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# Ground-based thermal imaging of lava lakes at Erebus volcano, Antarctica

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ABSTRACT

Mount Erebus, a large intraplate stratovolcano dominating Ross Island, Antarctica, hosts the world's only active phonolite lava lakes. The main manifestation of activity at Erebus volcano in December 2004 was as the presence of two convecting lava lakes within an inner crater. The long-lived Ray Lake, ~1400 $m^2$ in area, was the site of up to 10 small Strombolian eruptions per day. A new but short-lived, ~1000–1200 $m^2$ lake formed at Werner vent in December 2004 sourced by lava flowing from a crater formed in 1993 by a phreatic eruption. We measured the radiative heat flux from the two lakes in December 2004 using a compact infrared (IR) imaging camera. Daily thermal IR surveys from the Main Crater rim provide images of the lava lake surface temperatures and identify sites of upwelling and downwelling. The radiative heat outputs calculated for the Ray and Werner Lakes are 30–35 MW and 20 MW, respectively. We estimate that the magma flux needed to sustain the combined heat loss is ~250–710 kg $s^{-1}$, that the minimum volume of the magma reservoir is 2 $km^3$, and that the radius of the conduit feeding the Ray lake is ~2 m.



## 1. Introduction

Lava lakes are rare and fascinating phenomena found at only a few volcanoes in the world. Active lava lakes are considered to be fed by volatile-rich, buoyant magma reaching the surface through a conduit from a deep, larger reservoir. Contrastingly, inactive lava lakes form by the ponding of lava flows and are not connected to a magma chamber (Swanson et al., 1972). Studies of inactive lava lakes, such as Kilauea Iki, have yielded important information concerning lava cooling and crystallization (Evans and Moore, 1968; Hardee, 1980; Jellinek and Kerr, 2001), however they cannot provide insight into conduit dynamics and underlying magmatic processes (Swanson et al., 1979). Active lava lakes are considered to be the exposed top of a convecting magma column, and as such, provide a window into the cryptic magmatic system (Tilling, 1987; Tazieff, 1994). Long-lived, persistently active lava lakes are especially rare; widely-known current examples are hosted at three volcanoes: Nyiragongo, Democratic Republic of Congo; Erta 'Ale, Ethiopia, and Mount Erebus, Ross Island, Antarctica (Tazieff, 1994; Harris et al., 1999; Wright and Pilger, 2008-this issue).

Convection within an active lava lake, and between the lake and the underlying magma body, is likely driven and sustained by density gradients due to crystallization, degassing, and cooling (Worster et al., 1993; Kazahaya et al., 1994; Jaupart and Tait, 1995; Stevenson and Blake, 1998). Observations of thermal flux from active lava lakes can be used to estimate mass flux, conduit dimensions, reservoir size and rates of intrusive growth (Francis et al., 1993; Kazahaya et al., 1994; Harris et al., 1999) giving greater insight into unseen magmatic processes. Previous authors have also estimated these parameters using seismicity (Kumagai et al., 2001), geodesy (Locke et al., 2003), rate of degassing (Whitham and Llewellin, 2006) and geochemical indicators including crystal growth and trace element ratios (Dunbar et al., 1994; Blake and Rogers, 2005).

In this study, the first ground-based thermal radiometric imaging surveys at Erebus volcano are used to examine the magmatic processes responsible for sustained lava lake activity. The observations provide a detailed picture of lava lake surface temperatures and the surface heat budget. These are used to explore conceptual and physical models for magma convection in conduits in order to shed further light on the volcano-magmatic system of Erebus volcano. The data also provide a useful comparison for spaceborne thermal observations (e.g., Davies et al., 2008-this issue).

In December 2004, two active lava lakes were present in the Main Crater of Erebus volcano (Fig. 1). The first is referred to as the Ray lava lake, which has been active since at least 1972. The second, Werner lava lake, was an ephemeral feature that formed in December 2004 but froze over during the Austral winter of 2005. The Werner vent has been the site of persistent high-temperature fumarolic activity since the first observation of the inner crater in the early 1970's (Kyle et al., 1982). It has sometimes hosted a glowing, sputtering hornito, and was the site of short run-out lava flows in 1979 (Kyle, 1979) and 2002 (R. Esser, pers. comm. 2005). Incandescent glow has typically been observed inside Werner Vent since December 1974 (Kyle et al., 1982). In December 2004 both lakes were actively circulating and overturning, allowing an

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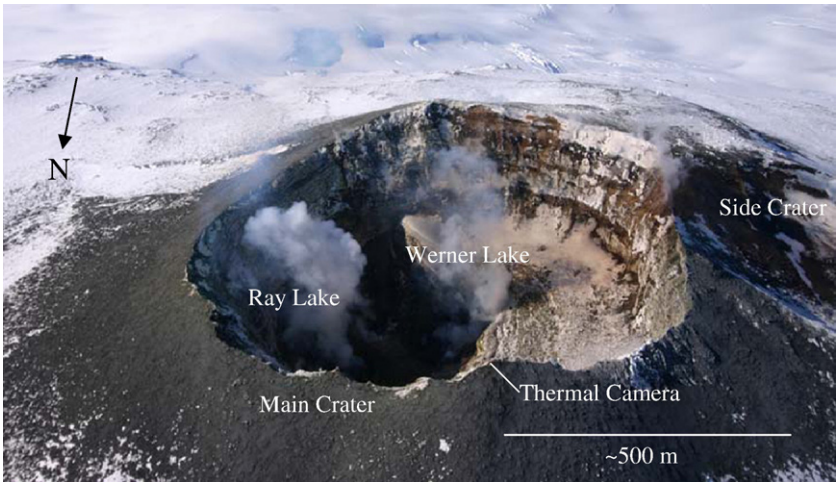


**Fig. 1.** Main Crater of Erebus volcano. Ray lava lake surface area is ~1400 $m^2$ and Werner lava lake is ~1200 $m^2$. Active Vent is located between the lakes. The Side Crater is seen to the west of the Main Crater.

opportunity for observation of thermal characteristics and activity that provide insights into deeper magmatic processes.

## 2. Erebus volcano

Mount Erebus (77°32′ S, 176°10′ E, 3794 m) is an alkaline intraplate volcano formed as a result of crustal thinning, recent faulting, and magmatic activity along a section of the regionally extensive West Antarctic Rift System, known as the Terror Rift (Kyle, 1990a,b; LeMasurier, 1990; Behrendt et al., 1991). Erebus is a large polygenetic stratovolcano, which dominates the western side of Ross Island (Fig. 2). Seismic observations (Watson et al., 2006) suggest there is a major thermal anomaly under Ross Island, which is consistent with the assertion that Erebus is underlain by a hot spot or mantle plume (Kyle et al., 1992).

In December 2004, the lava lake activity was associated with occasional (0–10 daily), small gas bursts (Jones et al., 2008-this issue), feeding a constant plume of gas and aerosol (Fig. 1). The Ray lava

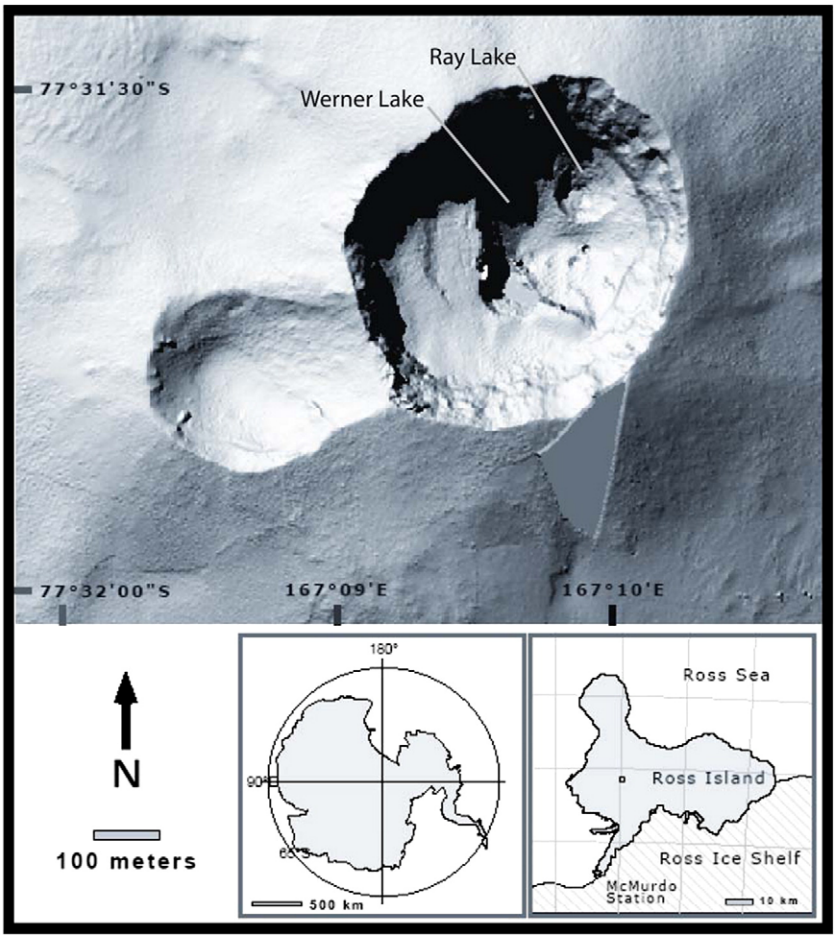


**Fig. 2.** Location of Mount Erebus volcano, Ross Island, Antarctica. The location of Ray and Werner lava lakes are indicated.