HECATE PROJECT: THE EVOLUTION OF VENUS: CORONAE, SUBSURFACE STRUCTURE AND VOLCANO-TECTONICS B. De Toffoli[1] and A.-C. Plesa[2]; [1] Department of Geosciences, University of Padova, Padova, Italy (barbara.detoffoli@unipd.it), [2] German Aerospace Center, DLR, Institute of Planetary Research, Berlin, Germany.

Introduction: The analysis of the Venusian geological record and in particular of coronae, one of the most puzzling volcano-tectonic features of our Solar System, holds pivotal clues to reconstruct the tectonic evolution of Venus and could reveal crucial information for understanding the planet's interior and its thermal evolution.

Here we present the HECATE project that proposes a multidisciplinary approach intertwining geological observations and mapping, statistical analytical procedures, and geodynamical modeling to address major scientific questions for the geological and geodynamical evolution of Venus. The project aims to collect observable geological evidence of the surface and use this to determine the structure of the shallow subsurface and further to constrain the dynamics of the deeper interior. HECATE will hence connect the different planetary layers (the surface, the shallow subsurface, and the deep interior) that are often addressed individually.

HECATE will be carried out in close collaboration between the hosting institution (University of Padova) and DLR (German Aerospace Center, Berlin) and will provide the first comprehensive, multidisciplinary, and well-rounded study on Venusian coronae, by producing high quality, accessible, and reusable datasets of planetary mapping products, mechanical and rheological structure of the shallow subsurface, and geodynamical investigations with a strong focus on magmatic processes.

HECATE is a highly ambitious but timely project. The results obtained herein will provide valuable information to identify targets of interest for the future Venus missions, EnVision (ESA) and VERITAS (NASA), whose aims include the determination of the volcano-tectonic activity of Venus.

State of the art: Despite being called Earth's twin, on Venus there is no sign of active plate tectonics [1] and whether Venus is geologically active today along with the tectonic evolution that shaped early Venus remains unclear [2]. Venus present-day tectonics is likely to be associated with a geodynamic framework ruled by the occurrence of a stagnant lid convection. Such geodynamic framework is characterized by an immobile, highly viscous layer on top of the slowly creeping solid-state mantle, meaning that this so-called lithospheric lid sits on top of a convecting solid-state mantle. Nonetheless, more recently models agree that magmatic heat transport has played, and most likely still plays, a major role on Venus [2].

In the absence of plate tectonics, as we know from the Earth, the present-day surface deformation on Venus is primarily controlled by mantle convection and plume–lithosphere interaction. Among the documented tectonic structures, large volcano-tectonic features known as coronae are the most distinct surface manifestations of mantle plume activity and hold clues to the global Venusian tectonic regime [3]. However, the origin and evolution of these landforms remain debated. Coronae are circular features surrounded by concentric fractures that display a wide range of sizes, 60 to more than 1,000 km [4]. Coronae are generally interpreted as a response to crustal stresses developed above an upwelling mantle plume, followed by gravitational relaxation or collapse due to magma withdrawal [5]. A portion of documented large coronae resulted to be active today providing evidence for widespread ongoing plume activity on Venus [6]. Overall, coronae of different sizes and morphologies could represent not only different styles of plume–lithosphere interactions but also different stages of evolution of these interactions [6]. HECATE aims to collect observable geological evidence of the surface and use this to determine the structure of the shallow subsurface and further to constrain the dynamics of the deeper interior. HECATE will hence connect the different planetary layers (the surface, shallow subsurface, and the deep interior) that are often addressed individually

Objectives: The aim of this project is to examine the Venusian geological record to shed new light on coronae formation, one of the most puzzling volcano-tectonic features of our Solar System, opening a window into the planet's interior and its thermal evolution, and ultimately unveiling pivotal clues to reconstruct the tectonic evolution of Venus. With the multidisciplinary approach that HECATE will employ we will also bridge the hosting institution (University of Padova) which has a leading experise in geological mapping and analyses and DLR (German Aerospace Center, Berlin), which will provide key aspects for numerical modeling.

The project is divided into four work packages (WP) that mirror the key macro-objectives (figure below) necessary to reach HECATE scientific goal:

WP 1) Coronae Classification: within this work package we aim to produce a meaningful classification of coronae based on their key traits, that could include the diameter, and their geological and structural context. This effort aims to identify populations as homogeneous as possible of the hundreds of coronae globally observed on Venus. This will highlight possible recurrencies in the appearance of these volcano-tectonic structures and relations with other geological elements, thus laying the groundwork for an organized and systematic analysis of the main objects of interest of this study. The final goal of work package 1 is to compile a list of high interest targets obtained by sampling the coronae population of each class. Only the selected targets will undergo the whole analytical process. Accordingly, this work package needs to be completed before moving on to the following ones.

WP 2) Plumbing System Analysis: within this work package our goal is to extrapolate a complete picture of the coronae's feeding system. As outlined above, the set of analyses foreseen in this work package will be performed only on a representative sample of coronae obtained in WP1. Hence, for each selected corona we will produce a map of the features produced by fracturing, faulting, and magma injection visible from orbit (e.g., grabens, fractures, collapse pit, etc.) and perform structural analyses to identify the local stress regime and deformation. We will then run statistical analytical procedures investigating size and distribution of relevant structures to determine how the plumbing system of the examined coronae develop underneath the surface. These techniques will allow to deduce the subsurface extension of the coronae's feeding system and the location of magmatic reservoirs, pushing the exploration in the deep interior of the planet.

WP 3) Subsurface Structure: the objective of this section is to reconstruct the subsurface structure of Venus on local, large, and global scales. According to the overall goal of this project of putting together multiple disciplines, this work package constitutes the bridge between geology and numerical modeling. We thus aim to approach the exploration of the planet interior by constraining the plume–lithosphere interactions and the subsurface structure/rheological layers with the data collected in WP2 about magma accumulation levels and subsurface cracking. Synergistically with all the other WP activities, we will also test the hypothesis of a wet or dry crust and mantle and thus investigate the possibility of the presence of volatiles in the Venusian subsurface.

WP 4) Geodynamical and Thermal Modeling: the goal of this work package is to produce numerical models of the evolution of Venus's subsurface. We will apply geodynamical thermal evolution models of the interior of Venus to select models that are able to produce the amount and distribution of magmatism consistent with the subsurface structure from previous work packages. This will allow to explore the tectonic regime that sustained the formation of coronae. The location and distribution of subsurface layers as determined in WP3, will provide important constraints on the magmatic history and present-day magmatic processes on Venus. These are closely linked to the thermal state of the shallow subsurface and deep interior, as well as to the production of partial melt and the presence of volatiles. In particular, water is directly linked to the magmatic evolution and can affect the rheology of the mantle, lithosphere, and crust, and, in turn, the formation of geological surface features.

References: [1] Smrekar et al.'18. doi.org/10.1007/s11214-018-0518-1 [2] Rolf et al.'22. doi.org/10.1007/s11214-022-00937-9; [3] Ghail et al.'21. EnVision: Understanding why Earth's closest neighbour is so different. ESA Rep; [4] Basilevsky & Head '03. doi.org/10.1063/1.3047684; [5] Janes et al.'92. doi:10.1029/92JE01689; [6] Gülcher et al.'20. doi.org/10.1038/s41561-020-0606-1.

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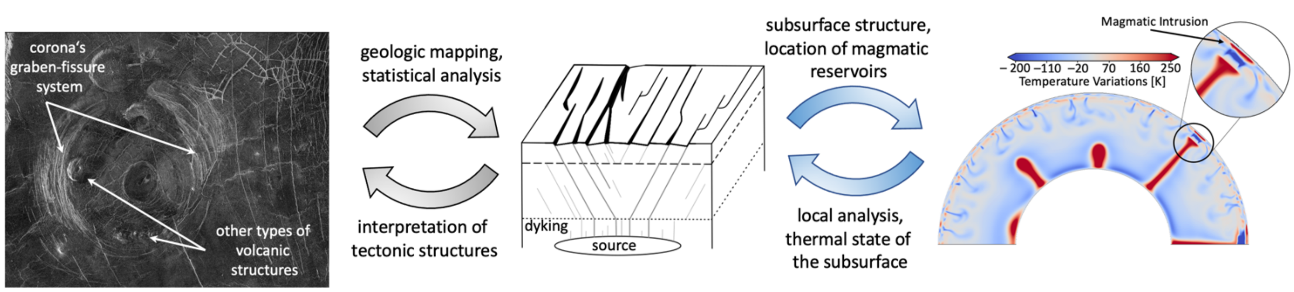

Figure 1: Investigations proposed by the HECATE project. The multidisciplinary approach adopted here includes geological observations and mapping, statistical analytical procedures, and geodynamical modeling.