

## TES AND GRS COMPOSITIONS OF THE MARTIAN SURFACE: EVIDENCE FOR IGNEOUS AND SECONDARY CHEMICAL FRACTIONATION PROCESSES.

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**Introduction:** The TES and GRS datasets provide unique and complementary insights into martian surface compositions. TES measures the composition of the upper hundred microns of the surface while GRS measures the composition of the upper few tens of centimeters. In this study, we examine TES derived major oxide abundances of low-albedo surface materials and compare global distributions to GRS derived element abundances to constrain the relative roles of igneous and alteration processes on Mars. By combining datasets, and comparing chemistries sampled from different depths, we find evidence for both igneous and secondary chemical fractionation processes on Mars.

**Background:** The TES instrument has mainly been utilized as a mineralogical tool, but thermal emission spectroscopy also provides a means for deriving chemical oxide abundances.

*Laboratory.* Chemical compositions of laboratory-analyzed rocks can be accurately calculated from deconvolved modal mineralogies (vol. %) by combining the compositions of the spectral endmembers (wt. % oxides) in proportion to their relative modeled abundances [1]. Wyatt *et al.* [2] quantified the uncertainties in derived chemical compositions and demonstrated their use in correctly classifying volcanic rocks. The one-sigma standard deviations of the absolute differences between measured and modeled major oxide abundances range from 0.4 to 2.6 wt. % [2].

*TES.* Spectral data of volcanic rocks were convolved to the lowest spectral resolution of TES and used to show that derived bulk rock chemistry errors are not degraded (0.4 to 2.4 wt. %) [3]. These results demonstrate the feasibility of using similar laboratory techniques and classification schemes for TES spectral resolution data.

*Mini-TES.* Major oxide abundances of basaltic sands measured by Mini-TES and APXS at the Meridiani MER landing site differ by 0.5 to 3.3 wt. % [4], similar to results from laboratory studies. Specifically, SiO<sub>2</sub> and FeO abundances differ by only 0.8 wt. %.

Derived chemical abundances from thermal emission spectra have thus been shown to compare accurately to laboratory measurements and in situ techniques on Mars.

**TES Data:** The bulk variability of low-albedo surface compositions measured by TES is accounted for by two distinct global spectral endmembers (ST1 and

ST2) [5]. Recent studies have identified eleven unique regional spectral endmembers while noting that groups of these spectral shapes can be averaged to produce spectra that are similar to ST1 and ST2 [6]. ST1 and ST2 spectra are linearly deconvolved using a spectral endmember set that includes a broad range of igneous and secondary mineral-phases. Mineral abundances (vol. %) are converted to oxide abundances (wt. %) using the methods described by [1, 2]. Major oxide abundances (SiO<sub>2</sub>, Na<sub>2</sub>O, K<sub>2</sub>O, CaO, MgO, FeO, Al<sub>2</sub>O<sub>3</sub>) for ST1 and ST2 are listed in Table 1.

**GRS Data:** Recent GRS studies report Si, K, Fe, Th, and K/Th for “regions” with TES ST1 areal fractions exceeding 17% (RT1) and TES ST2 areal fractions exceeding 36% (RT2) [7,8]. GRS element abundances (Si and Fe converted to oxides) are reported in Table 1 for comparison to TES data.

Table 1. TES and GRS Measured Chemistries (wt. %)

	TES ST1	ST2		GRS RT1	RT2
SiO <sub>2</sub>	53.9	57.9	K	44.7	45.8
Na <sub>2</sub> O	1.7	2.2		-	-
K <sub>2</sub> O	0.6	1.4		0.3195	0.433
CaO	7.1	5.9		-	-
MgO	12.0	7.1		-	-
FeO	15.2	12.4		17.6	20.1
Al <sub>2</sub> O <sub>3</sub>	9.3	12.4		-	-
Th	-	-		0.633	0.94
K/Th	-	-		5050	4600

**TES +/-:** SiO<sub>2</sub> = 0.8, Na<sub>2</sub>O = 0.5, K<sub>2</sub>O = 0.5, CaO = 1.4, MgO = 2.9, FeO = 0.8, Al<sub>2</sub>O<sub>3</sub> = 3.3 [This Study]

**GRS +/-:** SiO<sub>2</sub> = 0.6-1.4, K = 0.0014-0.008, FeO = 0.2, Th = 0.023-0.05, K/Th = 0.18-0.3 [7, 8]

**TES Results:** The most significant chemical differences between TES ST1 and ST2 (considering uncertainties) are higher abundances of FeO for ST1 and higher abundances of SiO<sub>2</sub> for ST2. These variations reflect modeled mineral abundances reported in previous studies [3,5-6,9]. ST1 consists of high abundances of plagioclase (~ 40-50 vol %) and high-calcium clinopyroxene (~ 30-40 vol %) and small amounts of olivine (~ 10 vol %). ST2 consists of high abundances of plagioclase (~ 30-40 vol %) and amorphous high-silica phases (~ 20-30 vol %) and less high-calcium clinopyroxene (~ 10-20 vol %) and no detectable olivine.

Several studies have proposed different petrologic models for ST1 and ST2 (basalt, andesite / partly altered basalt) to explain mineral-phase variations [5, 10], however all studies generally agree on the primary differences between these global spectral endmembers: ST1 consists of higher abundances of Fe-mafic phases (pyroxene and olivine) compared to ST2 and ST2 consists of higher abundances of amorphous high-Si phases compared to ST1.

Recent results from the OMEGA instrument are in agreement with TES oxide abundances [11, 12]. OMEGA observations are sensitive to electron transitions of metals, especially iron, and molecular vibrational transitions in minerals in the upper few tens of microns of the martian surface. Global pyroxene maps from OMEGA are closely correlated with high abundances of pyroxene measured by TES and the mapped distribution of ST1 materials (High FeO) [11]. Conversely, OMEGA observations of ST2 materials lack evidence of distinct mafic mineral bands [12] and are consistent with an enrichment of either primary or secondary high-silica phases.

**GRS Results:** RT2 chemistries have higher abundances of FeO, K, and Th compared to RT1 [7, 8]. Abundances of SiO<sub>2</sub> and K/Th ratio are similar to the bulk planet and do not show significant spatial variations [7, 8]. It should be noted that absolute Si measurements from GRS are tied to Pathfinder values and that the normalization is a constant factor across the Si dataset [8]. GRS estimates of relative variations in Si content are rigorous; however estimates of absolute Si content are not. As a result, GRS data cannot be used to evaluate processes that require accurate knowledge of absolute Si content [8].

**Discussion:** Taken at face value, the major oxide trends in TES and GRS chemistries appear to be in disagreement. TES ST1 is enriched in FeO while GRS RT1 is depleted in FeO. TES ST2 is enriched in SiO<sub>2</sub> while GRS RT2 shows no relative enrichment in SiO<sub>2</sub>. However, by considering the dramatic sampling depth differences between TES (upper hundred microns) and GRS (tens of centimeters), we propose a model that accounts for major oxide and minor element trends and find evidence for both igneous and secondary chemical fractionation processes on Mars.

The relatively constant K/Th ratio across RT1 and RT2 is not consistent with subaqueous or deep (centimeters to meters) subaerial aqueous weathering of basaltic compositions as K would fractionate from Th in both scenarios [e.g. 8, 13]. Fractional crystallization and subduction zone magmatism could enrich K and Th, however GRS does not detect any relative enrichment of Si which would be expected in both models [7, 8]. The favored GRS model [7, 8] is initial bulk

differentiation processes on Mars producing compositionally distinct magma source regions in the mantle. RT1 and RT2 basaltic provinces with distinct trace element compositions could then be produced [8]. SNC meteorites with differences in isotopic and trace element abundances are consistent with distinct magma source regions [14]. Deconvolved mineral abundances from the eleven regional TES endmembers identified by [6] also suggest distinct mantle source compositions for basaltic surface materials.

The lack of any significant relative enrichment in SiO<sub>2</sub> abundances between GRS RT1 and RT2 indicates that evolved volcanics (andesites) are not present in high-abundances within the upper few tens of centimeters of the surface at regional to global scales. However, the significant differences in SiO<sub>2</sub> abundances between TES ST1 and ST2 (upper hundred microns) must be taken into consideration. Thin coatings or rinds of secondary amorphous high-silica phases (tens of microns) can significantly affect the overall shape and position of absorptions in thermal emission spectra of basalt [e.g. 15] and may be undetectable to GRS due to its deep sampling depth. Such coatings on Mars may form from near-surface ice and/or surface-atmosphere interactions with little to no water penetrating or cycling into the surface [16]. Limited degrees of alteration in only the upper few tens of microns of the surface may significantly affect TES derived chemistries, but not GRS chemistries, which sample materials at greater depth.

**Summary:** We find that GRS and TES chemistries support: 1) Distinct magma source regions and basaltic compositions for ST1-RT1 and ST2-RT2 and 2) Thin secondary coatings or rinds of amorphous high-silica phases on ST2-RT2 basalt.

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