TYRRHENA PATERA: VOLCANIC HISTORY DERIVED FROM HRSC-BASED CRATER COUNTS.

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Introduction: The High Resolution Stereo Camera (HRSC) on the European Space Agency's *Mars Express* orbiter [1] obtained color and stereo images of the Martian highland volcano Tyrrhena Patera in May 2004 and again in July 2005. These data provide insights into the volcanic history of Tyrrhena Patera in the context of previous *Viking* orbiter-based geologic mapping, and enable use of crater counts to assign model ages to mapped units.

Previous Work: Tyrrhena Patera is one of four 'highland paterae' located in the Hellas region [2] of the martian southern cratered highlands. These volcanoes are thought to be among the oldest central vent volcanoes on Mars [3]. They are noted for shallow, central calderas, on low-relief, deeply dissected flanks with radial channels and ridges [4,5]. Their lack of primary lava flow features and the nature of their eroded flanks suggests that the paterae are composed mostly of friable pyroclastic deposits [5,6]. Computer modeling [6-8] supports the construction of these paterae by gravity-driven pyroclastic flows. A geologic map of MTM –20252, covering part of Tyrrhena Patera [9], was completed using *Viking* orbiter images to define its volcanic history.

HRSC Imaging: The HRSC imaged Tyrrhena Patera during orbit 440 (25 May 2004), and again during orbits 1909 (11 July 2005) and 1920 (14 July 2005). Orbit 440 covered the caldera and west flank, and included nadir imaging at 36 m/pixel, with corresponding stereo imaging at 72 m/pixel and 4-color imaging at 144 m/pixel. Orbit 1909 covered part of the caldera and the east flank, and included nadir imaging at 30 m/pixel, with corresponding stereo imaging at 60 m/pixel and 4-color imaging at 120 m/pixel. Orbit 1920 was centered on the caldera, and was a full-resolution stereo observation including nadir and stereo imaging at 28 m/pixel. Super Resolution Camera (SRC) mosaics were also obtained on orbits 1909 and 1920. The orbit 1909 SRC mosaic covers Basal shield material (unit Ns) and Ridged & Etched plains material [9] NE of the caldera at ~12 m/pixel. The orbit 1920 SRC mosaic covers Upper Summit shield material (unit Nsu) and Rille-floor material (unit AHrf) [9] on the south side of the caldera at 11 m/pixel.

Crater Count Results: Using the *Gregg et al.* [9] geologic map as a guide, we mapped discrete units on the HRSC orbit 440 nadir image and assessed their ages (**Figure 1**). Crater counts were performed following the guidelines established in *Hartmann and Neukum* [10]. The typical age uncertainty from these counts is ±100 Ma for ages >3 Ga, but may vary by a factor of 2 for ages <3 Ga. We want to emphasize that cratering model age "absolute" dates are model dependent, and that existing models for Mars are not as tightly constrained as desirable (e.g., as for the Moon.) Nonetheless, the crater retention ages (crater frequencies) are useful for relative dating of various geologic events in a given region.

Caldera-Rille floor: The floors of the caldera and SW rille are the smoothest, least cratered parts of the volcano. These materials were mapped by *Gregg et al.* [9] as Amazonian-Hesperian Rille-floor materials (unit AHrf) that crosscut all other units and were interpreted to be late-stage lava flows. The caldera-rille has a cratering model age of 3.3 Ga, and a later resurfacing age of 1.1 Ga. These cratering model results suggest that activity (volcanic or other resurfacing) within the caldera was pervasive throughout much of martian history, with the most recent activity extending well into the Amazonian (<2-2.9 Ga). This is consistent with similar results obtained for other martian volcanoes [11, 12].

Upper summit shield materials: We mapped an areally large unit of Upper summit shield material (unit Nsu) for age assessment. *Gregg et al.* [9] interpreted this unit as likely pyroclastic flow deposits erupted from Tyrrhena Patera. Our crater count results for this unit show kinks in the size-frequency curve indicative of multiple resurfacing events. The oldest cratering model age is 4.0 Ga, confirming the extreme age of the Tyrrhena edifice, dating back to the Noachian (and consistent with the oldest ages for Hadriaca Patera: 3.7-3.9 Ga [11]). Other age dates for this unit suggest possible resurfacing events at 3.5 Ga and again at 1.6 Ga.

Lower summit shield materials: We mapped as one unit several locales of Lower summit shield materials (Nsl), which are described by *Gregg et al.* [9] as pyroclastic deposits erupted from Tyrrhena Patera that are more modified by erosional activity than unit Nsu. We obtained cratering model ages of 3.5 Ga and later resurfacing at 1.6 Ga for this unit. There is no statistical difference in cratering model age between Upper and Lower summit shield materials on Tyrrhena Patera.

Basal shield materials: We mapped two units of Basal shield materials (unit Ns: [9]), Ns_1 and Ns_2. The morphology of unit Ns_2 suggests erosion by fluvial activty that is not present for unit Ns_1. *Gregg et al. [9]* mapped these surfaces as one unit (although their map does not extend as far west as the HRSC image). They interpreted this material as pyroclastic deposits from Tyrrhena Patera modified by groundwater sapping,

with local morphologic variations resulting from differential erosion or separate eruptive events. We obtained cratering model ages of 3.9 Ga, 3.5 Ga, and 1.9 Ga for Ns_2 and 3.6 Ga and 2.6 Ga for Ns_1. We suggest a major eruptive event at 3.5-3.6 Ga emplaced these plains, and extensive fluvial activity eroded unit Ns_2 at 1.9 Ga, to a greater degree than Ns_1 at 2.6 Ga.

Channel-floor materials: NW of the summit is a region of eroded plains, with a lower albedo likely indicative of dark mafic material exposed by fluvial erosion from a nearby large channel. We obtained a cratering model age of 3.1 Ga with a resurfacing age of 1.2, the latter date marking the time of the last major fluvial event(s) at Tyrrhena Patera (TP).

Conclusions: Our new crater counts using HRSC data show that Tyrrhena Patera was active through a long period of martian history, and activity correlates well with activity at Hadriaca Patera. The earliest shield-building events at TP occurred ~3.9-4.0 Ga, prior to the end of the Noachian period (3.5-3.7 Ga: [10]). Major pyroclastic eruptions occurred ~3.5-3.6 Ga, and the most recent activity (volcanic and/or fluvial) occurred in the Amazonian, at 1.1-1.2 Ga and 1.6 Ga. Additional work is in progress [e.g., 13].

References: [1] *Neukum et al*., 2004, *ESA SP-1240*, ESA Pub. Div., Noordwijk, The Netherlands, 17-36; [2] *Peterson*, 1978, *Proc. 9th LPSC*, 3411-3432; *Schultz*, 1984, *LPSC XV*, 728-9; [3] *Scott and Carr*, 1978, *USGS Misc Inv Ser Map I-1083*, 1:25M; [4] *Plescia and Saunders*, 1979, *Proc 10th LPSC*, 2841-2859; [5] *Greeley and Spudis*, 1981, *Rev Geophys Space Phys 19*, 13-41; [6] *Crown and Greeley*, 1993, *JGR 98*, 3431-3451; [7] *Greeley and Crown*, 1990, *JGR 95*, 7133-7149; [8] *Gregg and Crown*, 2004, *IAVCEI Gen Assem, Pucon, Chile Abst*; [9] *Gregg et al., 1998, USGS Misc Inv Ser Map I-2556*, 1:500K; [10] *Hartmann and Neukum*, 2001, *Sp Sci Rev 96*, 165-194; [11] *Williams et al.*, 2005, *LPSC XXXVI*, #1470; [12] *Neukum et al*., 2004, *Nature 432*, 971-979; [13] *Crown et al*., 2005, LPSC XXXVI, #1476.

Figure 1. Summary of crater count areas and ages obtained thus far for Tyrrhena Patera using HRSC data. Crater counts performed by Stephanie Werner, FU-Berlin. Basemap is HRSC image h0440_0000.nd3, 36 m/pixel.