Supporting Information for ”A geophysical model for the origin of volcano vent clusters in a Colorado Plateau volcanic field”
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Additional Supporting Information (Files uploaded separately)
1. List of new gravity data: list_new_gravity_data.xlsx

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Introduction

We show the details of how we tied our new gravity data to the UTEP database. More details of the density inversion model are described. Comparison between observed and simulated gravity anomalies shows that the inverted crustal density contrasts can account for the main features of the gravity anomaly in and around the Springerville volcanic field (SVF). Sensitivity analysis of parameters $N_1$ and $N_2$ suggests appropriate values used in our model. We discuss the necessity to re-map crustal density into vertical diffusivity and to model the change in magma flux.
Text S1. Before we tied our new gravity measurements to the UTEP database, we redid the terrain correction for the UTEP database. This guarantees the new and previous gravity data use the same digital elevation model (DEM) for inner and outer terrain corrections. After all gravity anomaly correction, our new gravity anomaly data were tied to the UTEP database by applying a constant shift. The constant shift, -211.24 mGal, is the average of differences between the previous and new gravity anomaly measurements at three locations (Table S1).
Table S1. Comparison between our new and previous gravity anomaly measurements (from UTEP database) at three locations (Figure S2). The average difference is -211.24 mGal.

<table>
<thead>
<tr>
<th>New gravity measurement</th>
<th>Previous gravity measurement</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitude (WGS84)</td>
<td>Longitude (WGS84)</td>
<td>Distance (meter)</td>
</tr>
<tr>
<td>Latitude (WGS84)</td>
<td>Latitude (WGS84)</td>
<td></td>
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<tr>
<td>Complete Bouguer Gravity anomaly reduced to the base (mGal)</td>
<td>Complete Bouguer Gravity anomaly (mGal)</td>
<td></td>
</tr>
<tr>
<td>-109.728062 34.344426 5.84</td>
<td>-109.728159 34.343875 -205.44</td>
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<tr>
<td>-109.915659 34.115515 -0.04</td>
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<td>52</td>
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<td>-110.080915 34.204376 4.24</td>
<td>-110.080496 34.204873 -207.19</td>
<td>67</td>
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</table>

*Gravity station az001 in the file list_new_gravity_data.xlsx*
Figure S1. Complete Bouguer gravity anomaly map of the SVF based on previous gravity data. Red dots in (a) are gravity stations from UTEP database. Black dots in (b) are Quaternary volcanic vents. Grey lines are contours of gravity anomaly with 2 mGal interval. The gravity anomaly map is gridded at a spacing of 0.5 km based on the minimum curvature algorithm using GMT software. Compared with the new gravity anomaly map (Figure S2a), gravity gradients, especially in the east and northeast part of the volcanic field, do not correspond well with the ENE and NNE trending of vent alignments.
Figure S2. (a) New complete Bouguer gravity anomaly map of the SVF based on our new and previous gravity data. Grey lines are contours of gravity anomaly with 2 mGal interval. The gravity anomaly map is gridded at a spacing of 0.5 km based on the minimum curvature algorithm using GMT software. Black triangles are volcanic vents. (b) Gravity gradient map. Red and green dots (green dots are overlain by the red dots) are three pairs of gravity stations used to tie our new gravity data to the UTEP database (Table S1). They locate at area of relatively low gravity gradient. The gravity gradient in the volcanic field is steepest in the central and northeast parts, with highest gradient reaching 4 mGal km$^{-1}$. 
Figure S3. Example calculation of the complete Bouguer gravity anomaly caused by very large vertical (dike-like) and horizontal (sill-like) slabs. (a) Parameter setting for a dike. The top of the dike is on the surface. $\Delta \rho$ is the density contrast, which is negative in our case meaning the magma is lighter than the crust. (d) Parameter setting for a sill. (b), (c) and (e) are calculated gravity anomalies along the dashed blue, green and red profiles (on the surface, crossing the horizontal center of slabs) in (a) and (b), respectively. (f) Dashed lines are the re-plotted (b), (c) and (e) in Figure S6c after shifting axes. The gravity anomalies caused by such large dikes and sills cannot explain the long-wavelength features of the observed gravity anomaly.
Figure S4.  (a) Inverted crustal density contrast of a 45 by 45 prism grid. Red and green dots are new and old gravity stations, respectively. Prisms extend several kilometers horizontally beyond the study area (red box) to reduce edge effects. In some areas, particularly in the southern part of the map, undulation in density contrast between adjacent prisms may indicate a model equivalency issue. In other words, the gravity can be modeled by abrupt change in gravity in adjacent prisms or a smoother variation - the solution is nonunique. Thus, there is an inevitable trade-off between model smoothness and equivalency. (b) Histogram of inverted crustal density contrasts of the 2025 prisms. The inverted density contrasts range from -137.9 kg m$^{-3}$ to 147.8 kg m$^{-3}$. The peak value is about 0 kg m$^{-3}$. 95.1% (approximately 2 standard deviations) inverted density contrasts fall in the range -55 kg m$^{-3}$ to 55 kg m$^{-3}$. 
Figure S5. Comparison between observed and simulated gravity anomalies. (a) Scatter plot of observed and simulated complete Bouguer gravity anomalies. 538 gravity stations (279 new stations and 259 previous stations) were used. (b) Residual (observed minus simulated) gravity anomalies. (c) Histogram of the residual gravity anomalies. The peak value is about 0 mGal. 95.6% (about 2 standard deviations) residual gravity anomalies fall in the range -3.5 to 3.5 mGal.
Figure S6. (a) Residual Bouguer gravity anomaly map gridded at a spacing of 0.5 km based on the minimum curvature algorithm using GMT software. (b), (c) and (d) show observed and simulated gravity anomalies along profiles AA’, BB’ and CC’, respectively. The simulated gravity anomalies are smoothed compared to the observed anomalies. The long-wavelength features of the observed gravity anomalies are captured by the simulated gravity anomalies.
Figure S7. Sensitivity analysis of $N_1$ and $N_2$ in equation 3 in the paper based on 2D modeling of profile AB (Figure 3c in the paper). When $N_2 < 2$, we can always find a value for $N_1$ to match the simulated surface magma flux to vent density. This agreement is guaranteed by lateral changes of vertical diffusivity in the crust, instead of the diffusivity in the mantle lithosphere. We use $N_2 = 1$ in our model for simplification.
Figure S8. Sensitivity analysis of parameter $N_2$ (ratio between vertical diffusivity and horizontal diffusivity) based on 2D modeling of profile $AB$ (Figure 3c in the paper) when $N_1 = 1$. $N_2$ is the same for all model cells. The position of the maximum simulated magma flux at the surface is not governed by the horizontal diffusivity. Instead, it’s governed by the vertical diffusivity in the crust. When the ratio $N_2$ is too small (e.g., $N_2 < 50$), the south of the profile (south of 3770 km) has a relatively high magma flux. However, vent density is low there. When the ratio $N_2$ is too big (e.g., $N_2 > 250$), the simulated magma flux is too high at the shoulder. We suggest that a value between 100 to 250 for the ratio $N_2$ to be used when $N_1 = 1$ in our model.
Figure S9. (a) Spatial density map of volcanic vents in the SVF. Dots indicate the locations, at which the value is used to assess correlations with gravity data and model results. (b) Scatter plot of vent spatial density and complete Bouguer gravity anomaly. A negative correlation exists in the circled area. (c) Scatter plot of vent spatial density and the crustal density contrast. (d) Scatter plot of vent spatial density and the vertical diffusivity in the crust. (b)-(d) indicate that high vent density has a relatively high probability in corresponding with low gravity anomaly, low density contrast and high vertical diffusivity. (e) Scatter plot of vent spatial density and the simulated surface magma flux (Figure 5a in the paper). The dots are more concentrated compared with (b)-(d). Therefore, it is necessary to re-map crustal density into vertical diffusivity, and to model the change in magma flux.