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REMOTE GEOCHEMICAL EXPERIMENT PACKAGE FOR DISCOVERY CLASS MISSIONS

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Remote sensing X-ray and gamma-ray spectrometers can be used to infer elemental composition on atmosphereless bodies, such as asteroids, the moon, and Mercury (1). The composition of the planetary body and variations in its surface chemistry are of fundamental importance in understanding the formation and dynamics of that body. Thus, for Discovery class missions, X-Ray Fluorescence (XRF), Gamma-Ray Spectrometer (GRS) or a combined Geochemical Experiment Package (GEP) have been proposed. These instruments can meet the mission science objectives, while still meeting the weight, power, and cost constraints. These missions include NEAR (Near Earth Asteroid Rendezvous), MASTER (Main-belt Asteroid Rendezvous), and others such as HERMES (Mercury Orbiter). This paper presents the results of calculations done to assess the sensitivity of a combined instrument to obtain elemental compositions of planetary bodies with an uncertainty small enough to be scientifically useful.

The first orbital experiment package was flown on the Apollo 15 and 16 missions in the early 1970s. The Apollo experiments were highly successful in providing surface compositional data of a solar system body without an atmosphere (2, 3, 4, 5). Orbital determinations of major and some minor elements of lunar petrological interest extended the 'ground truth' provided by the lunar sample collection (3, 6). Specifically, the experiment consisted of XRF spectrometers that provided maps of Al/Si and Mg/Si abundance ratios at 30 km resolution, and a GRS that provided maps of Fe, Ti, Th, and K abundances, and overall radioactivity at varying resolutions.

Analyses of lunar orbital geochemical data led to a greater understanding of the distribution and relative abundances of major rock types on the Moon. This work, involving correlation of compositional data with geological maps and in situ data from sample sites, has been done on various scales: a) global (scale of thousands of km), to provide average composition of the surfaces of highland, maria, and plains terranes (e.g., 7); b) regional (scale of hundreds of km), to demonstrate compositional variations within terranes, which has provided crucial evidence in support of highland volcanism (e.g., 3); and c) local (scale of tens of km), to study surface expressions of underlying chemistry as exposed by local impact and volcanic features at or near landing sites and in other places of geological interest (e.g., 9).

Technological improvements that have occurred since Apollo mean that such a package flown today would have additional capabilities, including inherently higher spectral resolution. An XRF instrument flown today could provide compositional maps of Al, Mg, Si, Ca, Fe, Ti, and in some cases S. A GRS instrument would provide additional data on Mg, Al, Si, Fe, K, O as well as H, Ni, Th, and U, in some cases.

Datasets from each of the two experiments provide independent and yet complimentary measures of elemental abundances. In the presently proposed GEP, the two instruments will in some cases generate abundance data for the same elements (Fe, Mg, Al), but at different resolutions and for different sample depths. Depths sampled (from which meaningful signals are received) by the XRF and GRS experiments are micrometers and tens of centimeters, respectively, although signals may originate from a depth of up to 0.5 m for naturally radioactive elements such as Th. Thus, the uppermost regolith, a mixture of gardened materials, would be sampled by the XRF measurements while bedrock may be included in the GRS measurements. Comparison of XRF and GRS derived datasets for the same element will give information on near-surface regolith stratigraphy and/or differences between local and regional expressions of major rock types.

Previously developed models of gamma-ray emission (8) used for the Mars Observer mission and XRF (9) used for the Apollo experiments were used to determine integrations times required to obtain

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elemental compositions (with a 10% uncertainty at 2 sigma above background) for the targets of proposed Discovery class missions. These targets include both near-Earth and mainbelt asteroids.

The calculations were done for proposed orbital trajectories and time frames. The Sun, the primary source for fluorescent X-rays, was assumed to be at the mid-cycle level, appropriate for the years 1998-2003 proposed for these missions. The XRF instrument was assumed to have a field of view of 5° and 10° for NEAR and MASTER, respectively, while the GRS instrument was assumed to have a 45° field of view for both missions. Calculations shown here are for likely compositions for these targets: 1) Carbonaceous Chondrites Type 1 (CC1) and High Fe Chondrites (Chi) in the case of NEAR, and 2) Eucrites (Euc) for Vesta and Stony Irons (Pallasites) for Iris in the case of MASTER.

TIME TO MEASURE MODEL COMPOSITION TO 10% UNCERTAINTY
NEAR MASTER

| | NEAR | | | | | | MASTER | | | | | |
|----|----------|-------|-------|----------|-------|------|---------|------|-------|----------|------|-------|
| | MODEL | | TIME | | MODEL | | TIME | | MODEL | | TIME | |
| | CC1 | XRF | GRS | Chi | XRF | GRS | Euc | XRF | GRS | Pal | XRF | GRS |
| Mg | 9.6% | 8 m | 18 d | 14.2% | 6 m | 4 d | 4.3% | 10 m | 38 d | 11.9% | 4 m | 5 d |
| Al | 0.9% | 6 h | | 1.0% | 6 h | | 6.6% | 9 m | 180 d | 0.2% | 5 d | |
| Si | 10.3% | 9 m | 21 d | 18.1% | 6 m | 4 d | 22.9% | 3 m | 2 d | 8.0% | 15 m | 15 d |
| S | 5.9% | 15 m | 140 d | 2.0% | 2 h | | 0.2% | 3 d | | 0.0% | | |
| Ca | 1.1% | 7 h | | 1.2% | 7 h | | 7.4% | 1 h | | 0.2% | 11 d | |
| Ti | .05% | 160 d | | .08% | 90 d | | 0.4% | 7 d | | .05% | | |
| Fe | 18.4% | 55 m | 8 d | 27.6% | 46 m | 1 d | 14.6% | 3 h | 4 d | 54.5% | 1 h | 9 h |
| O | 46.4% | | 35 d | 33.9% | | 42 d | 46.4% | | 23 d | 19.5% | | 120 d |
| H | 2.0% | | 2 d | 0.1% | | | .01% | | | .01% | | |
| Ni | 1.1% | | 280 d | 1.7% | | | 0.5% | | | 4.7% | | 120 d |
| K | 430 ppm | | 19 d | 800 ppm | | 6 d | 350 ppm | | 29 d | 100 ppm | | 350 d |
| Th | .032 ppm | | | .042 ppm | | | .45 ppm | | 75 d | .01 ppm | | |
| U | .01 ppm | | | .014 ppm | | | .13 ppm | | 100 d | .002 ppm | | |

Where the times are given in m = minutes, h = hours, and d = days.

Our results indicate that surface mapping at up to tens of km resolution is potentially possible, and that asteroid classes should be readily distinguishable relatively early in a year-long mission: 1) carbonaceous chondrites on the basis of high H and S, and types within the class by variations in Mg, S, and H; 2) ordinary chondrites on the basis of high Mg, Si, K, Th, and U, and types within the class by variations in Fe; 3) achondrites on the basis of high Al, Ca, and Si, low Mg and Fe, and types within the class by variations in Al, Ca, and Fe; 4) stony irons on the basis of high Fe and Ti, and low Si and Al, and types within the class by variations in Fe and Si.

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