TRANSIENT VOLCANICALLY-INDUCED LUNAR ATMOSPHERE AND ITS VOLATILE TRANSPORT EFFICIENCY.

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Introduction: The history of post-accretion deposition, loss and transport of lunar volatiles is a necessary element for understanding the evolution of the Moon. It also became an important consideration in relation to possible future manned missions.

One of the possible sources of lunar volatiles is volcanic outgassing from the Moon's maria. Such outgassing could form a transient atmosphere, which would control the transport of volatiles to the polar regions, where they would be trapped in permanently shadowed regions (PSR) or buried under the regolith and thus preserved until modern day. Here we study such an atmosphere with the goal of estimating its ability to transport volatiles and determining the patterns of their possible deposition.

Typically, instances of such an atmosphere were believed to be very thin (~10^{-8} bars) [1]. Recent research by Needham and Kring [2] suggest that during the peak of volcanic activity ~3.5 Ga such an atmosphere could reach a thickness of 10^{-2} bar, though in a more recent study Wilson et al. [3] have argued that the thickness of such an atmosphere will be determined by the intervals between major eruptions, and in most cases may not exceed the scale of microbars.

Methods: To study the outgassed lunar atmosphere we use the ROCKE-3D [4] planetary 3-D General Circulation Model, which was configured for the Moon 3.5 Ga. We use solar constant 0.75 times the modern value and a solar spectrum from 2.9 Ga. For orbital parameters we set the distance from the Earth to be 75% of the modern value. Surface topography, albedo & the distribution of permanently shadowed regions use modern data, assuming the surface hasn't changed significantly since the era of the Late Heavy Bombardment. The model uses a 4°x5° horizontal resolution & 40 vertical layers for the atmosphere.

For chemical composition we use the list of outgassed species provided by Needham and Kring [2]: CO, H_2O, H_2 and S. We exclude H_2 and S from our current consideration, assuming that the former easily escapes to space, while latter condenses at the surface soon after being outgassed. Depending on atmospheric temperature and abundance of H_2O, H_2O can react with CO converting it to CO_2. In this study we consider limiting cases of pure CO and pure CO_2 atmospheres, dry or with small amount of water (0.005 kg/kg). We then use our 0-D chemistry model to determine which of the chosen atmospheric compositions is most plausible for simulated climate.

Experiments: In this study we consider a relatively "thick" (~10^{-3} bar) lunar atmosphere, although we believe that our results will scale for lower atmospheric pressures. The general questions of stability with respect to atmospheric escape and meteorological properties of such an atmosphere were investigated in [5]. Here we briefly review the results of this study and look at a wider parameter space. In particular, we consider several cases with non-zero obliquity. While the current lunar axial tilt to the ecliptic is very low (~1.54°), at 3.5 Ga the Moon would have just passed the Cassini state transition, when its obliquity could have been as high as 50°. So, in our experiments we study the cases of 0°, 8°, 25° and 40° obliquity and investigate its effect on polar temperatures. In particular, we look at the ability of a non-zero obliquity to prevent possible atmospheric collapse in cases of pure CO_2 atmospheres.

To investigate the ability of such an atmosphere to transport volatiles, we present an experiment with a single major volcanic eruption. We took a model of a pure CO_2 1 mb lunar atmosphere, which we ran to equilibrium and set up a typical major eruption [6]. The site of the eruption was chosen to be in the middle of Mare Imbrium. The duration was 100 days and H_2O outgassing flux was 3×10^4 kg/s. This corresponds to a 10^4 m^3/s lava flow, assuming 1000 ppmv H_2O in lava.

Results: We present maps of ground and atmospheric temperatures for the experiments described above. Our preliminary estimates with our 0-D chemistry model suggest that the atmosphere will most likely be CO_2 dominated, although more research is needed in this direction.

Our obliquity-effect studies show that in the zero-obliquity case a 1 mb CO_2 atmosphere is prone to collapse at the poles. However, an obliquity as small as ~2° takes it out of that regime. A seasonal CO_2 condensation (similar to the one on modern Mars) is possible until obliquity reaches ~17°, above which no atmospheric condensation is observed, and the atmosphere is perfectly stable.

Figure 1 shows the distribution of deposited water after a single major eruption. The red square marks the site of the eruption. The eruption continued for 100 days and then was shut down, but the model was run for a full 3 years. The results show, that after 3 years ~79% of outgassed H_2O was deposited in polar regions (either above 78° North or below 78° South). This proves, that a lunar atmosphere as thin as 1 mb can efficiently transport volatiles from the maria to the poles and can play a major role in their final distribution.

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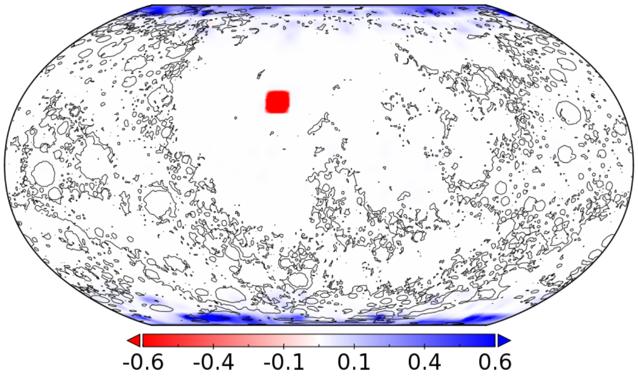

Figure 1. H_2O deposit after 3 years since the start of the eruption (kg/m^2).