Relating pumice permeability to vesicle properties using 3D printed models

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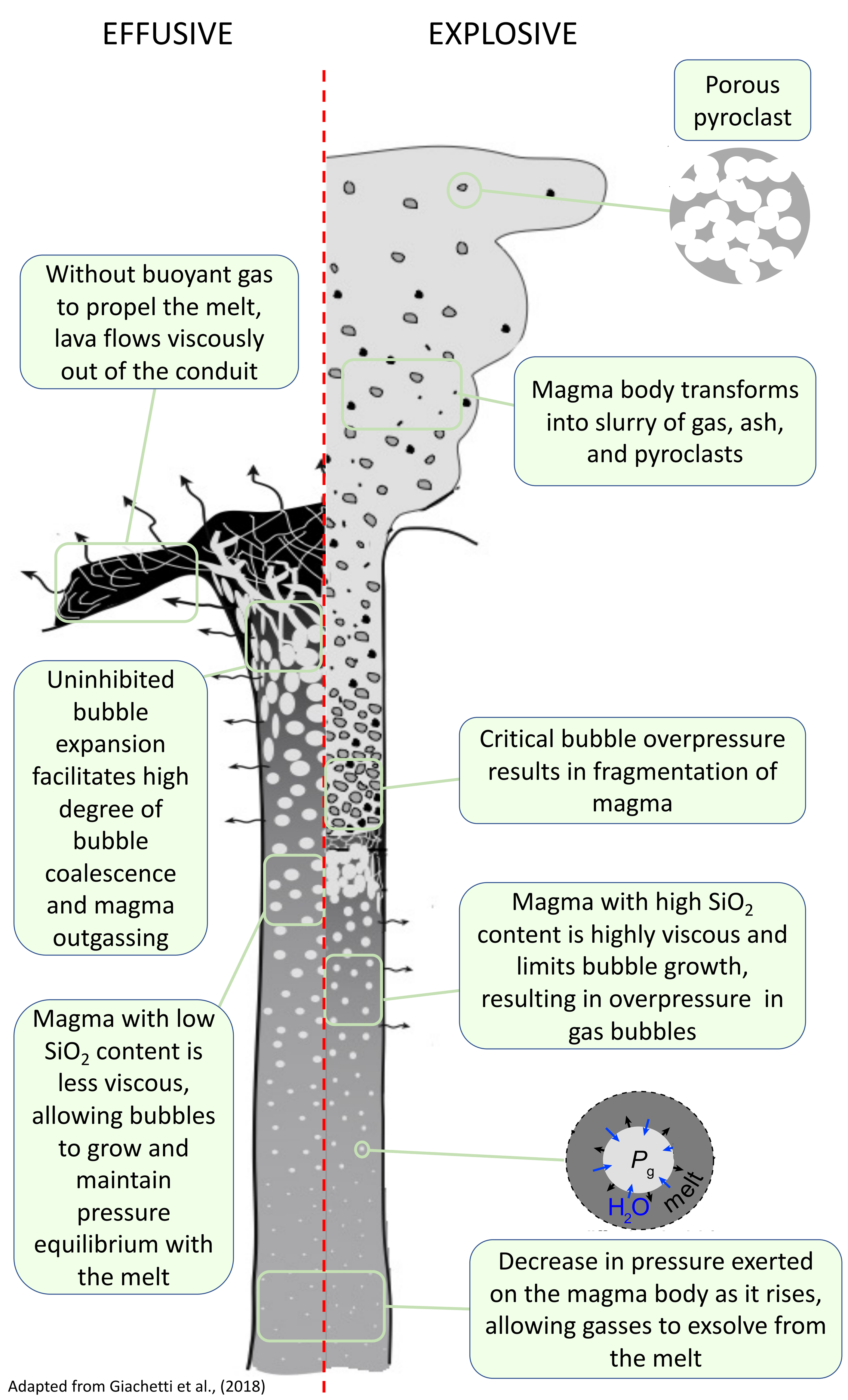
Introduction

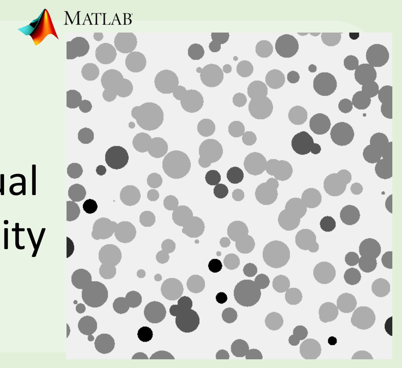
- Volcanic eruptions can be violently explosive, less hazardously effusive, or both, a characteristic largely determined by gas exsolution into bubbles and then out of the magma
- Explosive eruptions eject chunks of fragmented lava (e.g., scoria, pumice) that preserve vesicle networks and allow comparative analysis of network geometry and eruption intensity
- Because magma permeability during eruption controls eruptive style, it is critical that the relationship between vesicle properties (size, shape, orientation, etc.) and permeability is well understood
- Synthetic pumices are virtually created with controlled vesicle properties and theoretically calculated permeability. The samples are then printed in 3D and porosity and permeability are analyzed
- **GOAL:** quantify the relationship between permeability and pumice vesicle parameters for simple geometries (spheres) and then test more complex bubble shapes, size distributions, orientations, etc.



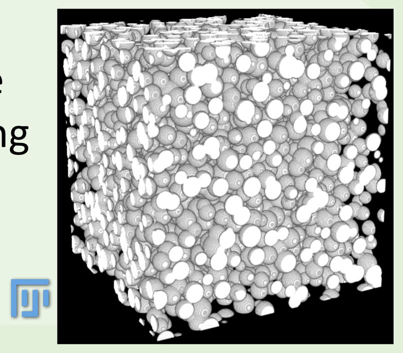
Adapted from Giachetti et al., (2018)

Methods

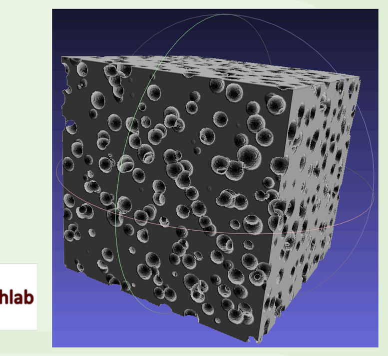
1) Parameters defining bubble number, size distribution, and connectivity are input into a numerical code, following Blower (2001). Generated images are then 'stacked' to form a 3D virtual pumice. The code output also predicts porosity and permeability and color-codes bubbles according to their connectivity.



2) Images are ordered and made binary, before being saved as a .obj 3D file.

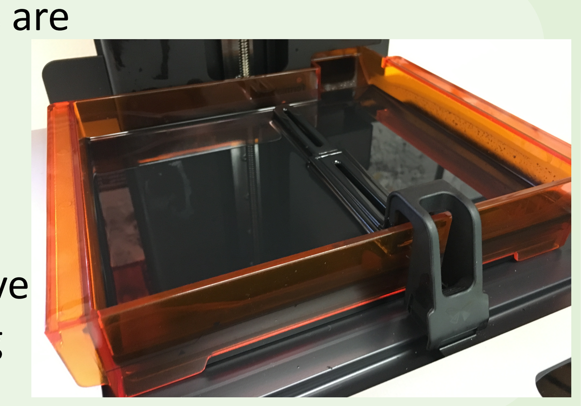


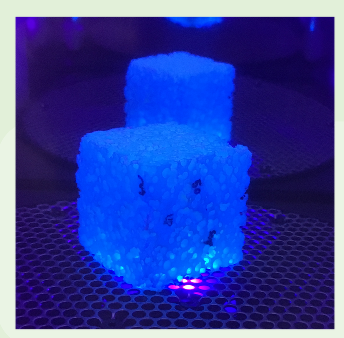
3) Models are examined using a variety of shaders and exported as a .stl 3D file.



4) Models are sized and oriented using 3D printer software and supports are generated.

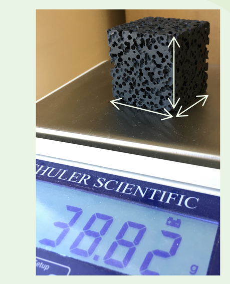
6) Models are printed layer by layer using UV-reactive solidifying resin.

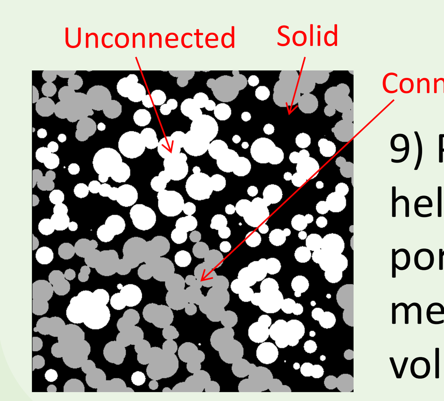




7) Models are then submerged in agitated isopropyl alcohol, dried, and cured using UV light and heat to maximize strength and rigidity.

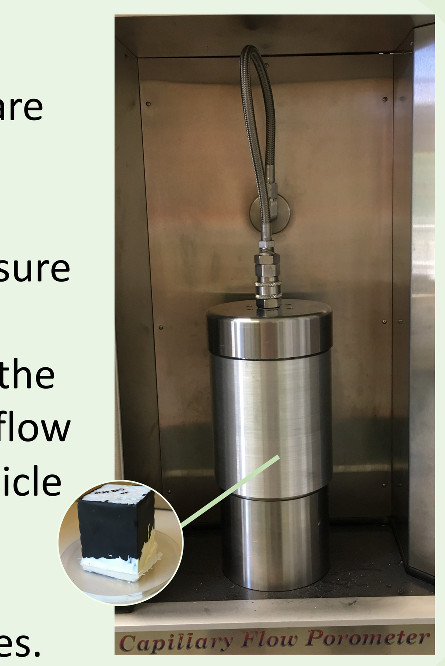
8) Total porosity measured via mass, volume, and resin density.



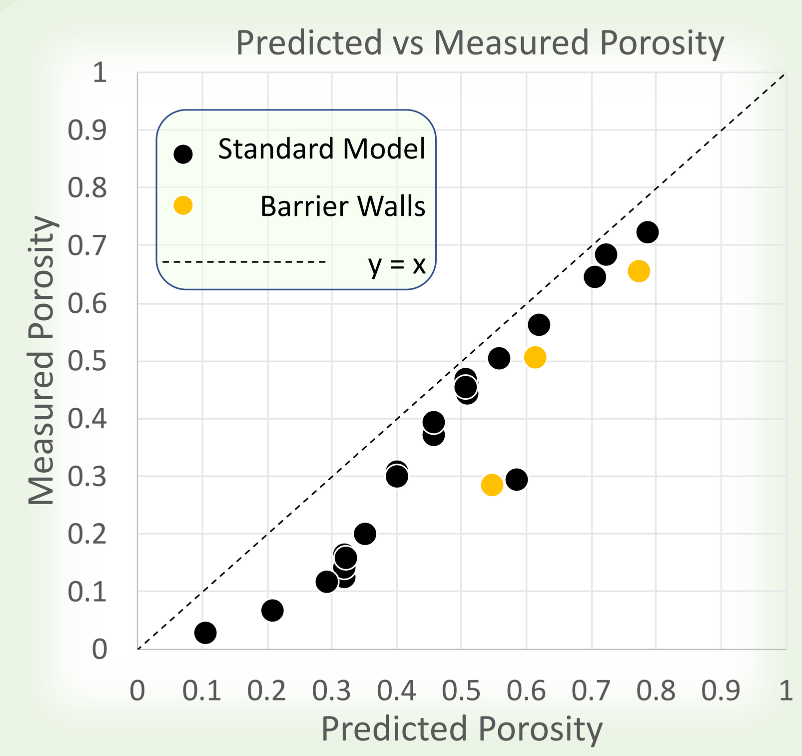


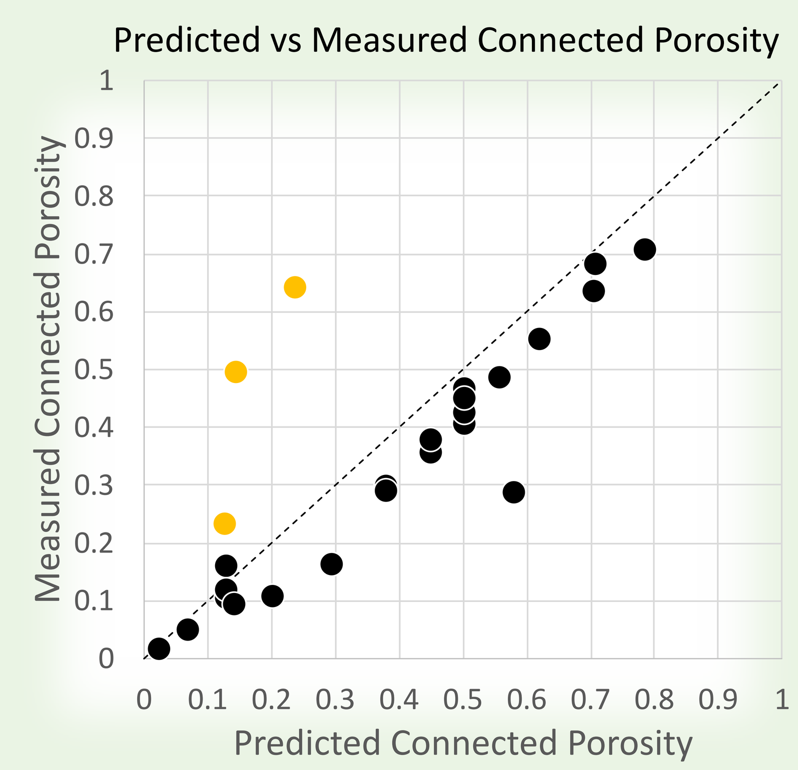
9) Pycnometer: helium infiltrates pore network to measure connected volume.

10) All but two opposite sides are sealed for permeability analysis. A pressure differential is induced across the sample and air flow through the vesicle network is measured at various pressures.

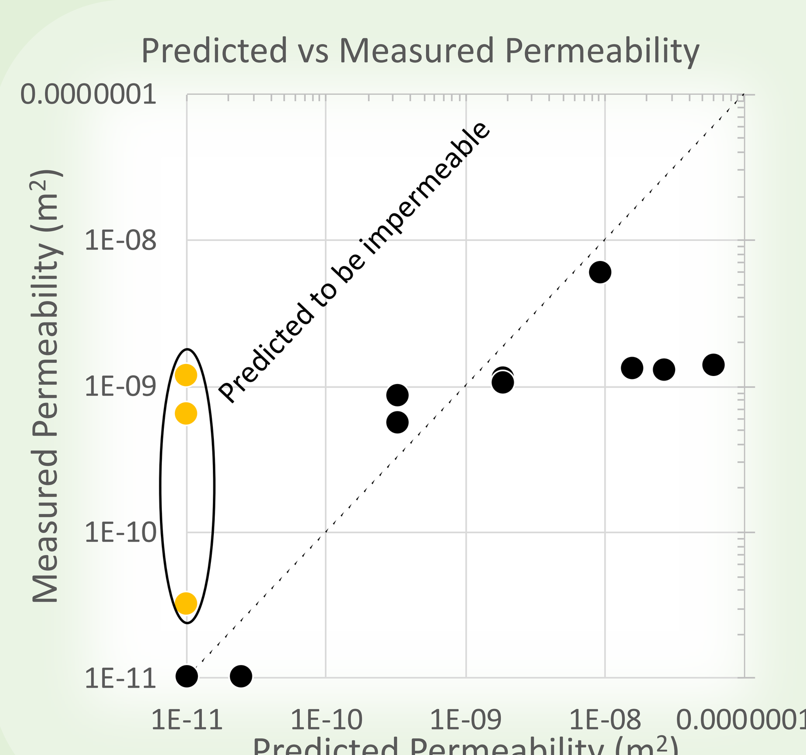


Results





- Yellow points are models printed with barrier walls in between isolated but overlapping bubbles. Measured porosity is lower than predicted by 5-20%. Measured connected porosity generally equals measured total porosity, suggesting that all printed pores are connected.
- Models with barrier walls have a measured connected porosity ~35% higher than was predicted, an indication that helium can still pass through these supposedly impermeable walls.



- While there is a minor correlation between measured and predicted permeability, most models were measured to have a permeability close to 10^{-9} m^2. Further, measured permeability slightly increased with measured porosity, though still within a limited range.
- Models with barrier walls were determined to be permeable despite being impermeable virtually.

Preliminary Conclusions

- Models with 40-80% virtual porosity may be printed in 3D with 5% porosity loss, while models with 10-40% porosity incur 10-20% porosity loss
- Models have little variation in measured permeability across all measured porosities, probably due to some bubble walls not being printed correctly
- Measured total and connected porosity matches predicted with relative accuracy, while further experimentation is required to improve permeability

Future Work

- Models will be printed with thicker barrier walls to more accurately simulate pumice vesicle networks improve permeability trends
- Investigate new printing and cleaning techniques and new resin types to minimize resin trapping and increase model accuracy
- Pumice models with elongate vesicles, fractures, and multiple vesicle populations will be tested. These are characteristics that are difficult to account for while predicting permeability numerically

Acknowledgements

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References

Blower, J. 2001, A three-dimensional network model of permeability in vesicular material. Computers and Geoscience, 27 (1), pp. 115-119

Giachetti, T., Hudak, M.R., Bindeman, I.N., Shea, T. 2018, Degassing and rehydration of explosive products of the 960 BP Glass Mountain rhyolitic eruption of Medicine Lake Volcano, California. GSA Poster.