurements of the H_2O contents of magmas on subduction zone magma genesis. Mindy Zimmer used new H_2O measurements from Aleutian volcanoes to argue that H_2O is the primary factor controlling tholeiitic versus calc-alkaline fractionation. Kirstin Nicolaysen showed that recycling of subducted sediment has an isotopic signal in east-central Aleutian arc lavas.

Shifting focus to active continental arcs, Mariek Schmidt gave geochronologic and isotopic evidence that the evolution of the Three Sisters volcano is controlled by processes in the upper and lower crust. Sue Kay spoke on the roles of "flat" subduction, subduction erosion, and delamination on the evolution of the Andean arc. Art Snoke described the magmatic arcs of Tobago and the Ivrea-Verbano zone, emphasizing the interaction between magmatism and deformation. Riccardo Tribuzio interpreted a mafic to ultramafic pluton in the Transantarctic Mountains as the result of formation from a boninite-like primary melt in a backarc continental environment.

Offering specific views of related topics, Neptune Srimal speculated on whether the Cenozoic alkaline magmatism of Tibet was produced by a slab window. Stephanie Briggs presented new ion microprobe zircon ages for the Altai Mountains of NW China, demonstrating Ordovician, Devonian, and Permian crustal growth.

Experimental studies provide an increasingly detailed characterization of the effects of crystal fractionation of arc magmas and at the same time open dramatic new vistas into the range of pressures, temperatures, and bulk compositions that are involved in arc melt generation. Peter Ulmer summarized the results of fractional crystallization experiments on basaltic andesite and picrobasalt and noted that calculated velocities for these rocks suggest that some arc seismic sections likely contain ultramafic cumulates that are being interpreted as mantle tectonite. Tim Grove used new melting experiments on H_2O-saturated peridotite to demonstrate that the H_2O-saturated solidus of peridotite is similar to that determined in much older studies, but colder than has been inferred or assumed in relatively recent work. Max Schmidt summarized a comprehensive suite of experiments on materials at conditions relevant to subduction zones, including a tutorial on super-critical behavior in silicate-H_2O systems at high pressure and temperature. Robert Rapp detailed experiments on the production of adakites by melting of mantle wedge metasomatically altered by slab melts.

Lower crustal and upper mantle processes in arcs were the focus of several presentations. Massimo Tiepolo spoke on chemical disequilibria in mafic magmas, drawing on examples from the Alps and Antarctica. Mike Dungan lectured on the effect of xenolith melting and assimilation on volcanic rock composition, noting that the effect may be most pronounced during the assimilation of mafic rocks by mafic magma. Geoff Clarke presented examples of melt production and garnet granulite formation from hornblende-bearing plutonic rocks in New Zealand. Peter Luffi calculated that water-fluxed melting of vapor-free arc rocks generates mainly trondhjemitic liquids and 3–5 times more garnet than melting in closed systems, concluding that garnet porphyroblasts in trondhjemitic leucosomes need not form by dehydration melting.

Focusing more on tectonics than geochemistry, Jason Saleeby spoke on the deep structures and exhumation of the southern Sierra Nevada batholith, emphasizing the variations in magmatic-structural processes at different depths. Ned Brown showed persuasive evidence that the metamorphic pressures in the Coast Plutonic Complex and Fiordland were caused by magmatic loading. Gene Yogodzinski and Jason Bryant described mafic and ultramafic xenoliths from deep crust and shallow mantle of the Aleutians, whose composition constrains the origin of several different types of primitive lava with widely differing trace element contents.

Taking a more theoretical approach, Greg Hirth gave a wide-ranging overview of the latest developments in the rheology of mafic and ultramafic rocks. Erik Kneller showed the results of calculations using recent experimental determinations of olivine rheology to simulate olivine fabrics in subduction zones. Marc Parmentier showed results of subduction zone models coupling temperature with melt production and flow. Richard Katz presented models of reactive flow and channelized melt transport in subduction zones, showing that cold plumes develop in the hot part of the mantle wedge and hot plumes develop in the crust.

Taber Hersum explained recent work on finite element models that simulate the elastic deformation of partially molten basaltic microstructures and infer wave speeds and yield stress. Thierry Menand presented an analog model of sill injection into the crust, concluding that rigidity contrasts may play a major role in the location and geometry of sills and the development of igneous complexes. George Bergantz assessed the thermal and dynamic response of the lower crust to the intrusion of basaltic dike swarms, showing that thicker arcs produce garnet pyroxenite residues that are convectively unstable. Mark Behn showed how Rayleigh-Taylor instabilities may perturb arc-wedge corner flow and affect densities and seismic velocities.

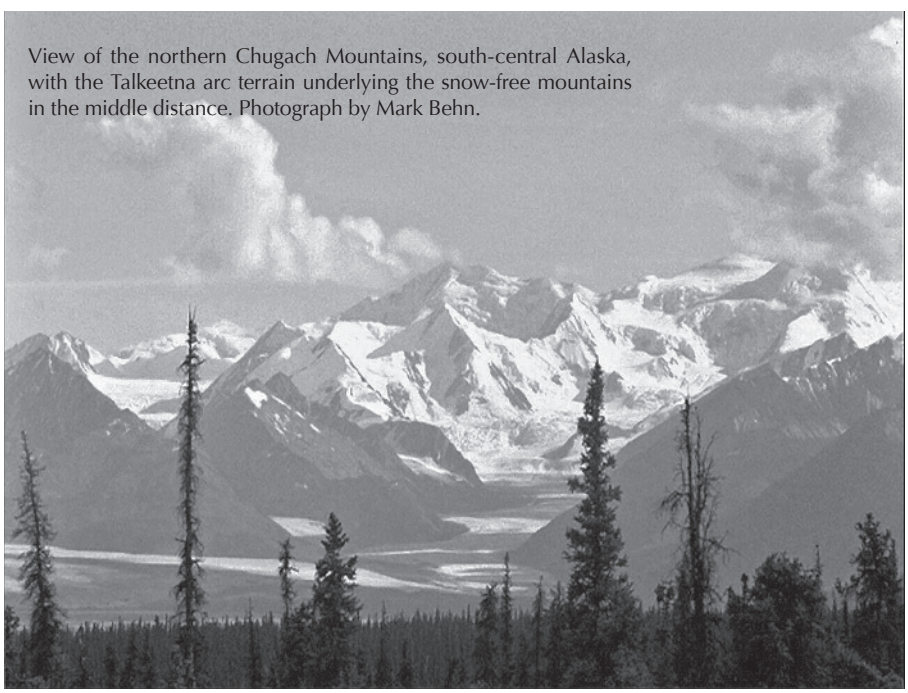
Last, but certainly not least, the genesis of continental crust through arc magmatism and crustal recycling was a central focus

of the Talkeetna Continental Dynamics Project and a theme in many talks at the Penrose Conference. Peter Kelemen and Brad Hacker showed that new bulk compositional estimates for the Talkeetna arc section, informed by thermobarometry indicating the possible depth variation for different lithologies, range from basaltic to andesitic, with the most felsic estimates falling into the range for bulk continental crust. However, Talkeetna trace elements, and even potassium contents, are very different from both Precambrian and Phanerozoic continental crust. This is also true for the tonalitic Tanzawa batholith in SW Japan and its inferred extension in the mid-crust of the Izu-Bonin-Marianas arc system (e.g., presentations by Fryer, Klemperer).

In contrast, some modern arc lavas (western Aleutian) and accreted arc plutons (Peninsular Ranges; Kimbrough and M. Grove presentations) do have the right major and trace element characteristics to form juvenile continental crust. The reasons this varies from place to place remain unclear. In presentations focusing on these and closely related issues, Bob Kay proposed that adakites—lavas close to continental crust in composition—can form from partial melting of crustal material that enters the mantle wedge beneath arcs as a result of subduction erosion. Peter Clift and David Scholl presented separate views of processes and magnitudes of subduction erosion and its effects on trench retreat rates and rates of crustal subduction.

The group gathered for the Valdez Penrose Conference was highly multidisciplinary, with much to learn from each other. The conveners learned a great deal as a consequence, and have received highly positive reports from other participants, focusing on the benefits of such a multidisciplinary discussion. We would like to take this opportunity to thank everyone for traveling so far, both geographically and intellectually, to share results on this important topic.

Participants: Carlos Aiken, Mohammed Alfarhan, Frank Arnott, Jerome (Jerry) Bellian, Richard Blewett, Nicola Boak, Clare Bond, Simon Bukley, Christian Carlsson, Chris Crosby, Mauro De Donatis, Wetherbee Dorshaw, Amy Ellwein, Havard Enge, Luigi Ferranti, Kurt Frankel, Klaus Gessner, Alan Gibbs, Jiulin Cole Guo, Ronan Hennessy, Paul Henson, Bob Holdsworth, Nick Holliman, Andy Howard, John Howell, David Hughes, David Hunt, Jonny Imber, Don Keefer, Tobias Kurz, Zbigniew Malolepszy, Ken McCaffrey, Erik Monsen, Robert Moroz, Ian Mynatt, Iulia Olariu, John Oldow, Douglas Paton, Geoffrey Phelps, Jamie Pringle, Adam Pugh, Steven Smith, Bonnie Souter, Ken Thomson, John Thurmond, Mark Tomasso, Dean Tuck, Erik Venteris, Douglas Walker, Cameron Walsh, Tim Wawrzyniec, and Ruth Wightman.



View of the northern Chugach Mountains, south-central Alaska, with the Talkeetna arc terrain underlying the snow-free mountains in the middle distance. Photograph by Mark Behn.