JEZERO CRATER

Location (lat,lon): **18.85N,77.52E**

Summary of observations and interpreted history, including unknowns:

Jezero is a Noachian crater basin at the western edge of the Isidis Basin. It is characterized by Late Noachian/Early Hesperian fluvial/deltaic sediment deposition into a circum-neutral/low salinity (i.e. habitable) paleolake. A Western and Northern Delta have been observed from orbit. The Western Delta is dominated by Fe/Mg smectites and exhibits well defined sedimentary layering, including bottomset deposits. The Northern Delta is dominated by Mg-carbonates and associated olivine, but is less well preserved than the Western Delta. The Basin Fill is also dominated by olivine and Mg-carbonates, though it is unclear whether this represents primary detrital deposition, re-working of pre-lacustrine sediments, or exposure of the regional Mg-carbonate/olivine unit observed more broadly in Nili Fossae (also of unknown origin). A Volcanic Unit (~3.5 Ga) overlies most of the Basin Fill, embays the eroded delta scarps, and surrounds deltaic remnants which have been separated from the main delta bodies by aeolian deflation at some time prior to volcanism.

Summary of key investigations

Deltaic bottomsets, Fe-Mg smectites, and lacustrine carbonate can be investigated for preserved organic matter both *in situ* and in returned samples. Investigation of the stratigraphy and sedimentary structures of the delta deposit will also help to constrain the formative conditions for the deposit (e.g., flow magnitudes, duration, etc.), which are thought to be representative of early martian valley network activity. This may also help give insights into the early martian climate. Fe/Mg smectites may give insights into the hydrothermal nature and atmospheric exchange processes of Pre-Early Noachian crustal material. Investigation of detrital smectites would also provide insight into the link between surface runoff and aqueous alteration on early Mars. Examination of carbonate basin fill texture in place may help with interpretation of this basin fill unit. Returned carbonate samples can provide insight into early Martian atmospheric processes, as well as martian carbon reservoirs, past fluid geochemistry, and aqueous temperatures of carbonate formation. Returned volcanic samples can be dated providing further constraints on timing of regional events and help constrain the absolute timing of martian production functions.

Cognizant Individuals/Advocates:

Tim Goudge, Bethany Ehlmann, Jack Mustard, Nicolas Mangold, Jim Head, Caleb Fassett, Sanjeev Gupta, Ralph Milliken, Adrian Brown, Suniti Karunatillake, Joel Hurowitz, Woody Fischer

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

http://marsnext.jpl.nasa.gov/workshops/2015_08/20_Goudge_Jezero_Mars_2020_2nd_Workshop_for_Web.pdf

https://docs.google.com/spreadsheets/d/16Rmn2qHFQc6BKJtiyIeDLcyBxJqq8Oq4VO3etqrZ8lo/edit?invite=CNm8lqYF&pref=2&pli=1 - gid=868597987

Key Publications list (grouped by topic):

Site Overview

Goudge, T. A., R. E. Milliken, J. W. Head, J. F. Mustard, and C. I. Fassett (2017), Sedimentological evidence for a deltaic origin of the western fan deposit in Jezero crater, Mars and implications for future exploration, Earth Planet. Sci. Lett., 458, 357–365, doi: 10.1016/j.epsl.2016.10.056.

Goudge *et al.* (2015) Assessing the mineralogy of the watershed and fan deposits of the Jezero crater paleolake system, Mars*, J. Geophys. Res. Planets, 120,* 775-808. doi:10.1002/2014JE004782

Schon *et al.* (2012) An overfilled lacustrine system and progradational delta in Jezero crater, Mars: Implications for Noachian climate, *Planetary and Space Science 67*, 28-45. doi:10.1016/j.pss.2012.02.003

Ehlmann *et al.* (2008) Clay minerals in delta deposits and organic preservation potential on Mars, *Nature Geoscience 11*, 355-358

Fassett and Head (2005) Fluvial sedimentary deposits on Mars: Ancient deltas in a crater lake in the Nili Fossae region, *Geophysical Research Letters 32*, L14201. doi:10:1029/2005GL023456

Regional Overview

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.

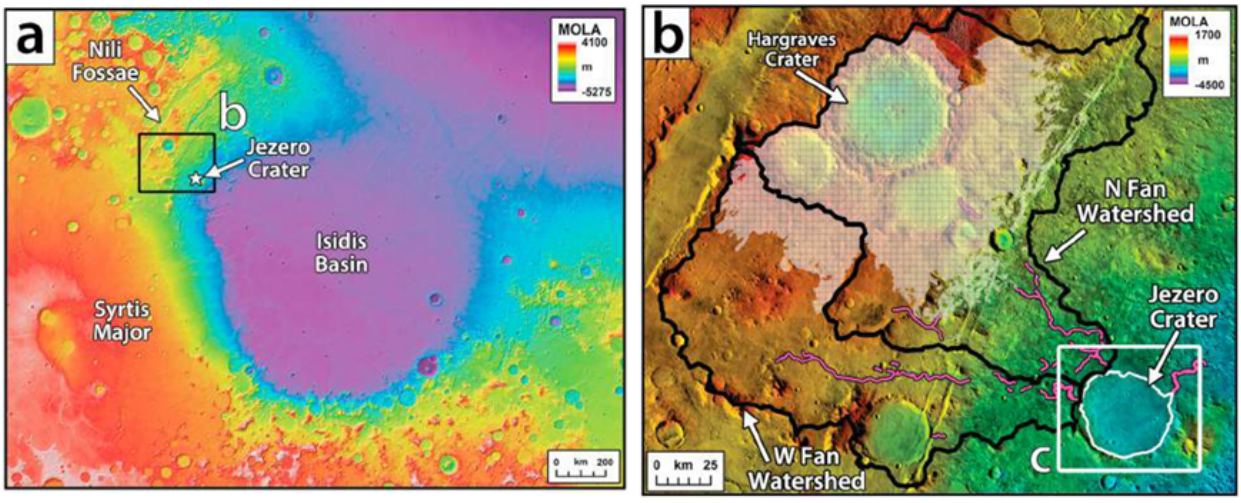
Ehlmann, B. L., et al. (2009), Identification of hydrated silicate minerals on Mars using MRO-CRISM: Geologic context near Nili Fossae and implications for aqueous alteration, J. Geophys. Res., 114, E00D08, doi:10.1029/2009JE003339.

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.

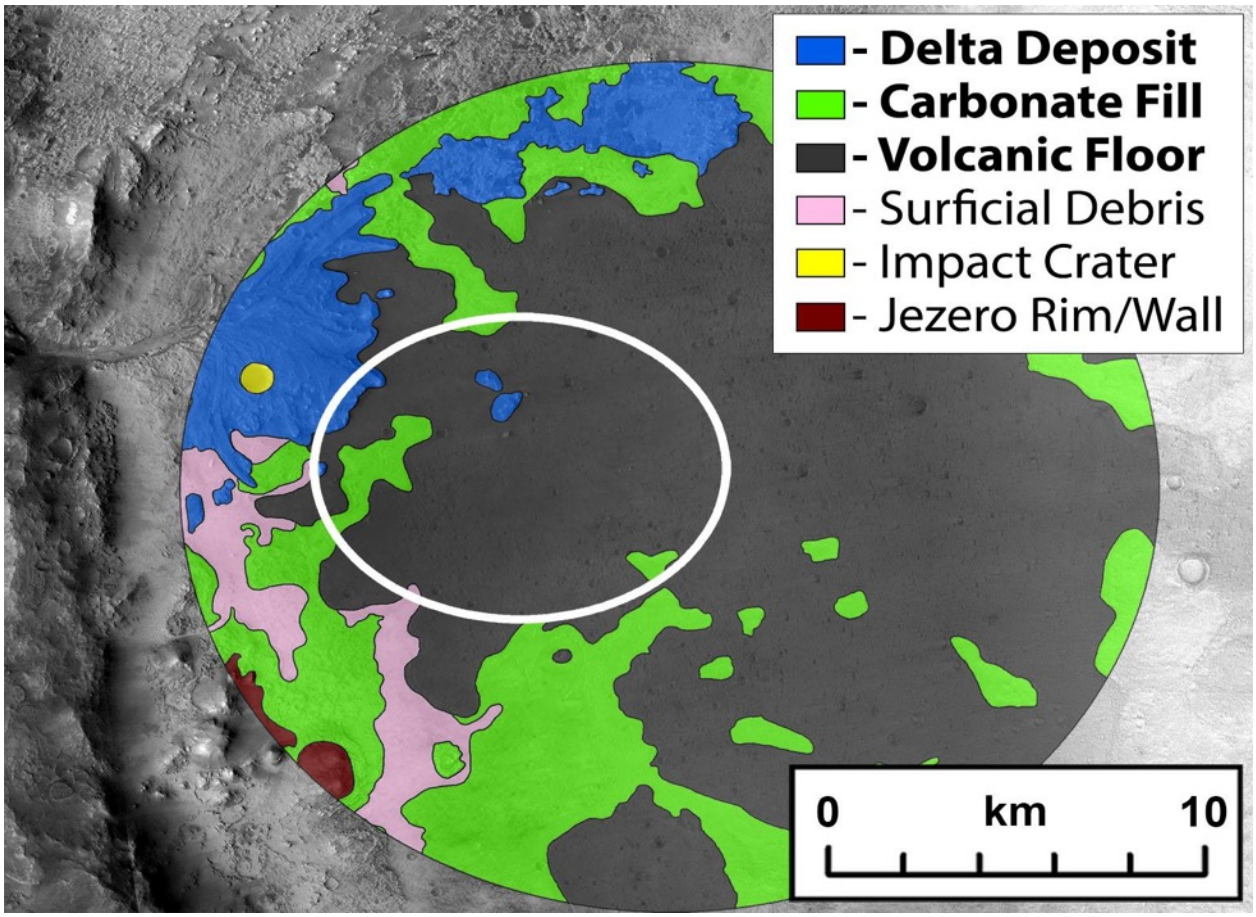
Brown, A. J., S. J. Hook, A. M. Baldridge, J. K. Crowley, N. T. Bridges, B. J. Thomson, G. M. Marion, C. R. de Souza Filho, and J. L. Bishop (2010), Hydrothermal formation of clay-carbonate alteration assemblages in the Nili Fossae region of Mars, Earth Planet. Sci. Lett., 297, 174–182, doi: 10.1016/j.epsl.2010.06.018.

Viviano, C. E., J. E. Moersch, and H. Y. McSween (2013), Implications for early hydrothermal environments on Mars through the spectral evidence for carbonation and chloritization reactions in the Nili Fossae region, J. Geophys. Res. Planets, 118, 1858–1872, doi:10.1002/jgre.20141.

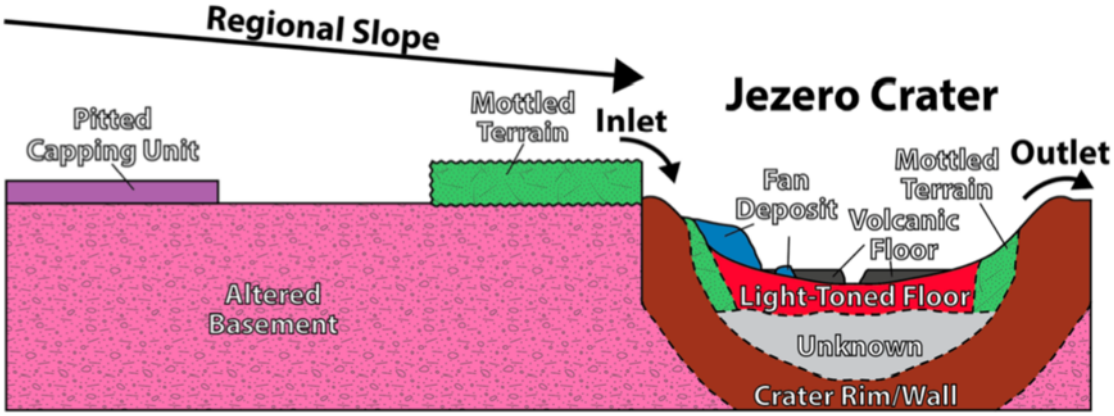
Regional Context Figure (ref: from Goudge et al 2015)

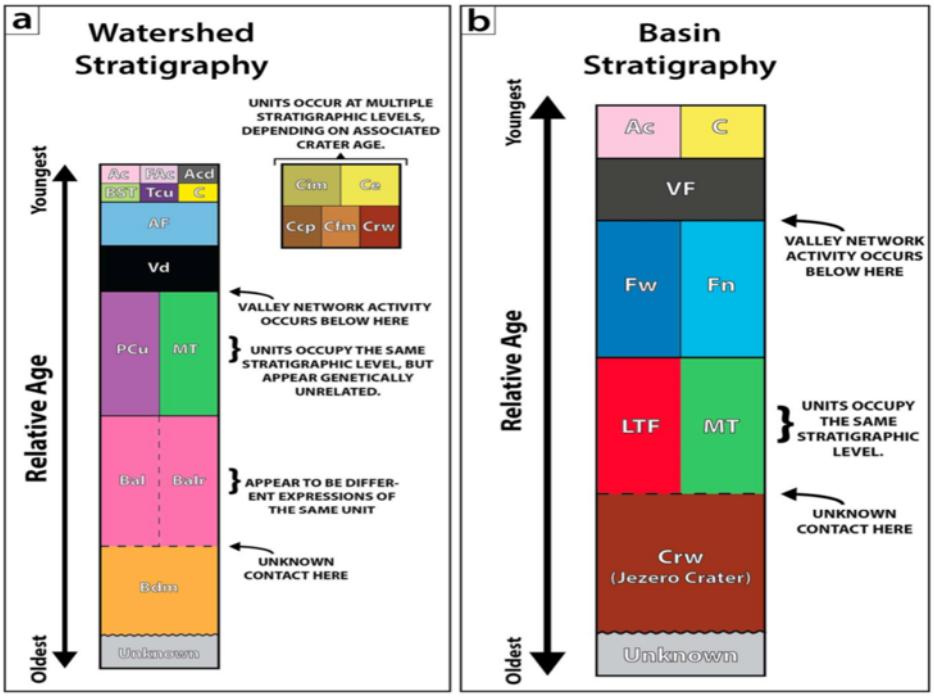


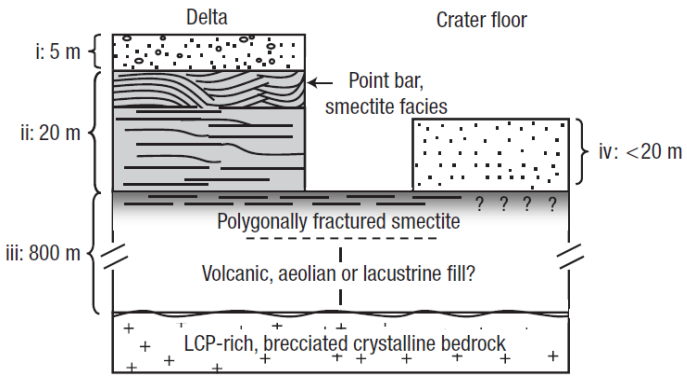
Ellipse ROI Map or Geologic Map Figure (ref: from Goudge 1-14-2017)



Regional (~3x ellipse) Stratigraphic Column Figure (ref: Goudge et al, 2015)



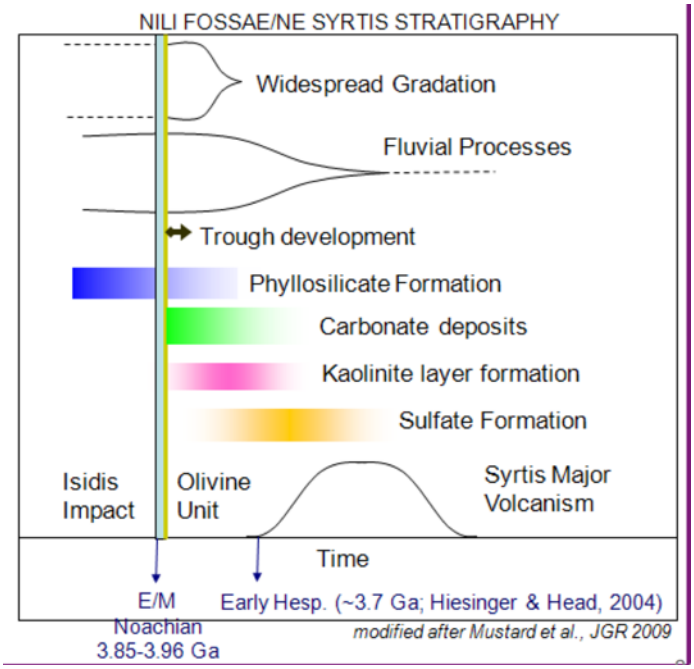




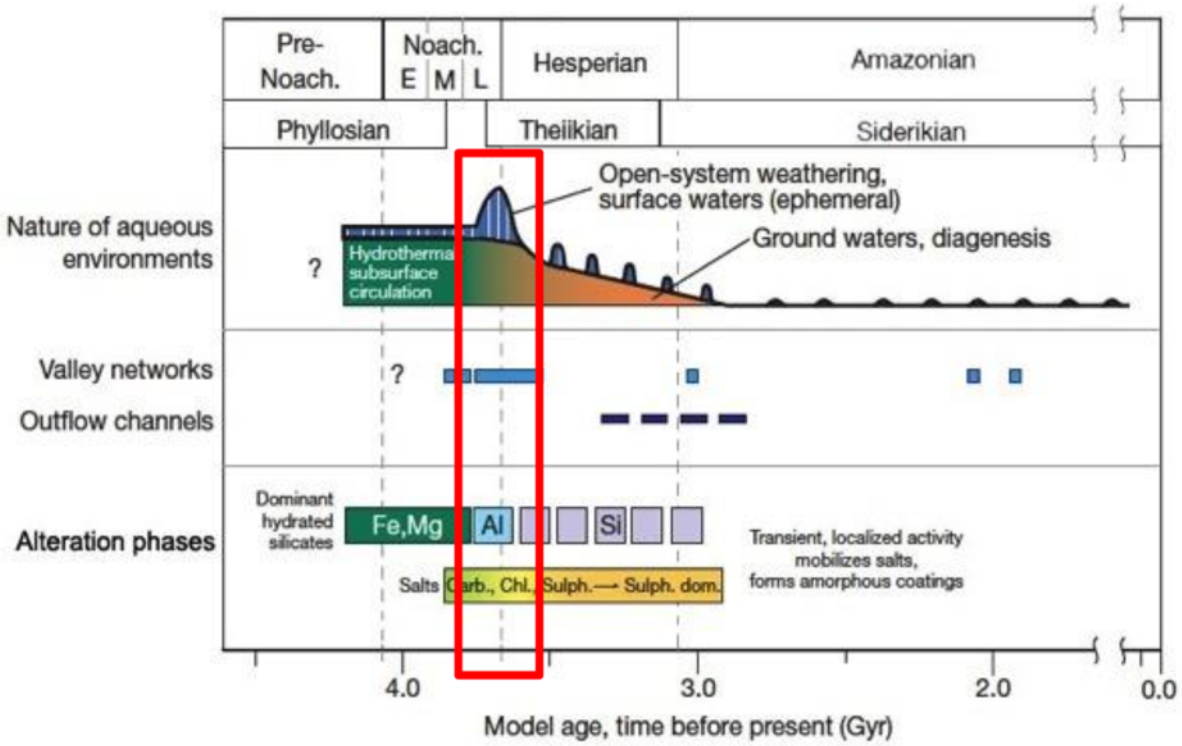
Ehlmann et al 2008

Inferred Timeline Figure (ref: after Ehlmann et al., 2011)

TIMING OF LOCAL GEOLOGY



TIMING OF LACUSTRINE ACTIVITY



Summary of Top 3-5 Units/ROIs

ROI	Aqueous or Igneous?	Environmental settings for biosignature preservation	Aqueous geochemical environments indicated by mineral assemblages
1. Delta Remnants	aqueous	sedimentary, fluvio-deltaic	Fe/Mg smectites
2. Basin Fill	aqueous	sedimentary, lacustrine	Mg-carbonates
3. Volcanic Floor	igneous	n/a	n/a
4. Western Delta Scarp	aqueous	sedimentary, fluvio-deltaic	Fe/Mg smectites, some Mg-carbonate

Top 3-5 Units/ROIs Detailed Descriptions

Unit/ROI Name: Delta Remnants

Aqueous and/or Igneous? Aqueous

Description: Well-layered, Fe/Mg smectite-bearing, sedimentary 'mounds' protruding from otherwise smooth Volcanic Floor of crater.

Interpretation(s):

- 'original' delta front separated from Western Delta Scarp by aeolian deflation
- deposited into circumneutral pH/low salinity (i.e., habitable) paleolake during LN/EH fluvial period

In Situ Investigations:

- search for organics in deltaic sediments- Fe/Mg smectites are known to concentrate and preserve organics
- Fe/Mg smectites originate in Syrtis terrain, potential hydrothermal minerals, ubiquitous in EN on Mars
- RIMFAX: examine internal layering structure, including location of subsurface block-bearing layers and channel deposits; if possible, map basal boundary
- Constrain formative conditions for the deposit (e.g., flow magnitudes, duration, etc) which are thought to be representative of early martian valley network activity. This may also help give insights into the early martian climate.

- Provide insight into the link between surface runoff and aqueous alteration on early Mars

Returned Sample Analyses:

- search for chemical and isotopic biosignatures
- D/H, O2, and other isotopes for Pre/Early Noachian water and atmospheric chemistry

Unit/ROI Name: Basin Fill

Aqueous and/or Igneous? Aqueous

Description: Flat lying basin fill at the bottom of the crater overlain by Volcanic Unit. Dominated by Mg-carbonate and associated olivine. Mineralogically similar to unit on Syrtis plateau.

Interpretation(s):

- paleolake deposit - circum-neutral/low salinity (i.e., habitable) deposited during LN/EH fluvial period
- unclear if this represents detrital deposition, reworking of pre-lacustrine deposits, or exposure of the regional Mg-carbonate/olivine unit observed more broadly in Nili Fossae (also of unknown origin)

In Situ Investigations:

- determine origin and emplacement history of Basin Fill unit
- search for organics trapped and preserved in carbonate deposits
- carbonate formed via interaction of olivine with water, but how exactly...??
- RIMFAX: Map stratigraphic contact between this unit and others while driving, search for subsurface layering, changes in buried rock size/abundance.

Returned Sample Analyses:

- search for chemical and isotopic biosignatures
- isotopic analysis to better understand early Martian climate history and C-sequestration as well as aqueous temperatures at carbonate formation (see Halevy et al., PNAS, 2011, doi: 10.1073/pnas.1109444108).
- determine pathway of carbonate formation from olivine

Unit/ROI Name: Volcanic Floor

Aqueous and/or Igneous? Igneous

Description: Flat unit overlying Basin Fill material, embaying Western Delta Scarp and surrounding Delta Remnants. Unit approximately 10-30 meters thick. Dominated by olivine and pyroxene.

Interpretation(s):

- basaltic volcanic flow emplaced subsequent to aeolian deflation of deltaic deposits
- crater counting gives it a Hesperian age of ~3.5 Ga; no obvious association with Syrtis Lavas besides age

In Situ Investigations:

- determine if this is volcanic or ash fall or some other igneous unit
- RIMFAX: Assess density of deposit, search for subsurface layering within the unit that could indicate ash or multiple volcanic episodes, possibly assess source regions. Map subsurface layering beneath the volcanic deposit.

Returned Sample Analyses:

- determine age of unit to better constrain timing of events in Isidis region and to help constrain the absolute timing of martian production functions
- isotopic measurements and geochemistry to better understand petrogenetic origin of magma

Unit/ROI Name: Western Delta Scarp

Aqueous and/or Igneous? Aqueous

Description: Layered sediments prograding into crater, overlying Basin Fill, demonstrating well defined fluvio-deltaic stratigraphy, including flat, stratigraphically low units consistent with deltaic bottomset deposits. Dominated by Fe/Mg smectites (nontronite, saponite, etc).

Interpretation(s):

- deltaic sediments deposited into circumneutral pH/low salinity (i.e., habitable) paleolake
- delta believed to be deposited during LN/EH fluvial period

- sediments derived from Syrtis watershed region dominated by Early Noachian Fe/Mg smectites

In Situ Investigations:

- search for organics in deltaic sediments - bottom sets (seen from orbit) especially ideal to concentrate OM
- also, Fe/Mg smectites are known to trap and preserve organics
- erosion scarps at delta front indicates relatively recent exposures - less time for OM to be exposed to surface degradation from radiation, etc.
- Fe/Mg smectites originate in Syrtis terrain, potential hydrothermal minerals, ubiquitous in EN on Mars.
- RIMFAX: examine internal layering structure, including location of subsurface block-bearing layers and channel deposits; if possible, map basal boundary
- Constrain formative conditions for the deposit (e.g., flow magnitudes, duration, etc) which are thought to be representative of early martian valley network activity. This may also help give insights into the early martian climate.
- Provide insight into the link between surface runoff and aqueous alteration on early Mars

Returned Sample Analyses:

- search for chemical and isotopic biosignatures
- D/H, O2, and other isotopes for Pre/Early Noachian water and atmospheric chemistry

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	Deltaic remnants and western deltaic scarps (clays and carbonate); basin fill (carbonates)	Deposition in low energy lacustrine or bottomset environments; clay minerals may bind to and/or sort organic material; carbonate may also trap organic matter
Chemical	Deltaic remnants and western deltaic scarps (clays and carbonate); basin fill (carbonates)	Deposition in low energy lacustrine or bottomset environments; clay minerals may bind to and/or sort organic material; carbonate may also trap organic matter
Isotopic	Carbonate basin fill	Carbonate isotopic signature can be interrogated for light isotopes
Mineralogical	Mg-carbonates; Noachian Fe-Mg smectites entrained in deltaic deposits	Carbonates can trap organic matter; clays may trap organic matter and/or have zones related to organic diagenesis
Micro-morphological	Deltaic remnants and western deltaic scarps (clays)	Possible preservation of microfossils in fine-grained sediments (clays)
Macro-morphological	Deltaic deposits and lacustrine basin fill	microbial -induced sed structures (mats, etc) may be preserved in quiet deltaic or lacustrine deposits

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?
Mafic Floor Unit	436 km^2	H	volcanic unit believed to be ~3.5Ga based on crater counts	crater distribution on unit, measured sample age

Key Uncertainties/Unknowns about the Site

List the most important uncertainties, unknowns or potential drawbacks about the site

- Fe-Mg smectites in this region may hold important clues as to early Martian aqueous processes, but orbital mapping suggests that clays present in deltaic deposits/remnants are detrital in origin sourced from the surrounding plateau, potentially complicating their petrogenetic interpretation.
- Mg-carbonate basin fill origin has been difficult to determine using stratigraphy observed from orbit - carbonate most likely formed from water interaction with olivine, but unclear if it was formed as primary *in situ* deposition, detrital deposition of minerals formed outside the crater, reworking of pre-lacustrine sediments in place, or some other possibility.
- Volcanic floor is estimated to be ~3.5 Ga which would give a good lower bound for activity in the crater and provide important regional constraints, but origin is uncertain - it appears to be a lava flow but provenance is unclear, could it be an ash fall, or some other possibility…?