

**IN SITU MEASUREMENTS ON VENUS PLAINS, DOMES, CANALI, AND TESSERA: CHOICES AND CONSTRAINTS FOR MINERALOGICAL AND GEOCHEMICAL MEASUREMENTS.** M. D. Dyar<sup>1</sup>, A. H. Treiman<sup>2</sup>, S. M. Clegg<sup>3</sup>, R. C. Wiens<sup>3</sup>, J. Filiberto<sup>4</sup>, S. K. Sharma<sup>5</sup>, and A. K. Misra<sup>5</sup>. <sup>1</sup>Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075, mdyar@mtholyoke.edu. <sup>2</sup>Lunar and Planetary Institute, 3600 Bay Area Boulevard Houston, TX 77058. <sup>3</sup>Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87545. <sup>4</sup>Geology Department, Southern Illinois University, Carbondale, IL 62901. <sup>5</sup>Hawai'i Institute for Geophysics and Planetology, Univ. of Hawai'i, Honolulu, HI, 96822.

**Table 1. Phases and Rock Types Surmised for the Venus Surface**

Venus Locale	Rock type	Phases	Citations
volcanic plains	basalt	Glass, plagioclase, pyroxenes (low- and high-Ca), olivine, Fe±Ti oxides	[1]
weathered plains	basalt with weathering rinds	Plagioclase, pyroxenes, anhydrite, wollastonite, andalusite, scapolite, sodalite, talc, amphibole hematite, magnetite, pyrite, perovskite, cordierite	[2]
canali	unknown	Pyroxene, glass, sulfates, carbonates	[3]
domes	high-Si lavas (andesitic?) from fractional crystallization	Quartz, plagioclase, alkali feldspar,	[4]
tessera	granite, rhyolite, phonolite, or non-igneous rocks	Quartz, plagioclase, alkali feldspar, amphibole?	[5]
mountaintops	unknown	Pyrite, sulfosalts, ferro-electric phases	[6]

#### Session: On the Surface

#### Targets: all

#### Science Goal(s): I.C.1, II.B.1, III.A.3, III.B.2

**Introduction:** These four VEXAG goals all relate to the geochemistry and mineralogy of Venus' surface. Minerals are the "alphabet" of geology, and their presence and chemical compositions inform our understandings of the past, present and future of Venus' surface. Here, we present an overview of putative rock types and mineralogy across Venus, and discusses possible modalities for their *in situ* analyses, and associated precisions and accuracies required for useful geochemical information.

Table 1 presents an overview of surmised rock types and mineralogy of Venus based on a combination of Venera data, experiments on alteration of basaltic material, and informed conjecture. Ideal instrumentation for the Venus surface would have the ability to discriminate among and identify these minerals as well as provide geochemical analyses of surface and subsurface (at least beneath weathering rinds) samples.

#### Instrumentation Possibilities for Geochemistry:

The alpha-particle x-ray spectrometer (APXS) has strong flight heritage from its use on all recent and current Mars rovers [7]. It can provide accurate chemical analyses of materials at bulk scales (~1.5 cm diameter area) under ideal conditions (e.g., 12-hour integration times very close to the target). Shorter (e.g., <1 hour) integration times needed on Venus would produce data with lower accuracy and limit analyses to only a few locations in the lifetime of a lander. APXS cannot analyze H but it produces excellent analyses of major elements as well as Cl, S, Br, Zn, and Ge. The

main limitation of APXS is sample delivery. Use of an arm to extend the APXS to the surface introduces unwanted complexity. Different terrains may not have appropriately smooth surfaces for contact science, and APXS only samples the surface of a rock. Alternatively, APXS could be used inside a lander, but that would require a sample delivery system.

The CheMin X-ray fluorescence (XRF) with an active X-ray source has heritage from Venera/VEGA, Viking, and had been baselined for CheMin on MSL [8]. XRF is the standard for chemical analyses of terrestrial samples, but requires significant sample handling, and possibly cryogenic cooling of detectors. Moreover, particulate samples suitable for vacuum transfer into the lander body would need to be easily accessible from the landing position without an arm; deployment of a drill would likely be too complex. Finally, only a few analyses would likely be accomplished in the short lifetime of such a mission.

Gamma-ray spectrometry, also used on the Venera missions, would require cryogenic cooling and an enhanced detector of large volume [9].

Pulsed neutron sources [10] could provide trace element analyses and data on some major elements, but is untested in remote applications.

Finally, laser-induced breakdown spectroscopy [LIBS], as implemented on the ChemCam instrument [11] on MSL, could sample thousands of locations on rocks and soil, as each analysis takes only a few  $\mu$ s. LIBS can ablate to depths of 10-15  $\mu$ m into rock or regolith, providing compositional profiles through coatings or weathering rinds. Experiments under Venus-analog conditions demonstrated that all major el-

ement lines can be readily resolved with LIBS, and could be improved through use of intensified charge-coupled device detectors to optimize gate time and reduce noise [12]. LIBS is highly dependent on calibration weakness and would require a spectral library acquired under difficult experimental conditions. Moreover, both S and Cl are very difficult to analyze, though these two elements will be very important for understanding rock alteration on Venus.

**Instrumentation Possibilities for Mineralogy:** X-ray diffraction (XRD) is the standard method for determining mineralogy; crystalline phases are determined unambiguously, and phase abundances can be determined at ~3% detection limit and  $\pm 15\%$  accuracies for minerals >12% concentration [12]. In the current implementation, XRD requires delivery of powdered sample and long run durations (~10 hours) [8], which would be difficult to achieve on Venus.

Raman spectroscopy is a useful tool for mineral identification, because Raman scattering is diagnostic for molecular groups (e.g.,  $\text{CO}_3^{2-}$ ) and nearly so for specific minerals containing them. Raman can probe to depths of ~3 cm. Raman vibrational modes are insensitive to pressure and shift only slightly with high temperatures [13], so spectral libraries acquired under ambient conditions can be used for mineral identification. Techniques for deconvolving contributions from mixtures of minerals are rapidly being developed. Raman is limited by its inability to detect phases that are opaque to the laser light (e.g., many sulfides and Fe oxides). LIBS and Raman analyses can use the same laser system, which reduces cost and complexity.

Finally, some combination of VNIR, FTIR, or mid-IR spectroscopy [14] could also be effective in identifying mineralogy but new spectral libraries would be needed to produce quantitative results at high T and P.

**Instrument Requirements:** Elemental analyses must be able to distinguish among major rock types, and permit quantification of the degree of weathering. As presently conceived, this requirement is for minimum accuracies of  $\pm 5\%$  for  $\text{SiO}_2$ ,  $\pm 5\text{-}10\%$  for  $\text{TiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{FeO}$ , and  $\text{CaO}$ , and  $\pm 10\text{-}15\%$   $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{SO}_4$ , and  $\text{P}_2\text{O}_5$  would be required. Precision should be at least as good as accuracy. For proper petrology and classification, error bars of  $\pm 2\%$  for  $\text{SiO}_2$  and 5% on all other major elements would be ideal, albeit optimistic to expect from measurements acquired on the Venus surface.

More accurate analyses would be desirable for refining rock identifications and their petrogenetic settings (mid-ocean ridge basalts, island arcs, ocean islands, hot spots, continental volcanism, etc.). Verma [15] identified the element abundances most critical for discrimination among petrogenetic settings; the most

important elements would require accuracies  $2\times$  better than those cited above.

For mineralogy, detection limits for all minerals listed in Table 1 would be 1-3 volume %, with accuracies of 10-15 volume %. All these values are well within known benchmarks for many of the techniques discussed above.

Chemical analyses for other elements would add great value to the mission. For example, APXS data on Cl and/or LIBS/IR analyses of  $\text{H}_2\text{O}$  or hydrous species would help constrain atmospheric interactions and address the critical question of the presence/absence of water and/or hydrous phases in tessera.

Finally, it must be emphasized that, given the paucity of chemical or mineralogical data currently available, Venus remains largely “a geochemical terra incognita” [9]. Any new chemical or mineralogical data on Venus would provide critical constraints on all of the science questions addressed in the VEXAG document as noted above.

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