Nili Fossae	Location (lat,lon):	21.3 N, 74.1 E

Summary of observations and interpreted history, including unknowns:

The Nili Fossae landing site is within a canyon, one of a series of tectonic graben, located west of Mars' Isidis basin. The canyon includes eroded exposures of multiple geologic units with a variety of mineral phases, including Fe/Mg clay minerals, two distinctive high- and low-Ca pyroxene dominated igneous units, and a carbonate bearing unit, spanning a total of 600 m of section (with the lowest 100s of meters accessible to rovers). The geological units record relatively recent crater ejecta and additional geologic units from the Early Hesperian to Early or Pre-Noachian time periods.

The geologic history has been interpreted as follows: Terrains including low-Ca pyroxene and Fe/Mg phyllosilicates existed in the Pre-Noachian/Early-Noachian. In the Early to Mid Noachian, the Isidis impact occurred, disrupting the Pre-Noachian/Early-Noachian terrains present. Following the impact (10^6-10^8 years), the Nili Fossae graben formed by tectonic activity. The canyons (graben) were then eroded, probably by alluvial/fluvial activity, resulting in the filling of the bottom of the trough as a succession of Fe/Mg clay-bearing deposits, called "trough fill". Then, in the early Hesperian, lavas from the Syrtis major volcano to the south covered the sediments with a resistant lava caprock. Finally, diverse ejecta including both unaltered and clay-rich material from 65-km Hargraves crater, located to the east of the graben, were emplaced atop the lavas.

Thus, Nili Fossae presents an opportunity to sample ancient units on Mars spanning 100s of Myr of time and including some of the most ancient units accessible at the surface (Early- or Pre-Noachian). With this age comes uncertainty as to environmental setting and the nature of biosignatures preservable: it is an open question whether the oldest Fe/Mg clay-rich unit(s) at the site in the basement formed by lacustrine, diagenetic, weathering or hydrothermal processes because the sub-cm textures needed to make this determination require landed investigation. What is more certain is that clay-bearing materials of probable fluvial/alluvial origin, and perhaps derived from erosion of the graben walls, are stratigraphically above these Pre-Noachian/Early-Noachian clay- and pyroxene-bearing units. There are also igneous units of two distinct compositions that record a proposed change in the nature of Martian magmatism (low-Ca pyroxene dominated early Noachian vs. high-Ca pyroxene dominated early Hesperian) as well as impact ejecta from Hargraves. The ages of units are well-bracketed and constrained by crater counting of the Isidis basin and the Syrtis lavas.

Summary of key investigations

-M2020 would search for evidence of organics and other biosignatures in fluvial/alluvial sedimentary clay units, and Pre-Noachian/Early-Noachian clay-bearing units (which are of uncertain origin). Impact glass, potentially present in Hargraves ejecta might also provide a mechanism of organic matter preservation [Schultz et al., 2015], though the relevance of this model for organic-preservation on the ancient surface of Mars is speculative. Perhaps more importantly, impact glasses and porous impact rocks are colonized by microbial communities on Earth, leaving trace fossils and chemical biosignatures from their metabolic activity [Sapers et al., 2015; Pontefract et al., 2016]. Thus the Hargraves ejecta itself represents a potentially habitable environment.
-M2020 would establish the nature of the Early Noachian "crustal" clay-bearing units, answering the question of whether the Fe/Mg smectites formed via lacustrine, diagenetic, weathering, or hydrothermal processes. M2020 would also establish the nature of the environments recorded in the overall site stratigraphy and the relative prevalence of each across a significant span of Martian geological history.

-M2020 would investigate the geological effects of impacts in terms of mineral formation/chemical transformation, both in the recent (later than early Hesp.) Hargraves ejecta and in the Isidis-disrupted basement (Pre-Noachian to Early Noachian)
-M2020 would sample impact glass (for dating and astrobiological relevance), multiple igneous units (for dating and for assessment of the evolution of volcanic processes on Mars), and multiple clay-bearing units to constrain their geochemical environment(s) of formation, determine their organic-carbon contents and assess whether any biological record is contained in their chemistry, mineralogy, isotopic composition, or micro- morphology.

Cognizant Individuals/Advocates:

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Link to JMARS session file | Link to Workshop 2 rubric summary

http://marsnext.jpl.nasa.gov/workshops/2015_08/28_Cannon_Mars2020_PPTforWebsite.pdf

https://docs.google.com/spreadsheets/d/16Rmn2qHFQc6BKJtiyIeDLcyBxJqq8Oq4VO3etqrZ8lo/edit#gid=868597987

Key Publications list (grouped by topic):

Stratigraphy & Geologic History (incl. Mineralogy); *=most holistic overview

Ehlmann, B. L., et al. (2009), Identification of hydrated silicate minerals on Mars using MRO-CRISM: Geologic context near Nili Fossae and implications for aqueous alteration, J. Geophys. Res., 114, E00D08, doi:10.1029/2009JE003339.

Mangold, N., et al. (2007), Mineralogy of the Nili Fossae region with OMEGA/Mars Express data: 2. Aqueous alteration of the crust, J. Geophys. Res., 112, E08S04, doi:10.1029/2006JE002835.

Michalski J. et al. (2010) Analysis of phyllosilicate deposits in the Nili Fossae region of Mars: Comparison of TES and OMEGA data. Icarus, 206, 269-289

Mustard, J. F., F. Poulet, J. W. Head, N. Mangold, J.-P. Bibring, S. M. Pelkey, C. I. Fassett, Y. Langevin, and G. Neukum (2007), Mineralogy of the Nili Fossae region with OMEGA/Mars Express data: 1. Ancient impact melt in the Isidis basin and implications for the transition from the Noachian to Hesperian, J. Geophys. Res., 112, E08S03, doi:10.1029/2006JE002834.

(*) Mustard, J. F., B. L. Ehlmann, S. L. Murchie, F. Poulet, N. Mangold, J. W. Head, J.-P. Bibring, and L. H. Roach (2009), Composition, Morphology, and Stratigraphy of Noachian Crust around the Isidis basin, J. Geophys. Res., 114, E00D12, doi:10.1029/2009JE003349.

Tornabene, L. L., J. E. Moersch, H. Y. McSween Jr., V. E. Hamilton, J. L. Piatek, and P. R. Christensen (2008), Surface and crater-exposed lithologic units of the Isidis basin as mapped by coanalysis of THEMIS and TES derived data products, J. Geophys. Res., 113, E10001, doi:10.1029/2007JE002988.

Brown, Adrian J., et al. (2010) Hydrothermal Formation of Clay-Carbonate Alteration Assemblages in the Nili Fossae Region of Mars. Earth and Planetary Science Letters 297, 174–82.

Habitability/Biosignatures

P.H. Schultz, R. Scott Harris, S.J. Clemett, K.L. Thomas-Keprta, and M. Zárate (2015) Preserved flora and organics in impact melt breccias, Geology, July 1, 2015, v. 43, p. 635-638

Sapers, H. M., Banerjee, N. R., and Osinski, G. R. (2015) Potential for impact glass to preserve microbial metabolism, Earth and Planetary Science Letters 430, 95-104.

Pontefract Alexandra, Osinski Gordon R., Cockell Charles S., Southam Gordon, McCausland Phil J.A., Umoh Joseph, and Holdsworth David W.. Astrobiology. October 2016, 16(10): 775-786. doi:10.1089/ast.2015.1393.

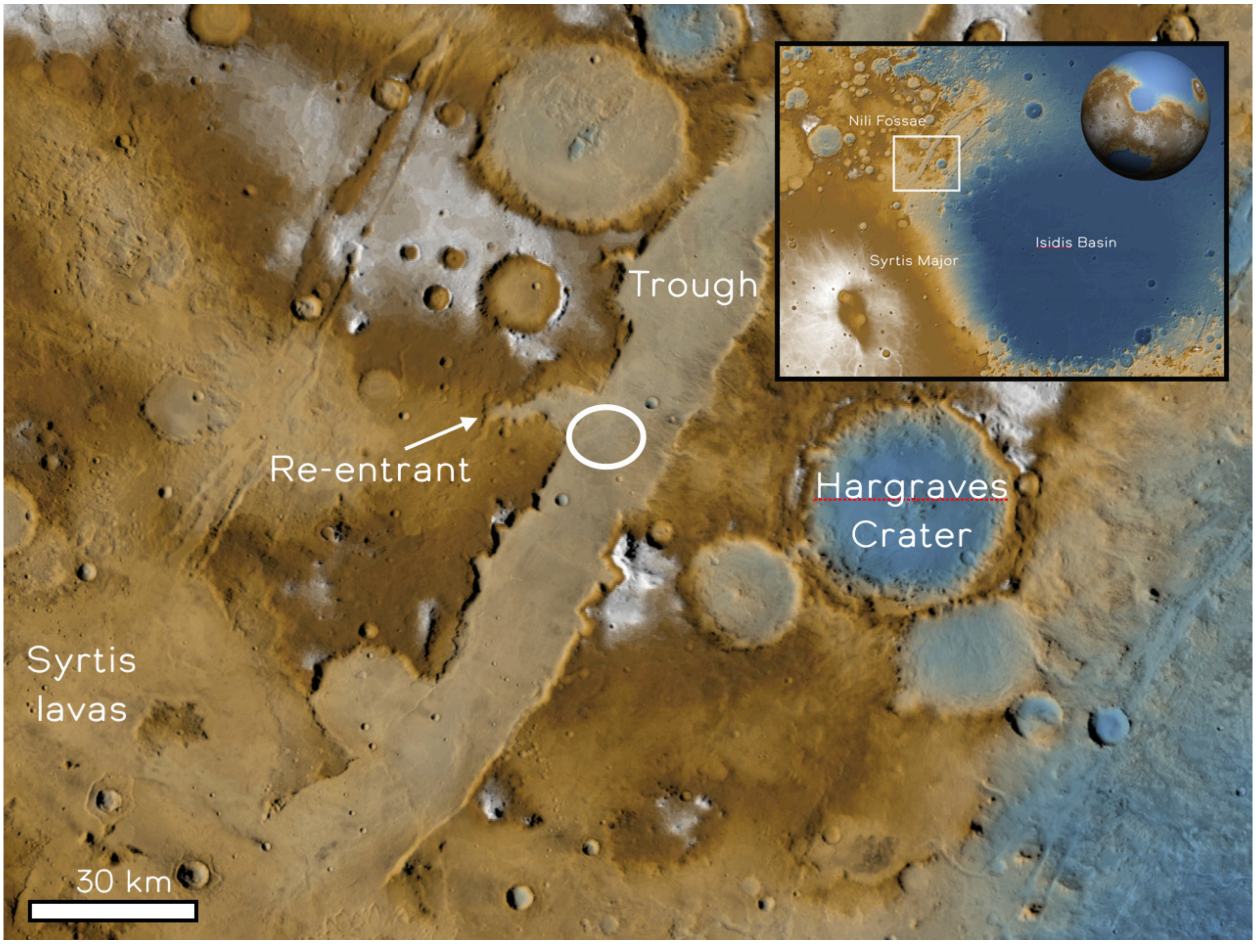
Tectonics

Ritzer, JA and SA Hauck (2009) Lithospheric structure and tectonics at Isidis Planitia, Mars. Icarus 201, 528–539

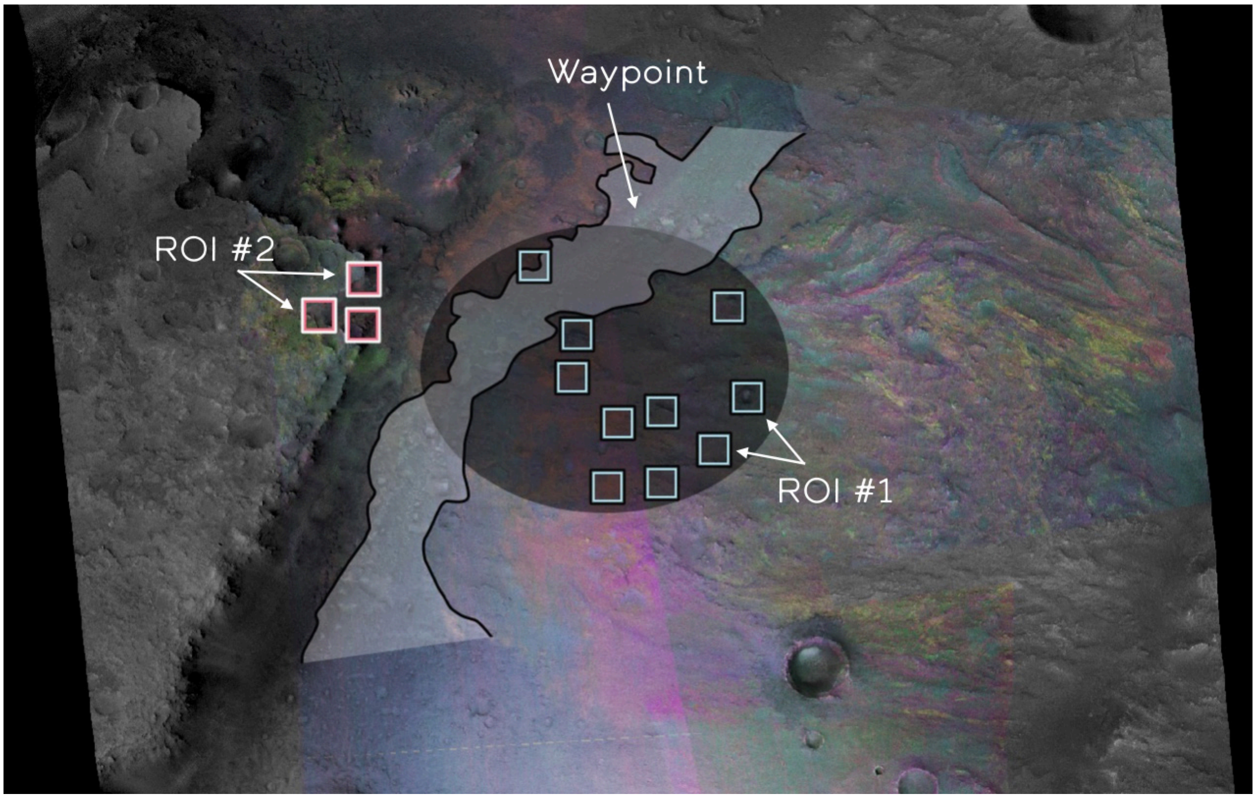
Nature of the Basement Unit

Saper, L., and J. F. Mustard (2013), Extensive linear ridge networks in Nili Fossae and Nilosyrtis, Mars: implications for fluid flow in the ancient crust, Geophys. Res. Lett., 40, 245–249, doi:10.1002/grl.50106.

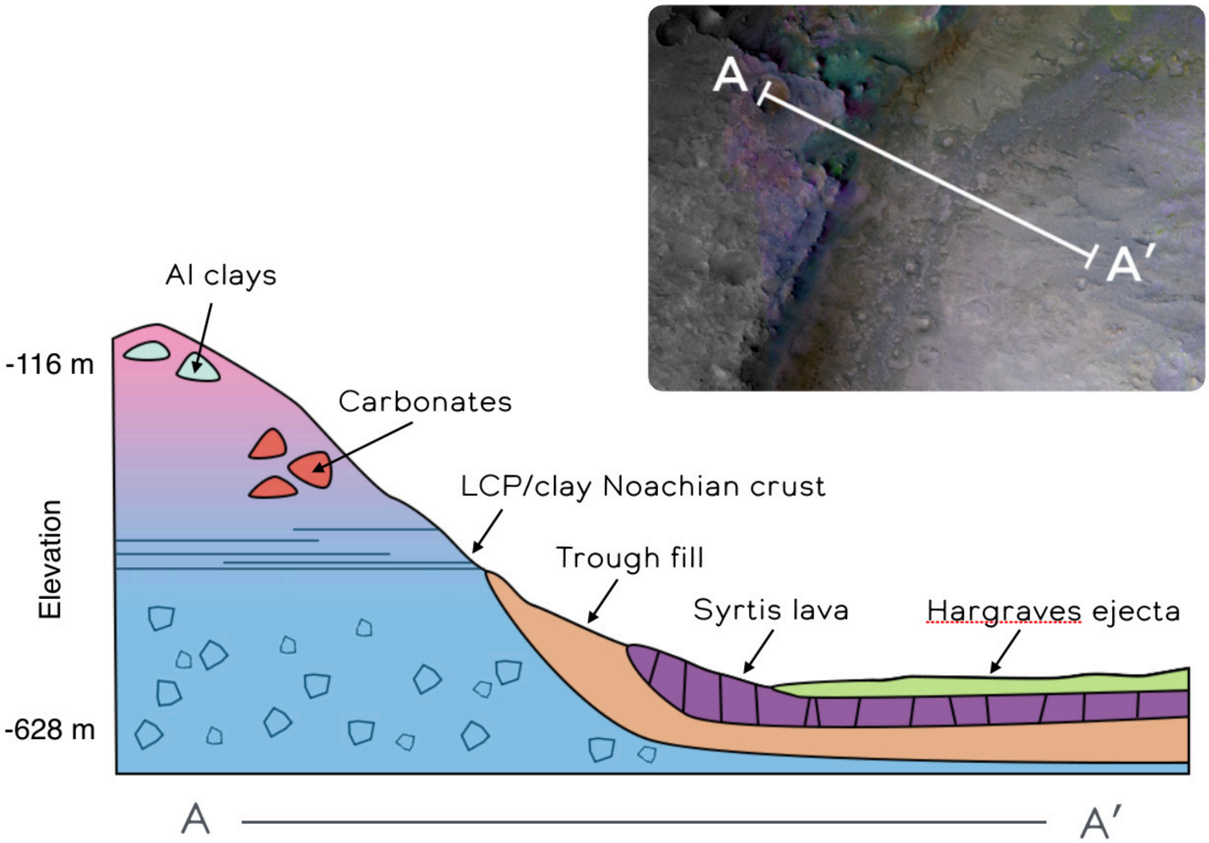
Regional Context Figure (courtesy K. Cannon)



Ellipse ROI Map (courtesy K. Cannon)



Regional Stratigraphic Column Figure (courtesy K. Cannon)



Inferred Timeline Figure (ref: Mustard et al., 2009; Syrtis age from Hiesinger & Head, 2004)

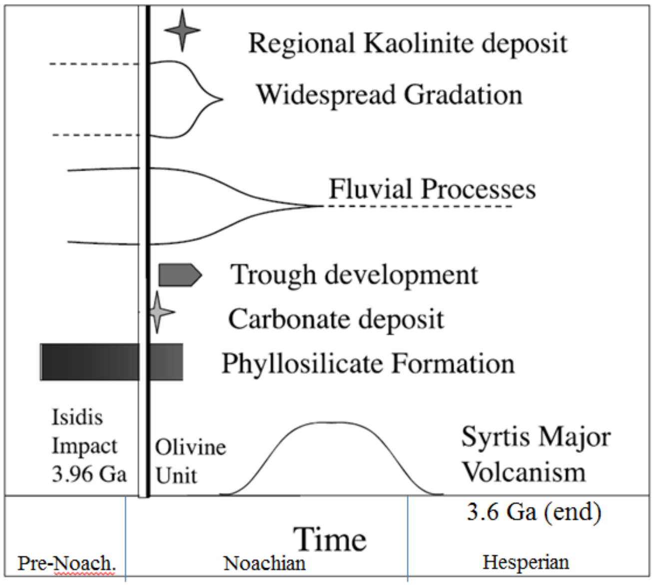


Figure 18. Schematic timeline of the geological history of the circum-Isidis region from the Noachian through the emplacement of the Syrtis Major volcanic rocks in the Hesperian.

Summary of Top 3-5 Units/ROIs

ROI	Aqueous or Igneous?	Environmental settings for biosignature preservation	Aqueous geochemical environments indicated by mineral assemblages
1. Noachian crustal clays and LCP	Aqueous (in contact with igneous protolith)	Largely unconstrained. Possible record of deep biosphere processes.	Unconstrained. Lacustrine, diagenetic, weathering, or hydrothermal are offered as possibilities
2. Trough fill clays and Syrtis Lavas	Both	Potential fluvial/alluvial setting for trough fill clays. None for Syrtis lavas	Potential fluvial, alluvial (+/- mass wasting?)
3. Olivine-clay unit (not in ellipse)	Aqueous (in contact with igneous protolith)	Possible hydrothermal activity related to olivine carbonation leads to suggestion of preserved hydrothermal biosignatures	Hydrothermal olivine-carbonate-clay association. Also, possible later pedogenic episode resulting in generation of aluminous clays.

Top 3-5 Units/ROIs Detailed Descriptions

Unit/ROI Name:	**Noachian crustal clays and LCP**
Aqueous and/or Igneous?	Aqueous (in contact with igneous protolith)

Interpretation(s):

- Crustal clays and unaltered rocks from mid-Noachian crust demonstrate pervasive water-rock interaction, possibly in a hydrothermal subsurface environment.

In Situ Investigations:

- What is the Noachian crust made of? When and to what extent was it altered?
- Do the clays in the ejecta represent excavated subsurface material?
- Did any of them form post-impact through hydrothermalism, possibly related to emplacement of Hargreaves ejecta?

Returned Samples and Analyses:

- Altered and unaltered Noachian crustal material – igneous petrologic and aqueous mineral studies (chemical, mineralogical, isotopic). Search for organic carbon +/- biosignatures.
- Pristine impact products from Hargreaves. Geochronology, impact physics.
- Diversity of clasts within ejecta. Igneous petrologic and aqueous mineral studies (chemical, mineralogical, isotopic). Search for organic carbon +/- biosignatures.

Unit/ROI Name:	**Trough fill clays and Syrtis Lavas**
Aqueous and/or Igneous?	Both

Interpretation(s):

- Trough-fill material contains abundant clays and was possibly deposited in a sedimentary environment as indicated by layering.
- Syrtis lavas emplaced as part of regional Hesperian lava flows

In Situ Investigations:

- Were the trough fill clays deposited in a sedimentary environment?
- Do the clays contain preserved organic matter?
- Preservation state of Syrtis lavas

Returned Sample Analyses:

- Clay-rich trough fill material, especially where found in layered units. Sedimentary petrology, geochemistry, aqueous mineral studies (chemical, mineralogical, isotopic). Search for organic carbon +/- biosignatures.
- Syrtis lavas (textural/compositional endmembers, and chill margins). Geochronology, igneous petrology.

Unit/ROI Name:	**Olivine-clay unit (not in ellipse)**
Aqueous and/or Igneous?	Aqueous (in contact with igneous protolith)

Interpretation(s): (taken from NE Syrtis fact sheet, assumes same/similar origin)

- Olivine-bearing units formed by impact cumulates (Mustard et al) or lavas (Hamilton & Christiansen; Tornabene)
- Mg-carbonates from near-surface weathering of basaltic products, hydrothermal serpentinization-type reactions, direct hydrothermal precipitation, or shallow aqueous deposition
- Mg-carbonates and phyllosilicates from high-T contact metamorphism (McSween et al.)

In Situ Investigations:

- Is the olivine-rich unit volcanic in nature (Hoefen et al. 2003; Hamilton and Christensen 2005; Tornabene et al. 2008) or impact melt (Mustard et al. 2007, 2009)?
- Does the olivine-rich unit represent a serpentinizing system (Brown et al. 2010; Viviano-Beck et al. 2013)?

Returned Sample Analyses:

- Olivine-clay unit, incl. carbonate: Igneous petrologic and aqueous mineral studies (chemical, mineralogical, isotopic). Search for organic carbon +/- biosignatures.
- Associated LCP-rich Noachian crust: Geochronology, igneous petrology.
- Associated aluminous clay units: Sedimentary petrology, geochemistry, aqueous mineral studies (chemical, mineralogical, isotopic).

Biosignatures (M2020 Objective B and Objective C + e2e-iSAG Type 1A, 1B samples)

Biosignature Category	Inferred Location at Site	Biosig. Formation & Preservation Potential
Organic materials	All ROI's	1. Synthesis of organic molecules in hydrothermal environments (ROIs 1 &3). Hydrothermal biosphere. Preservation in impact glass from Hargraves ejecta. 2. Accumulation of organic molecules in sedimentary environments (ROI 2). Preservation through burial.
Chemical	Not specified	Not specified

Isotopic	All ROI's	1. Synthesis of organic molecules in hydrothermal environments (ROIs 1 &3). Hydrothermal biosphere. Preservation in impact glass from Hargraves ejecta. 2. Accumulation of organic molecules in sedimentary environments (ROI 2). Preservation through burial.
Mineralogical	Not specified	Not specified
Micro-morphological	All ROI's	1. Synthesis of organic molecules in hydrothermal environments (ROIs 1 &3). Hydrothermal biosphere. Preservation in impact glass from Hargraves ejecta. 2. Accumulation of organic molecules in sedimentary environments (ROI 2). Preservation through burial.
Macro-morphological	All ROI's	1. Synthesis of organic molecules in hydrothermal environments (ROIs 1 &3). Hydrothermal biosphere. Preservation in impact glass from Hargraves ejecta. 2. Accumulation of organic molecules in sedimentary environments (ROI 2). Preservation through burial.

Dateable Unit(s) for Cratering Chronology Establishment

Unit Name	Total Area (km^2)	Time Period	Geologic Interpretation and uncertainties	What constraints would the unit provide on crater chronology?
Syrtis lava	XX	EH	Extensive lava flows sources from the Syrtis Major volcanic complex, located to the southwest of the landing site	Syrtis lavas are an aerially extensive lava flow field that is well studied (e.g., Hiesinger and Head, 2004) and rocks dated from this unit would be readily tied into the Mars cratering chronology.

Key Uncertainties/Unknowns about the Site

- While the large-scale lithological units can be placed into a time-ordered succession, considerable uncertainty exists surrounding the origins of each unit that is associated with aqueous activity, with multiple possible origins posed for each.
- Due to the uncertainty associated with the emplacement of aqueous minerals, it is difficult to assess the astrobiological potential of the site with confidence. Generally, the site is thought to host multiple potential hydrothermal environments of astrobiological interest (deep crustal + impact hydrothermal), plus the possibility of a near-surface region of astrobiological interest associated with the emplacement of trough fill. The primary mechanism of biosignature preservation cited for the former is

through preservation in impact glass. Presumably the preservation mechanism associated with the latter would involve burial by sediment.