THE APOLLO 15 X-RAY FLUORESCENCE EXPERIMENT

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I want to give you a brief report of the results of an X-ray fluorescence experiment that we flew as one of the components of a number of orbital science experiments carried in the service module of the Apollo 15 spacecraft. The framework for what I am going to say has been very neatly laid by Charlie Schnetzler because it is in light of his presentation that we want to examine the results.

The objectives of our experiment were to obtain a partial chemical map of a large portion of the Moon. As Dr. Schnetzler has pointed out, what we know about the Moon was learned by sampling given selected sites, but what is really needed is a large global survey. This was the objective of our experiment as well as some other component experiments of this Apollo 15 mission, such as the gamma ray and alpha particle experiments.

Our present estimate is in fact that we did succeed in mapping a fairly large portion of the lunar surface; approximately 10 percent. This represents the part of the surface that was illuminated during the course of the Apollo 15 mission and includes the area over which the spacecraft flew. We actually succeeded in getting mapping information from approximately 150° east on the Moon to about 50° west.

Just to briefly describe the experiment, we know that the Sun bombards the lunar surface with high fluxes of very soft X-rays and that these X-rays are sufficiently energetic to produce secondary X-rays by photoelectric processes. These secondary X-rays are characteristic of silicon, aluminum, and magnesium. I talk about these three elements because the nature of the spectral distribution is such that these and the lighter elements are the only ones that are excited.

We flew in the SIM Bay of the service module three large-area proportional counters; two of these had selected filters, one for aluminum, and one for silicon, in order to give us both information about the X-ray intensities and the spectral distribution of the X-rays from which we were then able to deduce something about the composition.

We actually succeeded in determining aluminum/silicon ratios and magnesium/silicon ratios for large portions of the Moon. As we see in Figure 1, the

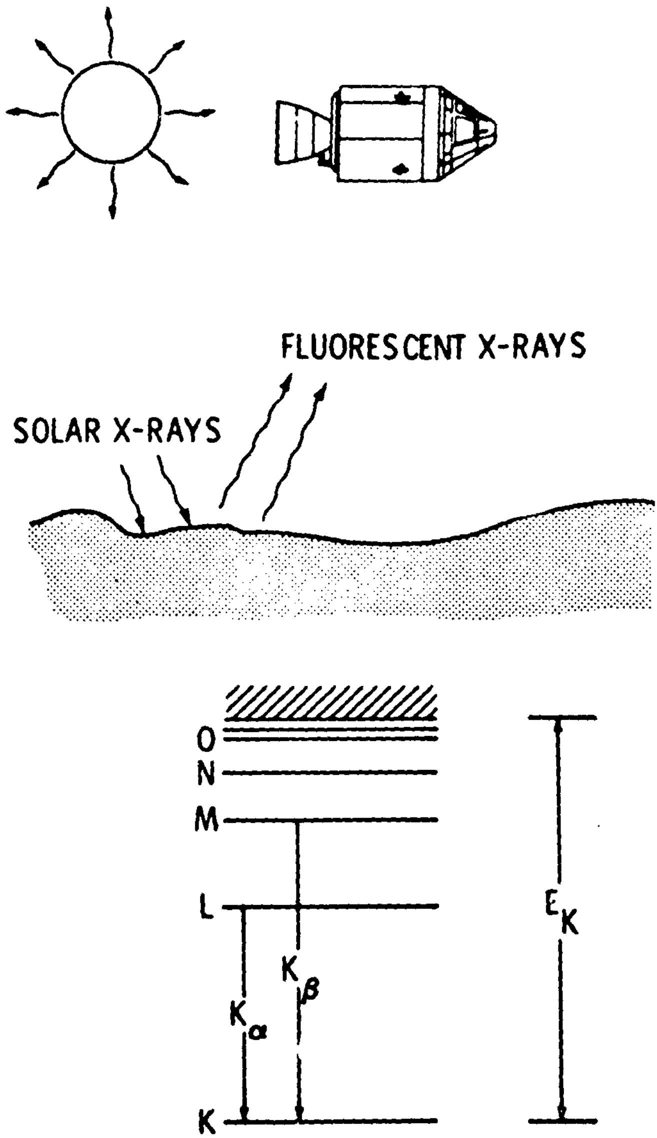

Figure 1—X-ray fluorescence at lunar surface. Lower diagram shows the electron transitions giving rise to characteristic *K* X-ray spectra.

spacecraft flew around the lunar surface. Some of the energies necessary for exciting these characteristic X-rays are given in Table I. We can see that the energies are relatively low, of the order of 0.2 to 0.3 fJ (1 to 2 keV). The kinds of transitions involved in the production of these characteristic X-rays are also shown in Figure 1.

TABLE I—Energies of Absorption Edges and Characteristic Lines

Element	$E(K_\alpha)$, keV	Absorption edges E_k, keV
O	0.54	
Na	1.04	
Mg	1.25	1.37
Al	1.49	1.57
Si	1.74	1.85
K	3.35	
Ca	3.70	

I should say a little bit about the resolution of our experiment. The collimators permitted a 60° field of view which at orbital altitudes represented a sector on the lunar surface of about 110 km (60 n. mi.) on edge. However, to talk about the spatial resolution, one has to be concerned with the spacecraft motion.

The preliminary data which I will discuss resulted from the upgrading of our spectra at 1-min intervals, and at 1-min intervals then we were looking at a portion of the surface which was approximately 110 by 220 km (60 to 120 n. m.).

Our prime data have now begun to come in. These data were taken at 8-s intervals, so we are going to do another iteration on the data processing at a much better spatial resolution, something on the order of 110 by 150 km (60 by 80 n. m.).

Let me show you the sorts of games we have been playing with the data. In Figure 2 we have actually been able to make a plot of aluminum/silicon intensity ratios versus longitude and have identified some of the features over which we have flown. These values are intensity ratios. We have now reduced them actually to concentration ratios and so if you look at this plot of the aluminum/silicon ratio versus longitude, you can see what aluminum/silicon ratios correspond to the various features on the Moon. These numbers can in fact be compared with numbers of known sites and known analyzed lunar materials (as shown to the right in Figure 2).

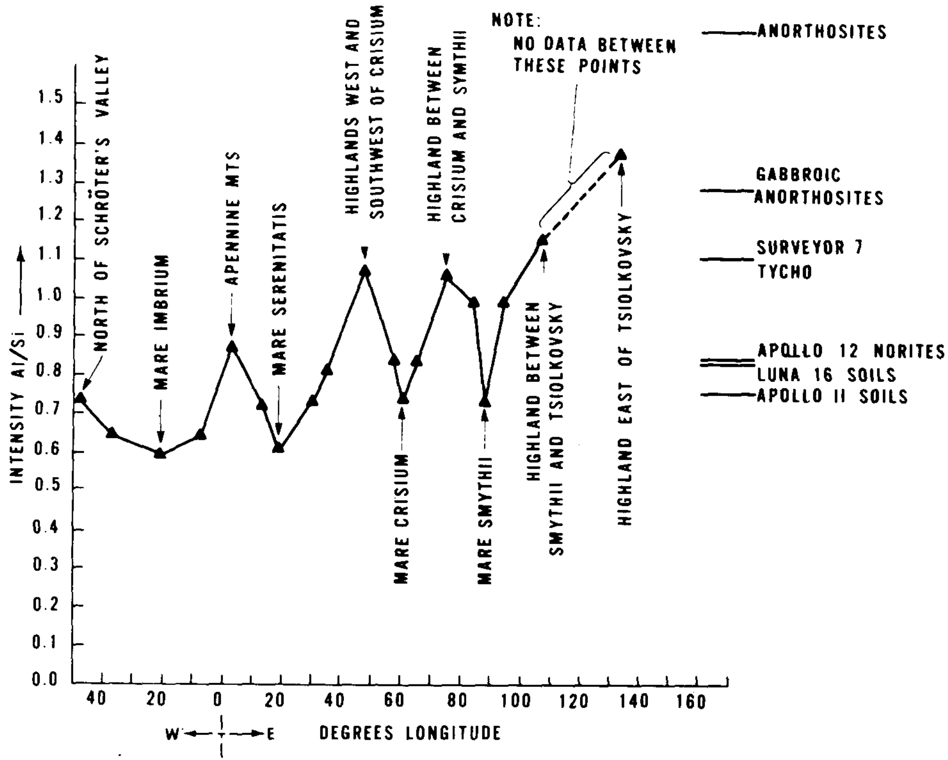

Figure 2–Plot of Al/Si intensity ratios along a northerly ground track.

We see as one goes from west to east that there are gradually increasing concentrations of aluminum. The mare areas tend to be low, which is in fact characteristic of the basalts as we have come to know them.

The interesting thing is that in the highland areas we find rather high aluminum/silicon ratios; this fact has considerable bearing on the subject that Dr. Schnetzler talked about, the fact that the highlands are probably very rich in these feldspars which have been found at the various sites. The fact that they are rich in these feldspars is of great significance in trying to understand the origin of the highlands.

We had one problem, I hope when we see our prime data we will be able to do something about it. When we flew over this very strange crater, Tsiolkovsky, we were able to get data on both sides of the crater, but in the middle of the crater the instrument decided to calibrate itself, which is one of the frustrations you sometimes have to put up with.

We have also made a plot of aluminum/silicon intensity ratios against optical albedo to see if there is a correlation (Fig. 3). We find that for large-scale features there is excellent correlation; where the albedo is high, as for example in the highlands, the aluminum/silicon ratios are high. In the mare areas we find that they are low.

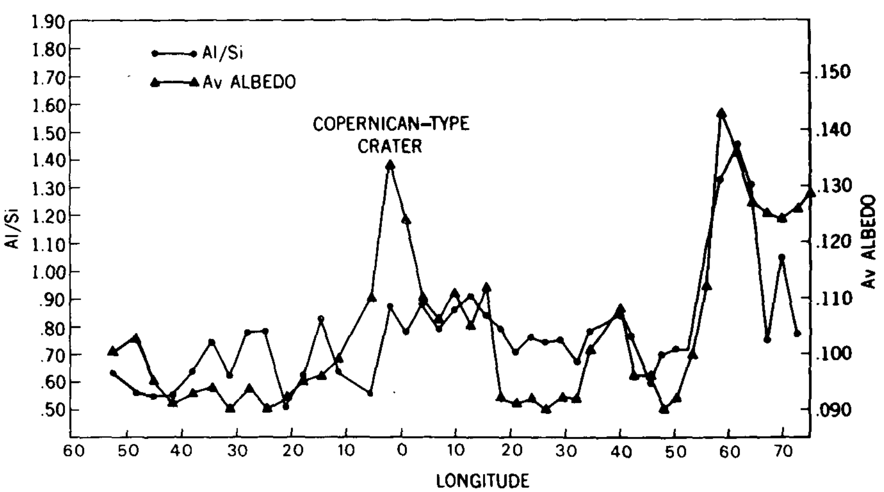

Figure 3–Comparison of average albedos and Al/Si intensity ratios for revolution 72.

Every now and then you find some anomaly such as a high value in albedo which is not reflected in the chemistry. Herb Blodget has pointed out that from the actual albedo maps, the high albedo in this case is clearly identifiable as a Copernican-type crater. I think this is a very good way of actually relating albedo to chemistry. We can in fact distinguish whether the albedo actually represents chemical differences or perhaps some sort of cratering event. The result of the high albedo is sometimes due to mechanical factors rather than chemistry.

Let me sum this up by telling you some of our conclusions today. The most important one I think is that we seem to bear out that the plagioclase rocks that have been found at the Apollo sites actually have as their source or point of origin the highlands. This is very important.

We also have this information on the albedos, which is very, very nice.

An interesting implication of these experiments is that we are looking at very soft X-rays which is essentially a surficial type of analysis. In fact if it were not for the gardening which occurs on the Moon, we would perhaps have trouble because the sampling would not be representative. But the soil is nicely turned over, so even though we are looking at the surface, we are getting information from below the surface.

But because it is a surficial analysis, we now think we have an upper limit on the effectiveness of horizontal transport which is supposed to be a highly active mechanism on the Moon for transporting material. The fact is that if this horizontal transport were very effective, then we would have great difficulty seeing chemical differences between the highlands and the mares. The fact of the matter is that we do see detailed differences. So there is I think a very distinct limit to the effectiveness of the transport.

The data which I presented here have been essentially for aluminum and silicon. We are now working on the magnesium/silicon ratio which is again a very important diagnostic element if one is concerned with magmatic differentiation. We hope to be able to publish something about that.

As an additional bonus on this experiment, we were actually able to do some X-ray astronomy. The results are being reduced. Actually the astronauts were very obliging and agreed to point the spacecraft at some of these newly exciting X-ray objects such as Cygnus X-1 and Sco X-1. We have begun to reduce the data, but before we can publish the results, we must determine what the spacecraft was doing at the time. They fixed on these objects, but we want to be sure that there was no spacecraft rotation, which would then be responsible for some of the variations that we have seen.