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Analysis of lava flow features on Venus for radar sounder simulations

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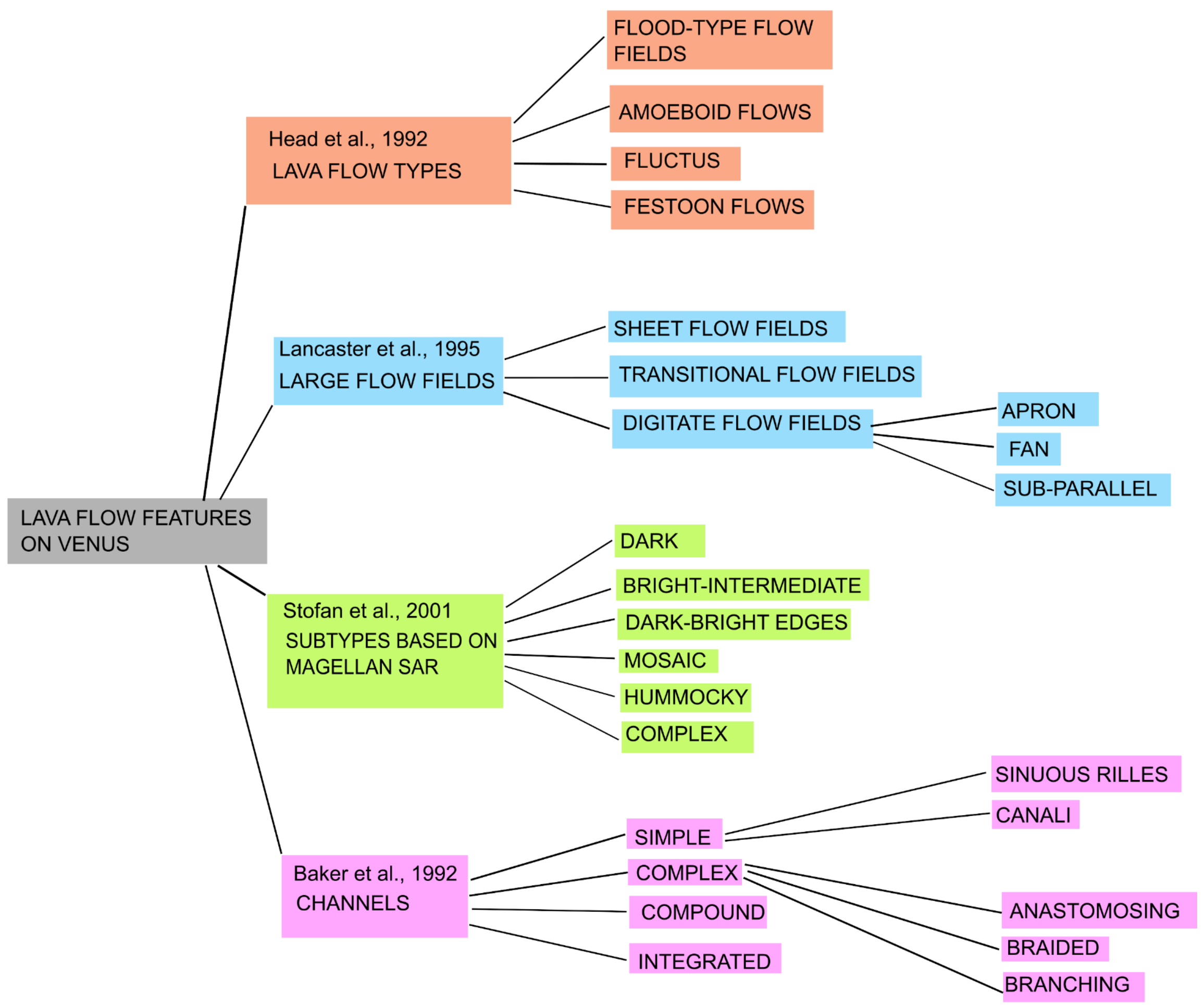
INTRODUCTION

Previous missions to Venus depicted an environment dominated by volcanic landforms and hostile atmospheric conditions, with a surface temperature around 475°C and a surface pressure of 93 bar. The surface was almost globally imaged by the Magellan mission, and compositional information were extracted firstly from the Venera and VEGA missions and later from the VIRTIS instrument on board of Venus Express mission. However, these data are imprecise, with low resolution and uncertain geologic correlation. To improve our knowledge, new missions towards Venus are planned for the future: NASA's DaVinci+ and Veritas, and ESA's EnVision. EnVision main objective is to study the surface and subsurface of Venus and its relationship with the atmosphere, and it is going to achieve this thanks to various instruments, among which a subsurface radar sounder (SRS). SRS is going to operate at a central frequency of 9 MHz with a bandwidth of 5 MHz, allowing a penetration of few hundred meters through the subsurface, with a vertical resolution of about 20 m [1]. One of SRS targets are lava flow features, fundamental in understanding the eruptive processes that shaped and are probably still shaping the surface of Venus. This work is focused on the analysis of existing literature related to lava flow features on Venus, in order to extract morphometric and compositional information to improve the SRS performance prediction through simulations based on geological analogues. This approach has already been tested for the analysis of lava flows on Mars, and it exploits existing radargrams in geologically analogous terrains to produce realistic simulations of the investigated target, using parameters related to the composition and morphometry of the target [2].

Lava flow morphology and morphometry

Several classifications have been employed to describe lava flow features on Venus, based on morphology and radar backscatter. The classes (Figure 1,2) reflect different emplacement styles, source characteristics, influence of the topography and local emplacement processes. These morphologies are then compared to terrestrial common effusive features: pahoehoe, a'a, and blocky. Panoramas of the Venera landing sites are also used for interpretation, and they reveal decimetric layering similar to sheet pahoehoe. Pahoehoe interpretation generally prevails based on Magellan radar backscatter of Venus flows and comparison with terrestrial lava flows, with values of rms slopes at Magellan SAR resolution of 75 m ranging from 2.5° to 8° [3]. Estimates of individual flow thicknesses on Venus from Magellan altimetric data and stratigraphic relationships with other features yielded a lower limit of 10-30 m, while a maximum thickness estimate is of the order of 400 m even though it may be an underestimation if subsidence occurred [4]. The extension of flows ranges from tens up to thousands kilometres. Considering these parameters, SRS is expected be able to detect changes between individual lobes or sequences of flows.



- LAVA FLOW FEATURES ON VENUS
  - Head et al., 1992 LAVA FLOW TYPES
    - FLOOD-TYPE FLOW FIELDS
    - AMOEBOID FLOWS
    - FLUCTUS
    - FESTOON FLOWS
  - Lancaster et al., 1995 LARGE FLOW FIELDS
    - SHEET FLOW FIELDS
    - TRANSITIONAL FLOW FIELDS
    - DIGITATE FLOW FIELDS
      - APRON
      - FAN
      - SUB-PARALLEL
  - Stofan et al., 2001 SUBTYPES BASED ON MAGELLAN SAR
    - DARK
    - BRIGHT-INTERMEDIATE
    - DARK-BRIGHT EDGES
    - MOSAIC
    - HUMMOCKY
    - COMPLEX
  - Baker et al., 1992 CHANNELS
    - SIMPLE
      - SINUOUS RILLES
      - CANALI
    - COMPLEX
      - ANASTOMOSING
      - BRAIDED
      - BRANCHING
    - COMPOUND
    - INTEGRATED

Figure 1: Classifications of lava flow features (elaboration from [5], [6], [7], [8]).

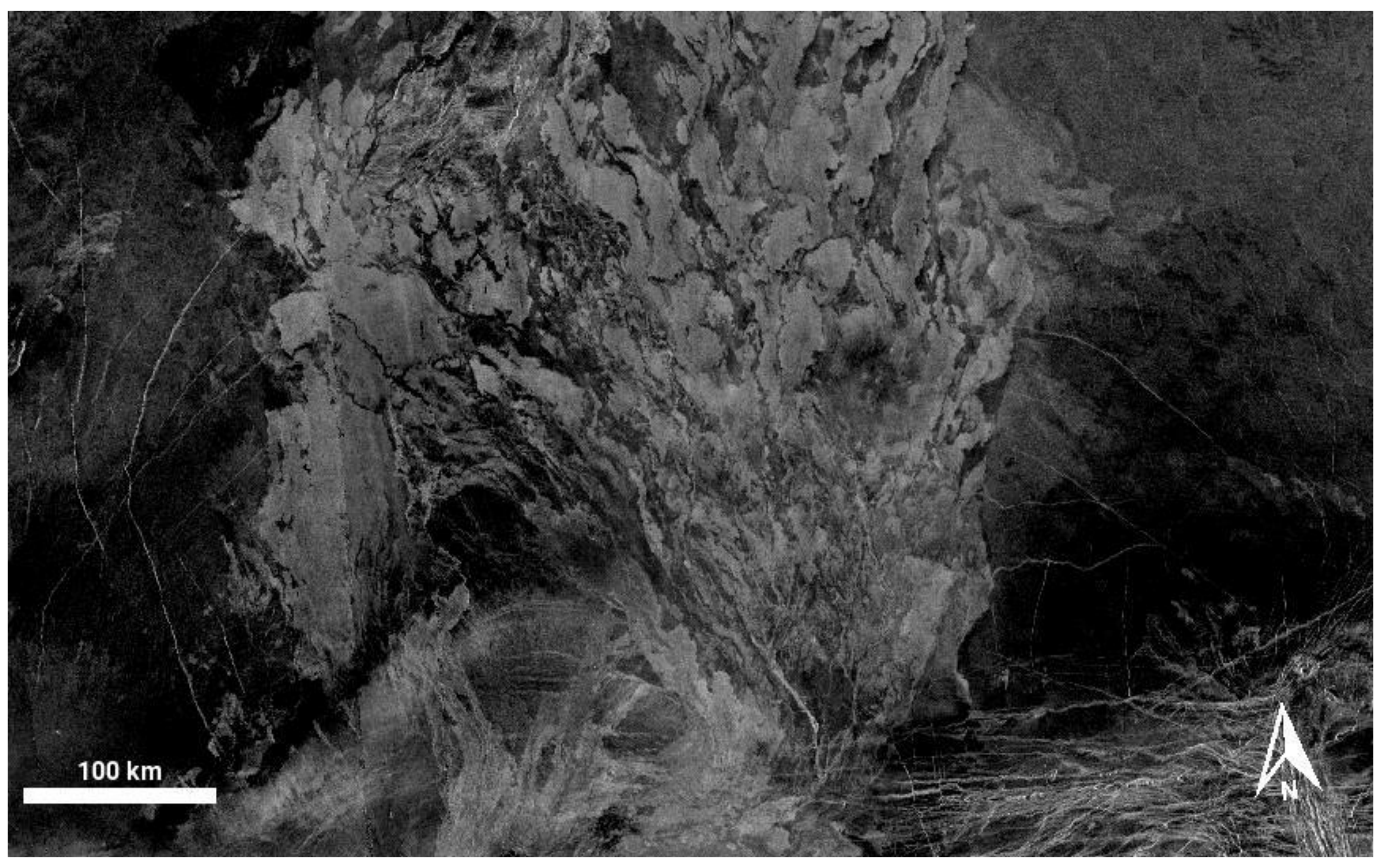


Figure 2: Example of digitate subparallel flow field, Mylitta Fluctus.

Lava flow composition

The composition of lava flows has been inferred by previous missions and morphological observations suggest a predominantly mafic composition, mostly tholeiitic and alkali basalts (Table 1)[9]. The pahoehoe-like behaviour supports a basaltic composition as on Earth, but unlike terrestrial basalts the high pressure on Venus surface probably prevents high porosity. Predicted values of porosity for Venusian basaltic magmas vary from 0.05 to 0.75 (bubble volume fraction), considering different concentrations of CO2 and H2O, while on Earth they may reach 0.9 [10]. More exotic compositions for the longest flows are considered, such as carbonatite or sulphur and more evolved compositions are possible. Emissivity measurements of Venus flows range from 0.7 to 0.9, with corresponding dielectric constants ranging from 3.5 to 7, consistent with basaltic samples [3]. High emissivity may also be indicative of fresh or currently active lava flows.

Landing site (Lat°, Long°)	Geochemistry	Inferred porosity
Venera 8 (-10.70, 335.24)	Very high K, Th, U	-
Venera 9 (31.01, 291.64)	Low K, U; high Th	-
Venera 10 (15.42, 291.51)	Low K, U, Th	1–7%
Venera 13 (-7.55, 303.69)	High K basalt	50–53 %
Venera 14 (13.05, 310.19)	Tholeiitic basalt	60–62 % (top layer)/ 50–53 % (below)
VEGA 1 (8.10, 175.85)	Low K, U, Th	-
VEGA 2 (-7.14, 177.67)	Tholeiitic basalt; low K, U, Th	13%

Table 1: Characteristics of Venera and VEGA missions landing sites from [9].

Lava flow distribution and geodynamic context

Lava flows have been observed in association with volcanic edifices, rift zones and coronae. Volcanic edifices and volcanic fields have been identified all around Venus, excluding tesserae terrain. The distribution of lava flow fields does not seem to be random: there is a distinctive concentration in the eastern Lavinia Planitia-Alpha Regio area, within Aphrodite Terra and Atla Regio, in Beta-Phoebe regiones, and in Sedna Planitia south of Lakshmi Planum (Figure 3) [6]. The geodynamic context can be inferred by comparing the probable composition of lava flows to that of their terrestrial analogues. Tholeiitic basalts would be consistent with melting of peridotite in the shallow mantle, with an analogue comparable Earth environment identified in NMORB, islands arcs and hot spots. Alkaline basalts, would be consistent with melting at much greater depth [11]. Flows emanating from coronae may have formed due to mantle upwelling and hot spots [12]. Carbonatite volcanism suggested for channels, which are usually associated with coronae, occurs on Earth in intraplate regions, on hotspots, near plate margins associated with orogenic activity or plate separation, and is mantle-derived [8].

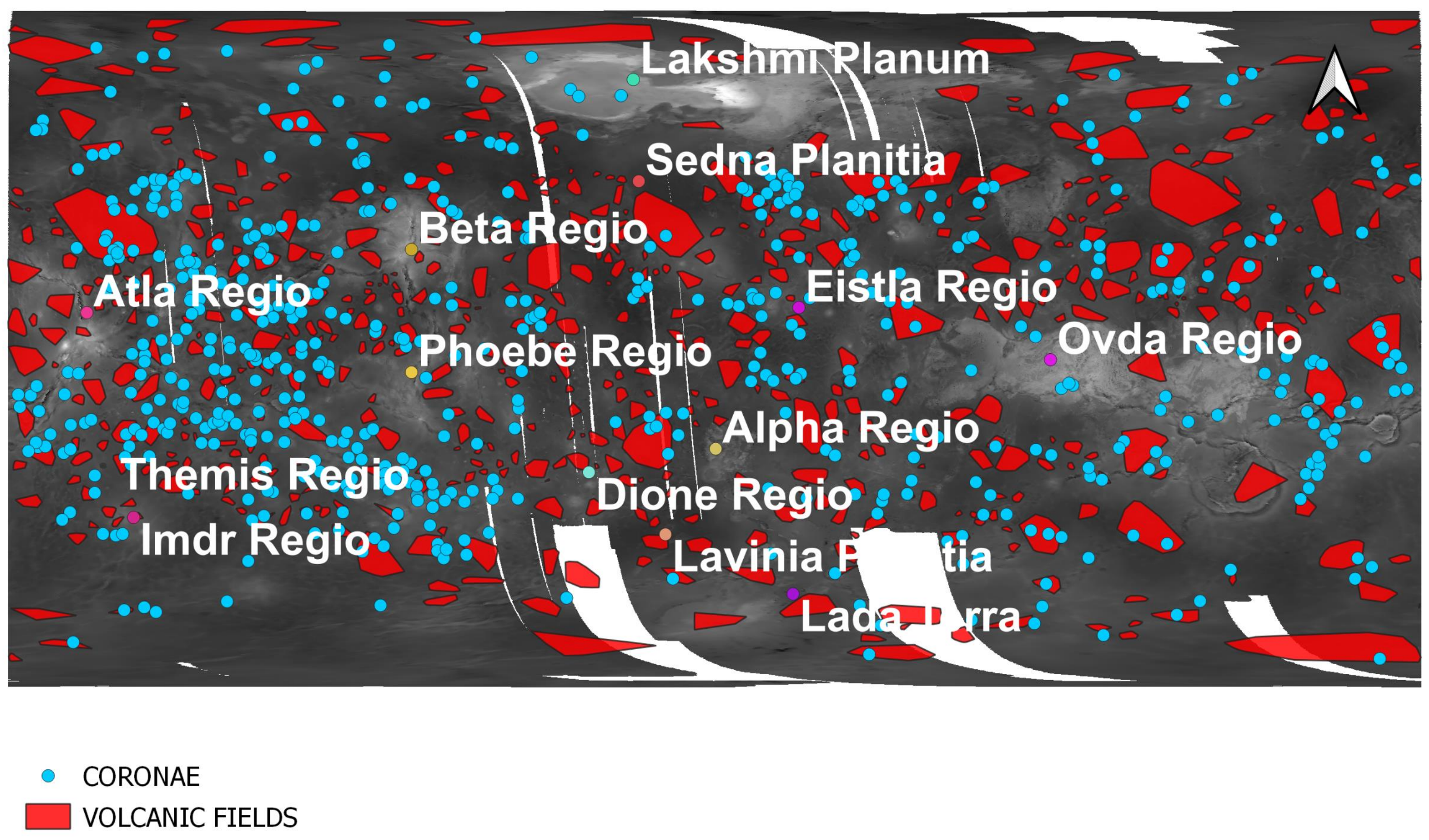


Figure 3: Map of Venus with major volcanic environments (elaboration from [13], [14]).

CONCLUSIONS

The analysis of the existing literature on lava flows on Venus is useful for both fine tuning the expected performance of SRS on this kind of features and defining detailed scenarios to be accurately simulated. The ability of the instrument to penetrate up to several hundred meters allows the discrimination between individual lobes or sequences of lava flows based on composition, porosity, surface roughness and thus it could provide a new stratigraphic perspective of Venus history.

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