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EVIDENCE ON THE COMPOSITION AND MINERALOGY OF THE LUNAR HIGHLANDS

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Today I would like to show some lines of evidence that give us some indication of the composition and mineralogy of the lunar highlands, a region not directly sampled by Apollo landings.

Figure 1 shows our analyses of rare Earth elements in various lunar samples. The elements are listed in order of increasing atomic number and the abundances are relative to primordial abundances as determined from stony meteorites.

We show here our analyses of soils from Apollo 11, 12, and 14 and Luna 16 missions. Note that the abundances of the rare Earth elements are in general smooth functions of atomic number. This is the reason we study these elements – they show small regular differences in chemical and physical properties with atomic number.

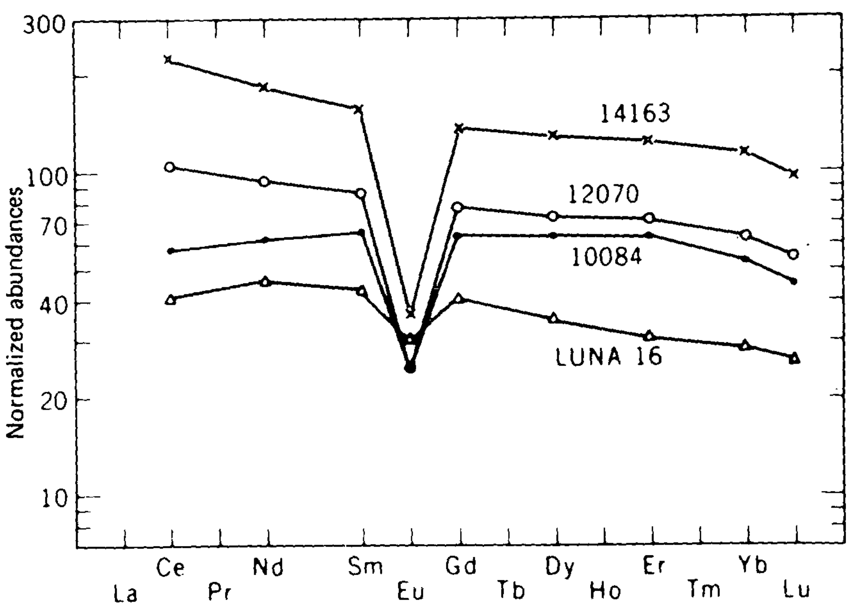

Figure 1–Abundances of rare Earth elements in lunar samples.

Exception to this smooth function is europium, which is depleted relative to the abundances expected from the extrapolation of the other rare Earth elements. This europium depletion is observed in every whole-rock sample, with one exception, returned by lunar missions to date, whether the samples be soil, breccia, or igneous rock. This is known in the lunar business as the europium anomaly.

Now why is *this*? Figure 2 shows our measurements of the partitioning of rare Earth elements between liquid magma and minerals crystallizing in the magma. We have studied the common rock-forming minerals including the minerals that make up the bulk of the lunar rocks. The main point to be seen here is that for most of these minerals, the partitioning of the rare Earth elements including europium, is a smooth function of atomic number. For any particular mineral, even though there is a wide range in absolute abundances, the patterns are roughly the same. The only exception is the common mineral feldspar. Every feldspar-melt pair measured to date (approximately 25) have positive europium anomalies.

Europium is the only rare Earth element that can be reduced in nature from the normal +3 valance state to the +2 state and, for some reason not completely understood, feldspar prefers the +2 state. It is the only mineral known to have this preference. Thus since the mare basalts and soils are depleted in europium, there is reason to think that feldspar with the europium occurs somewhere else on the Moon, somewhere that is older than the

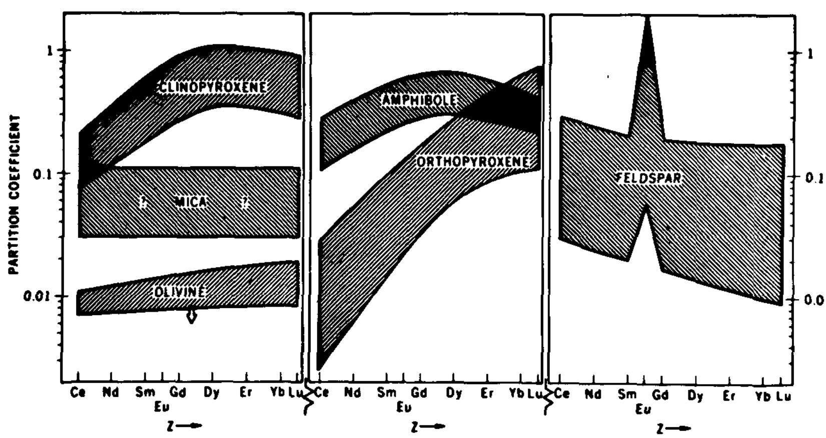

Figure 2—Mineral/liquid partition coefficients for rare Earth elements.

mare basalts. Large amounts of feldspar cannot be at depth as it would convert with high pressure to a high-density form that is not compatible with a bulk density of the Moon. As feldspar is light it is reasonable to suggest that it floated upward to the surface of the Moon and concentrated in the highlands.

Figure 3 shows a rather representative sampling of small particles found in the Apollo 11 soil. The scale represents 1 mm. The sample contains small pieces of fine- and medium-grained basalt and some glasses that have representatives in the large bulk igneous rocks that were brought back. However, there is one piece which is exotic, the white, translucent piece, which has no representative in the larger samples brought back from the Apollo 11 mission. This piece is composed almost entirely of feldspar. Terrestrial rocks composed mainly of feldspar are called anorthosites and are rather rare. They are all very ancient (over about 1.7 billions yr old) and their origin has been a subject of much debate. Approximately 5 percent of the less than 1-mm size particles in Apollo 11 and 12 soils are anorthositic; that is, they are very high in feldspar. Interestingly, cratering studies indicate that approximately 5 percent of the particles of this size should come from greater than 100 km away.

A third line of evidence on the composition of the highlands comes from the alpha back-scattering chemical determinations by Surveyor 7 on the rim of Tycho in the highlands. Calcium and aluminum are high, compatible with a high feldspar content. This brings us to the Apollo 15 mission. The indirect evidence preceding Apollo 15 (discussed in this paper), indicated the highlands should be high in feldspar. One large fist-size anorthositic rock was returned on Apollo 15, the famous "Genesis" rock. In this rock europium is approximately 50 times the relative abundances of the other rate Earth elements. The rock is also very old, about 4.2 billion yr old.

The second line of evidence that came from Apollo 15 is a subject of the next talk. Dr. Adler will discuss the X-ray fluorescence experiment flown in lunar orbit.

Figure 3–Apollo 11 lunar soil sampling.