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Interdisciplinary Studies of Eruption at Chaitén Volcano, Chile

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High-silica rhyolite magma fuels Earth's largest and most explosive eruptions. Recurrence intervals for such highly explosive eruptions are in the 100- to 100,000-year time range, and there have been few direct observations of such eruptions and their immediate impacts. Consequently, there was keen interest within the volcanology community when the first large eruption of high-silica rhyolite since that of Alaska's Novarupta volcano in 1912 began on 1 May 2008 at Chaitén volcano, southern Chile, a 3-kilometer-diameter caldera volcano with a prehistoric record of rhyolite eruptions [*Naranjo and Stern,* 2004; *Servicio Nacional de Geología y Minería* (*SERNAGEOMIN*), 2008; *Carn et al.*, 2009; *Castro and Dingwell,* 2009; *Lara,* 2009; *Muñoz et al.*, 2009]. Vigorous explosions occurred through 8 May 2008, after which explosive activity waned and a new lava dome was extruded.

In early 2010, seismicity, sulfur dioxide emissions of less than 100 tons per day, thermal imagery, and visual observations showed that the lava dome was still growing slowly, but there was no indication of an impending explosion or dome collapse. Capitalizing on this relative quiescence of the volcano, an interdisciplinary team of 21 geologists, geophysicists, geochemists, hydrologists, and ecologists from Chile, the United States, Mexico, Australia, and Italy (for a complete list of participants, see the online supplement to this *Eos* issue (http://www.agu.org/eos_elec/)) conducted an intensive, helicopter-supported field campaign at Chaitén volcano from 19 January to 8 February 2010.

Observations of the Eruption and Aftermath

The Chaitén eruption, having a volcano explosivity index (VEI) of 4–5 [*Carn et al.,* 2009], initially produced spectacular ash columns suffused with lightning to heights greater than 20 kilometers and then transitioned into rapid extrusion of a high-silica (~75% by weight) rhyolite lava dome. Heavy rainfall beginning 10 days after the onset of the eruption triggered extensive flooding and associated wood and sediment deposition, especially along the Rio Chaitén, which drains the southern sector of the volcano. Floodwater and sediment devastated much of the town of Chaitén (population ~5000), a coastal village built on a fan of older volcanic flood and lahar deposits 10 kilometers south of the volcano. Collapse of about 10% of the new lava dome on 19 February 2009 sent a hot pyroclastic flow, which charred trees, to within 3 kilometers of the town [*Duhart et al.,* 2009; *SERNAGEOMIN,* 2009].

Field teams investigated and sampled eruption products on and flanking the lava dome and volcano, conducted stratigraphic studies of the 2008–2009 deposits, surveyed thermal and gas fluxes from the lava dome, and investigated ecologic and hydrologic impacts of the eruption. Researchers mapped and sampled multiple lava lobes on the dome using short-duration helicopter landings within the caldera's moat and helicopter dredging of areas that were otherwise inaccessible. Fieldwork confirms that after the initial explosions, the volcano erupted a rhyolite lava dome, which grew to a size of approximately 500 million cubic meters (see Figure S1a in the online supplement) within about 3 months [*Carn et al.,* 2009]. Like the prehistoric lava dome at Chaitén, the current dome is composed of rhyolite obsidian and microcrystalline rhyolite lava. The rapid eruption rate (averaging ~60 cubic meters per second) is unusual for rhyolite magma, which is generally considered too viscous to sustain such high rates without fragmenting. Photogrammetric analysis of oblique aerial photographs and satellite imagery combined with studies of the petrology of the rhyolite are under way to better quantify and understand the conditions that enabled the rapid eruption rate.

Curiously, the eruption severely damaged extensive tracts of forest despite producing only limited column collapse pyroclastic flows but left trees standing on caldera walls within hundreds of meters of vents opened through the prehistoric lava dome. Field observations documented a directed blast deposit (similar to, but 2 orders of magnitude smaller than, that from the 1980 eruption of Mount St. Helens) within and on the caldera rim and on the north flank of the volcano, and thick volcaniclastic fill in channels on the east and south flanks. The northward blast leveled forest over 4 square kilometers and left a narrow, outer zone of standing trees with scorched foliage and limbs (see Figure S1b in the online supplement).

Altogether, approximately 400 square kilometers of forest in rugged terrain to the north, east, and south of the volcano experienced severe damage. Forest damage in proximal areas beyond the blast-affected area resulted from a rain of tephra that stripped foliage and branches from the forest canopy; from tephra deposition in tree crowns, leading to limb fall; and from possible but as yet unknown physiological effects of tephra and volcanic gases on foliage and of burial of the soil surface by tephra fall deposits. Many species in these native, broadleaf, evergreen forests have the capacity to sprout from scorched, delimbed, and fallen trees, which is influencing ecological responses to the eruption. The diverse taxa and suite of ecological disturbance mechanisms operating at Chaitén make it a rich environment for extending knowledge of volcano ecology.

Sedimentological observations show that during the explosive phase of the eruption, volcaniclastic deposits to 8 meters thick choked the upper reaches of Rio Chaitén, and at least 6 meters of sediment filled the river channel in and near the town of Chaitén during a period of intense rainfall in the waning stages of the explosive phase (see Figures S1c and S1d in the online supplement). Sediment transport, storage, and flooding in the river system have been strongly affected by newly introduced woody debris and local diversion of the river through extensive floodplain forest cover. Sediment overwhelmed the Chaitén airport and parts of the town, rerouted the river through the middle of town, and nearly buried the highway bridge on the only Chilean land route to southern Patagonia, graphically illustrating the hazards posed by volcanic flooding and sedimentation to a vulnerable downstream community. The river is delivering sediment and felled logs to the Gulf of Corcovado, building a delta that extends more than a kilometer from the original shoreline, and threatening the only ferry port in the region. Additional studies are needed to evaluate and forecast the long-term impacts of sediment delivery on local river systems and the gulf.

It has been widely reported that 2008 marked the first eruption at Chaitén in 9400 years [*Naranjo and Stern,* 2004; *Carn et al.,* 2009; *Castro and Dingwell,* 2009]. Volcanoes that erupt after long dormant periods tend to have large eruptions [*Blong,* 1984], a relationship to which Chaitén appears to conform. However, observations of fresh rhyolite pyroclastic deposits, ash beds, and apparently eruption-related flood deposits newly exposed near the surface but below the 2008 deposits raise doubts about the presumed length of dormancy since the last eruption. Observations, as well as historical records [*Guarda and Moreno,* 2008], suggest the possibility that the volcano may have been active much more recently. Radiometric dating and additional stratigraphic and petrologic studies are needed to better understand the volcano's eruptive history.

Current goals in this continuing project are to better understand the magmatic and eruptive processes at this rhyolite volcano and the sedimentological and ecological impacts of its eruption, to glean insights regarding rhyolite eruptions in general, and to forecast probable future activity including downstream hazards and patterns and trends of ecologic change. Efforts are under way to promote further discussion of the Chaitén eruption at future geosciences meetings, including a special session at the 2010 AGU Fall Meeting.

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Atmospheric Remote Sensing on the International Space Station

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The Remote Atmospheric and Ionospheric Detection System (RAIDS) is a new NASA experiment studying the Earth's thermosphere and ionosphere from a vantage point on the International Space Station (ISS). The RAIDS mission focuses on the coupling and transition from the coldest part of the atmosphere, the mesopause near 85 kilometers, up to the hottest regions of the thermosphere, above 300 kilometers in altitude. Built jointly by the Naval Research Laboratory (NRL) and The Aerospace Corporation, RAIDS also is serving as a pathfinder experiment for atmospheric remote sensing aboard the ISS. RAIDS and a companion experiment, NRL's Hyperspectral Imager for the Coastal Ocean (HICO), make up the HICO-RAIDS Experiment Payload (HREP), the first U.S. payload on the Japanese Experiment Module–Exposed Facility (JEM-EF). The experience developing and operating RAIDS for this mission provides useful insights for utilizing the ISS as a platform for atmospheric science.

RAIDS Instrumentation

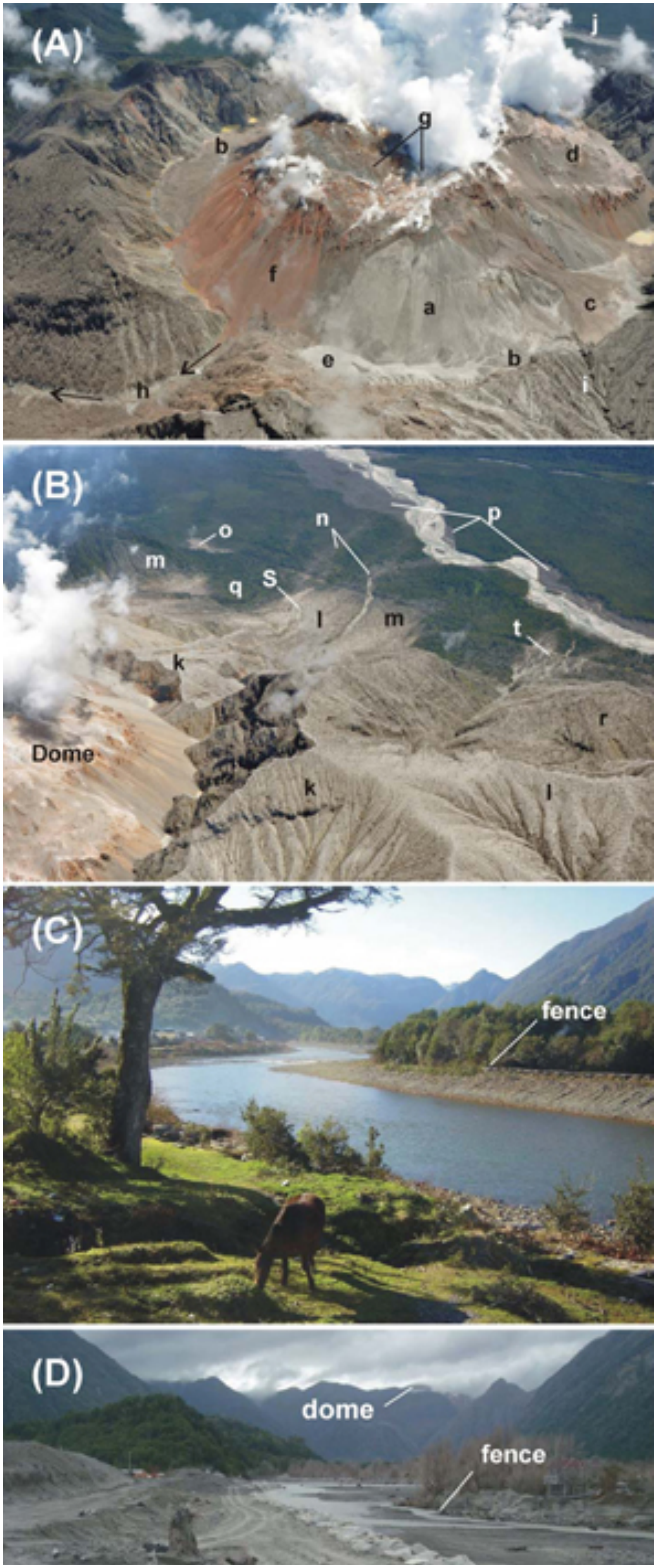
The thermosphere and ionosphere occupy a rarefied (low-density) region of the atmosphere above 90 kilometers. Far from being empty space, this part of the atmosphere where satellites operate has important relevance for today's high-tech, space-dependent society. The ionosphere can affect the propagation of electromagnetic radiation and adversely influence operational systems, such as Global Positioning System navigation and radio and satellite communications. The thermosphere changes in response to solar activity, geomagnetic storms, and dynamical forcing from the lower atmosphere. Thermospheric composition, density, and winds directly affect satellite drag and reentry and influence the development and structure of the ionosphere.

RAIDS is a suite of eight optical sensors that view the limb (edge) of the planet. These limb-viewing sensors measure naturally occurring airglow from extreme ultraviolet to near-infrared wavelengths (55–870 nanometers). Airglow is produced by excitation of ambient atmospheric gas via solar radiation, charged particle precipitation, and chemical processes. Airglow spectra and limb emission profiles are interpreted using physical models of excitation and radiative transfer processes to reveal the composition, density, and temperature of the upper atmosphere. The primary scientific objective of RAIDS is to measure the temperature of the lower thermosphere to address the paucity of global temperature measurements in the 100- to 200-kilometer altitude range.

HREP was launched 10 September 2009 from Tanegashima, Japan, on the inaugural voyage of the H-IIB rocket and the H-II Transfer Vehicle (HTV), a Japanese unmanned resupply capsule for the ISS. The HTV includes an unpressurized section that carries modular payloads for installation onto the JEM-EF. After a week of tests and flight maneuvers, the HTV docked with the ISS, and astronauts used both the ISS's Canadarm2 remote manipulator and the

The international, interdisciplinary team that conducted the field campaign consisted of: John S. Pallister, Jon J. Major, Thomas C. Pierson, and Richard P. Hoblitt, U.S. Geological Survey, Vancouver, Washington; Jacob B. Lowenstern, U.S. Geological Survey, Menlo Park, California; John C. Eichelberger, U.S. Geological Survey, Reston, Virginia; Luis Lara, Alvaro Amigo, Servicio Nacional de Geología y Minería, Santiago, Chile; Hugo Moreno, Daniel Basualto, Servicio Nacional de Geología y Minería, Temuco, Chile; Jorge Muñoz, Servicio Nacional de Geología y Minería, Puerto Varas, Chile; Jonathan M. Castro, Monash University, Melbourne, Victoria, Australia; Andrés Iroumé, Antonio Lara, and Héctor Ulloa, Universidad Austral de Chile, Valdivia, Chile; Andrea Andreoli and Alvaro Merino, Universidad de Concepción, Concepción, Chile; Marco Da Canal, University of Padova, Padova, Italy; Julia Jones, Oregon State University, Corvallis; Charlie Crisafulli, U.S. Forest Service, Olympia, Washington; Fred Swanson, U.S. Forest Service, Corvallis, Oregon; and Nick Varley, University of Colima, Colima, Mexico.

Figure S1. (A) Aerial view to the northwest of the 3-km-diameter Chaitén caldera, showing the 2008–2010 rhyolite lava dome. (a) May 2008 tephra over prehistoric dome. (b) May 2008 pyroclastic-flow and blast deposit in caldera moat. (c) Talus from June 2008 lava lobe. (d) August 2008 lava lobe. (e) February 2009 pyroclastic-flow deposit. (f) Talus from February 2009 lava lobe. (g) Post-February 2009 endogenous growth region. (h) Unnamed tributary to Río Chaitén; arrows point downstream. (i) Newly developed drainage channel breaching southeast caldera wall. (j) Río Rayas channel north of volcano. USGS, 24 January 2010. (B) Aerial view on north side of volcano of deposits and forest disturbance resulting from Chaitén eruption. Distance from caldera rim (k) to Río Rayas channel about 3 km. Image shows zones of tree removal (k), tree toppling (l), and tree scorching (m); fluvial deposition in stream channels (n), wetlands (o), and on Río Rayas floodplain (p). Thin (5–15cm) deposits of sandy tephra fall are found in green forested areas (q); thicker (15–50cm) gravelly tephra fall is found in severely damaged forest (r). Syn- or posteruption debris flows are found along small stream channels and tributary floodplains (s,t). USGS, 24 January 2010. (C) Preeruption and (D) posteruption views of Río Chaitén looking upstream (north) from the National Highway 7 bridge in Chaitén town. Note position of fence with respect to channel bed in each view, stump of tree pictured in preeruption view, and new lava dome visible on the skyline. The river eroded its left bank, and the main channel now passes east of the fenced land visible in photographs.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