

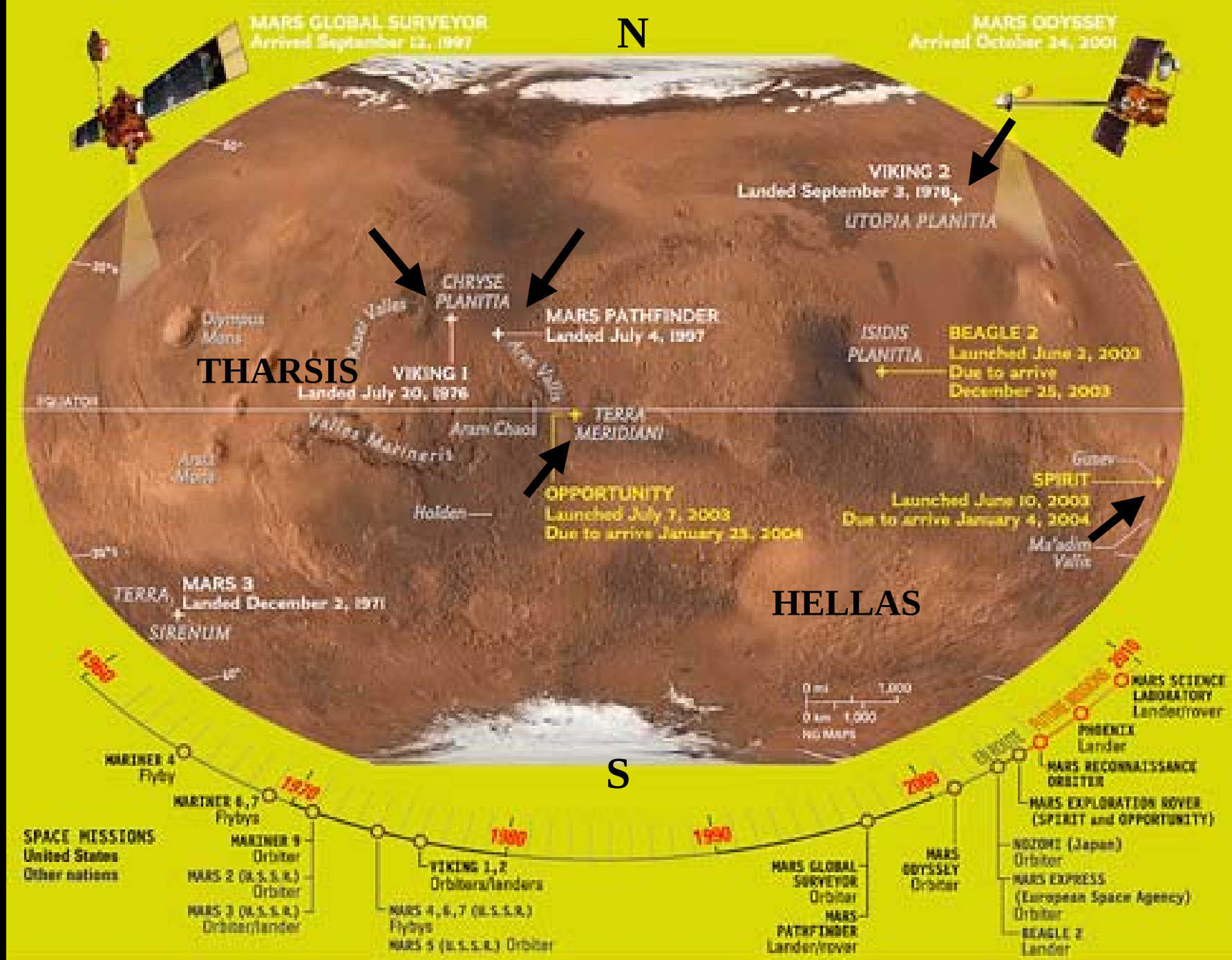
EVOLUTION OF MARS

LECTURE 18 NEEP 533

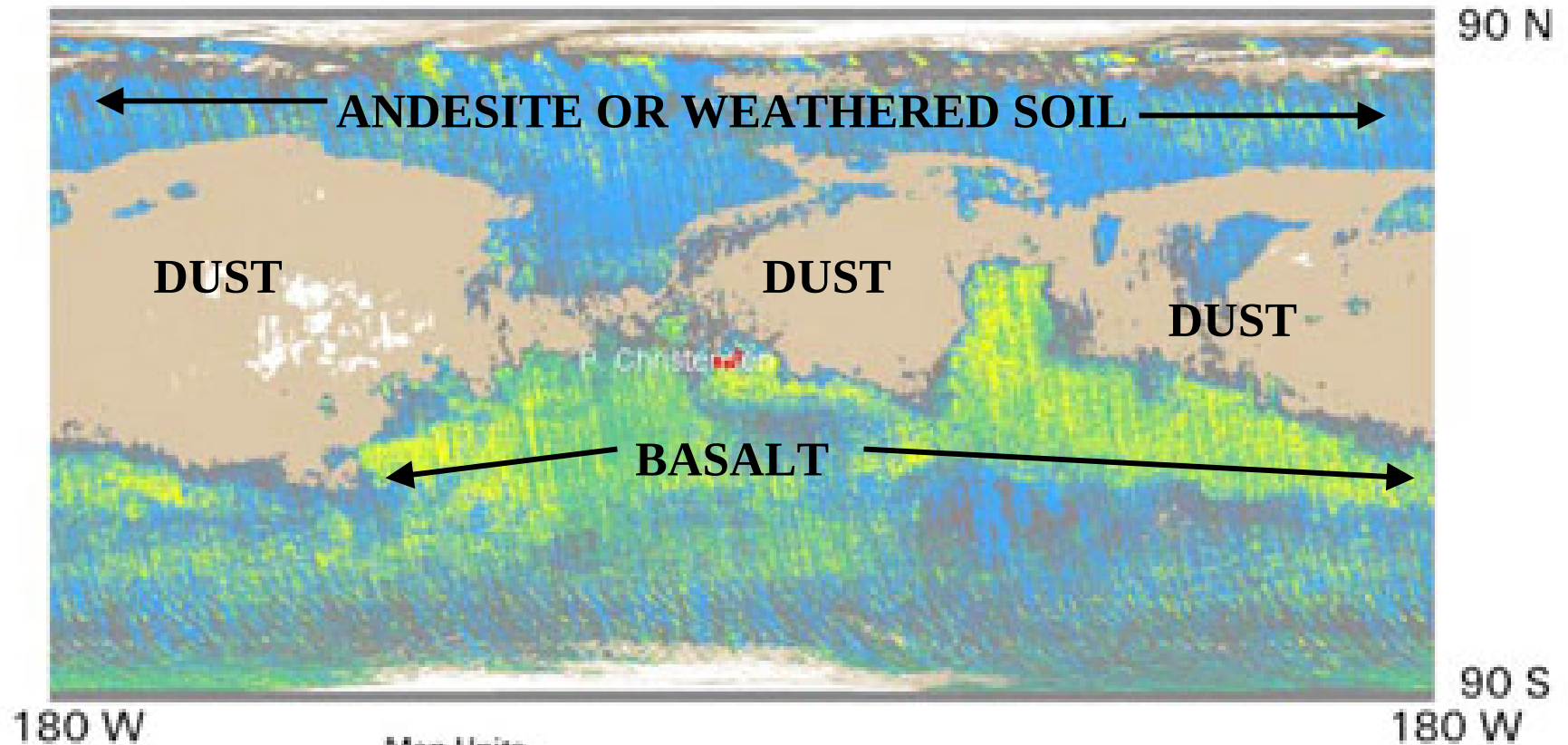
HARRISON H. SCHMITT



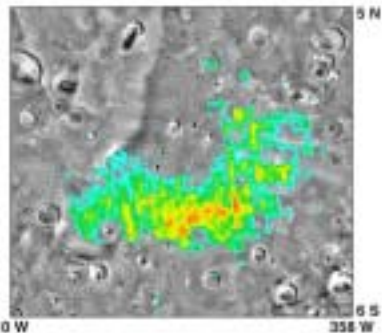
NASA HST IMAGE



TES Geologic Map of Mars

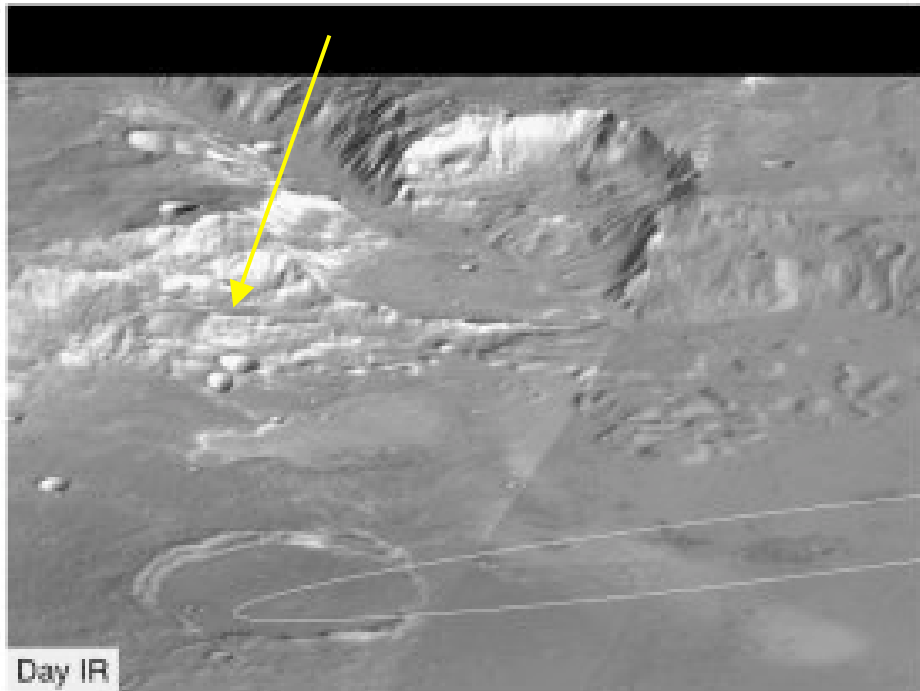
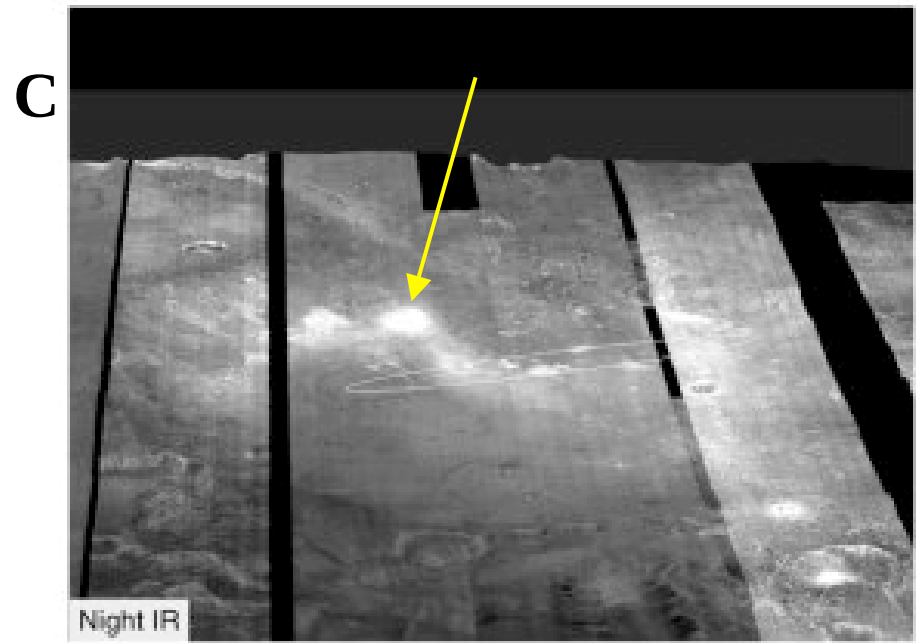
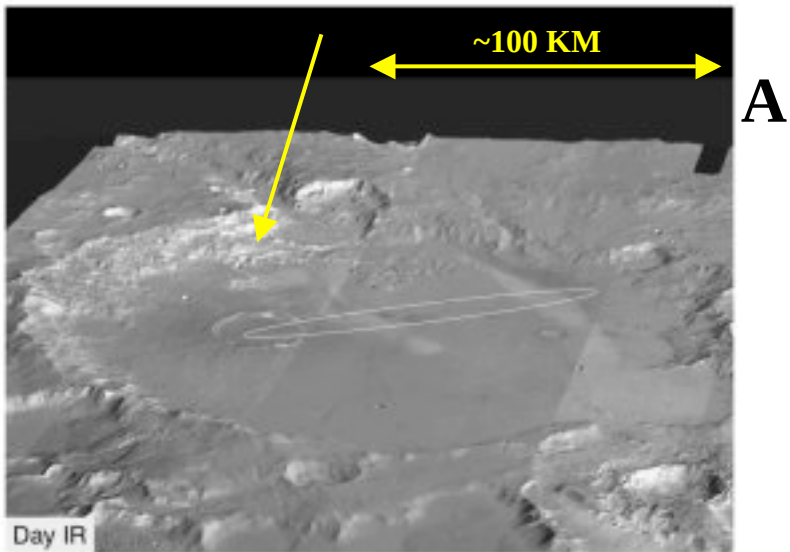


TES Hematite Abundance



Map Units

	Basalt		Dust
	Andesite		Hematite-rich
	Basalt/Andesite		Ice/Clouds
	Other		



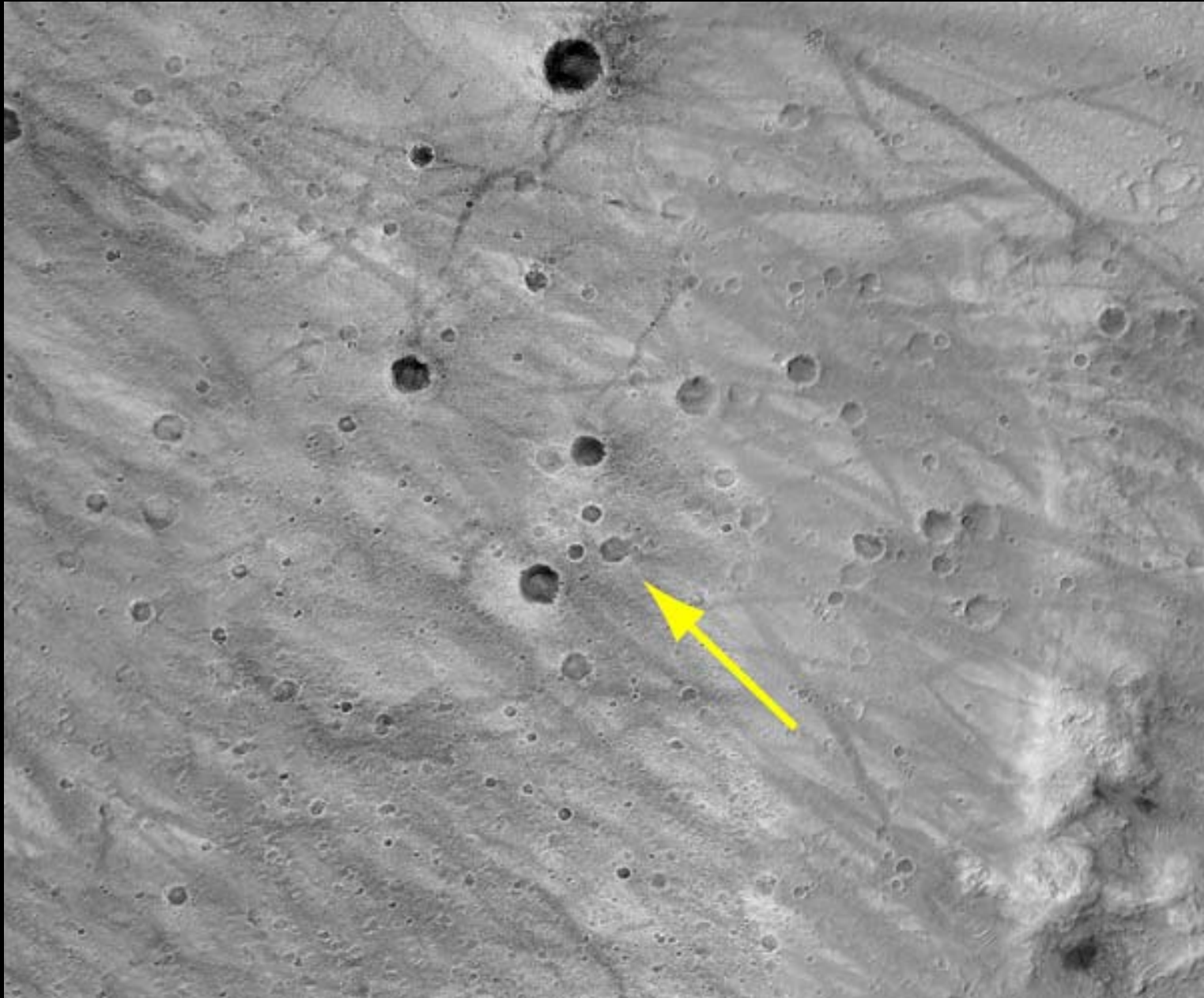
THEMIS THERMAL IMAGING OF SPIRIT LANDING AREA IN GUSEV CRATER

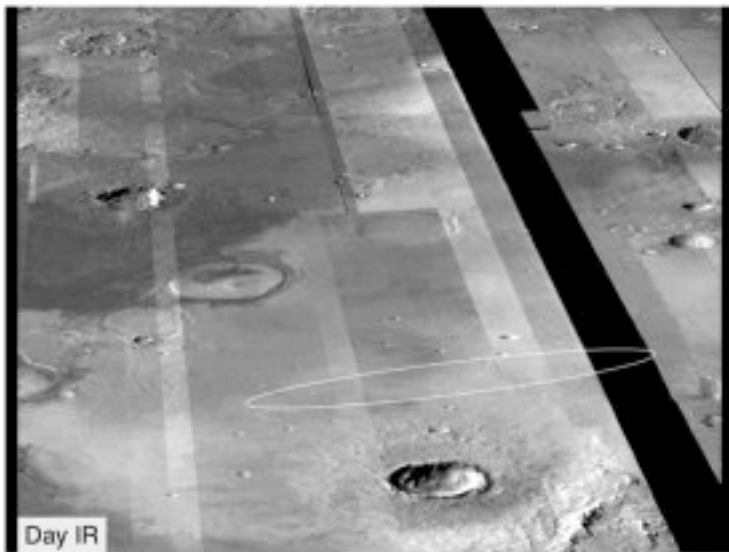
A. SPIRIT LANDING ELLIPSE

B. CLOSER VIEW OF SPIRIT LANDING ELLIPSE

C. NIGHT IR IMAGE: BRIGHT AREAS ARE MORE ROCKY. ARROW POINTS TO ROCKY SLOPE

**SPIRIT MOVED TO GUSEV CRATER
POSSIBLE LAKE BED IN LARGE BASIN**



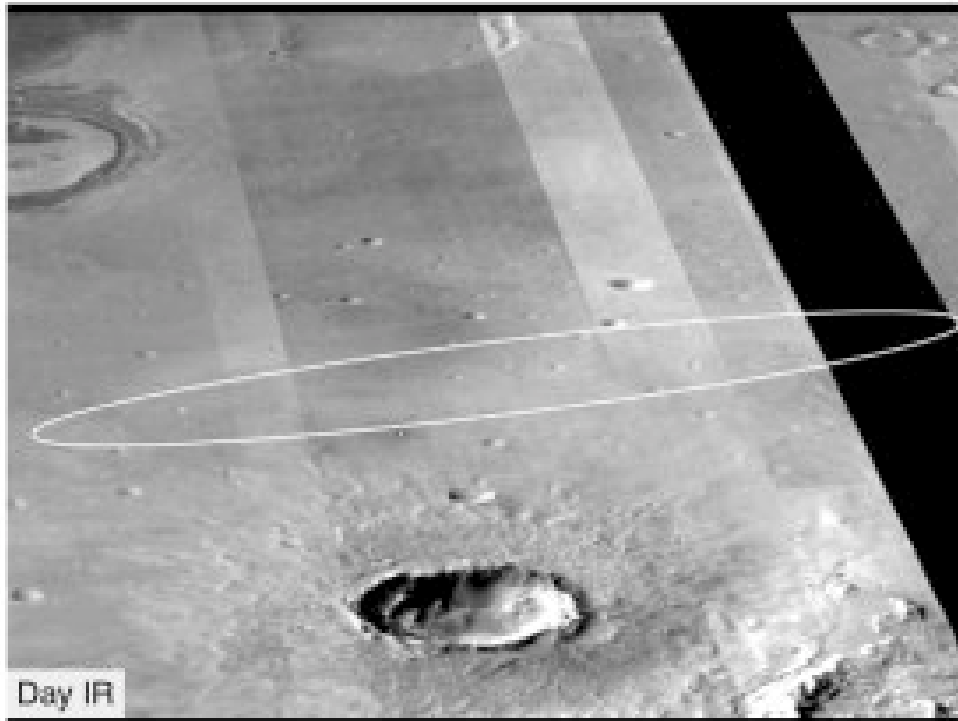


A

C



B



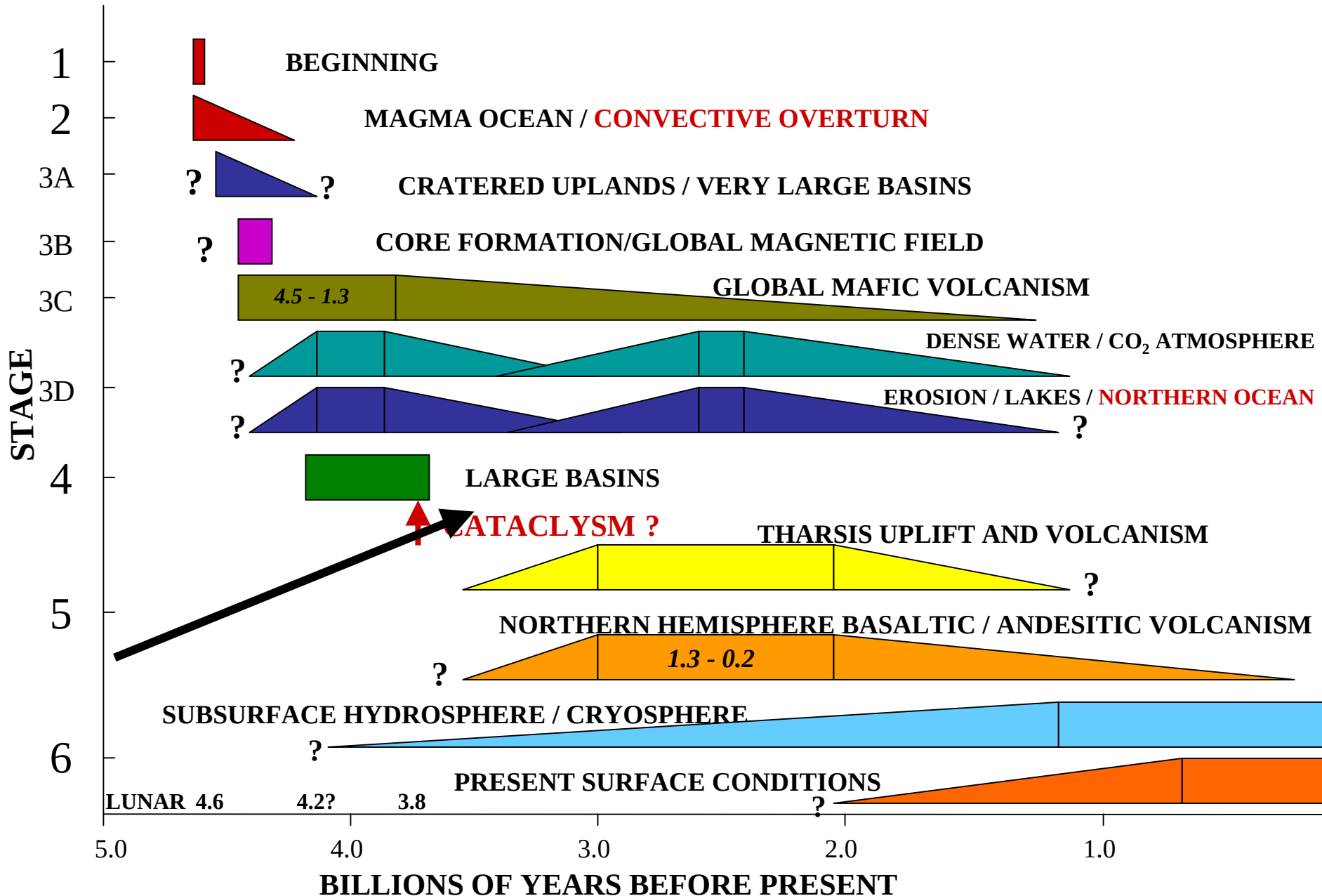
THEMIS THERMAL IMAGING OF OPPORTUNITYLANDING AREA IN MERIDIANI PLANUM

A. LANDING ELLIPSE (~120 KM LONG)

**B. CLOSER VIEW OF LANDING
ELLIPSE**

**C. NIGHT IR IMAGE: BRIGHT AREAS ARE
MORE ROCKY. ARROW POINTS TO
ROCKY SLOPE**

MAJOR STAGES OF MARS' EVOLUTION

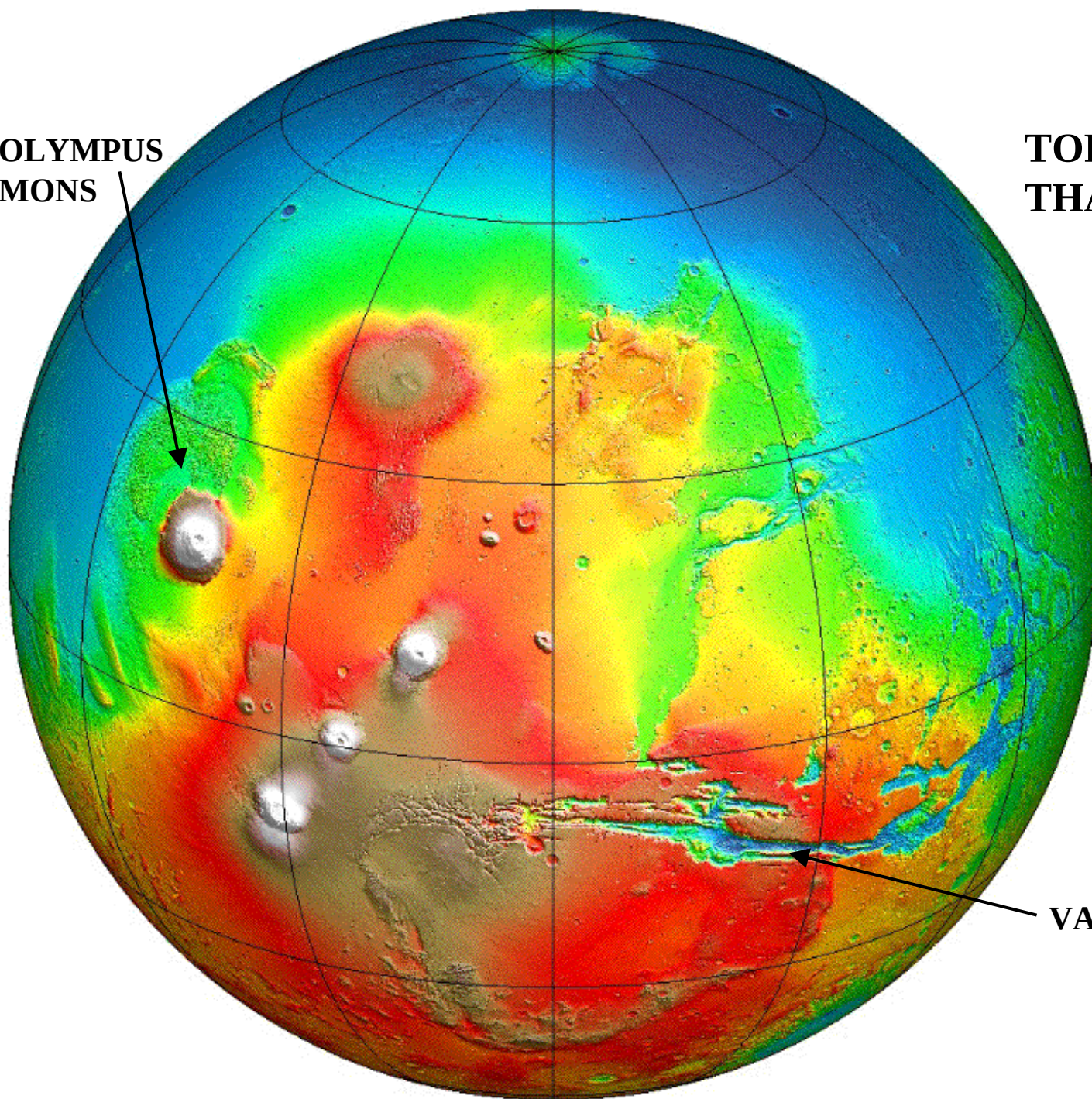


ITALICS = SNC DATES

RED = MAJOR UNCERTAINTY

**OLYMPUS
MONS**

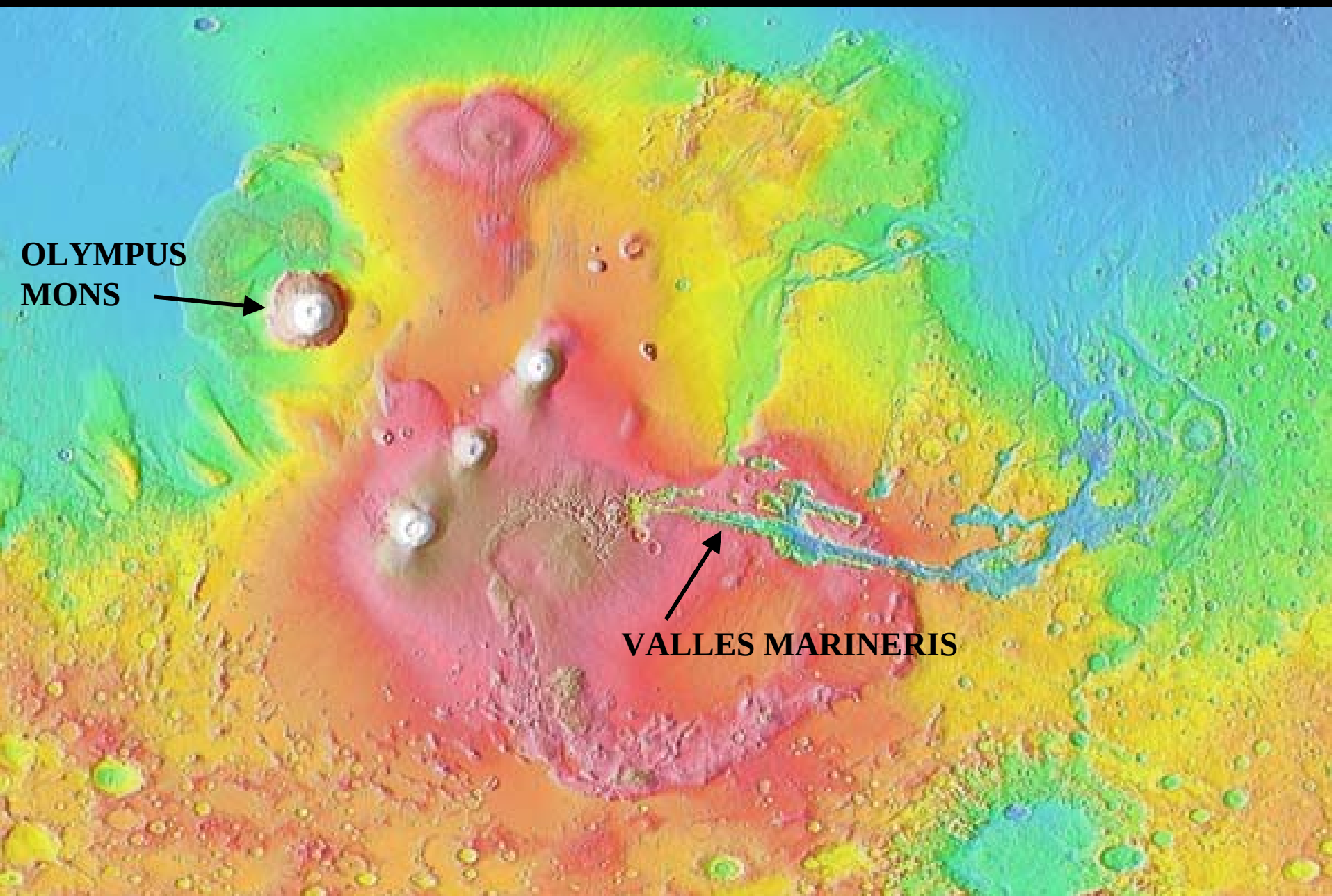
**TOPOGRAPHY OF
THARSIS REGION**



VALLES MARINERIS

THARSIS REGION SHADED RELIEF DETAIL

MARS GLOBAL SURVEYOR MOLA



APOLLO MODEL OF MARS EVOLUTION

THARSIS EVENTS <3.8 B.Y.

THICKENING
ATMOSPHERE:
 CO_2 , H_2O

CRYOSPHERE /
HYDROSPHERE

OLIVINE/ NA-
PYROXENE
CUMULATE

OLIVINE
CUMULATE

GARNET / NA-CPX
NA-BIOTITE?/NA-
HORNBLLENDE/
"RUTILE"
CUMULATES

RELIC MAGNETIC
STRIPING

©Harrison H. Schmitt
University of Wisconsin-
Madison

ELYSIUM MONS

ANDESITIC
EXTRUSIONS

THARSIS

MAFIC UPPER
MANTLE WITH
INCREASING
SI AND FE
UPWARDS

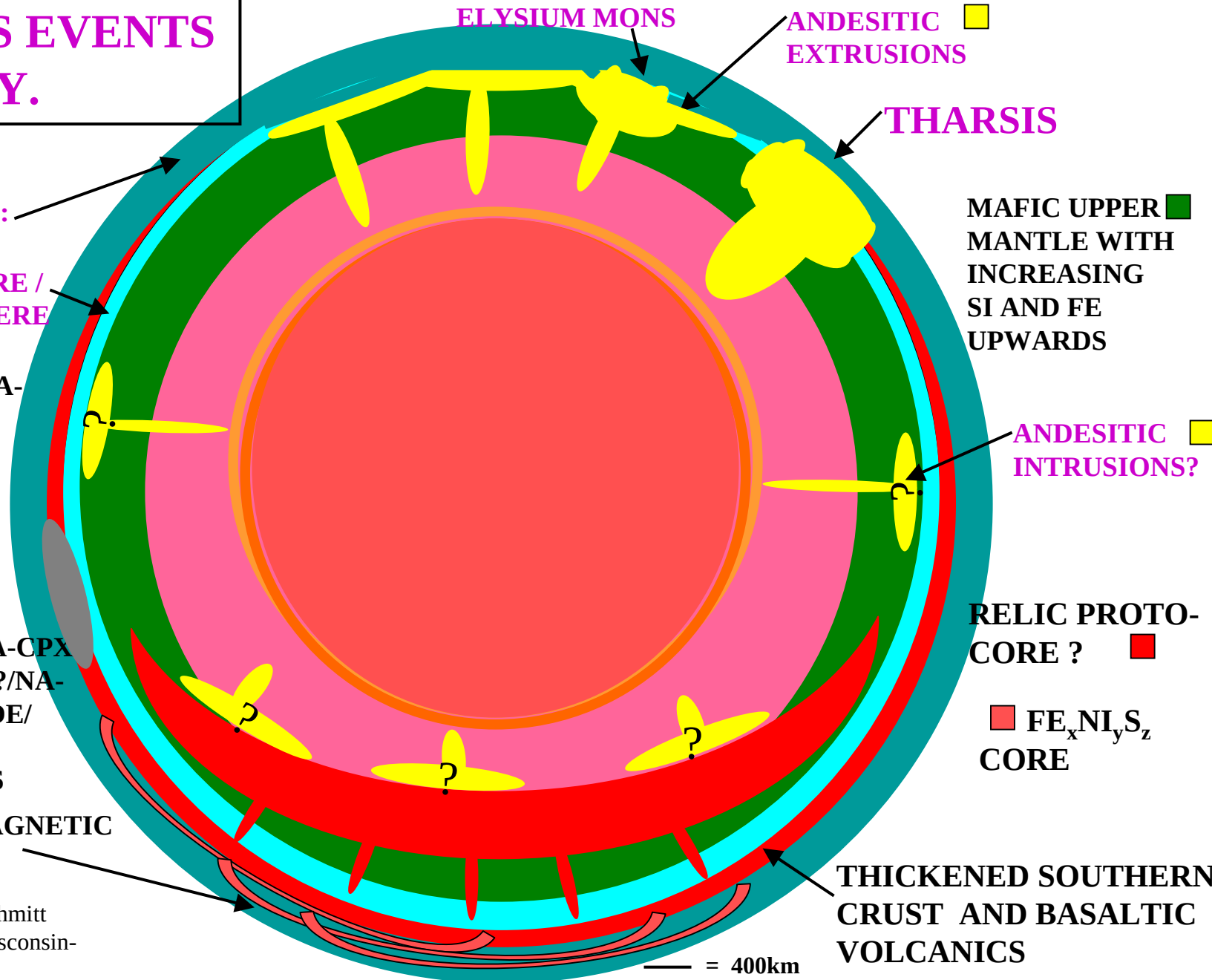
ANDESITIC
INTRUSIONS?

RELIC PROTO-
CORE ?

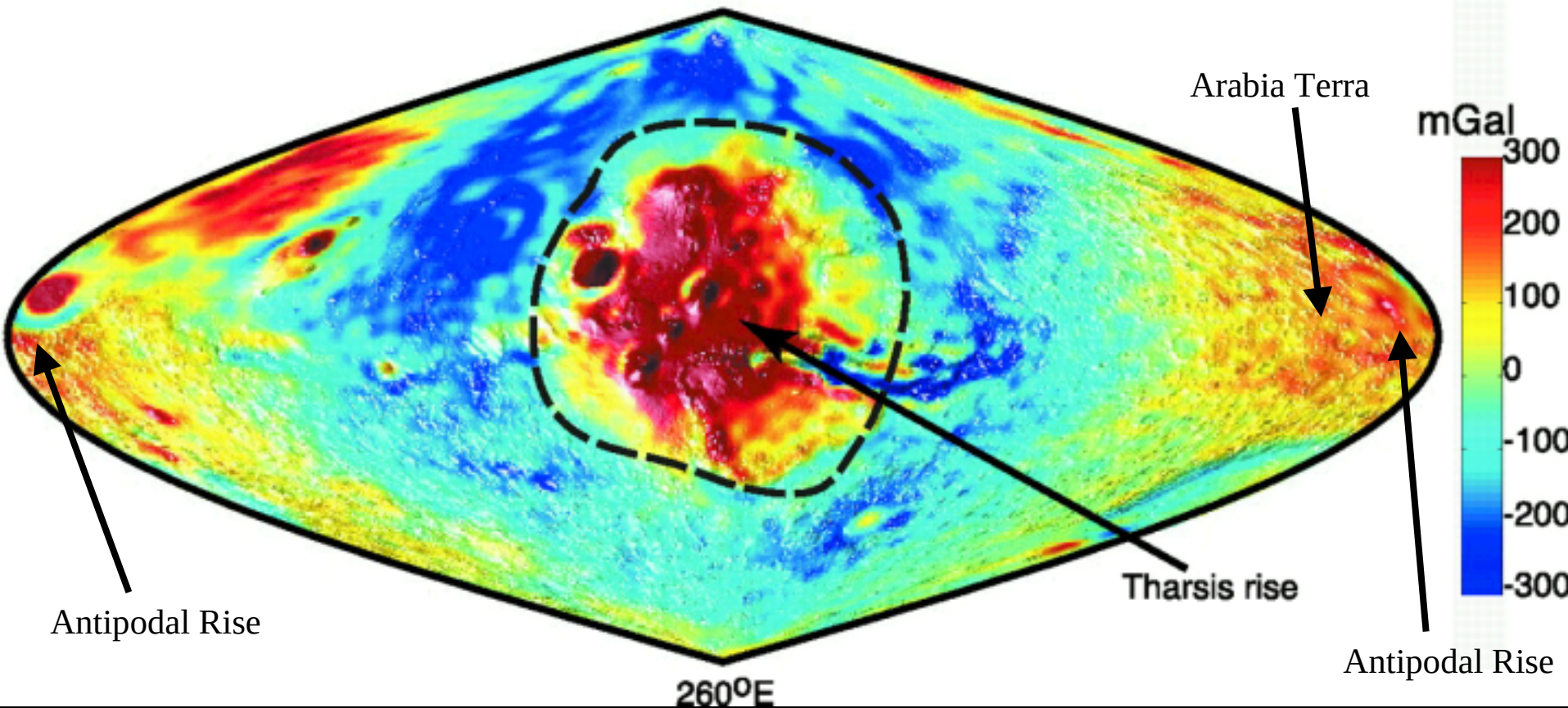
$\text{Fe}_x\text{Ni}_y\text{S}_z$
CORE

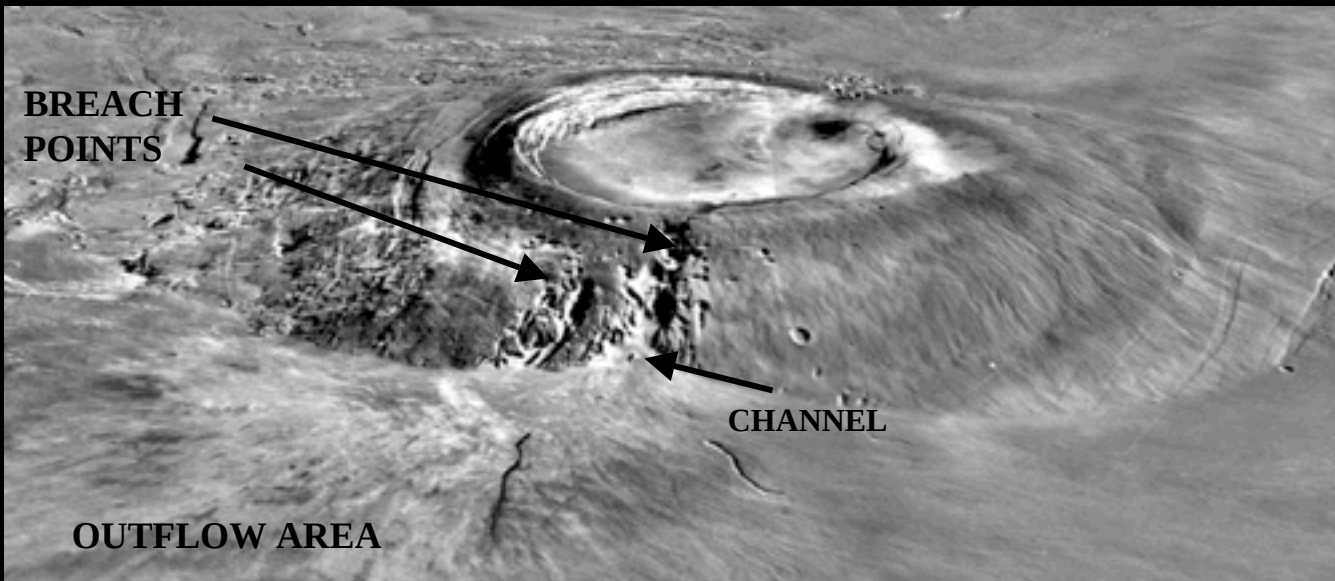
THICKENED SOUTHERN
CRUST AND BASALTIC
VOLCANICS

— = 400km



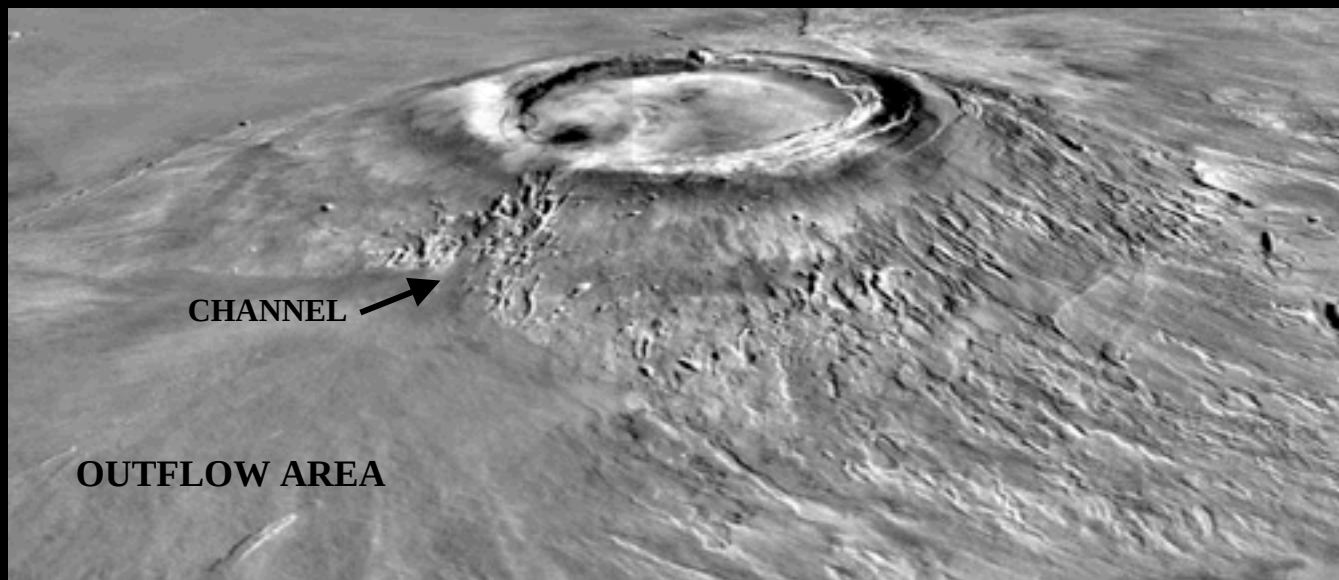
**GRAVITY ANOMALY IMAGE
DRAPED OVER A THREE-DIMENSIONAL (3D) VIEW OF TOPOGRAPHY**





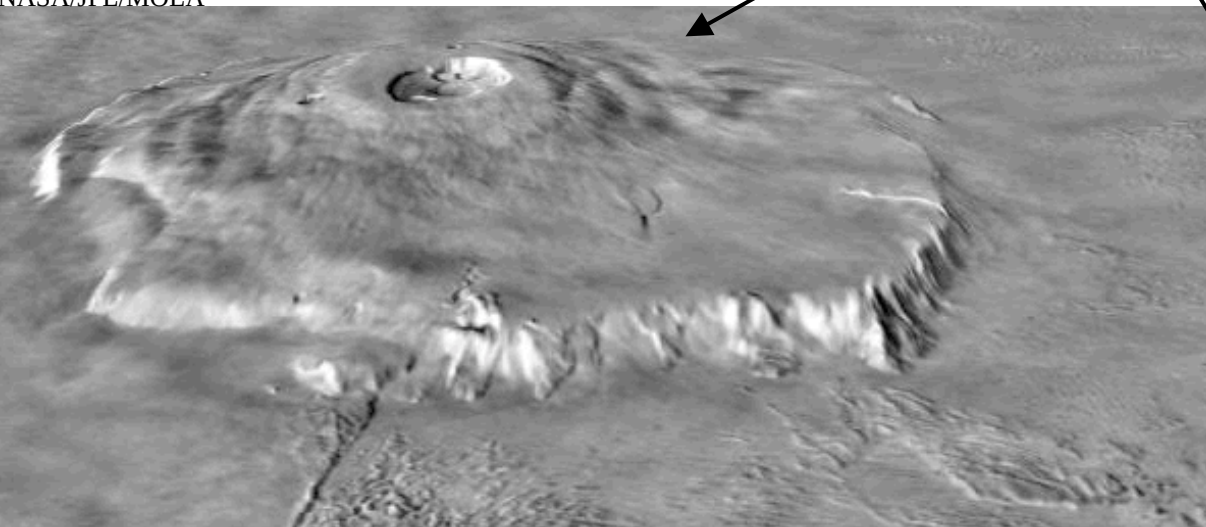
ARSIA MONS (SOUTH THARSIS

**MOLA DATA APPLIED
TO VIKING IMAGES**



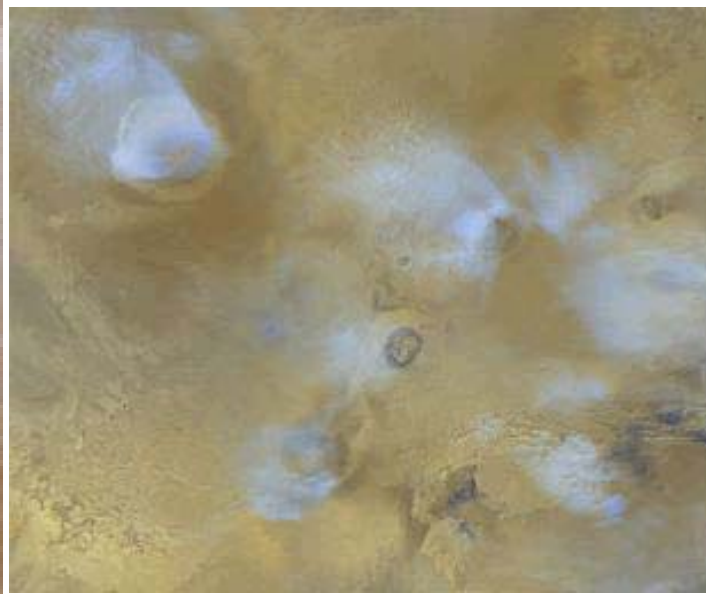
NASA/JPL/MOLA

OLYMPUS MONS



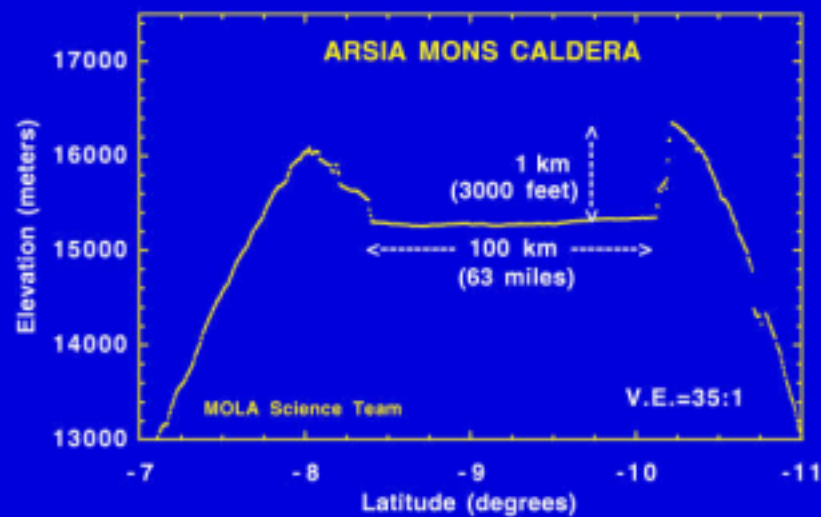
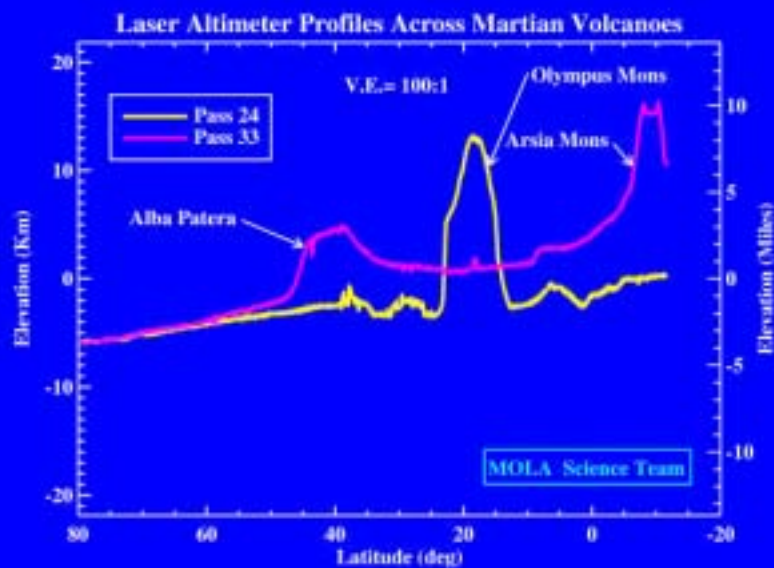
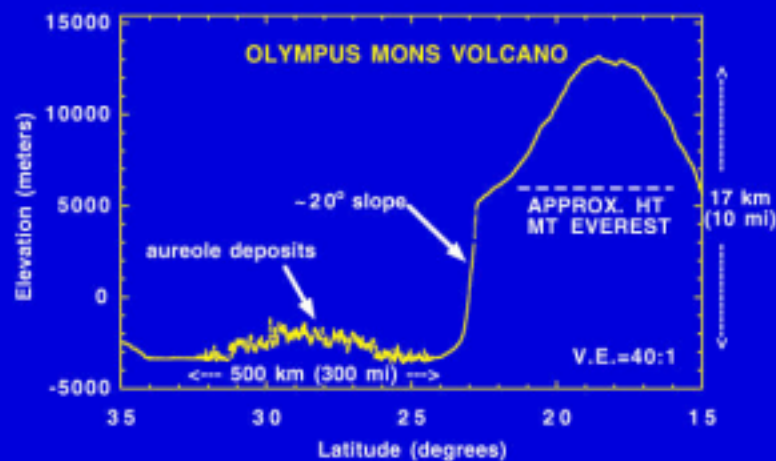
50 KM

APOLLINARIS
PATERNA



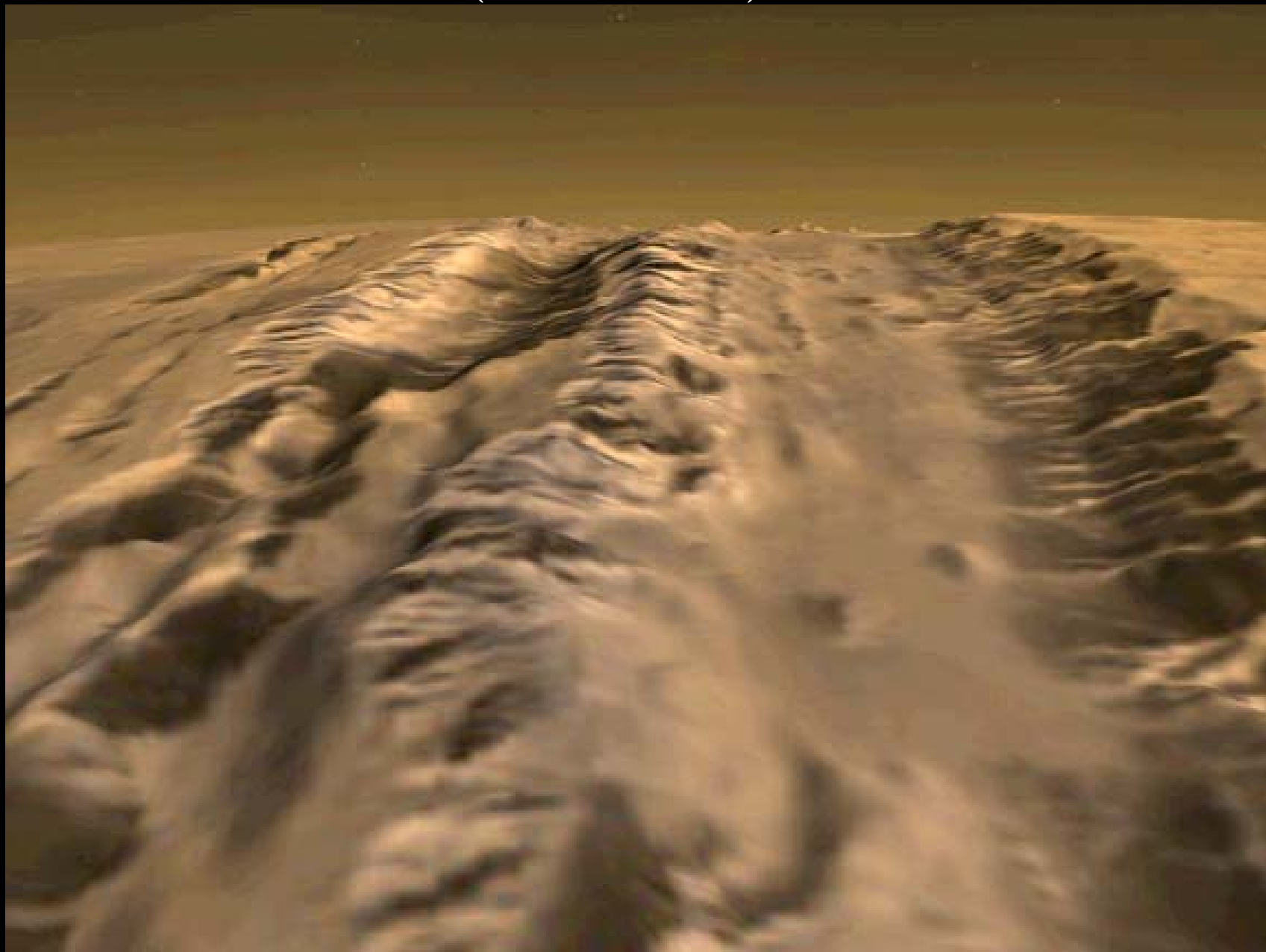
NASA/JPL/MALIN SCIENCE SYSTEMS

MOLA PROFILES ACROSS OLYMPUS MONS ALBAPATERA ARSIA MONS MOLA SCIENCE TEAM



WESTWARD VIEW DOWN VALLES MARINERIS

(MOLA SCIENCE TEAM)



APOLLO MODEL OF MARS EVOLUTION

THARSIS EVENTS
<3.8 - ? B.Y.

THICKENING
ATMOSPHERE:

CO₂, H₂O

CRYOSPHERE /
HYDROSPHERE

OLIVINE/ NA-
PYROXENE
CUMULATE

OLIVINE
CUMULATE

GARNET / NA-C
NA-BIOTITE?/NA
HORNBLLENDE/
"RUTILE"
CUMULATES

RELIC MAGNETIC
STRIPING

©Harrison H. Schmitt
 University of Wisconsin-
 Madison

ELYSIUM MONS

THARSIS

LATE NORTHERN
OCEAN AND
OTHER LAKES
WITH OUTFLOW
SEDIMENTATION

MAFIC UPPER
MANTLE WITH
INCREASING
SI AND FE
UPWARDS

VALLES
MARINERIS
OUTFLOW

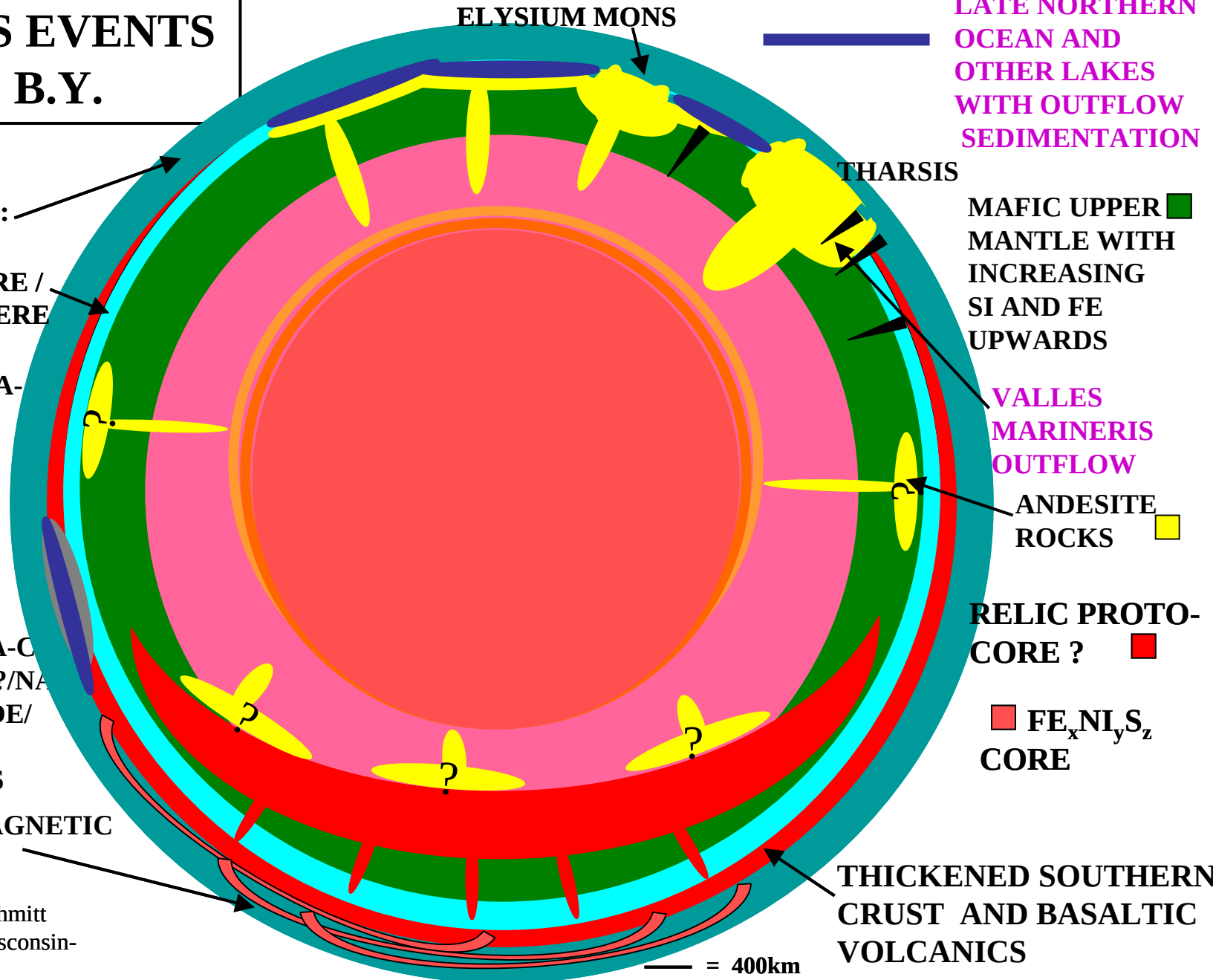
ANDESITE
ROCKS

RELIC PROTO-
CORE ?

FE_xNI_yS_z
CORE

THICKENED SOUTHERN
CRUST AND BASALTIC
VOLCANICS

= 400km



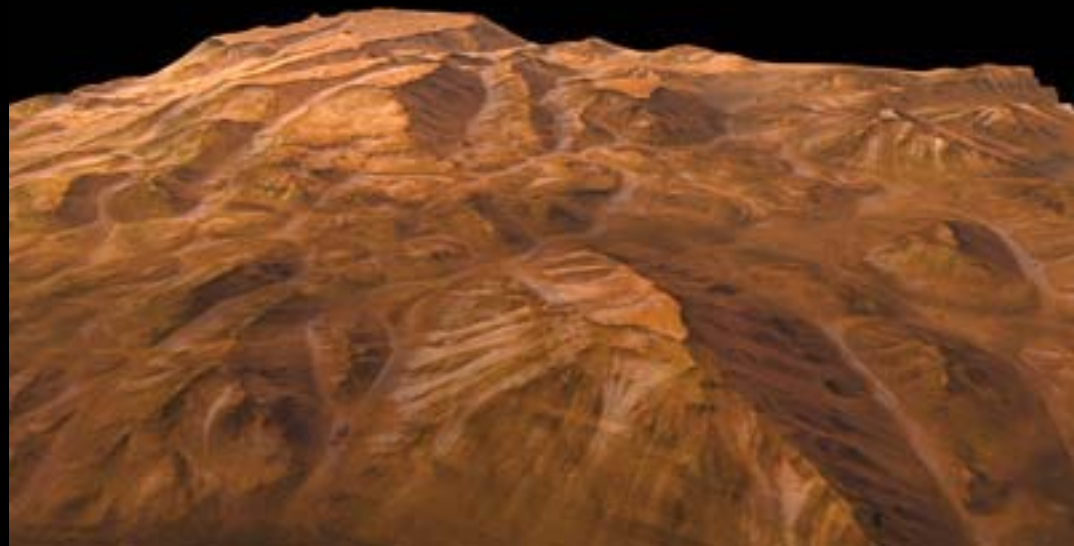


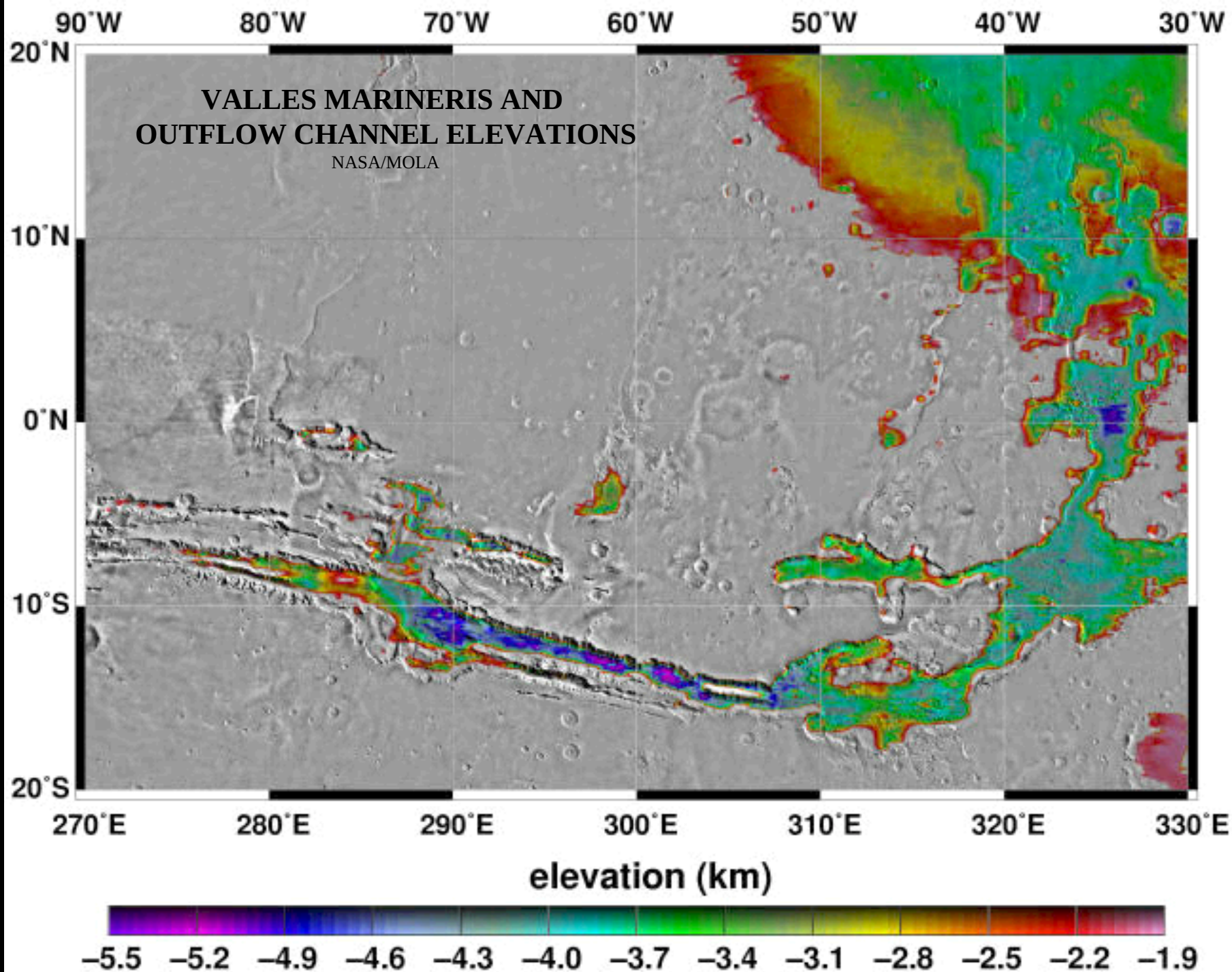
**VALLES MARINARIS
LOOKING NORTH**

ESA MARS EXPRESS ORBITER

1700 KM

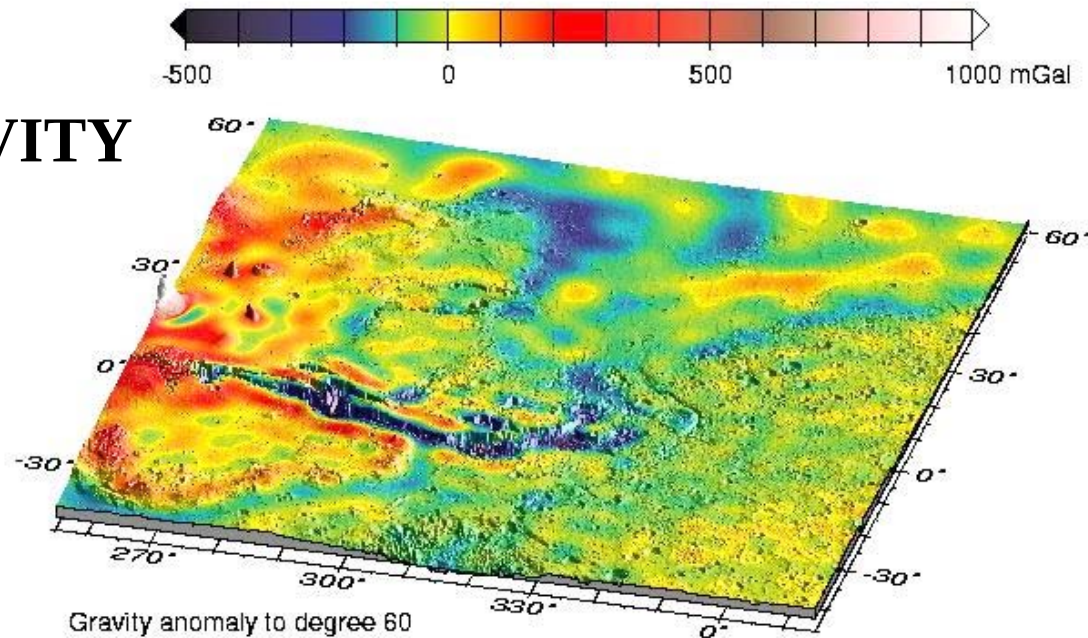
65 KM





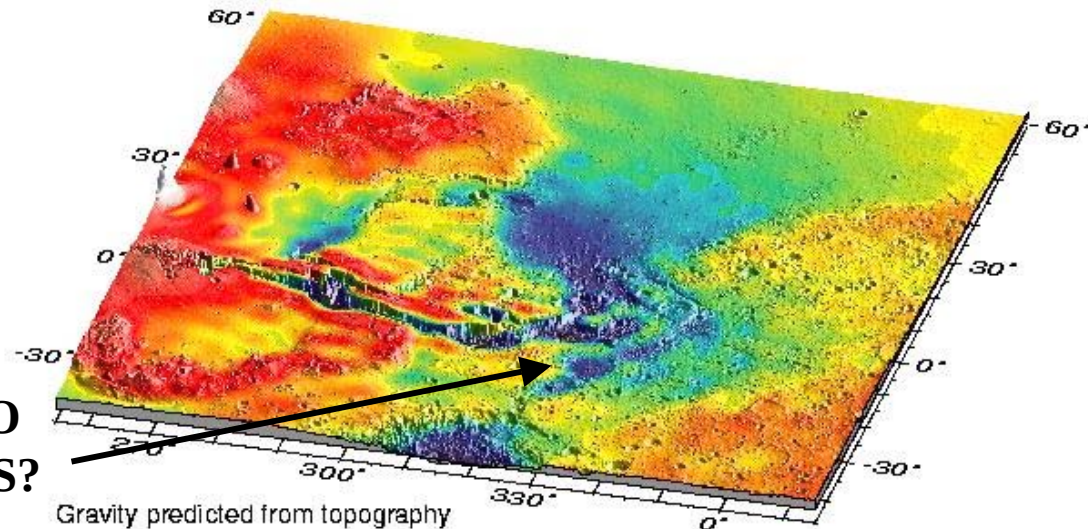
MARS GLOBAL SURVEYOR

MEASURED GRAVITY



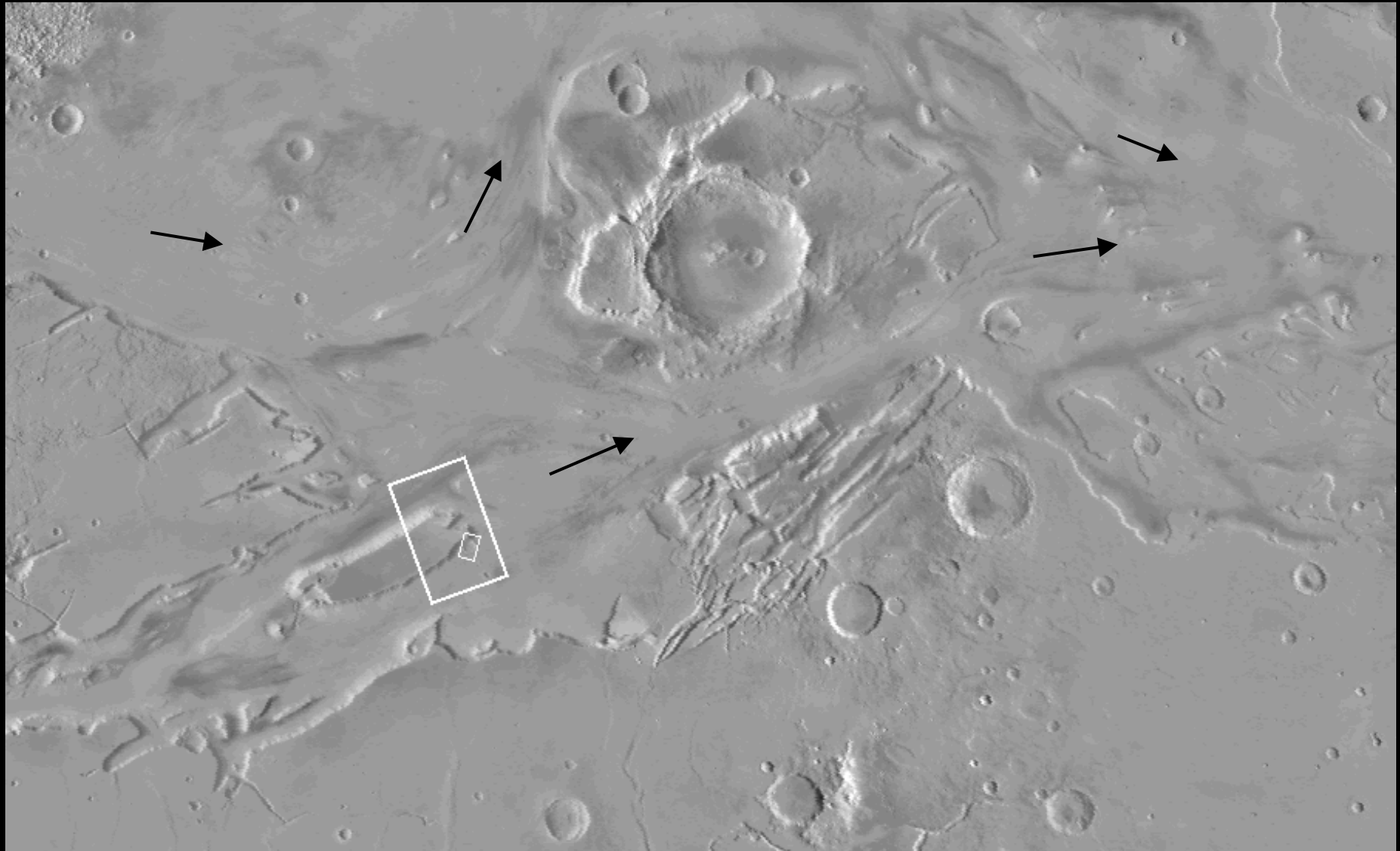
TOPOGRAPHIC PREDICTION OF GRAVITY

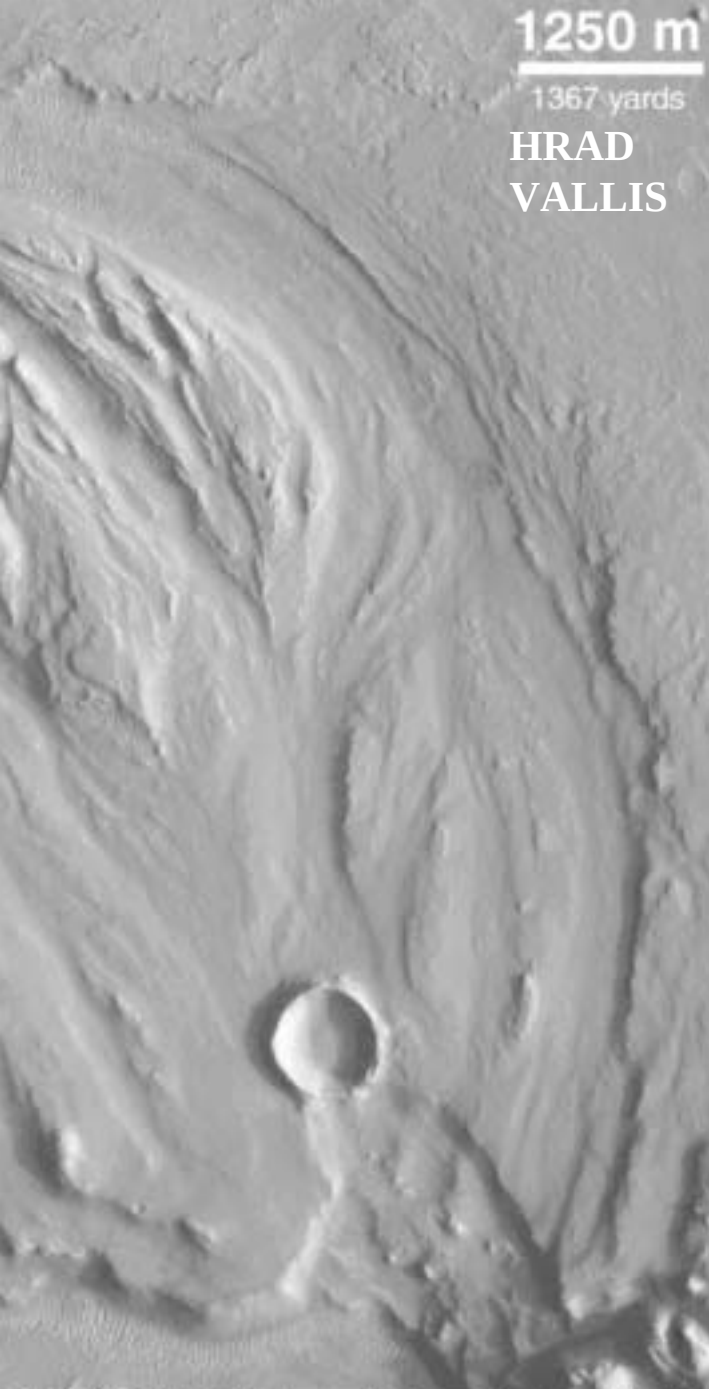
**BURIED CHANNEL INTO
NORTHERN LOWLANDS?**



OUTFLOW CHANNEL, KASEI VALLES

NASA VIKING MOSAIC





1250 m

1367 yards

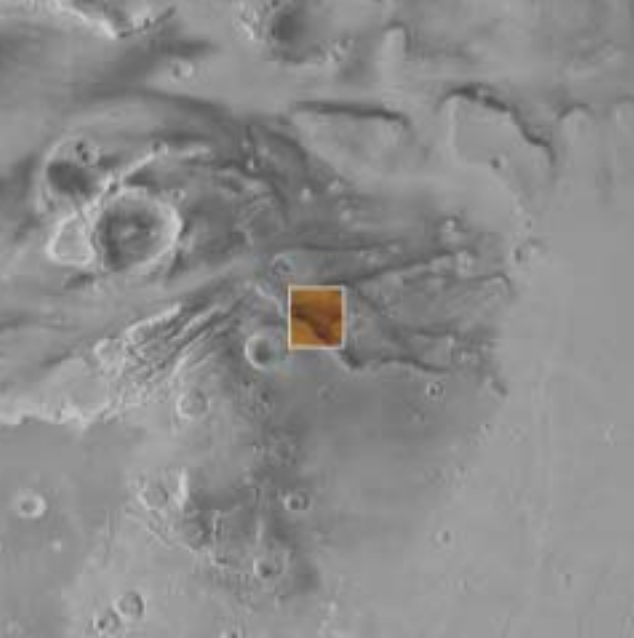
HRAD
VALLIS

OUTFLOW CHANNEL FEATURES

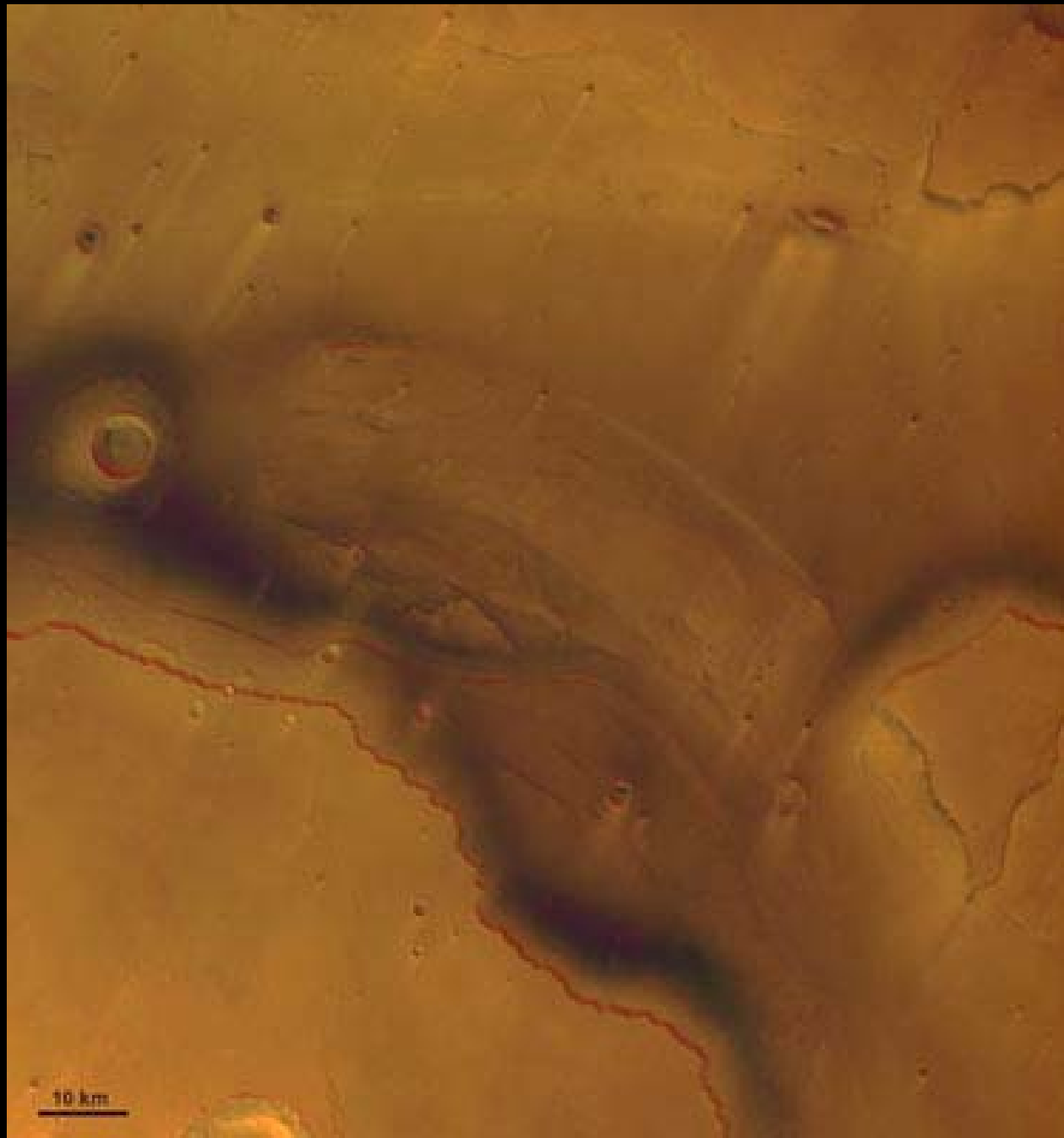


GANGES CHASMA OUTFLOW 3D

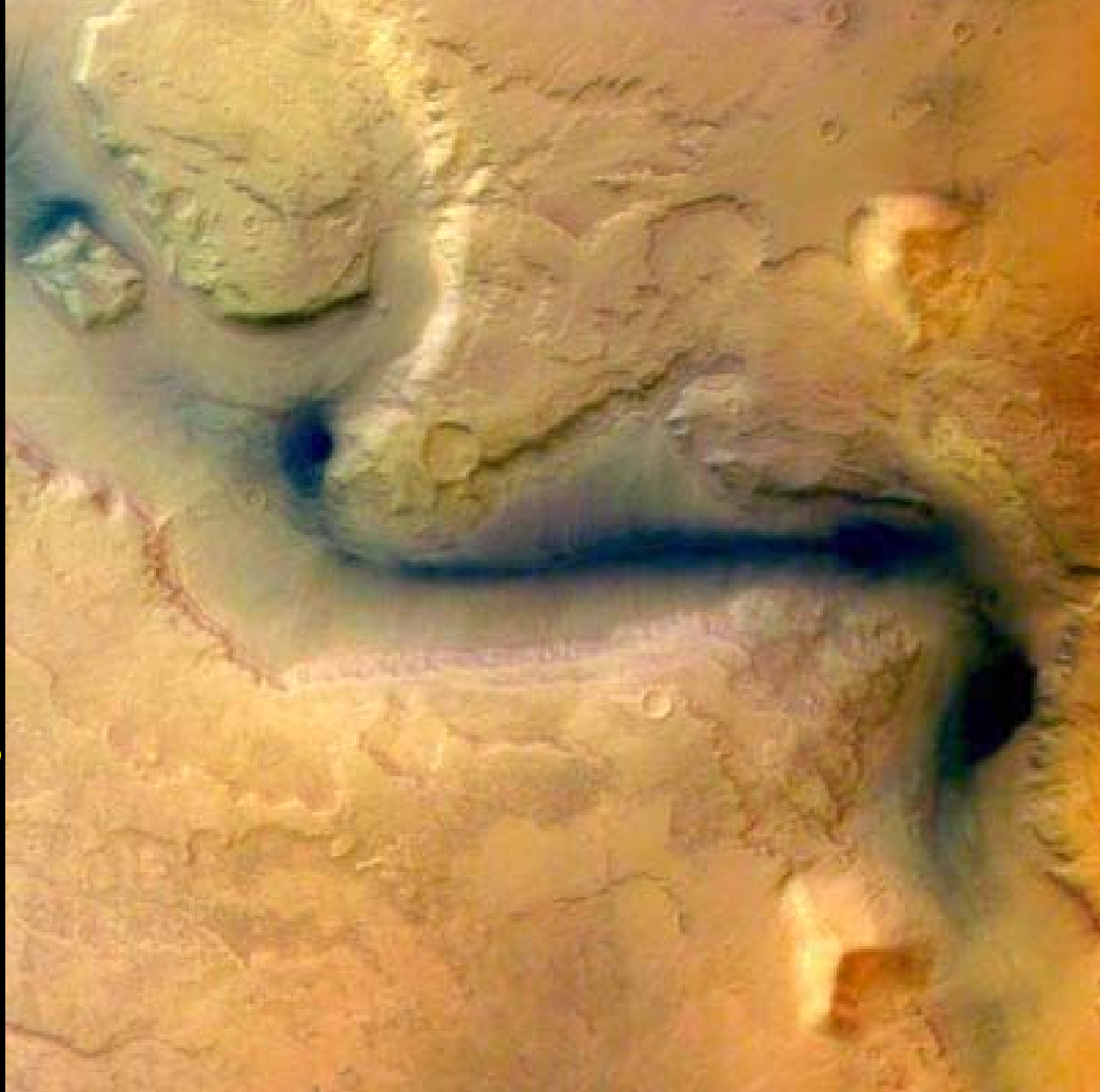


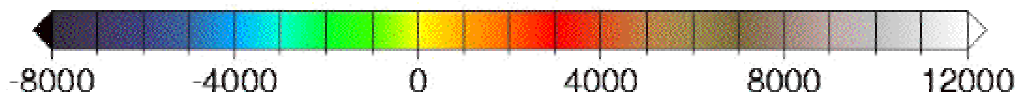


KASEI VALLI
ESA MARS EXPRESS ORBITER



**REULL VALLIS,
EAST OF HELLAS
ESA MARS EXPRESS**

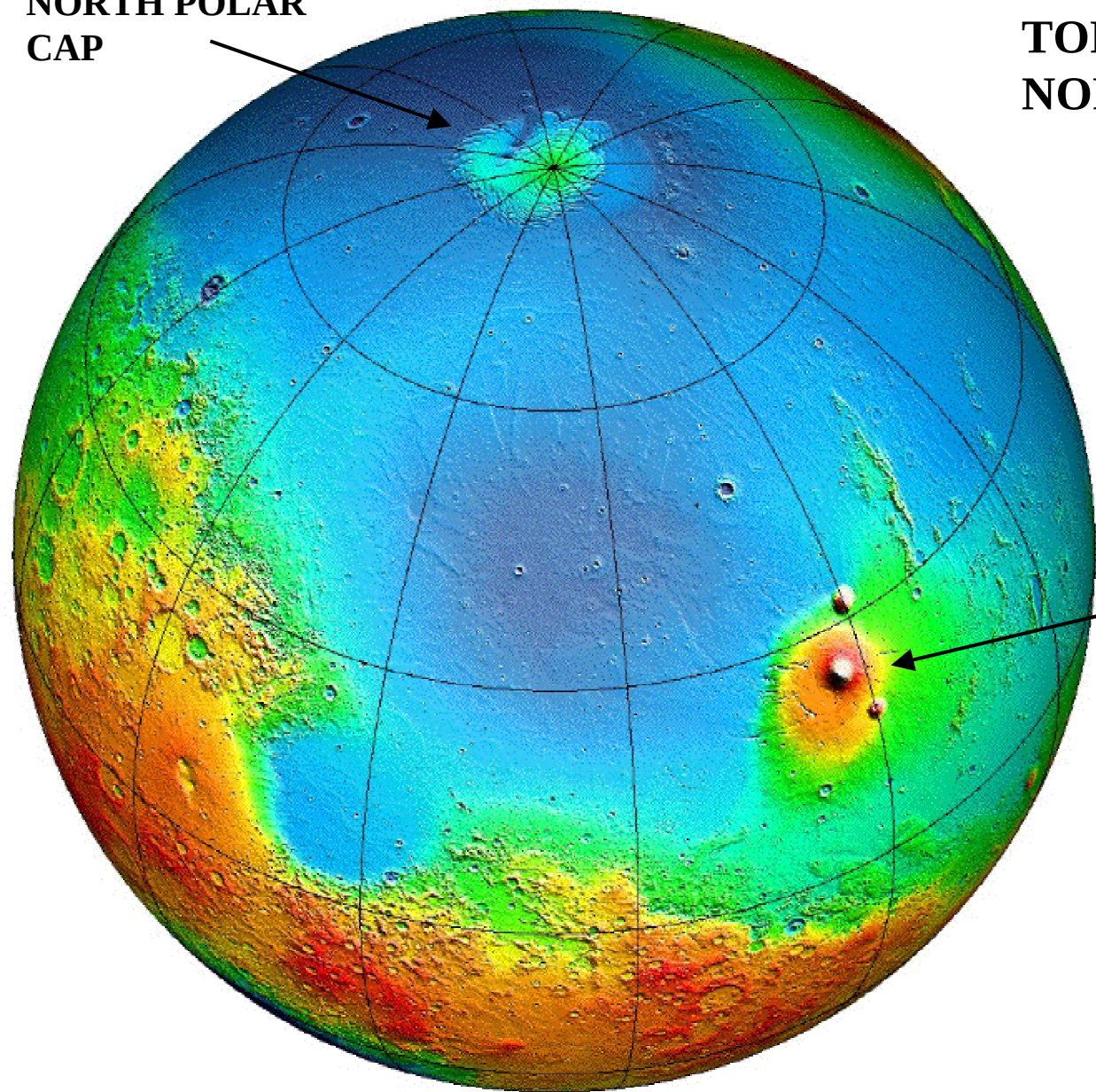


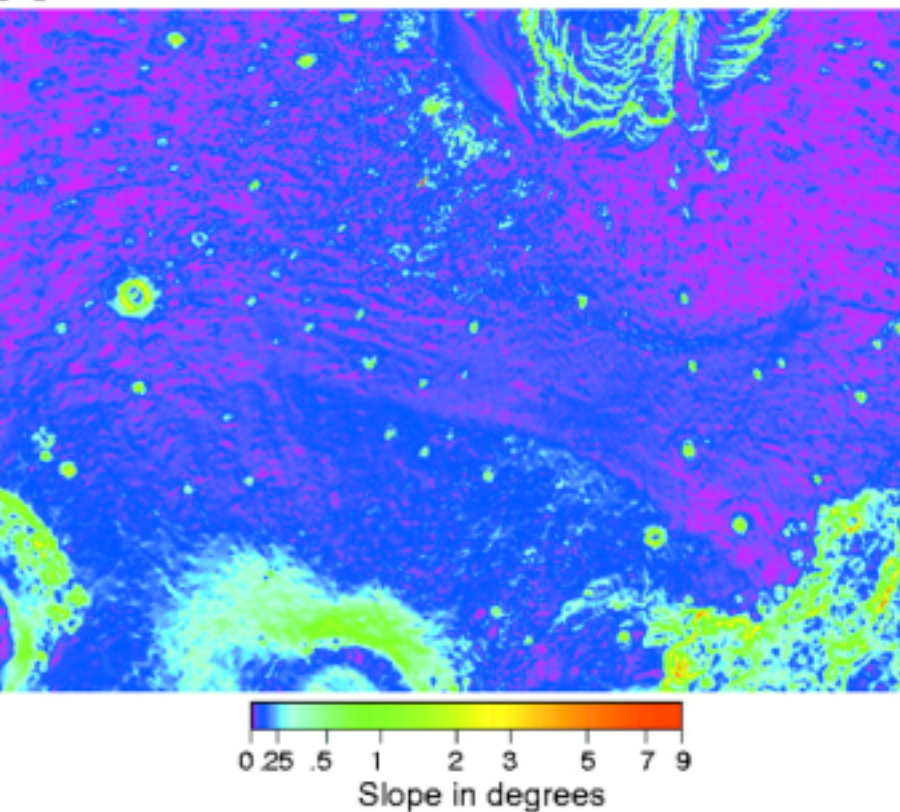


**NORTH POLAR
CAP**

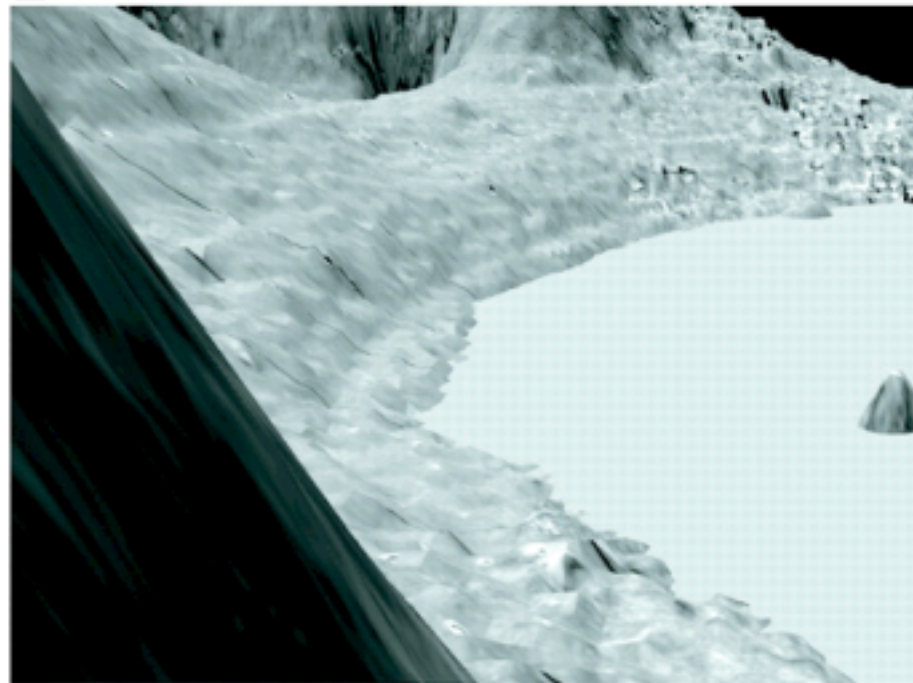
**TOPOGRAPHY OF
NORTHERN LOWLANDS**

**ELYSIUM VOLCANIC
REGION**

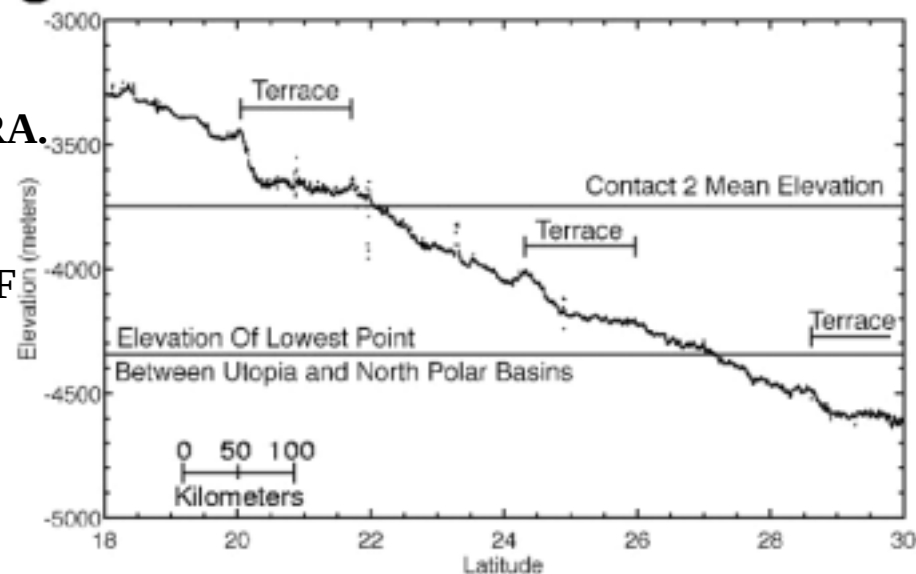


A

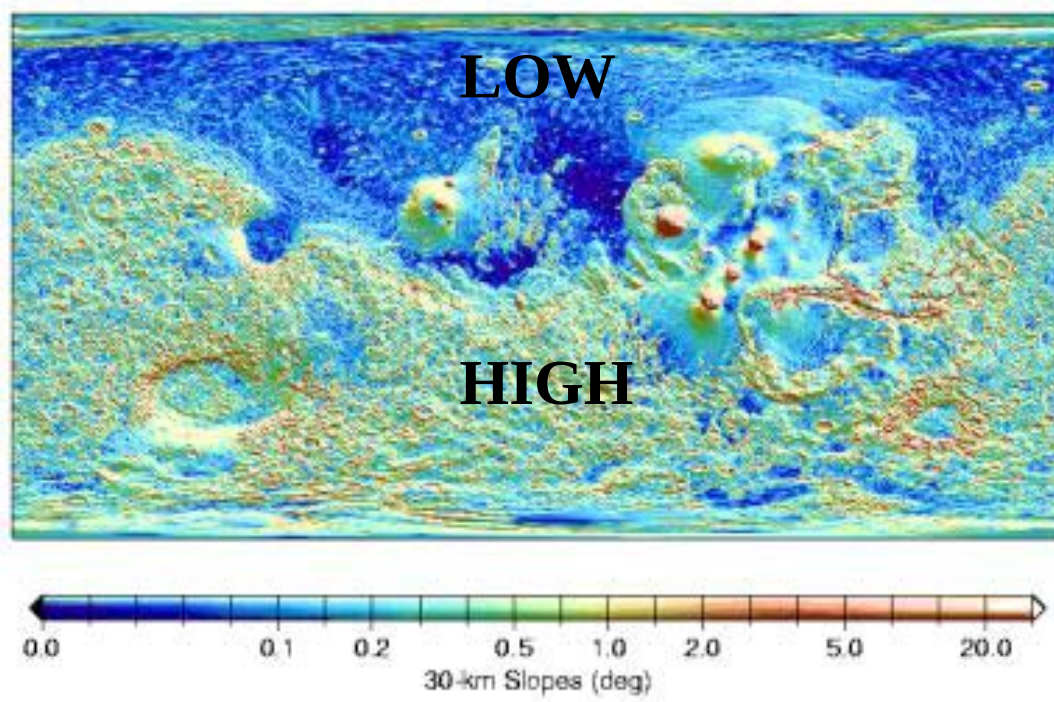
A. LINEAR SLOPE CHANGES ON ALBA PATERA.

B

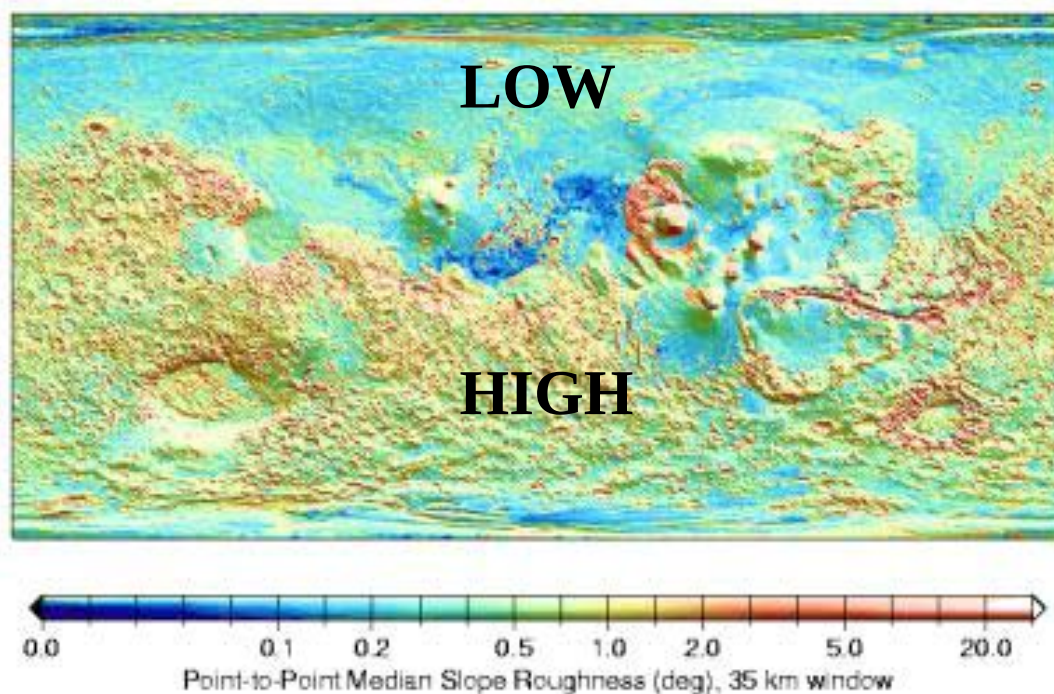
B. MOLA PERSPECTIVE VIEW OF APPARENT TERRACES AT THE SOUTHERN MARGIN OF UTOPIA PLANITIA.

C

C. MOLA PROFILE ACROSS SOUTHERN UTOPIA PLANITIA



**MOLA SLOPE MAP
(OVER 30 KM)**

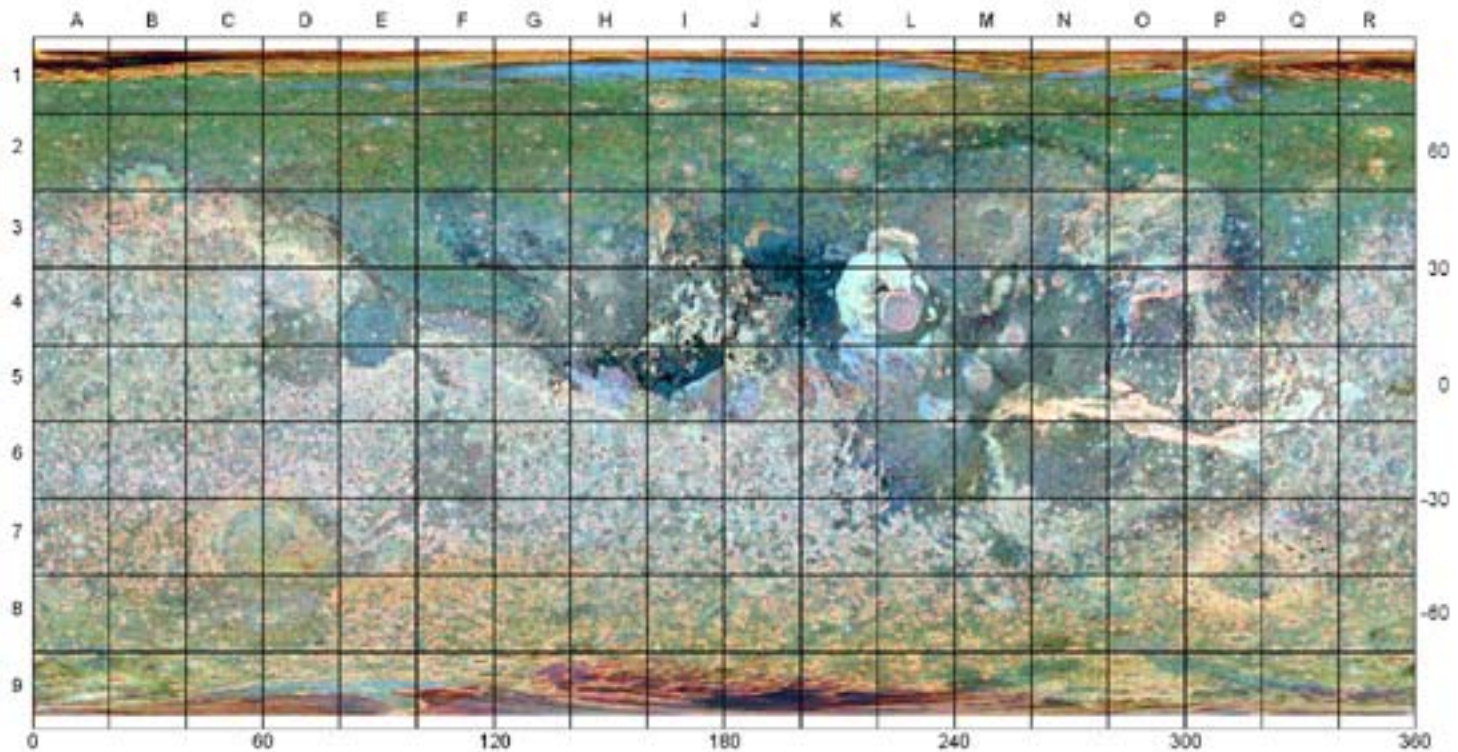
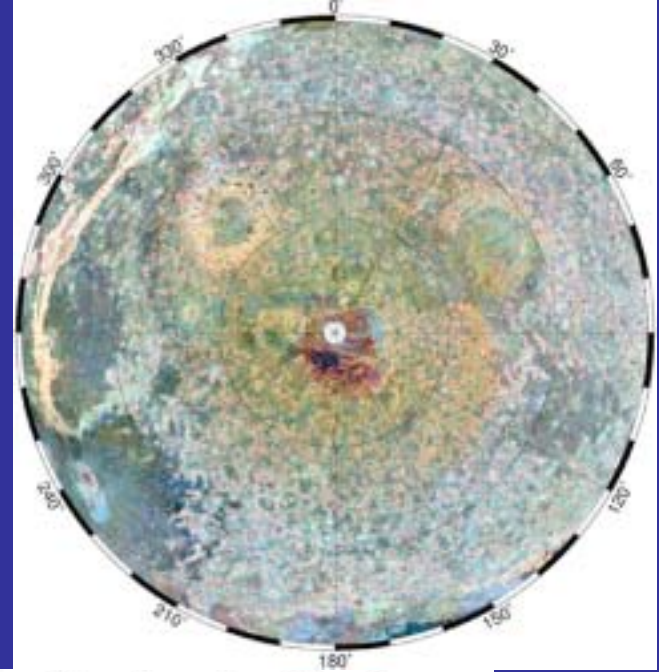
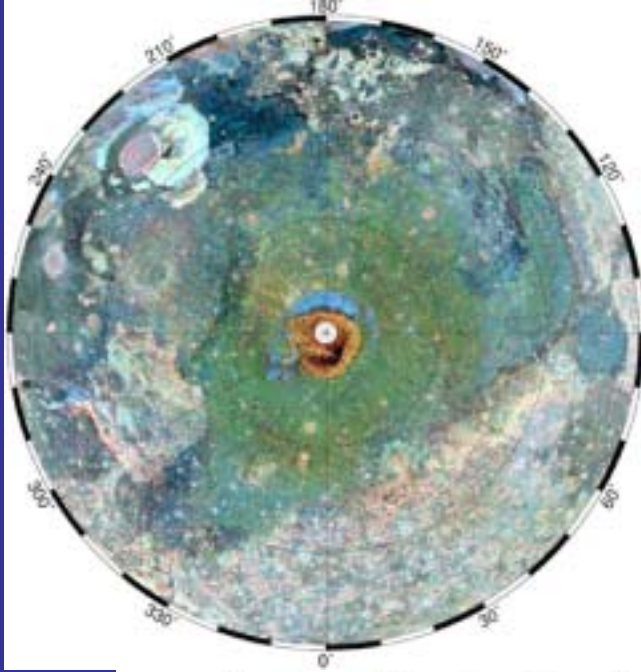


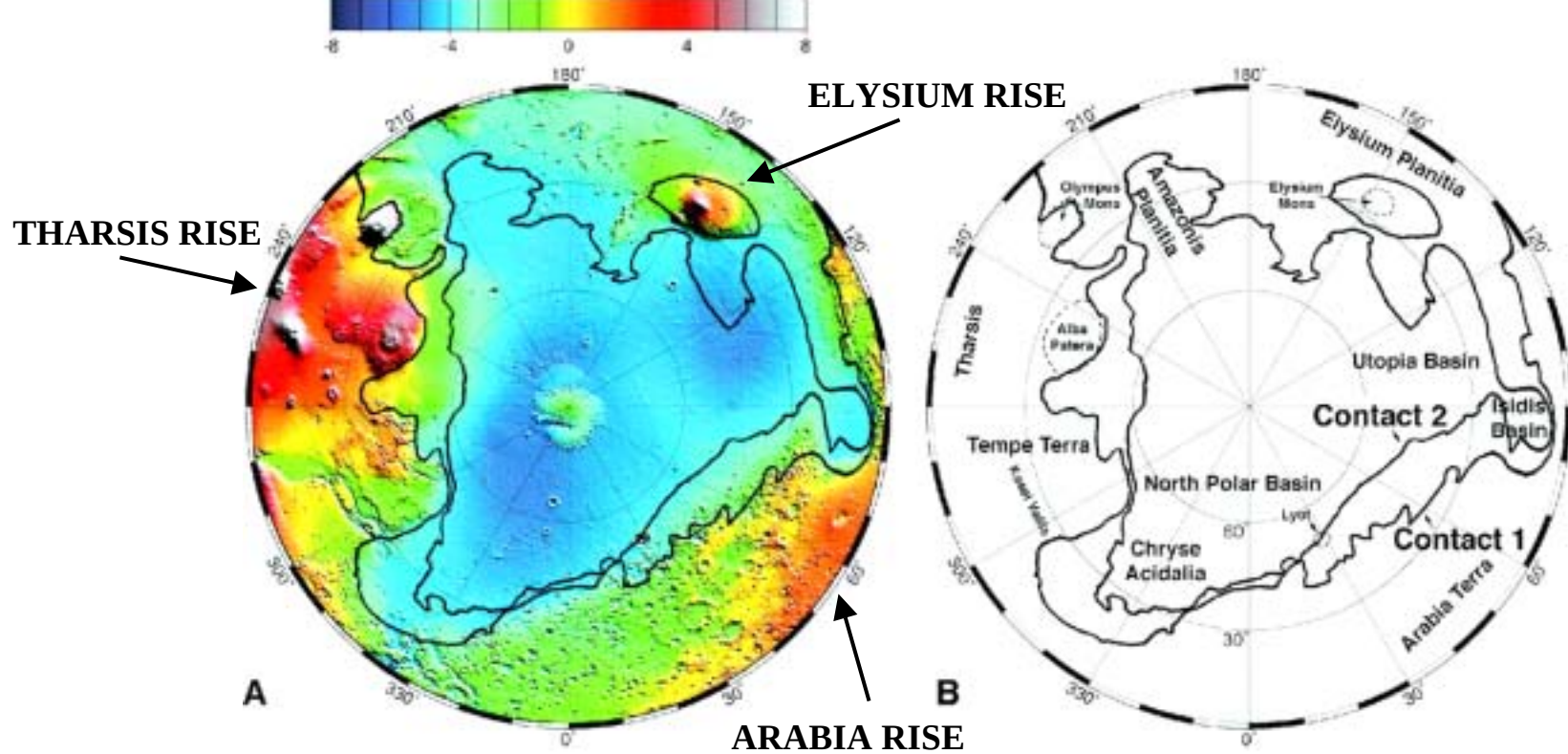
**MOLA ROUGHNESS MAP
(OVER 35 KM WINDOW)**

MOLA ROUGHNESS

BRIGHT IS
ROUGH

MARS GLOBAL SURVEYOR

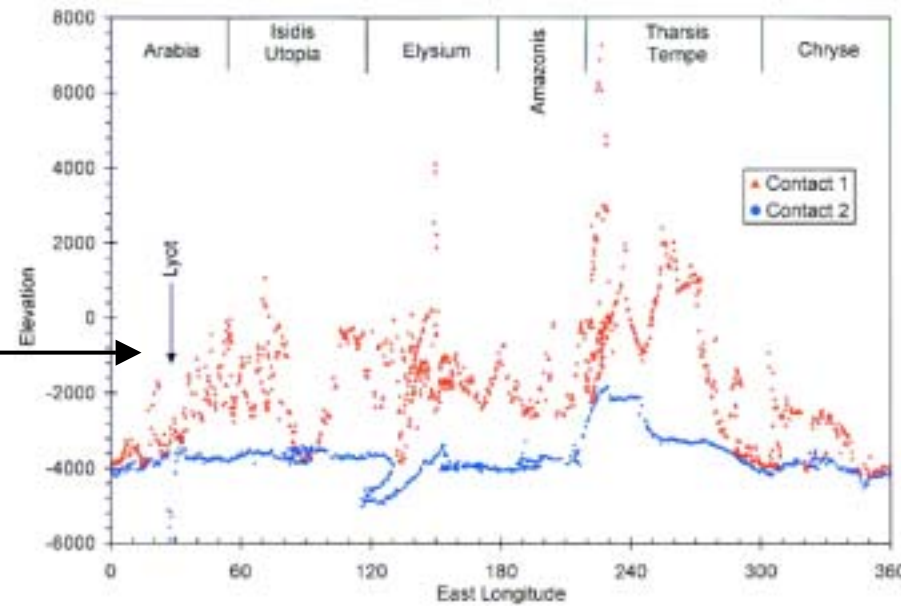




PROPOSED SHORELINES FOR A NORTHERN OCEAN ON MARS

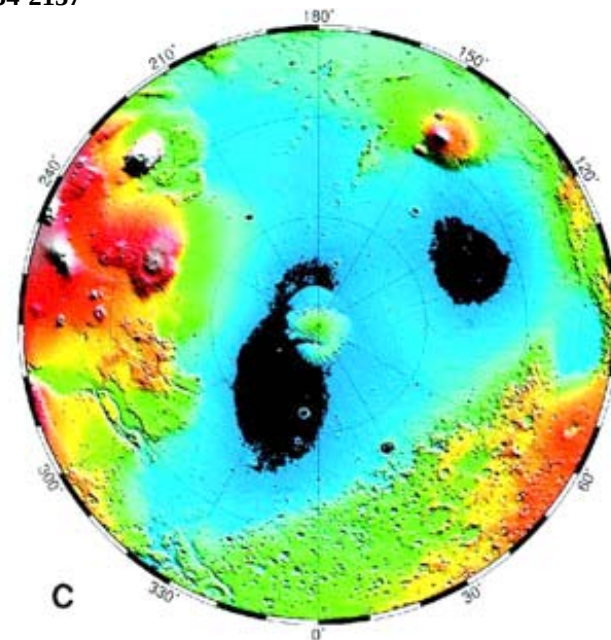
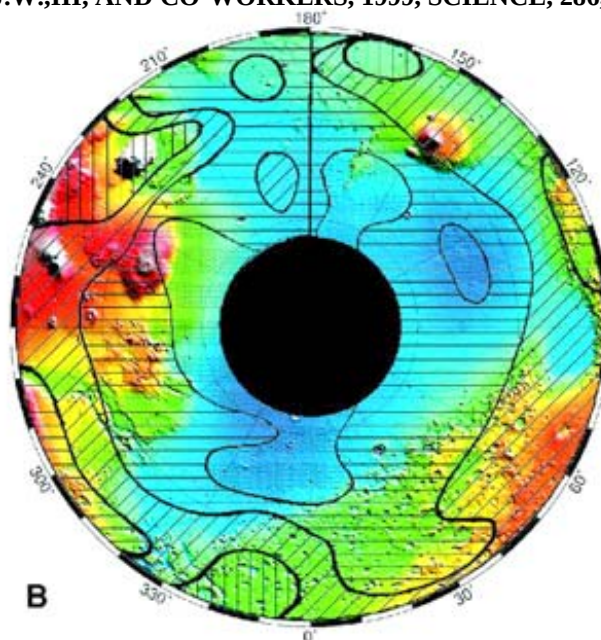
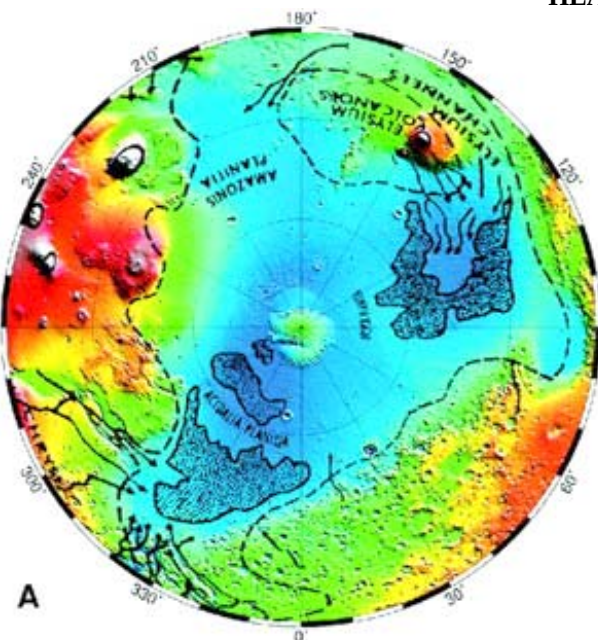
HEAD, J.W., III, AND CO-WORKERS, 1999, SCIENCE, 286,2134-2137

NOTE: OLDER, **CONTACT 1**, AND TO A LESSER DEGREE, **CONTACT 2** ARE MOST DISPLACED UPWARD IN AREAS OF THE THARSIS, ARABIA, AND ELYSIUM RISES WHICH MUST POST-DATE A POSSIBLE “EARLY” NORTHERN OCEAN.



SEQUENTIAL FLOODING OF NORTHERN LOWLANDS

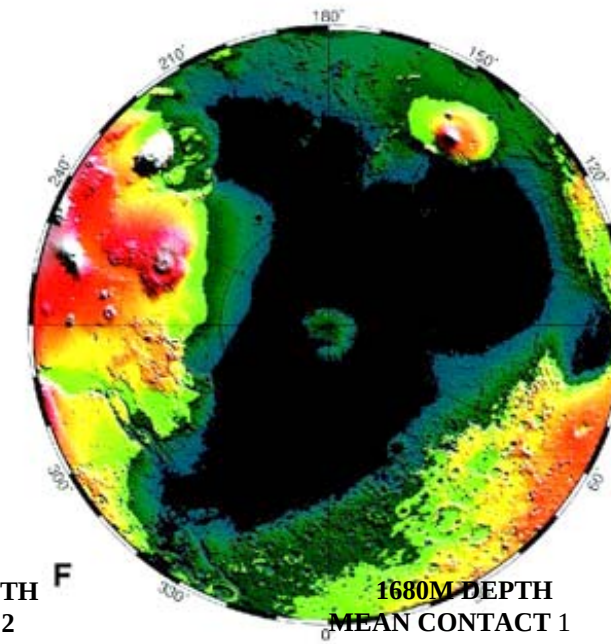
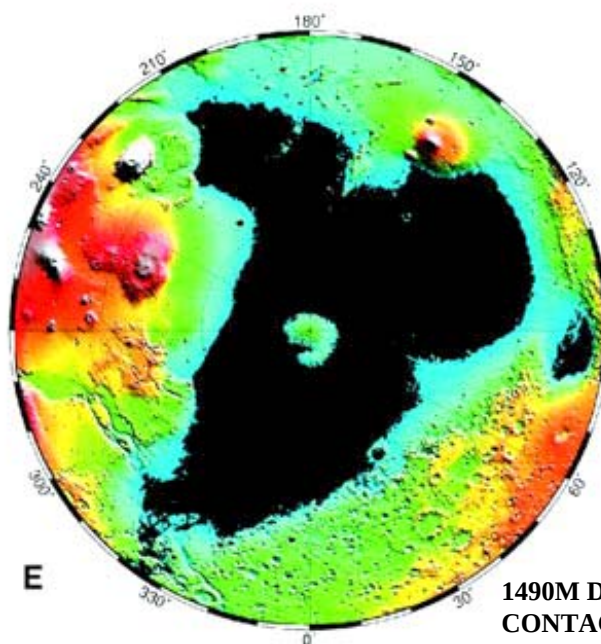
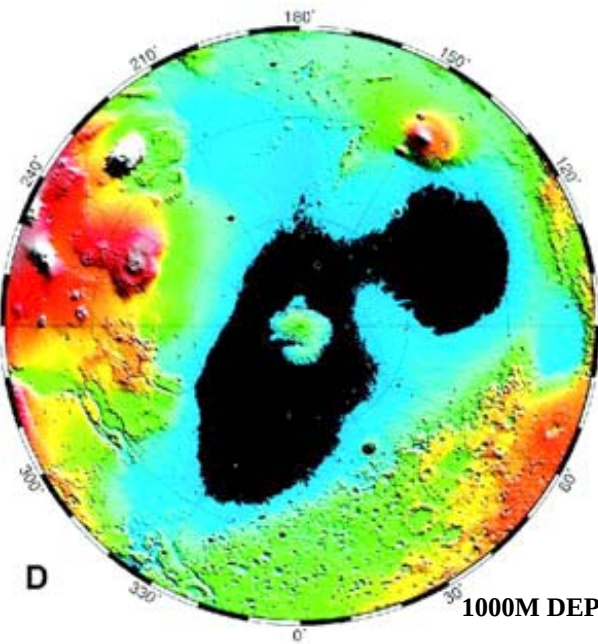
HEAD, J.W.,III, AND CO-WORKERS, 1999, SCIENCE, 286,2134-2137



STIPPLED SHOWS POLYGONAL GROUND

CRATER ONSET DIAMETERS INCREASE RADially

500M DEPTH



1000M DEPTH

1490M DEPTH
CONTACT 2

1680M DEPTH
MEAN CONTACT 1

THARSIS / ELYSIUM VOLCANISM UPLIFT CONSEQUENCES - 1

- THARSIS / ELYSIUM VOLCANISM
 - PARTIAL MELTING OF MANTLE
 - » CONCENTRATION OF RADIOISOTOPES IN HIGH PRESSURE MANTLE (?)
 - $3 \times 10^3 \text{ KM}^3$ MAGMA IN SURFACE EXPRESSION OF THARSIS RISE
 - DENSE CO_2 AND H_2O ATMOSPHERE
 - ACTIVATION OF HYDROSPHERE, CRYOSPHERE AND CARBONATE DEPOSITS
 - PRIMARY WATER FROM HYDROUS MINERALS IN LOWER MANTLE (?)
 - ANDESITIC RESURFACING OF NORTHERN LOWLANDS

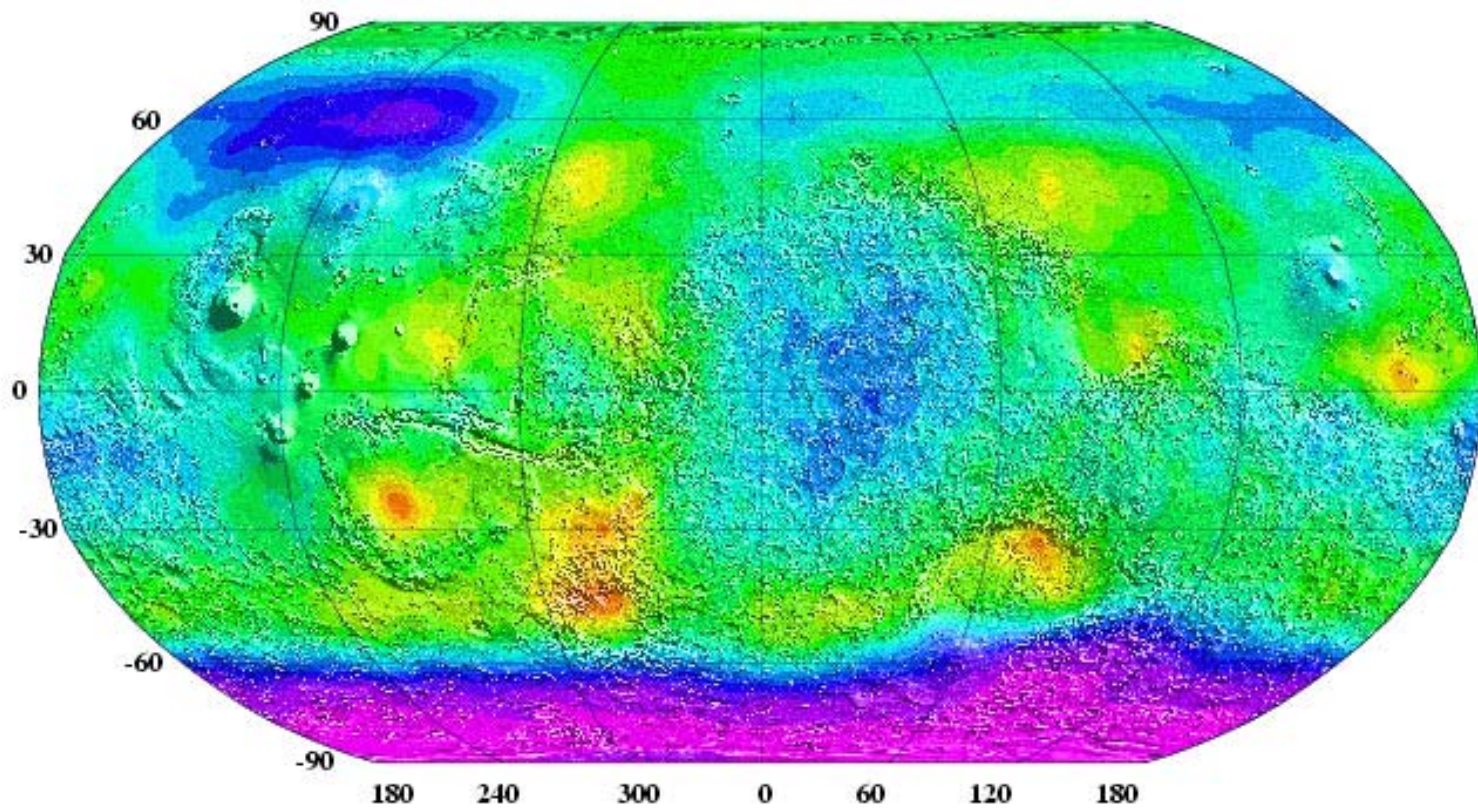
THARSIS / ELYSIUM VOLCANISM UPLIFT CONSEQUENCES -2

- **THARSIS RISE BEGAT ARABIA TERRA RISE**
 - **EXTENTIONAL FRACTURING TO GIVE GIANT RIFT VALLEYS**
 - **BECAME OUTFLOW CHANNELS**
 - **HEAT TO ACTIVATE THE HYDROSPHERE/CRYOSPHERE**
 - **SOURCE FOR OUTFLOW FLOODS**
 - **TROUGH SURROUNDING THARSIS**
 - **NORTHWARD FLOW FROM MAJOR OUTFLOW CHANNELS**
 - **ERODED MATERIALS DEPOSITED ON NORTHERN OCEAN BED**
 - **UPWARD DEFORMATION OF THE EARLY NORTHERN OCEAN SHORELINE**
 - **LATE, LOCAL DEFORMATION OF LATE NORTHERN OCEAN SHORELINE**

NORTHERN LOWLANDS/OCEANS

- **LARGE, IRREGULAR BASIN**
 - **SEVERAL VERY LARGE IMPACTS(?)**
 - **DICHOTOMY SIMILAR TO MOON**
 - **INTERNAL PROCESS THAT THINNED CRUST(?)**
- **EVIDENCE FOR NORTHERN OCEAN(S)**
 - **DRAINAGE FROM VALLEY NETWORKS (EARLY VOLCANISM)**
 - **ABUNDANCE OF OLD LAYERED ROCKS**
 - **DRAINAGE FROM OUTFLOW CHANNELS (THARSIS VOLCANISM)**
 - **SHORELINE / STANDSTILL TERRACES(?)**
 - **SMOOTH TOPOGRAPHY RELATIVE TO SOUTHERN UPLANDS**
 - **VOLUME ENCLOSED PLAUSIBLE RELATIVE TO POTENTIAL WATER VOLUME**
 - **EVIDENCE FOR RECENT OR CURRENT GROUND ICE OR GROUND WATER**
 - **POLYGONAL GROUND**
 - **RAMPART CRATER EJECTA**
 - **NEUTRON SPECTROMETRIC DATA FROM MARS ODYSSEY**

Late Southern Summer



Epithermal Neutrons



← HYDROGEN

APOLLO MODEL OF MARS EVOLUTION

**PRESENT
CONDITIONS
? B.Y.**

**THIN
ATMOSPHERE:
CO₂, DUST**

**CRYOSPHERE /
HYDROSPHERE**

**OLIVINE/ NA-
PYROXENE
CUMULATE**

**OLIVINE
CUMULATE**

**GARNET / NA-CPX
NA-BIOTITE?/NA-
HORNBLLENDE/
"RUTILE"
CUMULATES**

**RELIC MAGNETIC
STRIPING**

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Madison

NORTH POLAR ICE CAP

ELYSIUM MONS

THARSIS

**MAFIC UPPER
MANTLE WITH
INCREASING
SI AND FE
UPWARDS**

**VALLES
MARINERIS
OUTFLOW**

**ANDESITE
ROCKS**

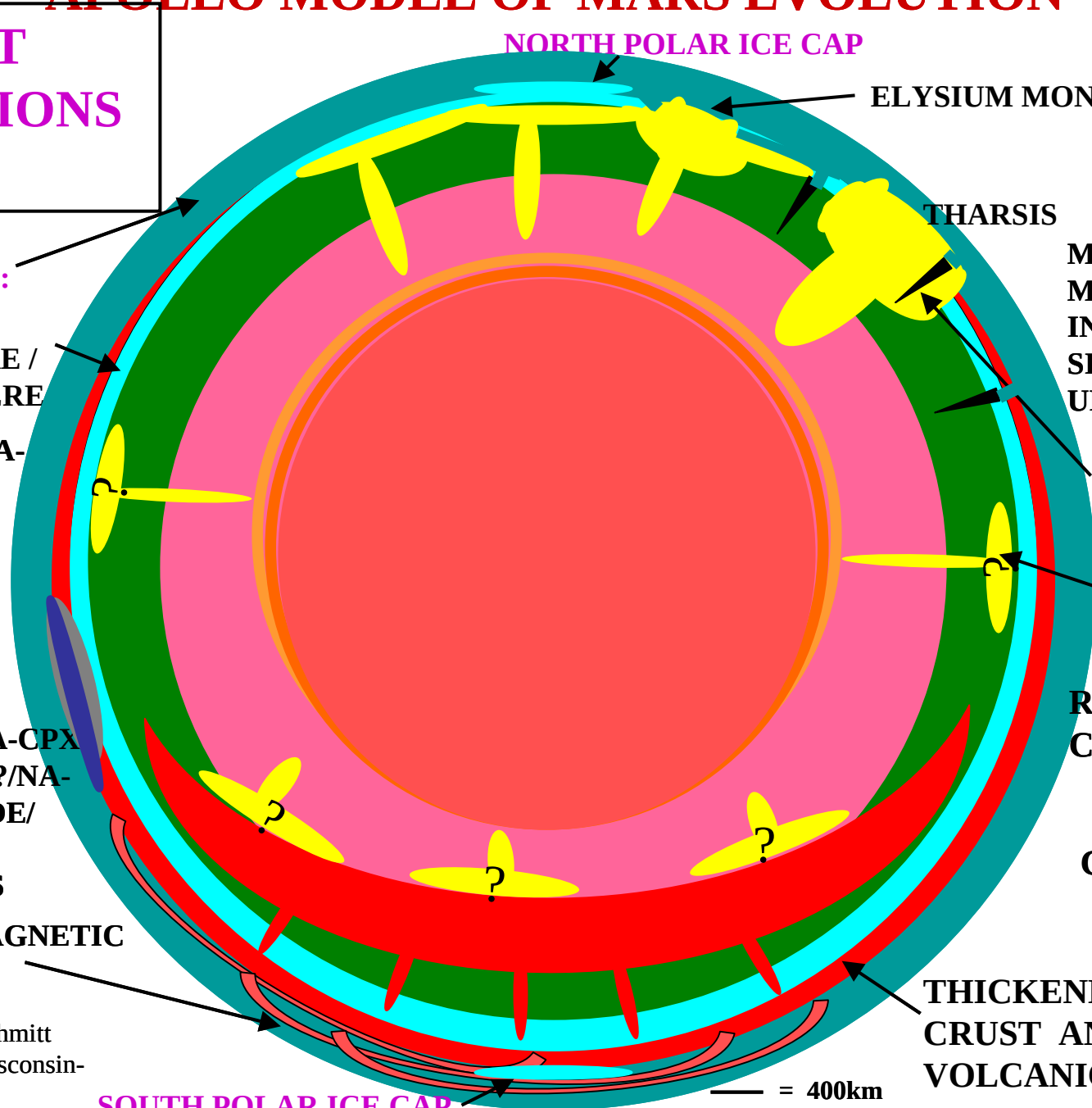
**RELIC PROTO-
CORE ?**

**FE_xNI_yS_z
CORE**

**THICKENED SOUTHERN
CRUST AND BASALTIC
VOLCANICS**

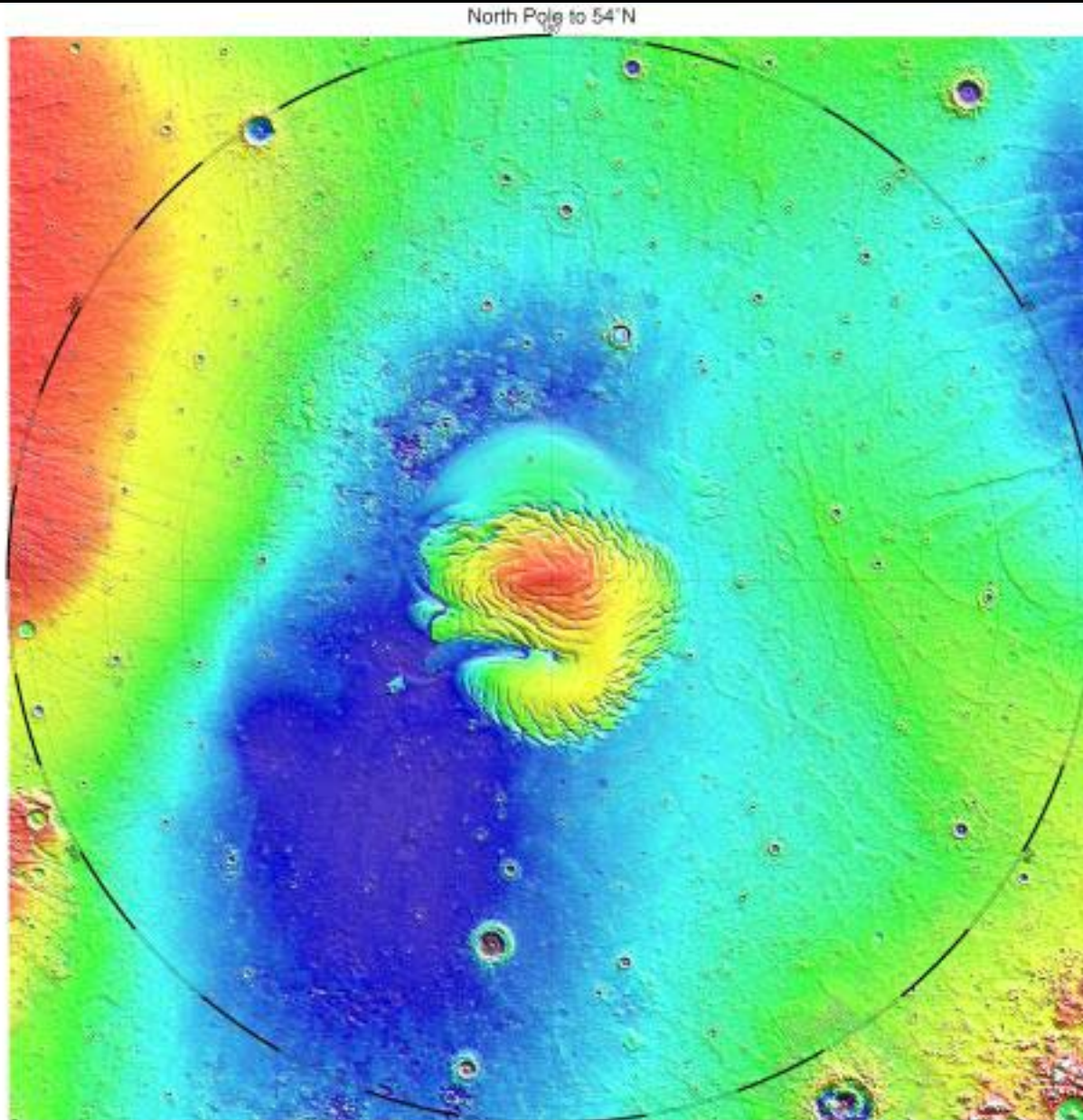
= 400km

SOUTH POLAR ICE CAP



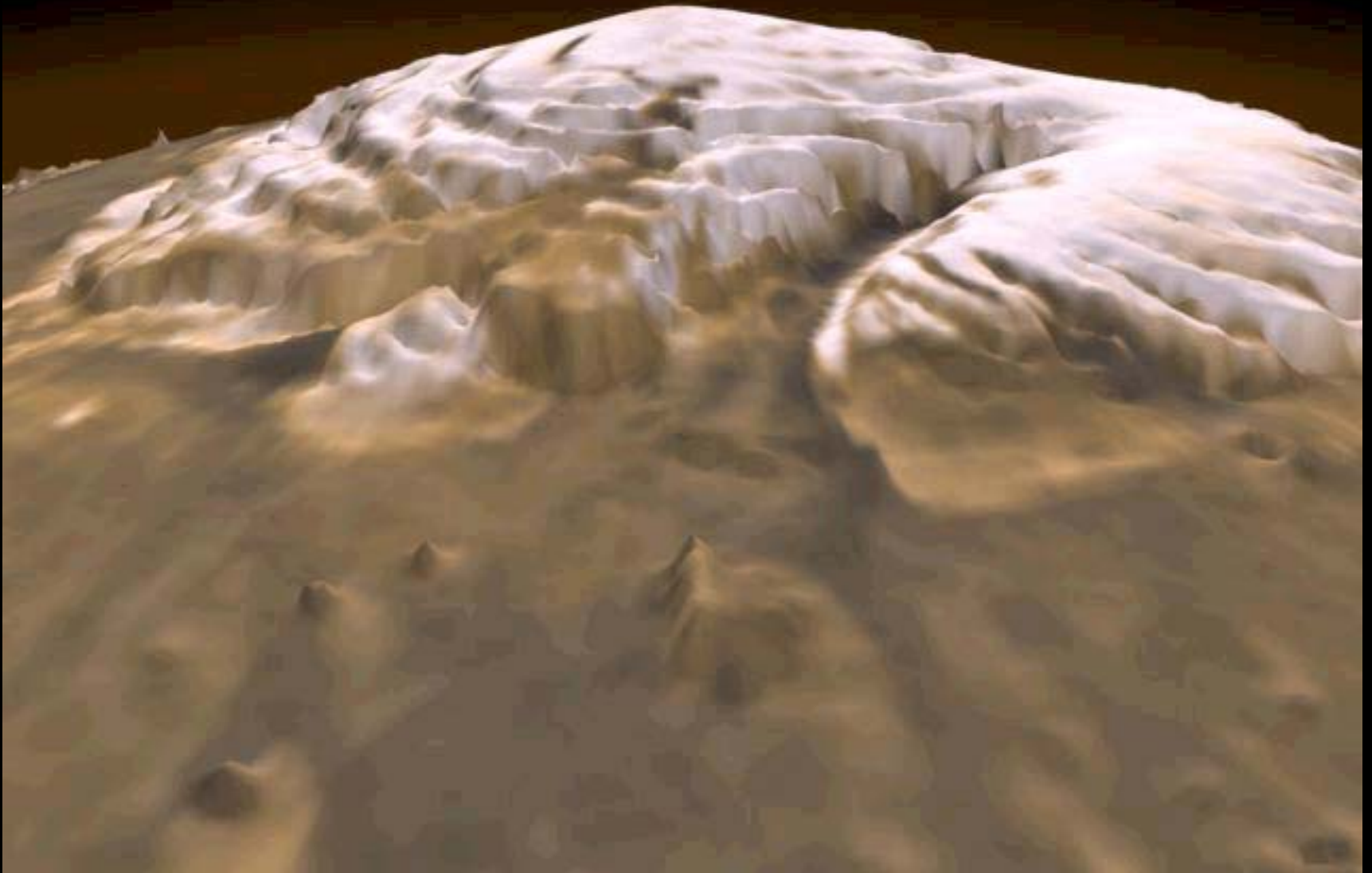
NORTH POLE TOPOGRAPHY

MOLA SCIENCE TEAM



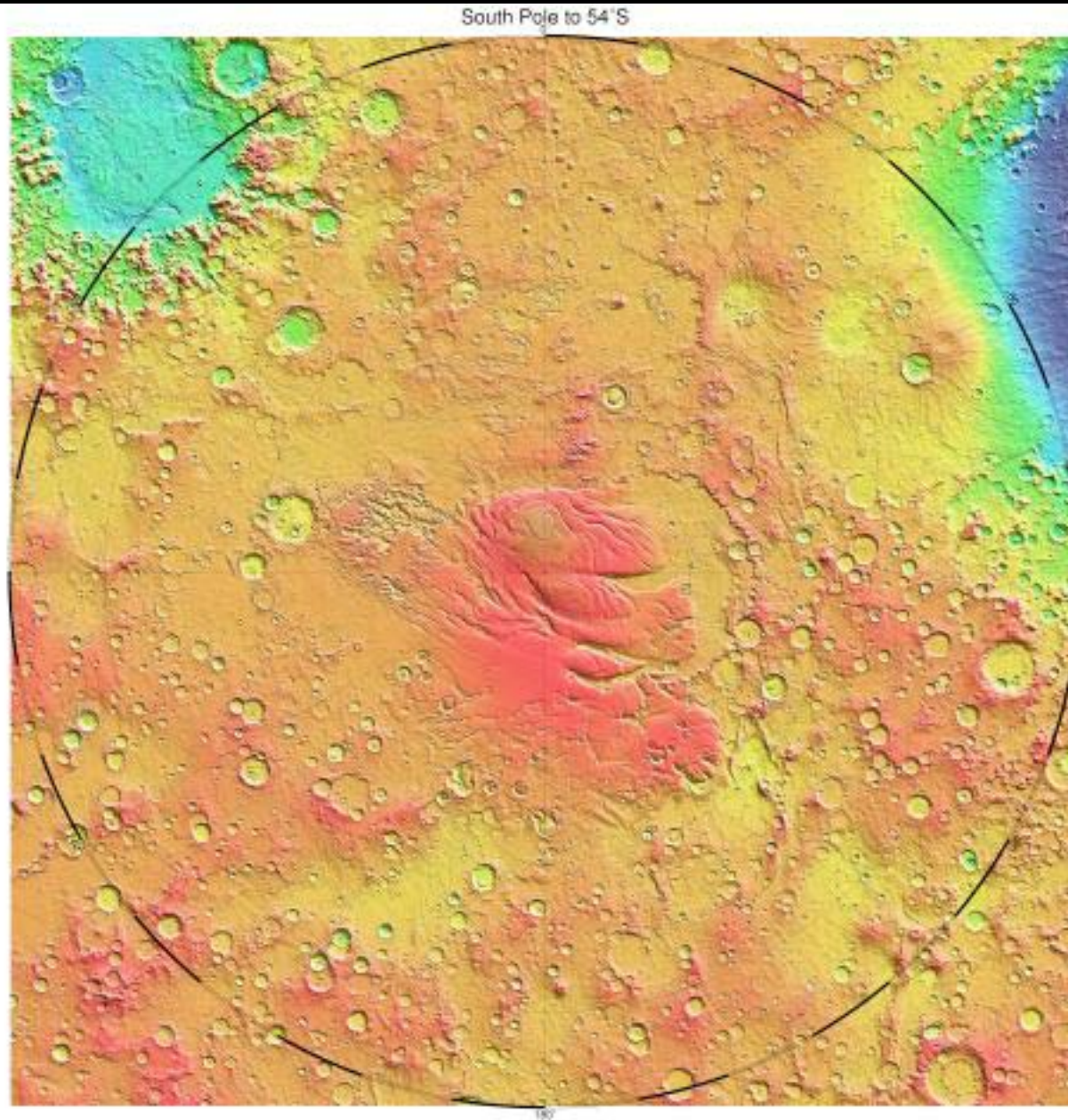
3D VIEW OF NORTH POLAR CAP

MOLA SCIENCE TEAM/ NASA/GFSC SVS



SOUTH POLE TOPOGRAPHY

MOLA SCIENCE TEAM





SOUTH POLAR CAP
NASA/JPL/MALIN SCIENCE SYSTEMS

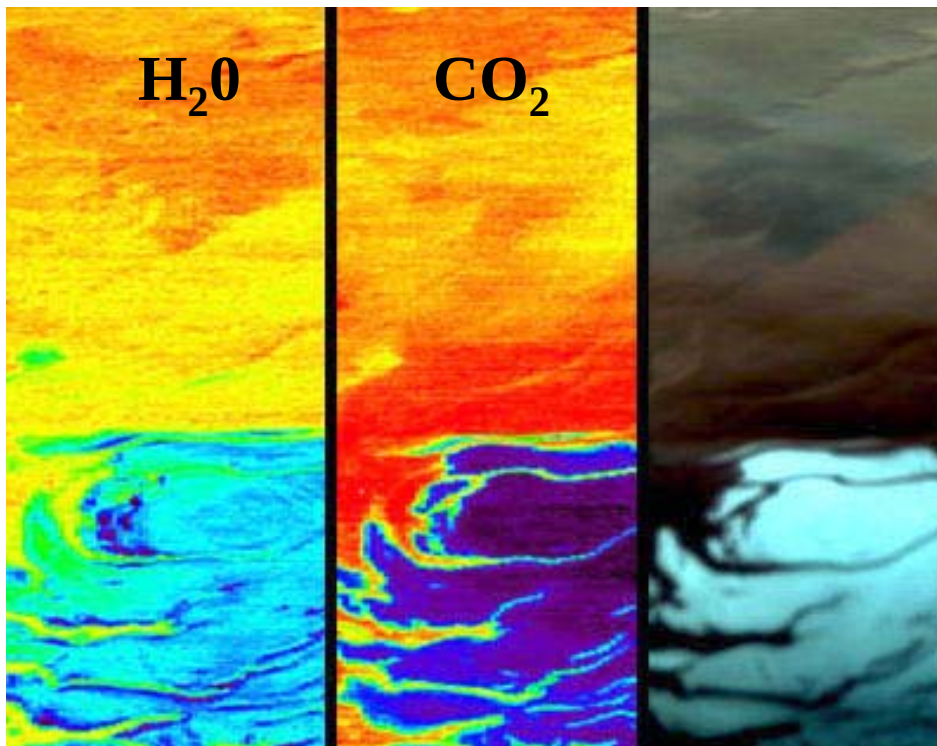


March 1999



January 2001

MARS ORBITER



ESA-OMEGA

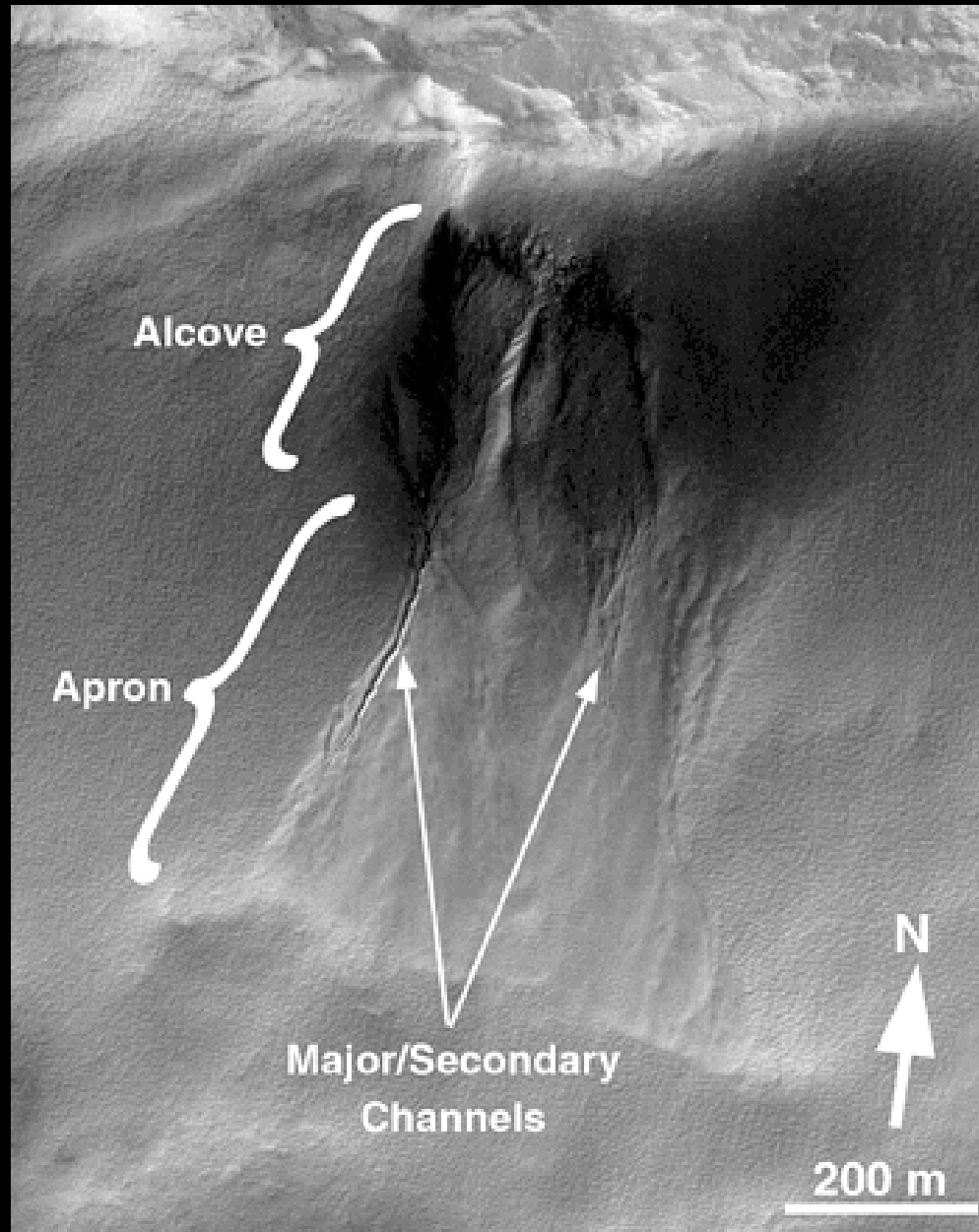
VISIBLE / IR

MARS EXPRESS

JANUARY 2004

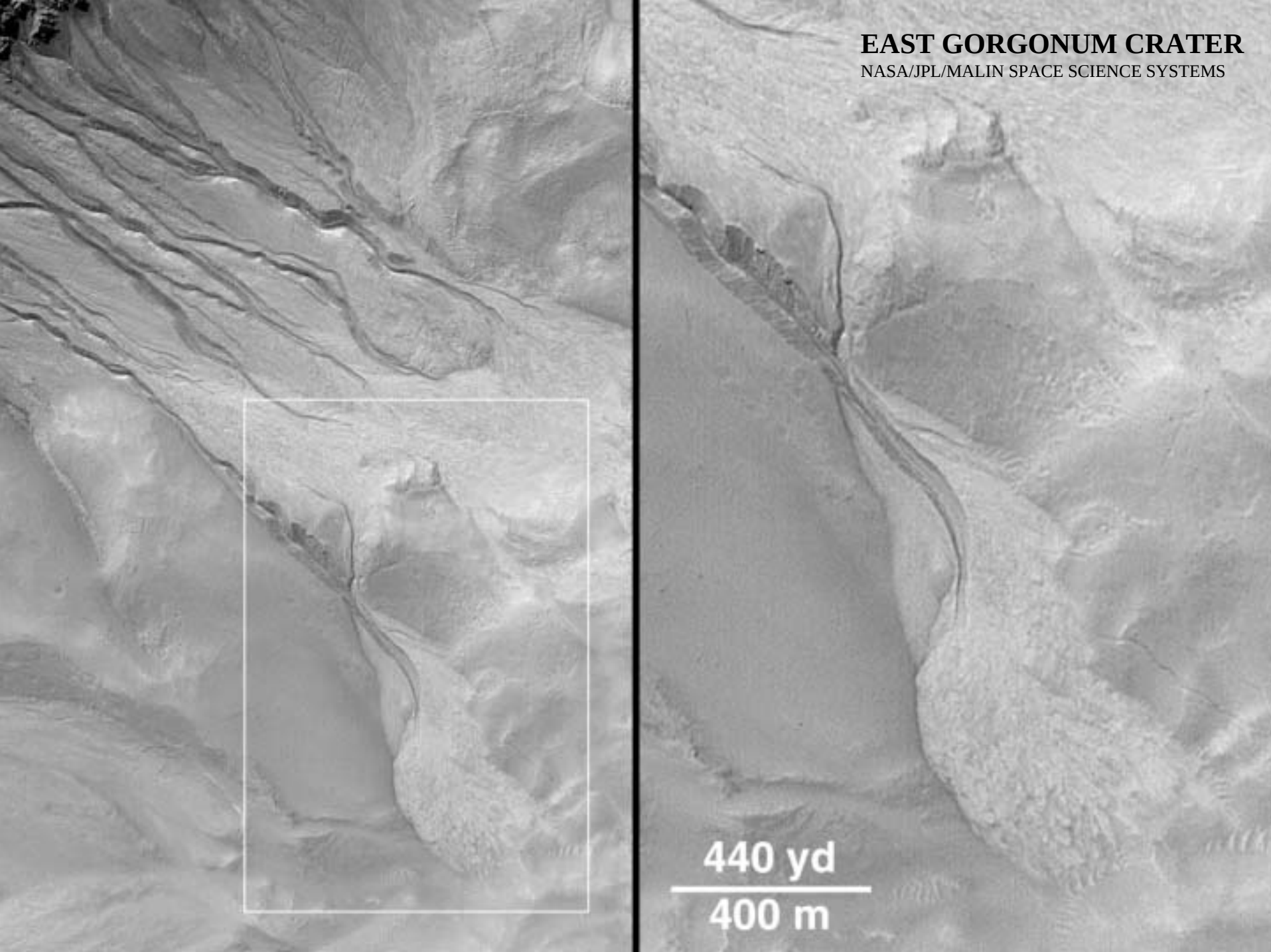
EVIDENCE OF RECENT WATER FLOW

MALIN, M.C., AND K.S. EDGETT, 2000, SCIENCE, 288, 2330-2335



EAST GORGONUM CRATER

NASA/JPL/MALIN SPACE SCIENCE SYSTEMS



440 yd
400 m

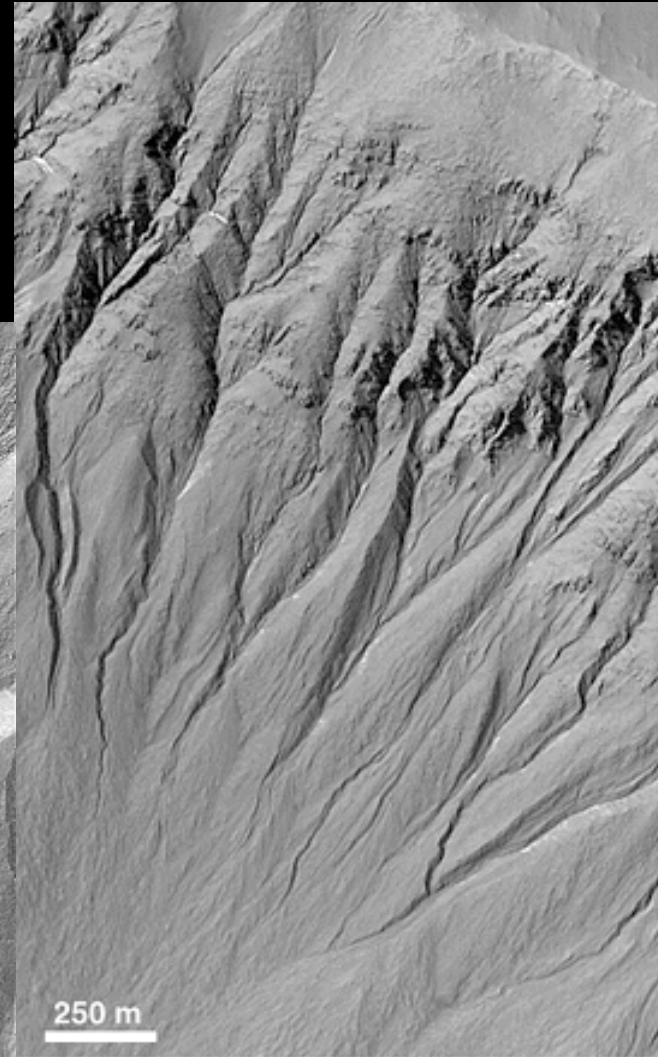
DIGITATE APRON

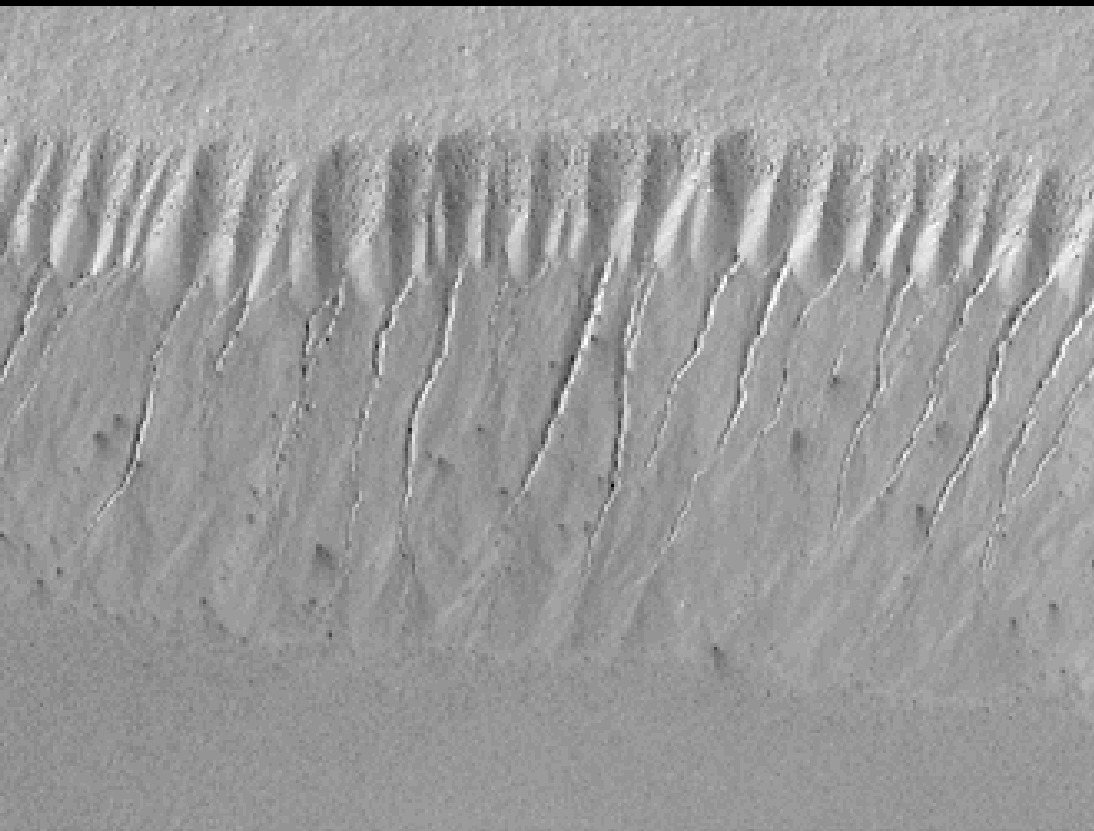


ANASTOMOSING GULLIES



PRIMARY CHANNELS

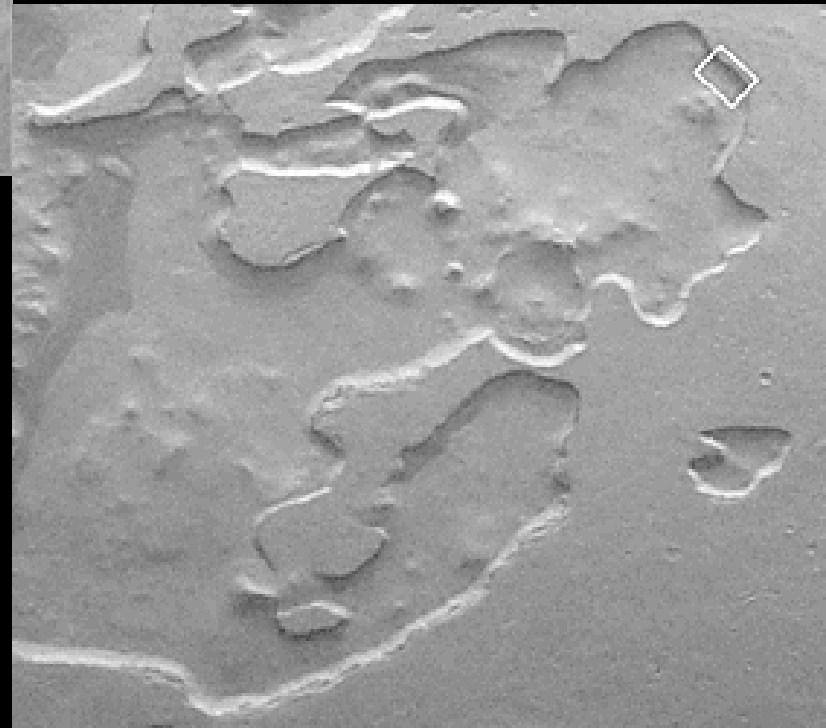




GULLIES AT 70 S. IN POLAR PIT WALL

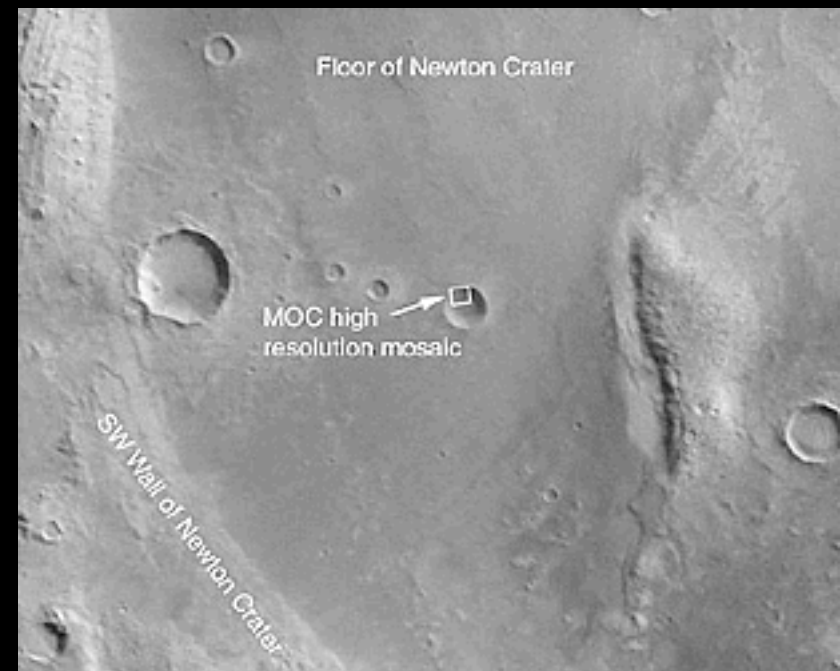
NASA/JPL/MALIN SPACE SCIENCE SYSTEMS

VIKING CONTEXT





GULLIES IN CRATER IN NEWTON CRATER



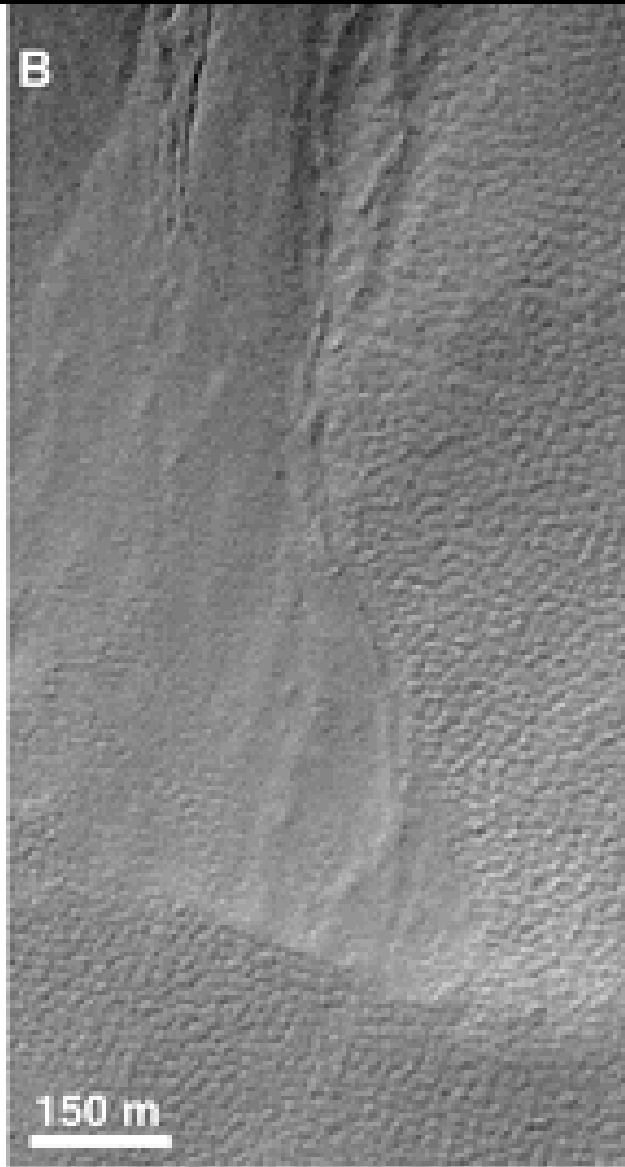
YOUNG RELATIVE AGE FOR EROSION

MALIN, M.C., AND K.S. EDGETT, 2000, SCIENCE, 288, 2330-2335

APRON COVERING DUNES



APRON COVERING POLYGONS

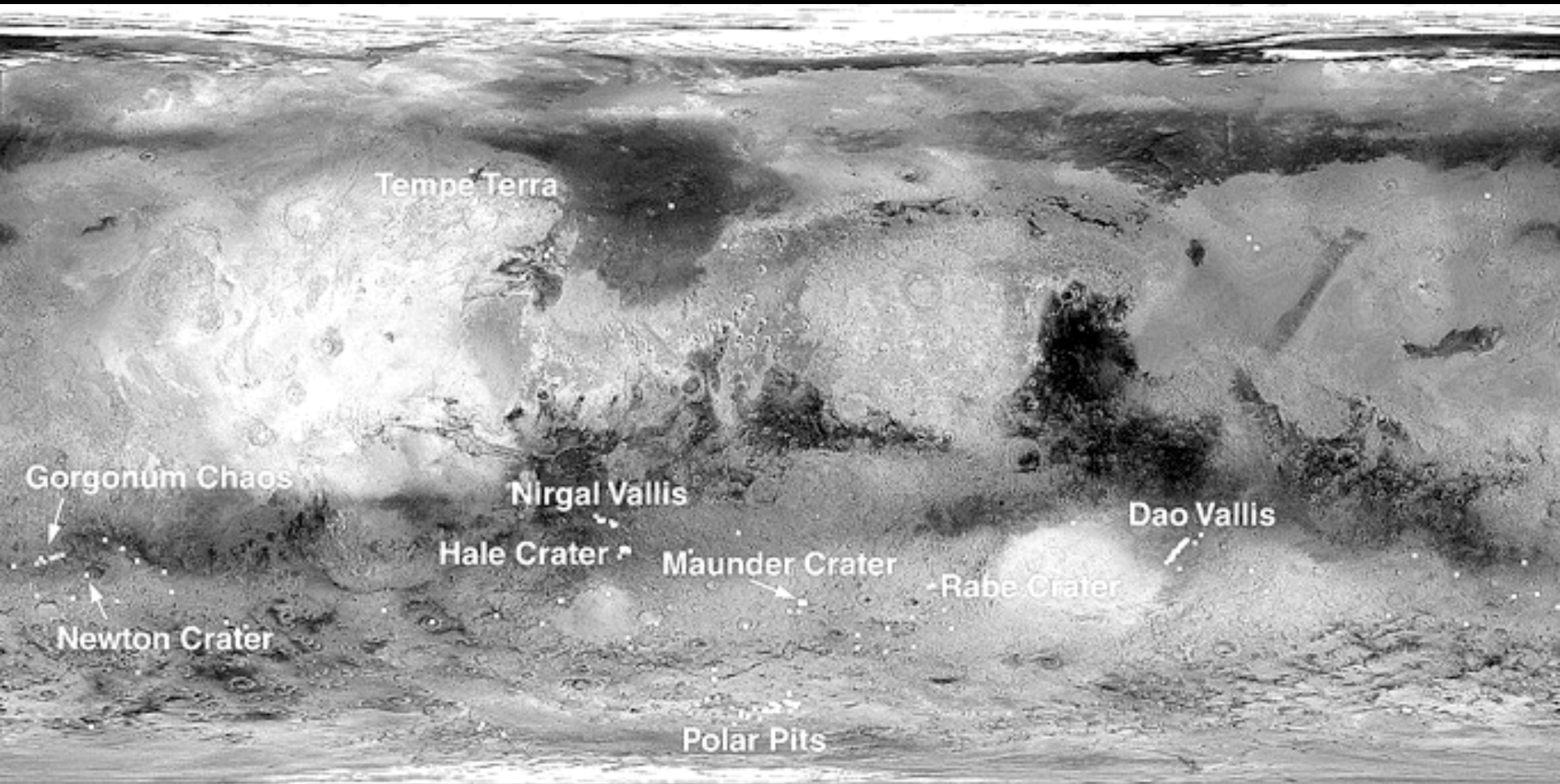


FRESH, DUST FREE SURFACES



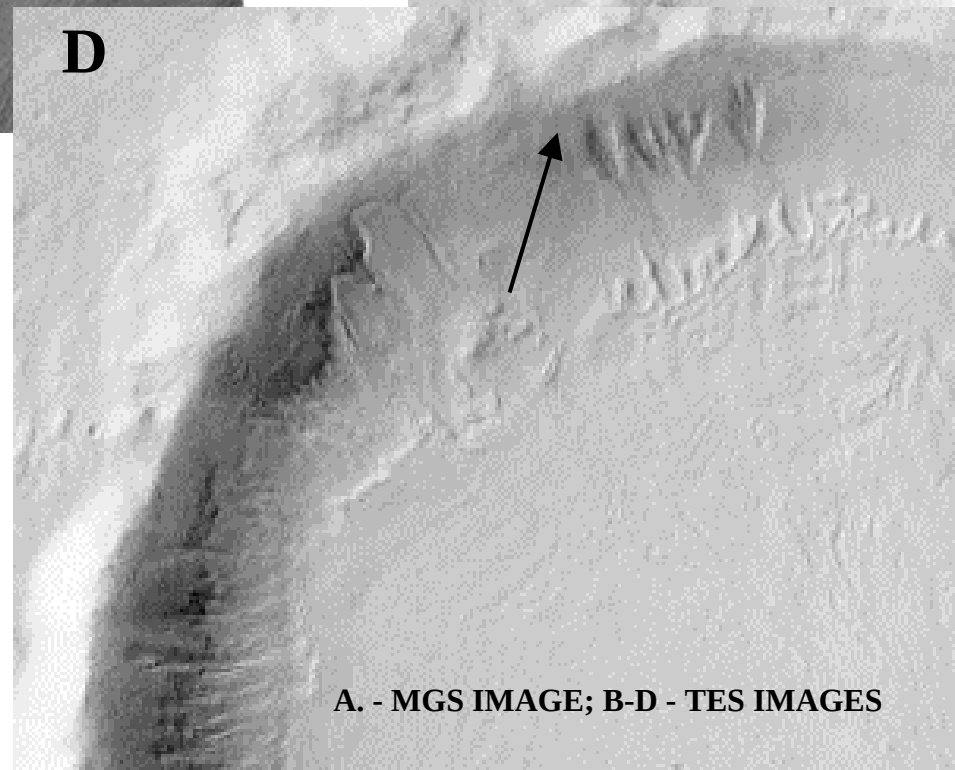
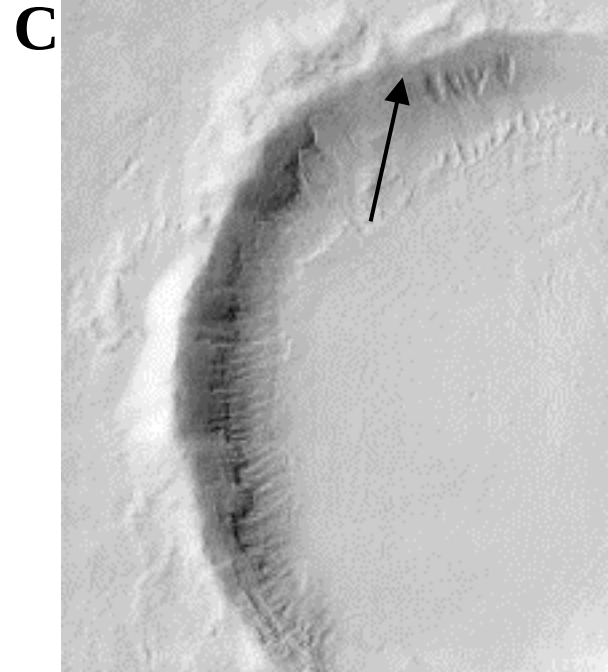
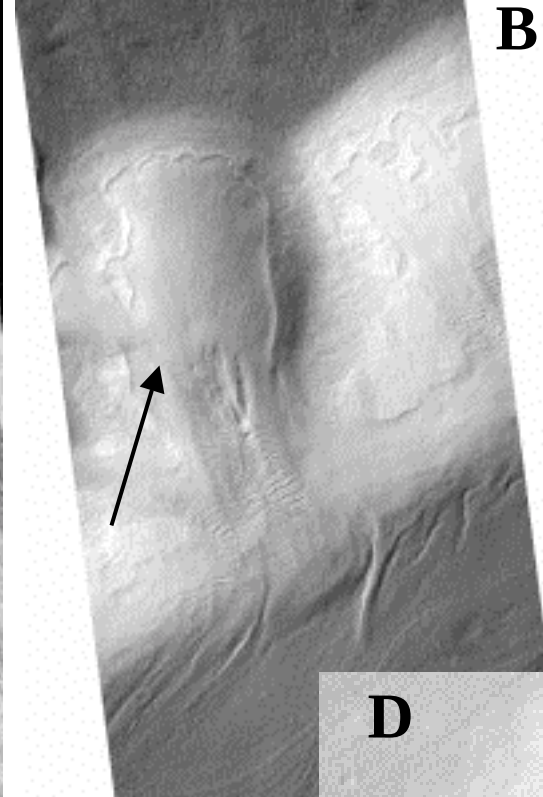
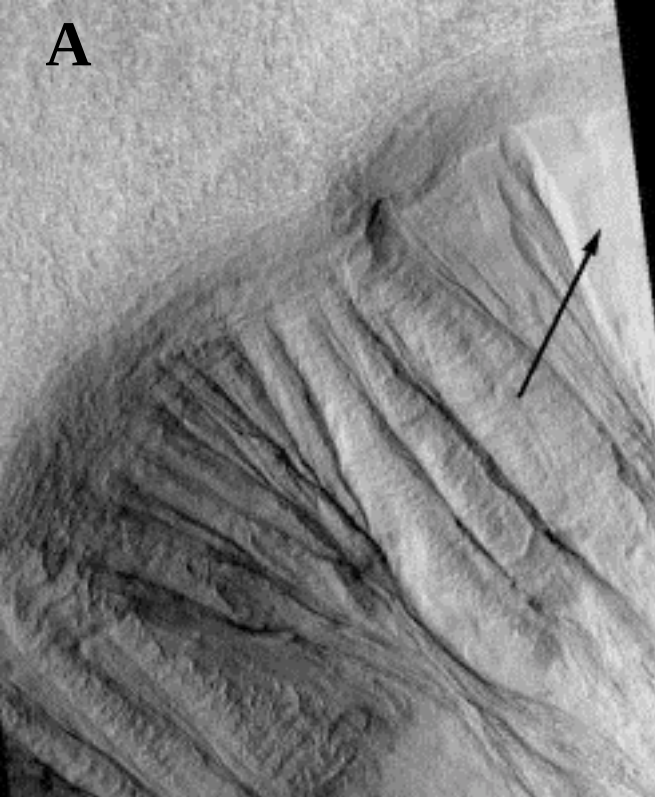
GLOBAL DISTRIBUTION OF OBSERVED GULLY LANDFORMS

MALIN, M.C., AND K.S. EDGETT, 2000, SCIENCE, 288, 2330-2335



SOUTH POLE

NOTE: SLOPES FACE POLE-WARD 2.5 X MORE OFTEN THAN OTHERWISE



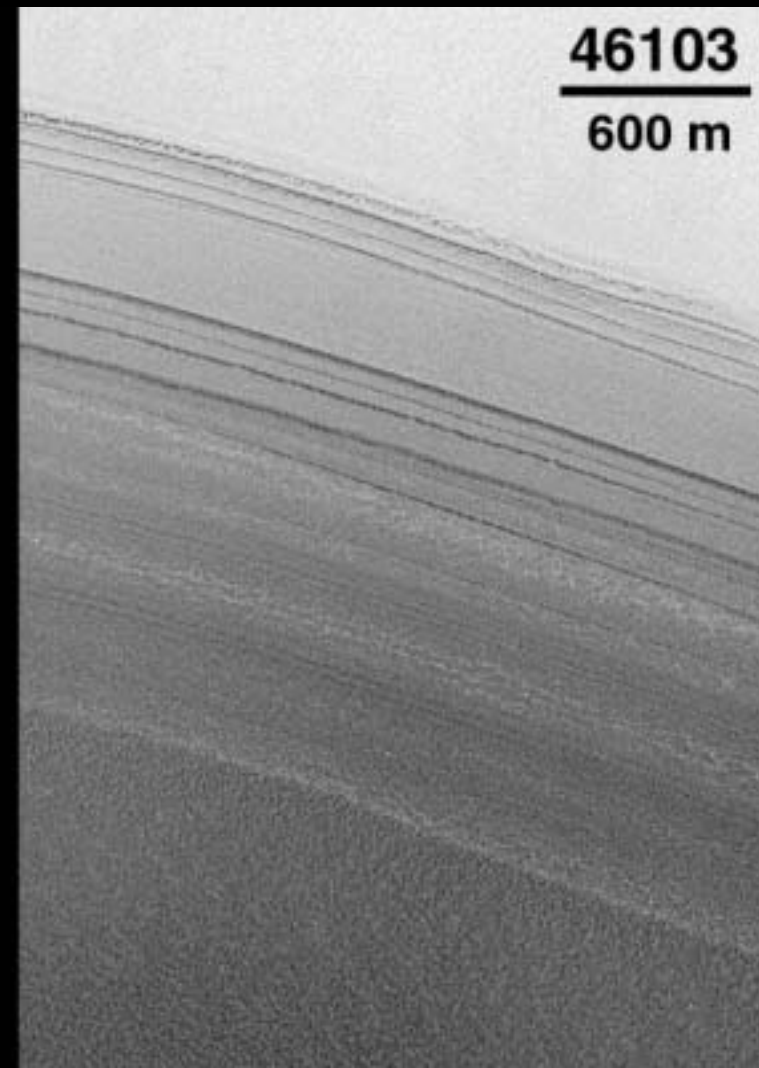
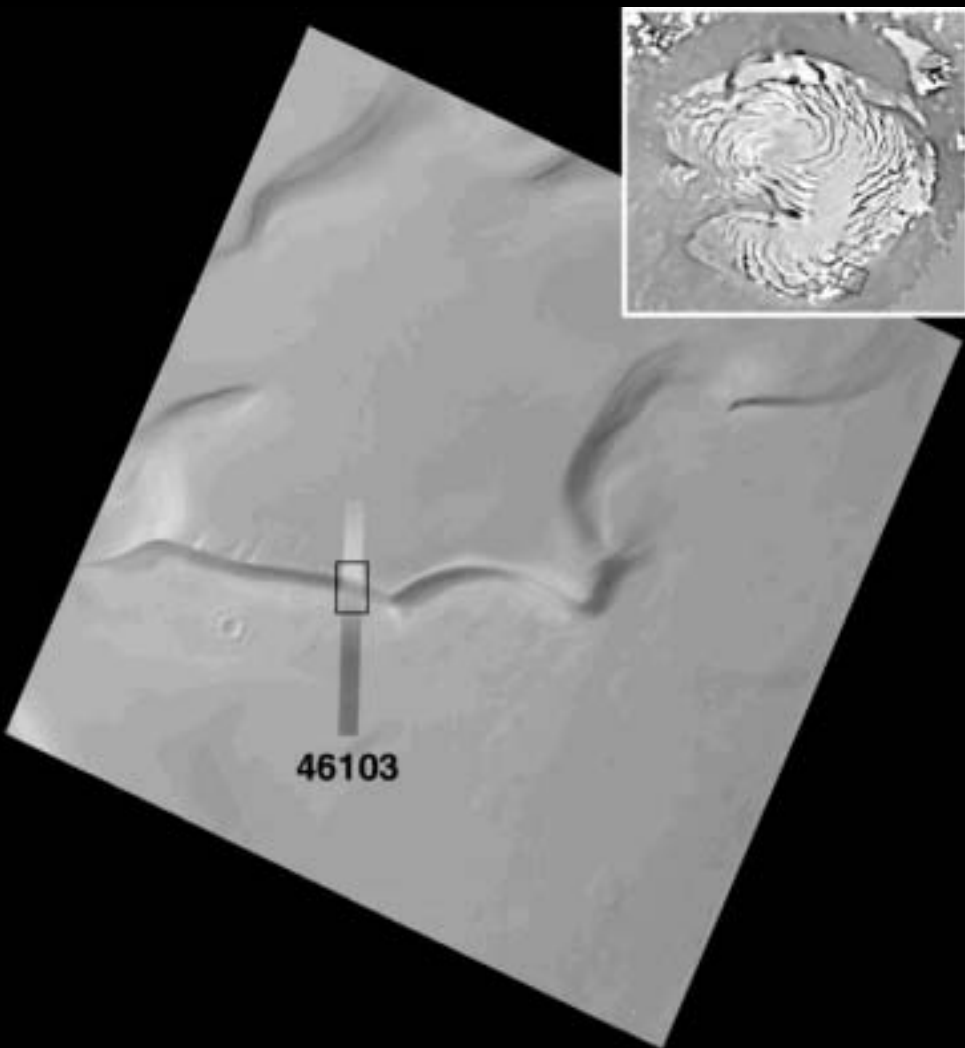
SNOW PACK ON MARS

**ARROWS POINT TO AREAS
INTERPRETED TO BE REMNANT
SNOW PACK.**

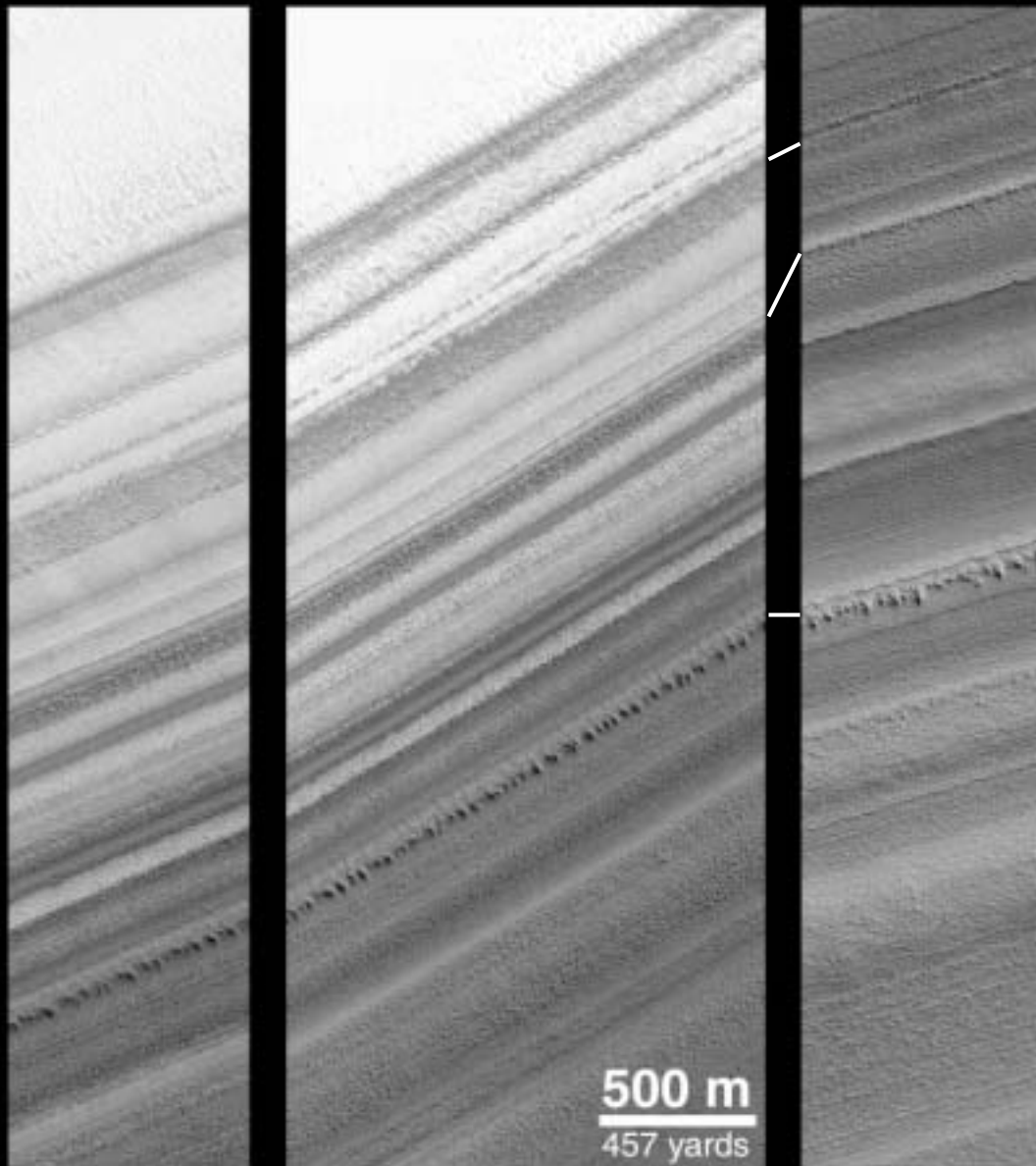
**MELT WATER FROM
THESE POLE FACING SNOW COVERED
AREAS APPARENTLY CAUSE GULLY
FORMATION.**

A. - MGS IMAGE; B-D - TES IMAGES

NORTH POLAR CAP LAYERS



North Polar Layers in Same Trough



86.5°N
281.5°W

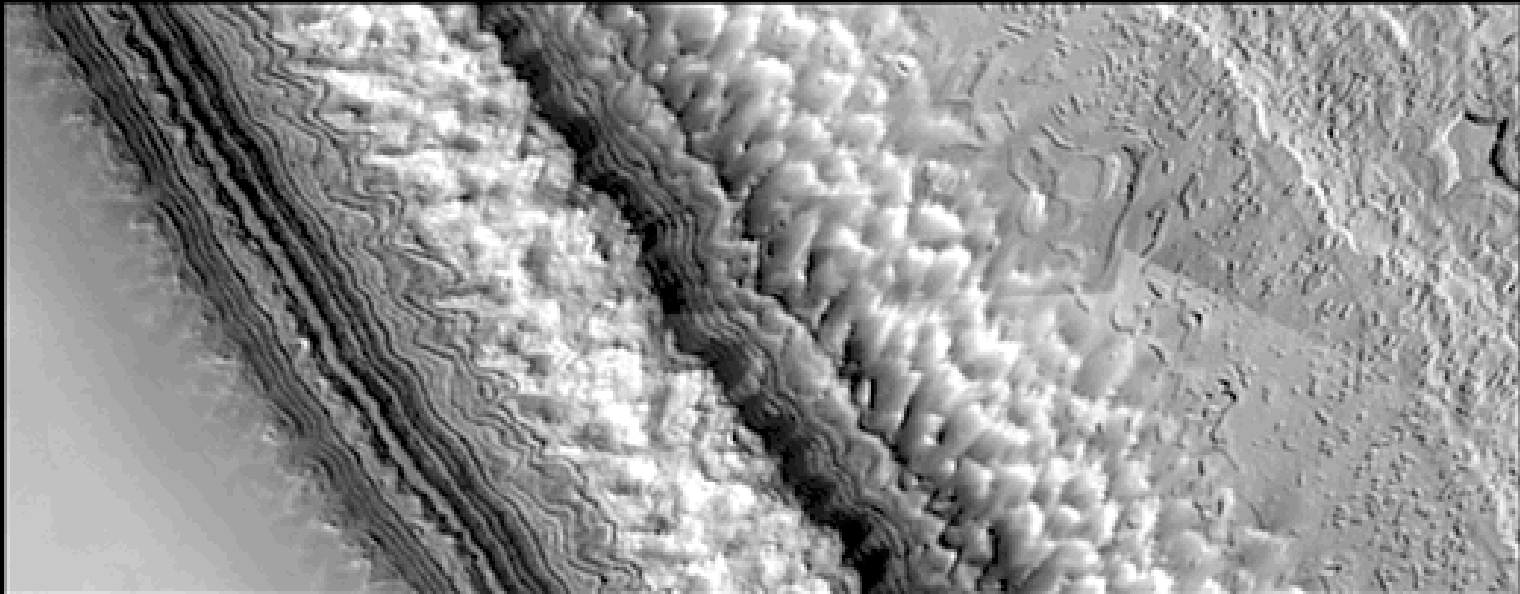
86.4°N
278.7°W

85.9°N
257.9°W

**100 KM BETWEEN LEFT AND RIGHT
IMAGES**

**SOUTH
POLAR CAP
LAYERING
AND
EROSION**

1 KM



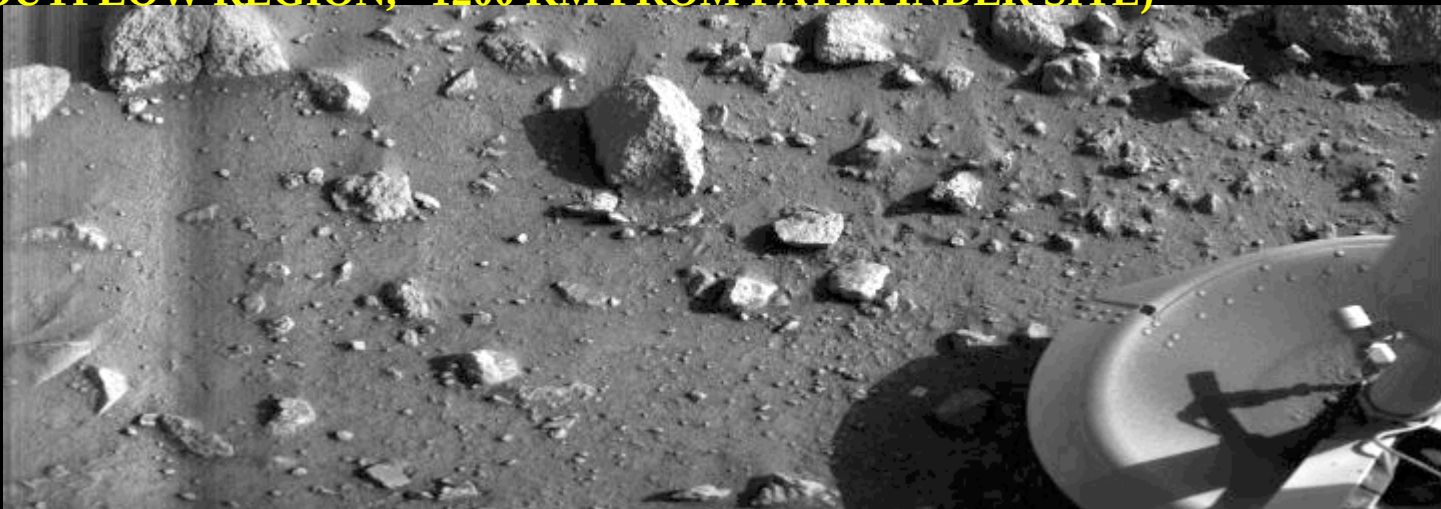
PIA02391



PIA02392



**VIKING 1 LANDER VIEWS, CHRYSE, 7500 KM SW OF VIKING 2 SITE NASA/JPL
(IN OUTFLOW REGION, ~1200 KM FROM PATHFINDER SITE)**





FROST ON DUNES

**VIKING 2 LANDER
VIEWS
UTOPIA,
NORTHERN
LOWLANDS
7500 KM NE
OF VIKING 1 SITE
NASA/JPL**

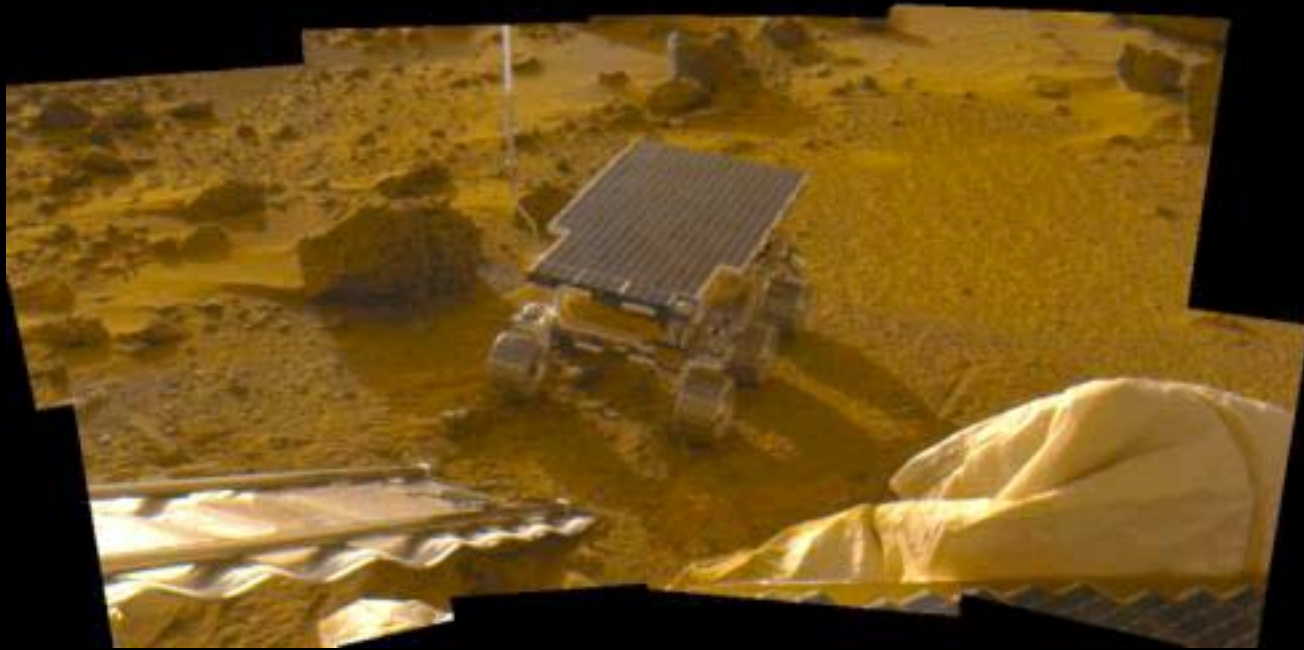
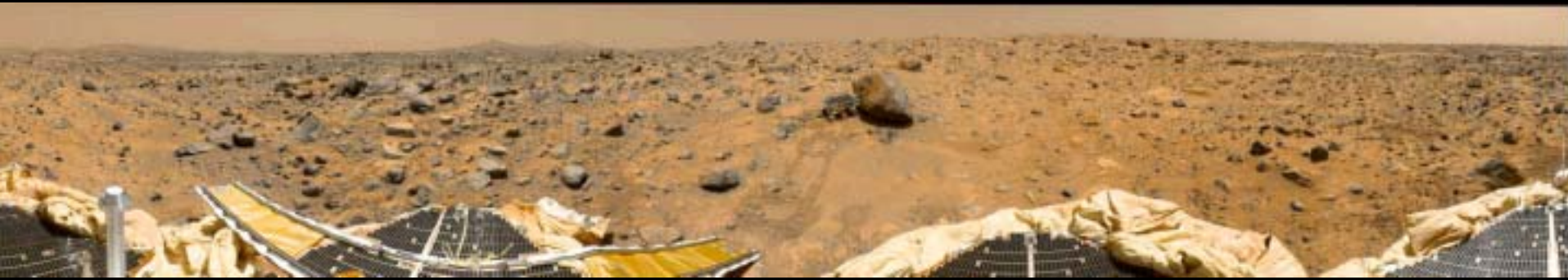




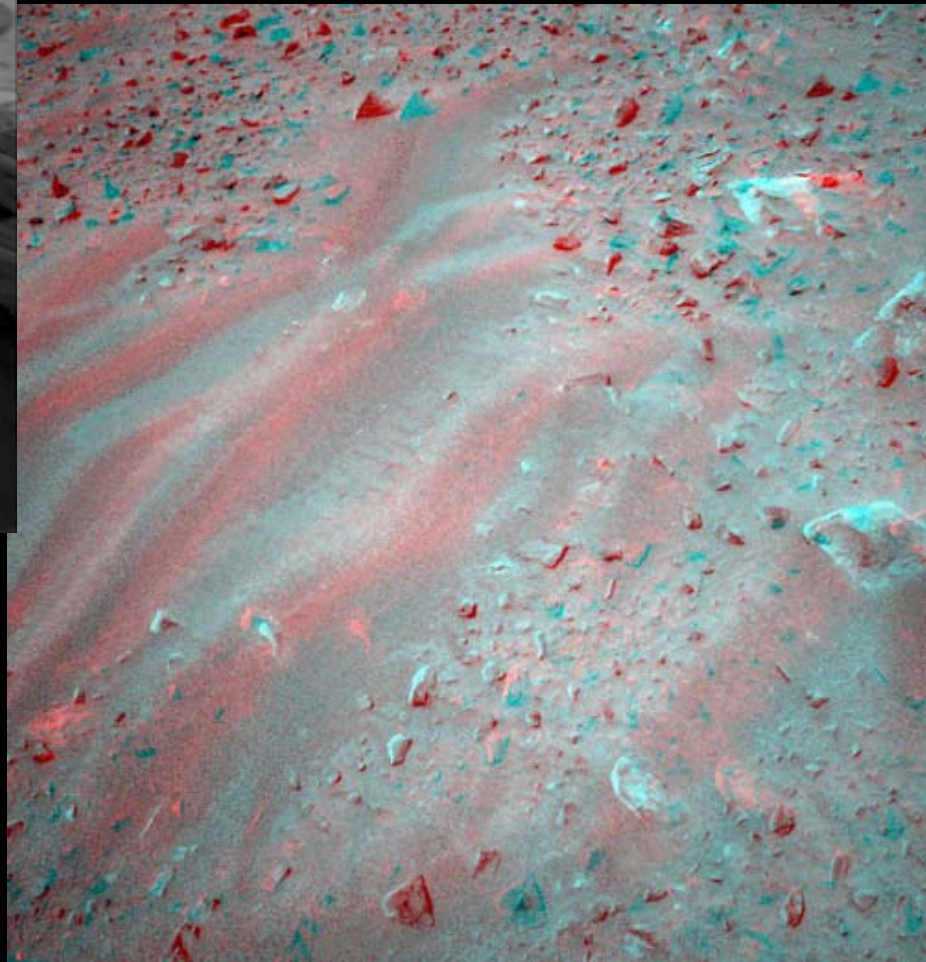
NASA/JPL



PATHFINDER/SOUJOURNER



SPRITE'S RIPPLES



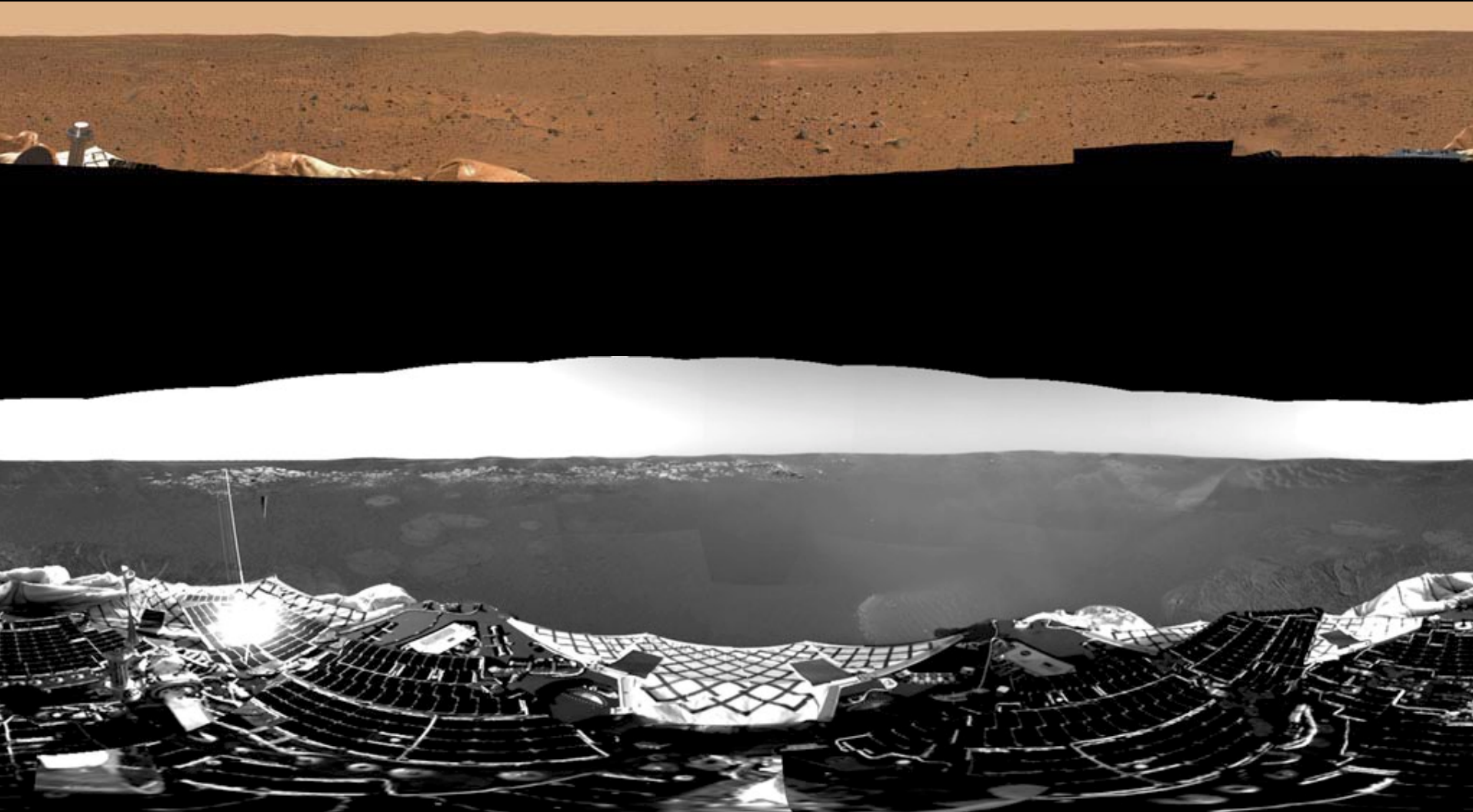
**“TRUE COLOR OF MARS”
PATHFINDER LANDER VIEW**

NASA/JPL



**“TRUE COLOR OF MARS”
“SPIRIT” AND “OPPORTUNITY” VIEW**

NASA/JPL



TERM PAPER TOPICS

- **COMPARISON OF EVIDENCE FOR OLD AND YOUNG MARTIAN OCEANS**
- **SIGNIFICANCE OF VARIATIONS IN MARS OBLIQUITY**