The Role of mantle dynamics in the Rejuvenation of Venus' surface: Insights from Numerical modelling. U. Sruthi* , T. Rolf, F. Crameri and S.C. Werner Centre for Earth Evolution and Dynamics, P.O. Box 1028 Blindern, NO-0315 Oslo, Norway (*sruthiu@geo.uio.no).

Introduction: Venus' mean surface age is suggested to be ~250-750 Ma [1]. Also, the surface age seems, compared to Earth's, rather uniform given the nearly random distribution of Venus' craters [2]. Yet, the origin of these observations remains debated. Previous studies addressing this issue of resurfacing used Monte Carlo simulations and parametrized modelling [3, 4]. These techniques, however, typically follow predefined rules and do not capture the self-organizing dynamics of planetary evolution.

From a dynamic perspective, Venus currently seems to operate in the stagnant lid regime of mantle convection in which the mantle is mostly decoupled from the surface. Such a regime, however, is thought to have difficulty to generate a Venus-like globally uniform surface age. This gave rise to the suggestion of an episodic regime in which periods of stagnant lid are interrupted by phases of global surface mobilization and recycling, so called overturns.

Given the sparsity of observations on Venus, investigation of these regimes and their capability of reproducing the surface age characteristics is mostly done via numerical models, constrained by data from the Magellan and Venus Express missions (e.g., surface gravity, topography, radar imaging). Several of such models have previously been employed to reveal the thermochemical evolution of Venus in both the stagnant lid and the episodic overturn regimes [5]. As a key result, these models were more capable of reproducing Venus' current surface gravity and topography in a phase of stagnant lid. On the other hand, with a continuous stagnant lid since Venus' early days, the model-inferred thickness of basaltic crust becomes very large. With a global resurfacing event that ceased sufficiently long ago, however, predicted surface gravity may match the observations while crustal thickness is much reduced [6]. The predicted distribution of surface ages has yet only rarely been used to constrain such models though [6,7].

In this study, we thus derive surface age distributions generated self-consistently from numerical models featuring both volcanic (induced by magmatic activity) and tectonic resurfacing (induced by overturns). Our aim is to better understand the coupling between Venus' interior and surface signature of which the age distribution is a characteristic.

Methodology: The mantle convection code StagYY [3] is used to compute the thermochemical evolution of Venus' interior; the general setup is similar to those described previously [5,6]. These models consider compositional variations in the mantle which arise from partial melting in the upper mantle where the solidus is exceeded. (Part of) the melt erupts vertically above the melting zone at the surface, which parametrizes extrusive volcanism (intrusive volcanism is not considered yet).

Surface age is estimated based on tracers, which are used to track material composition in the model. At any time, the surface age of a grid cell is calculated by tracking the residence time of tracers in the surface cells of the model grid, i.e. the time until recycling into the deeper interior. The characteristic age of this part of the surface is then the average age of all particles within the cell. Having estimated the surface age of each grid cell, we can compute an age-area distribution (Fig.1) with basic statistical characteristics (mean, spread, ...). These measures provide insight into the mean age of the surface as well as its uniformity across the surface. We can thus test how Venus-like distributions may be generated dynamically.

Results & Discussions:

Our computations include two sets, one in stagnant lid and one in the episodic regime. Each case starts with the same initial conditions, but parameters governing the dynamic evolution differ between cases, e.g. reference viscosity (η_0), melt eruption efficiency etc.. Only one example for each set of results is shown in this abstract. In each set, the computed diagnostics include the total eruption volume, average top heat flux and crustal thickness. At the same time, in addition to surface mean age and age distributions as explained above. Wherever possible we compare our predicted range of values to the observational inferences to constrain our models. Age distributions are normally analyzed for one instant of time via histograms (Fig. 1); for the temporal evolution of surface age we mostly look at the mean age plus its standard deviation (Fig. 2).

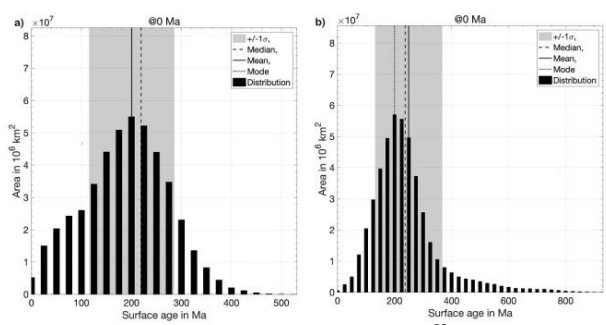

Fig.1.Histograms of surface age (using $\eta_0=2*10^{20}$ Pa s) at one time instant in (a) a stagnant lid and (b) an episodic model. Simple statistical measures are indicated as explained in the legend.

In stagnant lid cases, the mean surface age is typically as young as ~250±50 Ma and crustal thickness is as great as 90-200 km, thicker than inferred by other methods. Also, the age distribution across the surface is often not uniform but shows significant lateral variation in particular on small-wavelength. Increasing the internal heating rate enhances volcanic activity and tends to further reduces mean surface age. Reducing melt eruption efficiency should counteract this trend, but results do not show a substantial increase in mean age, unless when eruption efficiency is very small.

In episodic models, the frequency of overturns depends on the lithospheric yield stress. Here, we test cases featuring at least 1-3 overturns with each lasting ~150-200 Myr. In Fig. 2b the latest overturn occurs at 1.5 Ga and lasts until ~650 Ma. During this period, surface age is small because of efficient tectonic and volcanic resurfacing. After this activity has ceased, mean surface age increases with time since the overturn event, reaching values of up to 500 Myr. In contrast, the stagnant lid example features a much smoother evolution with almost constant mean age throughout the last billion year of model evolution.

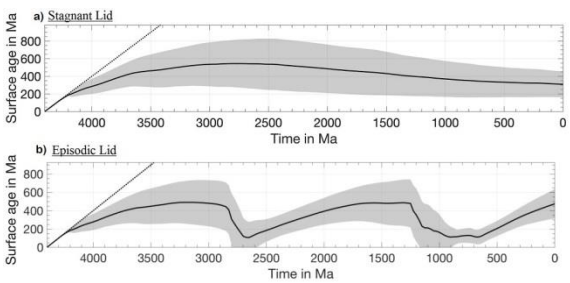

Fig.2.Evolution of mean surface age for (a) a stagnant lid and (b) an episodic lid case in 3D where the y-axis represents average surface age (shaded region represents the standard deviation, $\eta_0 = 10^{21}$ Pa s).

Uniformity of the surface age:

Throughout the evolutions, it is difficult to attain a near uniform surface age; instead, there is typically quite some spread in the distribution (Fig. 3), even after filtering the shortest wavelength that typically captures most variation. This holds even in episodic cases, because of the on-going volcanic activity in the long phases of tectonic quiescence between overturns. Only for some time directly after an overturn, surface age is relatively uniform. Episodic cases feature reduced volcanism during the stagnant phases of evolution, which leads to mean surface ages of up to 600 Ma, in line with the observationally inferred range.

In the stagnant models, magmatism is often correlated with the mantle plume pattern, which varies with the viscosity structure [7]. Regions above plumes are younger than elsewhere, which implies substantial lateral variation. This holds also for episodic cases, but here plumes seem somewhat weaker and more time-dependent due to the reorganizations induced by overturns, at least for some time after the overturn. In some episodic cases, parts of the surface may survive an overturn episode.

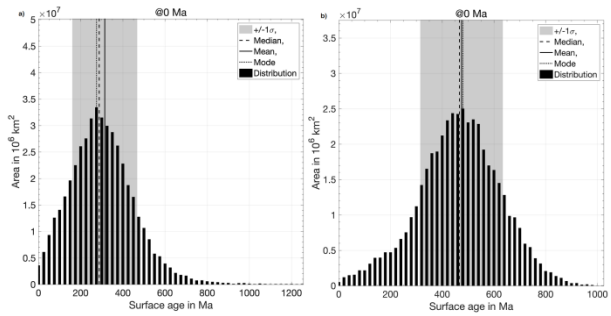

Fig.3 Histogram of surface age from 3D models shown for a (a)stagnant lid and (b) an episodic lid model with the last overturn ceased around ~0.75Ga (blue, $\eta_0 = 10^{21}$ Pa s). This indicates the distribution at the final snapshot of the evolution shown in Fig. 2. Simple statistical measures are indicated as explained in the legend.

Conclusions:

Our study provides a fully dynamic framework to analyse the origin of Venus' surface age characteristics. Our preliminary models typically feature a rather young surface age compared to the observational constraints, but can match these constraints in episodic cases when the overturn event has ceased sufficiently long ago. Uniformity of surface age is difficult to observe in all of our models, probably because of too efficient volcanic resurfacing. In a next step, we will continue to vary the governing parameters and will also include intrusive magmatism, which shall decrease the efficiency of eruptive volcanism.

References:

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