SUPPLEMENTARY MATERIAL

Estimates on the possible annual seismicity of Venus

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Contents Supplementary Material

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S1. Description additional supplementary files on Zenodo

All* the scripts and data we used to do our study are shared in *the Zenodo reference to be finalised*. Here, we provide a brief overview of all the files in this Zenodo repository.

- Venus_seismicity_estimates.ipynb
  Jupyter notebook to calculate all the data and results presented Tables 1 and 2 and S1 to S3 and Figures 1 and 2 and S1 and S2.

- map_figures.ipynb
  Jupyter notebook to plot the maps in Figures 1 and 2.

- areas_tectonic_settings.xlsx
  Excel workbook containing the areas of the different tectonic settings for Earth (worksheet 1) and Venus (worksheet 2) as listed in Tables S1 and S2.

- estimate_seismogenic_zone_depth.xlsx
  Excel workbook used to calculate minimum and maximum estimates for the seismogenic zone of Venus. It contains three worksheets that each consider data from different settings on Venus. Worksheet 1 ('Smrekar 2023 - Rifts') contains the location and thermal gradients for 7 rift zones on Venus from Smrekar et al. (2023). From these thermal gradients, we calculate the seismogenic thickness based on both the 600°C and 800°C isotherm. We use the resulting seismogenic thickness for rifts as the minimum seismogenic thickness of Venus in the paper (indicated in green). Worksheet 2 ('Smrekar 2023 - Coronae') is similar to worksheet 1, except that it considers data for 89 Venusian coronae from Smrekar et al. (2023). Worksheet 3 'Bjonnes 2021 - Crater' lists the location and end-member thermal gradient of the Mead crater as proposed by Bjonnes et al. (2021). Calculating the corresponding seismogenic thickness results in the maximum seismogenic thickness of Venus used in the paper (indicated in green in the worksheet).

- earthquake_data/cmt_2020.csv
  CSV file containing data from the CMT catalogue from 1976 – 2020 used in this study.

- earthquake_data/quakes-*.csv
  CSV files containing the earthquakes from the CMT catalogue (from earthquake_data/cmt_2020.csv) sorted into different tectonic settings. Each file is named after one of the tectonic settings that we consider (subduction zones, collision zones, transform and strike-slip regions, rift zones, mid-oceanic ridges, and oceanic and continental intraplate regions) and contains the earthquakes that were sorted into that setting. Earthquakes are sorted uniquely, as the areas of tectonic settings do not overlap.

- tectonic_settings_Earth/all_tectonic_settings.*
  Geospatial vector data (shapefiles) describing polygons of the areas corresponding to the tectonic settings of subduction zones, collision zones, transform and strike-slip regions, rift zones, and mid-oceanic ridges based on Hasterok et al. (2022). These polygons are used to plot Figures 1a and b.

- tectonic_settings_Earth/continental_crust_polygons.*
  Geospatial vector data (shapefiles) describing polygons of the areas corresponding to continental crust derived from the file oc_boundaries.shp by Hasterok et al. (2022). Continental crust defines one of the tectonic settings in which the CMT catalogue earthquakes are sorted, i.e., a continental intraplate setting. Earthquakes are assigned to continental crust or oceanic crust based on these polygons after it has been determined that they are not associated with any of the plate boundary tectonic settings. These continental crust polygons are also used to plot Figures 1a and b.

****Note****: We use the Venus mapping data (specifically the areas spanning coronae, rifts, and ridges) from Price and Suppe (1995); Price et al. (1996). We have contacted Maribeth Price about data sharing and she will publish the mapping data in an online, open-access repository. When this becomes available, we will link to that repository here.*

Tectonic setting	**Area** (km^2)	**% of total surface area**	**Number of earthquakes** $\geq M_w4$ (year^{-1})	**Seismicity density for earthquakes** $\geq M_w4$ ($\cdot 10^{-6}$ year^{-1} km^{-2})
Global	510064472.00	100	12207.00	23.93
Subduction	26164756.47	5.13	8028.39	306.84
Collision	11394312.46	2.23	383.13	33.62
Transform / strike-slip	15480054.17	3.03	420.78	27.18
Rift	11049695.41	2.17	187.62	16.98
Mid-oceanic ridge	23975223.25	4.70	5956.87	248.46
Oceanic intraplate	257257596.08	50.44	82.85	0.32
Continental intraplate	164742834.15	32.30	125.87	0.76
Intraplate	422000430.24	82.73	204.42	0.48

Table S1: Area and earthquake data for the Earth for different tectonic settings obtained from dividing the Earth into areas and the CMT catalogue (also see Figure 1). Number of earthquakes and annual seismicity density are reported for earthquakes with a magnitude $\geq M_w4$ (extrapolated from the observations assuming the earthquakes follow Gutenberg-Richter statistics; see Section 2.4.3).

Tectonic setting	**Area** (km^2)	**% of total surface area**
Global	460234317.00	100
Coronae	35718832.79	7.76
Ridge / mountain belt	7568096.24	1.64
Rift	37967130.85	8.25
Intraplate	378980257.12	82.35

Table S2: Surface areas for different tectonic settings on Venus (Figure 2a).

Tectonic setting Venus	**Tectonic setting Earth**	**Minimum scaling factor**	**Maximum scaling factor**
	Inactive Venus		
Global	Continental intraplate	0.76	2.35
	Active Venus - lower bound		
Coronae	Subduction	0.10	0.32
Ridge / mountain belt	Collision	0.18	0.56
Rift	Rift	0.93	2.90
Intraplate	Continental intraplate	0.67	2.07
	Active Venus - upper bound		
Coronae	Subduction	0.37	1.15
Ridge / mountain belt	Collision	0.18	0.56
Rift	Mid-oceanic ridge	0.43	1.33
Intraplate	Continental intraplate	0.62	1.94

Table S3: Scaling factors for the different tectonic settings for each of the three Venus scenarios. The first column denotes the tectonic setting on Venus for which we aim to estimate the seismicity. The second column lists the tectonic setting on Earth with which we scale. Minimum and maximum scaling factors are indicated according to the range of possible seismogenic thicknesses we consider for Venus.

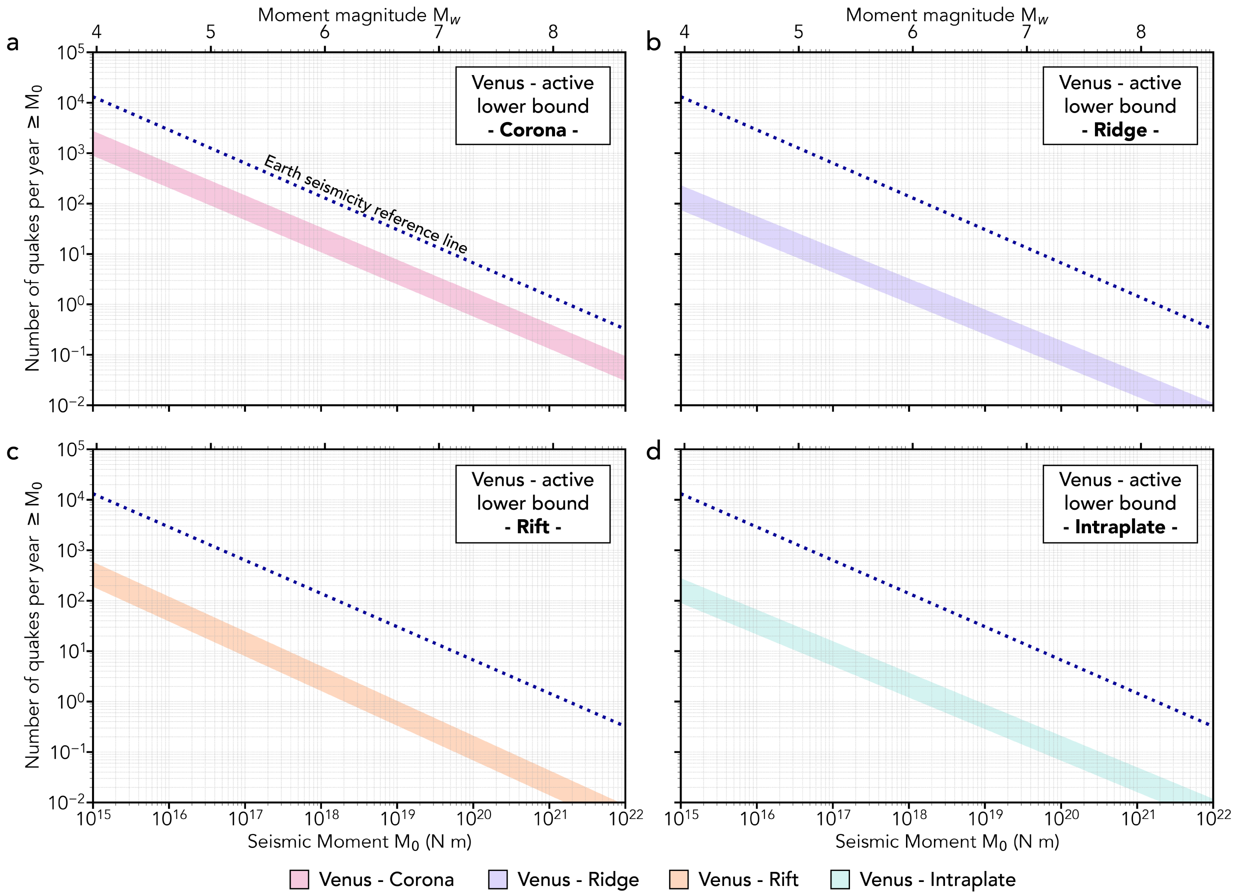

Figure S1: Ranges of potential quake size-frequency distributions on an active Venus (lower bound) for different tectonic settings: (a) corona; (b) ridge; (c) rift; (d) intraplate. Dotted dark blue line indicates the reference Earth seismicity line, which corresponds to the slope of the global seismicity size-frequency distribution on Earth. These four estimates together, as well as the summed global estimated seismicity of this scenario can be found in Figure 2c.

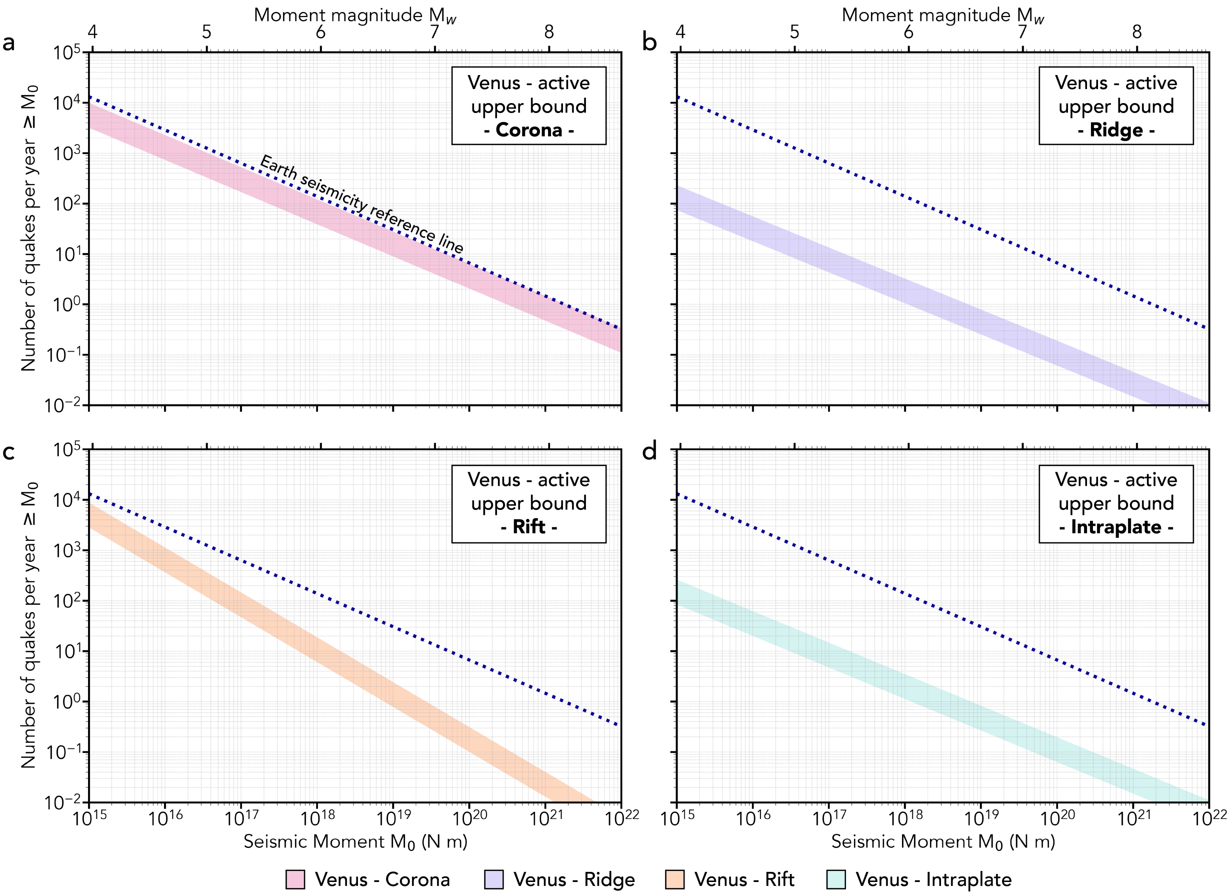

Figure S2: Ranges of potential quake size-frequency distributions on an active Venus (upper bound) for different tectonic settings: (a) corona; (b) ridge; (c) rift; (d) intraplate. Dotted dark blue line indicates the reference Earth seismicity line, which corresponds to the slope of the global seismicity size-frequency distribution on Earth. These four estimates together, as well as the summed global estimated seismicity for this scenario can be found in Figure 2d.

References used in the supplementary material

Bjonnes, E., Johnson, B., Evans, A., 2021. Estimating Venusian thermal conditions using multiring basin morphology. Nature Astronomy 5, 498–502.

Hasterok, D., Halpin, J.A., Collins, A.S., Hand, M., Kreemer, C., Gard, M.G., Glorie, S., 2022. New maps of global geological provinces and tectonic plates. Earth-Science Reviews 231, 104069.

Price, M., Suppe, J., 1995. Constraints on the resurfacing history of Venus from the hypsometry and distribution of volcanism, tectonism, and impact craters. Earth, Moon, and Planets 71, 99–145.

Price, M., Watson, G., Suppe, J., Brankman, C., 1996. Dating volcanism and rifting on Venus using impact crater densities. Journal of Geophysical Research: Planets 101, 4657–4671.

Smrekar, S.E., Ostberg, C., O'Rourke, J.G., 2023. Earth-like lithospheric thickness and heat flow on Venus consistent with active rifting. Nature Geoscience 16, 13–18.