MIDDLE TENNESSEE STATE UNIVERSITY

INSIGHT INTO INTERRELATIONSHIPS AMONG DENSITY, VISCOSITY, CRYSTALLINITY AND CHEMICAL COMPOSITION WITHIN HYPOCRYSTALLINE INTERMEDIATE LAVAS, MT. HOOD VOLCANO, OREGON

MTSU Department of Geosciences

Abigail Choisser, Dr. J. Warner Cribb

Department of Geosciences, Middle Tennessee State University

ABSTRACT

Study of the relationships between rheological properties and the mineralogical and chemical compositions of lavas is important to understanding numerous magmatic processes, such as magma buoyancy, magma mixing, and rate of magma emplacement. Improved methods of magma analysis will allow for more efficient study and prediction of rheological properties. This study examines the relationships between density, viscosity, chemical composition, mineralogical content, and percent crystallinity in intermediate lavas erupted at Mt. Hood volcano in the Cascade Range. Mt. Hood lavas were chosen for study because many contain glass in the groundmass, suggesting possible systematic relationships between, crystallinity, density, viscosity, and chemical composition. Lavas chosen for analysis were erupted during the Main Stage period (~700,000 to 30,000 ybp). Most are two-pyroxene andesites (SiO2= 58 – 61 wt%) and basaltic andesites (SiO2 = 52 – 58 wt%) characterized by hypocrystalline groundmasses with plagioclase, clinopyroxene and orthopyroxene (in basaltic andesites) as major phases. Temperature - dependent melt viscosities were calculated from whole rock compositions using the method of Giordano et al. (2008). Melt densities were calculated using partial molar volumes of oxide components using the method of Bottinga and Weill (1970). Both density and viscosity were calculated at temperatures ranging from 700oC to 1200oC. Densities vary from 2.41 g/cm3 at 1200 oC to 2.54 g/cm3 at 700oC. Viscosities range from log η = 2.23 PaS at 1200 oC to logη=12.62 PaS at 700oC. Calculations of percent crystallinity using XRD sample spectra vary from 94% crystalline at log η = 3.44PaS (SiO2 = 60.08wt%) to 42% crystalline at logη=3.37PaS (SiO2=59.71wt%). Viscosity data, when graphically related to crystallinity and chemical composition using the R programming language, provide insight into interrelationships among these physical properties in three dimensions, allowing for development of a regression plane for predictive studies into Mt. Hood's subsurface magmatic processes.

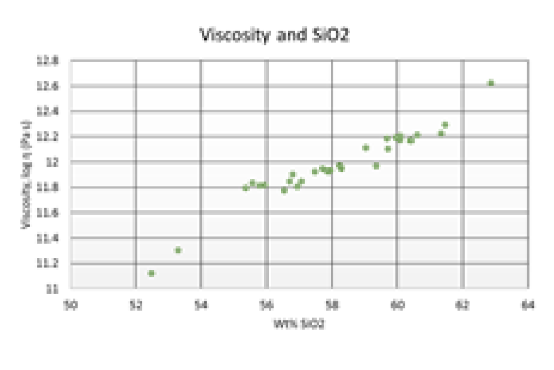
HYPOTHESIS

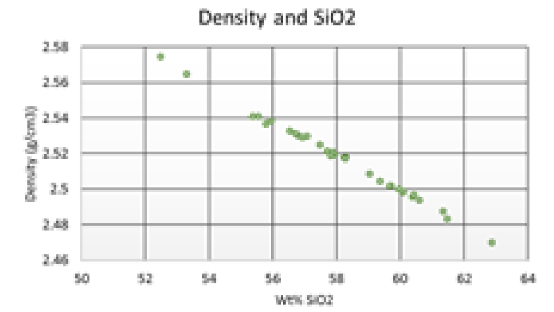
Specific Questions To Be Answered:

1. What is the relationship between magma chemical composition and magma densities at Mt. Hood? Is the relationship linear? If not, why?
2. What is the relationship between density and viscosity among Mt. Hood magmas of different chemical compositions?
3. Are the relationships between viscosity and temperature consistent among Mt. Hood Magmas of different compositions?
4. Are calculated differences in Mt. Hood magma densities and viscosities consistent with petrographic observations of the presence and amount of glass in each sample?
5. Are calculated differences in Mt. Hood magma chemical compositions, densities and viscosities consistent with the identification and quantification of glass in each sample using x-ray diffraction?

CALCULATIONS AND DATA COLLECTION

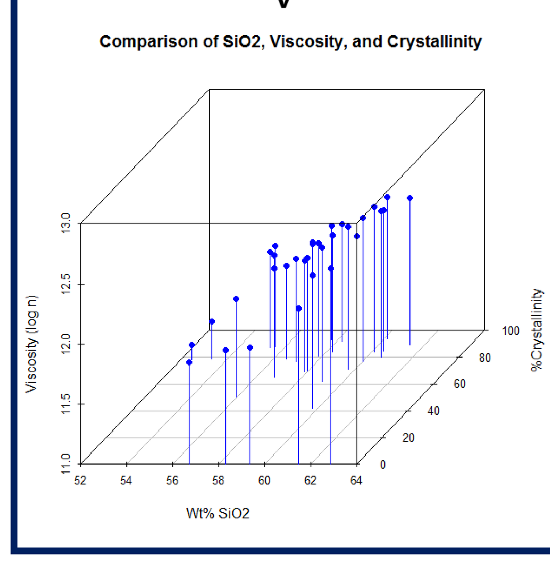
Certain challenges can prohibit our ability to measure density and viscosity of lavas in the field, so it becomes necessary to rely on mathematical models to determine their physical characteristics. Calculating viscosity of magmas involves assessing shear stress over shear strain rate. Using the Arrhenius Relation, it is possible to calculate the viscosity of the melt as it behaves as a Bingham liquid, allowing modeling of the change in lava viscosity with change in temperature, crystallinity, and wt% SiO2.





With the presence of crystals and gas bubbles - both of which Mt. Hood melts possess significant quantities of - it is expected that yield stress would increase with increasing quantity of crystalline phase.

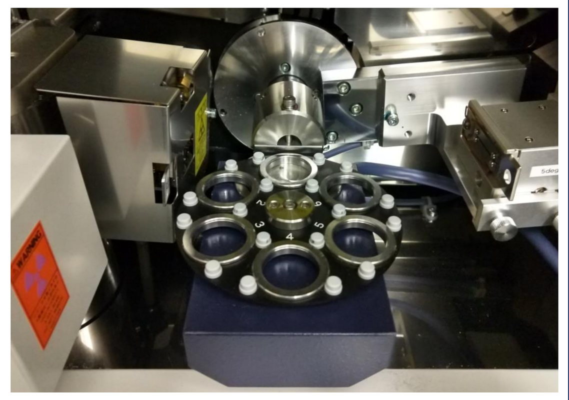
$$\rho = \frac{\Sigma_i M_i X_i}{\overline{V}}$$

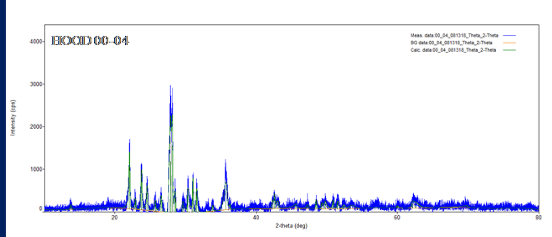


XRF (X-ray fluorescence spectroscopy) was implemented to collect whole rock chemical data within the Mt. Hood lavas, and powder XRD (X-ray diffraction) was relied on to elucidate relationships between crystallinity and major phases within lavas. Samples were prepared for XRF analysis through dilution of 1.52g powdered sample with 3.61g LiTetraborate, 8.17g LiMetaborate, and 6 drops of LiBromide solution before being melted at 1050 ºC. Analyses were performed on the Oxford Instruments XRF spectrometer in the Dept. of Geosciences using USGS Standard Reference Materials.

CRYSTALLINITY DETERMINATION

The American Mineralogist Crystal Structure Database (Downs and Wallace, 2003) provided individual mineral phase 2-Theta peaks. Through comparison of peaks to three significant figures crystalline phases were identified and amorphous peak values were then determined using PDXL software.





Once the samples were analyzed using the XRD, standard crystal structure datasets were compared to the data collected. This analysis was guided by a petrographic review, as this method elucidated which mineral phases were present in the individual samples.

2-THETA	INTENSITY	D-SPACING	H	K	L	Multiplicity
20.87	19.93	4.2574	1	0	0	6
26.65	69.90	3.3446	0	1	1	6
26.65	30.10	3.3446	1	0	1	6
36.56	7.13	2.4580	1	1	0	3

Example Quartz Crystal Standard Peak Values (Downs and Wallace, 2003).

For each mineral in each sample, the 2-Theta peak, relative intensity, and D-Spacing were compared for crystal structure identification. D-spacing and 2-Theta values were matched up to the 3rd significant figure for improved accuracy and reliability.

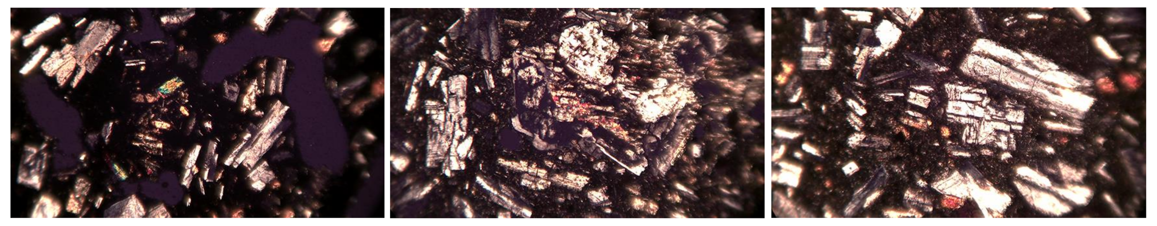
Once the peaks which correlated to crystalline phases were identified, all exceptions were identified as amorphous or "glassy" material. PDXL, despite being unable to initially identify the minerals present in the samples, was useful for calculating the percent crystallinity once amorphous peaks were identified and entered manually.

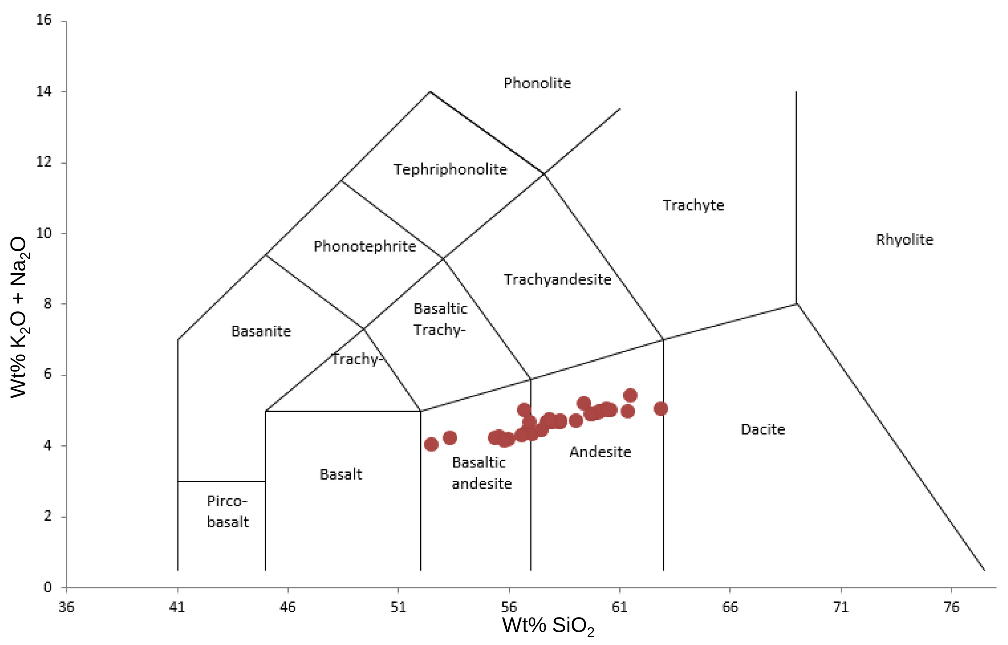
Percentage of amorphous material in comparison to quantity of crystalline phases provides insight into the rheological relationships of flow within Mt. Hood melts.

Once %Crystallinity has been determined, it is possible to compare it to physical characteristics determined through calculations such as viscosity, density, and the chemical composition. The preferred method of comparing these values would be graphically, through visual models using a three variable x, y, z axis system.

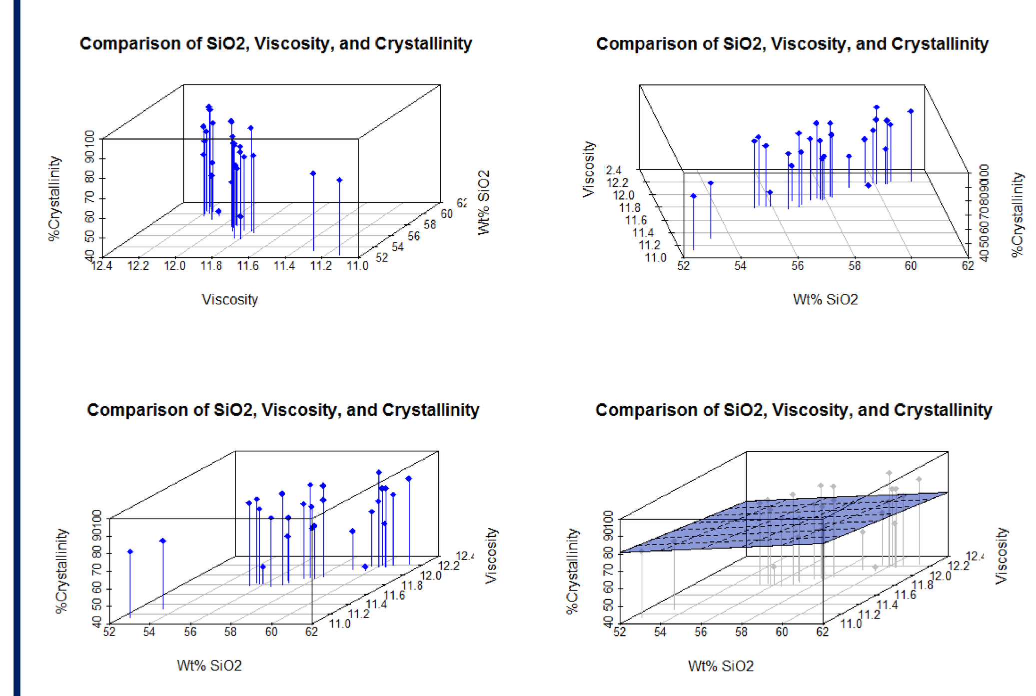
PETROGRAPHIC ANALYSIS

Petrographic analysis shows the complexities and similarities between samples along with the varying percentages of crystallinity within the Mt. Hood main stage magmas. Petrography became the primary backbone to mineral identification necessary for understanding the x-ray diffraction data collected for this project due to unforeseen software challenges. It became necessary to manually identify 2-theta peaks for mineral phases when determining mineral content. Prior knowledge of common mineralogy within Mt. Hood andesites and basaltic andesites also provided a preliminary road-map for determining crystallinity values.





GRAPHING



In order to achieve a three-variable analysis, it is necessary to plot data along a 3 axis chart. The software being utilized for this visual analysis is R, a programming language developed for statistical computing. The software is capable of creating a visual representation of the phase values, while also highlighting areas of highest concentration and planar slope if present for interpolation.

The package being used for this analysis is termed scatterplot3d, and is operated through the R command line. To process the data, text tables are converted into a more comprehensive format allowing for the software to more easily read and plot the x, y, and z axes. Future steps would be to further test the reliability of this regression with more data.

Equation of planar regression:
20.17x-150.02y-0.44z= -655.69 R=1

LITERATURE CITED

Bottinga Y, Weill DF (1970) Densities of liquid silicate systems calculated from partial molar volumes of oxide components. Am J Sci 269:169 182

Chambers, J. M. (1992) Linear models. Chapter 4 of Statistical Models in Seds J. M. Chambers and . J. Hastie, Wadsworth & Brooks/Cole.

Downs, R.T. and Hall-Wallace, M., 2003, The American Mineralogist Crystal Structure Database; American Mineralogist, v. 88, p. 247-250.

Giordano, D., Russell, J.K., Dingwell, D.B., 2008, Viscosity of Magmatic Liquids: A Model; Earth & Planetary Science Letters, 271, 123-134

Kress VC, Carmichael ISE (1991) The compressibility of silicate liquids containing Fe2O3 and the effect of composition, temperature, oxygen fugacity and pressure on their redox states. Contrib. Mineral Petrol 108:82±92

Lange RA, Carmichael ISE (1987) Densities of Na2O-K2O-CaOMgO-FeO- Fe2O3-Al2O3-TiO2-SiO2 liquids: new measurements and derived partial molar properties. Geochim Cosmochim Acta 51:2931±2946

Ligges, U. and Mächler, M. (2003). Scatterplot3d - an R Package for Visualizing Multivariate Data. Journal of Statistical Software 8(11), 1-20.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, www.R-project.org.

Rikagu (2010), PDXL: Integrated X-Ray powder diffraction software; The Rikagu Journal, 26(1), https://www.rigaku.com/downloads/journal/RJ26-1/Rigaku%20PDXL%20XRD%20analysis%20software.pdf.

Wilkinson, G. N. and Rogers, C. E. (1973). Symbolic descriptions of factorial models for analysis of variance. Applied Statistics, 22, 392–399. doi: 10.2307/2346786.

ACKNOWLEDGMENTS

This research is supported by the MTSU College of Basic and Applied Sciences; Dr. Warner Cribb provided research mentorship. Zada Law and Karen Wolfe of the MTSU Geoscience Department provided assistance in helping to prepare this poster.