INTERNAL CHARACTERISTICS OF PHOBOS AND DEIMOS FROM SPECTRAL PROPERTIES AND DENSITY: RELATIONSHIP TO LANDFORMS AND COMPARISON WITH ASTEROIDS. S.L. Murchie[1], A.A. Fraeman[2], R.E. Arvidson[2], A.S. Rivkin[1], R.V. Morris[3]. [1]JHU/Applied Physics Laboratory, Laurel, MD 20723 (scott.murchie@jhuapl.edu); [2]Washington University, St Louis, MO 63130; [3]NASA/JSC, Houston, TX.

Introduction: Compositional interpretations of new spectral measurements of Phobos and Deimos from Mars Express/OMEGA and MRO/CRISM and density measurements from encounters by multiple spacecraft support refined estimates of the moons' porosity and internal structure. Phobos' estimated macroporosity of 12-20% is consistent with a fractured but coherent interior; Deimos' estimated macroporosity of 23-44% is more consistent with a loosely consoidated interior. These internal differences are reflected in differences in surface morphology: Phobos exhibits a globally coherent pattern of grooves, whereas Deimos has a surface dominated instead by fragmental debris. Comparison with other asteroids ≤110 km in diameter shows that this correspondence between landforms and inferred internal structure is part of a pervasive pattern: asteroids interpreted to have coherent interiors exhibit pervasive, organized ridge or groove systems, whereas loosely consolidated asteroids have landforms dominated by fragmental debris and/or retain craters >1.3 body radii in diameter suggesting a porous, compressible interior.

Background: Models of asteroid internal structure include gradation from unaltered, through increasing degrees of fracturing, to a "rubble pile" structure [1]. As the degree of fracturing increases, internal mechanical properties are posited to change from "coherent" to "fractured but coherent", both with sufficient mechanical continuity to support globally continuous structural patterns, through a "transitional" category possibly with structural coherence regionally within large clasts, to "loosely consolidated" with a high degree of porosity that disrupts mechanical continuity [2,3]. Porosity of a small body can be estimated by assuming a composition based on remote spectral or *in situ* measurements, by assuming density characteristics typical of meteorites of that composition measured in the laboratory, and finally by comparing meteorite density with average density derived from ground-based or spacecraft measurements [2,4]. Porosity can be divided into two types: "macroporosity" at decimeter scale and larger due to fractures and void spaces between clasts, and "microporosity" due to intergranular spaces [4]. Whereas macroporosity is thought to control internal mechanical continuity, both types of porosity provide compressibility to absorb shock due to large impacts [e.g. 5,6]. Microporosity is determined in the laboratory from the difference between meteorite bulk density and "grain density" of the solid fraction [4].

Type Example Asteroids: Porosity estimates for 433 Eros and 25143 Itokawa are least uncertain because of knowledge acquired during the NEAR and Hayabusa missions. Both have near-infrared spectra that match LL ordinary chondrites [7,8], and for Itokawa this interpretation is confirmed by returned samples [9]. Mass and volume estimates from the spacecraft rendezvous provide densities with uncertainties of 1-7% [10,11]. These data yield estimated macroporosity for Eros of 10-24%, in the category "fractured but coherent", and for Itokawa of 32-49%, in the category "loosely consolidated" (Table 1). Surface morphology is strikingly consistent with inferred internal structure: Eros exhibits parallel ridges, troughs, and grooves that suggest mechanical continuity through much of its interior [3,12], whereas Itokawa has a surface dominated by large regolith clasts consistent with a rubble pile structure.

Phobos and Deimos: New results from MRO and Mars Express allow improved estimates of these bodies' internal structures. Mass determinations [13,14] and an updated volume estimate for Phobos from Mars Express [15], plus a previous volume estimates for Deimos [16], yield density estimates of 1876±20 and 1490±190 kg m^{-3} for Phobos and Deimos respectively. The highest-resolution information on composition comes from hyperspectral mapping by MRO/CRISM, and disk-resolved measurements from Mars Express/OMEGA at multiple phase angles from 38°-99° that support a photometric model to correct measurements from both instruments to a laboratory geometry (i=30°, e=0°, α=30°) like that at which meteorite analogs are measured [17]. Both moons' reflectances are a factor of ~2 darker than the most highly space-weathered lunar soils, analogs for a basaltic composition that has been proposed for the moons [e.g. 18]. Both moons' spectra closely match desiccated CM carbonaceous chrondrites [17], and exhibit a broad mineral absorption near 0.65 µm consistent with that observed in C- and D-type asteroids. The most plausible phases responsible for this feature (Fe-phyllosilicates, graphite) are also typical of CM chondrites [19], which have an analogous feature near 0.7 µm.

Assuming a CM composition, Phobos's estimated macroporosity is 12-20%, consistent with a "fractured but coherent" interior, and Deimos' is 23-44% (Table 1), consistent with a "loosely consolidated" interior. As with Eros and Itokawa, these structures are reflected in surface morphology. Phobos exhibits a globally coherent pattern of grooves generally thought to result from deep fractures, requiring a mechanically continuous interior [3,20] (Fig. 1). In contrast, Deimos' surface lacks grooves and is dominated by mass wasting features formed in fragmental debris. Deimos' having survived formation of its south polar crater ~1.7 body radii in diameter (Fig. 1) [21] is consistent with a compressible interior having high total porosity. Alternatively, that crater may have created high macroporosity.

Comparison with Other Asteroids: The correspondence between landforms and inferred internal structure on Eros, Itokawa, Phobos and Deimos extends to other asteroids for which there is well-constrained density and coverage by spacecraft images. 253 Mathilde [22] and 243 Ida [23] have porosities in the "transitional" range and exhibit ridges tens of km in length that suggest a degree of structural continuity. Ida also exhibits grooves regionally. 21 Lutetia has low porosity and widespread, regionally parallel grooves [24]. From these observations, we hypothesize that regionally to globally organized ridges and grooves are a manifestation of mechanical continuity in small body interiors, whereas fragmental surfaces and (on large enough bodies) craters much larger than a body radius indicate a loosely consolidated interior. This may be tested during future encounters with small asteroids.

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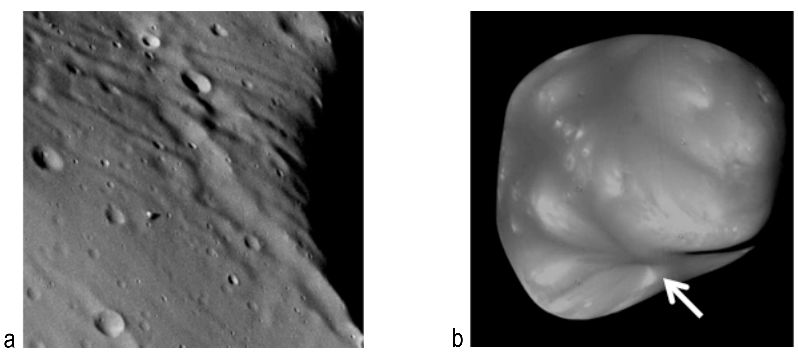

Fig. 1. Viking Orbiter images showing (a) Phobos' well-organized pattern of grooves [20] and (b) Deimos' surface dominated by bright streaks due to mass wasting, with a large depression in the south polar region that is thought to be a large impact crater [21].

Body	R_m, km	Assumed composition	Est. macroporosity	Est. total porosity	Coherent ridge/ groove patterns?	Craters >1.3 R_m?	Fragment-dominated surface?	Refs.
Coherent to fractured but coherent								
Lutetia	49	E	≤15%	≤17%	Y	N	N	25,26
Phobos	11.1	CM	17±4%	35±3%	Y	N	N	13,17,18
Eros	7.3	LL	17±7%	24±4%	Y	N	N	7,10
Fractured but coherent to transitional								
Mathilde	26.5	CI	18±14%	55±9%	insufficient resolution	Y	insufficient resolution	5,22
Ida	15.7	LL	20±20%	26±16%	Y (only regionally)	N	N	27,28
Loosely consolidated								
Deimos	6.2	CM	34±11%	48±8%	N	Y	Y	14,16-18
Itokawa	0.18	LL	41±8%	46±6%	N	N	Y	8,9,11

Table 1. Sizes, assumed compositions, estimated porosities calculated using meteorite densities reported by [4], and morphology of asteroids <110 km in diameter having well-determined densities and coverage by spacecraft images. R_m=mean radius.