Factors Influencing Lunar Surface Analysis Using X-ray Fluorescence Spectography. J. A. Carter[1], M. Grande[1] and the C1XS Team, [1]IMAPS, Aberystwyth University, Wales, SY23 3BZ. Contact: jac08@aber.ac.uk

Introduction: In recent years there have been several X-ray fluorescence spectography instruments flown on lunar missions, and in the near future there will be more, both on missions to the Moon and beyond, for instance to Mercury. An X-ray spectrometer instrument can remotely detect the mineralogy of the surface of atmosphere-less terrestrial bodies by recording the X-ray fluorescence caused when the surface is bombarded by solar X-ray events. The Chandrayaan-1 X-ray Spectrometer (C1XS), which flew on ISRO's Chandrayaan-1 mission in 2008, was one such instrument [1].

Remote sensing with X-ray spectrometers samples only the upper few microns of the surface [2]. Clearly any surface feature or process that alters the elemental abundances of the upper surface will affect the signal received by such instruments, and may disguise the bulk mineralogy under investigation. More quantitative understanding of these effects will be useful for analysing C1XS data, and for planning similar up-coming missions. We have investigated two such sources of signal contamination: crater rays and surface/atmospheric volatiles.

Lunar crater rays rank amongst the brightest and most impressive features of the Moon. A ray will typically consist of a long, bright feature stretching out from a source crater [3]. Rays are thought to consist of several types – immaturity rays, where the brightness is due to the relative youth of the overlying ray material; compositional rays, where the mineralogical content of the ray is different to the underlying surface; and combination rays, which are formed by a mixture of the two effects.

This distinction between ray types is important in the context of interpreting data from recent lunar missions. A large portion of the C1XS final coverage consists of the near-side highlands, which is crossed in several places by rays of Tycho (Figure 1), so it is important to determine whether a compositional difference exists between these rays and the underlying terrain, and whether this is high enough to be detectable by C1XS. It would be useful to ascertain whether other rays on the Moon would have an effect – in areas were highland material is rayed across Mare terrain (for instance to the North of Tycho) we could expect this difference to be more pronounced.

Sodium and other volatile species cling to the grains of lunar surface dust in absorption wells. These deposits form in the lunar night, and in the heat of the lunar day many volatiles are desorbed into the lunar atmosphere. This is thought to be one of the main sources of lunar atmospheric sodium [4]. As fluorescence X-ray spectrometers such as C1XS view the very surface of the moon, volatile species could be detected. It is also possible that incident solar X-rays could strike atmospheric species, adding to the signal C1XS received from the surface.

Surface volatiles escape from the surface under sunlight, which means that viewing geometry is key to detecting them. As X-ray spectrometers view the surface in the daytime only it is unlikely that they could directly measure volatiles in any great concentration, but enough may remain or be present in the atmosphere to influence fluorescence outputs.
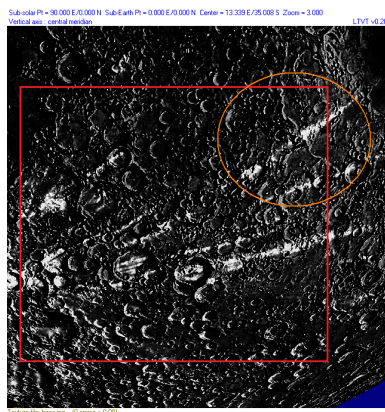
Methodology: Lunar Rays.

Figure 1: A gamma-adjusted image of the nearside lunar highlands. The area where C1XS coverage is concentrated is inside the red box, and the orange circle indicates the ray under investigation.

Figure 2: A gamma-adjusted version of the titanium map. The ray is very faint, and stretches from Tycho in the bottom-left to Mare Nectaris in the top-right.

Mineralogical maps derived from Clementine data are publicly available. Algorithms have been applied to the pure UV-VIS data to separate out maturity effects from mineralogical effects by Lucey et al [5], and they

have been improved upon by Gillis et al [6]. Iron and titanium maps for the region stretching between Tycho and Mare Nectaris were studied. While other rays emanating from Tycho showed marked iron differences to their surroundings, the ray being studied did not. In the titanium map there is a very slight difference between the ray and the surroundings. Figure 2 shows a gamma-adjusted version of the titanium map showing the region in question.

The color values of the map images correspond directly to the mineralogy of the terrain. In the Ti map, in the file format used (.png), the %wt of TiO_2 is found by dividing the color value of a given pixel by 10. As C1XS measures elemental abundances rather than minerals, this was then converted to the wt% of Ti alone.

A section of the ray was selected and the average color values for the pixels recorded. The Ti abundances of the non-ray areas to the North and South were then measured. This process was repeated several times and the average Ti in the ray, North of the ray, and South of the ray was found. The difference between the ray values and the surrounding terrain were then calculated, with a value of 0.0596 wt% to the North and 0.0214 wt% to the South. These values are well below the error margins of the algorithms used to produce these maps. C1XS fluorescence modeling software was used to see if C1XS could detect such a small difference, and the difference, while resolvable in principle under good conditions, was below the noise level at the low illumination levels present during the actual observation.

Methodology: Sodium and other volatile species.

Volatile Na is detectable by C1XS only on the upper surface of the Moon: the depth of C1XS measurement is 2-5 microns (figure 3), on the order of individual grains of lunar dust. This suggests that even small amounts of volatile species would make up an appreciable percentage of the volume measurable by C1XS.
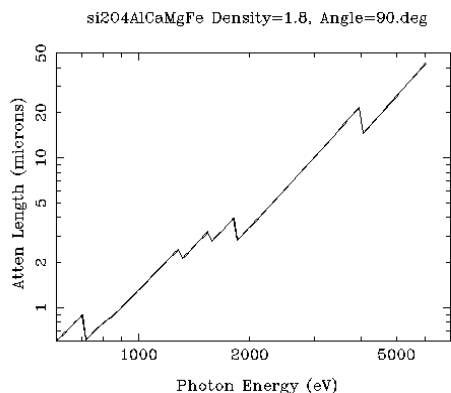
si2O4AlCaMgFe Density=1.8, Angle=90.deg

Figure 3: A plot showing the attenuation length of X-rays into a lunar soil-like material. At the range C1XS is most sensitive (1-2 keV) this depth is between 1- 5 microns.

The density of the lunar atmosphere is known for some species but not others. As the exosphere is surface bounded, individual species and indeed molecules are independent in their dynamics. The number density of Na in the lunar atmosphere is 70 cm^{-3} [4]. From the geometry of the C1XS instrument's viewing area, we can calculate that there are 1.16×10^{22} atoms (or 0.019 moles, or 0.44 grams) of Na in the C1XS line of sight.

This was then compared to the amount of Na in the surface that could be measured by C1XS. Using a standard value of Na for lunar highlands (0.33%) and C1XS's footprint of $25km^2$ (in a 100km orbit) we can find a value in the top 2 micron layer of 4.7×10^7g of Na (41 tonnes). This value is from bulk surface values of Na, and may not be accurate when the surface volatile component is added. The surface Na detectable by C1XS therefore swamps the atmospheric population, making it impossible to detect.

The first results from C1XS indicate a clear Na line, and first elemental analysis of the signal shows a Na wt% of a few %, which is sensible when compared to values taken from returned-sample analysis [7].

Discussion: The investigation of factors that could affect fluorescence return is of critical importance when it comes to the analysis of XRF data. These studies found that neither ray material nor atmospheric Na has an effect on C1XS data analysis, but it poses further questions: Are there areas on the Moon (and other planets) where rays might change the mineralogy to the extent where the contrast is visible through XRF? Will volatile species such as sodium contribute to the signal received from the surface of such bodies? These questions, which will be addressed in future work, are of interest not only to C1XS but also to the next generation of X-ray fluorescence spectrometer missions.

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