THE LAFAYETTE METEORITE: PRETERRESTRIAL AQUEOUS ALTERATIONS. A.H. Treiman1, R.A. Barrett2, J.L. Gooding1; 1SN21, NASA/JSC, Houston TX 77058; 2Lockheed Engineering & Sciences Co. Houston TX 77058

Lafayette, one of the SNC (Martian) meteorites, contains pre-terrestrial aqueous alteration materials. Rusty veinlets of smectite and ferric oxides replace olivine and transect other minerals. The veinlets are older than the meteorite's fusion crust, against which they are truncated and degraded. The mineralogy and compositions of the veinlets will provide constraints on the compositions of Martian groundwaters.

The Lafayette achondrite, one of the nakhlites of probable Martian origin, is an igneous rock consisting mostly of augite and olivine [1,2]. Like Nakhla itself, Lafayette contains rusty alteration materials, "iddingsite"-[1,2]. Aqueous alterations in Nakhla are pre-terrestrial-[3], suggesting that Lafayette's may also be. Documentation of the timing of alteration is critical for Lafayette, as it was "found" in a collection and may have experienced terrestrial weathering.

SAMPLE AND METHODS: We studied thin sections from chips of Lafayette, sample ME2116 (Field Museum, Chicago), using scanning and transmission electron microscopy (SEM and TEM) with energy dispersive X-ray spectrometry (EDS) as in [4,5]. SEM elemental analyses were done in spot mode (1 μm) and in rastered selected area mode (to 10 μm). Standards were well-characterized minerals [3]; SEM/EDS analyses of olivine in Lafayette are nearly identical to EMP analyses from [1,2].

PETROGRAPHY: Rusty, aqueous alteration material replaces Lafayette olivine as veinlets and as spikes of rhombic cross-sections (Fig. 1), similar to replacements of terrestrial olivine [6,7]. The veinlets and spikes commonly have exterior zones of 3-5 μm phyllosilicate plates or fibers, which are cut by one or more veinlets of sub-100 nm material ±100 nm grains of high secondary electron (SEI) brightness. These fine-grained veinlets may cross-cut each other, and commonly have cores with higher SEI brightness than the rims. By TEM, the veinlets consist of felted masses of smectite (platy or fibrous grains, 1.0 nm lattice fringes, composition consistent with trioctahedral clay) and iron oxides, probably hematite and ferrihydrite (Fig. 2).

This aqueous alteration material is pre-terrestrial, as shown by changes in the alteration veinlets as they approach the fusion crust. Veinlets more than 1 mm distant from the fusion crust are as described above. Between 1 mm and 0.5 mm, the veinlets appear as above, and are depleted in volatile elements: alkalis, Cl, and S. Within 0.5 mm of the crust, the veinlets are transformed (melted) to uniform fine-grained material containing vesicles (Fig. 1). The transformed vein material is truncated by the fusion crust. These data suggest that the veinlets existed before the fusion crust formed (i.e. before Lafayette entered the Earth's atmosphere), and that the veinlets were progressively affected by the short, intense heating event that produced the fusion crust [3].

COMPOSITION: The average compositions of all petrographic varieties of alteration materials are similar (Table 1). Among the analyses, abundances of Fe and Si are inversely correlated, and are nearly collinear with the compositions of the host olivine and ferric oxide. Mn/Fe in the alteration is nearly constant. Abundances of K and Al are correlated, and are inversely correlated with those of Cl. Abundances of Cl and S are correlated (with some scatter) for analyses with less than 1% SO3 and 0.5% Cl; the remaining analyses are richer in SO3 or Cl. The EDS analyses are consistent with mineralogy determined by TEM, and also suggest the presence of phases containing S and Cl. The molar ratio (Fe+Mg+Mn+Ni)/Si of the alteration ranges from 0.79-1.22 (avg 0.93), consistent with a mixture of ferric oxide and/or hydroxide and Fe-Mg smectite (ratio = 0.75). Presence of a smectite is consistent with the

TABLE 1: Aqueous alteration materials in Lafayette and Nakhla [3]; average SEM/EDS compositions, normalized to 100%. Na values inaccurate [3].

<table>
<thead>
<tr>
<th></th>
<th>SiO2</th>
<th>TiO2</th>
<th>Al2O3</th>
<th>Cr2O3</th>
<th>FeO</th>
<th>NiO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>K2O</th>
<th>Na2O</th>
<th>P2O5</th>
<th>SO3</th>
<th>Cl</th>
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</thead>
<tbody>
<tr>
<td>Lafay.</td>
<td>48.7</td>
<td>0.01</td>
<td>4.73</td>
<td>0.00</td>
<td>28.84</td>
<td>0.10</td>
<td>0.48</td>
<td>13.79</td>
<td>0.70</td>
<td>0.41</td>
<td>1.08</td>
<td>0.09</td>
<td>0.68</td>
<td>0.36</td>
</tr>
<tr>
<td>Nakhla</td>
<td>46.6</td>
<td>0.02</td>
<td>0.86</td>
<td>0.03</td>
<td>37.94&lt;0.01</td>
<td>0.73</td>
<td>7.90</td>
<td>1.32</td>
<td>1.34</td>
<td>0.80</td>
<td>0.07</td>
<td>0.16</td>
<td>0.76</td>
<td></td>
</tr>
</tbody>
</table>
correlation of K and Al. Analyses rich in S and Cl suggest discrete S-rich (sulfate) and chloride phases similar to those in Nakhla [3]. The correlation of S and Cl at lower abundances suggests a separate carrier phase, perhaps ferrihydrite acting as an ionic sorbent.

COMPARISON WITH NAKHLA: The aqueous alteration materials in Lafayette are similar, but not identical, to those in Nakhla [3,5]. Alteration material is much more abundant in Lafayette than in Nakhla, and coarse-grained phyllosilicates are apparently absent from Nakhla. Chemical analyses of the Lafayette alteration materials are clustered near the extreme Fe-poor analysis from Nakhla ('A' of [3]). Compared to alteration materials in Nakhla, those in Lafayette are enriched in Al, Mg and S, and depleted in K, Ca, Fe and Cl (Table 1).

GEOCHEMISTRY: The processes in the pre-terrestrial alteration of Lafayette involve significant aqueous mobility of most elements, as the smectite textures imply precipitation from solution and not topotactic growth [6,7,8]. Alteration of Lafayette olivine involves loss of iron relative to other elements, while most terrestrial examples involve loss of silicon and magnesium [6,7]. The altering solutions were probably saturated in Ca-sulfate (gypsum? [3]) and a chloride salt (halite? [3]). In general, the altering waters must have been saline, alkaline (to dissolve silica) and only moderately oxidizing to permit mobility of Fe.

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Figure 1. SEM/SEI image of alteration veinlet (A) in Lafayette olivine. Veinlet is degraded and bubbled near the fusion crust (C). Augite at bottom of image is becoming engulfed in fusion crust.

Figure 2. TEM image of alteration veinlet at augite-plagioclase grain boundary. Smectites with 1 nm lattice fringes; dark spots are ferric oxides. Scale bar 20 nm.