

Silicate Atmospheres: A Study of Proto-Mercury

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Abstract

We combine thermodynamic two existent equilibrium models of high temperature silicate surface constituents. Given the planetary composition, temperature, and gravity, we calculate the composition of the atmosphere resulting from the magma ocean evaporation using modeled and MESSENGER derived data. We calculate the temperature-dependent pressure and composition of vapor in equilibrium with the molten silicate magma using an evolution model of the surface temperature. Considering the period before the first crust was formed, we estimate the evaporation and sublimation flux from the molten silicate magma, use these values conditions to form an isothermal atmosphere, and do a numerical calculation of the exospheric loss including the contribution of the early Suns radiation.

1. Introduction

During the early stages of Mercury's formation and before the existence of the first surface crust, the overall temperature of the planet was presumably high enough to form a global magma ocean. The evaporation of the molten surface produced an atmosphere together with an exosphere that expanded into space, which was partially lost due to the radiative environment. In this work we investigate, to some extent, the conditions of this primitive atmosphere, estimate the exospheric loss, and propose a quantitative model of its evolution.

2. Models

2.1 Thermal Evolution Model

We use the results from the numerical simulations presented by [1]. We extracted the sub-surface temperature values at each time step and used these to calculate the temperature-dependent vapor pressures for the magma ocean composition (see Fig 1).

2.2 Evaporation Model

We use the vapor pressures from the MAGMA model by [2], which calculates the equilibrium between melt and vapor in a magma at temperatures > 1500 K for Al, Ca, Mg, Fe, Si, Na, O, Ti, and their pseudo-compounds (see Figure 2). Due to the extreme temperatures of the magma ocean, we expect that the silicate atmosphere produced from the evaporation is free of volatiles (H, C, N, S) as they will escape rapidly into space.

2.3 Atmospheric Model

We apply the isothermal and vertically stratified atmosphere model using the partial pressures calculated before to create altitude density profiles. We determine the exobase altitude and calculate numerically the exospheric loss.

3. Figures



Illustration 1: Thermal evolution of the subsurface (-40 km) of proto-Mercury. [1]



Illustration 2: Vapor Pressures for the assumed magma composition. [5]

4. Tables

Oxide/Ref.	[3]	EH4 [4]	[5]
SiO ₂	45.9	52.7	57.4
MgO	38.7	19.1	19.0
Al_2O_3	5.7	13.5	13.9
CaO	2.3	11.7	5.8
Na ₂ O	2.2	b.d.	3.6
FeO	1.5	0.25	Fe: 1.5
CrO	0.1	-	Cr: 0.11
MnO	0.1	0.12	Mn: 0.11
K ₂ O	0.1	b.d.	0.15
TiO ₂	0.1	0.21	Ti: 0.34
Total	96.3	97.58	100

Table 1: Assumed early Hermean magma ocean oxide compositions, given in wt%.

5. Equations

The most important equations used in this work are: (1) Vapor Pressure P, with the enthalpy of vaporization H_vap, gas constant R, temperature T, and the constant of integration C; (2) Vertical mixing expressed in terms of density and thermal gradients with the density of the species i n_i , the height z, the scale height H, and the vertical flux on the ith constituent Φ , $\chi_{j=1,2}$ stand for the eddy diffusion coefficient and the molecular coefficient.

$$lnP = \frac{-\Delta H_{vap}}{RT} + C \tag{1}$$

$$\Phi_i = n_i \left[-\chi_j \sum_{j=1}^2 \left(\frac{1}{n_i} \frac{dn_i}{dz} + \frac{1}{H_j} + \frac{1}{T} \frac{dT}{dz} \right) \right]$$
(2)

6. Summary and Conclusions

We present the results for a range of mineralogical average Hermean surface compositions as given by [3, 4, 5, see Table 1]. We predict the evaporation and sublimation loss of the molten silicate lava, and give estimates of the column densities and exobase altitude of the primordial Hermean atmosphere. We found that it is likely that Mercury experienced a short lived silicate atmosphere that existed before crust formation. Such an atmosphere was likely characterized by pressures in the 10^{-8} – 10^{2} bar range, with temperatures greater than 1700 K.

Acknowledgements

We thank Dan Bower for his help shaping the initial conditions of this study.

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