

Table 4. Derived Chemistry for MGS-TES Surface Types 1 and 2 Materials^a

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO*	MgO	CaO	Na ₂ O	K ₂ O	Total
<i>Surface Type 1</i>									
Uncorrected									
<i>Bandfield et al.</i> [2000]	52.2	0.3	17.5	4.9	7.7	10.5	2.3	1.7	97.2
<i>Hamilton et al.</i> [2001]	53.5	0.1	15.3	6.8	8.4	10.5	2.9	0.6	98.1
<i>Wyatt and McSween</i> [2002]	50.7	0.1	9.7	15.0	9.2	9.7	1.6	0.8	96.8
This study	52.3	0.2	13.8	8.7	7.4	10.9	2.0	0.4	95.6
H ₂ O- and CO ₂ -free									
<i>Bandfield et al.</i> [2000]	53.7	0.3	18.0	5.1	8.0	10.8	2.4	1.8	100.0
<i>Hamilton et al.</i> [2001]	54.5	0.1	15.6	6.9	8.5	10.8	2.9	0.6	100.0
<i>Wyatt and McSween</i> [2002]	52.5	0.1	10.1	15.5	9.5	10.0	1.6	0.8	100.0
This study	54.7	0.2	14.4	9.1	7.8	11.4	2.1	0.4	100.0
<i>Surface Type 2</i>									
Uncorrected									
<i>Bandfield et al.</i> [2000]	56.6	0.1	16.5	5.4	5.4	6.8	2.3	3.0	96.1
<i>Hamilton et al.</i> [2001]	57.6	0.1	16.9	3.8	8.6	7.0	2.6	1.3	97.8
<i>Wyatt and McSween</i> [2002]	53.8	0.1	16.8	7.0	4.6	9.3	0.9	2.5	95.2
This study	55.3	0.7	13.9	10.2	5.4	5.7	1.9	1.4	94.4
H ₂ O- and CO ₂ -free									
<i>Bandfield et al.</i> [2000]	58.9	0.1	17.2	5.6	5.6	7.1	2.4	3.1	100.0
<i>Hamilton et al.</i> [2001]	58.9	0.1	17.3	3.9	8.8	7.1	2.6	1.4	100.0
<i>Wyatt and McSween</i> [2002]	56.5	0.1	17.7	7.4	4.8	9.8	1.0	2.6	100.0
This study	58.6	0.7	14.7	10.8	5.7	6.0	2.0	1.5	100.0
Errors (1σ)	1.4	0.9	1.5	1.2	2.6	0.7	0.4	0.4	

^aMeasured in wt.% oxides.

Table 4). These figures explore the likelihood that surface types 1 and 2 represent volcanic rock compositions. The normalization has the effect of increasing the other oxide components, especially silica contents. Surface type 2 deconvolutions typically contain more hydrous minerals and thus their derived compositions contain more water; consequently, their silica contents are increased more than for surface type 1. Figures 10 and 11, which explore the possibility that the derived compositions represent partly weathered volcanic rocks, are unaffected by this normalization.

[31] Surprisingly, there is relatively little difference between chemical compositions estimated using the various spectral end-member sets. Using the total alkalis versus silica classification of *Le Bas et al.* [1986], all surface type 1 compositions plot within the field of basaltic andesite and are clearly distinct from Martian meteorites (Figure 2). Surface type 2 compositions plot within the andesite field (Figure 2) and near the Mars Pathfinder dust-free rock composition (in this figure, but not necessarily in other diagrams). However, surface type 2 compositions that are not recalculated as H₂O-free would plot within the basaltic andesite field, closer to surface type 1 compositions. The clustering of compositions suggests that chemistry derived from TES data is relatively robust, although we caution that thermal emission spectra sample only the outer few hundred microns of grains.

4. Petrogenesis of Crustal Materials

[32] Martian surface compositions could reflect either igneous materials or a combination of basalt and alteration products. Below, we consider each possibility.

4.1. Origin of Andesitic Magmas

[33] *Miyashiro* [1974] introduced the FeO*/MgO versus SiO₂ diagram (Figure 8) (* indicates that all iron is reported as FeO) to delineate the tholeiitic (TH) and calc-alkaline

(CA) magmatic trends. In this diagram, anhydrous fractional crystallization paths (tholeiitic trends) are nearly vertical, as illustrated by arrows in the TH field showing the trends of Galapagos mid-ocean ridge lavas (kinked arrow, analyzed by *Juster et al.* [1989]) and the dry liquid line of descent for basaltic shergottites (short arrow, calculated using the MELTS program by *Hale et al.* [1999]). In contrast, fractional crystallization under hydrous conditions follows distinctive paths (calc-alkaline trends) that lead to higher silica contents, as illustrated by the diagonal arrows in the CA field [*Sisson and Grove, 1993; Grove et al., 2003*]. The effect of H₂O is to expand the primary phase volumes for olivine and clinopyroxene, causing plagioclase to crystallize late. Primitive melts produced by low degrees of hydrous partial melting of mantle peridotite (olivine + orthopyroxene + clinopyroxene + spinel) have compositions indicated by the large open circle in Figure 8. These magmas would follow a fractionation trend like the diagonal arrow emanating from the circle and paralleling the TH-CA boundary. The heavy gray arrow illustrates the compositions of liquids derived from higher degrees of hydrous melting after clinopyroxene and spinel are exhausted from the source, leaving only olivine and orthopyroxene (harzburgite) in the mantle residue. The length of the heavy arrow represents the 20 to 40% melting interval at 1.2 GPa [*Gaetani and Grove, 1998*]. This extent of melting is encountered in the mantle wedge in terrestrial subduction zones. Liquids along this arrow are produced by incongruent melting of orthopyroxene to form olivine + liquid at high water contents [*Grove et al., 2003*]. These conditions are only met on Earth when the mantle wedge above the subducted slab is fluxed by an H₂O-rich fluid derived by dehydration of subducted oceanic plates. Subsequent fractional crystallization of these water-rich melts at shallow crustal levels produces a family of diagonal trends, as illustrated by diagonal arrows representing various terrestrial arc lavas [*Grove et al., 2003*] in Figure 8.