Mineral abundances of the phyllosilicate-bearing deposits of the four candidate MSL landing sites

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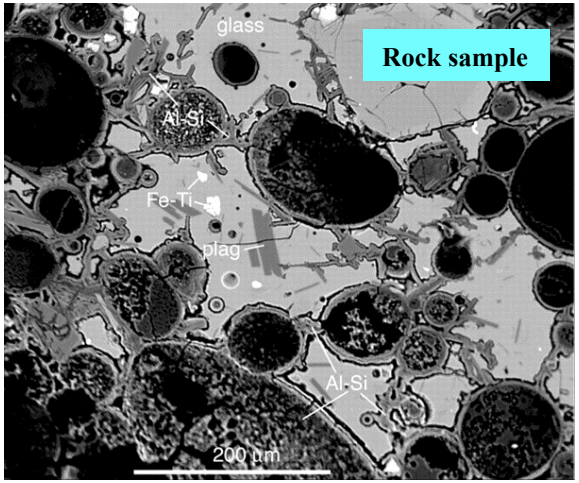
How to derive the modal mineralogy

Surface model to fit CRISM and OMEGA spectra based on the Shkuratov radiative transfer theory

To simulate the scattering properties of a mineral mixture:

- Microscopic Level (⇔ composition, grain size)
- Macroscopic Level (⇔ type of mixture)



Skhuratov et al. 1999; Poulet et al. 2002; Poulet and Erard 2004; Arvidson et al. 2006; Poulet et al. 2008, Poulet et al. 2009a, 2009b

Data: - CRISM lambertian spectra (1.35-2.52 µm)
- OMEGA lambertian spectra (0.99-2.51 µm)

Fit procedure

Mineral endmembers

Abundance (Vol%) for each mineral

Average grain size for each mineral

Mineral Library

Smectite group
- Nontronite (Fe^{3+},OH,H_2O)
- Montmorillonite (Al,Fe,Mg,OH,H_2O)
- Al/Fe/Mg-Smectite (Fe^{3+},Mg,Al,OH,H_2O)
- Illite (Fe,Mg,Al,OH,H_2O)
- Mg-Saponite (Mg, OH,H_2O)
- Beilledite (Al, OH, H_2O)
- Hectorite (Mg, OH)

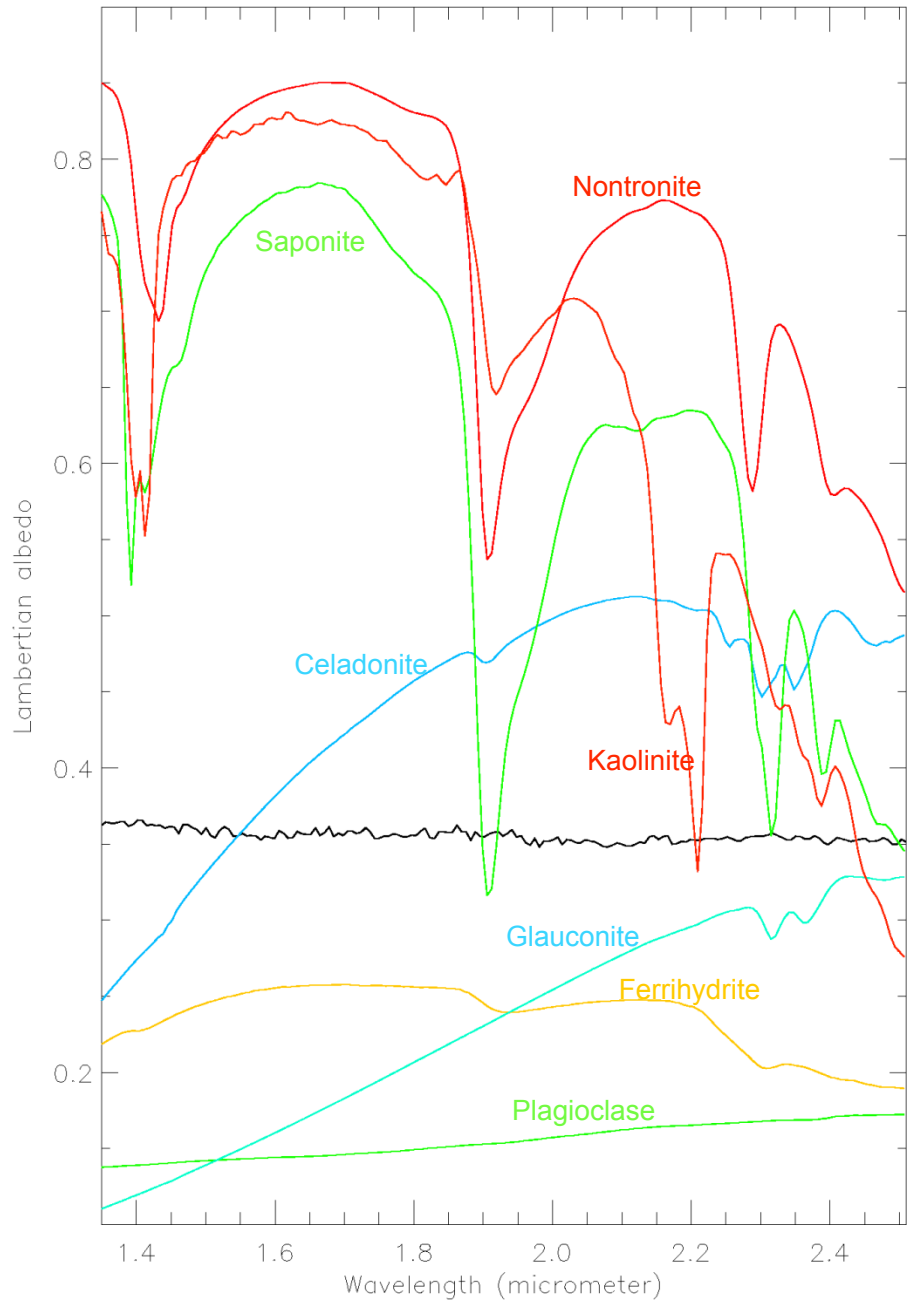
Chlorite group
- Chamosite (Fe^{3+},Fe^{2+}, Mg,Al,OH)
- Clinochlore(Fe^{3+},Fe^{2+},Mg,Al,OH)

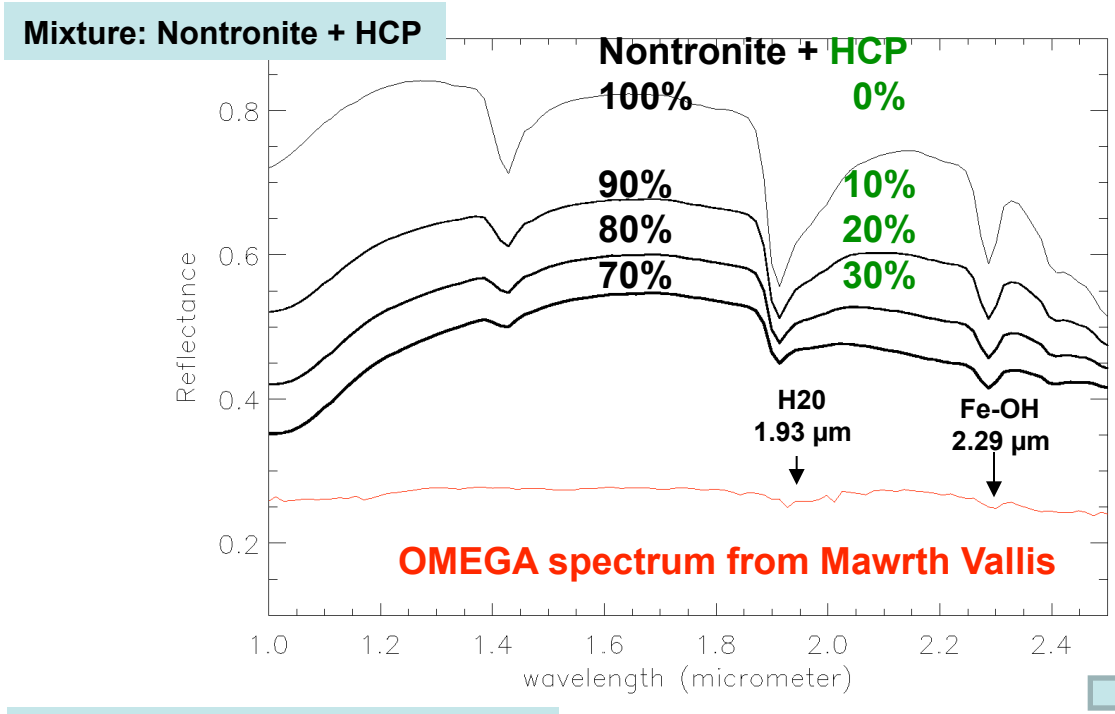
Mica group
- Glauconite (Al,Fe,Mg,OH)
- Celadonote (Al,Fe,Mg,OH)

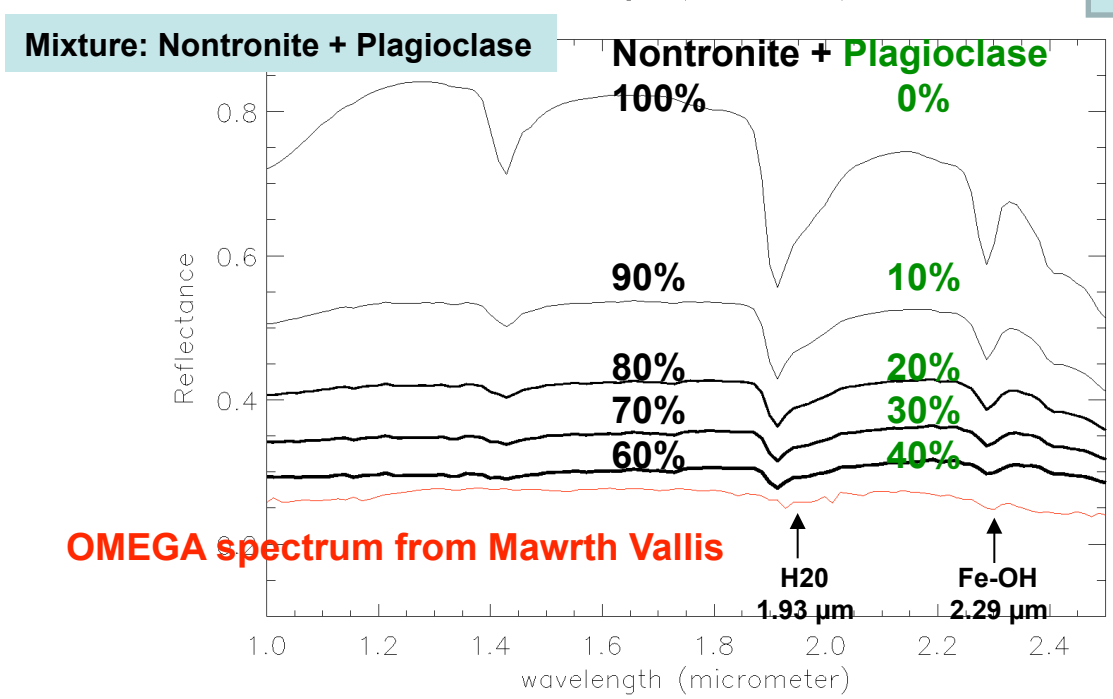
Kaolinite group
- Kaolinite (Al,OH)

Other hydrated Minerals
- Al/Si-OH phases (altered volcanic material)
- Opal
- Ferrihydrite (Fe^{3+},OH, H_2O)
- Zeolites
- Pumpellyite (sorosilicate) (Mg,Al)(OH)($H_2$0)

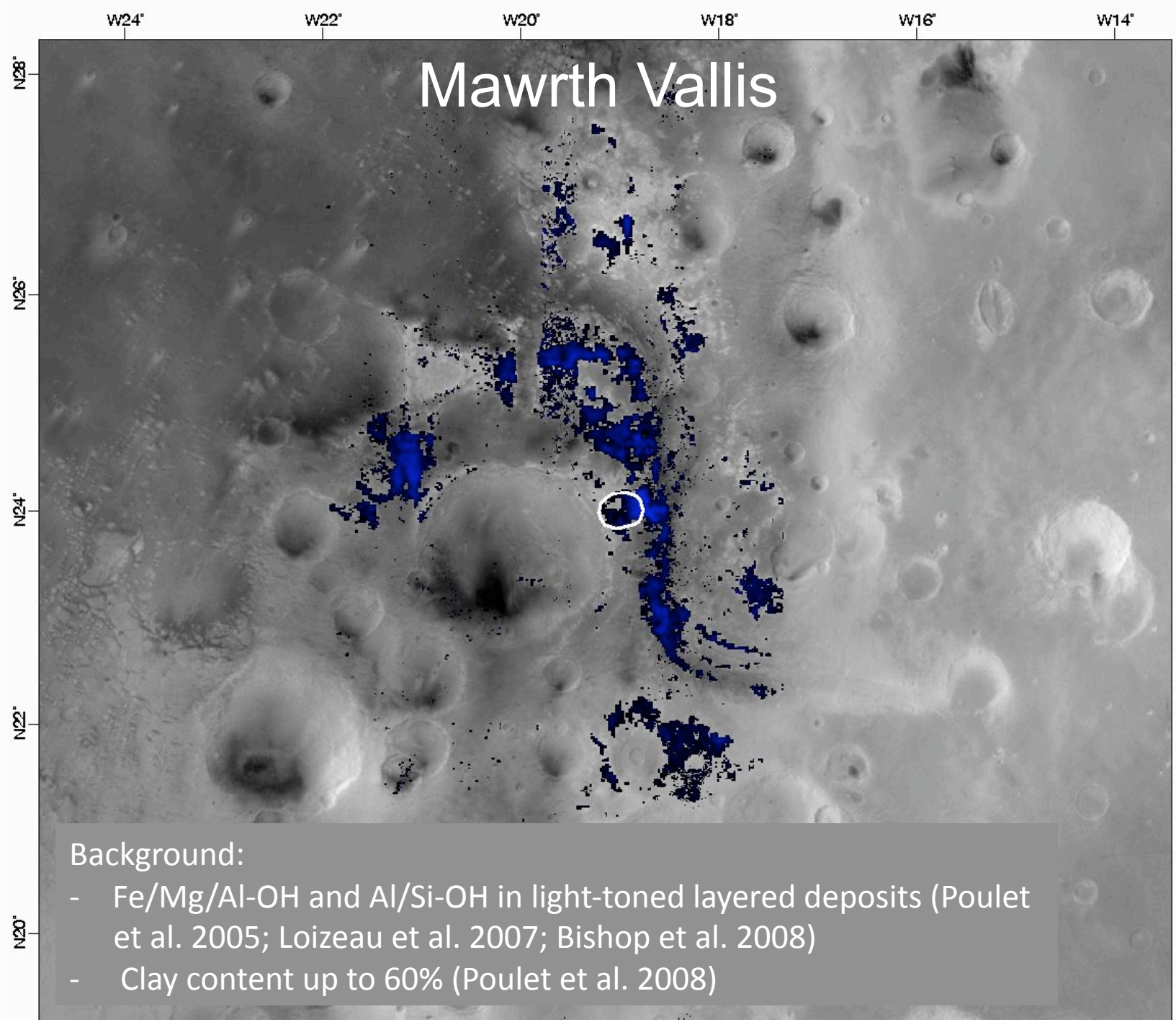
Anhydrous silicates:
- Pyroxenes (HCP and LCP)
- Plagioclase
- Martian dust





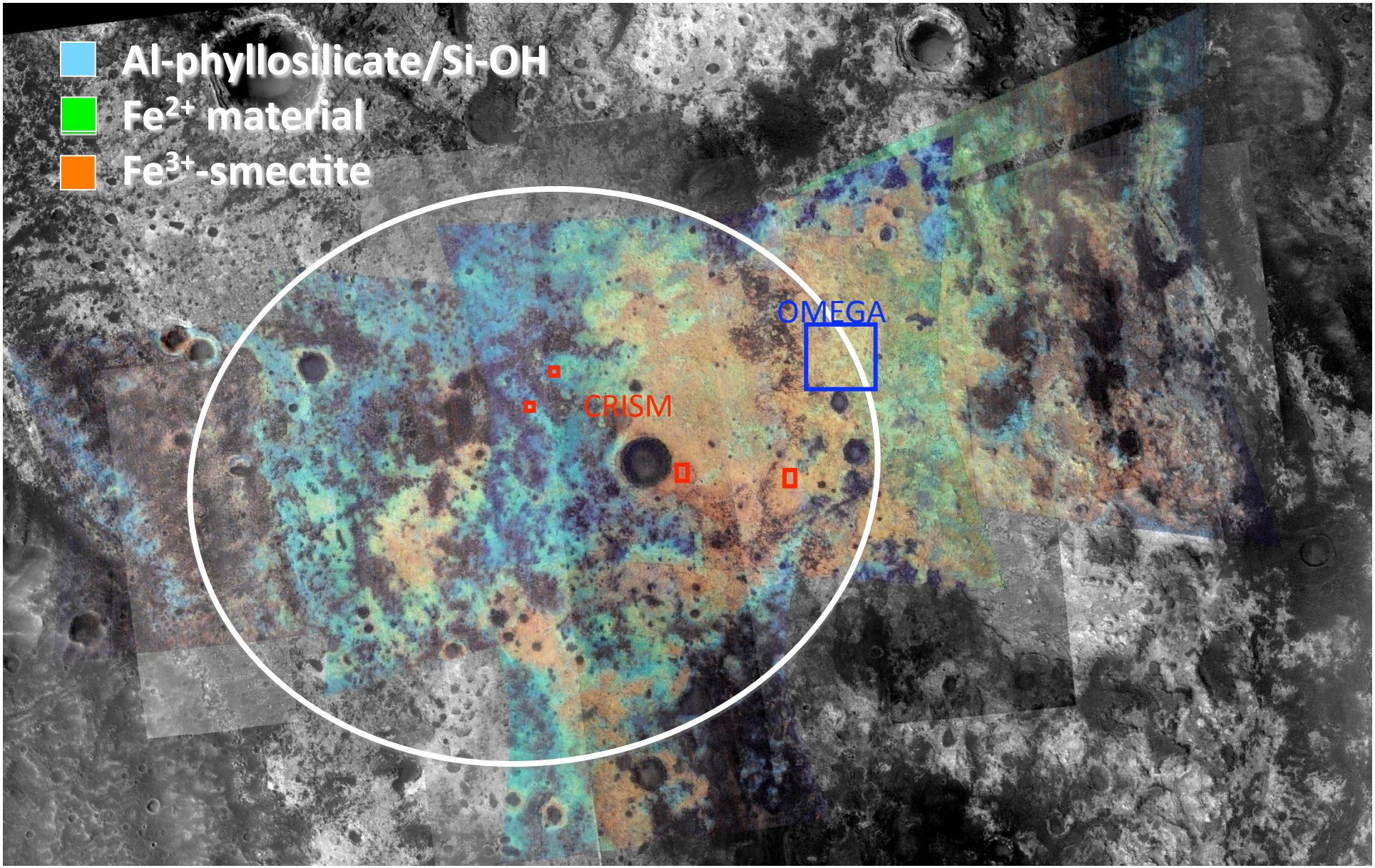


ADDITION OF
NON-PHYLLOSILICATE
ANHYDROUS COMPONENTS

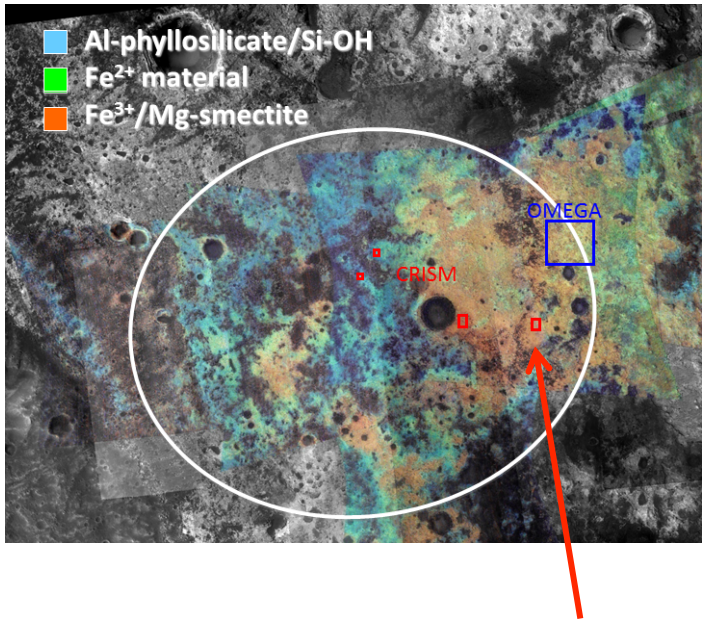


Background:

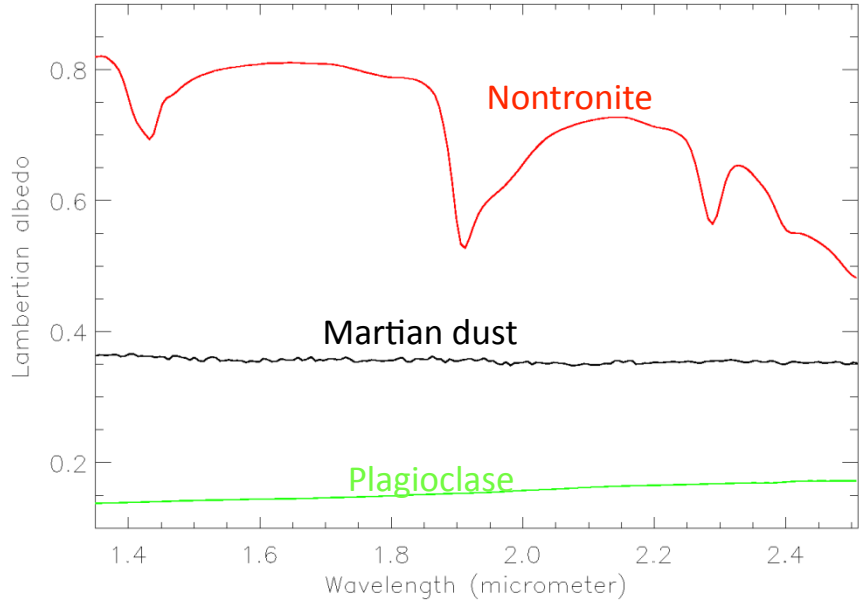
- Fe/Mg/Al-OH and Al/Si-OH in light-toned layered deposits (Poulet et al. 2005; Loizeau et al. 2007; Bishop et al. 2008)
- Clay content up to 60% (Poulet et al. 2008)

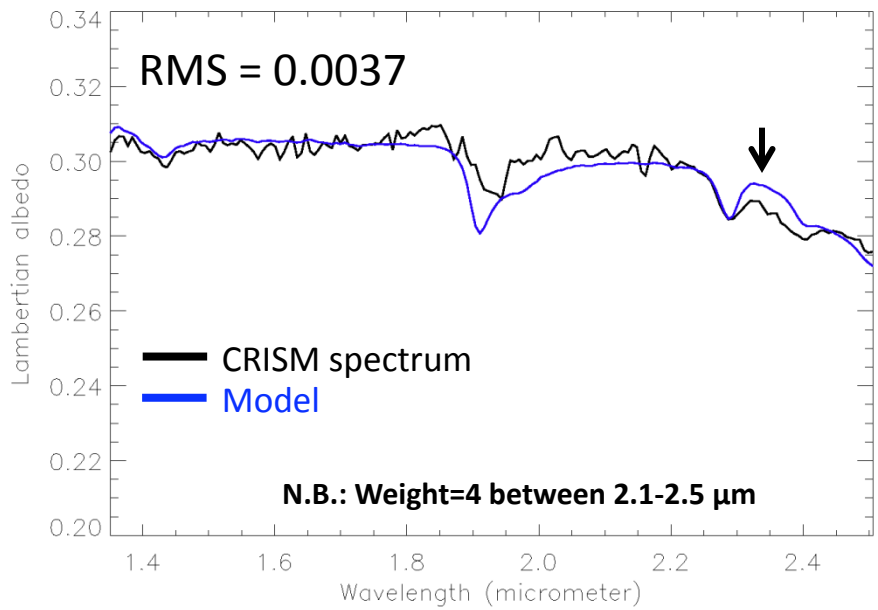

Al-phyllosilicate/Si-OH
Fe^{2+} material
Fe^{3+}-smectite
OMEGA
CRISM

Mawrth Vallis: Fe-rich clays in the ellipse

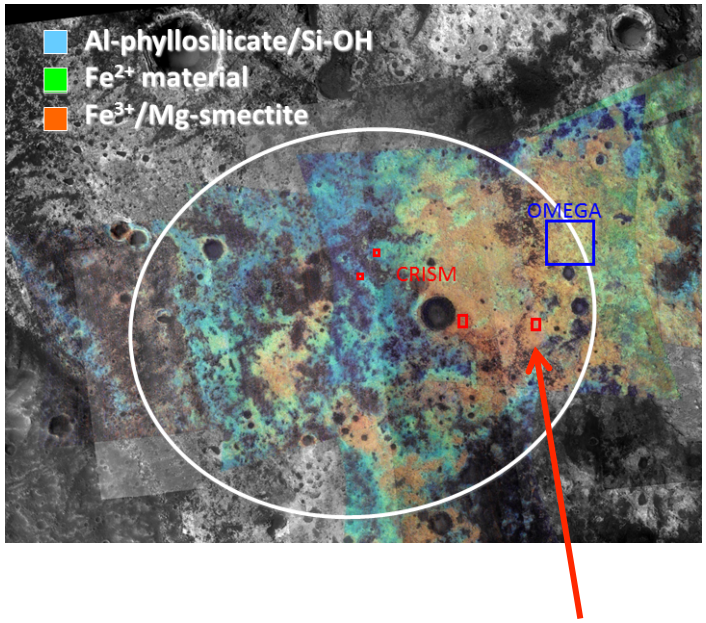


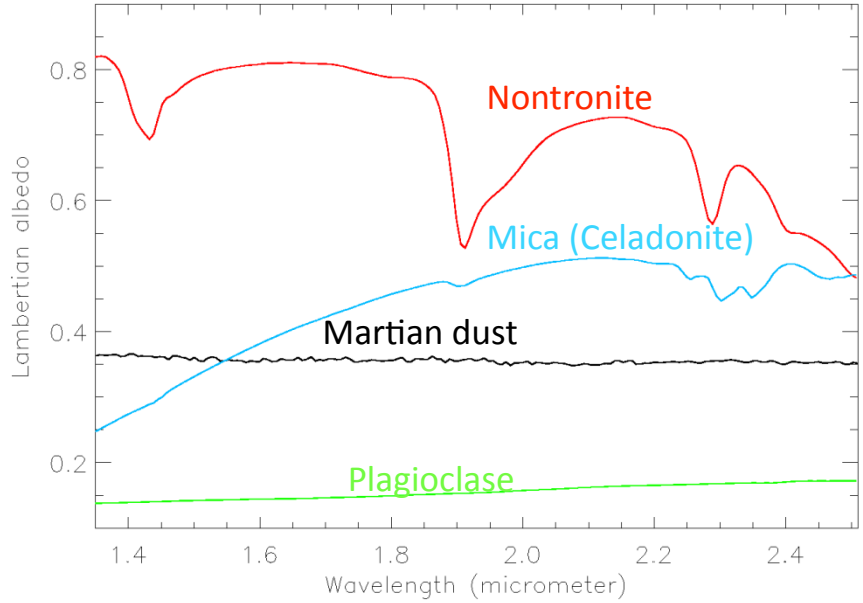
Average of 121 pixels

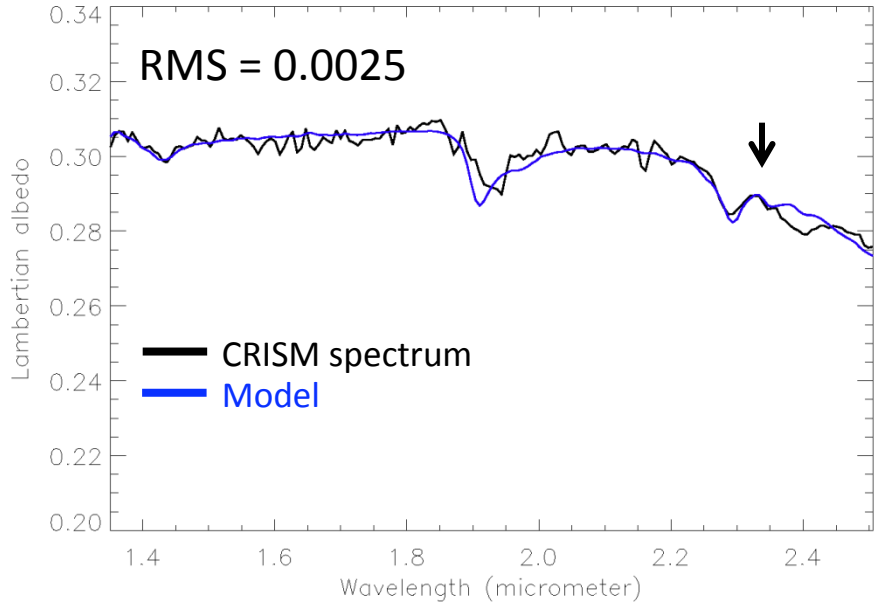




Mawrth Vallis: Fe-rich clays in the ellipse







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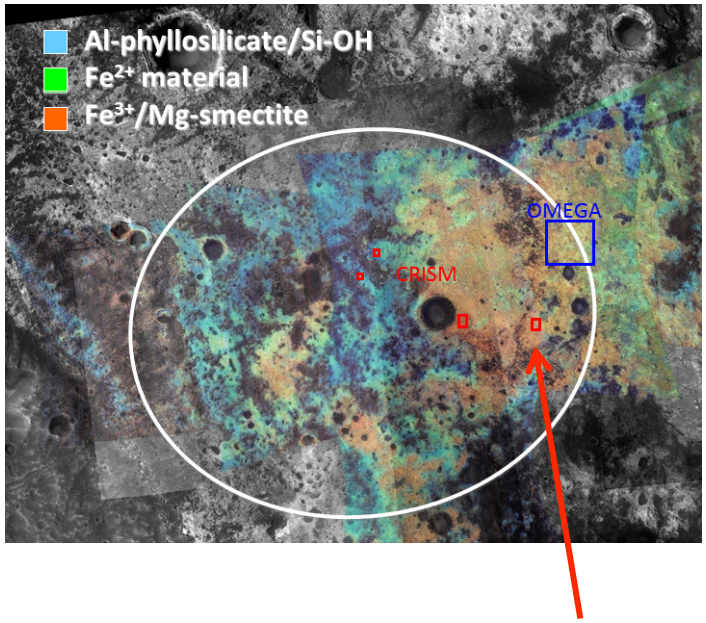
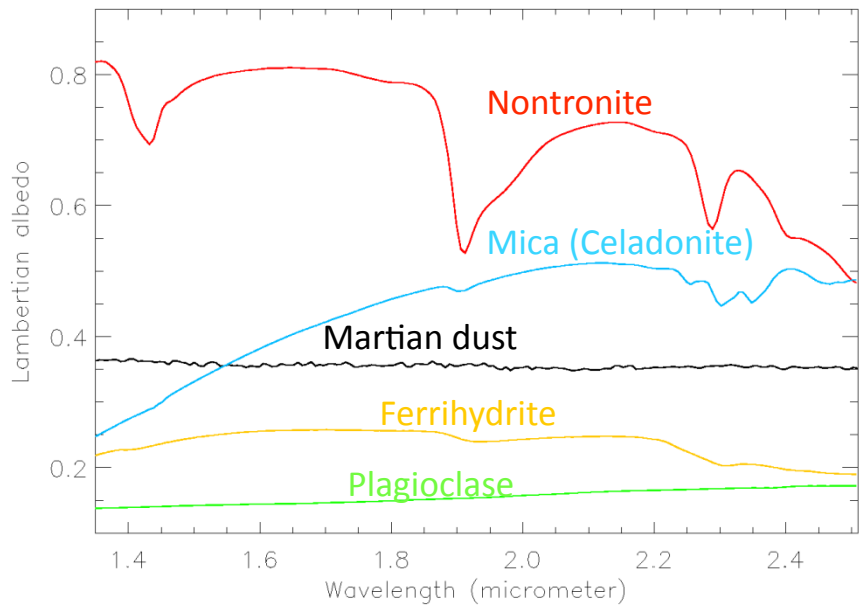
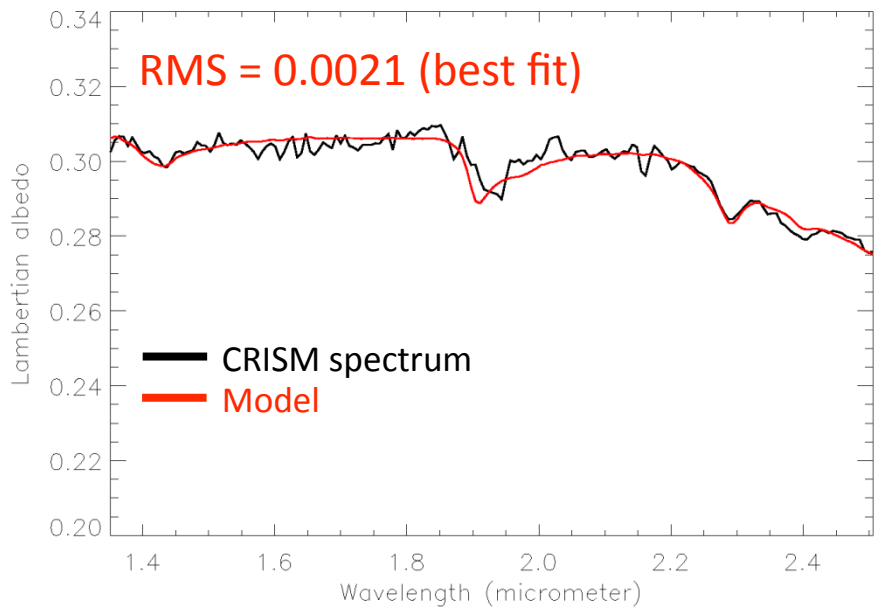
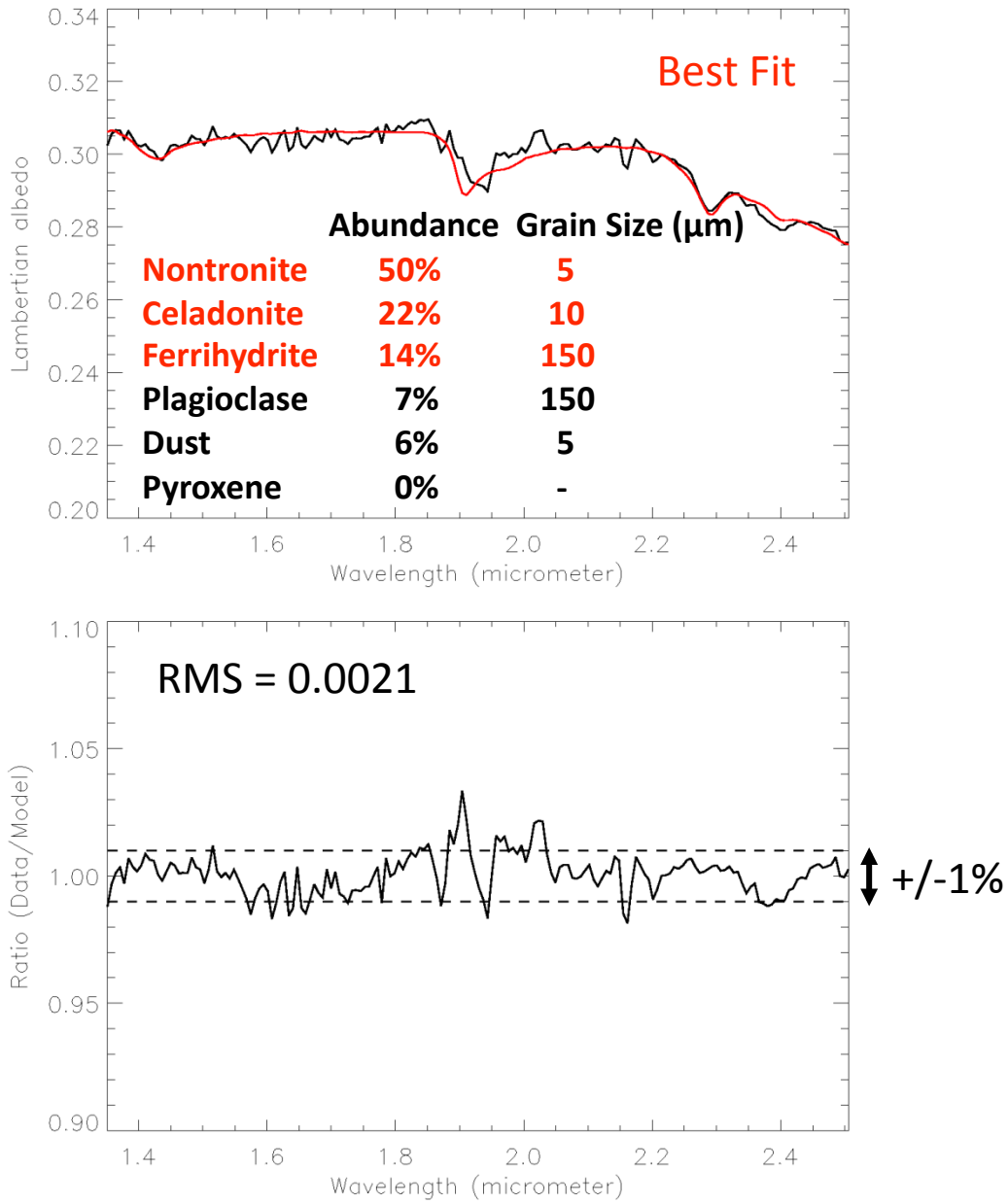




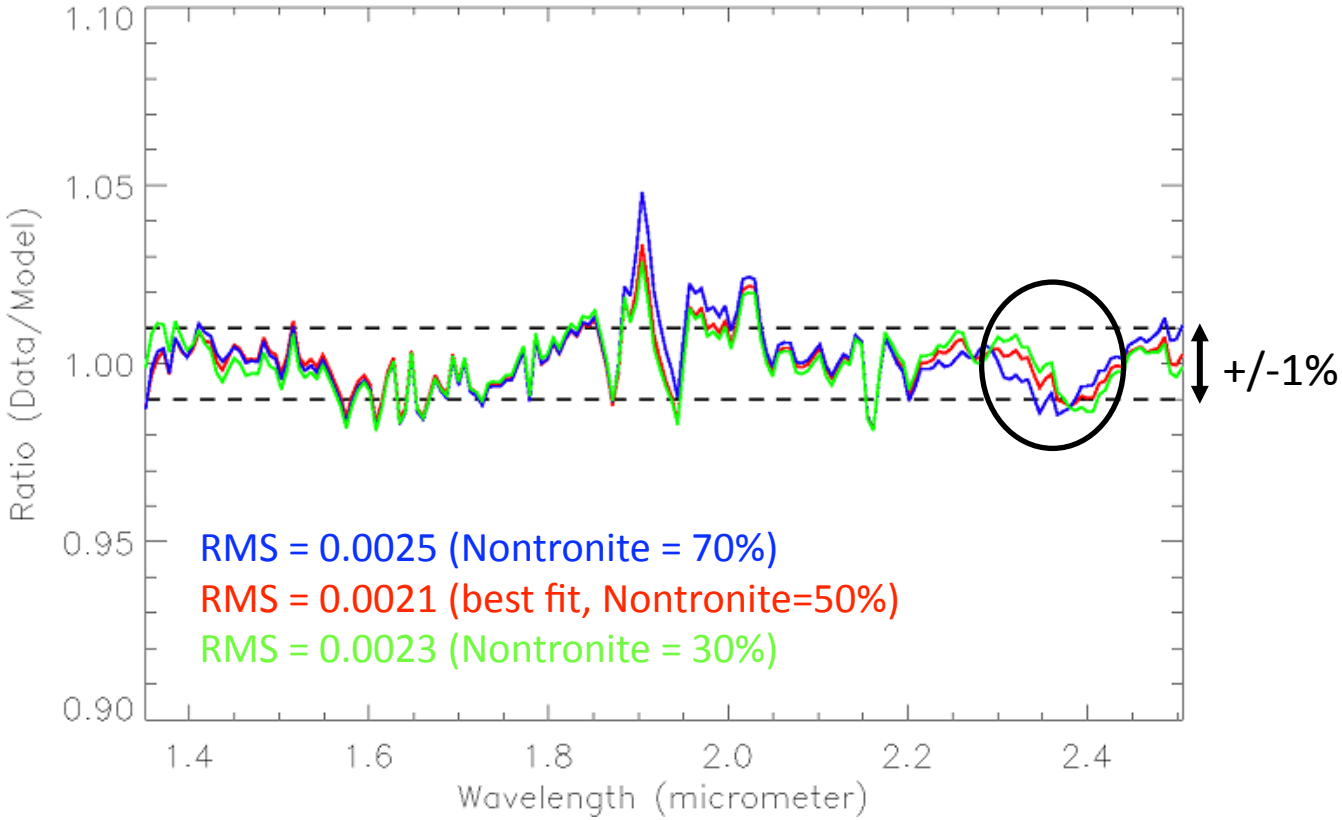


Mawrth Vallis: Fe-rich clays in the ellipse



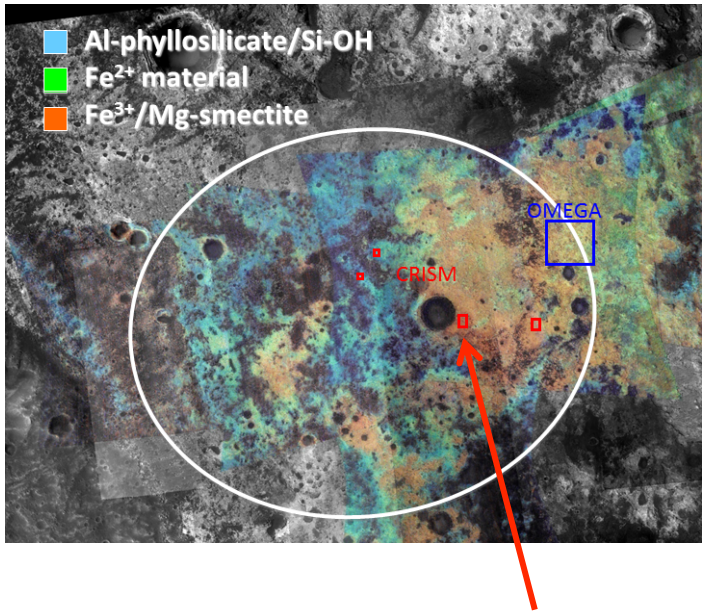
Mawrth Vallis: Fe-rich clays in the ellipse

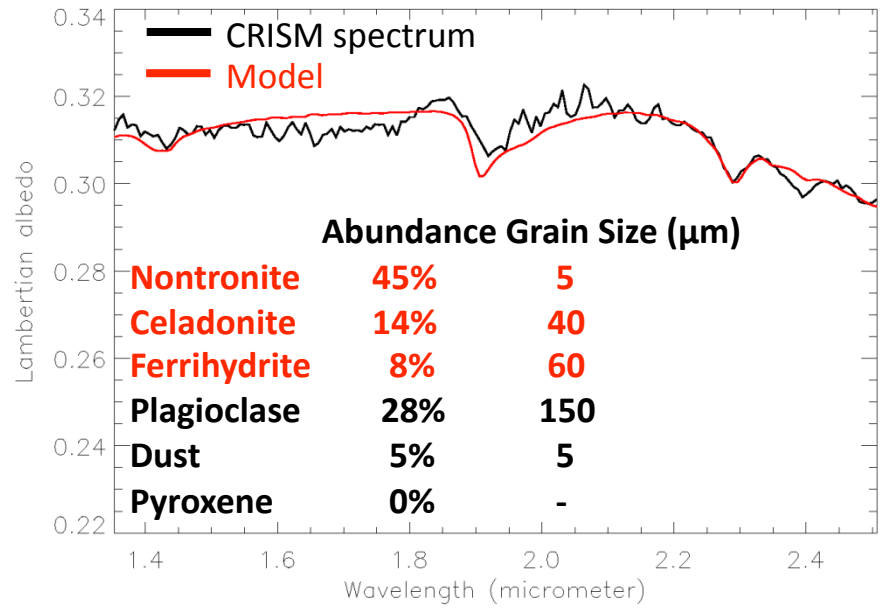
Errors on Nontronite abundance : +/-20%



	Abundance (%)	Grain Size (µm)
Nontronite	50±20	<10
Celadonite	10±10	<50
Ferrihydrite	15±5	10-100
Plagioclase	15±15	100-200
Dust	5±5	5
Pyroxene	0	-

Mawrth Vallis: Fe-rich clays in the ellipse





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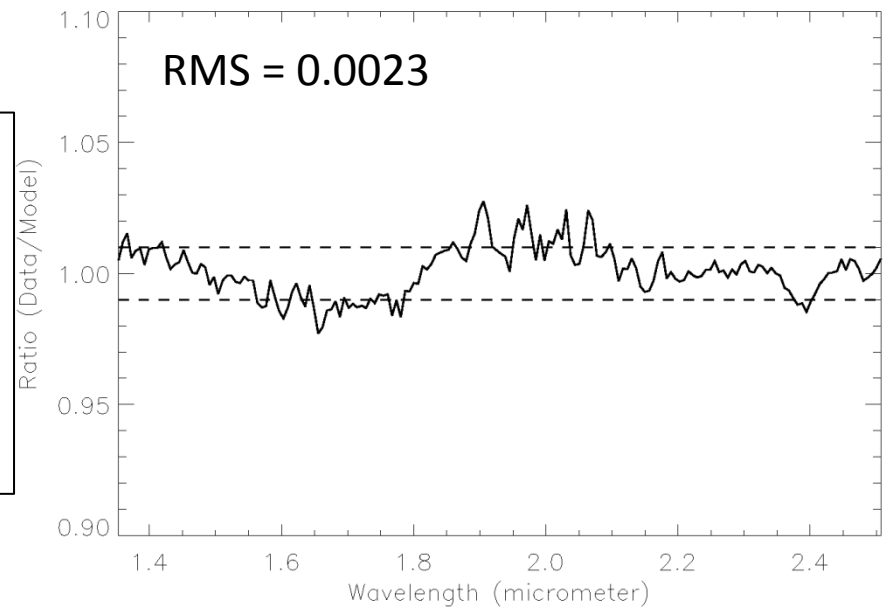
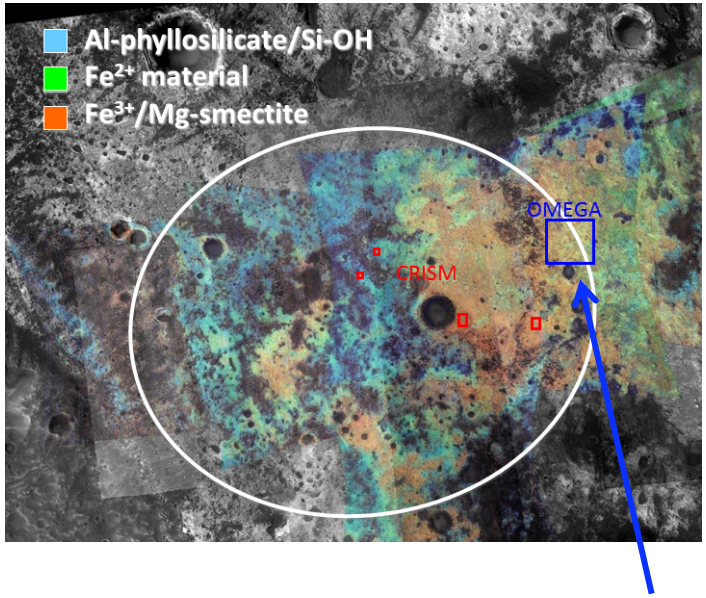
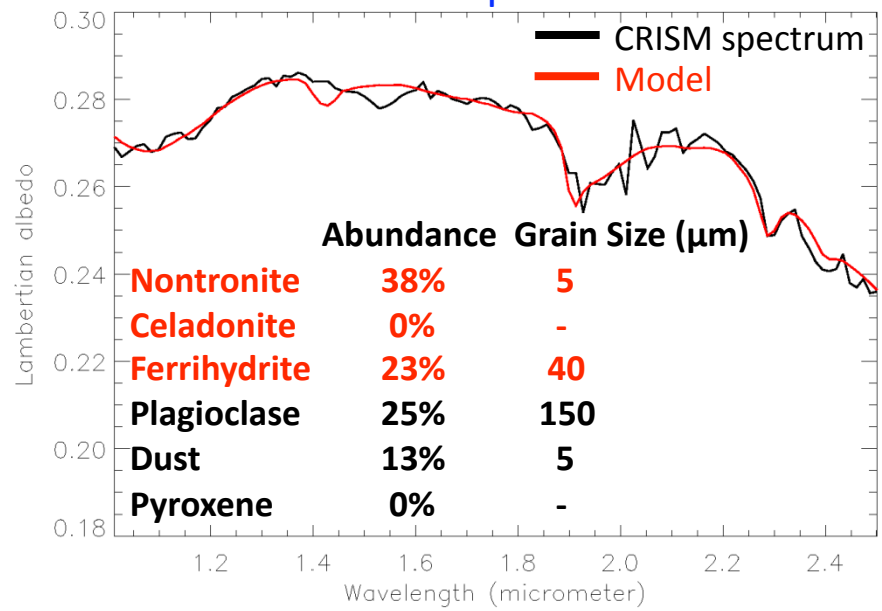


Mawrth Vallis: Fe-rich clays in the ellipse

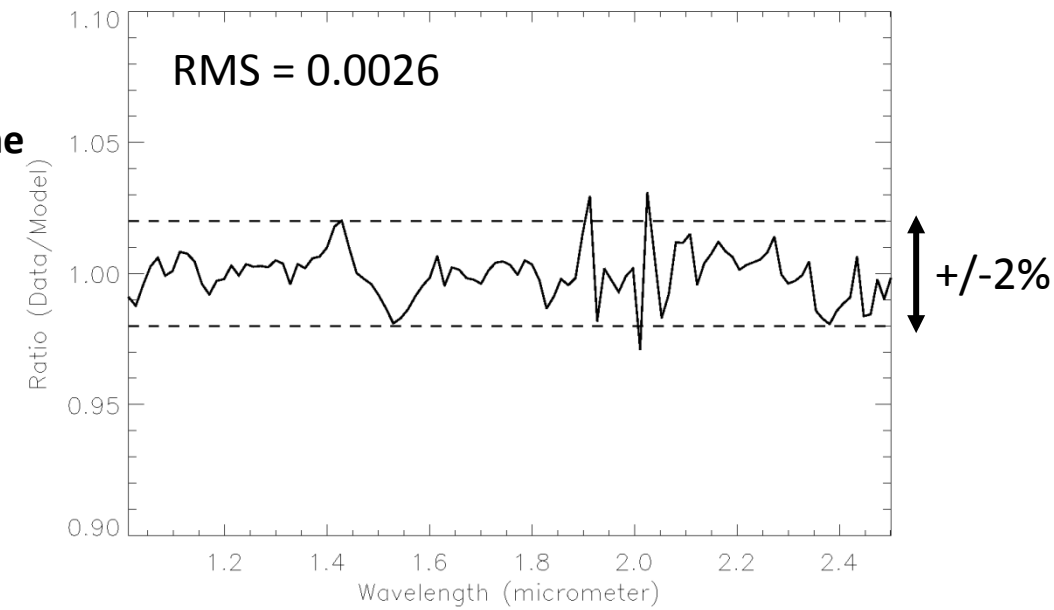


OMEGA spectrum



	Abundance	Grain Size (µm)
Nontronite	38%	5
Celadonite	0%	-
Ferrihydrite	23%	40
Plagioclase	25%	150
Dust	13%	5
Pyroxene	0%	-

=> Except for mica, OMEGA-derived modal mineralogy consistent with CRISM-derived one



Mawrth Vallis: Fe-rich clays in the ellipse

	Abundance (%)	Grain Size (µm)
Nontronite	**50±20**	**<10**
Celadonite	**10±10**	**<50**
Ferrihydrite	**15±5**	**10-100**
Plagioclase	**15±15**	**100-200**
Dust	**5±5**	**5**
Pyroxene	**0**	**-**

- OMEGA and CRISM give similar results except for mica
- Large abundance of Fe-rich smectite (30-70% vol)
- No pyroxene, but small amount of anhydrous mineral is required (<30%)
- Mica celadonite required in the CRISM spectra modeling
  - Usually a product of the submarine weathering of volcanics on Earth (Velde 1995)
  - Hydrothermal fluid (T° between 20°C and 60°C)
- Mica Glauconite usually found with Nontronite but Glauconite does not provide a good fit
- Presence of iron-hydroxide required:
  - Ferrihydrite and Nontronite in equilibrium in subsurface environments
  - Ferrihydrite metastable, but transformation could be blocked by impurities

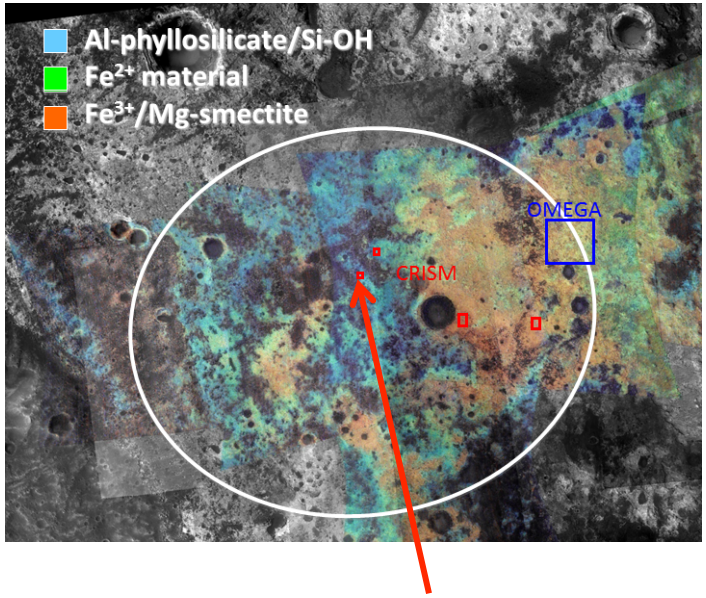
=> Formation processes?

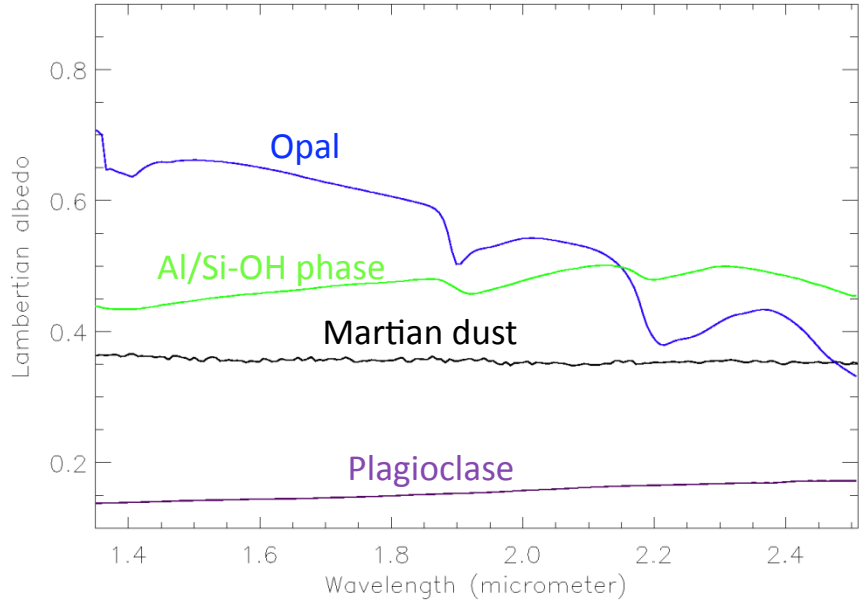
Surface weathering in wet, neutral conditions

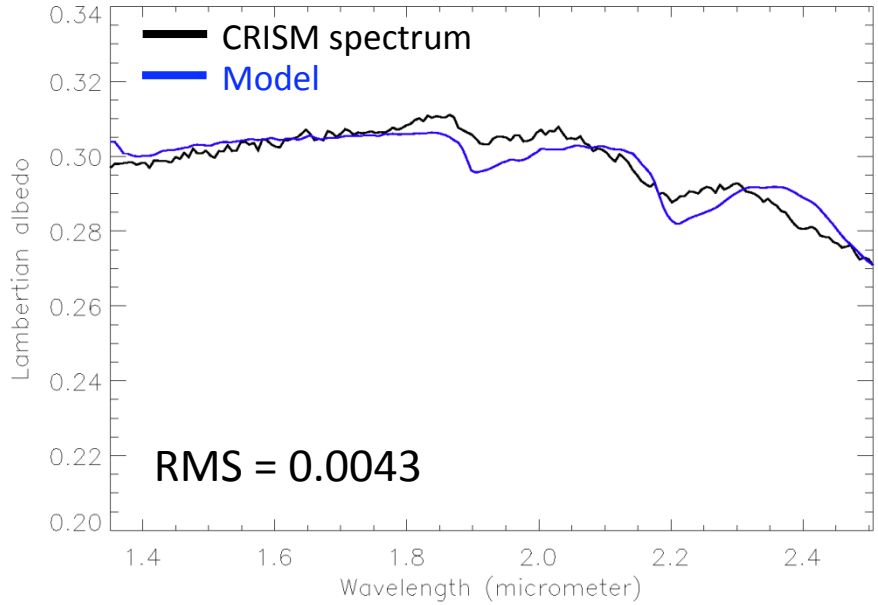
Submarine hydrothermal

Subsurface hydrothermal

Mawrth Vallis: Al-clay/Si-OH material in the ellipse







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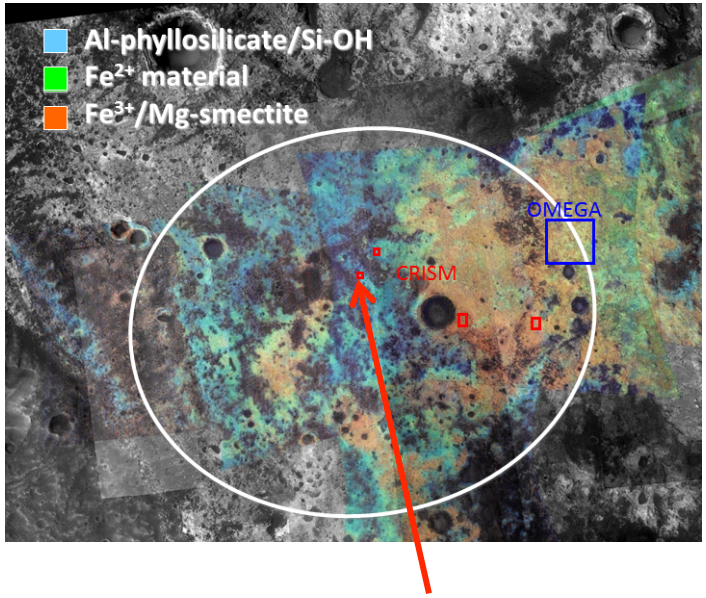

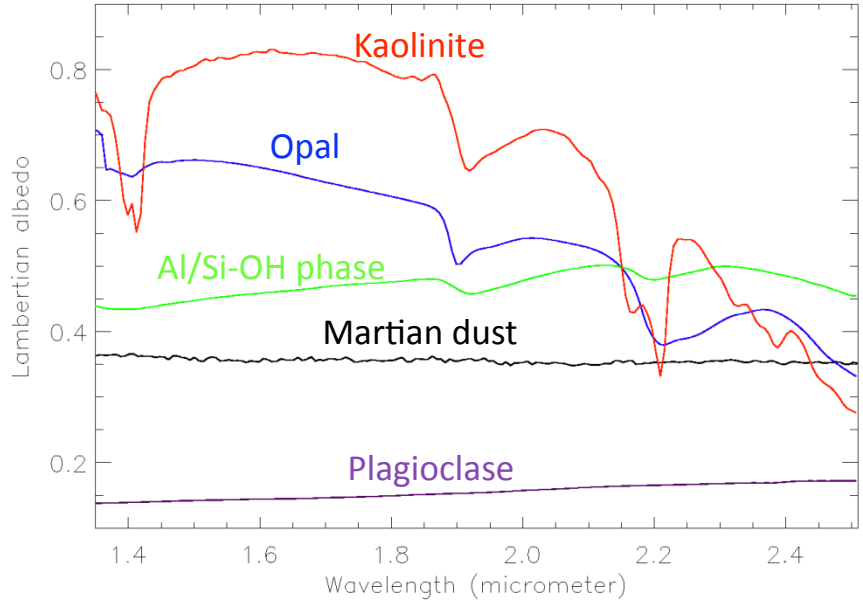

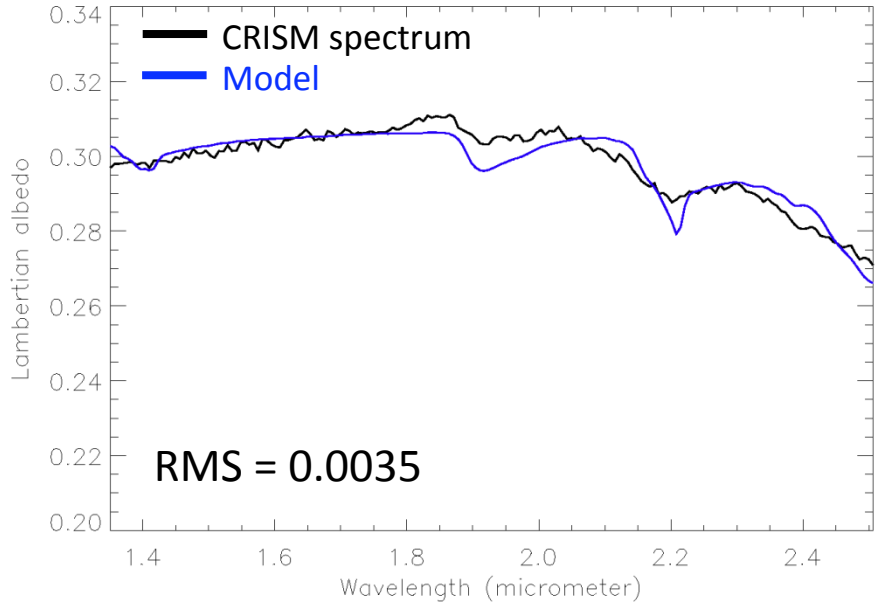

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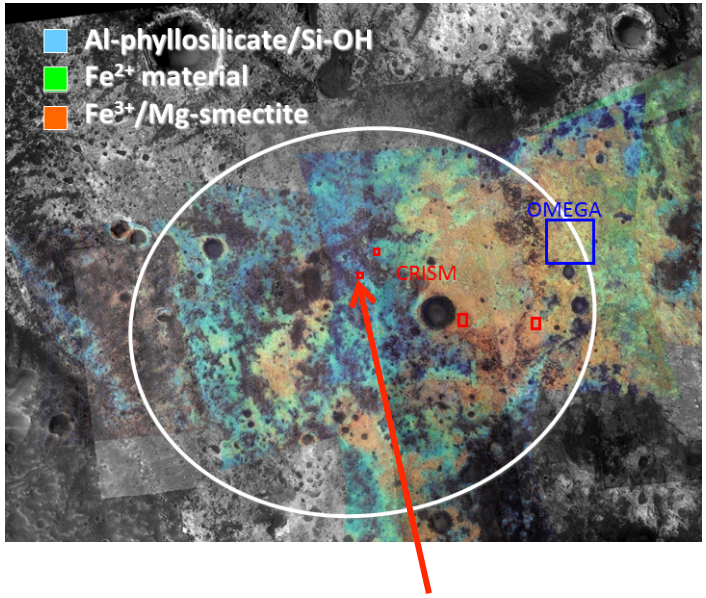

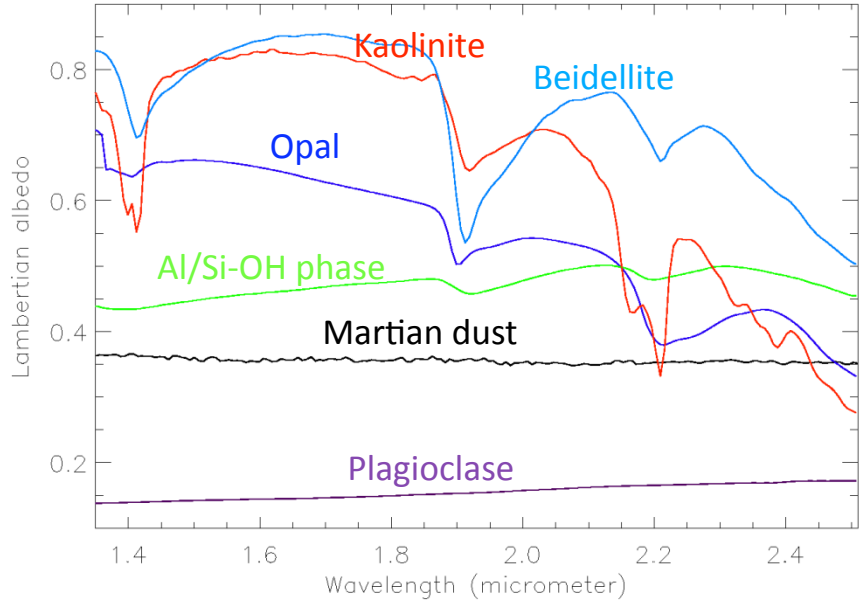

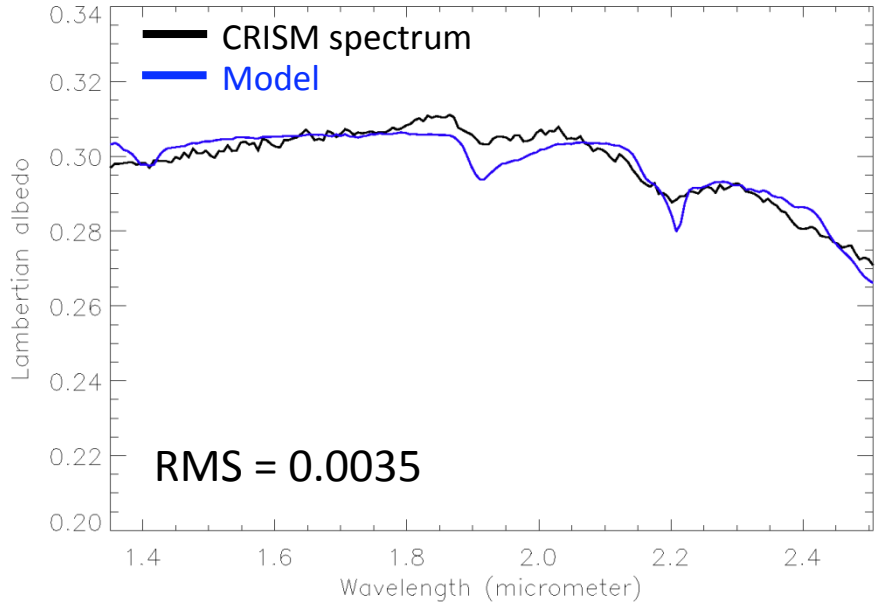

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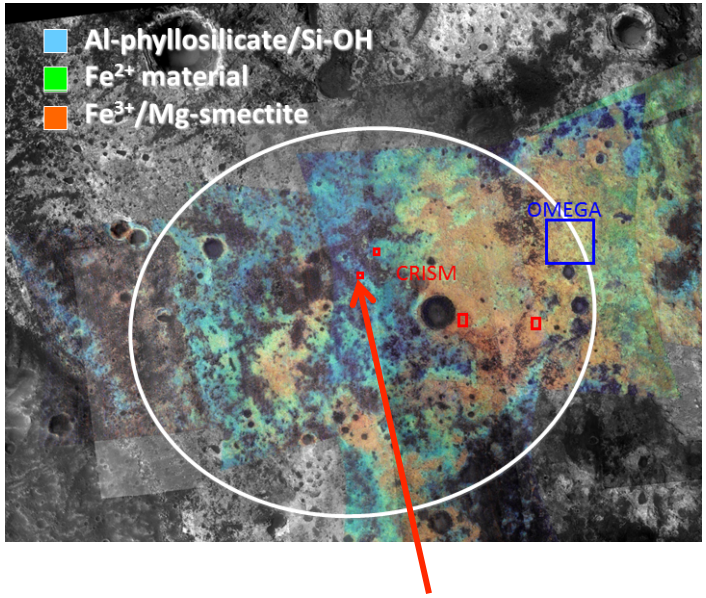

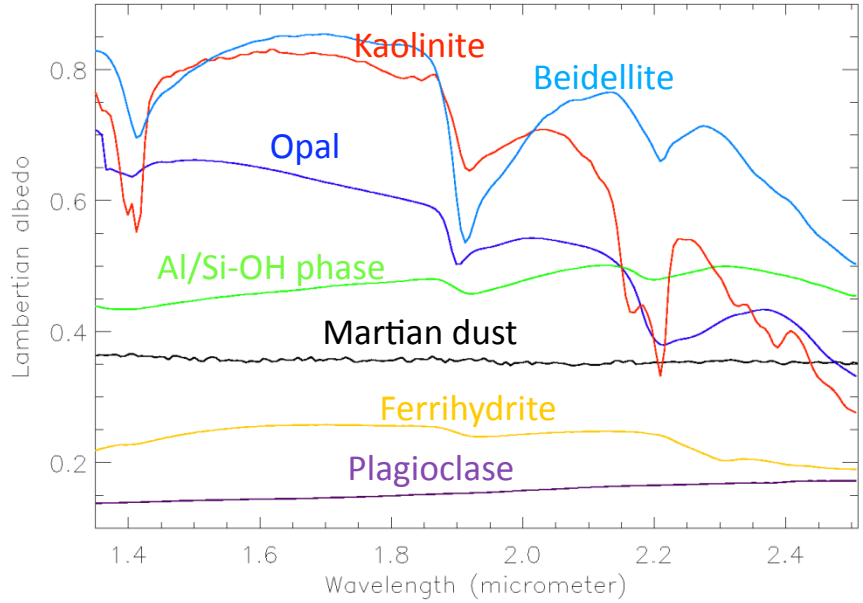

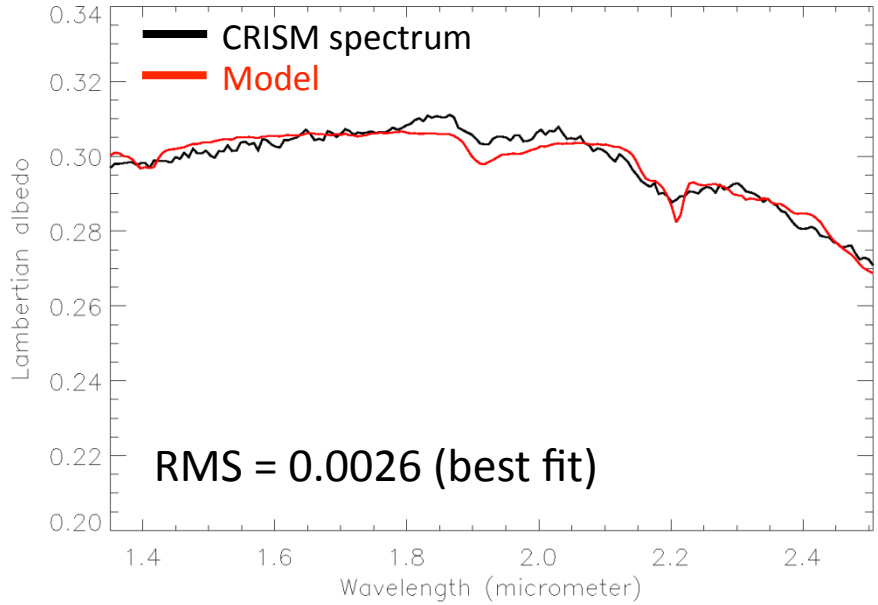

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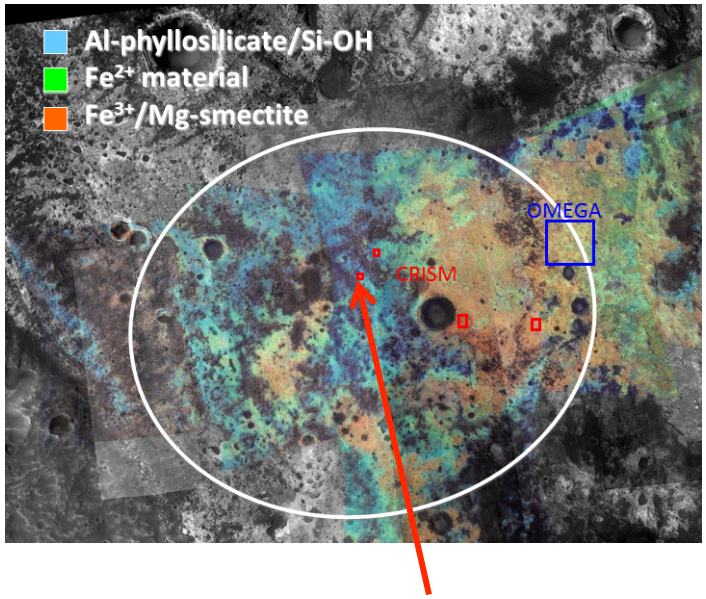
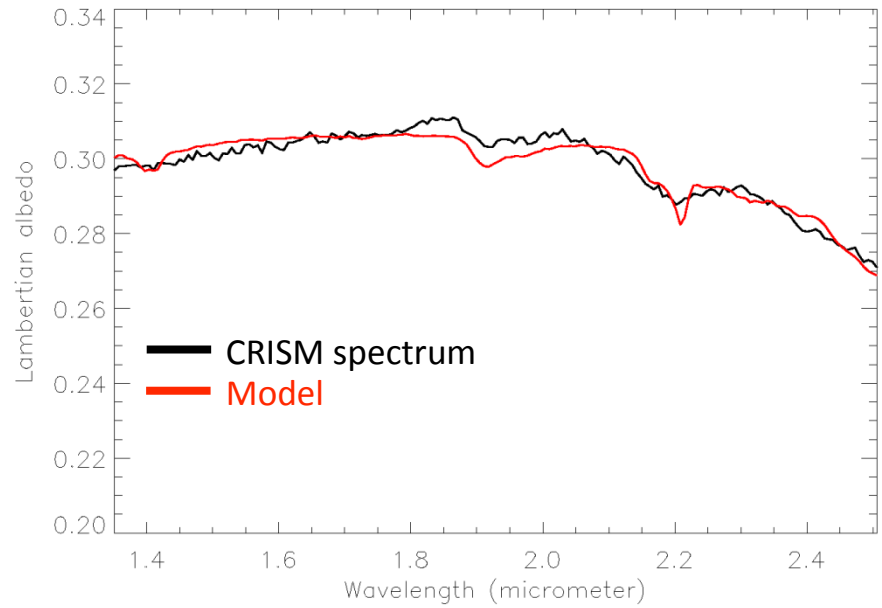
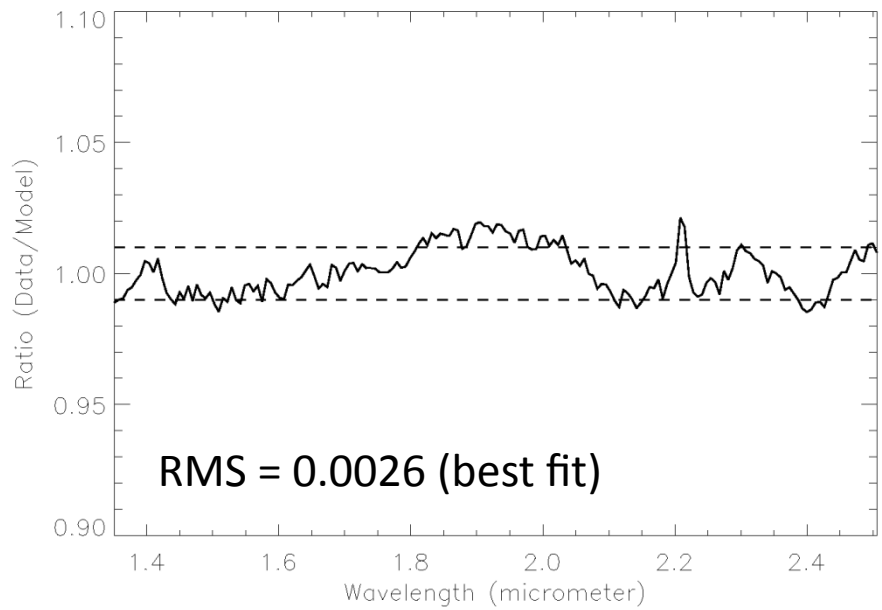


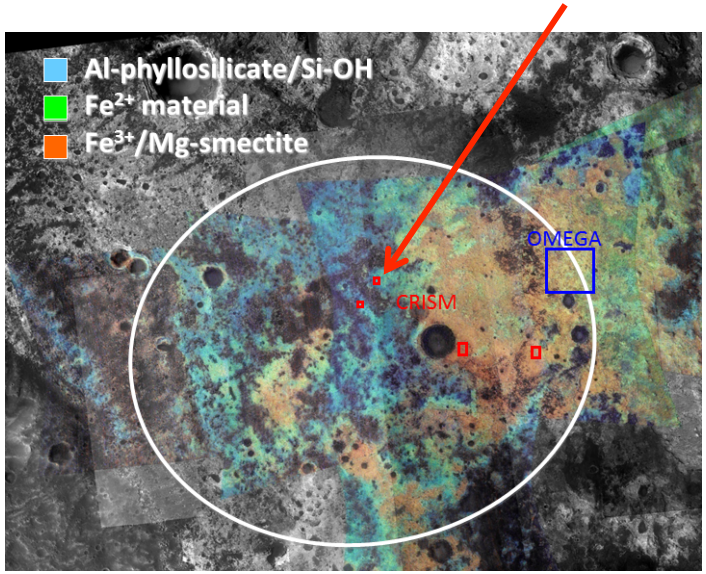


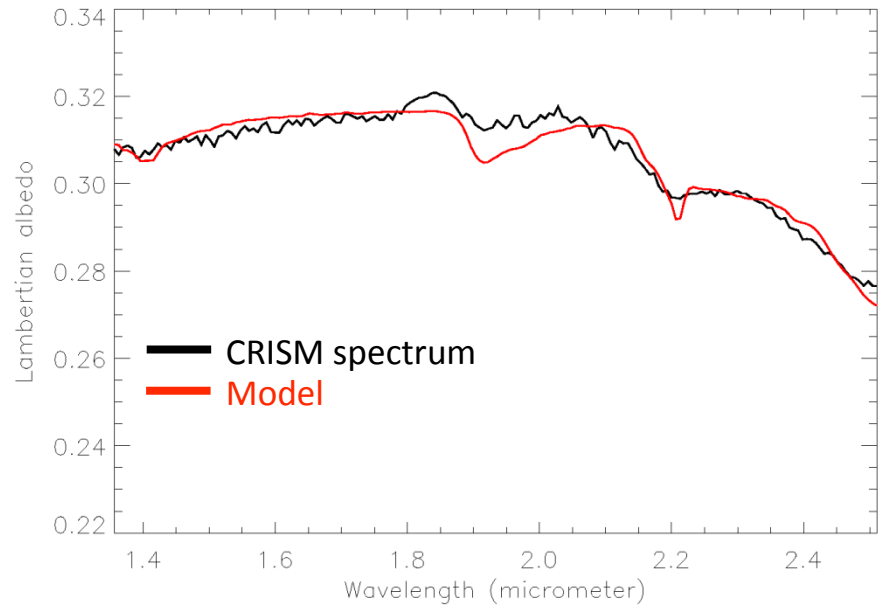
	Abundance (% Vol)	Grain Size (µm)
Kaolinite	12%	40
Al/Si-OH	29%	10
Opal	7%	60
Ferrihydrite	17%	10
Beidellite	<10%	<10
Plagioclase	17%	150
Dust	8%	5
Pyroxene	0%	-

75%



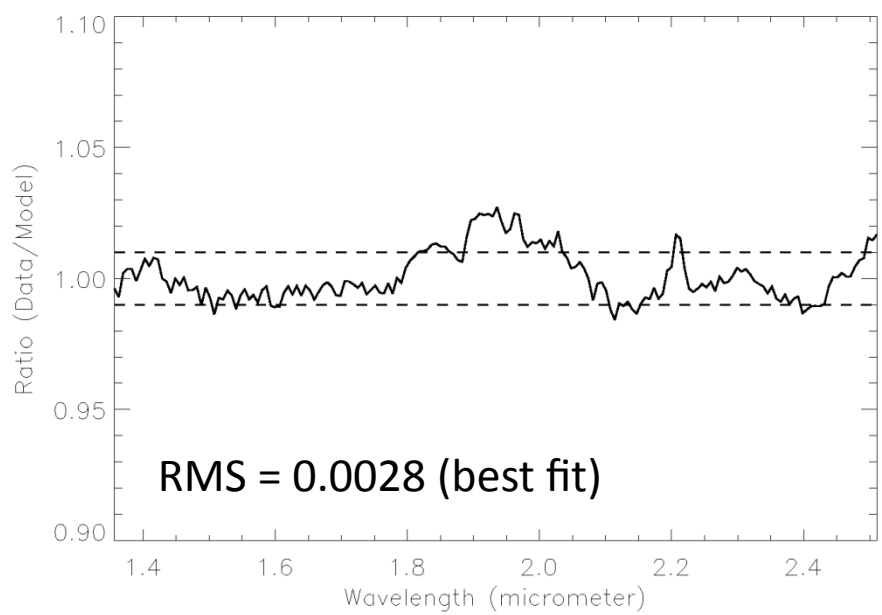
Mawrth Vallis: Al-clay/Si-OH material in the ellipse

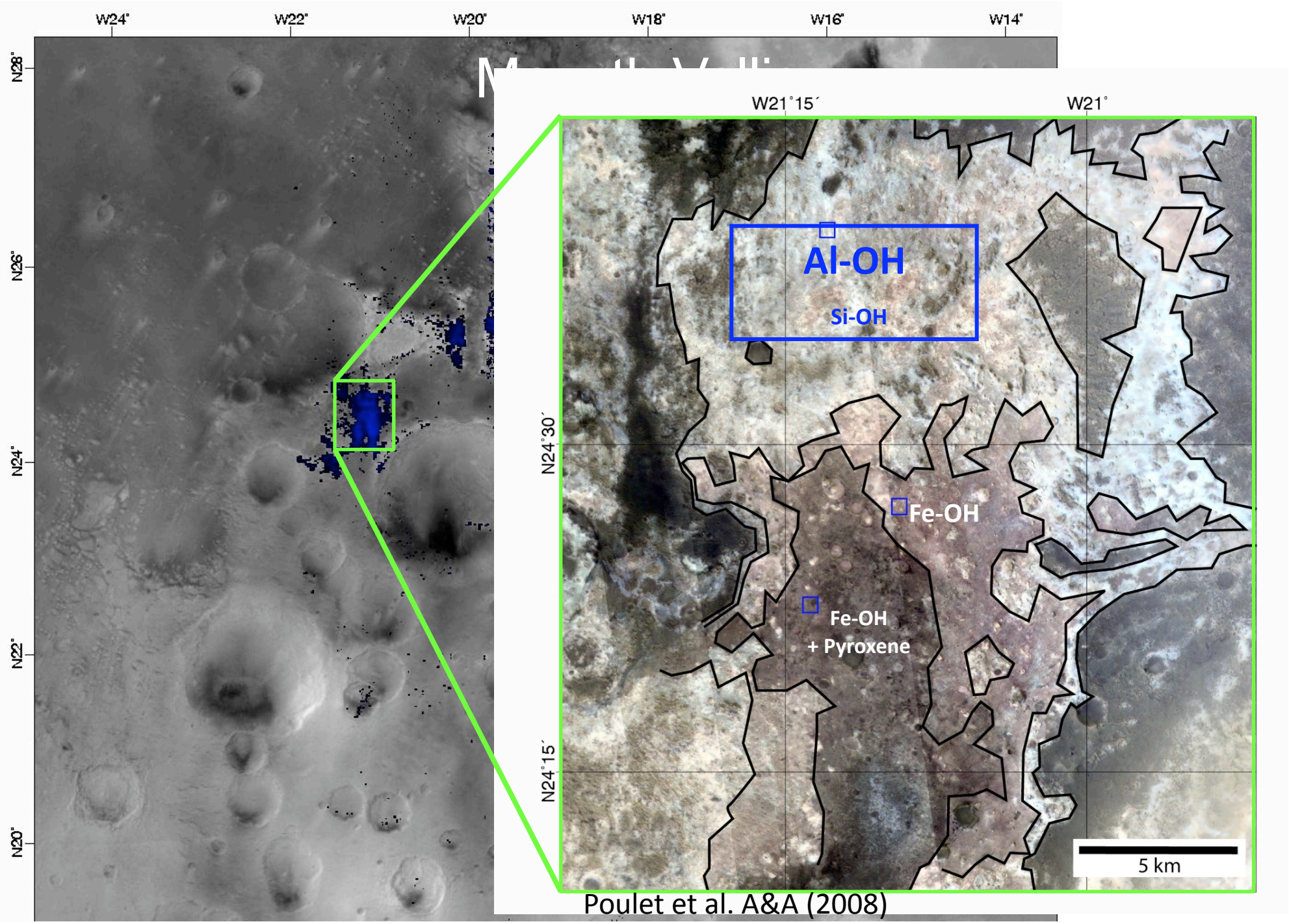




	Abundance (% Vol)	Grain Size (µm)
Kaolinite	30%	10
Al/Si-OH	23%	70
Opal	12%	40
Ferrihydrite	11%	10
Beidellite	<10%	<10
Plagioclase	4%	150
Dust	9%	5
Pyroxene	0%	-

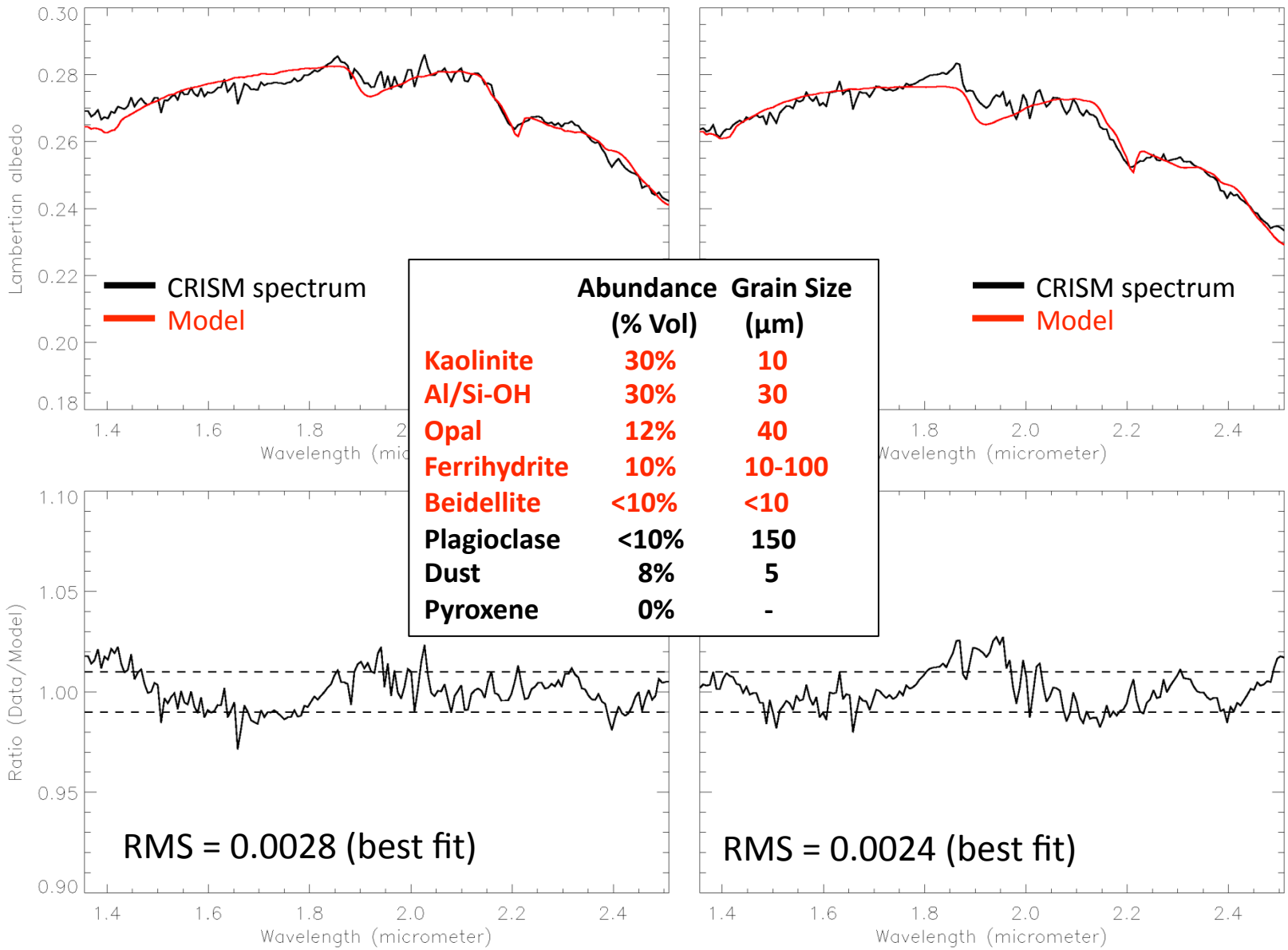
85%





Poulet et al. A&A (2008)

Al/Si-OH Unit in Western MV



	Abundance (% Vol)	Grain Size (µm)
Kaolinite	30%	10
Al/Si-OH	30%	30
Opal	12%	40
Ferrihydrite	10%	10-100
Beidellite	<10%	<10
Plagioclase	<10%	150
Dust	8%	5
Pyroxene	0%	-

=> Mixture is well representative of the Al/Si-OH unit

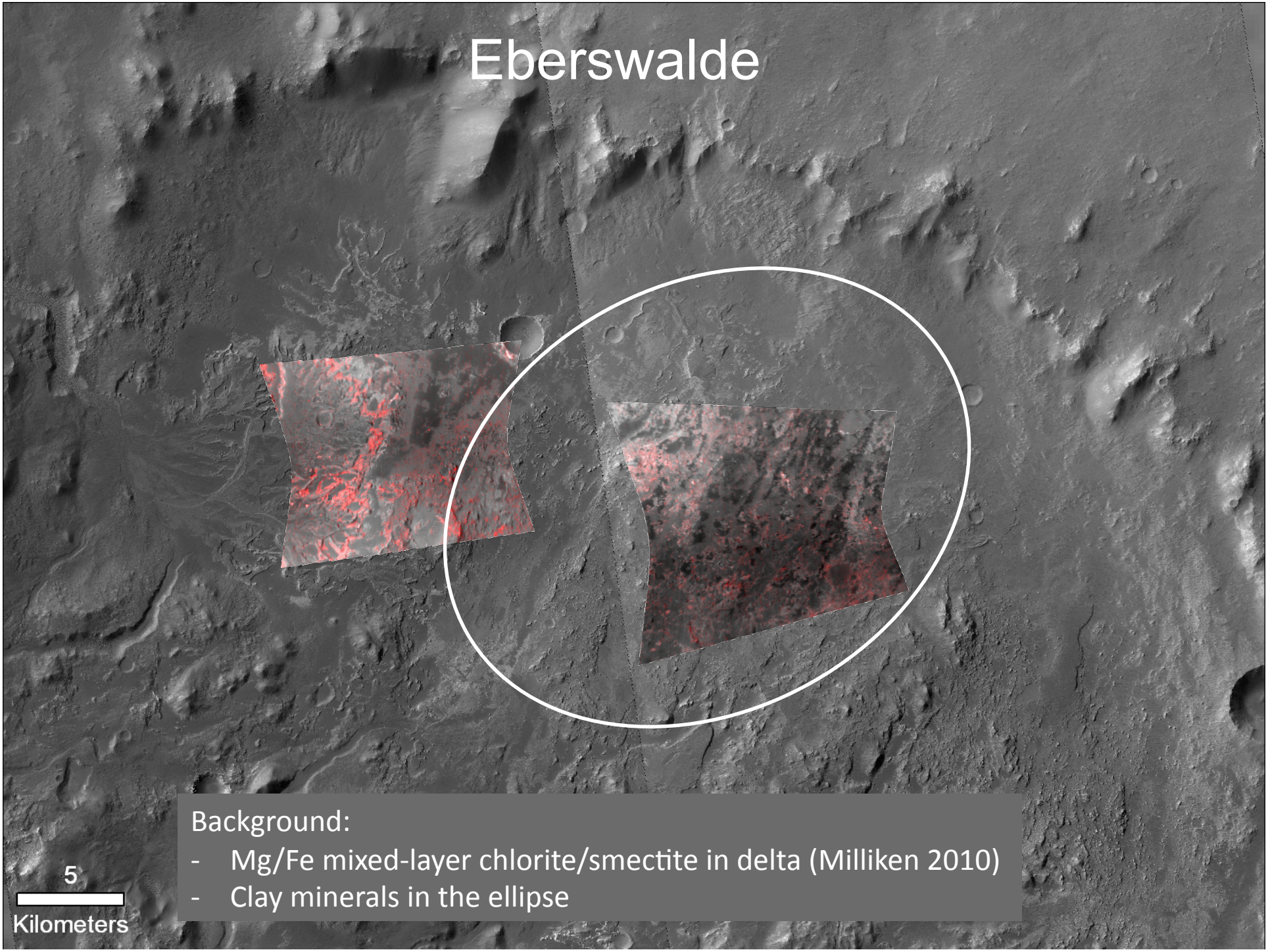
Mawrth Vallis: Al-clay/Si-OH material in the ellipse

	Abundance	Grain Size (µm)
Kaolinite	10-30%	<50
Al/Si-OH	10-30%	<100
Opal	5-15%	<100
Ferrihydrite	5-15%	<100
Beidellite	<10%	<10
Plagioclase	5-15%	150
Dust	<10%	5
Pyroxene	0%	-

- Mineral mixture is more complex than for the Fe-rich clay unit
- Al/Si-OH phases and Al-smectite are the dominant minerals (40±20% Vol)
- Small amount of opal <15%
- No pyroxene, minor amount of plagioclase (<15%) => indication of a strong alteration

=> Formation process?

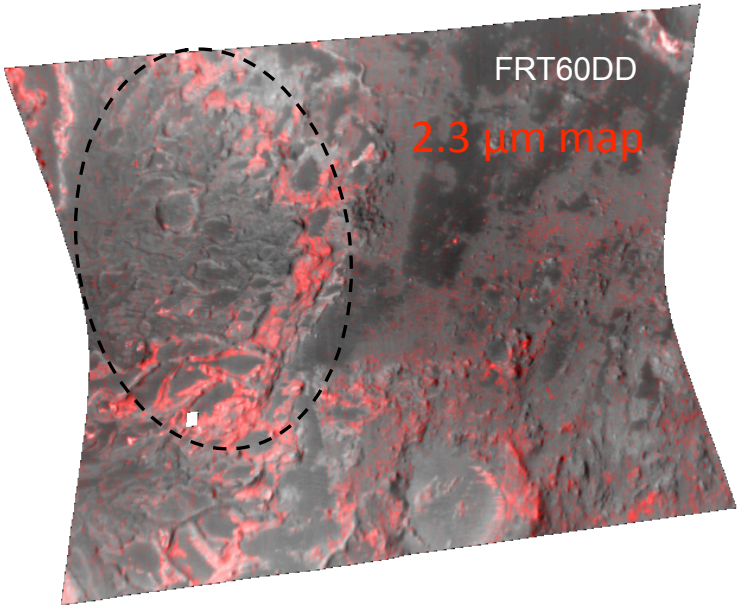
- Active hydrolysis and ion leaching due to acidic conditions or hot and humid climates(Bishop et al. 2008)
- Presence of Fe^{3+}-oxyhydroxide necessary: Iron-oxides can be coated on silica sand particles during humic acid interactions (biological activity?)

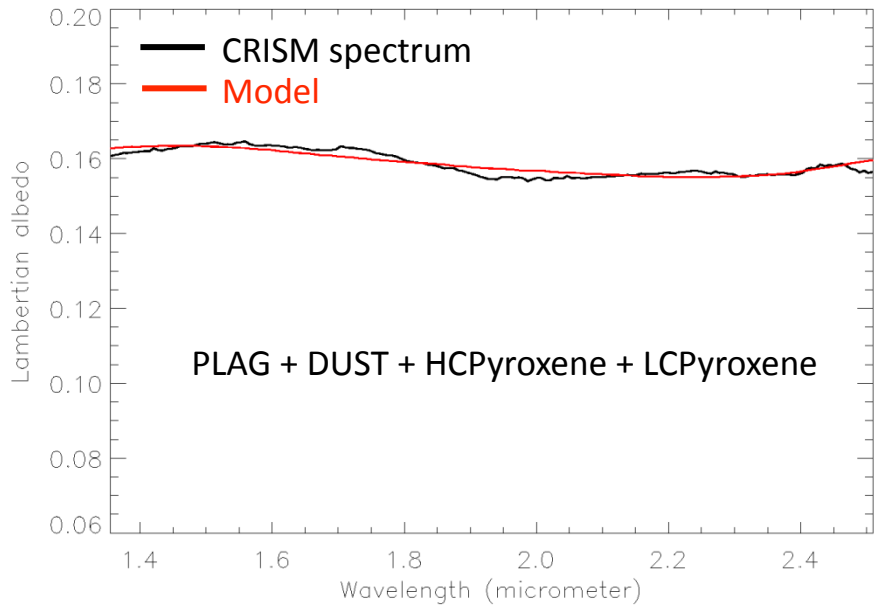


Background:

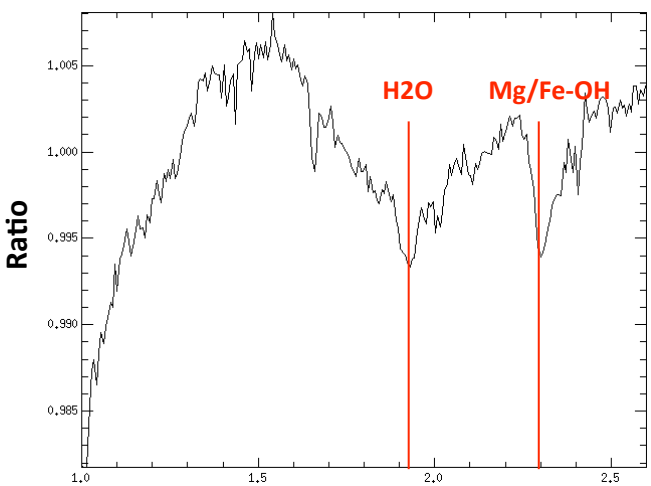
- Mg/Fe mixed-layer chlorite/smectite in delta (Milliken 2010)
- Clay minerals in the ellipse

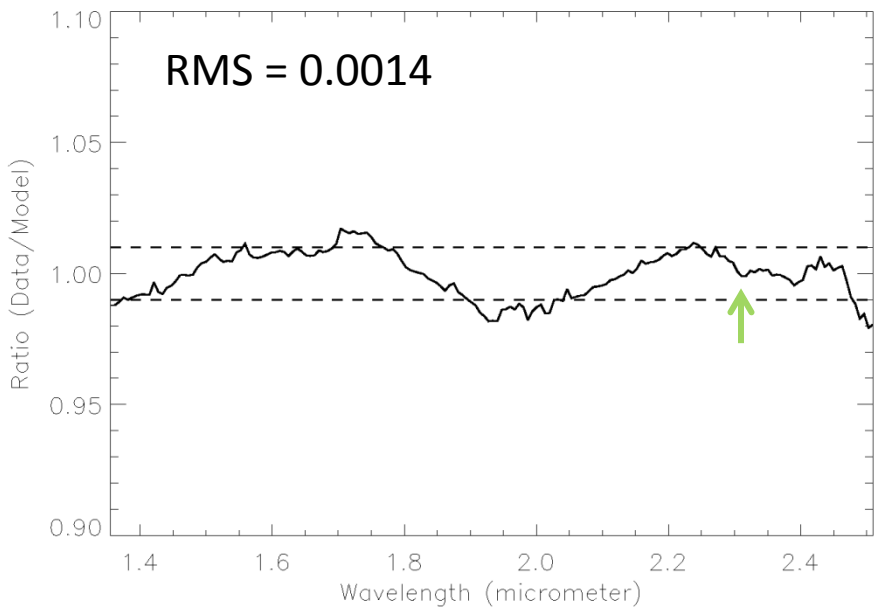
Eberswalde : Clay-bearing deposits in the deltaic units



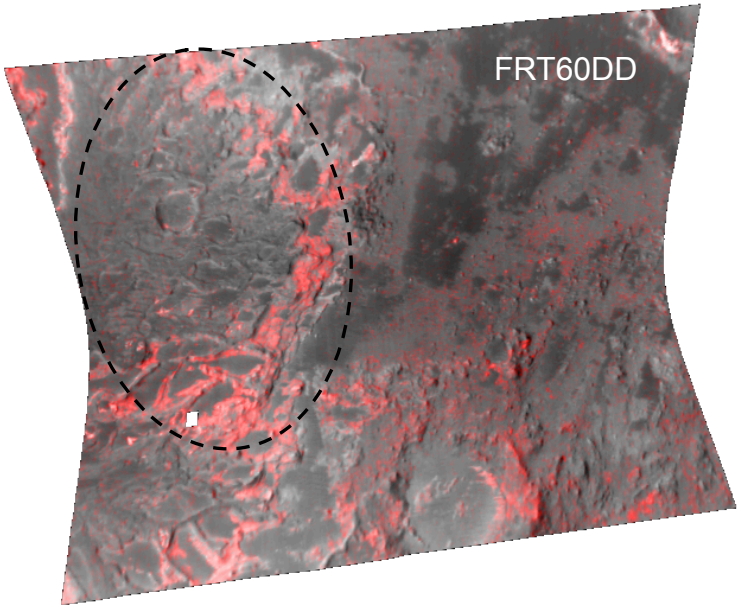


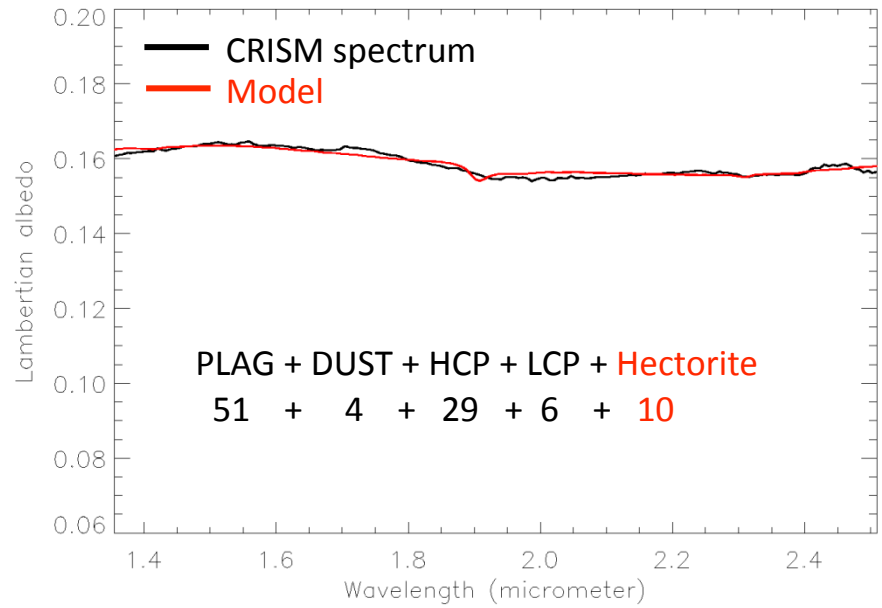
Average of 121 pixels
with strongest Mg/Fe-OH signatures



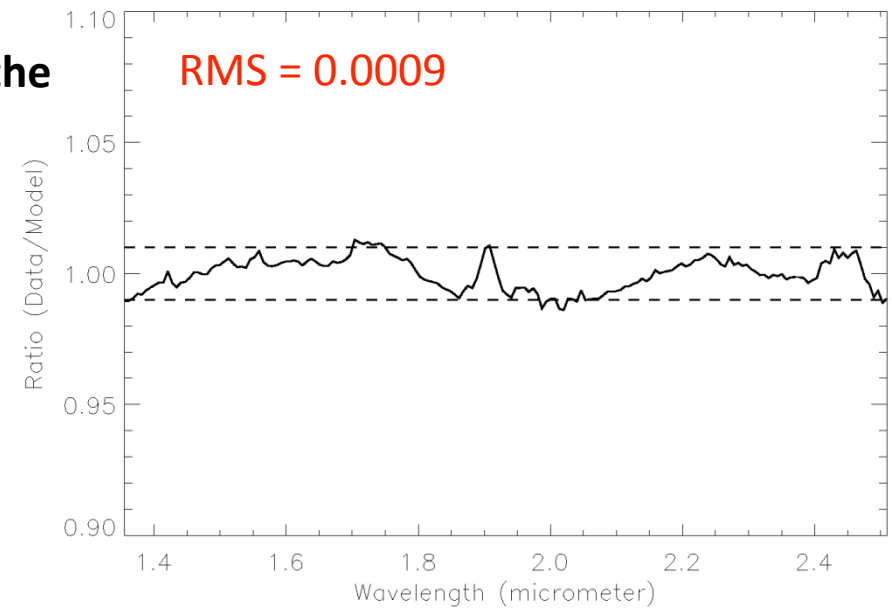


Eberswalde : Clay-bearing deposits in the deltaic units

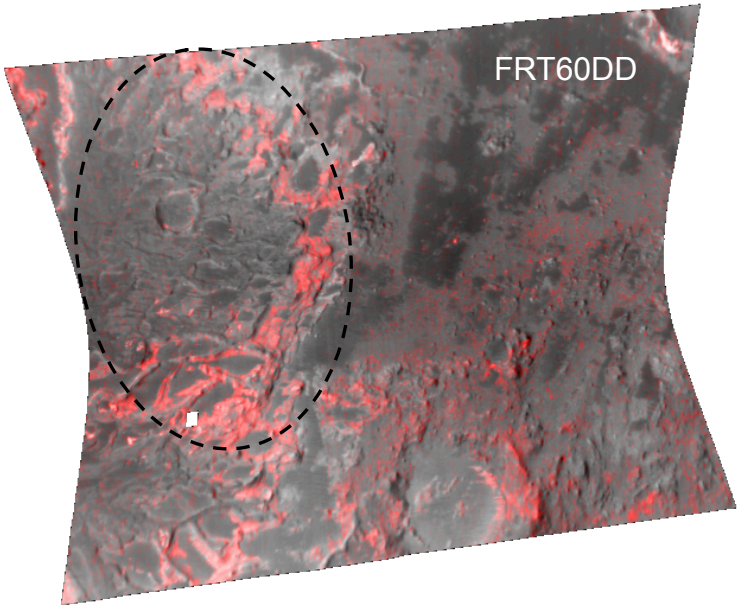


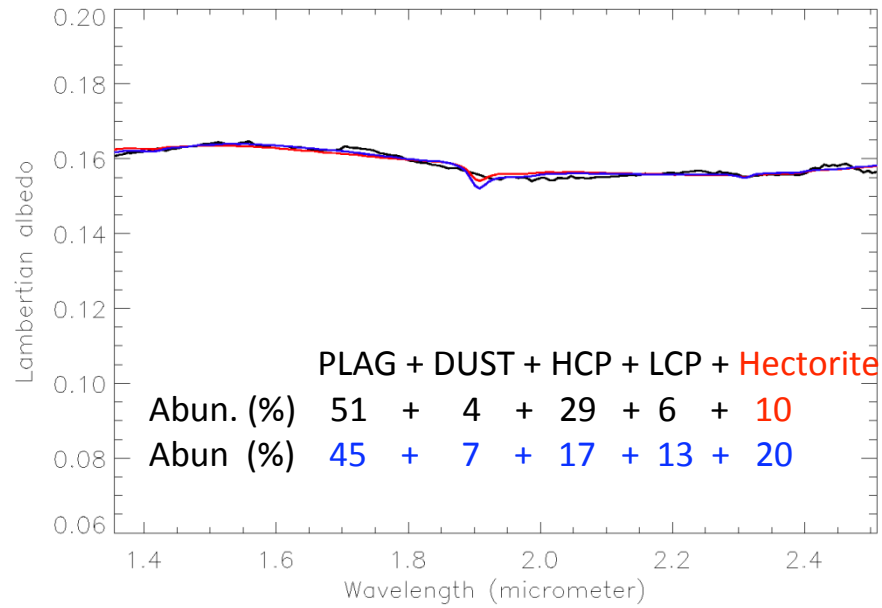


- **Anhydrous mafic minerals (80%) are the dominant phases**
- **Pyroxenes (HCP and LCP) required**
- **Mg-rich smectites ≤ 20%**

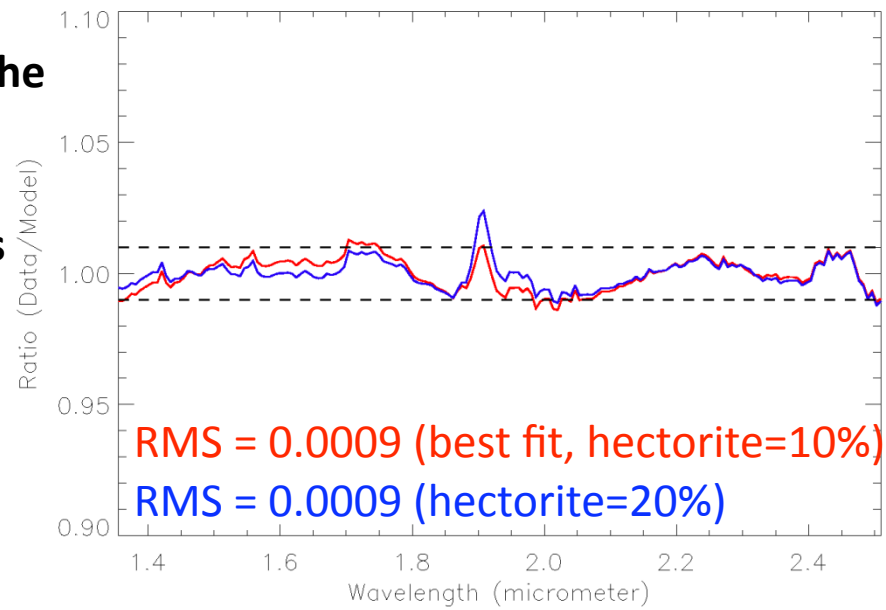


Eberswalde : Clay-bearing deposits in the deltaic units

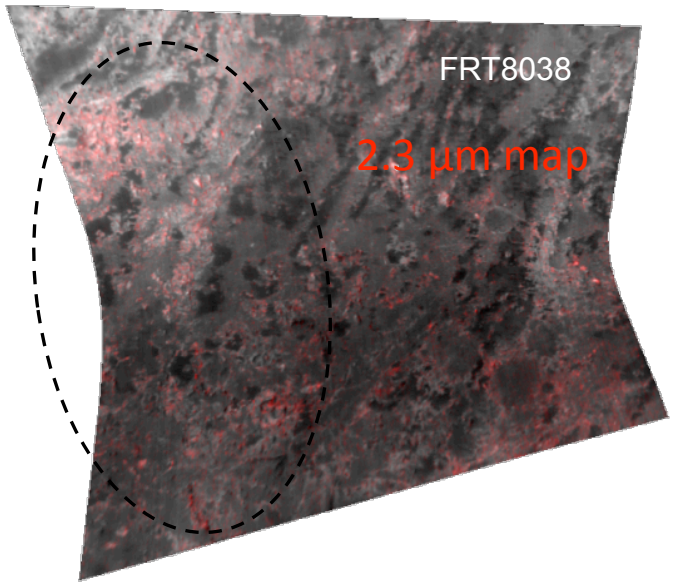




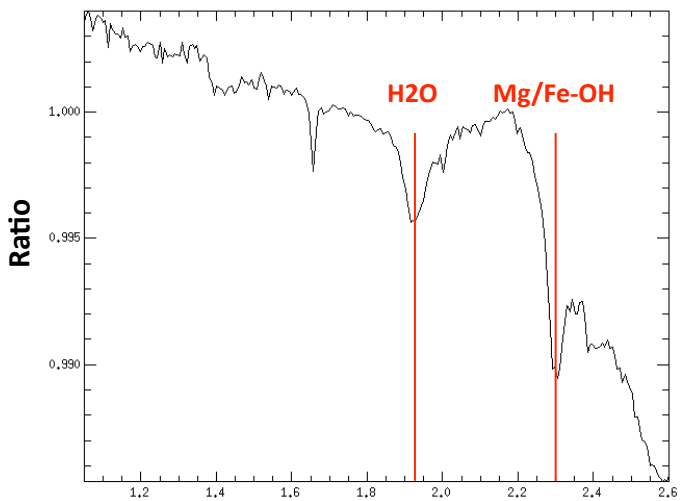
- **Anhydrous mafic minerals (80%) are the dominant phases**
- **Pyroxenes (HCP and LCP) required**
- **Clay content ≤ 20%, Mg-rich smectites**



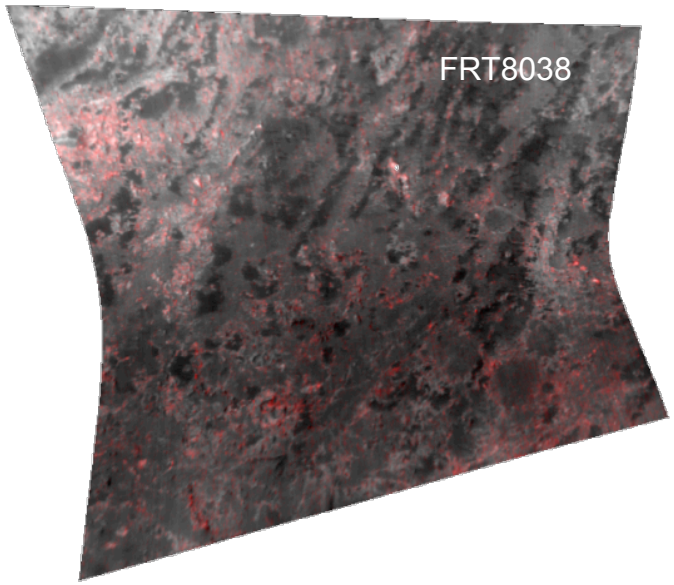
Eberswalde : Clay-bearing materials in the ellipse

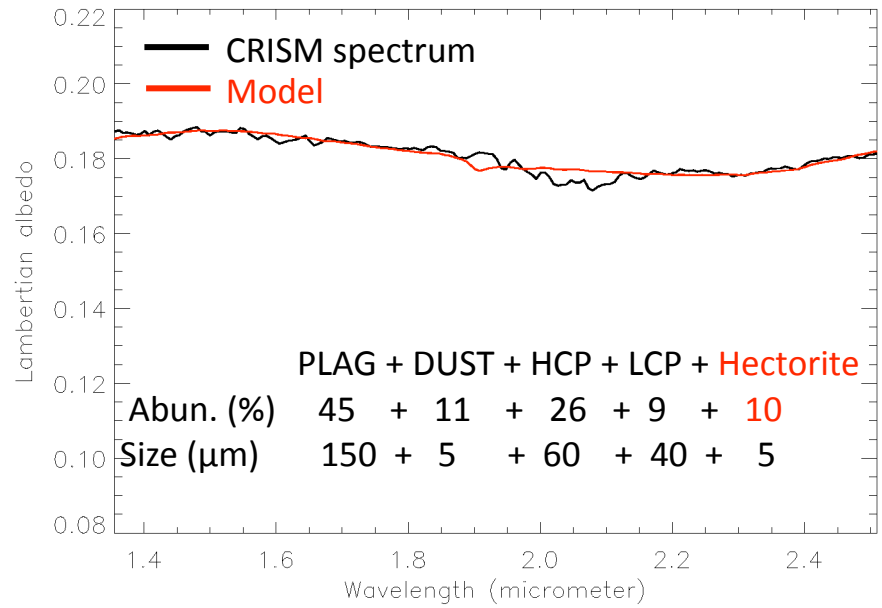


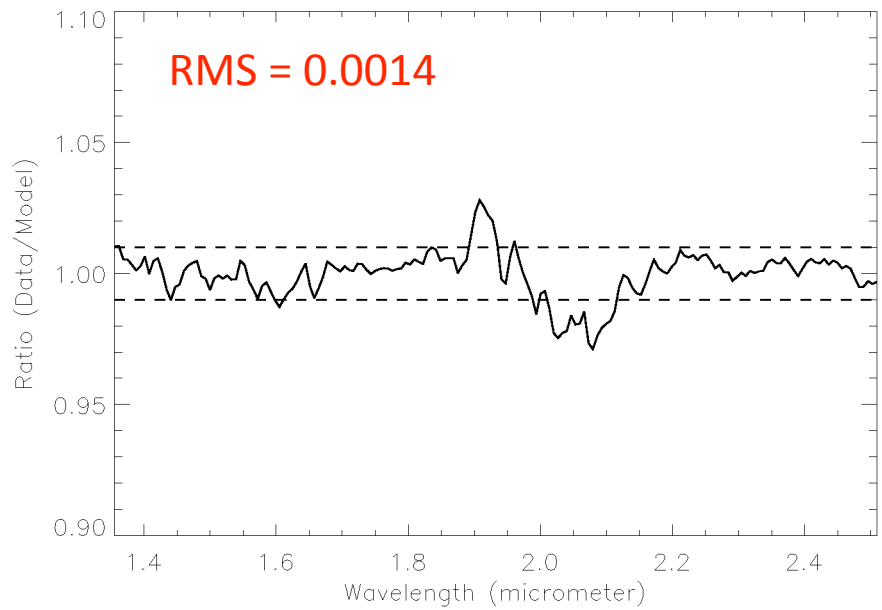
Average of 282 pixels
with strongest Fe/Mg-OH signatures



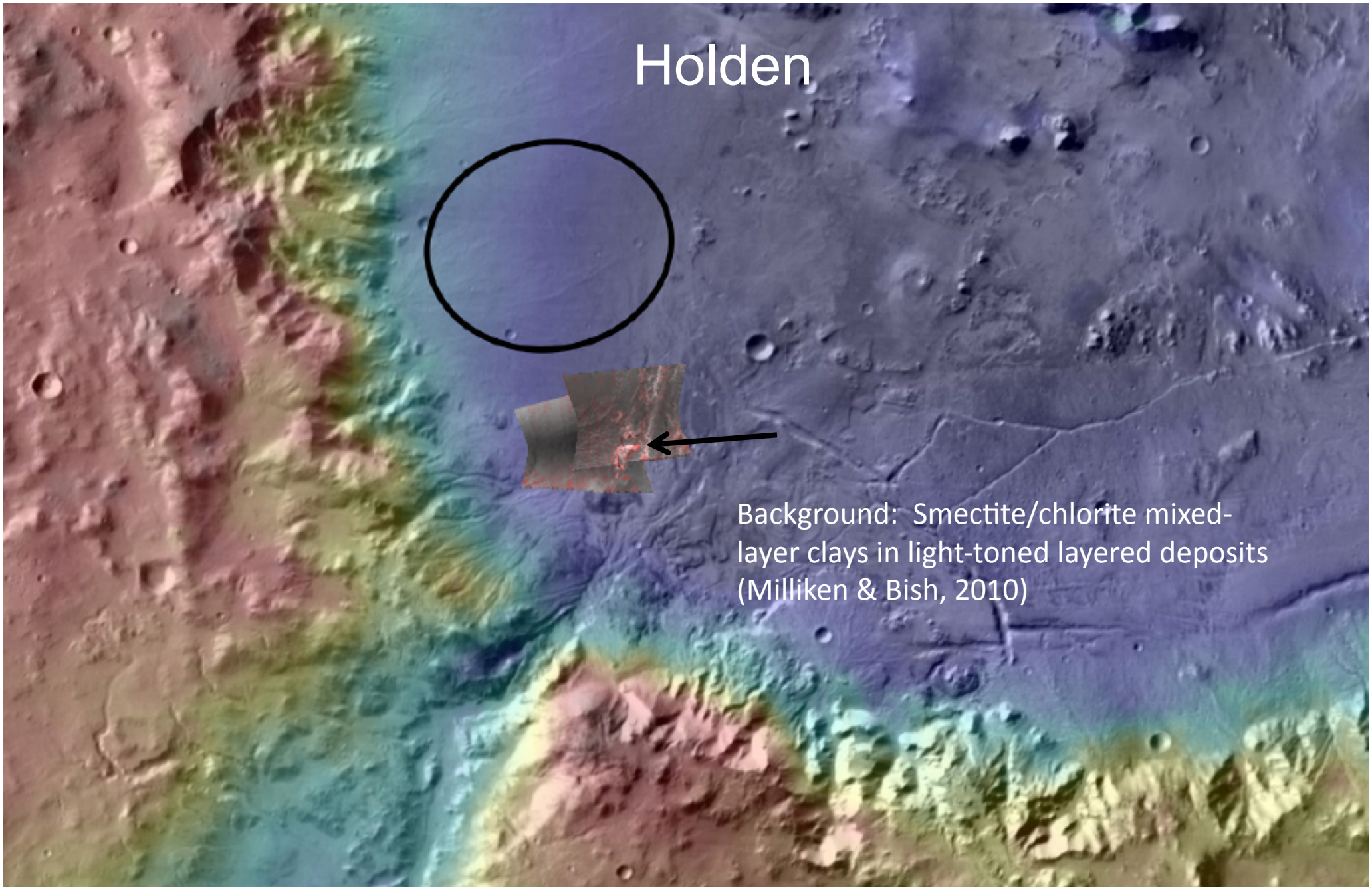
Eberswalde : Clay-bearing materials in the ellipse



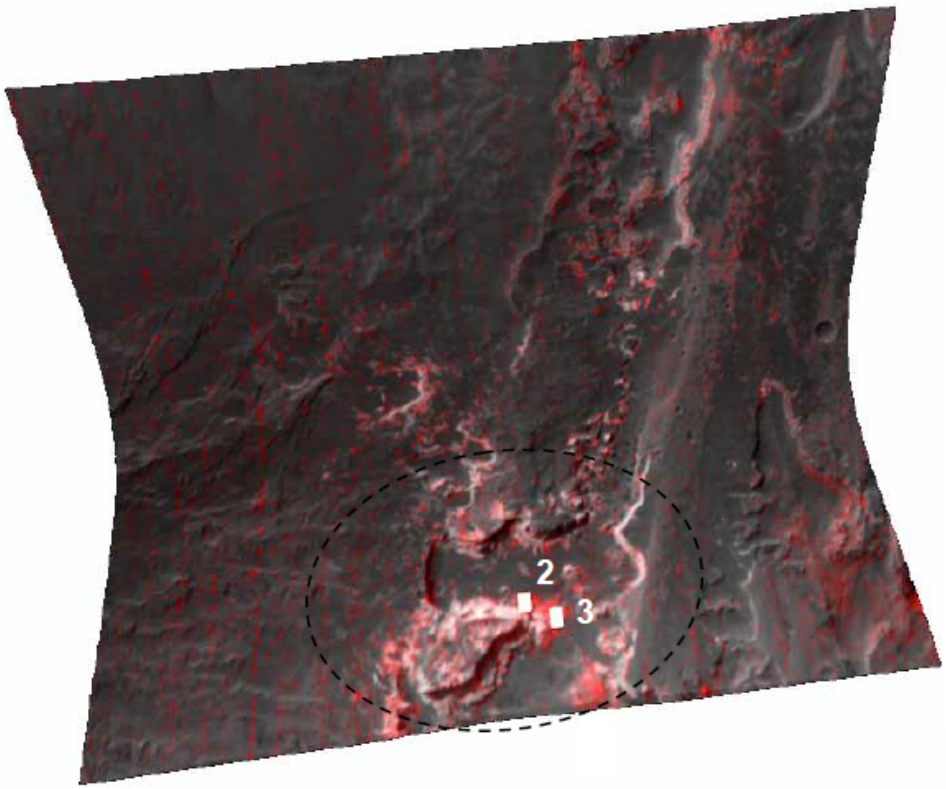


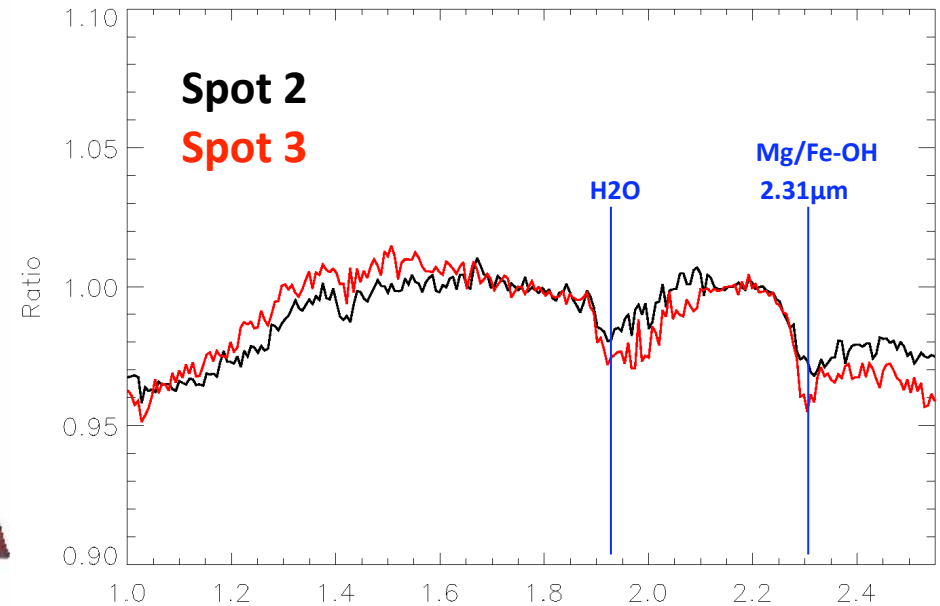


- **Composition similar to the deltaic materials composition**
- **Clay content ≤ 20%**

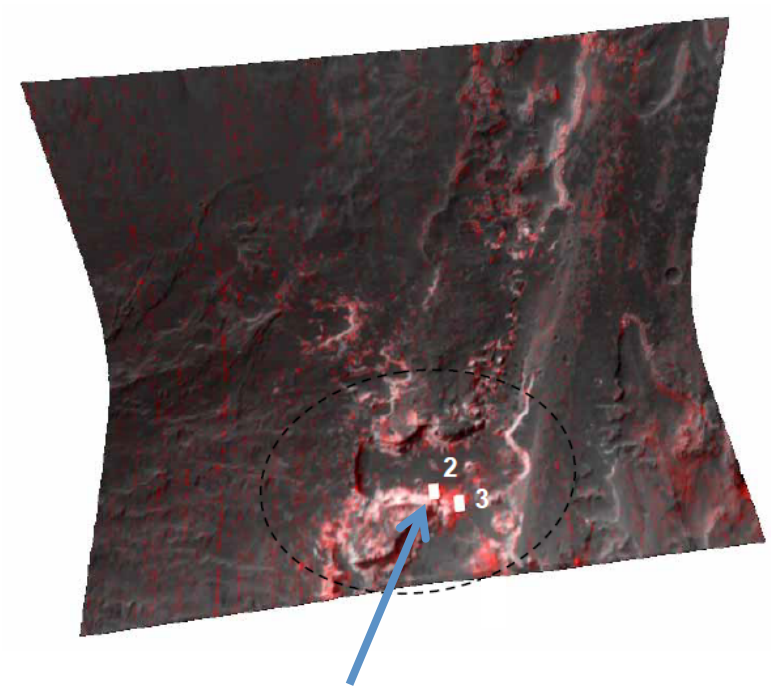

Holden
Background: Smectite/chlorite mixed-layer clays in light-toned layered deposits (Milliken & Bish, 2010)

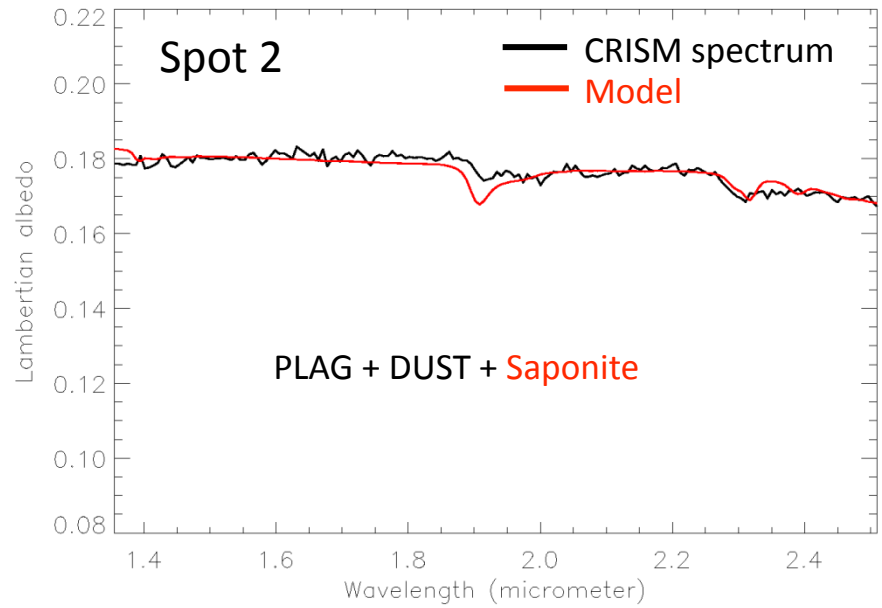
Holden

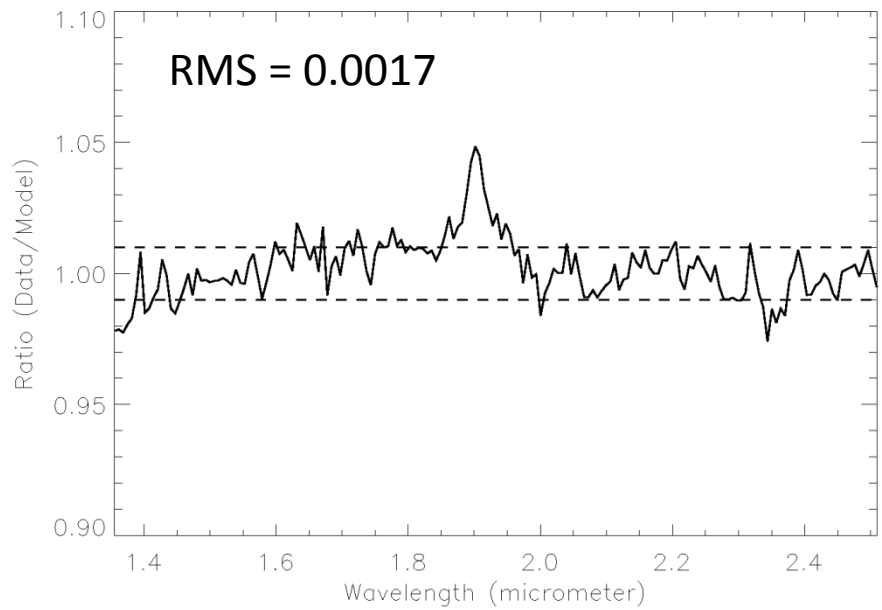

2
3


Spot 2
Spot 3
H2O
Mg/Fe-OH
2.31µm
Ratio
1.10
1.05
1.00
0.95
0.90
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

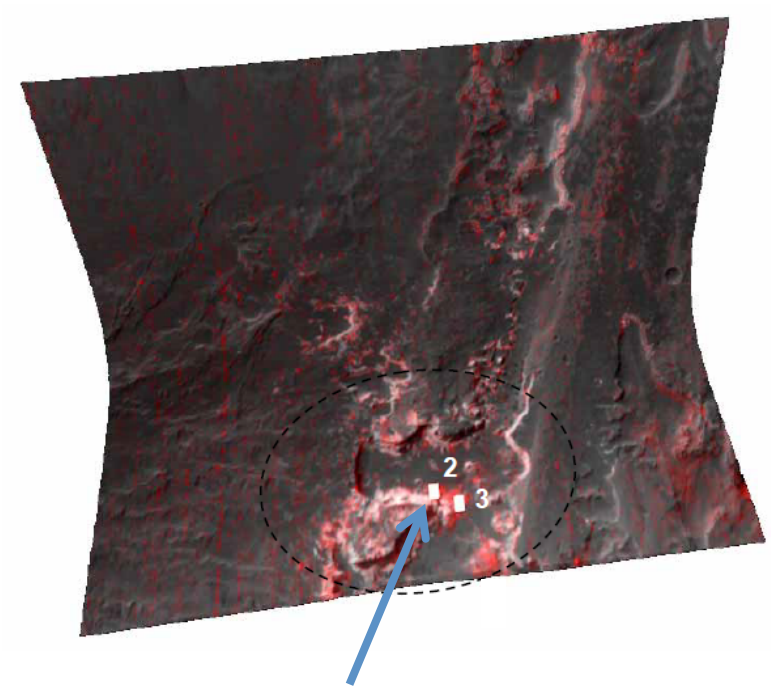
Holden : clay-bearing material in layered deposits

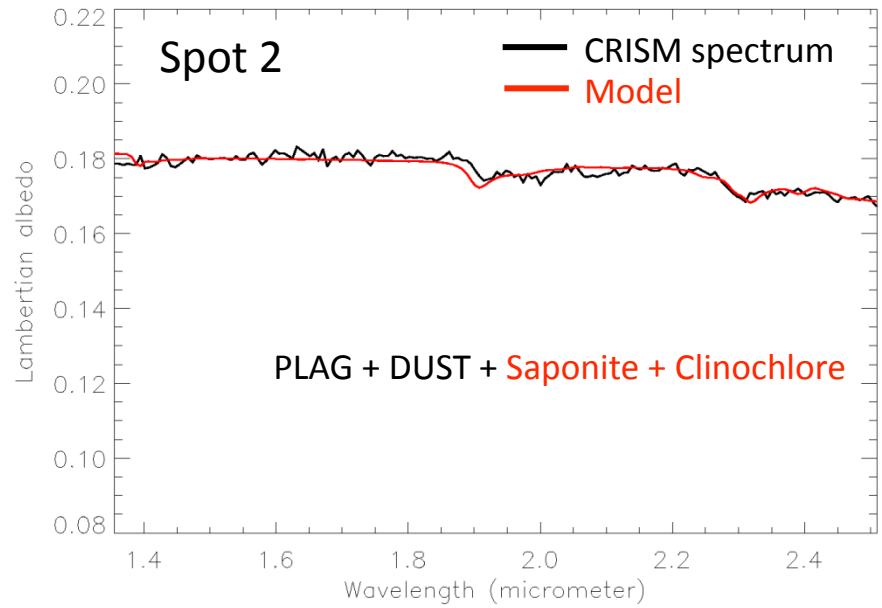


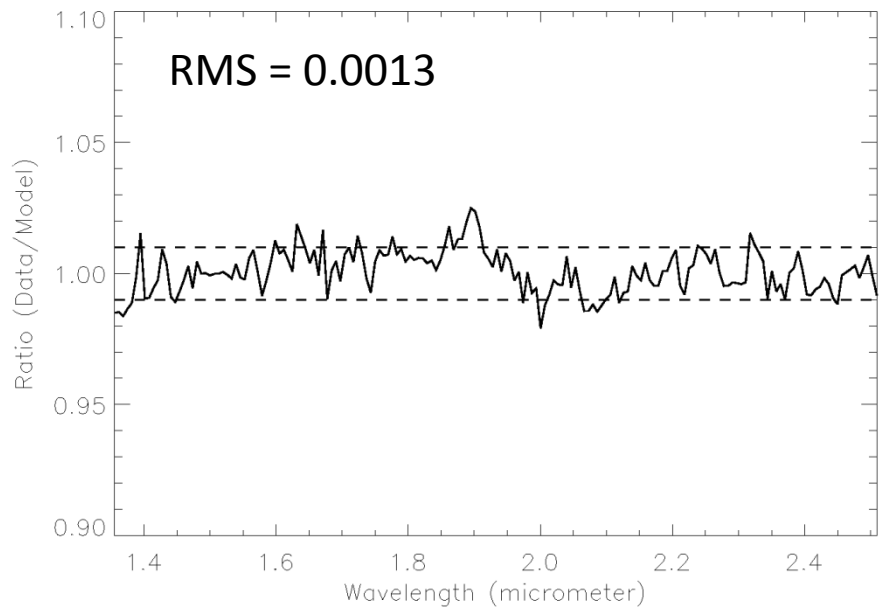




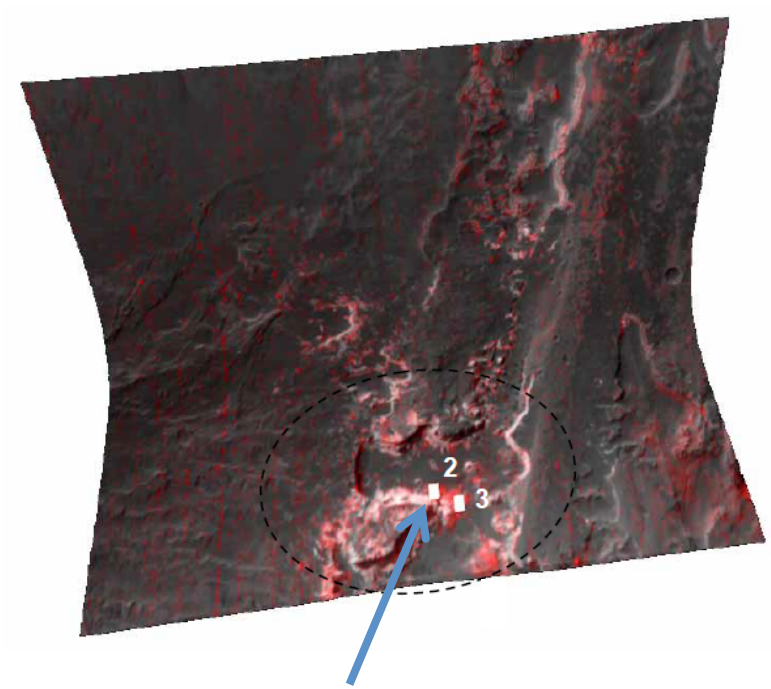
Holden : clay-bearing material in layered deposits

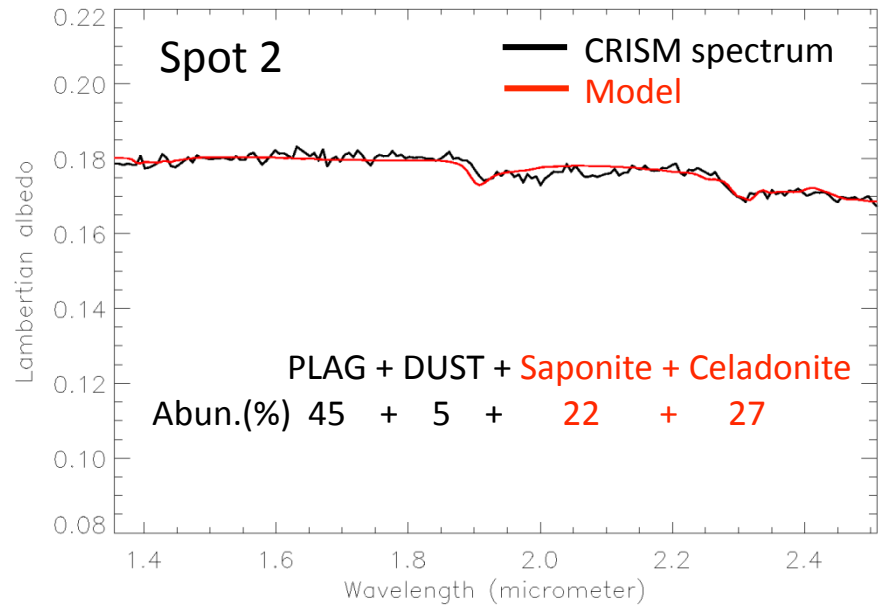


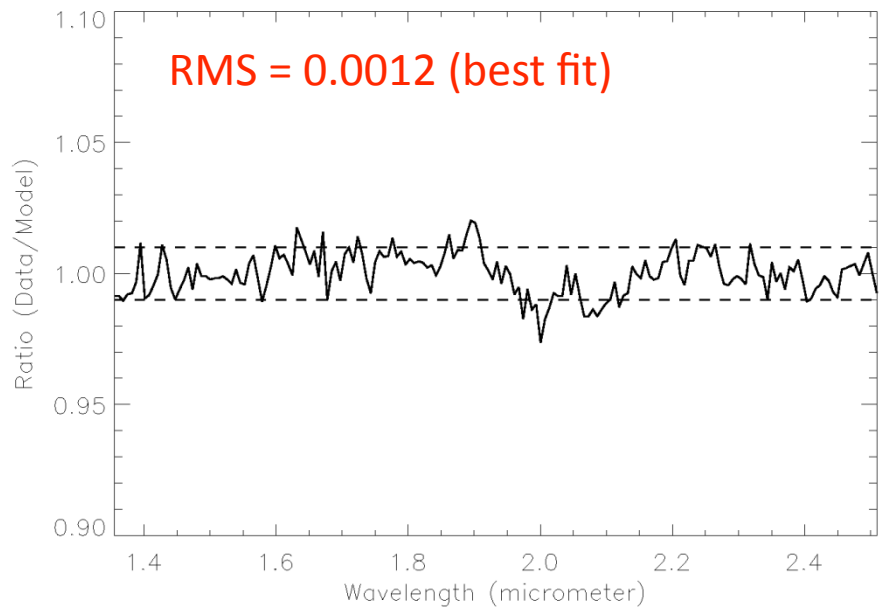




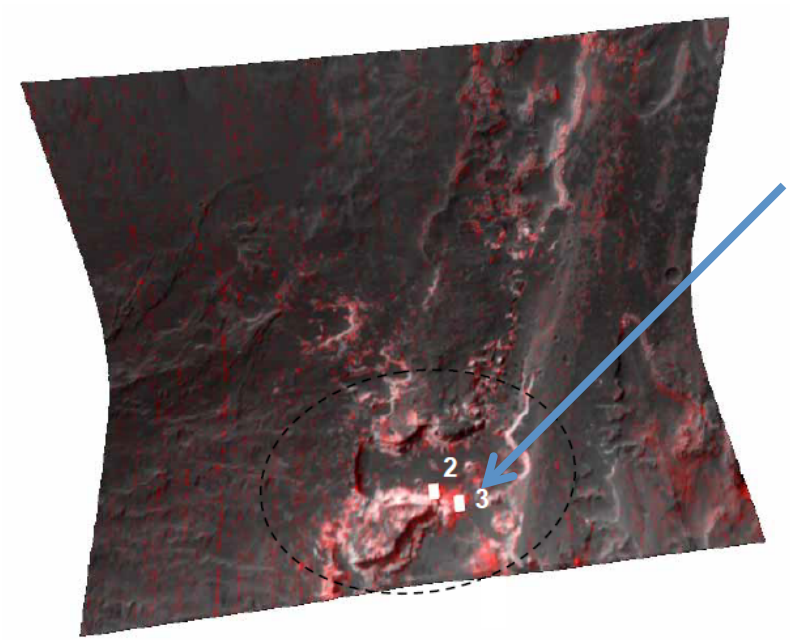
Holden : clay-bearing material in layered deposits

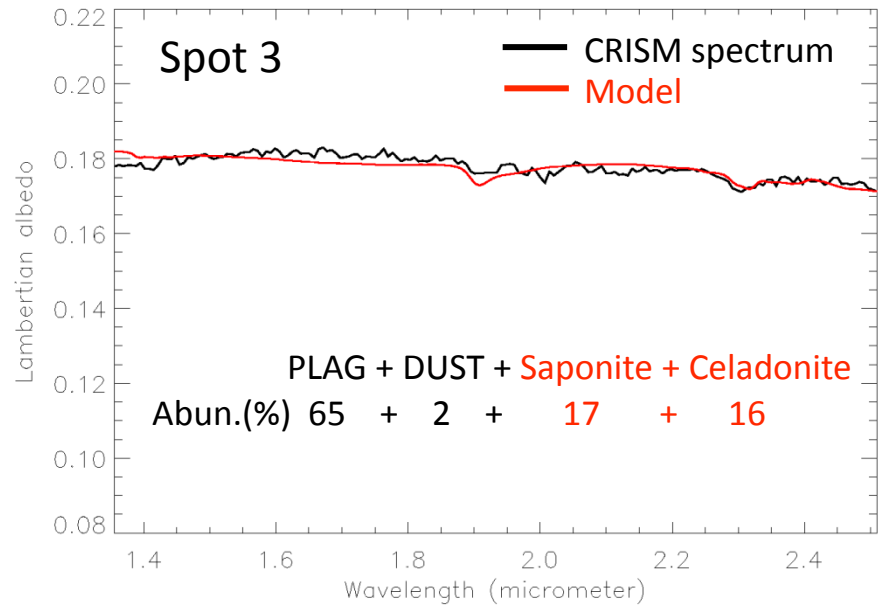


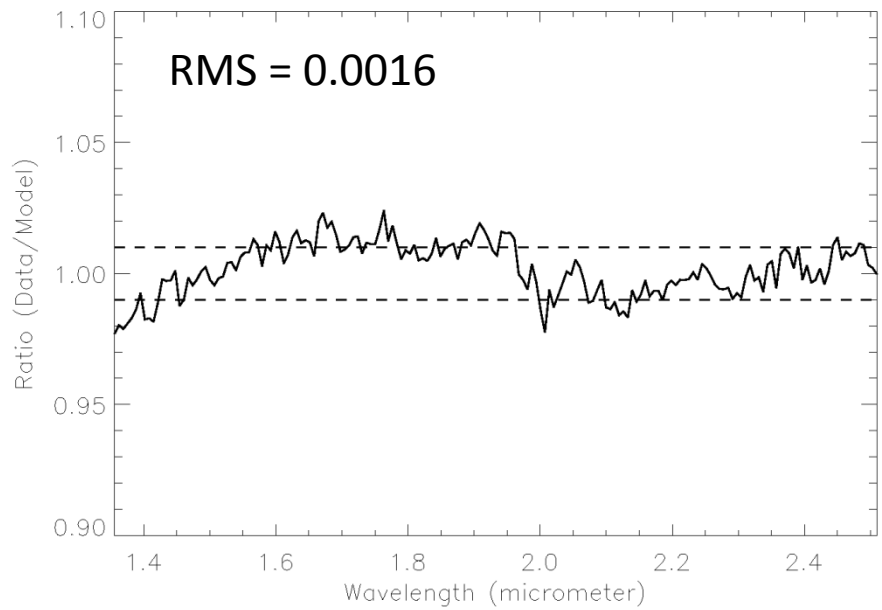




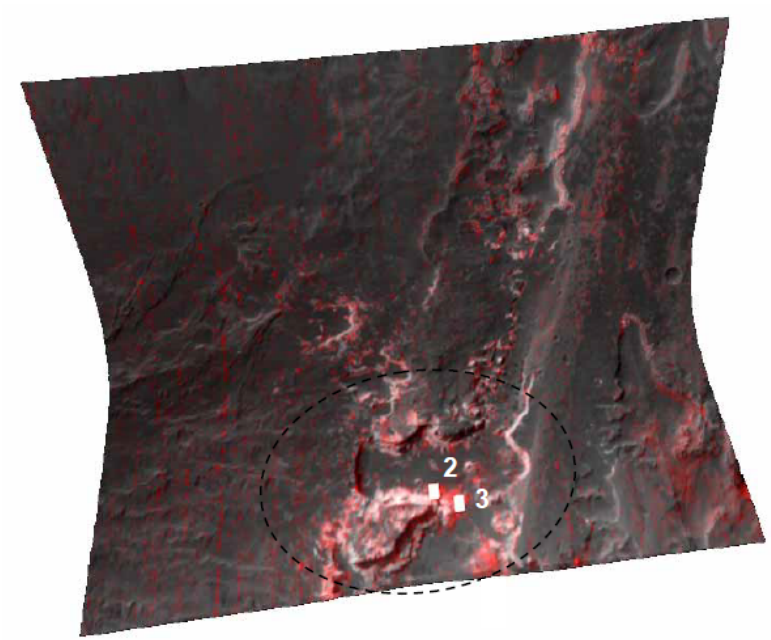
Holden : clay-bearing material in layered deposits

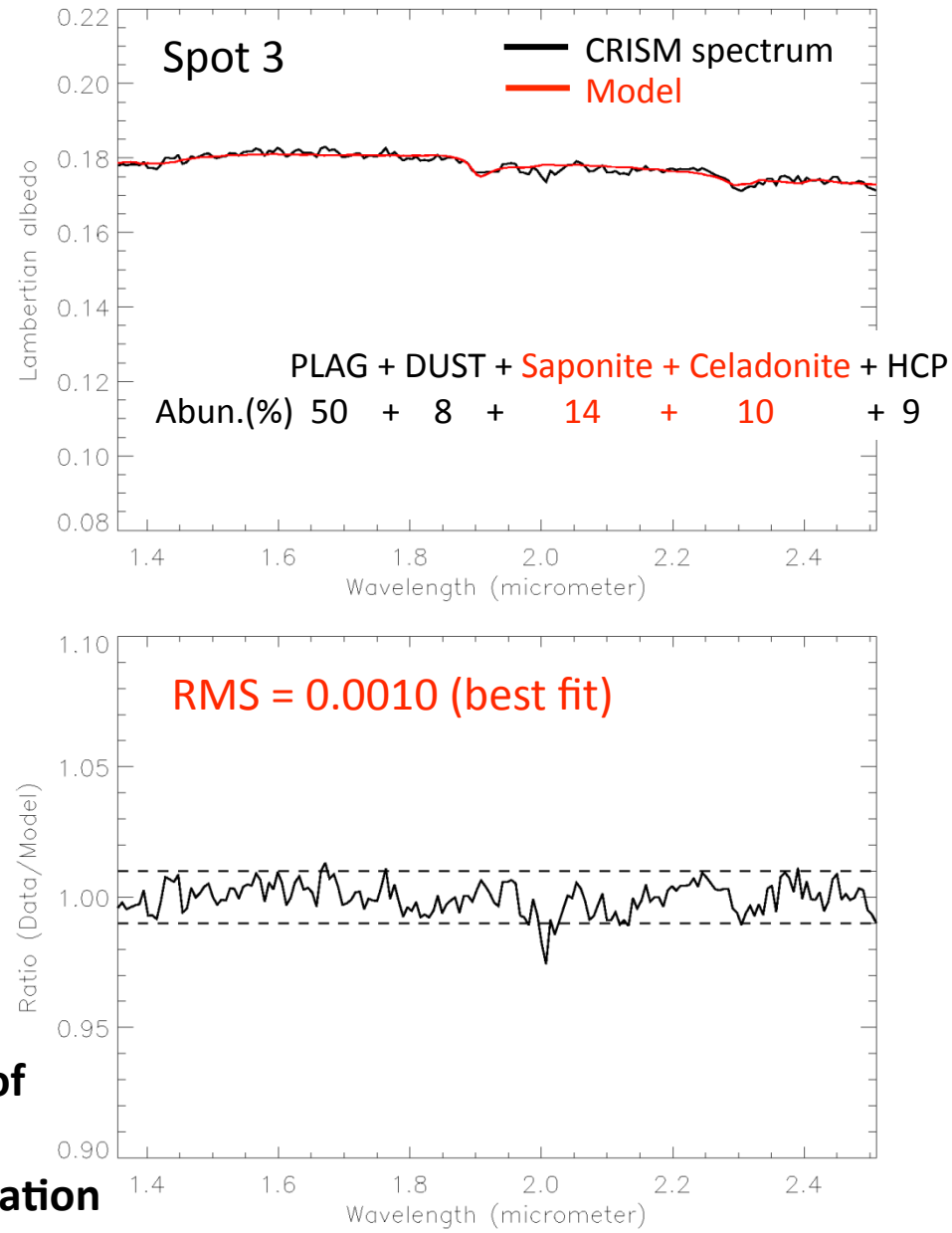






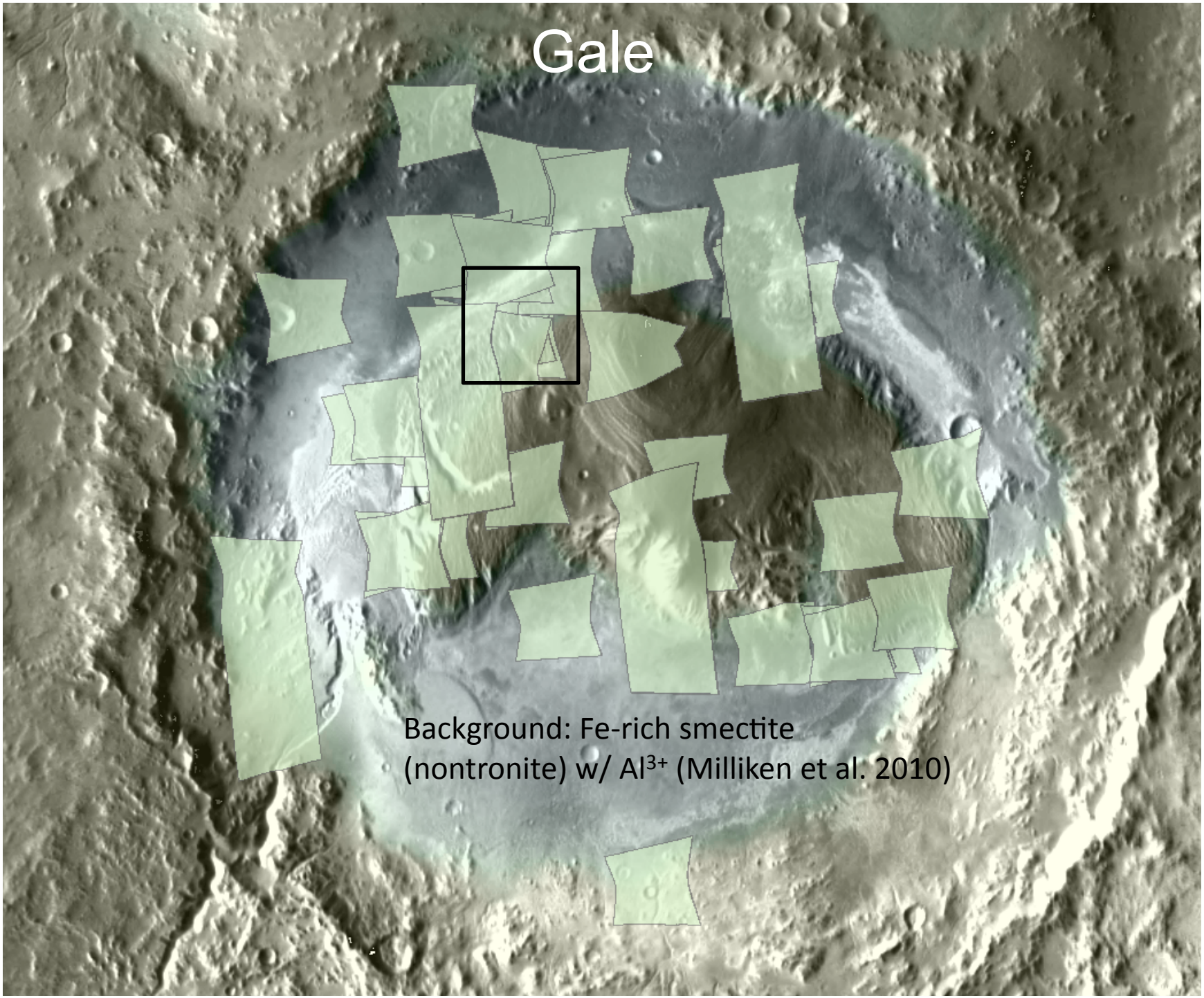
Holden : clay-bearing material in layered deposits



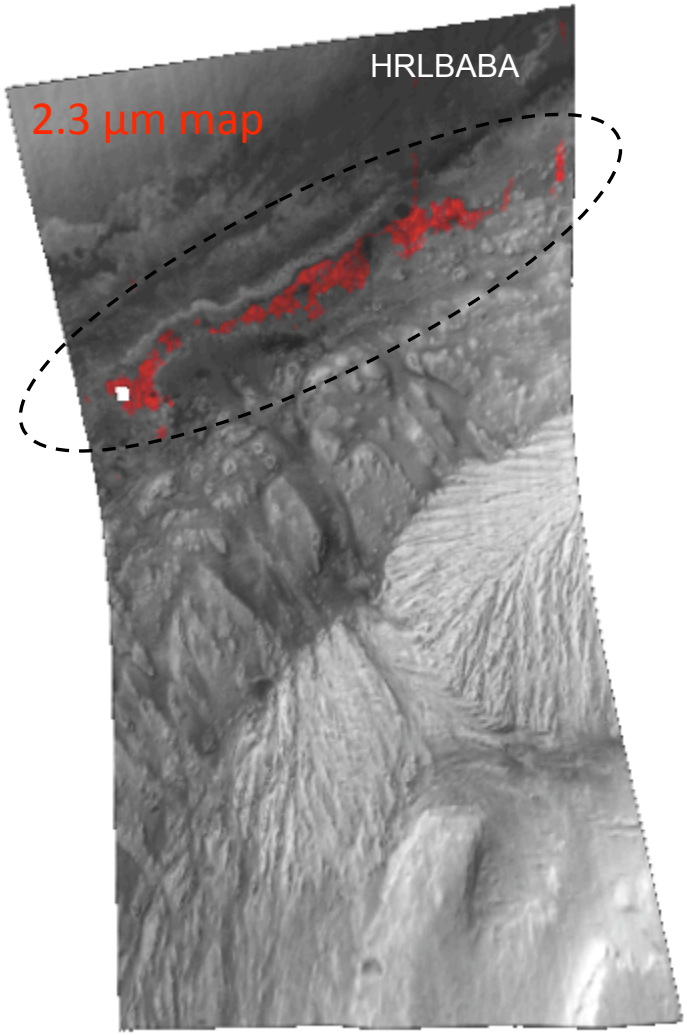


- **Anhydrous mafic minerals are the dominant phases (>50%)**
- **Clay content ~ 25-45%**
- **Mg-smectites,-micas**
- **Mixture of Saponite and Celadonite could indicate hydrothermal alteration of basalts (20-60°C) (Duplay et al. 1989)**

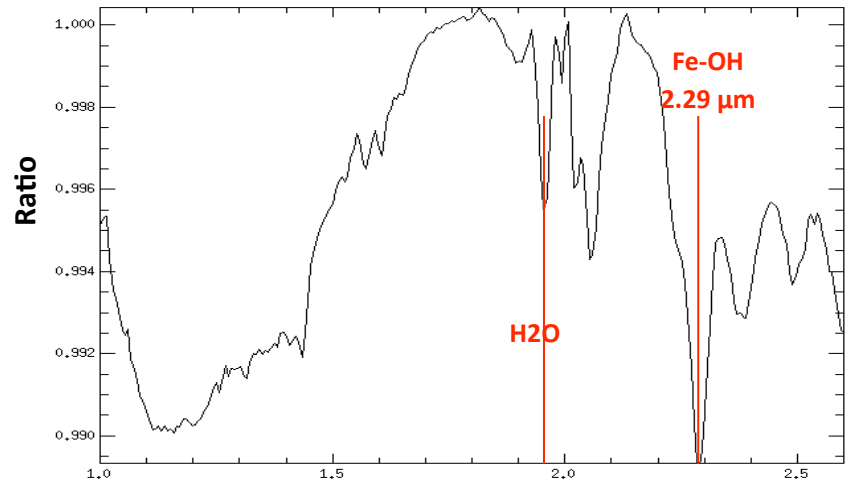
=> Support transport without transformation


Gale
Background: Fe-rich smectite
(nontronite) w/ Al^{3+} (Milliken et al. 2010)

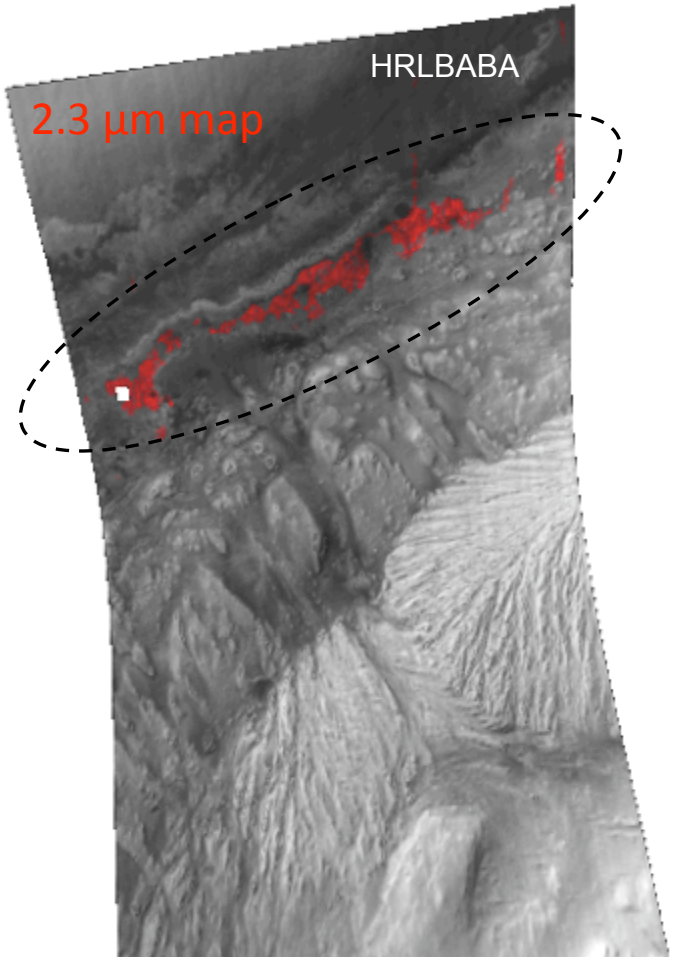
Gale : Clay-bearing materials

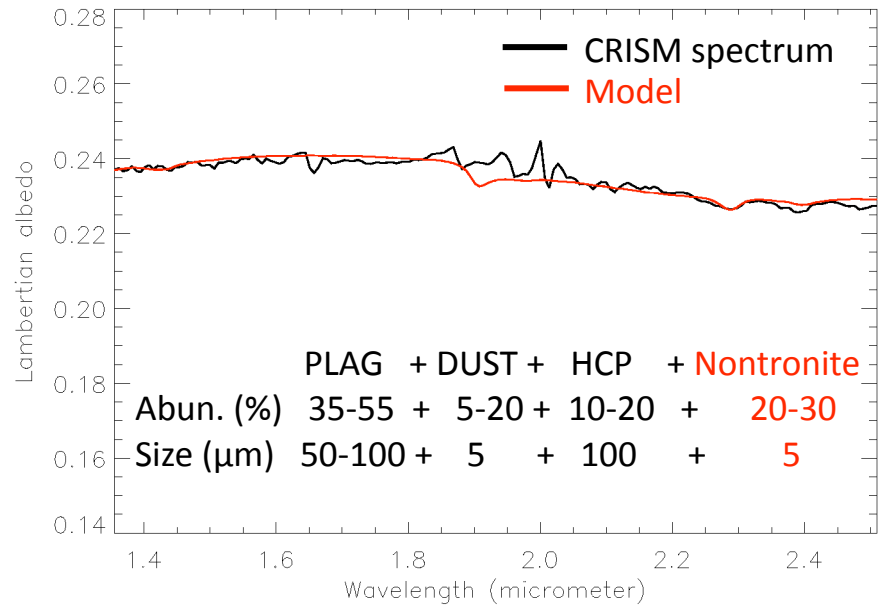


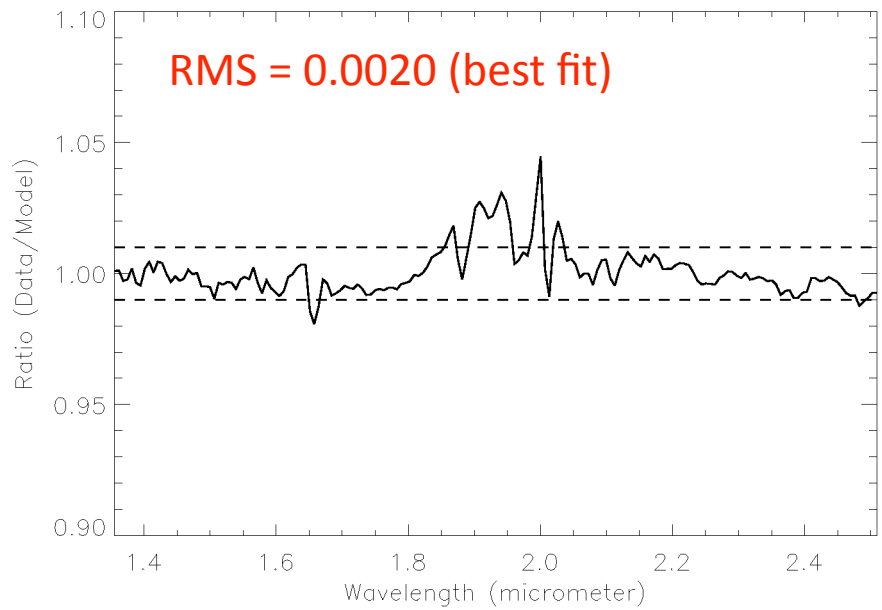
Average of 917 pixels
with strongest Fe/Mg-OH signatures



Gale : Clay-bearing materials







- **Anhydrous mafic minerals are the dominant phases (45-70%)**
- **Nontronite abundance ≤ 30%**
- **Pyroxene (HCP) required**

Eberswalde

- Clay abundance < 20%
- Mg-rich smectites
- Anhydrous mafic minerals

are the dominant phases (>80%)

Gale

- Clay abundance < 30%
- Fe-rich smectites
- Anhydrous mafic minerals

are the dominant phases (45-70%)

Holden

- Anhydrous mafic minerals

are the dominant phases (>50%)

- Clay abundance ~ 25-45%
- Mg-smectite + Micas

Mawrth

- Clay abundance ~ 30-70%
- Either Fe-rich smectites or

Al/Si-OH phases

- Fe/Mg-mica in Fe-rich clay unit
- Fe^{3+}-oxyhydroxide
- Anhydrous mafic minerals <30%
- Fe-OH vs Al/Si-OH units: two very

distinct compositions