CHEMICAL AND TEXTURAL CHARACTERISATION OF TWO PHOBOS REGOLITH SIMULANTS.

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Introduction: Phobos, the larger of Mars' moons, is scientifically important because it holds clues to Mars system planetary formation processes [1], and its regolith may hold a detectable fraction, up to 250 ppm, of material ejected from the surface of Mars [2,3]. This material, delivered to Phobos throughout its history is representative of Mars' surface over geological time, and may preserve martian crust, potentially containing biosignatures, that have otherwise been altered by changing geological processes on Mars [4]. Future missions, such as JAXA's Martian Moons eXploration mission (MMX), aim to test these hypotheses and provide further understanding of Phobos' viability for *in-situ* resource utilization [5] and its effectiveness as a record keeper of martian biosignatures [4,6].

However, in the absence of direct sampling or analysis of Phobos' surface, regolith simulants are required. Physical simulants can be used to aid mission engineering capability testing and the identification of potential contaminants. Compositional simulants support investigations into planetary protection and biosignature preservation, and assessment of the accuracy and reliability of analytical techniques to be used on future samples from Phobos.

As a part of ESA-funded concept studies, physical and compositional simulants were designed and produced. Achieving the desired physical and compositional characteristics were balanced against material availability, cost and safety [2].

Physical simulant: The following physical properties, in order of importance, required for microgravity sampling tests of NEAs and Phobos, were accounted for [7]:

Particle size distribution - Remote sensing observations of thermal inertia indicate that the mean grain size of the regolith is ~1 mm [8]. However, it has been suggested that grain sizes < 300 μm are depleted [9]. We modeled the size distribution using a power law that truncates in the lower grain sizes, summarized by the equation: $N(>D) = k\,(D^b + D_0^b)^{-s/b}$ [7].

Particle shape distribution and texture - Remote sensing resolution of Phobos is insufficient to define grain shape and texture, but we assume the regolith consists of angular grains with a large range of shapes as found on small NEAs (Fig. 1 left).

Particle and regolith strength - Regolith strength is controlled by particle size distribution. Assuming similarity to Eros, the regolith should be loose and weak, ~few kPa. The particle strength is controlled by the composition, ~few MPa.

Density and porosity - Controlled by composition and packing. Based upon Phobos' mean density of 1.85 ± 0.07 g cm^{-3} [10], and its surface density of ≤1.6 ± 0.3 g cm^{-3} [11], the regolith is expected to have significant porosity.

The physical simulant was made from crushed and sieved cellular building blocks, with a compressive strength of 3.5 MPa and density of 1.9-2.0 g cm^{-3}, providing a good physical match to Phobos at low cost.

Compositional simulant: To accurately represent the hypothesized composition of Phobos' regolith, for use in planetary protection studies, the compositional simulant focused only on composition requirements, leaving its physical properties as by-products.

Composition. The surface composition of Phobos has remained ambiguous, despite years of remote and ground-based observation. Spectral data indicate that the surface resembles D- or T-type asteroid or carbonaceous chondrite composition [12]. Therefore, Tagish lake has been widely considered a close comparison to the composition of Phobos' regolith [2,12,13]. Using this as a baseline, a compositional regolith simulant was designed. The regolith simulant component proportions are summarized in Table 1.

Component	Wt %	Comments
JSC-1A	46	Vesicular glass component accounts for space weathering processes [2,11]
Antigorite	35	Phyllosilicate component present on Phobos' surface according to 0.65 and 2.8 μm spectral absorptions [12]
Pseudo-agglutinate	15	A plasma welded noritic sand Contributes vesicular glassy mineral aggregates, typical of lunar regolith [2]
Gilsonite	4	Contributes complex organics seen in Tagish Lake [2]

Table 1: Chemical proportions in compositional Phobos regolith simulant.

Physical properties. The simulant was split into three size fractions: <425 µm, 1.2-3.3 mm and >5 mm, ready for different experiments. The density of the regolith simulant is a good representation of Phobos' surface, because it is based on Tagish lake with a density of 1.67 ± 0.02 g cm^{-3} [10], which is comparable to the surface density of Phobos [11].

Chemical and textural characterization: At the Open University, simulant grains on carbon stubs and carbon coated polished blocks were prepared and analysed: qualitatively, using Backscattered and Secondary Electron imaging (BSE and SE) and Energy Dispersive X-ray Spectroscopy (EDS) mapping with an FEI Quanta 3D FIB-SEM, and quantitatively, using the Cameca SX-100 electron microprobe.

Texturally, the compositional and physical simulants are very similar in grain shape distribution, both being dominated by angular grains, but having a large range of grain shapes (Fig. 1). The physical simulant has a larger grain size range; however, this may be because of differences in sieving methods.

Chemically, the compositional simulant contains plagioclase (green-like in Fig. 2; $An_{3.4-74}Or_{0-3.8}Ab_{26-96.6}$), pyroxene (cyan-like in Fig. 2; $Wo_{0-48.8}En_{27.6-83.8}Fe_{8.5-48.1}$), and olivine (darker cyan-like in Fig. 2; $Fo_{74.5-84.8}Fa_{15.2-25.5}$), quartz and glassy phases.

Further characterization work is underway to evaluate whether the simulants meet the requirements with respect to:

1.) Grain shape and size distribution of Phobos regolith.
2.) Compositional equivalence to Tagish Lake and models of the Phobos regolith
3.) Homogeneity between extracted regolith simulant and the bulk simulant.

Applications: After chemical and textural characterization, the compositional and physical simulants can be applied to identifying contaminants such as, exhaust fumes at landing sites, the delivery of organic molecules in impactors from Mars, and mission landing and sample return mechanism testing.

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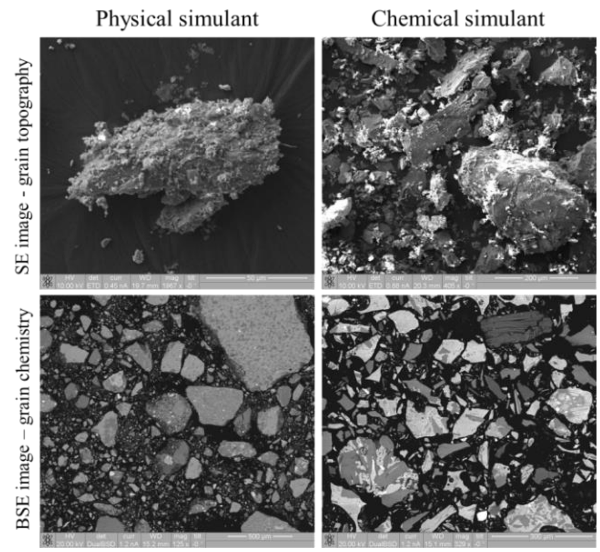

Fig. 1: Secondary Electron and Backscatter Electron images of the physical (left) and compositional (right) regolith simulants.

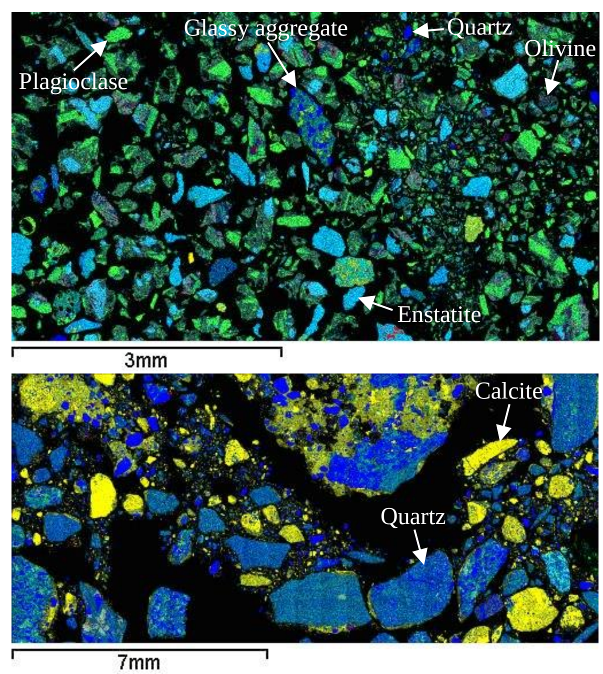

Fig. 2: EDS map of the compositional (top) and physical simulant (bottom). Colour scale: Fe = Red, Si = Blue, Al = Green, Mg = Cyan and Ca = Yellow.