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MINING FOR HELIUM - SITE SELECTION AND EVALUATION

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Part of the University of Wisconsin study of the feasibility of recovering He-3 from the moon is selection and evaluation of potential mining sites. Selection and evaluation are based primarily on four salient findings by the numerous investigators of lunar samples:

1. Regoliths from areas underlain by highland materials contain less than 20 wppm He.

2. Regoliths of certain maria or parts of maria also contain less than 20 wppm He, but mare regoliths at the Apollo 11 and Apollo 17 sites contain 25 to 49 wppm He.

3. The helium content of a regolith is a function of its composition. Regoliths with high He content are high in titanium content.

4. Helium is concentrated in the -50 micron size fractions of regoliths.

The first three findings are illustrated in Figure 1, in which helium content is plotted against TiO_2 content for samples of highland and mare regoliths. Note that highland samples are low in both He and TiO_2. Mare samples, however, fall into two groups, one low in He and TiO_2, the other markedly higher in both. There is scattering of points, particularly at the high-TiO_2 end of the range, but a broad correlation of He content with TiO_2 content is evident, and it seems clear that the TiO_2 content of regolith can be used as a general guide in the selection of areas where the regolith contains 20 wppm of helium or more.

In site selection we are therefore concerned with the compositions of lunar regoliths, in particular with their titanium contents. It is widely accepted that compositions of mare regoliths are controlled by the nature of the underlying basalts from which the regoliths are largely derived. A number of types of basalts, differing in mineral and chemical composition, have been recognized by lunar investigators. In terms of titanium content, however, they fall into three general groups (1):

1. Very high-Ti basalts, containing 8% to 14% TiO_2. These were sampled by the Apollo 11 and 17 missions.

2. Low-Ti basalts, containing 1.5% to 5% TiO_2. Such basalts were sampled by the Apollo 12, Apollo 15, Luna 16, and Luna 24 missions.

3. Very low-Ti basalts, containing less than 1.5% TiO_2. They were recovered by the Luna 24 and Apollo 17 missions.

The distribution and extent of the three groups of basalts and the regoliths derived from them are the first basis for site selection and evaluation. Since sampling is thus far confined to very small areas of a few of a maria, information on distribution and extent is mostly from remote sensing of two general types - gamma-ray spectroscopy done by the Apollo 15 and 16 orbiter; and earth-based telescopic measurements of lunar reflectance. The results of both types of measurements have been calibrated, so far as possible, against lunar samples of known titanium content.

Figure 2 shows the results of gamma-ray spectroscopy as interpreted by Metzger (33). Coverage by the two orbiters was limited to two bands lying between 30 degrees N. and 15 degrees S. Two principal areas of high-Ti regolith are indicated, one the area of Mare Tranquillitatis with its extension northward into the Taurus-Littrow region of Apollo 17, the other a part of Oceanus Procellarum. Other interpretations of the gamma-ray data differ somewhat from the one shown here, but the broad picture remains the same.

There are various maps showing the distribution of high, low, and intermediate-Ti basaltic regoliths as interpreted from earth-based telescopic observations of reflectance at various wavelengths and combinations of wavelengths ranging from the ultraviolet to the near-infrared. Figure 3 was prepared from superposed ultraviolet negatives and infrared positives. It shows color groups of basaltic regoliths, with TiO_2 values thought to be represented by the groups. High-Ti areas are shown in solid black. Mare Tranquillitatis again appears as high-Ti area extending into the Taurus-Littrow region. The map also indicates large areas of high-Ti regolith in the western Hemisphere, especially in Imbrium and Procellarum, but none of them has been sampled.

Quantitative spectral ratio mapping has been used by some investigators (2, 21, 24, 25, 28, 32). Compared to gamma-ray spectroscopy, spectral ratio mapping has the advantages of broader coverage of the lunar nearside and higher resolution. Resolution is important in site selection. On the basis of present information, Mare Tranquillitatis is of prime interest as a potential source of helium. However, a map by Johnson et al. (32), produced by imaging measurements of the 0.38 um/0.56 um spectral ratio, indicates that the TiO_2 content of regolith in Mare Tranquillitatis varies from part to part of the mare. Figure 4 shows a region of high-Ti regolith separating two regions of lower-Ti regolith. We have no hard data for the TiO_2 content of the latter two regions, but obviously they must be assigned a low priority in selection of sites for mining.

The scenario envisioned by the Wisconsin group calls for recovery of 244 metric tons of He-3 between 2015 and 2050. If we assume an average mining depth of 3 m, and an average He content of 30 wppm in regolith, then in Figure 5 Line A shows the areas that would contain the helium required during successive 5-year periods through 2050, and the total of those areas. Total recovery being impossible, line B shows the areas that would be involved if recovery were 80 percent. Line C shows the areas that would have to be mined if recovery were 60 percent, probably a more realistic figure. The diagram shows that mining areas of thousands of square kilometers must be delineated if the requirements of the scenario are to be met.

As indicated earlier, various investigators have demonstrated that helium is concentrated in the finer size fractions of regoliths. For the regolith sampled by Apollo 11, this relation is shown in Figure 6. Of the total helium in the regolith, 72.5 percent is in the -40 um fractions, 80 percent in the -60 um fractions. For recovery of helium, therefore. we have no interest in the coarse materials of regoliths. This, and considerations of ease of mining, means that mining areas should be as free as possible of blocks of rock and sizeable craters. Information on such features must be obtained from lunar photographs, from photogeologic maps, and from radar surveys that indicate roughness of the surface at various scales (2, 21, 31). Photogeologic maps can also shed light on variations in the composition of mare regoliths and can help in delineating areas that should be sampled.

The present study is necessarily a preliminary one. Data available have significant limitations. Only very small fractions of a few of the maria have been sampled. No area has been systematically sampled. Information on depth of regolith is limited. Remote sensing maps, both those based on gamma-ray spectroscopy and on reflectance measurements, have insufficient resolution from the standpoint of site selection. All remote sensing maps show large areas of intermediate-Ti regolith, but no such regolith has yet been sampled. Ash deposits are extensive in the Rima Bode and Sulpicius Gallus regions of the lunar nearside (29), and it is possible that black ash of high TiO_2 content contains significant amounts of helium. However, nothing is known of its helium content in areas where it must have been gardened and exposed to the solar wind for long periods of time. These are serious deficiencies in present information. As a prelude to helium mining they must be remedied by systematic exploration and sampling of mare regoliths. Such work should have a high priority in future lunar missions.

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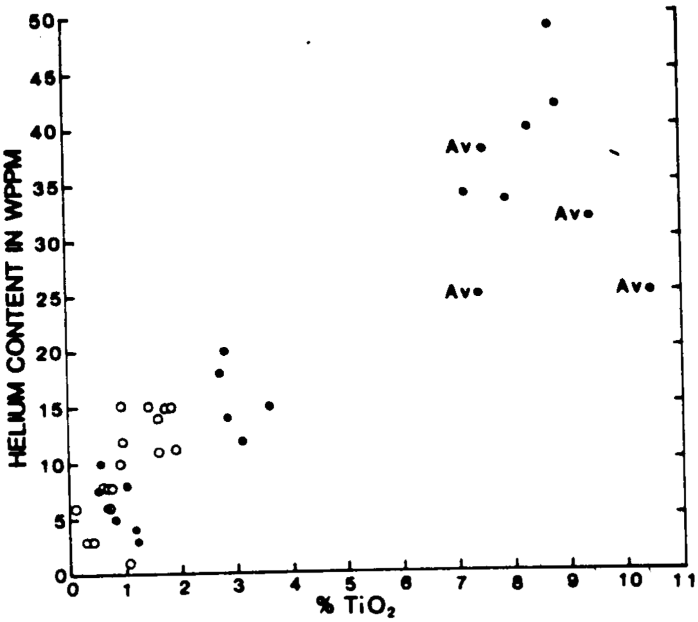

RELATION BETWEEN HELIUM CONTENTS AND TiO_2 CONTENTS OF LUNAR REGOLITH SAMPLES

o Sample of highland regolith
• Sample of mare regolith
Av Average of reported values

Figure 1. Data from references 3, 4, 5, 6, 7, 8, 9, 10, 11, 1, 13, 14, 15, 16, 17, 19, 20, 22, 23, 25, 26, 29.

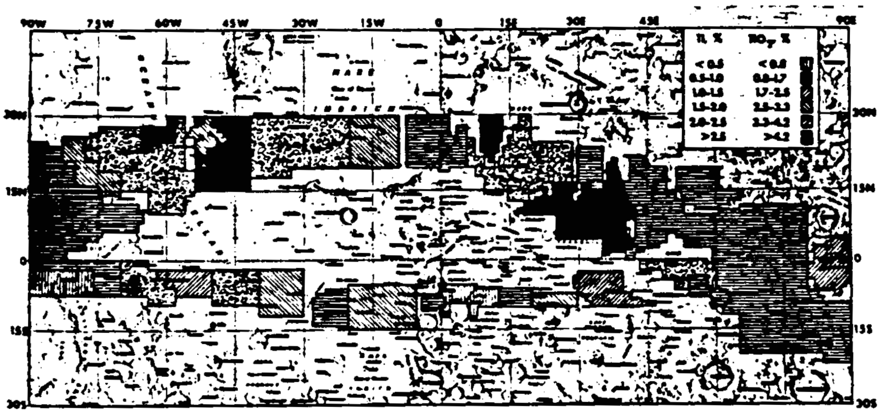

Figure 2. Map of the titanium content of the lunar regolith covering nearside regions overflown by Apollo 15 and 16. From Metzger and Parker (33).

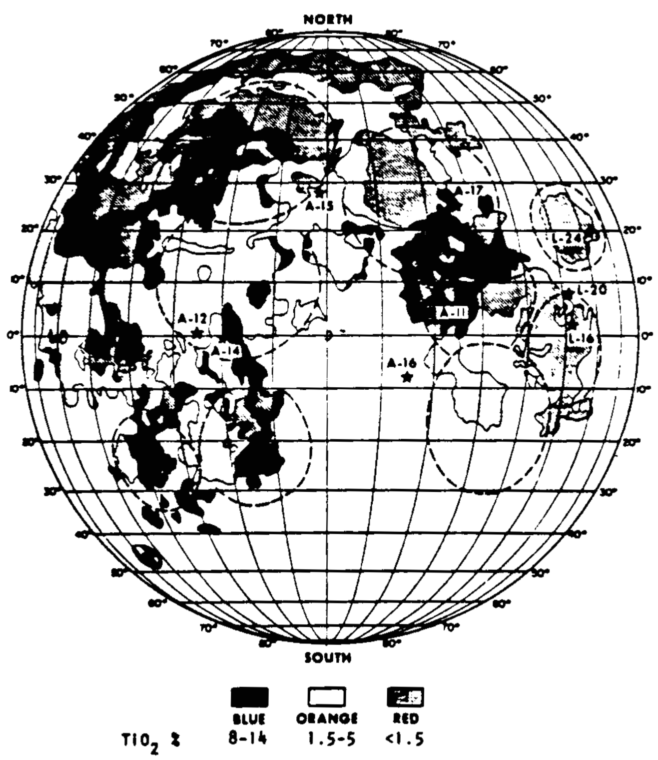

Figure 3. Color groups of mare regoliths and TiO_2 values thought to be represented by the groups. From Basaltic Volcanism (1).

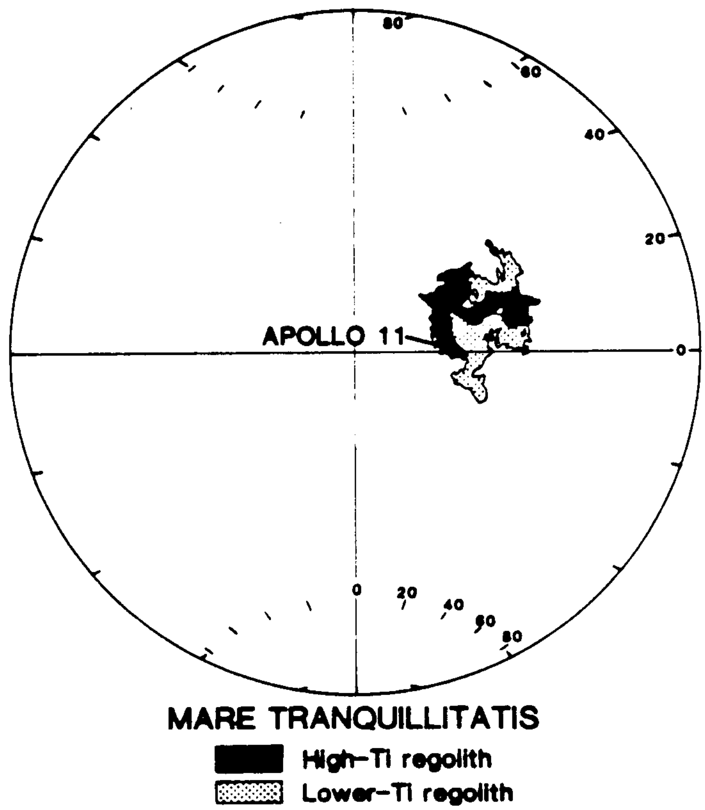

Figure 4. Regoliths of Mare Tranquillitatis. Based on map of lunar nearside by Wilhelms (29, Pl. 4A).

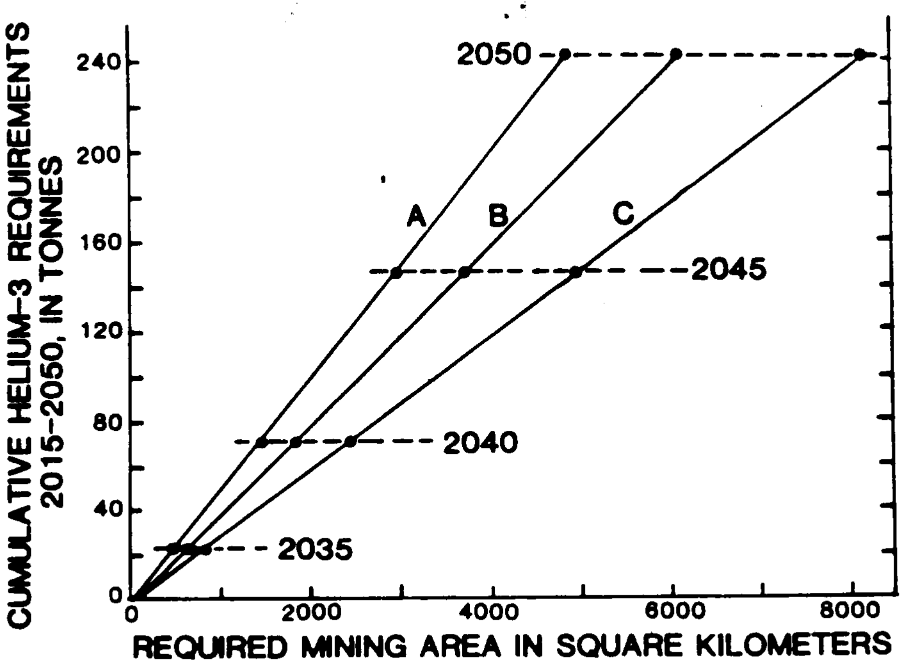

Figure 5. Required mining areas of lunar regolith, 2015 to 2050, assuming a mining depth of 3 m and an average of 30 wppm helium.

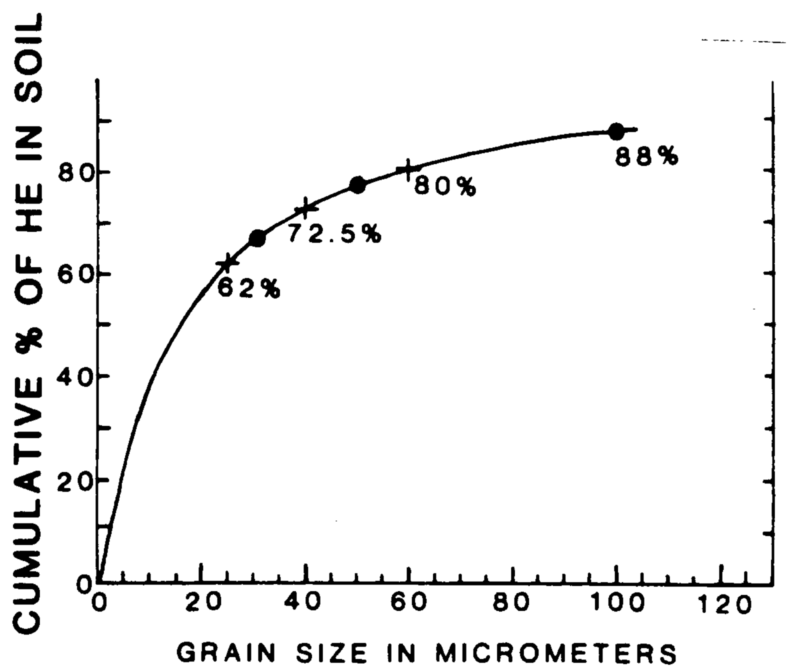

Figure 6. Percentage of total helium in relation to grain size in Apollo 11 regolith sample 10084. Based on Data from Criswell and Waldron (4) and Hintenberger et. al. (10).