THE SCIENTIFIC CASE FOR THE CHANDRAYAAN-1 X-RAY SPECTROMETER. K.H. Joy[1,2], I.A. Crawford[1],B. Kellett[2], M.N. Grande[3] and the C1XS Science Team[4]. [1]Birkbeck/UCL Research School of Earth Sciences, Gower Street, London, WC1E 6BT. [2]The Rutherford Appleton Laboratory, Didcot, Oxon, OX11 0QX, UK. [3]Institute of Mathematical and Physical Sciences University of Wales, Aberystwyth, SY23 3BZ, UK.[4]The other members of the C1XS Science Team are identified in the Acknowledgments. (Email: k.joy@ucl.ac.uk).

Introduction: Theories of lunar evolution born out of petrological investigations of the Apollo and Luna samples have been greatly refined by the global geochemical and mineralogical datasets provided by the Clementine and Lunar Prospector missions. Simplistic models of a Moon-wide plagioclase floatation event in a magma ocean appear to be inconsistent with the heterogeneous nature of the lunar crust, and the dichotomy between near, and far-side crustal geochemistry [1]. This has necessitated a re-examination of lunar geological history and upcoming missions to the Moon provide a new opportunity for mapping the compositional diversity of the lunar surface in greater detail. Here we describe the scienic objectives of one such instrument: the Chandrayaan-1 X-ray spectrometer (C1XS) that will be launched during 2008 on India's first mission to the Moon.

A Brief History of Lunar X-ray Spectroscopy: X-ray fluorescence (XRF) spectroscopy provides an opportunity to map planetary surfaces in low-energy X-rays, including the characteristic signatures of the main rock forming elements. The Sun is the main source of lunar X-ray excitation and typical levels of solar intensity will result in the excitement of low atomic number elements, including Mg, Al and Si. In periods of intense activity (i.e. solar flares) X-ray lines for heavier elements (e.g. Fe, Ti, Ca, P, Na, Co, Mn and K) may also be detected. Incident solar X-rays only penetrate into the upper few micrometers of a planetary surface, producing fluorescent X-rays from the upper surface regolith environment. Lunar X-ray fluorescence was first successfully detected by the Russian Luna 12 mission in 1968 [2]. The Apollo 15 and 16 XRF experiments were the first attempt to conduct compositional XRF spectrometry on a planetary scale, where a simple proportional counter instrument measured the X-ray photon count-rate from the lunar surface. Data were presented as intensity ratios of Al/Si and Mg/Si as Si varies little (no more than ~5 %) in lunar regoliths. These datasets provided an initial understanding of the variable geochemistry of the lunar surface, paving the way for a new generation of lunar X-ray spectrometers.

The UK flew a Demonstration version of a Compact Imaging X-ray Spectrometer (D-CIXS) on the European Space Agency's SMART-1 mission to the Moon between 2003 and 2006 [3]. The new C1XS instrument, due to fly on the Indian Chadrayaan-1 mission, builds on the technology inherited from this precursor instrument. D-CIXS and C1XS demonstrate a new approach to building miniaturized technology, and utilize innovative swept charge device (SCD) solid-state detectors [3,4]. A detailed overview of the C1XS instrument and details of ongoing instrument calibration will be presented at this meeting (see abstracts by Grande et al., Narendranath et al. and Weider et al.).

Scientific objectives: C1XS will be a scientifically more powerful instrument than D-CIXS, both because its low circular orbit (100 × 100 km) will result in higher spatial resolution of the lunar surface (~25 km FWHM), and because it will operate during a more active period of the solar cycle, resulting in higher X-ray fluxes and greater sensitivity to compositional variations. This provides a unique opportunity to address the following observational lunar science objectives:

- Mapping the abundances of the major rock-forming elements (principally Mg, Al, Si, Ca and Fe) in the lunar crust, especially in previously unsampled regions. Specific areas of interest include the far-side highlands (with a view to determining whether compositional differences with the near-side are consistent with models of a global magma ocean [1,5]), and the giant South Pole-Aitkin impact basin (which may have penetrated and exposed the lower crust/upper mantle [1]).

- Use these measurements to determine the regional variations in the magnesium to iron (Mg/Fe) ratio, which is especially important for constraining different models of lunar crustal evolution (eg. [6]).

- Use these measurements to determine the composition of far-side mare basalts (e.g. Mare Moscoviense) to determine whether they are derived from mantle source regions geochemically similar to the near-side mare basalts.

- Compare the major element geochemistry of distinct lava flows in the same geographical region (e.g., Oceanus Procellarum, Imbrium Basin, etc.) to study mantle evolution with time in specific regions.

- Determine the major element geochemistry of dark haloes surrounding endogenic craters, which may comprise pyroclastic picritic glasses whose chemical composition most closely resembles that of the original mantle partial melts, providing important windows into lunar mantle evolution.

- Search for outcrops of high-Al basalts (distributions of which are poorly constrained due to burial and mixing processes), Mg-Suite rocks and exotic magmatically evolved lithologies (High-Alkali Suite: granitic and alkali-suite-rich regoliths).
- Determine the composition of exposures of presumed pre-mare volcanism (e.g. the Apennine Bench Formation) and lunar cryptomaria.
- Exploit the relatively high spatial resolution of C1XS to probe the stratigraphy of the lunar crust by determining the major element geochemistry of the central peaks and/or ejecta blankets of impact craters 50 km in diameter or larger.
- Use the orbital determinations of major element abundances to identify the regional settings from which different lunar meteorites are derived, so that laboratory determinations of minor and trace elements (which cannot be determined from orbit) can be used to further constrain lunar geochemical models (see e.g. [7]).

Science Requirements: Consideration of the principal science aims identified above leads to the following top-level science requirements for C1XS [8]:

(a) Spatial resolution (FWHM): 25 km
(b) Spectral resolution: sufficient to clearly resolve the three low-energy lines (Mg, Al, Si): 250 eV requirement [180 eV goal]
(c) Specifically, the Mg line must be clearly resolvable from the lower energy oxygen line and zero-energy 'noise peak'.
(d) Mg/Si ratio should be measurable to 10% (3σ) requirement; [5% goal] for C-class flares or above. (Fig. 1 indicates that 10% errors in elemental ratios are sufficient to distinguish between different lunar lithologies.)
(e) Absolute Mg concentrations (Mg wt%) should be measurable to 20% (requirement) [10% goal] in mare regions for C-class flares or above.

Conclusions: The C1XS science objectives all bear on important, and currently unresolved, questions in lunar science, including the structure and evolution of any primordial magma ocean, as revealed by vertical and lateral geochemical variations in the crust, and the composition of the lunar mantle, which will further constrain theories of the Moon's origin, thermal history and internal structure.
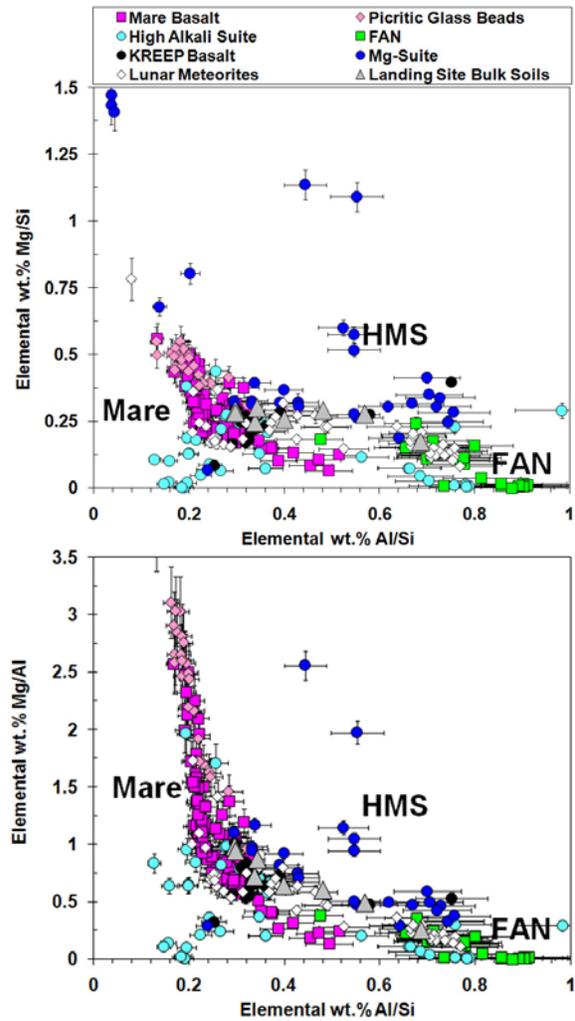

Fig. 1. A number of different lunar lithologies (key at top) shown on plots of Al/Si vs. Mg/Si (top) and Mg/Al vs. Al/Si (bottom). The error bars indicate 10% errors on these elemental ratios and the major lithological groupings are still resolvable given this level of precision. C1XS will aim to achieve this level of precision or better.

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