# CheMin-V: A Definitive Mineralogy Instrument for Landed Science on Venus

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## Abstract

An X-ray diffraction instrument is described that will provide quantitative mineralogical analyses of up to 4 individual samples of Venus regolith in ~1 hour.

## 1. Introduction

### 1.1 Science Objectives of a Venus Lander

Science objectives of a Venus Lander [1] include: 1). Determine the elemental composition of surface rocks, and 2). Identify mineral phases to address atmosphere and surface evolution along with surface mineralogy (searching for any possible bound water (e.g., phyllosilicates))." These objectives must be met within the 1-2 hour lifetime of the lander.

### 1.2 Mineralogical Analysis using X-ray Diffraction and X-ray Fluorescence

X-ray Diffraction (XRD) is the only *in-situ* technique able to definitively identify, quantify and determine the elemental composition of minerals present in planetary regolith. XRD can also determine the quantity of X-ray amorphous material present in a regolith sample, and when combined with X-ray Fluorescence (XRF), the elemental composition of the amorphous component(s). Taken together, these two techniques provide a comprehensive analysis of regolith mineralogy that can only be improved upon by sample return.

The CheMin XRD/XRF instrument was included in the payload of the Mars Science Laboratory mission and has during the past six years revolutionized our knowledge of the mineralogy of early Mars [e.g. 2-5]. Descriptions of CheMin's analyses and all publications related to the instrument can be viewed and downloaded from the CheMin website: https://odr.io/Chemin.

## 2. The Terra XRD/XRF Instrument

Prior to CheMin's deployment on Mars, a prototype portable instrument called "Terra" was developed. Terra shares its diffraction geometry with CheMin, but in many ways exceeds CheMin's performance. Terra delivers more X-ray flux to the sample yielding much improved diffraction intensity as well as slightly increased 2θ resolution. Terra became a commercial product in 2009 and currently more than 600 instruments are in daily use in the oil & gas, minerals and pharmaceutical industries.

A basalt cobble from Hawai'i having a Venus-like composition (Mid-Ocean Ridge Basalt, MORB) was analyzed in a Terra instrument for 15 minutes, then reanalyzed for 8 hours in a Rigaku laboratory X-ray Diffractometer. The XRD pattern from the Fifteen minute integration (100 frames collected for 10 seconds each) is shown in Fig. 1.

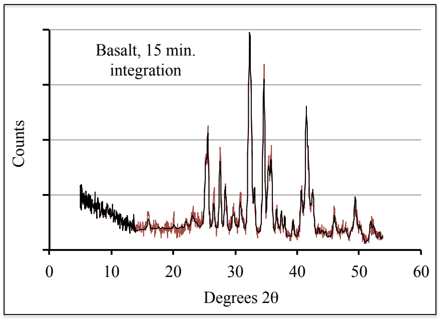

Figure 1: Fifteen minute analysis of a basalt cobble from Hawai'i using the Terra XRD/XRF instrument. Brown = raw pattern, Black = fitted model pattern from Rietveld refinement.

Table 1 shows the resulting Rietveld refinement and quantitative analysis from Terra, compared to that from a commercial Rigaku XRD. Mineral compositions are derived from the refined lattice parameters for andesine, augite, pigeonite and forsterite from the Terra instrument.

Table 1. Quantitative analysis of a basalt cobble using Rietveld refinement and Full Pattern fitting.

| | | Terra 15 minutes | Rigaku 8 hours |
|---|---|---|---|
| Phase | Formula | Wt % | Wt % |
| Andesine | $Ca_{0.24}Na_{0.26}(Al_{0.735}Si_{3.265})O_8$ | 34.9 | 27.9 |
| Augite | $Mg_{0.82}Fe_{0.52}Ca_{0.66}Si_2O_6$ | 15.4 | 19.9 |
| Pigeonite | $(Mg_{0.54}Fe_{0.46})SiO_3$ | 10.8 | 13.3 |
| Forsterite | $(Mg_{0.69}Fe_{0.31})SiO_4$ | 7.3 | 7.5 |
| Ilmenite | $FeTiO_3$ | 0.8 | 1.5 |
| Hematite | $Fe_2O_3$ | 0.3 | 0.4 |
| Magnetite | $Fe_3O_4$ | ND | 1.1 |
| Cristobalite | $SiO_2$ | 5.1 | 2.6 |
| Palag./Allophane | | 20.3 | 20.9 |
| Nontronite 10.0 | | 4.4 | 4.0 |
| Total | | 99.3 | 99.1 |

## 3. The CheMin-V instrument

Fig. 2 shows a 3D model of the CheMin-V XRD/XRF geometry. A single X-ray source (having the same accelerating voltage and beam current as Terra) emits a cone of CoKα radiation intercepted by two pinhole collimators. The two collimators produce ~70 µm diameter beams of X-rays directed at the centers of two sample cells. The direct beams from the source/collimators strike beam stops at 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 longtitudinally, 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 the XRF spectrum from 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). Estimated dimensions of the instrument are 27X18X15 cm with a mass of 5 kg (Fig. 3). CheMin-V meets or exceeds all mineralogical requirements for landed science on Venus.

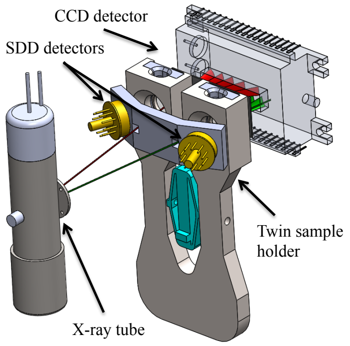

Figure 2: Geometry of the CheMin-V diffraction experiment. Two samples are analyzed at the same time on a single CCD detector. SDD detectors record the XRF spectrum from each sample.

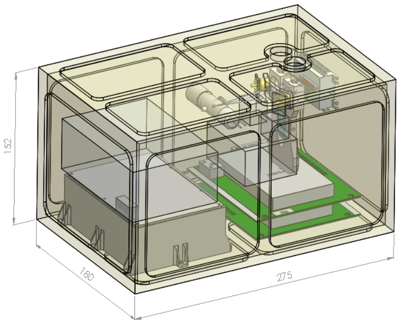

Figure 3. Notional model of the CheMin-V instrument.

## References

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