
Introduction: The mineralogy instrument CheMin onboard the MSL rover Curiosity analyzed by transmission XRD [1] the <150 µm 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 1σ except for MgO and Na2O which are the same within 2σ. These compositions exclude soils with a significant “local component” (high-SO3 and high-SiO2 for Gusev and high-Fe2O3 for Meridiani). The Gale analysis (Rocknest_Portage) [2] is within 2σ of the MER analyses, except for TiO2, 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., H2O = CO2 = 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., TiFeO3) 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 Fe3+/ΣFe with SO3 (Fig. 1) [5], the Rocknest SO3 abundance implies it has Fe3+/ΣFe ~ 0.32. This Fe3+ must be in the amorphous component as nanophase ferric oxide (npOx) and its concentration is represented by “Fe2O3-npOx”. The Fe3+ concentration required for the crystalline Hm and Mt components is represented by “[Fe2O3-Crystalline]”. The concentrations of SO3 and Cl are correlated (Fig. 2) [6], implying that they are also associated with the amorphous component. The bulk compositions and relative proportions (~36 and ~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.

<table>
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<tr>
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<th></th>
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<tbody>
<tr>
<td>APXS Results (wt.%)</td>
<td>48a</td>
<td>29b</td>
<td>1b</td>
</tr>
<tr>
<td>SiO2</td>
<td>46.1 ± 0.9</td>
<td>45.7 ± 1.3</td>
<td>43.69 ± 0.43</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.88 ± 0.19</td>
<td>1.03 ± 0.12</td>
<td>1.54 ± 0.04</td>
</tr>
<tr>
<td>Al2O3</td>
<td>10.2 ± 0.7</td>
<td>9.2 ± 0.5</td>
<td>9.56 ± 0.19</td>
</tr>
<tr>
<td>Cr2O3</td>
<td>0.33 ± 0.07</td>
<td>0.41 ± 0.06</td>
<td>0.42 ± 0.02</td>
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<tr>
<td>Fe2O3+FeO</td>
<td>16.3 ± 1.1</td>
<td>18.8 ± 1.2</td>
<td>21.01 ± 0.09</td>
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<tr>
<td>MnO</td>
<td>0.32 ± 0.03</td>
<td>0.37 ± 0.02</td>
<td>0.44 ± 0.03</td>
</tr>
<tr>
<td>MgO</td>
<td>8.67 ± 0.60</td>
<td>7.38 ± 0.29</td>
<td>6.53 ± 0.17</td>
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<tr>
<td>CaO</td>
<td>6.30 ± 0.29</td>
<td>6.93 ± 0.32</td>
<td>7.38 ± 0.07</td>
</tr>
<tr>
<td>Na2O</td>
<td>3.01 ± 0.30</td>
<td>2.21 ± 0.18</td>
<td>2.22 ± 0.14</td>
</tr>
<tr>
<td>K2O</td>
<td>0.44 ± 0.07</td>
<td>0.48 ± 0.05</td>
<td>0.59 ± 0.06</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.91 ± 0.31</td>
<td>0.84 ± 0.06</td>
<td>0.53 ± 0.12</td>
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<tr>
<td>SO3</td>
<td>5.78 ± 1.25</td>
<td>5.83 ± 1.04</td>
<td>5.18 ± 0.19</td>
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<tr>
<td>Cl</td>
<td>0.70 ± 0.16</td>
<td>0.65 ± 0.09</td>
<td>0.61 ± 0.02</td>
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<tr>
<td>Total</td>
<td>99.9</td>
<td>99.9</td>
<td>99.7</td>
</tr>
<tr>
<td>Cl/ΣSO3</td>
<td>0.12 ± 0.02</td>
<td>0.11 ± 0.01</td>
<td>0.10 ± 0.02</td>
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Table 2. Crystaline phases.

<table>
<thead>
<tr>
<th>Number</th>
<th>Olivine</th>
<th>Pyroxene</th>
<th>Ilmenite</th>
<th>Magnetite</th>
<th>npOx</th>
<th>Hematite</th>
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<tbody>
<tr>
<td>32</td>
<td>34 ± 6</td>
<td>34 ± 4</td>
<td>0 ± 1</td>
<td>8 ± 2</td>
<td>20 ± 6</td>
<td>3 ± 3</td>
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<td>11</td>
<td>31 ± 7</td>
<td>35 ± 4</td>
<td>0 ± 0</td>
<td>6 ± 1</td>
<td>22 ± 8</td>
<td>6 ± 4</td>
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<td>MB Results (% of ΣFe in Fe-bearing phases)</td>
<td>32</td>
<td>11</td>
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<tr>
<td>34 ± 6</td>
<td>34 ± 4</td>
<td>0 ± 1</td>
<td>8 ± 2</td>
<td>20 ± 6</td>
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<tr>
<td>31 ± 7</td>
<td>35 ± 4</td>
<td>0 ± 0</td>
<td>6 ± 1</td>
<td>22 ± 8</td>
<td>6 ± 4</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>---</td>
<td></td>
<td></td>
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<tr>
<td>Fe3+/ΣFe</td>
<td>0.29 ± 0.07</td>
<td>0.32 ± 0.11</td>
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Table 3. Amorphous and crystalline components.

<table>
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<tr>
<th>Number</th>
<th>Amorphous</th>
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<th>Total</th>
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<tr>
<td>Number</td>
<td>48a</td>
<td>29b</td>
<td>1b</td>
</tr>
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<tr>
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</tr>
<tr>
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<td>0.41 ± 0.06</td>
<td>0.42 ± 0.02</td>
</tr>
<tr>
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<td>18.8 ± 1.2</td>
<td>21.01 ± 0.09</td>
</tr>
<tr>
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<td>0.37 ± 0.02</td>
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<tr>
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<tr>
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<tr>
<td>Na2O</td>
<td>3.01 ± 0.30</td>
<td>2.21 ± 0.18</td>
<td>2.22 ± 0.14</td>
</tr>
<tr>
<td>K2O</td>
<td>0.44 ± 0.07</td>
<td>0.48 ± 0.05</td>
<td>0.59 ± 0.06</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.91 ± 0.31</td>
<td>0.84 ± 0.06</td>
<td>0.53 ± 0.12</td>
</tr>
<tr>
<td>SO3</td>
<td>5.78 ± 1.25</td>
<td>5.83 ± 1.04</td>
<td>5.18 ± 0.19</td>
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<tr>
<td>Cl</td>
<td>0.70 ± 0.16</td>
<td>0.65 ± 0.09</td>
<td>0.61 ± 0.02</td>
</tr>
<tr>
<td>Total</td>
<td>99.9</td>
<td>99.9</td>
<td>99.7</td>
</tr>
<tr>
<td>Cl/ΣSO3</td>
<td>0.12 ± 0.02</td>
<td>0.11 ± 0.01</td>
<td>0.10 ± 0.02</td>
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</tbody>
</table>
Because the detected crystalline phases are nominally anhydrous, the amorphous component must contain the H₂O and CO₂ 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 SiO₂/Al₂O₃ ratio for the amorphous component implies allophane is not prevalent, and the FeO concentration implies an amorphous Fe³⁺-bearing component (basaltic glass?) or an underestimated Fe³⁺/ΣFe ratio. The low SiO₂ and high TiO₂ and Fe₂O₃ (npOx) concentrations compared with bulk soil suggest aqueous weathering of basaltic precursors under near neutral conditions followed by accumulation of S and Cl, for 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.


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

<table>
<thead>
<tr>
<th>Component</th>
<th>Plagioclase</th>
<th>Olivine</th>
<th>Pyroxene</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Or₃Ab₄₉An₄₈</td>
<td>Fa₃₉Fo₆₁</td>
<td>Wo₂₁En₄₀Fs₃₈</td>
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<tr>
<td>SiO₂</td>
<td>55.9</td>
<td>36.3</td>
<td>51.0</td>
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<tr>
<td>TiO₂</td>
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<td>FeO</td>
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<td>33.2</td>
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<td>MnO</td>
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<td>0.69</td>
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<tr>
<td>MgO</td>
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<td>13.7</td>
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<td>CaO</td>
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<td>Na₂O</td>
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<tr>
<td>K₂O</td>
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<tr>
<td>Total</td>
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<td>100.3</td>
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**Table 3. Chemical composition and relative proportion of Rocknest soil amorphous and crystalline components**

<table>
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<tr>
<th>Wt.% Component</th>
<th>Redox</th>
<th>Plag</th>
<th>Ol</th>
<th>Px</th>
<th>Ilm</th>
<th>Hm</th>
<th>Mt</th>
<th>Anh</th>
<th>Qz</th>
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<tr>
<td>SiO₂</td>
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<td>TiO₂</td>
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<td>1.54</td>
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<td>1.26</td>
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<td>Al₂O₃</td>
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<td>1.6</td>
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<tr>
<td>Cr₂O₃</td>
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<tr>
<td>Fe₂O₃-Crystalline</td>
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<td>Fe₂O₃-npOx</td>
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<td>0.46</td>
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<td>P₂O₅</td>
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<td>0.53</td>
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<td>0.53</td>
<td>0.53</td>
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<td>39.1</td>
<td>38.6</td>
<td>37.5</td>
<td>36.6</td>
<td>35.6</td>
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</tbody>
</table>

| XRD Crystalline | 45.4 | 20.3 | 28.2 | 0.6  | 0.8  | 1.7  | 1.4  | 1.6  | 0.0  | 100.0 |
| Whole Sample    | 29   | 13   | 18   | 0.4  | 0.5  | 1.1  | 0.9  | 1.0  | 36.1 | 63.9  |

*aPlag=plagioclase; Ol=olivine; Px=pyroxene; Ilm=ilmenite; Hm=hematite; Mt=magnetite; Anh=anhydrite; Qz=quartz.*