**Venus Exploration Targets:
Update of 2014 Venus Exploration Targets Workshop Tables to 2019 Venus GOI, and
findings from the 2019 Venera-D Landing Site Workshop**

A White Paper for the Planetary Science and Astrobiology Decadal Survey 2023-2032

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Context and Relevance: Determining how and where to explore Venus has been the subject of numerous studies and technical reports in the last decade. This white paper provides updates to two critical and topical Venus exploration documents: The Final Report of the Venus Exploration Targets Workshop (VETW), and the Phase II report of the Joint Science Definition Team for the Roscosmos Venera-D mission. These updates refresh the two documents' currency and relevancy ahead of the 2023–3032 Decadal Survey.

Part 1: Venus Exploration Targets Workshop Report Update

In the spring of 2014 the Venus community participated in an exercise to identify in-situ targets for Venus exploration; the “living document” of the final report is located at the VEXAG website (VETW, 2014).

The Workshop's conveners and group leads compiled, from the input of 54 scientists, a set of exploration targets justified by science objectives and linked to the then-current Venus Goals, Objectives, and Investigations (GOI) document (2014 edition). The GOI was revised in 2016, before being comprehensively rewritten in 2019, requiring re-matching of the Workshop's science justifications to the revised categories. There has not yet been a second exploration targets workshop, so this document updates the tables produced by the 2014 effort to keep that document current into the next decadal period.

From the Report (VETWR, 2014), the tables and references that required updating are as follows:

Table 2: “Geochemistry measurement requirements for surface targets linked to investigations listed in the VEXAG GOI document,” and

Table 6: “Qualitative Findings of the Atmospheric Platform Subpanel.”

Further, the Venus Exploration Targets Workshop Traceability Matrix also needed to be mapped to the new GOI.

The 2019 GOI Appendix B contains a concordance table that matches the 2019 GOI with the 2016 revision of the 2014 GOI. Although the 2016 revision refined and updated some of the detailed explanations in the 2014 GOI, the goals, objectives, and investigations themselves were not changed, and thus the 2014 and 2016 versions were functionally identical. Table 1 of this white paper summarizes the concordance between GOI versions. The 2019 version of the GOI document treats prioritization differently than previous iterations; see the 2019 GOI for details. Because different investigations have been split and concatenated between GOI editions, the table has two parts, A and B. Part A describes how the 2019 GOI Investigations relate to the previous editions, whereas Part B provides a description in the other direction. Note that Table 1B covers the detailed science traceability matrix in the Appendix of the VETWR to the current GOI.

Table 2 of this white paper is a revision of Table 2 in the VETWR (2014) document. The GOI indices in the table are listed in “CURRENT (former)” format, where “CURRENT” is the GOI 2019 version index and “former” is the 2016/2014 GOI version index.

Table 3 of this white paper is a revision of Table 6 in the VETWR (2014) document. The GOI indices in the table are listed in “CURRENT (former)” format, where “CURRENT” is the GOI 2019 version index and “former” is the 2016/2014 GOI version index.

Table 1. Concordance of Investigations between the 2019 version and the 2014 and 2016 iterations of the VEXAG GOI document.

A) Concordance of Investigations between 2019 and 2014-2016 editions.

2019 GOI	2016 & 2014 GOI
I.A.HO. Hydrous Origins	III.A.2. III.A.3.
I.A.RE. Recycling	II.A.3.
I.A.AL. Atmospheric Losses	I.A.2.
I.A.MA. Magnetism	II.A.3.
I.B.IS. Isotopes	I.A.1. I.A.2. II.A.2. III.A.1. III.B.1. III.B.4.
I.B.LI. Lithosphere	II.A.3.
I.B.HF. Heat Flow	II.A.3
I.B.CO. Core	II.B.4.
II.A.DD. Deep Dynamics	I.B.1. I.B.3. I.C.1.
II.A.UD. Upper Dynamics	I.B.1. I.B.3.
II.A.MP. Mesoscale Processes	I.B.1. I.B.3. I.C.1.
II.B.RB. Radiative Balance	I.B.2.
II.B.IN. Interactions	I.C.1.
II.B.AE. Aerosols	I.C.1. I.C.2. I.C.3.
II.B.UA. Unknown Absorber	I.C.2. I.C.4.
II.B.OG. Outgassing	III.B.4.
III.A.GH. Geologic History	II.A.1. II.B.6.
III.A.GC. Geochemistry	II.B.1. II.B.2. II.B.5.
III.A.GA. Geologic Activity	II.A.4.
III.A.CR. Crust	II.B.3. II.B.6.
III.B.LW. Local Weathering	III.B.2.
III.B.GW. Global Weathering	III.B.2.
III.B.CI. Chemical Interactions	III.B.3.

B) Reverse concordance of Investigations between 2014-2016 and 2019 editions.

2016 & 2014 GOI	2019 GOI
1.A.1.	I.I.B.IS. Isotopes
1.A.2.	I.A.AL. Atmospheric Losses I.B.IS. Isotopes
I.B.1.	II.A.DD. Deep Dynamics II.A.UD. Upper Dynamics II.A.MP. Mesoscale Processes
I.B.2.	II.B.RB. Radiative Balance
I.B.3.	III.A.CR. Crust
I.C.1.	II.A.DD. Deep Dynamics II.A.MP. Mesoscale Processes II.B.IN. Interactions II.B.UA. Unknown Absorber
I.C.2.	II.B.AE. Aerosols II.B.UA. Unknown Absorber
I.C.3.	II.B.AE. Aerosols
I.C.4.	II.B.UA. Unknown Absorber
II.A.1.	III.A.GH. Geologic History
II.A.2.	I.B.IS. Isotopes
II.A.3.	I.A.RE. Recycling I.A.MA. Magnetism I.B.LI. Lithosphere I.B.HF. Heat Flow
II.A.4.	III.A.GA. Geologic Activity
II.A.5.	III.A.AA. Absolute Ages*
II.B.1.	III.A.GC. Geochemistry
II.B.2.	III.A.GC. Geochemistry
II.B.3.	III.A.CR. Crust
II.B.4.	I.B.CO. Core
II.B.5.	III.A.GC. Geochemistry
II.B.6.	III.A.GH. Geologic History III.A.CR. Crust
III.A.1.	I.B.IS. Isotopes
III.A.2.	I.A.HO. Hydrous Origins
III.A.3.	I.A.HO. Hydrous Origins
III.B.1.	I.B.IS. Isotopes
III.B.2.	III.B.LW. Local Weathering III.B.GW. Global Weathering
III.B.3.	III.B.CI. Chemical Interactions
III.B.4.	I.B.IS. Isotopes II.B.OG. Outgassing

* Future investigations (see 2019 GOI Appendix)

Table 2. Geochemistry measurement requirements for surface targets linked to investigations listed in the VEXAG GOI document. (VETWR Table 2)

Needs	GOI indices from VEXAG document
Major Elements	I.A.HO., III.A.GC., III.B.LW., III.B.GW. (III.A.3., II.B.1., III.B.2.)
Sulfur	I.A.HO., I.B.IS., III.A.GA., III.A.GC., III.B.LW., III.B.GW. (III.A.3., III.B.4., II.B.1., III.B.2.) +
Chlorine	I.A.HO., III.A.GC., III.B.LW., III.B.GW. (III.A.3., II.B.1., III.B.2.)
Heat Producing Elements	III.A.GC., III.B.LW., III.B.GW. (II.B.5., III.B.2.)
Mineralogy	I.A.HO., III.A.GC., III.B.LW., III.B.GW. (III.A.3., II.B.1., III.B.2.)
Wants	
Trace Elements	III.A.GC., III.B.LW., III.B.GW. (II.B.1., III.B.2.)
Fluorine	I.A.HO., III.A.GC., III.B.LW., III.B.GW. (III.A.3., II.B.1., III.B.2.)
Fe-Oxidation State	I.A.HO., III.A.GC., III.B.LW., III.B.GW. (III.A.3., II.B.1., III.B.2.)
Carbon	I.A.HO., III.A.GC., III.B.LW., III.B.GW. (III.A.3., II.B.1., III.B.2.)

Table 3. Qualitative Findings of the Atmospheric Platform Subpanel (VETWR Table 6)

GOI	Preferred Platform and/or Measurement Technique	Requirements
I.B.IS. (I.A.1.)	Long-term for improved accuracies	Measure most gaseous abundances and ratios to at least 5% levels.
I.A.AL. (I.A.2.) I.B.IS.	Spatially separated measurements (mobile platform or multiple probes)	
II.A.DD. (I.B.1.) II.A.UD. II.A.MP.	Long-lived aerial platform or multiple probes	Global momentum and energy transport. Horizontal resolution preferred to vertical
II.B.RB. (I.B.2.)	Multiple probes or constant altitude mobile platform for spatial coverage	Order of resolution preferences: Spectral, Vertical, Horizontal
II.A.DD. (I.B.3.) II.A.UD. II.A.MP.	Sustained aerial platform	Vertical resolution preferred to horizontal. Measure accelerations (precision not noted)
II.A.DD. (I.C.1.) II.A.MP. II.A.IN. II.B.AE.	Mobile platform and aerosol characterization	Vertical resolution to 0.5 km. Spatial resolution to 10 ⁴ km for diurnal variability. 10-100km resolution for small scale dynamics
II.B.AE. (I.C.2.) II.B.UA.		
II.B.AE. (I.C.3.)	Long term observation for statistical significance	Subpanel did not quantify E-field measurement precision
II.B.UA. (I.C.4.)	See I.B.IS., I.A.AL., II.A.DD., II.A.MP., II.A.IN., II.B.AE., and II.B.UA. (I.A. and I.C.1,2)	
II. III.	(II.)	Many requirements for this Goal made from an atmospheric platform mirror those from orbit and the surface, or are impossible from a platform not bound to the surface. It was noted that observations from a lofted platform can allow observation of multiple physiographic terrain types.
II. III.	(III.)	Most requirements here mirror either those described from Goal I or those associated with observations of the surface from the surface or atmosphere.

Part 2: Findings of Venera-D Landing Site Workshop

The Venera-D Landing Site Workshop took place October 2–3, 2019 at the Space Research Institute (IKI) in Moscow, Russia, and was attended by an international group of Venus scientists. The purpose of the workshop was to gather community input on the criteria for scientifically desirable landing sites at Venus for the Venera-D lander as it is currently configured (Venera-D JSDT, 2019), and the best measurements and approaches that can advance our understanding of Venus' habitability present and past.

The Venera-D mission concept has been in development since 2014, with the goal of advancing the investigation of Venus' atmosphere, surface, and interior, and the processes that link them as a system. The baseline Venera-D mission includes an orbiter, a VEGA-like lander, and one long-duration surface station; the Long-Lived In-situ Solar System Explorer (LLISSE). Potential mission augmentations may include more LLISSEs, two small seismic stations, a variable-altitude aerial platform, or perhaps one or two sub-orbiters. The primary product of the Joint Science Definition Team (JSDT) is its Phase II report (Venera-D JSDT, 2019), and the landing site discussions at the workshop began with the recommendations of that report in mind.

The Venera-D workshop featured a productive set of discussions regarding landing site selection over two days. Presentations on outstanding science questions, and the terrain types and locations where those questions could be addressed by the main Venera-D lander, led to the formulation of a Venus Terrain Subgroup, designed to further investigate prospective lander destinations. Although there was consensus that tesserae are a high-priority target, current technology preclude a safe and controlled landing on the rough tesserae. Thus, the primary landing site terrain targets were identified to be: 1) stratigraphically young plains (ideally, the youngest); 2) stratigraphically old plains (ideally, the oldest); 3) lobate plains; and 4) canali-fed plains. These terrain types represent the majority of the Venus surface; as volcanic units, they each provide valuable insights into the timing and mechanisms of volcanism on Venus, as well as on the composition and interior processes of the mantle and crust.

The Venus Terrain Subgroup was given a charter comprising: 1) Establish the science driver(s) for each of four principal terrain types; 2) Produce as a main deliverable a map (in a geographical information system-compatible format) of each terrain type, assuming the baseline Venera-D mission architecture and instruments; and 3) Assess whether possible mission augmentation options (as described in Venera-D JSDT, 2019) require changes to the mapped regions from 2).

As part of its charter, this Subgroup will also consider a fifth terrain type, the planet's tessera terrain, as a prospective landing site. Importantly, presentations during the Venera-D workshop and the findings of the Venera-D JSDT report show that the main lander will not be capable of safely touching down in the tessera, given uncertainties in the morphology and lander-scale roughness of this unit. But augmentations of the Venera-D baseline mission, e.g., the long-lived surface elements, may not face those same landing site constraints and could possibly be capable of setting down successfully within a tessera exposure. There was near-unanimous agreement at the workshop that the tesserae represent a scientifically compelling destination, and that it is worth considering how the Venera-D mission could allow for the exploration of this enigmatic terrain.

Finally, a sixth exercise will be carried out, after the five terrain types (i.e., four primary and the tesserae) are characterized, to assess the engineering risks to the main lander and augmentations posed by those landing site types. This work, which will consider the mapped extents of each terrain type against a set of engineering constraints (e.g., slope, roughness, latitude, etc.), will help establish a ranking scheme for the terrains to aid future discussion of the Venera-D landing site(s).

References

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