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# Corrigendum: Magmatic Processes at La Soufrière de Guadeloupe: Insights From Crystal Studies and Diffusion Timescales for Eruption Onset

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**Keywords:** diffusion timescales, orthopyroxene, magma “mush”, unrest, monitoring, eruption style, forecasting, La Soufrière de Guadeloupe

## A Corrigendum on

### Magmatic Processes at La Soufrière de Guadeloupe: Insights From Crystal Studies and Diffusion Timescales for Eruption Onset

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In the original article, there was a mistake in **Table 2** and in **Figures 5, 9** and **10** as published. An error occurred in our calculations of the  $D_0$  value, which was then propagated into the numerical routines used to perform our calculations. Calculations with the corrected  $D_0$  value imply that the timescales of magmatic processes preceding eruptions of La Soufrière de Guadeloupe, shown in **Table 2**, and discussed in our original manuscript, are lower than previously estimated by a factor of ~2. The corrected **Table 2** and **Figures 5** and **9** appear below. The corrected **Figure 10** also appears below, and the trend of the figure is not altered.

Further errors were made in **Figures 11, 12** and **13**. The timescales are now corrected in the captions of the figures. The correct timescale values, now presented below, range from 18.8 to 361.0 days confirming that magmatic processes prior to eruption occur on short timescales at La Soufrière de Guadeloupe. Updated and corrected versions of our python scripts are available on GitHub: [https://github.com/djessop/mineral\\_diffusion\\_timescales](https://github.com/djessop/mineral_diffusion_timescales). The corrected figures appear below.

A correction has been made to the **Abstract**, Paragraph 3:

“We model the timescale populations as random processes whose probability distributions provide expected (“mean”) timescales and the associated standard errors for each eruption. This provides a new statistical method for comparing magmatic timescales between disparate eruptions. From this, we obtain timescales of magma storage at La Soufrière de Guadeloupe ranging from  $18.8 \pm 0.37$  days to  $361 \pm 0.40$  days, with no clear distinction between eruption style/size and timescales observed. Based on these data, magmatic interaction timescales are a poor predictor of eruption style/size.”

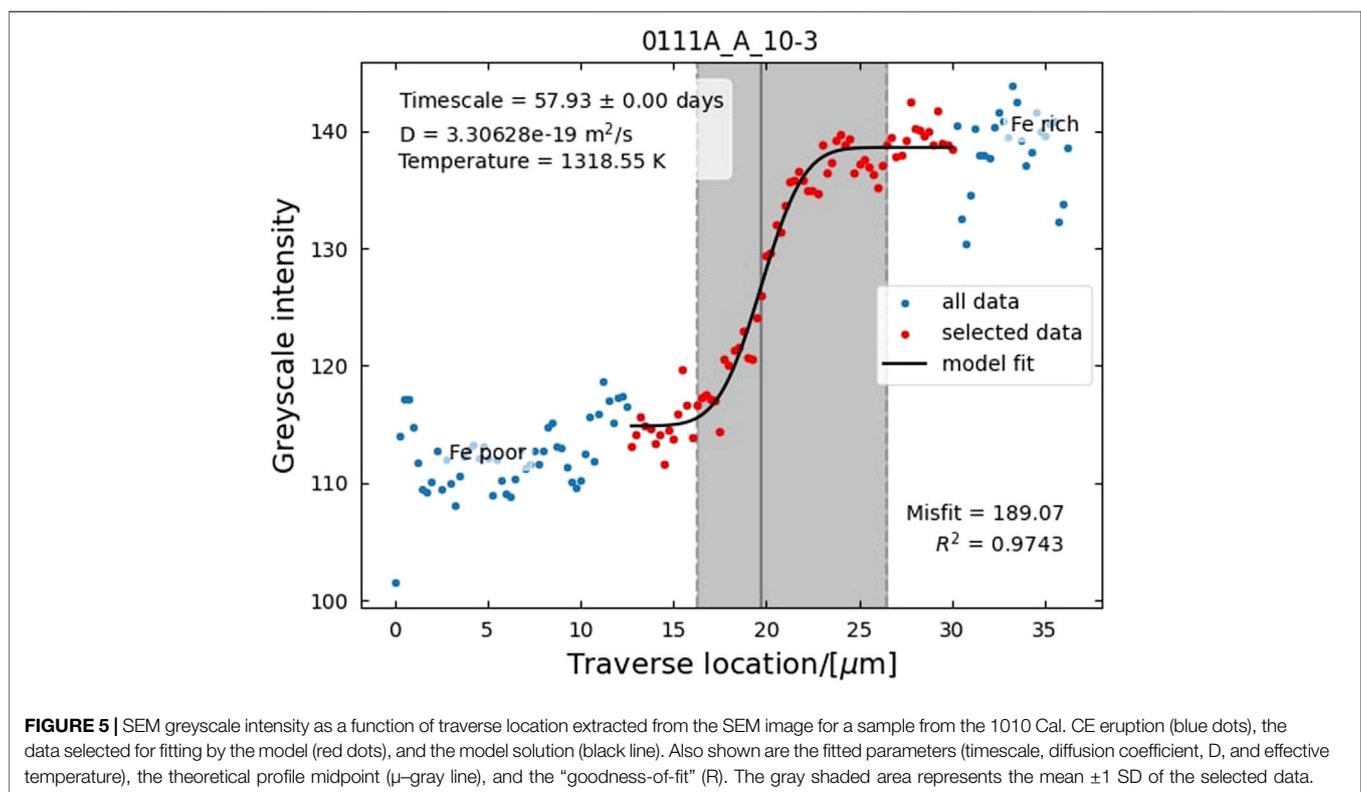
A correction has also been made to Section **Results**, Sub-section **Timescale Modelling Results**, Paragraphs 1–4:

“Diffusion timescales across the core-rim boundaries for the eruptions studied give a timescale range from <1 to 3,052 days (**Table 2**). Our method has investigated how the timescale populations are distributed, highlighting clear differences between eruptions, including variations in the maximum values, range of values and expected timescales.

**TABLE 2** | Summary table for the eruptions showing the key features for each eruption and sample location.

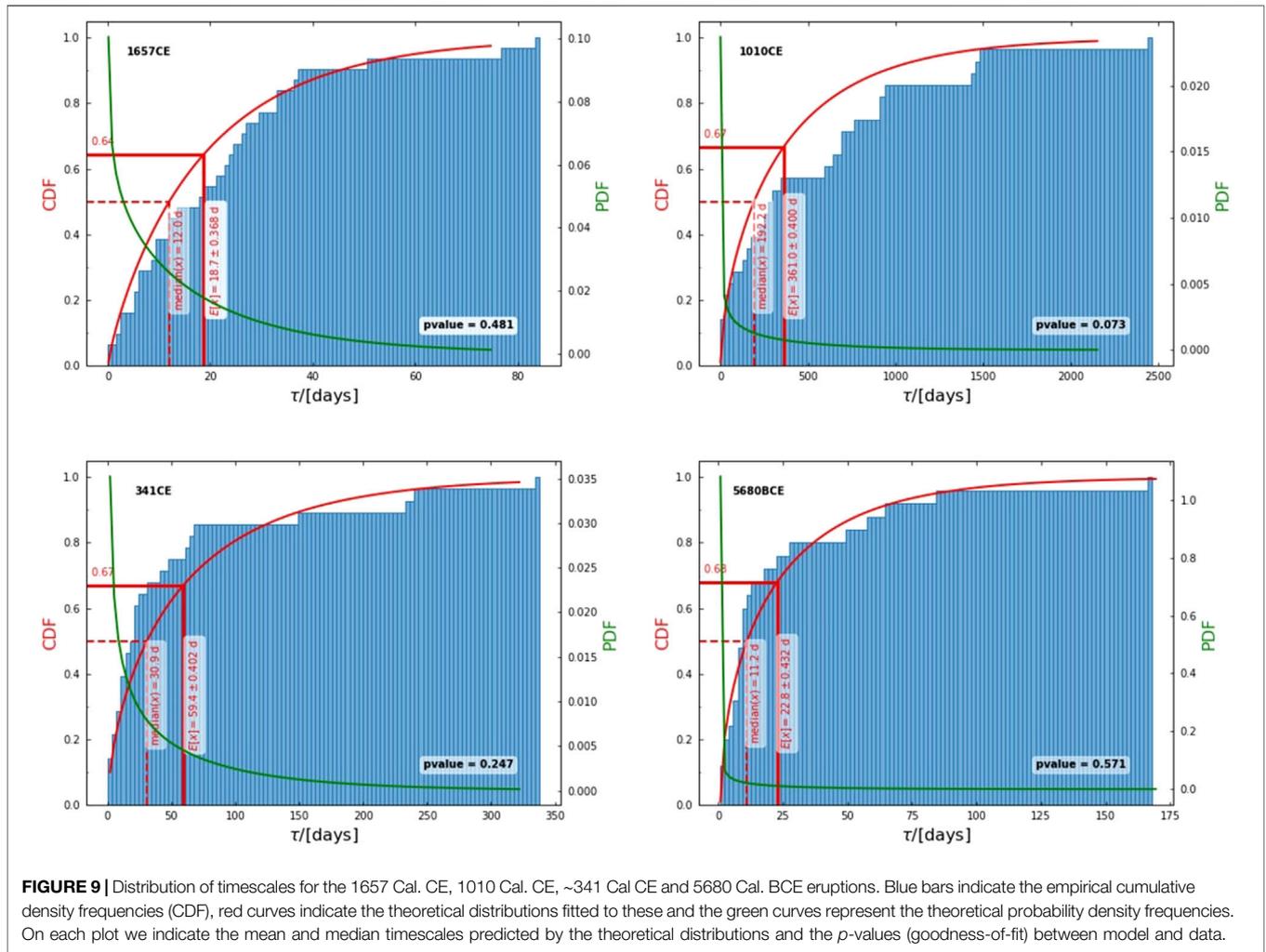
Eruption	Vent	Sample GPS position			Eruption style	Expected timescale (days)	Median timescale (days)	Min. timescale (days)	Max. timescale (days)	Timescale std. error (days)	Crystals analysed	Temp °C (±30°C)	Av. Bulk SiO <sub>2</sub> (wt %)	VEI
		UTM N (m)	UTM O (m)	Unit sampled from										
1657 CE	Soufrière	641,466	1,773,774	Fallout Unit	Vulcanian	18.8	12.00	0.1	84.3	0.37	41	975	58.1	2–3
1530 CE	Soufrière	643,318	1,774,407	Fallout Unit	Sub-Plinian	20.5*	—	10	90	—	24	900	57.5	3
1010 CE	Soufrière	638,266	1,769,743	Fallout Unit	Plinian	361.0	192.2	0.4	2,462.3	0.40	34	1,025	59.7	4
341 CE	Echelle	663,019	178,011	Scoria Clasts	Strombolian	59.4	30.9	0.4	3,051.7	0.40	33	1,010	51.2	2
5680 BCE	Soufrière	637,417	1,770,276	Fallout Unit	Plinian	22.8	11.2	0.9	167.9	0.43	31	1,010	—	4

The crystal number refers to the number of crystals diffusion timescales were calculated on [\*Mean timescale not expected timescale, calculated from available data Bourgeoisat (2018); Boudon et al. (2008); Pichavant et al. (2018)].

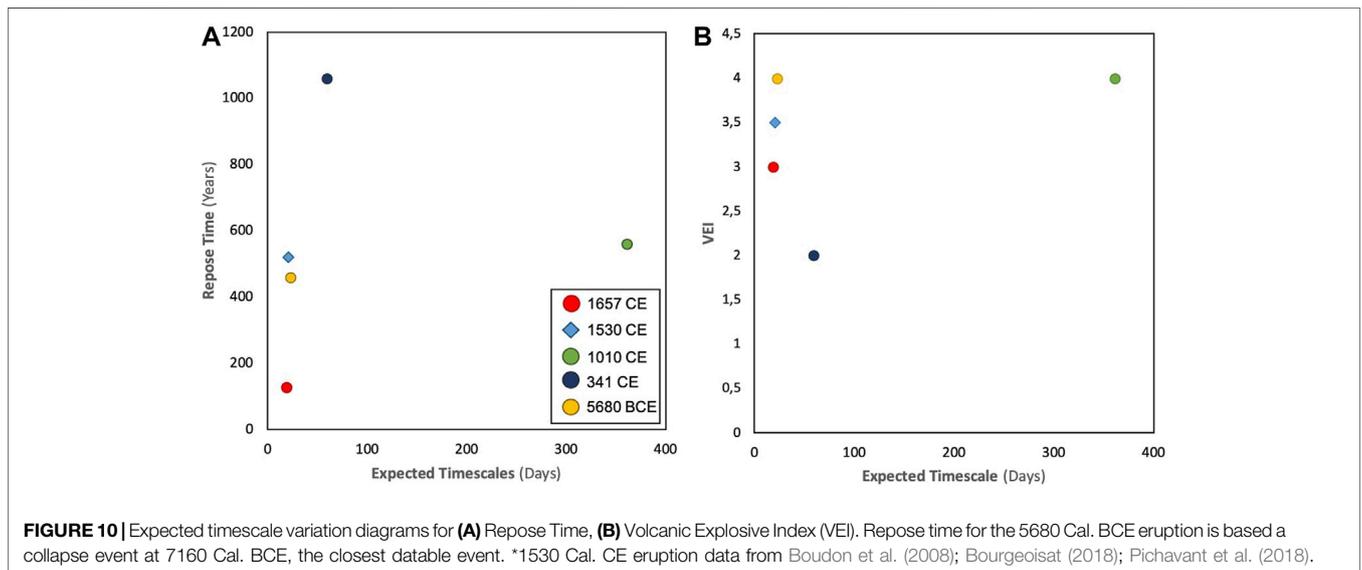


The 5680 Cal. BCE Plinian eruption records short timescales with a range from <1 to 169 days and the expected (mean) timescale calculated as  $22.8 \pm 0.43$  days (Figure 9). The ~341 Cal. CE Strombolian eruption records a large range of timescales from <1 to 3,052 days. The modelled data yield an expected timescale value of  $59.4 \pm 0.40$  days. This expected value is not comparable to any other eruption studied, though the range of values is comparable.

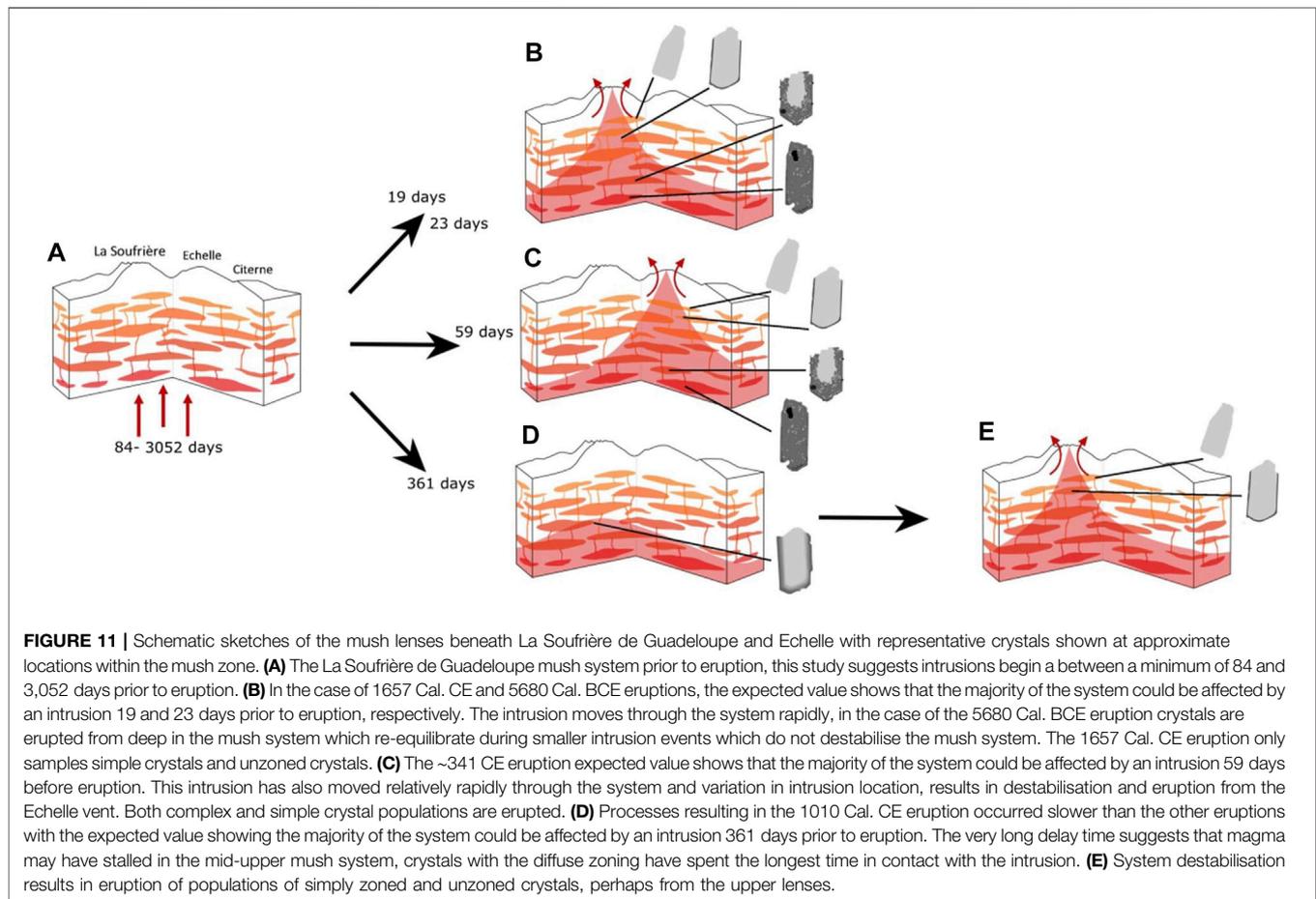
The 1010 Cal. CE Plinian eruption records the longest timescales from <1 to 2,462 days. These data have an expected timescale value of  $361.0 \pm 0.40$  days, considerably higher than calculated for any other eruption (Figure 9). This eruption is considerably different to the 5680 Cal. BCE Plinian eruption, despite the expectation that these eruptions are comparable. This is a direct consequence of the characteristic crystal populations in the 1010 Cal. CE eruption which shows a large proportion of



**FIGURE 9 |** Distribution of timescales for the 1657 Cal. CE, 1010 Cal. CE, ~341 Cal CE and 5680 Cal. BCE eruptions. Blue bars indicate the empirical cumulative density frequencies (CDF), red curves indicate the theoretical distributions fitted to these and the green curves represent the theoretical probability density frequencies. On each plot we indicate the mean and median timescales predicted by the theoretical distributions and the *p*-values (goodness-of-fit) between model and data.



**FIGURE 10 |** Expected timescale variation diagrams for (A) Reuse Time, (B) Volcanic Explosive Index (VEI). Reuse time for the 5680 Cal. BCE eruption is based a collapse event at 7160 Cal. BCE, the closest datable event. \*1530 Cal. CE eruption data from Boudon et al. (2008); Bourgeoisat (2018); Pichavant et al. (2018).



Type-2 crystals with diffuse zoning, not present in the 5680 Cal. BCE eruption (Figure 8).

The 1657 Cal. CE Vulcanian eruption records the shortest range of timescales from <1 to of 84 days. The expected timescale was calculated as  $18.8 \pm 0.37$  days, the shortest expected timescale value calculated for the eruptions studied (Figure 9). This expected value is comparable to the 5680 Cal. BCE expected value of 22.8 days, with most crystals for both these eruptions recording timescales in the range of 3 weeks.”

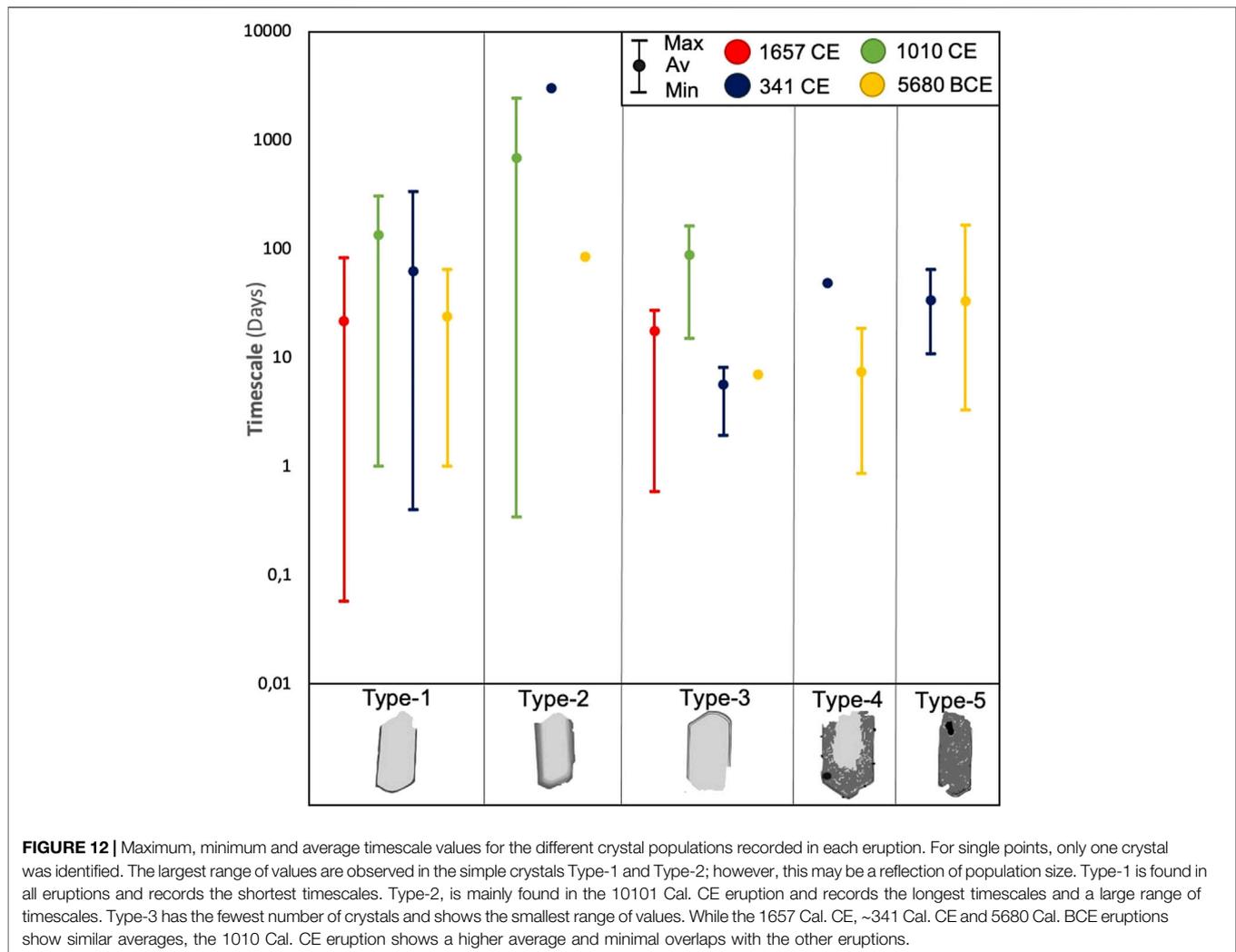
A correction has been made to Section **Discussion**, Sub-section **How Do We Interpret the Diffusion Timescales**, Paragraph 4:

“These processes are reflected in the gamma distribution, which describes all events that share the same properties (i.e., are generated by the same process) and models them as random processes. In this case, the gamma distribution is derived from the individual likelihood of all intrusion events across the eruption’s crystal populations. The timescale distribution reflects an intrusion producing a mixing bowl where the crystals come into contact with the intrusion at different times, with the expected timescale being the typical value of the distribution. The expected timescale/typical distribution value shows the average time it took a crystal for a specific eruption to come into contact with the intrusion. Therefore, the gamma

distribution allows the probability of a crystal experiencing an event at a given time to be estimated. In the case of La Soufrière de Guadeloupe, crystals have a smaller probability of recording a short delay time/longer timescale (on the order of a year; e.g., 1010 Cal. CE), and a larger probability of recording a longer delay time/shorter timescale (on the order of days; e.g., 1657 Cal. CE). This could relate to several parameters including: the intrusions interaction with the system, the composition of the system (including volatile content) and system geometry (crystals recording a longer delay time/shorter diffusion timescale farthest from the intrusion are more likely to be erupted than those closer to the system base which interact with the intrusion first).”

A correction has been made to Section **Discussion**, Sub-section **Which Mush System Processes are the Timescales Related To?**, Paragraph 5:

“The ~341 Cal. CE and 1010 Cal. BCE eruptions have similar maximum diffusion timescales but different expected timescales (Table 2). This indicates while intrusions may begin at similar times prior to an eruption, the diffusion timescale distribution and resulting expected timescales, suggest the intrusions interact differently with the system. A transition in conduit location to Echelle or the eruption of a monogenetic cone may result in different expected timescales of magmatic processes preceding



eruptions. In a shallow storage region, crystals interact with melt shortly before eruption and could explain the crystals recording short timescales observed, particularly in Echelle and in other monogenetic systems (Ruprecht et al., 2007; Johnson et al., 2008; Denis et al., 2013; Brenna et al., 2018; **Figure 11A,C**.)

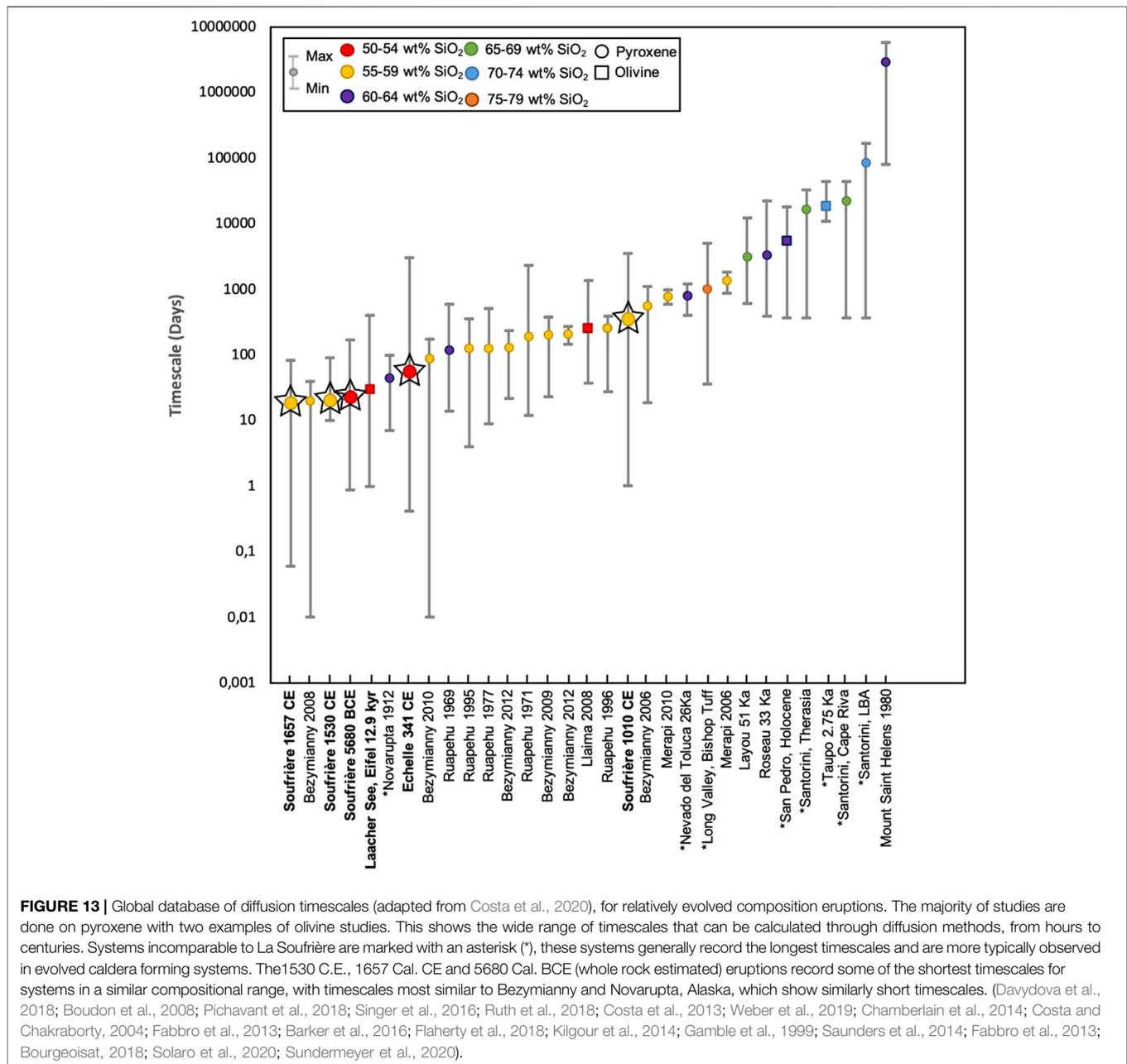
A correction has been made to Section **Discussion**, Sub-section **How Do the La Soufrière de Guadeloupe Timescales Fit Into a Global Context**, Paragraph 3:

“Some systems show magmatic processes occurring on timescales comparable to La Soufrière de Guadeloupe, such as the 1912 eruption of Novarupta (Alaska), which shows similarly short diffusion timescales. A smaller range of timescales are calculated for this eruption, but the average value, 45 days, is comparable to the expected values calculated for the 1657 Cal. CE, ~341 Cal. CE and 5680 Cal. CE eruptions (Singer et al., 2016). Despite the similarities in the timescales, the Novarupta system is much larger and is more evolved than La Soufrière de Guadeloupe, limiting the comparability.”

A correction has been made to Section **Discussion**, Sub-section **Can We Link Timescales to Unrest at La Soufrière de Guadeloupe?**, Paragraph 4:

“In the second scenario, long timescales on the order of a year (i.e., 1010 Cal. CE) suggest similar long unrest periods prior to the eruption could be observed. This unrest, recorded over months or years, may show a gradual increase in seismic activity and thermal anomalies, along with geochemical markers of the rising magma batch, peaking in a shallow degassing signature following its emplacement and the thermal (and chemical) exchange with the residing body. Behaviour corresponding to this scenario was observed prior to the May 2008 Bezymianny eruption, characterised by a decrease of  $\text{CO}_2/\text{H}_2\text{O}$ ,  $\text{S}/\text{HCl}$ ,  $\text{CO}_2/\text{S}$  and  $\text{CO}_2/\text{HCl}$  ratios (Lopez et al., 2013; Davydova et al., 2018).”

Finally, a correction has been made to Section **Conclusions**: “By investigating a range of eruption styles, we provide an in-depth analysis of the diffusion timescales of magmatic processes occurring at La Soufrière de Guadeloupe and provide new insights in the processes occurring in the mush system. The method constitutes a significant advance for the calculation of orthopyroxene diffusion timescales, eradicating biases induced by fitting the profiles by eye, and optimising data quality by using well-tested and robust numerical schemes and “goodness-of-fit” analyses. The six different crystal population distributions, found



across the four various types of eruptions of La Soufrière de Guadeloupe, indicate different eruptions are fed by different mush system lenses, which have distinct histories. We found distinct timescales for similar eruption styles, suggesting the diffusion timescales do not allow us to discriminate between eruptive styles. In detail, we determined expected values of  $22.8 \pm 0.43$  days for the 5680 Cal. BCE Plinian eruption,  $59.4 \pm 0.40$  days for the  $\sim 341$  Cal. CE Strombolian eruption,  $361.0 \pm 0.40$  days for the 1010 Cal. CE Plinian eruption and  $18.8 \pm 0.37$  days for the 1657 Cal. CE Vulcanian eruption. The 5680 Cal. BCE and 1657 Cal. CE eruption short timescales correlate to short repose suggesting a magma intrusion hotter than the existing mush moved rapidly through the mush system due to the presence of a magma system with a high

proportion of melt. The 1010 Cal. CE eruption long-expected timescale and large range of timescales indicates the system remobilised comparatively slowly with new magma interacting with the system slowly. The majority of timescales calculated in this study are short when compared to global data sets calculated for similar systems. This implies basaltic-andesitic to andesitic volcanoes can rapidly produce large-scale eruptions. Paramount for hazard assessment and crisis response, the lack of a correlation between eruption explosive intensity (VEI) and timescales that also applies to short timescales, indicates that a future eruption of La Soufrière de Guadeloupe could broadly span a range from low to high explosivity. These results underscore the necessity to further: improve the reliability of detecting and interpreting multiparameter monitoring

data as eruption precursors, expand eruption forecast modelling, develop probabilistic expert judgement for crisis response, as well as enhance risk reduction and societal resilience.”

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