Exploring the Volcanic, Alteration, and Fluvio-Lacustrine History of Early Mars at the Jezero Crater Paleolake

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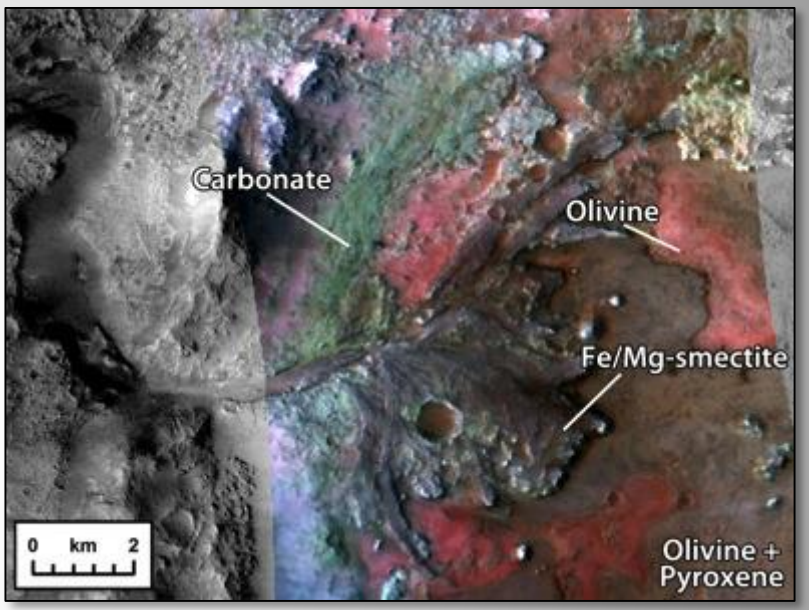
Meeting Mars 2020 Science Criteria

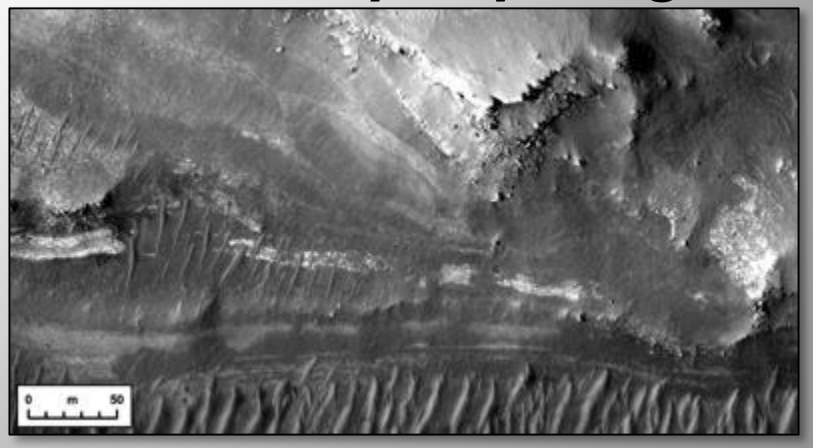
Jezero crater paleolake basin addresses key areas outlined in the Mars 2020 SDT report:

- Paleolake with sedimentary carbonate and Fe/Mg-smectites indicates a likely habitable standing body of water with circumneutral pH conditions [*Ehlmann et al.*, 2008a; *Goudge et al.*, 2015].
- Deltaic and lacustrine sediment is an excellent site for concentration and preservation of organic matter [*Summons et al.*, 2011].

Mineralogic Diversity

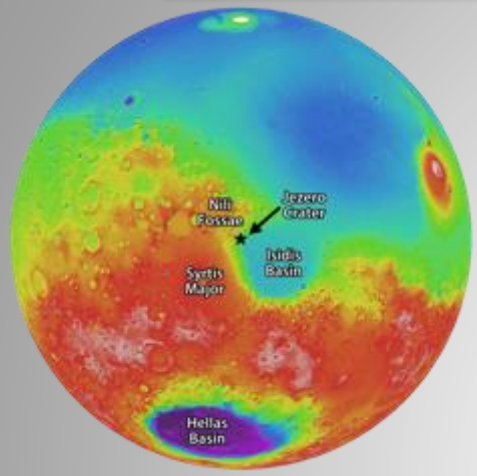


Sedimentary Layering

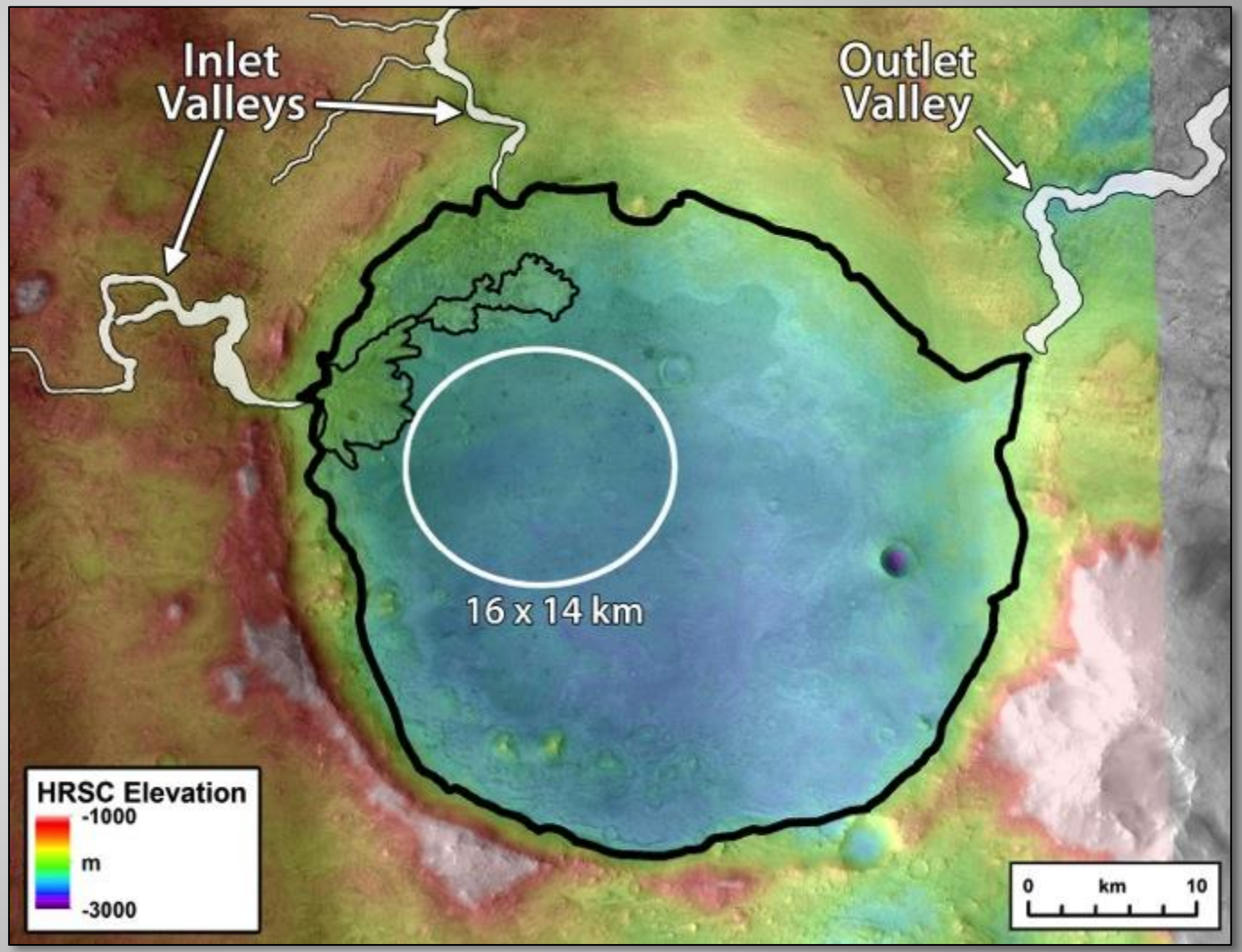


Landing Site Factor		Jezero	Explanation
Environmental Setting for Biosignature Preservation and Taphonomy of Organics	**Deltaic or Lacustrine (perennial)**	●	Delta remnants in ellipse, and western delta at ellipse edge [*Fassett and Head,* 2005; *Ehlmann et al.,* 2008a; *Schon et al.,* 2012; *Goudge et al.,* 2015].
	Lacustrine (evaporitic)	~	Unknown what happened during final stages of lacustrine activity.
	Hydrothermal (<100°C) surface	~	Unknown origin of carbonate-bearing basin fill [*Ehlmann et al.,* 2008b].
	Hydrothermal (<100°C) subsurface	~	Unknown origin of carbonate-bearing basin fill [*Ehlmann et al.,* 2008b].
	Pedogenic	–	–
	Fluvial/Alluvial	●	Fluvio-deltaic deposits exposed in ellipse and at ellipse edge [*Fassett and Head,* 2005; *Ehlmann et al.,* 2008a; *Schon et al.,* 2012; *Goudge et al.,* 2015].
	No diagenetic overprinting		
	Recent exposure	~	Boulders shed from delta erosional scarp [*Ehlmann et al.,* 2008a; *Schon et al.,* 2012].
Type 1A & 1B Samples: Aqueous Geochemical Environments indicated by Mineral Assemblages	Crustal phyllosilicates		
	Sedimentary clays	●	Fe/Mg-smectite within delta deposit (in ellipse and in bottomsets at edge) [*Ehlmann et al.,* 2008a, 2009; *Goudge et al.,* 2015].
	Al clays in stratigraphy	–	–
	Carbonate units	●	Carbonate-bearing basin fill unit and within western delta deposit [*Ehlmann et al.,* 2008b, 2009; *Goudge et al.,* 2015].
	Chloride sediments	–	–
	Sulfate sediments	–	–
	Acid sulfate units	–	–
	Silica deposits	–	–
	Ferric Ox./Ferrous clays	–	–
Type 2 Samples: Igneous	**Igneous unit (e.g., lava flow, pyroclastic, intrusive)**	●	Volcanic floor unit [*Goudge et al.,* 2012, 2015; *Schon et al.,* 2012].
	2nd Igneous unit	–	–
Context: Martian History Sampled, Timing Constraints	Pre- or Early-Noachian Megabreccia	–	–
	Oldest stratigraphic constraint	**LN**	Fluvio-deltaic deposit formed at approximately Noachian-Hesperian boundary [*Fassett and Head,* 2008].
	Youngest stratigraphic constraint	**EA**	Volcanic floor unit emplaced in Early Amazonian [*Goudge et al.,* 2012].
	Stratigraphy of units well-defined	●	Well-defined stratigraphy in basin and in watershed [*Goudge et al.,* 2015].
	Dateable surface, volcanic (unmodified crater SFD)	●	Volcanic floor unit dated with crater counting [*Goudge et al.,* 2012].

Jezero Crater Paleolake

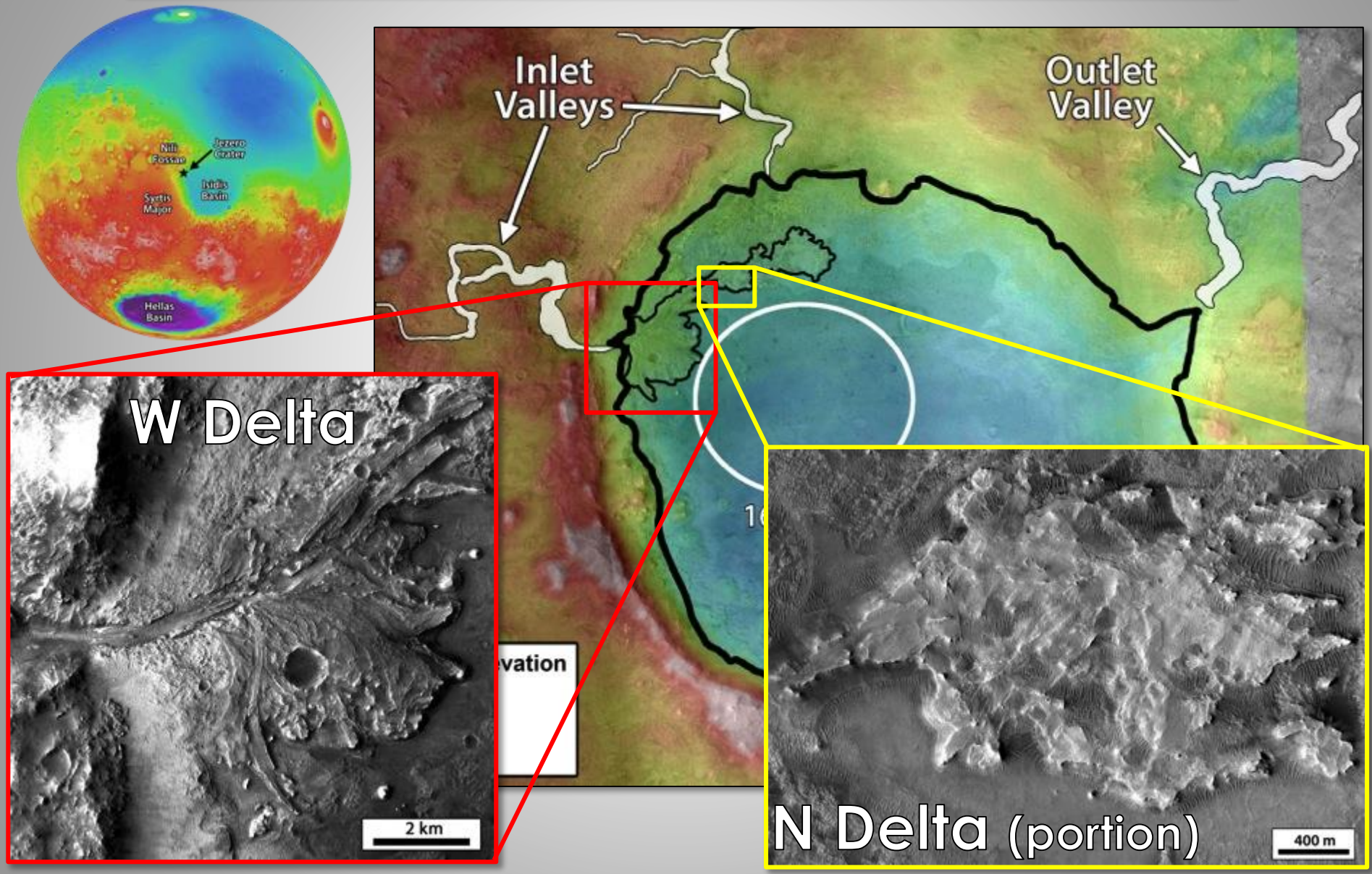


Hydrologically open paleolake with defined minimum lake level. Lake volume is ~250 km^3, similar to Lake Tahoe or Lake Winnipeg [*Fassett and Head*, 2005; *Ehlmann et al.*, 2008a; *Schon et al.*, 2012; *Goudge et al.*, 2015].

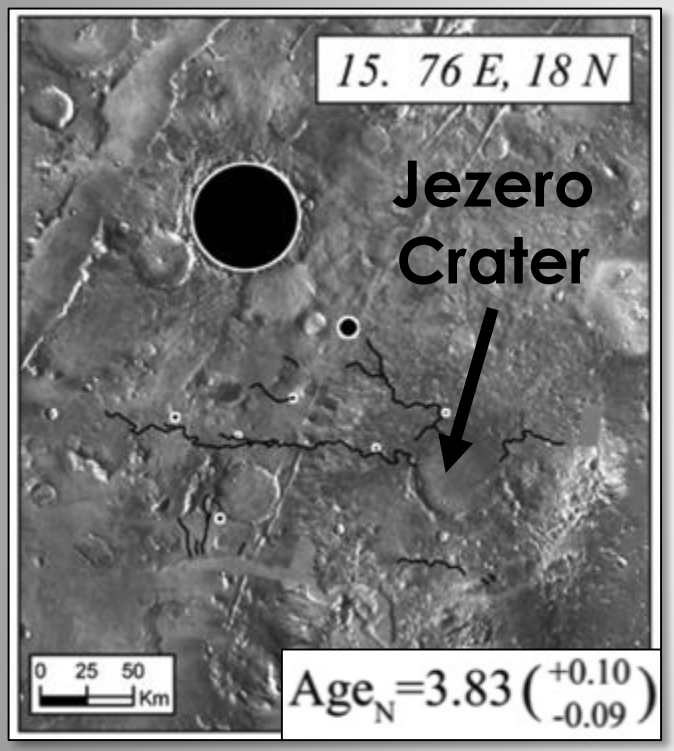


HRSC topography overlain on CTX mosaic.

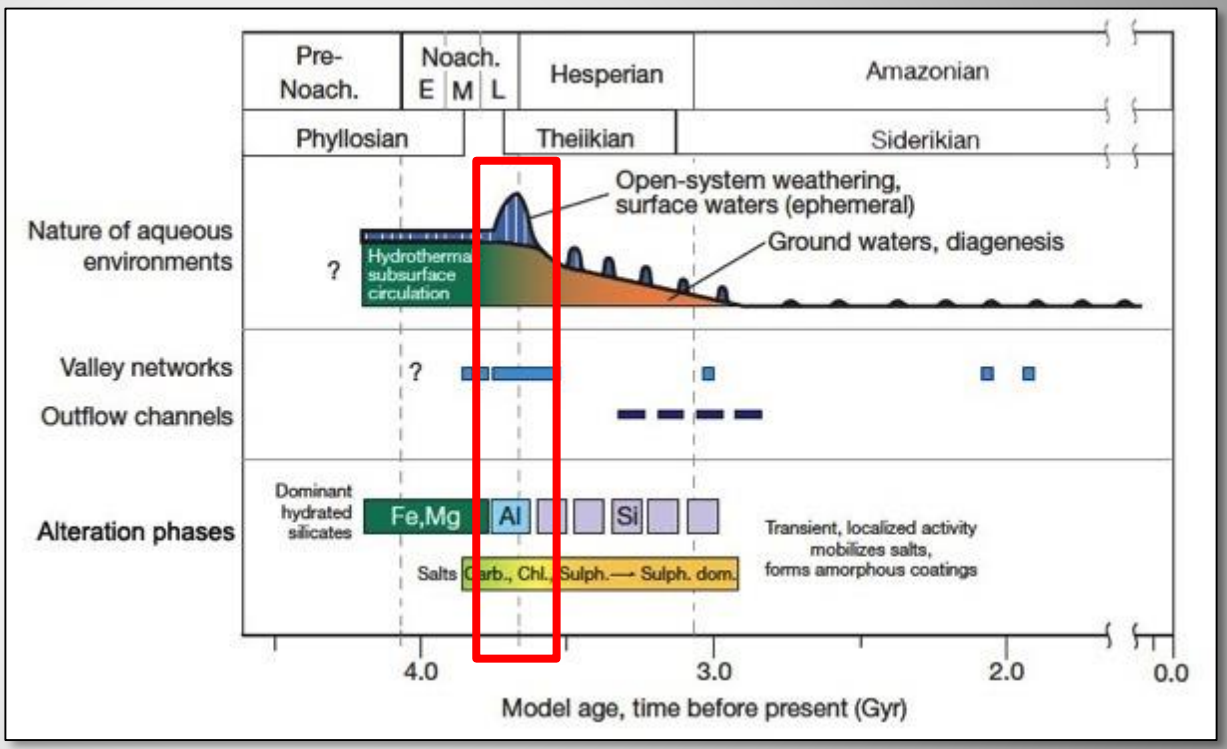
Jezero Delta Deposits



Timing of Lacustrine Activity

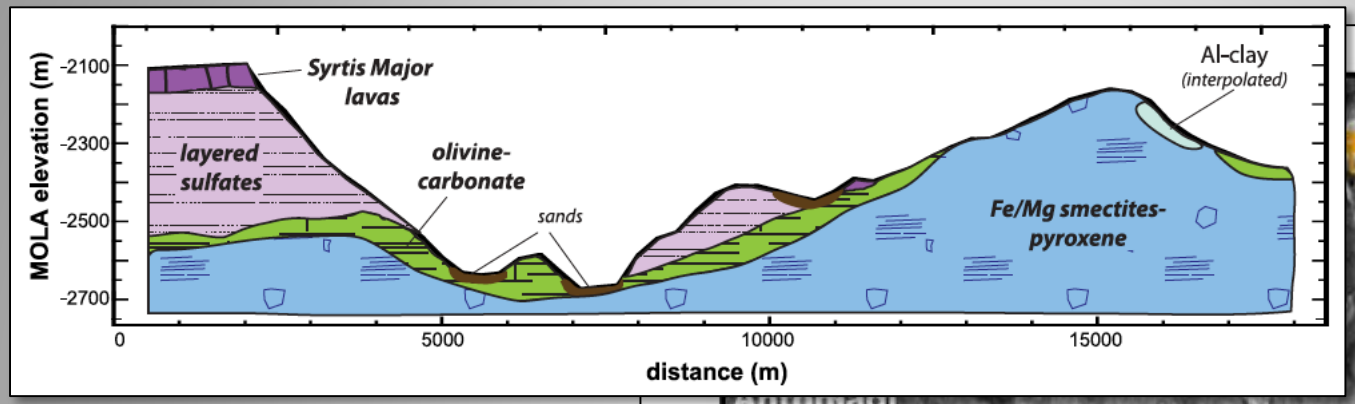


Fassett and Head [2008]

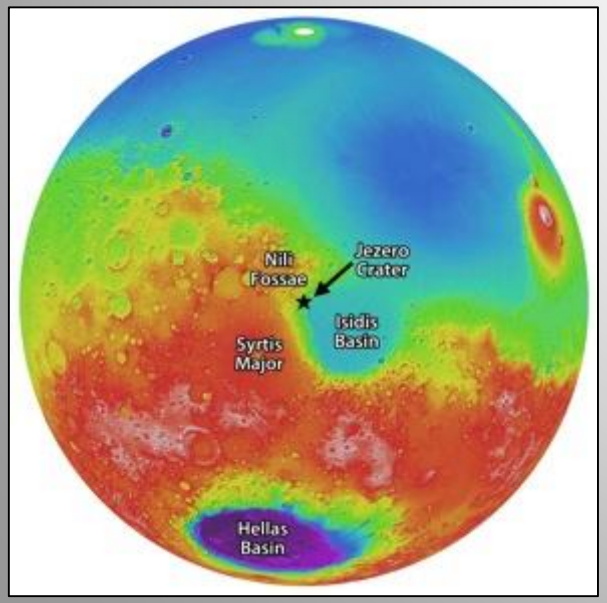


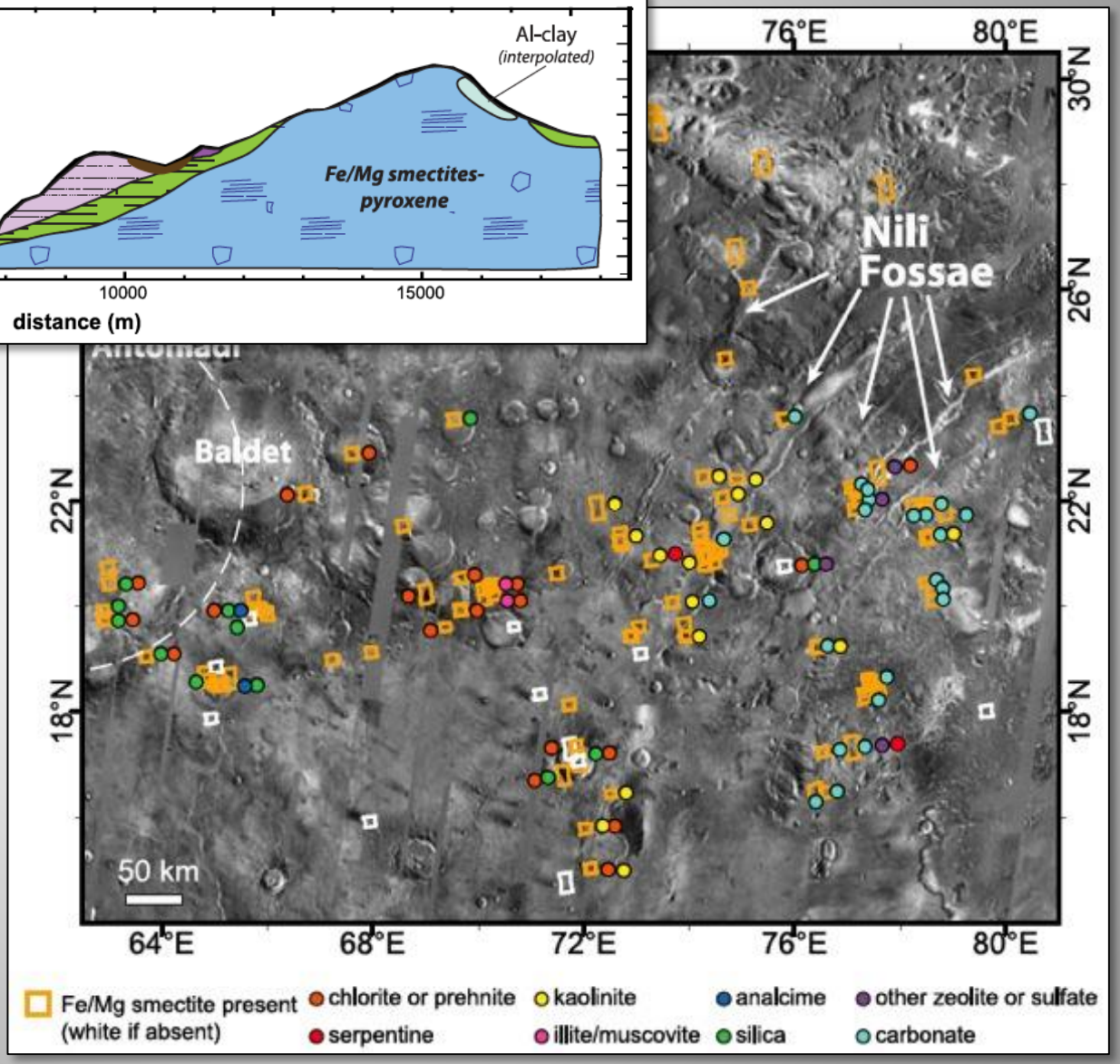
Ehlmann et al. [2011]

Alteration-Mineral-Rich Regional Terrain

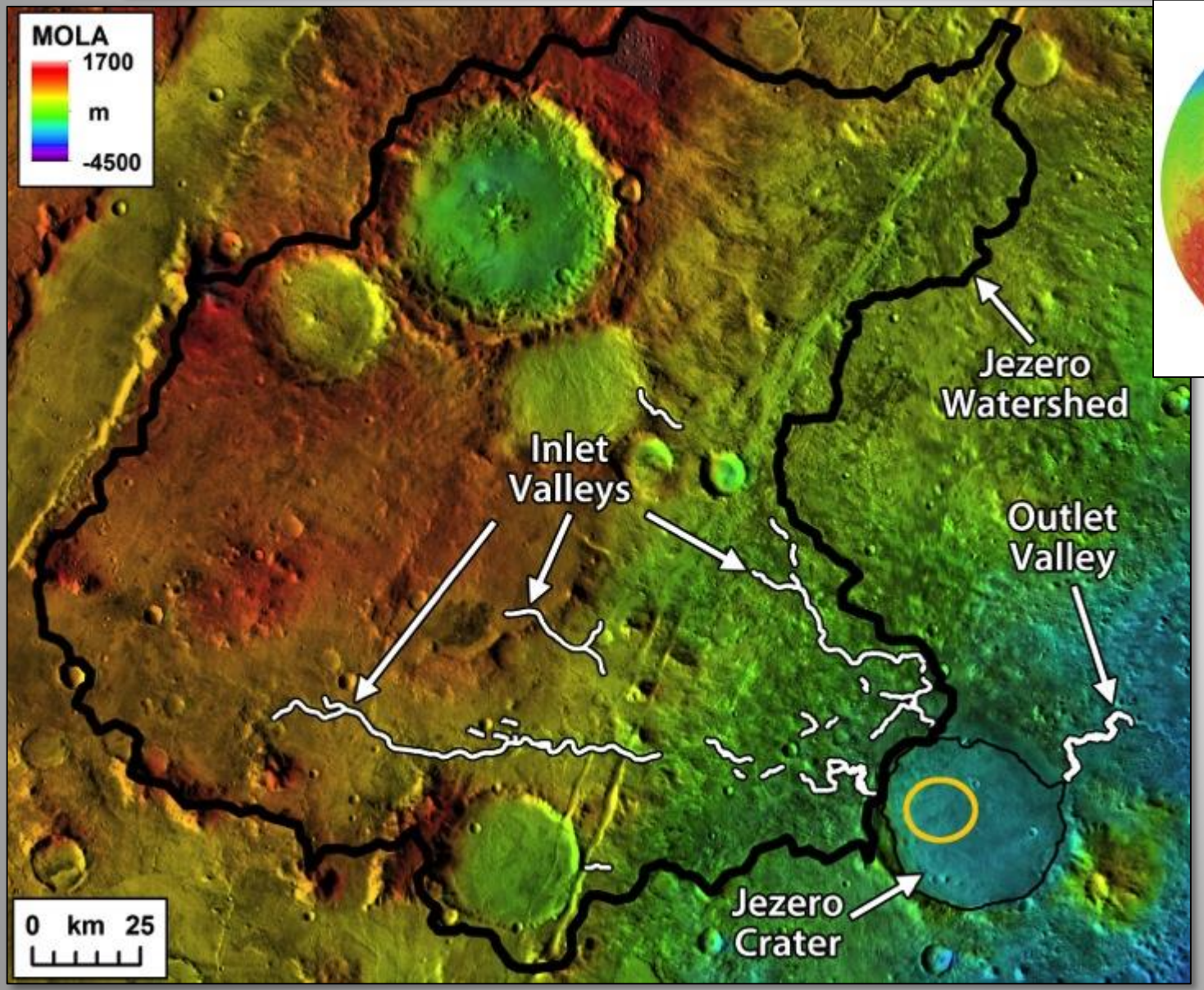


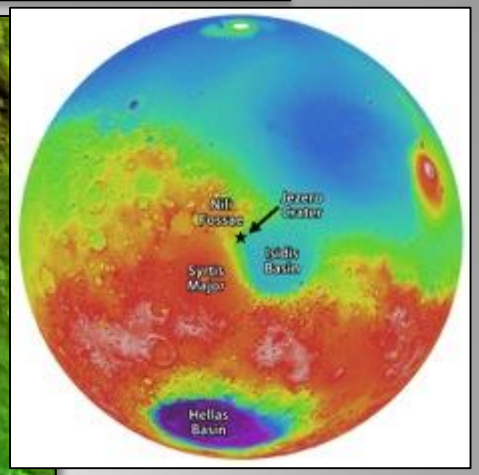
Above: *Ehlmann and Mustard* [2012]
Right: *Ehlmann et al.* [2009]





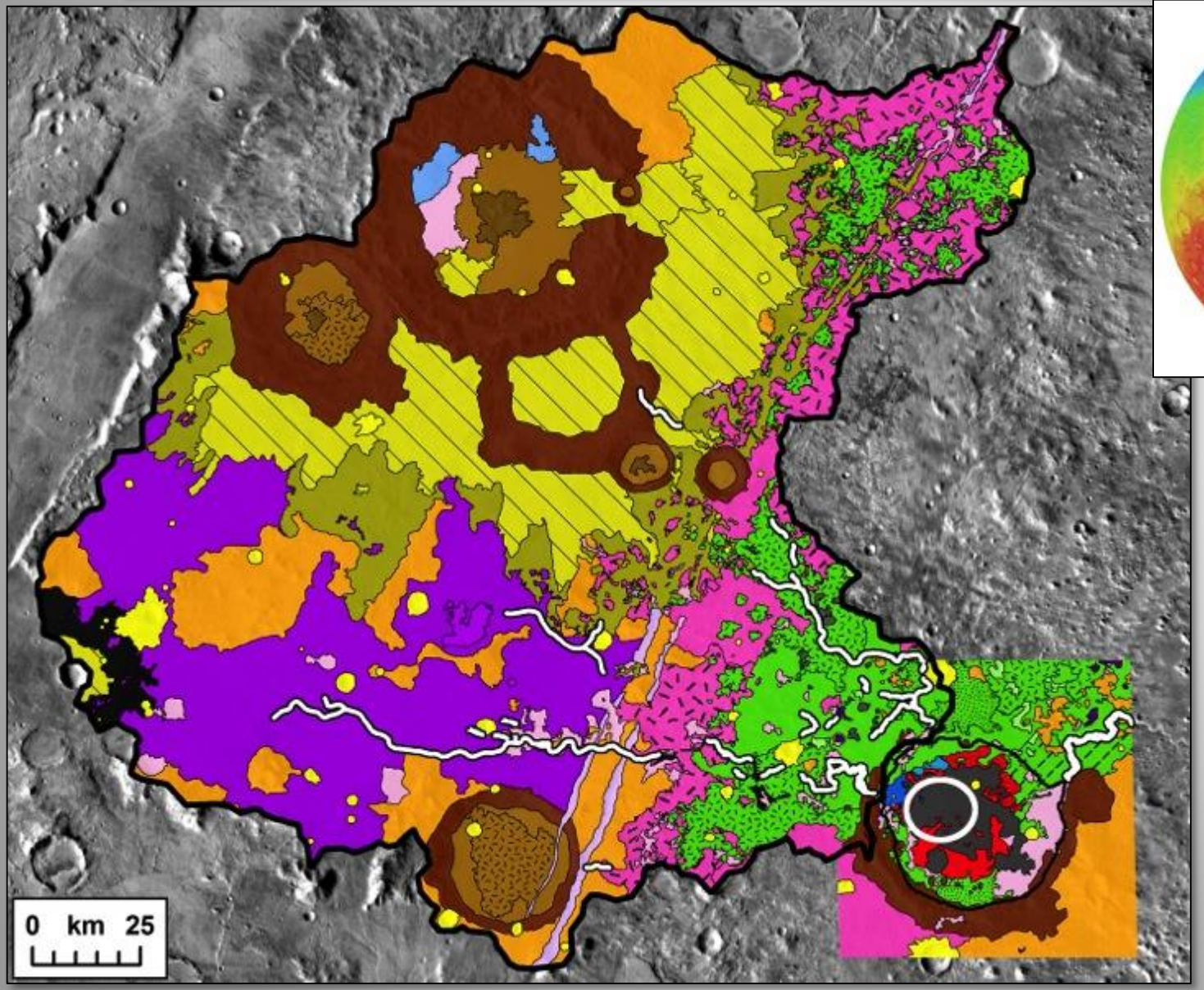
Jezero Watershed

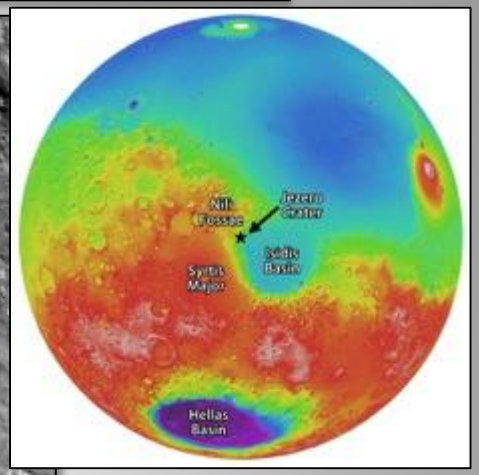




MOLA topography overlain on THEMIS daytime IR mosaic.

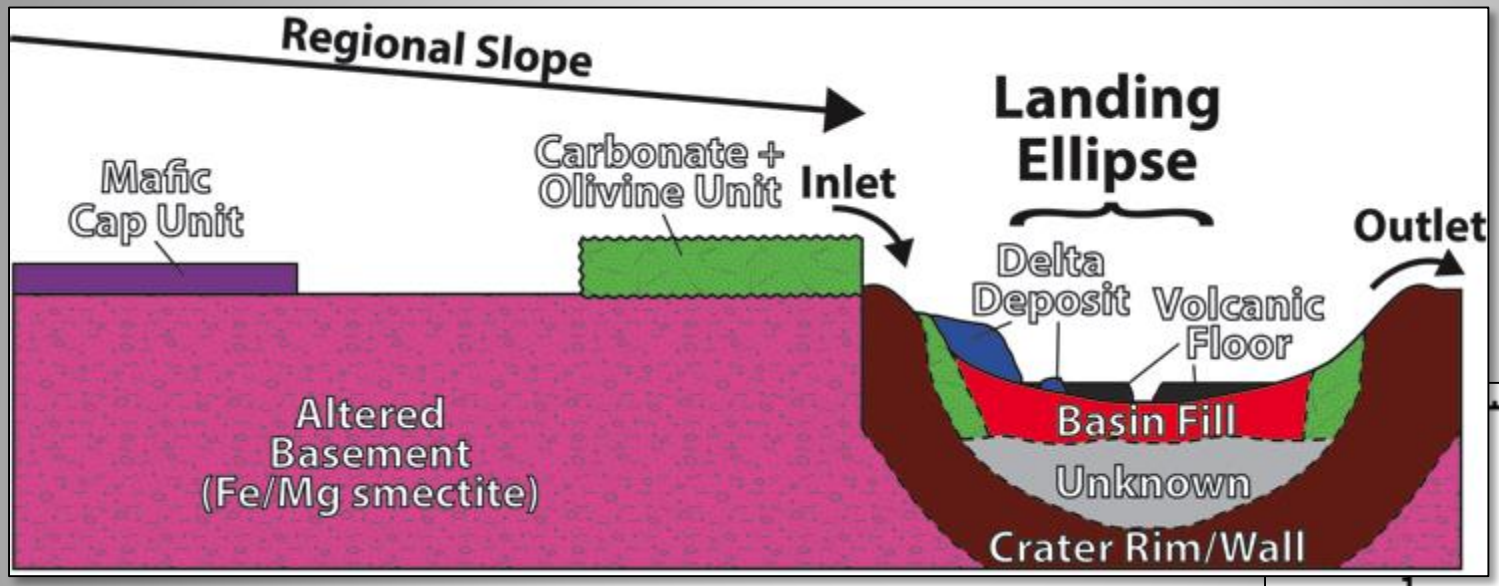
Jezero Watershed Diversity



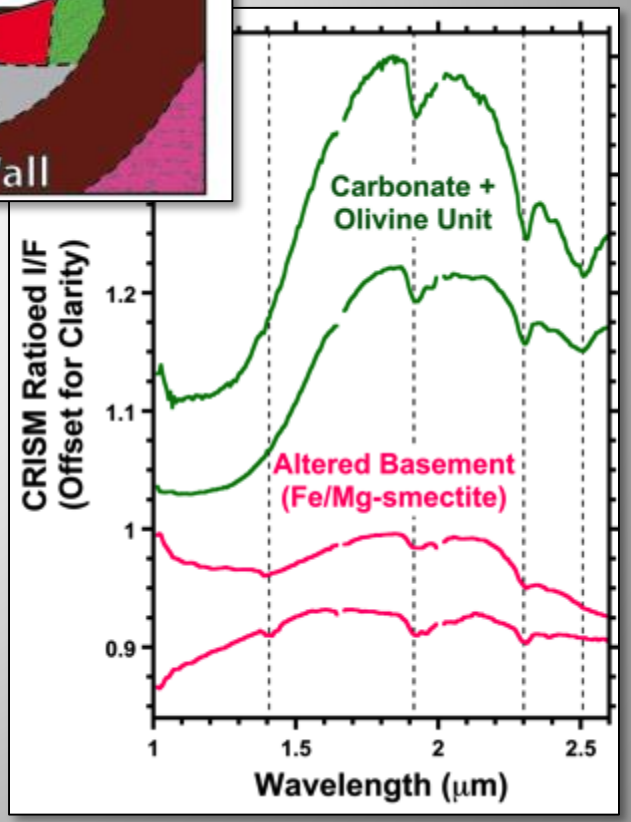


Goudge et al. [2015]

Jezero Watershed Stratigraphy



Goudge et al. [2015]

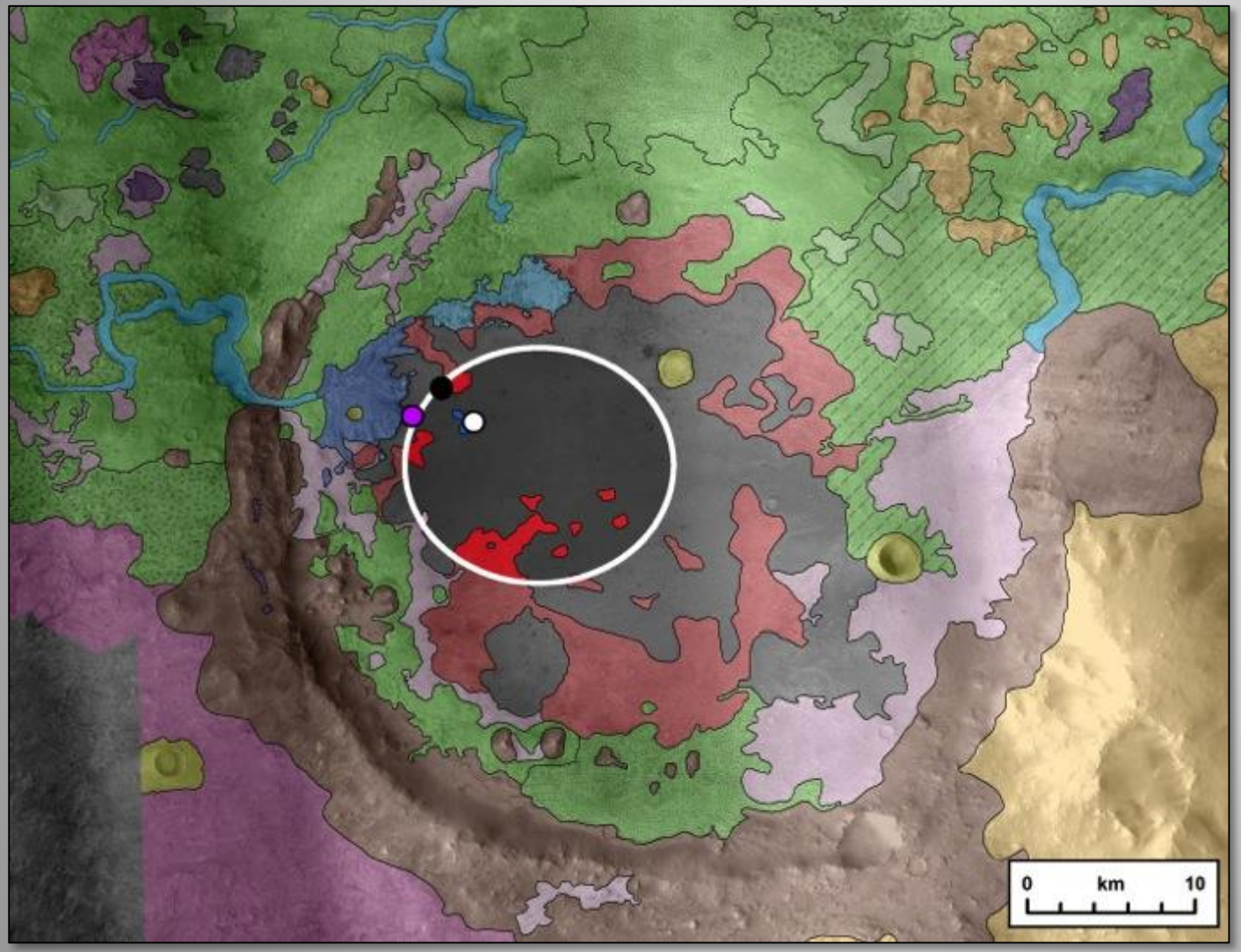


Stratigraphy of units well-defined

Jezero crater paleolake watershed draws from one of the most alteration-mineral-rich locations on Mars [e.g., Poulet et al., 2005; Bibring et al., 2006; Mangold et al., 2007; Ehlmann et al., 2008b, 2009; Mustard et al., 2008, 2009].

Opportunity to investigate material with diverse provenance.

Exploring Diversity at ROIs



Stratigraphy of units well-defined

Goudge et al. [2015]

Legend:

White ellipse = 16x14 km landing ellipse.

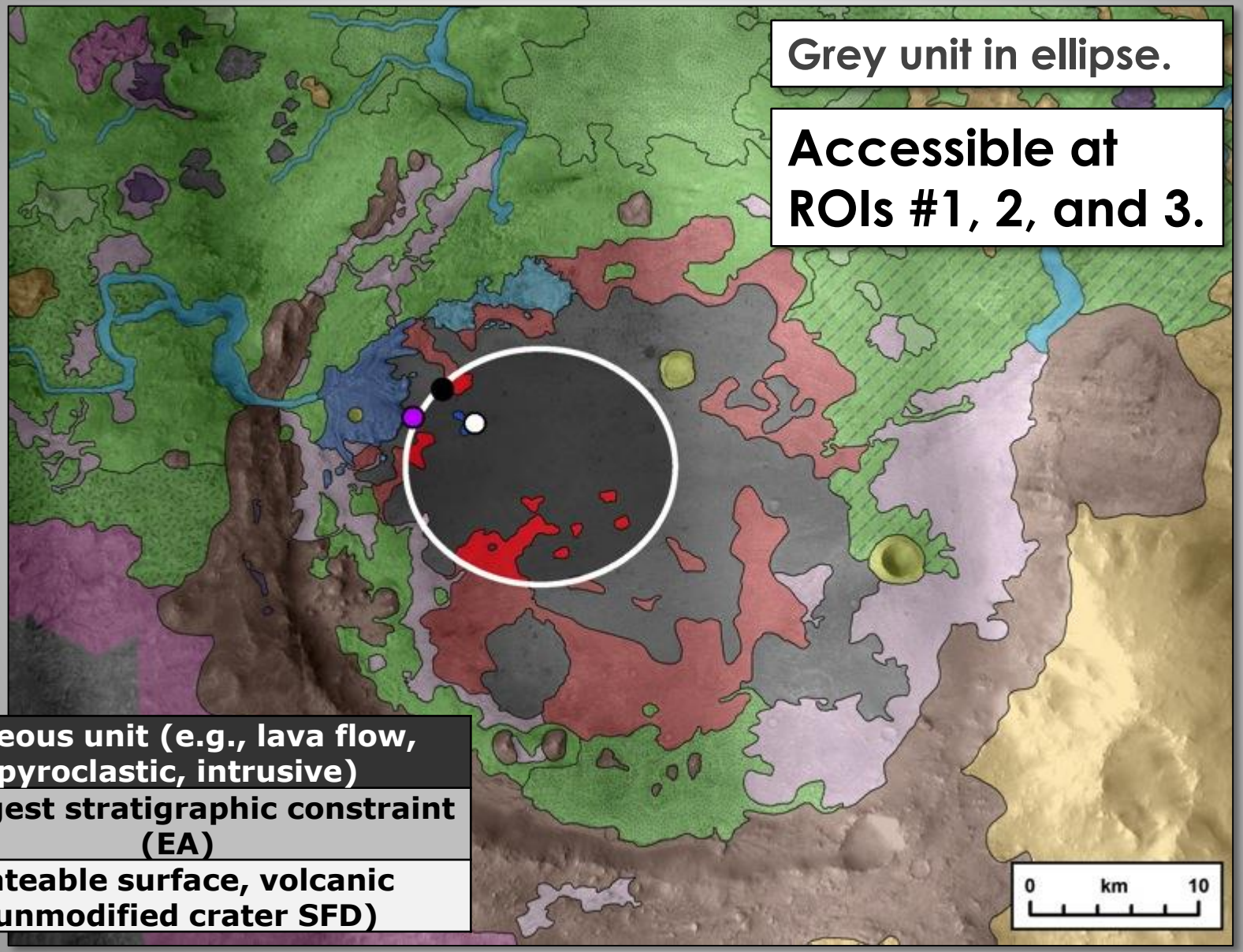
White dot = ROI #1; Delta remnant

Red unit in ellipse (black dot is example) = ROI #2; Carbonate fill

Purple dot = ROI #3; Delta bottomsets

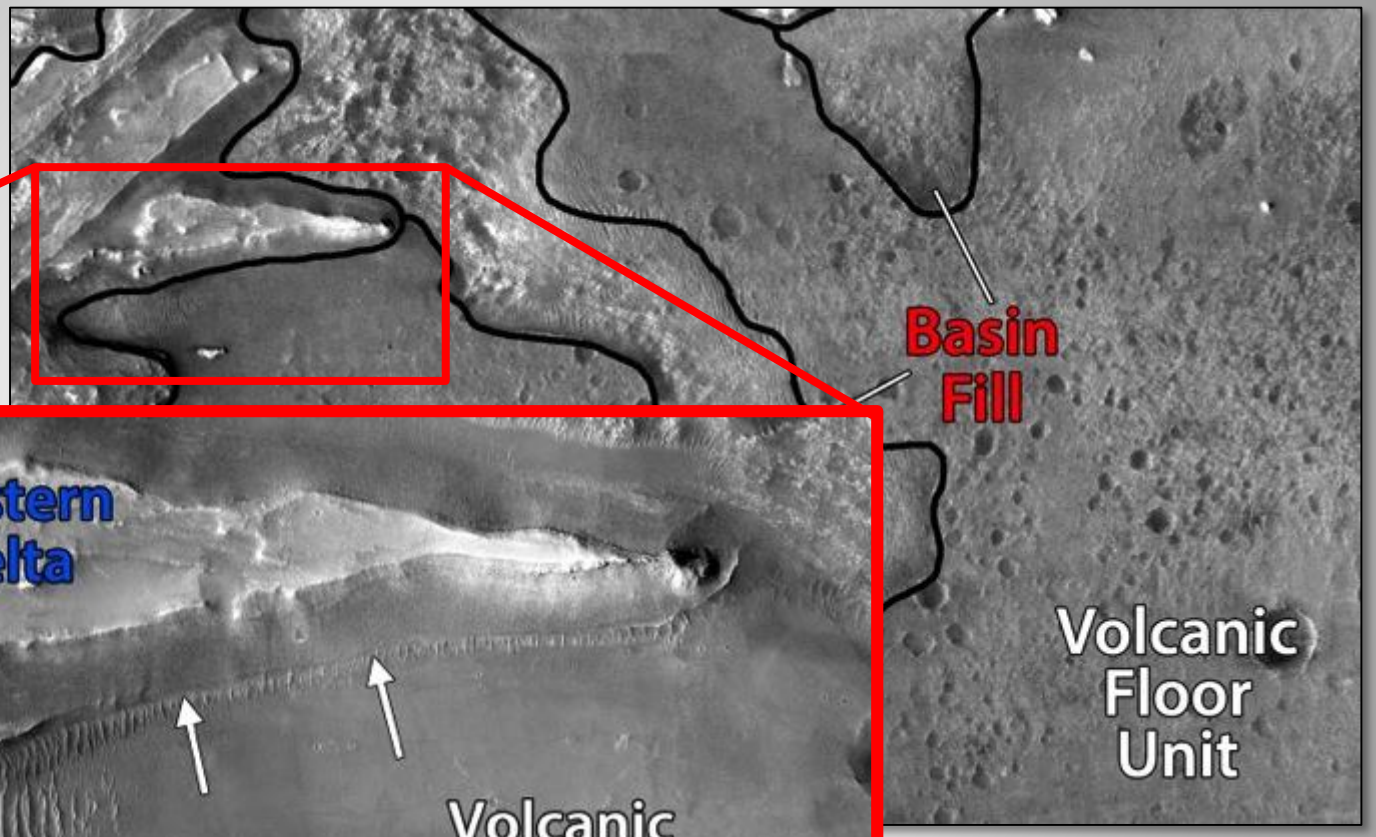
Grey unit in ellipse = unit of interest accessible at ROI #1-3; Volcanic floor

Unit of Interest – Volcanic Floor

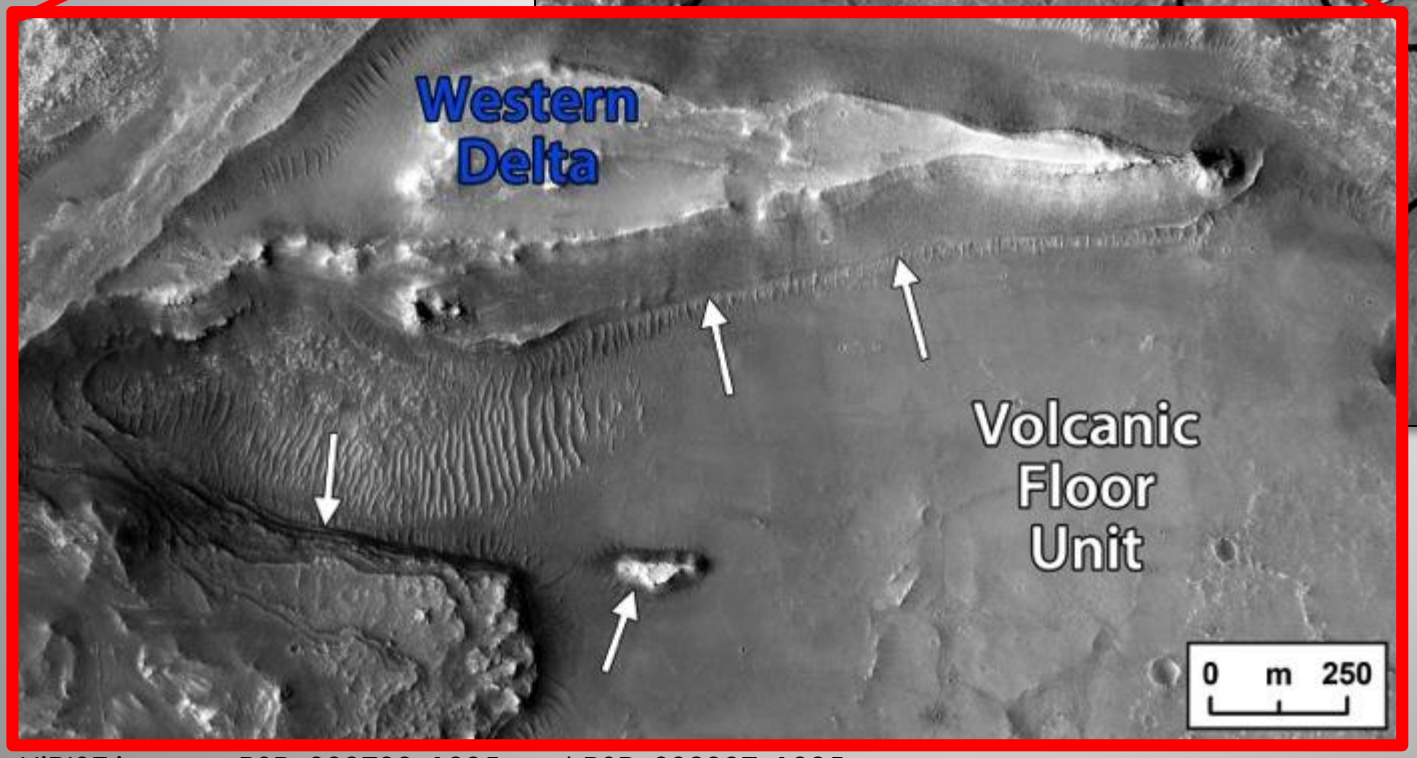


Igneous unit (e.g., lava flow, pyroclastic, intrusive)
Youngest stratigraphic constraint (EA)
Dateable surface, volcanic (unmodified crater SFD)

Unit of Interest – Volcanic Floor



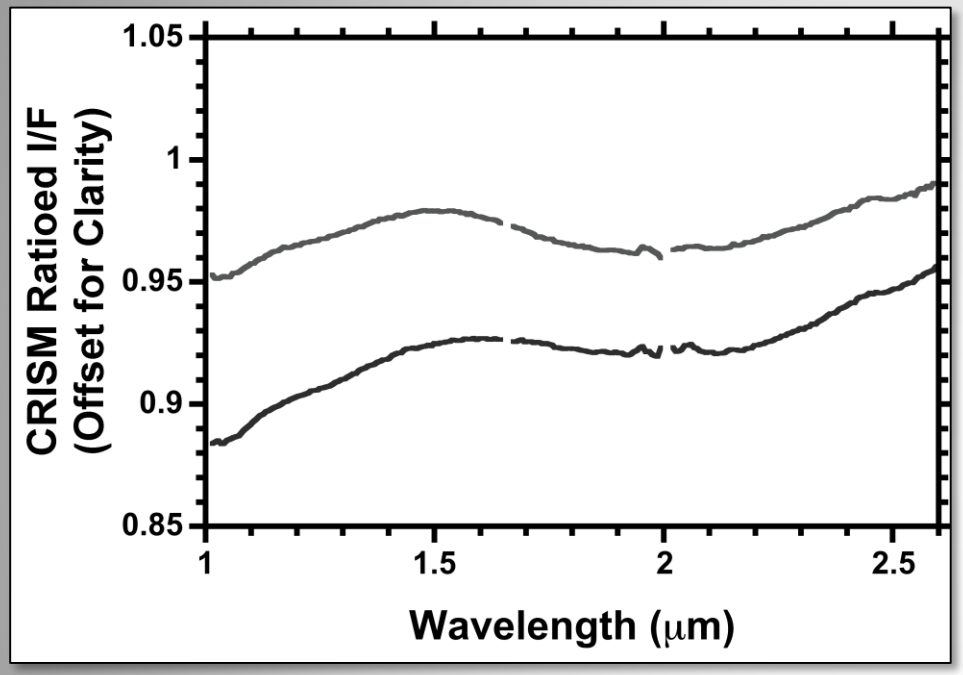
CTX Image P04_002664_1988.



HiRISE images PSP_003798_1985 and PSP_002387_1985.

Goudge et al. [2015]

Unit of Interest – Volcanic Floor

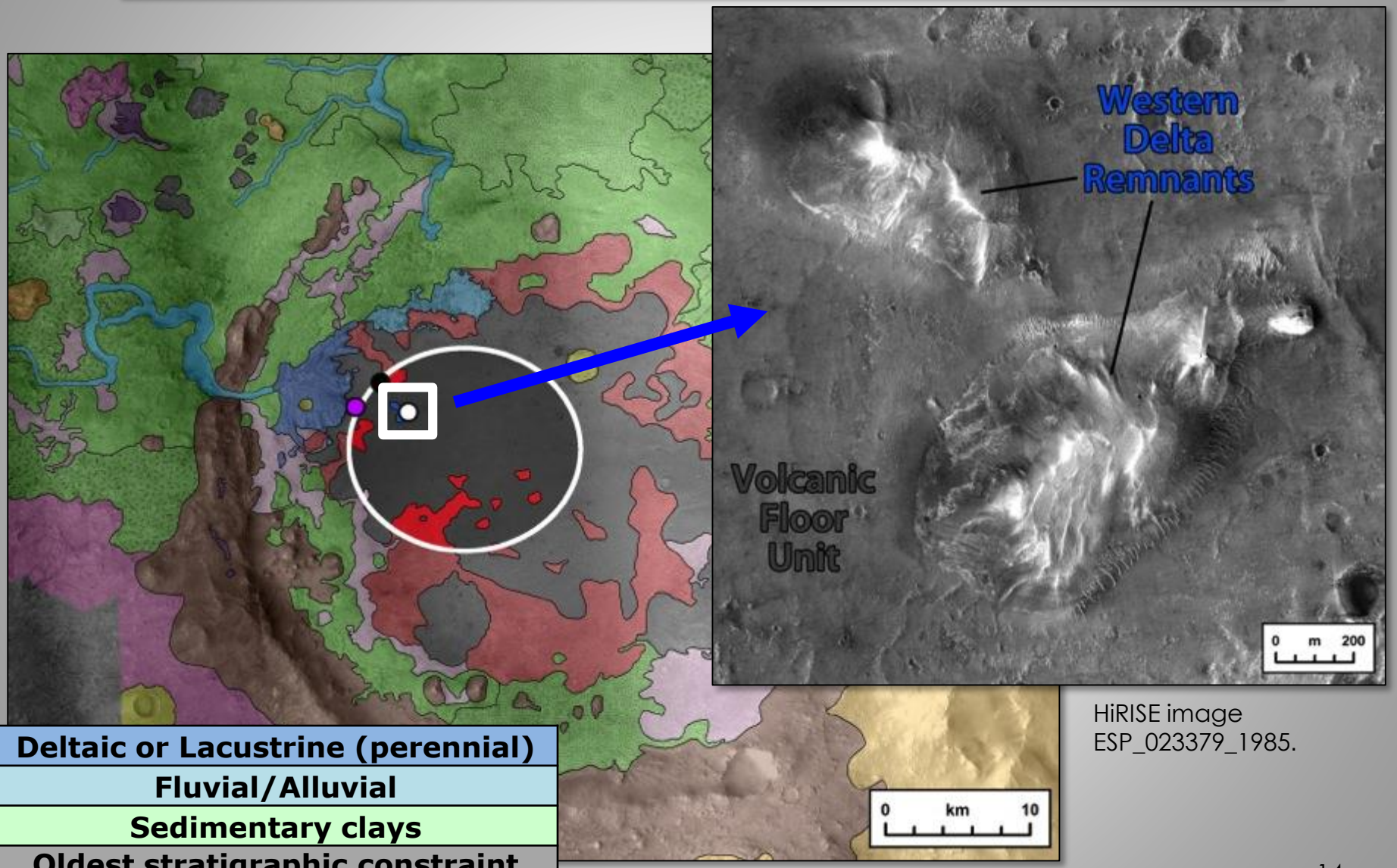


Testable Hypothesis with Mars 2020: Floor unit is volcanic in origin, has a similar composition to other martian basalts and was emplaced at ~3.5 Gyr.

Absolute age would allow us to constrain martian crater production functions.

- Spectral signature consistent with other exposures of Hesperian ridged plains (mixture of olivine and pyroxene) [*Goudge et al.*, 2012].
- Crater retention age of 3.45 (+0.12/-0.67) Gyr [*Goudge et al.*, 2012].
- Substantially younger than cessation age of valley network activity at 3.83 (+0.10/-0.09) Gyr [*Fassett and Head*, 2008].

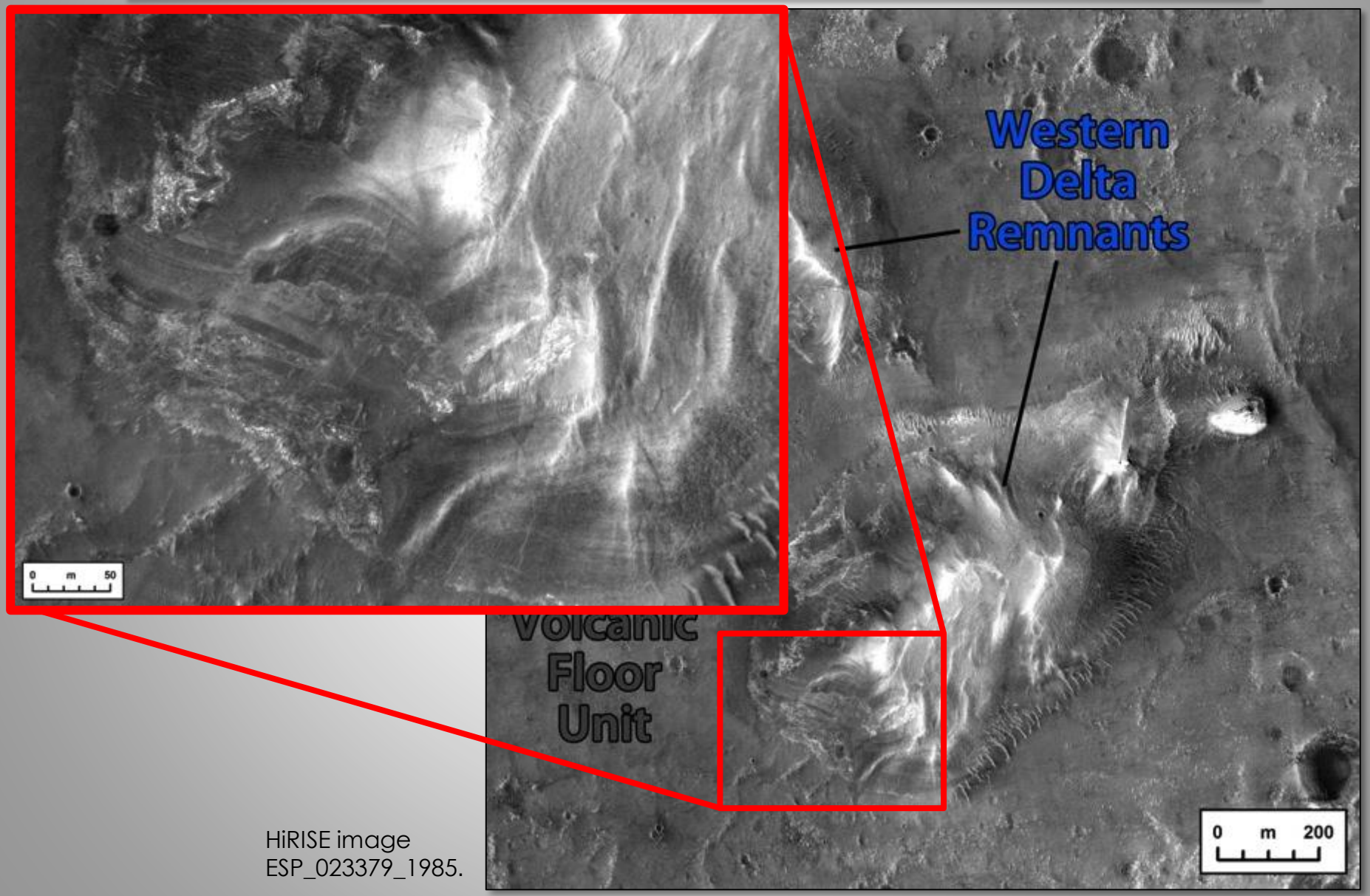
ROI #1 – Delta Remnants



HiRISE image ESP_023379_1985.

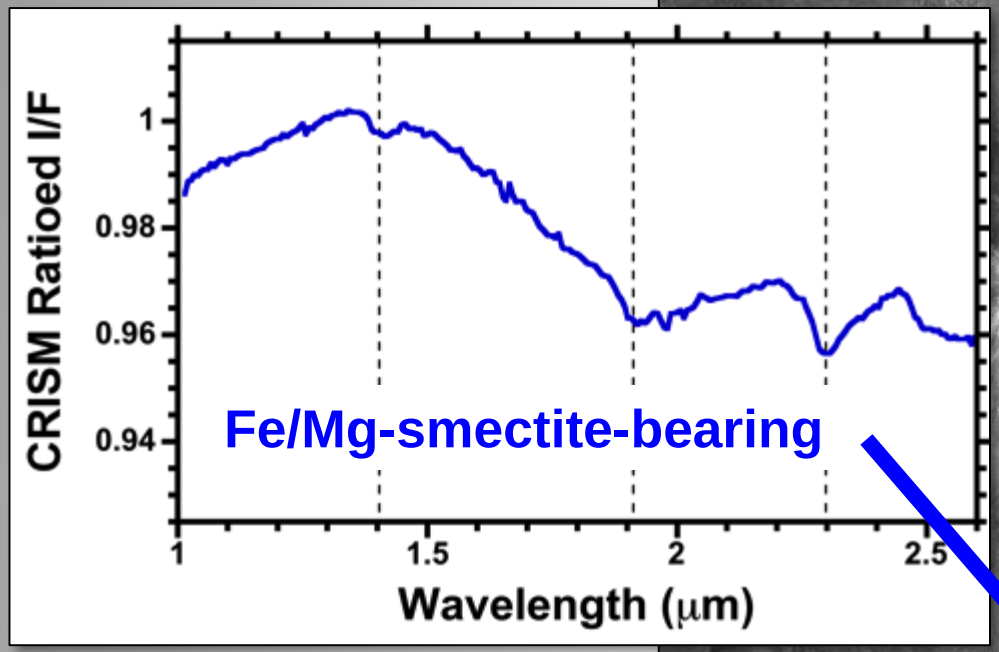
Deltaic or Lacustrine (perennial)
Fluvial/Alluvial
Sedimentary clays
Oldest stratigraphic constraint (LN)

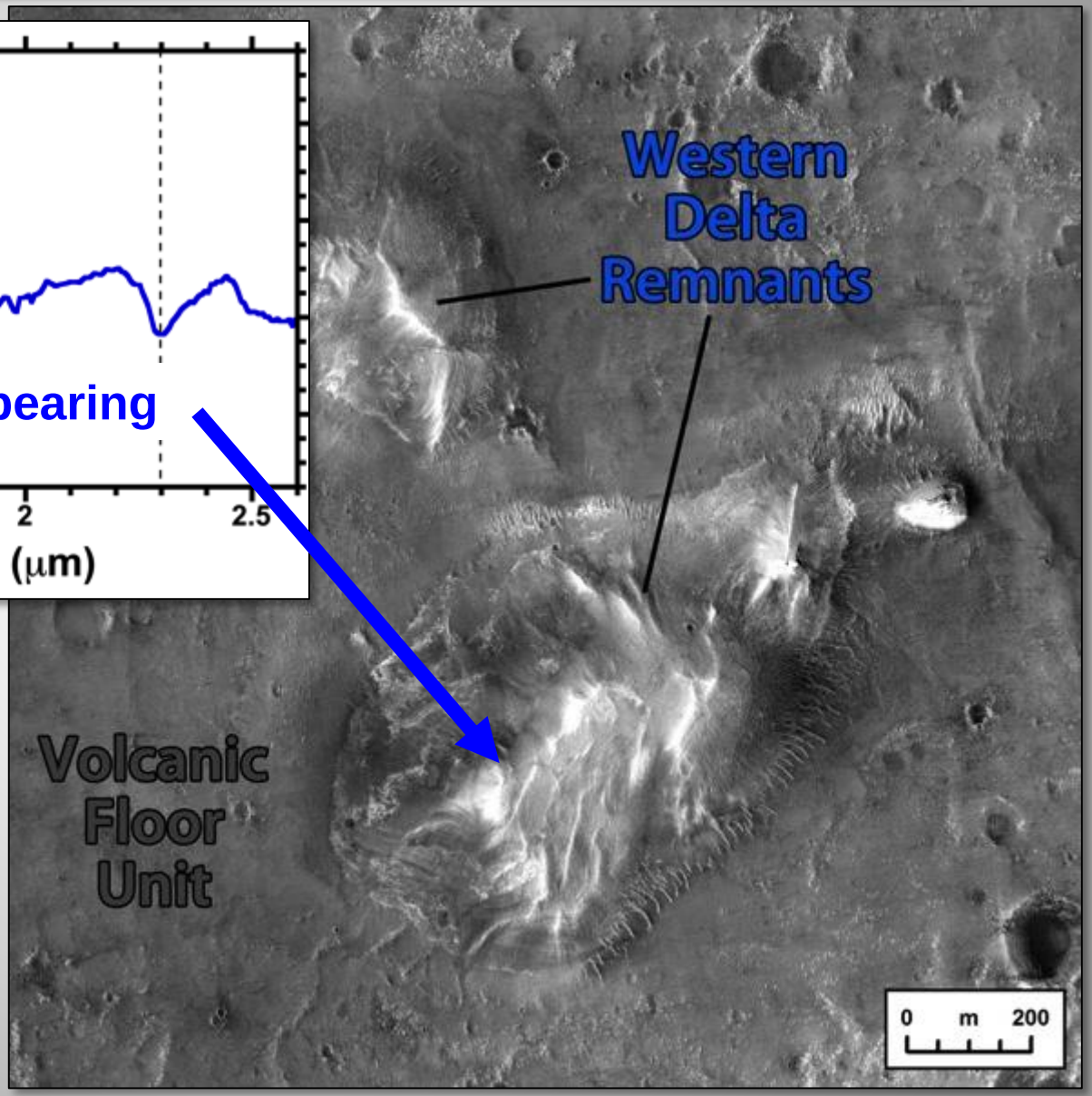
ROI #1 – Delta Remnants



HiRISE image ESP_023379_1985.

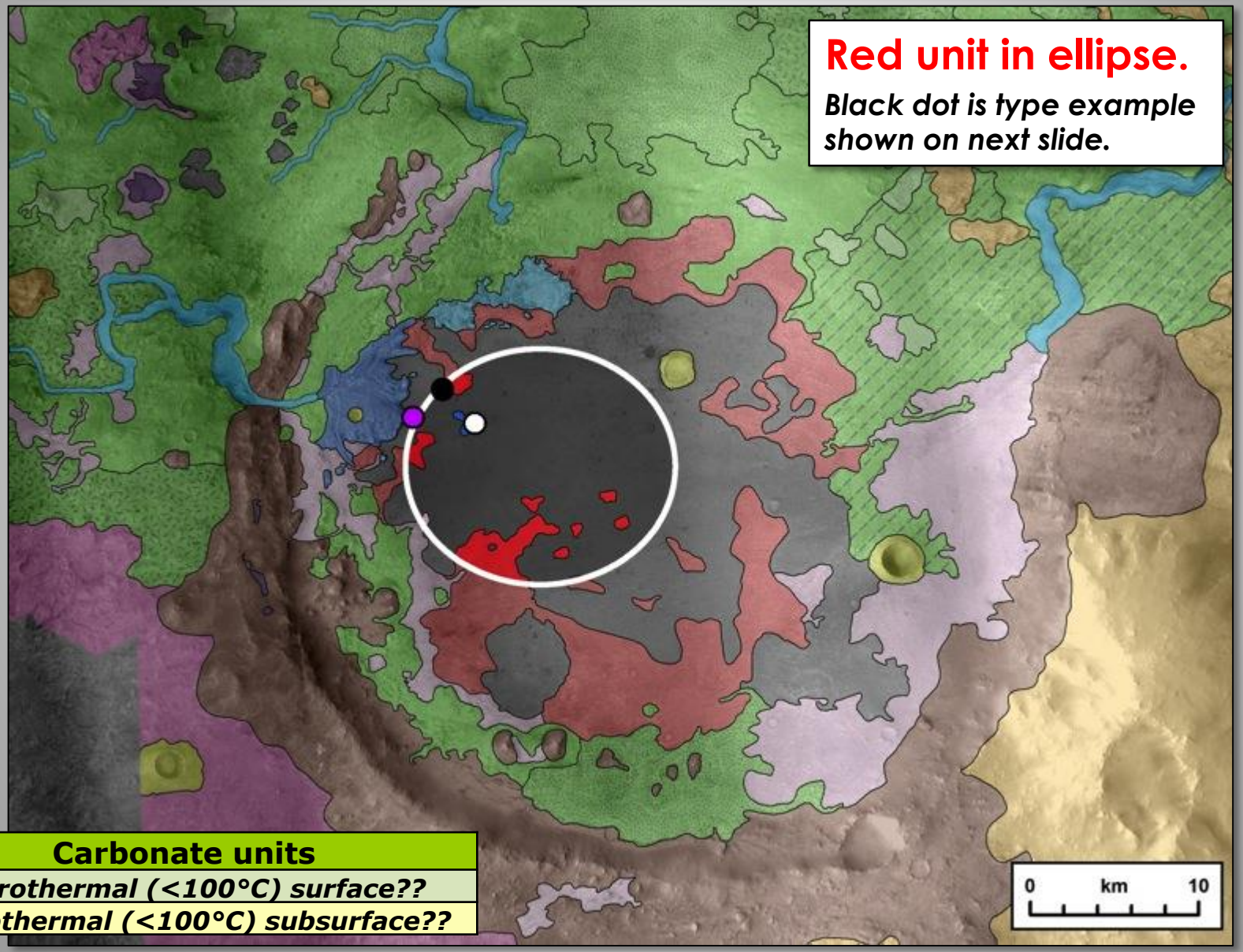
ROI #1 – Delta Remnants





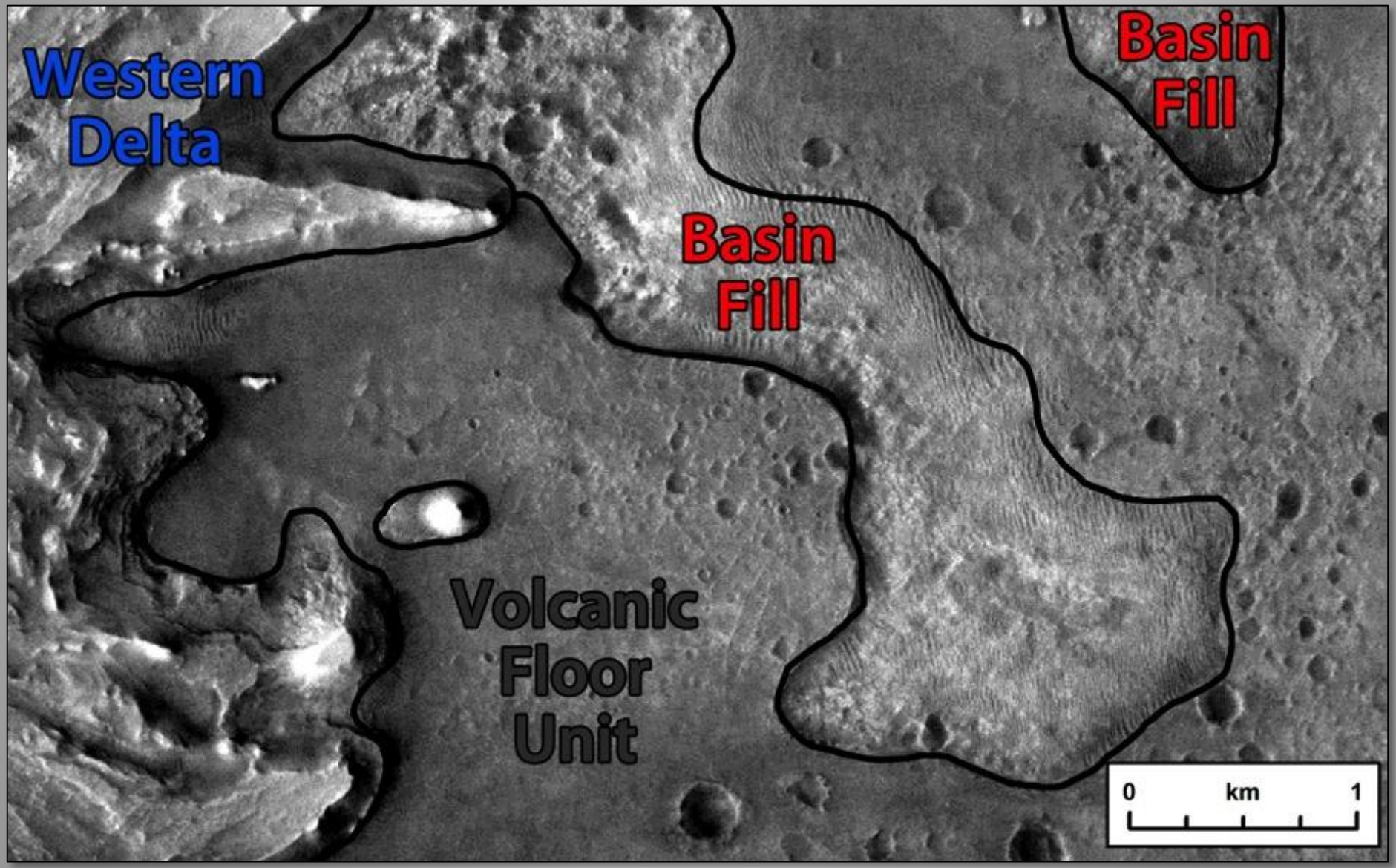
Testable Hypothesis with Mars 2020: Deltaic sediment was deposited in a circumneutral pH paleolake that was habitable and had high potential for concentrating and preserving organic matter

ROI #2 – Basin Fill



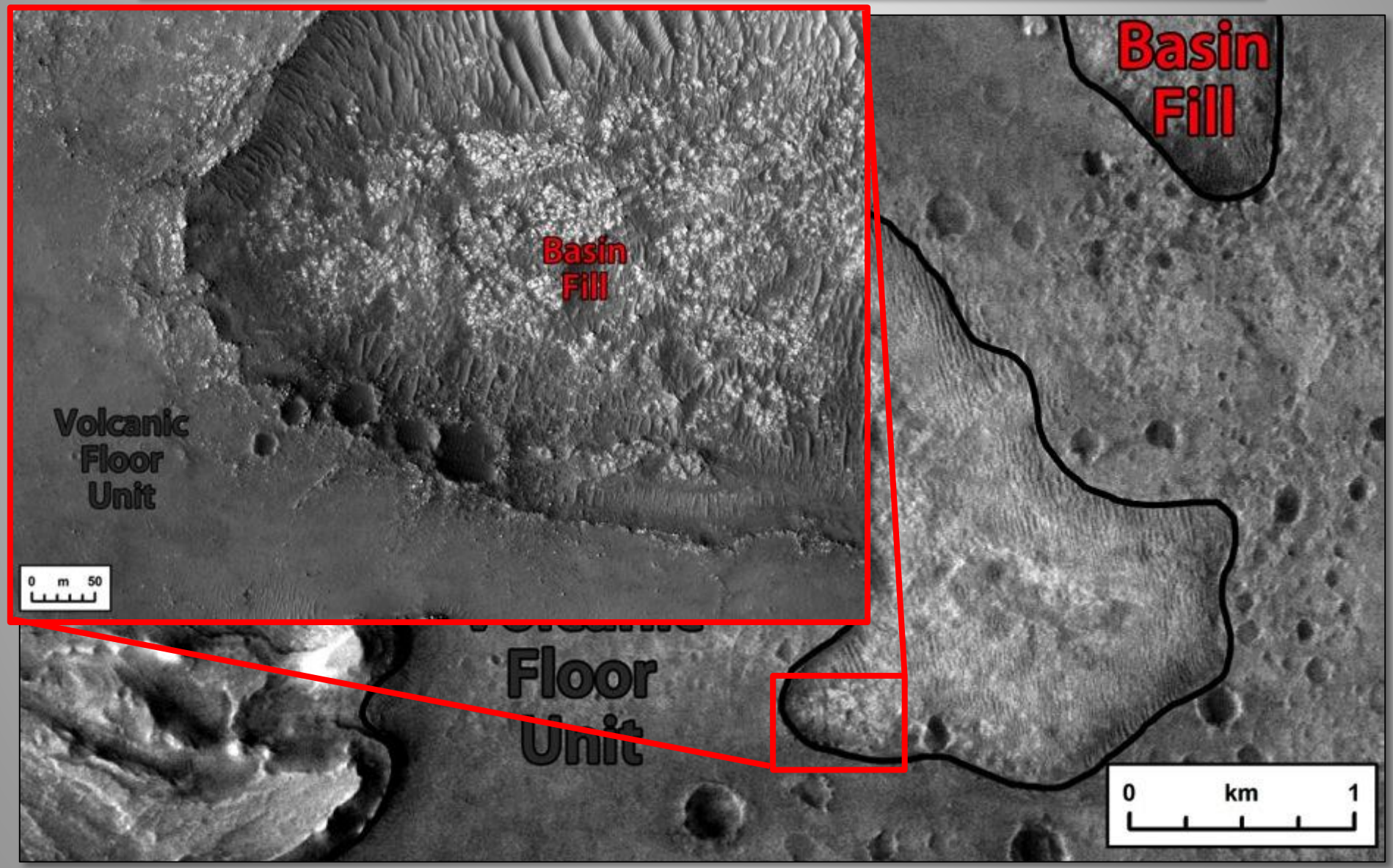
Carbonate units
Hydrothermal (<100°C) surface??
Hydrothermal (<100°C) subsurface??

ROI #2 – Basin Fill



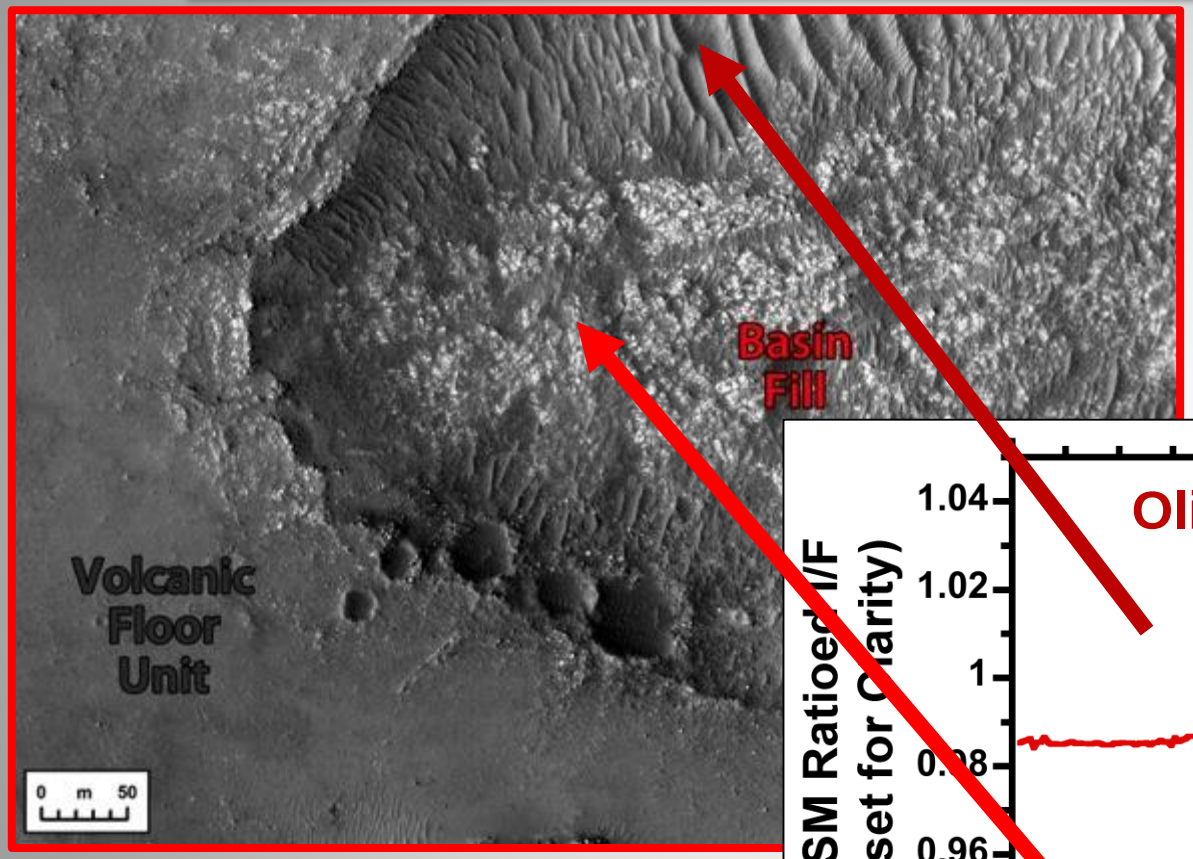
CTX Image P04_002664_1988.

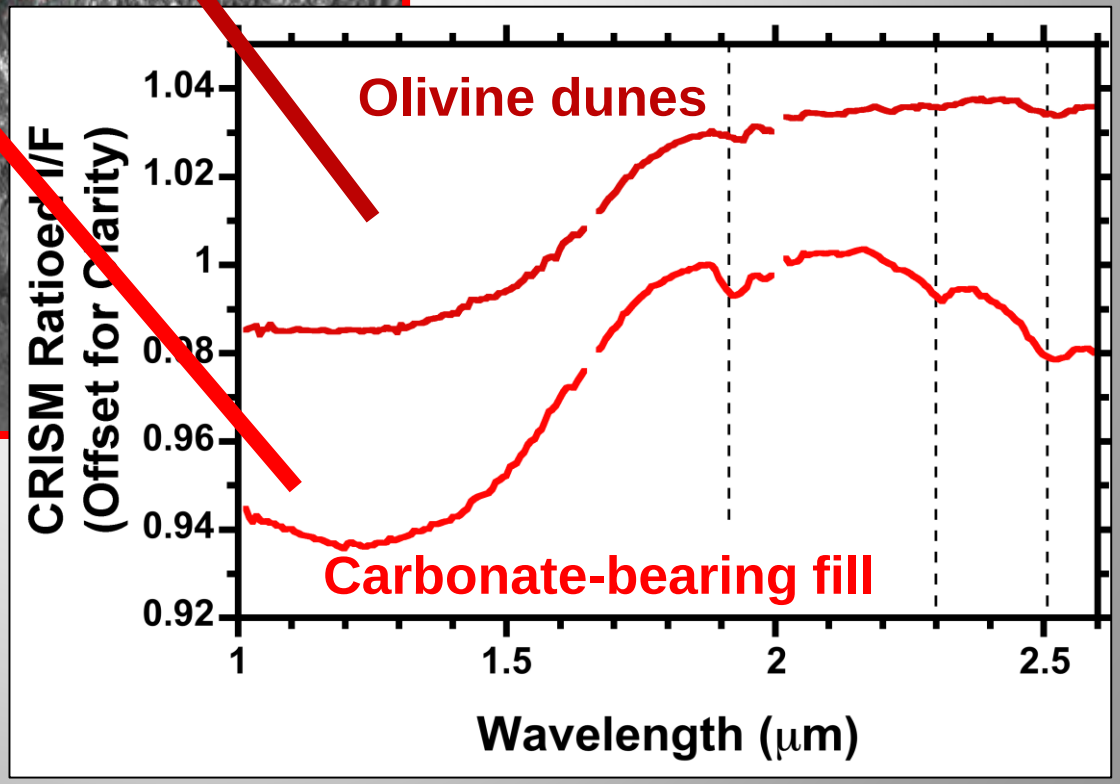
ROI #2 – Basin Fill



CTX Image P04_002664_1988, HiRISE Image PSP_002743_1985.

ROI #2 – Basin Fill





Testable Hypotheses with Mars 2020: Carbonate fill formed from alteration of an olivine-rich unit, prior to/during the lacustrine activity in the basin.

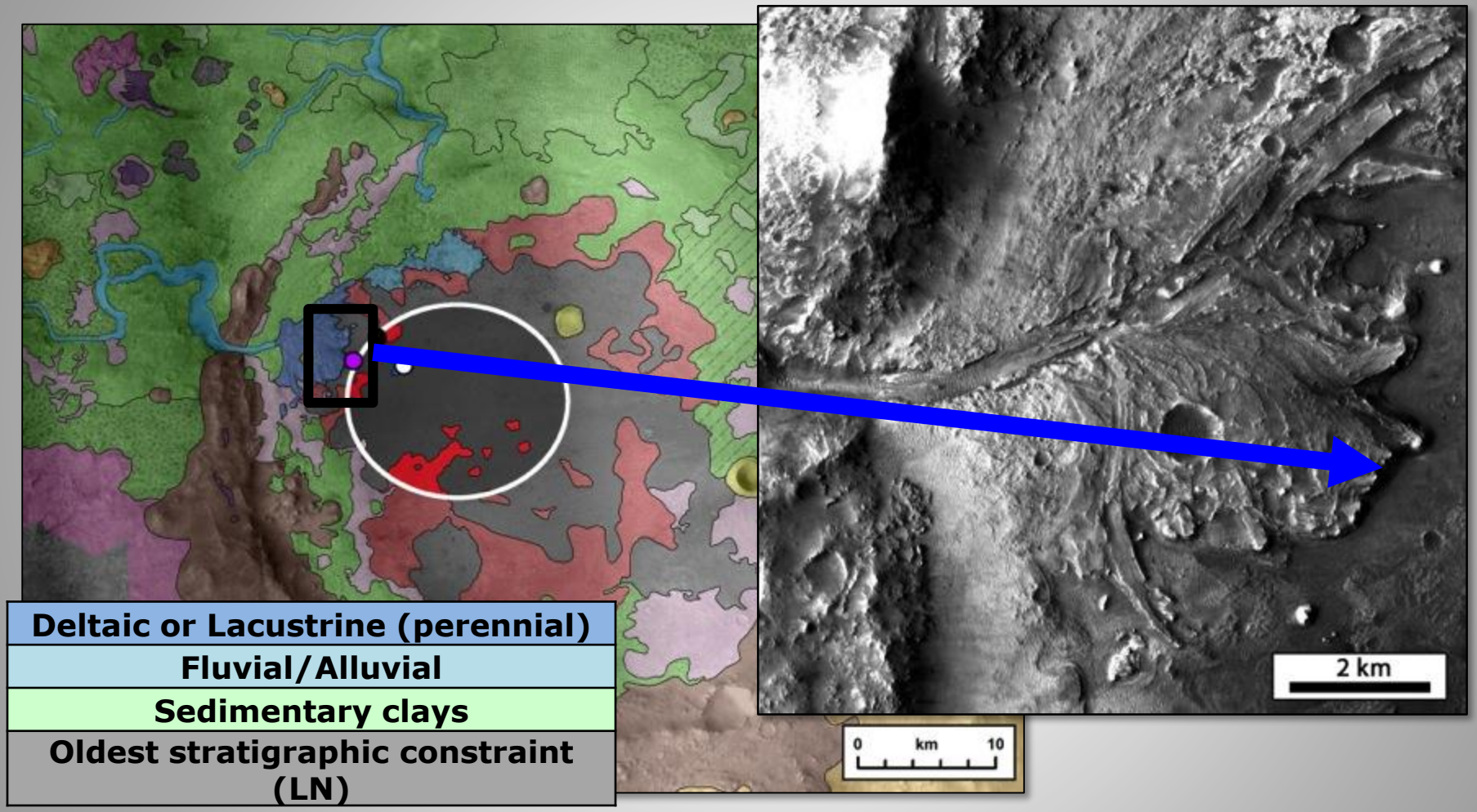
Regional Carbonate Unit

- Jezero carbonate is an *in situ* example of regional unit first mapped by *Ehlmann et al.* [2008b] [*Goudge et al.*, 2015].
- Carbonate is hypothesized to have formed from aqueous alteration of associated olivine-rich material [e.g., *Ehlmann et al.*, 2008b, 2009; *Mustard et al.*, 2009].
- Hypotheses for origin of protolith olivine unit include:
    - Isidis impact melt sheet [*Mustard et al.*, 2007, 2009].
    - Basaltic lava flows [*Hamilton and Christensen*, 2005].
    - Exposure of a subsurface layer [*Hoefen et al.*, 2003].

Importance of Carbonate

- Carbonate-bearing units are globally rare from an orbital perspective [*Niles et al.,* 2012].
- In situ analysis, and analysis of cached and returned samples provide unique opportunity to study:
  - Martian carbon reservoirs.
  - Atmospheric chemistry.
  - Surface-atmospheric coupling, including temperature of carbonate precipitation [e.g., *Halevy et al.,* 2011].

ROI #3 – Western Delta Scarp



Testable Hypothesis with Mars 2020: Deltaic sediment was deposited in a circumneutral pH paleolake that was habitable and had high potential for concentrating and preserving organic matter.

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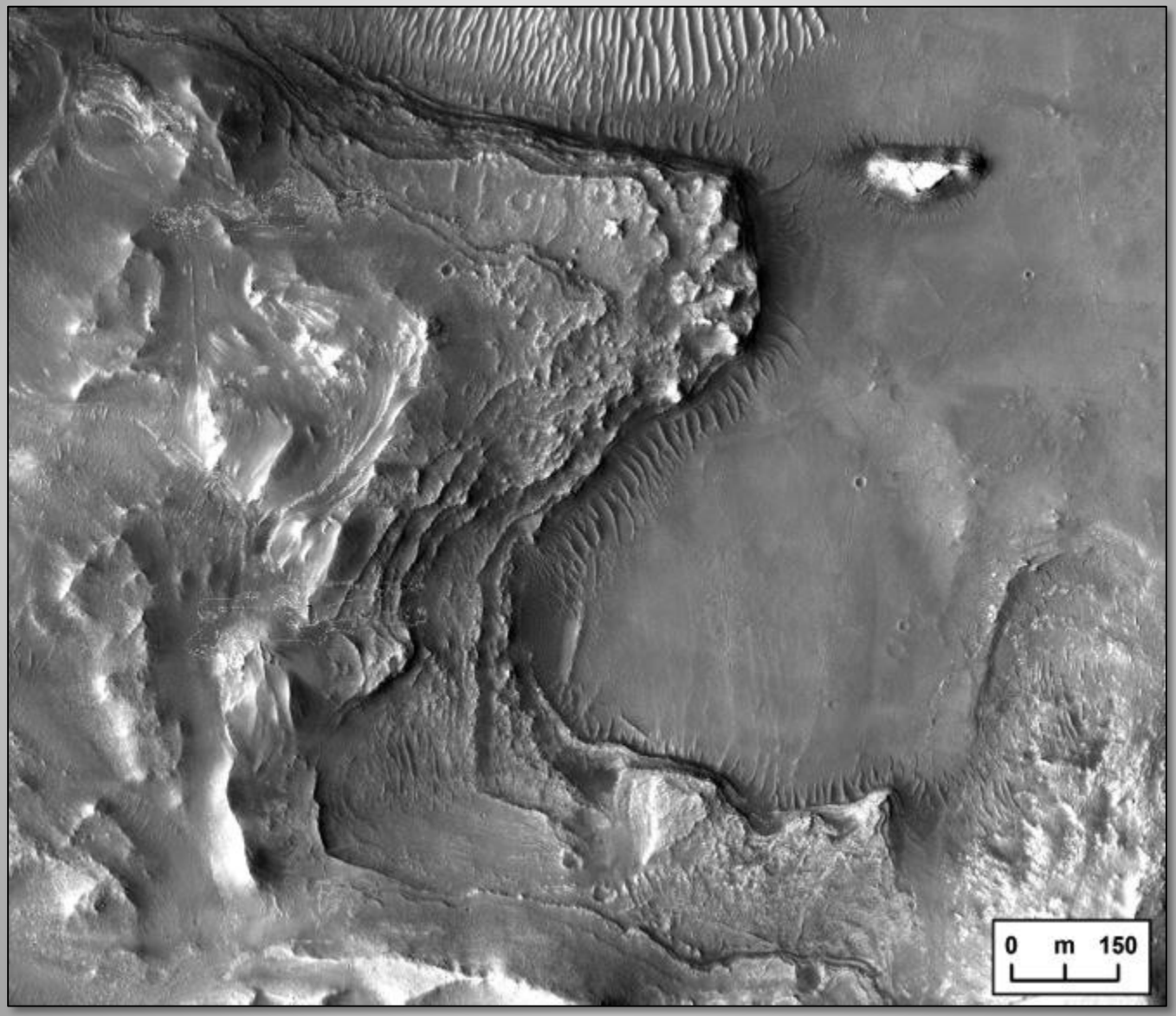
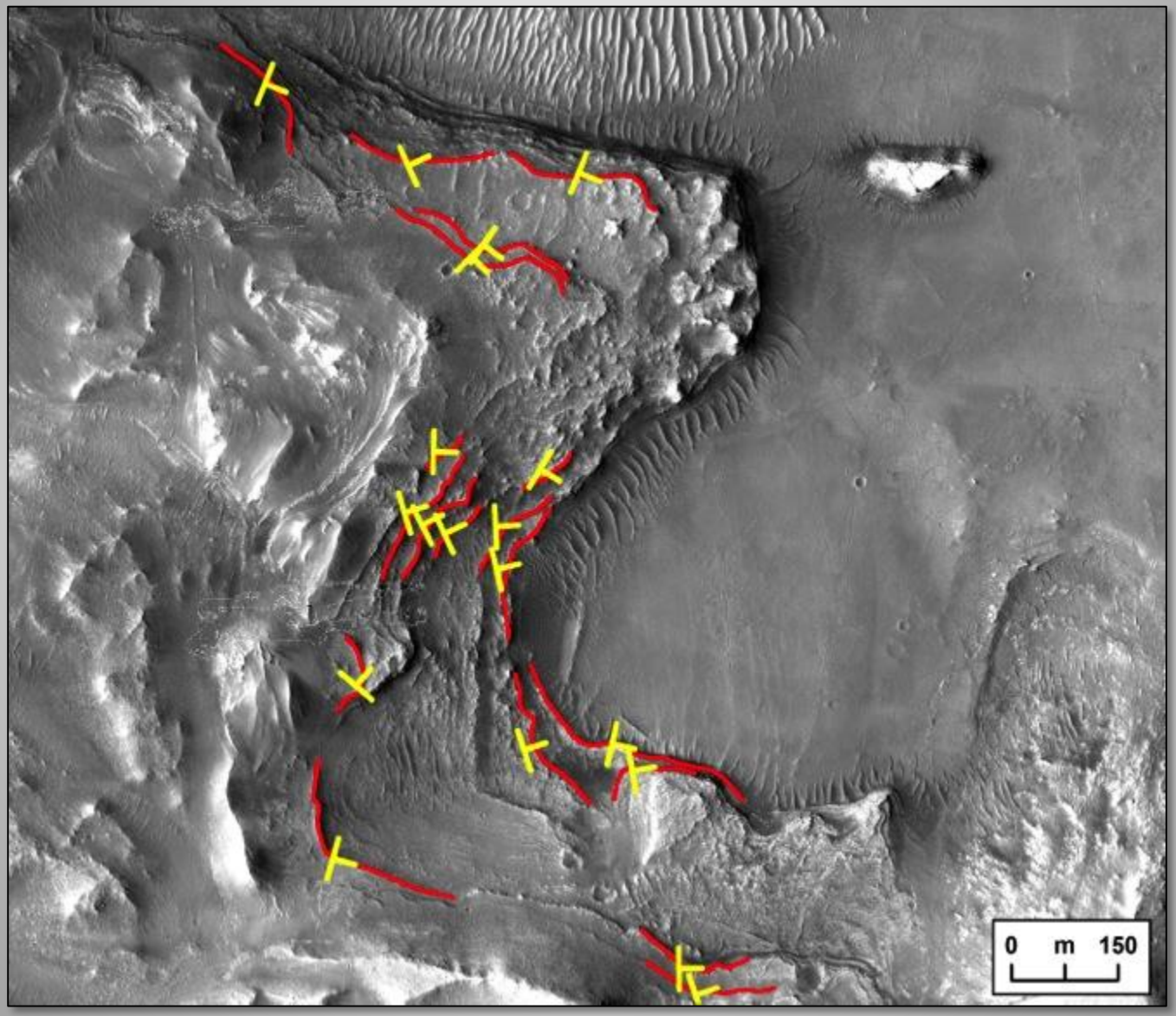
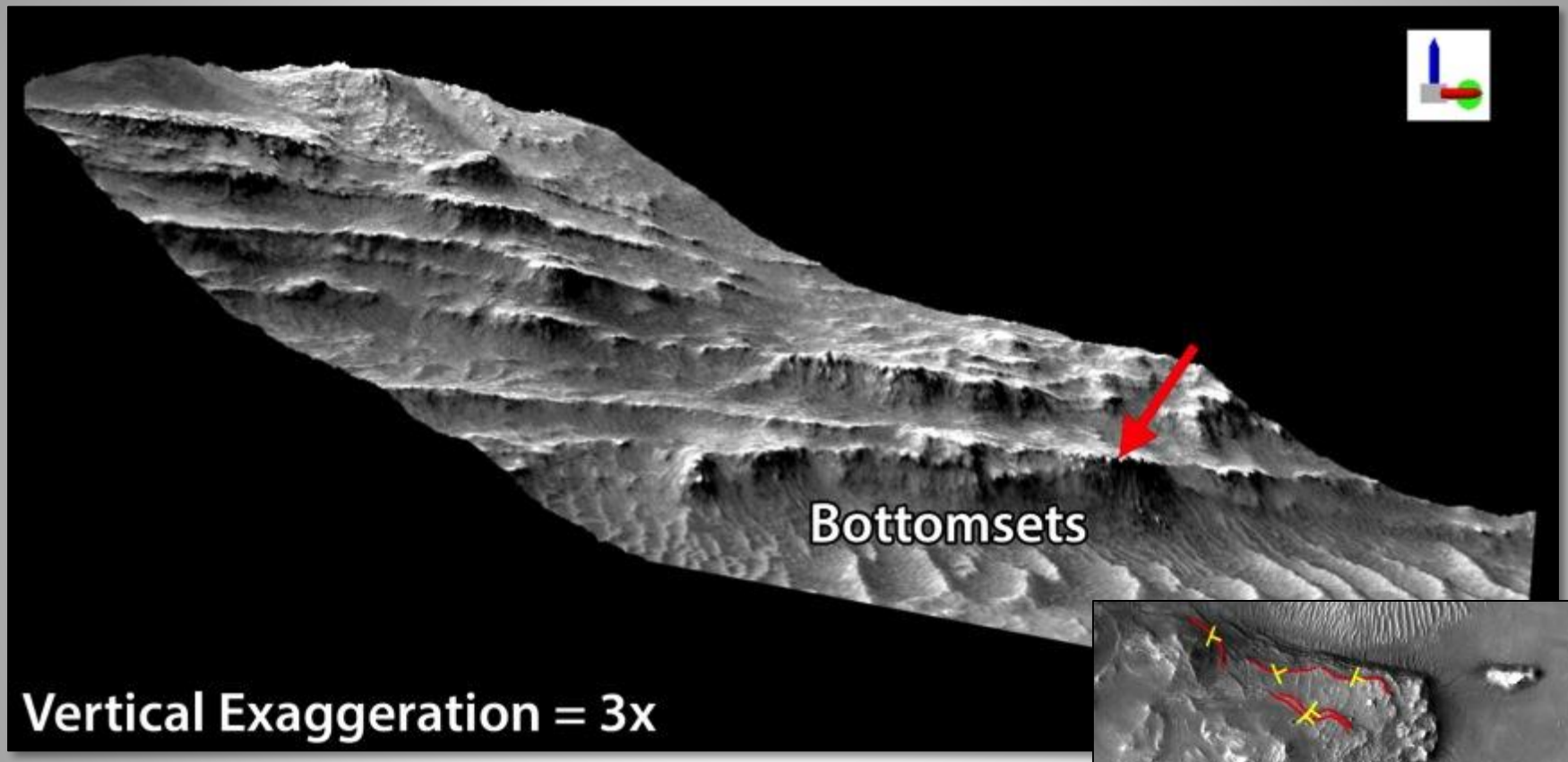
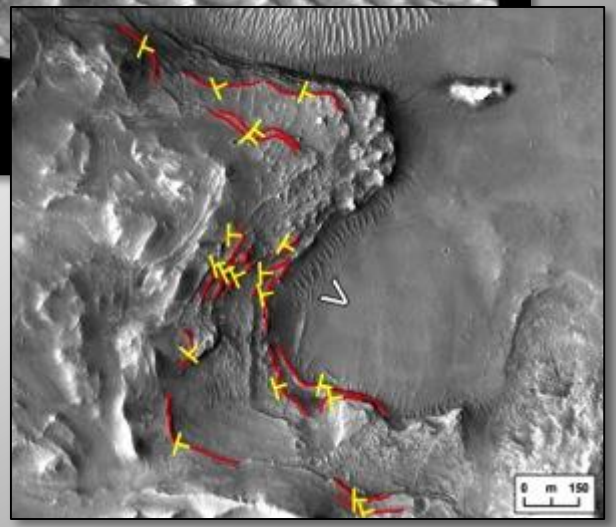


ROI #3 – Western Delta Scarp



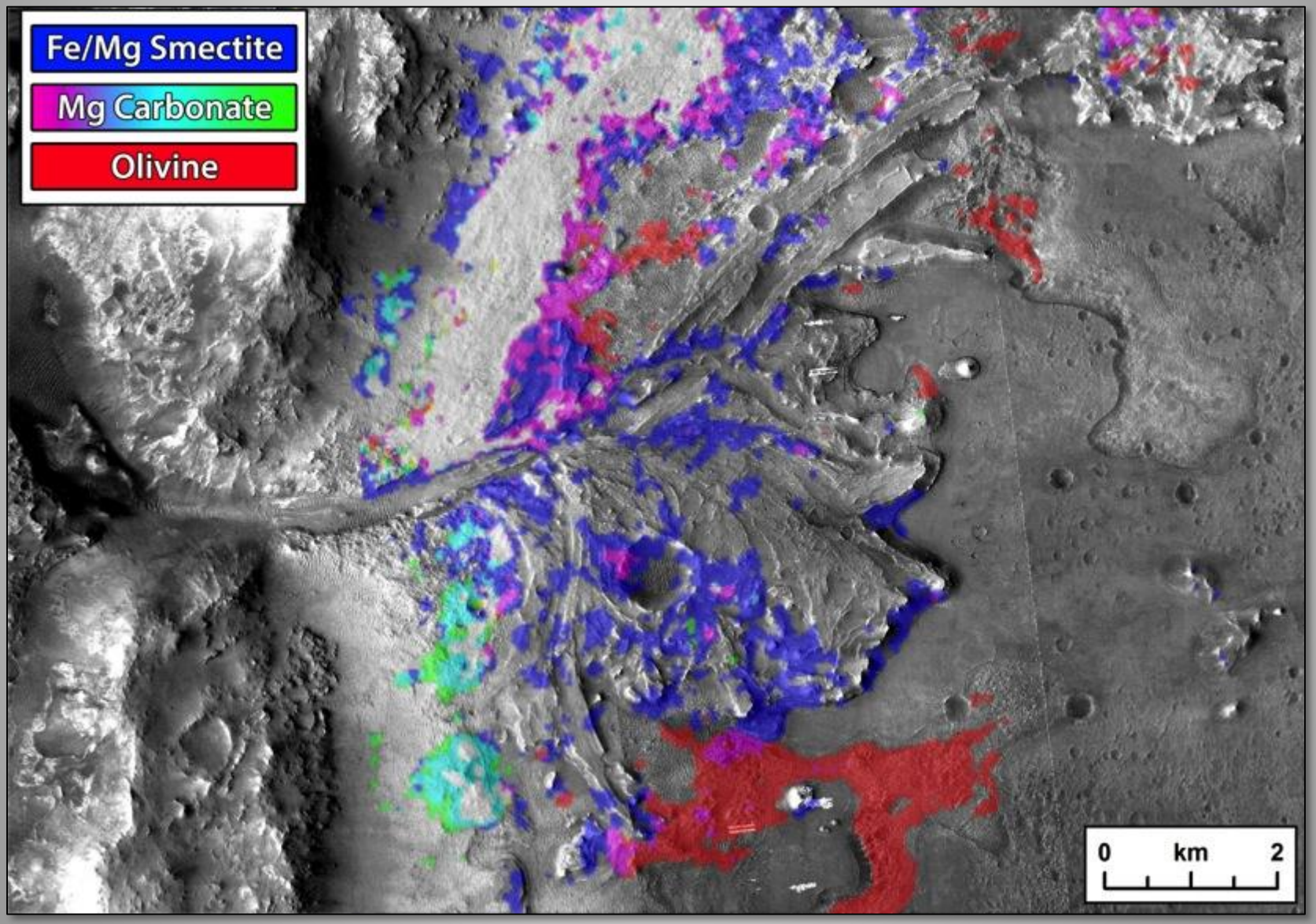
ROI #3 – Western Delta Scarp



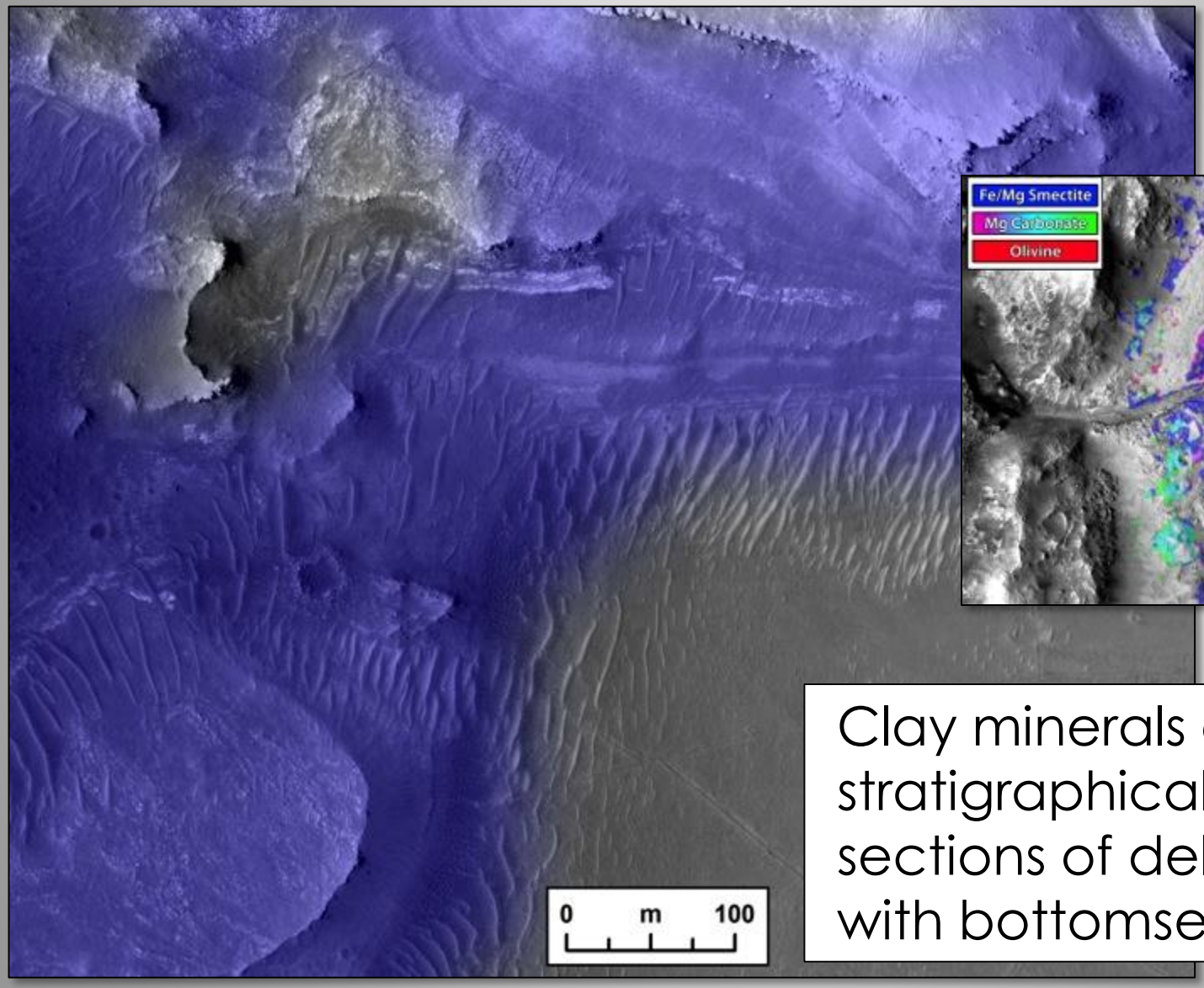


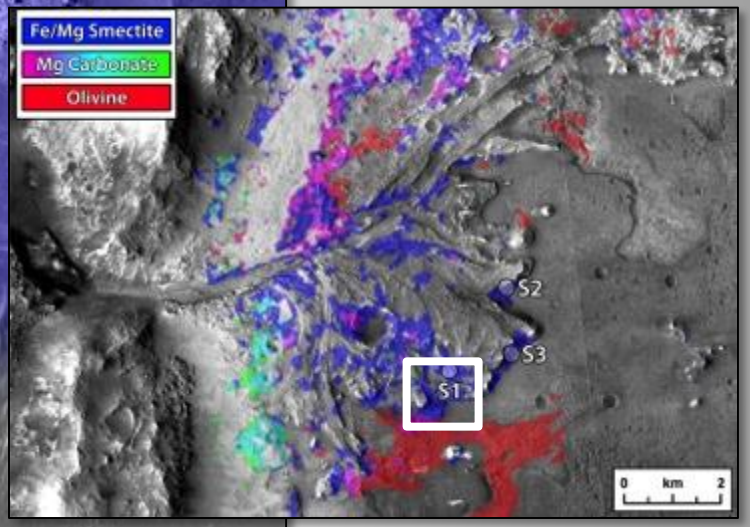
Flat, stratigraphically low units consistent with delta bottomsets. Higher strata exhibit downlapping layer truncations, suggestive of a prograding delta.

ROI #3 – Western Delta Scarp



ROI #3 – Western Delta Scarp

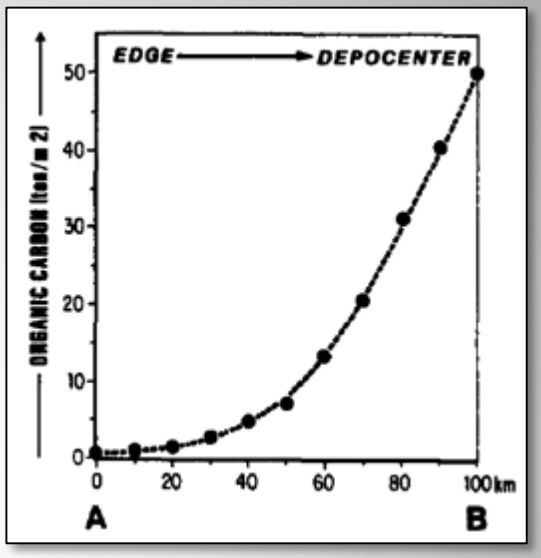




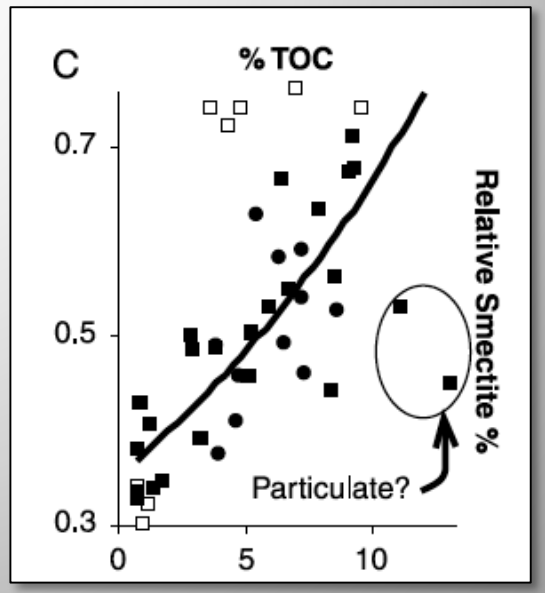
Clay minerals exposed in stratigraphically low sections of delta consistent with bottomsets.

OM Preservation in Delta Deposits

- Organic matter is often highly concentrated and well preserved in offshore deltaic environments [*Huc*, 1988; *Summons et al.*, 2011].
- Smectite clays have the ability to bind and stabilize organic matter [*Wattel-Koekkoek et al.*, 2001; *Kennedy et al.*, 2002; *Ehlmann et al.*, 2008a].
- **Fe/Mg-smectite-rich delta bottomsets at Jezero crater provide ideal location to explore for preserved martian organic carbon.**



Huc [1988]



Kennedy et al. [2002]

Jezero Crater Summary

- Jezero crater hosted a likely **habitable lacustrine environment**, and preserves volcanic, alteration mineral-bearing (smectite + carbonate), and fluvio-lacustrine units in a **well defined stratigraphy**.
- **Sink for regional sediment** – ability to examine and cache samples from one of the most alteration-mineral-rich regions on Mars.
- **Mineralogic and morphologic diversity** exposed in ellipse, plus delta at edge of ellipse.
  - Western delta would allow for exploration of well-exposed deltaic bottomsets, which provide **excellent accumulation and preservation potential for organics**.