WIDESPREAD EXPOSURES OF SMALL SCALE SPINEL-RICH PYROCLASTIC DEPOSITS IN SINUS AESTUUM. Jessica M. Sunshine (jess@astro.umd.edu)[1], Noah E. Petro[2], Sébastien Besse[3], and Lisa R. Gaddis[4]. [1]University of Maryland, Department of Astronomy, College Park, MD, USA, 20742; [2]NASA Goddard Space Flight Center, Greenbelt, MD, USA, 20771; [3]ESA/ESTEC, Keplerlaan 1, Noordwijk, The Netherlands; [4]Astrogeology Science Center, U.S. Geological Survey, Flagstaff, AZ, USA 86001.

Introduction: Spinel-bearing units in Sinus Aestuum (SA) were first reported by Sunshine *et al.* [1] using global data acquired with the Moon Mineralogy Mapper (M^3) [2]. These spinel-rich deposits are found only among the SA pyroclastic or dark mantle deposits (DMD) and are notably absent from the immediately adjacent Rima Bode DMD. The presence of these compositionally unique and likely Fe- and Cr-rich SA spinels has recently been confirmed [3, 4].

Here we report on the widespread distribution of spinel in the Sinus Aestuum region. Using full spatial resolution global mode M^3 data (140 m/pix), we find spinel signatures to be strongest in small deposits at <500 m scales. These features are exposed in mare deposits between the two major SA DMD's (mantled highlands units in SE and SW Sinus Aestuum [5]) and extend as far north and west as the edges of the continuous ejecta blankets of both Copernicus and Eratosthenes craters, and as far south as the crater Gambart. The extent of the SA spinel-rich DMD is thus far more expansive than previously reported [1,4].

Identification of Spinel: The SA spinel deposits are defined spectrally in the near infrared by their strong 2 μm absorptions and extremely weak or absent 1 μm absorptions [1], as is characteristic of spinel-group minerals [6]. Unlike the Mg spinel-hercynites (*i.e.*, pink spinel anorthosites) associated with large impacts [7, 8], the SA DMDs are low in albedo, have longer wavelength 2 μm features, and have absorptions in the visible [4]. The precise spinel-group mineralogy remains poorly constrained due to the difficulty of modeling thermal effects in the presence of strong 2 μm absorptions and the lack of good terrestrial analogs; however, Fe- and/or Cr-enrichment is likely.

Geologic Setting: The broader SA region has a complex geologic history, including formation of the putative Insularum Basin, the emplacement of Imbrium basin ejecta, pyroclastic eruptions, mare flooding, and modification by ejecta from Eratosthenes and Copernicus [see 9]. The spinel-bearing DMD deposits are often exposed on hummocky highs or isolated kipukas, or they are exposed under nearby thin mare deposits [10]. This suggests that the spinel-rich deposits are ancient, but they are also seen in small exposures mantling mare deposits, indicating that spinel-rich DMD emplacement extended beyond that of at least some of the local mare units. Four general types of exposure of dark material with strong 2 μm absorption features have been identified in the SA region.

Irregular Features/Vents: Many of the strongest spinel signatures are associated with dark, irregularly shaped positive-relief dome- or cone-like deposits that appear to be volcanic in origin. Nearby these pyroclastic features are smooth, dark mantling deposits that overlay adjacent units. **Figure 1** illustrates the strongest spinel signature in eastern SA ("The Beacon"), which includes several such small (100-300 m) diameter cone-like features that appear to be vents.

Downslope Erosion in Crater Walls: A number of small (~5 to 10 km) craters include dark spinel-bearing material exposed within their walls that extend downslope in streaks. These streaks are not uniformly distributed, but occur as discrete spokes or partial spokes. The spinel deposits typically originate close to the rim, suggesting that they were originally shallowly buried, in some cases <100 m below the crater rim. **Figure 2** shows an example from the wall of Gambart L (3.8 km diameter). High-resolution views of the deposits show locations where concentrations of the dark spinel-bearing material mix with wall material downslope of the main deposit. Such spinel-spoked craters are widespread and are found as far north as around the mare flooded crater Stadius.

Exposed on Crater Walls: Located ~230 km SW of the extensive SA deposit, Gambart crater (**Figure 3;** 24.7 km diameter) is an Imbrian aged, mare-flooded crater. Unlike other occurrences, this crater has several exposures of spinel along and outside the crater rim and, through excavation by smaller craters, in its continuous ejecta. Some of these DMDs have been previously mapped [10], but others were unrecognized.

Excavated by Small Impacts: A few small, dark, fresh craters have ejecta that is dominated by the spinel-bearing material. The type locality is a small dark crater ("Darth Crater"; ~200 m diameter) located NW of Gambart B and G **(Figure 4)**. The ejecta from this crater is dominated by dark spinel-bearing material. Based on scaling relationships [11], the ejected material likely originates from at least 20 m below the surface of the overlying mare. A number of similarly sized fresh craters nearby lack the spinel signature, suggesting discontinuous emplacement prior to the last basalt flows.

Discussion: The overall extent of the spinel-bearing DMD is remarkable. The most continuous spectral signatures are seen in the mantled highlands of SA SW and SE DMDs [5], whereas weaker spinel signatures, spread among numerous small concentrations, are associated with more isolated pyroclastic vents.

Exposures of spinel are also seen in ejecta of craters in thin margins that embay these highs and on small isolated kipukas. These occurrences suggest that the spinel DMD deposits underlay, discontinuously, the entire region extending over an area of ~60,000 km^2, as far south as Gambart crater and as far north and west as Eratosthenes and Copernicus. Some, but not all of these deposits, have been previously mapped morphologically [10, 12, 13], but our observations indicate that not all mapped DMD in the region are spinel-rich.

Given the wide areal extent of the spinel-bearing DMD in the SA region, it is surprising that it is not observed *anywhere* else on the Moon. Furthermore, while chromite has been observed as small fragments in some lunar samples, the SA Fe/Cr-spinel pyroclastics are absent from our sample collection. The association of SA spinel deposits with the KREEP terrane [14] suggests longer-lived or more complex volcanism originating within an ancient crustal unit and sustained by the high concentrations of Thorium in the region.

References: [1] Sunshine *et al.* (2010), *LPSC 41*, #1508. [2] Pieters *et al*. (2009), *Current Science*. [3] Bhattacharya *et al.* (2013), LPSC 43, #1387. [4] Yamamoto, *et al.* (2013), *GRL*. [5] Gaddis *et al.* (2003), *Icarus*. [6] Cloutis *et al.* (2004), *MAPS*. [7] Pieters *et al.* (2011), *JGR*. [8] Dhingra *et al*., (2011), *GRL*. [9] Gaddis *et al.* (2014), *this vol.* [10] Schmitt *et al*. (1967), USGS I-515 map, LAC-58. [11] Melosh (1989), *Impact Cratering, A Geologic Process*. [12] Wilhelms, (1987), *USGS Prof. Paper 1348*. [13] Wilhelms (1968) USGS I-548 map, LAC-59. [14] Jolliff *et al.* (2000), *JGR*.

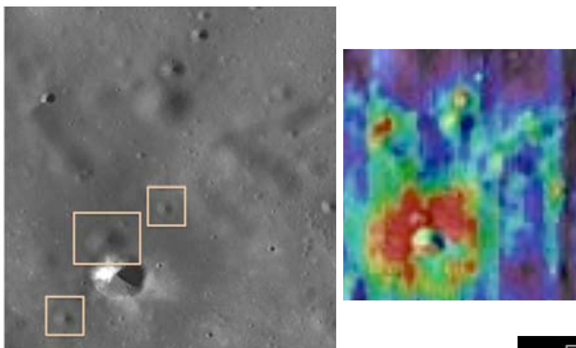
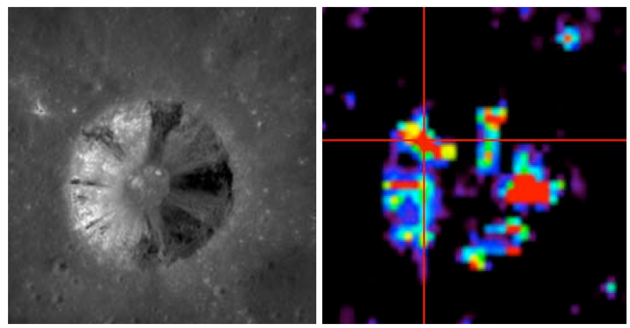


Figure 1 (Left) Kaguya Terrain Camera (TC) image of the "Beacon" area with strongest spinel signature in Eastern Sinus Aestuum. Three possible pyroclastic vents are identified. A small (1.45 km diameter) crater post-dates the emplacement of the pyroclastic deposit. (Right) Spinel map based on the strength of the 2 µm absorption feature relative to the 1um feature in M^3 data.



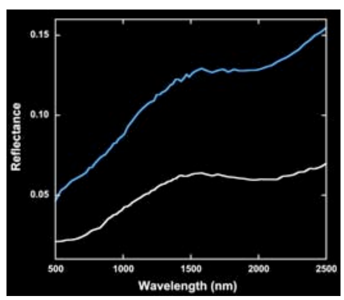


Figure 2: Kaguya TC image of the 2.8 km diameter crater Gambart L. (Right) M^3 derived map of spinel. The locations of spinel-bearing material correspond to the dark downslope streaks seen in the Kaguya image. The cross-hair in the M^3 map shows the location of a typical spinel spectrum (blue at left), which lacks a 1µm (1000 nm) absorptions but has a strong absorption near 2µm (2000nm).

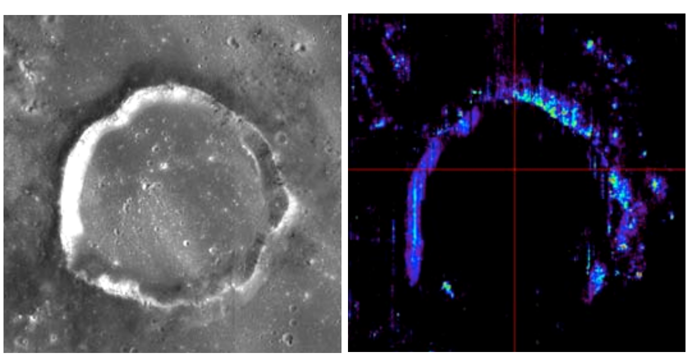


Figure 3. (Left) Kaguya TC image of the mare flooded Gambart crater (24.7 km diameter). (Right) Spinel map, as in Figures 1 and 2, showing distribution of spinel along the crater wall and portions of it's exterior. As in other examples where smaller craters expose the spinel-bearing material, the spinel is exposed in discrete patches, typically near the rim suggesting shallow burial. Outside the eastern rim of the crater are small impacts that have excavated the spinel material.

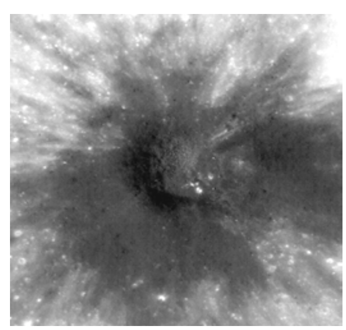


Figure 4: LRO NAC image (M170640532L) of a 200 m diameter dark, fresh crater that excavates material with a very strong 2 µm spinel signature from beneath the mare (white spectrum in Figure 2 plot). This so-called "Darth Crater" is located in the mare NW of Gambart C and G. The image is stretched significantly to show the crater and interior boulders.