**AVAILABILITY OF METAL OXIDES IN THE LUNAR REGOLITH FOR RESOURCES UTILIZATION**, by Kevin J. Cole, Science Applications International Corporation, Schaumburg, Ill.

As human activity beyond Earth orbit increases into the next century, a greater emphasis will be placed upon the exploitation of extraterrestrial resources in order to reduce the dependence upon Earth supplied fuels and materials. The Moon will play an important role in this scenario due to its close proximity to the Earth and the potential availability of many natural resources. Specifically, these resources have the potential of supplying oxygen for liquid propulsion applications and life support and, metals (Al, Fe, Ti, Mg, Si) necessary to manufacture metallized mono-propellants and structural materials. If these products are to be developed from local lunar mineral deposits, it is necessary to know the relative availability of Si, Ti, Al, Fe, and Mg and their distribution across the lunar surface. These factors will influence the location of the initial lunar base, mining and manufacturing operations. This study, therefore, focused on determining the relative concentrations, as a function of sample site locale, of these metal oxides as they appeared in samples returned from Apollo missions 11, 12, 14-16 and Luna missions 16, 20, and 24. It is expected that the analysis conducted in this study will assist in the selection of a lunar resources utilization scenario and site selections.

**REGOLITH GEOCHEMISTRY**: Samples returned from the Moon included regolith, rocks, breccias, and agglutinates. These samples have been examined extensively over the past twenty years for their mineral, geochemical, and elemental compositions. These studies provided the raw data for the statistical analysis conducted in this study. Data from individual samples (regolith only) were compiled so that a statistical average of the sample weight percent (wt%) of the metal oxides of interest could be determined for each sample site. The results of this analysis are illustrated in Figure 1 (lunar mare) and Figure 2 (lunar highlands). As these figures suggest, the geochemistry of the sampled material is dominated by $SiO_2$ with concentrations varying between 40 to 50 wt%. In the lunar highlands, $Al_2O_3$ occurs in concentrations ranging from 15 to 25 wt% but, is also rather high in the mare regions where concentrations as high as 15 wt% are evident. Availability of $TiO_2$ and FeO are greatest in the maria where they constitute 5-8 wt% and 12-16 wt% respectively of the sampled regolith geochemistry. The highest concentrations of $TiO_2$ occur in the older mare sampled by Apollo 11 and Apollo 17. Concentrations fall to less than 2 wt% in the highlands. FeO is also somewhat depleted in the highlands as compared to the mare. MgO is available in concentrations of 10 wt% in both regions.

**LUNAR MINERALOGY**. Analyses of the whole-rock mineralogy of the lunar samples have shown the lunar material to be composed of three primary rock forming silicate minerals: Plagioclase, pyroxene, and olivine. Secondary minerals, unique to the mare regions, include ilmenite. The plagioclase is composed of orthoclase ($KAlSi_3O_8$), albite ($NaAlSi_3O_8$), and anorthite ($CaAl_2Si_2O_8$). Anorthite, is the dominant plagioclase and is the primary mineral of the igneous rock anorthosite. It is also the primary source of aluminum. The pyroxenes are represented by the minerals diopside ($CaMg(SiO_3)_2$) and hypersthene ($(Mg, Fe)SiO_3$) and are a major source of Mg, Ca, and some Fe. Olivine is present as either fayalite ($Fe_2SiO_4$) or forsterite ($Mg_2SiO_4$) from which Mg and Fe may be obtained. Silicon, of course is common to each of these. The only non-silicate that is relatively abundant, at least in the mare, is ilmenite ($FeTiO_3$) from which Fe and

Ti can be extracted.

**CONCLUSIONS.** This study indicates that the most available feedstock for potential development is, of course, Si, located in relatively equal abundances across the lunar surface and in high concentrations. Aluminum, the next most available feedstock, is available in large quantities in lunar highlands and would be a prudent alternative or enhancement to Si, from a resources point of view. Although Ti is relatively abundant in the lunar mare, its lower concentrations as compared to Al, Si and Fe may make this mineral less attractive as a propellant or structural material.

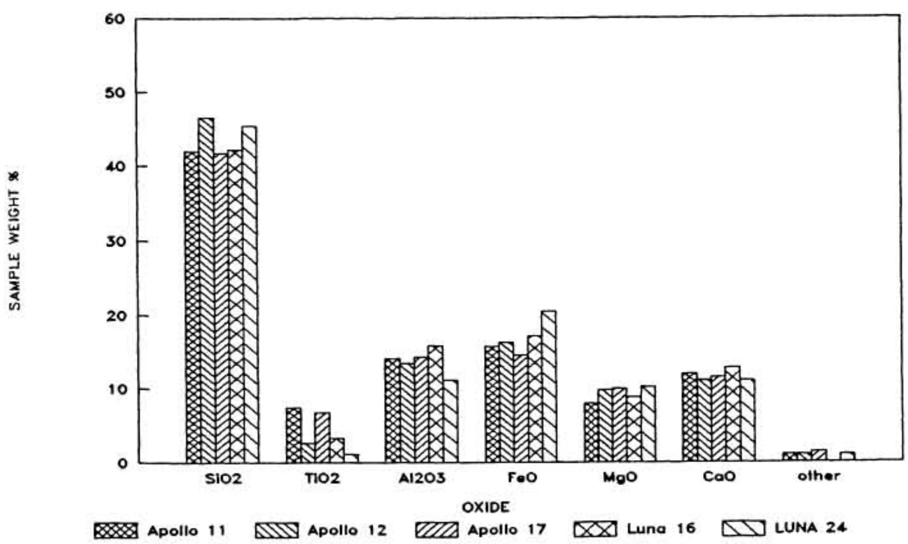


FIGURE 1: Sample weight percent of the major oxides in the lunar regolith from samples representing mare material.

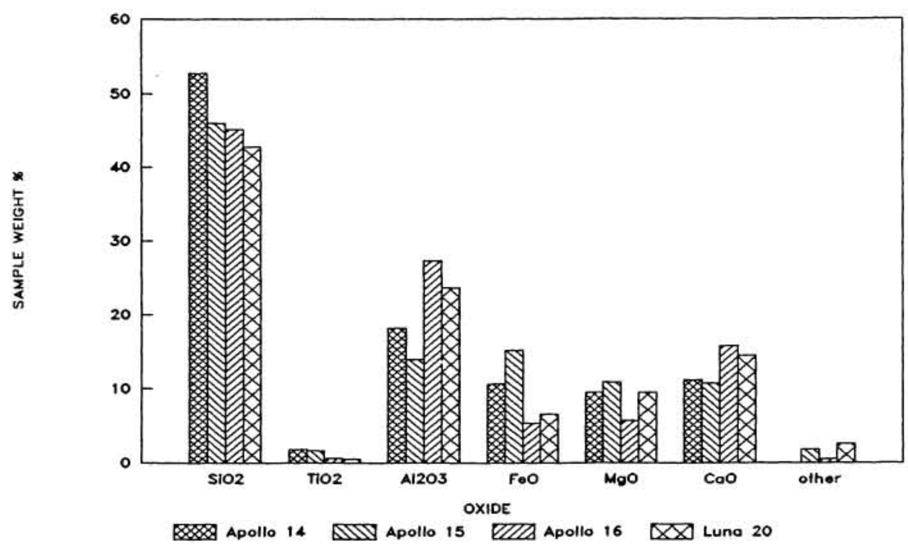


FIGURE 2: Sample weight percent of the major oxides in the lunar regolith from samples representing highlands material.