REGIONAL GEOLOGY OF LUNAR SPINEL-RICH UNITS IN SINUS AESTUUM. L. R. Gaddis[1], J. Sunshine[2], N. Petro[3], J. Hagerty[1], J. Skinner[1] and T. Gaither[1]. [1]Astrogeology Science Center, U.S. Geological Survey, Flagstaff, AZ, (lgaddis@usgs.gov). [2]University of Maryland, Department of Astronomy, College Park, MD, 20742. [3]NASA\GSFC, Code 698, Greenbelt, MD, 20771.

Introduction: The unexpected discovery of the unique spinel-rich units in Sinus Aestuum region of the Moon from the Moon Mineralogy Mapper (M^3) instrument on Chandrayaan-1 [1] has resulted in other studies confirming the composition of these deposits [2, 3]. Here we describe and interpret the regional geology of the Sinus Aestuum region as a means to infer the origin and character of the spinel-rich unit.

Data: We used data from the Kaguya Terrain Camera (TC; ~10 m/pixel, [4]) and Multiband Imager (MI; 5 visible or VIS wavelength channels at 415 to 1000 nm, ~20 m/pixel [5]), the Lunar Reconnaissance Orbiter Narrow Angle (NAC; 0.5 to 2.0 m/pixel) and Wide Angle Cameras (WAC; ~100 m/pixel [6]) and the Lunar Orbiter Laser Altimeter (LOLA [7]), and GRAIL derived free-air gravity [8] and crustal thickness (model 2 [9]) maps.

Spinel Deposits: The Fe/Cr spinel-rich units are found only in the Sinus Aestuum (SA) region [1] and are associated with the regional pyroclastic deposits very dark units that mantle two hummocky highland regions located to the SE and ESE of Copernicus crater (93 km dia., [10-12]) (**Figures 1, 2**). The spectral signatures of spinel, including strong 2 μm/1 μm ratios, are observed throughout mantled highlands of SA, but the strongest signatures occur as localized concentrations associated with many of the numerous, small volcanic vents (**Figure 1,** [13]) previously mapped across the SA region [14, 15]. The spinel-rich pyroclastic units are observed in association with mare basalts and basaltic pyroclastic glasses and it provides information on the oxygen fugacity of the magmatic systems within which they formed and their behavior during the early stages of crystallization [16].

Regional Geology: Located in the central region of the lunar near side, the formally named Sinus Aestuum is a mare-filled basin about 316 km across (centered at 12.1 N, -8.3 W), situated south of Eratosthenes crater (58 km dia.), east of Copernicus crater, west of Rima Bode (RB), and north of Gambart crater (25 km dia.). The informal SA region is much larger, extending ~450 km from RB to the SW, merging with mare units mapped as part of NE Mare Insularum [17]. The full SA region is characterized by a mare-filled basin to the NE bordered to the S by hummocky upland units with NW-SE trending lineations characteristic of the Fra Mauro Formation formed by Imbrium basin ejecta [14, 15]. The pre-Imbrian basin of SA is filled with thick mare units of Imbrian age [17] with wrinkle ridges to the NE, and thinner maria occurring to the south and west [18]. Partially buried impact craters in SA indicate that the mare units have a maximum thickness of ~1250 m to the northeast and an average thickness of 192.5 m [18] over an area of ~168,000 km^2. Mare units to the southwest of SA in northeast Mare Insularum were dated at ~2.8 to 3.5 Ga [17] on the basis of crater counts. The entire SA region is scoured and superimposed by deposits from the Copernicus crater impact event (~800 Ma, [14]).

The SA region occurs in the SE area of the Procellarum KREEP terrain [PKT, 19] and is characterized by high FeO (15-17 wt %) and a positive thorium anomaly of 6-8 (up to 9 in places) ppm, with the higher values possibly linked to the mantled highland unit in SA and south of RB [18]. The PKT is thought to originate as a widespread, non-mare unit [19]; the Fra Mauro Formation was derived from Imbrium ejecta and may include igneous rocks such as magnesian and alkali norite as well as more evolved lithologies [20].

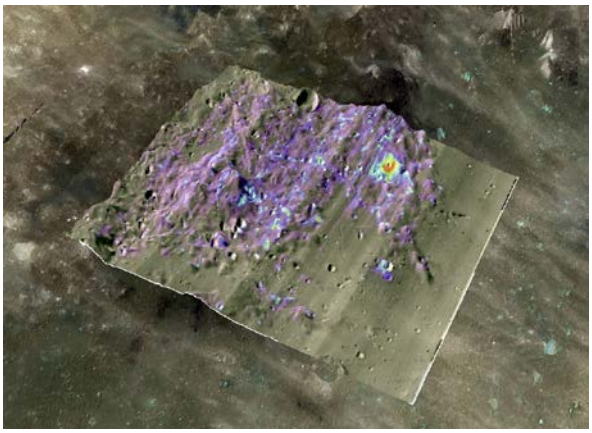

Figure 1. MI-VIS mosaic of mantled highlands of southeast SA. The view is to the SSE. The enhanced color M3 image [~90 km across, after 1] is overlaid, showing the distribution of spinel-rich materials.

From W to E, SA topography ranges from -1200 m to -400 m (**Figure 2**, [8]); the SW hummocky unit averages -950 m, the SE unit averages -650 m and the maria in between is -1200 m. Crustal thickness varies from ~12 to 40 km and averages ~29 km [9]. Free-air gravity data for the SA region indicates the presence of a mass concentration ("mascon"), suggesting the pres-

ence of a voluminous melt pool from which the local maria were derived [21].

The volcanic history of SA is complex and a wide variety of volcanic features are observed. In addition to the regional mantling deposits on the hummocky highlands, numerous (>30) small cone- and dome-like features have been mapped within the maria between and north of the two SA mantled highlands units, and small dark-halo craters within the maria mark the locations of excavated dark materials that were likely pyroclastic in origin [14, 15]. Numerous likely volcanic fissures and rilles are observed in the younger SA maria, but they largely appear to be superimposed on and thus postdate the emplacement of the pyroclastic materials [22]. In some cases, volcanic cone-like features [13] are surrounded by dark mantles that appear to overlay localized maria north of the mantled highlands, suggesting that eruption of some of the pyroclastic material occurred after the maria. More work is necessary to fully characterize volcanic features and their stratigraphic relationship to the spinel-bearing materials.

Discussion: The geologic history of the SA region is complex and the surficial expression of the observed rocks extends back before the origin of the Imbrium basin to the north (~3.85 Ga [23]). The spinel-bearing rocks of SA appear to be co-located with deposits of the ancient Fra Mauro Formation, extending as far north as Eratosthenes crater. However, only the SA portions of the Fra Mauro Formation are spinel-bearing. The largest continuous expanses of spinel-bearing rocks are located within the darkest hummocky highlands, SE of the SA maria and SW of RB (***Figure 2***). However, not all mantled highlands in SA show spinel signatures [13, 24]. Younger maria (~2.8-3.5 Ga [16]) embay the mantled highlands, and cover, surround and embay a large population of likely localized pyroclastic vents. Occasional vents with mantle superimposed on the mare in SA suggest that this type of volcanism also occurred intermittently after mare emplacement. It appears that the regional pyroclastic mantle on the highlands in SA originated from multiple explosive eruptions, at least some of which may have been large [11]. Further work is needed to determine whether spinel-bearing exposures of SA are associated strictly with the pyroclastic deposit or whether subsurface rocks also contain spinel.

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Figure 2. 3-D view of Sinus Aestuum looking NE (~25X vertical exaggeration). False-color MI-VIS mosaic (R=750/415, G=750/950, B=415/750) showing dark blue (high Fe, Ti) pyroclastic materials of SA covering the hummocky highlands (left and right, center). Copernicus crater is to the upper left (northwest) out of view, and the mantled Rima Bode region is to the northeast (upper right). Gambart crater at lower left is 25 km across.