SUPPLEMENTARY INFORMATION

Geothermometry
Two feldspar geothermometry was applied to coexisting plagioclase and sanidine phenocrysts in the SCL flow using the SOLVECALC software (Wen and Nekvasil, 1994) with the ternary feldspar solution model of Elkins and Grove (1990) assuming a pressure of 3 kbar. Sanidine and plagioclase rims yield temperatures of 819°C and crystal interiors yield a temperature of 773°C. 2σ uncertainties are ±20°C (Elkins and Grove (1990). The assumed pressure is based on two pyroxene barometry (Putirka et al., 2008), depth of the current shallow crustal magma reservoir (Farrell et al., 2014), and quartz geobarometry (Girard and Stix, 2012). Decompression is ruled out as the cause for the apparently high temperature rims because reduced pressure would crystallize compositions yielding apparently lower temperatures, i.e., normal zoning. Experiments determining the phase relations of other Yellowstone hotpost rhyolites indicate that the order of plagioclase versus sanidine crystallization depends on the composition of the melt (Almeev et al., 2012; Bolte et al., 2015). However, in all cases, sanidine crystallizes within 100°C of the solidus and most commonly ≤50°C above the solidus. The Fe-rich SCL clinopyroxene phenocrysts (Fe/(Fe+Mg)=0.7) commonly exhibit exsolution lamellae in their cores parallel to [100], which indicates slow cooling to near-solidus conditions (<<825°C) (Huebner, 1980; Lindsley, 1983). The exsolved cores are mantled by zones with lower Fe/Mg, indicating growth from less-evolved magma. Pyroxene thermometry using QUILF (Andersen et al., 1993) for quartz-saturated rhyolite at 3 kbar yields average temperatures of ~900°C for the cores and rims of the pyroxene, and an average temperature of the ~920°C for the Mg-rich intermediate zones. Rims on SCL zircon yield an average Ti-in-zircon temperature (Ferry and Watson, 2007) of ~860°C (assuming aTio2=0.5) whereas the zircon interiors yield temperatures of ~820°C, suggesting that the rims grew from hotter (or higher aTio2) melts. Equilibrium Fe-Ti oxide pairs adjacent to groundmass glass yield temperatures of ~730-860°C and log 10 fO2 of -13 to -15 (NNO +2 to +3), calculated using the formulation of Anderson & Lindsley (1998) with the Stormer (1983) activity model.

Thus, the core-to-rim compositions of SCL sanidines, pyroxenes and zircons all indicate a transition from lower temperature interior zones to higher temperature rims (see Figure 1 in main text) due to the addition of a hotter, less evolved rhyolitic melt, rather than the progressive cooling producing pronounced changes in partitioning. The evidence discussed here, as well as the observed 18O/16O isotope disequilibria, which indicates exchange between hydrothermal fluids and solid rock prior to melting (Bindeman et al., 2008), confirms that the SCL magmatic system was at near- or sub-solidus conditions prior to the rejuvenation event.

NanoSIMS Trace Element Profiles in Sanidine
Trace element profiles were measured with a CAMECA 50L NanoSIMS at Stanford University in multi-collection mode using beam-controlled line scans varying from 45 to 75 microns in length with 0.3 micrometer (μm) spacing. Primary beam intensities of 100-200 pA of negatively charged O ions on the sample surface generated secondary ion intensities of ~700 nA that were measured in four cycles with dwell times of 5 sec/point. We tested the method of collecting profiles via adjacent rasters of 1 x 1 μm areas, but the results were convoluted relative to those
collected as simple line scans. Hence, only line scan data is used for the diffusion modeling. The concentrations of the trace elements of interest were calculated by normalizing their secondary ion yields to those for stoichiometrically fixed Si, and referenced to working curves from NIST and RLS glasses (Macdonald et al., 1992; Pearce et al., 1997).

The 2-3 fold variability of Ba and Sr concentrations observed in the SCL sandine rims is also observed in other rhyolitic magmas (e.g., Dunbar and Hervig, 1992; Bachmann et al., 2002; Stelten et al., 2013) and thus is not just an artifact of the standardization. For example, rims on sanidines from the Bishop Tuff have a ~ 3–fold variation in Ba and Sr concentrations despite identical major element compositions (e.g., Dunbar and Hervig, 1992). A several-fold variation of Ba concentrations is observed for the rims of sanidine crystals in younger Yellowstone rhyolites (Stelten et al., 2013). Accordingly, the variability of Ba and Sr in the rims of SCL sanidines likely results from concurrent growth of sanidine crystals within regions of the magma reservoir that differed in degrees of re-melting and renewed crystallization. Dispersal and mixing of crystals from different portions of a magma reservoir is a consequence of thermal rejuvenation (e.g., Couch et al., 2001).

**Crystallographic Orientation and Choice of Diffusion Coefficients**

The crystallographic orientations of the NanoSIMS profiles used in the diffusion modeling were determined via electron backscatter diffraction (EBSD) using an FEI Quanta 600 scanning electron microscope at California State University—Northridge. The EBSD patterns were collected using a 25 kV acceleration voltage, a filament current of 2.7 A and an emission current of 93–95 μA. The working distance was varied between 12 to 25 mm depending on the sample mount. Maps measuring 10x12 mm were collected and their EBSD patterns were indexed using the Oxford Instruments AZtec software package.

The profiles in the sanidine crystals are oriented to record diffusion within 30° of normal to [100] or [010], as color coded in main text Figure 3. Experimental data for diffusion of Ba and Sr in sanidine indicates that diffusion of these elements in sanidine is isotropic (Cherniak, 2010). Hence, the profiles were modeled using the diffusion coefficient (D\text{Ba}) of Cherniak (2002) for Ba diffusion in sanidine (Or61) normal to the [001] cleavage face and the D\text{Sr} of Cherniak (1996) for diffusion normal to [001] in sanidine (Or61). Published data for Mg diffusion in feldspars suggest anisotropy with diffusion parallel to the c axis occurring three times faster than parallel to the b axis (LaTourrette and Wasserburg, 1998). EBSD results indicate that the Mg profile for Grain 04-43 is within 30° of the b axis. To determine the appropriate D\text{Mg} for our calculations of diffusion along the b axis, in addition to issues of anisotropy, the relationship between feldspar composition and the experimentally measured diffusivities for Ba, Sr and Mg was examined, including the relationships between D\text{Mg} and plagioclase composition proposed by Costa et al. (2003), Faak et al (2013), and Van Orman et al. (2014). The range of experimentally determined D\text{Mg} values for sanidine compositions is limited (D\text{Mg} measurements are restricted to four data points between Or40-Or50: Van Orman et al., 2014), which necessitates extrapolation to the Or50 composition of SCL sanidines based on the relation of diffusion and sanidine composition for another divalent alkaline earth metal (Sr). D\text{Sr} is constrained over a wide range of alkali feldspar compositions (Or60 to Or93; Cherniak and Watson, 1992; Cherniak, 1996), and is effectively insensitive to variation in the Or component at temperatures of 800-900°C; analogous behavior is
expected for divalent Mg. Similar behavior of $D_{\text{Mg}}$ and $D_{\text{Sr}}$ is also observed in anorthite in the 800-900°C range (Cherniak, 2010), therefore here we employ the $D_{\text{Mg}}$ of LaTourette and Wasserburg (1998) for diffusion in anorthite (An$_{95}$) parallel to the $b$ axis. This diffusion coefficient is the lowest measured for feldspar and thus provides the longest and most conservative estimate of diffusion duration.

**Diffusion Model**

In these systems, there is no compositional or oxygen fugacity dependence so the diffusivities are calculated using the expression:

$$D_i = D_0 e^{\frac{-E}{RT}} \quad (1)$$

where $D_i$ is the $D_0$ for the species $i$, $E$ is the activation energy, $R$ is the gas constant, and $T$ is temperature.

The modeling employed an analytical solution to the diffusion equation appropriate for an abrupt change in composition in the middle of a crystal (far from the rim or where the diffusive distance is small):

$$C = C_0 + \frac{(C_1 - C_0)}{2} \text{erf} \left( \frac{x}{2\sqrt{D_i t}} \right) \quad (2)$$

where $C$ is the normalized concentration, $C_0$ and $C_1$ are the initial amounts of the elements on each side of the interface at time zero, $D_i$ is the calculated diffusivity in m$^2$/s, $t$ is the diffusion time and $x$ is the midpoint of concentration gradient. Ba, Sr and Mg model results presented in Figure 3 of the main text assume an initial step-function geometry for the interface. Textural relationships within the SCL sanidines (zones that truncate previous zone boundaries, reversals in composition inconsistent with fractional crystallization processes) and electron probe profiles at 10 mm spacing support an initial step-function condition (Fig. DR3). Table DR1 illustrates the range of variables used for the modeling to determine the values that produce the lowest misfit to the measured profile. $C_1$ and $C_0$ are determined by testing a range of values during the grid space searching and locating those values that produce the smallest misfit between the measured and modeled profiles. The one exception to this model protocol was for the Mg profile for Grain 04-43, where the diffusion equation was solved numerically using a finite differences technique. For this case, the Ba profile from the same grain is scaled for relative concentration difference and used as the initial condition for the model to determine the time interval required for Mg to reach an equilibrium concentration profile (i.e., flat) as observed in the other three sanidine profiles. An equilibrium concentration profile is recognized as a uniform concentration within the analytical precision of the NanoSIMS Mg measurements ($2\sigma = 0.6$ ppm).

The best-fit time interval reported for each curve represents the time interval in our model search that produces the lowest misfit, which is calculated as the sum of square of the residuals between the measured concentration profile and the modeled concentration profile calculated using equation 2 normalized to the number of points in the profile. This can be visualized in
Figure DR6 where the modeled and measured profiles for core-rim boundary are plotted. The 95% confidence intervals for the durations of time calculated from the diffusion modeling were derived by converting the misfit curves into cumulative probability curves and locating the ages at the 2.5% and 97.5% limits (Sambridge, 1999; Beghein, 2010). The misfit relationships we obtain are bounded by time = zero and are approximately Gaussian in log(time) space. Therefore, these highly asymmetric uncertainty bounds are reported as asymmetric standard errors. The temperature range explored in the model space was the 2σ uncertainty for the temperature calculated for the sanidine rim growth using two feldspar thermometry (±20°C). Thus, the probability distribution function for each modeled profile, and therefore the uncertainties given with the best fit ages illustrated in Figure 3 of the main text include the propagated uncertainty from the mineral thermometry.

Alternative models exist for calculating timescales of diffusion using decoupled profiles of two elements such as the Binary Element Diffusion Model of Morgan and Blake (2006). However, these approaches were not employed here because at a minimum they require both Ba and Sr to have experienced resolvable diffusion, and our NanoSIMS profiles reveal that insufficient time has elapsed in order to yield Ba and Sr profiles that significantly differ in shape at the level of our ultra-high resolution analyses.

**Crystal Growth Rates**

Observations from experiments on feldspar crystal growth rates and natural samples suggest the range of possible sanidine growth rates are between ~10^-6 and 10^-10 cm/sec depending on degree of undercooling (Swanson, 1977; Swanson et al., 1989; Cashman, 1993; Couch, 2003; Zellmer and Clavero, 2006; Calzolaio et al., 2010). This range of crystal growth rates have been observed in felsic magmas for the temperature and pressure range relevant to this study (e.g., Swanson et al., 1989; Swanson, 1977). Observations of natural samples yield rates near the slower end of the reported range (e.g., Zellmer and Clavero, 2006). The slowest crystal growth rates (10^-10 cm/sec) predict the 4-7 micron zone of interest at the sanidine core-rim boundary would form in 1.5-3.5 months, and the entire sanidine rim could grow in 15 years, while the fastest rates (10^-6 cm/sec) predict 5-9 minutes and 11 hours, respectively. The degree of undercooling predicted for the Scaup Lake lava suggests the slower crystallization rates are likely more accurate for the scenario discussed here.

**Timescale Between Thermal Rejuvenation and Crystallization**

Bindeman et al. (2007) documented 18O/16O disequilibrium between ~50 mm diameter cores and high-Ti (i.e., high temperature) rims of single SCL zircon where the rims are in 18O/16O equilibrium with their host glass. Given experimental constraints on the kinetics of oxygen isotope diffusion in zircon under wet conditions (Watson and Cherniak, 1997) and a temperature of 819°C, a ~50 mm diameter zircon would anneal its oxygen isotope composition within 1200 years. If the rate of sanidine dissolution is controlled by rates of Na-K(-Al) diffusion in a silicic melt, then sanidine dissolution is expected to occur at rates similar to those for growth (Cashman, 1993; Zellmer and Clavero, 2006).
SUPPLEMENTARY INFORMATION ADDITIONAL REFERENCES CITED


Van Orman, J.A., Cherniak, D.J., and Kita, N.T., 2014, Magnesium diffusion in plagioclase:


Figure DRI. Postcaldera rhyolite lavas and tuffs of Yellowstone caldera (after Christiansen, 2001). Dashed line is the caldera margin formed during the ca. 640 ka eruption of the Lava Creek Tuff. Patterned flows represent Upper Basin Member rhyolites, including the Scaup Lake (SCL) lava shown in blue. Central Plateau Member rhyolites shown in gray erupted from the vent locations marked with stars. Extracaldera rhyolite flows are marked with vertical lines.
Figures DR2-DR5. Cathodoluminescence (CL) images of all Scaup Lake sanidine phenocrysts used in this study and their full trace element NanoSIMS profiles illustrated with 2σ analytical error. Profile locations on the CL images are indicated by red lines. The portion of the concentration profiles that we interpret as the rim is also shown for reference. Note the apparent sharpness of the core-rim boundary in the CL images, whereas the CL grayscale values plotted along the profile length reveal that the core-rim boundary is also a color gradient over 4-7 microns like the Ba, Sr and Mg NanoSIMS profiles.
Figure DR3.
Note the spatial resolution of the NanoSIMS profiles compared to electron probe profiles.

Grain 01-3c
-NanoSIMS transect:
01_3c profile 1
45 microns, 145 points
5 sec/pt, 4 cycles
~0.31 microns per step

-EPMA transect:
10 micron steps
207 microns total
Grain 04-43
04_43 profile 2
45 microns total length
140 points
4 cycles
5 sec/point
~0.32 micron step size
(error bars smaller than points in Ba and Sr profiles)

Figure DR4.
Grain 01-5a
01_5a profile
75 microns total
250 points
~0.3 micron spacing
5 sec/point
4 cycles
(error bars smaller than points for Ba and Sr profiles)

Figure DR5.
Figure DR6. The best-fit time interval reported for each curve represents the time interval from our model search that produces the lowest misfit, which is calculated as the sum of square of the residuals between the measured concentration profile and the modeled concentration profile in ppm normalized to the length of the profile, as can be visualized here.
Table DR1. Predicted widths of the Ba, Sr and Mg diffusion profiles after diffusion for 1000 years at 800°C using experimentally-determined diffusivities (LaTourrette and Wasserburg, 1998; Cherniak, 2002; 1996).

<table>
<thead>
<tr>
<th>Element</th>
<th>Predicted Width (microns)</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba</td>
<td>8</td>
<td>4.00E-23</td>
</tr>
<tr>
<td>Sr</td>
<td>44</td>
<td>1.60E-21</td>
</tr>
<tr>
<td>Mg</td>
<td>200</td>
<td>4.00E-20</td>
</tr>
</tbody>
</table>
Table DR2. Range of variables explored in the brute-force model space searching for the diffusion modeling. The range explored for each variable is the reported error for each variable from the supporting reference. The error on temperature is discussed in the section on geothermometry in the Supplement.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Ba in Sanidine</th>
<th>Sr in Sanidine</th>
<th>Mg in Sanidine</th>
</tr>
</thead>
<tbody>
<tr>
<td>t (k.y.)</td>
<td>0-5</td>
<td>0-5</td>
<td>0-5 (ky)</td>
</tr>
<tr>
<td>$D_0$ (m$^2$/s)</td>
<td>0.29*</td>
<td>8.4*</td>
<td>7.1e-08 (±0.1e-08)$^\dagger$</td>
</tr>
<tr>
<td></td>
<td>log $D_0$ = -0.54 ± 0.841*</td>
<td>log $D_0$ = 0.9252 ± 0.5893$^#$</td>
<td></td>
</tr>
<tr>
<td>E (kJ/mol)</td>
<td>455 (±20)*</td>
<td>450 (±13)$^\dagger$</td>
<td>254 (±43)$^\dagger$</td>
</tr>
<tr>
<td>Temp (°C)</td>
<td>819 (±20)</td>
<td>819 (±20)</td>
<td>819 (±20)</td>
</tr>
<tr>
<td># model runs</td>
<td>$10^6$</td>
<td>$10^6$</td>
<td>$10^6$</td>
</tr>
</tbody>
</table>

*Cherniak, 2002
#Cherniak, 1996
$^\dagger$LaTourette and Wasserburg, 1998