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Long-range volcanic ash transport and fallout during the 2008 eruption of Chaitén volcano, Chile

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ABSTRACT

The May 2008 eruption of Chaitén volcano, Chile, provided a rare opportunity to measure the long-range transport of volcanic emissions and characteristics of a widely-dispersed terrestrial ash deposit. Airborne ash mass, quantified using thermal infrared satellite remote sensing, ranged between 0.2 and 0.4 Tg during the period 3–7 May 2008. A high level of spatiotemporal correspondence was observed between cloud trajectories and changes in surface reflectivity, which was inferred to indicate ash deposition. The evolution of the deposit was mapped for the first time using satellite-based observations of surface reflectivity.

The distal (>80 km) ash deposit was poorly sorted and fine grained, and mean particle size varied very little beyond a distance >300 km. There were three particle size subpopulations in fallout at distances >300 km which mirror those identified in fallout from the 18 May 1980 eruption of Mount St. Helens, known to have a high propensity for aggregation. Discrete temporal sampling and characterisation of fallout demonstrated contributions from specific eruptive phases. Samples collected at the time of deposition were compared to bulk samples collected months after deposition and provided some evidence for winnowing.

Experimentally-derived ash leachates had near-neutral pH values and charge balance which indicates minimal quantities of adsorbed acids. X-ray Photoelectron Spectroscopy (XPS) analyses revealed surface enrichments in Ca, Na and Fe and the presence of coatings of mixed Ca-, Na- and Fe-rich salts on ash particles prior to deposition. Low S:Cl ratios in leachates indicate that the eruption had a low S content, and high Cl:F ratios imply gas–ash interaction within a Cl-rich environment. We estimate that ash fallout had potential to scavenge ~42% of total S released into the atmosphere prior to deposition. XPS analyses also revealed ash particle surfaces were strongly enriched in Fe (in contrast to the results from bulk leachate analyses), which suggests that Chaitén ash fallout over oceans had potential to influence productivity in high-nutrient, low-chlorophyl regions of the oceans. Therefore ash particle surface geochemical analysis should be applied to quantify Fe-modulated biologically-forced CO_2 draw-down potential of volcanic ash fallout over oceans.

1. Introduction

Ash fallout from explosive volcanic eruptions is rarely deposited in entirety on terrestrial surfaces and some fraction inevitably ends up deposited in the oceans. The May 2008 eruption of Chaitén volcano, Chile, provided a rare opportunity to measure the dispersion and long-range transport of volcanic emissions in the lower stratosphere, and characterise associated fallout over a largely terrestrial setting. Clouds from the eruption deposited ash over Chile and Argentina and formed the first continental-scale ash deposit since the eruptions of Mount St. Helens in 1980 and Cerro Hudson in 1991. Adsorbed soluble (ephemeral and mobile) chemical components related to eruption of volcanic gases and associated incrustations may generate a range of direct and indirect biological, chemical and physical effects following deposition into terrestrial and aquatic ecosystems (Óskarsson, 1980; Witham et al., 2005).

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The type and magnitude of these impacts depend on various factors, including the ash chemical and physical properties, deposit thickness and residence time, and sensitivity of the local environment. Although a large number of eruptions have been investigated (Witham et al., 2005), this is the first such investigation of a rhyolitic ash-fall and the environmental effects of associated rhyolitic ash leachates.

In this study, we analyse: (1) changes in airborne ash mass in the volcanic clouds produced by the eruption as a function of time from satellite observations and related to observed fallout; (2) sedimentological characteristics of ash fallout collected at or very near the time of deposition, i.e., pristine and unaffected by hydrological or aeolian processes post-deposition; and (3) the composition of chemical leachates released through deposition of rhyolitic ash fallout in aqueous environments.

1.1. The May 2008 eruption of Chaitén, Chile

The eruption chronology reported here combines previous accounts (Carn et al., 2009; Folch et al., 2008; Lara, 2009; Watt et al., 2009) and additional surface and remote sensing observations of the eruption (Table 1). The May 2008 eruption of Chaitén was unexpected as the previous documented eruption at the volcano occurred nearly 10,000 years ago (Naranjo and Stern, 2004) though new tephrochronological data from surface and lake records in Argentina suggest that there were other important explosive events during the Holocene (Iglesias et al., 2011). Seismic activity increased on 30 April 2008 with swarms of volcano-tectonic earthquakes ranging in magnitude from 3 to 5 (Carn et al., 2009). Between 1 May and 2 May 2008 the frequency of events increased and reached a maximum of 15–20 per hour prior to the first major eruption (Phase 1) at ∼08:00 UTC on 2 May (Table 1) that generated a column in excess of 21 km above mean sea level (MSL) (Lara, 2009). Geostationary Operational Environmental Satellite (GOES) thermal infrared imagery indicated a cloud height of 12 km MSL at 0800 UT on 2 May 2008 (Carn et al., 2009) for the dispersed part of the cloud which was corroborated a day later by cloud height estimates from a space-borne lidar (CALIOP; Thomason and Pitts, 2008). After a period of quiescence on the morning of 3 May 2008, Phase 2 of the eruption was initiated by a large column that reached 17–20 km MSL (observed by G. Villarosa at 14:15 ART/17:15 UTC) from the surface at a location near Esquel, Argentina (42.9°S 71.317°W), 124 km from the volcano). Low level ash emission continued to sustain an ash column with height of <10 km MSL between 3 and 5 May (Watt et al., 2009). Phase 3 of the eruption initiated on 6 May 2008 and generated a column that was estimated to have reached in excess of 30 km (GOES observations at 1200 UT on 6 May 2008) (Carn et al., 2009). Airborne ash and/or ice-coated ash in the dispersed cloud from this phase was observed using CALIOP at a height of ∼16 km MSL the following day between 41 and 42°S (Thomason and Pitts, 2008). Phase 4 began on 8 May 2008 with the eruption of an ash column to 20–22 km MSL. Volcanic aerosol from this phase was observed using CALIOP at a height of 13 km MSL the following day (Carn et al., 2009; Thomason and Pitts, 2008). Emission continued into May and June at low intensities with ash columns generally reaching mid- to upper tropospheric heights. By July activity had diminished and occasional ash eruptions generated plumes that reached between <2 and 3 km (Simkin and Siebert, 2002).

Ash fallout from the eruption was widespread and impacted large regions of Chile and Argentina (Watt et al., 2009). Ash emissions from Phase 1 were dispersed to the southeast over Argentina, although an early emissive pulse on 2 May was transported to the east and northeast of Chaitén volcano, and ash fallout was observed at Esquel, Argentina (42.907°S 71.308°W), ∼110 km away from Chaitén volcano and Epuyén (42.233°S 71.350°W) ∼130 km to the northeast (Fig. 5). Ash fallout was observed at Comodoro Rivadavia on the Argentine coast (45.87°S 67.48°W) over 500 km to the SE approximately 16 h after the eruption began. A sheared portion of the cloud was transported to the NW as far as Bariloche, Argentina (41.16°S 71.34°W), about 215 km NNE of Chaitén in the evening of 2 May 2008, although no ash-fall was reported at the time.

Emissions from Phases 2–4 were dispersed first to the southeast towards Comodoro Rivadavia on 3 May, and then east towards the Argentine coastal settlements of Trelew (43.249°S 65.307°W) and Puerto Madryn (42.754°S 65.049°W) where ash fallout was observed on 5 May. Ash emissions from Phase 3 of the eruption (Table 1) were carried to the northeast on 6 May and reached Neuquén,

Table 1
Eruption chronology for the May 2008 eruption of Chaitén volcano, Chile.

Phase	Date	Time (UTC)	Observation	Cloud height (location)	Measurement source	Reference
1	2 May 2008	08:00–14:00	Initial explosive ash column	>21 km (Chaitén volcano)	Visual observation (PIREP)	(Carn et al., 2009; Folch et al., 2008)
		Morning	Early column activity	10.7–16.8 km	Visual observation (SGVP)	(Folch et al., 2008)
			Stratospheric cloud height	12 km	GOES imagery	(Carn et al., 2009)
2	3 May 2008	18:15	Explosive ash column	17.4–19.6 km	Visual observation (clinometer)	G. Villarosa
	3–5 May 2008		Sustained explosive ash emission	<10 km (Chaitén volcano)		(Watt et al., 2009)
	3–4 May 2008		Fine volcanic ash and/or ice crystals	∼12 km (30°S)	CALIOP/OMI	(Carn et al., 2009)
3	6 May 2008	12:00*	Initial explosive ash column	30 km (Chaitén volcano)		(Carn et al., 2009)
	6 May 2008	13:30*	Initial explosive ash column	30 km (Chaitén volcano)	Visual observation (ONEMI)	(Folch et al., 2008)
		20:00	Increase in eruption intensity			(Folch et al., 2008)
	7 May 2008		Eruption column	7–10 km	CALIOP	(Folch et al., 2008)
	7 May 2010		Ash / ice-coated ash cloud	∼16 km (41–42°S)		(Thomason and Pitts, 2008)
4	8 May 2008	03:30	Initial explosive ash eruption	20–22 km (Chaitén volcano)	GOES imagery	(Carn et al., 2009)
	8 May 2008		Airborne ash	3–10 km (Buenos Aires)		(Folch et al., 2008)
	9 May 2008		Volcanic aerosol	13 km	CALIOP	(Carn et al., 2009)

CALIOP – Cloud-Aerosol Lidar with Orthogonal Polarisation (on Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations platform).
GOES – Geostationary Operational Environmental Satellite.
OMI – Ozone Monitoring Instrument.
ONEMI – Oficina Nacional de Emergencia del Ministerio del Interior (National Office of Emergency of the Interior Ministry, Chile).
PIREP – Pilot report.
SGVP – Smithsonian Global Volcanism Program.
* These reports conflict on the time of onset of the initial activity of Phase 3.