ESTIMATES ON THE FREQUENCY OF VOLCANIC ERUPTIONS ON VENUS. Siddharth Krishnamoorthy[1] and Paul K. Byrne[2], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA (siddharth.krishnamoorthy@jpl.nasa.gov), [2]Department of Earth and Planetary Sciences, Washington University in St. Louis, St. Louis, MO, USA.

Volcanic Venus: The NASA Magellan mission [1] showed Venus to be a world replete with lava flows, thousands of shield volcanoes, shield fields and domes [2], and a range of volcanotectonic landforms [3]. The planet also boasts a dearth of impact craters below 25 km in diameter and none <3 km across [4]. Crater statistics derived from global Magellan data give an average model age for the surface of 700–800 Myr [5], with global-scale volcanic resurfacing likely the dominant reason for such apparent youthfulness [6].

Ongoing Volcanism: But is Venus volcanically active today? Circumstantial evidence comes in the form of anomalously high thermal emissivity values of stratigraphically young flows recorded by the ESA Venus Express (VEx) Visible and Infrared Thermal Imaging Spectrometer. These values were interpreted as a lack of weathering arising from those flows having been emplaced perhaps within the last 250,000 years [7]. The VEx Venus Monitoring Camera also observed, over successive orbits, localized increases and decreases in surface temperature on a timescale of days to months, consistent with short-lived effusive activity [8].

The planet's atmosphere may also record the effects of ongoing volcanism, with the global H_2SO_4 cloud layer [9] itself likely maintained by the release of sulfur and water from the interior within the last several tens of millions of years [10]. And a dramatic reduction in the cloud top abundance of SO_2 observed during the Pioneer Venus mission is consistent with the injection into the atmosphere of that volatile by volcanism of a scale comparable to the 1833 eruption of Krakatau [11].

Earth Eruption Dataset: We collated volcanic eruption data from the Smithsonian Institution's Global Volcanism Program (GVP) database [12], extrapolating those findings to Venus to estimate the frequency of eruptive events there.

The strength of volcanic eruptions is typically recorded on the volcanic explosivity index (VEI) scale [13]. The VEI of any eruption reflects the interplay between the magnitude, intensity, and energy release rate during that eruption. The GVP database includes the number and duration of subaerial and submarine volcanic eruptions extending beyond the last 2,000 years. The catalog also records the VEI value assigned to each eruption. The reliability of the volcanic record of Earth has improved considerably over the last 100 years—older records are inevitably biased towards stronger eruptions, more prominent.

However, assuming that the underlying eruptive behavior of Earth has not changed, we expect to observe a convergence in the relative proportion of eruptions with different VEIs. Thus, we filtered the GVP database for eruptions starting at different cutoff dates between 1900 and 2000 (with end dates in January 2021), selecting 1 January 1980 as the cutoff start date for our analysis dataset to minimize the bias in the eruptive record yet retaining a statistically robust dataset (**Figure 1**).

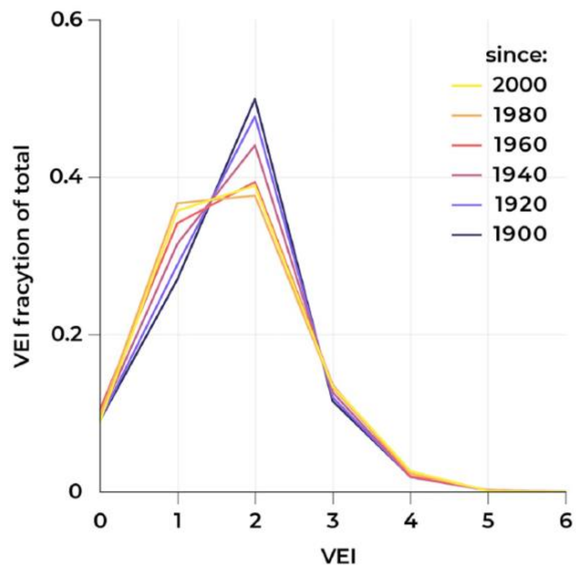

Figure 1. *The number of events assigned VEI values of 0–6 in our catalog, as a fraction of the total eruptions with varying start dates. (Reproduced from* [14]*)*

We identified 1,400 individual volcanic eruptions from 276 unique volcanoes with VEI assignments within our analysis period [14]. A key property of Earth is that it hosts a variety of tectonic settings, most notably plate tectonics, with varying degrees of applicability to Venus. We therefore classified the 276 volcanoes in our record into one of four tectonic settings: "continental intraplate," "rift zone" (including submarine and subaerial rifts), "oceanic intraplate," and "subduction zone," numbered classes 1–4 respectively (**Figure 2**). We then analyzed the eruptive pattern in each class separately and extrapolated the results to Venus.

Eruptive Frequencies: Most eruptions on Earth are relatively short-lived, with 14.7% ending within a day and 57.8% within 100 days; only 12.5% of eruptions persist beyond 1,000 days.

Bootstrap Analysis and Extrapolation to Venus: With the GVP dataset, we generated bootstrapped estimates of the expected number of new or ongoing eruptions within a random 60-day period on Earth. We find that an average of 5.6 new eruptions (σ = 2.5) of any duration are expected on Earth in any 60-day

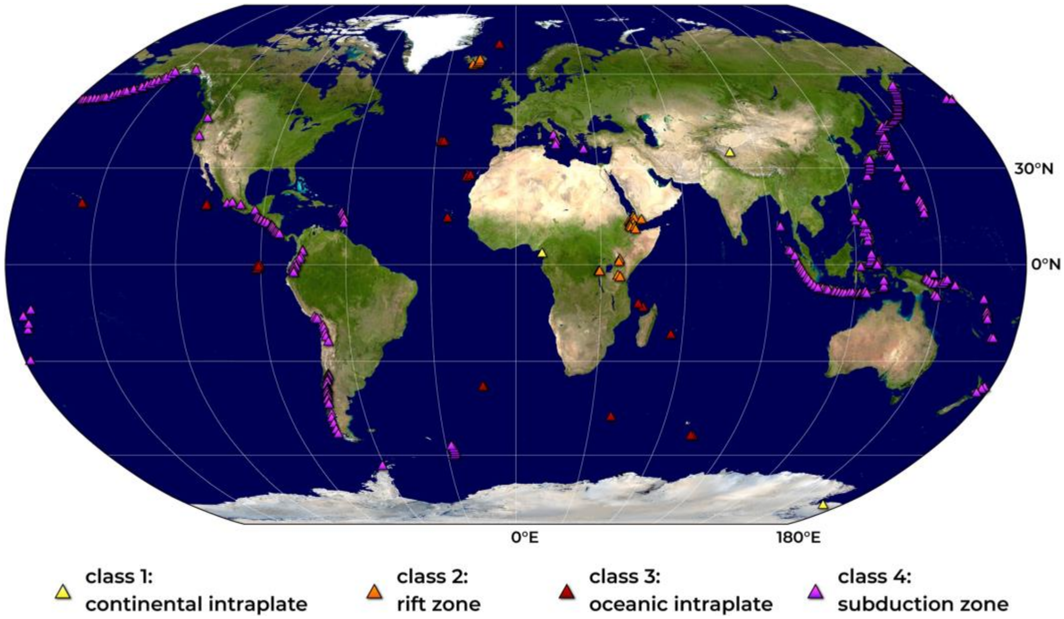

Figure 2. *The 276 volcanoes in our catalog (from which the 1,400 eruptions we consider were sourced), classified by their tectonic setting. The global map of Earth is in Robinson projection, centered at 0°E. (Reproduced from* [14]*)*

period. When considering both new *and* ongoing eruptions that endure 100 days, 10.9 ($\sigma = 3.7$) events are expected within 60 days. That frequency increases to 27.4 ($\sigma = 5.4$) eruptions lasting ≤1,000 days. Eruptions on Earth are expectedly dominated by those in Class 4 (subduction), which alone would account for an expected 24.35 eruptions under the 1000-day, new-and-ongoing eruption scenario.

We extrapolated our findings to Venus by assuming that eruptive frequency can be directly scaled first by surface area (0.902, from land surface on Earth to planetary surface on Venus), and then by some additional planetary parameter, e.g., mass, volume, silicate portion, or surface area. Of these parameters, planetary mass offers the lowest ratio: 0.816, resulting in a final scaling ratio of 0.736. (We did not attempt to scale VEIs or eruptive durations.)

We thus ran our bootstrap trials for Venus with a randomly selected subset containing 73.6% of the Terran eruption record. Bootstrap analyses for Venus indicate that 0.02, 0.29, 0.59, and 7.10 eruptions take place in a random 60-day interval on Venus for classes 1–4, respectively, when considering new and ongoing eruptions. The number of expected eruptions increases to 0.02, 0.7, 1.56, and 17.86 for classes 1–4, respectively, when eruptions lasting up to 1000 days are considered.

Limitations and Outlook: This scaling approach is simplistic, and likely suffers from extrapolating errors in the Terran eruption record. However, our analysis serves to illustrate that, should Venus' volcanic activity resemble that of Earth, a nominal 60-day [15] aerial platform mission in the Venus atmosphere might reasonably expect to detect volcanic eruptions (via infrasound through direct atmospheric coupling, say, or pre- and co-eruptive seismicity [16]). Moreover, an orbiter equipped to detect changes in surface thermal emissivity [17] could, over a nominal four-year mission, be present for more than 1,000 discrete eruptive events. In summary, our analysis yields volcanic eruption estimates that can be tested by orbital and in-situ missions on Venus.

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