TRACE ELEMENT GEOCHEMISTRY OF LUNAR BRECCIA 67016; Marc D. Norman and Stuart Ross Taylor, Research School of Earth Sciences, Australian National University, Canberra, A.C.T. 2601 Australia

Lunar rock 67016 is one of the feldspathic fragmental breccias collected from Station 7 on the rim of North Ray Crater. It contains abundant lithic clasts of light-colored anorthositic material and darker melt breccias in a light grey matrix dominated by plagioclase. KREEP-rich and regolith components are rare [1, 2]. The anorthositic clasts comprise recrystallized granulitic breccias and plutonic anorthosites from sources deep within the lunar crust. In some of these clasts, olivine has been replaced by a sulfide-rich intergrowth, that probably reflects reaction with a vapour phase. The dark melt breccia clasts are composed of abundant mineral clasts (predominantly plagioclase) in a continuous matrix of fine-grained melt. Melt breccias often have aerodynamic shapes and major element compositions close to that of the bulk rock, suggesting they formed during the assembly of 67016, possibly analogous to terrestrial suevite [1].

Feldspathic fragmental breccias probably represent regionally extensive units similar to those exposed on the Kant Plateau and in the Descartes Highlands near the Apollo 16 site. These units may represent Nectaris ejecta [3, 4]. If so, they represent a vital link for attempts to reconstruct the evolution of the lunar crust. We have analyzed a bulk rock split, several anorthositic clasts and one melt breccia clast from 67016 for major and trace elements with the goal of understanding the petrogenesis of the breccia and the role of the anorthositic lithologies in the lunar crust.

The anorthositic clasts we have analyzed fall into two compositional groups (data in Table 1). One group (samples ,338, 346 and .351) has the high alumina contents (34-35%), low concentrations of incompatible elements (Ce 1.1-2.14 ppm, Th 0.04-0.09 ppm), and large positive Eu anomalies typical of lunar anorthosites (Fig. 1). The other group (samples ,34, 322, 326, 332, 349, 318, 330, 334, 339, 343) is somewhat more mafic (Al2O3 24.1-32.5%, FeO 1.5-8.7%) with higher concentrations of incompatible elements (Ce 4.2-10.2 ppm, Th 0.1-0.8 ppm), and smaller but still positive Eu anomalies (Fig. 1). Both groups are LREE-enriched with relatively flat HREE patterns. Breciated samples of the more-mafic group tend to have higher concentrations of incompatible elements than samples with well-preserved crystalline textures (Fig. 2). Here we will call the less-mafic group "anorthosites" and the more mafic group "granulites" because of the similarities of the REE patterns with other lunar feom anorthosites and granulitic breccias, respectively. We recognize that some of these "granulites" may have plutonic precursors, and do not wish to imply genetic connotations.

The melt breccia (sample .320) has a composition similar to the less mafic group of anorthosites but with slightly higher concentrations of incompatible elements (Al2O3 33.8%, FeO 2.0%, Ce 2.0 ppm Th 0.1 ppm). Our split of bulk rock (.16) has the highest LREE content of any of our samples (Ce 15 ppm), but contents of the other incompatible elements close to or within the range of concentrations found in the anorthositic clasts.

The "granulites" (i.e., more-mafic anorthositic clasts) have major element compositions close to that of the average lunar crust, but with significantly lower concentrations of incompatible elements (Fig. 3). We have used only the crystalline granulite clasts in computing the average composition shown in Fig. 3 because the higher incompatible element contents of the brecciated samples suggests a small amount of KREEP was introduced during the brecciation. The LREE, Nb, Hf, Zr, U, and Th abundances of these clasts can be reproduced by mixing a small amount (2-4%) of Apollo 16 KREEP with the anorthosites. However, the lower Al, higher Fe and Mg, and sloping HREE patterns of the crystalline granulites relative to the calculated mix (Fig. 3) precludes this simple model. The granulite clasts may have incorporated a significant amount of the well-known but elusive "Mg-component" required from mass-balance studies of highland breccias [5, 6], or they may represent plutonic precursors which themselves contributed a sizable ferromagnesian component to the lunar crust.

The sulfide-replacements observed in some of the more-mafic anorthositic clasts probably resulted from invasion of S-rich vapours into the granulite parent rock, rather than during or after their assembly into 67016 because olivines in the bulk breccia matrix are unaffected. Possible scenarios for the introduction of these vapours include: mobilization of a volatile regolith component, invasion of KREEP into the (lower?) crust, incorporation of cometary material, or outgassing from the lunar interior. High concentrations of volatile elements in some Apollo 16 breccias (e.g., Rusty Rock 66095) have been suggested to result from the mobilization of volatiles during impact metamorphism and incorporation of a large KREEP component. However, the KREEP content of the granulite clasts in 67016 is small to nil, and the Pb contents of the affected clasts in 67016 are much lower than those in other volatile-rich Apollo 16 breccias (e.g., <1 ppm Pb in the 67016 clasts compared to 15 ppm in Rusty Rock 66095). This argues against impact-induced mobilization of volatile elements as the mechanism for introducing the sulfur into the 67016 granulites. Addition of endogenous volatiles from the lunar interior is possible, but strong evidence favoring this alternative is lacking at this time.
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**Fig. 1**

Bulk rock
Granulites
Melt breccia
Anorthosites

**Fig. 2**

Th vs Ce

**Fig. 3**

Sample/Lunar Crust

Table 1. Major and trace element compositions of 67016

<table>
<thead>
<tr>
<th>Element</th>
<th>SiO2</th>
<th>TiO2</th>
<th>Al2O3</th>
<th>FeO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na2O</th>
<th>K2O</th>
<th>Cr</th>
<th>Ni</th>
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<td>5.4</td>
<td>21.5</td>
<td>1.2</td>
<td>2.6</td>
<td>2.1</td>
<td>0.1</td>
<td>0.06</td>
<td>9.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Trace element data by spark-source mass spectrometry, majors by fused bead electron microprobe except % from [2].


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