## Appendix B: How to apply the OSaS barometers to holocrystalline basalts

Application of the OSaS barometers requires compositional information for olivine and spinel, as well as for some liquid plausibly in equilibrium with the crystalline phases. In the following appendix, we provide a possible approach for applying the OSas using a dataset of whole rock compositions, point counts, mineral compositions from holocrystalline basalts that contain (1) olivine with reported representative compositions for cores and rims, (2) chromite inclusions in olivine, and (3) titanomagnetite crystals a holocrystalline groundmass documented in Wang (1985). The basalts erupted in the Eastern margin of the Basin and Range province, in Snowville, UT (Wang, 1985). We use data from this study because the author reports all information required to calculate interstitial melt compositions. We stress that this is merely one of many possible approaches to apply the OSaS model to holocrystalline basalts and that there may be other equally viable approaches, depending on the nature of samples. Critical evaluation of one's own samples is required to carry out any modeling approach.

*Step 1: Estimation of Liquid Composition*

The simplest assumption one can make about a liquid composition is that the whole rock composition is representative of liquid composition in equilibrium with crystalline phases. This may be true for crystal-poor samples (<5% crystals), as is the case for the Snowville basalts reported in Wang (1985) (Table A1). As sample crystallinity increases, it becomes more challenging to determine a liquid composition. Given that magmas may potentially inherit crystalline phases during ascent (e.g., plagioclase accumulation in basalts), it is possible that the whole rock composition may actually reflect crystalline phases that have been mixed in to an erupted rock. An interstitial melt composition can be determined using mass balance between whole rock compositions, mineral proportions and mineral compositions.

To determine the interstitial melt composition for the Snowville basalts. We use the fractional crystallization model (Eq. A1), as the olivine crystals are clearly zoned based on core and rim analyses reported in Wang (1985) to solve for the concentrations of major oxide components in the liquid phase ($C_L$).

$$C_L = C_0 F^{K_D - 1} \qquad \text{Eq. A1}$$

We make the assumption that the concentration of each major element in the whole rock compositions are the starting concentration ($C_0$) and F is the fraction of melt remaining (1 – the modal abundance, as a decimal). The partition coefficients ($K_D$) for major elements between olivine and melt are determined using the compositions of olivine cores reported in Wang (1985) (Eq. A2), where $C_i$ is the concentration of any oxide component.

$$K_D = C_i^{olivine} / C_i^{whole\ rock} \qquad \text{Eq. A2}$$

The same approach could be used for a sample with higher crystallinity and a more complex mineral mode.

| Table A1: | | |
|---|---|---|
| Samples | SUV8326 | SUV8336 |
| *Whole Rock* | | |
| $SiO_2$ | 51.84 | 51.57 |
| $TiO_2$ | 1.08 | 1.50 |
| $Al_2O_3$ | 14.41 | 14.55 |
| $FeO^T$ | 10.13 | 9.84 |
| MnO | 0.15 | 0.15 |
| MgO | 7.35 | 7.60 |
| CaO | 8.74 | 8.55 |
| $Na_2O$ | 2.31 | 2.35 |
| $K_2O$ | 1.50 | 1.62 |
| Total | 97.51 | 97.73 |
| *Mode* | | |
| Olivine | 3.8 | 4 |
| *Olivine Partition Coefficients* | | |
| $SiO_2$ | 0.70 | 0.78 |
| $TiO_2$ | 0.00 | 0.00 |
| $Al_2O_3$ | 0.00 | 0.00 |
| $FeO^T$ | 4.14 | 1.71 |
| MnO | 4.40 | 1.80 |
| MgO | 3.07 | 5.85 |
| CaO | 0.03 | 0.02 |
| $Na_2O$ | 0.00 | 0.00 |
| $K_2O$ | 0.00 | 0.00 |
| *Interstitial Melt* | | |
| $SiO_2$ | 52.46 | 52.04 |
| $TiO_2$ | 1.12 | 1.56 |
| $Al_2O_3$ | 14.98 | 15.16 |
| $FeO^T$ | 8.97 | 9.56 |
| MnO | 0.13 | 0.15 |
| MgO | 6.78 | 6.24 |
| CaO | 9.08 | 8.90 |
| $Na_2O$ | 2.40 | 2.45 |
| $K_2O$ | 1.56 | 1.69 |

In some cases where a sample may have experience obvious mixing between two different magmas (instead of inheriting crystals), a melt composition could be estimated by analyzing the groundmass with a defocused microprobe beam. There are limitations to all assumptions made about the composition of the liquid phase. In this suggested method, we assume that the whole rock compositions could be a viable liquid composition and that the calculated interstitial melt composition (Table A1) could also be a viable liquid composition.

*Step 2: Pairing crystalline and liquid compositions*

To understand if the liquid compositions could be in equilibrium with the olivine crystals, we calculate the standard equilibrium test of Fe-Mg partitioning between olivine and melt (Eq. A3).

$$^{Fe^{2+}-Mg}K_{D^{mineral-melt}} = \frac{(X_{Fe^{2+}}/X_{Mg})^{mineral}}{(X_{Fe^{2+}}/X_{Mg})^{melt}}$$ 
Eq. A3

We assume all iron in olivine is ferrous. As we have no a priori information about the concentration of ferrous iron in the melt, we also assume all iron is ferrous in the melt. The resultant $^{Fe-Mg}K_D$ values are minimum values and range between 0.24-0.28 for the olivine-whole rock and olivine-estimated interstitial liquid pairs, for all four samples of the Snowville basalts (Table A2). Accounting for ferric iron in the melt will cause these $K_D$ values to increase close to the widely accepted value of ~0.3.

*Step 3: Estimate pre-eruptive temperature and $H_2O$ contents*

We use the olivine-liquid thermometer of Putirka (2008) to determine temperature for the olivine-whole rock and olivine-calculated interstitial liquid pairs. Many models are available to estimate pre-eruptive temperatures based on mineral-liquid pairings. Temperatures are reported in Tables A2 and A3.

We use the plagioclase-liquid hygrometer of Waters and Lange (2015) to estimate water contents in equilibrium with the reported plagioclase composition in Wang (1985), the temperatures, and the respective liquid compositions (most approach 0 wt%). We assume these basalts are anhydrous.

*Step 4: Enter dataset into OSaS and obtain results*

We input the datasets (whole rock- chromite inclusions-olivine cores and interstitial liquid-chromite inclusions-olivine cores) into the model and find both melt compositions return the same values of oxygen fugacity (ΔNNO 0 to ΔNNO –0.1) for both models (Table A2).

We also input the interstitial liquid-groundmass magnetite-olivine rim compositions into the OSaS models. We find that the oxygen fugacity recorded by the groundmass magnetites and olivine rims is more reducing (ΔNNO –1) than that of the olivine cores and chromite inclusions. Wang et al (1985) also reports compositions for magnetite-ilmenite pairs for the SUV samples, which we incorporated into the model of Ghiorso and Evans (2008). The magnetite-ilmenite pairs record oxygen fugacities that range from –0.9 to 1.0 ΔNNO. The oxygen fugacities recorded by MELTS-OSaS closely match the oxygen fugacities recorded by the ilmenite-magnetite pairs, whereas the Classic-OSaS model recovers $fO_2$ values that are more reducing.

Table A2: Olivine Cores, Chromite Inclusions, Whole Rock as Liquid

| | SUV8326 | SUV8336 |
|---|---|---|
| *olivine* | *core* | *core* |
| $SiO_2$ | 40.21 | 40.44 |
| $FeO^T$ | 16.86 | 16.54 |
| MnO | 0.27 | 0.18 |
| MgO | 44.43 | 44.73 |
| CaO | 0.18 | 0.18 |
| *chromite* | | |
| $SiO_2$ | 0.4 | 0.25 |
| $TiO_2$ | 1.7 | 1.86 |
| $Al_2O_3$ | 20.5 | 21.38 |
| $Cr_2O_3$ | 32.36 | 33.5 |
| $FeO^T$ | 29.73 | 32.16 |
| MnO | 0.37 | 0.49 |
| MgO | 10.44 | 9.16 |
| CaO | 0 | 0.03 |
| NiO | 0.1 | 0.04 |
| Results (Whole Rock) | | |
| $K_D$ (olivine) | 0.3 | 0.3 |
| T (°C) | 1207 | 1218 |
| log $fO_2$ (Classic OSaS) | -7.5 | -7.4 |
| ΔNNO (Classic OSaS) | -0.1 | -0.1 |
| log $fO_2$ (MELTs-OSaS) | -7.4 | -7.4 |
| ΔNNO (MELTs-OSaS) | 0.0 | -0.1 |
| Results (Interstitial Liquid) | | |
| $K_D$ (olivine) | 0.3 | 0.3 |
| T (°C) | 1183 | 1140 |
| log $fO_2$ (Classic OSaS) | -7.8 | -8.3 |
| ΔNNO (Classic OSaS) | -0.1 | -0.1 |
| log $fO_2$ (MELTs-OSaS) | -7.7 | -8.3 |
| ΔNNO (MELTs-OSaS) | 0.0 | -0.1 |

Table A3: Groundmass Magnetite, Olivine Rims, Interstitial Liquid

| | SUV8326 | SUV8336 |
|---|---|---|
| olivine | rim | rim |
| $SiO_2$ | 36.32 | 35.59 |
| $FeO^T$ | 39.89 | 40.08 |
| MnO | 0.57 | 0.59 |
| MgO | 23.99 | 24.39 |
| CaO | 0.23 | 0.2 |
| magnetite | | |
| $SiO_2$ | 0.69 | 0.36 |
| $TiO_2$ | 19.88 | 23.26 |
| $Al_2O_3$ | 1.31 | 2.2 |
| $Cr_2O_3$ | 0.05 | 0.06 |
| $FeO^T$ | 71.16 | 67.88 |
| MnO | 0.57 | 0.47 |
| MgO | 1.28 | 1.13 |
| CaO | 0 | 0 |
| NiO | 0 | 0 |
| Results (Interstitial Liquid) | | |
| T (°C) | 1183 | 1140 |
| log $fO_2$ (Classic OSaS) | -9.0 | -10.0 |
| ΔNNO (Classic OSaS) | -1.3 | -1.8 |
| log $fO_2$ (MELTs-OSaS) | -8.4 | -9.5 |
| ΔNNO (MELTs-OSaS) | -0.7 | -1.3 |
| ΔNNO Ilm_Magnetite Thermometry | -0.9 | -1.0 |