SYRTIS MAJOR AS THE SOURCE REGION OF THE NAKHLITE/CHASSIGNY GROUP OF MARTIAN METEORITES: IMPLICATIONS FOR THE GEOLOGICAL HISTORY OF MARS. R. P. Harvey1,2 and V. E. Hamilton1. 1Department of Geological Sciences, Case Western Reserve University, Cleveland OH 44106-7216 (rph@case.edu). 2Hawai‘i Institute of Geophysics and Planetology, University of Hawai‘i, Honolulu, HI 96822 (hamilton@higp.hawaii.edu).

Introduction: A major challenge facing ongoing studies of Mars is that the lack of datable surface samples leaves accepted crater counting-based chronologies proposed for Mars merely relative [1-3]. Although the mechanism of Martian meteorite delivery destroys their original geographical context, it is theoretically possible for these samples to provide the missing context. Through matching the unique physical, geochemical and spectral properties of meteorites with potential parent volcanic units on Mars. An obvious additional requirement is that such regions must contain at least one crater whose size and apparent age provides a plausible mechanism for transfer of material to Earth.

Syrtis Major: At nearly ~1100 km across, Syrtis Major is the largest of several relatively ancient shield volcanoes superimposed on the Southern Highlands of Mars. Clues to the composition of Syrtis Major volcanics come from both geomorphological and spectroscopic studies [e.g. 4]. Although often described as "basaltic" [e.g. 5], Syrtis Major does not exhibit the profile of a typical basaltic shield. Flank slopes are shallow: at its peak Syrtis Major rises only 500 m above the inferred regional northward-sloping Southern Highlands surface. Long, thin lava flows are prevalent, with some extending into nearby Nili Fossae, Antoniadi crater and the Isidis basin [4]. The combination of low slopes and long thin flows requires a very low viscosity magma [4,6-8]. Large regions of the Syrtis lava plains also lie significantly below the inferred regional surface, suggesting widespread thermal erosion [4, 8-11]. The deep calderas of Syrtis Major with their significant positive gravity anomaly further suggest a high-density magma chamber rich in accumulated olivine and/or pyroxene [12]. Together these suggest magmas of predominantly ultramafic compositions.

The presence of ultramafic eruptives at Syrtis Major is also supported by spectroscopic data. Pinet and Chevrel [13] interpreted data from the PHOBOSS imaging spectrometer (ISM) and suggested the presence of an olivine-bearing lithology. Mustard et al. [14, 15] suggested the presence of high-Ca pyroxene (augite) at Syrtis Major favoring a lithology dominated by a mixture of both high- and low-Ca pyroxene in a ratio of 2:4 to 1. These authors also suggested the presence of a feldspathic and/or “glass” components rather than olivine. However, the signature of olivine in ISM data was favored by Reyes and Christensen [8], who argued for Mg-rich ultramafic lithologies, such as komatiites or komatiitic basalts.

More recently, TES and THEMIS data has provided data with much higher spectral and geographical resolution [16, 17]. TES data were used by Bandfield et al. [18] to map the main Syrtis shield as basaltic, and Hamilton et al. [16] concluded that rocks in a region of Nili Fossae were consistent with the presence of up to 20% of an olivine-dominated dunite-like endmember similar to the Martian meteorite Chassigny. The presence of the olivine-bearing lherzolitic shergottite Martian meteorite endmember was also identified in the region, whereas the presence of a clinopyroxenite-like endmember similar to Nakhlite was identified along the margins of Syrtis Major. The presence of an olivine-bearing lithology in Nili Fossae was identified by Hoefen et al. [20] as well, who showed that the major concentration of olivine in Nili Fossae was consistent with Fo60-70 compositions, while more widespread olivine of Fo40 composition was spread throughout the eastern edge of Syrtis Major.

The observed geomorphology and spectroscopy of Syrtis Major are consistent with a dramatically differentiated ultramafic volcanic complex that shares many traits with komatiite-bearing units from the terrestrial Archean [21]. By analogy, early eruptions at Syrtis would consist of voluminous, low-viscosity and olivine-dominated magmas whose powers of thermal erosion would create the wide depressed footprint of Syrtis Major. As the original magma differentiated, later flows would become richer in feldspar and pyroxene, producing thick flows where crystal settling would produce pyroxene-dominated lower units and more feldspathic (basaltic) upper units. The result is a volcanic complex whose youngest surface rocks would be glassy and basaltic but whose earlier and most voluminous rocks would be cumulate and ultramafic. In the absence of global tectonics, these deeper seated rocks would have limited exposure in the Martian environment, being seen only at the margins of the volcano or where significant tectonic deformation or erosion had occurred.

Ties to the Nakhliites: Among the known Martian meteorites, a group made up of all the 7 known Nakhliites and Chassigny show compelling correspondence with the observed mineralogy and the suggested history of the Syrtis Major region. The Nakhliites and Chassigny share common crystallization (about 1.3 billion years) and ejection ages (about 11 million years) and are thus thought to be members of a single differentiated ultramafic series of flows ejected during a single impact event. High-Ca pyroxene and
high-Fe olivine are unique features of the Nakhlites and pursuasively similar to the mineralogy of eastern Syrtis Major. Likewise, Chassigny's mineralogy is compellingly similar to that linked to sites in adjacent Nili Fossae, where early olivine-rich, hot and very fluid lavas from Syrtis may have invasively penetrated that terrain. Although the presence of relatively Mg-rich olivine spectral signatures is not unique to this region, the presence of Mg-rich olivine adjacent to rocks rich in clinopyroxene and Fe-rich olivine compellingly suggests the Nakhlites and Chassigny were derived from the northeast region of Syrtis Major volcanics.

**Delivery Mechanism:** The surface of Syrtis Major has many craters of sufficient size (>5km dia) to support mass transfer to Earth [22]; however, one specific crater in the northeast region of Syrtis Major is both large and elliptical (~14 x 22 km), favored characteristics for ejecting Martian meteorites. Analysis of high resolution MOC and THEMIS images suggests a young, but not zero-age surface, consistent with the ejection hypothesis.

**Significance:** Tying the crystallization age of the Nakhlites and Chassigny to Syrtis Major has significant implications for the history of Mars. Syrtis Major has been most recently placed in the Early Hesperian [4], widely accepted to be 2.9 - 3.8 billion years old [1-3]. If Syrtis Major is actually only 1.3 billion years old, much of the Martian surface must be 2-3x younger than previously thought, and cratering rates must be correspondingly 2-3x higher. Given an assumed Mars/Moon cratering ratio with a factor of 2-4 uncertainty. This poses less of a problem than one might think [23]. Furthermore, a generally younger relative stratigraphy helps answer several persistent enigmas in Martian studies. For example, the basaltic shergottites, with crystallization ages from 165 to 650 Ma, come from many ejections and seem anomalously young and difficult to place in crater-count-based geological histories of Mars [24]. A younger absolute age for Tharsis and Elysium volcanic terrains makes them better parents for the shergottites. A younger stratigraphy also helps solve a paradox concerning the history of water on Mars. By limiting the current "mostly dry" period to the most recent 1.3 rather than 3+ billion years, some very welcome time is provided for the transition between hypothesized ancient “wet” conditions, better accommodating both within Martian history.

Finally, associating the crater in question with the Nakhlites provides a very interesting prediction for the future. MOLA data suggest the crater may intersect not only the younger Nakhlite- and Chassigny-like lavas of Syrtis Major, but also the older Noachian basement that is fully exposed in Nili Fossae. If true, it suggests that somewhere in space or on Earth there may be a Martian meteorite that shares the Nakhlite/Chassigny ejection age but has an ancient crystallization age, providing an absolute age for the ancient Martian highlands crust and another pin to the geologic timetable of Mars.

**References:**

![Figure 1](image.png)