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DISCOVERY OF EPISODIC VOLCANISM AT PROMETHEUS ON IO: IMPLICATIONS FOR MAGMA SUPPLY

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Galileo Near Infrared Mapping Spectrometer data show that the ionian volcano Prometheus exhibits an episodicity in activity on a time scale of 7 to 9 months. This episodicity yields valuable constraints to the mechanisms of magma supply and eruption at Prometheus. The total flux from Prometheus over the 1790 days covered by the NIMS dataset used in this analysis is 3.6×10^{19} J. Eruption volumetric rates derived from scaling rates derived from June 1996 NIMS data yield maximum and average volumetric eruption rates of 128 and 52 m^3/s (for cases where emission angle $< 60°$). Including all data at all emission angles, volumetric eruption rates range from 14 to 210 m^3/s. Taking one cycle of activity, from 19 Sept 1997 to 31 May 1998 (a period of 8.4 months) the total thermal output is 5×10^{18} J. The eruption apparently builds to a peak and dies away, very much like observed activity at some terrestrial volcanoes. Using models of thermal emission to estimate volume of erupted material the total volume erupted during this time is 0.8 to 3 km^3, with average supply rates in the range 40-143 m^3/s. The total pulse volume of material provides another constraint for modelers of the mechanisms of supply, ascent and eruption at Prometheus. The period might, for example, be the eruption-recharge period of a magma chamber. The volume of the magma chamber (or at least the volume evacuated) has a radius of ~600-900 m for the calculated total mass erupted. This behaviour at Prometheus greatly strengthens the Kilauea-Prometheus analogy. Kilauea undergoes a similar cyclic activity as magma moves through a complex plumbing system.

Discovery of Episodic Volcanism at Prometheus on Io: Implications for Magma Supply.

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1. Introduction.

Galileo Near Infrared Mapping Spectrometer (NIMS) data show that the Ionian volcanoes Prometheus and Amirani have significant thermal emission in excess of non-volcanic background emission in every geometrically appropriate NIMS observation. The 5 μm brightness of these volcanoes shows considerable variation from orbit to orbit. As part of an on-going study to chart and quantify the thermal emission of Io's volcanoes, determine mass eruption rates, and constrain eruption style, the variability of these eruptions has been analysed.

Table 1: Amirani variability

Observation	Date	5 μm flux, GW μm⁻¹	Emission angle, deg	Eruption rate m³ s⁻¹ (a)
g1inrspec01	26JUN96	22.7	35.5	79
g2inothemis02	7SEP96	62.6	49.8	64
o3inrtimon01	6NOV96	37.5	33.6	130
o3inothemis02	6NOV96	26.9	36.1	97
o6inothemis02	20FEB97	52.9	42.6	111
g8inothemis01	8MAY97	74.1	31.4	127
g8inothemis03	7MAY97	97.0	56.8	214
g8inothemis03	7MAY97	127.5	64.9	302
o8inrspec 01a	26JUN97	23.8	44.2	65
o8inothemis04	26JUN97	62.8	61.5	216
10involcan03	19SEP97	58.8	55.4	208
11inhrspec01	7NOV97	23.4	41.8	81
11inrspec 01a	7NOV97	39.0	41.8	136
11inothemis04	8NOV97	36.8	76.9	139
15inhrspec01a	31MAY98	288.5	67.3	961
15inhrspec01b	31MAY98	171.6	67.3	461
15inhrspec01c	31MAY98	291.8	67.3	869
Orbits 16-31 tbd				

Table 2: Prometheus variability

Observation	Date	5 μm flux, GW μm⁻¹	Emission angle, deg	Eruption rate m³ s⁻¹ (b)
g1inrspec01	26-Jun-96	9.6	19	35
g2inhrspec01	6-Sep-96	16.6	56	64
g2inothemis01	6-Sep-96	22.6	5	98
g2inothemis02	7-Sep-96	12.7	22	54
o3inothemis02	6-Nov-96	15.3	18	69
o3inhrspec01	6-Nov-96	6.4	18	26
o6inothemis02	20-Feb-97	17.8	9	89
g7inhrspec01	3-Apr-97	29.0	67	113
g8inothemis02	7-May-97	3.7	11	14
g8inothemis03	7-May-97	4.2	17	16
o8inhrspec01	26-Jun-97	16.2	9	63
o8inothemis04	26-Jun-97	10.7	35	42
10involcan03	19-Sep-97	7.1	39	28
11inhrspec01	7-Nov-97	16.0	10	63
11inrspec 01a	7-Nov-97	15.8	10	58
11inothemis04	8-Nov-97	32.5	28	127
11inthrmal04	8-Nov-97	32.9	29	129
14inhrspec01d	29-Mar-98	14.1	59	55
15inhrspec01a	31-May-98	8.5	41	33
15inhrspec01b	31-May-98	8.9	41	35
15inhrspec01c	31-May-98	8.8	41	35
16inhrspec02 1	31-May-98	12.1	40	47
16inhrspec02 2	31-May-98	11.5	40	45
16inhrspec01	30-Jul-98	53.9	76	210
20inhrspec01	2-May-99	28.5	68	111
24inregion01	11-Oct-99	8.7	(see note a)	40
25inregion01	26-Dec-99	10.3	(see note a)	48
27inregion01	27-Feb-00	8.8	(see note a)	38
30inglobal01	23-May-01	10.5	69	42

Note a Reference [4]

Note b Volumetric eruption rate scaled from estimates of flux seen during G1 [2]

Figure 1: Amirani
Located at ~116 W, 23 N, on the anti-jovian hemisphere of Io. The Amirani flow complex is the longest active lava flow in the Solar System [1]. Insulated silicate lava flows are emplaced at areal coverage rates of 50-80 m³/s. Mass eruption rates are estimated to be up to 100 m³/s [2]. Figure 1a (left) shows thermal emission as seen by NIMS along the flows and at nearby sites. Figure 1b (right) shows SSI imagery of the Amirani region at the same scale.

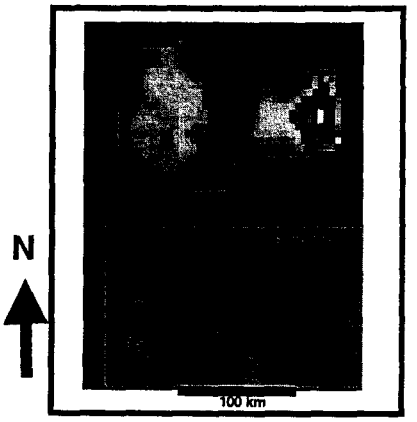

Figure 2: Prometheus
Located at 154 W, 2 S. The flows at Prometheus cover over 6000 km² [3] emplaced in the years between Voyager (1979) and Galileo (1996) encounters. Flow morphology and thermal emission is consistent with insulated silicate lava flows, with resurfacing at 5-35 m³/s [1, 2] and volumetric eruption rates of ~35 m³/sec [2]. The flows are estimated to be about 1 m thick [2]. Prometheus is a volcanic plume source, active at least since the Voyager epoch. The surface flows appear to have overflowed from Prometheus Patera. Fig 2a (top): NIMS 5 μm data showing thermal emission along entire flow field (after [4]). Fig 2b (bottom) shows the flow field, imaged by SSI during the I24 (October 1999) flyby.

Figure 3: Amirani 5 μm variability

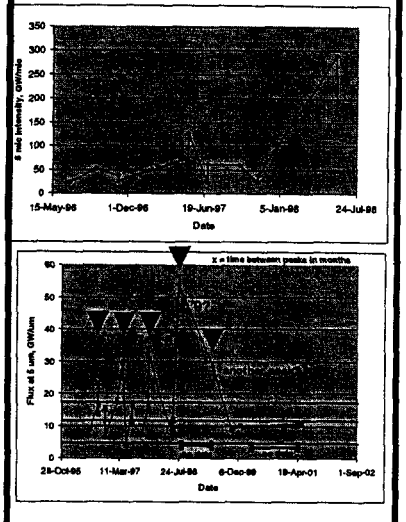

Figure 4: Prometheus 5 μm variability

2. Thermal output variation: periodic Prometheus!

Like the current eruptions of Kilauea, Hawai'i, these two Ionian volcanoes exhibit periods of elevated activity (see Tables 1 and 2 and Figures 3 and 4). A study of the 5 μm thermal emission in all low-spatial resolution NIMS observations (both night and day-time) from June 1996 (Orbit G1) to May 2001 (Orbit C30) shows that the Prometheus thermal output (corrected for emission angle, e, for cases where e < 60°) yields an average Prometheus output of 13.3 GW/μm (standard deviation of 7.3 GW/μm) and a larger average Amirani thermal output of 44 GW/μm (standard deviation of 26 GW/μm). Prometheus showed its greatest e-corrected thermal emission during November 1997 (33 GW/μm), more than four times that seen in June 1996 (orbit G1; see [2]) and Amirani showed its greatest thermal emission during May 1997 (orbit G8), nearly 100 GW/μm, nearly five times that seen during orbit G1. Including observations where e > 60°, Amirani's maximum observed 5 μm output is 291 GW/μm (May 1998), and the Prometheus maximum is 54 GW/μm (May 1998). Of great interest is the apparent periodicity of Prometheus (see Fig. 4) on a time scale of 7 to 9 months per episode, peak to peak. This might be the recharge rate for the magma chamber after an eruption.

3. Discussions: eruption style

The style and behavior of eruptions at Prometheus and Amirani are apparently very like current Kilauea flank activity, a more-or-less continuous eruption with emplacement of mostly insulated surface flows, punctuated with periods of increased activity. Prometheus and Amirani are on a much greater areal scale, however. These eruptions are generally effusive and non-explosive: that there is no large-scale fire-fountaining observed indicates that the magma is relatively low in volatiles. Magma, fed from a deep source, may be stored in near-surface magma chambers where degassing takes place, before erupting at the surface. Alternatively, the magma may already be low in dissolved volatiles, or is of such low viscosity that explosive release of gas is not taking place.

4. Estimates of mass eruption volumes

Prometheus and Amirani spectra obtained at night show that the overall spectral shape of the thermal emission from 2 to 5 μm does not greatly change. The style of eruption is not resulting in disproportionately large areas at very high temperatures in relation to cooler crustal areas, such as seen at Pillan in 1997 and at Pele, indicating that the style of eruption is not changing, just the areal extent of activity. Eruption volumetric rates derived from scaling rates derived from G1 NIMS data [2] are shown in Tables 1 and 2. Maximum and average volumetric eruption rates of 337 and 154 m³ s⁻¹ for Amirani, and 128 and 52 m³ s⁻¹ for Prometheus (for e < 60°). Including all data at all emission angles, rates at Prometheus range from 14 to 210 m³/s, and at Amirani from 87 to 869 m³/s (the maximum being 11 times that seen during G1).

5. Questions and Comments

Is Prometheus truly periodic? If so, it greatly strengthens the Kilauea-Prometheus analogy as Kilauea undergoes a similar periodicity in activity. With estimates of magma discharge rate and an established time scale, the dynamics of magma recharge can be modelled. The periodicity of Prometheus is very similar to that observed at Loki, where the periodicity has been proposed to be due to the foundering of the crust on a lava lake [5]. As demonstrated here however, such a resurfacing method is not necessarily diagnostic of a particular mode of lava emplacement: only lava flows have been seen at Prometheus.

References

[1] Keszthelyi *et al.*, 2001, *JGR*, 106, 33,025-33,052. [2] Davies *et al.*, 2000, *Icarus*, 148, 211-225. [4] Lopes *et al.*, 2001, *JGR*, 106, 33,053-33,078. [5] Rathbun *et al.*, 2002, *GRL*, 29,no. 10, 84-88.

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