CONTROLS OF IO2-BASED C-O-H DEGASSING AND DIFFUSIVE BUBBLE GROWTH ON EXPLOSIVE VOLCANIC Eruptions ON THE MOON. P. Moitra¹, A. Mallik¹, J. J. Barnes² J. C. Andrews-Hanna³. ¹Department of Geosciences, University of Arizona, Tucson, AZ; ²Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ; pmoitra@arizona.edu

**Introduction:** While effusive lava flows make up the vast majority of the maria, explosive eruptions were common as is evident from the wide occurrence of pyroclastic deposits [1-4]. The concentrations and behavior of volatiles in lunar magmas drive eruption explosivity. Recent studies provided important estimates on the C-O-H volatile contents in lunar melts [5-6]. However, which volatile species (H₂O, H₂, CO or CO₂) is the main propellant of explosive lunar eruptions is debated [7-10]. Furthermore, decompression and diffusion-induced bubble growth that primarily governs volatile degassing and eruption explosivity has not been considered in existing lunar eruption models.

As magma ascends to the surface during volcanic eruptions, the solubility of dissolved volatiles decreases due to a decrease in pressure [11]. For fast decompression during explosive eruptions, magma becomes supersaturated in dissolved volatiles causing exsolution of the dissolved volatiles into a gas (supercritical) phase, forming bubbles. The nucleated bubbles in magma further grow due to decompression and diffusion of exsolved volatiles (Fig. 1) as magma ascends to the surface.

This study investigates the effect of joint H₂-H₂O-CO or CO₂ solubility on diffusive bubble growth and magma ascent dynamics during explosive fire-fountain style volcanic eruptions on the Moon. The models are run at oxygen fugacity (fO₂) of Iron-Wüstite buffer (IW) to 2 log units below IW (IW-2), suitable for lunar magmatic conditions [12].

**Bubble growth and magma ascent modeling:** We model decompression and diffusion induced growth of bubbles in ascending magma under closed-system conditions during explosive fire-fountain style eruptions on the Moon. The model assumes homogeneous and unimodal distribution of bubbles in magma [13]. Each bubble is assumed to be surrounded by a melt shell (Fig. 1a). It is assumed that lunar picritic melts ascended through volcanic fissures similar to typical terrestrial explosive eruptions of mafic magma [14]. The model also assumes an isothermal and steady-state ascent of magma during explosive eruptions [15].

The bubble growth model includes the diffusive flux of three volatile species dissolved in the magma. Two sets of models were run: along with the dissolved H₂O and H₂, solubility of dissolved C species were included either as CO [6] or CO₂ [16]. We adopted C solubility formulation of [6] for CO₁, as an alternative solubility law of CO for lunar magma [17] is not sensitive to small pressures corresponding to several hundred meters from the surface of the Moon. The diffusivities of C-O-H volatiles [18] (diffusivity of CO is approximated as that of CO₂) were included in bubble growth calculations. The pressure of gas inside the bubbles was calculated from mass balance of a growing bubble in ascending magma, using the equation of state from [19].

The initial C content in the range of 4-64 ppm [6] corresponding to the initial saturation pressure of up to ~263 MPa was considered in the model. The initial dissolved H₂O content was varied from 100-1400 ppm [5], whereas the initial dissolved H₂ content was calculated using the gas phase reaction H₂+0.5O₂=H₂O, and the solubility formulations in [7-8] at magma temperature of 1350°C and fO₂=IW to IW-2. Considering that fragmentation of low viscosity mafic magma in fire-fountain style eruptions might take place at or above the surface [10,20], the model was run until it reaches a pressure of ~10³ Pa [8] to evaluate the degree of magma vesiculation that plays a key role in magma fragmentation and the generation of lunar pyroclasts [21].

The viscosity of magma depends on the magma composition, temperature and dissolved H₂O content [22], given a small content of other volatile species. The effect of bubbles on magma viscosity is included in the model [23]. A set of ordinary differential equations that couple mass and momentum balance of bubble growth and magma ascent in volcanic fissure with an appropriate friction factor [19] were modeled using implicit finite difference.
Model results and discussion: Fig. 2 shows representative model results, where partial pressures of all volatile species in bubbles decrease with decreasing depth due to a decrease in gas pressure, $P_g$, as a result of bubble growth. However, the exsolution of H$_2$O into bubbles increases at depths of ~100 m, causing relatively larger values of $p$/H$_2$O as compared to pCO and pH$_2$. This exsolution of H$_2$O drives bubble growth and magma vesicularity (Fig. 3) required for magma fragmentation. The initial dissolved volatile content varies with oxygen fugacity, however, the small contents of H$_2$ or CO$_2$ or CO do not significantly affect the development of high vesicularity in the ascending magma.

Our model results show that for a reasonable range of CO or CO$_2$, H$_2$O and H$_2$ content, magma reaches a threshold vesicularity of >60% at the surface (Fig. 3), required for magma fragmentation and formation of volcanic pyroclasts. We find that CO$_2$ or CO and H$_2$ likely provide the initial buoyancy to the ascending magma, but vesicularity remains small (<10%) until H$_2$O starts to exsolve at a shallow depth. These results are independent of the oxygen fugacity in lunar magmas. Along with the diffusive flux of H$_2$O, this also causes an increase in melt viscosity, increasing gas pressure that in turn increases bubble radius and magma vesicularity.

Fig. 2. Representative model results showing the mole fraction (shown as the ratio of partial pressures and the total gas pressure, $P_g$) of volatile species H$_2$O, CO and H$_2$ as a function of depth, z. Initial gas pressure of 50 MPa corresponds to initial dissolved CO content of ~12 ppm [6].

Given a fast decompression rate and that magma vesicularity of >30% is reached at only at upper ~100 m in the fissure, any significant open system gas loss during such explosive eruptions is unlikely. Furthermore, any degree of crystallization due to H$_2$O degassing would increase magma viscosity, likely contributing to bubble growth. We find that the partial pressure of H$_2$O inside bubbles stays larger than other volatile species at shallow depths independent of oxygen fugacity of IW-2 to IW (Fig. 3). On the other hand, for a small initial H$_2$O content of ~100 ppm, all else being equal, magma reaches only ~20% vesicularity at the surface. Thus, H$_2$O plays a key role for increasing vesicularity during lunar volcanism, governing magma fragmentation.

Fig. 3. Representative bubble growth and magma ascent model results show the increase in bubble radius, $R$, and gas volume (vesicularity), $\phi$ with decreasing depth, z. Results corresponding to calculations in Fig. 2 are shown for 1 km from the surface to highlight the increase in magma vesicularity.

Conclusions: Our coupled bubble growth and magma ascent model results for a suitable parameter space show that partial pressure of H$_2$O, as compared to the H$_2$ and CO or CO$_2$ volatile species, would be higher in bubbles at the upper few hundred meters of ascent to the surface of the Moon. The exsolution of H$_2$O drives magma vesicularity from 20% to >60%. We find that if the initial H$_2$O content is too low (~100 ppm), it would only cause a vesicularity of 20% in the magma and fragmentation would not occur. Thus, a wet Moon would likely provide favorable conditions required for explosive volcanic eruptions on the Moon.