Estimates on the possible annual seismicity of Venus

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Key Points:

- An inactive Venus with global background seismicity similar to Earth's continental intraplate seismicity has $11-34$ quakes $\geq M_w 5$ per year
- A lower bound on an active Venus where ridges, coronae, and rifts are seismically active predicts $126-391$ quakes $\geq M_w 5$ annually
- The upper bound for an active Venus results in $465-1446$ venusquakes $\geq M_w 5$ per year

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Abstract

There is a growing consensus that Venus is seismically active, although its level of seismicity could be very different from that of Earth due to the lack of plate tectonics. Here, we estimate upper and lower bounds on the expected annual seismicity of Venus by scaling the seismicity of the Earth. We consider different scaling factors for different tectonic settings and account for the lower seismogenic zone thickness of Venus. We find that 11 – 34 venusquakes $\geq M_w5$ per year are expected for an inactive Venus, where the global seismicity rate is similar to that of continental intraplate seismicity on Earth. For the active Venus scenarios, we assume that the coronae, ridges, and rifts of Venus are currently seismically active. This results in 126 – 391 venusquakes $\geq M_w5$ annually as a realistic lower bound and 465 – 1446 venusquakes $\geq M_w5$ as a maximum upper bound for an active Venus.

Plain Language Summary

Venus could be seismically active at the moment, but it is uncertain how many earthquakes (or to use the proper term: venusquakes) there could be in a year. Here, we calculate the minimum and maximum number of venusquakes we could expect in a given year on Venus based on different assumptions. If we assume there is not much seismic activity on Venus (comparable to the interior of tectonic plates on Earth), we find that we could expect about 11 – 34 venusquakes per year with a magnitude bigger than or equal to 5. For an estimate of the maximum amount of venusquakes, we assume that Venus has regions with more seismic activity: the so-called coronae, ridges, and rifts. Depending on our assumptions, we then find that there could be over a thousand venusquakes per year with a magnitude bigger than or equal to 5 on Venus.

1 Introduction

After the successful mapping of the Venusian surface by Magellan from 1990 to 1992, for a long time the prevailing hypotheses for Venus's geodynamic regime were that of a catastrophic or episodic resurfacing regime, which suggested that Venus is currently geologically inactive (Rolf et al., 2022; O'Rourke et al., 2023). Reason for this was the observation of a relatively low number of craters (932; Strom et al., 1994) on the surface, from which people deduced a uniform, relatively young surface age of 800–240 Myrs (McKinnon et al., 1997; Feuvre & Wieczorek, 2011).

In recent years, however, the view on Venus's current tectonic activity has shifted towards a more active planet, rivalled in the Solar System only, perhaps, by our own Earth. From a geodynamical point of view, other theories for its geodynamic regime have been put forward, such as the plutonic squishy lid regime (Lourenço et al., 2020), which are consistent with ongoing activity on Venus today. Additionally, the shift towards an active Venus is partly induced by compelling evidence from Magellan, Pioneer Venus, and Venus Express data that Venus might be currently volcanically active. Data from Venus Express shows regions of high emissivity which could be associated with chemically unweathered, and therefore likely geologically young (~ 2.5 Myrs), surfaces. These anomalies correlate with volcanic highlands, such as Imdr Regio (Smrekar et al., 2010), indicating geologically recent volcanism in these regions. Brossier et al. (2022) even postulate that the low radar emissivity values in Ganis chasma could be the result of volcanic eruptions in the last 30 years. The observed variability in SO_2 concentration in the clouds by Pioneer Venus and Venus Express from 1979-2011 could also be attributed to recent volcanic eruptions (Marcq et al., 2013). The most compelling evidence for active volcanism on Venus to date comes from Herrick and Hensley (2023), who observed changes in consecutive radar images of volcanic areas by Magellan, which they interpreted as volcanic flows and hence ongoing volcanic activity on Venus. In line with that, recent estimates from scaling the volcanism of Earth to Venus yield 12 – 42 volcanic eruptions on Venus in a year, depending on assumptions on the amount of volcanism associated with plume-induced subduction at coronae (Byrne & Krishnamoorthy, 2022; van Zelst, 2022). Future missions such as VERITAS (Smrekar et al., 2020) and EnVision (Ghail et al., 2016) will provide better constraints on Venus's volcanic activity.

In the meantime, since Venus seems to be volcanically and geologically active, it is reasonable to assume that it is also seismically active. Indeed, its seismicity could be more extensive than that of Mars and the Moon, which both are believed to be significantly less tectonically active than Venus (Stevenson et al., 2015). On these bodies, despite being in a stagnant lid regime, seismicity has been observed with the successfully deployed Apollo Lunar Surface Experiments Package on the Moon (Nakamura et al., 1982) and on Mars with the InSight mission (Banerdt et al., 2020). As Venus is now thought to be in a more tectonically active geodynamic regime than a stagnant lid (Rolf et al., 2022), its potential seismicity is thought to be at least comparable with Earth's intraplate seismicity (Stevenson et al., 2015; Tian et al., 2023; Ganesh et al., 2023). On top of that, observed rift systems (Ivanov & Head, 2011), ridges, and coronae features linked to active subduction (Gülcher et al., 2020) could be seismically active at present. There are even speculations that the Venera 14 lander recorded microseisms from far-away seismicity in the active Beta regio on Venus, although there are many other potential explanations for these recorded signals (Ksanfomaliti et al., 1982).

Here, we estimate upper and lower bounds of the amount of seismicity that could be expected for an active Venus, as well as an inactive Venus with seismicity reminiscent of intraplate seismicity on Earth. We obtain our results (Section 3) by scaling the seismicity of the Earth to Venus in Section 2 for different tectonic settings. We discuss the assumptions in our method and the estimates of previous studies in detail in Section 4. This is followed by our conclusions in Section 5.

2 Methods

In order to make estimates of the seismicity of Venus, we use a global earthquake catalogue for Earth and sort the earthquakes into different tectonic areas on the globe, thereby obtaining an effective seismicity density for each tectonic setting. We then apply this same density to analogous Venusian settings to obtain three different possible estimates of Venus's current seismicity: an estimate for an inactive Venus and an upper and lower bound for an active Venus, depending on the assumptions that we make. Here, we briefly detail our methods.

2.1 Tectonic settings on Earth

To obtain the seismicity density of different tectonic settings on Earth, we calculate the area of seven different tectonic settings on the Earth. For this, we use the recent maps of global geological provinces and tectonic plates from Hasterok et al. (2022). We define subduction and collision zone areas according to the zones of deformation defined by Hasterok et al. (2022), as the location of the seismicity associated with these types of plate boundaries typically encompasses a large, diffuse area. We extend the deformation zones of Hasterok et al. (2022) to account for deep earthquakes associated with subduction zones that lie outside of the deformation zones defined at the surface of the Earth. We further define the areas of transform and strike-slip regions, rift zones, and mid-oceanic ridges according to the mapping of Hasterok et al. (2022) by defining a 150 km wide band on either side of the respective plate boundary and correcting for overlapping areas. The remaining surface area of the Earth is divided into oceanic intraplate and continental intraplate regions, according to the mapped oceanic and continental crust by Hasterok et al. (2022). Hence, the surface area of the Earth is divided into seven distinct (non-overlapping) tectonic settings: subduction zones (5.13% of Earth's surface area),

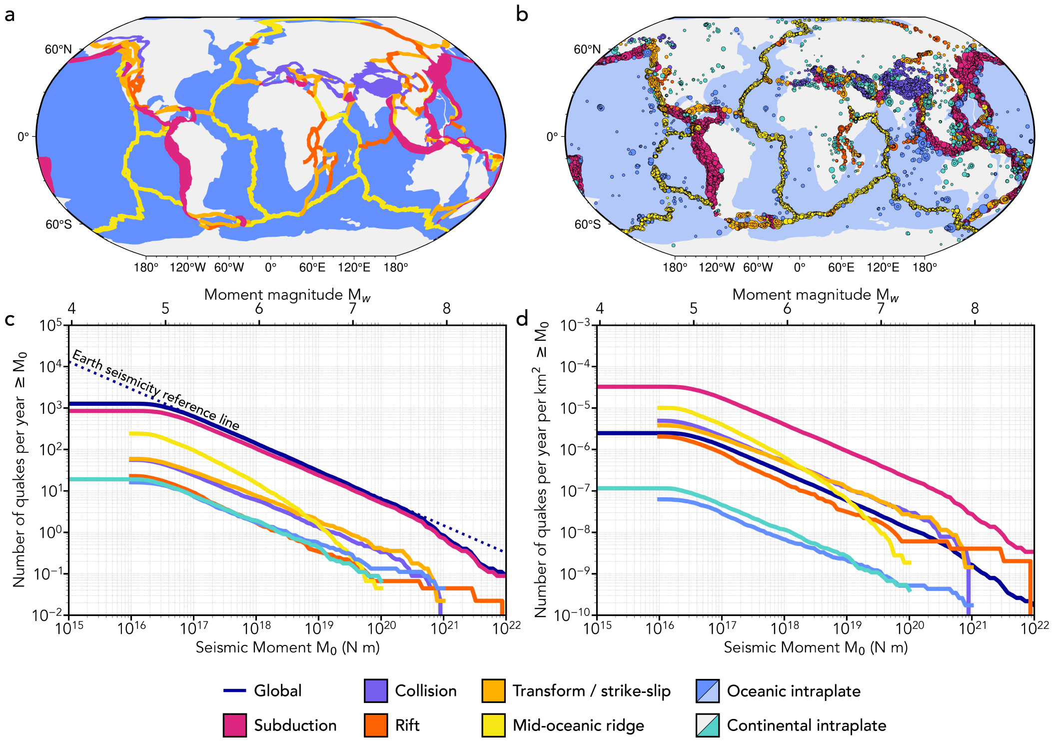

Figure 1. (a) Map of the Earth showing how its surface area is divided into seven discrete tectonic settings. (b) Earthquakes in the CMT catalogue from 1976 - 2020 coloured according to tectonic setting with the symbol size proportional to the earthquake magnitude. (c) Annual earthquake size-frequency distribution for the Earth based on the CMT catalogue and split into different tectonic settings. (d) Seismicity density on the Earth for different tectonic settings, i.e., number of earthquakes in the CMT catalogue per year per km^2. Maps are in Robinson projection.

collision zones (2.23%), transform and strike-slip regions (3.03%), rift zones (2.17%), mid-oceanic ridges (4.70%), and oceanic (50.44%) and continental intraplate (32.30%) regions (Figure 1a, Table S1).

2.2 Seismicity of the Earth

We use the global Centroid Moment Tensor (CMT) earthquake catalogue from 1976 – 2020 with a completeness magnitude of $M_w 5$ to characterise Earth's annual seismicity. We sort the earthquakes of the CMT catalogue in the predefined tectonic areas (Figure 1b) and obtain an earthquake size-frequency distribution for the different tectonic settings (Figure 1c). The seismicity density for each of the tectonic settings found on Earth is then calculated by dividing the earthquake size-frequency distribution by the surface area (Figure 1d; Table S1).

Subduction zones have the highest seismicity density, followed by the other plate boundary settings and the overall global seismicity density of the Earth (Figure 1d). The seismicity density of collision zones and strike-slip regions are similar, with a slightly lower seismicity density for the rift zones. Intraplate seismicity clearly has the lowest seismicity density (approximately one order of magnitude less than the global seismicity density) with continental intraplate seismicity density being slightly higher than oceanic intraplate seismicity density.

2.3 Tectonic settings on Venus

For Venus, we calculate the surface area covered by rifts (8.25% of Venus's surface area; Jurdy & Stoddard, 2007), coronae (7.76%), and ridges or mountain belts (i.e., compressional regions; 1.64%) from maps by Price and Suppe (1995); Price et al. (1996) as shown in Figure 2a (also see Table S2). We manually ensure that there are no overlapping regions by including rift-associated coronae as part of the rift system. For these three tectonic settings on Venus we define reasonable Earth analogues, as discussed in Section 2.4. We refrain from including other tectonic settings found on Venus, such as tesserae and wrinkle ridges, as they do not have a clear Earth analogue, which makes their seismicity density unconstrained. Instead, we consider the remaining area of Venus as an intraplate tectonic setting (82.35% of Venus's surface; Figure 2a).

2.4 Scaling from the Earth to Venus

We consider three different scenarios when scaling the seismicity from the Earth to Venus (Table S3). First, we consider an inactive Venus where the only seismicity on the planet is a background seismicity similar to the continental intraplate seismicity on Earth. This minimum level of seismicity on Venus is a popular hypothesis that has been used by other studies as well (e.g., Stevenson et al., 2015; Tian et al., 2023; Ganesh et al., 2023). Here we obtain this estimate by scaling the entirety of Venus with continental intraplate seismicity on Earth.

As a second estimate, we consider an active Venus with conservative assumptions on its level of activity to provide a lower bound. We assume that coronae are surface expressions of plume-induced subduction and therefore have a seismic signature similar to that of Earth's subduction zones (Davaille et al., 2017; Gülcher et al., 2020; Byrne & Krishnamoorthy, 2022). However, for this lower bound estimate, we do not consider the entire corona area to be active and associated with the high seismicity density of subduction zones. Instead, we assume that 27.8% of the area of coronae is active according to Gülcher et al. (2020) and we only scale this area with subduction zones on Earth. We further assume that the rift zones on Venus have seismicity similar to (continental) rift zones on Earth. The observed ridges and mountain belts on Venus that result from compressional deformation are assumed to have a similar seismicity signature to collision zones on Earth. Like the inactive Venus scenario, the remaining area of Venus is scaled according to continental intraplate seismicity on Earth.

Our third and last estimate is for an active Venus with the most liberal assumptions of plausible tectonic activity on Venus. In this estimate, we assume that all coronae are active, since the amount of active coronae is still highly uncertain (Gülcher et al., 2020). So, we scale the entire corona area with the subduction seismicity of the Earth. For the rift zones on Venus, we now scale the seismicity with mid-oceanic ridge seismicity on Earth, instead of continental rifting. Like our lower bound estimate for active Venus, we scale the area of ridges on Venus with collision zones on Earth and we assume that the rest of the planet is equivalent to continental intraplate seismicity on Earth.

In addition to scaling the areas of Venus to Earth's tectonic settings, we scale each of the three different scenarios by seismogenic thickness. Since Venus has a higher surface temperature than Earth, assuming the same seismogenic depth is likely incorrect. We therefore estimate an upper and lower bound for the seismogenic thickness that we apply to each of our three scenarios to provide a range of likely seismicity for each of them. In order to estimate the seismogenic thickness ratios, we first estimate an average seismogenic thickness for the Earth. For oceanic crust, we assume a representative seismogenic thickness of 36.5 km, which is the depth of the 600°C isotherm (McKenzie et al., 2005; Richards et al., 2018) for the average age of 64.2 Myrs of the oceanic crust (Seton et al., 2020). Following Wright et al. (2013), we assume a seismogenic thickness of 14 km for continental crust. Then, applying the ratio of oceanic / continental crust from Hasterok et al. (2022), we obtain an average seismogenic zone thickness for the Earth of 26.93 km. For Venus, we calculate a minimum seismogenic zone thickness from proposed thermal gradients of Venus's lithosphere (Smrekar et al., 2023; Bjonnes et al., 2021). Like for our Earth estimate, we calculate the depth corresponding to the 600°C isotherm, as this seems to limit the seismogenic zone on Earth (McKenzie et al., 2005). To obtain a minimum estimate of Venus's seismogenic zone thickness, we calculate the average thermal gradient for Venusian rifts estimated by Smrekar et al. (2023), which results in a seismogenic thickness of 7.3 km. As a maximum estimate, we use the proposed minimum thermal gradient of 6 K/km for the Mead crater on Venus by Bjonnes et al. (2021), resulting in a seismogenic thickness of 22.7 km. We note that these estimates represent the thermal gradients during the formation of the associated features, but given the young ages predicted for Venus's surface these values are likely representative for its current thermal state. This then yields minimum and maximum scaling ratios of 0.27 and 0.84, respectively, to account for the likely difference in seismogenic thickness between Venus and Earth. Scaling with the seismogenic thickness as well as the areas of the tectonic settings, effectively allows us to scale by seismogenic volume to obtain estimates for Venus's seismicity as accurately as possible (Table S3).

In order to actually calculate the potential amount of seismicity on Venus and to extrapolate to earthquake magnitudes below the completeness magnitude of M_w5 of the CMT catalogue, we scale the average slopes of the size-frequency distribution for the different tectonic settings on Earth (Figure 1c). We specifically assume that the size-frequency distribution of medium-sized earthquakes with a seismic moment of 10^{17} Nm to 10^{19} Nm is representative for the size-frequency distribution of smaller earthquake magnitudes, i.e., the earthquakes follow Gutenberg-Richter statistics (Gutenberg & Richter, 1956; Beroza & Kanamori, 2015). For large earthquake magnitudes $\geq M_w8$ this relationship breaks down, so we do not comment on the occurrence of quakes $\geq M_w8$ on Venus.

3 Results

Our results for the different Venus scenarios are summarised in Figure 2 and Table 1, where we list the estimated annual number of quakes for a given moment magnitude.

3.1 Inactive Venus

In our first estimate, we assume that the entirety of Venus can be scaled with the continental intraplate seismicity of the Earth, so the global estimate and the intraplate estimate overlap perfectly in Figure 2b. As expected, the amount of seismicity in this scenario is significantly less than that on Earth with 11 − 34 venusquakes $\geq M_w5$ estimated annually, compared to 1045 earthquakes $\geq M_w5$ per year on Earth. The associated seismicity density for quakes $\geq M_w5$ lies between 0.24 and 0.74×10^{-7} year^{-1} km^{-2}, which is on the same order of magnitude as that of intraplate seismicity on Earth.

3.2 Active Venus - lower bound

The lower bound for our active Venus estimate globally predicts more seismicity than the inactive, intraplate Venus estimate (Section 3.1). The ridge, rift, and intraplate tectonic settings on Venus have seismicity on the same order of magnitude in this estimate, as shown by the overlapping bands of seismicity in Figure 2c (also see Figure S1). The coronae have an order of magnitude more seismicity associated with them, although

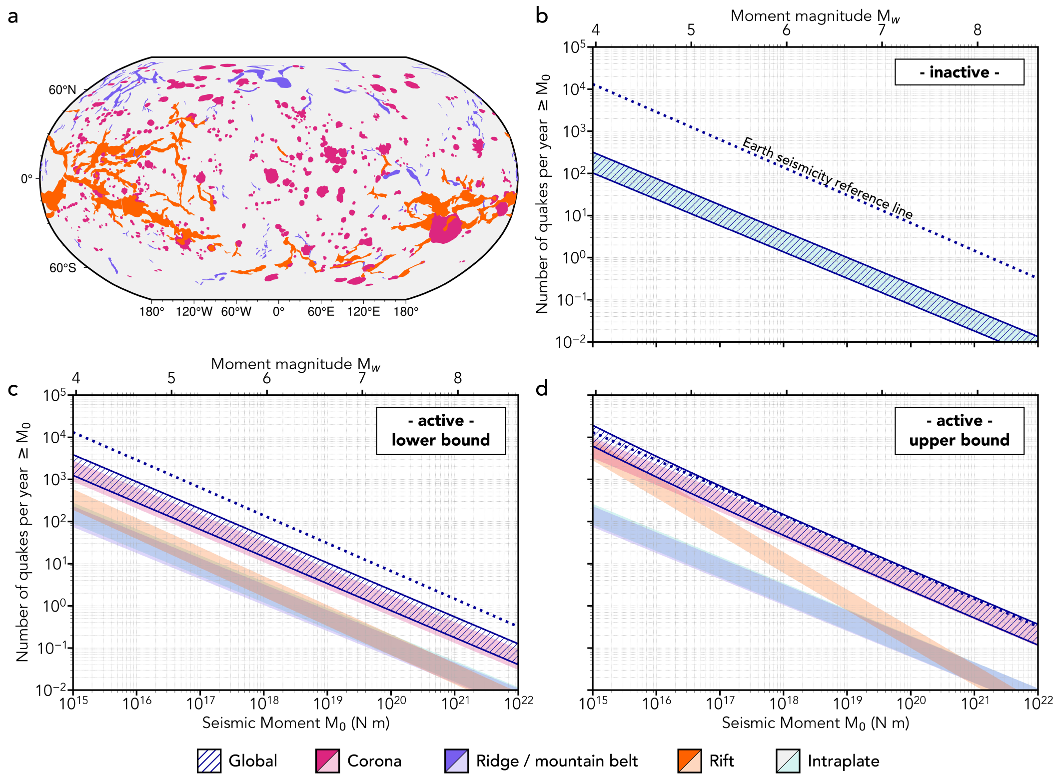

Figure 2. (a) Map of Venus (Robinson projection) showing the areas of mapped coronae, ridges and mountain belts, and rifts (Price & Suppe, 1995; Price et al., 1996). (b-d) Ranges of potential quake size-frequency distributions on Venus for (b) an inactive Venus with background seismicity analogous to Earth's continental intraplate seismicity; (c) a lower bound on an active Venus; and (d) an upper bound on an active Venus. The hatched area shows the global, accumulated annual seismicity that combines the seismicity of the different individual tectonic settings. Note that because of the log-log scale, the global estimate and the seismicity range of the highest individual tectonic setting are closely-spaced. Dotted dark blue line indicates the reference Earth seismicity line, which corresponds with the slope of the size-frequency distribution of global seismicity on Earth (Figure 1c).

only 27.8% of them are assumed to have a subduction-like seismicity density in this estimate. Summing up the seismicity of the different tectonic settings results in estimates of 126 – 391 venusquakes per year with a moment magnitude ≥5 and a seismicity density of 2.73 - 8.49×10^{-7} year^{-1} km^{-2} globally for venusquakes $\geq M_w 5$. This global seismicity density is significantly less than that of the Earth or any of its plate boundary settings.

3.3 Active Venus - upper bound

The upper bound of estimated seismicity for an active Venus (Figures 2d, S2) is very close to – and even slightly larger than – the annual seismicity observed on Earth, primarily due to the scaling of coronae with Earth's subduction zone seismicity in this estimate, which also dominates Earth's seismicity (Figure 1c). Since we scale the rifts on Venus with Earth's mid-oceanic ridge seismicity in this estimate, we have a different slope for Venusian rift seismicity. This results in an increase in smaller quakes with $M_w \leq$

Estimate	$M_w \geq 4.0$	$M_w \geq 5.0$	$M_w \geq 6.0$	$M_w \geq 7.0$
Inactive Venus	95 – 296	11 – 34	1 – 4	0 – 0
Active Venus - lower bound	1161 – 3609	126 – 391	14 – 42	2 – 5
Active Venus - upper bound	5715 – 17773	465 – 1446	44 – 136	4 – 15

Table 1. Number of venusquakes per year equal to or larger than a certain moment magnitude for our three possible Venus scenarios. A range is provided based on the uncertainties in the chosen scaling factor for the seismogenic thickness. See Table S4 for the range of seismic densities for each of these scenarios.

5. There is no difference between the seismicity expected for the ridge tectonic setting compared to the lower bound for an active Venus (Section 3.2), as it is scaled in the same way.

Globally, we then estimate 465 – 1446 venusquakes of moment magnitude ≥ 5, with the upper bound being larger than the number of $M_w \geq 5$ earthquakes observed on the Earth (1045). The seismicity density of quakes $M_w \geq 5$ varies from 10.1 to 31.41×10^{-7} year^{-1} km^{-2}. This lowest possible seismicity density for an upper bound to our active Venus estimate is slightly lower than the Earth's seismicity density for continental rift zones (14.97×10^{-7} year^{-1} km^{-2}) and the highest possible seismicity density is reminiscent of the seismicity density of transform and strike-slip settings on the Earth (30.22×10^{-7} year^{-1} km^{-2}).

4 Discussion

Generally, we estimate that the seismicity of Venus is lower than that of the Earth, except for the most active end-member of Venus activity. Indeed, there are large differences between the various estimates, indicating a range of possible seismic activity on Venus at present, depending on the many assumptions we are forced to make given the limited amount of data from Venus. For our inactive Venus estimate, we assume that the global background seismicity of Venus is similar to the continental intraplate seismicity of the Earth. This is a common assumption that has also been suggested by e.g., Lorenz (2012); Stevenson et al. (2015); Byrne et al. (2021); Tian et al. (2023). The number of venusquakes $\geq M_w5$ per year for this estimate (11 – 34) is also the same order of magnitude as the estimate of Ganesh et al. (2023), who calculate an estimate of Venus's seismicity based on the cooling of the planet and the corresponding contraction of the lithosphere and thereby predict 16 venusquakes $\geq M_w5$ per year. In their estimate, they assume a global average seismogenic thickness of 40 km, which is larger than our maximum assumed seismogenic zone thickness of 22.7 km. If both our study and the study of Ganesh et al. (2023) assumed the same seismogenic thickness, it is likely that the estimate of Ganesh et al. (2023) would lie closer to our lower limit for the inactive Venus scenario of 11 venusquakes $\geq M_w5$ per year. Ideally though, there would be stronger constraints on the seismogenic thickness from, for example, thermal gradients estimated from studies of the elastic and mechanical lithosphere thickness (e.g. Anderson & Smrekar, 2006; Borrelli et al., 2021; Maia & Wieczorek, 2022; Smrekar et al., 2023) or from impact crater modeling (Bjonnes et al., 2021). These studies rely on the analysis of gravity and topography data, for which a higher resolution will become available from the VERITAS (Smrekar et al., 2020) and EnVision (Ghail et al., 2016) missions. Estimates of the thermal gradient and associated seismogenic thickness could then be obtained with a higher accuracy and on a more global scale than currently available. They could be included in future studies of seismicity on Venus and improve on the estimates presented here.

For our estimates for an active Venus, we scale the areas of compressional deformation on Venus, i.e., the ridges and mountain belts, with the seismicity of collision zones on Earth, which we believe to be a reasonable assumption. The rifts on Venus are scaled with continental rift seismicity on Earth in the lower bound estimate for an active Venus. This is also a reasonable assumption, with many studies pointing to the morphological and geological similarities between the rift zones on Venus and continental rifts on Earth such as the East African rift zone (Solomon, 1993; Foster & Nimmo, 1996; Kiefer & Swafford, 2006; Basilevsky & McGill, 2007; Stoddard & Jurdy, 2012; Graff et al., 2018; Regorda et al., 2023). For our upper bound, we scale the rift zones of Venus with mid-oceanic ridge seismicity since it is also an extensional setting and the higher temperatures at the mid-oceanic ridges and the corresponding different slope of the size-frequency distribution on Earth might be a better fit for rift seismicity under Venus's high surface temperature. For the coronae, we scale with subduction, since multiple studies suggest that coronae are the surface expressions of plume-induced subduction (Davaille et al., 2017; Gülcher et al., 2020; Byrne & Krishnamoorthy, 2022). However, the seismicity associated with this type of plume-induced subduction is uncertain. In the interest of providing an upper and lower bound, scaling the coronae by activity is a good first order approximation. However, it is also possible that coronae seismicity does not scale with Earth's subduction seismicity, but is instead more analogous to, for example, transform fault seismicity related to the observed fracture zones at the rims of coronae. In general though, our upper bound for Venusian seismicity results in seismicity levels slightly higher than, but similar to, that of the Earth, which has also already been suggested previously (e.g., Lorenz, 2012).

Apart from the uncertainty in scaling the chosen tectonic settings correctly, there are also tectonic settings on Venus that we neglect to scale explicitly. For example, we do not explicitly scale the tesserae of Venus with a tectonic setting on Earth, although they are implicitly scaled with the background intracontinental seismicity of the Earth. This is arguably one of the most reasonable assumptions for tesserae, considering that prevailing hypotheses include that they are continental crust analogues (Romeo & Turcotte, 2008; Gilmore et al., 2015). We also do not consider the observed extensive regions of wrinkle ridges as seismically active beyond the background intracontinental seismicity of the Earth. A recent study by Sabbeth et al. (2021) predicted that the annual moment release for wrinkle ridges on Venus is on the order of 6.0×10^{19} N m to 1.6×10^{20} N m.

Note that in the estimates presented here, only one type of seismic source is considered, i.e. earthquakes, which by definition are associated with tectonics and volcanism. Other sources such as landslides (Pavri et al., 1992; M. Bulmer & Guest, 1996; M. Bulmer et al., 2006; M. H. K. Bulmer, 2012; Hahn & Byrne, 2023) could be responsible for seismic signals on Venus as well.

Some studies argue that there will be little to no seismicity on Venus, at least at higher magnitudes (e.g., Karato & Barbot, 2018), because the high surface temperatures on Venus may exclude the possibility of any kind of substantial seismogenic zone and the unstable slip mechanisms responsible for earthquakes. However, some of the assumptions in Karato and Barbot (2018) are unrealistically conservative (e.g., a global crustal thickness of 40 km; a seismogenic zone limit at 400°C) and not applicable to Venus.

To distinguish between these different scenarios and determine how seismically active Venus is, a seismological or geophysical mission to Venus is required to measure seismic signals. Although the NASA and ESA selected missions to Venus currently do not focus on this, there are promising proposals to measure Venus's seismicity in the not-too-distant future. For example, Kremic et al. (2020) presented a mission proposal for a long-duration Venus lander with a seismometer on board that can withstand Venus's high surface temperature. In addition, recent advances in the balloon-detection of earthquakes show great promise for applications to Venus (Garcia et al., 2022; Krishnamoorthy & Bowman, 2023). Our estimates for Venusian seismicity may help guide the design of these missions.

5 Conclusions

We estimate upper and lower bounds on the expected annual seismicity of Venus by scaling the seismicity of the Earth to Venus according to the surface area of different tectonic settings and the difference in seismogenic thickness between the two planets. Our most conservative estimate is an 'inactive Venus', where we assume the global seismicity of Venus is comparable to Earth's continental intraplate seismicity. This results in 11 – 34 venusquakes $\geq M_w 5$ per year depending on the assumption of seismogenic zone thickness. For our active Venus scenarios, we assume that the rifts, ridges, and coronae on Venus are seismically active. For a lower bound on an active Venus, we then find 126 – 391 venusquakes $\geq M_w 5$ annually, which increases to 465 - 1446 venusquakes $\geq M_w 5$ for assumptions that constitute our most active Venus scenario. This latter scenario is slightly larger than the seismic activity level of the Earth. We believe our lower bound estimate for an active Venus to be the most likely to represent Venus's current seismicity. Future seismological and geophysical missions could measure the actual seismicity of Venus and distinguish between our three proposed end-members of Venusian seismic activity.

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Data availability statement

The Jupyter Notebooks used to make the results and plot the figures as well as the CMT database and geospatial vector data (shapefiles) of the tectonic setting areas on

Earth can be found in *zenodo link to be finalised upon acceptance. For now the data is included as a zip file for the reviewer's convenience.* Explanation of individual files in this repository and additional figures and tables are provided in the Supplementary Material. Figures were made with Python and Adobe Illustrator. We used the colorblind friendly color map from the IBM Design Library (David Nichols, 2022; retrieved: February 16, 2023).

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