



*Supplement of*

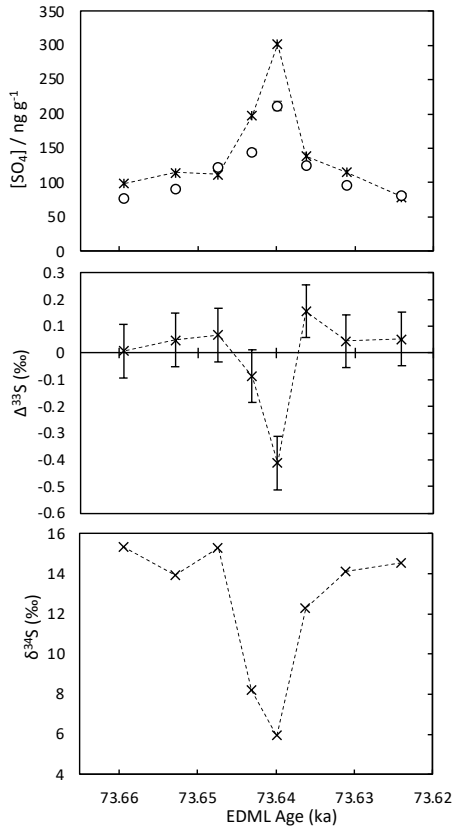
## **New insights into the $\sim 74$ ka Toba eruption from sulfur isotopes of polar ice cores**

**Laura Crick et al.**

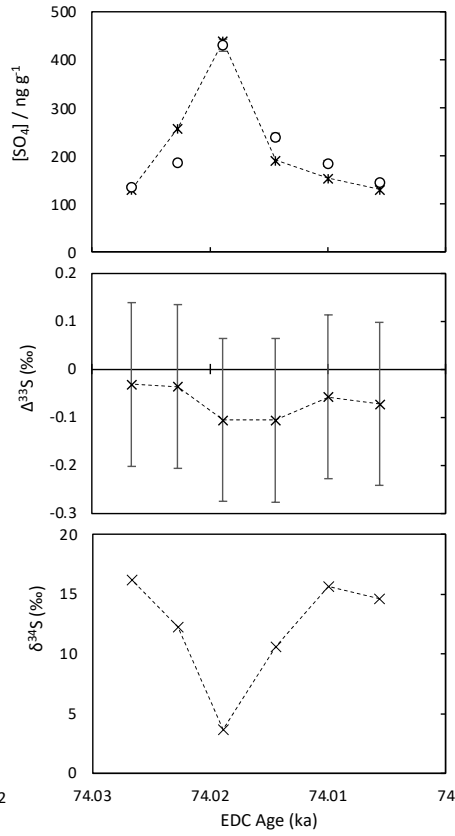
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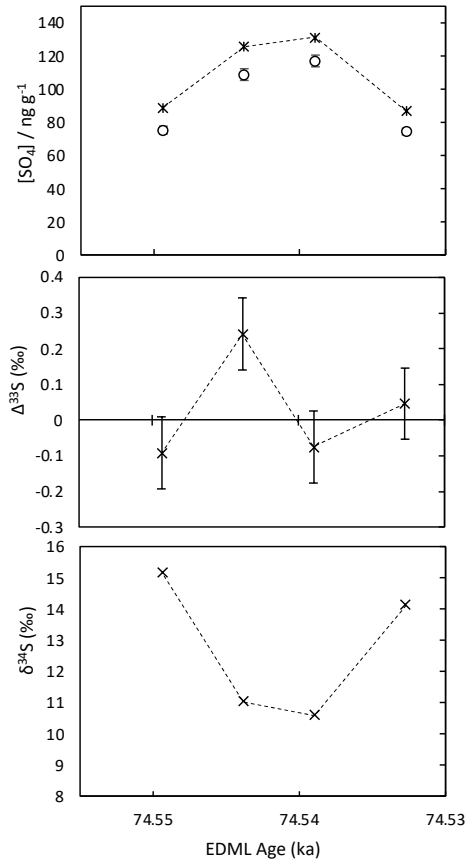
1. Pre-T1



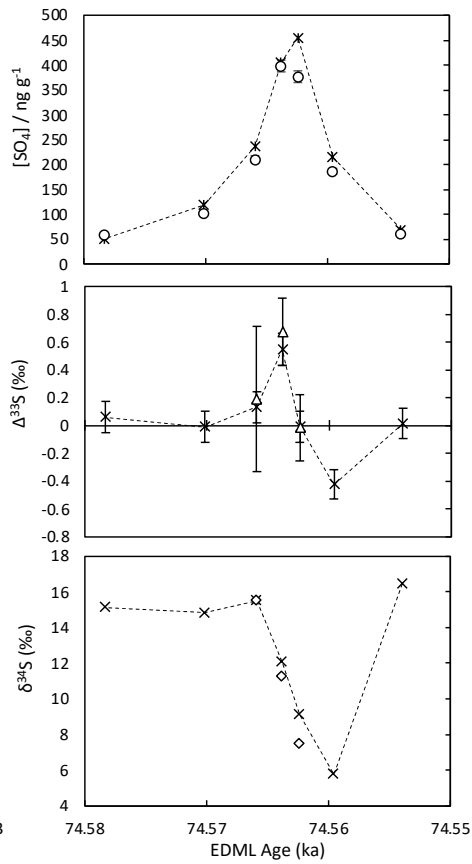
2. T4 (EDC)

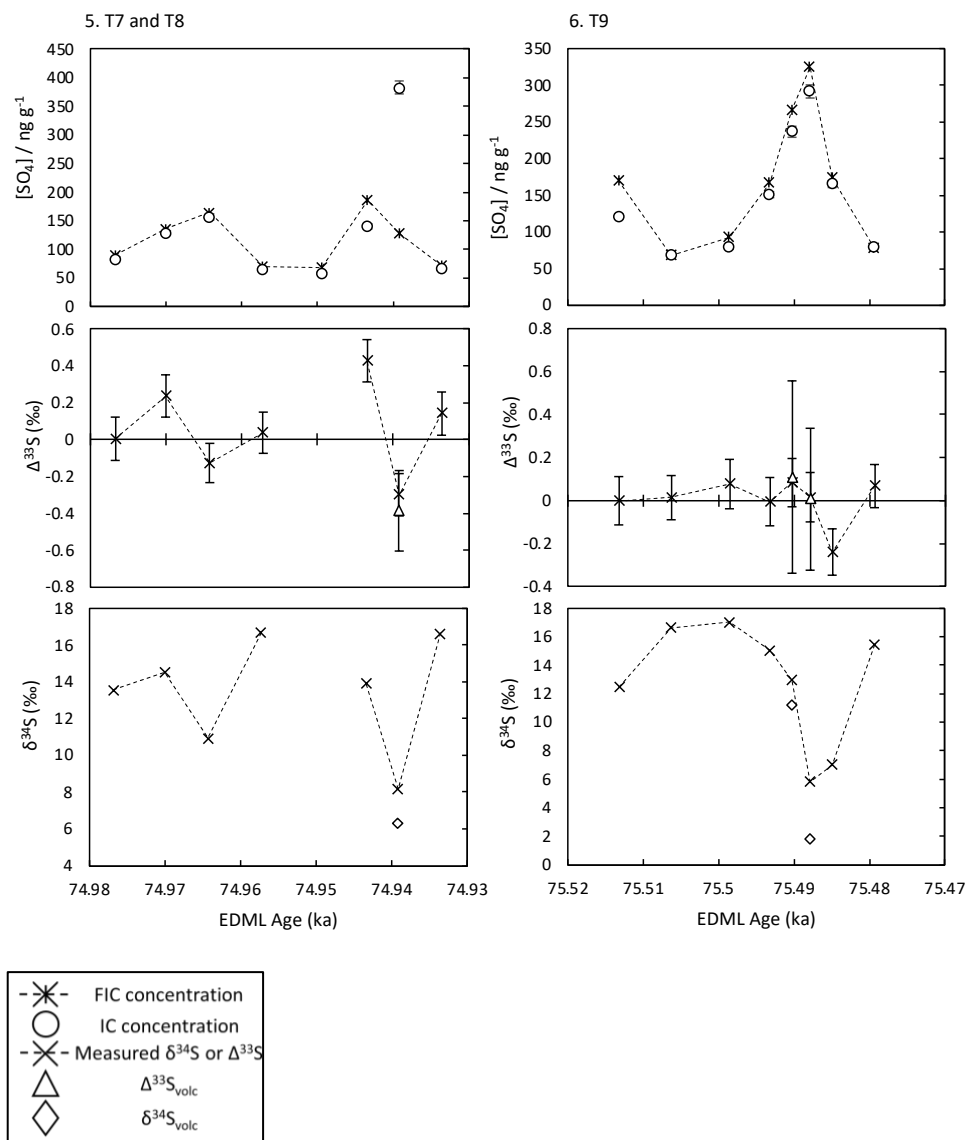


3. T5



4. T6





**Figure S1-6. Sulfate concentration measurements and sulfur isotopic composition data for 7 of the Toba candidates. For sulfate concentration crosses represent fast ion chromatography measurements (FIC) and open symbols are ion chromatography (IC) measurements. Measured isotopic ratios are shown by crosses and open symbols are data points with  $f_{volc} \geq 0.65$  and have been background corrected. All Error bars indicate  $2\sigma$  for measured ratios and  $1\sigma$  for background corrected ratios, where error bars are not visible the error is smaller than the symbol. All ages are on the AICC2012 age model (Veres et al., 2013).**

**Table S1. Summary of IC [S], total sulfate deposition, blank corrected  $\Delta^{33}\text{S}_{\text{measured}}$  and  $\Delta^{33}\text{S}_{\text{volc}}$  data for 14 peaks measured in this study. The error on IC sulfate concentration data is 5%.  $\Delta^{33}\text{S}_{\text{meas}}$  is reported with  $2\sigma$  errors and  $\Delta^{33}\text{S}_{\text{volc}}$  with  $1\sigma$ .**

| Core | Toba Candidate | Max [SO <sub>4</sub> ] (ng g <sup>-1</sup> ) | Total Deposition (mg m <sup>-2</sup> ) | Max +ve $\Delta^{33}\text{S}_{\text{meas}}$ (‰) | Max -ve $\Delta^{33}\text{S}_{\text{meas}}$ (‰) | Maximum $\Delta^{33}\text{S}_{\text{volc}}$ (‰) |
|------|----------------|--|--|---|---|---|
| EDML | Pre-T1         | 212  | 44.0                                   | +0.16 (± 0.10)                                  | -0.41 (± 0.10)                                  | No samples with $f_{\text{volc}} \geq 0.65$     |
| EDC  | T1             | 751  | 54.3                                   | -   | -3.64 (± 0.17)                                  | -4.75 (± 0.51)                                  |
| EDML | T1             | 306  | 87.7                                   | +0.98 (± 0.10)                                  | -2.23 (± 0.10)                                  | -3.08 (± 0.50)                                  |
| EDC  | T2             | 748  | 46.5                                   | +0.57 (± 0.17)                                  | -2.42 (± 0.17)                                  | -3.41 (± 0.28)                                  |
| EDML | T2             | 1161   | 424.3                                  | +0.61 (± 0.31)                                  | -1.40 (± 0.11)                                  | -1.72 (± 0.24)                                  |
| EDC  | T3             | 1178   | 133.5                                  | +0.42 (± 0.32)                                  | -0.78 (± 0.44)                                  | -0.93 (± 0.52)                                  |
| EDML | T3             | 394  | 103.3                                  | +0.95 (± 0.10)                                  | -0.06 (± 0.10)                                  | +0.99 (± 0.57) $f_{\text{volc}} = 0.63$         |
| EDC  | T4             | 431  | 26.5                                   | -   | -0.11 (± 0.17)                                  | -0.13 (± 0.13)                                  |
| EDML | T4             | 990  | 239.5                                  | +0.10 (± 0.12)                                  | -0.40 (± 0.10)                                  | -0.45 (± 0.15)                                  |
| EDML | T5             | 117  | 32.7                                   | +0.24 (± 0.10)                                  | -0.08 (± 0.10)                                  | No samples with $f_{\text{volc}} \geq 0.65$     |
| EDML | T6             | 399  | 95.8                                   | +0.55 (± 0.12)                                  | -0.42 (± 0.11)                                  | +0.67 (± 0.24)                                  |
| EDML | T7             | 383  | 27.5                                   | +0.43 (± 0.12)                                  | -0.30 (± 0.11)                                  | -0.39 (± 0.22)                                  |
| EDML | T8             | 157  | 33.3                                   | +0.23 (± 0.12)                                  | -0.13 (± 0.12)                                  | No samples with $f_{\text{volc}} \geq 0.65$     |
| EDML | T9             | 291  | 86.1                                   | +0.08 (± 0.11)                                  | -0.24 (± 0.11)                                  | All values within 2sd of 0                      |

**Table S2. Comparison of maximum positive and negative volcanic sulfur MIF signals in both this study and previous studies. See Fig. 1 for Toba candidate ages. A: Arctic, AN: Antarctic core. †These dates are taken from Sigl et al., (2015).**

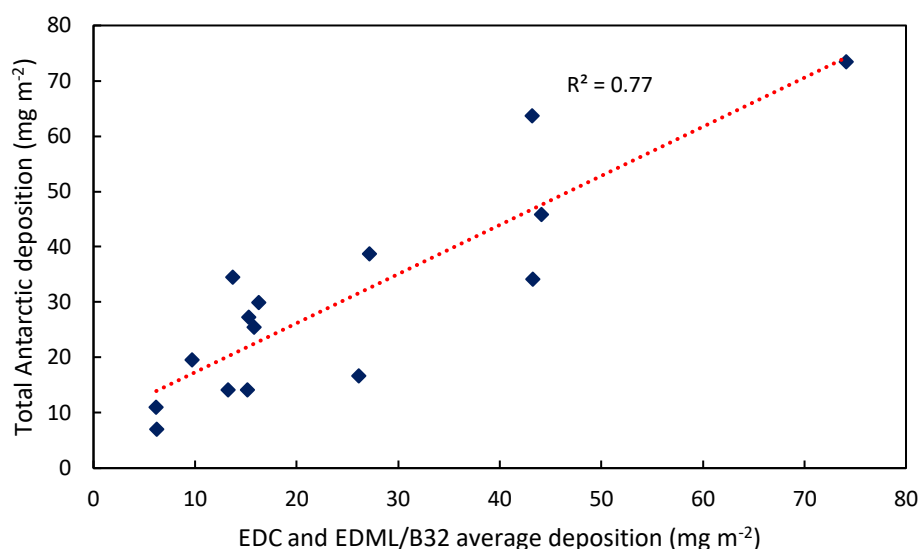
| Event (if known) | Date C. E. (year) | Core (Location) | Maximum $\Delta^{33}\text{S}_{\text{volc}}$ (‰) |                     | Study                 |
|------------------|-------------------|-----------------|---|---------------------|-----------------------|
|                  |                   |                 | Positive  | Negative            |                       |
| Pinatubo         | 1991              | South Pole (AN) | +0.67 ( $\pm$ 0.16)                             | -                   | Savarino et al., 2003 |
| Samalas          | 1257†             | South Pole (AN) | -   | -0.5 ( $\pm$ 0.16)  |                       |
| Pinatubo         | 1991              | Dome C (AN)     | +1.19 ( $\pm$ 0.12)                             | -1.03 ( $\pm$ 0.12) | Baroni et al., 2007   |
| Agung            | 1963              | Dome C (AN)     | +1.41 ( $\pm$ 0.12)                             | -0.81 ( $\pm$ 0.12) |                       |
| Tambora          | 1815              | South Pole (AN) | +0.20 ( $\pm$ 0.12)                             | -0.60 ( $\pm$ 0.12) | Cole-Dai et al., 2009 |
| -                | 1458†             | South Pole (AN) | +0.60 ( $\pm$ 0.12)                             | -0.55 ( $\pm$ 0.26) |                       |
| Samalas          | 1257†             | Dome C (AN)     | +2.22 ( $\pm$ 0.06)                             | -1.21 ( $\pm$ 0.28) | Gautier et al., 2018  |
| Ruang            | 1597              | Dome C (AN)     | +2.29 ( $\pm$ 0.34)                             | -                   | Gautier et al., 2019  |
| Tambora          | 1815              | Tunu (A)        | +2.16 ( $\pm$ 0.54)                             | -0.85 ( $\pm$ 0.33) | Burke et al., 2019    |
| Samalas          | 1257              | Tunu (A)        | +2.79 ( $\pm$ 0.79)                             | -2.47 ( $\pm$ 0.58) |                       |
| Toba             | T1                | EDC (AN)        | -   | -4.75 ( $\pm$ 0.51) | This study            |
| Toba             | T1                | EDML (AN)       | +1.34 ( $\pm$ 0.36)                             | -3.08 ( $\pm$ 0.50) |                       |
| Toba             | T2                | EDC (AN)        | -   | -3.41 ( $\pm$ 0.28) |                       |
| Toba             | T2                | EDML (AN)       | +0.74 ( $\pm$ 0.40)                             | -1.72 ( $\pm$ 0.24) |                       |
| Toba             | T3                | EDC (AN)        | +0.62 ( $\pm$ 0.15)                             | -0.93 ( $\pm$ 0.52) |                       |
| Toba             | T3                | EDML (AN)       | +0.99 ( $\pm$ 0.57)                             | -                   |                       |

**Table S3. Summary of the  $\Delta^{33}\text{S}_{\text{volc}}$  vs  $\delta^{34}\text{S}_{\text{volc}}$  York et al., (2004) regression data for this study including each core individually and eruptions where 3 or more data points are available with  $f_{\text{volc}} \geq 0.65$ .**

|                        | Slope             | Intercept          | R <sup>2</sup> |
|------------------------|-------------------|--------------------|----------------|
| All stratospheric data | 0.106 $\pm$ 0.003 | -0.464 $\pm$ 0.034 | 0.964          |
| EDML                   | 0.133 $\pm$ 0.010 | -0.634 $\pm$ 0.065 | 0.863          |
| EDC                    | 0.104 $\pm$ 0.003 | -0.413 $\pm$ 0.035 | 0.964          |
| T1 EDC                 | 0.082 $\pm$ 0.009 | -0.896 $\pm$ 0.366 | 0.972          |
| T2 EDML                | 0.137 $\pm$ 0.015 | -0.651 $\pm$ 0.096 | 0.954          |
| T2 EDC                 | 0.102 $\pm$ 0.004 | -0.813 $\pm$ 0.055 | 0.975          |
| T3 EDC                 | 0.092 $\pm$ 0.056 | -0.343 $\pm$ 0.056 | 0.936          |
| T6 EDML                | 0.081 $\pm$ 0.063 | -0.485 $\pm$ 0.647 | -0.659         |
| T4 EDML                | 0.037 $\pm$ 0.018 | -0.307 $\pm$ 0.099 | 0.183          |

**Table S4. Volcanic events identified in the VOGRIPA database of the Toba period, including their age, the error associated with the age and method and quality of the measurement as reported on VOGRIPA**

| Volcano            | Region                     | Age BP (years) | Error (years) | Method                                     | Quality | Magnitude / VEI |
|--------------------|----------------------------|----------------|---------------|--|---------|-----------------|
| The Barrier        | Africa and Red Sea         | 74000          | 20000         | Stratigraphy                               | Low     | 6.3 / 6         |
| Campi Flegrei      | Mediterranean and W Asia   | 80000          | 25000         | Stratigraphy                               | Low     | 6.1 / 6         |
| Coatepeque Caldera | Mexico and Central America | 72000          | 2000          | Ar-Ar                                      | High    | 6.6 / 6         |
| Daisen             | Japan, Taiwan, Marianas    | 80000          | 13000         | Stratigraphy                               | Low     | 6.9 / 6         |
| Los Humeros        | Mexico and Central America | 69000          | 16000         | Ar-Ar                                      | Med     | 6.6 / 6         |
| Los Humeros        | Mexico and Central America | 70000          | 23000         | Ar-Ar                                      | Med     | 6.4 / 6         |
| Newberry           | Canada and Western USA     | 62500          | 12500         | Tephrochronology                           | Low     | >6.1 / 6        |
| Taisetsuzan        | Japan, Taiwan, Marianas    | 58000          | 18000         | ITPFT isothermal plateau fission track age | Low     | 6 / ?6          |
| Tokachidake        | Japan, Taiwan, Marianas    | 141000         | 210000        | K Ar                                       | Low     | 6 / 6           |



**Figure S6.** Comparison of average sulfate deposition in EDC and EDML/B32 to total Antarctic deposition in corresponding events in Sigl et al., (2015).

**Table S5.** Sulfate deposition for Common Era events for EDML (before 800 CE), B32 (after 800 CE) and EDC, their average and Antarctic total. Antarctic depositions are from Sigl et al., (2015) with ages calculated with the WD2014 age model. EDML and EDC ages are determined from the AICC2012 age model and B32 ages are calculated from annual layer counting (Traufetter and Fischer, 2008).

| Sigl et al.,<br>2015 date (CE) | EDML/B32<br>date (CE) | EDC date (CE) | Sulfate deposition (mg m <sup>-2</sup> ) |       |         |                    |
|--------------------------------|-----------------------|---------------|--|-------|---------|--------------------|
|                                |                       |               | EDML/B32                                 | EDC   | Average | Antarctic<br>total |
| 1815.4                         | 1816.5                | 1824.4        | 34.77                                    | 53.40 | 44.09   | 45.77              |
| 1809.4                         | 1809.6                | 1818.3        | 15.67                                    | 15.95 | 15.81   | 25.41              |
| 1458.4                         | 1454.5                | 1452.8        | 46.33                                    | 40.01 | 43.17   | 63.64              |
| 1276.5                         | 1276.6                | 1275.9        | 24.91                                    | 7.67  | 16.29   | 29.92              |
| 1258.0                         | 1258.5                | 1254.0        | 73.75                                    | 74.54 | 74.14   | 73.42              |
| 1171.5                         | 1169.7                | 1172.0        | 16.96                                    | 2.45  | 9.71    | 19.47              |
| 1039.4                         | 1044.9                | 1035.7        | 9.09                                     | 3.27  | 6.18    | 10.94              |
| 713.7                          | 710.4                 | 705.1         | 8.72                                     | 3.76  | 6.24    | 7.01               |
| 682.0                          | 679.8                 | 672.4         | 17.88                                    | 36.49 | 27.19   | 38.71              |
| 574.9                          | 569.0                 | 569.2         | 54.53                                    | 32.03 | 43.28   | 34.06              |
| 540.3                          | 534.2                 | 539.7         | 17.46                                    | 9.90  | 13.68   | 34.44              |
| 434.5                          | 432.6                 | 429.0         | 17.42                                    | 13.19 | 15.31   | 27.21              |
| 304.1                          | 297.3                 | 298.4         | 19.02                                    | 33.19 | 26.11   | 16.60              |
| 236.4                          | 229.5                 | 231.5         | 11.28                                    | 15.20 | 13.24   | 14.07              |
| 206.3                          | 198.9                 | 199.1         | 20.79                                    | 9.53  | 15.16   | 14.03              |

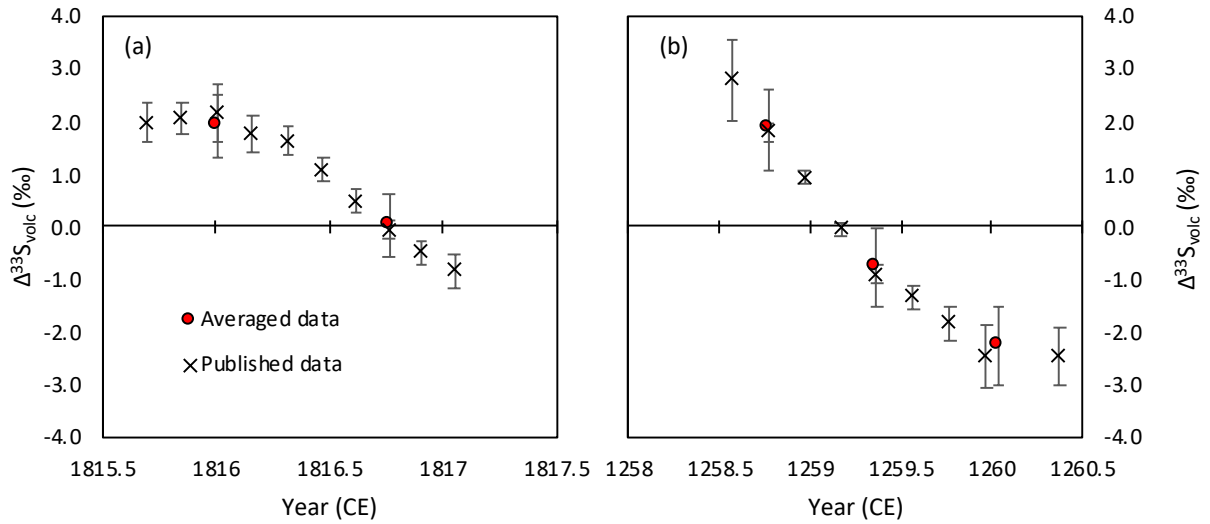


Figure S7. Averaged data for Tambora (a) and Samalas (b) from the high-resolution data set published by Burke et al., (2019). The process of averaging the samples from this study reduces the sampling resolution making it comparable to Baroni et al.'s 2007 data.

For each of the eruptions shown in Fig. S7 we have averaged the volcanic  $\Delta^{33}\text{S}$  values for a number of samples. In the case of Tambora we have averaged 2 sets of 5 samples resulting in an effective sampling resolution of 0.68 years per sample. Similarly, we have grouped the Samalas data into 3 sets of 3 data points, reducing the sampling resolution from 0.23 to 0.60 years per sample. These sampling resolutions are close to the 0.7 years per sample resolution for the Pinatubo eruption in Baroni et al., (2017).



**Table S6. Concentration and sulfur isotopic composition of procedural blanks measured at the University of St Andrews.**

|         | <b>nmol</b> | <b><math>\delta^{34}\text{S}</math> (‰)</b> | <b><math>1\sigma</math></b> |
|---------|-------------|---|-----------------------------|
|         | 0.20        | 4.28  | 0.94                        |
|         | 0.36        | 6.24  | 0.60                        |
|         | 0.33        | 3.66  | 0.40                        |
|         | 0.16        | 2.73  | 0.74                        |
|         | 0.21        | 3.68  | 0.50                        |
|         | 0.23        | 4.59  | 0.46                        |
|         | 0.22        | 3.53  | 0.46                        |
|         | 0.24        | 2.93  | 0.44                        |
|         | 0.24        | 4.06  | 0.46                        |
|         | 0.22        | 3.81  | 0.44                        |
|         | 0.29        | 4.11  | 0.38                        |
|         | 0.18        | 4.35  | 0.54                        |
|         | 0.23        | 3.27  | 0.46                        |
|         | 0.22        | 3.08  | 0.39                        |
|         | 0.26        | 4.84  | 0.42                        |
|         | 0.33        | 4.58  | 0.38                        |
|         | 0.25        | 5.89  | 0.43                        |
|         | 0.14        | 8.17  | 1.06                        |
|         |             |   |                             |
| Average | 0.24        | 4.32  |                             |
| 2 s.d.  | 0.12        | 2.67  |                             |

Table S7. Sulfur isotopic composition of Switzer Falls consistency standard measured at the University of St Andrews.

|         | $\delta^{34}\text{S}$ (‰) | $1\sigma$ | $\delta^{33}\text{S}$ (‰) | $1\sigma$ | $\Delta^{33}\text{S}$ (‰) | $1\sigma$ |
|---------|---------------------------|-----------|---------------------------|-----------|---------------------------|-----------|
|         | 4.13                      | 0.02      | 2.10                      | 0.06      | -0.02                     | 0.05      |
|         | 4.14                      | 0.02      | 2.20                      | 0.05      | 0.06                      | 0.09      |
|         | 4.15                      | 0.02      | 2.16                      | 0.05      | 0.03                      | 0.04      |
|         | 4.13                      | 0.02      | 2.11                      | 0.05      | -0.02                     | 0.09      |
|         | 4.14                      | 0.02      | 2.07                      | 0.05      | -0.06                     | 0.05      |
|         | 4.16                      | 0.02      | 2.12                      | 0.06      | -0.02                     | 0.09      |
|         | 4.12                      | 0.02      | 2.15                      | 0.05      | 0.03                      | 0.11      |
|         | 4.12                      | 0.02      | 2.14                      | 0.05      | 0.02                      | 0.07      |
|         | 4.18                      | 0.02      | 2.24                      | 0.06      | 0.09                      | 0.12      |
|         | 4.11                      | 0.02      | 2.16                      | 0.05      | 0.05                      | 0.04      |
|         | 4.21                      | 0.02      | 2.19                      | 0.05      | 0.03                      | 0.04      |
|         | 4.26                      | 0.02      | 2.28                      | 0.07      | 0.09                      | 0.08      |
|         | 4.16                      | 0.03      | 1.99                      | 0.11      | -0.15                     | 0.10      |
|         | 4.24                      | 0.02      | 1.96                      | 0.07      | -0.22                     | 0.07      |
|         | 4.22                      | 0.02      | 2.07                      | 0.07      | -0.10                     | 0.06      |
|         | 4.24                      | 0.02      | 1.99                      | 0.07      | -0.19                     | 0.10      |
|         | 4.30                      | 0.02      | 2.16                      | 0.06      | -0.05                     | 0.06      |
|         | 4.12                      | 0.03      | 2.14                      | 0.07      | 0.02                      | 0.13      |
|         | 4.09                      | 0.02      | 2.13                      | 0.07      | 0.02                      | 0.08      |
|         | 4.12                      | 0.02      | 2.17                      | 0.07      | 0.05                      | 0.09      |
|         | 4.18                      | 0.02      | 2.02                      | 0.07      | -0.13                     | 0.08      |
|         | 4.15                      | 0.02      | 2.19                      | 0.06      | 0.06                      | 0.06      |
|         | 4.15                      | 0.02      | 2.21                      | 0.08      | 0.07                      | 0.11      |
|         | 3.90                      | 0.02      | 1.92                      | 0.07      | -0.09                     | 0.08      |
|         | 4.07                      | 0.02      | 2.02                      | 0.07      | -0.08                     | 0.07      |
|         |                           |           |                           |           |                           |           |
| Average | 4.15                      |           | 2.12                      |           | -0.02                     |           |
| 2 s.d.  | 0.15                      |           | 0.18                      |           | 0.17                      |           |

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