

Table 1: Dry, bulk rock compositions for various volcanoes (wt%). Two different lavas were erupted at Unzen in the 1991-1995 eruption.

Volcano	Eruption	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	Fe ₂ O ₃	MnO	MgO	CaO	K ₂ O	Na ₂ O	P ₂ O ₅
Unzen ¹	1991-1995	64.27	16.13	0.71	0.00	5.10	0.10	2.47	4.69	2.54	3.81	0.17
Unzen ²	1991-1995	51.84	18.19	1.28	0.00	10.27	0.18	4.62	9.43	1.22	2.79	0.17
Kilauea	1992	49.78	12.79	2.37	0.00	12.40	0.17	8.75	10.59	0.41	2.14	0.22
MORB	N/A	50.47	14.70	1.68	10.43	0.00	0.18	7.58	11.39	0.16	2.79	0.18
Novarupta	1912	77.19	12.28	0.18	1.3	0.0	0.05	0.19	0.87	3.17	4.32	0.05

Table 2: Liquidus temperatures for rocks shown in Table 1 at 200 MPa for dry and wet (4 wt% water) compositions.

Volcano	Eruption	Dry Liquidus T / °C	Wet Liquidus T / °C
Unzen ¹	1991-1995	1148	1043
Unzen ²	1991-1995	1226	1079
Kilauea	1992	1237	1172
MORB	N/A	1215	1145
Novarupta	1912	1123	826.56

Magma viscosity and density

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1. Table 1 lists bulk rock compositions as measured for erupted lavas from various volcanoes.

- Use Figure 1 to classify the composition of the rocks in Table 1.
- Create a new table listing the compositions shown in Table 1, but presenting the data in mol%

Table 2 shows the liquidus temperatures of the magmas in Table 1 for both dry composition and 4 wt% water at 200 MPa.

- For the Novarupta volcano, determine the wet melt composition at the wet liquidus temperature at 200 MPa.

Furthermore, the volume V_m of 1 mol of melt of composition \mathbf{X} as a function of pressure P and temperature T is given by

$$V_m(T, P, \mathbf{X}) = \sum_i X_i \left[\bar{V}_i(T = T_R, P = P_R) + \frac{\partial \bar{V}_i(T, P = P_R)}{\partial T} \Big|_{T=T_R} (T - T_R) + \frac{\partial \bar{V}_i(T = T_R, P)}{\partial P} \Big|_{P=P_R} (P - P_R) \right], \quad (1)$$

where $T_R = 1673$ K and $P_R = 10^{-4}$ GPa. Values for the red, blue and green quantities can be found in Table 3.

- For the Novarupta volcano, determine the density of the **dry** melt composition at the **dry** liquidus temperature, at 200 MPa. Take care with units and show your method clearly (it may be helpful to draw a table).
- For the same volcano, determine the density of the **wet** melt composition at the **dry** liquidus temperature, at 200 MPa.

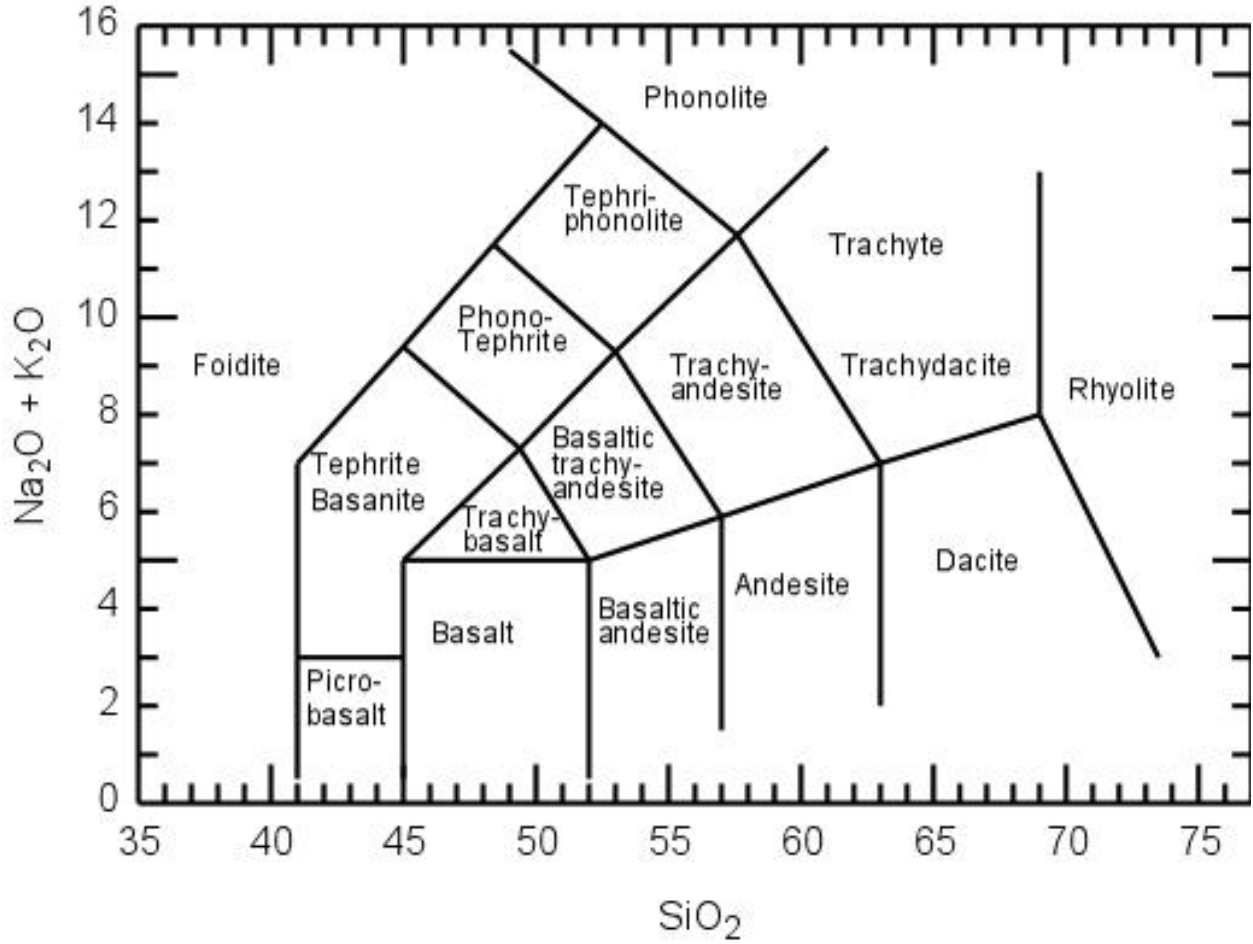


Figure 1: Total Alkali-Silica (TAS) diagram for characterisation of volcanic rocks.

Table 3: Partial molar volume, thermal expansions and compressibilities of oxide components

	$\bar{V}_i(T = T_R, P = P_R)$ / $10^{-6} \text{ m}^3 \text{ mol}^{-1}$	$\left. \frac{\partial \bar{V}_i(T, P = P_R)}{\partial T} \right _{T=T_R}$ / $10^{-9} \text{ m}^3 \text{ mol}^{-1} \text{ K}$	$\left. \frac{\partial \bar{V}_i(T = T_R, P)}{\partial P} \right _{P=P_R}$ / $10^{-6} \text{ m}^3 \text{ mol}^{-1} \text{ GPa}$
SiO ₂	26.86	0.0	-1.89
TiO ₂	23.16	7.24	-2.31
Al ₂ O ₃	37.42	0.0	-2.31
Fe ₂ O ₃	42.13	9.09	-2.53
FeO	13.65	2.92	-0.45
MgO	11.69	3.27	0.27
CaO	16.53	3.74	0.34
Na ₂ O	28.88	7.68	-2.40
K ₂ O	45.07	12.08	-6.75
Li ₂ O	16.85	5.25	-1.02
H ₂ O	26.27	9.46	-3.15
CO ₂	33.0	0.0	0.0

- (f) Again for Novarupta, determine the density of the **wet** melt composition at the **wet** liquidus temperature, at 200 MPa.
- (g) Describe the effect of both temperature and water content on the density of the magmatic melt at Novarupta. Be as quantitative as you can.
2. At a temperature of 767 °C and pressure of 200 MPa, the equilibrium crystal assemblage of the wet Novarupta magma is feldspar ($\phi_{\text{fld}} = 0.5, \rho_{\text{fld}} = 2.5 \text{ g cm}^{-3}$), quartz ($\phi_{\text{qz}} = 0.3, \rho_{\text{qz}} = 2.5 \text{ g cm}^{-3}$), spinel ($\phi_{\text{sp}} = 0.007, \rho_{\text{sp}} = 4.9 \text{ g cm}^{-3}$) and biotite ($\phi_{\text{bio}} = 0.5, \rho_{\text{bio}} = 2.75 \text{ g cm}^{-3}$) whilst the melt density is 2.21 g cm^{-3} and the melt viscosity is 147910.8 Pa s . Additionally, the gravitational settling velocity of a crystal of size d and density ρ_c in melt of density ρ_m and viscosity η_m is given by

$$v_s = \frac{(\rho_c - \rho_m)gd^2}{18\eta_m}, \quad (2)$$

where $g = 9.81 \text{ m s}^{-2}$ is the gravitational acceleration.

- (a) Calculate the settling velocities of each crystal phase in the Novarupta magma.

For the wet Kilauea composition, the equilibrium assemblage at the same pressure is olivine ($\phi_{\text{ol}} = 0.03, \rho_{\text{ol}} = 3.37 \text{ g cm}^{-3}$), orthopyroxene ($\phi_{\text{opx}} = 0.006, \rho_{\text{opx}} = 3.28 \text{ g cm}^{-3}$), clinopyroxene ($\phi_{\text{cpx}} = 8.21, \rho_{\text{cpx}} = 3.29 \text{ g cm}^{-3}$) and spinel ($\phi_{\text{sp}} = 0.02, \rho_{\text{sp}} = 4.9 \text{ g cm}^{-3}$), with a melt density of 2.31 g cm^{-3} and a melt viscosity of 28.1 Pa s .

- (a) Calculate the settling velocities of each crystal phase in the Kilauea magma.
- (b) It has been suggested that crystal cumulates can form at the base of magma chambers of sills by gravitational settling of crystals. Consider 10 m thick sills of both the Novarupta and Kilauea compositions. If the sills were maintained at constant temperatures, how long would it take for such a cumulate to form in each case?
- (c) What are the most important parameters in determining whether such cumulates can form? Also consider processes which have been neglected here.