MRO/CRISM OBSERVATIONS OF PHOBOS AND DEIMOS. S. Murchie[1], T. Choo[1], D. Humm,[1] A. Rivkin[1], J.-P. Bibring[2], Y. Langevin[2], B. Gondet[2], T. Roush[3], T. Duxbury[4], and the CRISM Team, [1]Applied Physics Laboratory, Laurel, MD (scott.murchie@jhuapl.edu), [2]Institute d'Astrophysique Spatial (IAS), Orsay, France, [3]NASA/Ames Research Center, Moffet Field, CA, [4]Jet Propulsion Laboratory, Pasadena, CA.

Summary: The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) has acquired disk-resolved hyperspectral images of the sub-Mars hemispheres of both Phobos and Deimos in the instrument's high-resolution mode (362-3920 nm in 544 channels at 6.55 nm/channel, with a spatial sampling of 60 μrad/pixel) [1]. Three Deimos images were acquired on 7 June 2007 at 1.2 km/pixel and a phase angle of 22°. Three Phobos images were acquired on 23 October 2007 at 350 m/pixel and a phase angle near 41°. These data confirm association of Phobos' "bluer unit" [2] with the interior and ejecta of Stickney. Phobos's redder unit and Deimos have a broad, shallow absorption at 0.65 μm resembling that in low-grade carbonaceous chondrites. There is no evidence for absorptions due to mafic minerals, bound water or organics.

Background: Early reconstructions of visible-IR spectra of Phobos and Deimos [3] yielded C asteroid-like spectra for both bodies, leading to speculation that they are captured primitive asteroids. Later, disk-resolved measurements of Phobos from the *Phobos 2* spacecraft showed that moon to be relatively red and lacking in evidence for absorptions due to bound H_2O, suggesting either a primitive but anhydrous composition (like D asteroids) or an evolved composition rich in mafic minerals but reddened by space weathering (like the lunar mare) [2]. In addition Phobos' surface is heterogeneous, with the crater Stickney exposing material that is significantly less red than other parts of Phobos or Deimos [2]. Subsequent telescopic measurements confirm the smooth, red spectrum of both moons and a general lack of H_2O absorptions [4,5,6]. TES data confirm the distinctiveness of Stickney material but do not provide definitive mineralogy [7].

The compositions of the two moons provide a window into the earliest part of Mars' history not preserved in Martian crustal rock [8]. If they are primitive bodies they may preserve a sample of impacting bodies that delivered volatiles to early Mars. A mafic-rich composition like Mars could imply an impact origin like that of Earth's Moon, or an ordinary chondrite-like composition would imply co-accretion with Mars or capture.

CRISM Results: Deimos (Figures 1 and 2) exhibits a nearly featureless red spectrum lacking strong absorptions due to H_2O, organics, or mafic minerals, corroborating earlier results. At a 4-km scale the only variations at the ≥1% level are continuum and thermal emission. A strong increase in emission at >2500 nm corrroborates high surface temperatures inferred by [6].

On Phobos, tens-of-percent spatial variations in slope of the spectral continuum are evident even in unstretched images (Figure 1). The region just east of the 9-km crater Stickney, which corresponds with the mapped extent of the crater's ejecta [9], exhibits a significantly higher 0.5/0.9-μm color ratio (Figure 3). This matches the "bluer unit" of [2], observed in *Phobos 2* data covering Stickney's interior and the crater's western flank. The bluer unit has shallower spectral slope at all wavelengths than the redder unit or Deimos, which are indistinct from each other (Figure 4).

The presence of mineralogic absorptions was assessed from shapes of spectra and from maps of spatial coherence of possible features. Both moons exhibit a narrow feature near 0.45 μm, but it is at the limit of the wavelength range over which CRISM's calibration (optimized for field-filling Mars scenes) remains valid for small targets. There is no evidence for 1- or 2-μm mafic mineral absorptions [2,10], localized enhancements of a 3-μm absorption due to bound water [10], or absorptions due to organics. The only definitive absorption is a broad feature up to several percent in depth, centered near 0.65 μm. This is present in Phobos's redder unit and on Deimos; on Phobos it is mappable and strongly correlated with the redder unit and with redder continuum slopes (Figure 3). This absorption also occurs in low-albedo asteroids interpreted as primitive, and probably indicates ferric iron-containing phyllosilicates [9,10]. Previous "detections" of a 1-μm band in 0.8- to 3.2-μm ISM data [2,10] were based on spectral ratios of less-red to more-red parts of the redder unit. Inadvertantly, these may have inverted the shoulder of the 0.65-μm band and created a spurious feature resembling a mafic mineral absorption.

Discussion: Implications of CRISM results for the Martian moons' composition and interrelationship are summarized in Table 1. The 0.65-μm band is the strongest spectral indicator to date of a primitive composition of Deimos and Phobos's redder unit. The lack of this absorption in the bluer unit means that it cannot be a less space-weathered version of the same material. However the bluer unit is clearly excavated by Stickney from depth, through a redder unit that is indistinguishable from Deimos and may be related genetically.

References: [1] Murchie, S. *et al.*, *J. Geophys. Res., 112*, doi:10.1029/2006JE002682, 2007. [2] Pang, K. *et al.*, *Science*, *199*, 64-66, 1978. [3] Murchie, S. and S. Erard, *Icarus*, *123*, 63–86, 1996. [4] Murchie, S. *et al*, *J. Geophys. Res.*, *104*, 9069-9080, 1999. [5] Rivkin, A. *et al.*, *Icarus*, *156*, 64-75, 2002. [6] Lynch, D. *et al.*, *Astron. J.*, *134*, 1459-1463, 2007. [7] Roush, T. *et al.*, *Lunar Planet Sci XXXII*, 1915, 2001. [8] Britt, D. and C. Pieters, *Astron. Vestn.*, *22*, 229–239, 1988. [9] Thomas, P., *Icarus*, *40*, 223–243, 1979. [10] Gendrin A. *et al.*, *J. Geophys. Res.*, *110*, doi:10.1029/2004 JE002245, 2005. [11] Gaffey, M. and T. McCord, in *Asteroids*, T. Gehrels, ed., pp. 688-723, Univ. Arizona, Tucson, 1979. [12] Vilas, F. *et al.*, *Icarus*, *102*, 225-231, 1993.

Table 1. Truth-table summary of tests for compositions of Phobos' bluer and redder units and relationship to Deimos. Gray indcates data inconsistent with hypothesis, and green indicates data consistent with hypothesis.

Hypothesis	Test	Result
What is the composition of Phobos's bluer unit?		
Mafic material (Mars basin ejecta or captured asteroid)	1-μm mafic mineral band	Not detected
Altered primitive material (e.g. C-type)	Bound water or OH	Not detected
Primitive material (e.g. D-type)	No bound water or OH	No bound water or OH; relatively gray material from depth
What is the composition of Phobos's redder unit?		
Space-weathered mafic material (Mars basin eject or captured asteroid)	1-μm mafic mineral band decreasing in strength in redder regions	No mafic band; lack of 0.65-μm band in bluer unit inconsistent with space weathering
Altered primitive material (e.g. C-type)	Bound water or OH	Not detected
Primitive material (e.g. D-type)	No bound water or OH	No bound water or OH, with Fe-mineral ab absorption like CM chondrite
What is the relationship of Phobos and Deimos?		
Distinct origins	Distinctive spectral features	True of Deimos and Phobos' bluer unit
Fragments of same body, or formed from common source	Nearly identical spectral features	True of Deimos and Phobos' redder unit
Phobos's is distinct but covered with accreted Deimos material	Close spectral similarity of Phobos redder unit and Deimos	Most consistent with the data of any model for origin of the redder unit

Fig. 1. False color images of Deimos (left) and Phobos (right) constructed with 0.9-, 0.7-, and 0.5-μm values of I/F in the red, green and blue image planes. North is to the upper right. Brightness has been enhanced while preserving color balance. Note the less red color of the interior and eastern ejecta of Stickney (the large crater to the upper left in the Phobos image).

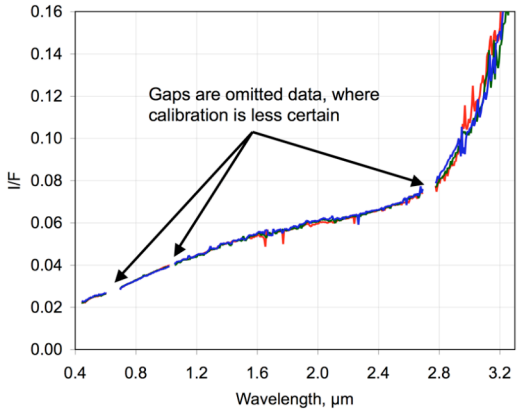

Fig. 2. 4x4 km average spectra from each of the three Deimos observations.

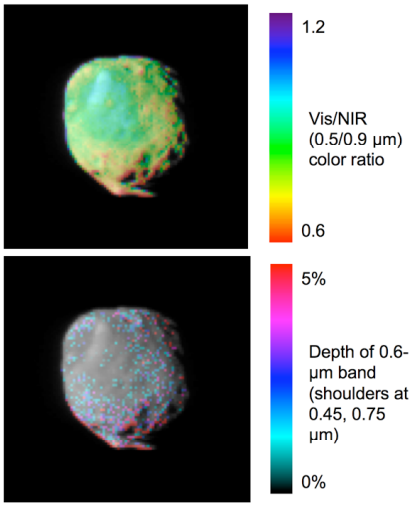

Fig. 3. Spatial variations in spectral continuum slope and strength of the 0.65-μm absorption on Phobos.

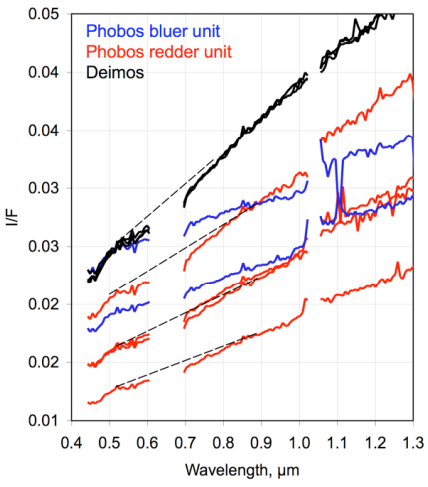

Fig. 4. Comparison of representative spectra of the bluer and redder units on Phobos with Deimos.