PATERAE ON IO: VOLCANIC ACTIVITY OBSERVED BY GALILEO'S NIMS AND SSI Rosaly Lopes[1], Lucas Kamp[1], W.D. Smythe[1], R. Carlson[1], , Jani Radebaugh[2], and Tracy K. Gregg[4]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, rlopes@lively.jpl.nasa.gov, [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona 85721, [4] Department of Geological Scineces, State University of New York at Buffalo, Buffalo, NY 14260.

Introduction: Paterae are the most ubiquitous volcanic construct on Io's surface [1]. Paterae are irregular craters, or complex craters with scalloped edges, interpreted as calderas or pit craters [1]. Data from Galileo has shown that the activity of Ionian paterae is often confined to its interior and that generally lava flows are not seen spilling out over the edges. We use observations from Galileo's Near-Infrared Mapping Spectrometer (NIMS) to study the thermal emission from several Ionian paterae and compare them with images in visible wavelengths obtained by Galileo's Solid State Imaging System (SSI).

Galileo's close fly-bys of Io from 1999 to 2001 have allowed NIMS to image the paterae at high spatial resolution (1-30 km pixel). At these scales, several of thse features reveal greater thermal emission around the edges, which can be explained as the crust of a lava lake breaking up against the paterae walls. Comparisons with imaging data show that lower albedo areas (which are indicative of young lavas) coincide with higher thermal emission areas on NIMS data. Other paterae, however, show thermal emission and features in the visible that are more consistent with lava flows over a solid patera floor. Identifying eruption styles on Io is important for constraining eruption and interior models on Io.

This paper focuses on the thermal analysis of NIMS data from the last two successful fly-bys of Galileo and examines the distribution of thermal emission, how it had varied with time, and the implications for eruption styles. The new observations suggest that lava lakes may be common on Io, perhaps much more than on Earth, possibly reflecting differences in volcanic plumbing and magma composition.

NIMS Thermal mapping of paterae: A NIMS pixel showing volcanic activity contains lavas at a range of different temperatures. When NIMS observations are obtained during night-time, the whole spectrum is used for temperature determination (1 to 4.7 microns). However, the majority of observations were obtained during day-time. For these cases, the albedo is extrapolated from the shorter NIMS wavelengths (1-2 microns) and applied as a correction to the longer wavelengths (beyond 2.4 microns), which are then used in the temperature determination. These longer wavelengths are dominated by emission from the relatively large but cooler areas of hot spots. A single color temperature, Tc, fitted to the spectrum of each pixel can be regarded as a lower estimate of the temperature range present in the pixel [2]. For night-time observations, two components can often be fitted to the spectrum, yielding a higher and a lower color temperature. However, because magma cools quickly when it reaches the surface, even the higher component is likely to underestimate the magma eruption temperature. Therefore, the temperatures obtained from the thermal maps should be considered minimum magma temperature estimates.

NIMS Observations: The observations we present here are of the hot spots Tupan, Emakong, Gish Bar, Culann, Chaac, Loki, Pele, and a small patera near Tohil. NIMS thermal maps are compared with SSI images in order to interpret the type of activity.

Loki, Io's largest patera (~200km in diameter) shows a smooth, dark floor that glows in the infrared, surrounding an island that is cold at NIMS wavelengths [3]. NIMS thermal maps show that the highest temperatures are found near the edges of the patera and around the edges of the cold island [4]. This is consistent with a lava lake interpretation, supporting the model of Rathbun et al. [5].

Tupan may be the site of a lava lake. The patera, about 75 km in diameter, is one of Io's most persistent hot spots [6]. Tupan was imaged at high spatial resolution by SSI and NIMS on October 2001. Radebaugh et al. [7] proposed that Tupan may contain a lava lake similar to Loki's. Comparison of the SSI image with the NIMS thermal map shows that the areas that appear dark in the SSI image are hot and that the activity is concentrated on the eastern side of the caldera. At NIMS wavelengths, Tupan has a cold "island" or topographic high similar to Loki's. The hottest areas mapped by NIMS are located near the edges of the patera, consistent with a lava lake interpretation.

Gish Bar, about 110 km in diameter, may also contain a lava lake. Gish Bar was observed by NIMS during August 2001 and by SSI during October 2001. Comparison of the SSI image with images obtained earlier in the mission suggest that a new eruption took place shortly before the October fly-by [8]. Comparison of the October SSI image with the NIMS thermal map obtained in August 2001 supports this idea.

Emakong is a heart-shaped patera, about 66 km in diameter, which may be the site of a molten lake. The consistently low temperatures observed at Emakong [2] and the suspected sulfur flows surrounding it [9] raise the intriguing possibility that Emakong may be the site of a sulfur lake. SSI images show a smooth dark floor, with darker areas close to the edges, possibly indicating exposed fresh materials as the lake's crust breaks up against the patera walls. The NIMS thermal map, from an observation acquired in October 2001, shows that the highest temperatures are found close to the edges of the patera, corresponding to the darkest areas in the SSI images. SSI and NIMS data are therefore consistent with a crusted over lava lake, with the crust breaking up as it abuts the patera walls.**Tvashtar Catena:** This chain of paterae showed a change in location of eruption over a period of a few months between 1999 and early 2000 [10]. Tvashtar was imaged by SSI during the October 2001 fly-by and by NIMS a few months earlier during the August 2001 fly-by. The contours on the SSI observation indicate areas that are 300K or higher in the NIMS temperature map. NIMS shows that several areas are active, including the location of the 1999 fire fountains [10], and the southern and eastern parts of the main patera. The main patera may contain a lava lake [11]. The darkest area in the SSI image are thought to corresponds to the youngest materials, but they do not appear as the most active areas in the NIMS thermal map. This may indicate that activity shifted between August and October 2001.

Unamed patera in Tohil region: SSI imaged the Tohil region during the October 2001 fly-by. NIMS did not independently observe this region, however, NIMS data were acquired while SSI obtained these images. Although the quality of these NIMS "ridealong" data is not as high as that of independent observations, it was sufficient to detect thermal emission from a small flow in a 25-km diameter unnamed patera imaged by SSI. This feature has been interpreted as a lava lake [7]. Thermal emission detected by NIMS comes from a small flow inside the patera. The power output at 4.7 microns derived from the NIMS data is 3.8 x 10^6 W μm^{-1}, making this the faintest hot spot detected by NIMS during the Galileo mission. Because of the very limited coverage by NIMS at high spatial resolution (the observation is 2.4 km/NIMS pixel), it is likely that many more faint hot spots such as this one are still undetected on Io.

Patera volcanism on Io: The three main styles of volcanic activity identified on Io [10,12]. These are "Pillanian" eruptions (violent fire-fountaining eruptions), "Promethean" eruptions (effusive eruptions of lava flows) and eruptions confined within paterae (which here we call "Lokian"). Our observations show that "Lokian" type eruptions are common on Io. Of the observations analyzed, several are interpreted as partly crusted over lava lakes in which the crust is breaking up where it abuts the walls of the paterae. In other cases, such as Tvashtar and Gish Bar, the thermal distribution may be the result of lava flows spreading over and filling the floor of the paterae.

Lokian-type activity appear to be long-lived on Io. With the exception of the very faint hot spot in the Tohil area, which would not have been detected in previous (lower spatial resolution) observations, all other hot spots examined here were observed to be active for periods varying from years to decades. This indicates that powerful and persistent activity on Io is often confined within paterae.

Persistent activity within paterae has important implications for the interior of Io, as it implies easy access to magma, possibly in the form of a magma ocean underneath the crust, as proposed by Kezthelyi et al. [13]. Moreover, this style of activity places constraints on how Io is being resurfaced. If a significant amount of Io's thermal energy is confined within paterae, then the rate of resurfacing may be lower than previously estimated from total thermal output.

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