Hydrothermal alteration and fluvial sites in the northwest Hellas region

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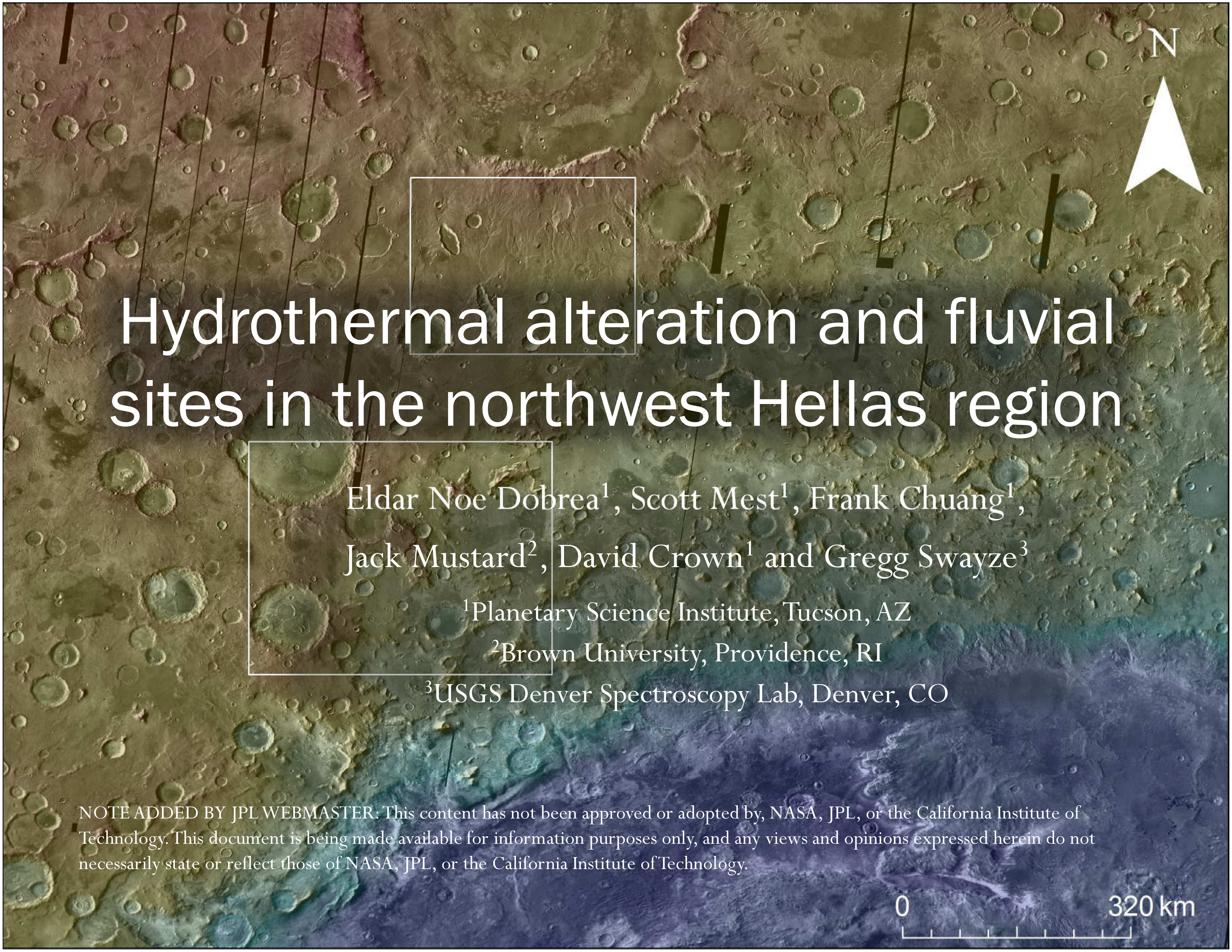


Mars 2020 science Objectives

A. Explore an astrobiologically relevant ancient environment on Mars;
B. Assess the biosignature preservation potential within the selected geological environment and search for potential biosignatures;
C. …progress towards the future return of … samples to Earth;
D. Provide an opportunity for contributed Human Exploration & Operations Mission Directorate or Space Technology Program participation.

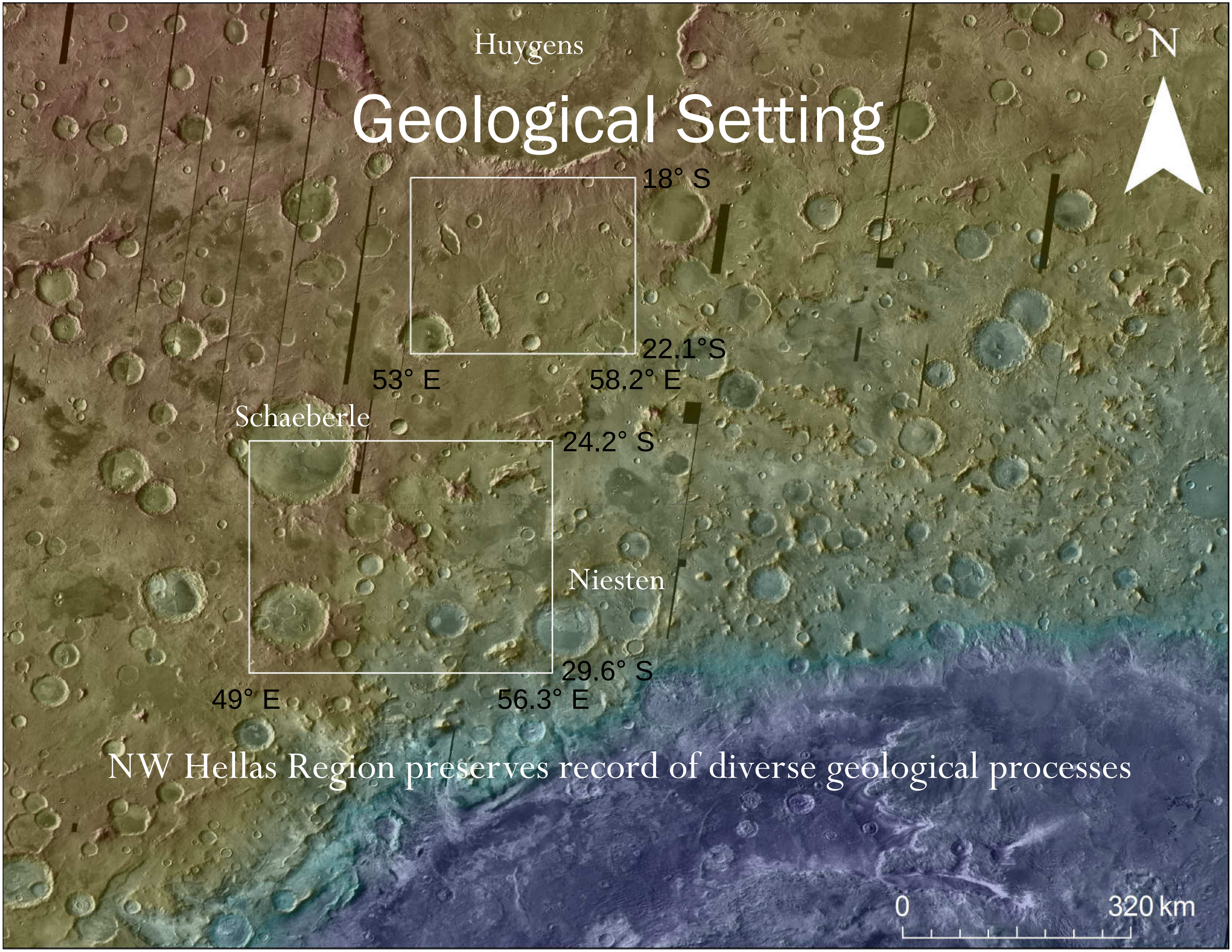
We can (partially) address objective A from orbit:

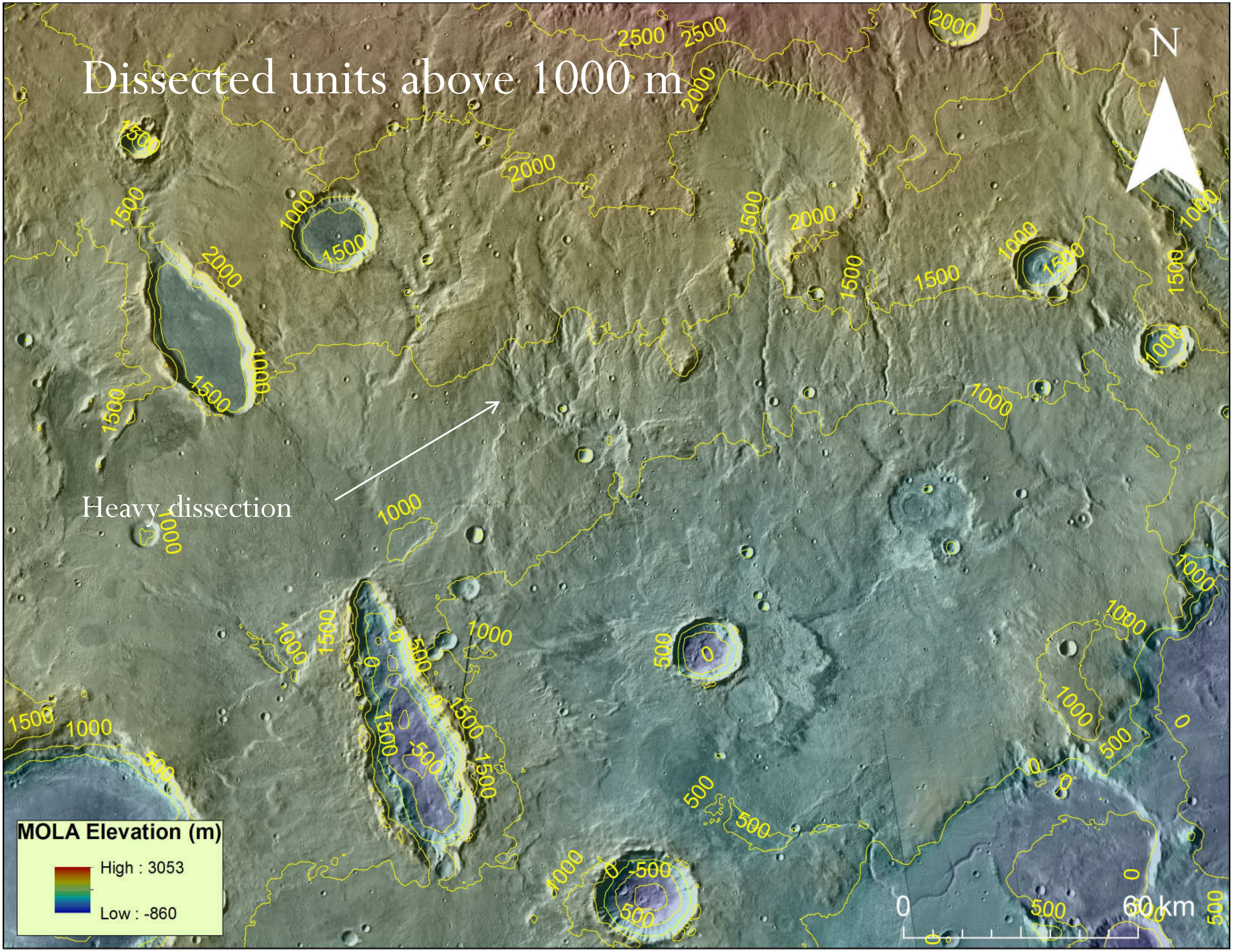
- ***Geological evidence for raw materials, energy, water, and favorable conditions***

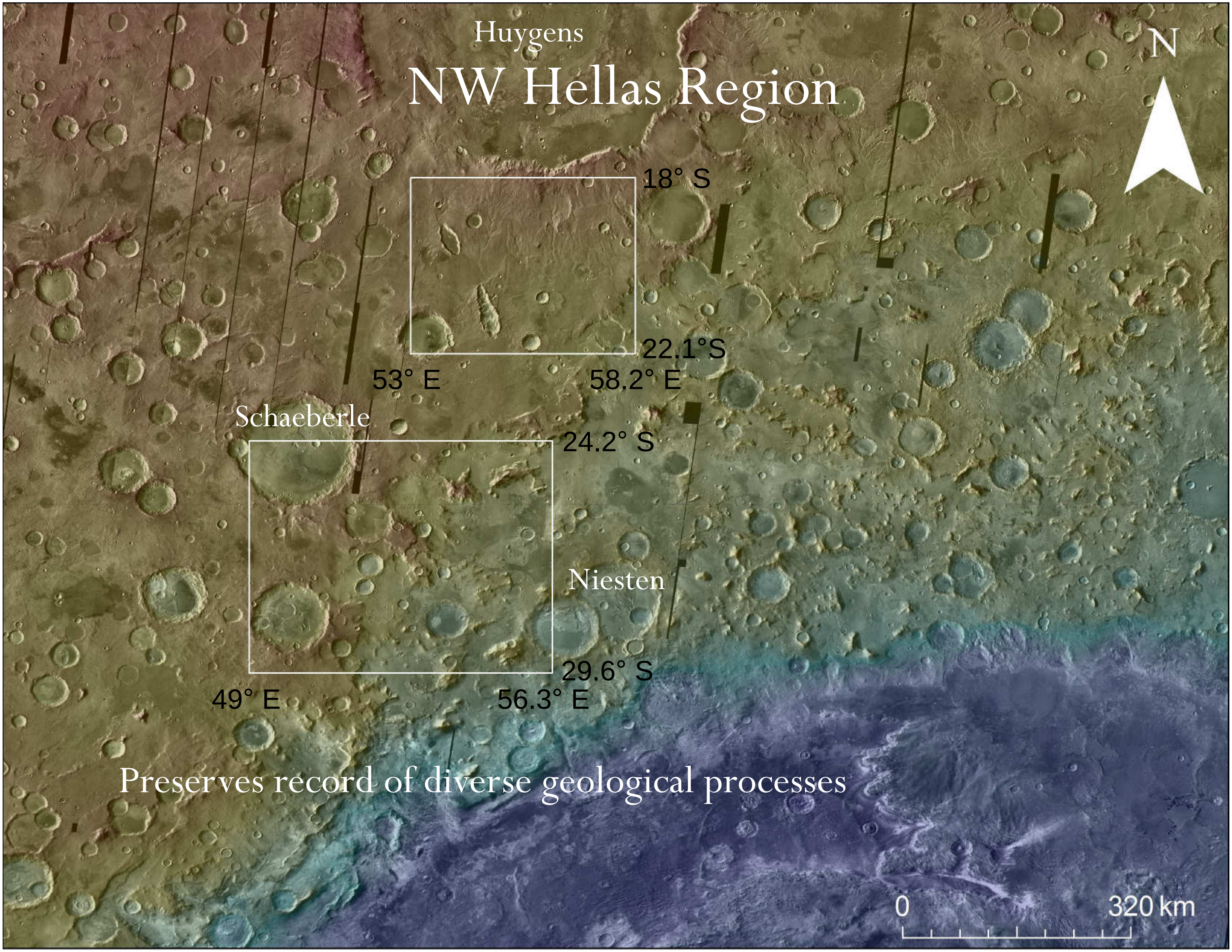
However, "Assessing the biosignature preservation potential within a formerly habitable environment and searching for potential biosignatures as called for in **Objective B** begins with the *in situ* measurements necessary to identify and characterize promising outcrops."

Hellas

- ~2300-km-diameter basin formed in Early Noachian by impact of ~250 km object (*e.g.*, Leonard and Tanaka, 2001)
- Energy deposited by impact should have produced elevated temperatures for a prolonged period (how long? how hot?)
- Subsequent modification by aeolian, fluvial, glacial/periglacial, volcanic processes gave rise to a diversity of geological environments and landforms inside Hellas and in the circum-Hellas region.
- Of particular interest to the question of *habitability* is the possibility that a variety of aqueous systems may have developed in the region after the Hellas impact.
  - Hydrothermal systems (*e.g.*, Newsom, 1980).
  - Marine/lacustrine (*e.g.*, Wilson *et al.*, 2007; Condit *et al.*, 2010 and references therein)
- Impact also thought to have triggered vent volcanism (*e.g.*, Williams *et al.*, 2009)
- Evidence for aqueous activity in the region during that time period:
  - Mineralogical: phyllosilicates in Tyrrhena Terra (Pelkey *et al.*, 2007; Loizeau *et al.*, 2009) and around Hellas (*e.g.*, Ansan *et al.*, 2011; Crown *et al.*, LPSC 2011).
  - Morphological: heavy dissection of the region, layered intercrater deposits


Huygens
Geological Setting
N
18° S
22.1°S
53° E
58.2° E
Schaeberle
24.2° S
Niesten
29.6° S
49° E
56.3° E
NW Hellas Region preserves record of diverse geological processes
0
320 km


Dissected units above 1000 m
Heavy dissection
N
MOLA Elevation (m)
High : 3053
Low : -860
0
60 km
2500
2000
1500
1000
500
0
-500



Huygens
NW Hellas Region
N
18° S
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Preserves record of diverse geological processes
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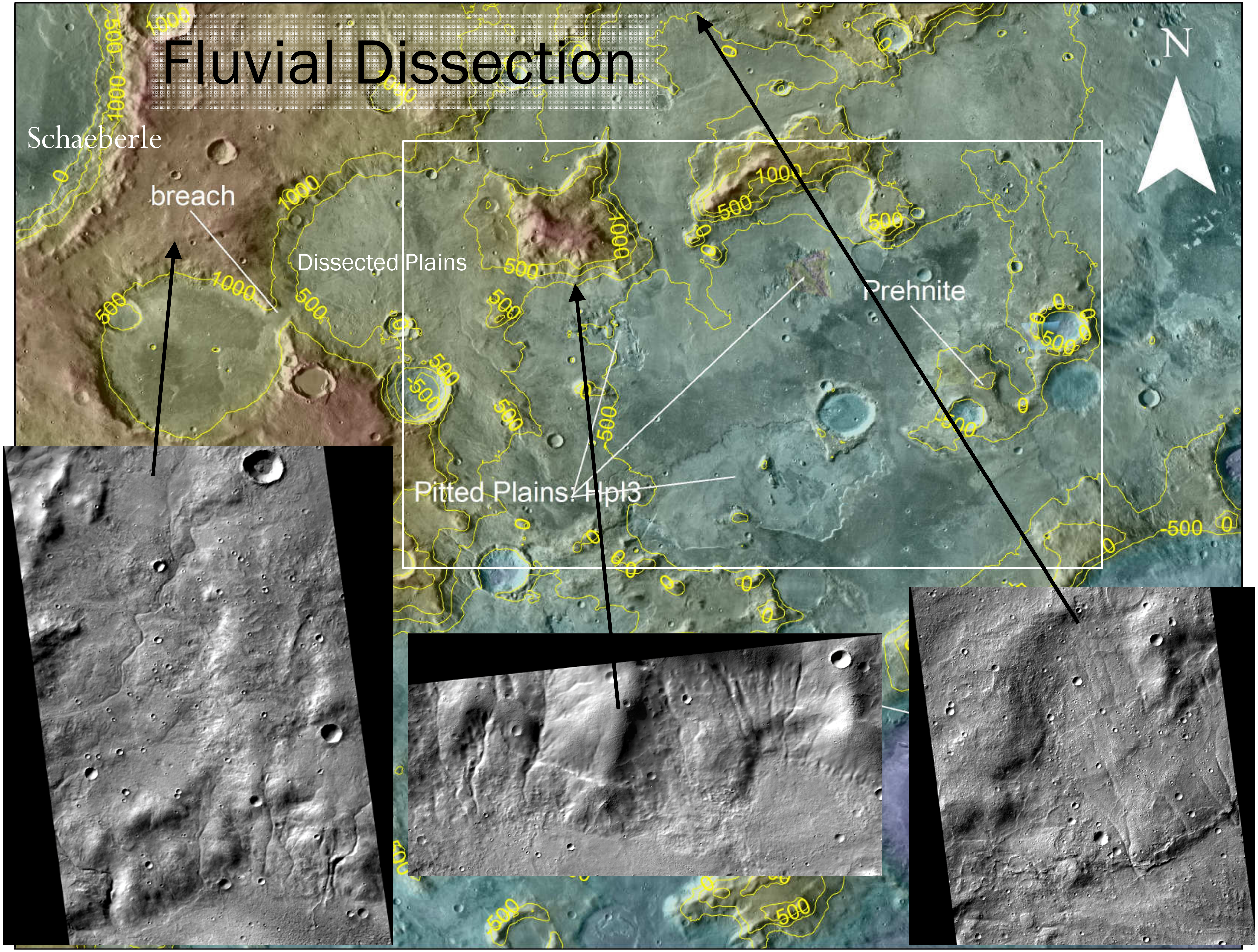
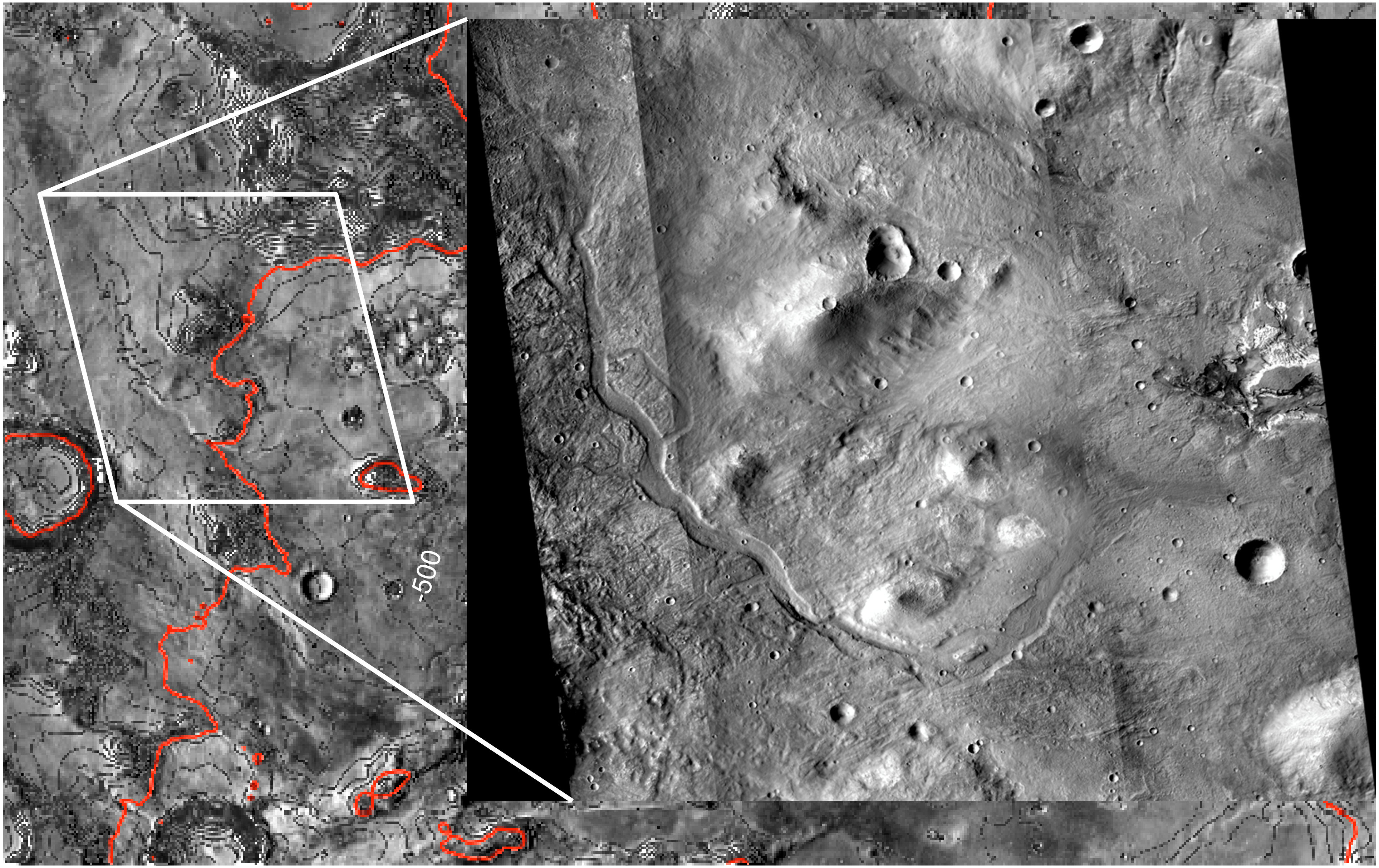
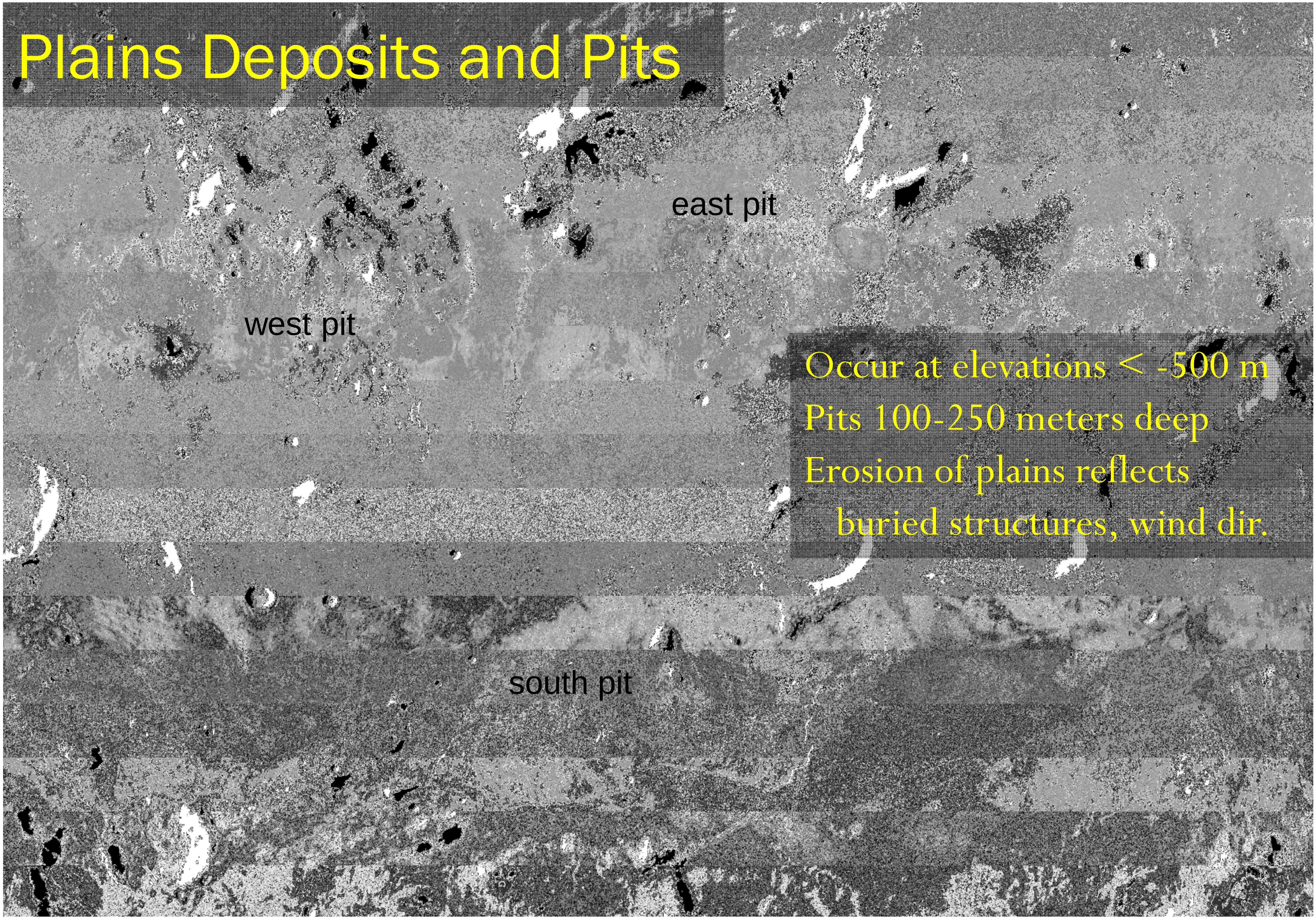
320 km


Fluvial Dissection
N
Schaeberle
breach
Dissected Plains
Prehnite
Pitted Plains: Hpl3

Fluvial Dissection



Plains Deposits and Pits

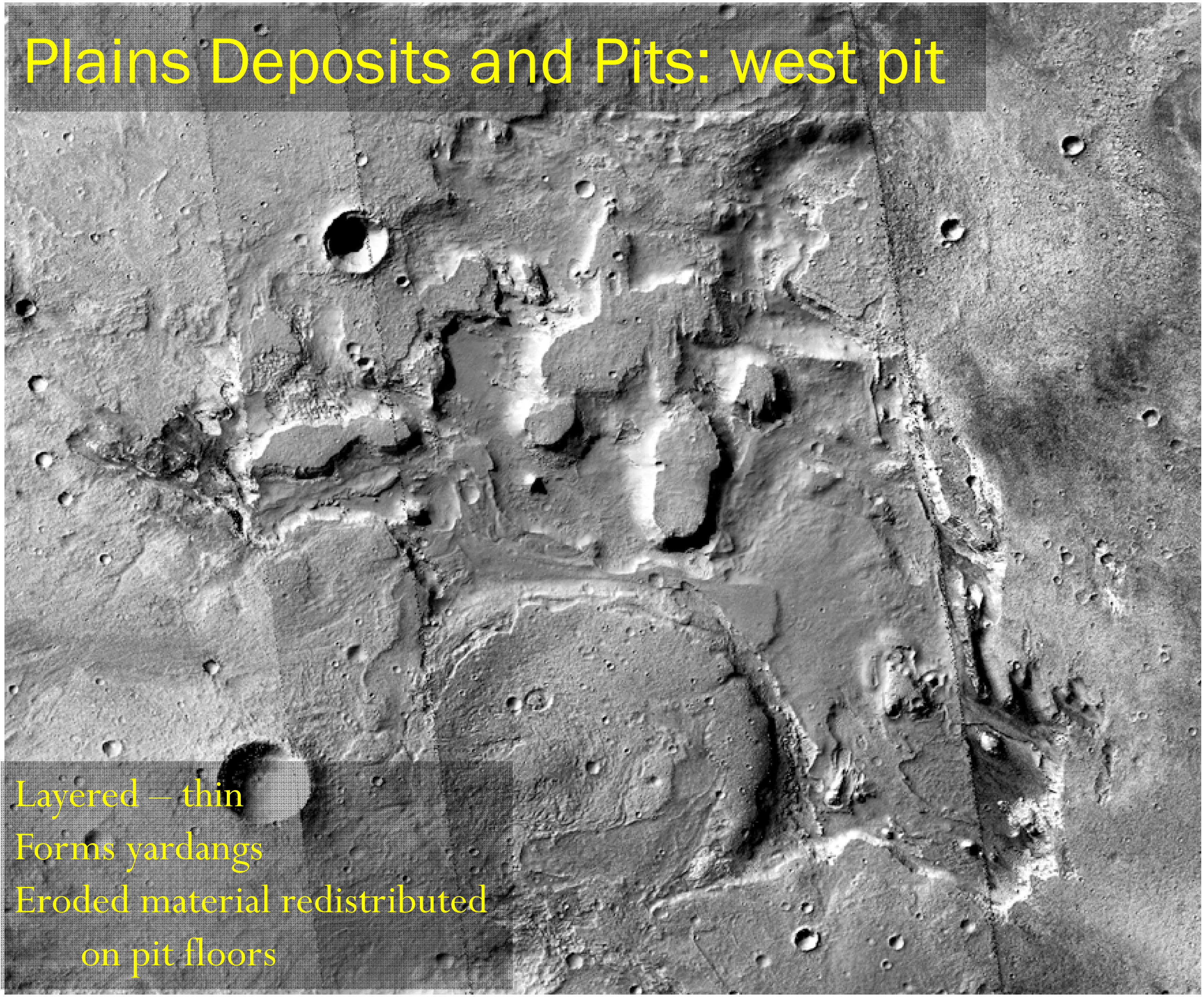


Occur at elevations < -500 m

Pits 100-250 meters deep

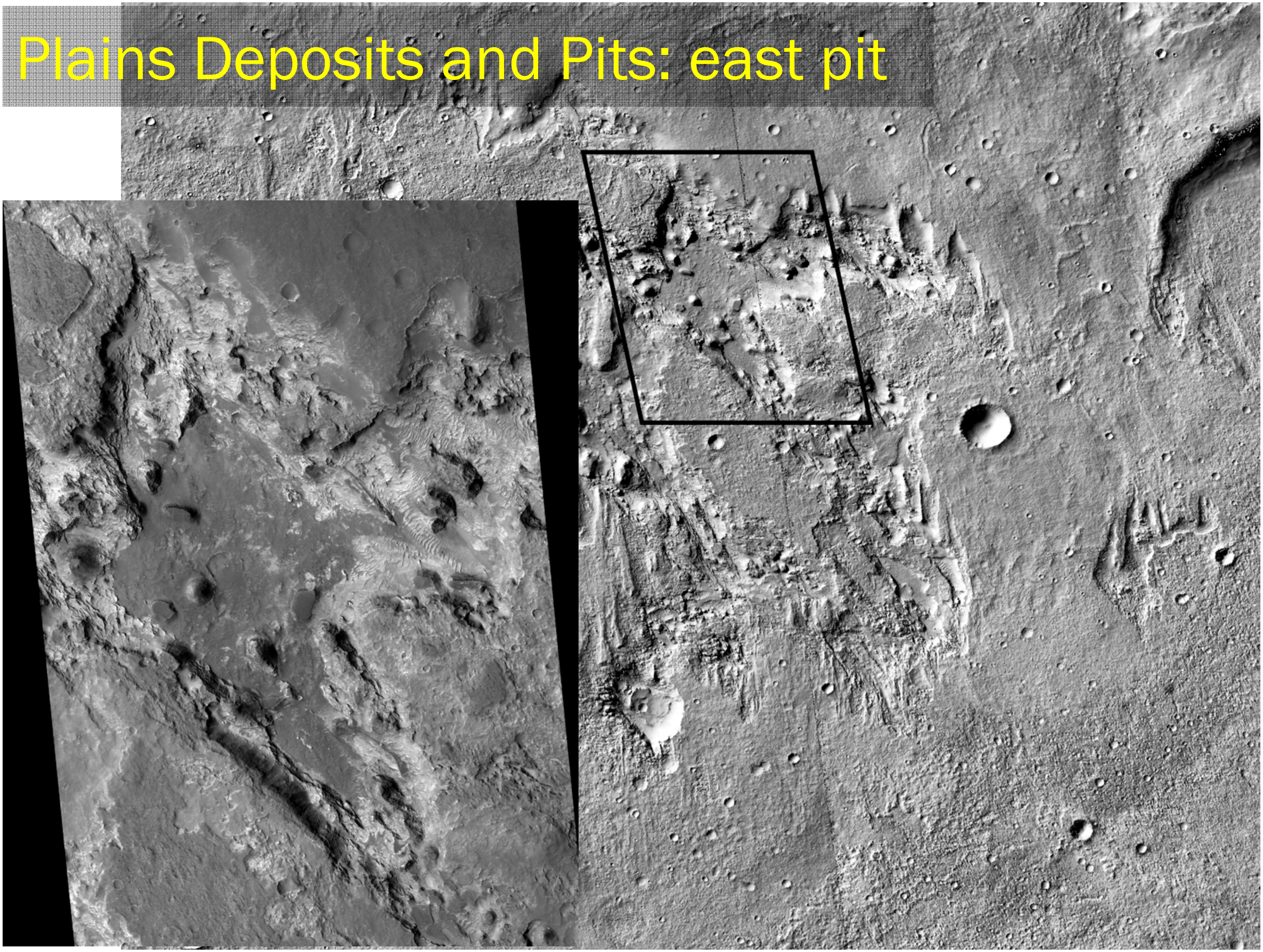
Erosion of plains reflects buried structures, wind dir.

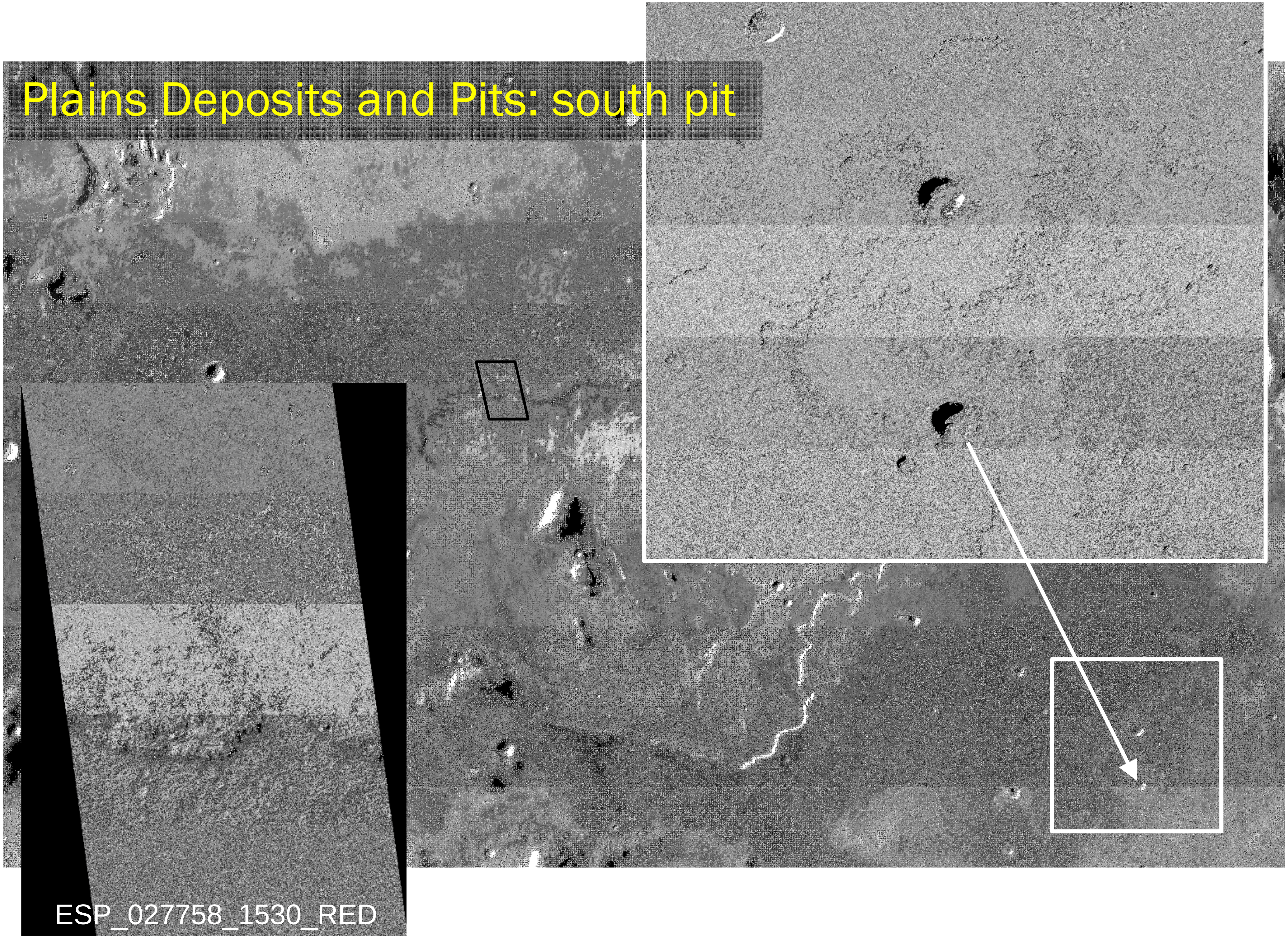
Plains Deposits and Pits: west pit

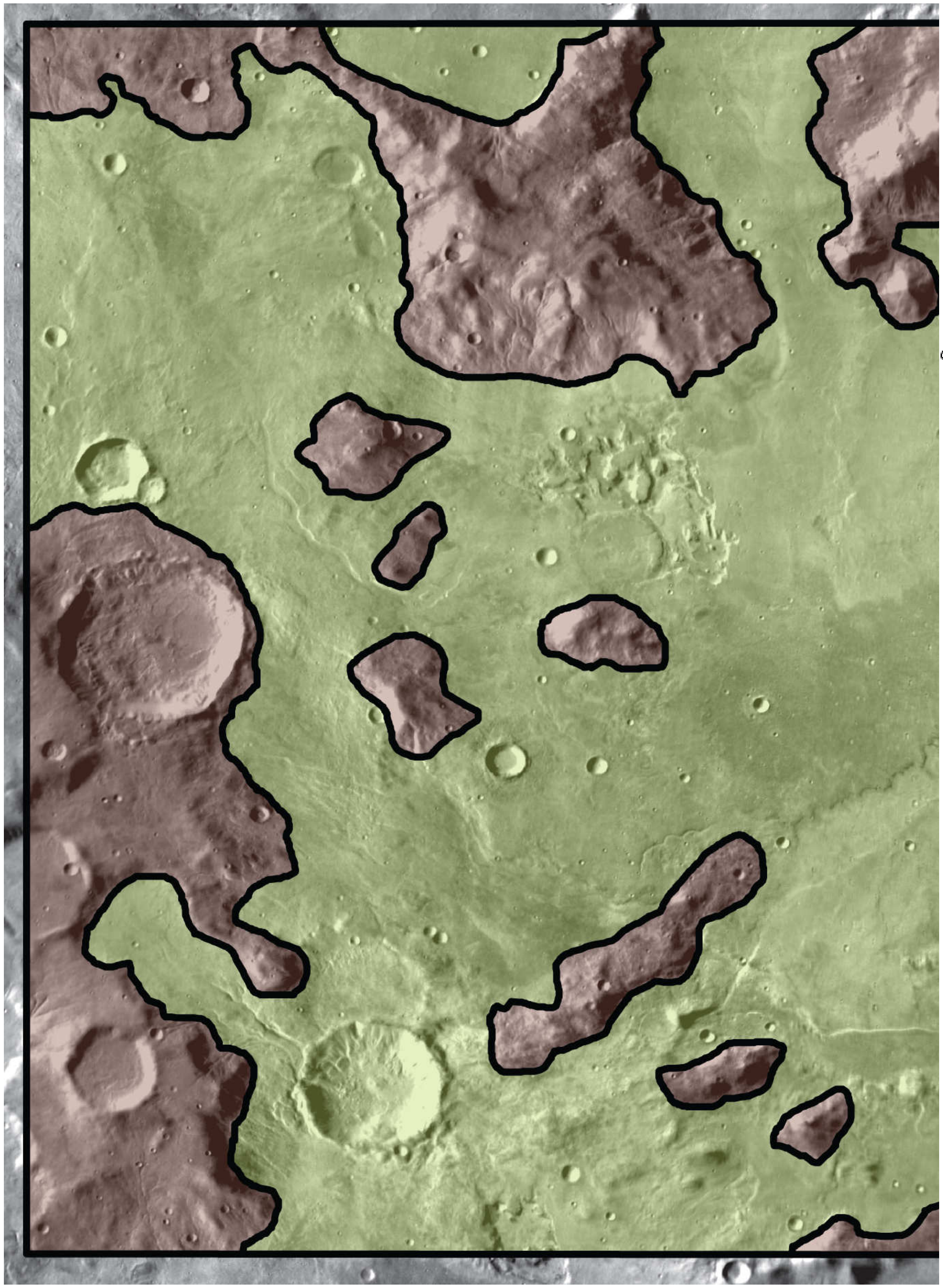


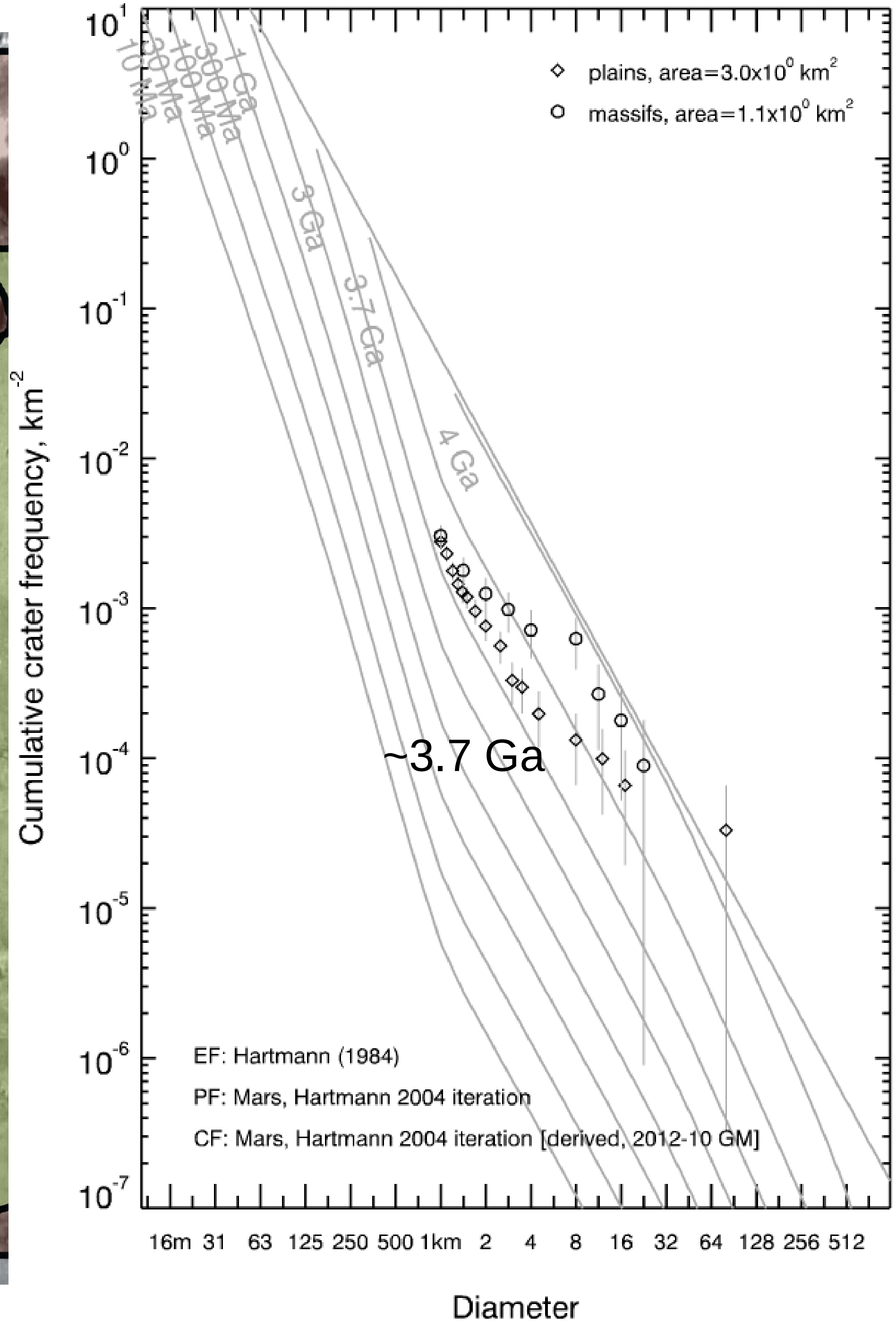
Layered – thin
Forms yardangs
Eroded material redistributed
on pit floors

Plains Deposits and Pits: east pit




Plains Deposits and Pits: south pit
ESP_027758_1530_RED





plains, area=3.0x10^0 km^2
massifs, area=1.1x10^0 km^2
10 Ma
30 Ma
100 Ma
300 Ma
1 Ga
3 Ga
3.7 Ga
4 Ga
~3.7 Ga
Cumulative crater frequency, km^-2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
16m 31 63 125 250 500 1km 2 4 8 16 32 64 128 256 512
Diameter
EF: Hartmann (1984)
PF: Mars, Hartmann 2004 iteration
CF: Mars, Hartmann 2004 iteration [derived, 2012-10 GM]

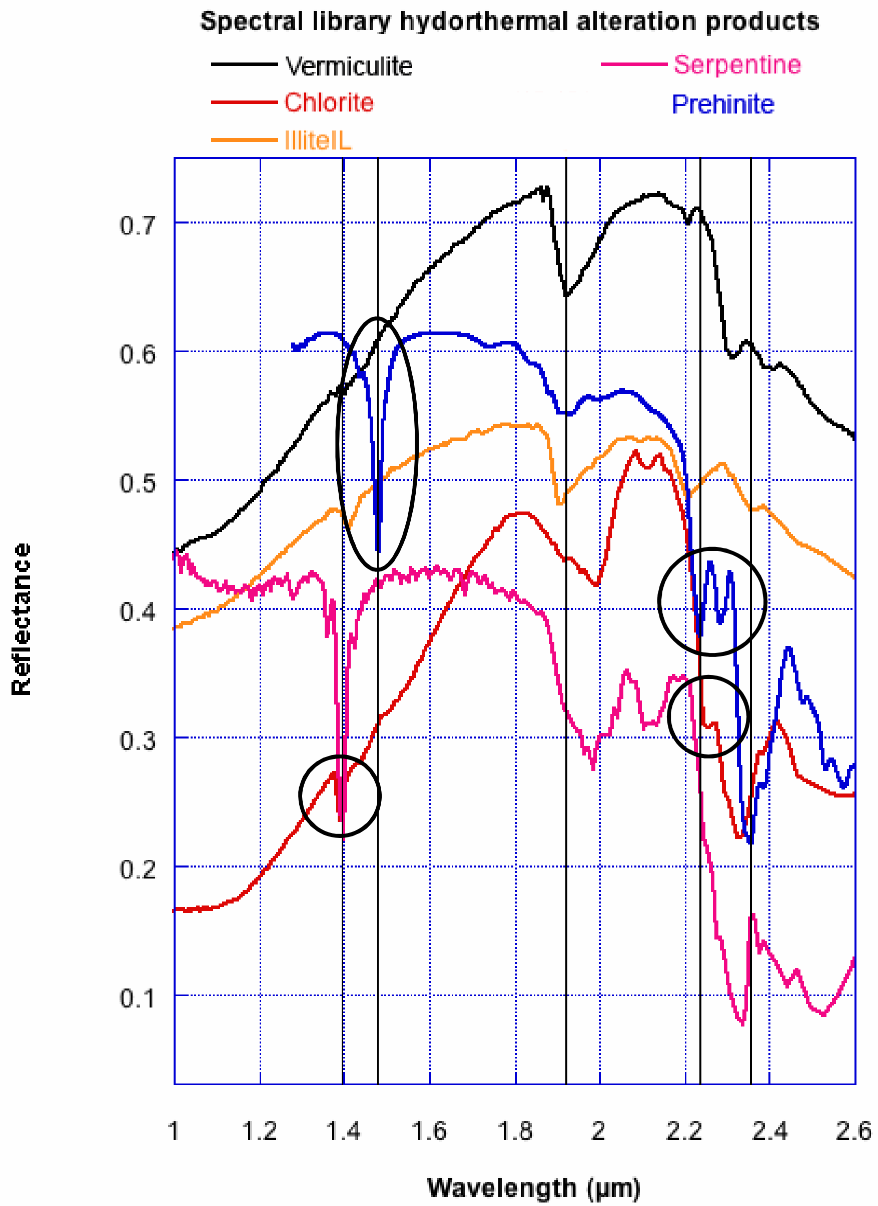
Primary mineral or rock	**Reported alteration minerals**	**Hydrothermal Alteration environment**	**Reference**
Basalt	Kaolinite, smectite, jarosite, alunite	Acidic pH	Morris *et al*., 2001; Morris *et al*., 2003
Pyroxene-amphibole andesite	Cristobalite, alunite, pyrite, kaolinite, goethite, hematite	Acidic pH	Isobe and Korenaga, 2010
Basalt	Mg-carbonate, talc	Neutral to basic pH	Brown *et al*., 2010
Wollastonite	Mg-montmorillonite, talc, mixed layer stevensite/chlorite	Neutral to basic pH groundwater	DeRudder and Beck, 1963; Whitney and Eberl, 1982
Granite, K-feldspar	Kaolinite, muscovite, biotite, halloysite	-	Thomas and Walter, 2004;
Impact melt rock	Fe-chlorite, Fe smectite, silica, K feldspar, zeolite	-	Newsom, 1980; Allen *et al*., 1982
Olivine	**serpentine**	-	Normand *et al*., 2002
Basalt, grabbro	**Prehnite**, quartz, calcite, epidote	Also in low-grade metamorphism	Freedman *et al*., 2009

Potential Hydrothermal/low grade metamorphic alteration products on Mars

- Prehnite: Nili Fossae (Ehlman *et al.*, 2009), Argyre rim (Buczkowski *et al.*, 2010), NW Hellas (Crown *et al.*, LPSC 2011)
- Serpentine: Nili Fossae (Ehlman *et al.*, 2009)
- Chlorite: Nili Fossae (*e.g.*, Ehlman *et al.*, 2009; Poulet *et al.*, 2005); NW Hellas (Crown *et al.*, LPSC 2011)
- Hydrated silica: Nili Fossae (Skok *et al.*, this session)

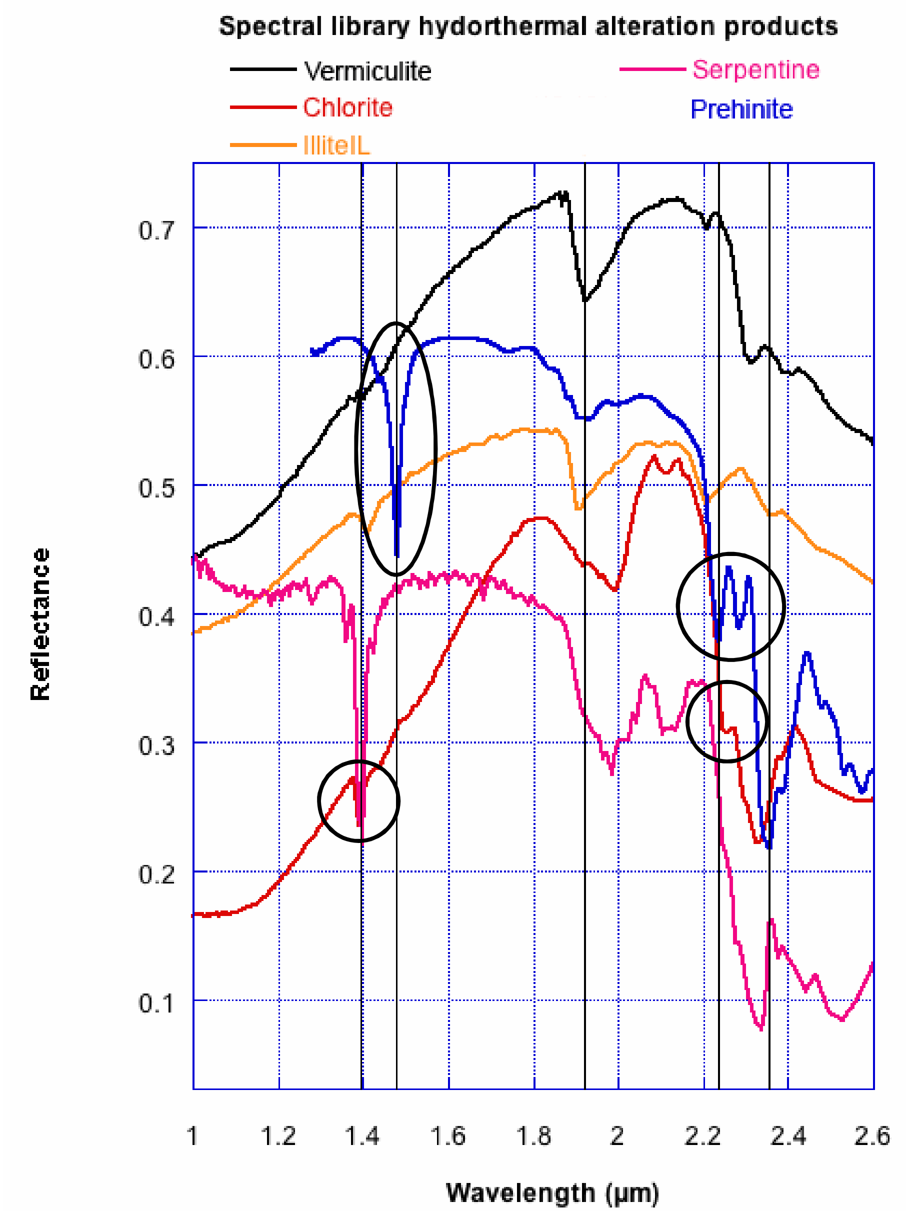
- Of particular interest is Prehnite ($Ca_2Al_2Si_3O_{10}(OH)_2$)
  - Metamorphic grade transitional between zeolite and greenschist facies
  - Forms under specific conditions: 2-7 kbar, 200 – 350°C, and XCO2< 0.004 (Blatt and Tracy, 1995)
  - Typically associated with chlorite and pumpellyite (*e.g.*, Frey and Robinson, 1999).

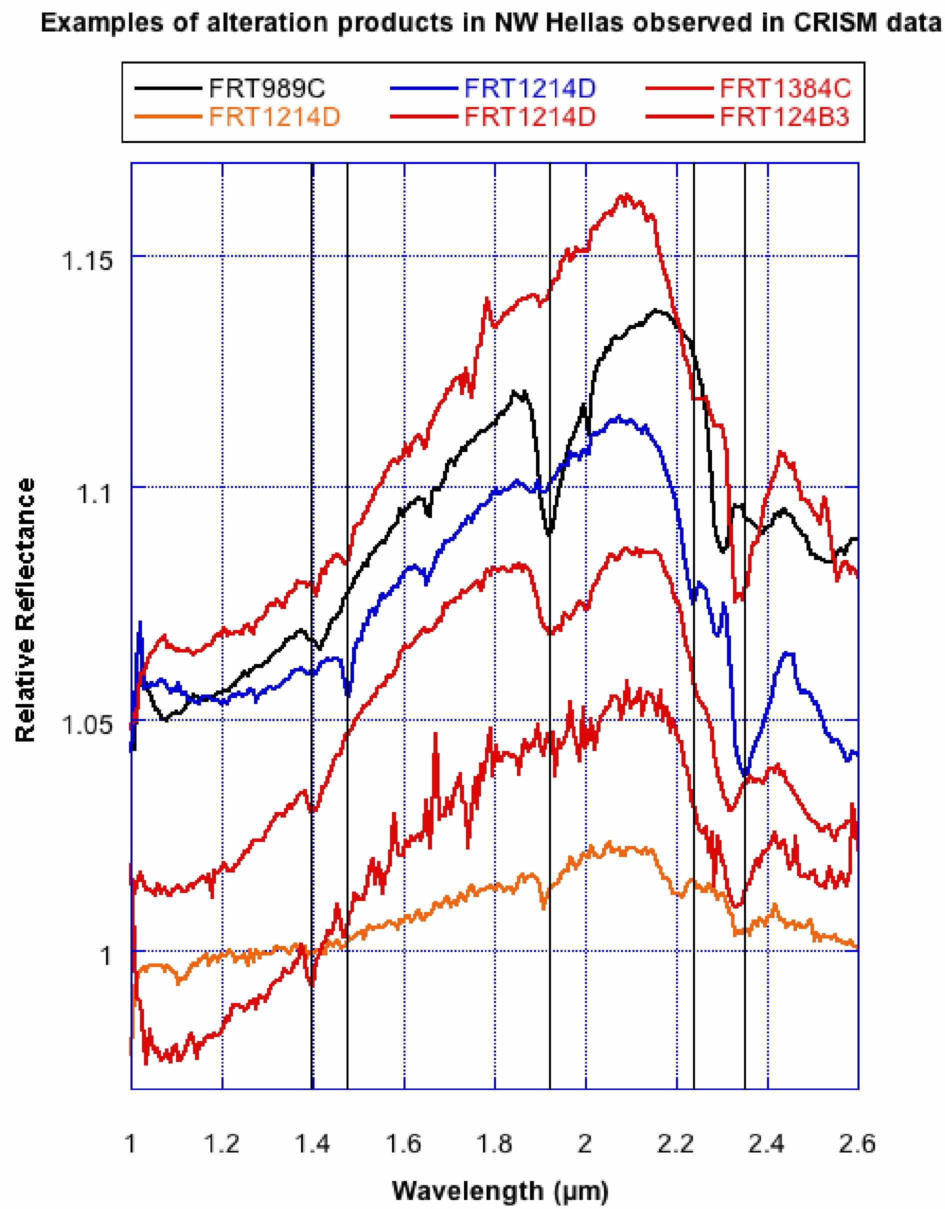
Results

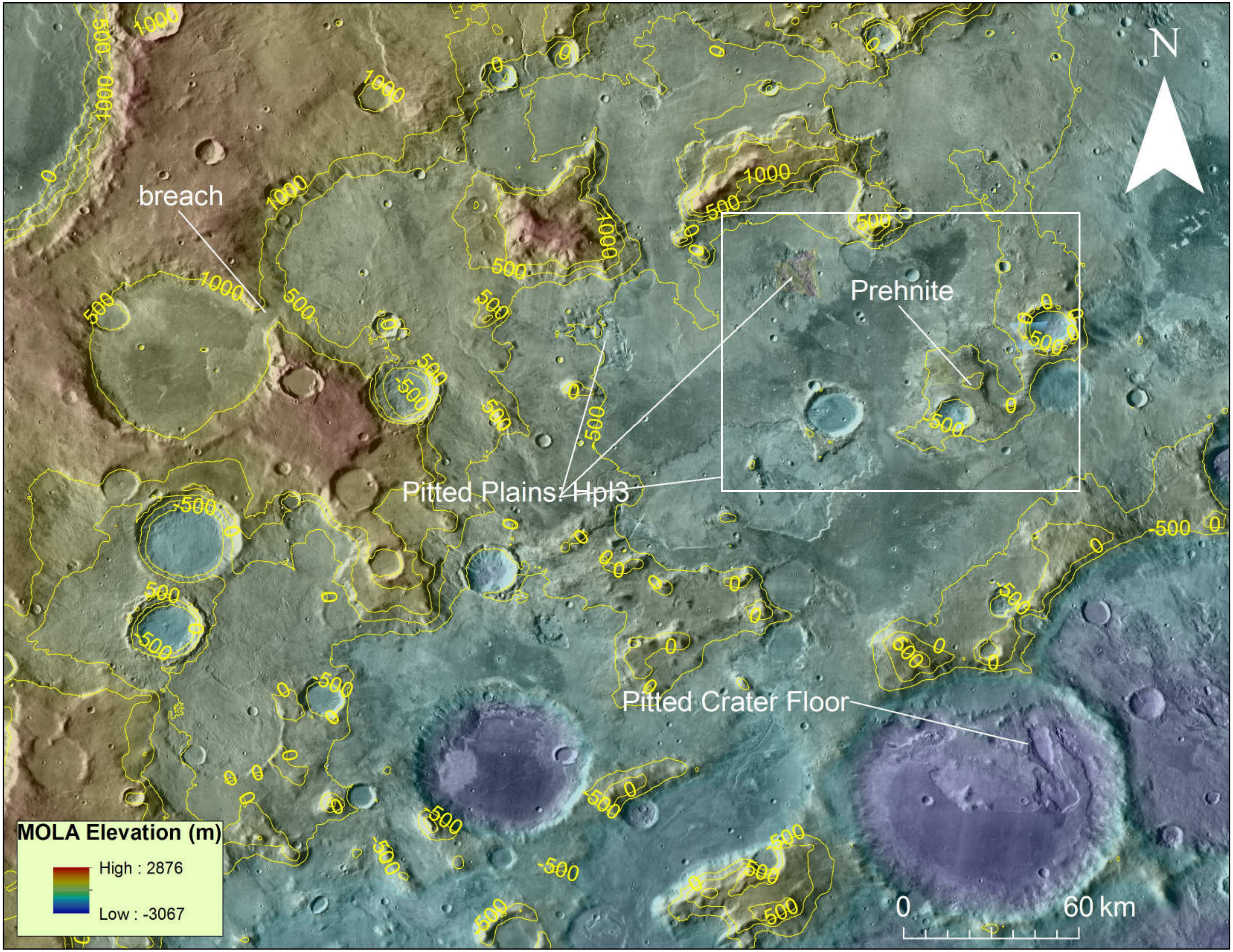


- Prehnite:
  absorptions at 2.35-2.36, 1.48, 2.23, 2.28, 2.57 µm
- Chlorite:
  absorptions at 1.40, shoulder at 2.25-2.26, 2.33-2.35
- Serpentine: absorptions at 1.40, 2.32-2.33, 2.50-2.51
- "Vermiculite" – mixed layer vermiculite/biotite.
  Can also be other mixed layer smectite/chlorite: absorption at 1.92, steep drop-off at 2.30-2.31
- Illite/muscovite -
  absorptions at 2.2, 2.35

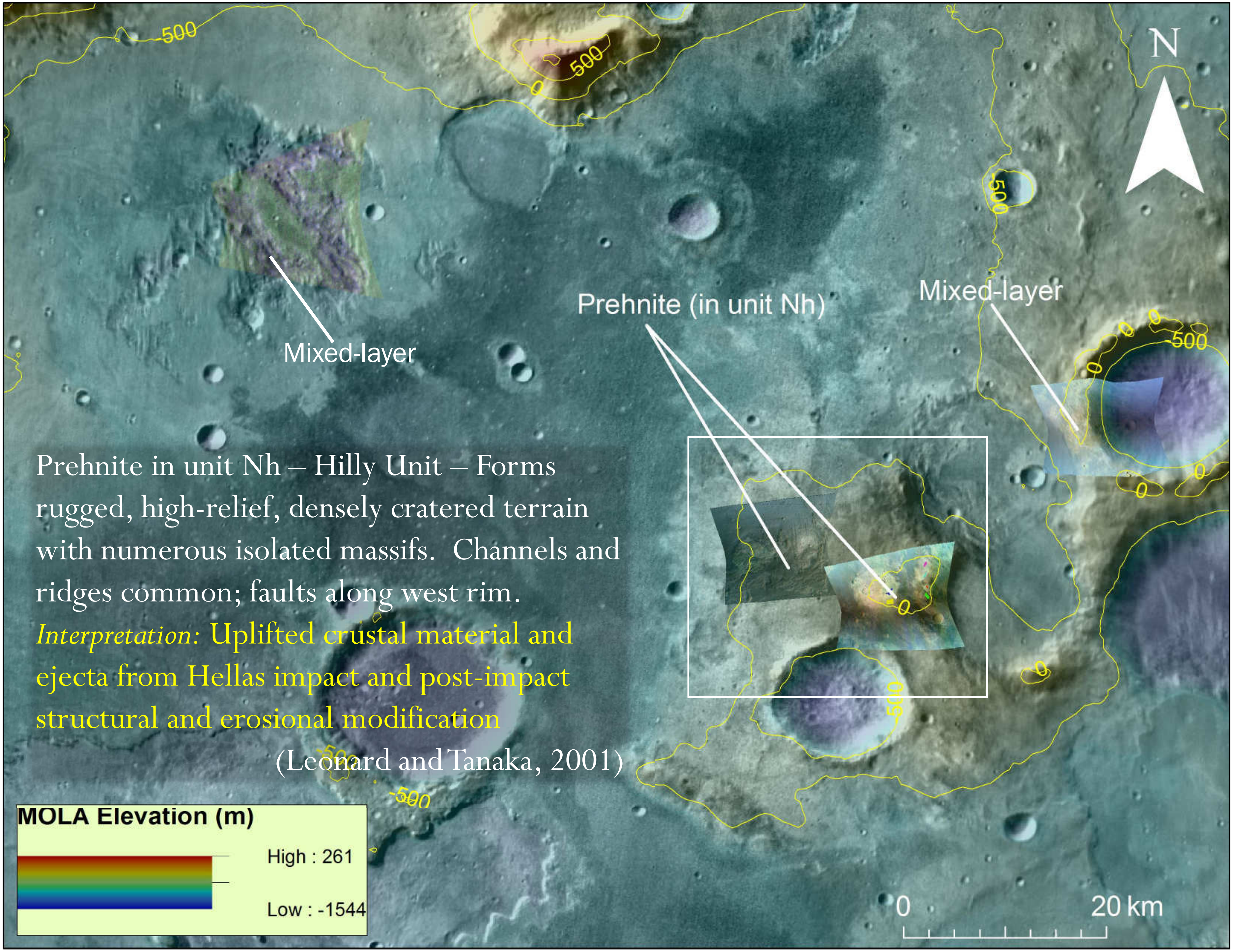
Results


Spectral library hydorthermal alteration products
Vermiculite
Chlorite
IlliteIL
Serpentine
Prehinite
Reflectance
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
Wavelength (µm)

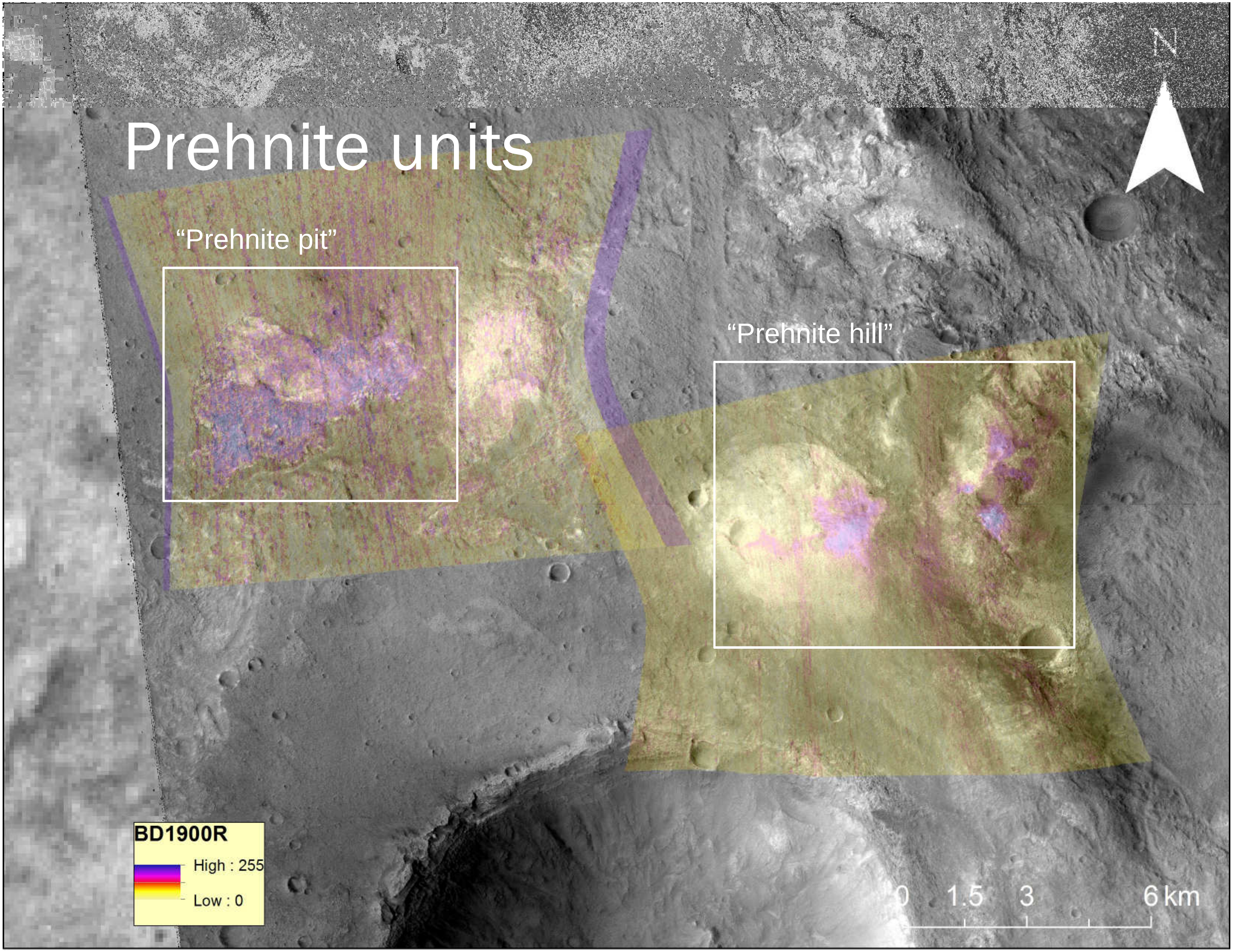

Examples of alteration products in NW Hellas observed in CRISM data
FRT989C
FRT1214D
FRT1214D
FRT1214D
FRT1384C
FRT124B3
Relative Reflectance
1.15
1.1
1.05
1
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
Wavelength (µm)



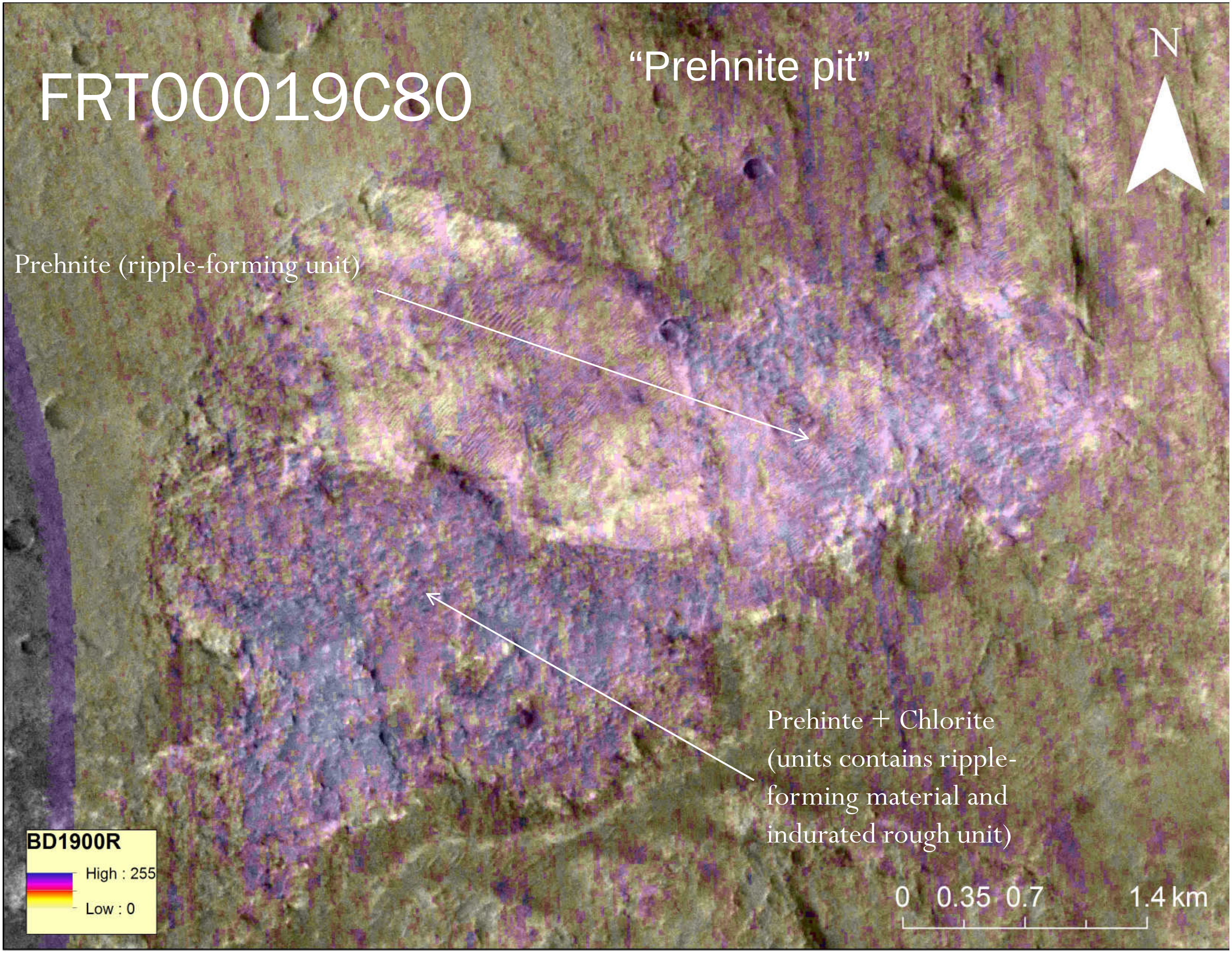
N
breach
Prehnite
Pitted Plains: Hpl3
Pitted Crater Floor
MOLA Elevation (m)
High : 2876
Low : -3067
0
60 km



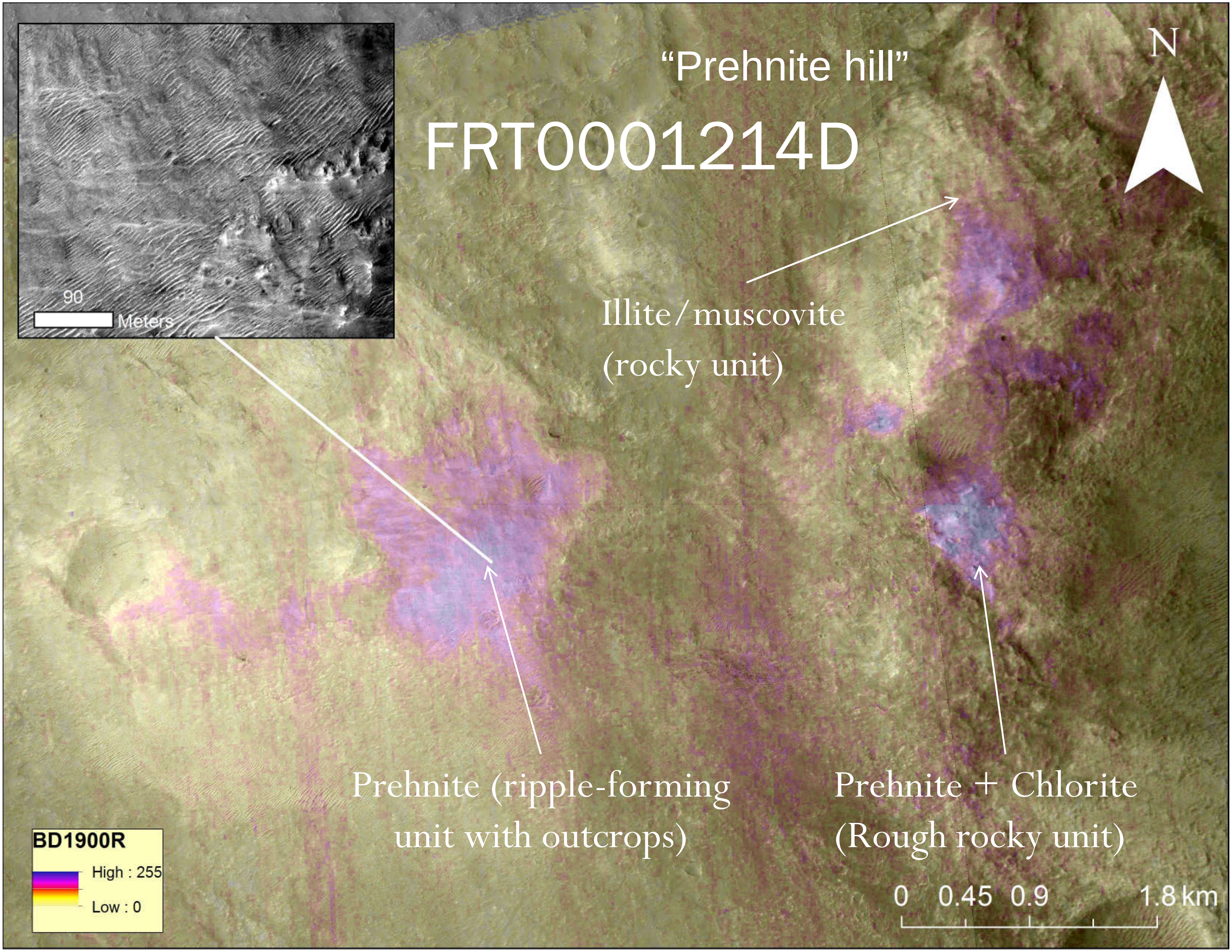
N
-500
500
0
Mixed-layer
Prehnite (in unit Nh)
Mixed-layer
-500
Prehnite in unit Nh – Hilly Unit – Forms rugged, high-relief, densely cratered terrain with numerous isolated massifs. Channels and ridges common; faults along west rim.
Interpretation: Uplifted crustal material and ejecta from Hellas impact and post-impact structural and erosional modification
(Leonard and Tanaka, 2001)
MOLA Elevation (m)
High : 261
Low : -1544
0
20 km



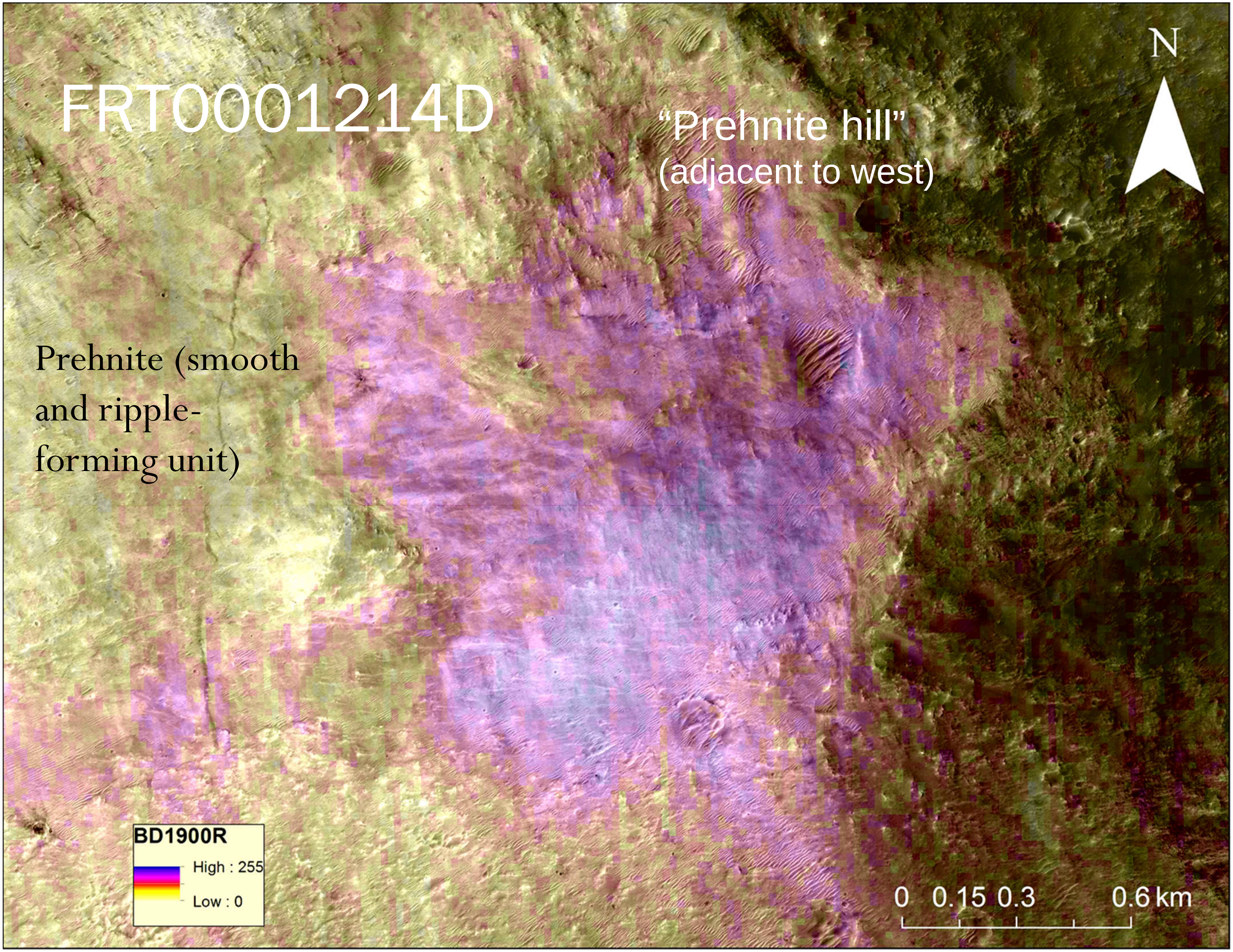
Prehnite units
N
"Prehnite pit"
"Prehnite hill"
BD1900R
High : 255
Low : 0
0 1.5 3 6 km

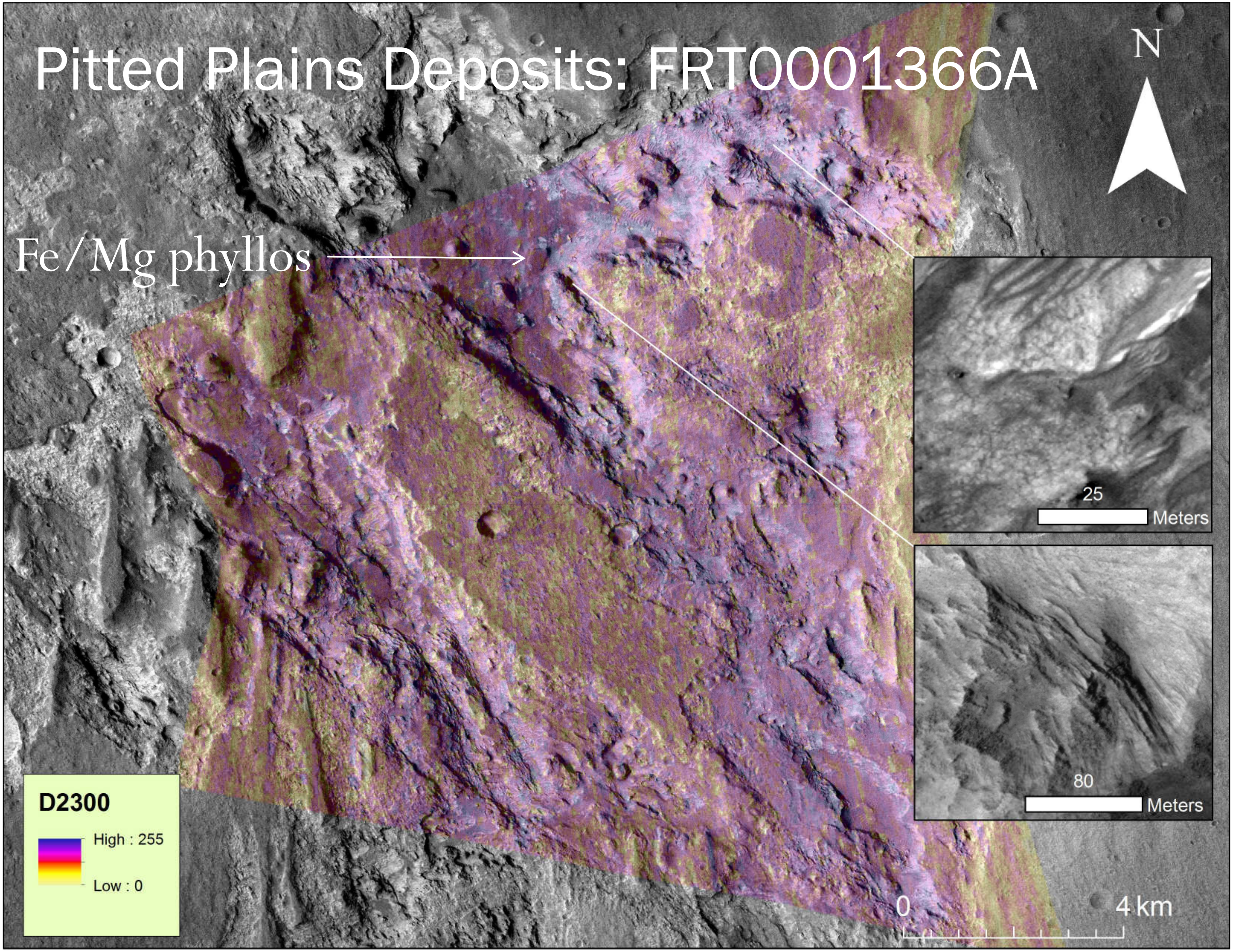


FRT00019C80
"Prehnite pit"
N
Prehnite (ripple-forming unit)
Prehinte + Chlorite
(units contains ripple-
forming material and
indurated rough unit)
BD1900R
High : 255
Low : 0
0 0.35 0.7 1.4 km



90
Meters
"Prehnite hill"
FRT0001214D
N
Illite/muscovite
(rocky unit)
Prehnite (ripple-forming
unit with outcrops)
Prehnite + Chlorite
(Rough rocky unit)
BD1900R
High : 255
Low : 0
0 0.45 0.9 1.8 km


FRT0001214D
"Prehnite hill"
(adjacent to west)
N
Prehnite (smooth and ripple-forming unit)
BD1900R
High : 255
Low : 0
0 0.15 0.3 0.6 km



Pitted Plains Deposits: FRT0001366A
N
Fe/Mg phyllos
25
Meters
80
Meters
D2300
High : 255
Low : 0
0
4 km

Geological inferences

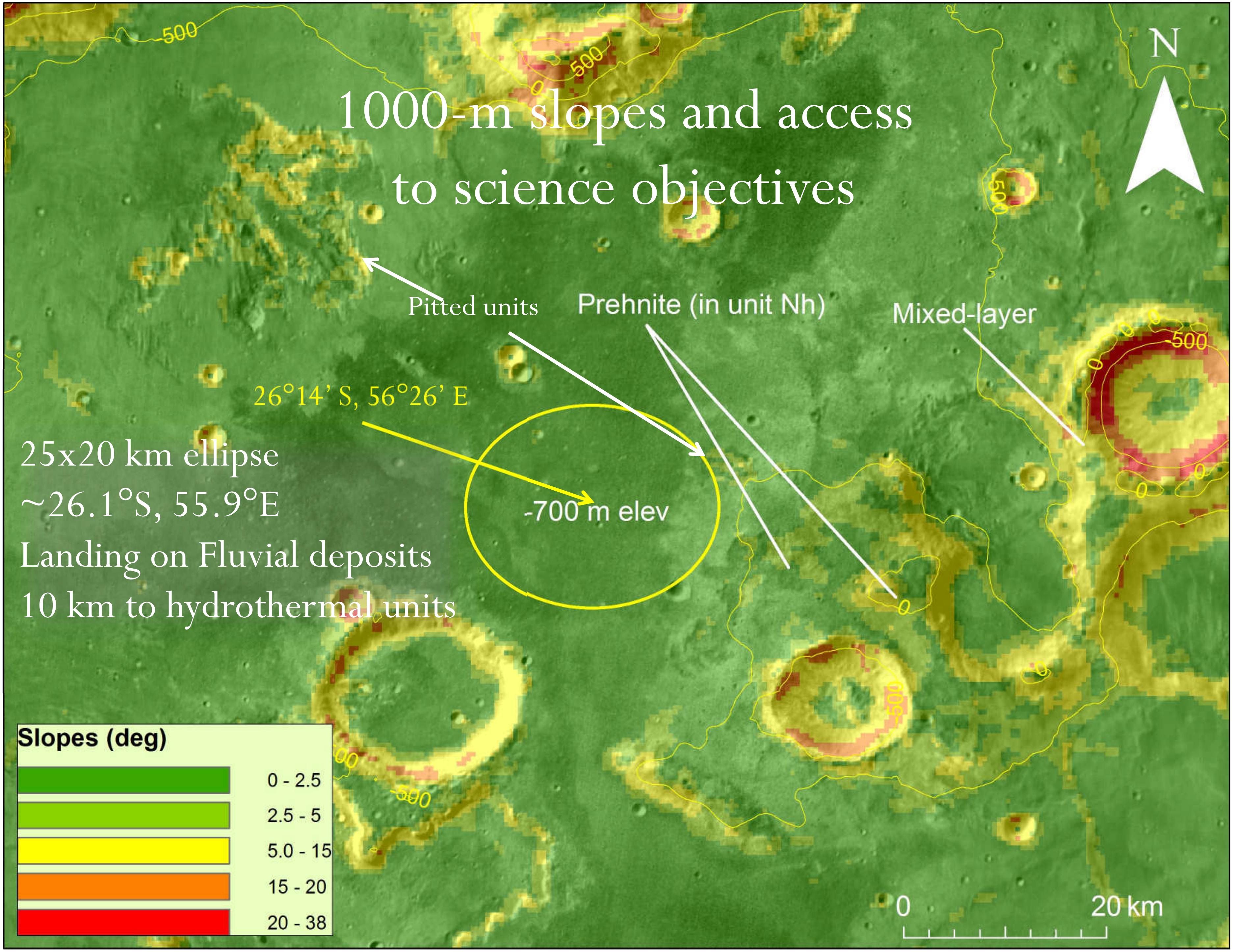
- We observe a variety of alteration products including prehnite, chlorite, illite/muscovite, mixed-layer S/C or B/V, saponite.
- Prehnite+chlorite+illite/muscovite in close spatial association strongly suggestive of hydrothermal activity.
  - observed in Hilly Unit - interpreted to be uplifted crustal material and ejecta from Hellas impact and post-impact structural and erosional modifications.
- Subsequent erosion of Noachian plains material resulted in dissection and redeposition to form smooth embaying plains and intracrater units 200-400 m in thickness.
- Fe/Mg phyllosilicates identified within pit walls in plains units.

Scientific framework at NW Hellas

- Astrobiology
  - Hydrothermal system provides all components needed for life. Whereas temperatures may be too high at prehnite-forming location, surrounding areas will be lower in temperature (this is true for hydrothermal systems on Earth – e.g. ocean vents).
  - Fluvial deposits contain material derived from highlands crust.
  - Fe/Mg phyllosilicates in fluvial materials → good for sequestration of organics
  - Hydrothermal system and fluvial deposits both present low-energy environments, → good for preservation

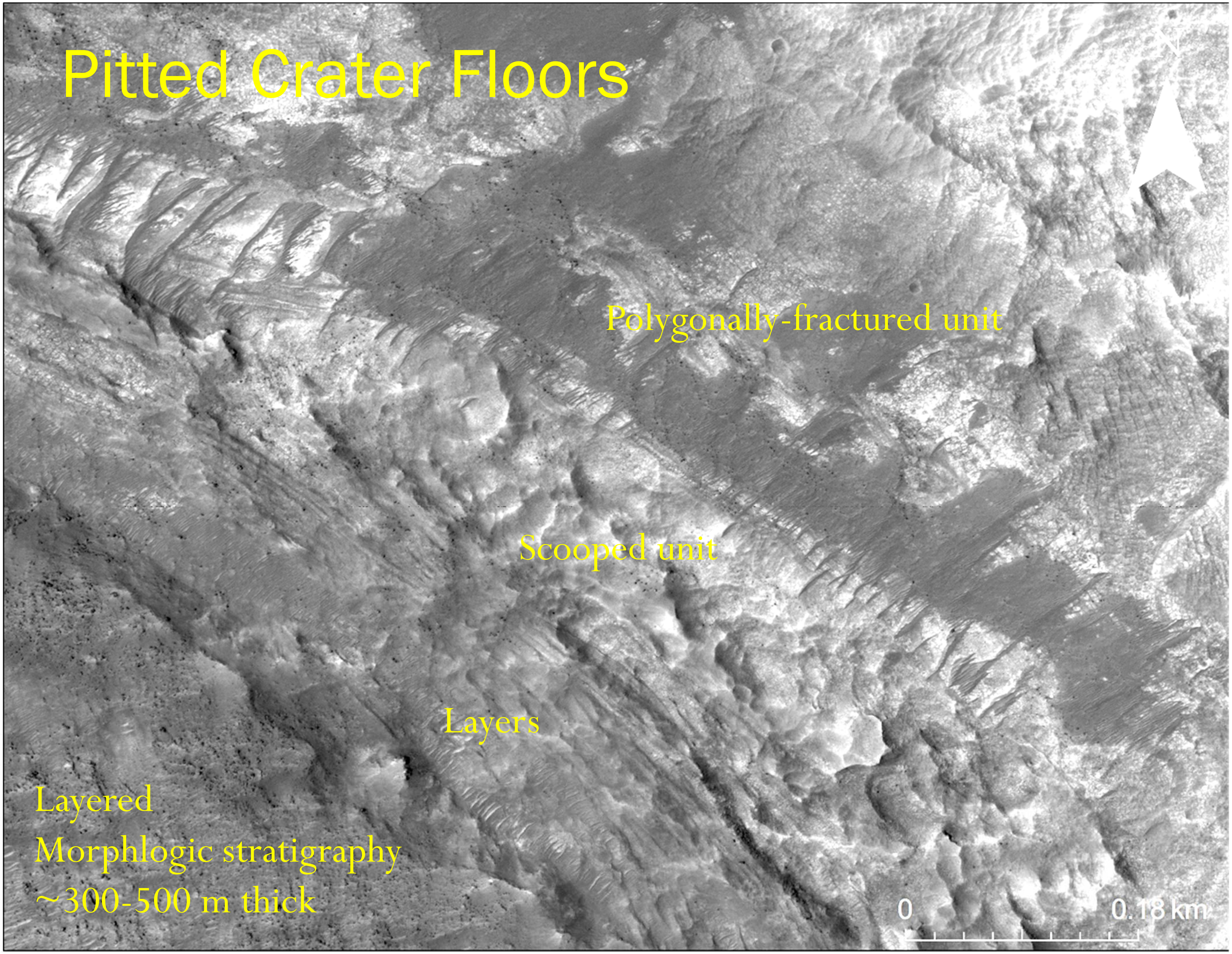
Scientific framework at NW Hellas

- Style, timing, and temporal extent of alteration and depositional processes on ancient Mars
  - Bedding, thickness, periodicity of layers
  - Mineralogy and extent of aqueous alteration
  - Aqueous chemistry
- Habitability
  - Soil chemistry
  - Water abundance
  - Redox potential
- Style and timing of erosional processes
  - Exposure ages
  - Small-scale textures (*e.g.*, aeolian pitting, glacial scouring, etc)


1000-m slopes and access
to science objectives
N
-500
500
0
Pitted units
Prehnite (in unit Nh)
Mixed-layer
26°14' S, 56°26' E
-700 m elev
25x20 km ellipse
~26.1°S, 55.9°E
Landing on Fluvial deposits
10 km to hydrothermal units
Slopes (deg)
0 - 2.5
2.5 - 5
5.0 - 15
15 - 20
20 - 38
0
20 km

Access to science objectives

- Plains units have very gentle ($<2.5°$) slopes throughout, and are easily accessible to landing system.
- Scarcity of boulders in this unit makes landing and traverse straightforward.
- Fluvial deposits occur within landing ellipse
- Hydrothermal units 10 km from center of 25x20 km ellipse
- Pitted units also 10 km from center of ellipse


Pitted Crater Floors
N
Polygonally-fractured unit
Scooped unit
Layers
Layered
Morphlogic stratigraphy
~300-500 m thick
0
0.18 km

- Unit above 500 m – Npl2 – Subdued cratered unit – Forms widespread moderate to heavily cratered, relatively smooth plains marked by subdued crater rims, small channels, ridges, and uneven terrain. Crater floors partly to completely infilled with smooth material; ejecta blankets rare. Some heavily eroded craters dissected by small channels. Faults rare. Material gradational with most adjacent units. *Interpretation* – Ancient veneer of aeolian, fluvial, and perhaps volcanic materials that partly resurface underlying cratered and dissected units (units Npl1 and Npld).

- Prehnite in unit Nh – Hilly Unit – Forms ruggst, high-relief, densely cratered terrain with numerous isolated massifs. Channels and ridges common; faults aong west rim. *Interpretation:* Uplifted crustal material and ejecta from Hellas impact and post-impact structural and erosional modifications.

- Smooth pitted plains in unit Hpl3 – Smooth unit – Forms moderately cratered, smooth, flat to undulating, relatively featureless pains and patches around the rim and within highlands surrounding Hellas basin. Channel common; faults and flow fronts rare. Embays all other materials of plateau sequence and fills man impact craters. *Interpretation:* Thick fluvial, aeolian, and volcanic deposits burying most underlying rocks

- (Leonard and Tanaka, 2001)