MINERALOGY DETERMINATIONS BY CHEMIN XRD, TESTED ON ULTRAMAFIC ROCKS (MANTLE XENOLITHS). A. H. Treiman[1], K. L. Robinson[1], D. F. Blake[2], and D. Bish. [1]Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058 <treiman#lpi.usra.edu>. [2]MS 239-4, NASA Ames Research Center, Moffett Field, CA 94035. [3]Dept. of Geological Sciences, Indiana Univ., 1001 E. 10th St., Bloomington, IN 47405.

The CheMin X-ray diffraction (XRD) instrument [1,2] is part of the MSL payload, slated to arrive on Mars in 2011. CheMin's performance is being validated through analyses of Mars analog materials, including volcanic rocks, lunar regolith, and rocks with hydrous and sulfate minerals [3-6]. We have continued that validation with ultramafic rocks, which are similar to those present at some potential landing sites [7,8]. In particular, we have evaluated the ability of the CheMin instrument to identify and quantify mineral ogy and mineral abundances in the ultramafic mantle xenliths, evaluated against results from measurements on thin sections.

Methods: Mantle xenoliths were collected on the 2008 AMASE expedition to Svalbard [9], from basalt outcrops on the Sverrefjell volcano [10]. Each xenolith was split into several fragments (a few gm each) for thin sectioning, XRD, and Raman analyses.

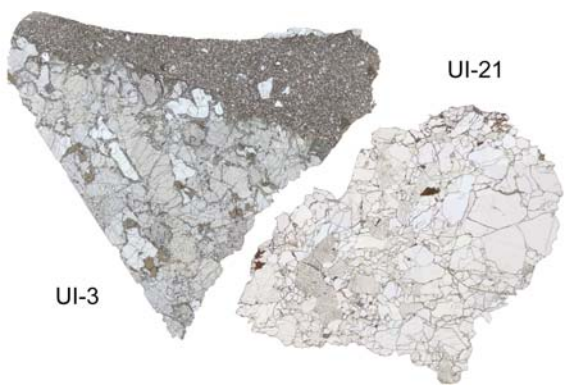

Figure 1. Optical photomicrographs of xenolith UI-3 (2 cm across) and UI-21 (1.5 cm across). UI-3 is a websterite, composed of augite (gray), orthopyroxene (white) and spinel (brown); at the top is the host basalt. UI-21 is a spinel lherzolite; spinel is brown, other phases near-white.

Petrographic and mineral chemical data were obtained on thin sections at LPI and Johnson Space Center (Fig. 1). Mineral identifications were by optical microscopy; mineral proportions were derived from optical images of the whole thin section area, manually annotated for mineral species and measured by area in an image-processing code. We believe that the proportion of *total* pyroxenes is accurate, but it was difficult in some samples to distinguish orthopyroxene from clinopyroxene. Mineral compositions were determined by wavelength-dispersive electron microprobe analysis at the Johnson Space Center, using well-characterized natural and synthetic standards.

X-ray diffraction analyses were obtained with a Terra™ diffractometer [11], a commercial version of the CheMin instrument slated for the Mars Science Laboratory spacecraft. Standard sample preparation methods were used [1,2] to generate powders of <150

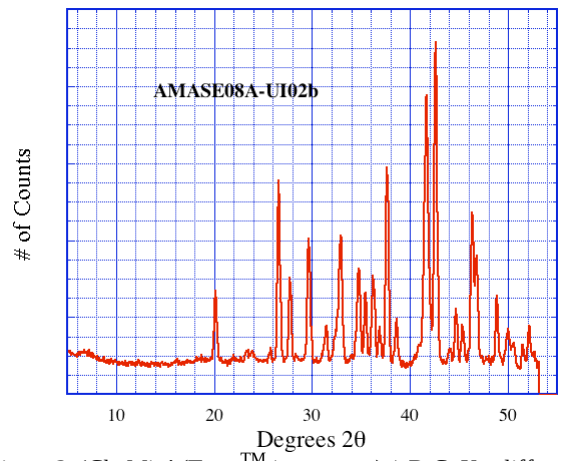

Figure 2. 'CheMin' (Terra™ instrument) 1-D CoKα diffraction pattern of xenolith UI-2b. The strongest peaks at 41.8° and 42.2° 2θ are forsterite 131 and 112 reflections.

μm grainsize. These powders were vibrated in the sample cell, illuminated with collimated CoKα X-rays, and the resultant 2-D transmission diffraction patterns were collected and converted to 1-D (Fig. 2). Qualitative analysis for mineral species identification was performed by comparison with the ICDD data base, and mineral proportions were calculated via Rietveld refinement [3] using the commercial MDI program JADE™.

Samples: The xenoliths span a range of compositions and degrees of alteration [12-14]. All but one are spinel lherzolites (Fig. 1, Table 1) with: olivine of Fo_{87-91}, orthopyroxene of $Wo_{01}En_{90-91}$; and augite of $Wo_{46-47}En_{49}$. Spinels vary widely in Cr and Al contents. Xenolith UI-3 (Fig. 1) is a pyroxenite (websterite), with abundant augite ($Wo_{47}En_{47}$), and lesser orthopyroxene ($Wo_{01}En_{86}$), spinel, and amphibole.

The xenoliths contain two types of secondary material: partial melts and products of aqueous alteration. Partial melts are concentrated near and around the spinels, and are composed of small (10s of μm) crystals of olivine, plagioclase, pyroxenes and spinel with

Table 1. Mineral Proportion in Xenoliths

Xeno	UI-2b		UI-3	
%	Pet	XRD	Pet	XRD
Ol	65	66	10	8
Opx	21	25	8	26
Cpx	10	6	75	59
Sp	1.6	1.4	2.7	2.9
Pl	~0.3	0.6	3	4.1
Am	0	0	1.6	0
Altn	~2	0	<1	0
PM	1.1	--	14.4	--

Xeno	UI-5		UI-21	
%	Pet	XRD	Pet	XRD
Ol	77	83	66	76
Opx	19	16	22	21
Cpx	3	1	9	3
Sp	0.7	0	0.9	0
Pl	~0.5	0	~1	0
Am	0	0	0	0
Altn	<1	0	<1	0
PM	2.1	--	5.9	--

Methods: Pet = petrographic mapping; XRD = Terra™ Rietveld. Minerals: Ol-olivine; Opx-orthopyroxene; Cpx-augite; Sp-spinel; Pl-plagioclase; Altn-'aqueous alteration' = carbonate, zeolites, clays; Am-amphibole; PM-'partial melt', which is ~ 2/3 olivine, 1/6 pl, & 1/6 px. These are included in the overall modal abundances.

glass and void spaces. The aqueous alteration products are veinlets and space fillings [14] that constitute less than a few percent of the xenoliths; the alteration materials include zoned spherules of $(Mg,Fe)CO_3$ [14], smectitic clays, silica, zeolites, and hematite replacing the carbonate and clay.

Discussion: The mineral identifications and proportions determined by Terra™ XRD and by optical petrography were very similar.

Mineralogy & Proportions. Terra™ detected all of the major minerals in the xenoliths, namely olivine, orthopyroxene, augite, and spinel. Mineral proportions are close to, but not identical to those determined petrographically. Most of the differences can be ascribed reasonably to heterogeneity in the xenoliths – the portion exposed in thin section may not be identical to that in the XRD fragment. Terra™ XRD and petrography gave nearly identical proportions of spinel. For some lherzolites, XRD gave slightly greater proportions of olivine that did petrography, but likely within counting uncertainties of the latter. Proportions of opx versus augite were commonly different by the two methods; sample heterogeneity is the likely cause. Terra™ XRD detected plagioclase feldspar in several xenoliths. Before petrographic examination, the presence of plagioclase in these rocks was thought unlikely. However, the xenoliths **do** contain plagioclase in the partial melt material, and the measured proportions in thin sections are close to those from Terra™ XRD. Similarly Terra™ XRD detected olivine in UI-3, although none was seen as large crystals. However, the partial melt material is mostly olivine, which was discovered by EMP analyses.

Detection Limits. Terra™ XRD was developed to be able to detect minerals at the 1% level, and our results indicate that CheMin meets and can exceed that specification for common ultramafic rock types. Abundances of spinel in these xenoliths demonstrate that limit: abundances above 1% (UI-2b & UI-3) were detected at the same levels by XRD and petrogrpahy (Fig. 2), but spinel was not detected by XRD in xenoliths (UI-5 & UI-21) where abundances measured in thin section are below 1%. Amphibole in UI-3, mapped at 1.5% vol, was not detected by Terra™. Carbonate, smectite, hematite and zeolites were not detected, but all are at abundance levels << 1%.

Conclusion: Terra™ XRD (and CheMin by implication) has been shown to be a superb tool for identification of minerals more abundant than ~1% volume, and the instrument is capable of producing data that can be used to retrieve mineral proportions in ultramafic rocks. It may be possible to reduce detection limits further through the judicious optimization of data collection strategies. With further analysis and calibration, CheMin XRD data will be useful in constraining the compositions of minerals in ultramafic rocks (e.g., [15]).

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