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Testing Carbonate Formation Mechanisms at Northeast Syrtis Major, Mars

Carbonate-bearing rocks at Nili Fossae

Edwards and Ehlmann, 2015

CRISM and TES unmixing reveals olivine-enriched basalts with $\leq 20\%$ Fe/Mg carbonate

Northeast Syrtis Major

TES unmixing confirms carbonate enrichments up to $\sim 10-15\%$ in an olivine-rich unit

Bramble et al., 2017
Salvatore et al., LPSC 2017 abstract 1154
Carbonate Formation Hypotheses For Nili Fossae

Ehlmann et al. 2008
Boynton et al., 2009
Brown et al., 2010
Morris et al., 2010
Viviano et al., 2013
Ruff et al., 2014

(a) Subsurface percolation

(b) Weathering

(c) Lake precipitation

(d) Contact metamorphism

Legend:
- Red: Olivine
- Green: Carbonate
- Yellow: Serpentine
- Pink: Talc
- Blue: Smectite
Carbonate Formation Hypotheses

IMPLICATIONS

- Water Limited
- Low Temperature
- Higher Carbonate Abundance
- Water Rich
- High Temperature

(a) Subsurface percolation

(b) Weathering

(c) Lake precipitation

(d) Contact metamorphism

Ehlmann et al., 2008
Brown et al., 2010
Viviano et al., 2013
Boynton et al., 2009
Morris et al., 2010
Ruff et al., 2014
Can we constrain these running hypotheses using high spatial resolution orbital imagery and spectroscopy?

Key observations:
1. Geomorphology
2. Stratigraphic position of mineral phases (namely, phyllosilicates)

(a) Subsurface percolation
(b) Weathering
(c) Lake precipitation
(d) Contact metamorphism

Ehlmann et al. 2008
Brown et al. 2010
Viviano et al., 2013
Boynton et al., 2009
Morris et al., 2010
Ruff et al., 2014
Methods – 0/2 – Study Region – Northeast Syrtis Major

- 7 CRISM FRT images
- Complete HiRISE coverage

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CRISM FRT images

Spectral parameter images guide spatial analysis

Pelkey et al., 2007
Viviano-Beck et al., 2014

Stratigraphy from HiRISE

Ratioed spectra for phase identification

Methods – 1/2 – Geomorphic and Manual Spectral Analyses

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Methods – 2/2 – Automated CRISM Analyses


- RTM
- CRISM Single Scattering Albedo
- Linear Least-squares Unmixing (next slide)
- Endmember Spectral Fraction Maps
- Laboratory Endmembers (Reflectance)
- RTM
- Laboratory Endmembers (SSA)
- RMSE Maps

Assumptions:
- Isotropic phase function = 1
- Opposition effect = 0
Methods – 2/2 – Automated CRISM

Linear least-squares unmixing:

• Image unmixed using non-physical and in-scene endmembers:
  • Bright (ref = 1), dark (ref≈0), positive slope, negative slope, **in-scene mean column**
  • Image unmixed again with the addition of a **laboratory endmember (phylllosilicates)**
  • If a **F-test** shows the model was improved at a 99% confidence level by the laboratory endmember, its spectral fraction was recorded.
Results - Manual Analysis

HiRISE ESP_027902_1975 & ESP_038029_1980

OLINDEX3 (olivine)
MIN2295_2480 (carbonate)
D2300
Upper unit with olivine and carbonate (yellow mixing), plus 1.9 (& 2.39?) μm hydration features.

Downsection unit with ~1.41–1.42, 1.92, 2.30–2.31, and ~2.39(?) μm consistent with Fe/Mg-smectites.
Results – Automated Analysis
“Best mineralogy” maps

>0.05 spectral fraction, highest F-test value, and passing critical threshold
Automated Analysis
Mean Column Endmember

HiRISE ESP_027902_1975 & ESP_038029_1980

SAPONITE / NONTRONITE / TALC
Discussion / Implications

- Best match to all observations
- Carbonate-free olivine outcrops appear rare in NE Syrtis
- Pervasiveness of carbonate in upsection unit may rule out carbonate formation via surface weathering

(a) Subsurface percolation

(b) Weathering

Observations

- Ol + Carb
- Smectite

Color Legend:
- Olivine
- Carbonate
- Serpentine
- Talc
- Smectite

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• Can be ruled out based on **morphology** of the carbonate-bearing unit
  • Drapes topographic highs and lows
  • Spectroscopy does not support the presence of pure carbonate outcrops
Discussion / Implications

- Difficult to favor with observations
- If present, entire serpentine, carbonate, and talc stratigraphy must be compressed to a layer neither detectable by CRISM nor visible in HiRISE
- Contradicted by the **intimate mixing** of olivine and carbonate (and serpentine) in a single stratum

(d) Contact metamorphism

**Observations**

- **Ol + Carb**
- **Smectite**

**Legend:***

- **Olivine**
- **Carbonate**
- **Serpentine**
- **Talc**
- **Smectite**

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Testing carbonate formation mechanisms at Northeast Syrtis Major

Conclusions

- High-resolution stratigraphy and near-infrared spectroscopy favors carbonate formation by subsurface percolation at NE Syrtis
- Alteration likely occurred in a low-temperature, water-limited system
- Carbonate alteration at NE Syrtis appears more complete and less spatially variable than observed elsewhere in Nili Fossae
- *In situ* exploration likely required to further constrain these running hypotheses
Extra Slides:
Secondary calibration analysis with two in-scene endmembers
Methods – 2/2 – Automated CRISM

Secondary calibration analysis:

- Used two in-scene user-selected endmembers in place of the mean-column endmember (after Goudge et al., 2015)
  - Bright (ref = 1), dark (ref ≈ 0), positive slope, negative slope,
    *in-scene unaltered olivine (lacking ~1.9, 2.3, or 2.5 µm absorptions), and*
    *in-scene dark-toned capping unit (spectrally bland in near-infrared)*
- Remainder of analysis and data-reduction methods left unchanged
Results – Automated Analysis

Mean Column Endmember

In-Scene Endmembers

SAPONITE / NONTRONITE / TALC

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Automated Analysis
Two In-scene Endmembers

SAPONITE / NONTRONITE / TALC

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