

**THE AMORPHOUS COMPONENT IN MARTIAN BASALTIC SOIL IN GLOBAL PERSPECTIVE FROM MSL AND MER MISSIONS.** R.V. Morris<sup>1</sup>, D.W. Ming<sup>1</sup>, D.F. Blake<sup>2</sup>, D.T. Vaniman<sup>3</sup>, D.L. Bish<sup>4</sup>, S.J. Chipera<sup>5</sup>, R.T. Downs<sup>6</sup>, R. Gellert<sup>7</sup>, A.H. Treiman<sup>8</sup>, A.S. Yen<sup>9</sup>, C.N. Achilles<sup>10</sup>, R.C. Anderson<sup>9</sup>, T.F. Bristow<sup>2</sup>, J.A. Crisp<sup>9</sup>, D.J. Des Marais<sup>2</sup>, J.D. Farmer<sup>11</sup>, J.P. Grotzinger<sup>12</sup>, L.A. Leshin<sup>13</sup>, A.C. McAdam<sup>14</sup>, J.M. Morookian<sup>9</sup>, S.M. Morrison<sup>6</sup>, E.B. Rampe<sup>1</sup>, P.C. Sarrazin<sup>15</sup>, N. Spanovich<sup>9</sup>, E.M. Stolper<sup>12</sup>, and the MSL Science Team. <sup>1</sup>NASA JSC ([richard.v.morris@nasa.gov](mailto:richard.v.morris@nasa.gov)), <sup>2</sup>NASA ARC, <sup>3</sup>PSI, <sup>4</sup>IndianaU, <sup>5</sup>CHK Energy, <sup>6</sup>UofA, <sup>7</sup>UofGuelph, <sup>8</sup>LPI, <sup>9</sup>JPL/Caltech, <sup>10</sup>ESCG/NASA JSC, <sup>11</sup>ASU, <sup>12</sup>Caltech, <sup>13</sup>RPI, <sup>14</sup>NASA GSFC, <sup>15</sup>in Xitu.

**Introduction:** The mineralogy instrument CheMin onboard the MSL rover Curiosity analyzed by transmission XRD [1] the <150  $\mu\text{m}$  size fraction of putative global basaltic martian soil from scoops 4 and 5 of the Rocknest aeolian bedform (sol 81-120). Here, we combine chemical (APXS) and mineralogical (Mössbauer; MB) results from the MER rovers with chemical (APXS) and mineralogical (CheMin) results from Curiosity to constrain the relative proportions of amorphous and crystalline components, the bulk chemical composition of those components, and the “mineralogical” nature of the amorphous component.

**APXS chemistry of global basaltic martian soil:** The APXS chemistry and MB mineralogy of basaltic soil obtained by the MER rovers at Gale Crater and Meridiani Planum landing sites (Table 1) are within  $1\sigma$  except for MgO and Na<sub>2</sub>O which are the same within  $2\sigma$ . These compositions exclude soils with a significant “local component” (high-SO<sub>3</sub> and high-SiO<sub>2</sub> for Gusev and high-Fe<sub>2</sub>O<sub>3</sub> for Meridiani). The Gale analysis (Rocknest\_Portage) [2] is within  $2\sigma$  of the MER analyses, except for TiO<sub>2</sub>, so that we accept that MER and MSL analyzed effectively the same basaltic soil. APXS concentrations were calculated with respect to zero excess light elements (i.e., H<sub>2</sub>O = CO<sub>2</sub> = 0).

**Chemistry of crystalline phases:** The relative proportion of crystalline phases in Rocknest soil from CheMin XRD data are reported by [3]. Their chemistry was assigned by stoichiometry (e.g., TiFeO<sub>3</sub>) or by the chemical composition of the XRD crystalline phases constrained by the bulk chemistry of Rocknest soil. The crystalline phases whose chemistry is not readily constrained by stoichiometry are feldspar, olivine, and pyroxene. We used chemical compositions (Table 2) from certain martian meteorites [4] constrained by Rocknest CheMin mineralogy and APXS chemistry.

**Amorphous and crystalline components:** We calculated the relative proportion of amorphous and crystalline components and their respective bulk compositions from the bulk composition of Rocknest, redox constraints, and the chemical composition of crystalline components weighted by their CheMin XRD abundance (Table 3).

Because APXS is insensitive to Fe oxidation state, MER MB data were used to estimate the redox state of

Fe in Rocknest soil. Using the MER correlation of Fe<sup>3+</sup>/ $\Sigma\text{Fe}$  with SO<sub>3</sub> (Fig. 1) [5], the Rocknest SO<sub>3</sub> abundance implies it has Fe<sup>3+</sup>/ $\Sigma\text{Fe}$   $\sim$  0.32. This Fe<sup>3+</sup> must be in the amorphous component as nanophase ferric oxide (npOx) and its concentration is represented by “Fe<sub>2</sub>O<sub>3</sub>-npOx”. The Fe<sup>3+</sup> concentration required for the crystalline Hm and Mt components is represented by “Fe<sub>2</sub>O<sub>3</sub>-Crystalline”. The concentrations of SO<sub>3</sub> and Cl are correlated (Fig. 2) [6], implying that they are also associated with the amorphous component. The bulk compositions and relative proportions ( $\sim$ 36 and  $\sim$ 64 wt.%) of amorphous and crystalline components (light-element free basis) are given in the last two columns of Table 3.

**Table 1.** Global soil compositions.

	Gusev [5]	Meridiani [6]	Gale [2]
APXS Results (wt.%)			
Number	48 <sup>a</sup>	29 <sup>a</sup>	1 <sup>b</sup>
SiO <sub>2</sub>	46.1 $\pm$ 0.9	45.7 $\pm$ 1.3	43.69 $\pm$ 0.43
TiO <sub>2</sub>	0.88 $\pm$ 0.19	1.03 $\pm$ 0.12	1.54 $\pm$ 0.04
Al <sub>2</sub> O <sub>3</sub>	10.2 $\pm$ 0.7	9.2 $\pm$ 0.5	9.56 $\pm$ 0.19
Cr <sub>2</sub> O <sub>3</sub>	0.33 $\pm$ 0.07	0.41 $\pm$ 0.06	0.42 $\pm$ 0.02
Fe <sub>2</sub> O <sub>3</sub> +FeO	16.3 $\pm$ 1.1	18.8 $\pm$ 1.2	21.01 $\pm$ 0.09
MnO	0.32 $\pm$ 0.03	0.37 $\pm$ 0.02	0.44 $\pm$ 0.03
MgO	8.67 $\pm$ 0.60	7.38 $\pm$ 0.29	6.53 $\pm$ 0.17
CaO	6.30 $\pm$ 0.29	6.93 $\pm$ 0.32	7.38 $\pm$ 0.07
Na <sub>2</sub> O	3.01 $\pm$ 0.30	2.21 $\pm$ 0.18	2.22 $\pm$ 0.14
K <sub>2</sub> O	0.44 $\pm$ 0.07	0.48 $\pm$ 0.05	0.59 $\pm$ 0.06
P <sub>2</sub> O <sub>5</sub>	0.91 $\pm$ 0.31	0.84 $\pm$ 0.06	0.53 $\pm$ 0.12
SO <sub>3</sub>	5.78 $\pm$ 1.25	5.83 $\pm$ 1.04	5.18 $\pm$ 0.19
Cl	0.70 $\pm$ 0.16	0.65 $\pm$ 0.09	0.61 $\pm$ 0.02
Total	99.9	99.9	99.7
Cl/SO <sub>3</sub>	0.12 $\pm$ 0.02	0.11 $\pm$ 0.01	0.10 $\pm$ 0.02
MB Results (% of $\Sigma\text{Fe}$ in Fe-bearing phases)			
Number	32	11	0
Olivine	34 $\pm$ 6	31 $\pm$ 7	---
Pyroxene	34 $\pm$ 4	35 $\pm$ 4	---
Ilmenite	0 $\pm$ 1	0 $\pm$ 0	---
Magnetite	8 $\pm$ 2	6 $\pm$ 1	---
npOx	20 $\pm$ 6	22 $\pm$ 8	---
Hematite	3 $\pm$ 3	6 $\pm$ 4	---
Total	100	100	---
Fe <sup>3+</sup> / $\Sigma\text{Fe}$	0.29 $\pm$ 0.07	0.32 $\pm$ 0.11	---

a.  $1\sigma$  of average. b. Analytical uncertainty.

Because the detected crystalline phases are nominally anhydrous, the amorphous component must contain the H<sub>2</sub>O and CO<sub>2</sub> detected by MSL-SAM. The relative proportion of the amorphous component in Rocknest will be ≥36 wt.% when these contributions are quantified and taken into account.

The high SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ratio for the amorphous component implies allophane is not prevalent, and the FeO concentration implies an amorphous Fe<sup>2+</sup>-bearing component (basaltic glass?) or an underestimated Fe<sup>3+</sup>/ΣFe ratio. The low SiO<sub>2</sub> and high TiO<sub>2</sub> and Fe<sub>2</sub>O<sub>3</sub> (npOx) concentrations compared with bulk soil suggest aqueous weathering of basaltic precursors under near neutral conditions followed by accumulation of S and Cl, for

**Table 2.** Crystalline component compositions (wt.%)

	Plagioclase Or3Ab49An48	Olivine Fa39Fo61	Pyroxene Wo21En40Fs38
SiO <sub>2</sub>	55.9	36.3	51.0
TiO <sub>2</sub>	---	---	0.40
Al <sub>2</sub> O <sub>3</sub>	27.45	0.06	1.01
Cr <sub>2</sub> O <sub>3</sub>	---	0.02	0.30
Fe <sub>2</sub> O <sub>3</sub>	0.73	---	0.49
FeO	---	33.2	22.7
MnO	---	0.63	0.69
MgO	0.10	29.7	13.7
CaO	10.13	0.25	10.00
Na <sub>2</sub> O	5.66	---	0.13
K <sub>2</sub> O	0.46	---	---
Total	100.4	100.3	100.3

**Table 3.** Chemical composition and relative proportion of Rocknest soil amorphous and crystalline components

Wt.% Component	Redox	Remove Crystalline Component <sup>a</sup>								Bulk Composition	
		Plag	Ol	Px	Ilm	Hm	Mt	Anh	Qz	Amorphous	Crystalline
SiO <sub>2</sub>	43.7	27.5	22.8	13.6	13.6	13.6	13.6	13.6	12.6	35.3	48.4
TiO <sub>2</sub>	1.54	1.54	1.54	1.47	1.26	1.26	1.26	1.26	1.26	3.52	0.42
Al <sub>2</sub> O <sub>3</sub>	9.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4	3.9	12.7
Cr <sub>2</sub> O <sub>3</sub>	0.42	0.42	0.42	0.37	0.37	0.37	0.37	0.37	0.37	1.03	0.08
Fe <sub>2</sub> O <sub>3</sub> -Crystalline	1.6	1.3	1.3	1.3	1.3	0.8	0.0	0.0	0.0	0.0	2.4
Fe <sub>2</sub> O <sub>3</sub> -npOx	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	19.0	-0.1
FeO	12.7	12.7	8.3	4.3	4.1	4.1	3.7	3.7	3.7	10.4	13.9
MnO	0.44	0.44	0.36	0.23	0.23	0.23	0.23	0.23	0.23	0.65	0.32
MgO	6.53	6.50	2.63	0.18	0.18	0.18	0.18	0.18	0.18	0.50	9.94
CaO	7.38	4.44	4.41	2.61	2.61	2.61	2.61	2.24	2.24	6.27	8.01
Na <sub>2</sub> O	2.22	0.58	0.58	0.55	0.55	0.55	0.55	0.55	0.55	1.55	2.60
K <sub>2</sub> O	0.59	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	1.28	0.20
P <sub>2</sub> O <sub>5</sub>	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	1.48	-0.01
SO <sub>3</sub> -Crystalline	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.00	0.00	0.00	0.83
SO <sub>3</sub> -Amorphous	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	13.02	-0.08
Cl	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	1.71	-0.01
Total	99.7	70.6	57.6	39.5	39.1	38.6	37.5	36.6	35.6	99.7	99.7
<b>XRD Crystalline</b>		45.4	20.3	28.2	0.6	0.8	1.7	1.4	1.6	0.0	100.0
<b>Whole Sample</b>		29	13	18	0.4	0.5	1.1	0.9	1.0	36.1	63.9

<sup>a</sup>Plag=plagioclase; Ol=olivine; Px=pyroxene; Ilm=ilmenite; Hm=hematite; Mt=magnetite; Anh=anhydrite; Qz=quartz.

example from volcanic emanations by specific anion adsorption by npOx, when aqueous activity decreased in intensity on Mars [7]. The crystalline component in global basaltic soil may be predominantly the product of physical weathering after this time.

Refs: [1] Blake et al. (2012) *JGR*; (2013) *LPSC44*. [2] Yen et al. (2013) *LPSC44*. [3] Bish et al. (2013) *LPSC44*. [4] Papike et al. (2009) *GCA*. [5] Morris et al. (2006a, b, 2008) *JGR*. [6] Yen et al. (2005) *EPSL*; Ming et al. (2006) *JGR*; Morris et al. (2006a, b, 2008) *JGR*. [7] Bibring et al. (2006) *Science*.

