FACTORS LIMITING THE EXPLOSIVITY OF VOLCANIC ERUPTIONS ON MARS. Karl L. Mitchell, Lionel Wilson and Steve J. Lane. Environmental Science Dept., Lancaster University, Lancaster LA1 4YQ, U.K. (k.l.mitchell@lancaster.ac.uk)

Introduction: Numerical models (e.g. [1]) have been used to demonstrate that long-lived, steady-state Martian volcanic eruptions should considerably more explosive than terrestrial eruptions [2]. Given conservative estimates of the supply of mantle volatiles to rising magmas we find that plinian, ignimbrite-forming or “Ionian”-style eruptions should be the norm [3]. However, this is at odds with observation as there are many interpretations of products of effusive volcanoes on Mars, particularly extensive lava flow deposits, with high degrees of certainty [4].

We consider several factors that could account for the suppression of volcanic explosivity on Mars, particularly (1) volatile depletion, (2) poor gas-clast coupling, (3) external interactions and (4) environmental change. The significance of these factors are assessed using our conduit ascent model, erupt.

Martian lava flows: Martian lava flows tend to be significantly longer than equivalents on the Earth (by a factor of ~6 – [3]) and longer lived (potentially lasting for years) due to much less efficient atmospheric cooling, higher effusion rates and lower gravity. Numerous lava flows have been identified on Mars, with total lengths ranging from tens to hundreds of kilometres, and thickness from 40 to 125 m [4] even for relatively recent eruptions (e.g. Olympus Mons). Such flow lengths are inconsistent with ponded or rootless flows (referred to here as secondary flows) associated with explosive eruptions on the Earth (usually only a few kilometres in length), and so must be accounted for.

Volatile depletion: Explosive volcanic eruptions (defined as when fragmentation of magma occurs in the conduit) are driven by the exsolution and expansion of volatiles as ambient pressure decreases [5].

We consider eruptions sourced from Neutral Buoyancy Zone (NBZ) magma chambers [3], in which CO₂ will tend to be saturated at ~0.2 wt% (c.f. Kilauean CO₂ supply of ~0.65 wt% [6]). H₂O will be undersaturated and variable (c.f. Kilauean H₂O supply of ~0.3 wt% [6]) due to the relatively high saturation levels (~2-3 wt%) at the NBZ, unless there is considerable volatile enrichment within the magma chamber.

Simulations with erupt demonstrate that even ~0.2 wt% CO₂ with no H₂O will tend to produce fragmental explosive eruptions (fig 1). Adding H₂O (which is associated with more violent explosive eruptions) causes fragmentation to increase, and if H₂O contents exceed those of CO₂, the style of activity will be dominated by H₂O expansion. We assume that exsolution and expansion of volatiles are well coupled with ambient pressure, and so magma volatile contents stay close to predicted supersaturation levels. This seems reasonable as, unlike rhyolitic magmas, there is little evidence for significant oversaturation of basalts in the literature [7].

Depletion of CO₂ within the magma chamber can occur over time. However, if CO₂ contents fall greatly volcanic eruptions are unlikely to occur without a significant driving pressure in the magma chamber (which is usually a result of bubble formation within the chamber), or else negative buoyancy effects in the conduit make it extremely difficult to trigger an eruption.

Poor gas-clast coupling: When magma rise speeds are low (or non-existent) in a vertical or near-vertical conduit, exsolved volatiles will tend to accumulate leading to heterogeneous flow typically resulting in Strombolian-style activity. The transition between Strombolian and steady-state explosive volcanism is not explored in depth here. However, dynamical models of Strombolian activity [8, 9, 10] appear to be compatible with the Martian environment [3] and may result in ponding and secondary lava flows.

Homogeneous flows through inclined conduits have been simulated using erupt, and we have found that there is a decrease in rate of volatile expansion and an increase in cumulative friction. This results in a reduction of exit velocity and an increase in temperature which becomes more extreme with increasing angle.

However, sugar-solution volcano analogue system experiments have revealed that heterogeneous flow is more likely through off-vertical conduits. We have observed a de-coupling of exsolved gas and magma that increases with conduit angle, leading to a considerable decrease in explosivity. We find that inclination
of conduits (figure 2) is an efficient way of removing gas from eruptants before they reach the surface.

Figure 2. Results from sugar-solution analogue experiments. From left to right: (a) vertical bubbly flow, (b) vertical slug flow, (c) bubbles show tendency to rise at 6°, (d) bubbles accumulate at 29°.

At low inclination, gas bubbles tend to rise towards the top of the flow, resulting in slight differential velocities. As inclination increases, the bubbles tend to accumulate to form a continuous laminar gas pocket, the expansion of which does not contribute significantly to the velocity of the liquid components within the system. Hence, an inclined volcanic eruption will tend to result in a de-coupled eruption of both a gas plume and a slow, gas-poor lava flow, from different parts of the same vent system. The magmatic component is likely to be non- to poorly-explosive, depending on vent geometry and volatile supply.

**External interactions:** Interactions with wallrock can suppress the explosivity of volcanic eruptions, due to decreases in specific kinetic energy and momentum associated with the dislodging and acceleration of lithics. However, it seems unlikely that this will result in a transition from explosive to effusive volcanism unless the style of activity is only marginally explosive to begin with. In addition, the low velocities associated with effusive volcanism result in significant decreases in friction (friction is proportional to the velocity squared) and hence a decrease in mechanical erosion.

Although interactions with surface and near-surface volatiles are generally thought to enhance explosivity, when conditions are right near-vent explosions can disrupt the flow field causing a de-coupling of volatile gases and magma and potentially disruption of the eruption plume. However, the non-steady nature of such near-vent hydrovolcanic explosions is not consistent with the formation of sustained lava flows, particularly over the long time scales (weeks to years) associated with larger Martian flows.

Sub-aqueous volcanism may result in lava flows, and the identification of such flows would be of great interest regarding climate studies. However, it is also likely that cooling due to magma-water interactions would be significant, minimising the formation of long lava flows.

**Environmental change:** Models of past climate change on Mars are usually associated with changes in atmospheric density. Previous investigations [3, 11, 12] have revealed that increased atmospheric pressure can significantly modulate explosive volcanism. This is a result of a reduction of gas bubble nucleation and expansion, which also causes an increase in likelihood of effusive and mildly explosive activity, both of which can result in lava flows. In effect, and Earth-like atmosphere would produce eruptive styles similar to those on the Earth, but with greater plume heights in the explosive case. We investigate the effects on explosive activity elsewhere [2].

**Conclusions:** Several causes can account for the reduction of explosivity, predicted by numerical models of magma ascent, on Mars. However, we find H2O depletion, either in the crust or in magma source regions, to be an insufficient explanation for the apparent trend from explosive to effusive activity [13]. It is more likely that this trend is a result of inclined conduit geometry causing separation of volatile and magma phases within the conduit. This effect may be enhanced by other factors, particularly an increase in atmospheric pressure.

Observations of massive, sheet-like lava flows often associated with Martian shields are not convincing evidence for depletion of magmatic volatiles. Hence, apparent changes of styles of volcanic activity over time from explosive to effusive are unlikely to be a direct response to volatile depletion in magma source regions, and more likely to be due to (a) progressive changes associated with construction of volcanic provinces, leading to an increase in the occurrence of inclined conduits, or (b) changes in atmospheric pressure, relating to climate change.