CHEMIN-V: A DEFINITIVE MINERALOGY INSTRUMENT FOR LANDED VENUS SCIENCE. D.F. Blake¹, A. Treiman², P. Sarrazin³, T. S. Bristow¹, R. Downs¹, A. Yen² and K. Zacyny⁶, ¹Exobiology Branch, MS 239-4, NASA Ames Research Center, Moffett Field, CA 94035 (david.blake@nasa.gov), ²Lunar and Planetary Institute, Houston, TX, ³SETI Institute, Mountain View, CA, ⁴Univ. of Arizona, Tucson, AZ, ⁵Jet Propulsion Laboratory, Pasadena, CA, ⁶Honeybee Robotics, Pasadena, CA.

The Case for Scientific Exploration of the Venus Surface: Venus and Earth were presumably formed from the same protoplanetary material, at a similar radial distance from the center of the solar nebula and they likely had similar early histories. Venus should be Earth’s twin, but conditions on Venus and are radically divergent from those of Earth. What events transpired to yield present-day Venus? Did conditions ever exist on Venus that could have fostered life? How and why did the evolutionary paths of Venus and Earth diverge? These are questions posed by a recent report on Venus exploration [1].

Science Objectives of the Venus Lander: In-situ mineralogically-related goals, objectives and investigations are delineated in a recent VEXAG document [1] and abbreviated here:


Mineralogical Analysis using X-ray Diffraction: The history of a planet is written in its rocks and the minerals they contain. Because minerals are stable under known ranges of temperature, pressure and composition, a rock comprised of specific minerals can be used to identify the conditions under which it formed as well as subsequent environmental changes on the basis of the individual stabilities of the minerals and the presence or absence of equilibrium between them. However, such determinations are seldom possible if only qualitative data are available, or if only a portion of the mineralogy is known.

X-ray Diffraction (XRD) – The Gold Standard for Mineralogical Analysis: XRD is the preferred method for mineralogical analysis of unknowns in terrestrial laboratories. Quantitative mineralogical results are obtained from XRD data by Rietveld refinement and other full-pattern fitting techniques [2-3]. Both crystalline and amorphous materials can be analyzed in this way. Quantitative elemental compositions for crystalline phases are calculated from refined lattice parameters [5]. X-ray Fluorescence (XRF) data are constrained to elements 11 < Z due to the internal atmosphere of the lander (N₂?) but can be useful for quantifying major cations and identifying trace elements. Taken together, XRD and XRF provide a comprehensive analysis of regolith mineralogy that can only be improved upon by sample return.

The CheMin instrument on Mars Science Laboratory. XRD was deployed in robotic planetary exploration for the first time on the MSL Curiosity rover. During its 7+ year employment on Mars, CheMin established the quantitative mineralogy of the Mars soil [6], characterized the first habitable environment on another planet [7], and provided the first in-situ evidence of Martian silicic volcanism [8]. CheMin is now employed in characterizing the depositional and diageneric environments of basaltic lacustrine mudstones – elucidating for the first time, the early aqueous and oxidative history of Mars. Raw XRD patterns, the CheMin team’s preferred analytical results and all publications related to the analyses can be viewed and downloaded from the CheMin website [9].

The Honeybee Robotics Venus Drill: A drill intended for use on a Venus lander has been developed and tested at JPL’s Venus chamber. The drill is at TRL6. It has successfully drilled in 120 MPa Saddleback basalt under Venus conditions [10]. Fig. 1 shows the HBR drill acquiring a sample from Saddleback Basalt under Venus surface conditions.

Fig. 1: The HBR Venus drill successfully drilled in JPL’s Venus chamber. 90% of the retrieved powder is < 150 μm grain size, suitable for analysis in CheMin-V.
Quantitative Mineral Analysis with Terra: Terra, a commercial spinoff of the CheMin instrument, has the same diffraction geometry as CheMin-V. A ~100 mg sample of powdered Saddleback Basalt drilled and collected under Venus surface conditions was analyzed in Terra for 15 minutes, then reanalyzed for 8 hours in a Rigaku laboratory X-ray Diffractometer. Table 1 shows the resulting Rietveld refinement and quantitative analysis from Terra, compared to that of the Rigaku instrument. Compositions (formulæ) for minerals having variable chemistry are derived from the refined lattice parameters for andesine, augite, pigeonite and forsterite from the Terra instrument.

With the exception of andesine, results are within error of each other. The benefit of increased integration time is an improved detection and measurement of minor and trace phases; however all major phases are identified, quantified, and their major element chemistry determined in 15 minutes.

The CheMin-V instrument for the Venus lander. Fig. 2 shows a 3D model of the CheMin-V XRD/XRF geometry. A single X-ray source emits a cone of CoKα radiation intercepted by two pinhole collimators. The two collimators produce ~70 µm diameter parallel beams of X-rays directed at the centers of two sample cells. The direct beams from the source/collimators strike opposite ends of a 256X1024 pixel CCD, and the diffracted beams from each sample are detected by the CCD along its long dimension. The CCD is split into two halves, yielding two separate 128X1024 pixel detectors, each recording an XRD pattern. Silicon Drift Diode detectors (SDD) are placed on the X-ray entrance side of each sample cell, recording an XRF spectrum of each sample.

Powdered samples delivered to the sample cells are vibrated, producing a random motion of the grains in the X-ray beam (as in the CheMin and Terra instruments). CheMin-V can return quantitative mineralogical results from two different samples in 15 minutes, leaving margin for sample delivery and data transmission. If desired, two additional samples can be analyzed with a second sample cell pair, rotated into position by a single actuator (not shown).

Fig. 2: Geometry of the CheMin-V diffraction experiment. Two samples are analyzed at the same time with a single CCD detector. SDD detectors record the XRF spectrum from each sample.

Estimated dimensions of CheMin-V are 27X18X15 cm with a mass of 4 kg (Fig. 3).

Fig. 3: Notional model of the CheMin-V flight instrument.