Io and the Early Earth. D. L. Matson, D. L. Blaney, T. V. Johnson, G. J. Veeder and A. G. Davis, Jet Propulsion Laboratory, MS 183-501, 4800 Oak Grove Drive, Pasadena, CA 91109, email: Dennis.L.Matson@jpl.nasa.gov

Introduction: The youngest surface in the solar system may be giving us clues about the earliest volcanics on Earth. The style and magnitude of volcanic eruptions currently observed on Io have striking similarities to what has been inferred about volcanism on Earth in the pre-Cambrian, >2.5 Gyr B.P. Io can act as a natural laboratory for studying these types of eruptions. Conversely, geochemical data preserved on Earth can help constrain Io's chemical history. Comparative planetology can provide a fresh perspective for the study of both bodies. In this paper we will consider two points of comparison: lava composition and heat flow.

Lava Compositions: Observations of high temperature eruptions on Io constrain the composition of Io lavas dramatically. Table 1 shows the melting point data for various proposed Io lavas. Galileo images of Io in eclipse show ~20 areas larger than 10^4 m^2 with temperatures in excess of 1000 K (Belton *et al.* 1996, McEwen *et al.* 1997a). Stansberry *et al.* (1997) observed two eruptions in ground-based eclipse imaging with temperatures in excess of 1450 K and with eruptive rates of 10^4 – 10^6 m^2s^{-1}. Davies *et al.* (1997) modeled the Galileo NIMS and SSI data for the South Voland volcano on Io with two thermal components: one at 450 K and another at 1100 K. Keszthelyi and McEwen (1997) found that the thermal emission in the Galileo SSI data are consistent with basaltic lava flows. These observations compare well with the earlier groundbased observations of Johnson *et al.* (1987), Veeder *et al.* (1994), Blaney *et al.* (1995) which characterized eruptions in 1986 (1550 K) and 1990 (1225K, $1.5x10^5$ m^2s^{-1} eruption rate). Recently, McEwen *et al.* (1997b) reported a volcanic region requiring temperatures in excess of 1800 K.

Table 1. Typical Melting Temperature Data

Lava Composition	Melting Temperatures
Sulfur	715 K
Na_2S	1450 K
Rhyolite	975-1125 K
Andesite	1125-1325 K
Basalt	1325-1475 K
Komatiite	1575-1825 K

The 1800 K observation of McEwen *et al.* (1997b) makes a strong case for komatiites on Io. The temperatures observed by Stansberry *et al.* (1997) and Blaney *et al.* (1995) near the high end of the basalt range add further support to this idea. Keszthelyi and McEwen (1997) further argue that the observed temperature is probably ~200 K cooler than the actual eruption temperature due to rapid cooling of the exposed lava. This adjustment would put the Blaney *et al.* (1995) and Stansberry *et al.* (1997) observations in the komatiite temperature field also. Thus, the single lava which is consistent with all of the temperature data is mafic to ultra mafic in composition. On the Earth such high temperature lavas include komatiites and picrites. For simplicity we will refer to all of these high temperature lavas as "komatiitic".

There may also be geomorphic evidence for komatiites. Using Voyager stereo imaging, Schenk *et al.* (1997) found that the long lava flows on Ra Patera occurred on slopes of 0.1° - 0.3°, which are much shallower than those of terrestrial basaltic shield volcanoes and thus imply low viscosity, high eruption rates or both. So far high temperatures have not been observed at Ra Patera by Galileo (McEwen *et al.* 1997a, Lopes-Gautier *et al.* 1997), so sulfur cannot be excluded at this point as a possible lava. However, terrestrial komatiite lavas also match these properties of low viscosity and high mass eruption rates (e.g., Williams and Lesher 1998, Lesher 1989, Hill *et al.* 1995).

Komatiite lavas on earth are rare today. They were most common on earth in the pre-Cambrian and are associated with higher mantle temperatures. Emplacement mechanisms of komatiite lavas on the early earth are problematic. The high density of these lavas make them difficult to erupt through the crust. This problem also exists for Io. On the earth preserved komatiites seem to be associated with flood basalt provinces. Different models suggested for the eruption of komatiites involve: dynamic melting in mantle plume heads (Arndt *et al.* 1997); komatiite dyke propagation being less prone to freezing than basaltic dyke propagation (Lister *et al.* 1991); high dissolved CO_2 content providing buoyancy (Edwards 1992, Anderson 1995); adjacent thick and thin lithosphere causing convection instabilities (King and Anderson, 1995); and pressure release melting in a hotter mantle (Vlaar *et al.* 1994).

If Io is currently erupting lavas similar to komatiite lavas then determining how they erupt on Io could allow for a better understanding of the eruption of komatiite lavas in the early earth. There is no evidence for plate tectonics or a continental type lithosphere on Io to mask the surface expressions of convective processes. The differences between Io and the Earth (Io is smaller, has lower mantle pressures, and higher heat flow) may provide insight into the relative importance of different effects.

Sulfur provides a compositional link between Io and terrestrial komatiites. The geochemistry of komatiites have been extensively studied because of their association with massive iron sulfide deposits (e.g. Lesher 1989). While the thermal data observed on Io indicates widespread silicate volcanism, Io's coloration is dominated by sulfur and sulfur dioxide frost. How sulfur behaves in komatiitic magma systems may help us to explain Io's colors and surface chemistry.

Heat Flow: Data from the ground based infrared observations (Matson *et al.* 1981, Veeder *et al.* 1994) and the Voyager IRIS experiment (McEwen *et al.* 1993) have been used to derive Io's global heat flow of >2.5 W/m^2. This value is significantly higher than the Earth's current global heat and 100 times that of the moon, a body the same size as Io (Table 2).

Table 2. Heat Flow Values

Solar System Body	Heat Flow (Wm^{-2})	Power (W)
Io	~2.5	10^{14}
Moon	0.02	7.6×10^{11}
Earth (current)	0.087	4.4×10^{13}
Earth Archaen (mantle)	0.3	1.5×10^{14}

(Io value from Veeder *et al.* 1994; Lunar value- Langseth *et al.* 1976: Current Earth value- Pollack, *et al.*, 1993: Earth Mantle value at 3.5 Gyr B.P.-Vlaar *et al.* 1994).

The heat flow measured on Io is caused by a series of lava flows in various stages of cooling. The eruption and cooling of lava flows is apparently the dominant method of heat loss from Io's interior. The observed heat flow of ~2.5 Wm^{-2} can be supplied by a resurfacing rate of 1.33 cm / yr (Blaney *et al.*, 1995). This is consistent with the lack of impact craters on Io's surface.

Models of heat generated in the Earth's mantle from radioactive decay indicate that the mantle heat flow in the past was significantly higher than it is today. The Vlaar *et al.* (1994) model for mantle heat flows yields 0.3Wm^{-2} at 3 Gyr B.P.. This higher heat flow may have resulted in a different style of heat loss than occurs on the Earth today. Mass transport and energy released by the latent heat of cooling magmas in the oceanic lithosphere may have been the dominant method for removing heat from the early terrestrial mantle (e.g. Takahashi 1990, Vlarr *et al.* 1994). This may be very similar to Io's current way of getting rid of its heat.

Keszthelyi and McEwen (1996, 1997) argue Io's high heat flow should have resulted in the development of a silica-rich crust. However, no direct evidence exists for this crust. For instance, observed silicate magma eruption temperatures are greater than the 975-1125 K of rhyolite magmas which might be expected for an evolved silica crust. The lack of plate tectonics on Io implies that crustal recycling is done be other methods than currently occur on Earth. The lack of high silica magmas implies that crustal recycling must be relatively complete for Io to still be erupting unevolved magmas after 4 billion years. Perhaps Io's volcanism is similar to what was occurring on Earth prior to large-scale continent formation and the start of plate tectonics as we know it today.

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