CHARACTERIZATION OF MICROCRACKS IN LUNAR IGNEOUS ROCKS;
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Microcracks are very common in lunar samples, affect signifi-
cantly the physical properties of the rocks, and may provide
significant petrogenetic clues. Three techniques appear to be
useful in studying cracks in rocks: (1) Differential Strain
Analysis (DSA) in which strain is measured with very high preci-
sion in several directions as a function of hydrostatic pressure
[1]; (2) Optical Microscopy of rock sections approximately 100-
150 μ thick [2]; and (3) Scanning Electron Microscopy of ion-
milled surfaces. Petrographic examination of normal thin sec-
tions can also be used to recognize some types of cracks. In
this paper, we describe the cracks in several lunar rocks that
almost surely were present in the rocks in situ on the Moon.

DSA. This technique [1] was used to examine the crack dis-
tributions in 14310, 15075, and 75055. The parameter determined
with the DSA technique [ζ(P)] is the linear strain in the di-
rection X at P=0 due to the presence of cracks closing at pressures
less than P. ζ(P=0) in 3 orthogonal directions is the crack
porosity at P=0 due to cracks closing at P<P0. Figure 1 is a
typical DSA curve which shows the major features observed in the
three samples. 15075 and 75055 contain a population of cracks
closing at P<100 bars, and all three samples contain a much lar-
ger (in porosity) population due to cracks closing at P>a few
hundred bars. Table 1 lists values of several DSA parameters.
The salient features of the data are the apparent bimodal dis-
tribution of cracks in closure pressure for 15075 and 75055, and
the clear absence of low closure pressure cracks in 14310. All
three samples appear to contain cracks continuously distributed
in closure pressure from P2 to at least 2kb, where our data stop.
The characteristics of thermal cycling cracks (TCC) and shock

Figure 1. A DSA curve for
15075. Differential
Strain is the difference
in the strain of the rock
sample and that of the
fused silica reference
sample. ζ(P1) is the zero
pressure strain due to
cracks closing by P1.
ζ(P2)=ζ(P1) since the lin-
ear segment between P1 and
P2 indicates that no cracks
close between these pressures. ζ(2kb)-ζ(P2) is the strain due
to cracks closing between P2 and 2kb. The curves are not linear
by 2kb, implying that all cracks are not yet closed by 2kb.
Table 1: P in bars, $10^6$, D=direction

<table>
<thead>
<tr>
<th>Sample</th>
<th>P1</th>
<th>P2</th>
<th>P1</th>
<th>P2</th>
<th>$\xi(2kb)-\xi(P2)$</th>
</tr>
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<tr>
<td>15075</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>15075</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>14310</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>75055</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>75055</td>
<td>2</td>
<td>2</td>
<td>2</td>
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</table>

induced cracks (SHIC), obtained from the data of Todd et al. [3] are: TCC have closure pressures $<200$ b and SHIC have closure pressures $>1kb$. Hence, 14310, 15075, and 75055 probably contain SHIC, but only 15075 and 75055 contain TCC.

Observations with Petrographic Microscope. The petrographic microscope can be used to examine cracks in both standard thin sections and crack sections. The crack sections, 100 to 150µ thick, are prepared in such a way as to minimize the production of new microcracks [2]. Reconnaissance of 100 standard thin sections reveals a wealth of crack-features in lunar samples that includes (a) healed cracks (15415, 60335, 15556) demonstrated by planes of $\mu$ sized inclusions, displaced plagioclase twin lamellae, and trains of crushed grains, (b) circulare tubes, nominally $\mu$ in diameter, that are common in plag (15085, 15555, 75055) (some tubes contain solids, others are hollow), (c) concentric and radial cracks (15085, 12020, 14053).

Shock induced cracks are very common. In a crack section of 14310 we observe relatively few cracks with the petrographic microscope. The plagioclase appears to be quite free of cracks; although a few curving cracks arch across lath, no longitudinal cracks were observed. The pyroxene contains many curved cracks which cross the grain but apparently stop at the grain boundaries.

In a crack section of 75055, the plagioclase contains few flat microcracks, but in some grains, tubes are locally abundant and are both hollow and filled with a solid phase. Solid inclusions are associated with tubes and may be genetically related. The pyroxene contains more cracks than the plagioclase although a few grains of pyroxene are also relatively uncracked. Cristobalite contains characteristic thin, short, curved cracks.

SEM. The crack sections of 14310 and 75055, polished by hand and thinned for 12 hours on an ion mill, were examined by the SEM. These samples have distinctly different crack characteristics. 14310 contains few transgranular cracks but it does contain abundant small grain boundary cracks and non-cleavage intragranular cracks, most of which are unresolvable with the petrographic microscope. Pyx-plag grain boundaries commonly contain cracks which vary in width from $0.1\mu$ to $1\mu$. Plag-plag boundaries are less commonly cracked and pyx-pyx boundaries were not recognized. The width of intragranular cracks closely correlates with mineralogy. Pyroxene crystals have cracks 0.5µ
MICROCRACKS

Simmons, G., et al.

wide that usually extend across the crystal from the grain boundary and they commonly have blunt terminations. The plagioclase crystals contain as many cracks but they are usually much thinner (.05-.1μ) and rarely cross the whole crystal. The plag cracks are usually a network of smaller cracks not always connected with the grain boundary and commonly having long gentle terminations.

75055 is characterized by many wide 1-2μ transgranular cracks which commonly have irregular walls and contain debris. Grain boundary cracks have not been separated from the transgranular cracks. We infer an impact origin for these cracks. Intragranular cracks are not as abundant as in 14310. The pyroxene grains have many non-cleavage 0.2-0.5μ cracks, usually associated with the grain boundary. The plagioclase contains troughs associated with solid tubular inclusions, and other non-cleavage cracks. Neither feature is associated with grain boundaries. The cristobalite grains contain a regular array of curved cracks 0.1-0.2μ wide.

Conclusions. Several types of cracks are present in lunar samples. Detailed examination of cracks with DSA, SEM, and the petrographic microscope shows the following characteristics for two samples:

14310 has (a) relatively low crack porosity for lunar samples, (b) no cracks with closure pressure below 200 bars and therefore contains no significant volume of TCC's, (c) many very narrow (<1μ) cracks, (d) significant volume of cracks with closure pressure above 1.5kb and therefore contains some SHIC's, (e) grain boundary microcracks.

75055 has (a) cracks with closure pressures below 200 bars and therefore may contain TCC's, (b) cracks with closure pressures above 1.5kb and therefore contains SHIC's, (c) plagioclase grains that contain locally abundant microtubes, (d) many very wide cracks (~1μ).

REFERENCES: