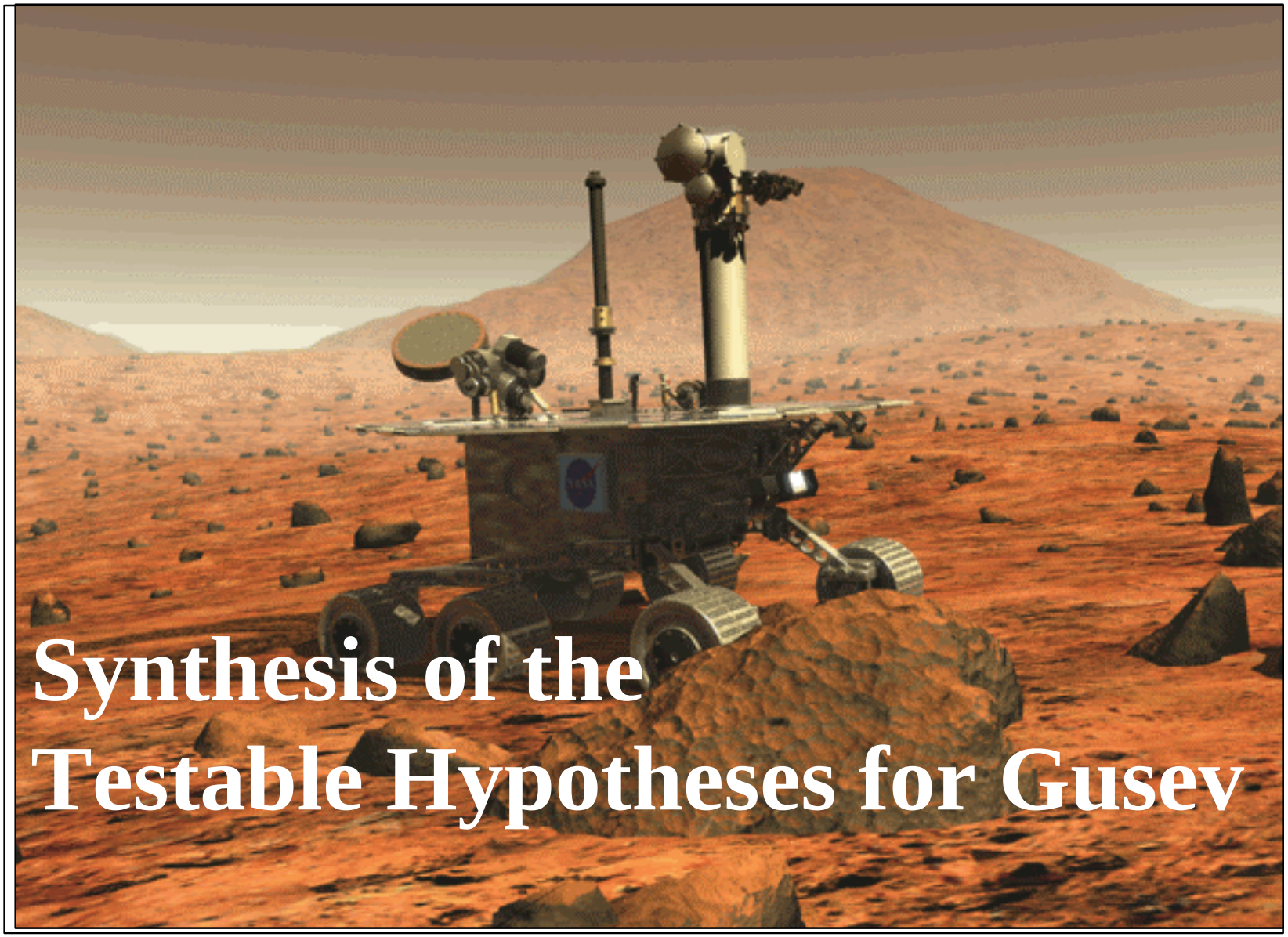

Synthesis of the Testable Hypotheses for Gusev

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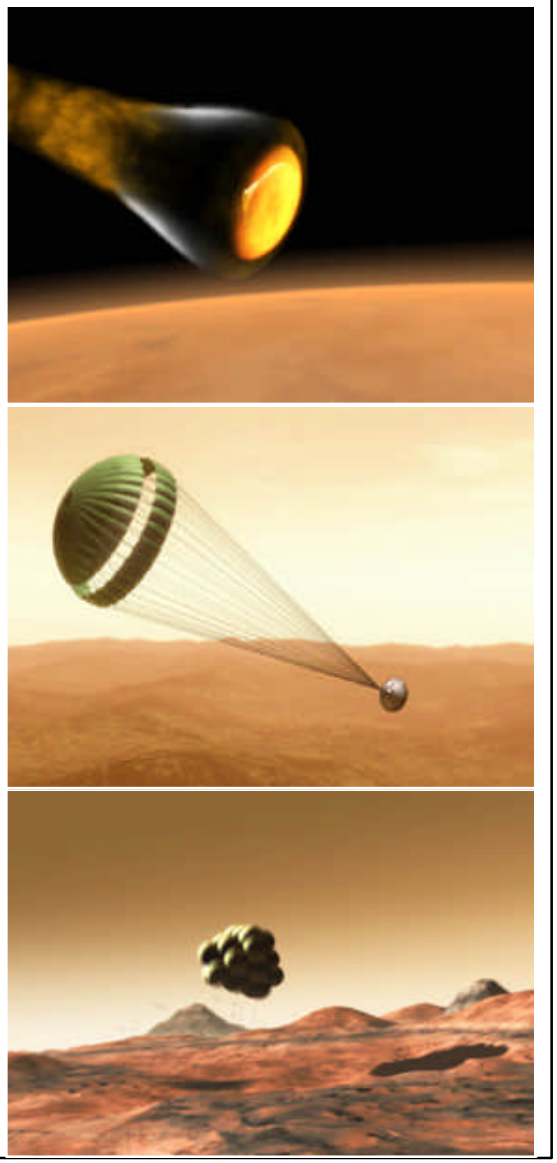
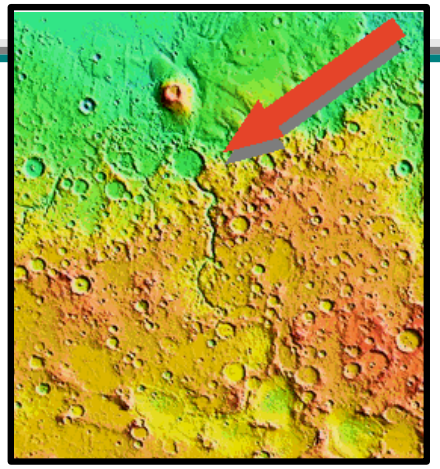


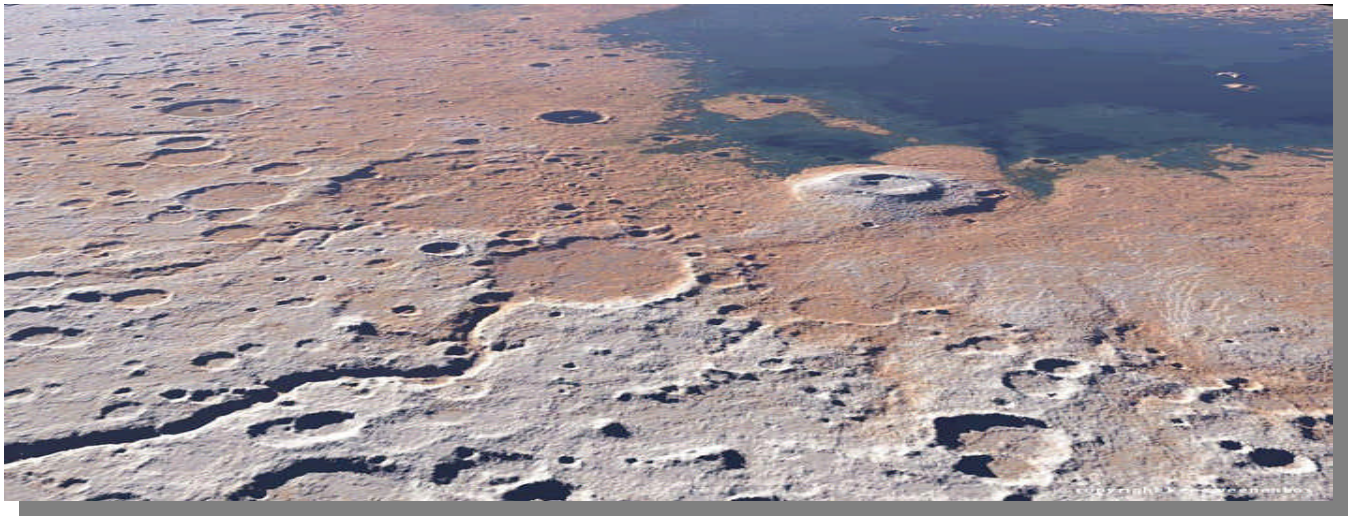
Keys for an Outstanding MER A Mission



- **A unique site configuration**:
  - Valley: Ma'adim Vallis
  - Volcano: Apollinaris Patera
  - Basin: receptacle for a potentially **broad diversity** of material (*aeolian*, *fluvial*, *lacustrine*, *volcanic*, *glacial*)
- **Age: 3.9 Ga**
  - Noachian may be accessible in ellipse in ejecta material;
  - Hesperian and Amazonian accessible at the surface and in exposures.
- **Broad Diversity of Units in the Ellipse**
  - Morphological diversity, and
  - Geological and mineralogical diversity (see also THEMIS)

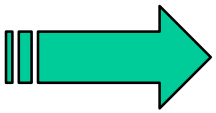
Keys for an Outstanding MER A Mission

- **Many testable hypotheses at various scales**:
  - Global, Regional, Local.
  - Allows to test the new hypotheses on the meaning of hydrogen abundance (MO) and recent climate changes (MGS and MO).



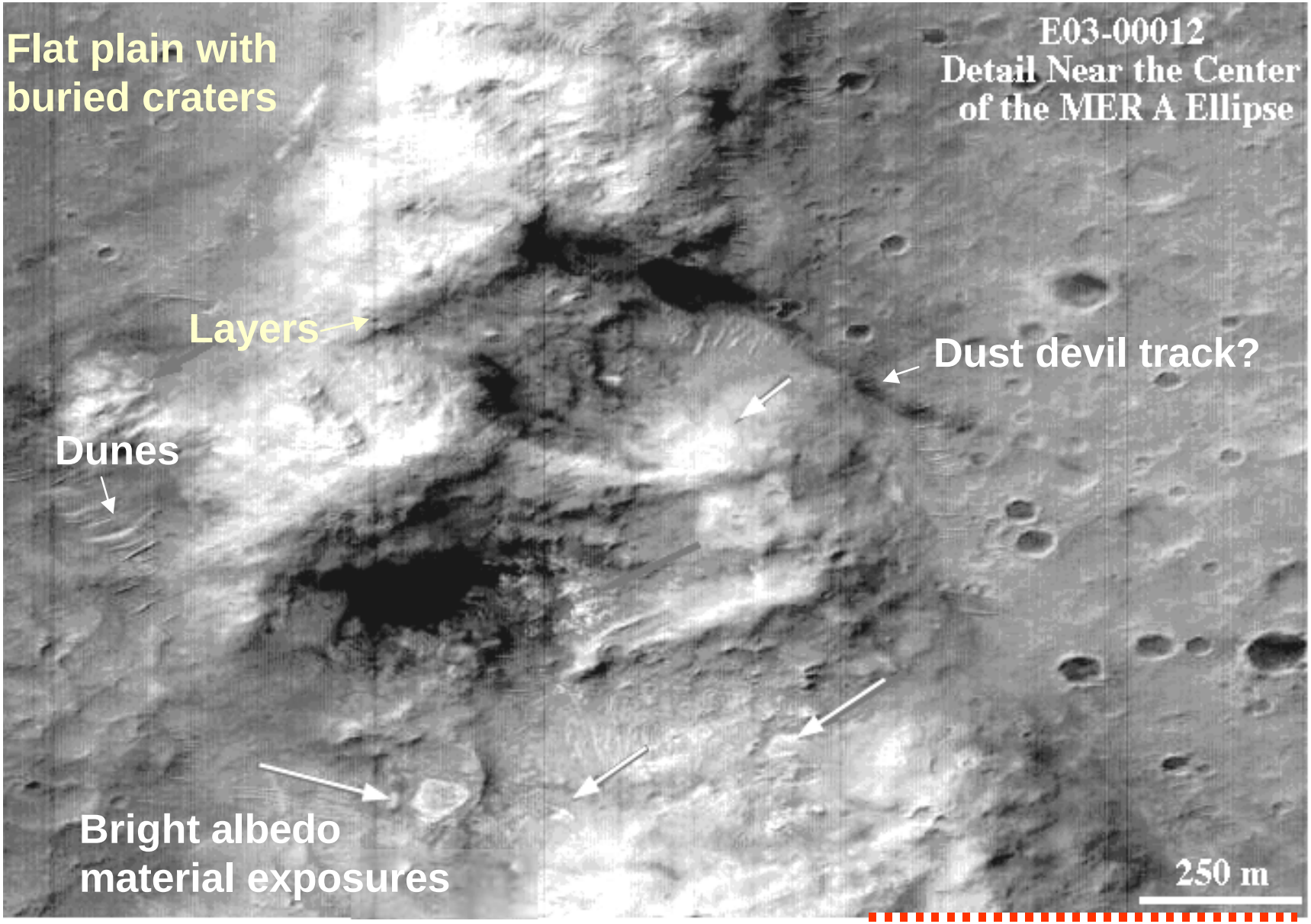
Diversity in Landing Ellipse

- Complex and intriguing site:
  - Diversity of morphologies
  - Diversity of terrains
  - Diversity of units
  - Diversity at rover mission traverse scale

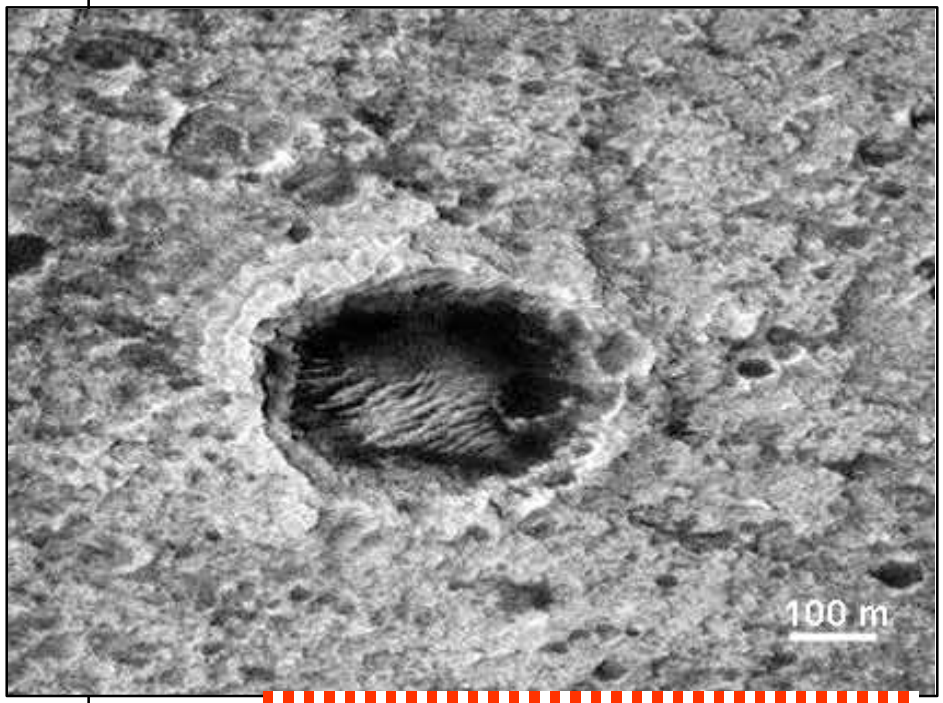


High potential for rewarding mission wherever the landing occurs in the ellipse.

- Layered Hills and Variable Albedo Material. Center Ellipse -

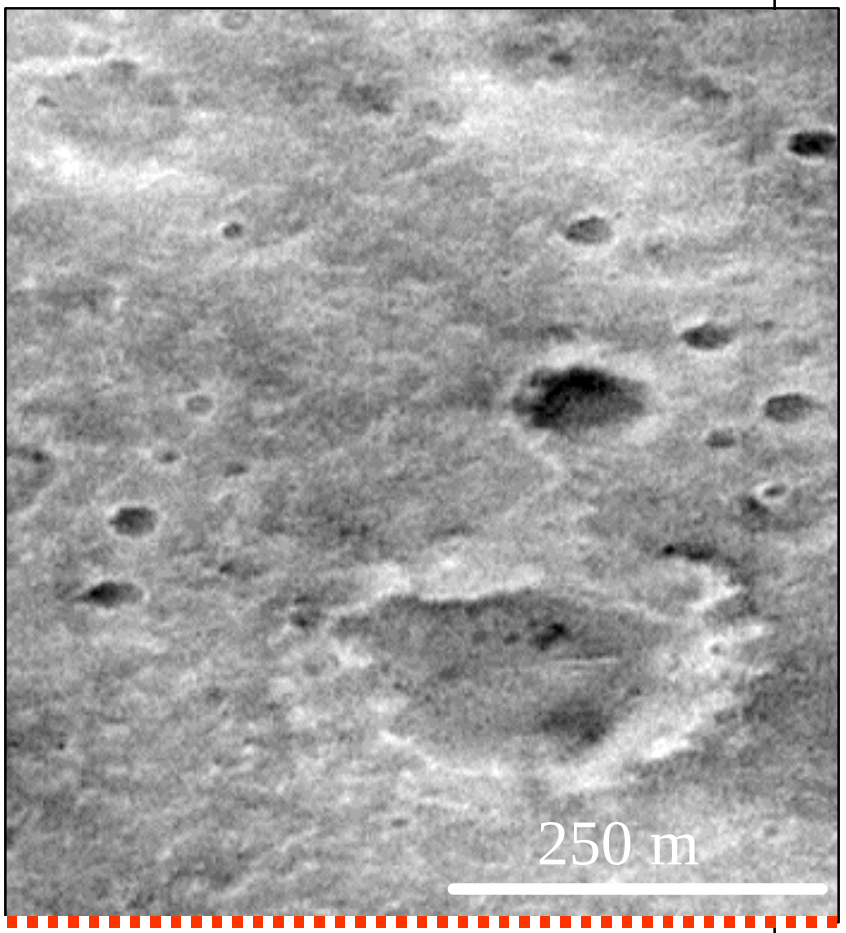


- Eroded Crater and Layered Material -



Eastern Ellipse

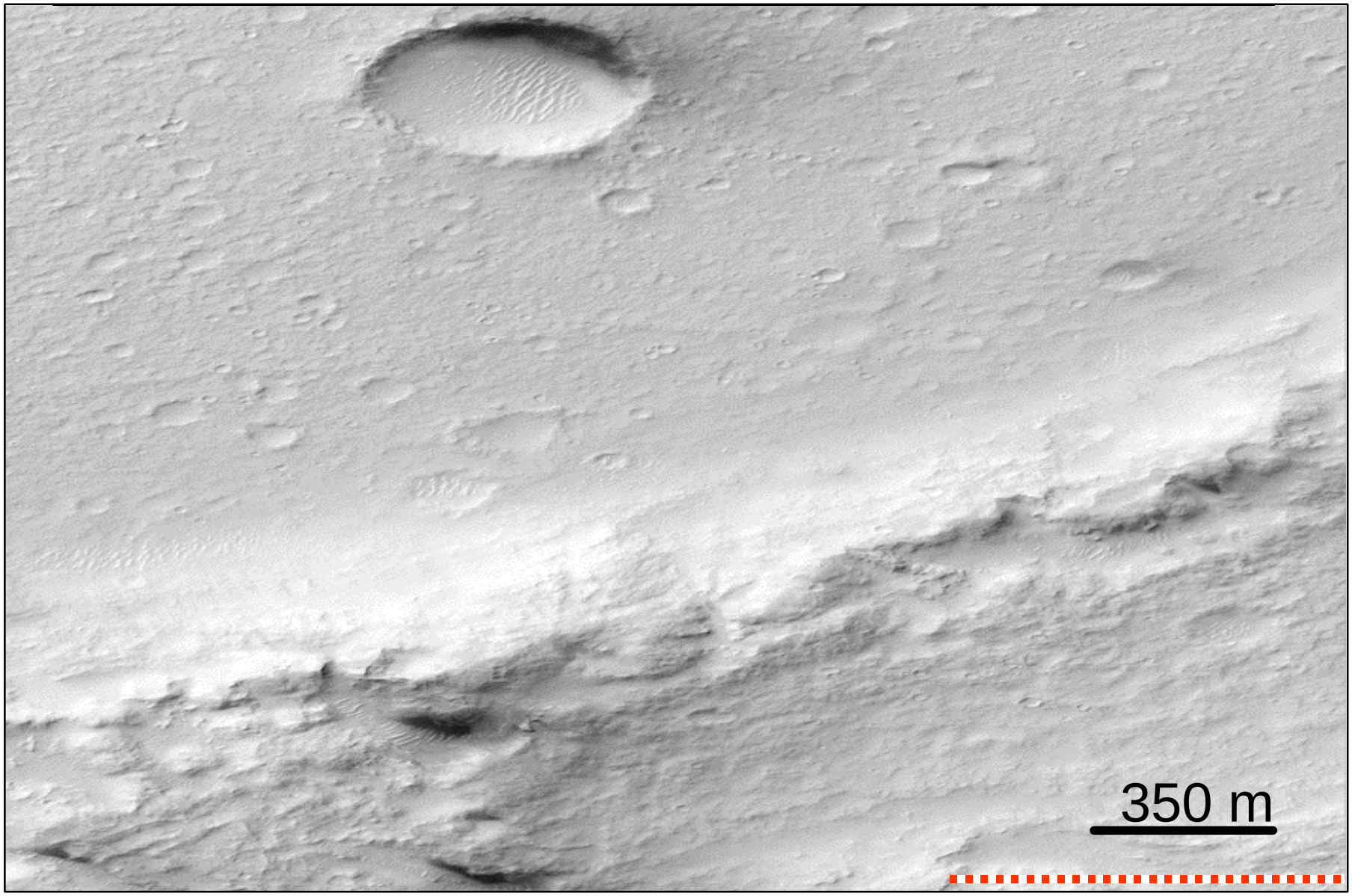
E05-00471



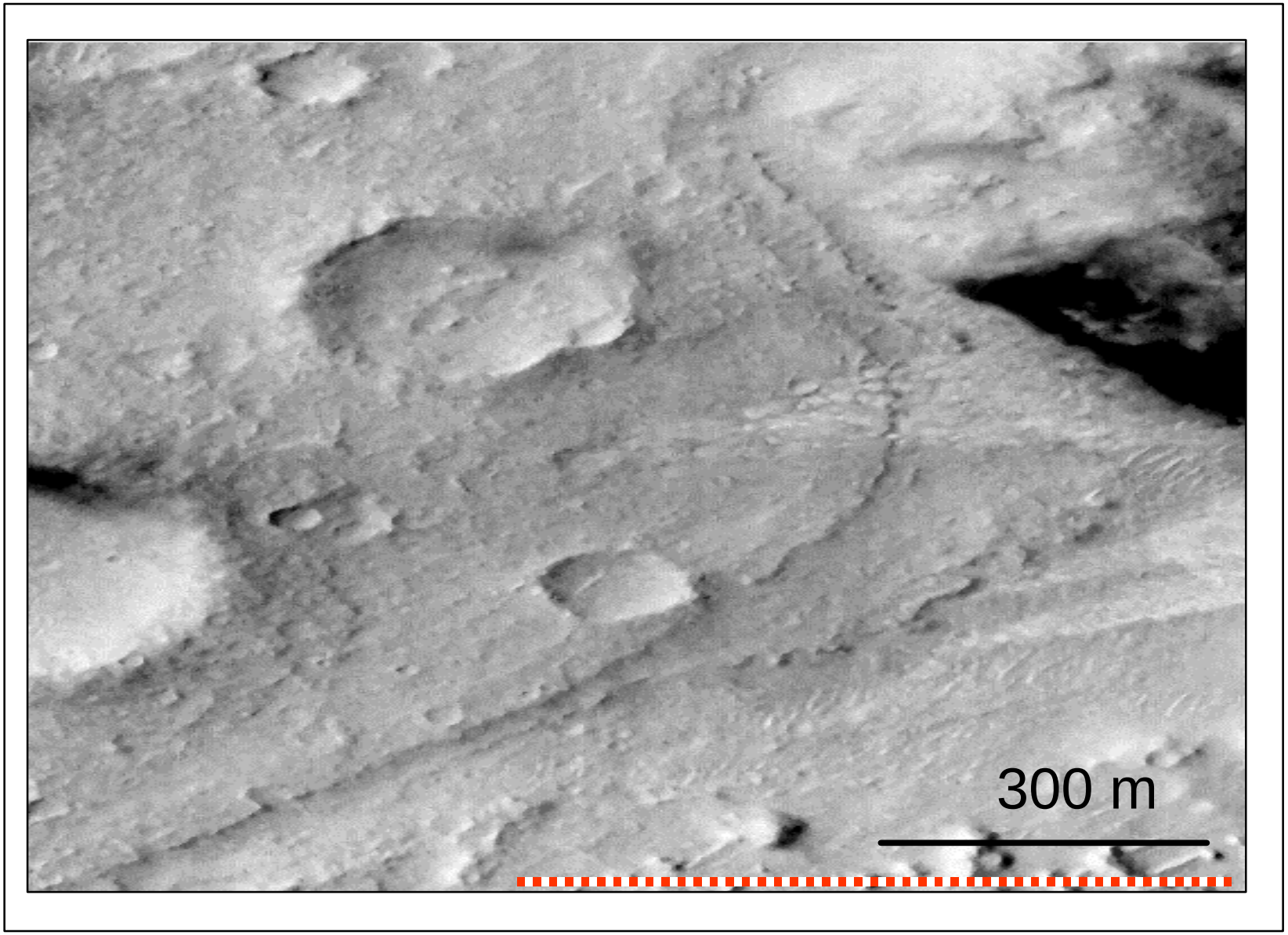
Center Ellipse

E13-01593

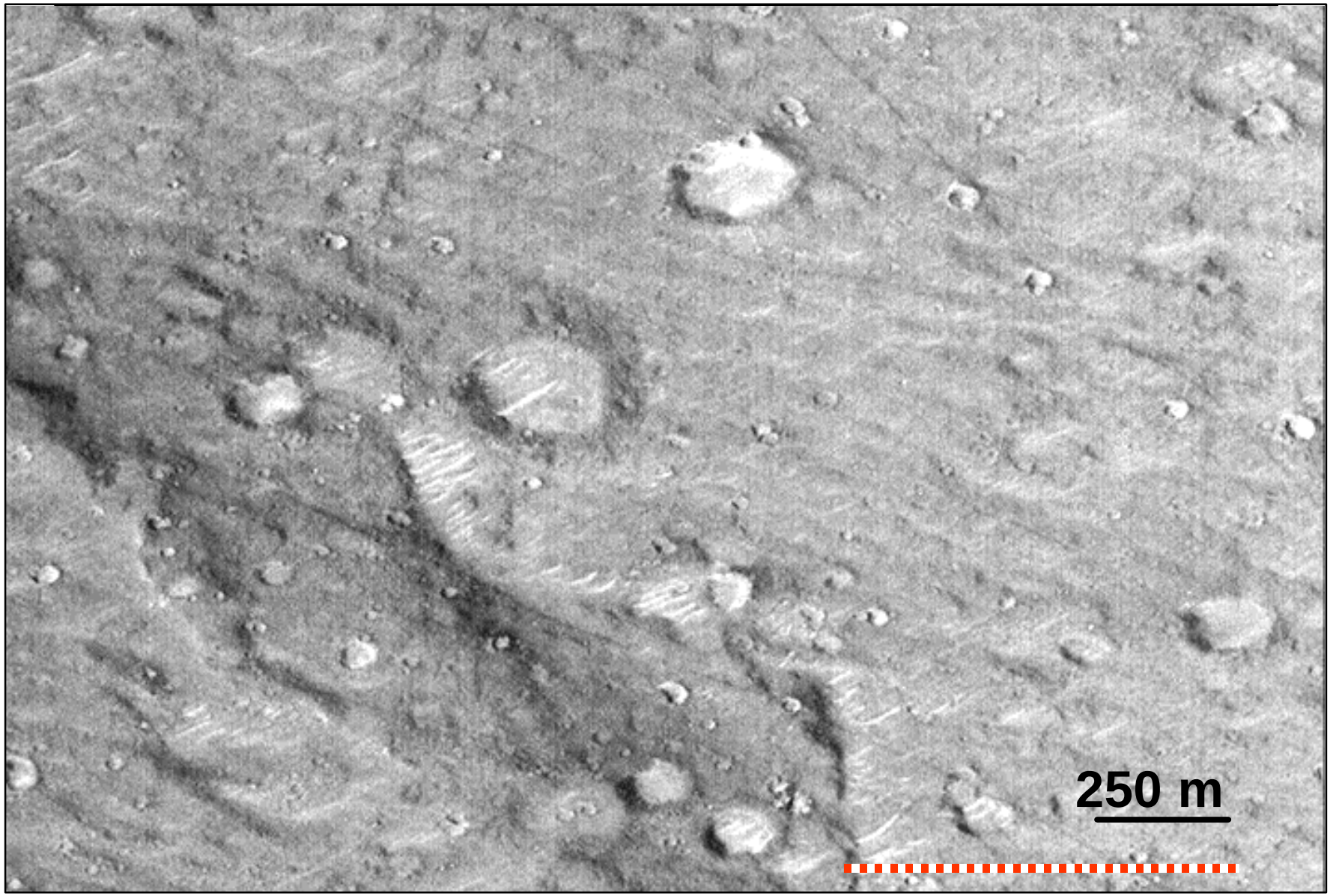
- Flat Cratered Plain, Thyra, Eastern Ellipse -



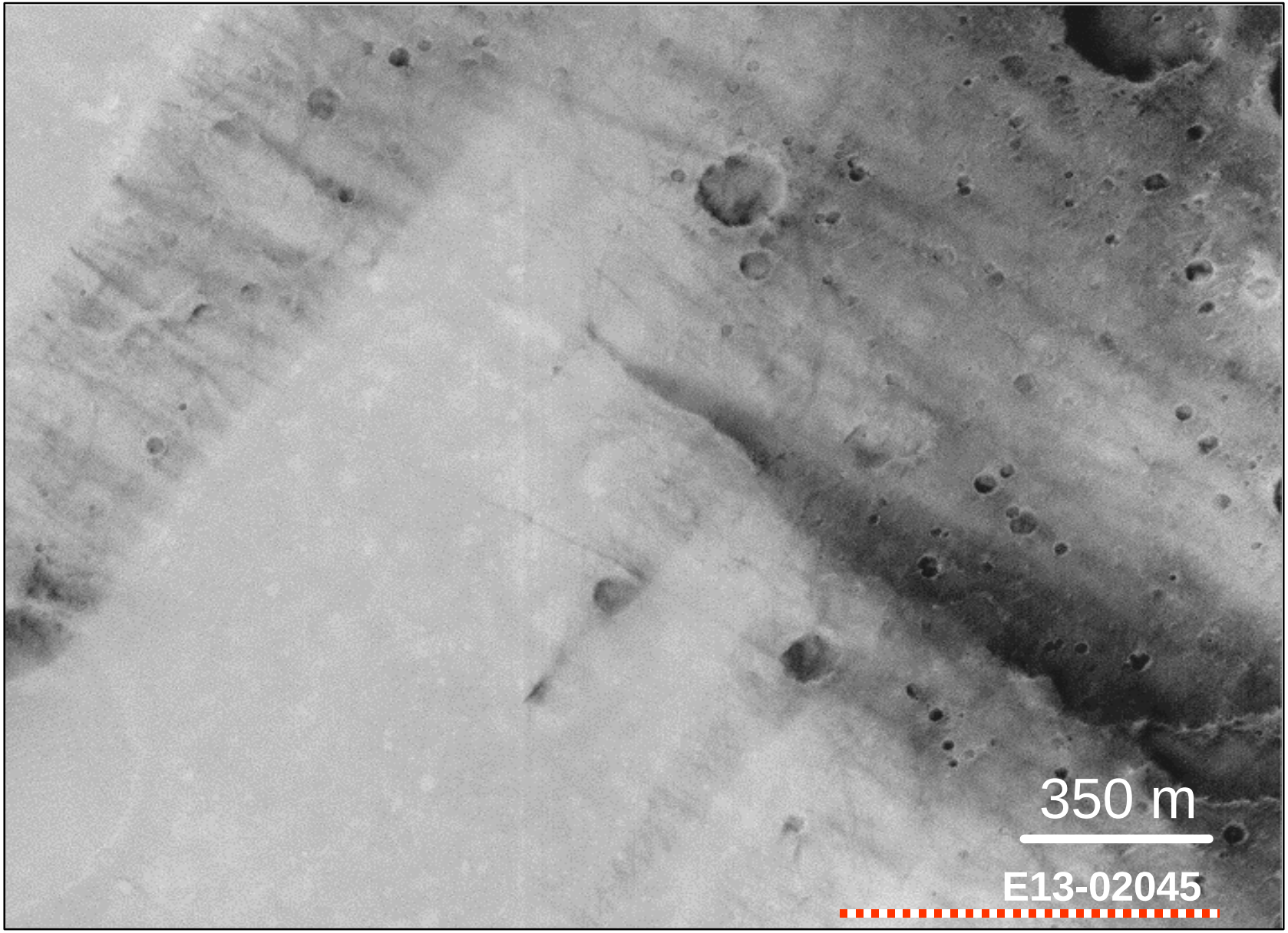
- Terraced Material, Buttes, Thyra region, Eastern Ellipse -



- Eroded Deposits and Dunes. Center West Ellipse -



- Wind Deflated Areas, Dust Devil Tracks, West Ellipse -



Questions and Hypotheses

- What origin(s) for these:
  - Materials and deposits
  - Units
  - Landforms
- What Gusev will teach us about Mars at:
  - Global Scale
  - Regional Scale
  - Local Scale

Scales of Testable Hypotheses in Gusev

- **I. Global**:
  - *Hypotheses based on the plausible origins of the processes that have affected --are still affecting- the planet at global scale, have been recorded in Gusev and will give information not only about Gusev but also about the planet evolution, water, climate changes, and habitability potential through time both for Gusev and Mars.*
- **II. Regional:**
  - *Hypotheses based on the plausible origins of the processes and materials in the hydrological basin and the geological region of Gusev and Ma'adim that relate to the deposits, rocks, soils, minerals, features, and landforms observed in Gusev today.*
- **III. Local:**
  - *Hypotheses based on the plausible origins of the deposits, rocks, soils, minerals, features, and landforms observed in the ellipse and crater basins.*

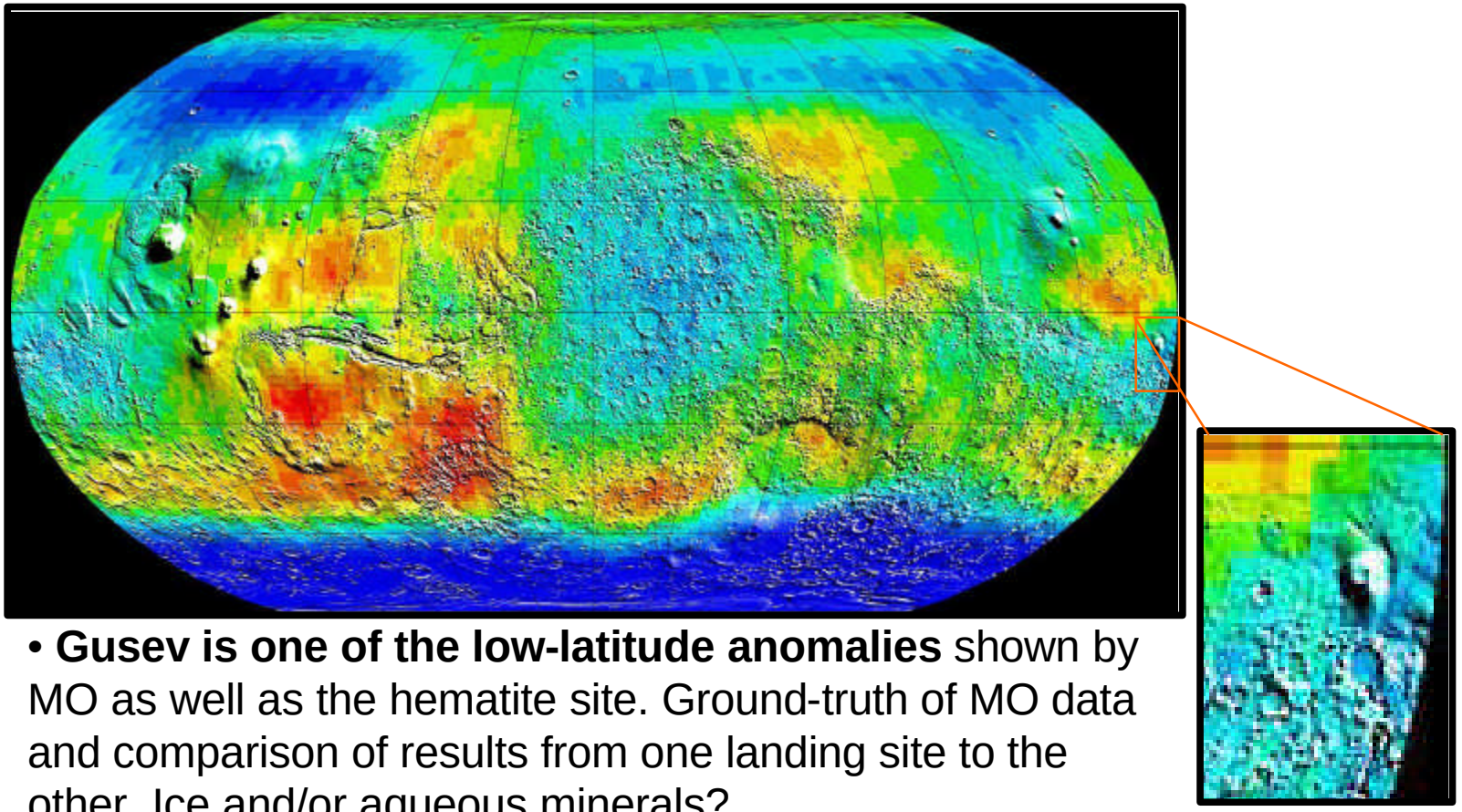
***Global Scale**: Gusev and the Significance of Mars Odyssey Map of Hydrogen Abundance*

How the investigation of Gusev by MER A can uniquely *ground-truth* the question raised by MO about hydrogen abundance and complement the orbiter mission?

- **#1. Gusev shows a high hydrogen abundance in the MO global map of epithermal neutrons. Hypotheses:**
  - ***#1.1. Ice is close to the surface in Gusev and stable today.***
  - ***#1.2. MO hydrogen signature reflects an abundance of hydrated minerals related to a past aqueous activity***
  - ***#1.3. All the above.***

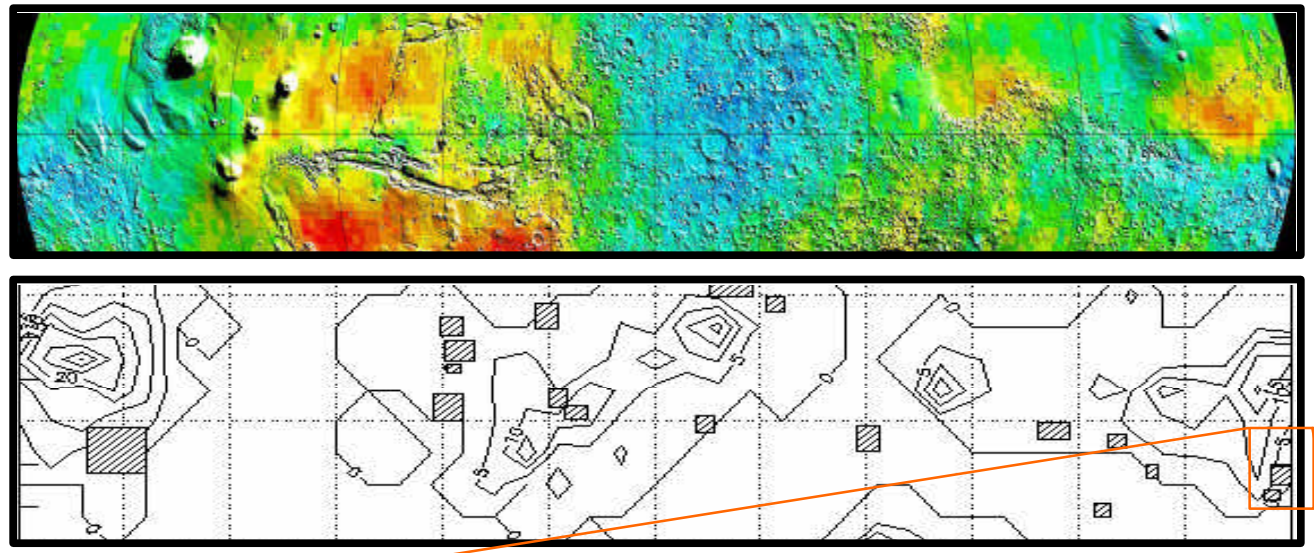
Implications: A new vision of water on Mars, habitability potential, and its current reservoir. Ground-truth of orbital data.

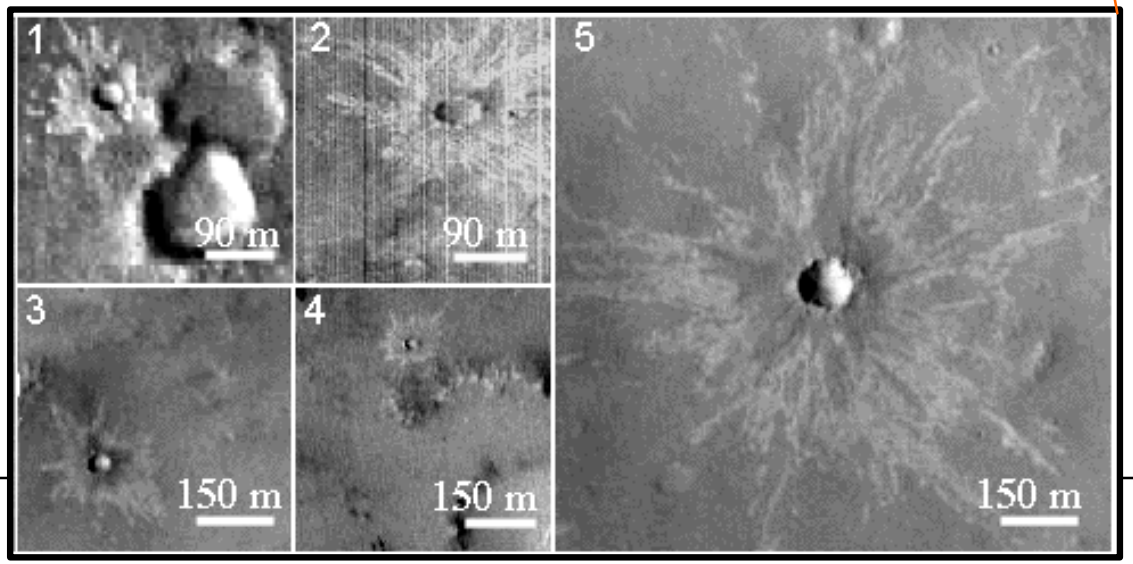
MO Map of Epithermal Neutrons



- **Gusev is one of the low-latitude anomalies** shown by MO as well as the hematite site. Ground-truth of MO data and comparison of results from one landing site to the other. Ice and/or aqueous minerals?

Could Ice be Stable Near the Surface in Gusev?





MO: Comparing Gusev and Hematite Results

- **Gusev and Hematite** are both located in regions showing high abundance of hydrogen.
- Their abundances are similar to that of high-latitude regions (~50º latitude) and could correspond to up to **35 ±15 %** of subsurface H20 **within 1 m** of the surface.
- Similar abundances but very different landscapes and histories. Meaning? It is important to compare the two sites (e.g., how morphologies, mineralogies relate to abundances).Strong complementarity between the two sites.
- ***Isidis and Elysium*** do not show high hydrogen abundances and therefore will not allow the testing and ground-truthing of one of the most critical hypothesis about recent water on Mars raised since the past 30 years.

Testing the MO Hypotheses in Gusev

Instrument	Abundant Near-Surface Ice	Aqueous Minerals
PanCam	**Step 1.** Search for abundant cryokarstic features: • Pits, small cavities • Irregular landscape at small to large scale • Observation of frost, icy deposits.	**Step 1.** Variable landscapes • Perenial Lake (flat, homogeneous surface) • Ephemeral Pond (evaporite) • Runoff (localized deposits, exposures) • Outflow (ridges, debris, rocks)
RAT	**Step 2.** If ice is present close to the surface, it could be stable. Rating is a priority. Goal: expose ice-rich material.	**Step 2.** Clean surfaces of dust to acquire spectra
MiniTES	**Step 3.** Tasks: • Acquire spectra of icy and hydrated material. • Characterize the temperature of the ice-rich soil (thermophysical properties). • Detect water vapor in the atmosphere (from sublimation)?	**Step 3.** Acquire spectra to search for and deternine the nature of: • Clays • Muds • Evaporite Sequences
MI	**Step 4.** Obtain micrographs of ice crystals.	**Step 4.** Micrographs to characterize: • Abundance of matrix < resolution • Distribution of grain-size and shape
APXS	**Step 5.** Elemental composition of soil.	**Step 5.** Elemental composition of soil and rocks.
Mössbauer	**Step 6..** Composition and abundance of iron-bearing minerals.	**Step 6.** Composition and abundance of iron-bearing minerals.

** The two hypotheses do not exclude each other.*

Global Scale: Airfall Deposits

How the investigation of Gusev by MER A will allow the investigation of a 3.9 Ga basin which collected material recording all major atmospheric changes and climate cycles.

- **#2. Sediments in Gusev are made of material extracted over the planet and deposited in the basin by global atmosphere circulation.**
  - *#2.1. Deposits may include ice from cyclic atmospheric freeze out ("White Mars" hypothesis, Nick Hoffman) and volcanic material.*

Implications: There might not have been any lake in Gusev. However, the mission will provide a deep insight into climate and atmosphere evolution. Other consequences: How to read MO's hydrogen signature? How does it fit the "White Mars" model?

Testing the Airfall Deposits Hypothesis

- ***PanCam***: detection of > 20 m thick loess deposits with little stratification.
- ***MI***: Grain size not easily discernable (loess), mostly below instrument resolution.
- ***MiniTES***: Similar multi-spectra characteristics as MPF soil.

- ***APXS***: Similar elemental chemistry as MPF and VL1, 2 soil.
- ***RAT***: important to verify that subsurface materials shows comparable characteristics.
- ***Rover Mobility*****:** should be used to confirm repetition of sequences from one science target to the other.

Regional Scale: The Lake Hypothesis

How the investigation of Gusev by MER A will allow the investigation of a 3.9 Ga basin which collected material recording lacustrine events and possibly biological evidence.

- **#1. Gusev hosted lakes in its history.**
  - ***#1.1. Perenial (long, sustained), possibly glacial***
  - ***#1.2. Ephemeral (short-lived, playas)***
  - ***#1.3 Favorable for life development and preservation***
  - ***#1.4. All the above***

Implications: Water was flowing and ponding on Mars. Studying the deposits and mineralogies exposed in Gusev will help better understand its evolution through time, climate variations through mineralogy and morphology, and the habitability potential of Mars.

Testing the Lake Hypothesis

- **PanCam**: Layers, varve thickness, sorting, rounding, grain-size, discontinuities in beddings, intermixing of material from different origins (i.e. dry cycles), morphology
- **Mini-TES:** Aqueous minerals, clays...
- **MI**: thin varving, mud, clay/silt, cementation, microflame and convolution for glacial lake sediments). Complete study of varving by providing grain-size, grain shape. Search for microfossils.
- **APXS**: role of water activity
- **Mössbauer**: presence of carbonates, sulfates, nitrates in ponding environment?
- **RAT**: Access to rock and sediment interior. Clean surfaces. Search for life.
- **Rover Mobility:** Use rover to reach several exposures and establish, for instance, stratigraphy and shorelines --to be correlated with MGS and MO. Mobility ideal to study evaporite transition at rover mission traverse scale.

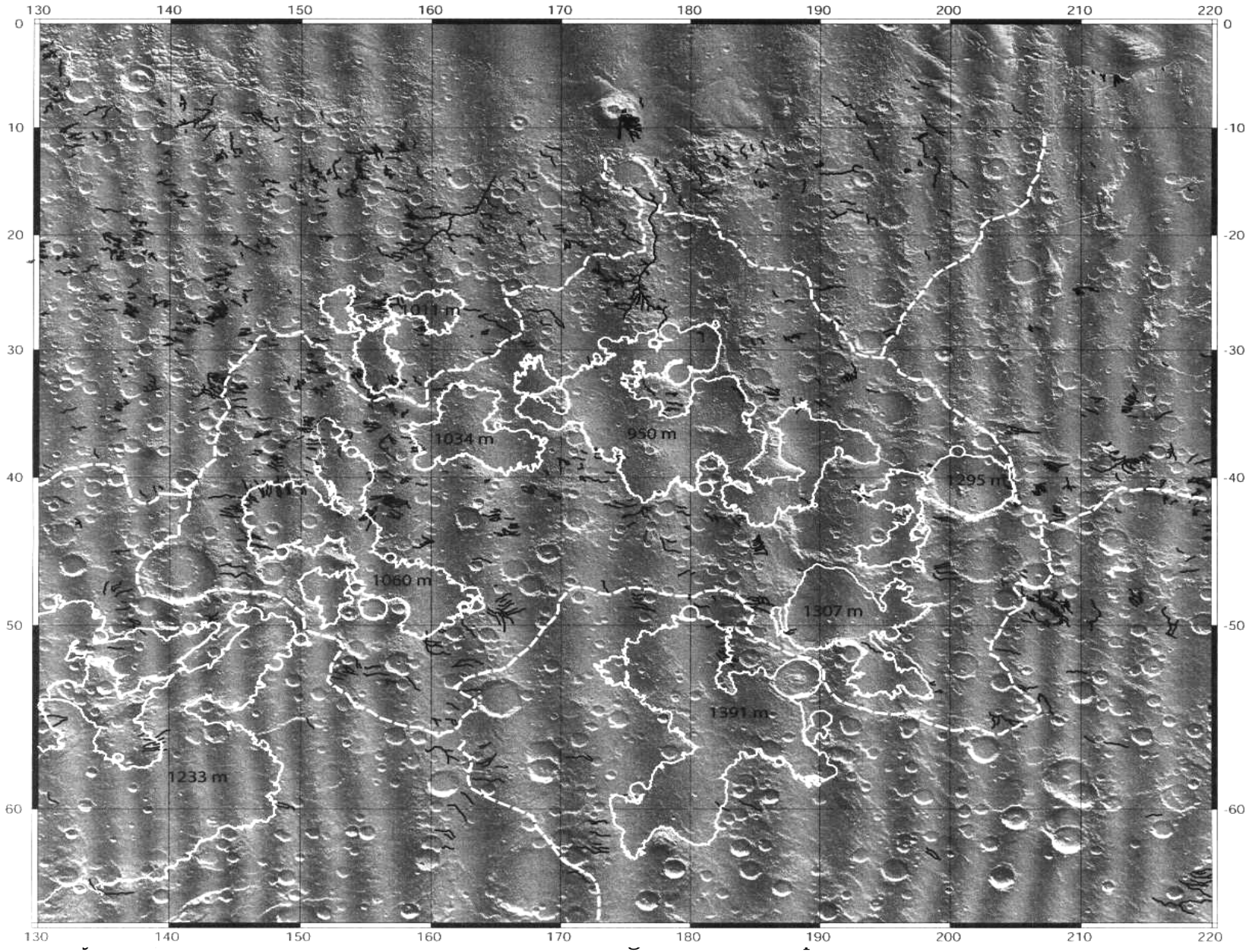
Regional Scale: The Fluvial Channel Hypothesis

How the investigation of Gusev by MER A will allow to characterize the type of flow that ponded in the crater basin.

- **#2. Ma'adim Vallis was a fluvial channel and deposited aqueous sediments in Gusev through:**
  - ***#2.1. Low and sustained discharge from runoff activity***
  - ***#2.2. Short-lived catastrophic outburst from outflow activity***
  - ***#2.3. All the above***

Implications: *If evidence of aqueous mineralogy and flow dynamics are found in Gusev, it will be an important step toward proving that channels on Mars were likely to be formed by water. The study of the deposits and minerals will help understand the relative duration of flow episodes and the nature of the watershed area. Flow does not mean necessarily lake.*

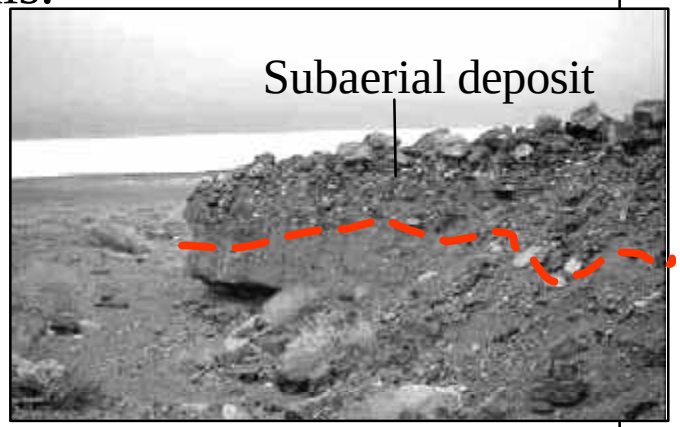
- Ma’adim/Gusev Hydrogeologic Basin -



Testing the Fluvial Channel Hypothesis

Searching for Rocks and Sediments:

- ***PanCam***: deposit morphology, conglomerate facies (round/subrounded), clasts up to 30 cm; Sanstone facies, tabular and trough cross bed, ripple bed.
- ***Mini-TES***:Primary minerals with cementing mineralogy; Fe-oxyhydroxide, carbonate, or clay minerals.
- ***MI***:rounded sand grains. Distribution.
- ***APXS***: Weathering processes
- ***Mössbauer***:mineralogy of Fe-cementing if present.
- ***RAT****:* used to remove oxydized layer.



- ***Rover Mobility:*** used to study contacts of flow and crater basin, transition in grain-size, and basin environment. Stratigraphy should be correlated with MGS and MO data.

Regional Scale: The "All Volcanic" Hypothesis

How the investigation of Gusev by MER A could give the opportunity of studying for the first time the record of volcanic activity.

- **#3. Deposits in Gusev are volcanic material from Apollinaris Patera.**
  - ***#3.1. Deposits in Gusev are stratas of ashes, pyroclasts, and lava flows.***
  - ***#3.2. Ma'adim channelized fluid lava which deposits mimic deltaic landforms and lacustrine environment from orbit***
  - ***#3.3. Maar activity in Gusev could have contributed to the volcanic deposits***

Implications: *Need to reassess the role of volcanic activity in the formation of channels on Mars. However, Gusev could be an isolated case. No generalization possible. Some craters on the basin floor may not be of meteoritic origin. Environment less favorable for life.*

Testing the "All Volcanic" Hypothesis

- ***PanCam:*** Sandwich, massive planar sedimentary deposits; Soft sediment deformation, vesicles, bedding sags.
- ***MiniTES:*** Poorly crystalline to crystalline material (e.g., plagioclase, pyroxene, hornblende).
- ***MI:*** Glass shards cupsate, blocky, platy, <250 µm.
- ***APXS:*** Any range of Si content. Chemistry may be different from local rock.
- ***Mossbauer:*** Could detect ilmenite, titanomagnetite, titanomaghemite, magnetite, Fe-pyroxene.

Regional Scale: The Glacial Hypothesis

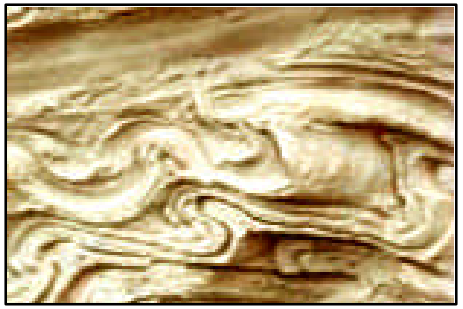
How the investigation of Gusev by MER A will allow the investigation of a basin which collected material recording 3.9 Ga of climate changes

- **#4. Deposits in Gusev are of glacial origin and reflect cycles of climate changes.**
  - ***#4.1. From polar wandering.***
  - ***#4.2. From glacier channeled through Ma'adim Vallis.***

Implications: *Access to large climate record involving a high proportion of volatile without going to the high latitude or polar regions.*

Testing the Glacial Hypothesis

- ***PanCam****:* Glacier: Poorly sorted material from till and moraine (cm to boulders), striated, rocks, gravels, boulders. Flattened rocks and gravels. If glacial lake: varves and rain out debris.”Polar” type deposits: beddings, layering including material of various albedo (dusty to volatile-rich).
- ***MiniTES****:* Aqueous minerals
- ***MI****:* Striated rocks and gravel
- ***APXS****:* Elemental analysis --Parent-rocks
- ***Mossbauer****:* Fe-bearing rocks and soils-- Parent-rocks
- ***RAT:*** Access non oxydized layers and varves



III. Local Scale Hypotheses

- **#1. Lacustrine activity resulted in the formation of aqueous minerals *in situ* in Gusev, e.g., evaporites, clays, muds.**
- **#2. Hydrothermal minerals were formed *in situ* from the interaction of impact craters melt material with a volatile-rich subsurface.**
- **#3. The various morphologies are related to:**
  - ***#3.1. Various geological units***
  - ***#3.2. Various level of weathering of same material***

Possible Results from Athena Instruments on hypothetical Soils and Sediments in Gusev

Hypothesis	***Pancam***	***MI***	***APXS***	***Mini-TES***	***MB***
Global soil	Similar multi-spectral characteristics as MPF soil	Particles lower than resolution	Loess	Similar elemental chemistry as MPF and VL 1, 2 soil	Similar multi-spectral characteristics as MPF soil
Soils from physical weathering of local rock	Angular rocks and blocks	Angular soil grain morphology	Soil elemental chemistry similar to rock chemistry	Soil spectra similar to rock spectra No secondary mineralogy	Soil Fe mineralogy similar to rock Fe mineralogy. No secondary Fe-oxyhydroxides
Volcanic ash	Layered deposits, thin to massive	Glass shards cupsate ,blocky, platy < 250 um.	Any range of Si content. Chemistry may be different than local rock	Poorly crystalline to crystalline material (e.g., plagioclase, pyroxene, hornblende)	Ilmenite, titanomagnetite, titanomaghemite, magnetite, Fe-pyroxene
Maar Base Surge Deposit	Sandwhich, massive, planar sedimentary deposits. Soft sediment deformations, vesicles, bedding sags	Glass Shards, blocky. Fine grained material < 1 mm	Any range of Si content.	Poorly crystalline to crystalline material (e.g., plagioclase, pyroxene, hornblende)	Ilmenite, titanomagnetite, titanomaghemite, magnetite, Fe-pyroxene
Soil from aqueous weathering (e.g., rain)	Soil structure Columns, wedge, blocky, platy, Vesicular porosity near surface	Vesicular porosity near soil surface	Loess or accumulation of Ca, Mg, K, Na relative to local surface rock	Clay minerals, carbonates, sulfates, Secondary Fe-oxyhydroxides	Secondary Fe-oxyhydroxides.
Fluvial Deposit	Conglomerate facies; (rounded/ subrounded clasts up to 30 cm) facies; sheet, tabular cross stratified, lateral, channel fill Sandstone facies; tabular and trough cross bed and ripple bed Shale facies; planar bed	 Rounded sand grains. No visible grains		Primary minerals with cementing mineralogy ; Fe-oxyhydroxide, carbonate, or clay minerals	Detect mineralogy of Fe-cementing mineral if present. Possible siderite ($FeCO_3$) Fe^{2+}-smectite, if outer oxidized layer on sedimentary rock is removed by the RAT
Lacustrine Deposit	Alternating planar layers of light colored evaporite layers with darker clay layers. Layer thickness few cm to 10's cm Lake's margin: Sandstone facies Possible similar to fluvial facies Lake's middle: Shale facies; planar layers of silt/clay	Sand and gravel grains at lake's margin; Clay/silt grains towards lake's center Rounded sand grains No visible grains	High levels of Ca, Mg, K, Na, S, Cl, N in lake basin	Mineralogy variation from lake margin to lake center (e.g., calcite → gypsum → halite) Clay mineralogy	Possible siderite ($FeCO_3$) Fe^{2+}-smectite, if outer oxidized layer on sedimentary rock is removed by the RAT
Aeolian Deposit	No particles larger than can be moved by creeping Sandstone facies - Planar, laminar, cross-bedding or ripple bedding. No through cross-bedding.	Garin size <4 mm			
Glacial Deposit	Till/Moraine. Poorly sorted, cm to large boulders, striated rocks gravels. Flattened. Glacial Lake: varve, rain-out debris.	Poorly sorted, striated			

Conclusion 1

MER A in Gusev will:

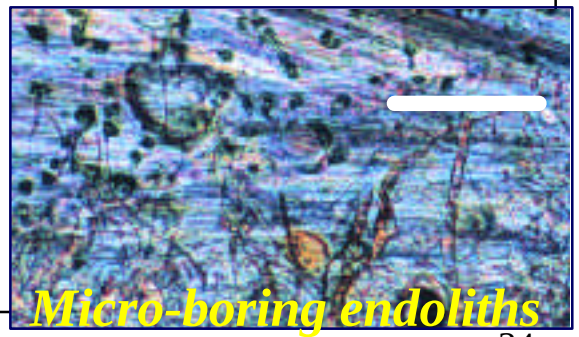
- Test a broad diversity of hypotheses at global, regional, and local scale using the complete Athena Science Paylod.
- Determine the ancient depositional environment and the specific role of wind, water, ice, and volcanism.
- Analyse a diversity of units and terrains, rocks and soils.
- Assess the habitability potential of such environment.

Conclusion 2

- Calibrate and validate orbital remote sensing data:
  - Testing the most recent science hypotheses of MO and theoretical models regarding the potential abundance of water on Mars today, the distribution of its reservoir, and its stability.
  - Providing MiniTES high-resolution to THEMIS data (MO) in a site where aqueous minerals and possibly ice are likely abundant.
  - Assessing if the variability of morphologies, textures, and albedo observed by MOC at the landing site is related to various processes and origins or different levels of weathering and alteration of the same type of material.
  - Use the mobility of the rover and its payload to establish stratigraphic relationship between units that can be correlated with orbital data.

Conclusion 3

- Testing the Habitability Potential of Mars in Gusev:
  - Basin = most favorable to:
    - Accumulate fine-grained, clay-rich sediment and/or water-lain volcanic ash deposits in deeper basin areas
    - Accumulate chemical precipitates (e.g., evaporates) along shallow basin margin, or on basin floor playas.
    - Preserve fossil biosignatures.
    - Precipitates of hydrothermal systems are important repositories for a variety of microbial signatures.



Summary

- ***Advantages***
  - None of the hypotheses exclude each other leading to a potentially diverse site and exciting mission;
  - The levels of hypotheses that can be tested encompass local to global questions;
  - Hypotheses raised by recent missions can be documented by going to Gusev;
  - A mission to Gusev will fully take advantage of the Athena Science Payload.
  - The rover mobility will be important to reconstruct the stratigraphy and correlate various units with orbital data.

Summary

- ***Disadvantages***
  - Shorter mission (104 days) but better energy conditions at the beginning of the mission
  - Need information about winds but…
  - It is worth it.