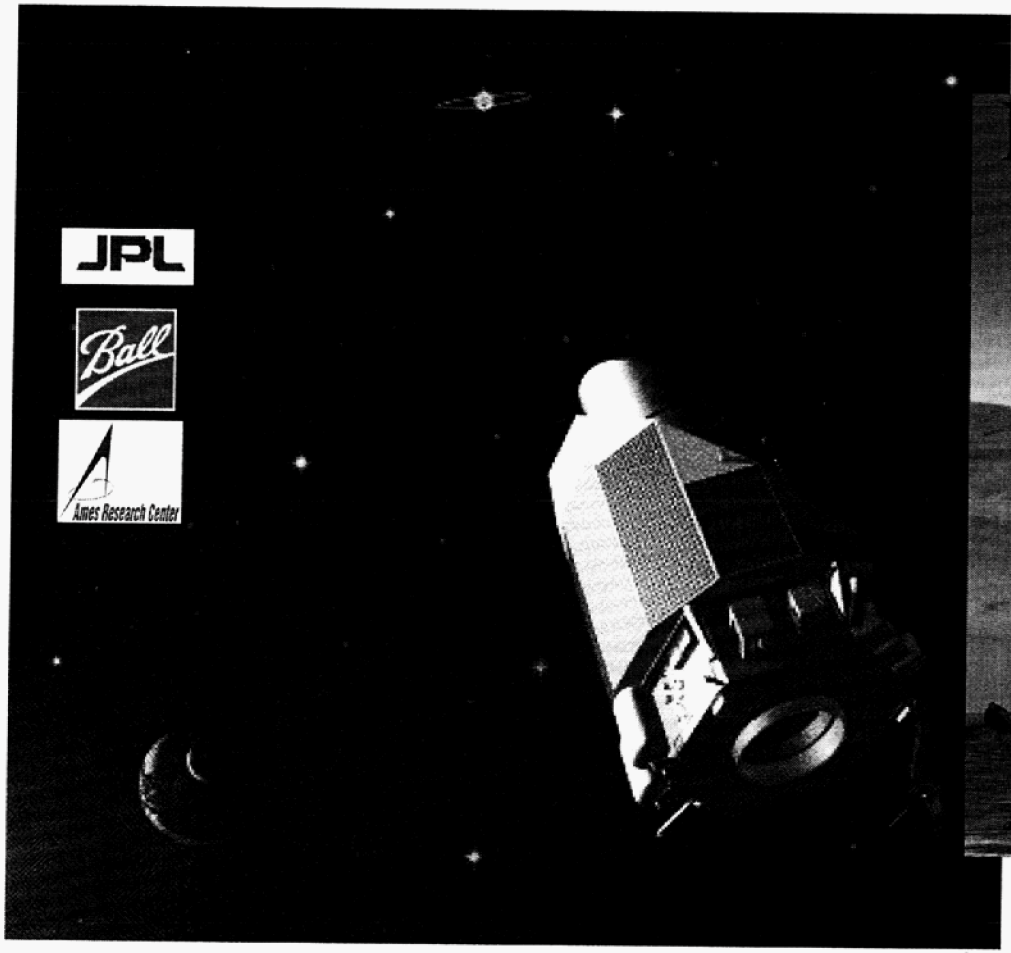
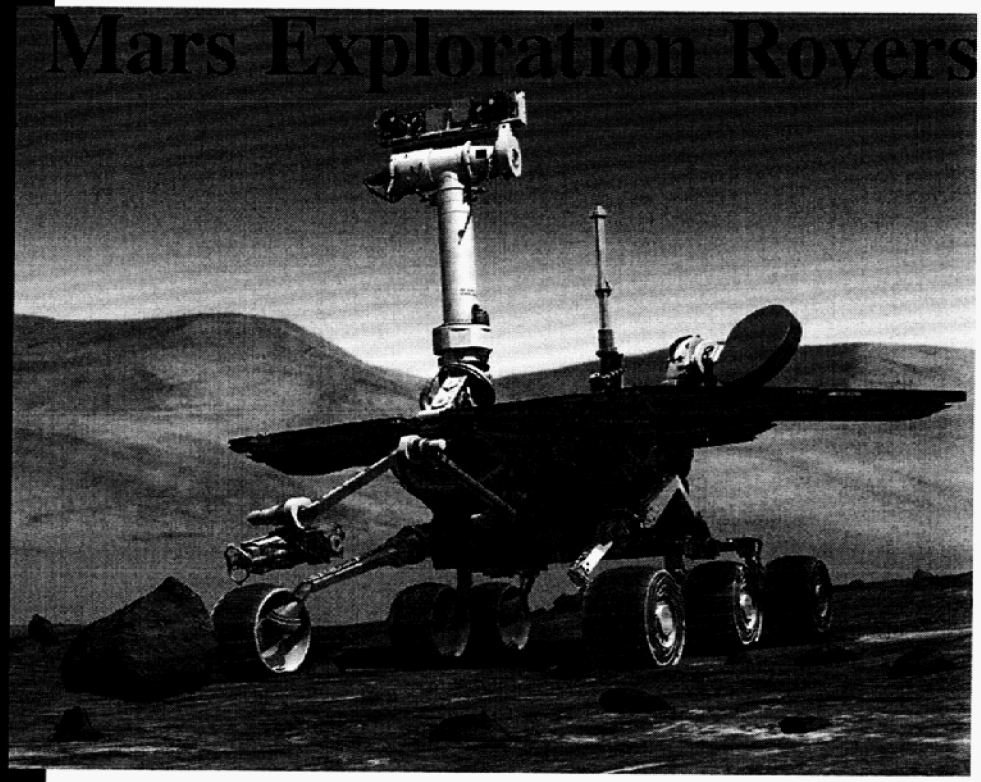
From Mars Rovers to Exo-Planets: The Lure of Liquid Water



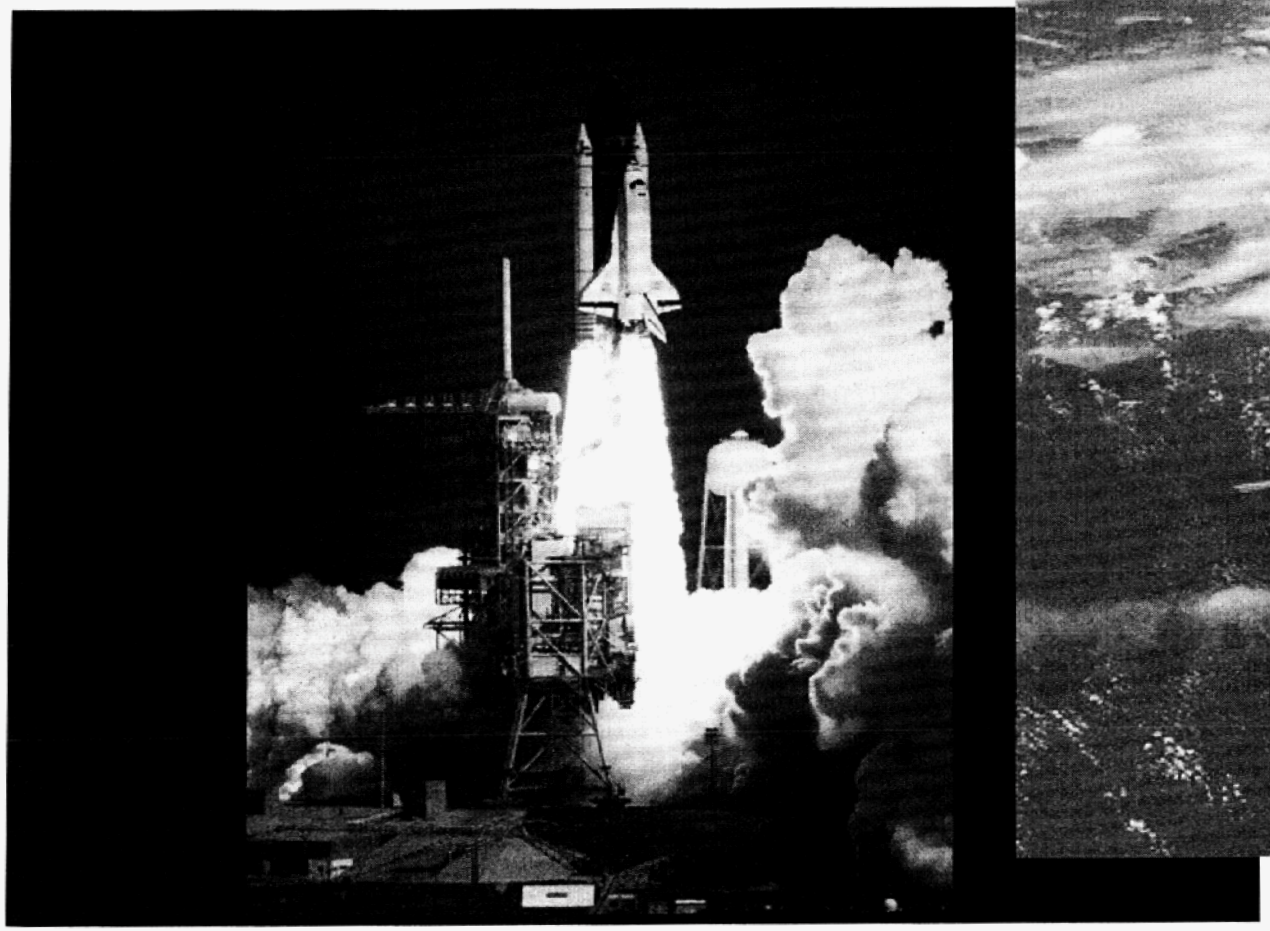


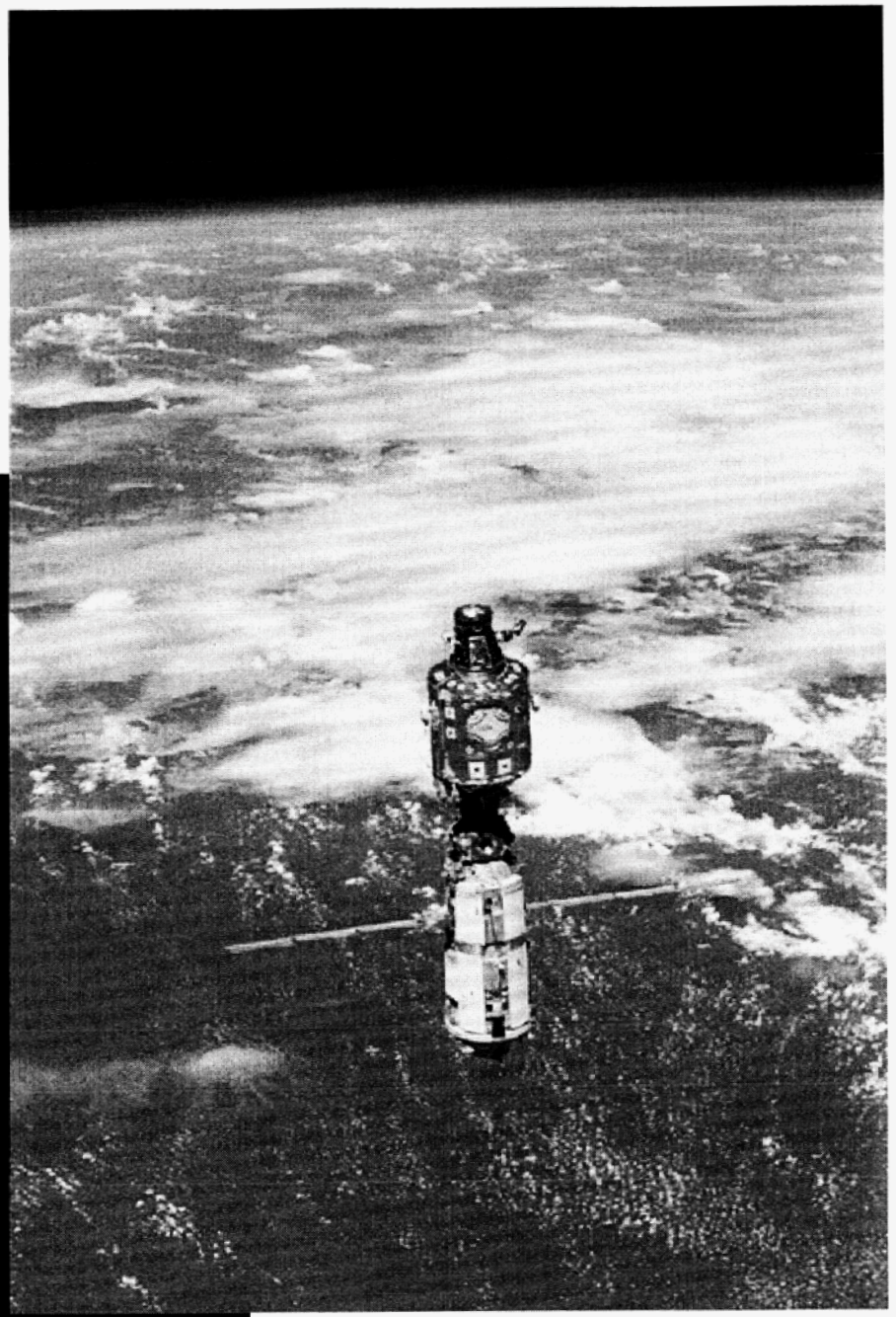
Nagin Cox

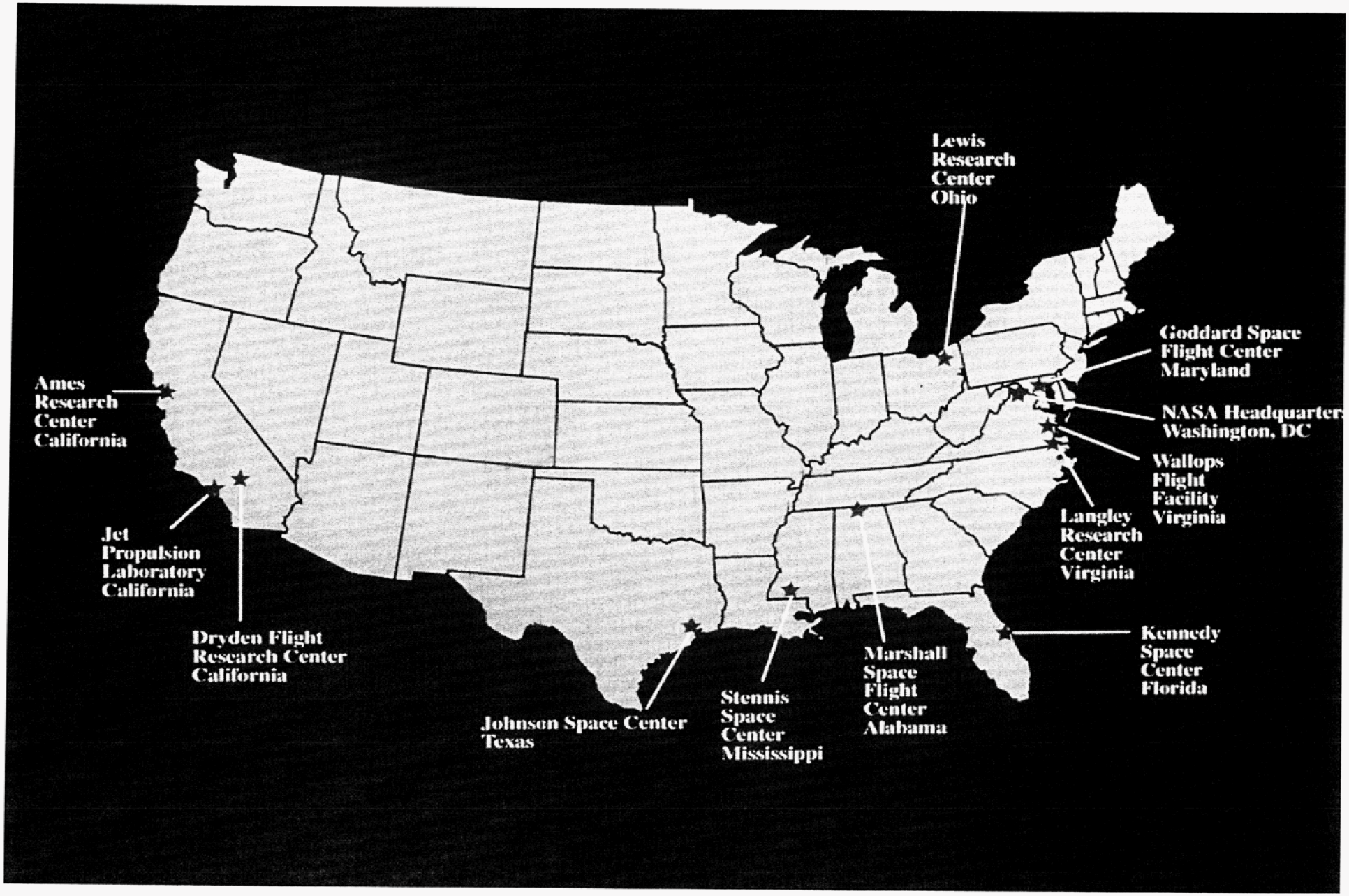
Former Deputy Team Chief MER Spacecraft/Rover Engineering Flight Team

Kepler Deputy Project Engineer

Jet Propulsion Laboratory, NASA/Caltech






Lewis
Research
Center
Ohio
Goddard Space
Flight Center
Maryland
NASA Headquarters
Washington, DC
Wallops
Flight
Facility
Virginia
Langley
Research
Center
Virginia
Kennedy
Space
Center
Florida
Marshall
Space
Flight
Center
Alabama
Stennis
Space
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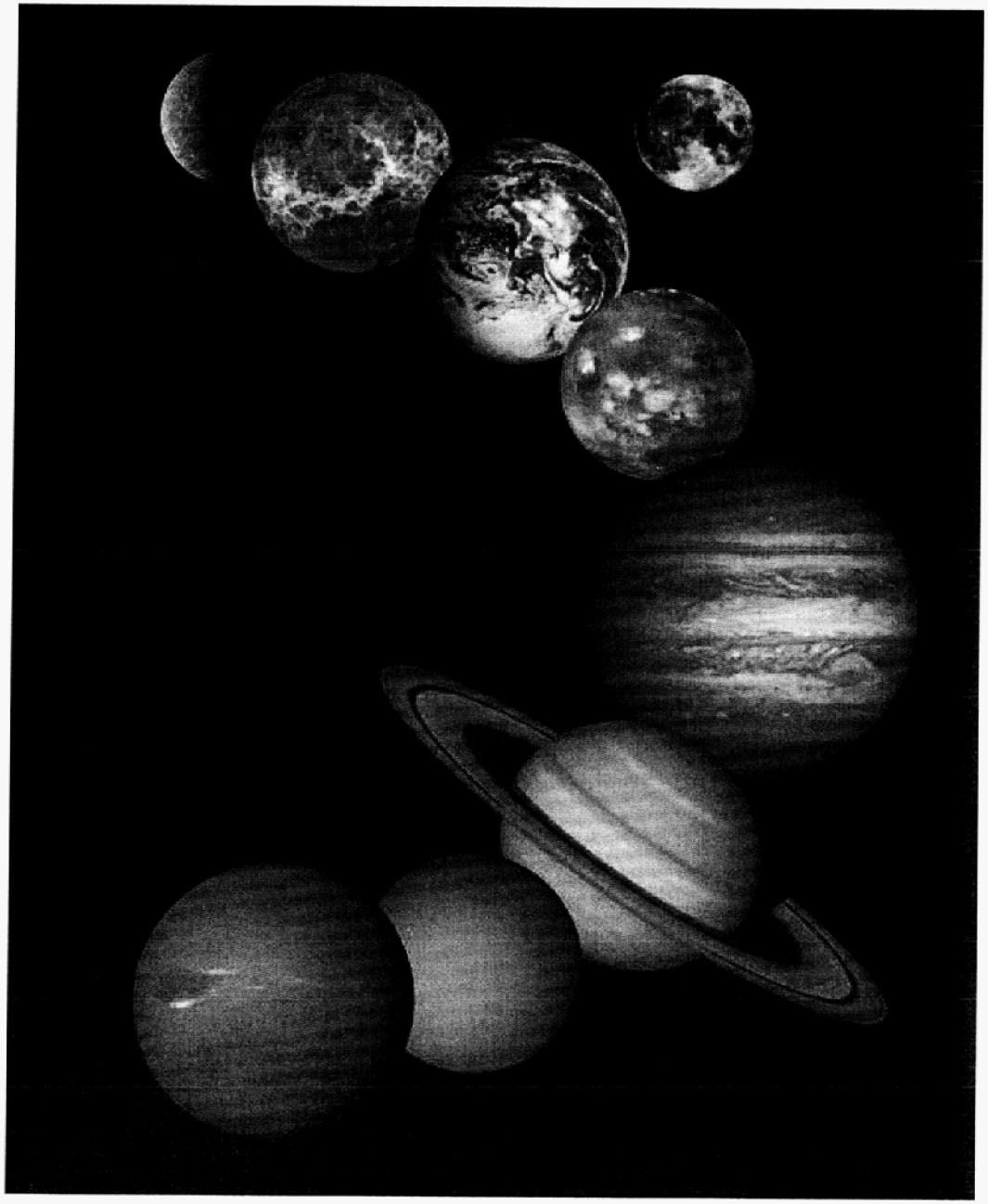
Johnson Space Center
Texas
Dryden Flight
Research Center
California
Jet
Propulsion
Laboratory
California
Ames
Research
Center
California

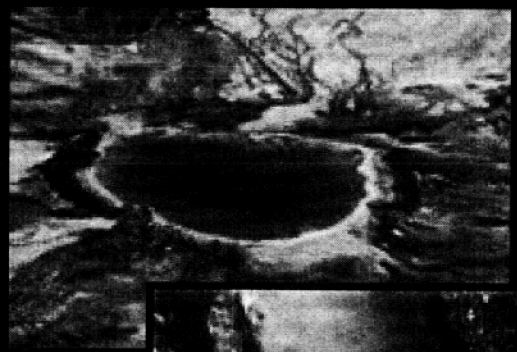


Mount St. Helens

Too Hot to Handle

Living Organisms

Thermal Springs



Underwater Vent

Desolate Deserts

MARS SCIENCE STRATEGY: Follow the Water!

Common Thread

W A T E R

When? Where? Form? Amount?

Determine if Life Ever Arose on Mars

LIFE

Characterize the Climate

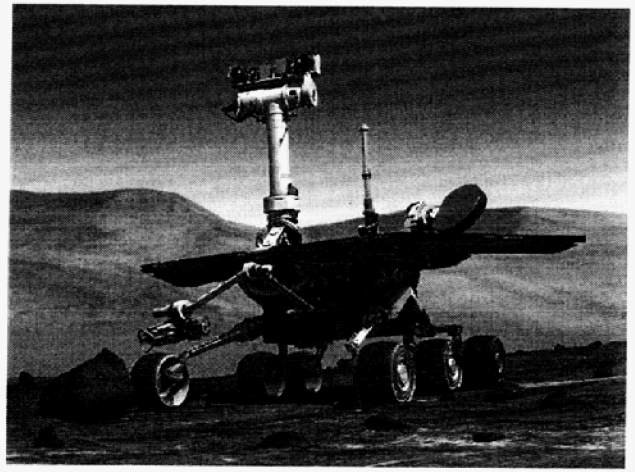
CLIMATE

Characterize the Geology

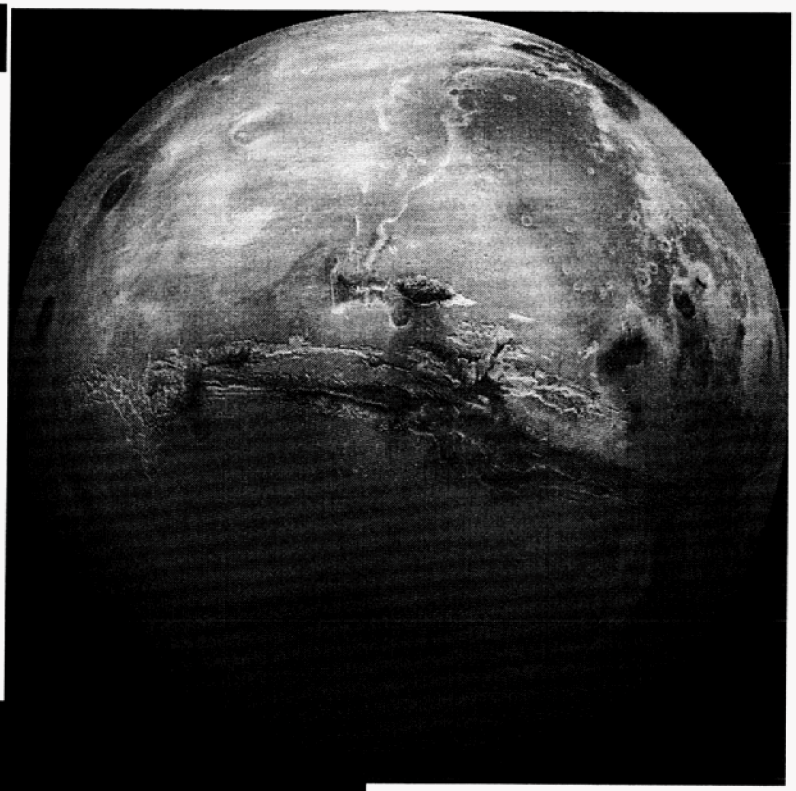
GEOLOGY

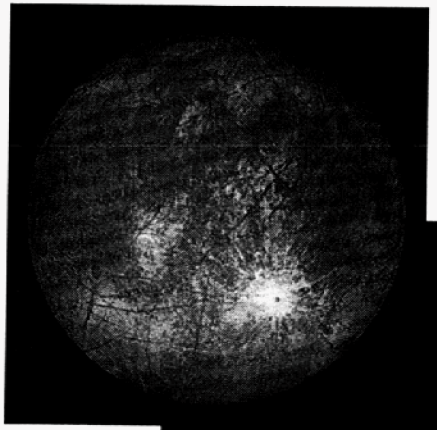
Prepare for Human Exploration

HUMAN



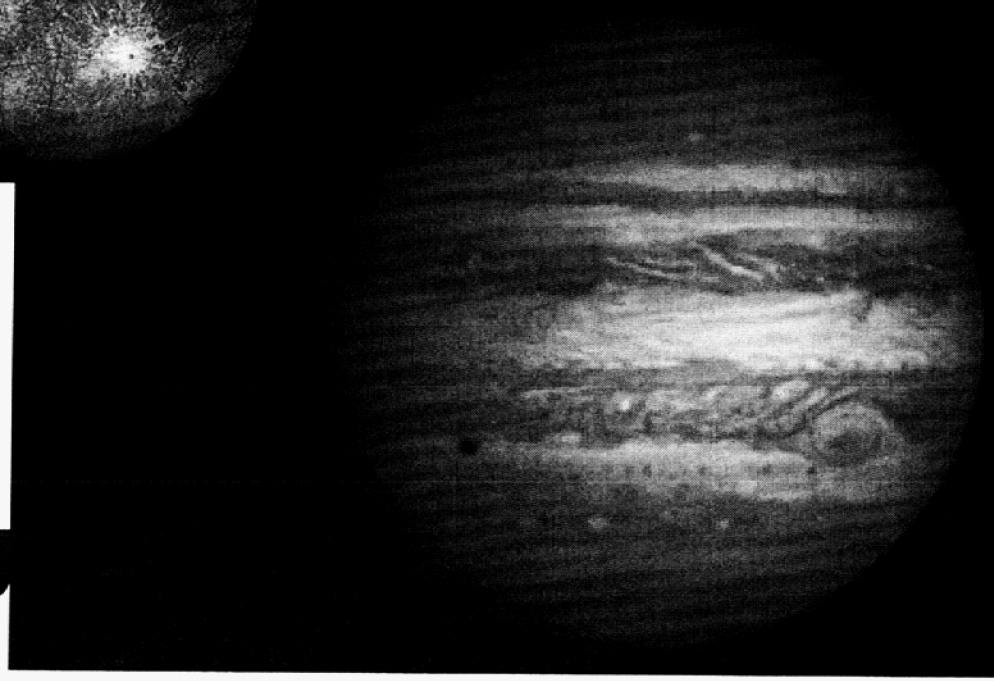
M

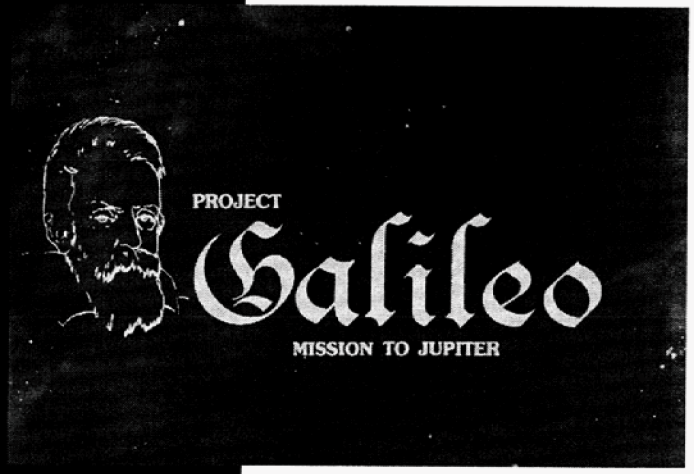


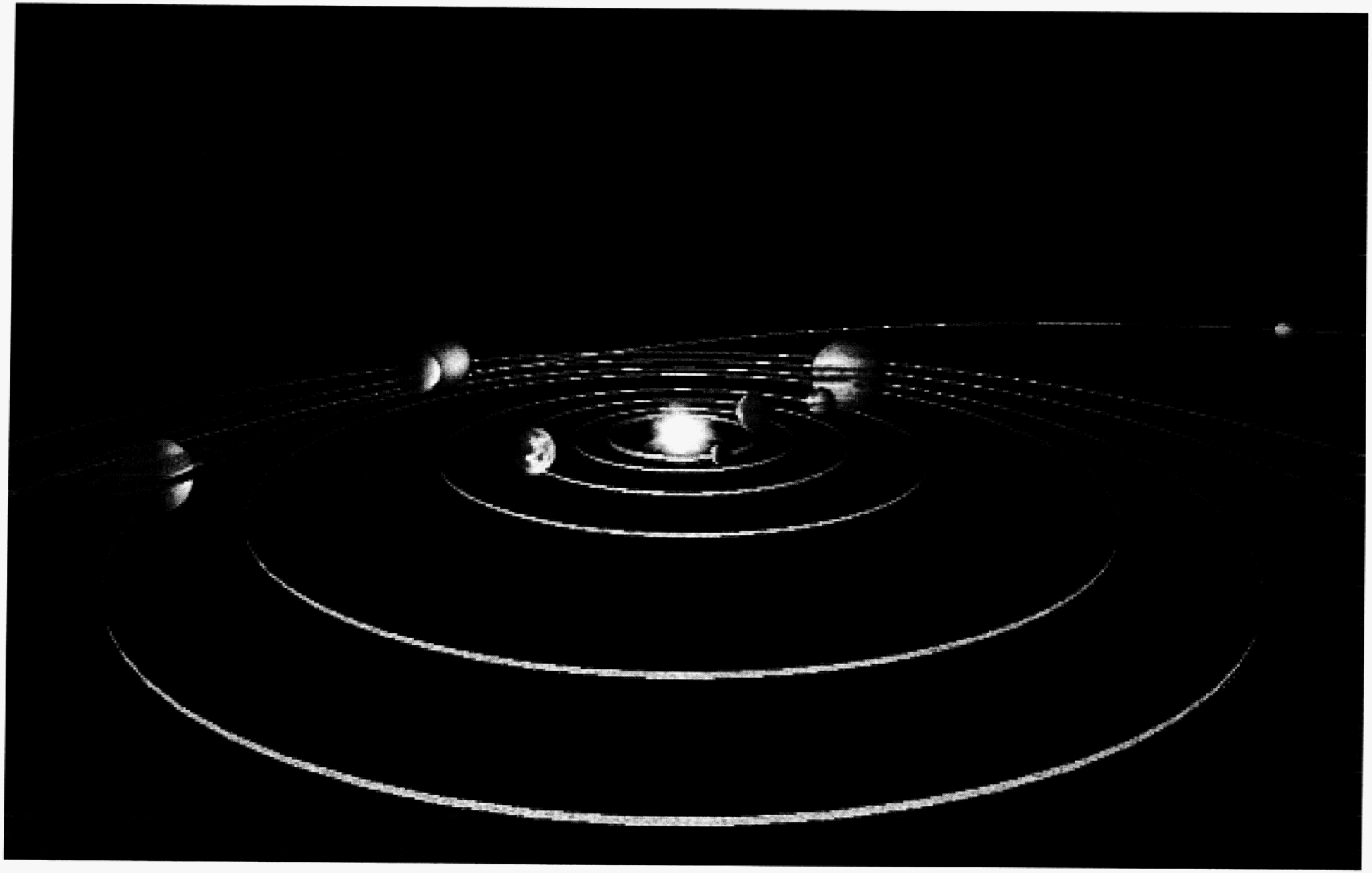


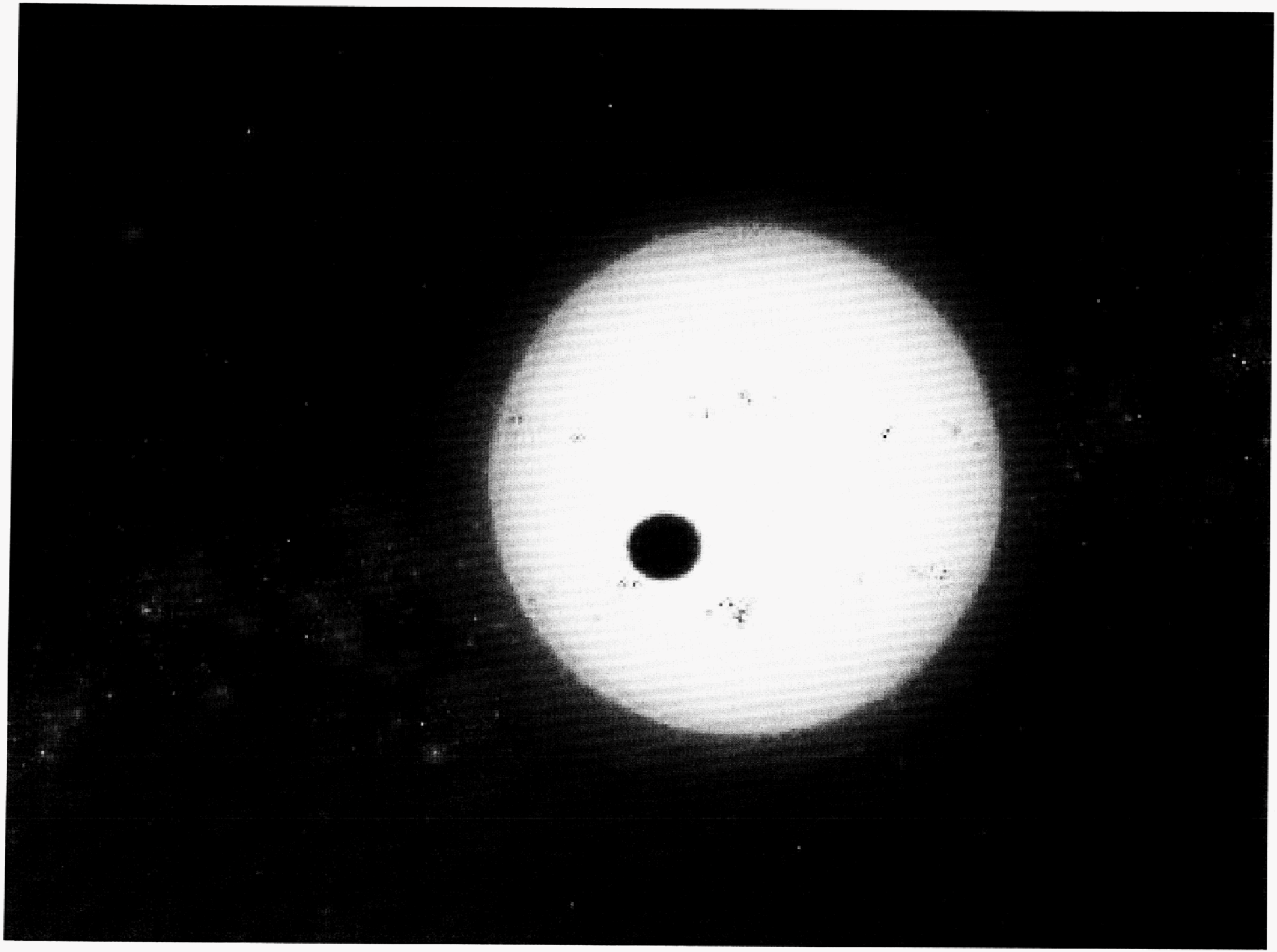
Europa

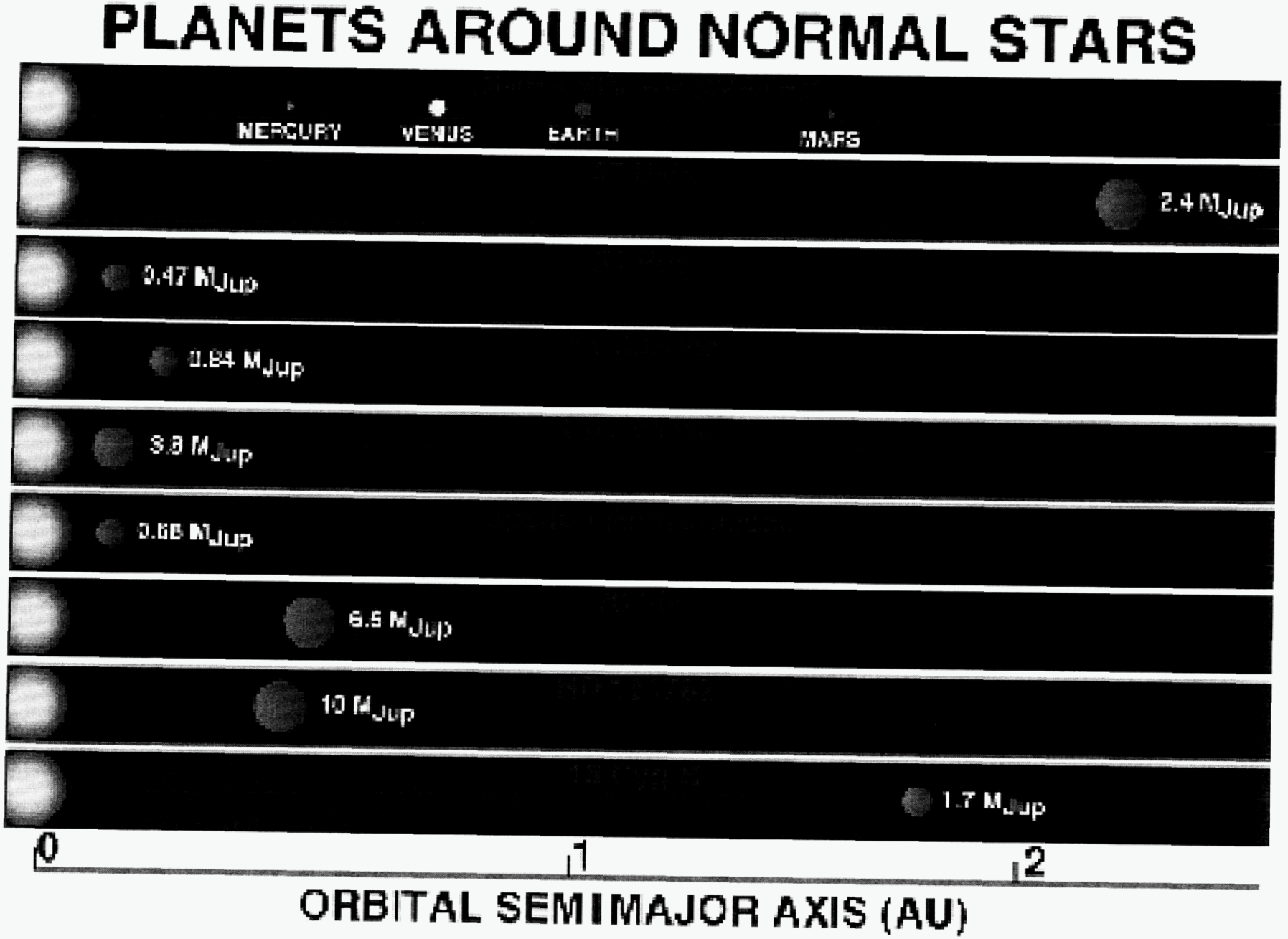
J



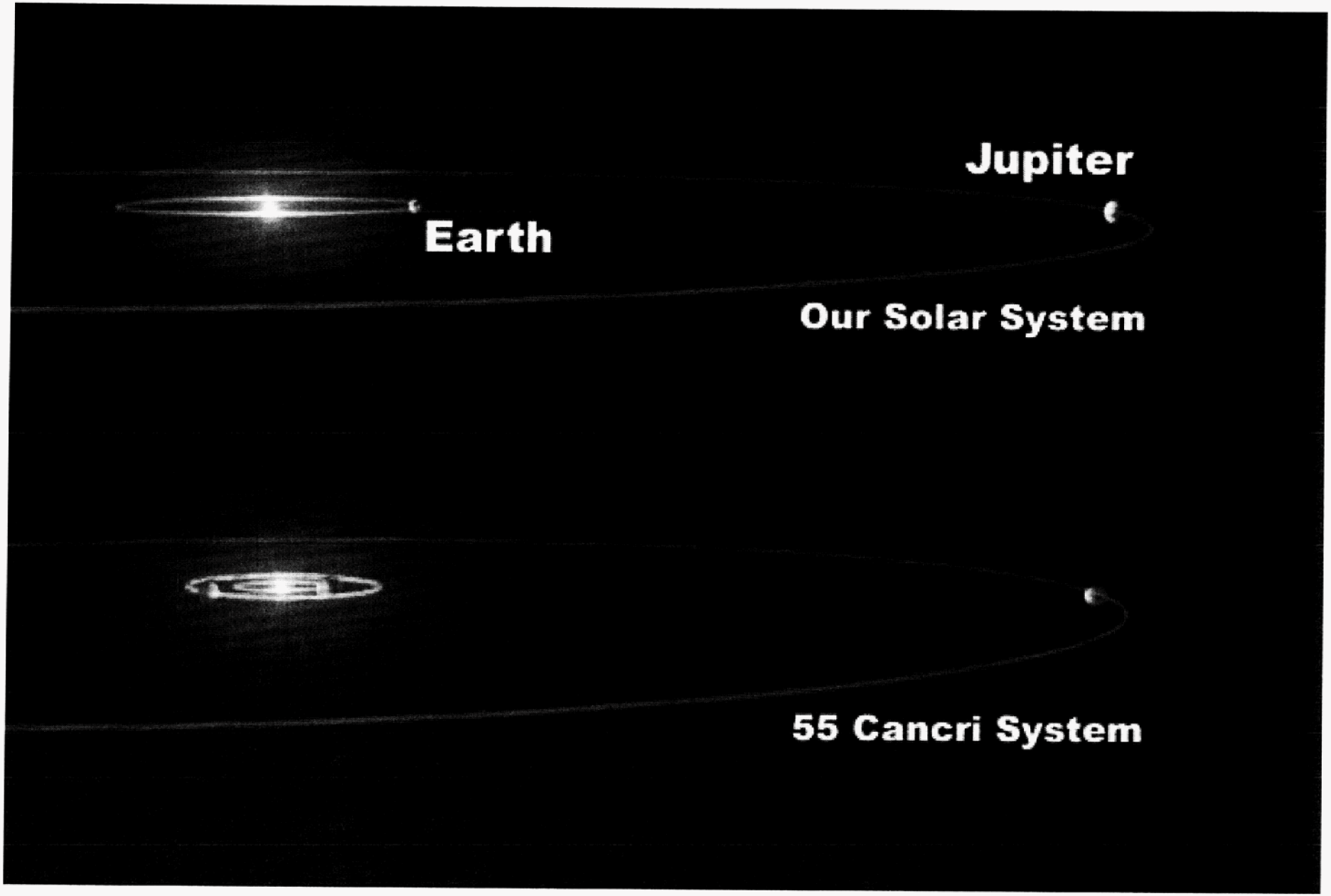


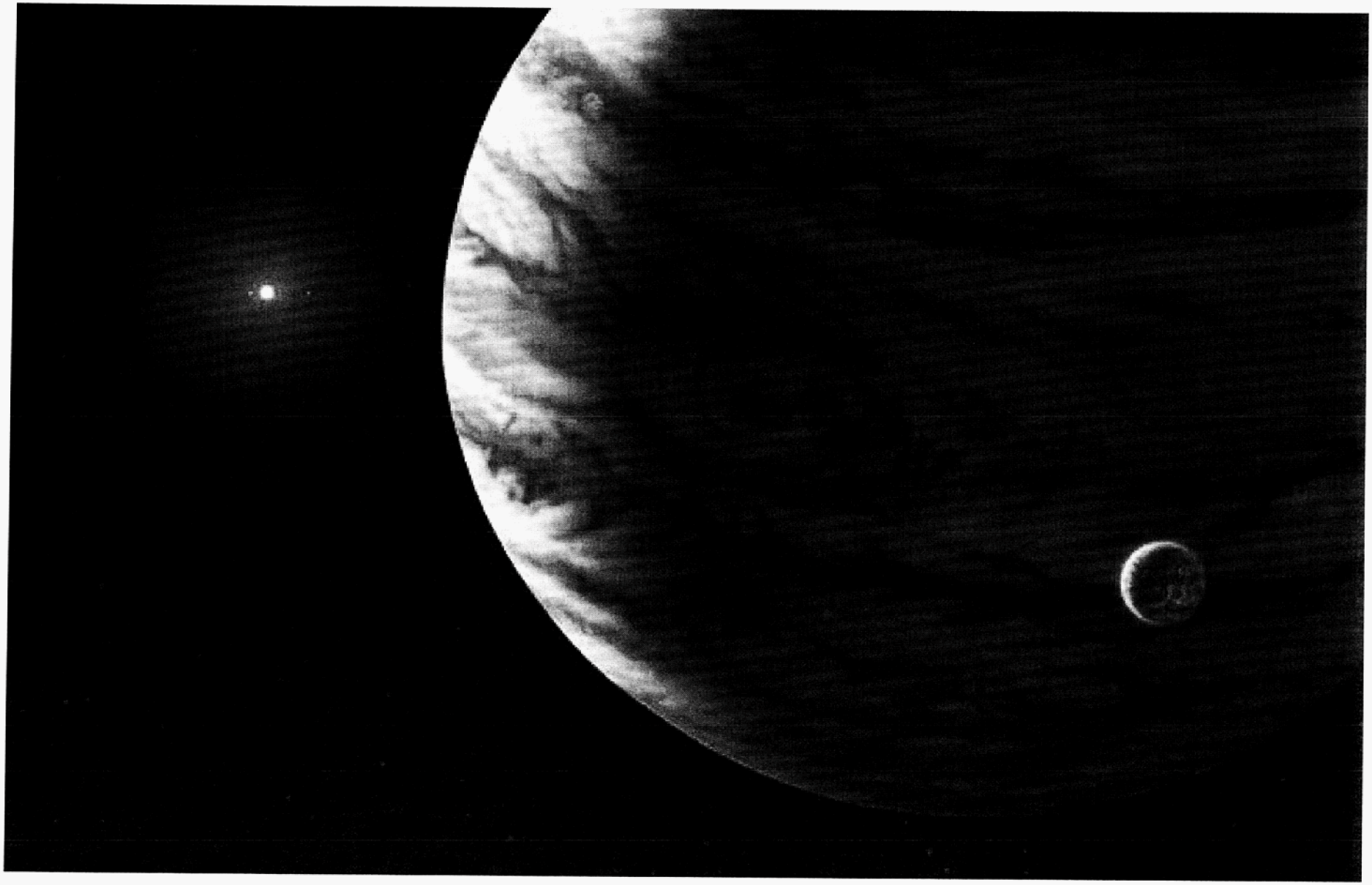


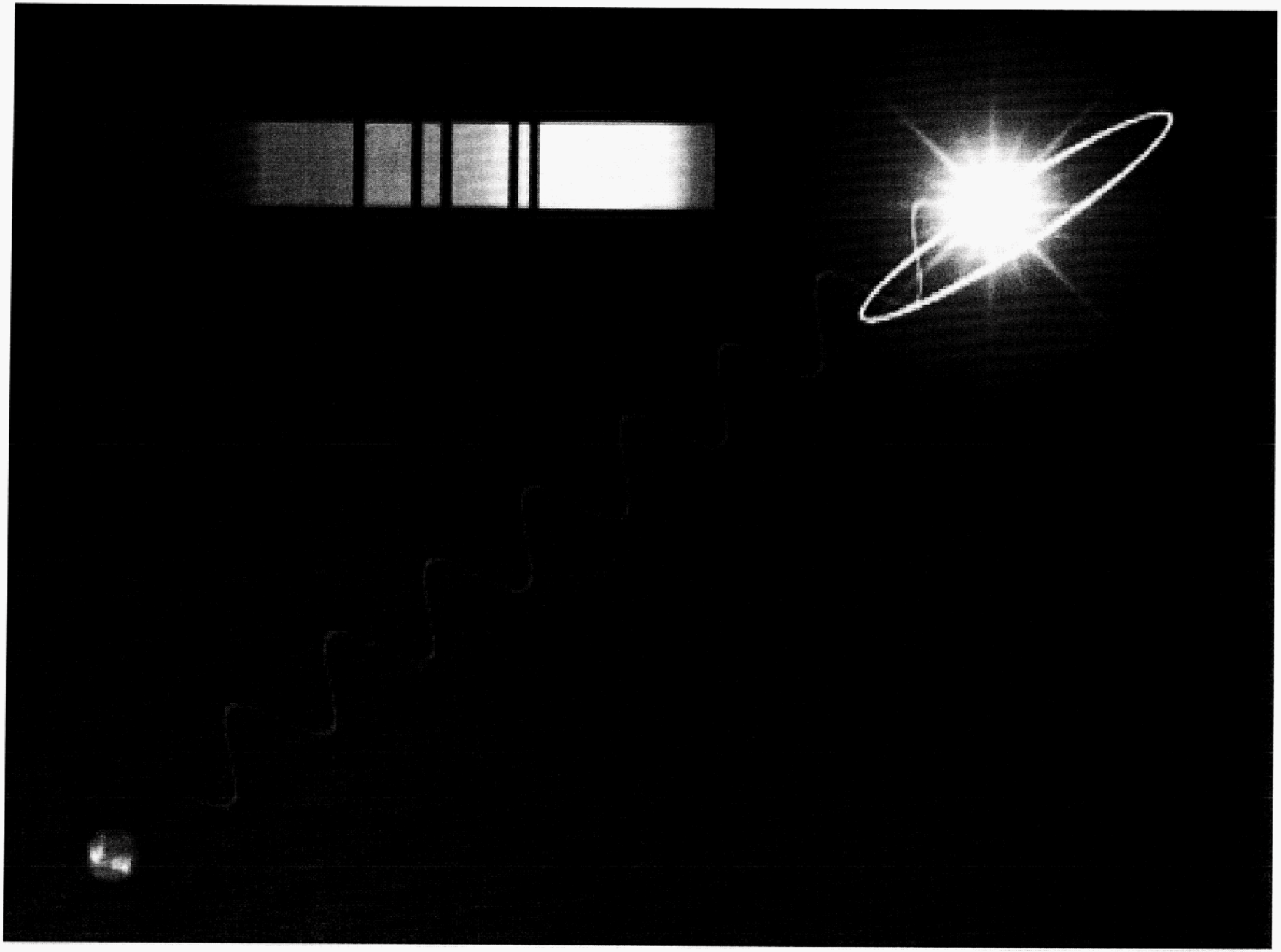




Credit: Planetquest-Courtesy G. Marcy / E. Williams)

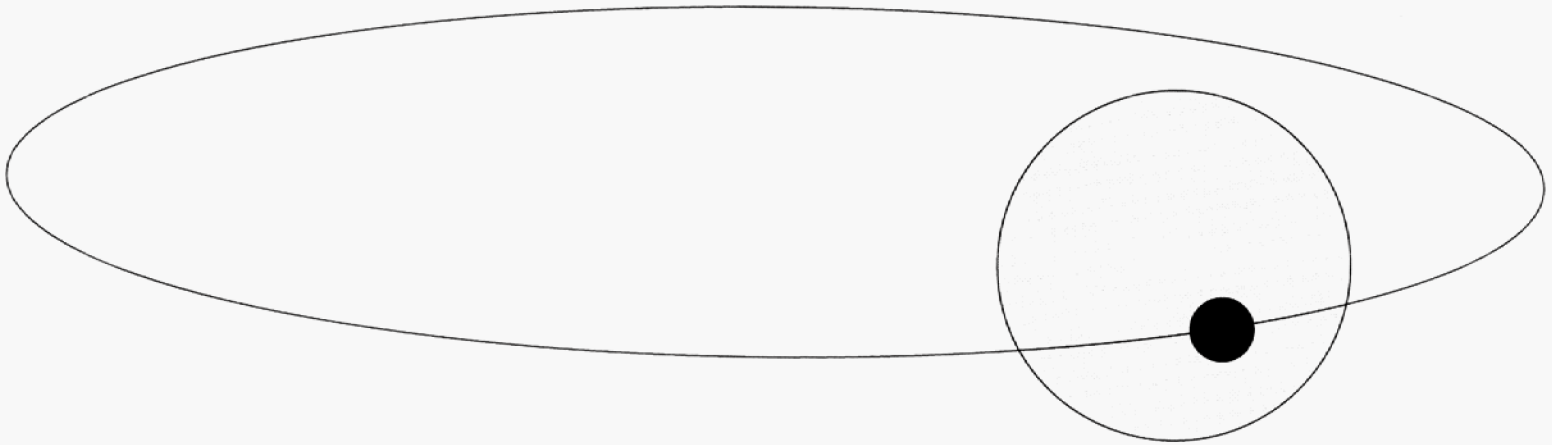

Jupiter
Earth
Our Solar System
55 Cancri System

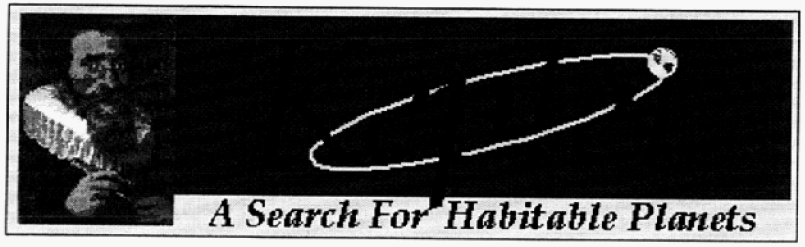


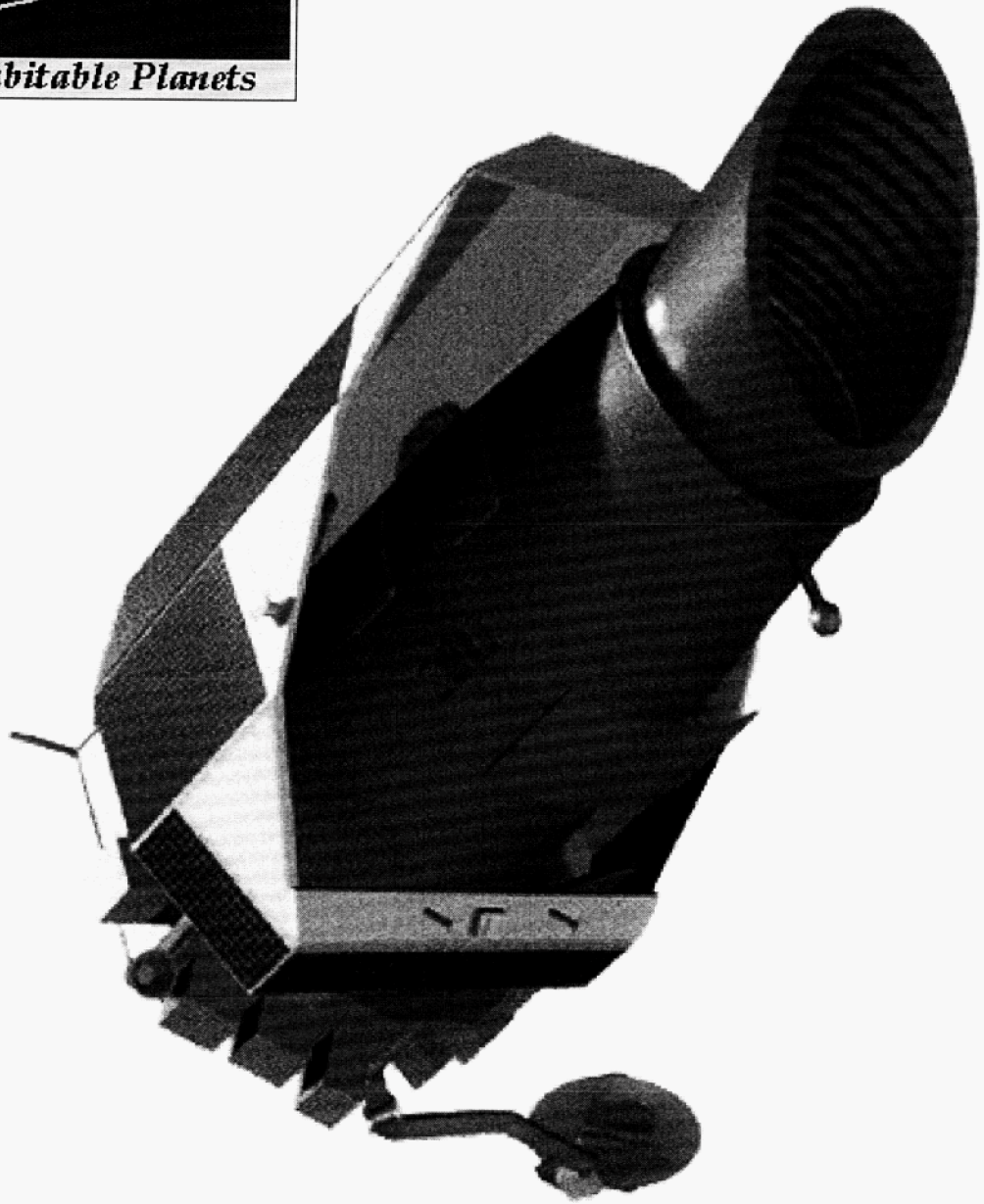


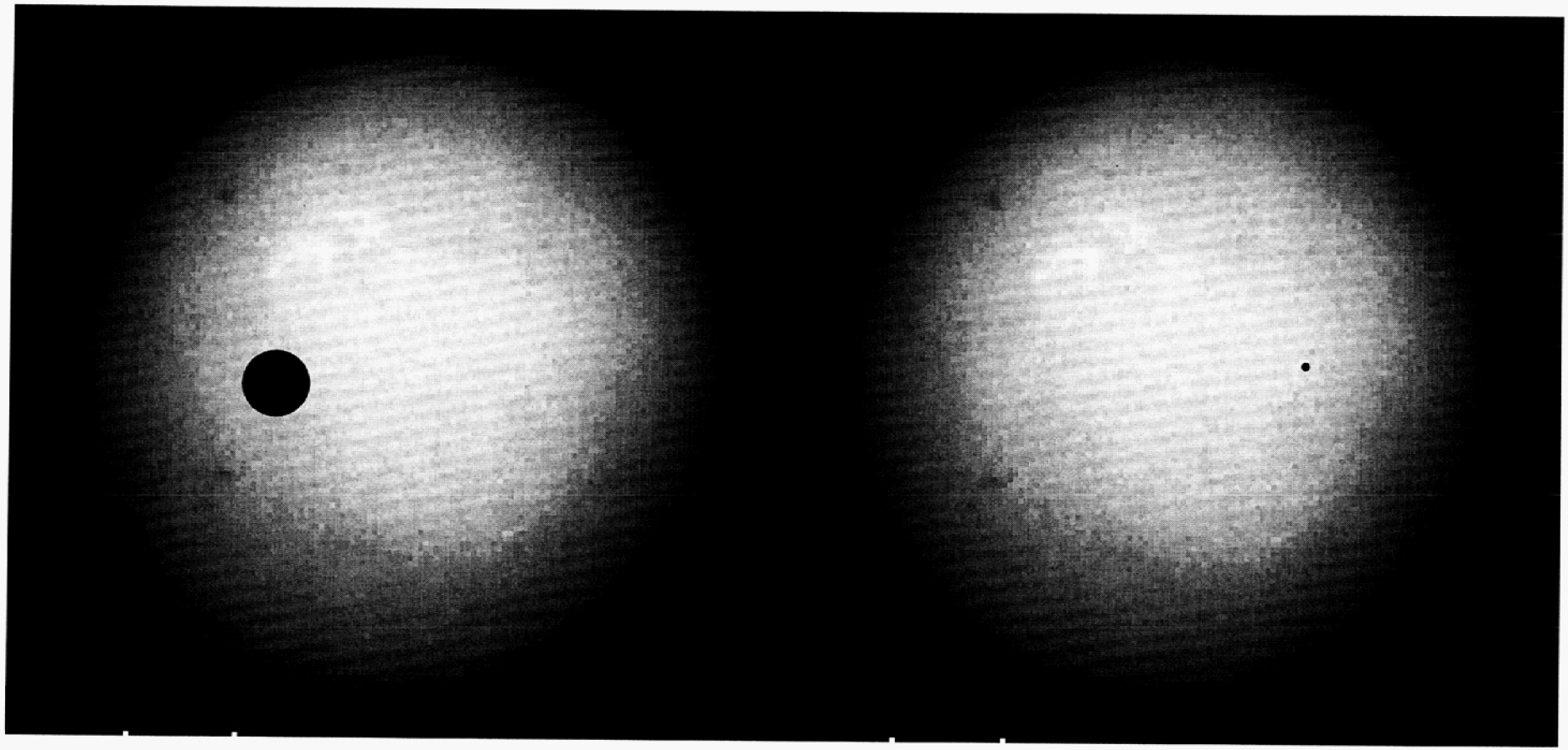
Radial velocity this

Photometry this



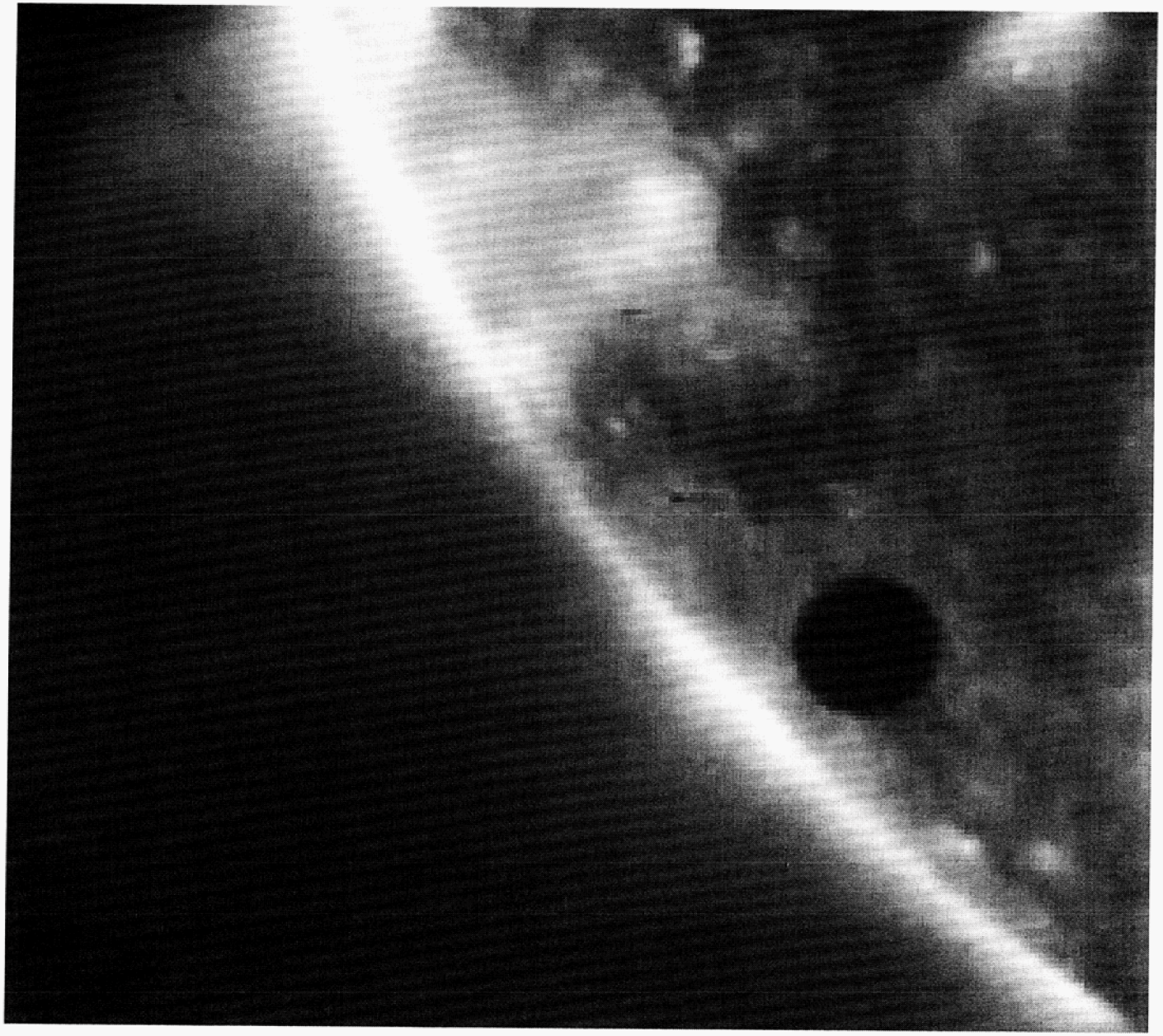

A Search For Habitable Planets

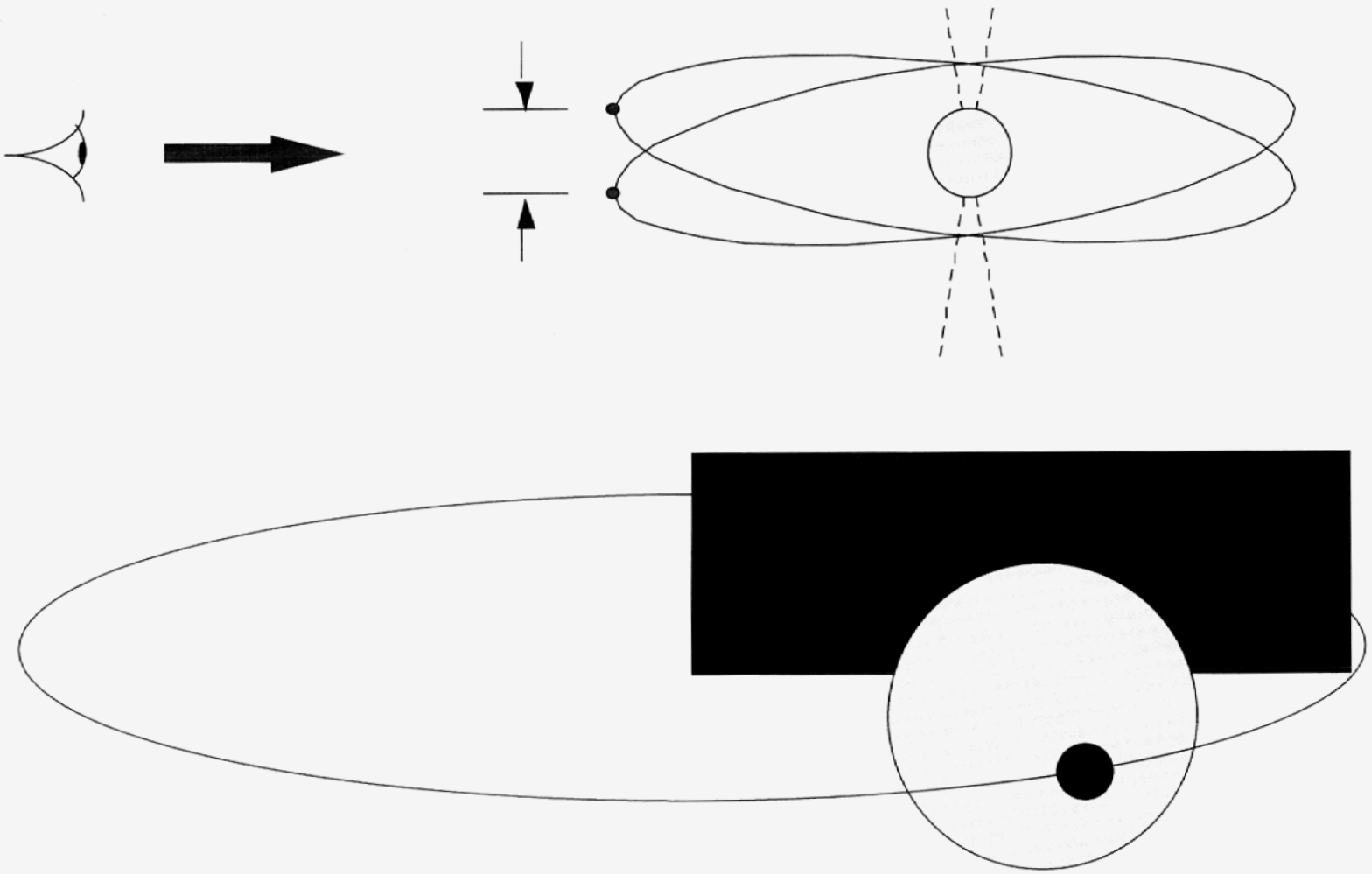


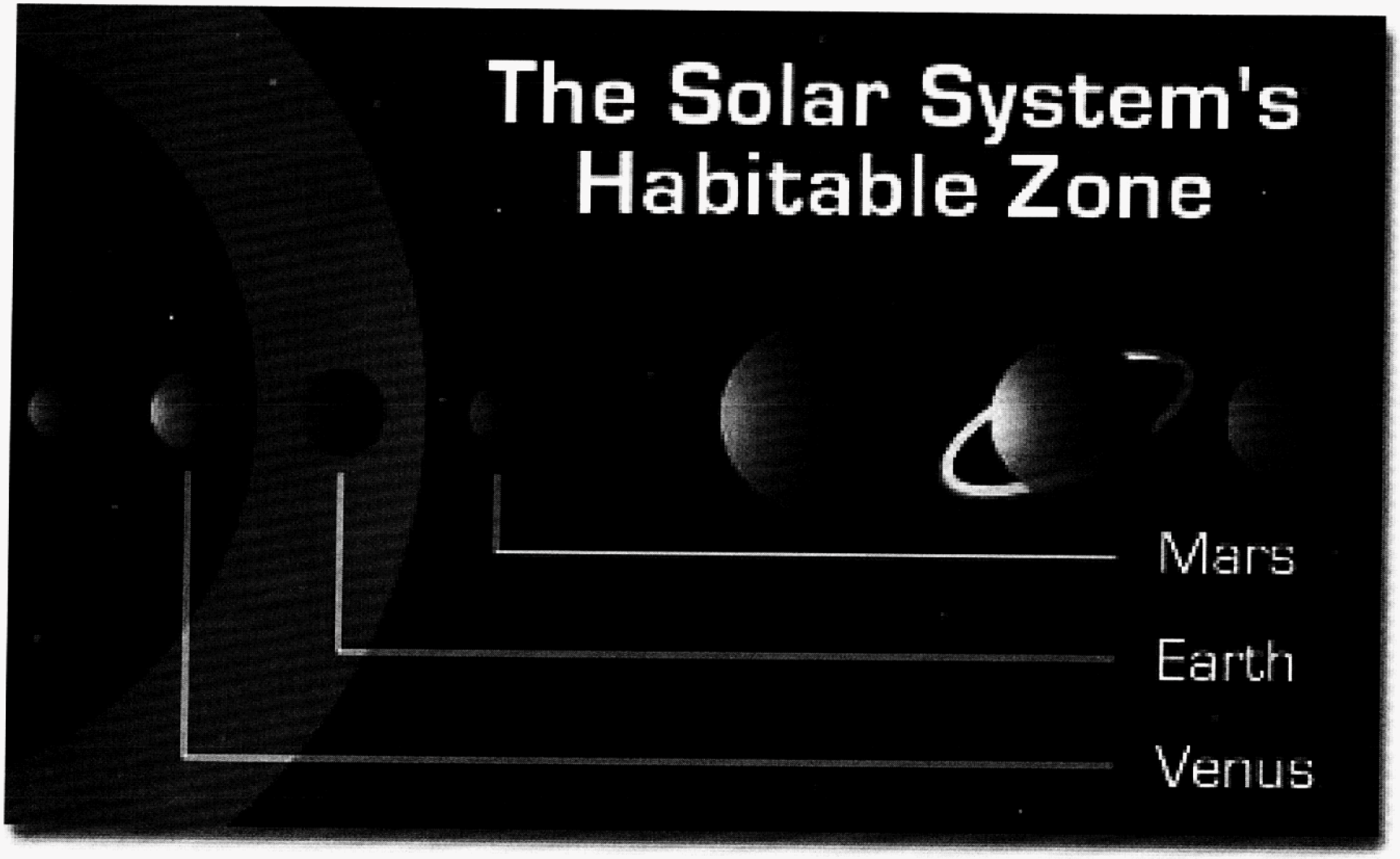


Jupiter:
1% area of the Sun (1/100)

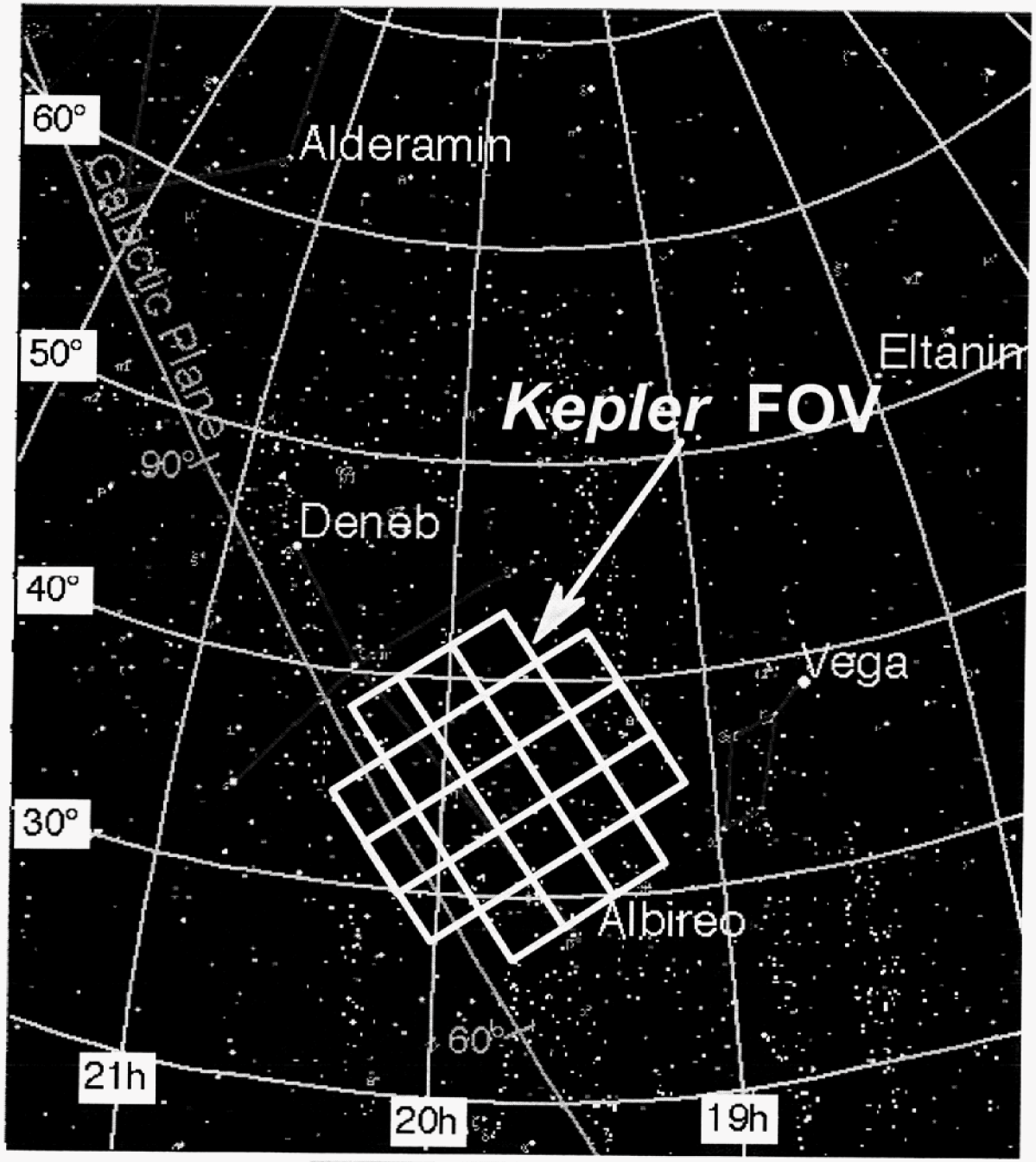
Earth or Venus
0.01% area of the Sun (1/10,000)

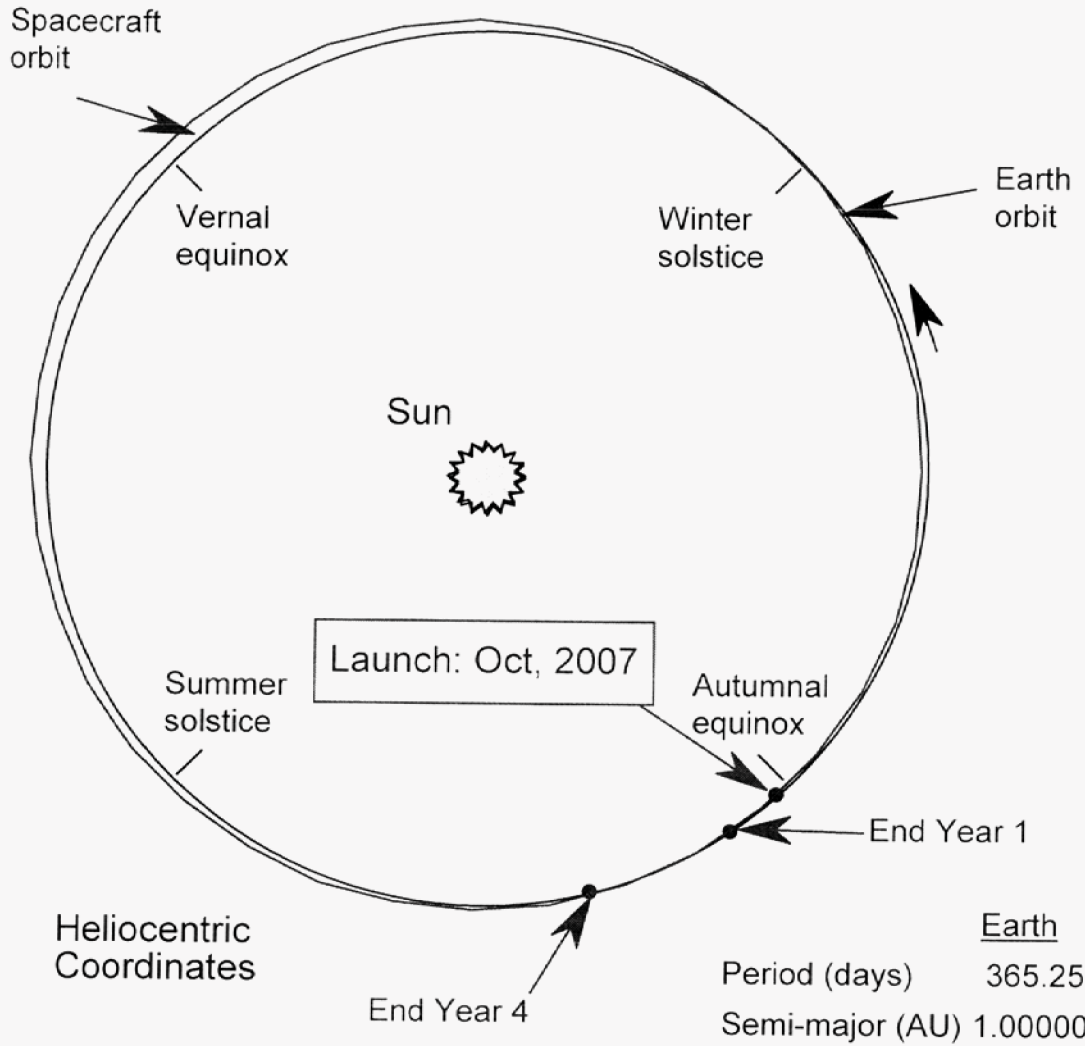


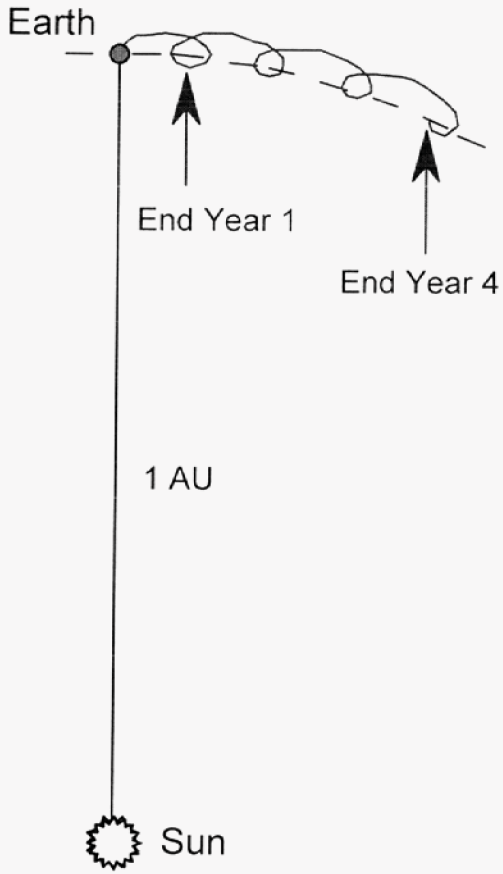




aka "Goldilocks zone"

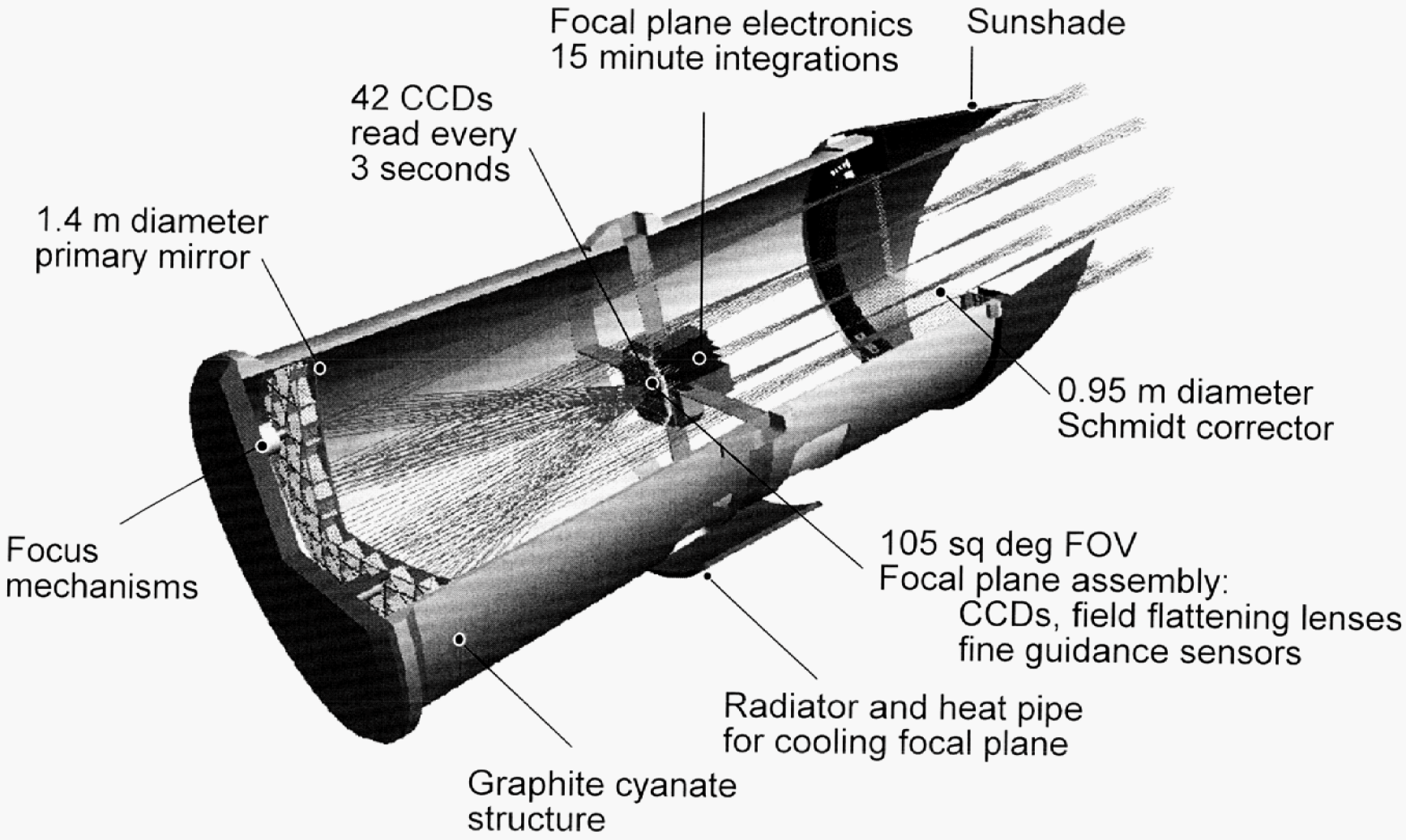

60°
50°
40°
30°
21h
20h
19h
Alderamin
Eltanin
Deneb
Vega
Albireo
Kepler FOV
Galactic Plane
90°
60°



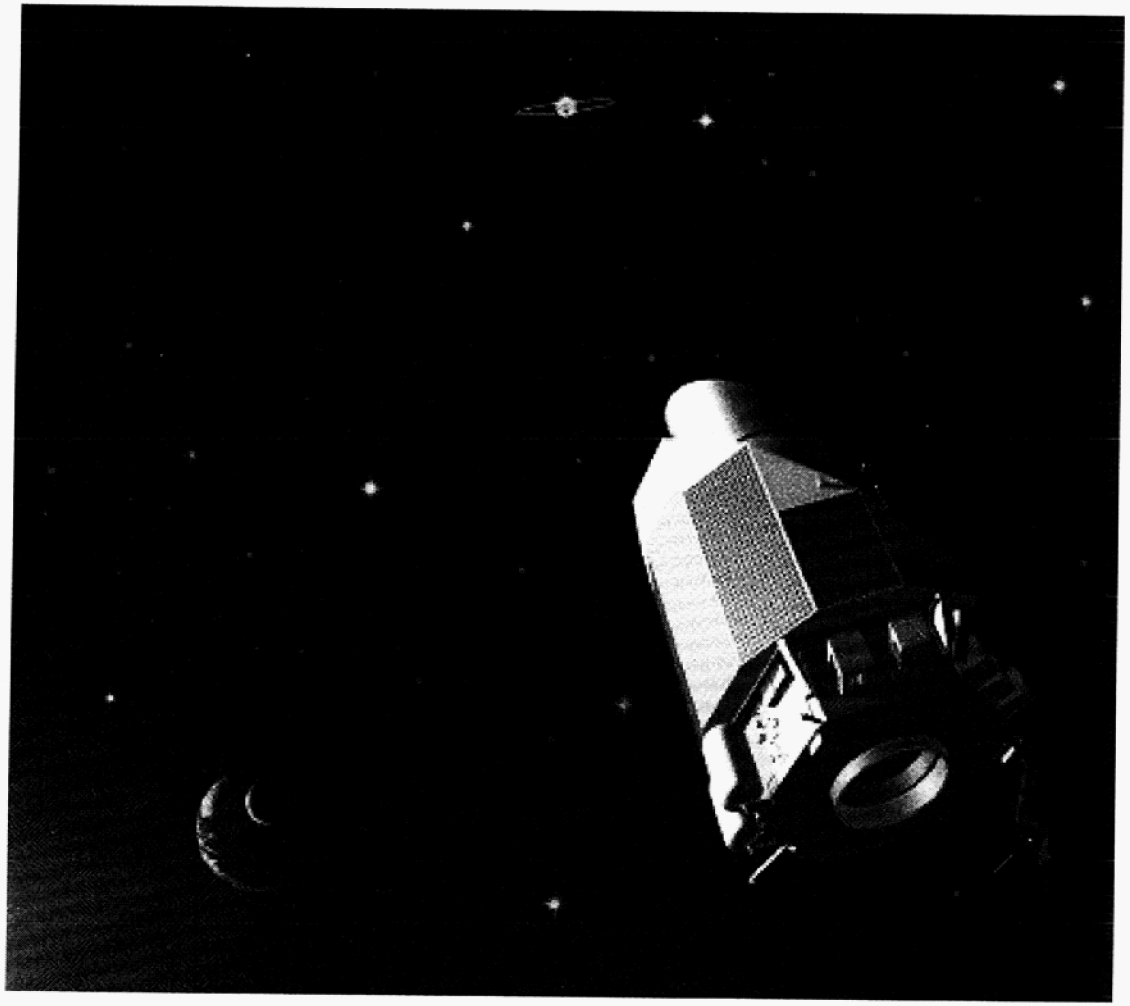


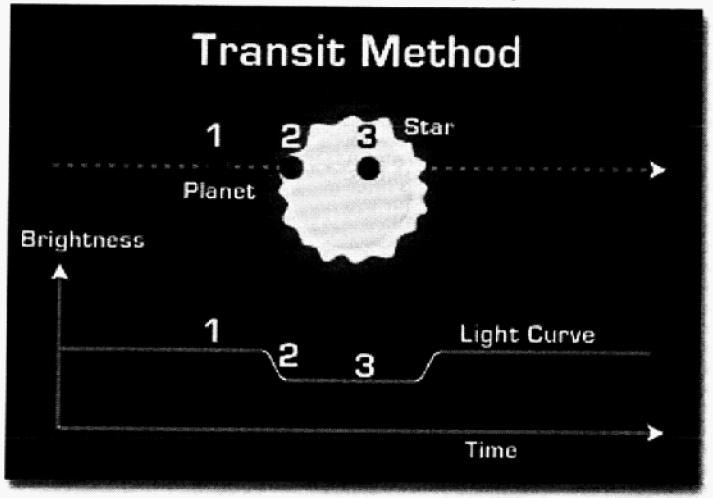
	Earth	Spacecraft
Period (days)	365.25	372.50
Semi-major (AU)	1.00000	1.01319
eccentricity	0.01675	0.03188

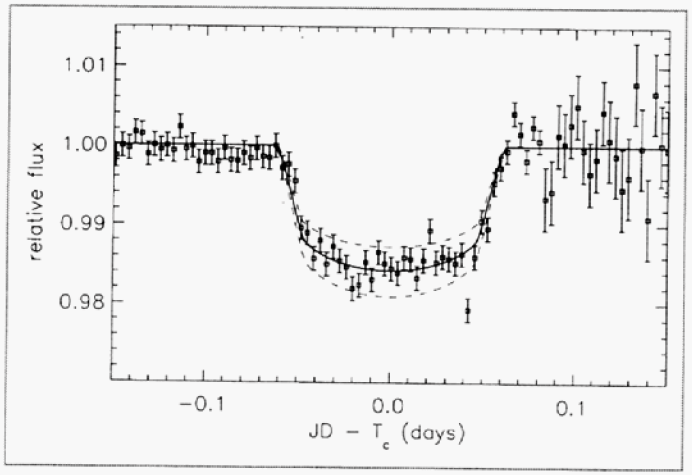
Kepler Photometer

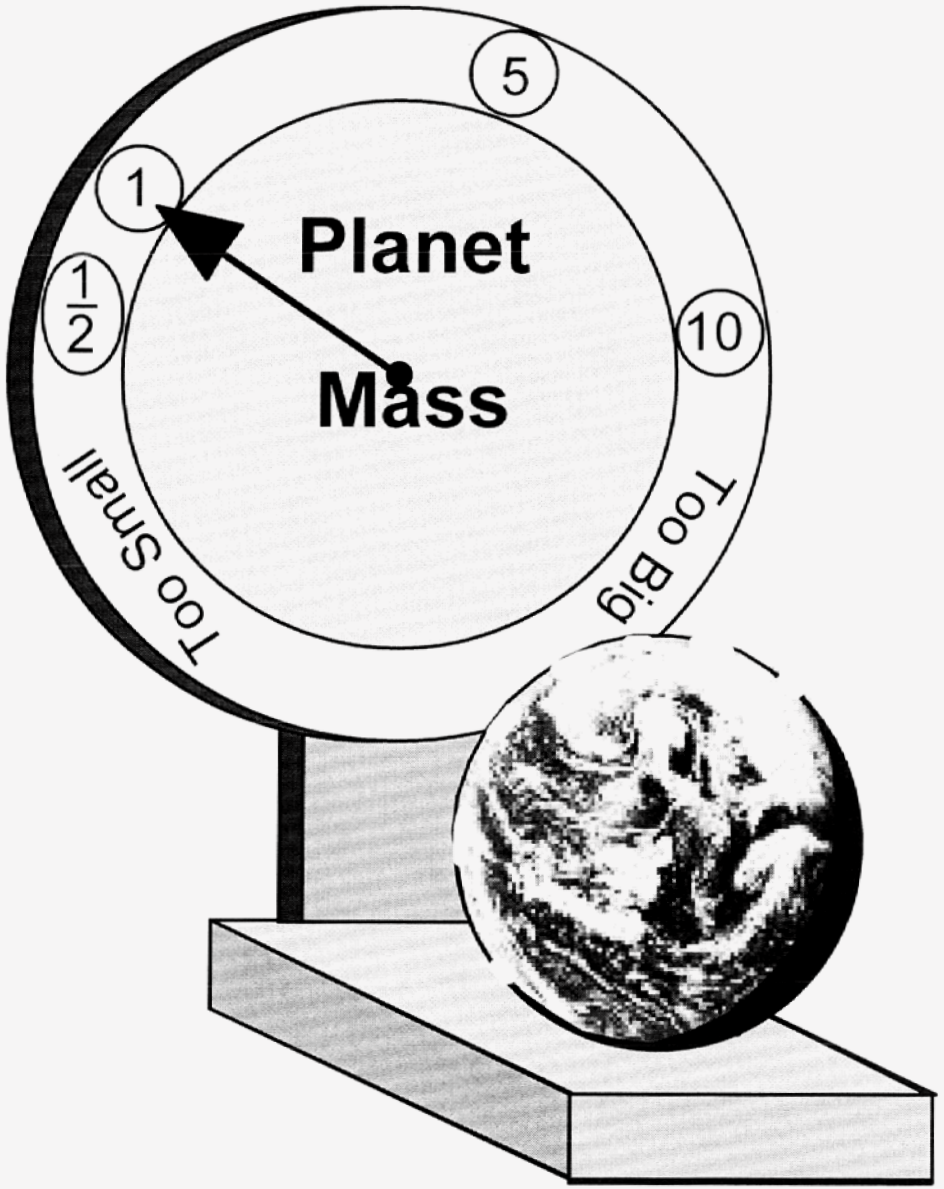


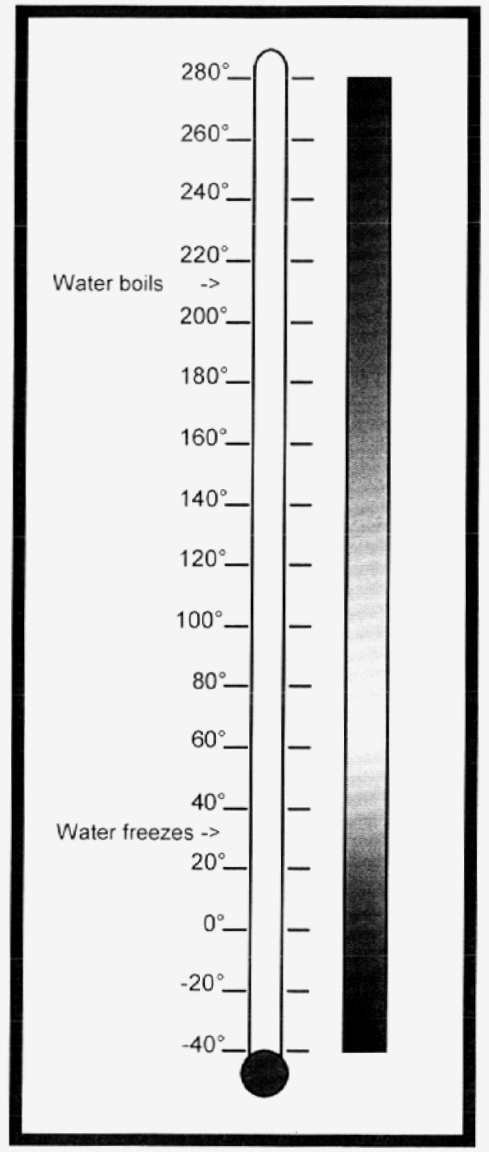
Detecting Planets by Photometry



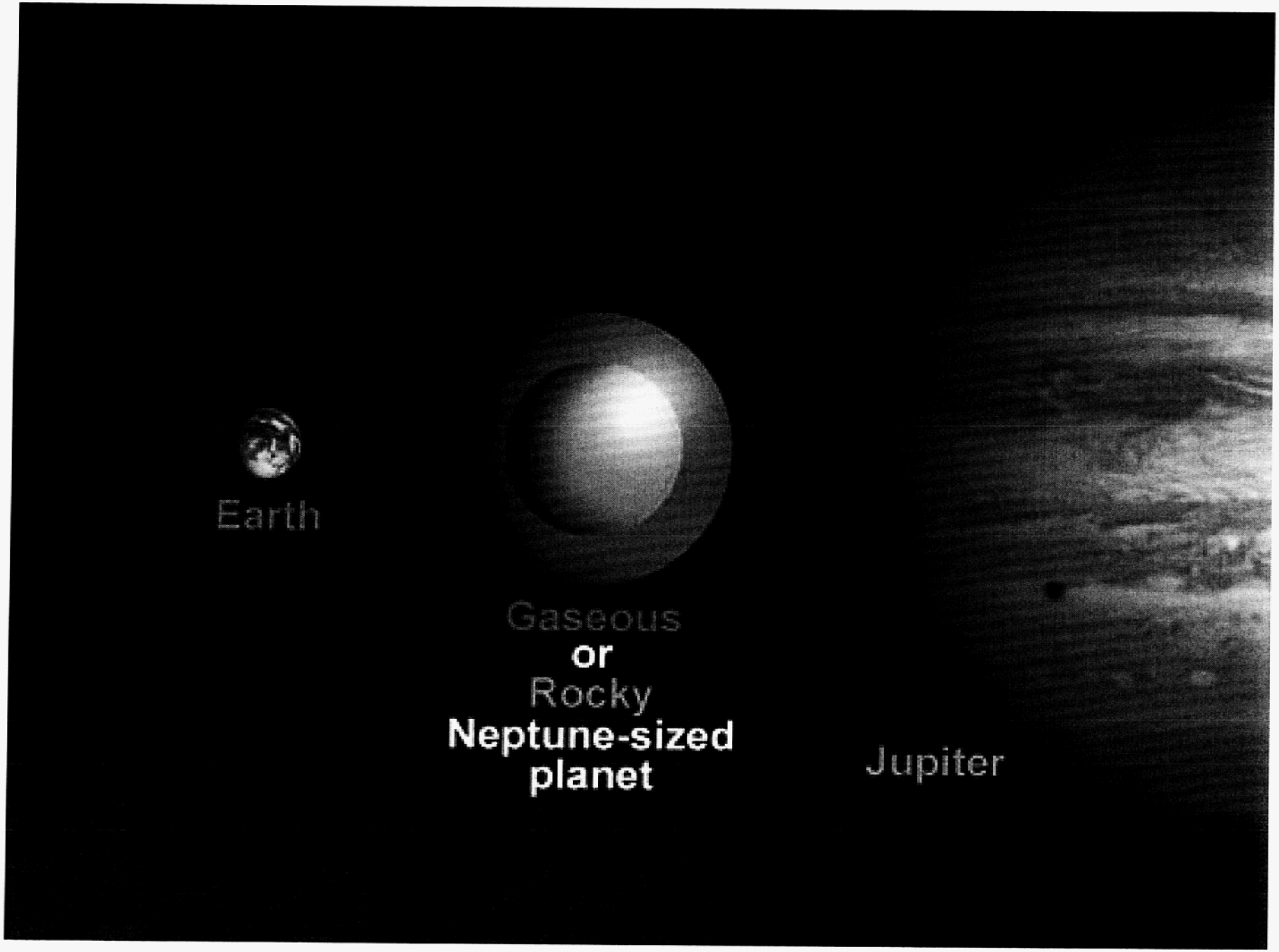


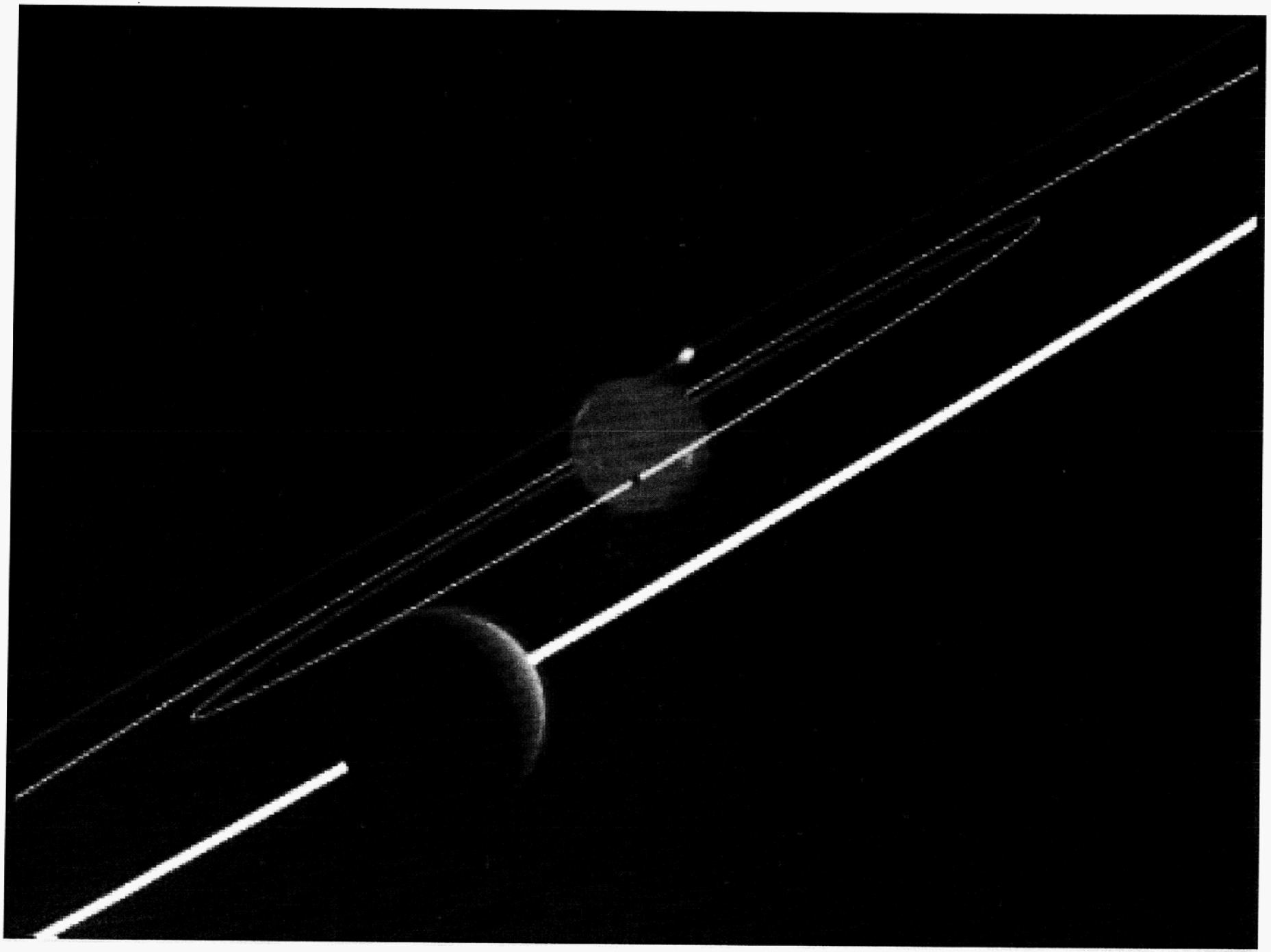


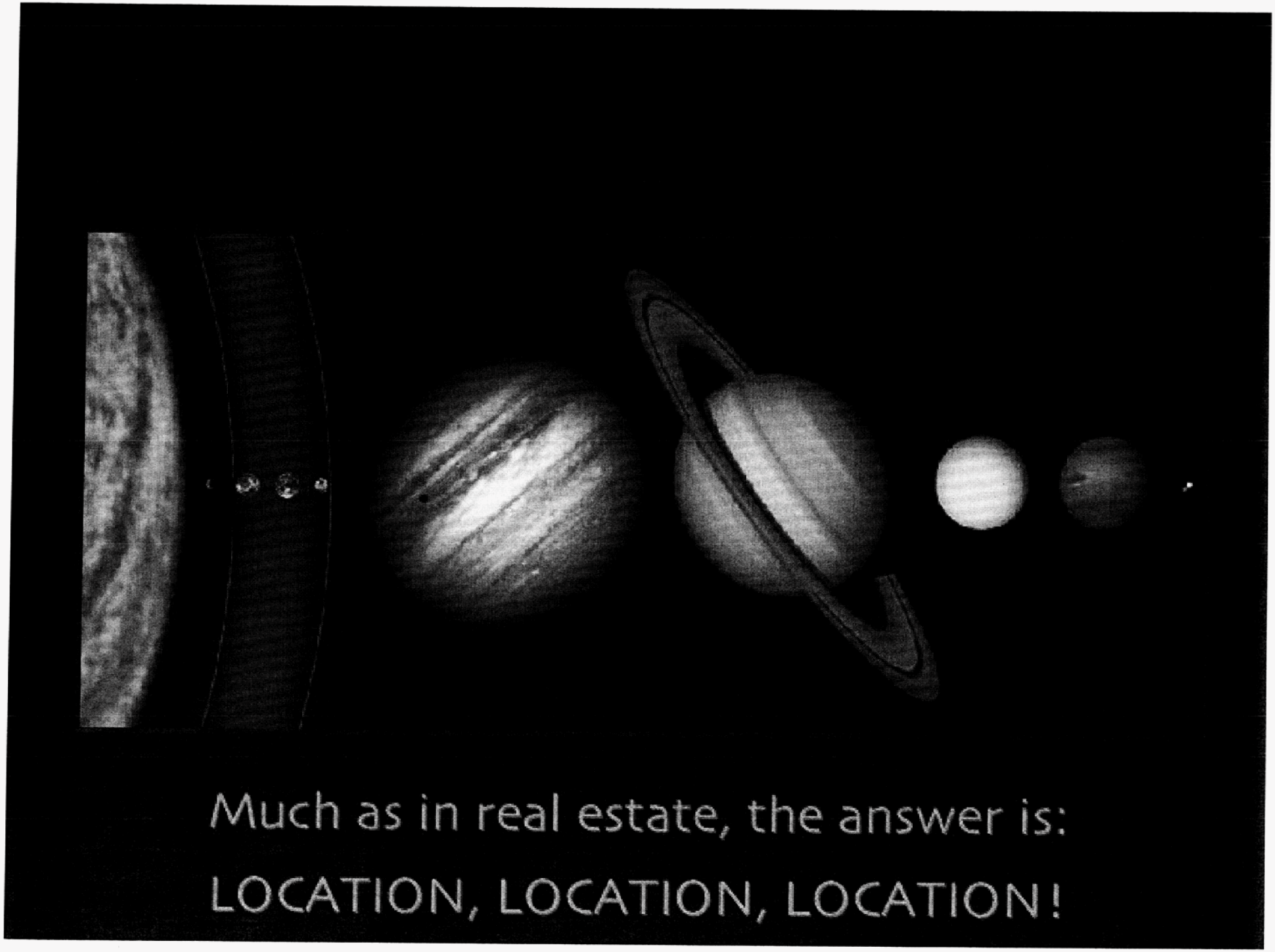


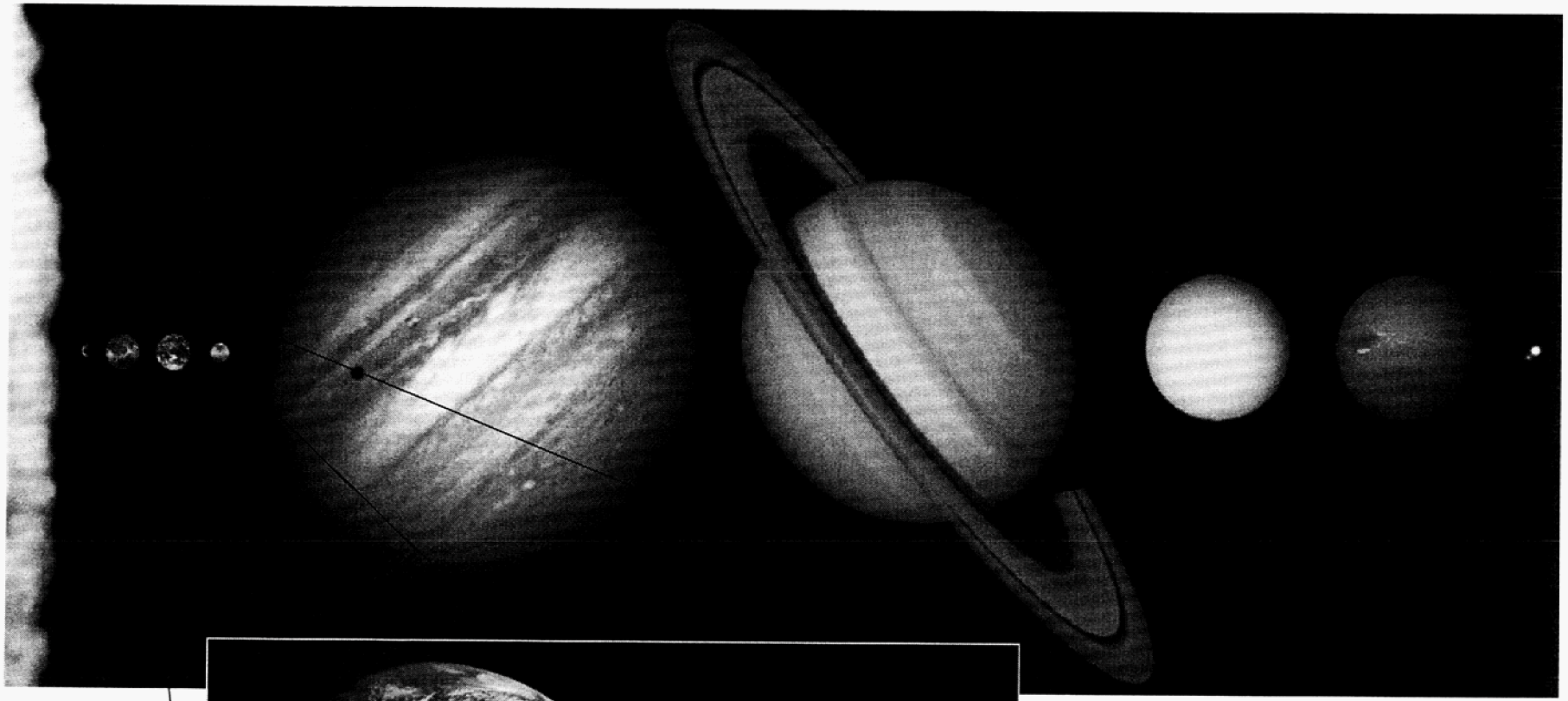


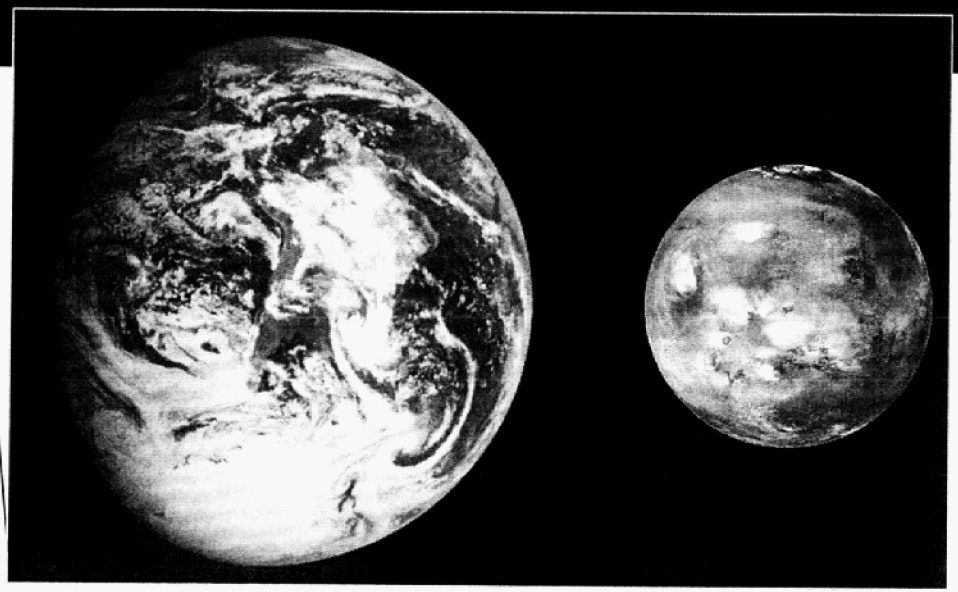
Reference: *Rare Earth*, Ward and Brownlee, Copernicus (Springer-Verlag) ISBN 0-387-98701

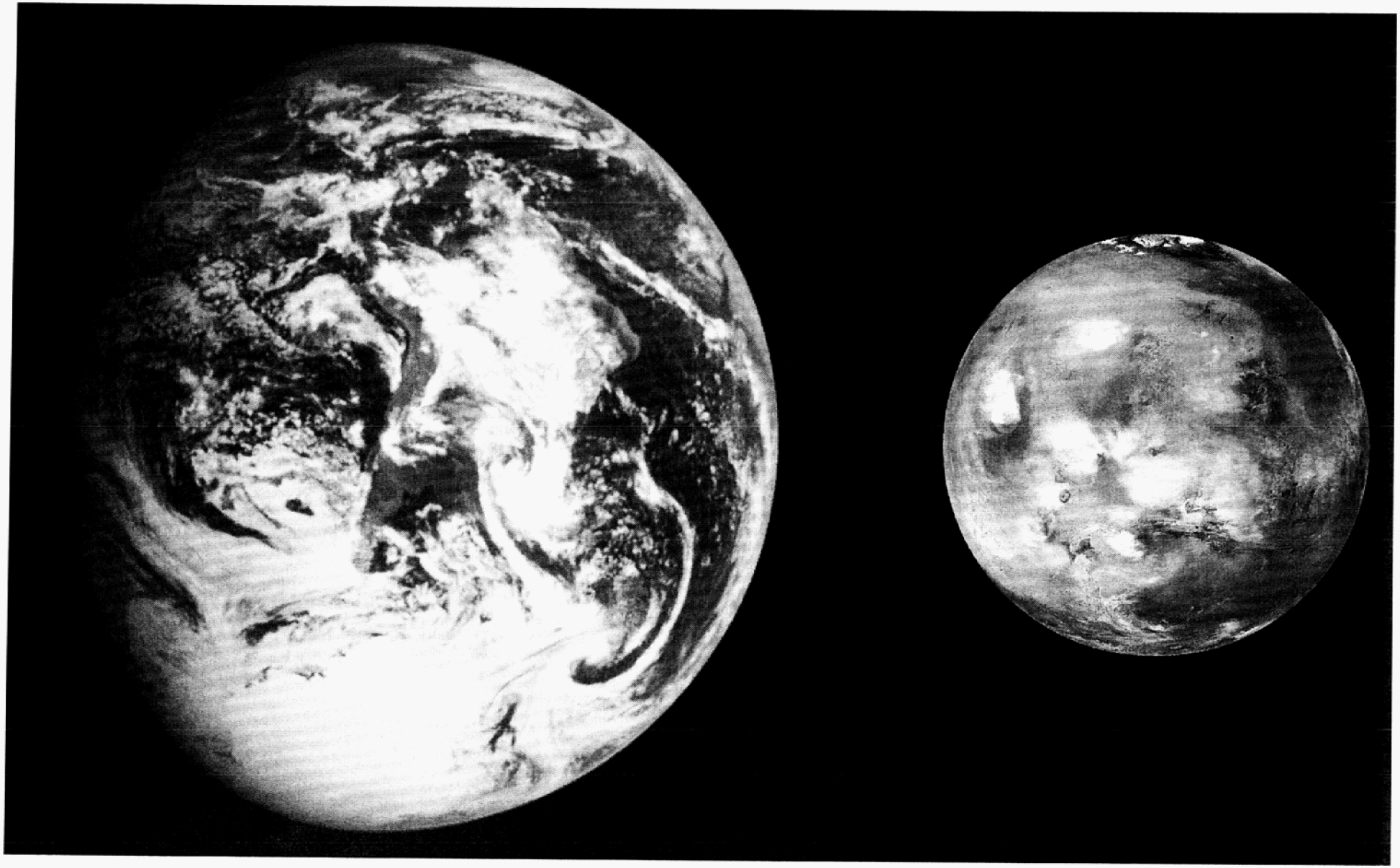

Earth
Gaseous
or
Rocky
Neptune-sized
planet
Jupiter



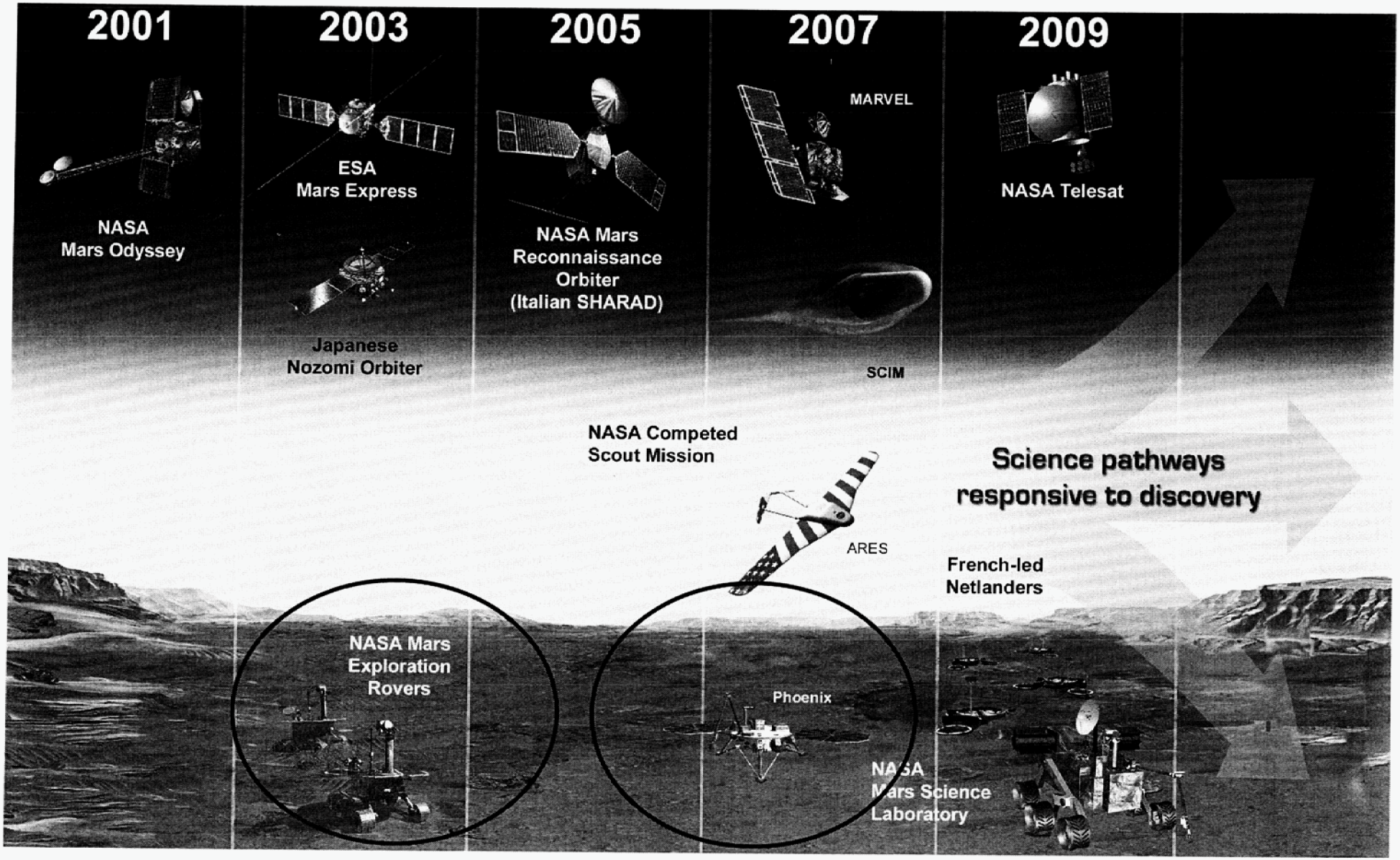

Much as in real estate, the answer is:
LOCATION, LOCATION, LOCATION!

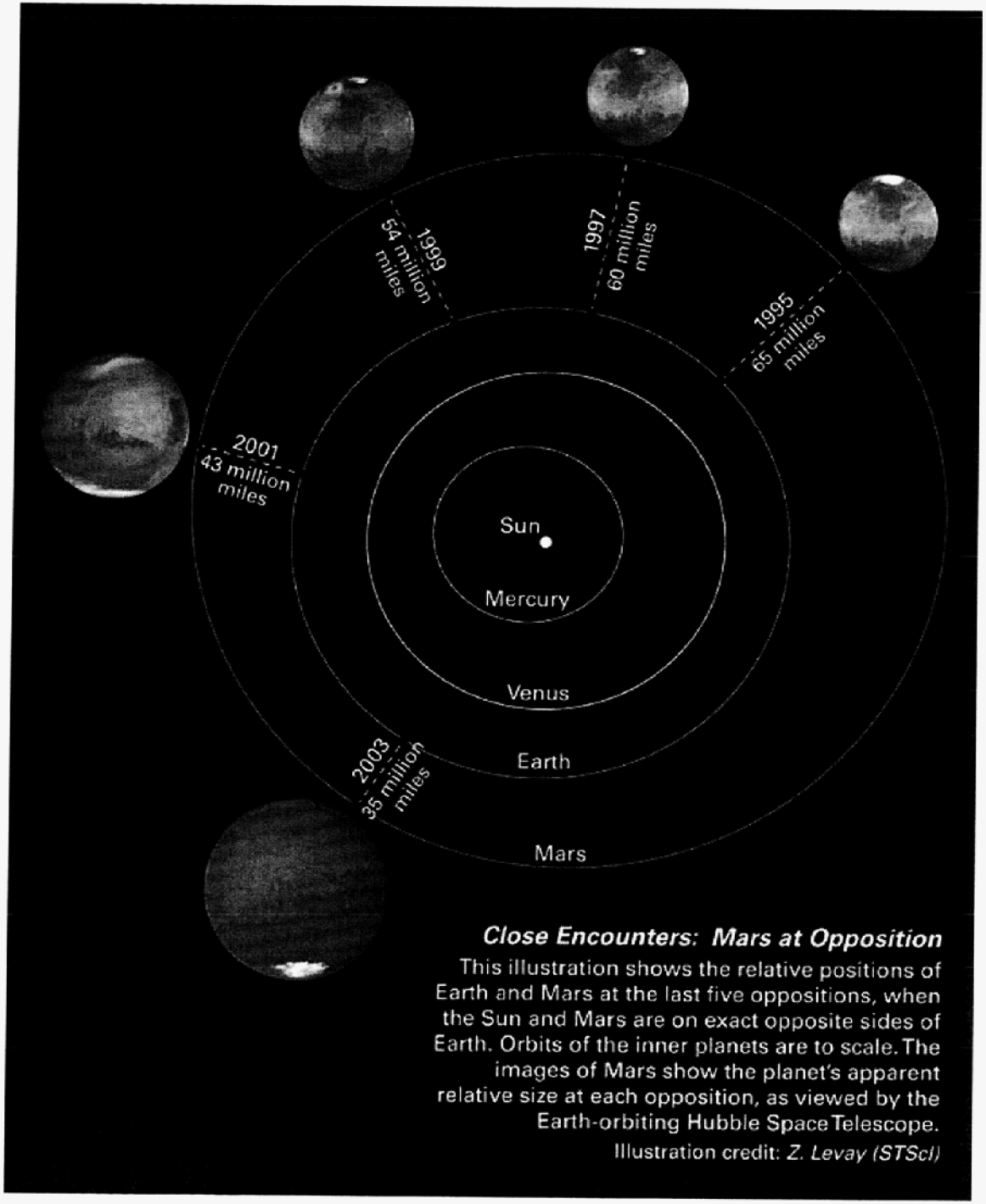






Mars Missions: 2001-2009

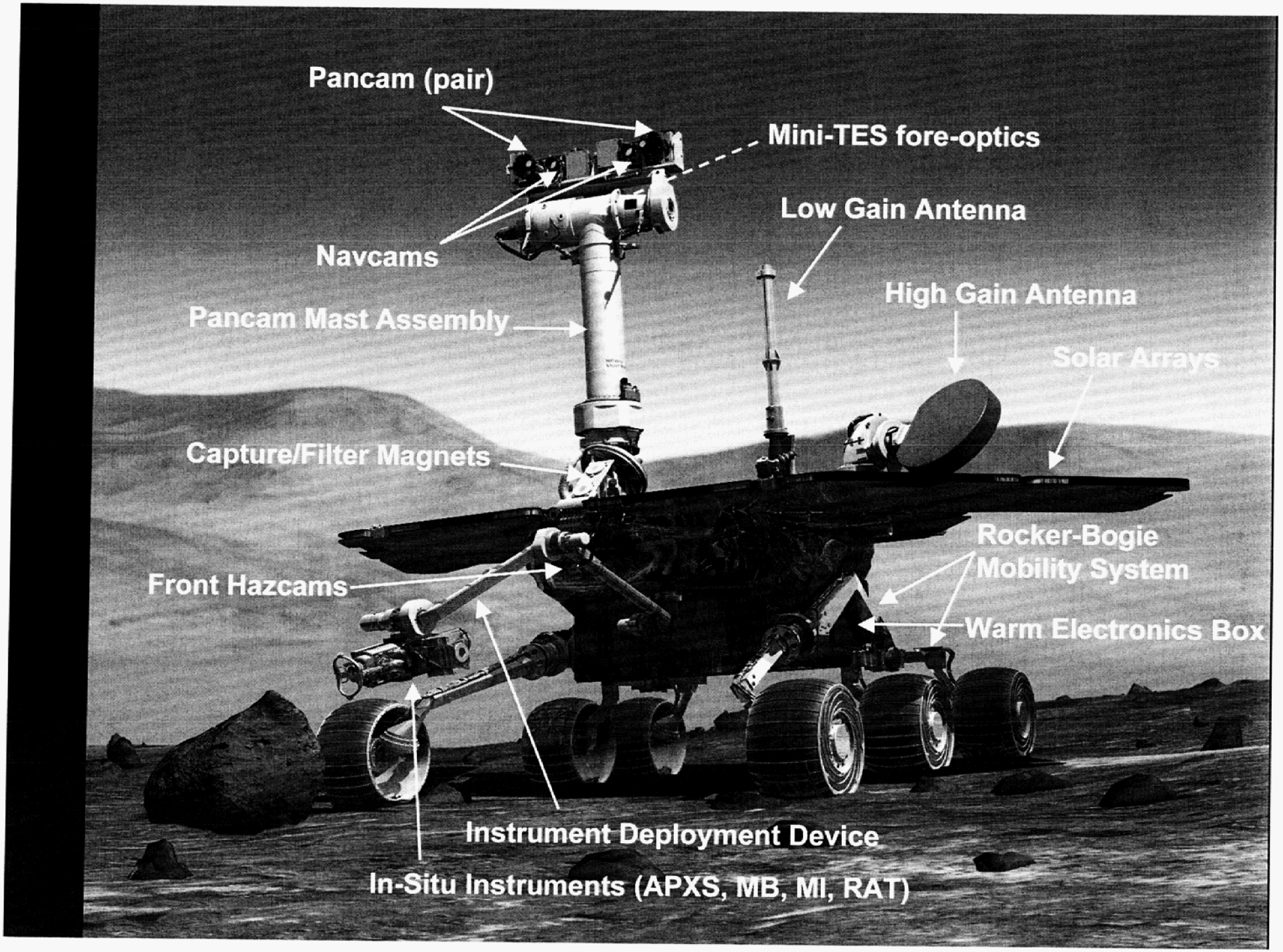


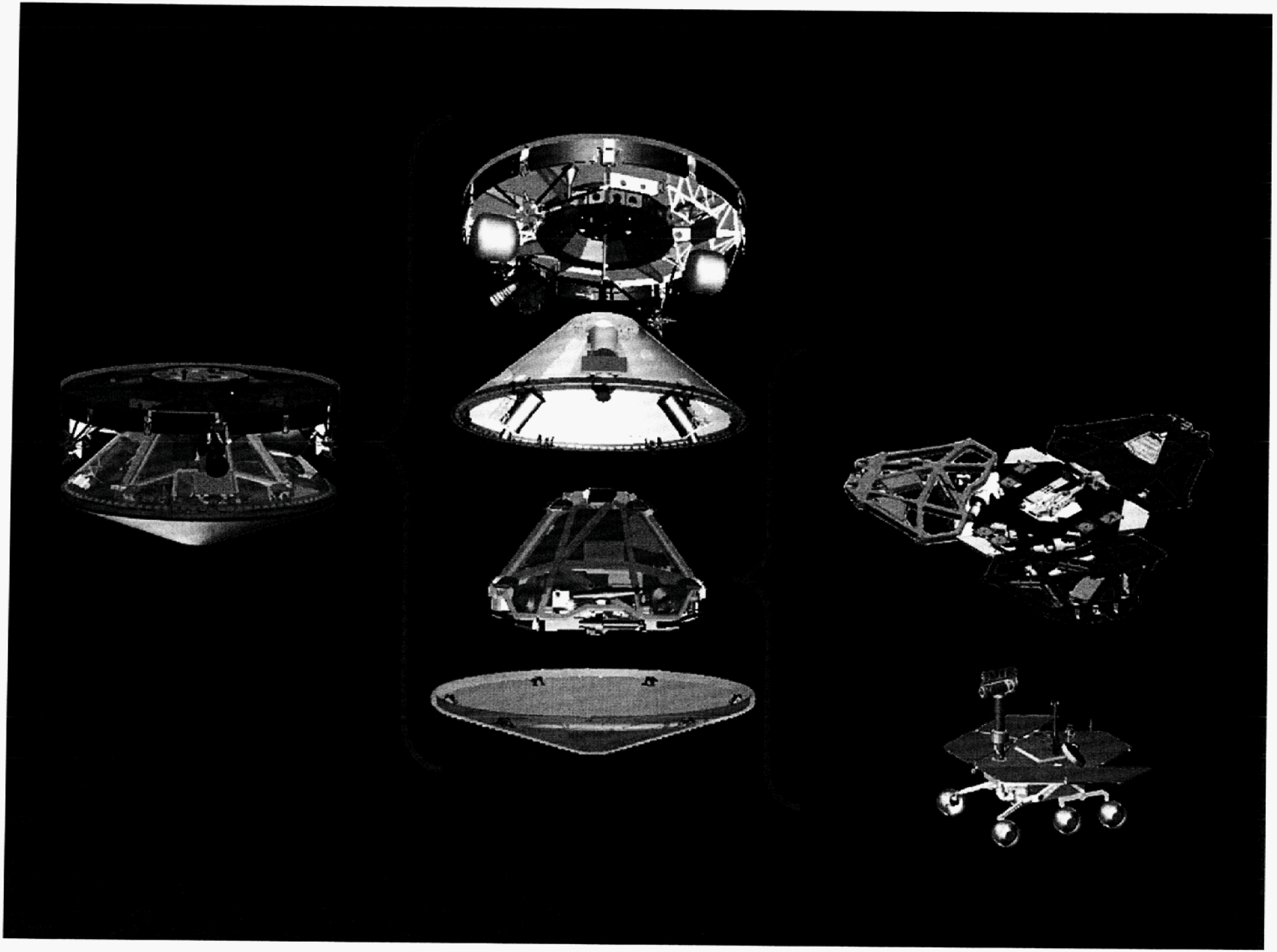


Close Encounters: Mars at Opposition

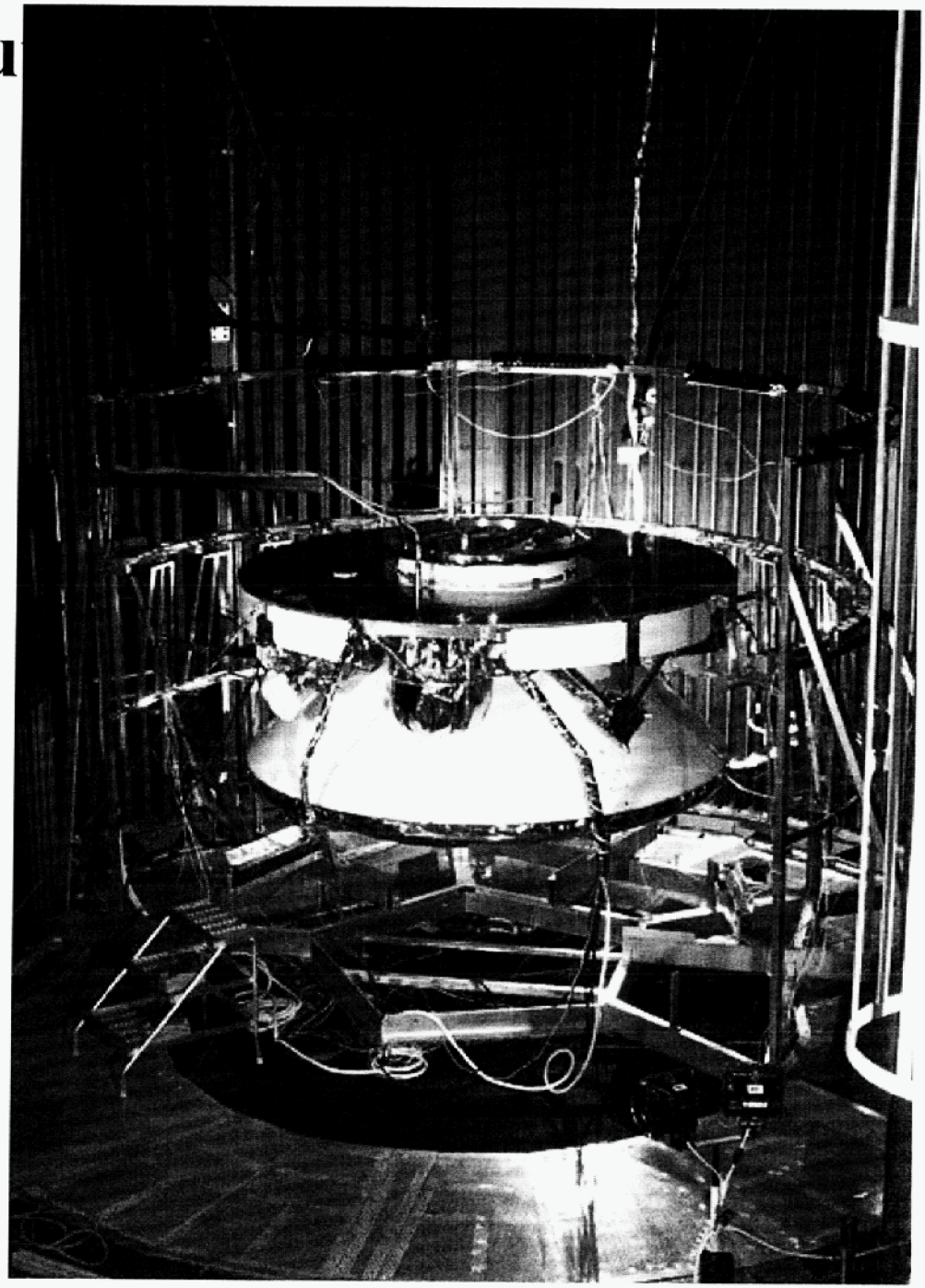
This illustration shows the relative positions of Earth and Mars at the last five oppositions, when the Sun and Mars are on exact opposite sides of Earth. Orbits of the inner planets are to scale. The images of Mars show the planet's apparent relative size at each opposition, as viewed by the Earth-orbiting Hubble Space Telescope.

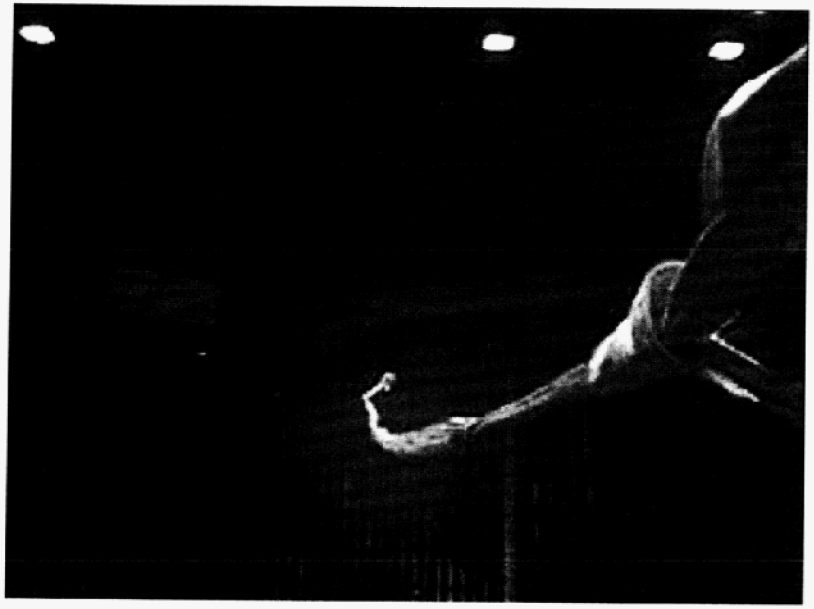
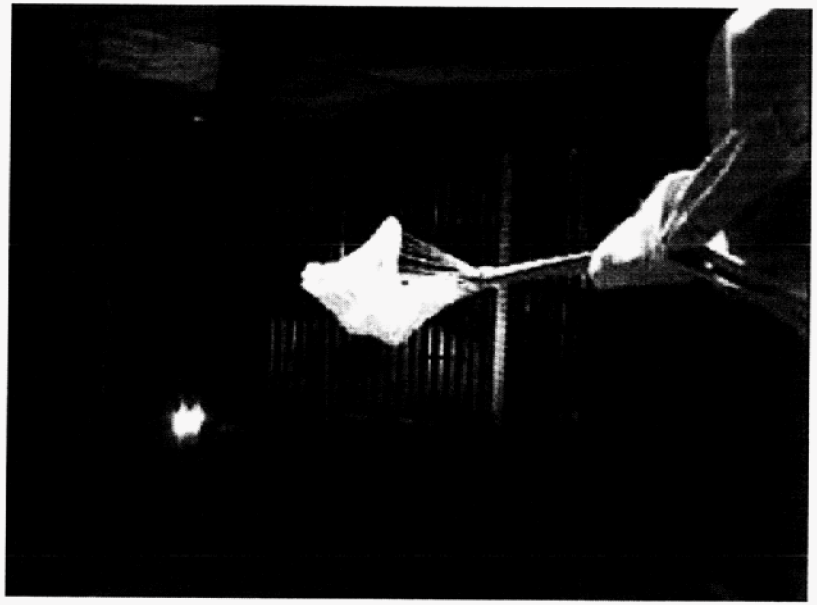
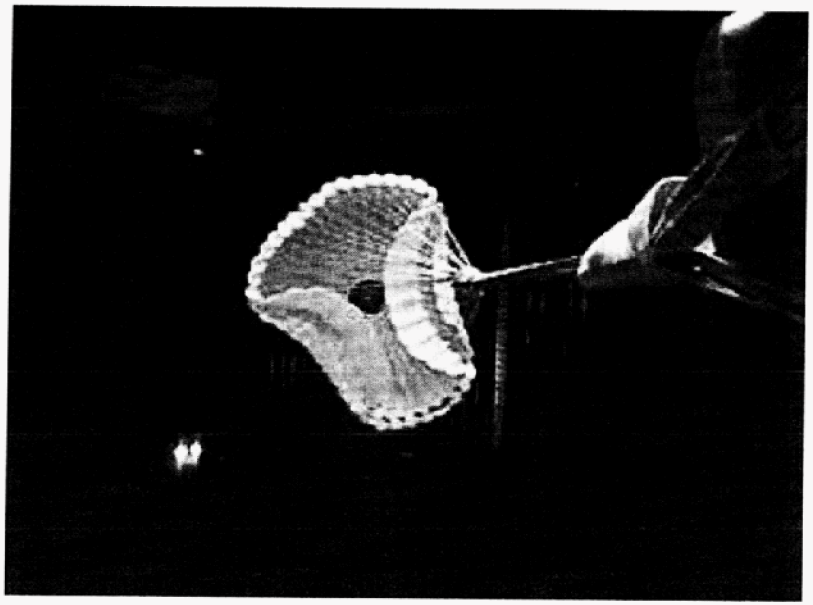
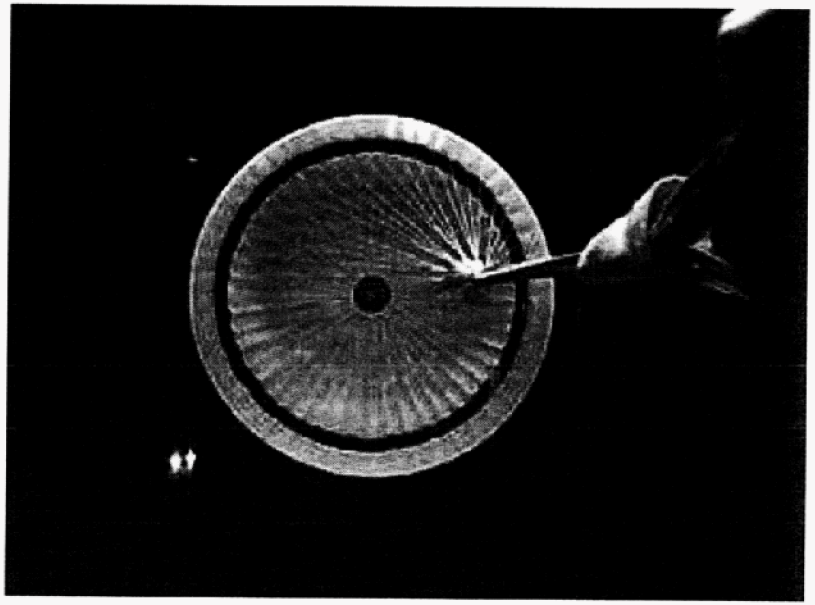
Illustration credit: *Z. Levay (STScI)*

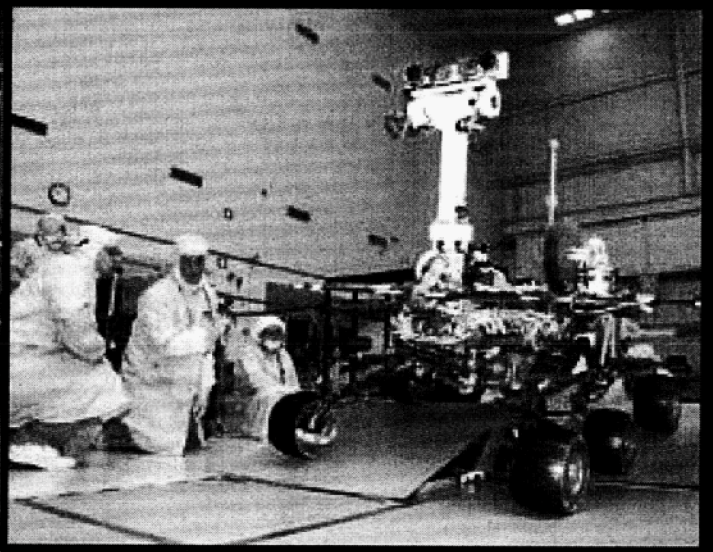

Pancam (pair)
Mini-TES fore-optics
Low Gain Antenna
Navcams
High Gain Antenna
Pancam Mast Assembly
Solar Arrays
Capture/Filter Magnets
Rocker-Bogie
Mobility System
Front Hazcams
Warm Electronics Box
Instrument Deployment Device
In-Situ Instruments (APXS, MB, MI, RAT)

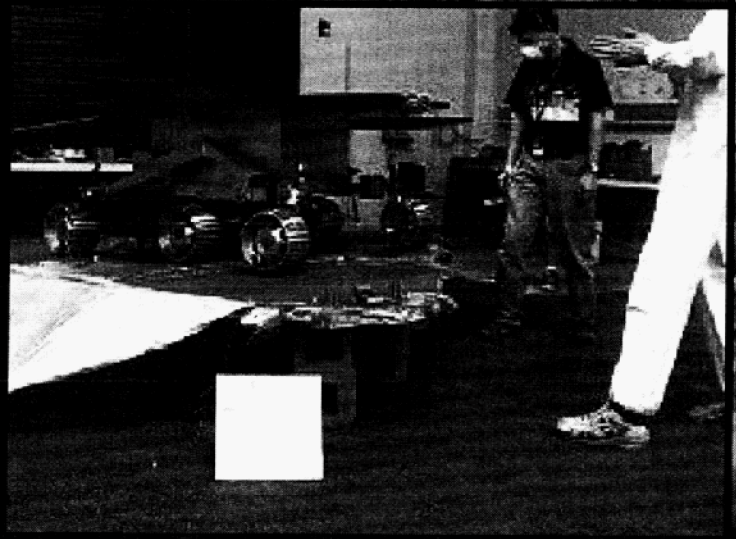


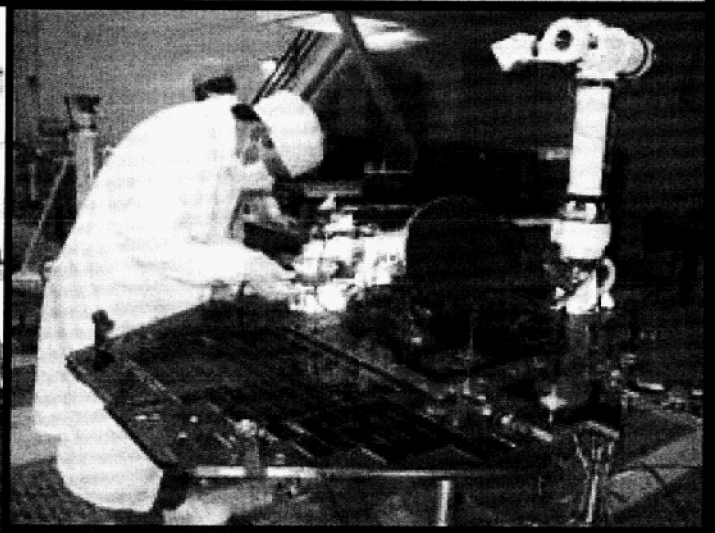
Parachu



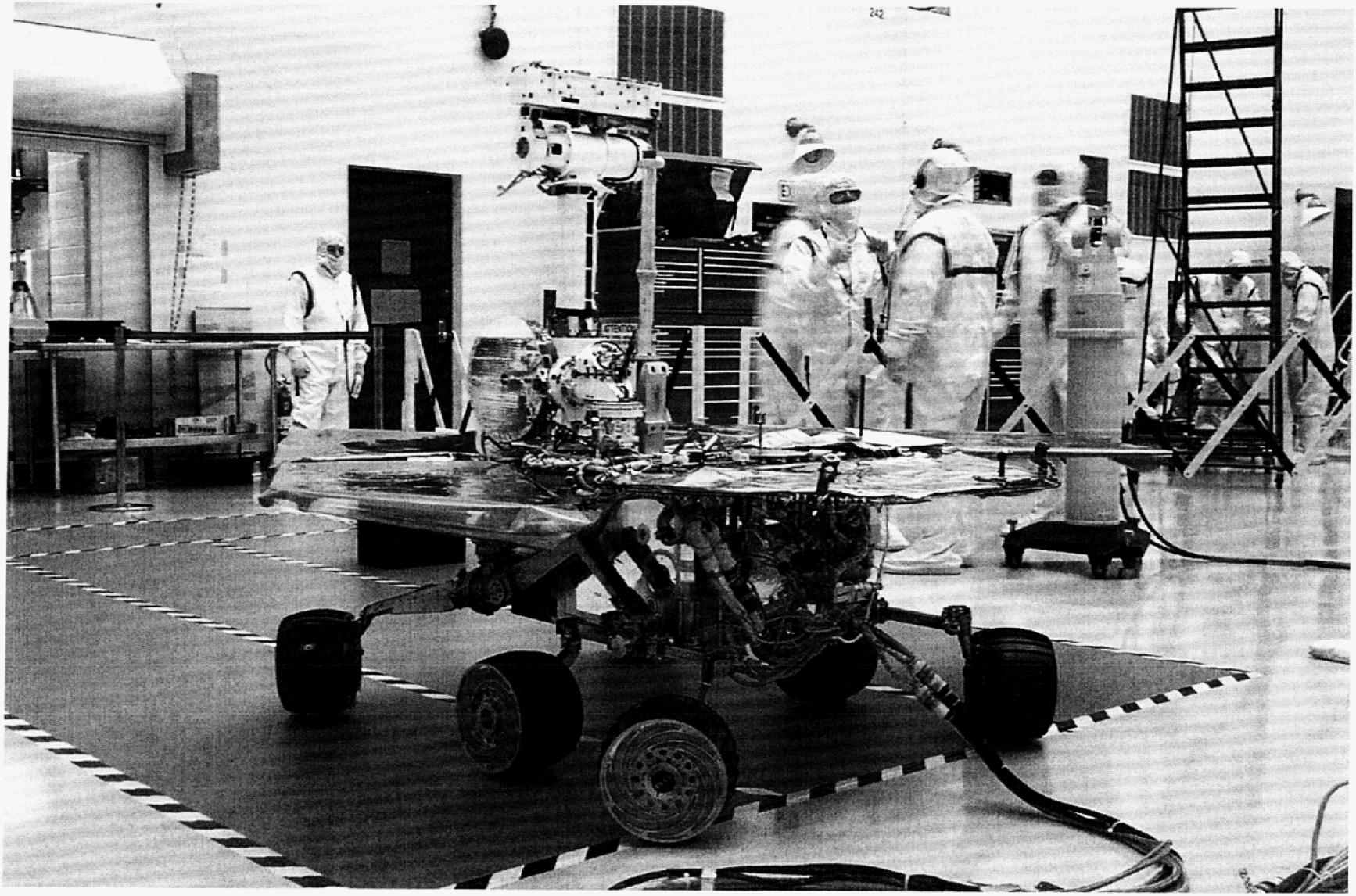









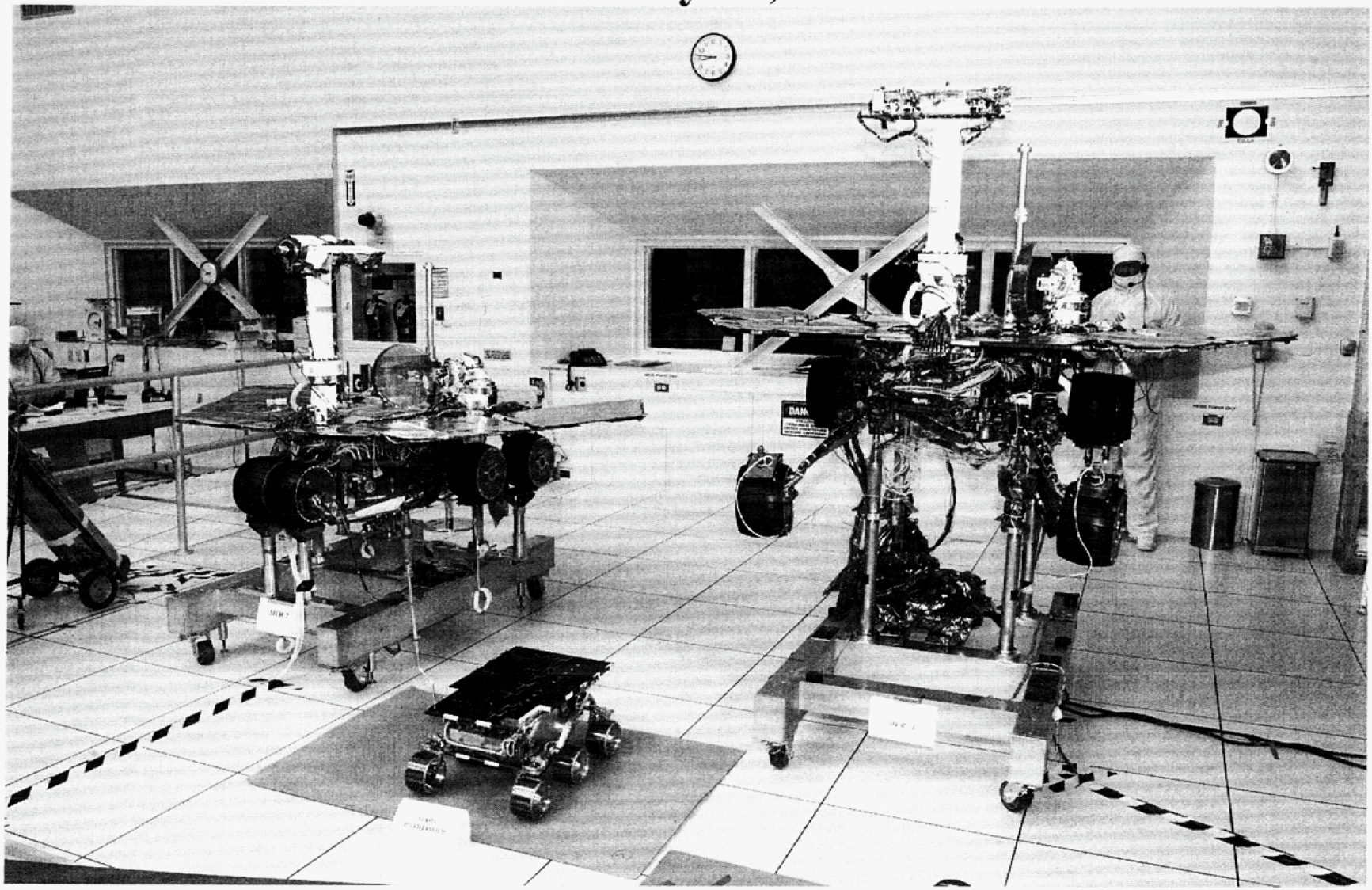


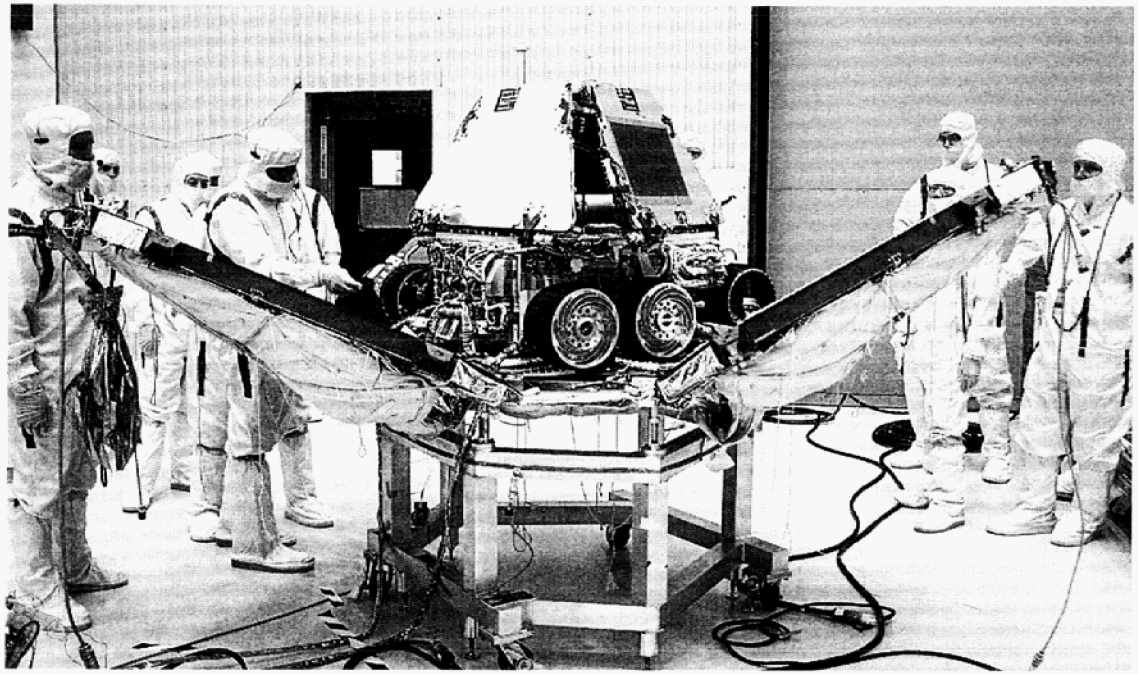
Spirit Driving Testing at KSC

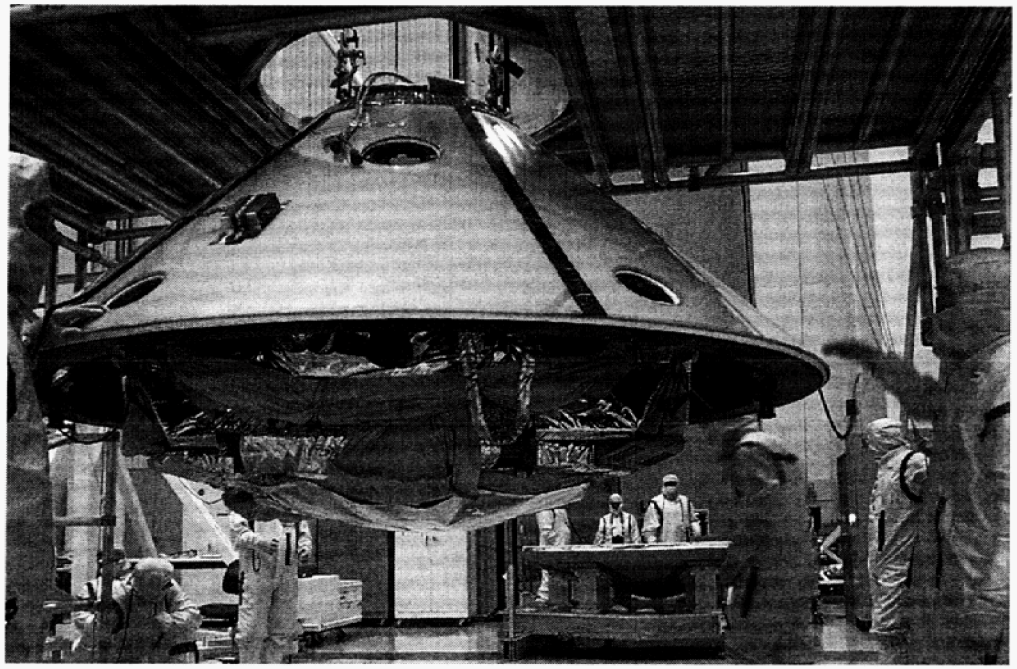


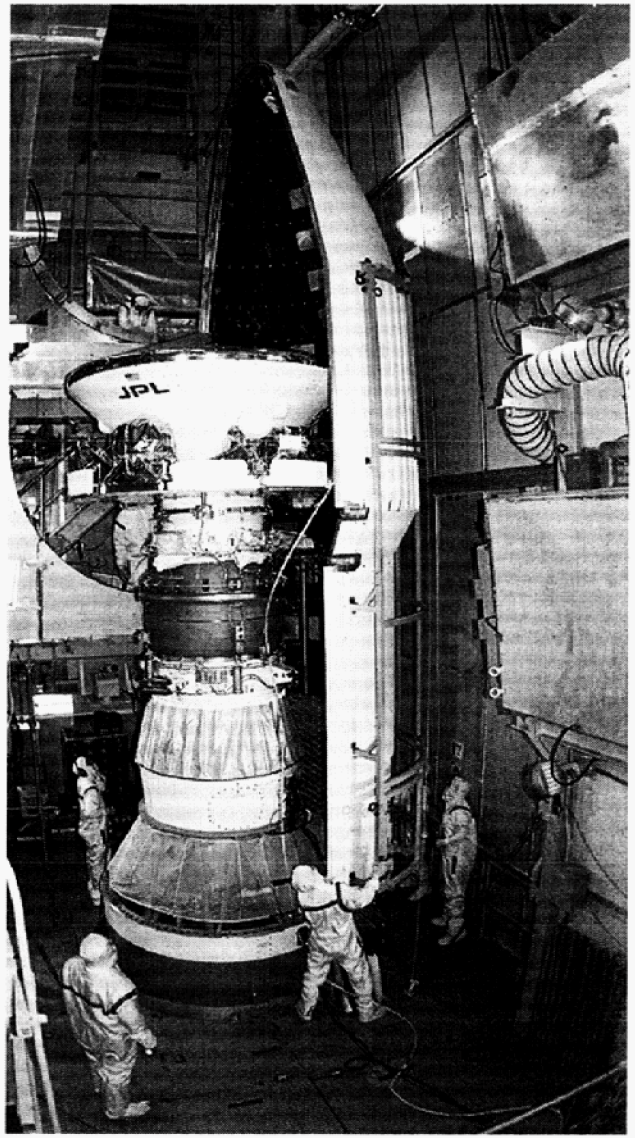
MER #1, MER #2, & Sojourner Spare Rovers

February 10, 2003





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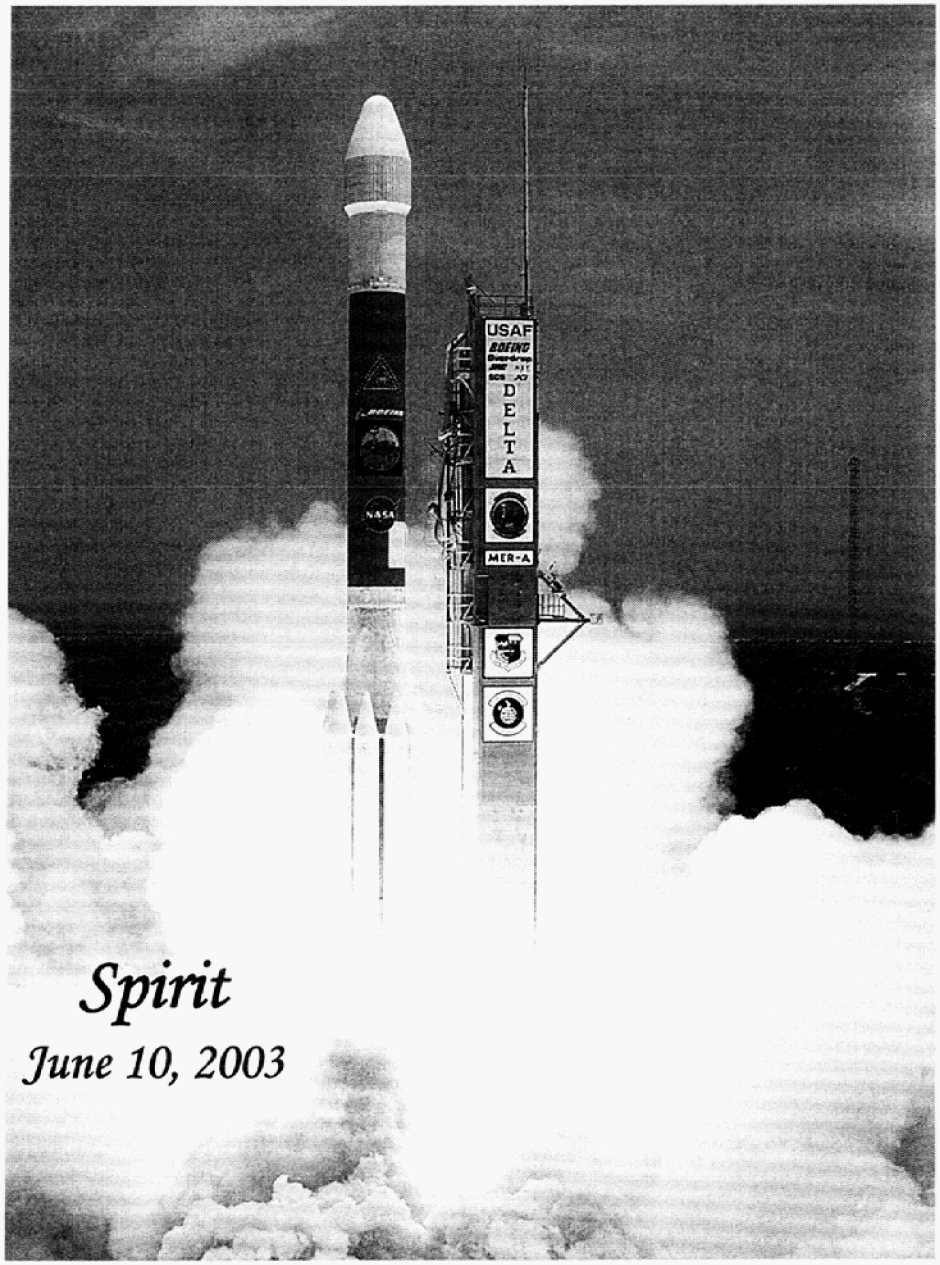
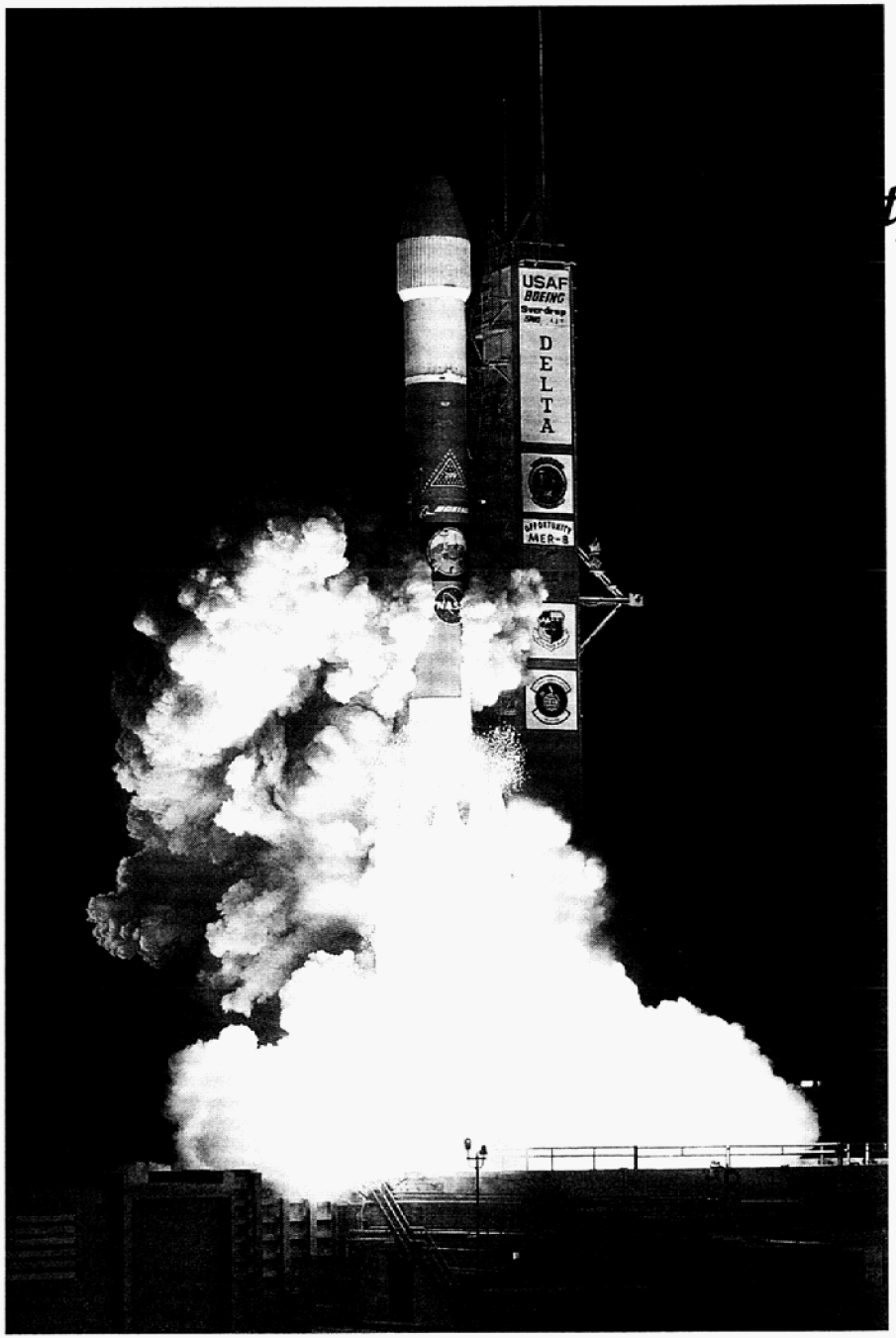


Spirit

June 10, 2003



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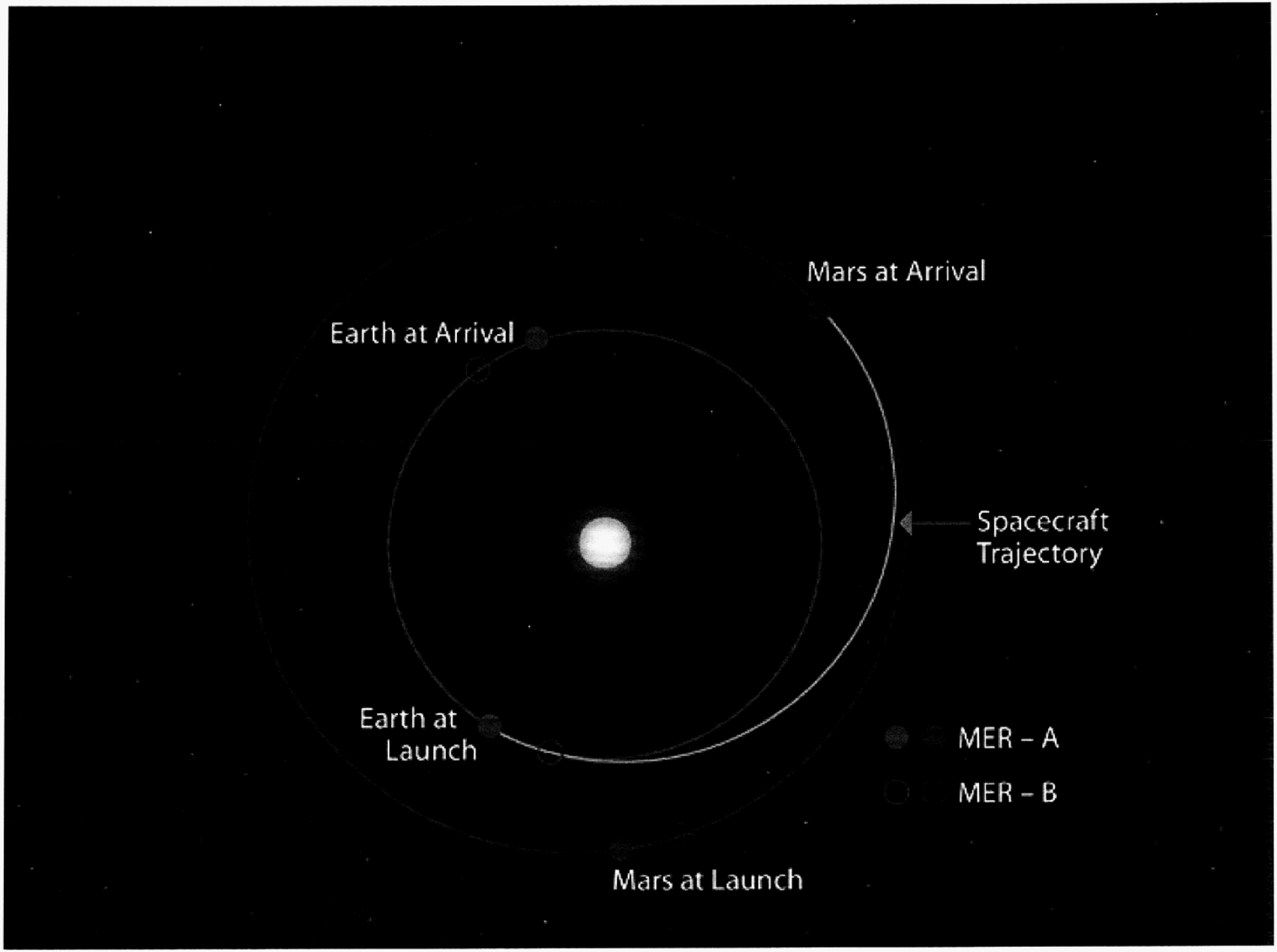
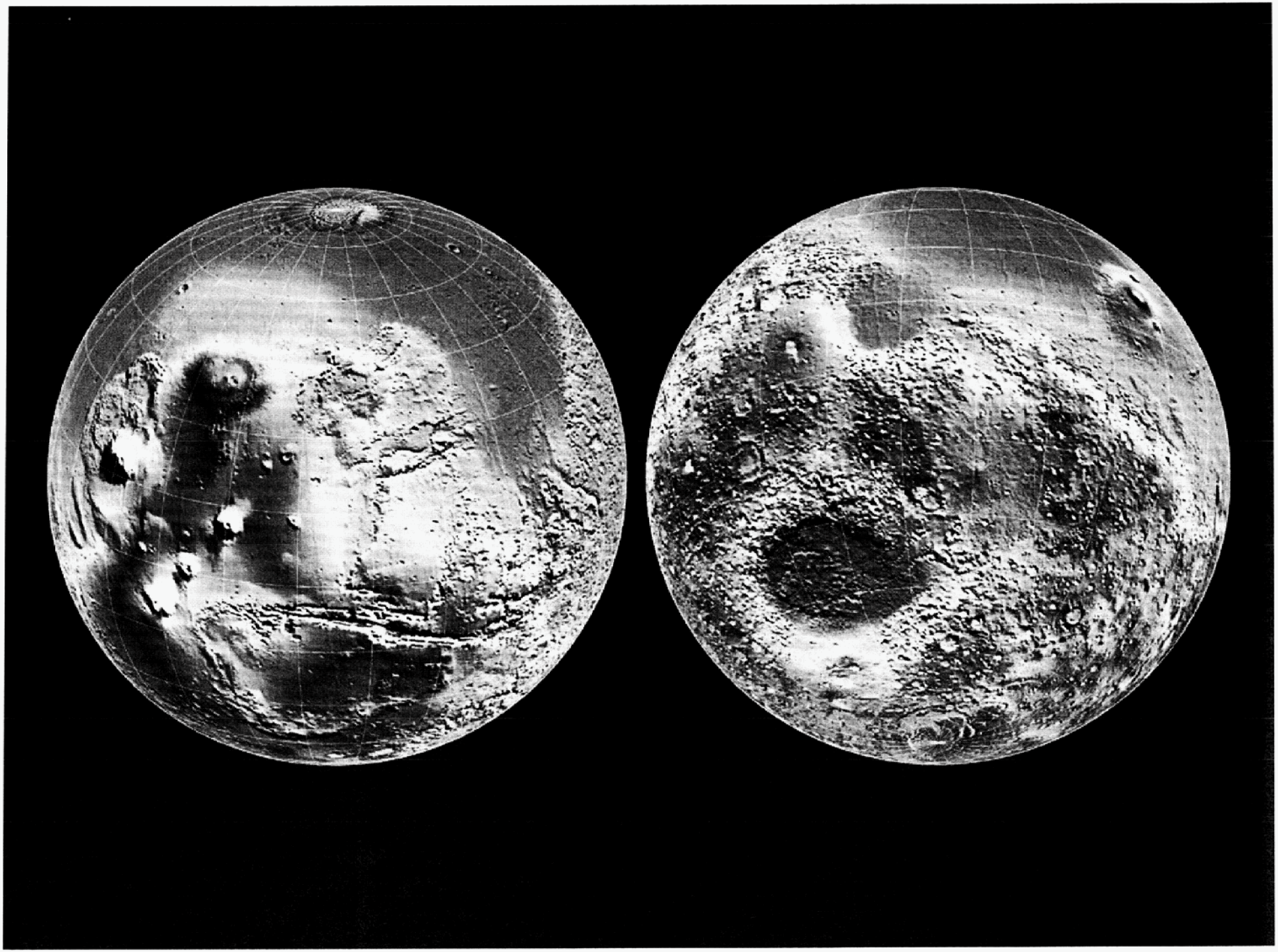
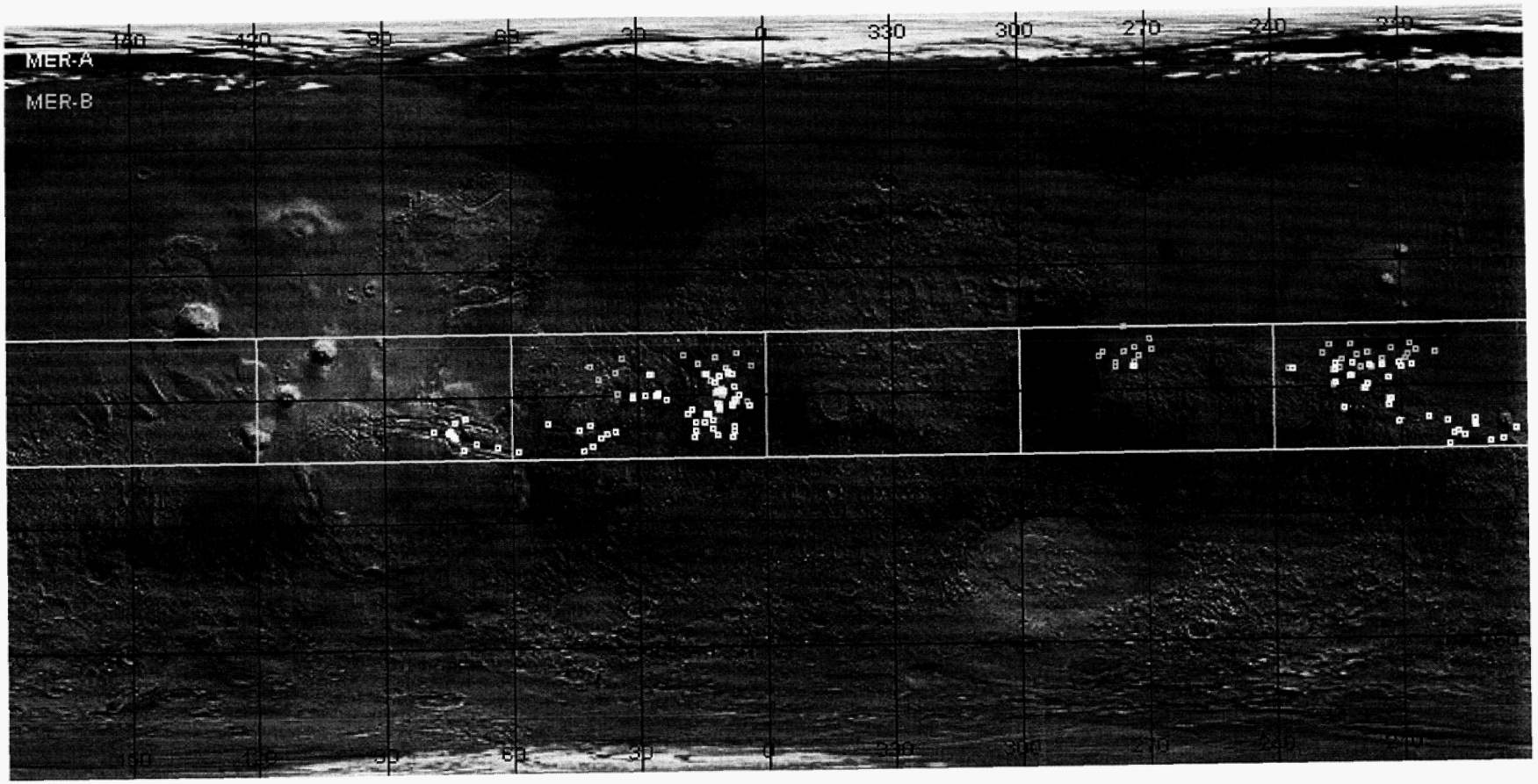
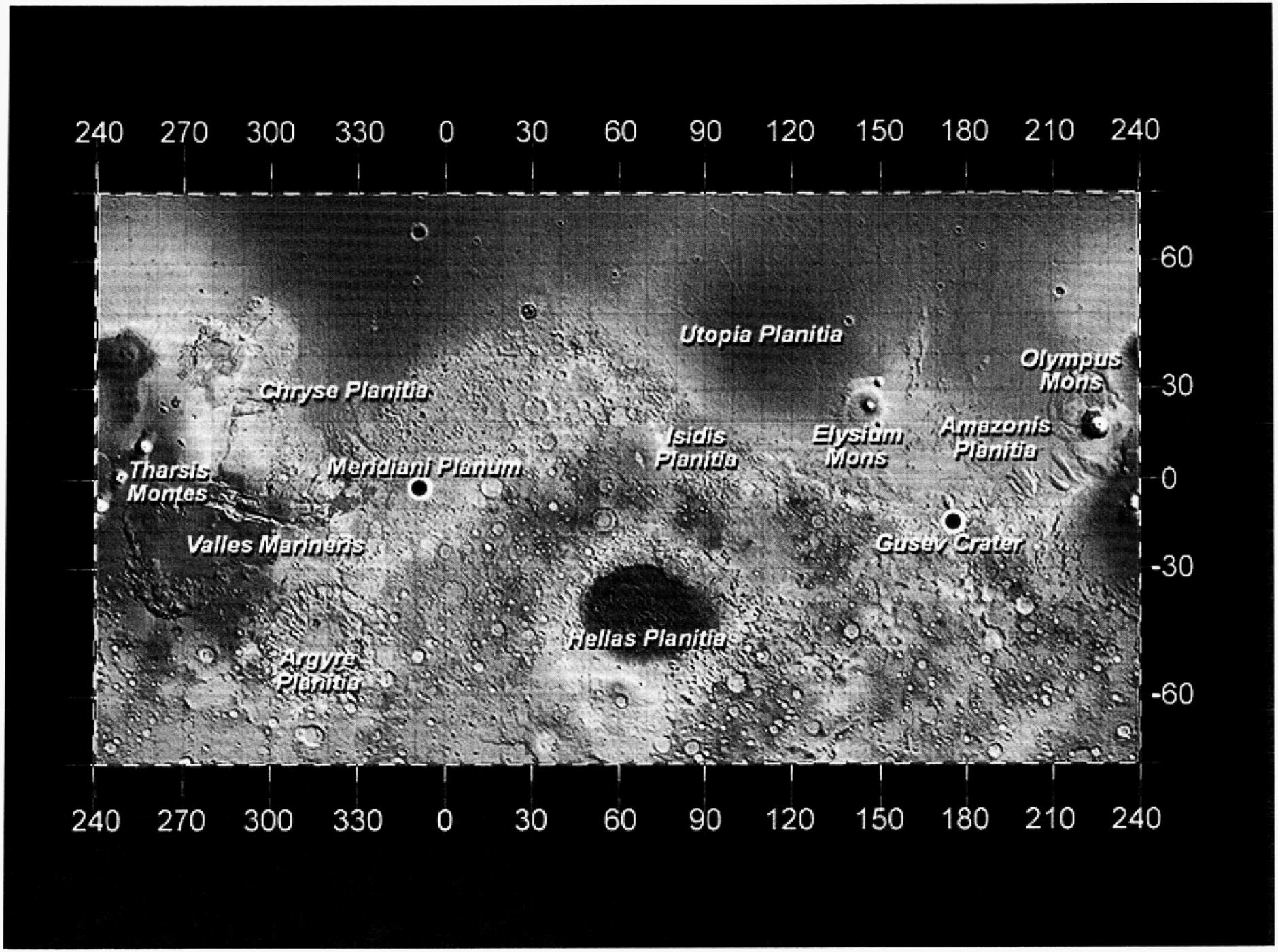

Mars at Arrival
Earth at Arrival
Spacecraft
Trajectory
Earth at
Launch
MER – A
MER – B
Mars at Launch




MER-A
MER-B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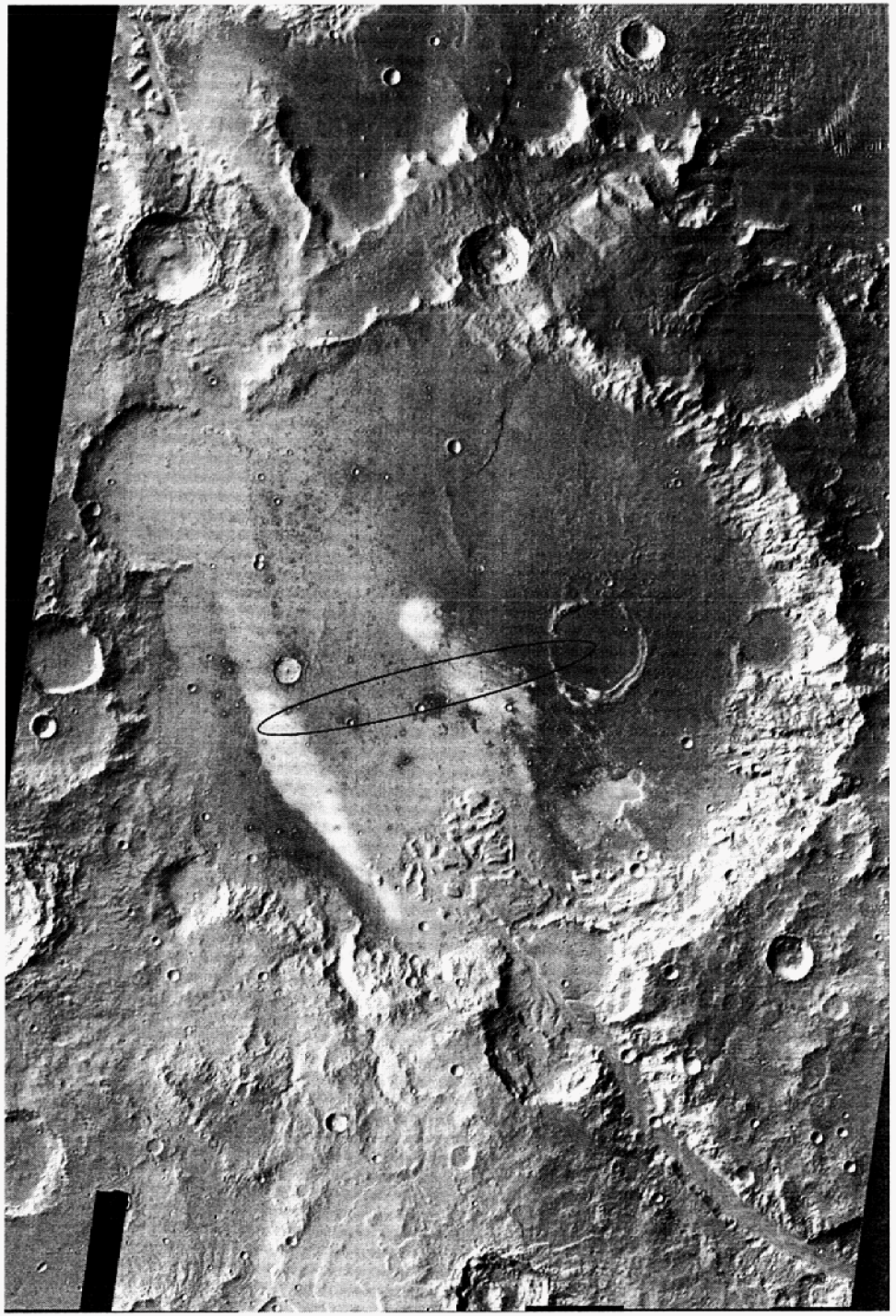
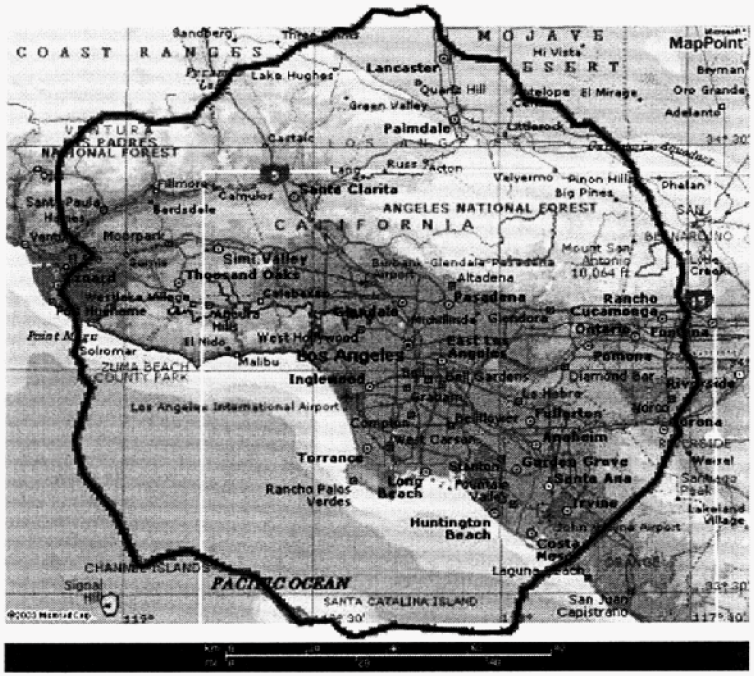
Utopia Planitia
Olympus Mons
Chryse Planitia
Isidis Planitia
Elysium Mons
Amazonis Planitia
Tharsis Montes
Meridiani Planum
Valles Marineris
Gusev Crater
Hellas Planitia
Argyre Planitia




COAST RANGES
MOJAVE DESERT
MapPoint
Lancaster
Palmdale
Santa Clarita
ANGELES NATIONAL FOREST
CALIFORNIA
Simi Valley
Thousand Oaks
Pasadena
Rancho Cucamonga
Ontario
Fontana
Los Angeles
Inglewood
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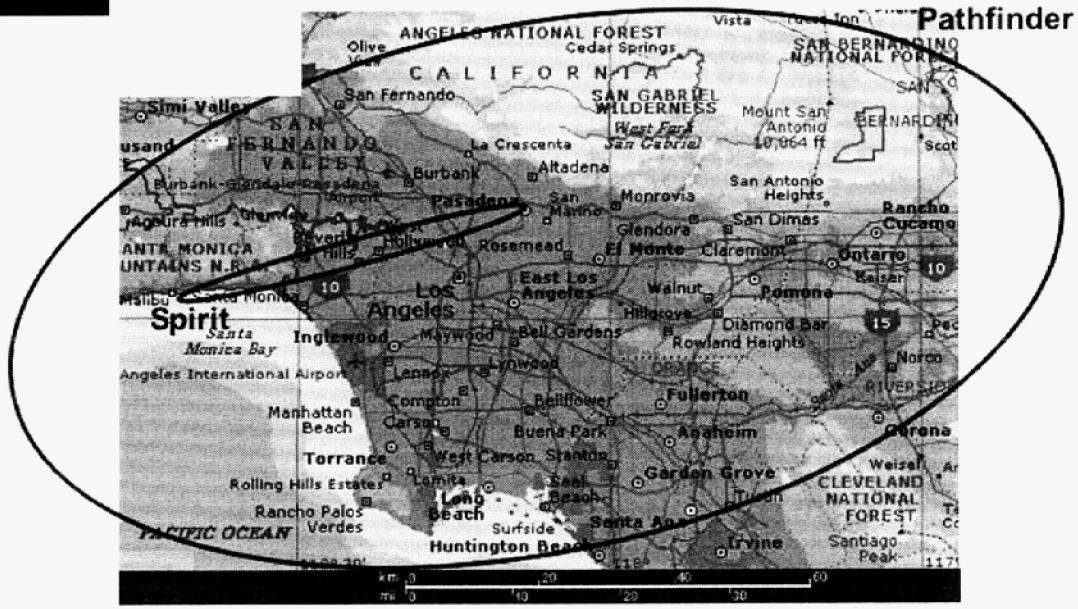
Garden Grove
Santa Ana
Irvine
Rancho Palos Verdes
Los Angeles International Airport
PACIFIC OCEAN
SANTA CATALINA ISLAND


Pathfinder
Spirit
ANGELES NATIONAL FOREST
CALIFORNIA
SAN GABRIEL WILDERNESS
SAN FERNANDO VALLEY
Simi Valley
San Fernando
Burbank
Pasadena
Altadena
Monrovia
Glendora
El Monte
Rosemead
Los Angeles
East Los Angeles
Inglewood
Maywood
Bell Gardens
Lynwood
Compton
Carson
Bellflower
Fullerton
Anaheim
Buena Park
Torrance
Garden Grove
Long Beach
Santa Ana
Huntington Beach
Irvine
Ontario
Pomona
Rancho Cucamonga
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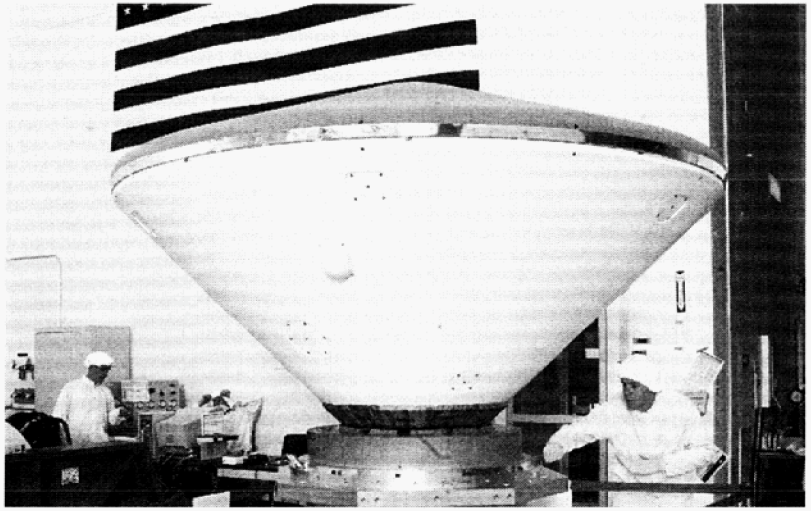
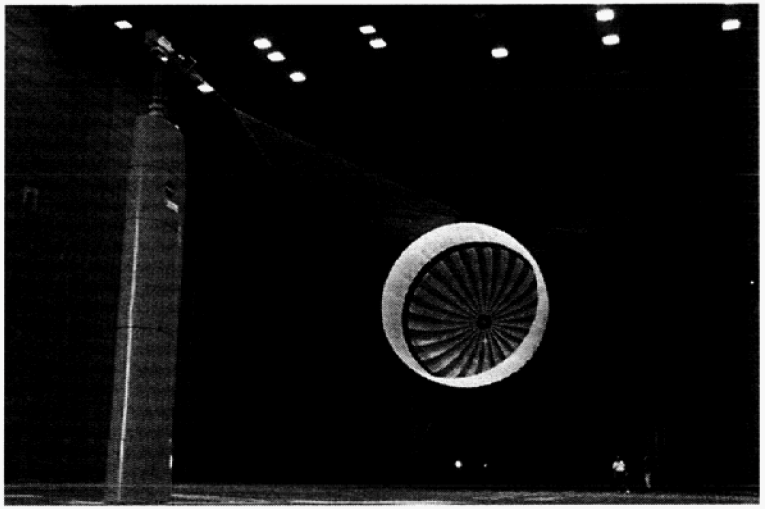
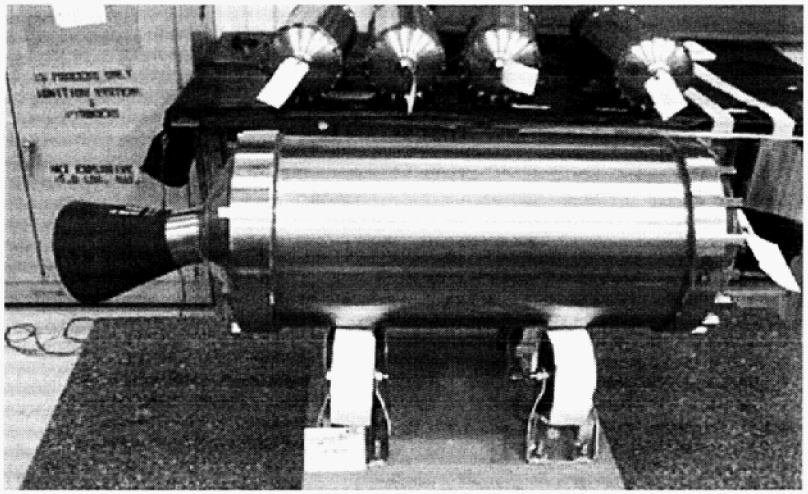
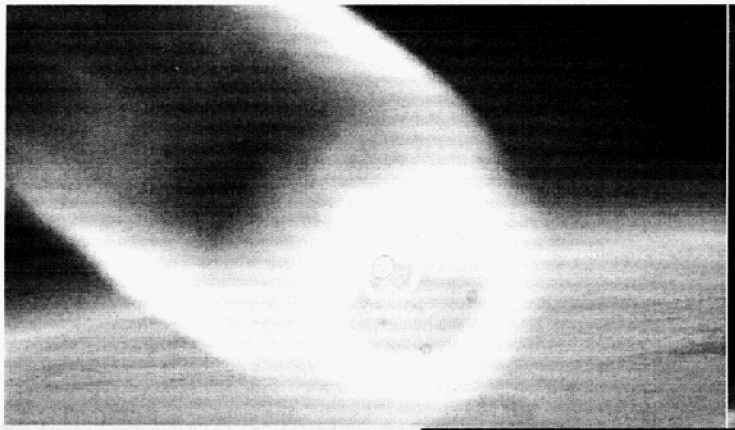
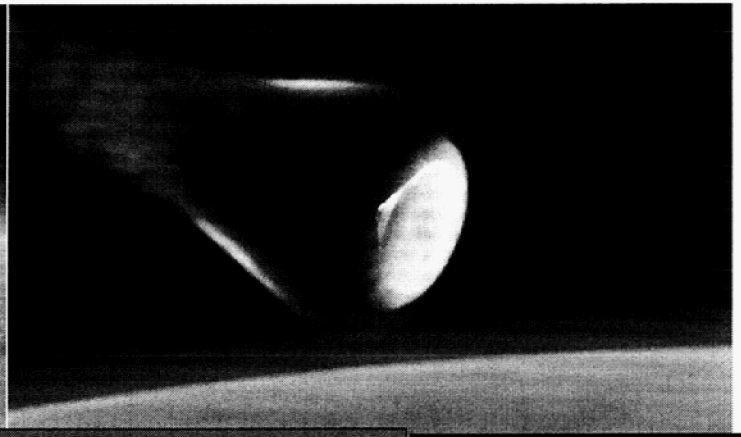
Manhattan Beach
Angeles International Airport
Santa Monica Bay
PACIFIC OCEAN
CLEVELAND NATIONAL FOREST

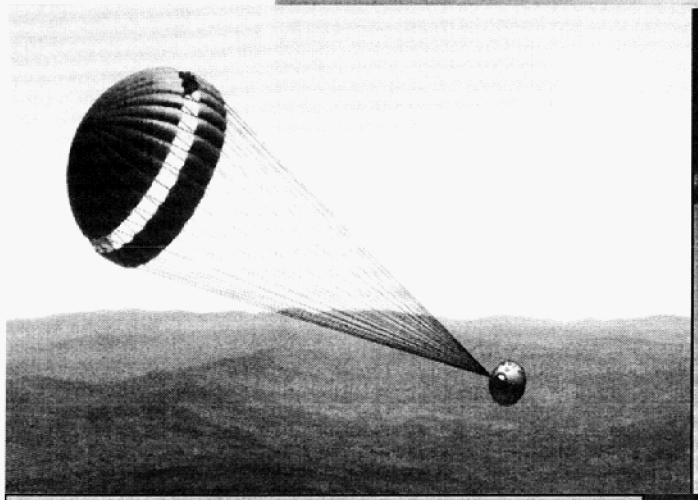


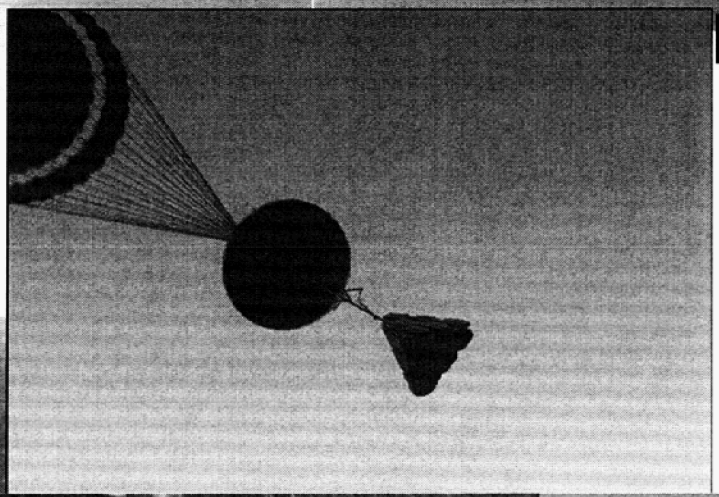


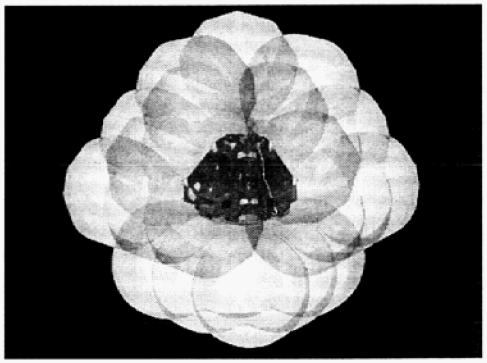


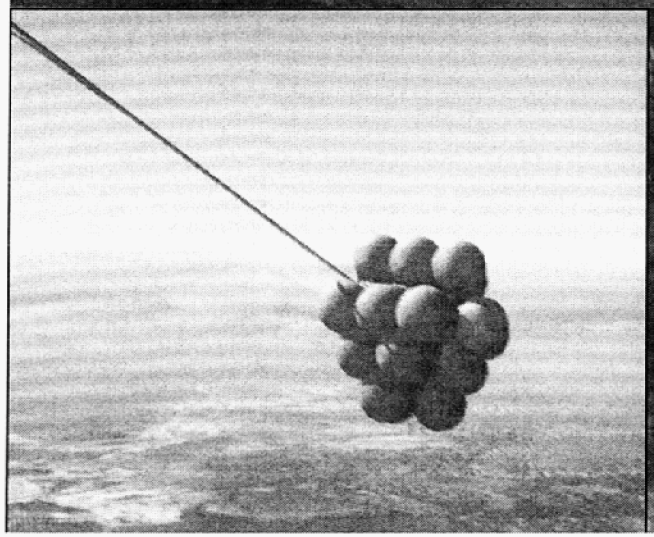


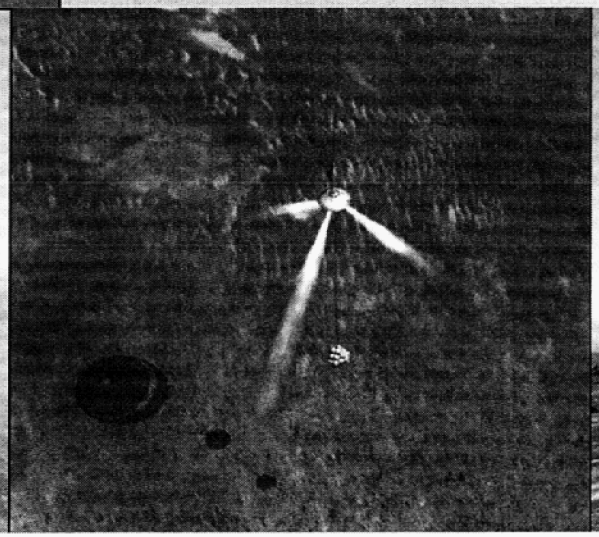


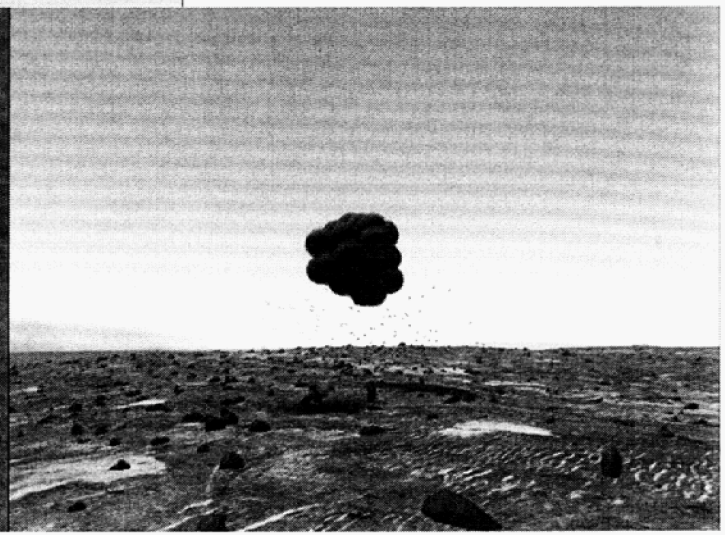


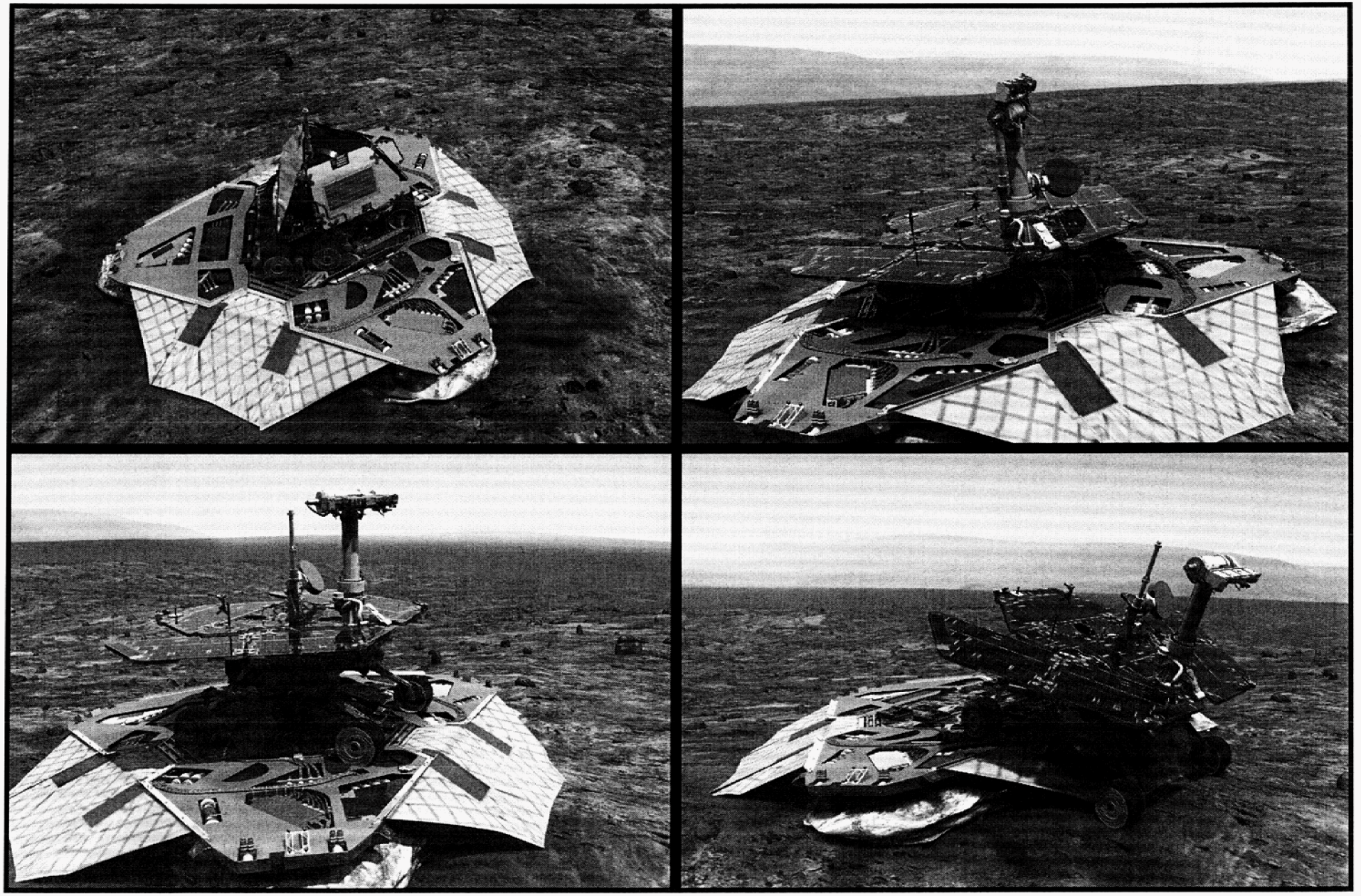


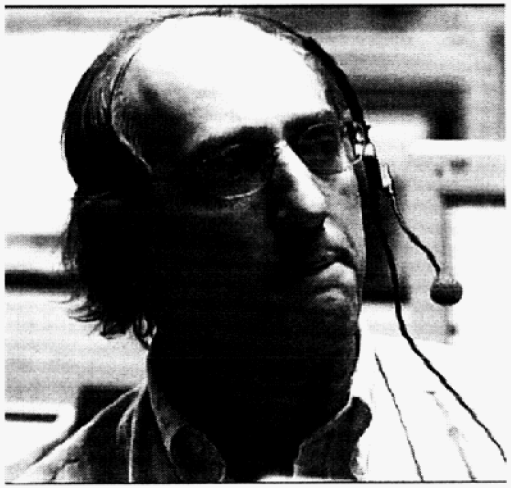












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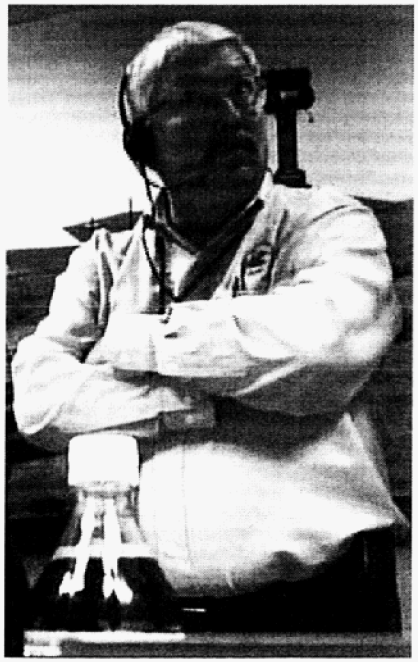
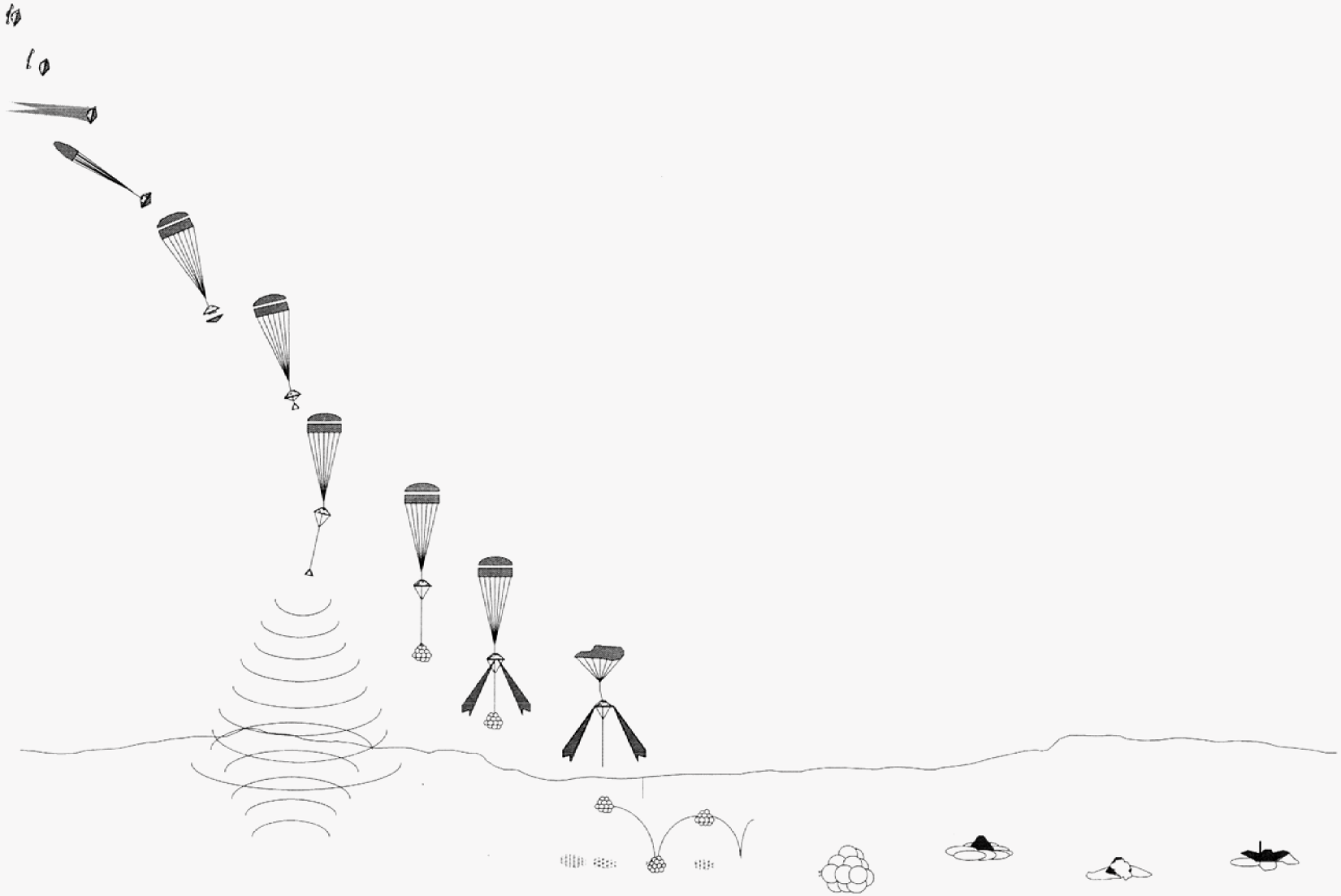
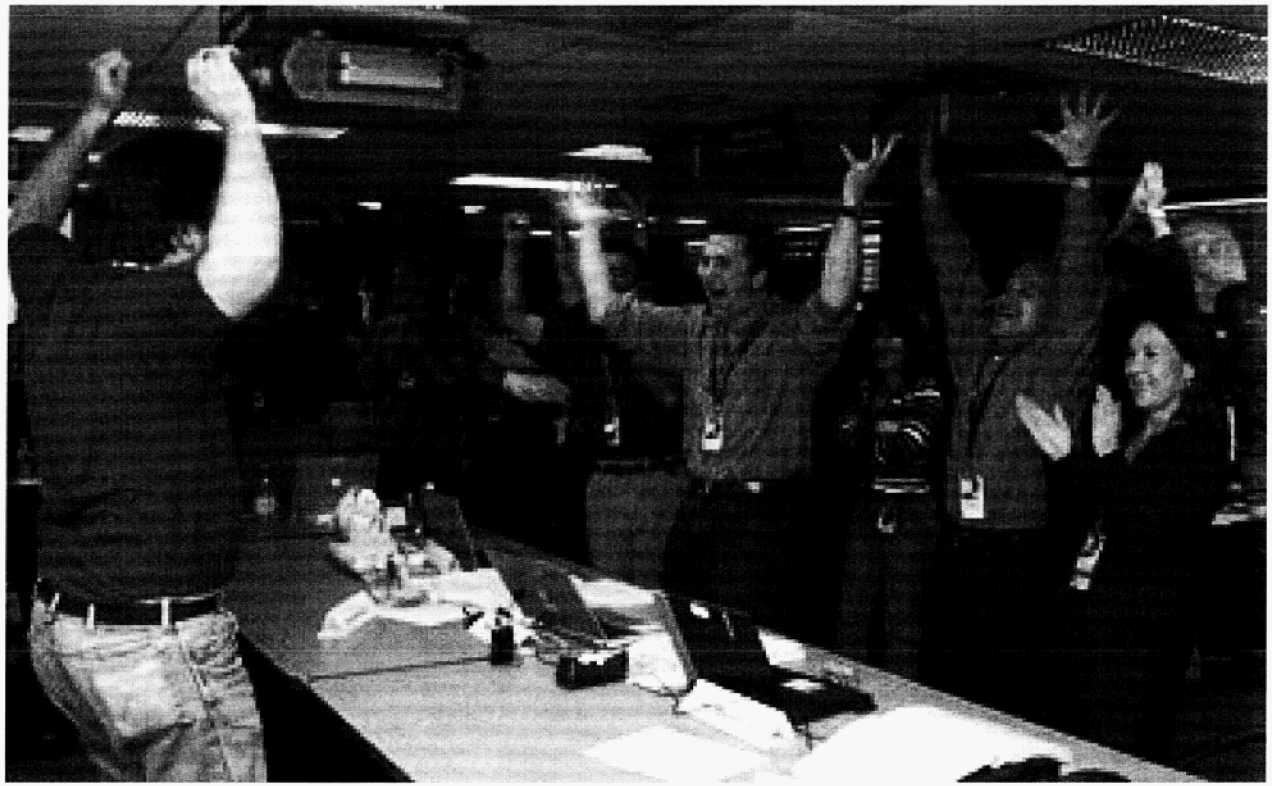
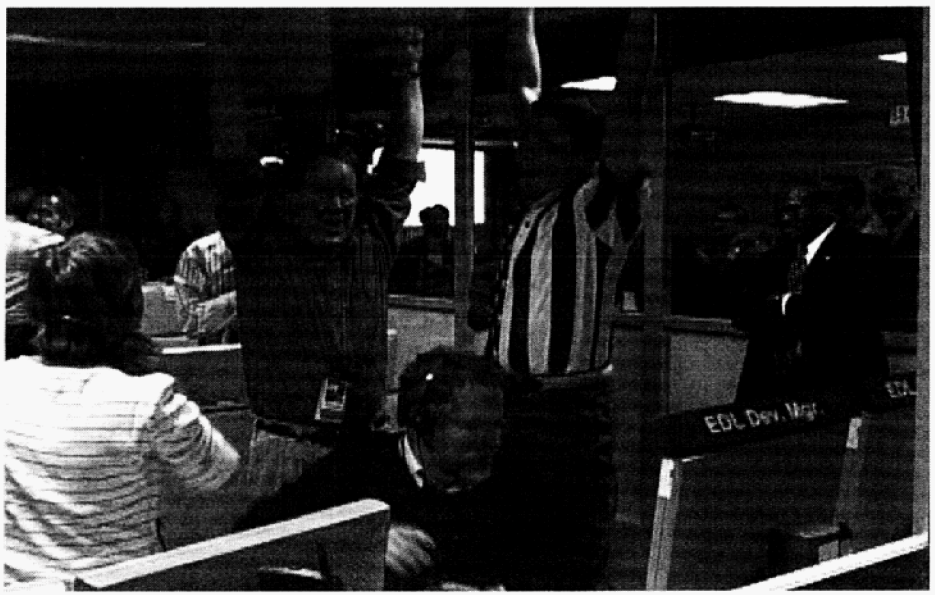
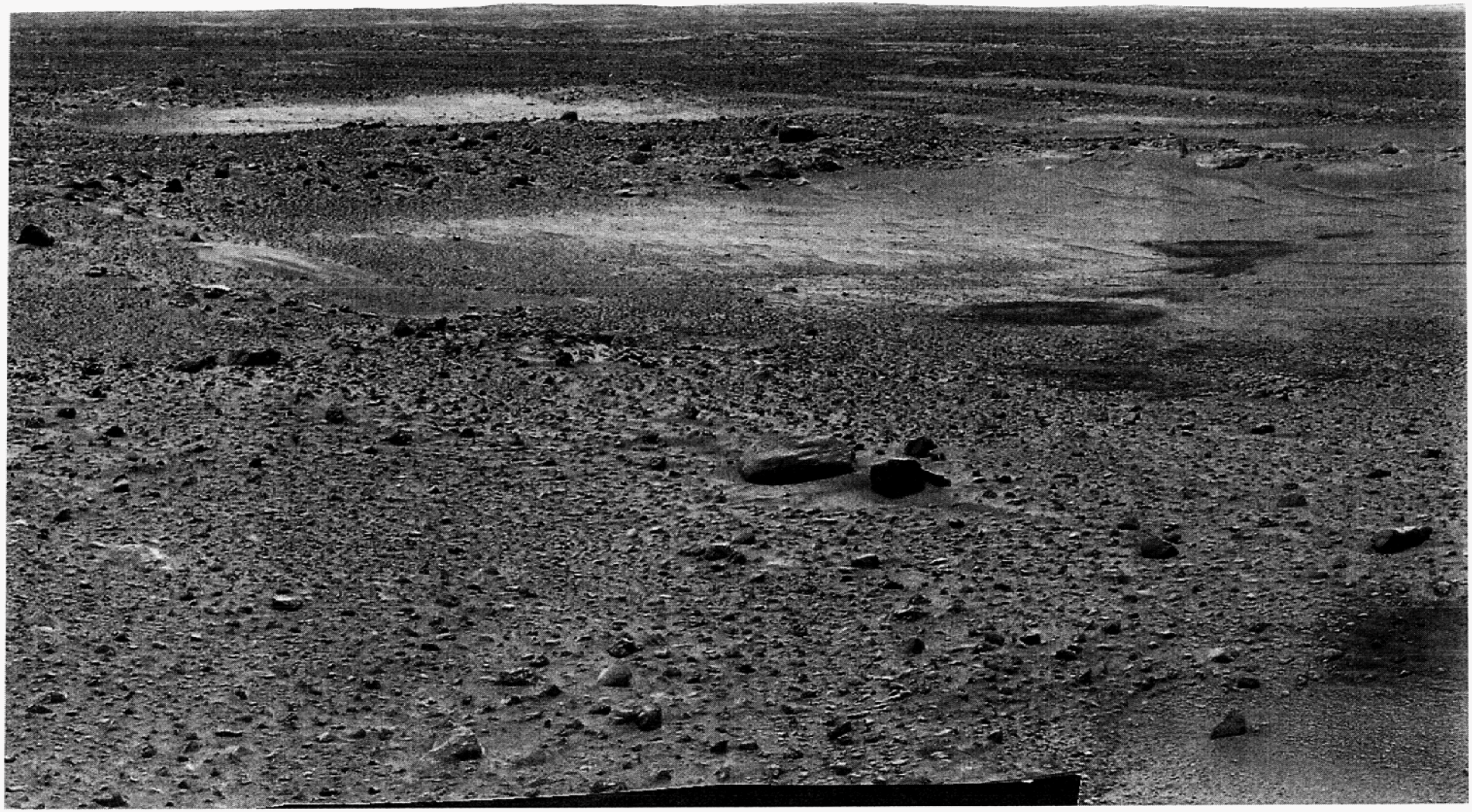


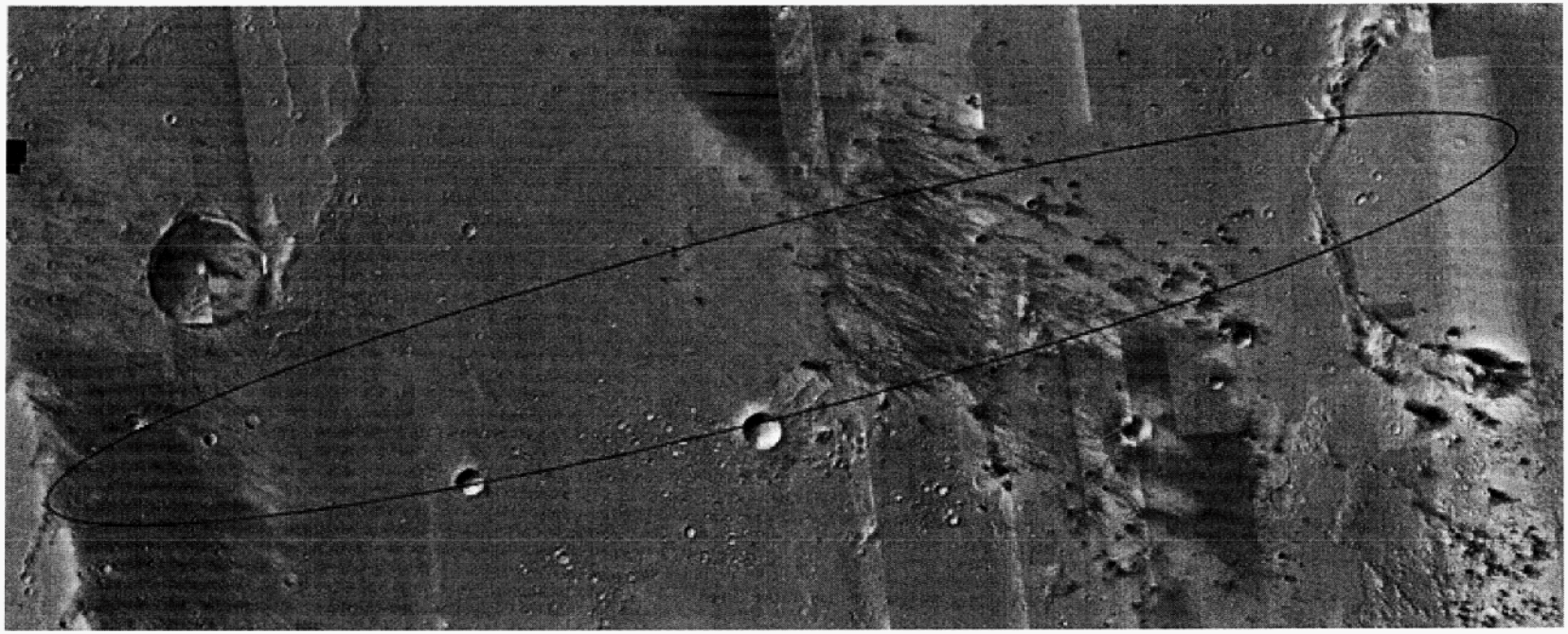
Entry, Descent & Landing Timeline

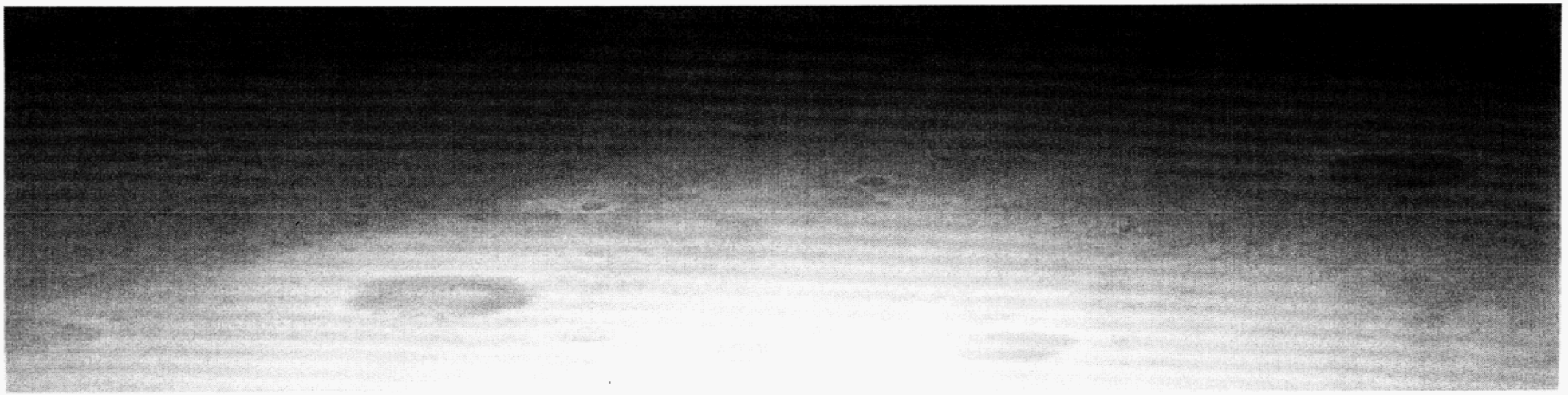




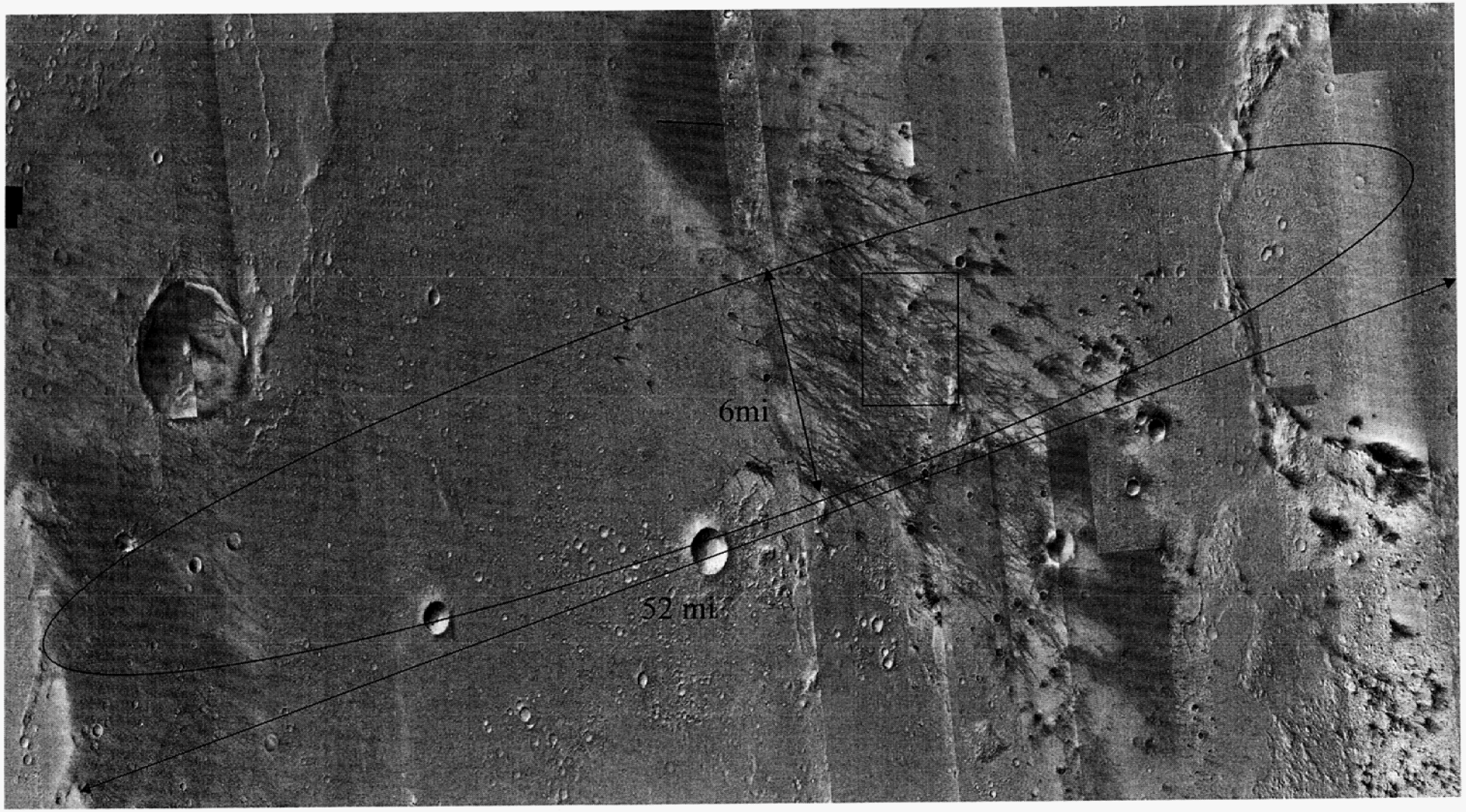




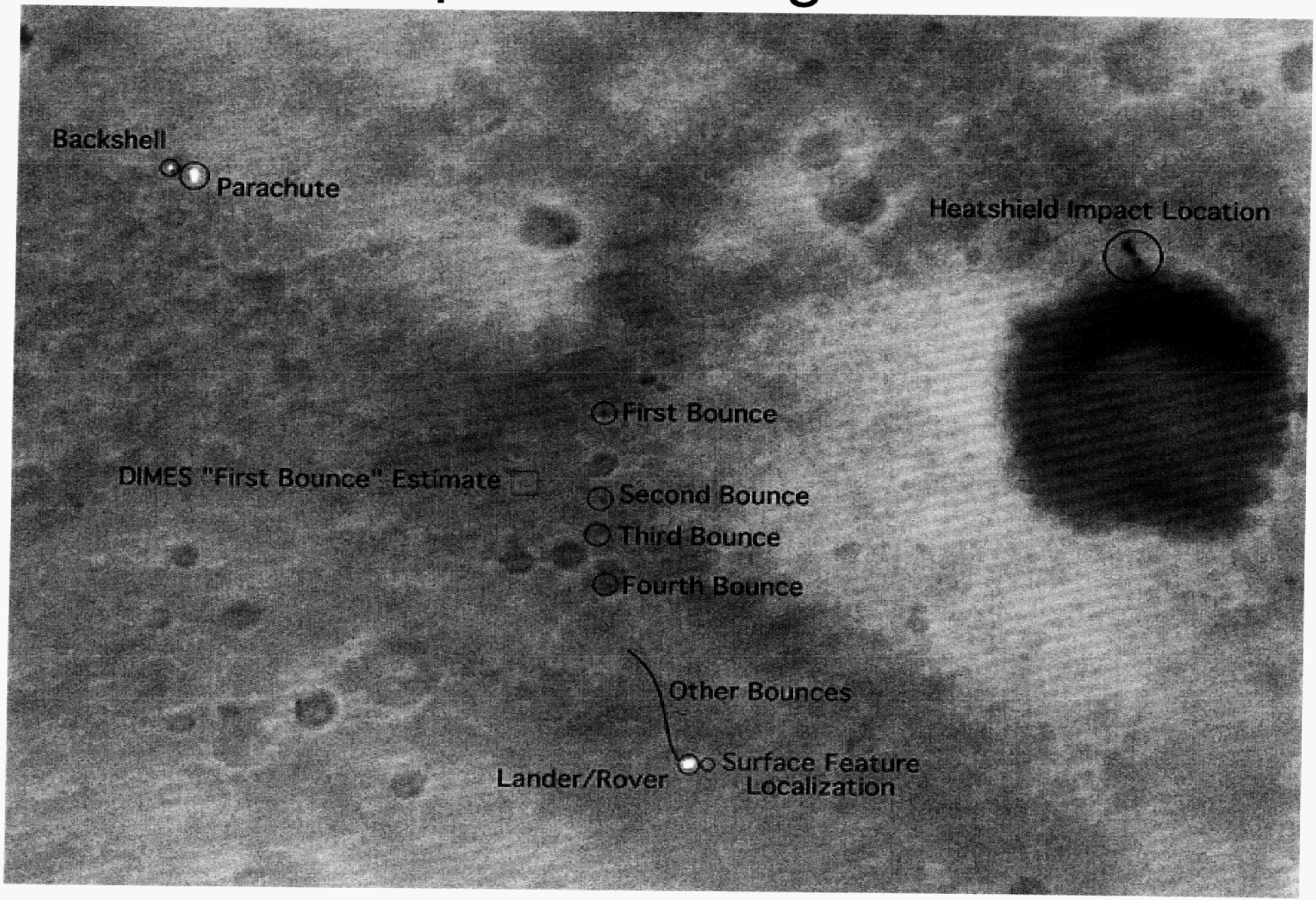


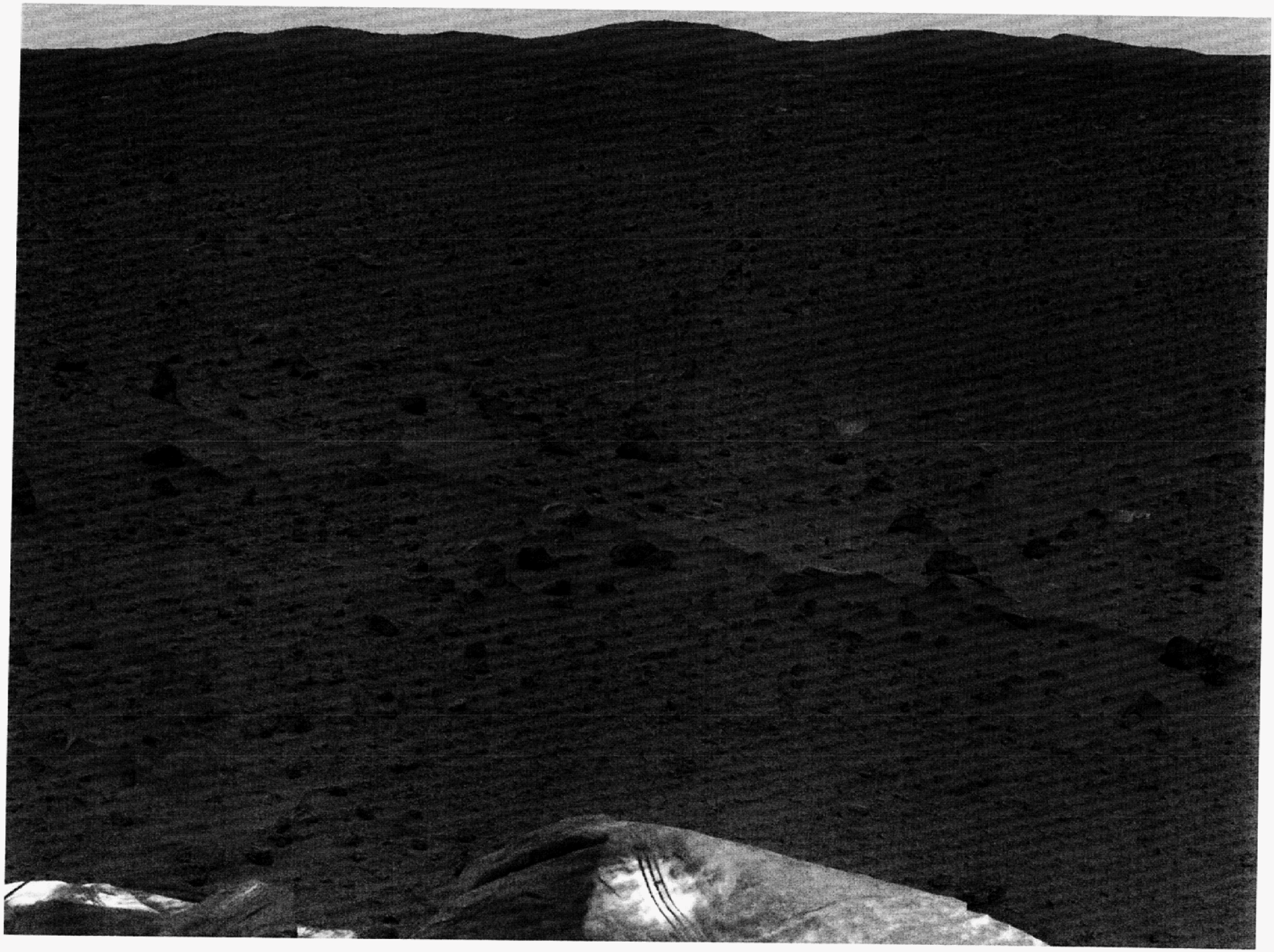


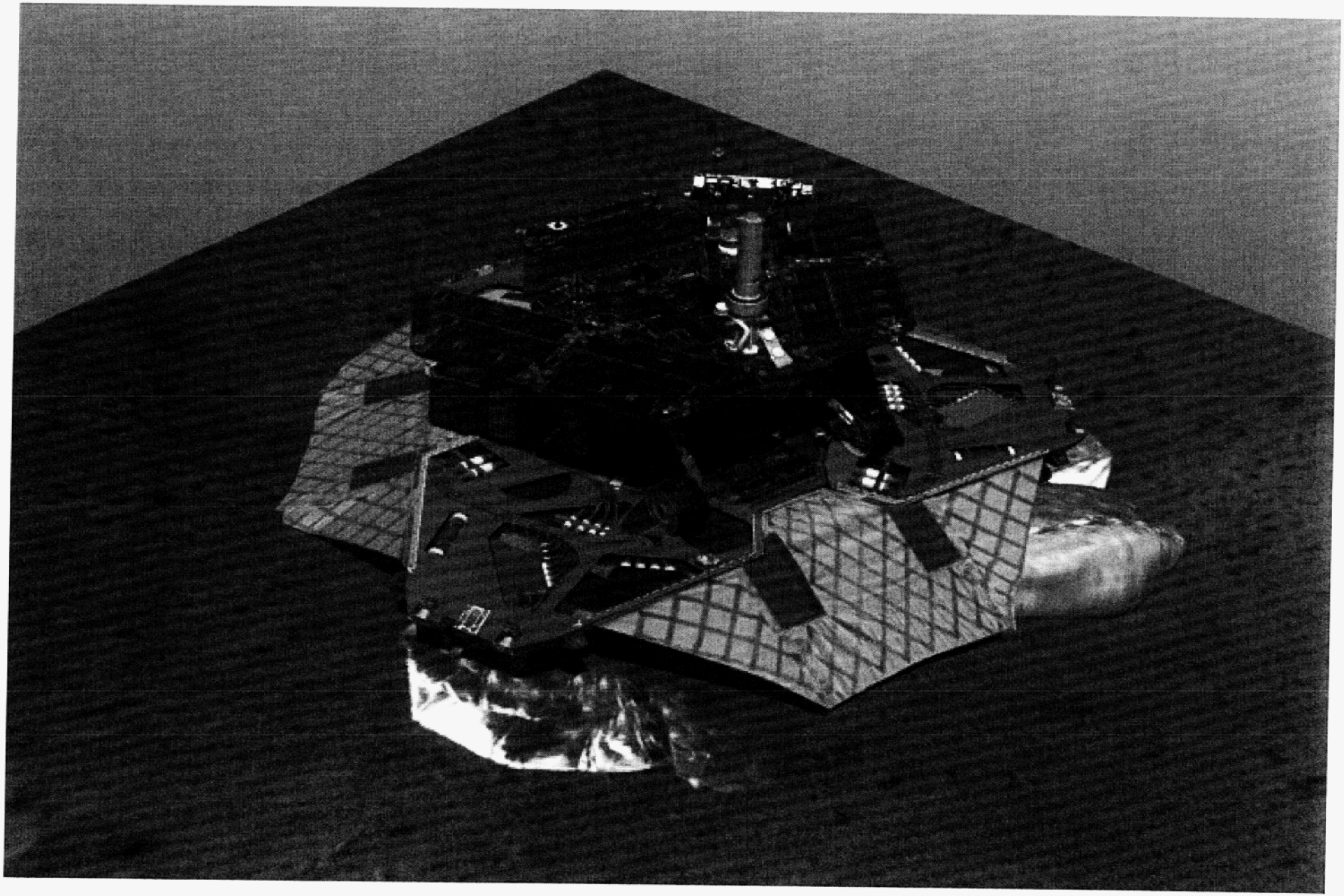
Gusev Landing Ellipse

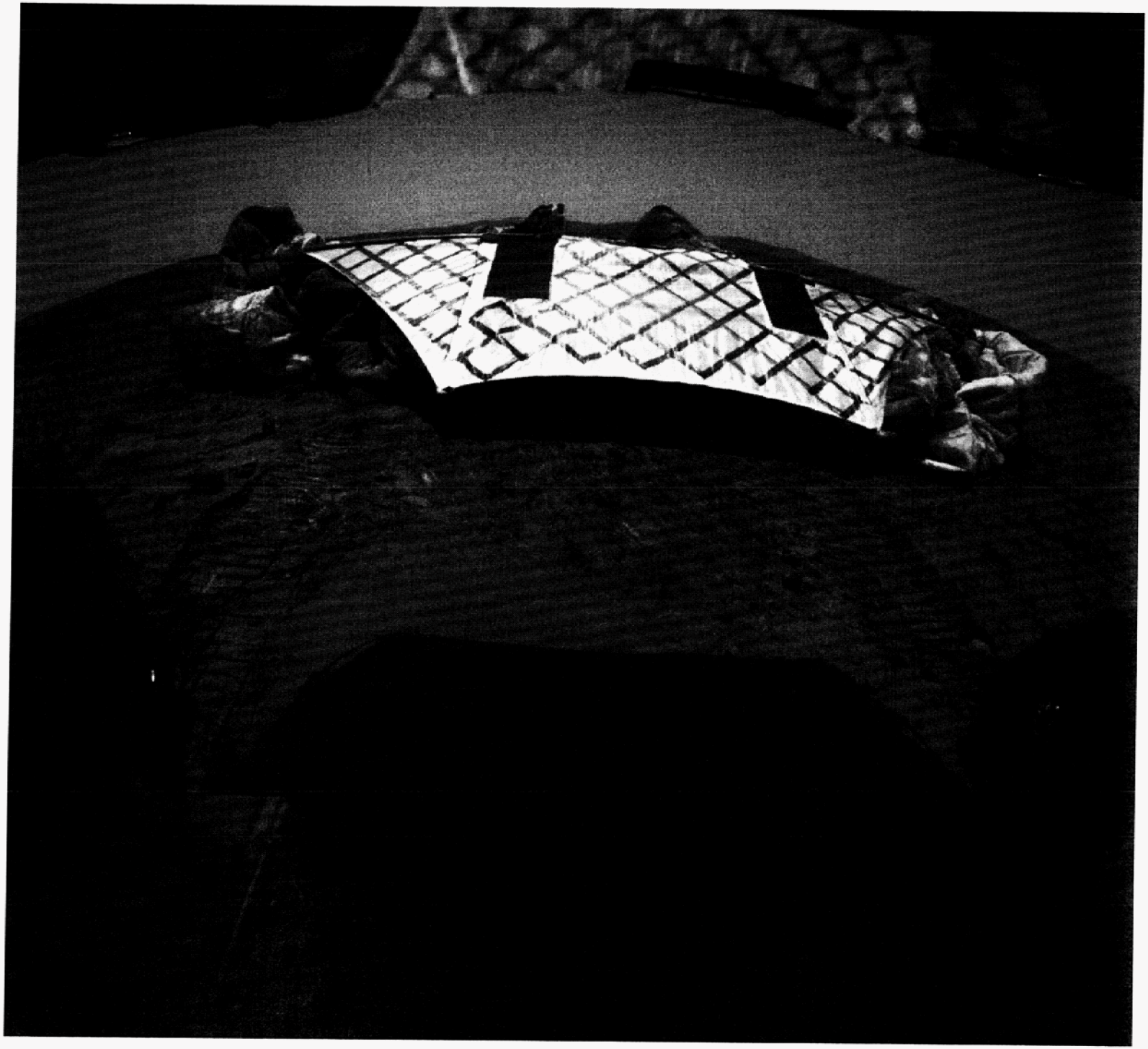


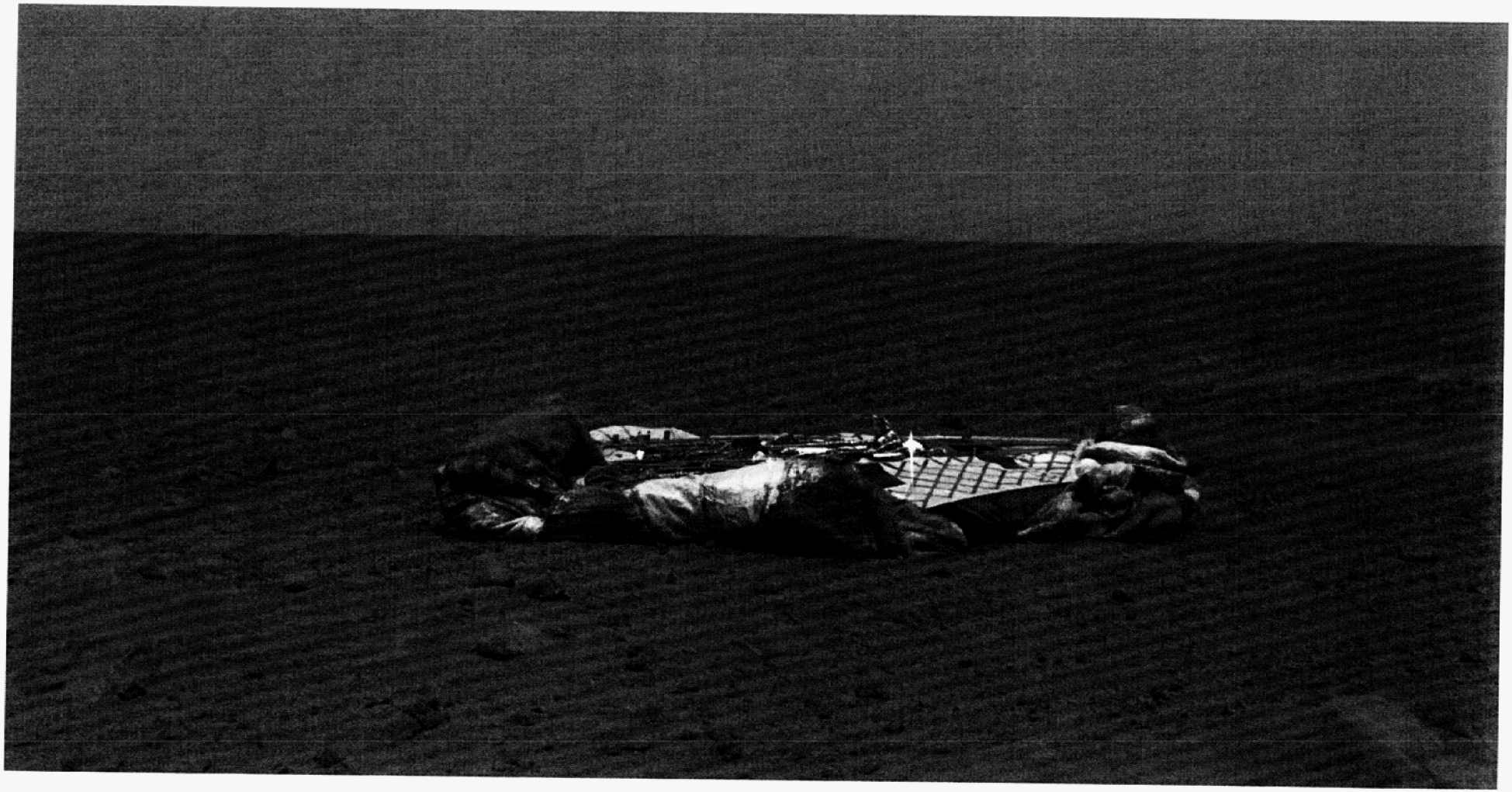
Spirit Landing Site

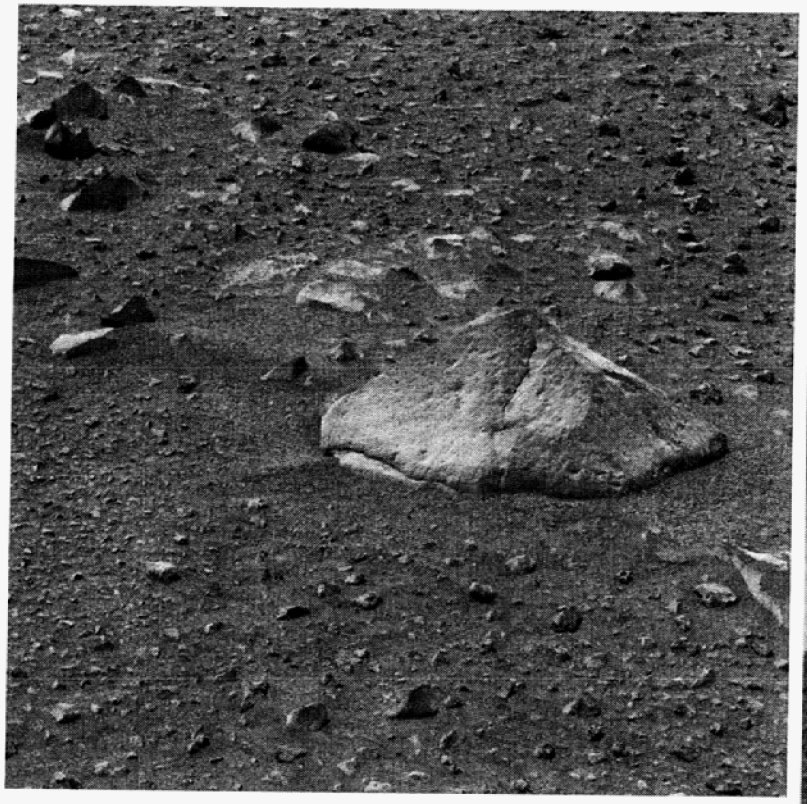


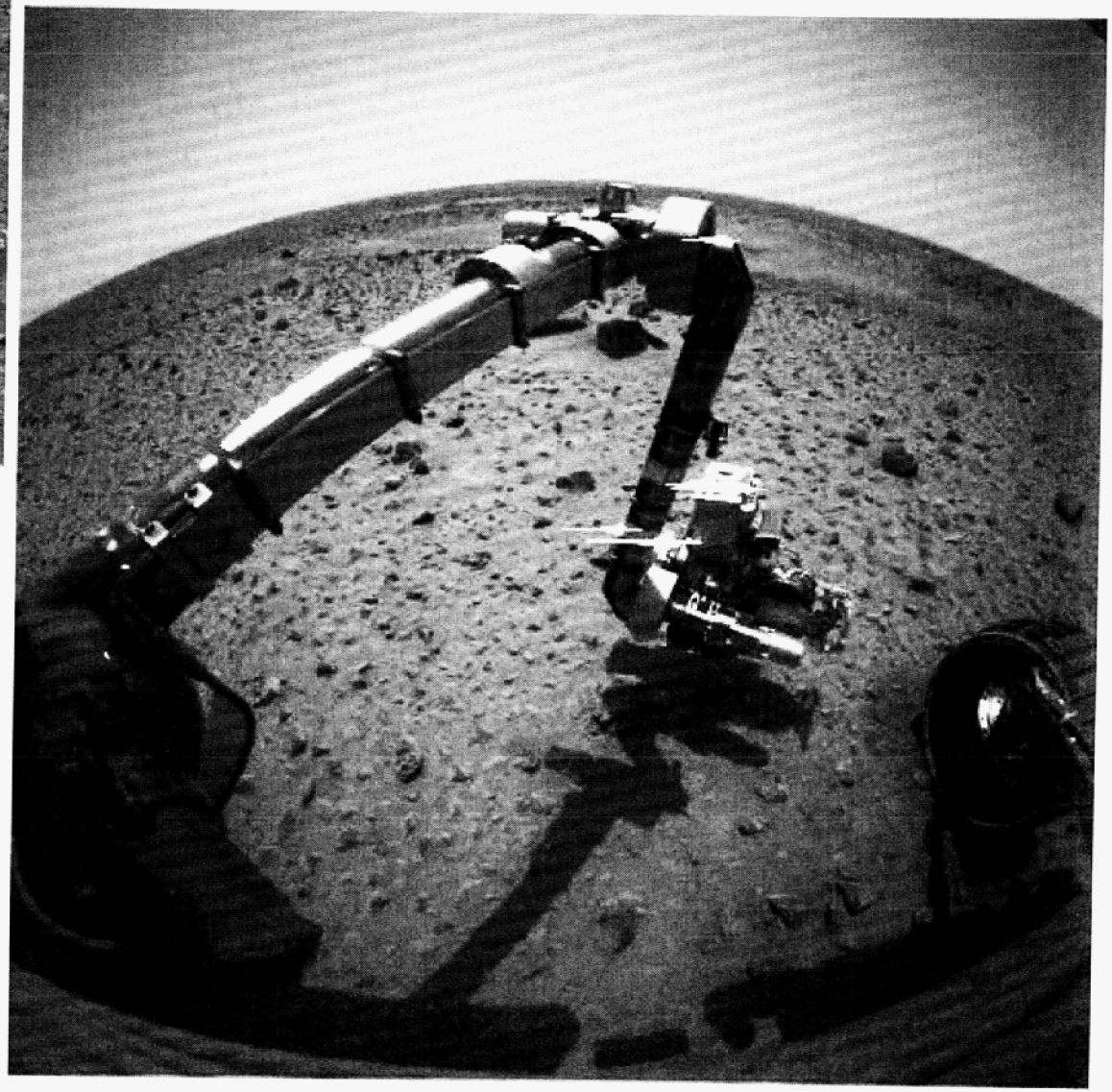


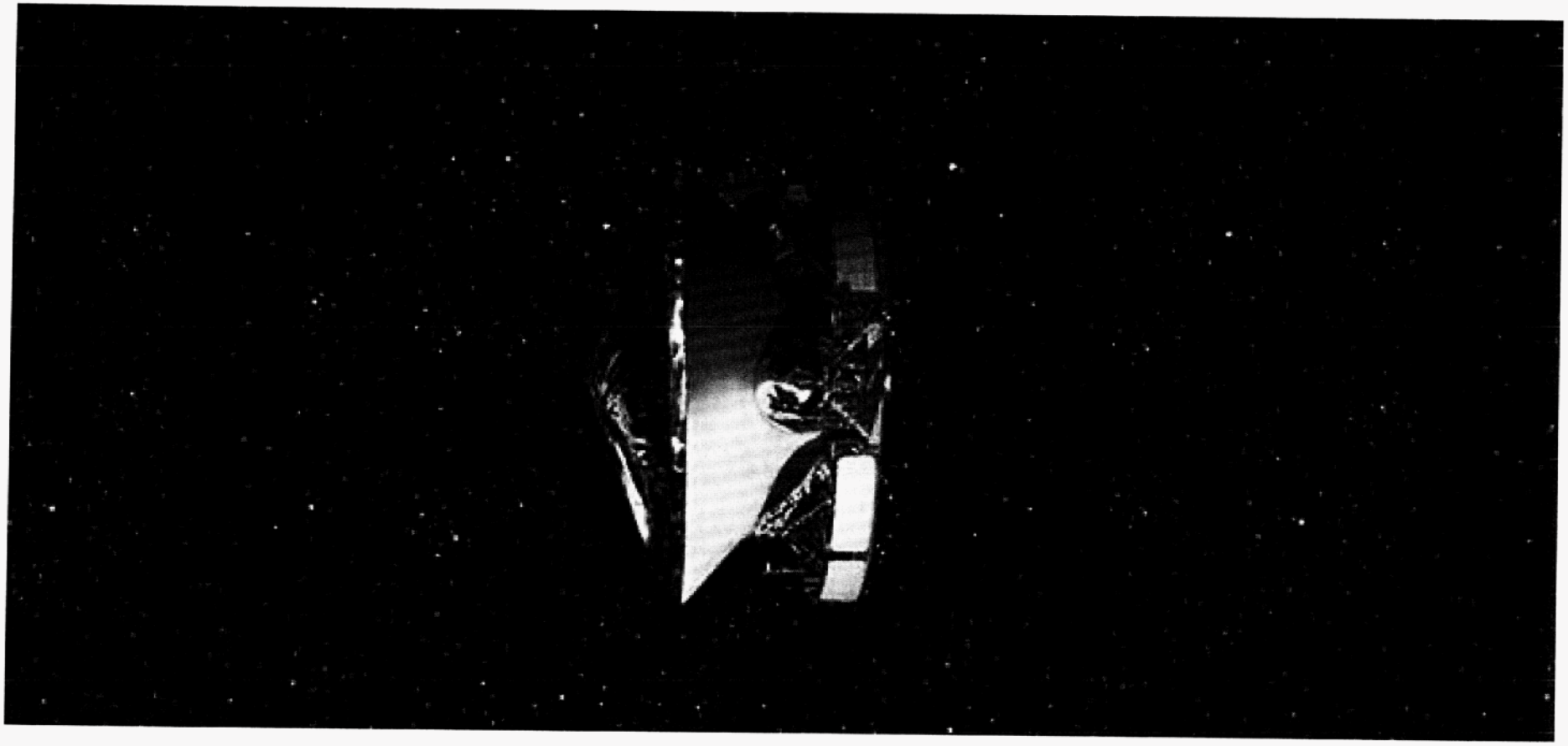












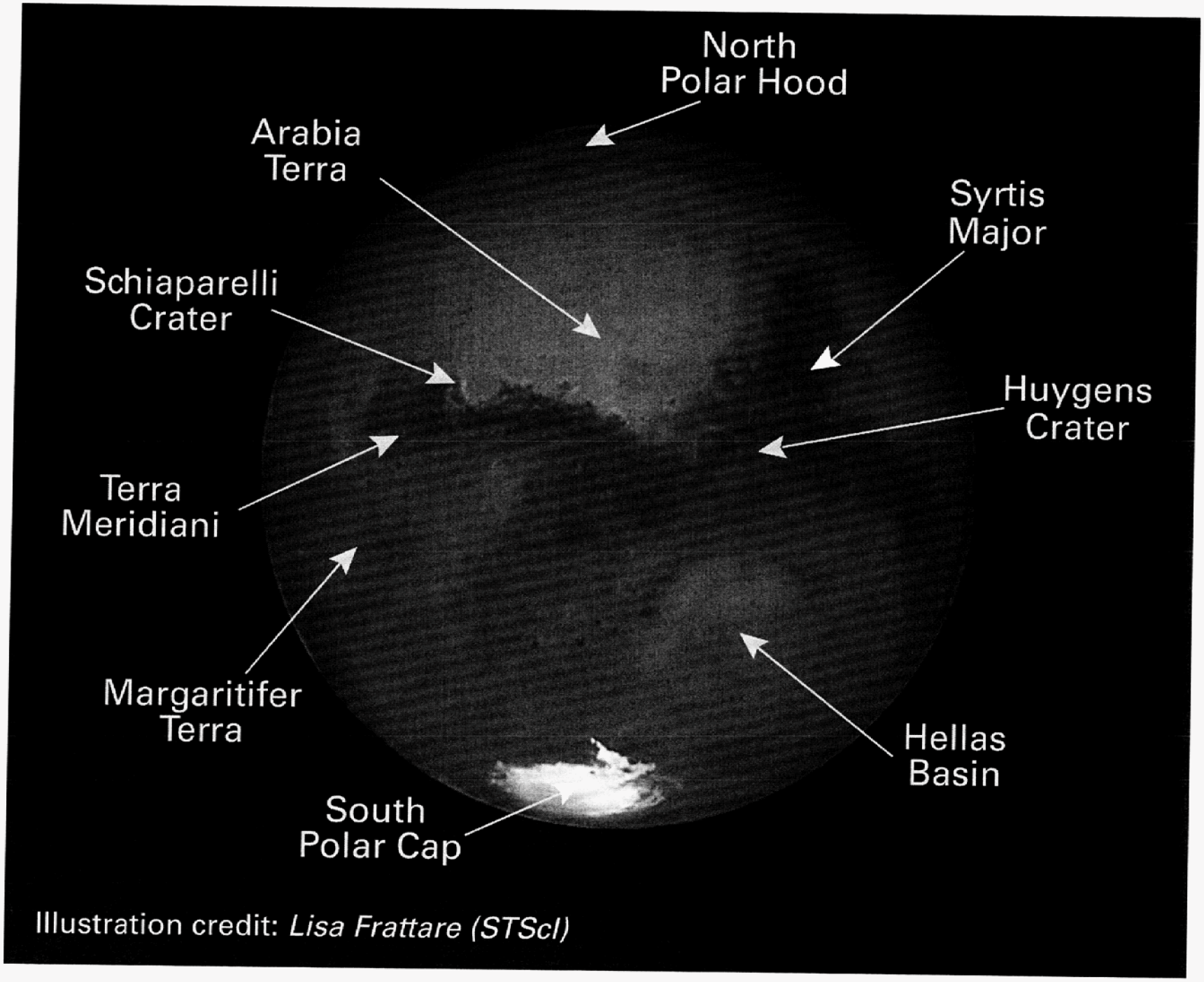


Illustration credit: *Lisa Frattare (STScI)*

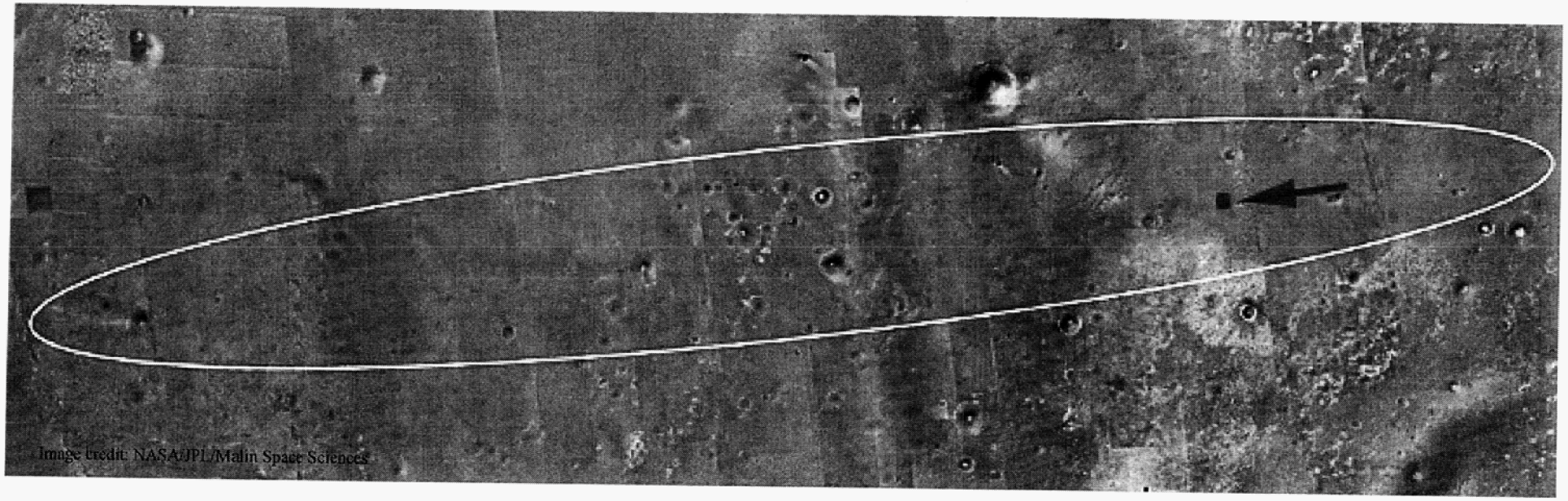
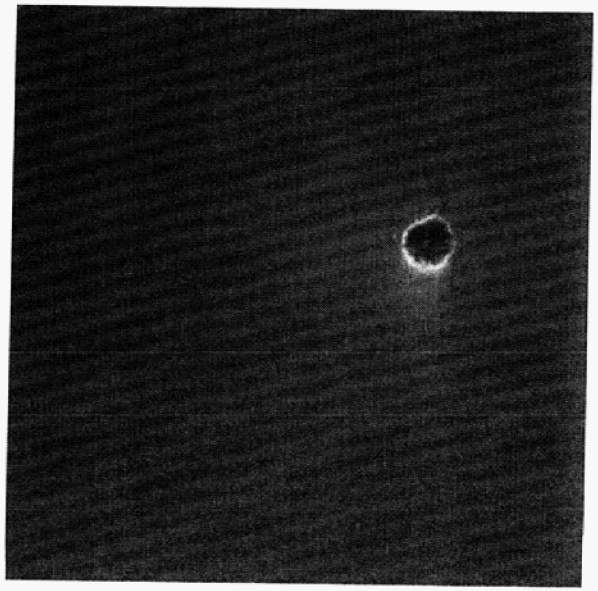
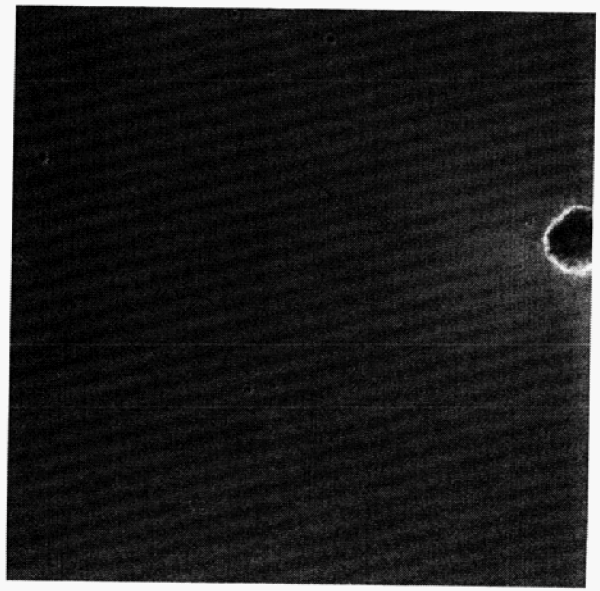
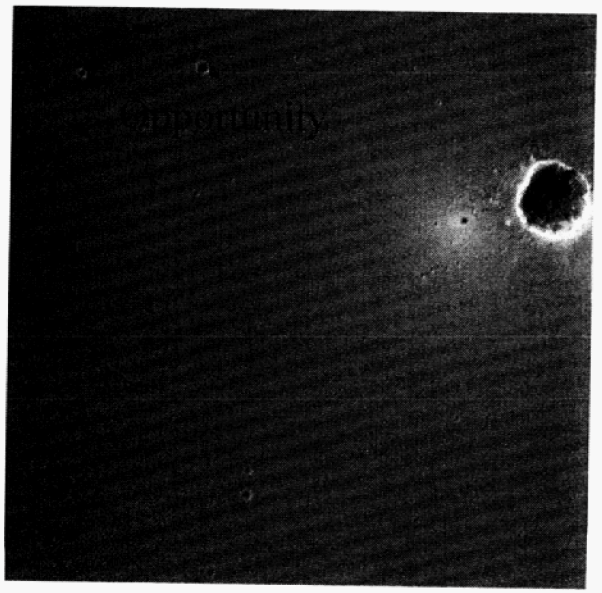
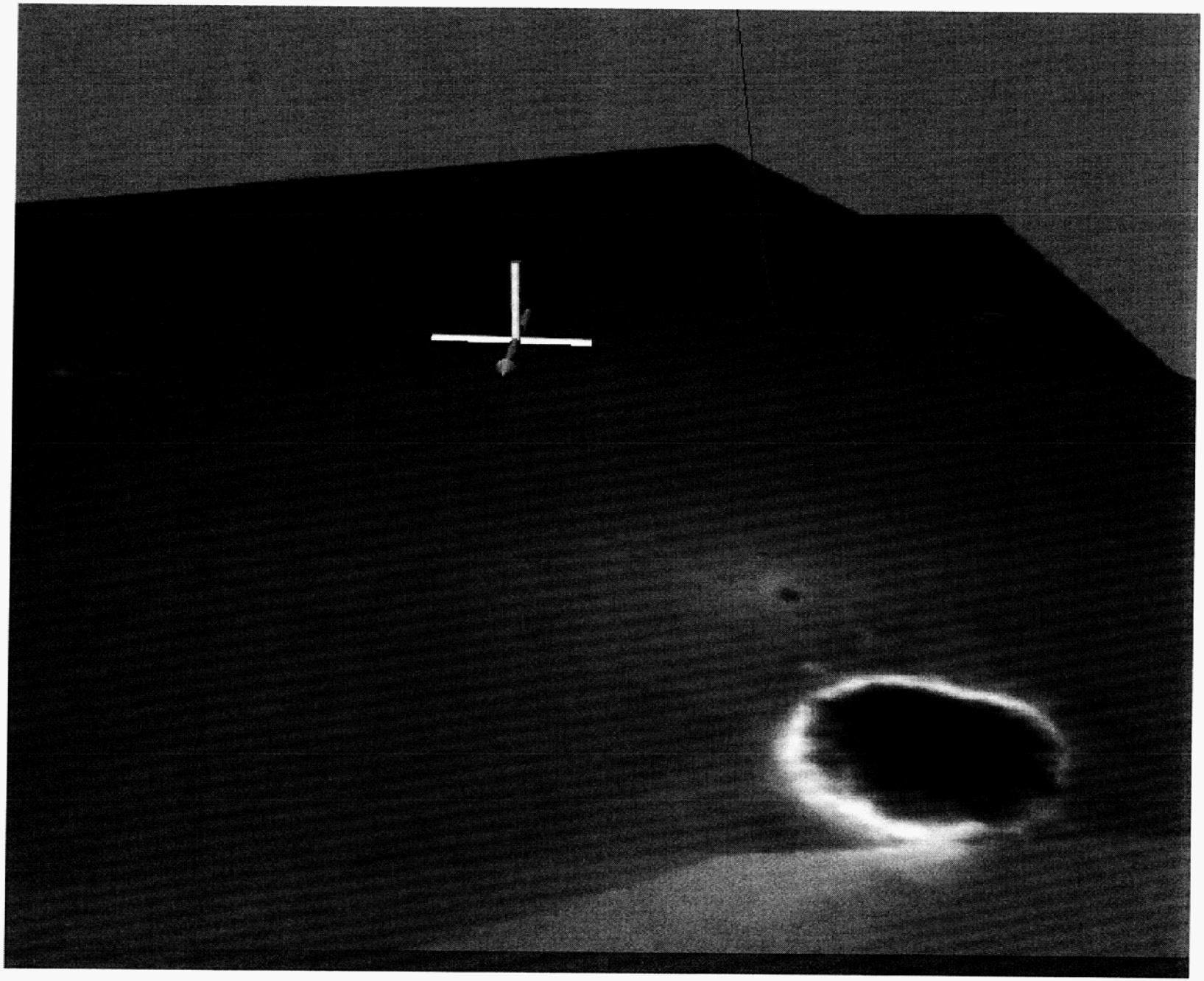


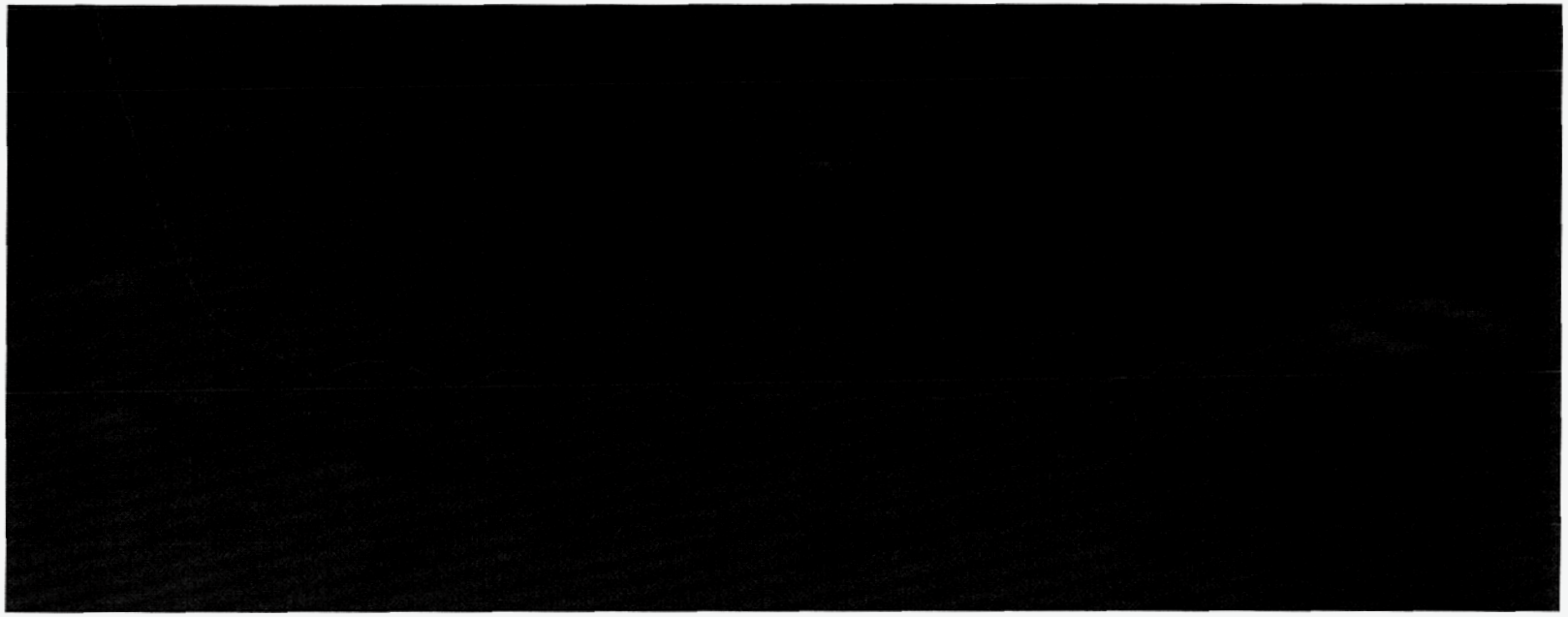
Image credit: NASA/JPL/Malin Space Sciences

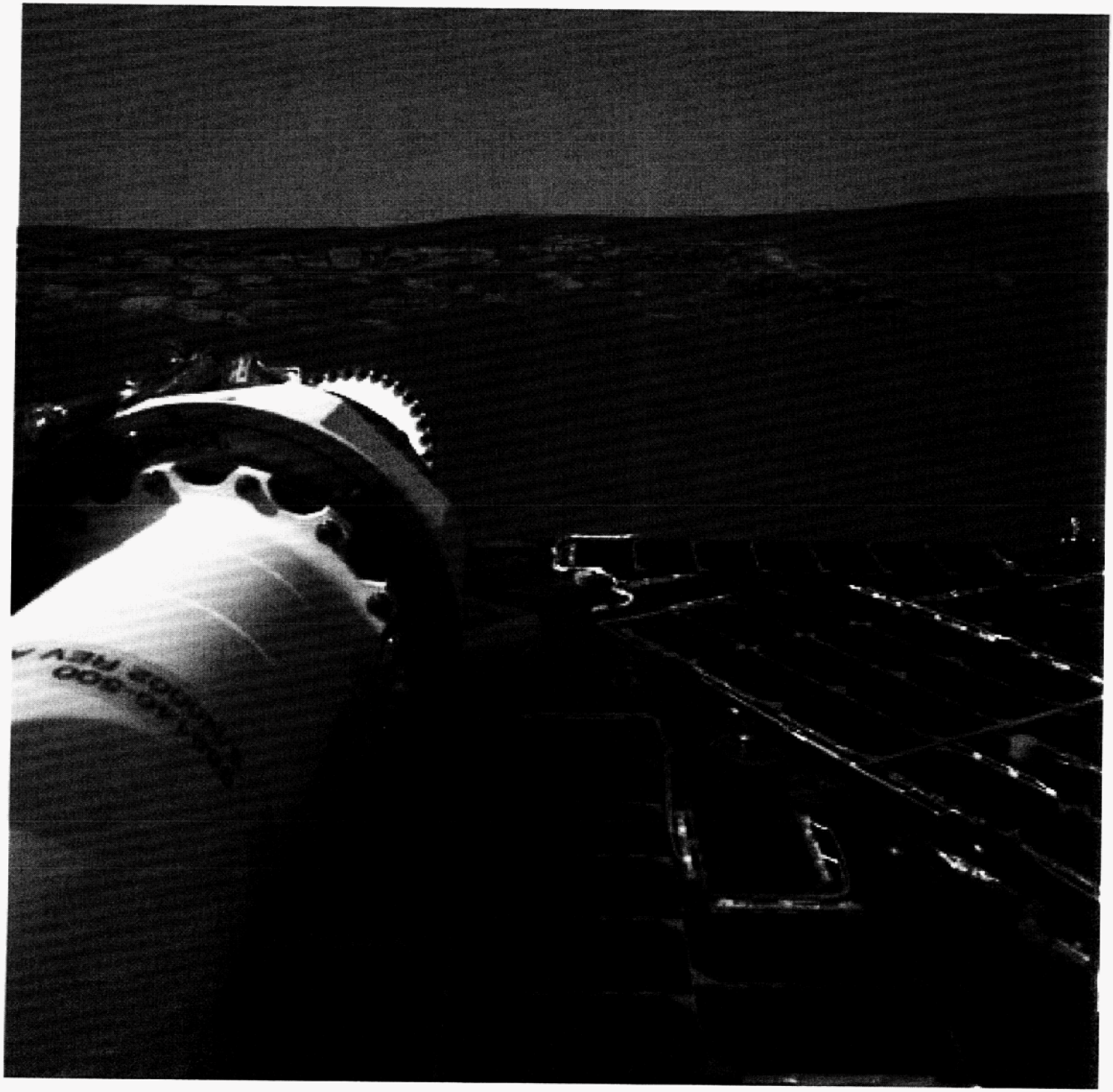


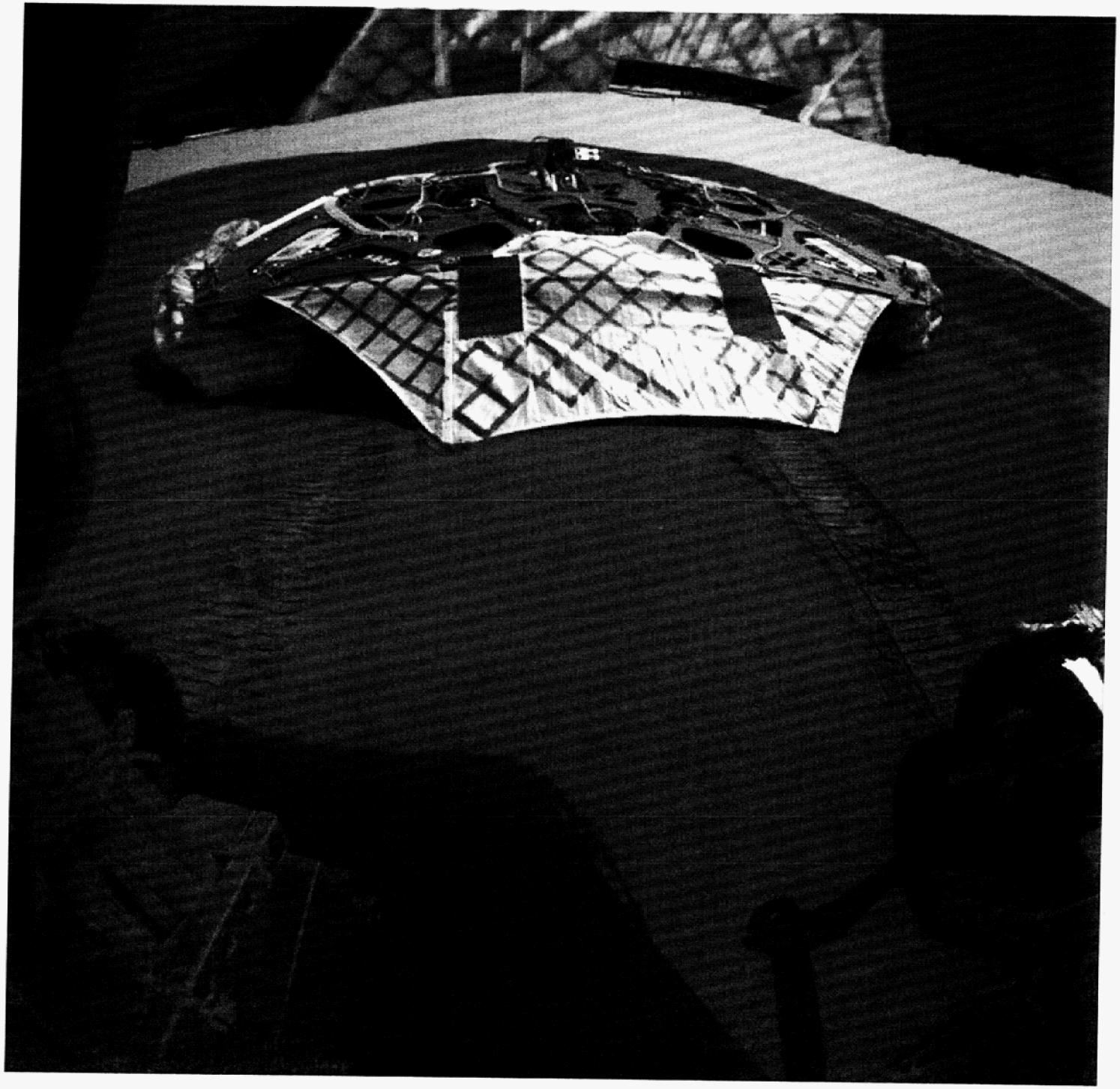


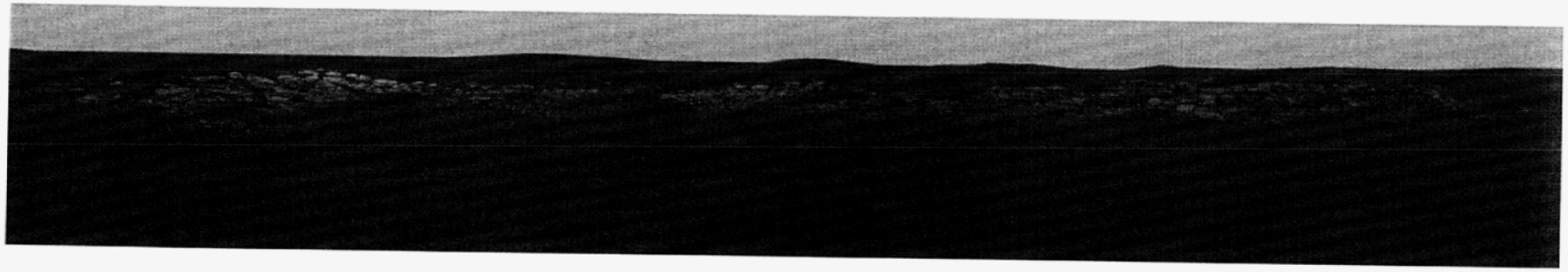

Opportunity

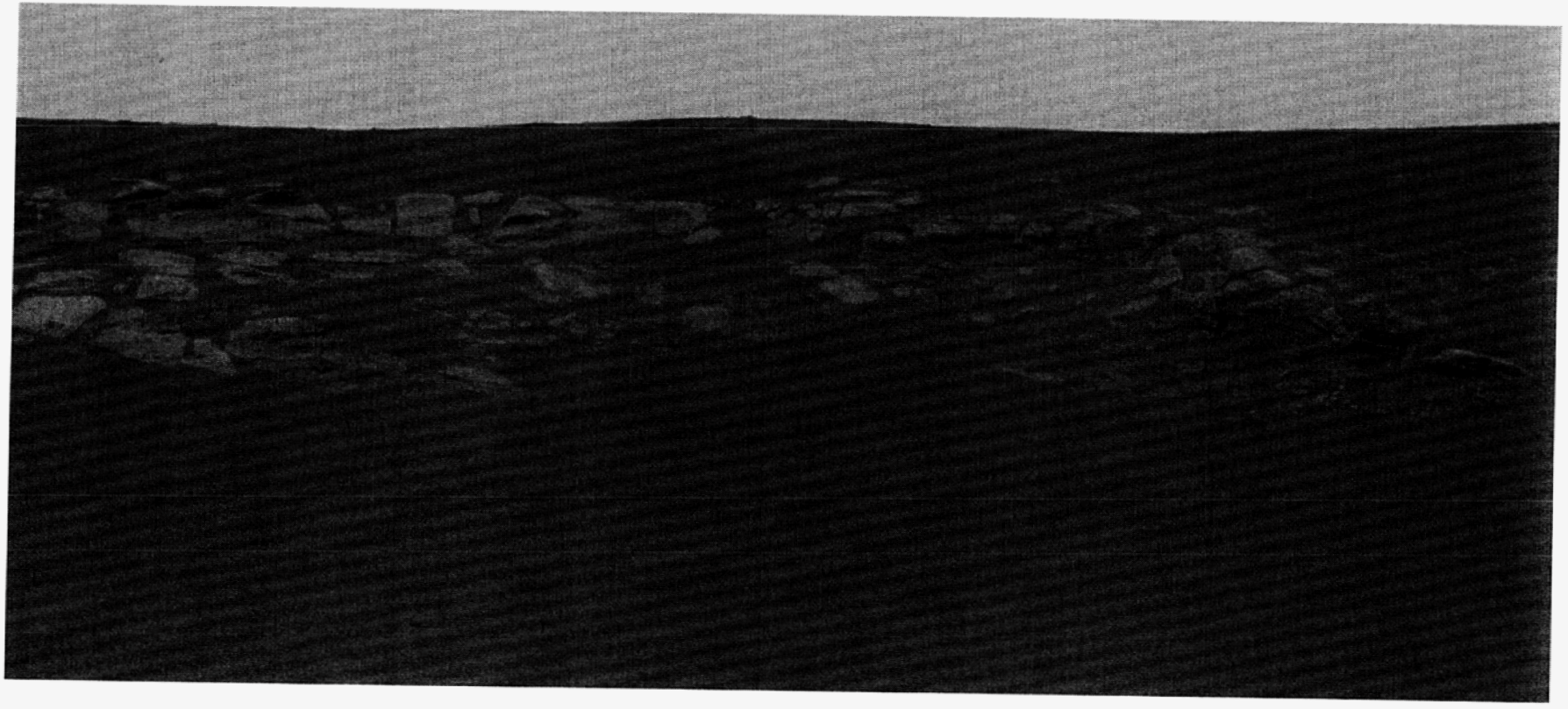


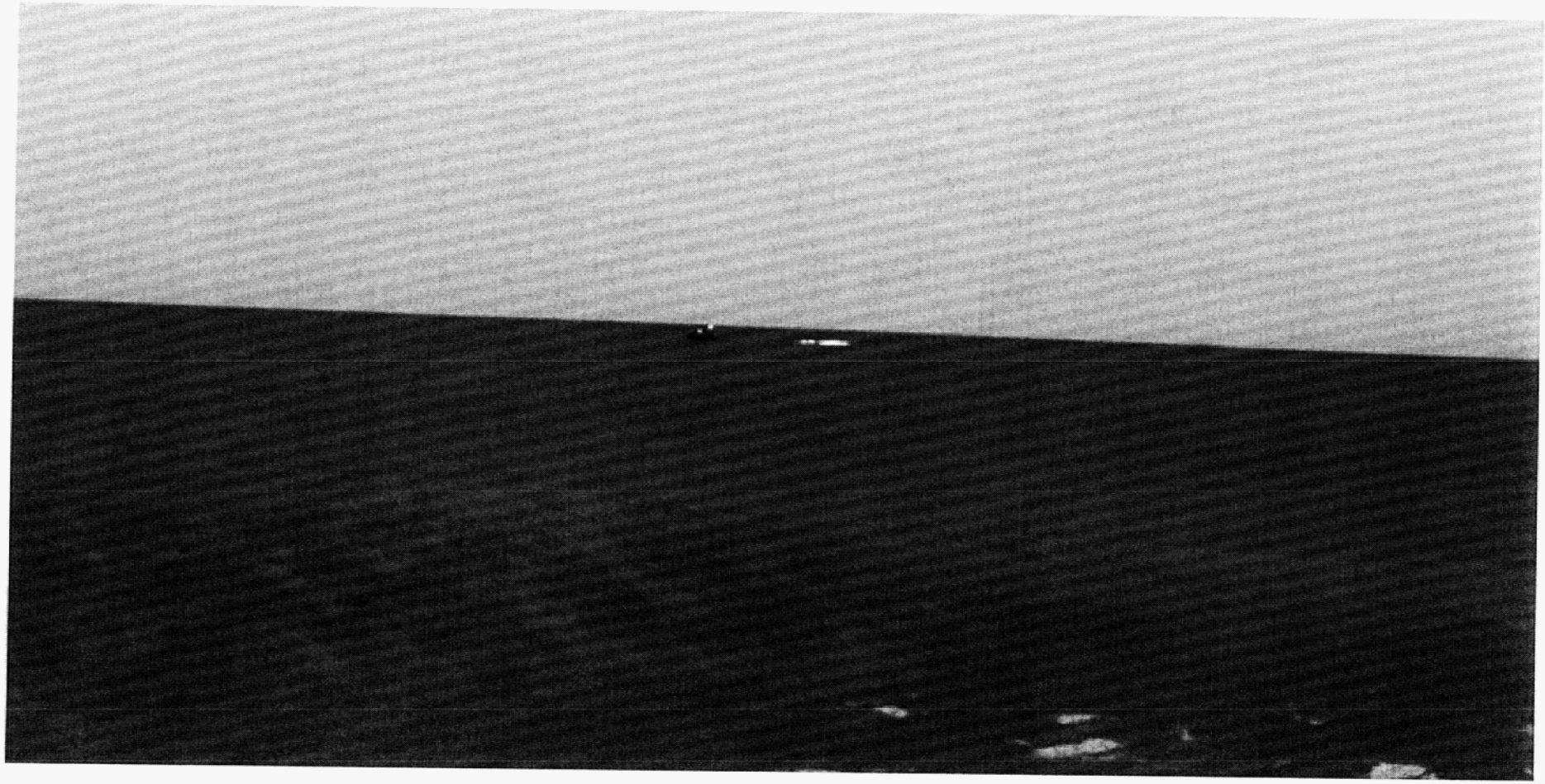


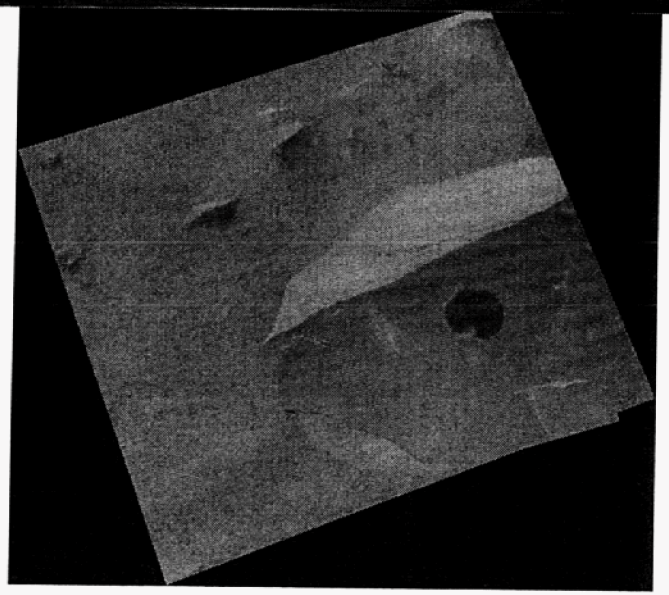


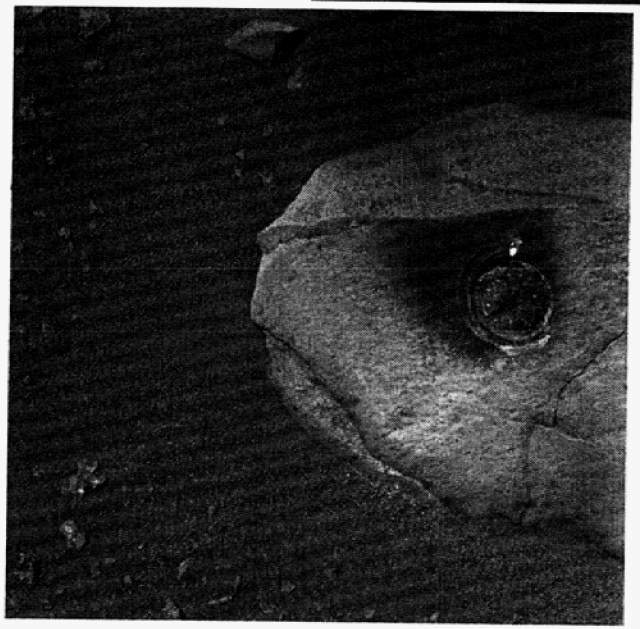




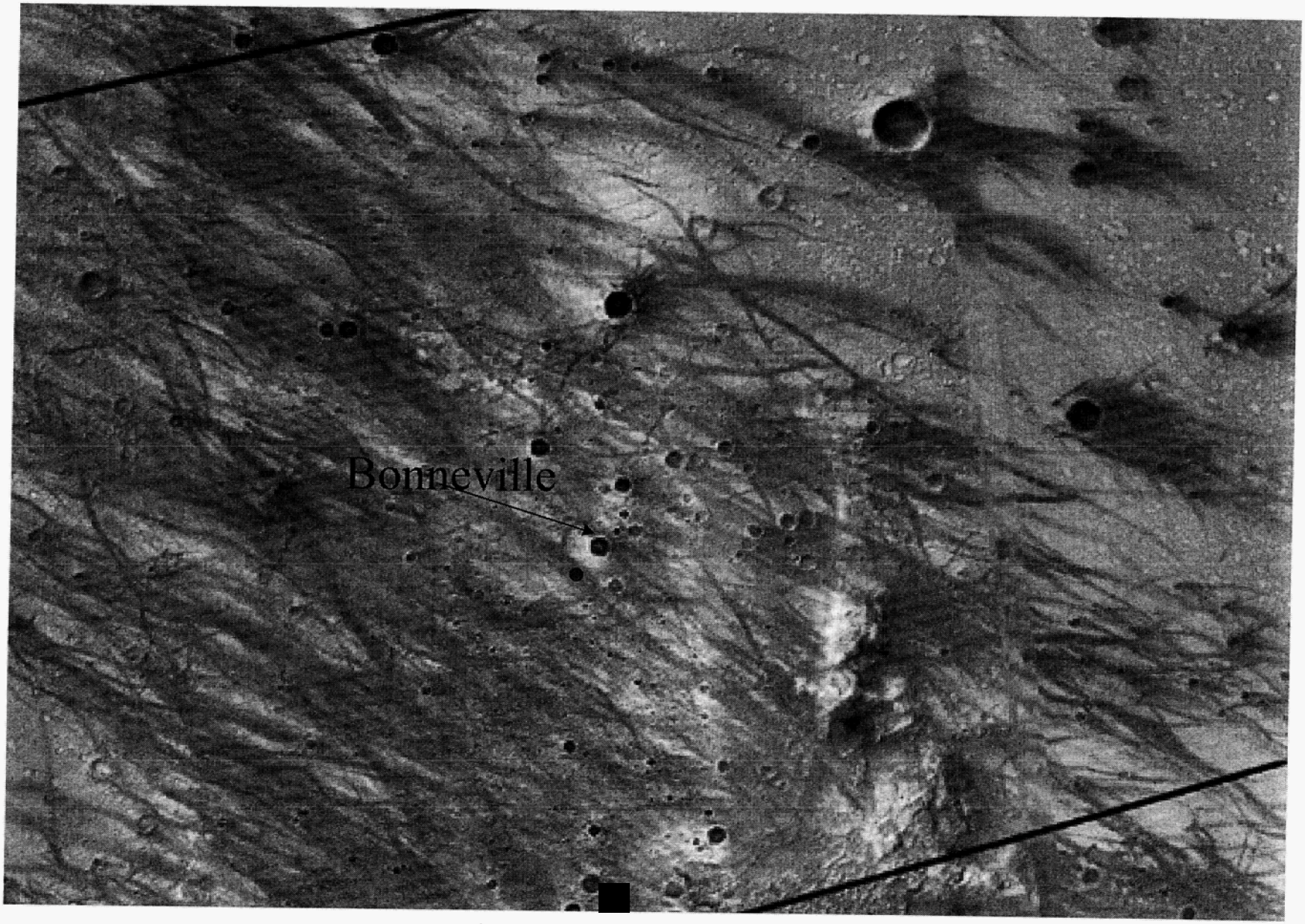


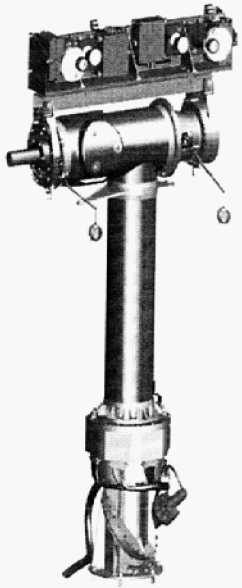


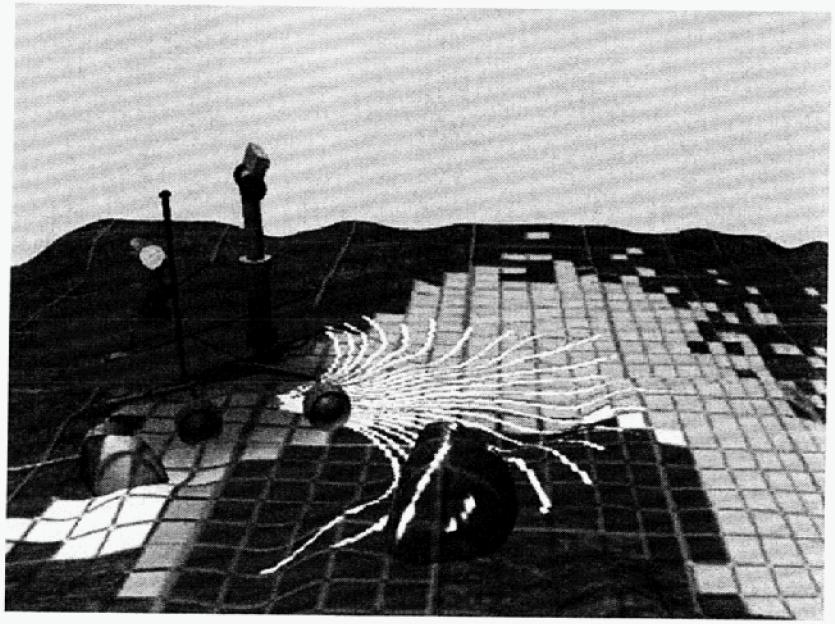


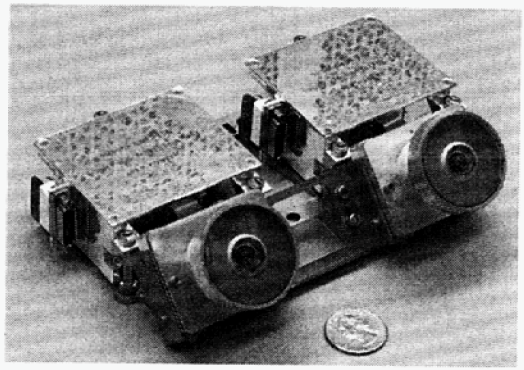


Adirondack
Sols 15-35

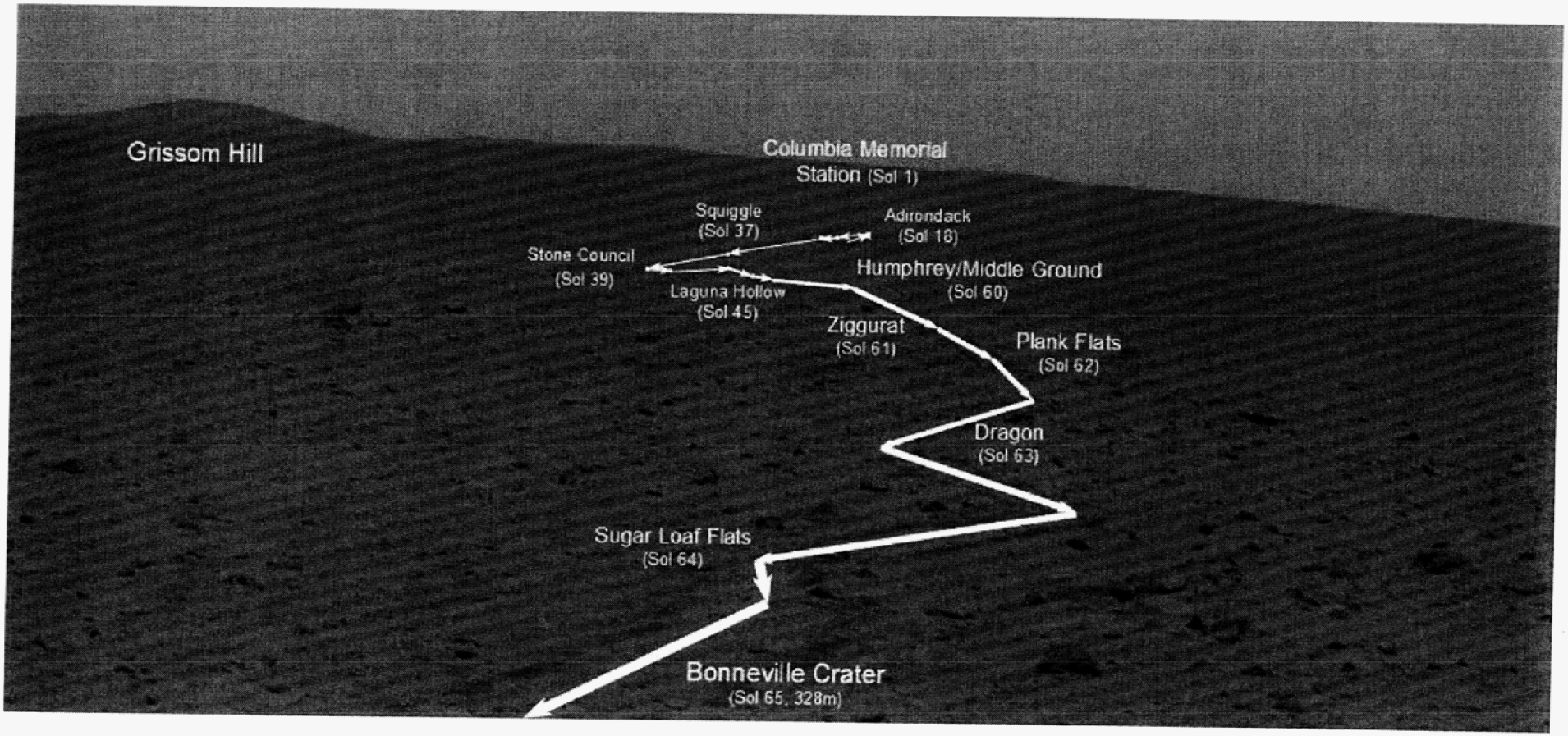

Bonneville



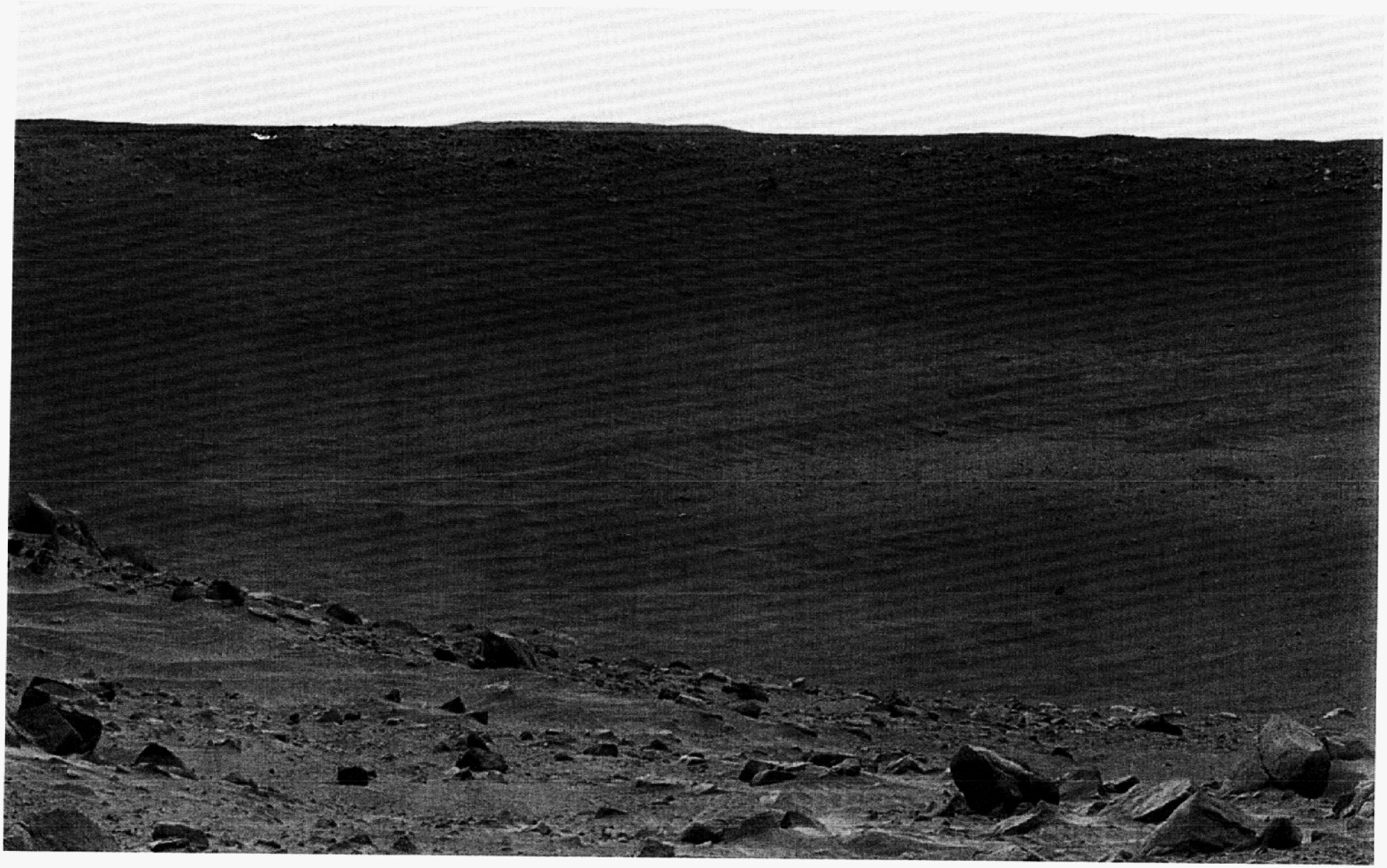


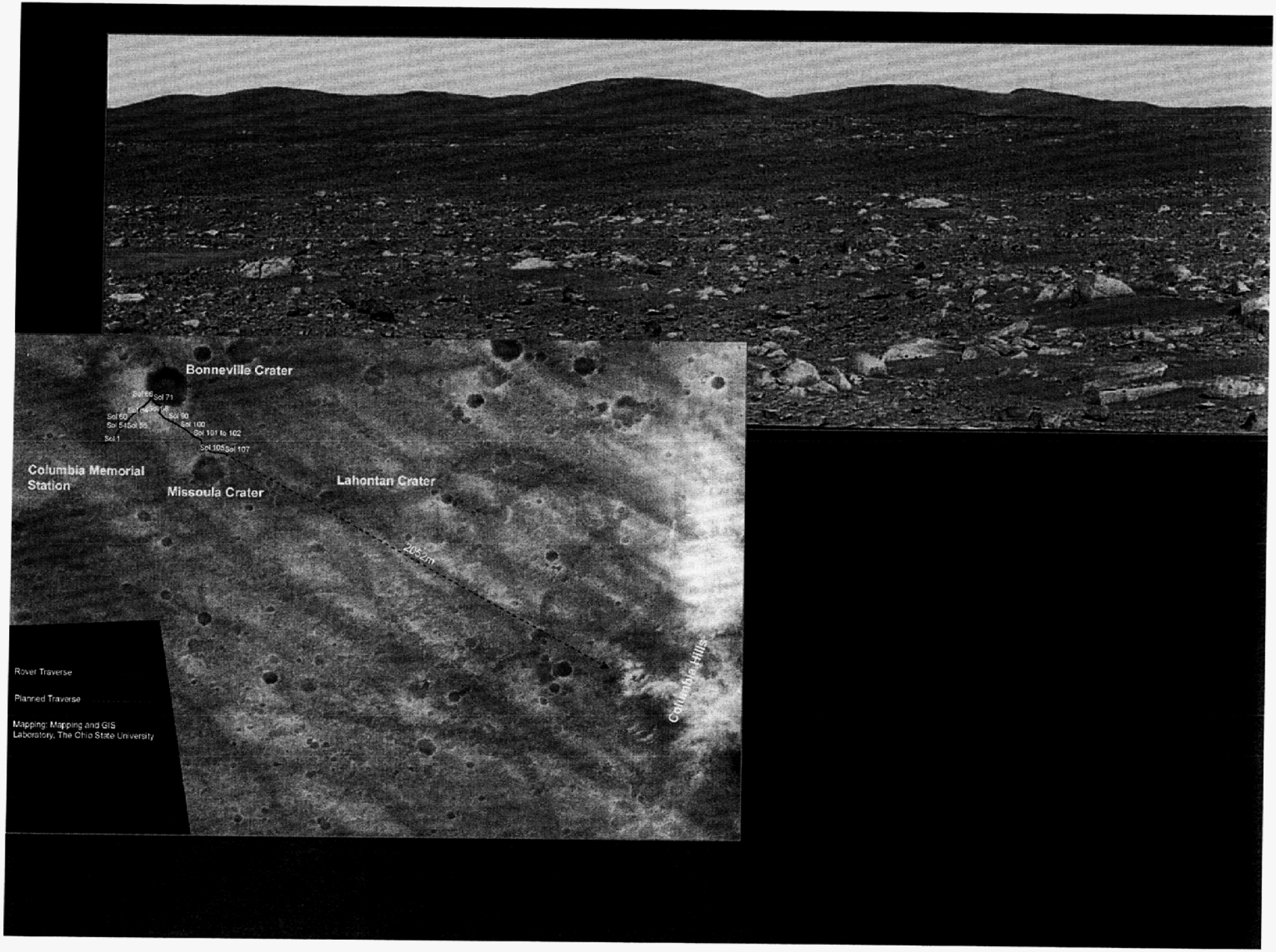


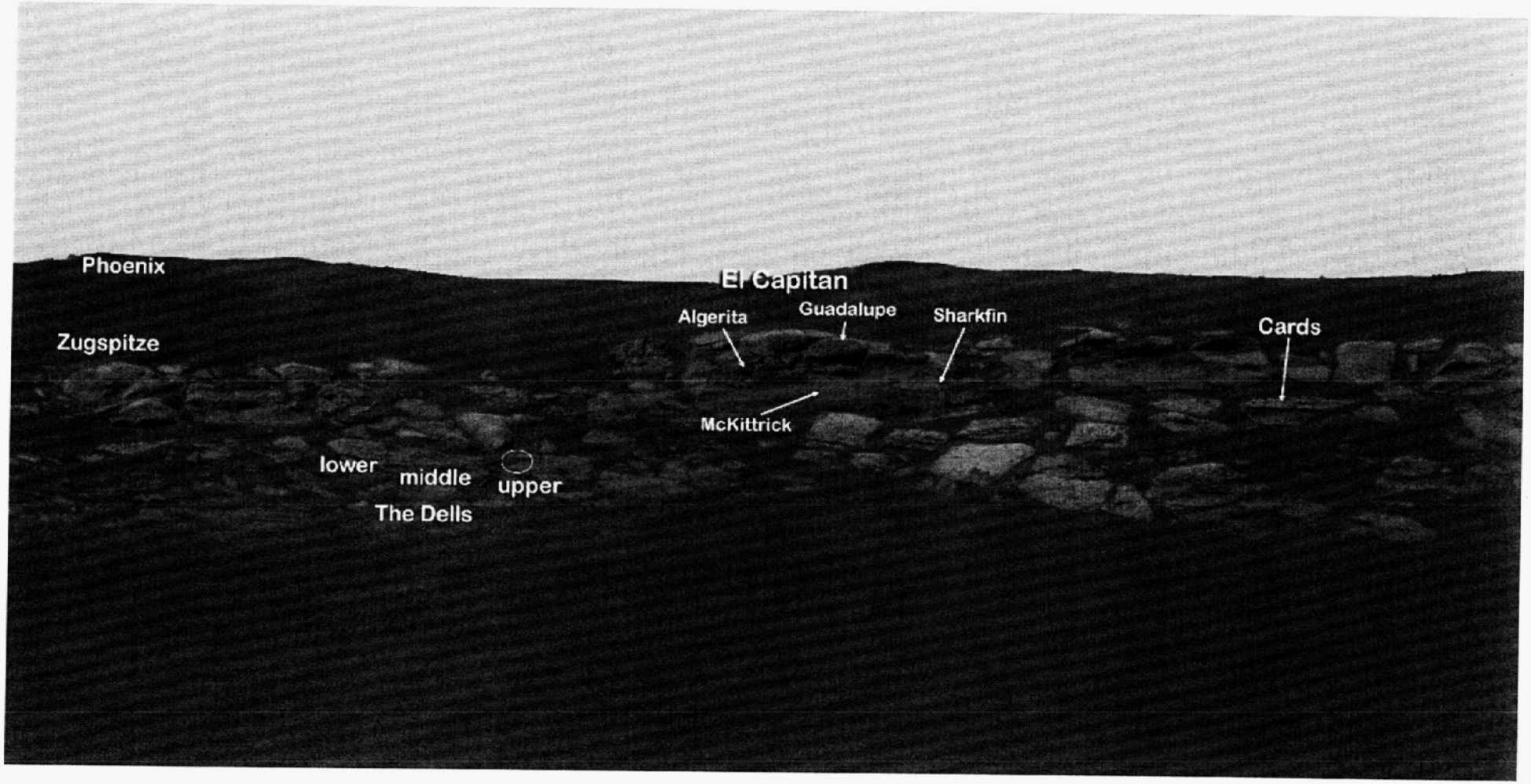
Spirit Rover Traverse – Bonneville Crater (Sol 65)



Mapping and GIS Laboratory, OSU

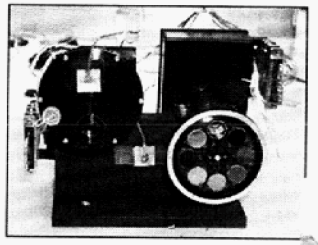



Bonneville Crater
Sol 66
Sol 71
Sol 80
Sol 90
Sol 100
Sol 101 to 102
Sol 105
Sol 107
Sol 60
Sol 54
Sol 1
Columbia Memorial Station
Missoula Crater
Lahontan Crater
Rover Traverse
Planned Traverse
Mapping: Mapping and GIS Laboratory, The Ohio State University

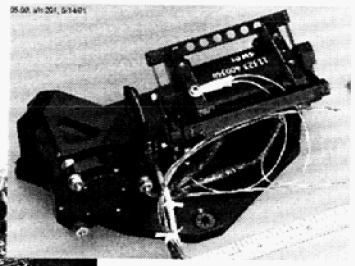

Phoenix
Zugspitze
El Capitan
Algerita
Guadalupe
Sharkfin
Cards
McKittrick
lower
middle
upper
The Dells

Athena Science Payload

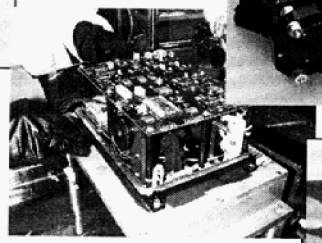
- **Pancam** – high-resolution (16°x16°) color panchromatic stereo cameras
- **Mini-TES** – a mid-infrared point spectrometer
- **Microscopic Imager** – close-up imaging of rock and "soil"
- **Mössbauer Spec trometer** – analysis of iron in rocks
- **Alpha Particle X-Ray Spectrometer** – detects elements in rocks and "soils"
- **Rock Abrasion Tool** – used to remove outer surface of rocks for analysis of non-weathered rock material
- **Magnets and calibration targets** – To collect iron containing dust and for comparison to known sources
- **Engineering cameras**
  - Navcam – wide-angle stereo cameras (45°x 45°) used for traverse planning
  - Hazcam – very-wide-angle (120°x120°) stereo cameras used for identifying potential hazards to rover driving and arm movement

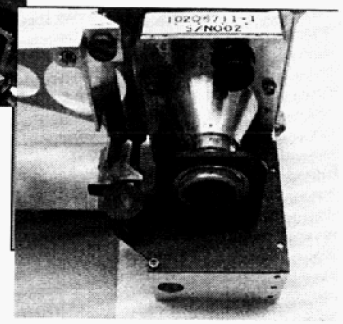


Pancam

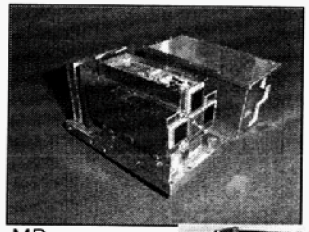


Mini-TES

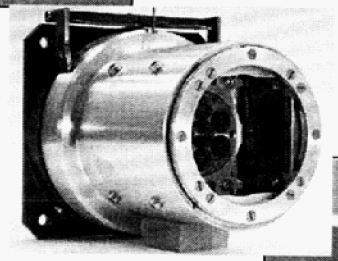




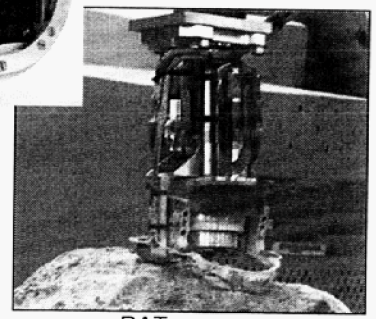
MI



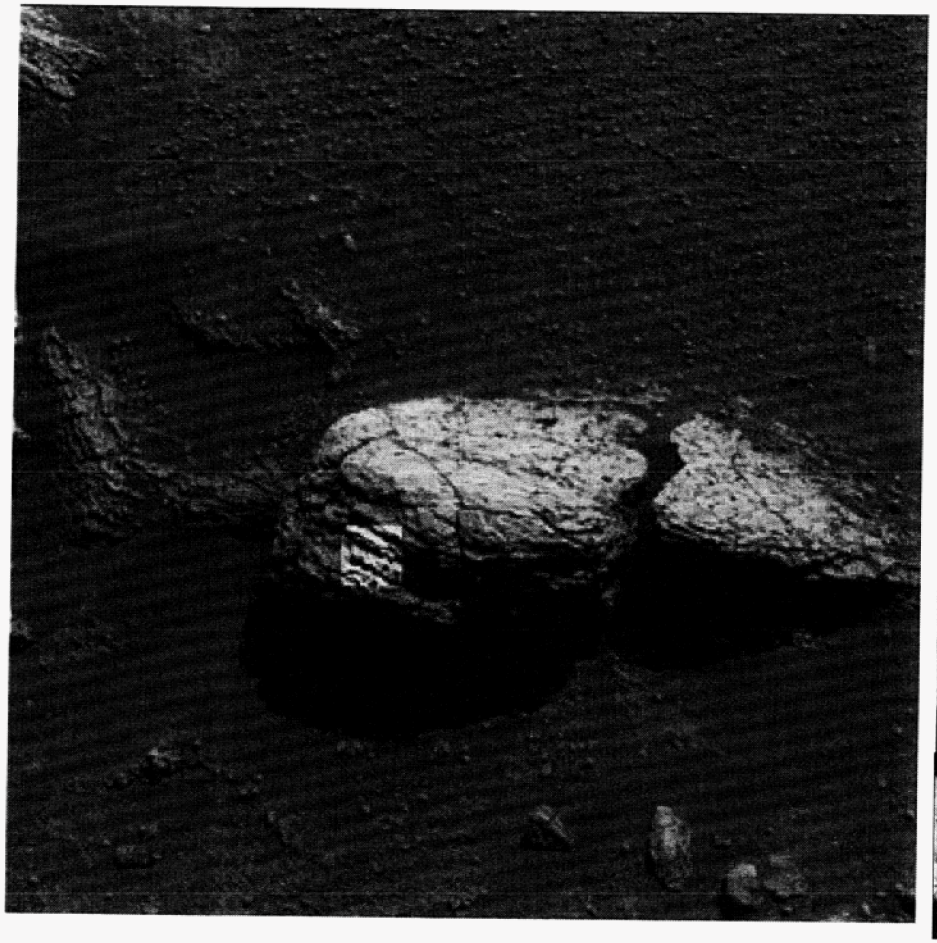
MB

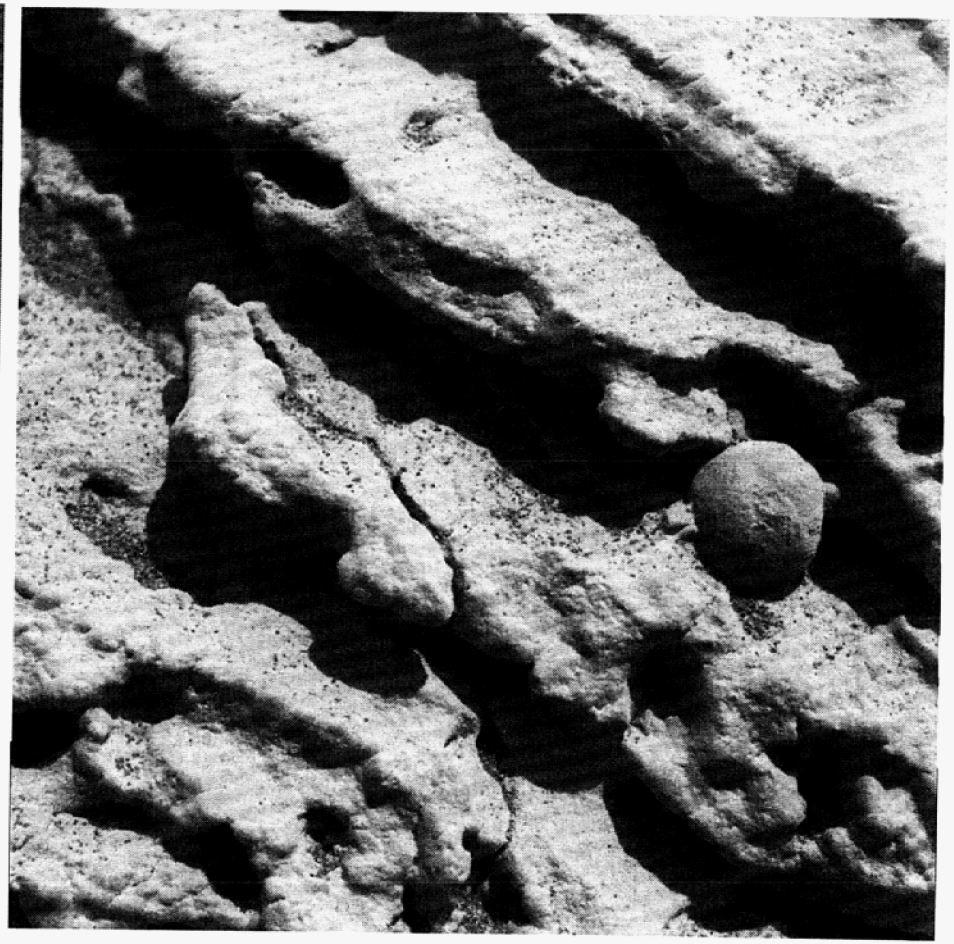


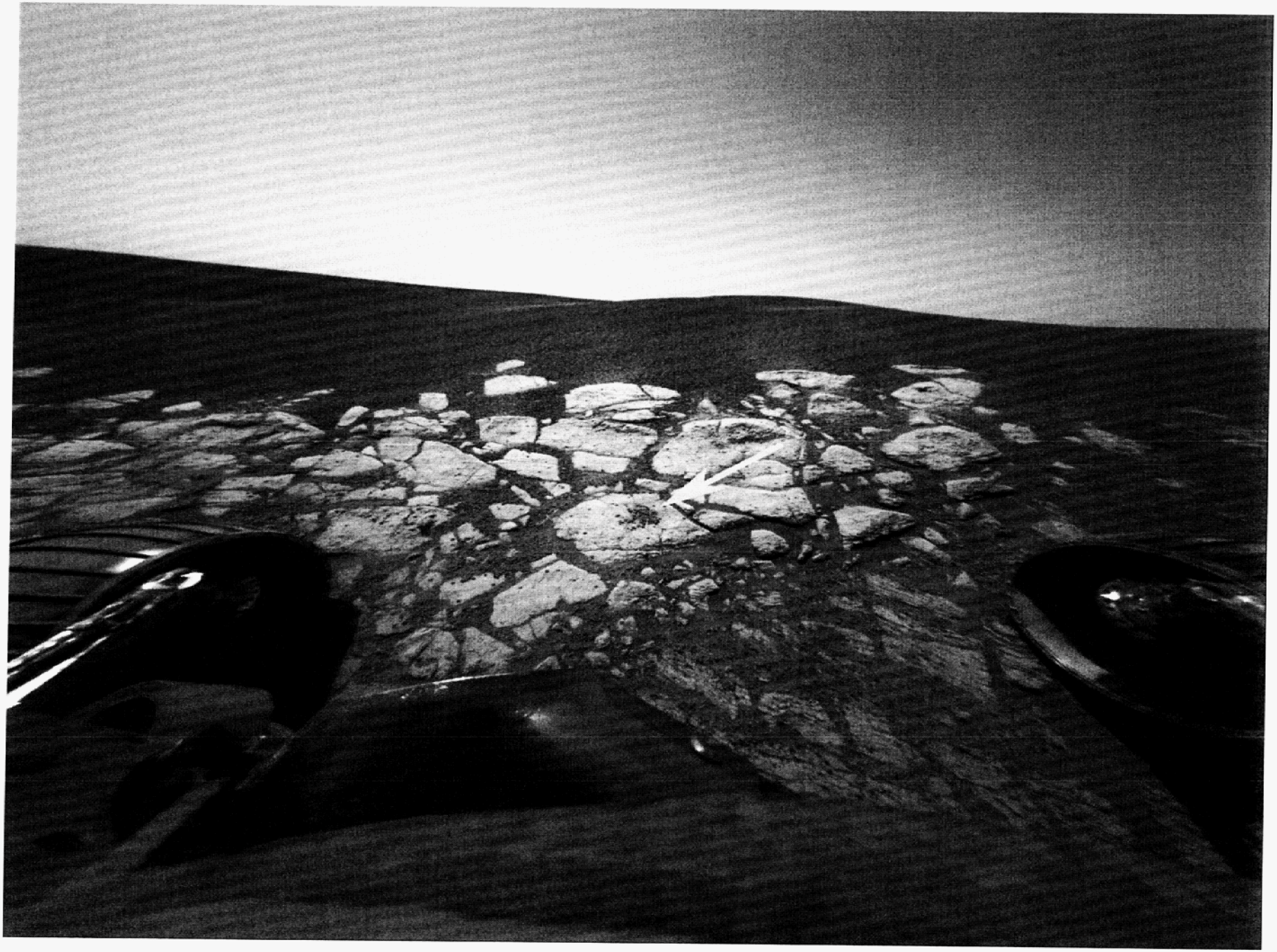
APXS

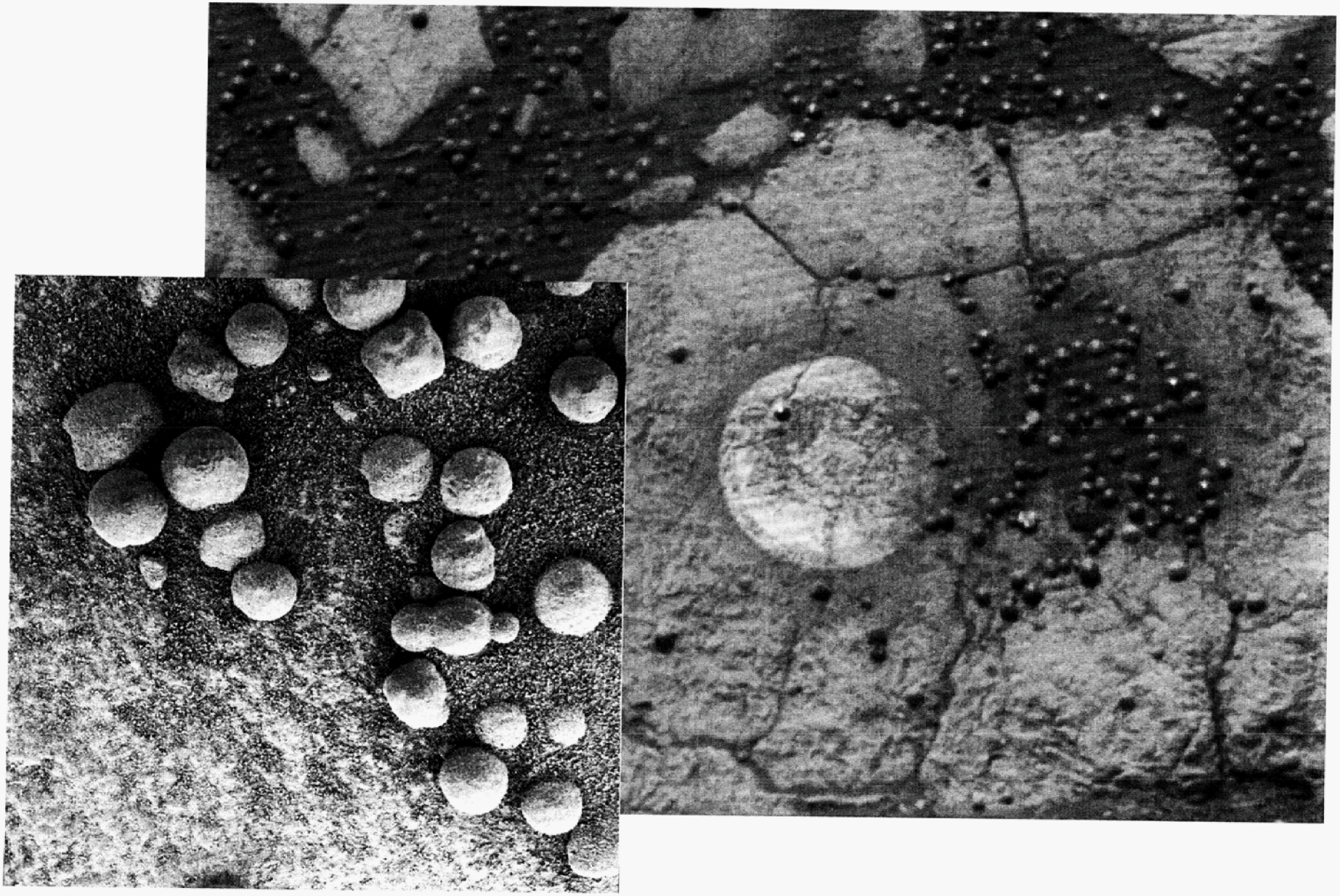


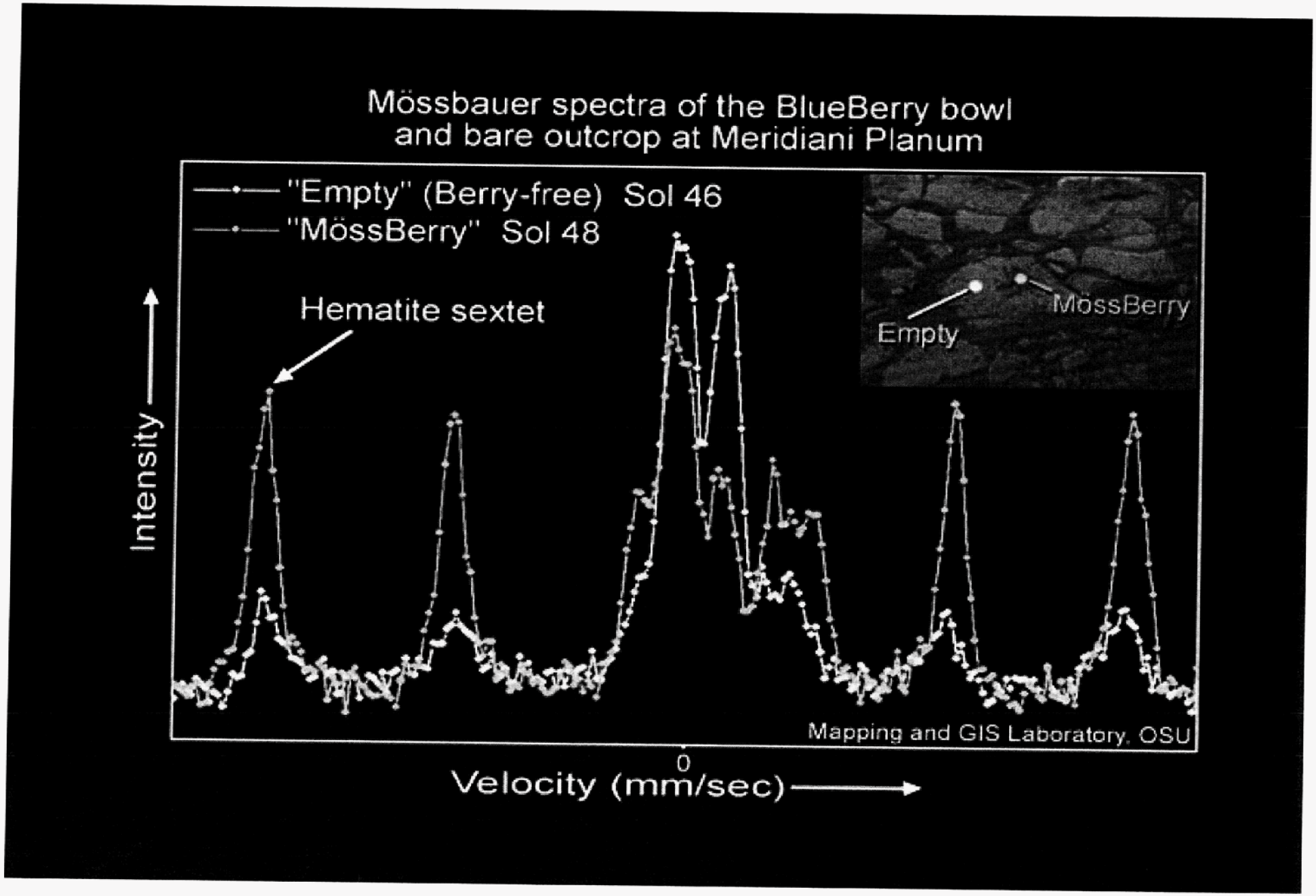
RAT

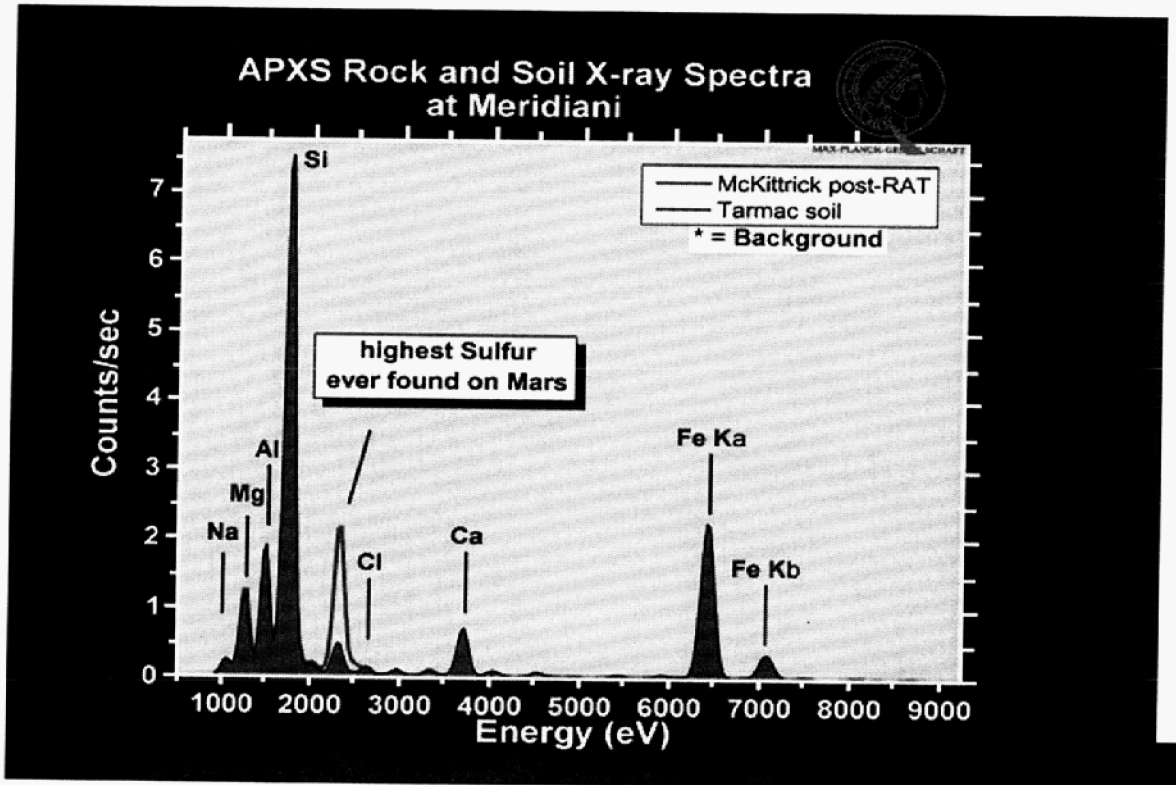


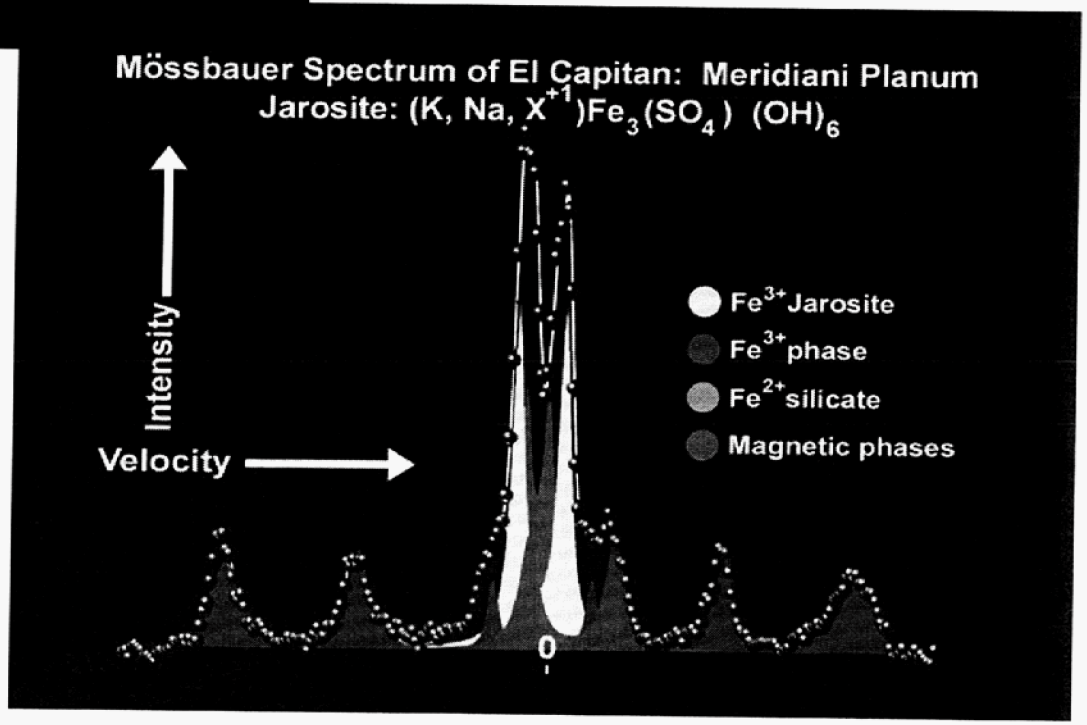


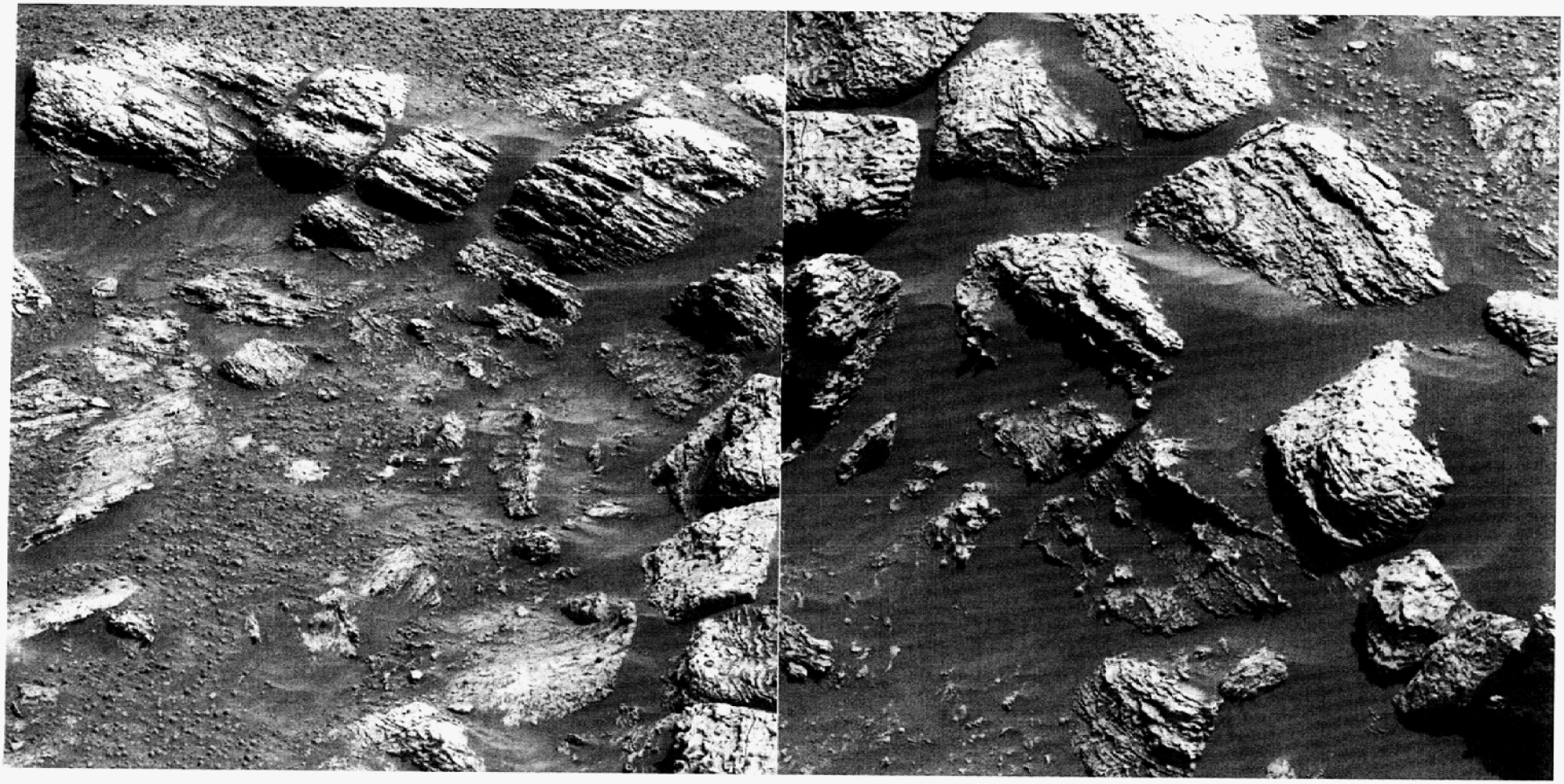




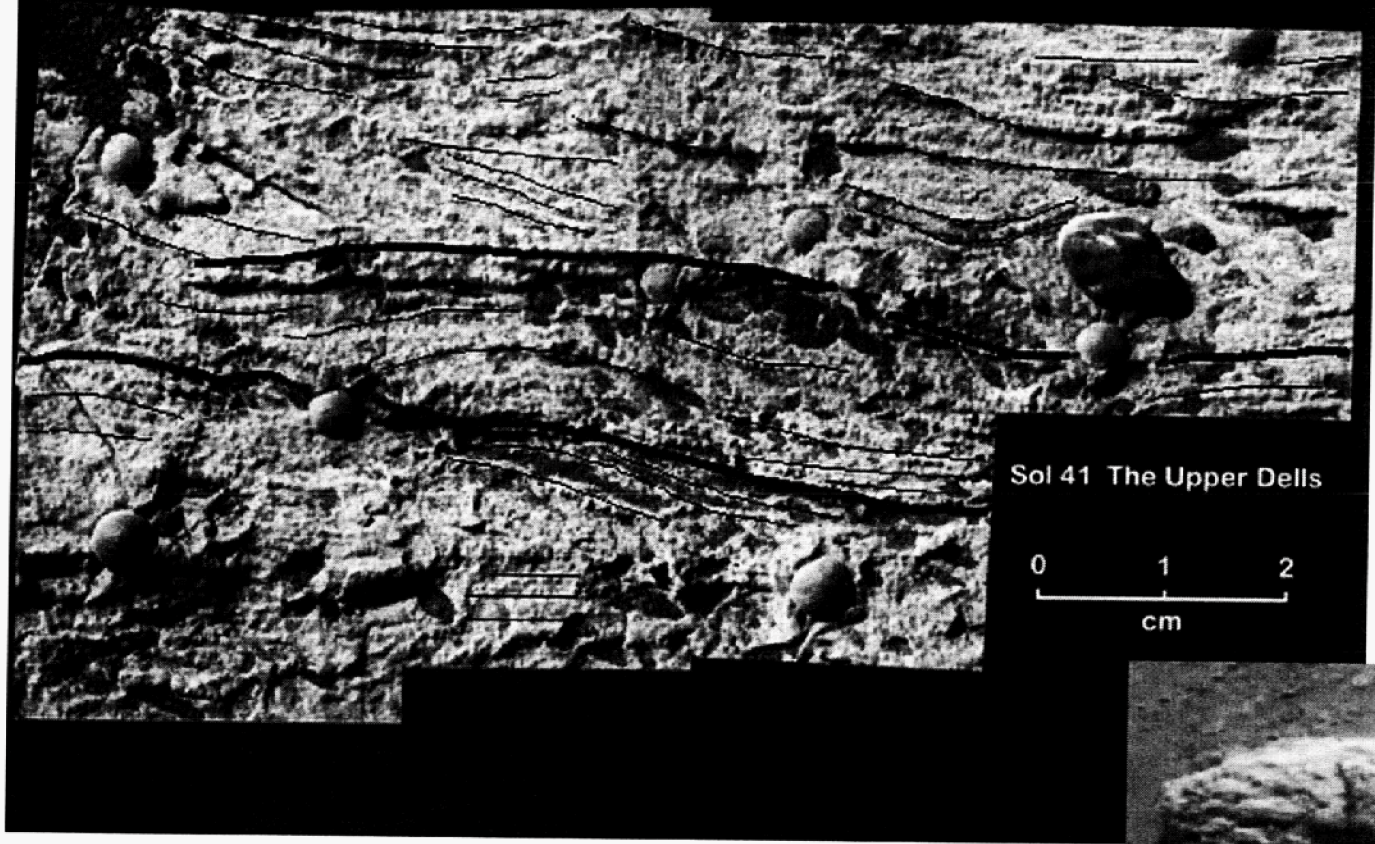

Mössbauer spectra of the BlueBerry bowl
and bare outcrop at Meridiani Planum
"Empty" (Berry-free) Sol 46
"MössBerry" Sol 48
Hematite sextet
Intensity
Empty
MössBerry
Mapping and GIS Laboratory, OSU
0
Velocity (mm/sec)

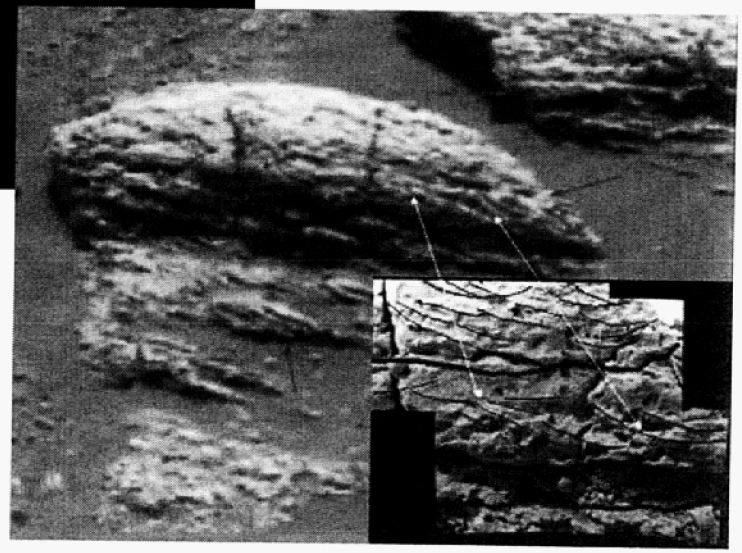

APXS Rock and Soil X-ray Spectra
at Meridiani
McKittrick post-RAT
Tarmac soil
* = Background
highest Sulfur
ever found on Mars
Si
Al
Mg
Na
Cl
Ca
Fe Ka
Fe Kb
Counts/sec
Energy (eV)
0
1
2
3
4
5
6
7
1000
2000
3000
4000
5000
6000
7000
8000
9000

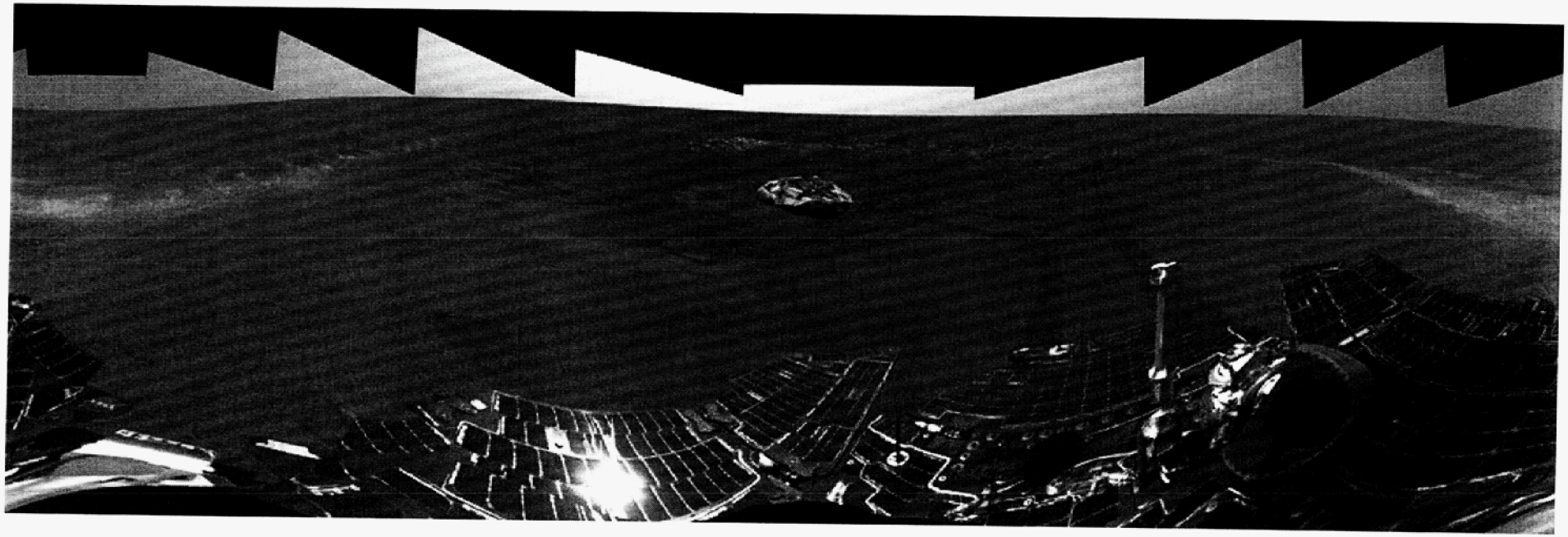

Mössbauer Spectrum of El Capitan: Meridiani Planum
Jarosite: (K, Na, X+1)Fe3(SO4) (OH)6
Intensity
Velocity
Fe3+Jarosite
Fe3+phase
Fe2+silicate
Magnetic phases
0

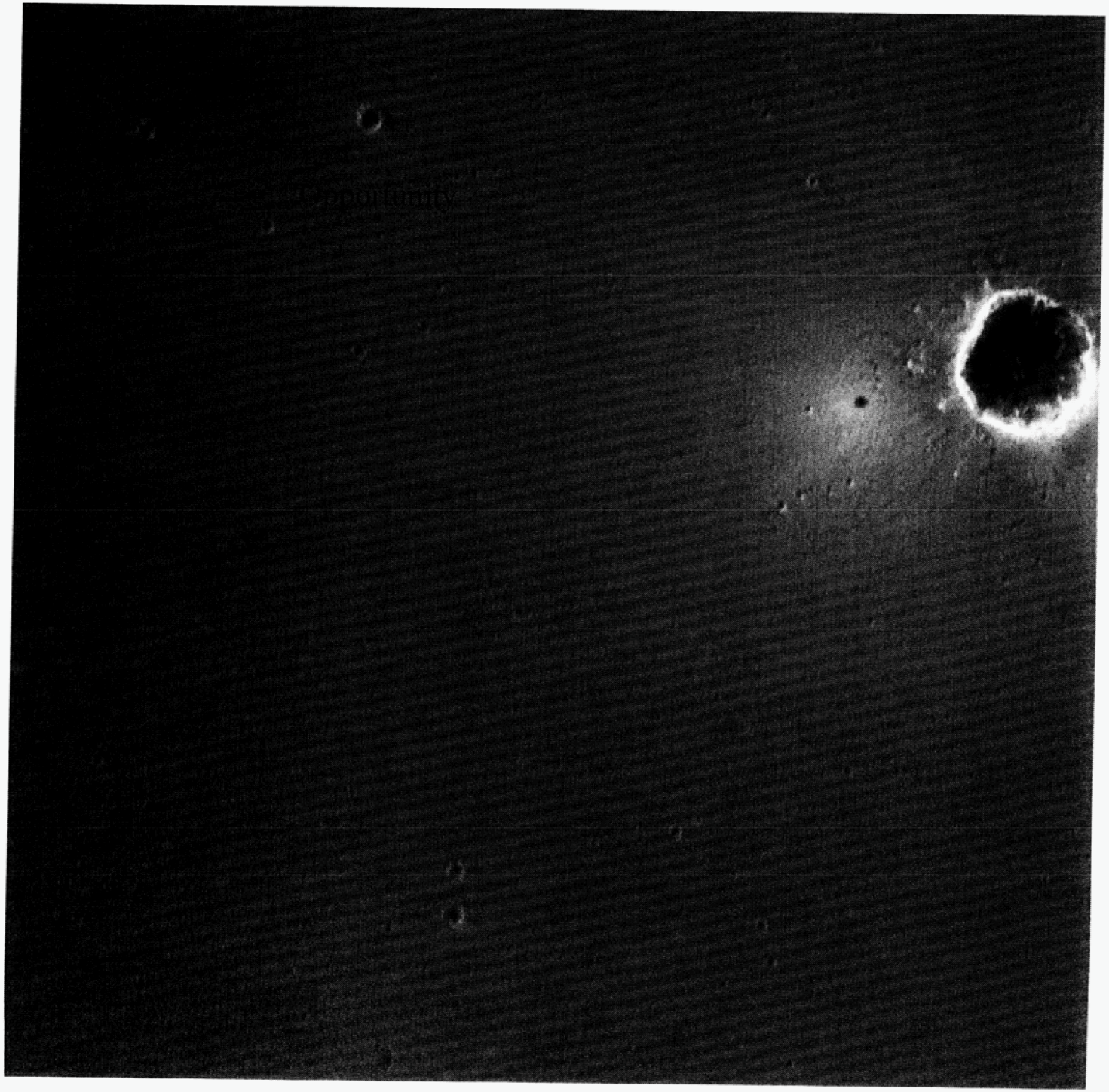


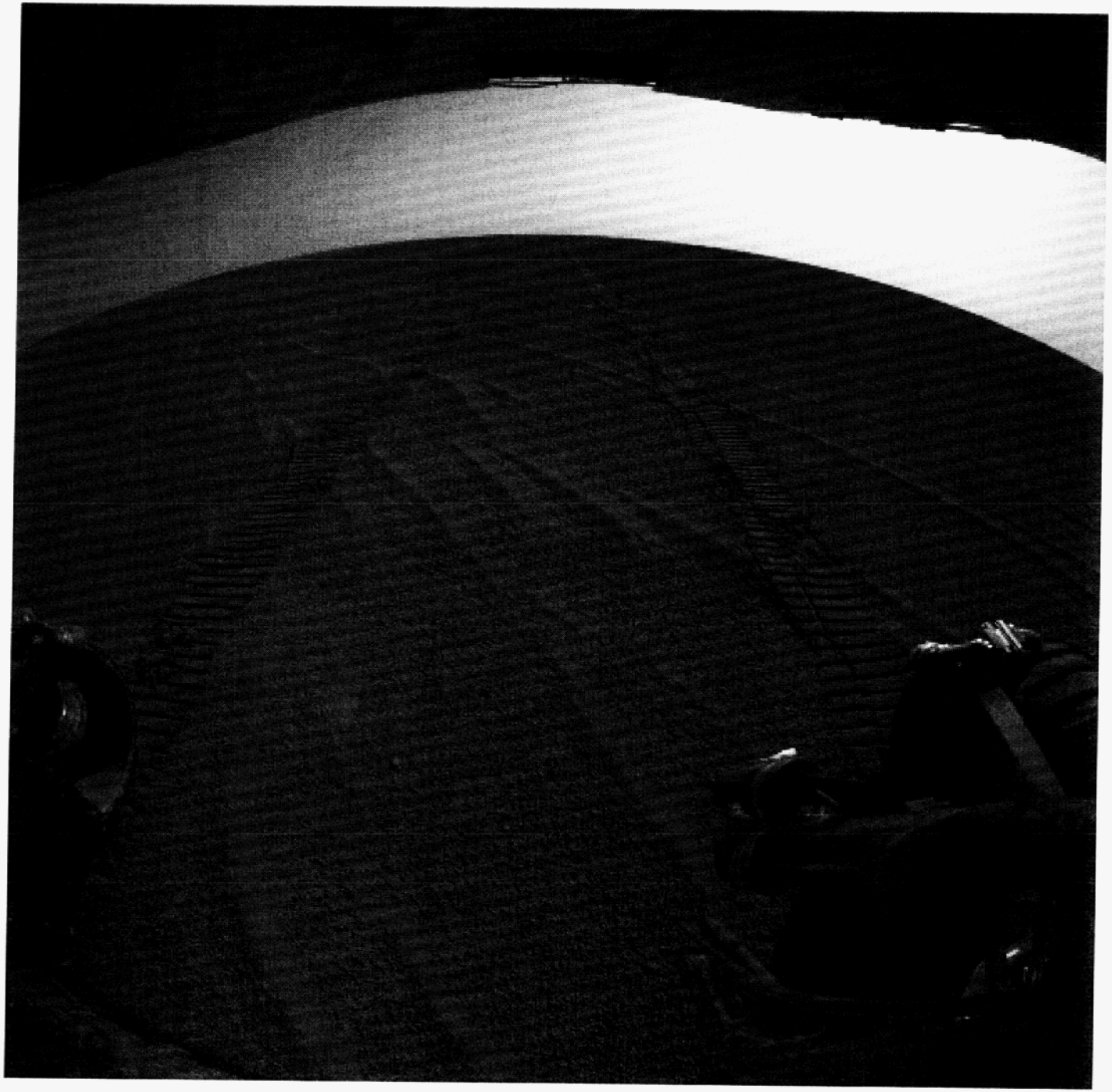
Upper Dells MI Mosaic

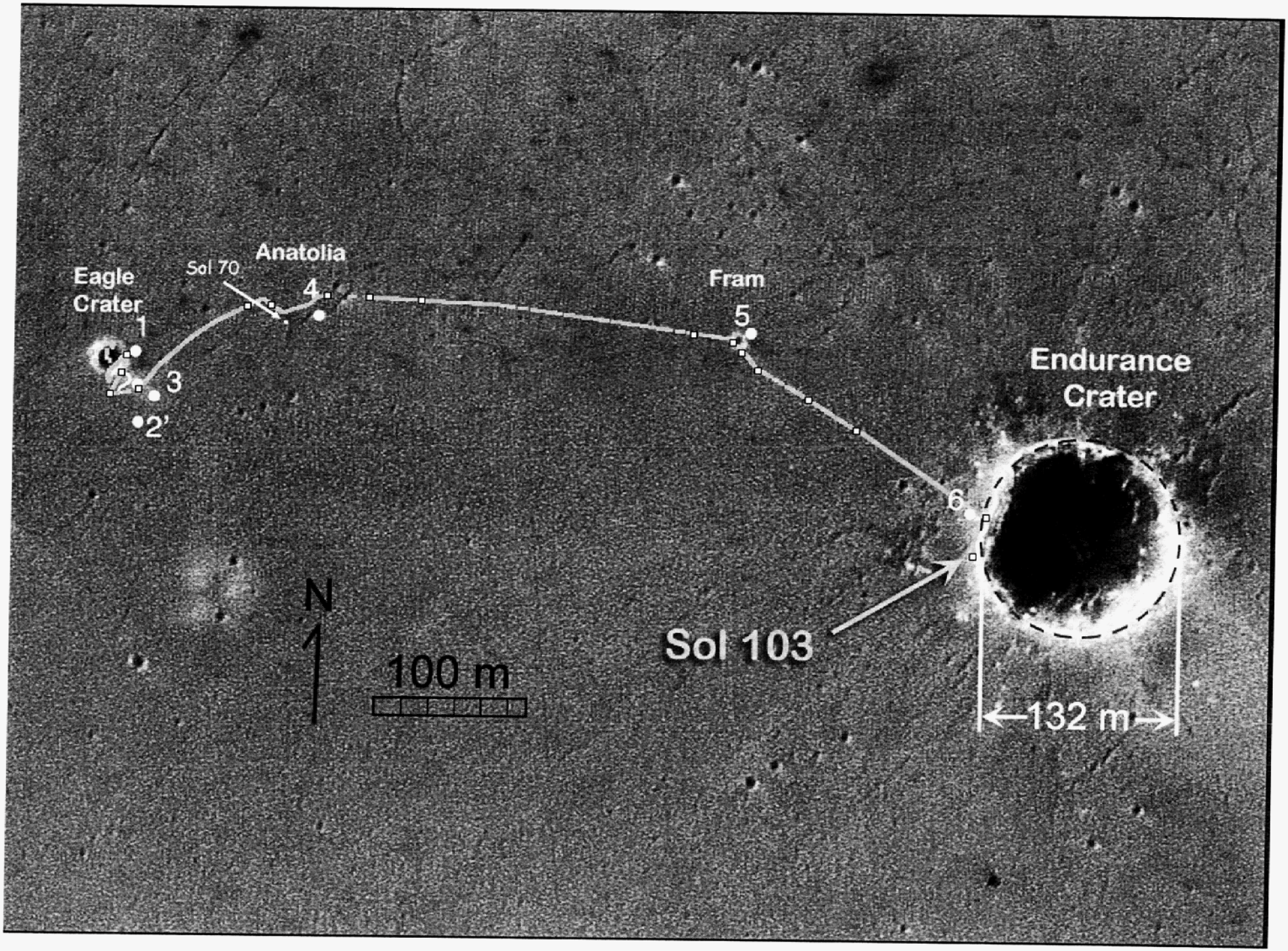




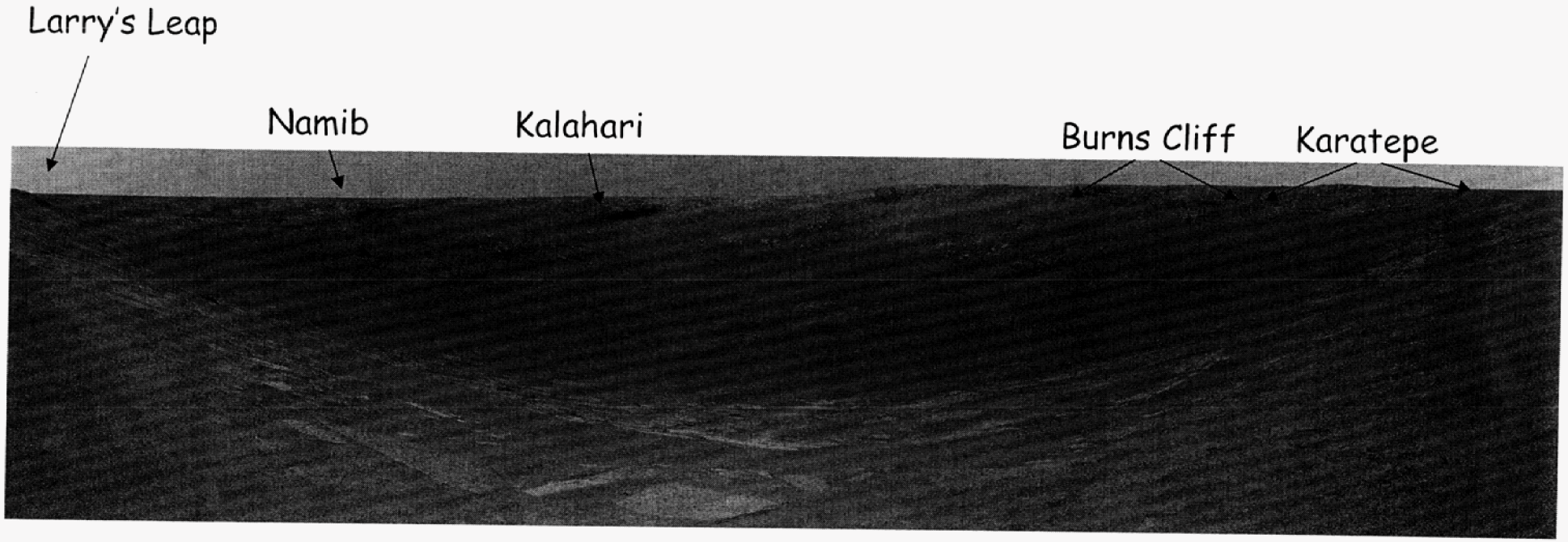




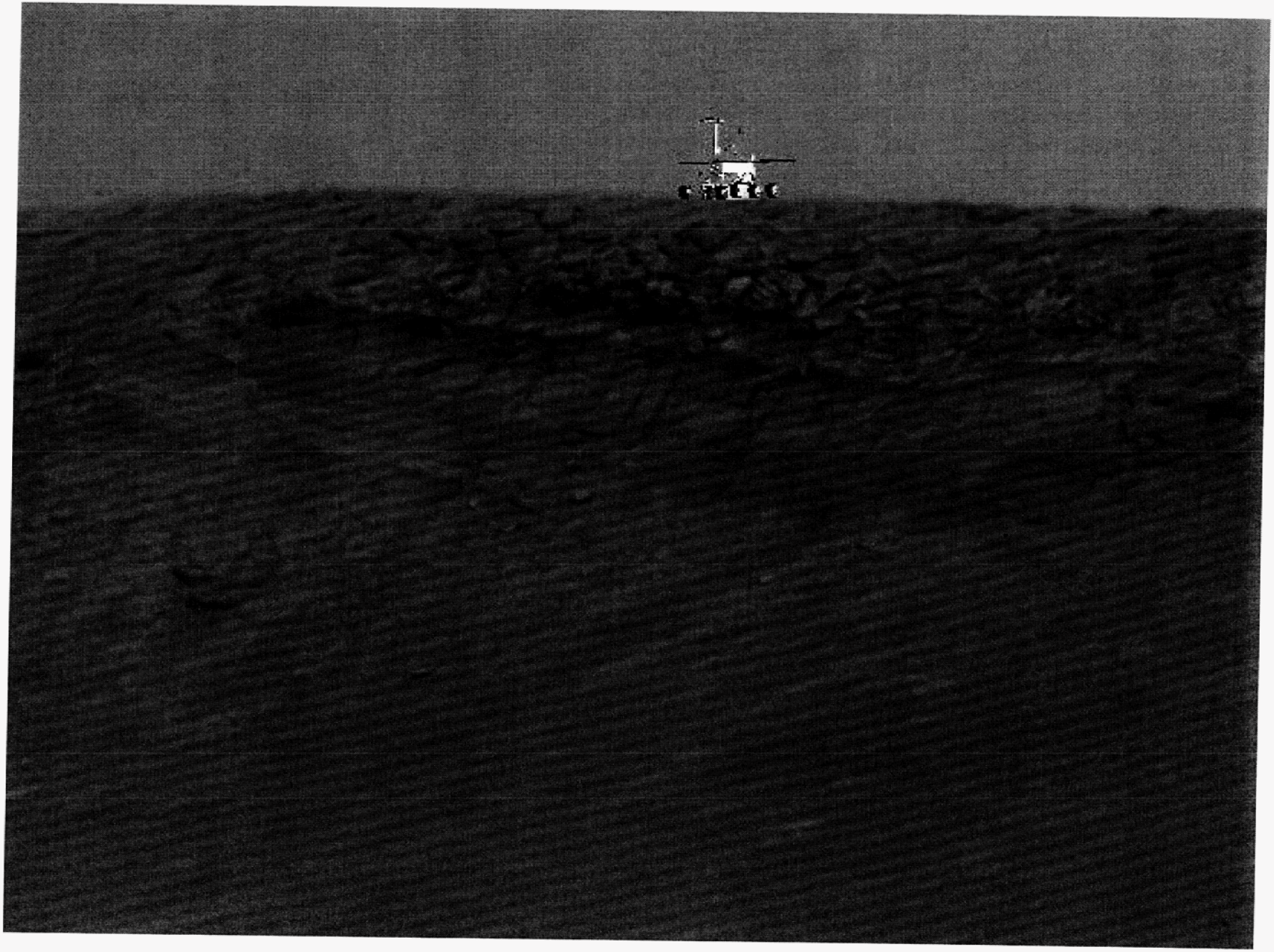


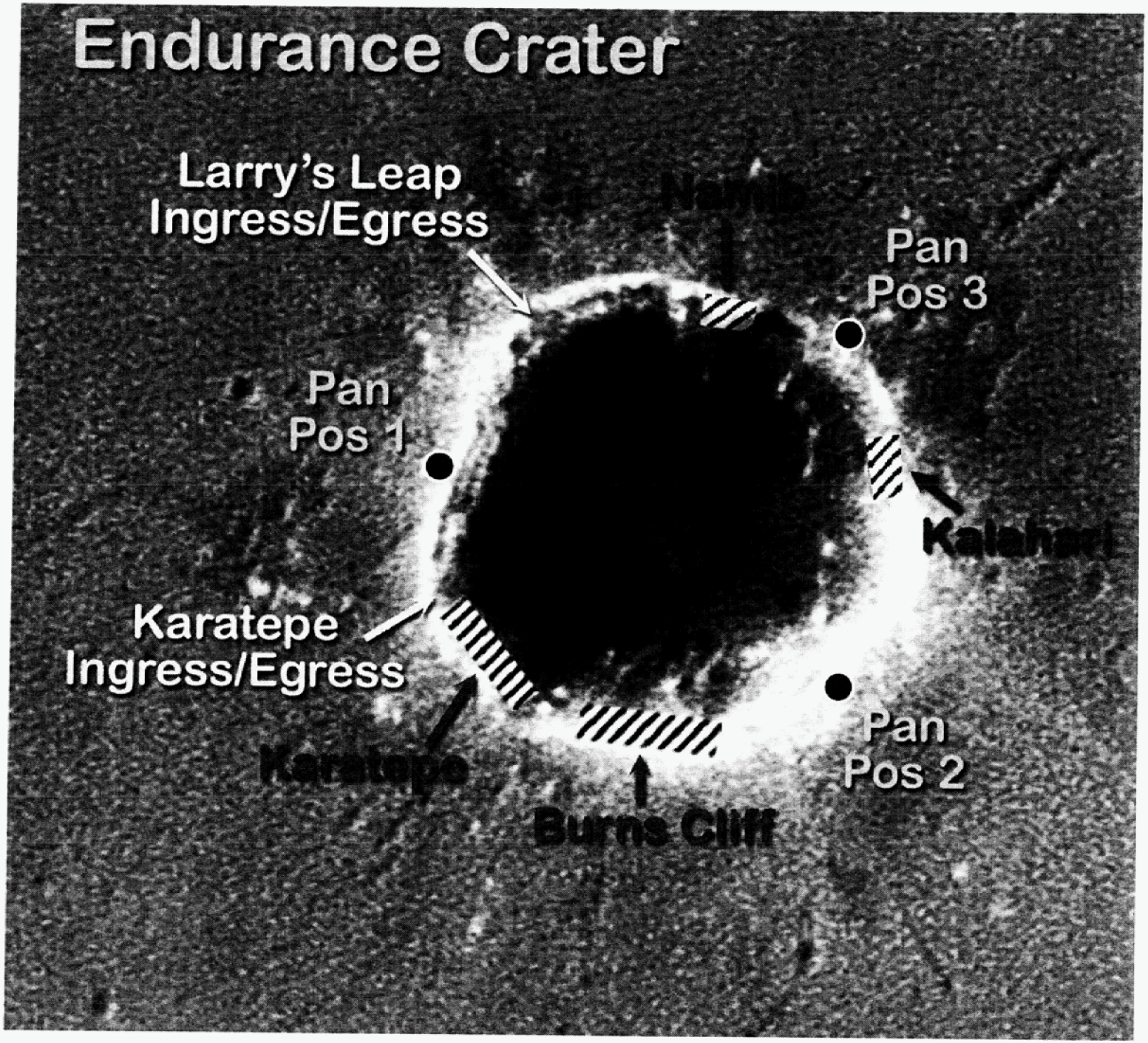

Eagle Crater
Sol 70
Anatolia
Fram
Endurance Crater
1
2
2'
3
4
5
6
N
100 m
Sol 103
132 m

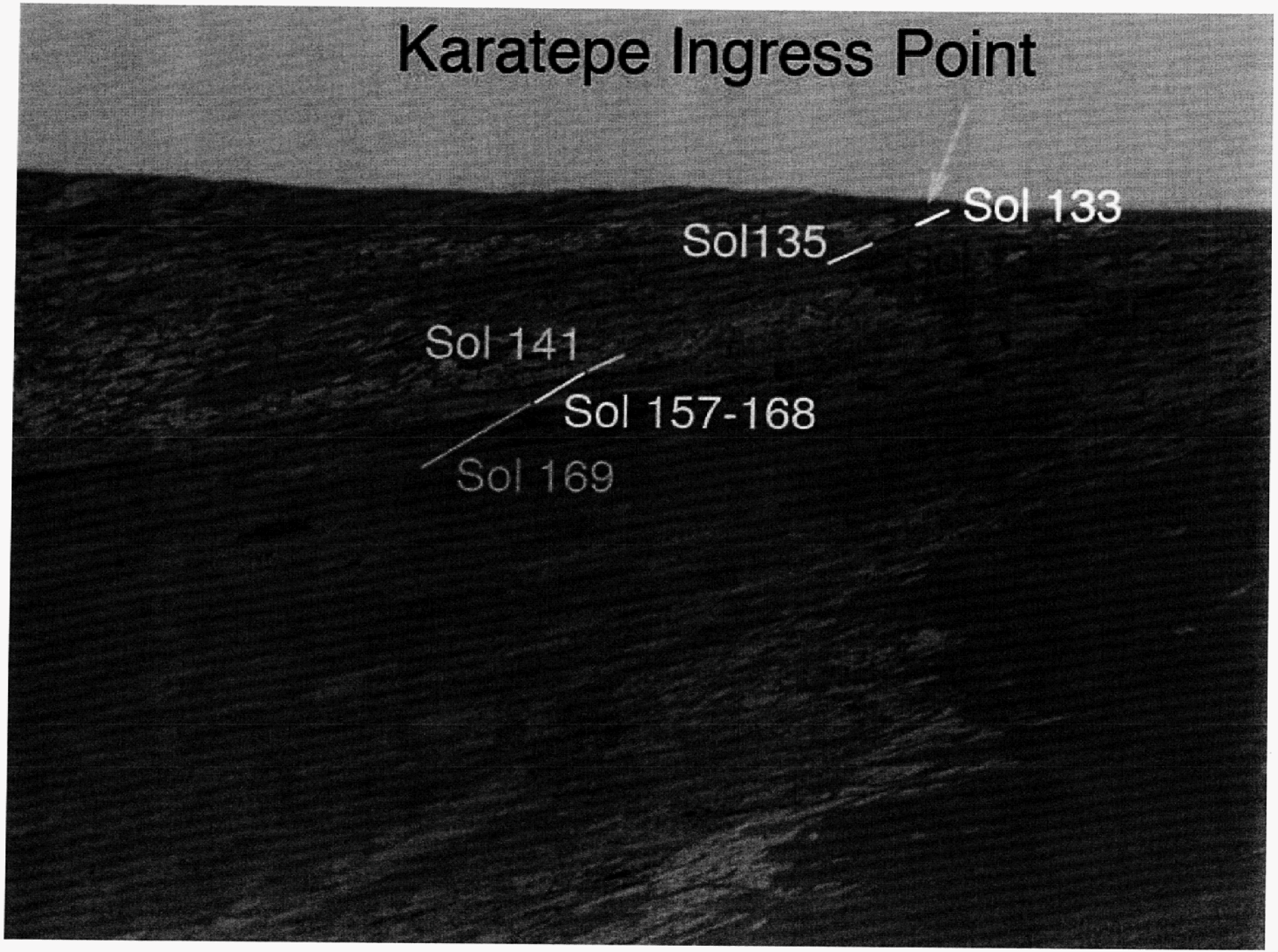
Endurance Crater

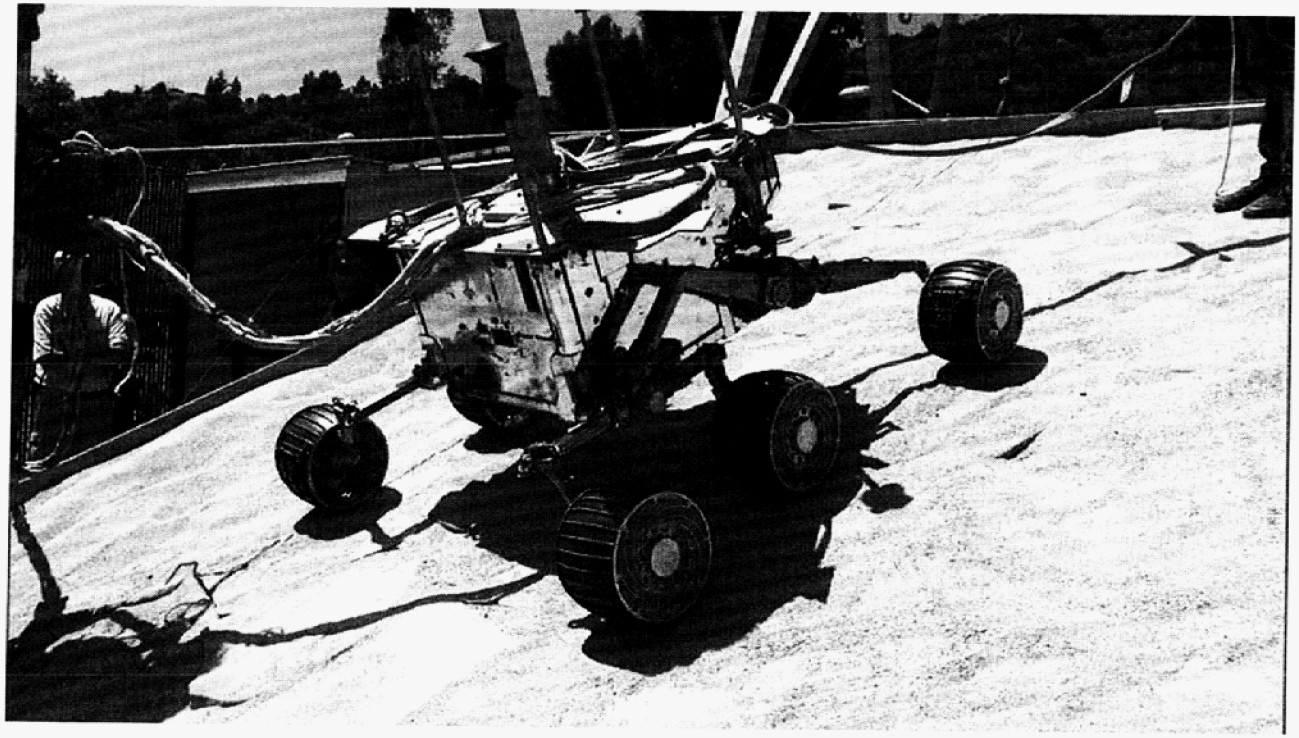


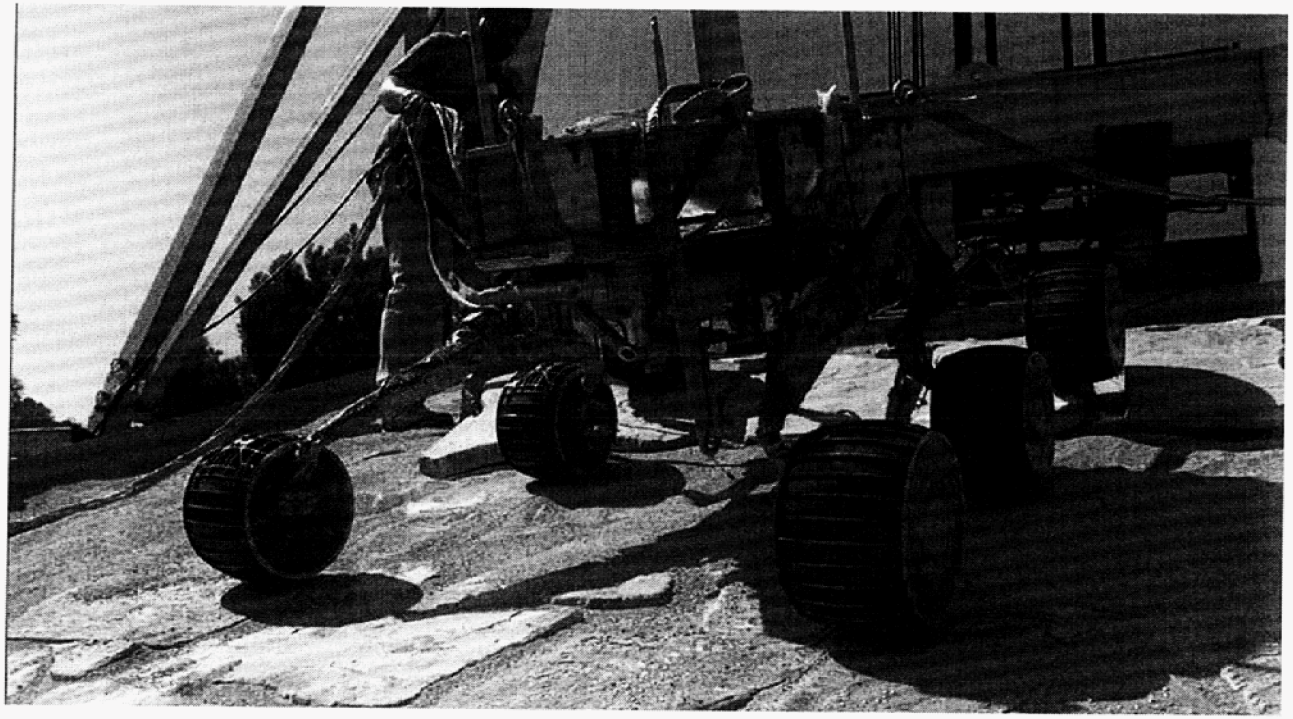
Pancam West Rim -(Sol 101)

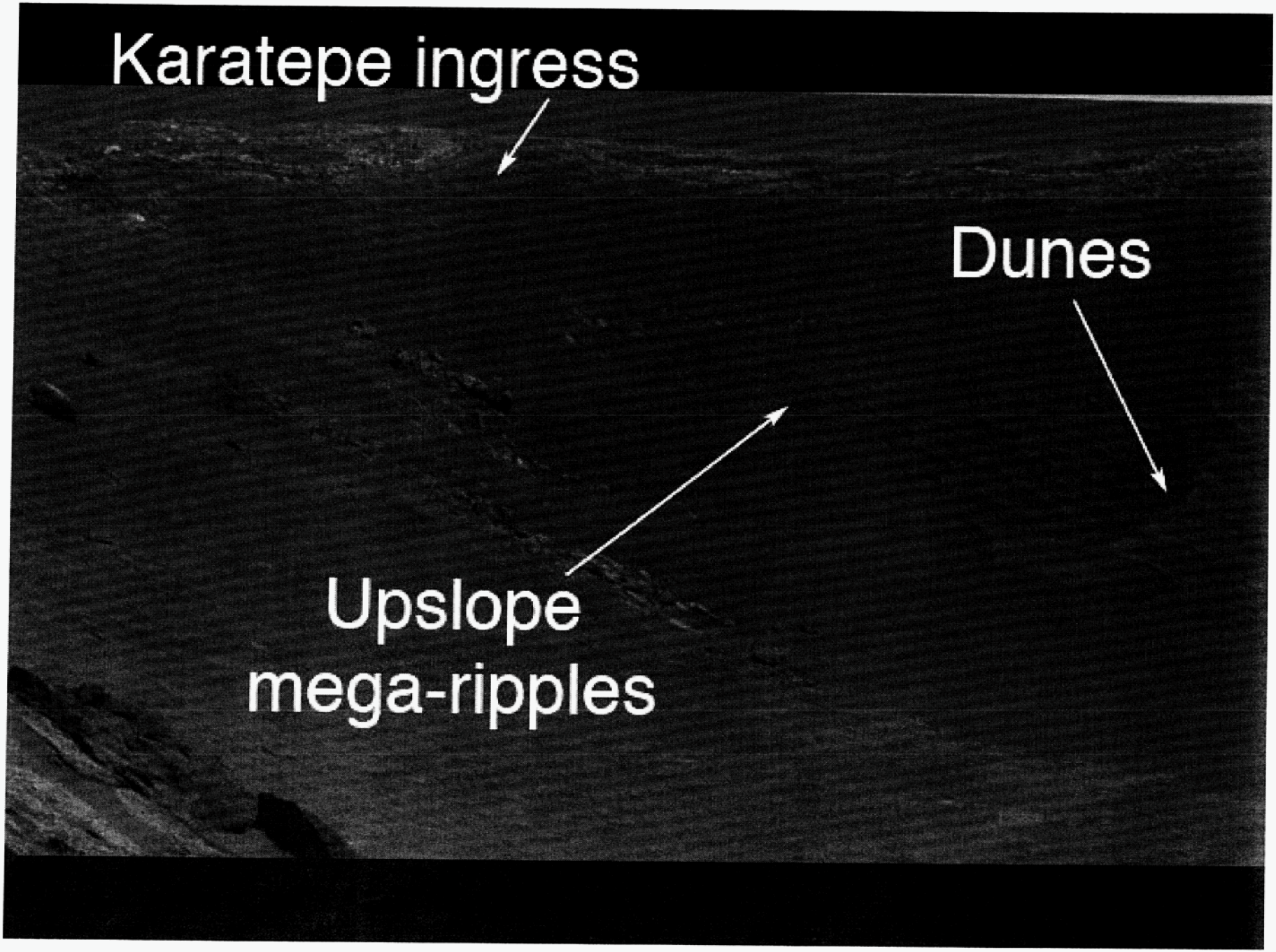


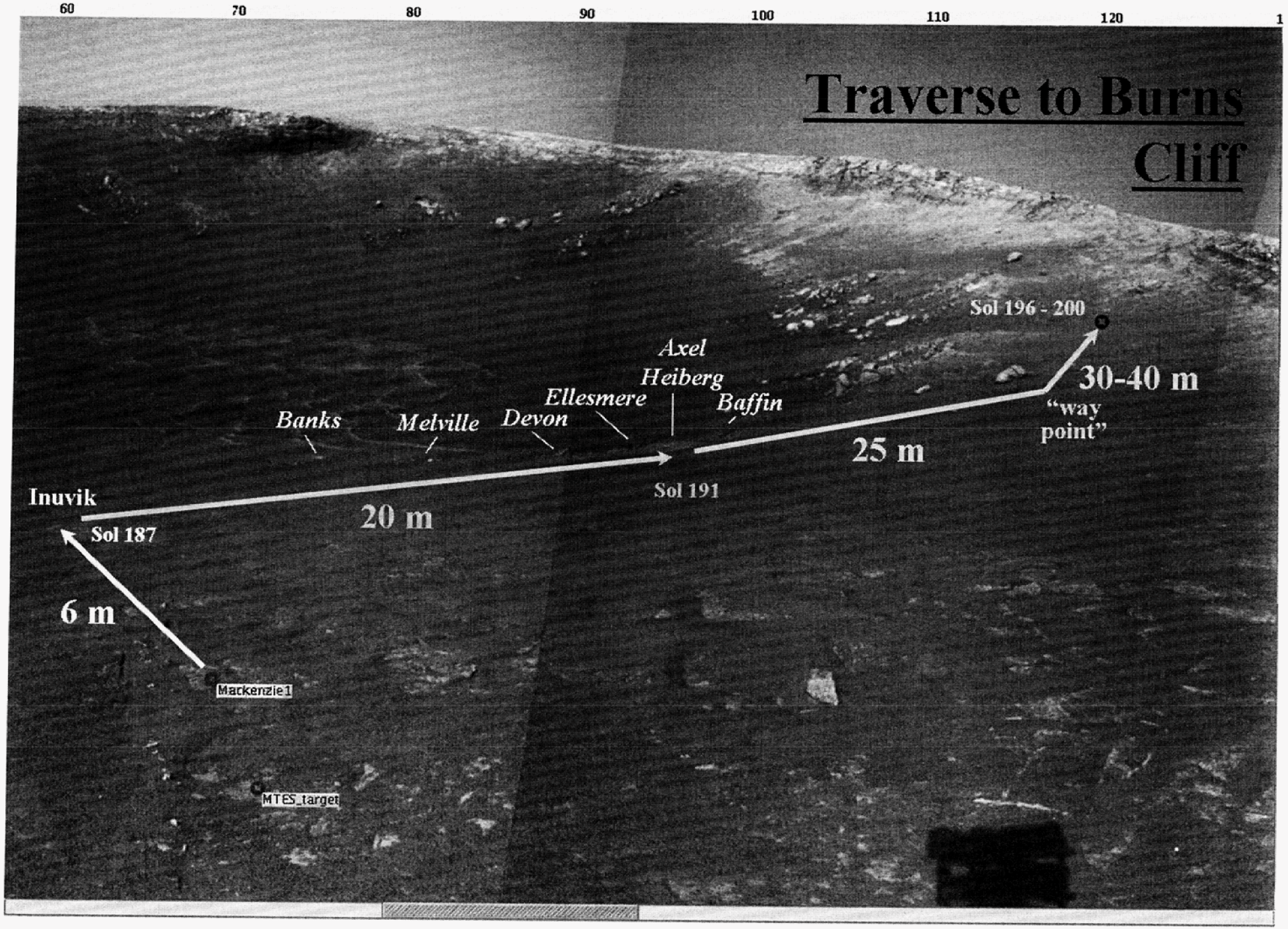

Endurance Crater
Larry's Leap
Ingress/Egress
Pan
Pos 3
Pan
Pos 1
Karatepe
Ingress/Egress
Pan
Pos 2
Burns Cliff

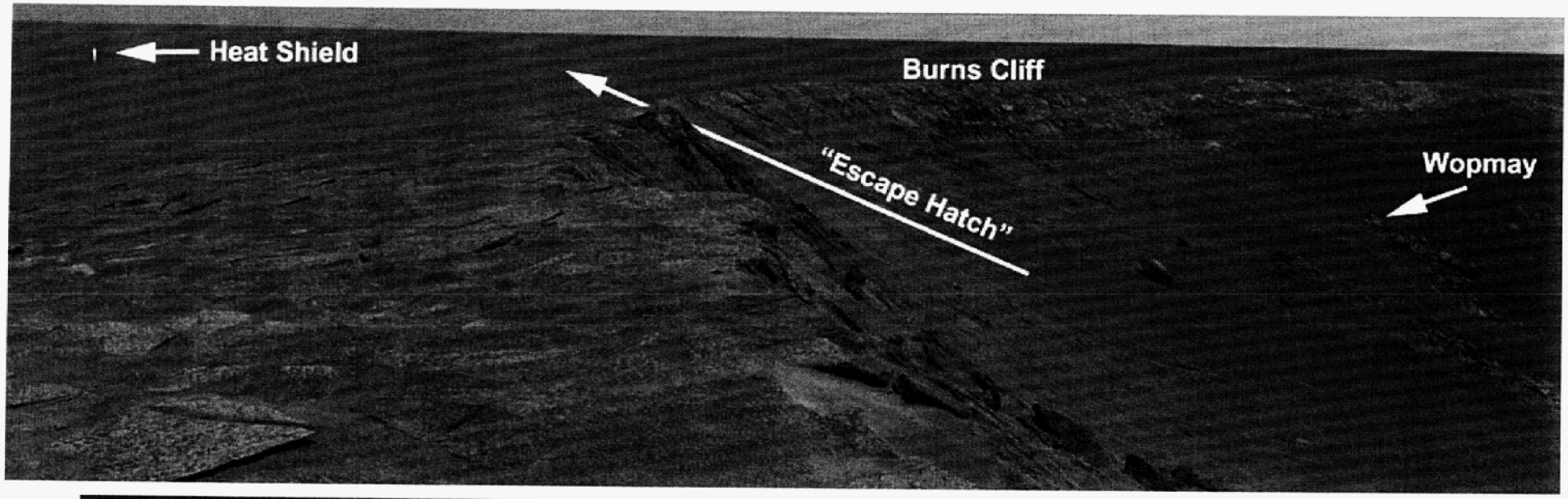

Karatepe Ingress Point
Sol 133
Sol135
Sol 141
Sol 157-168
Sol 169

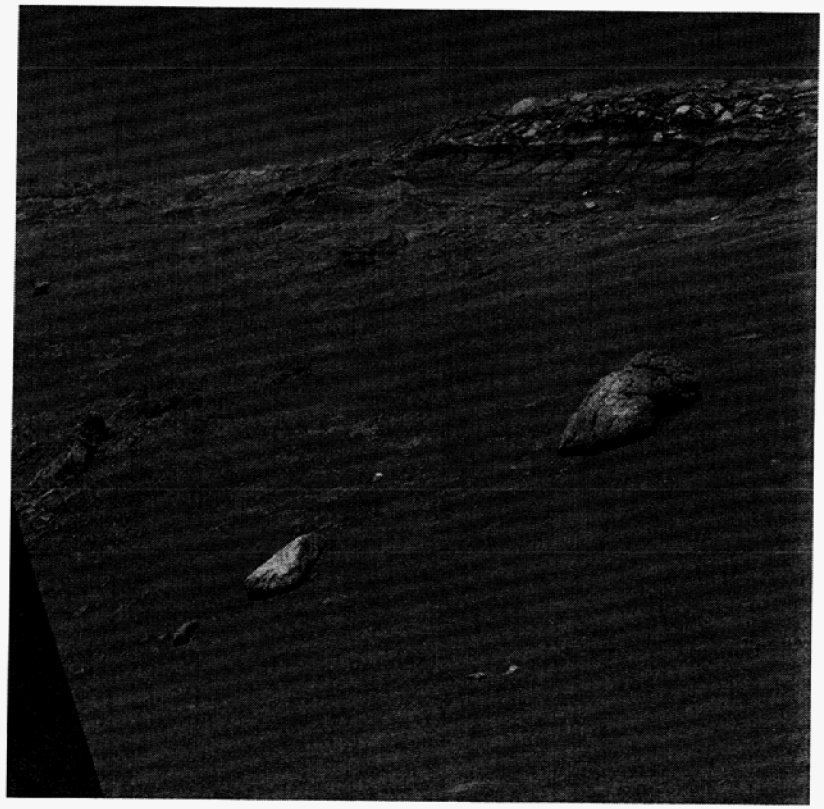


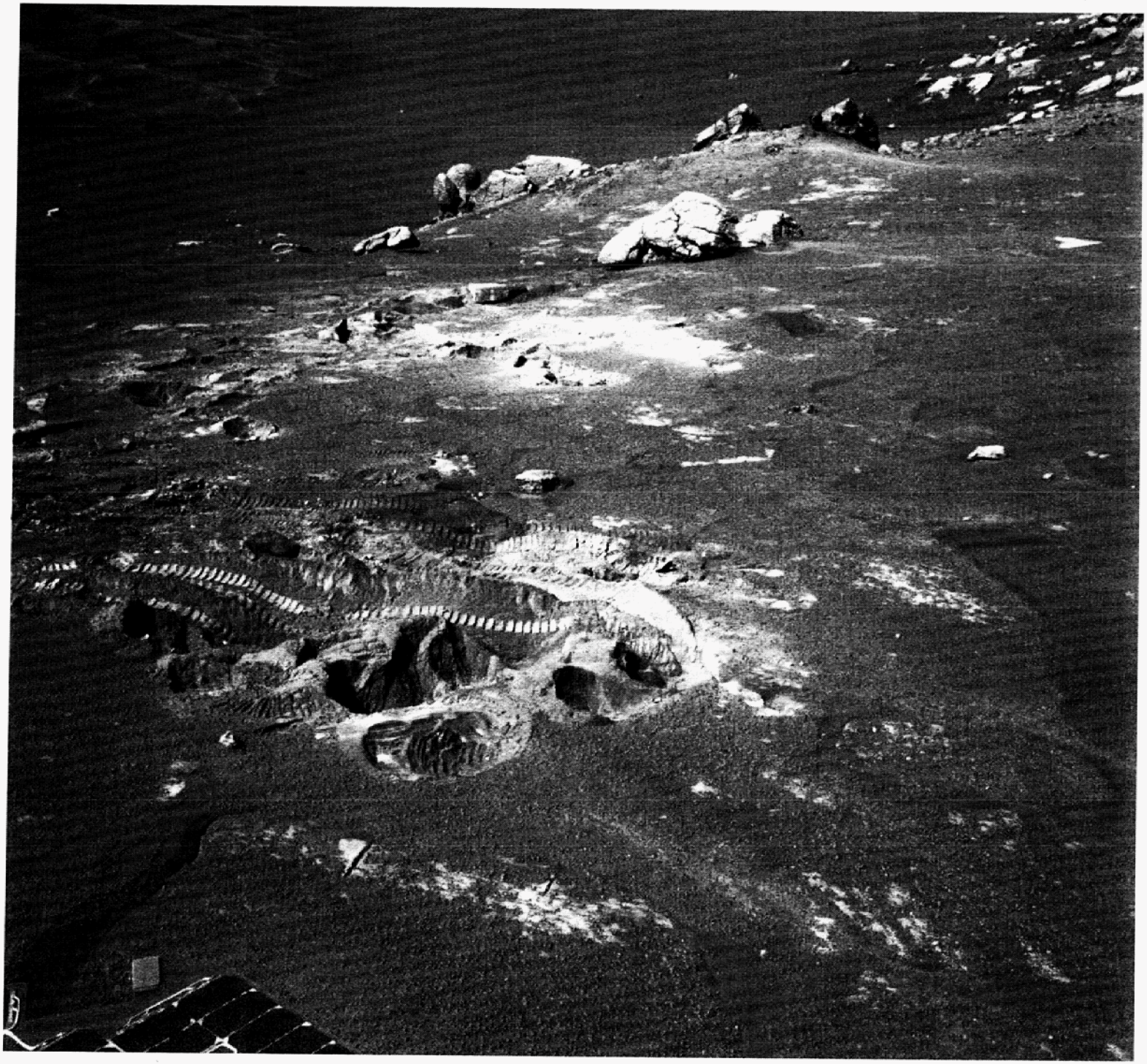


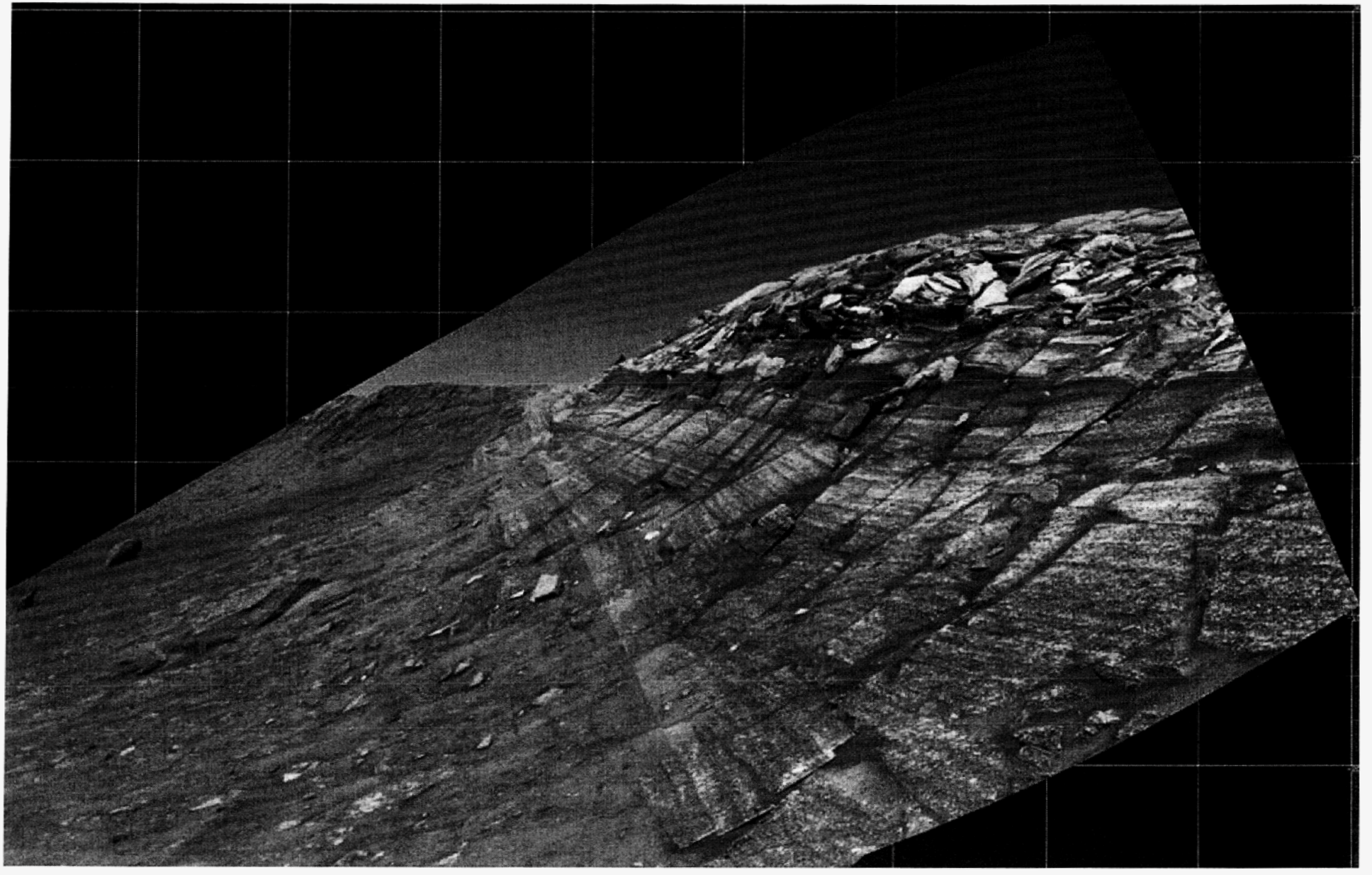

Karatepe ingress
Dunes
Upslope
mega-ripples


60
70
80
90
100
110
120
Traverse to Burns Cliff
Sol 196 - 200
Axel Heiberg
Ellesmere
Baffin
Devon
Melville
Banks
30-40 m
"way point"
25 m
Sol 191
Inuvik
20 m
Sol 187
6 m
Mackenzie1
MTES_target


Heat Shield
Burns Cliff
"Escape Hatch"
Wopmay

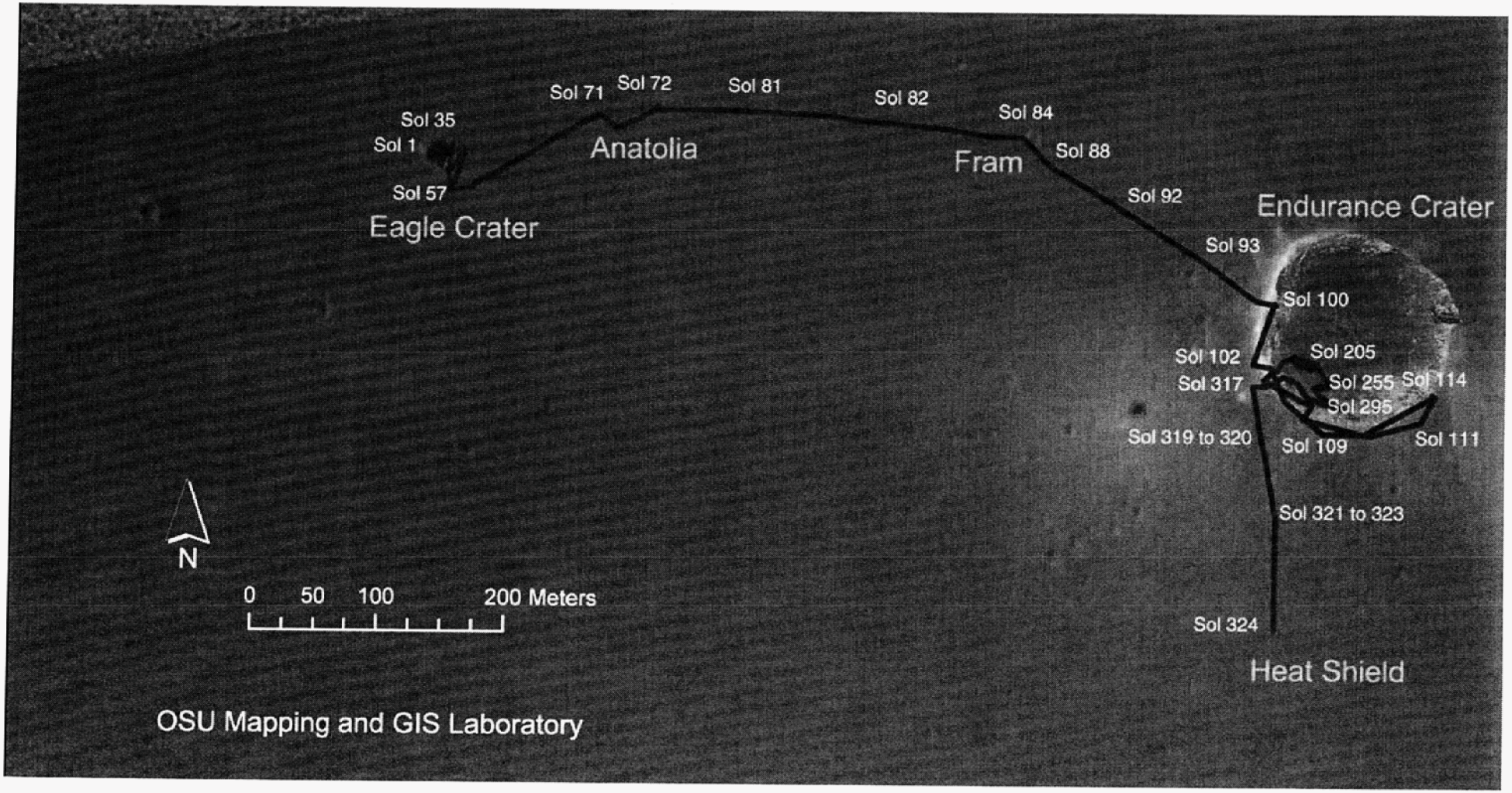


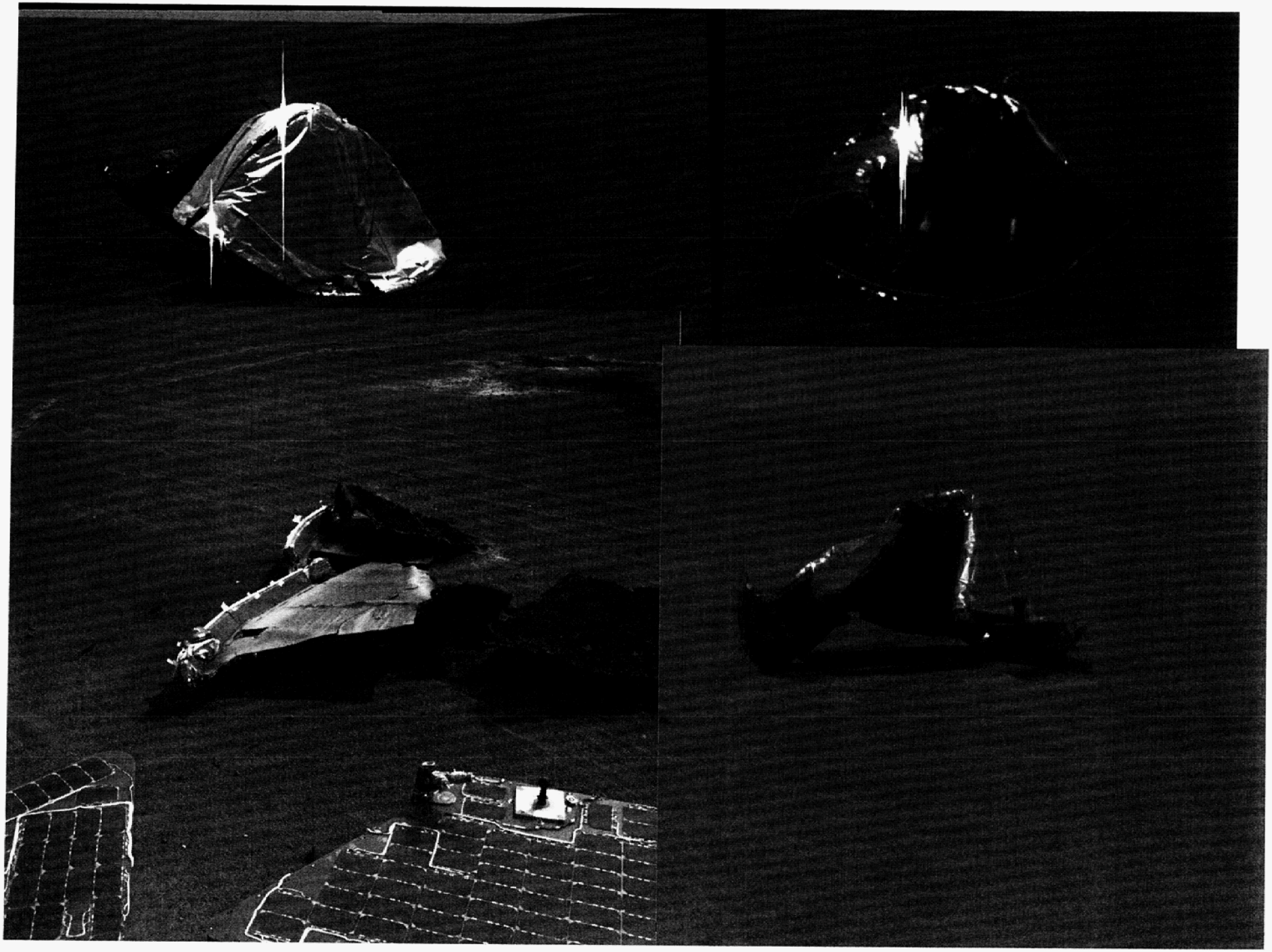




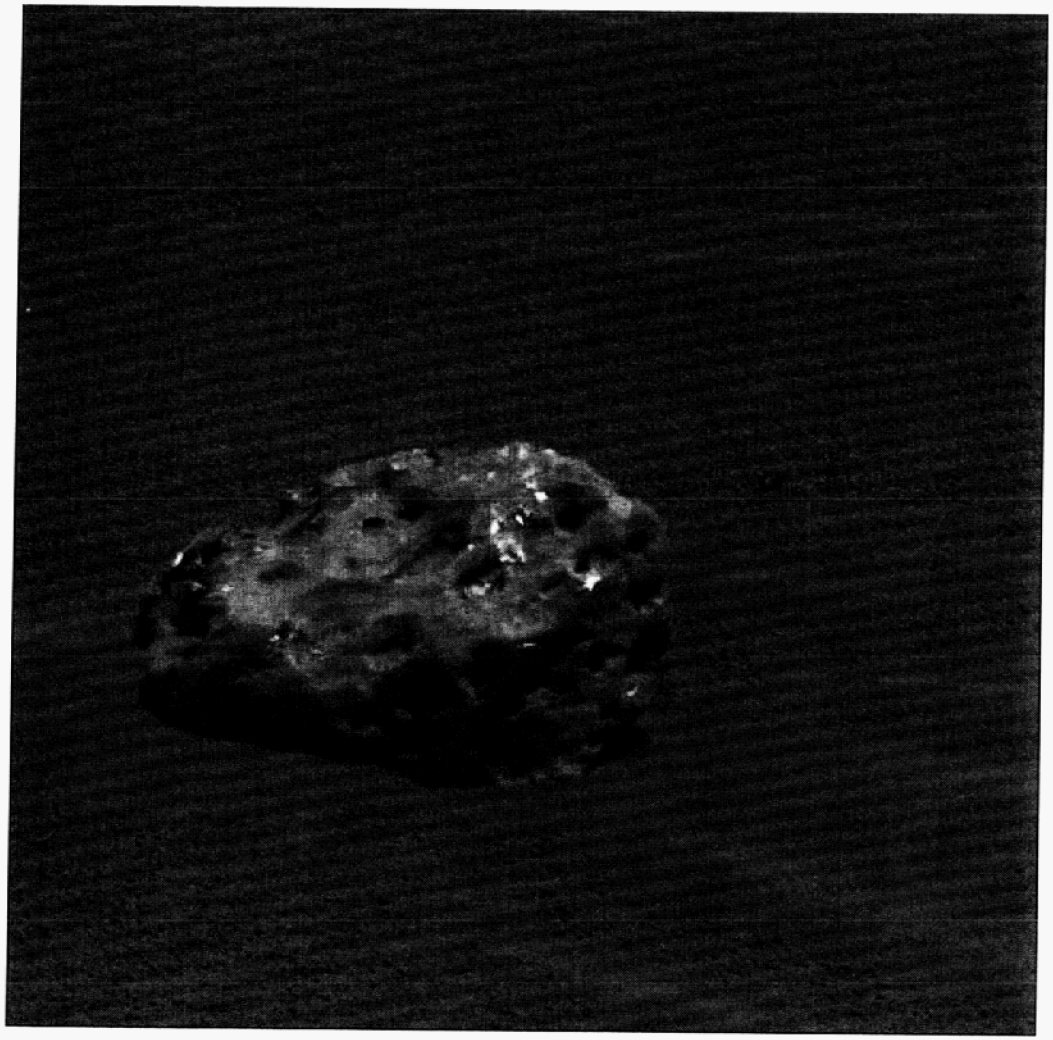
Spirit Landing Site
"Columbia Memorial Station"

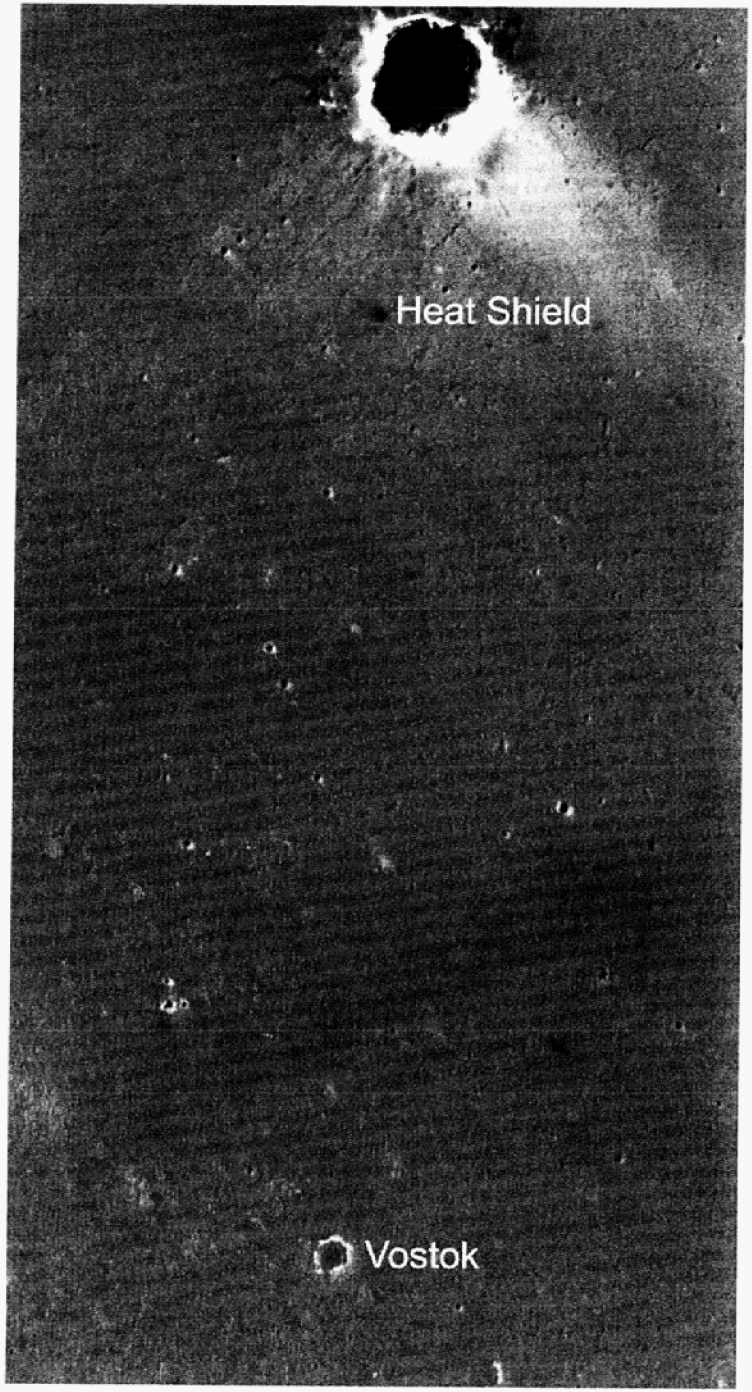
Opportunity Rover Traverse Map (Sol 324)



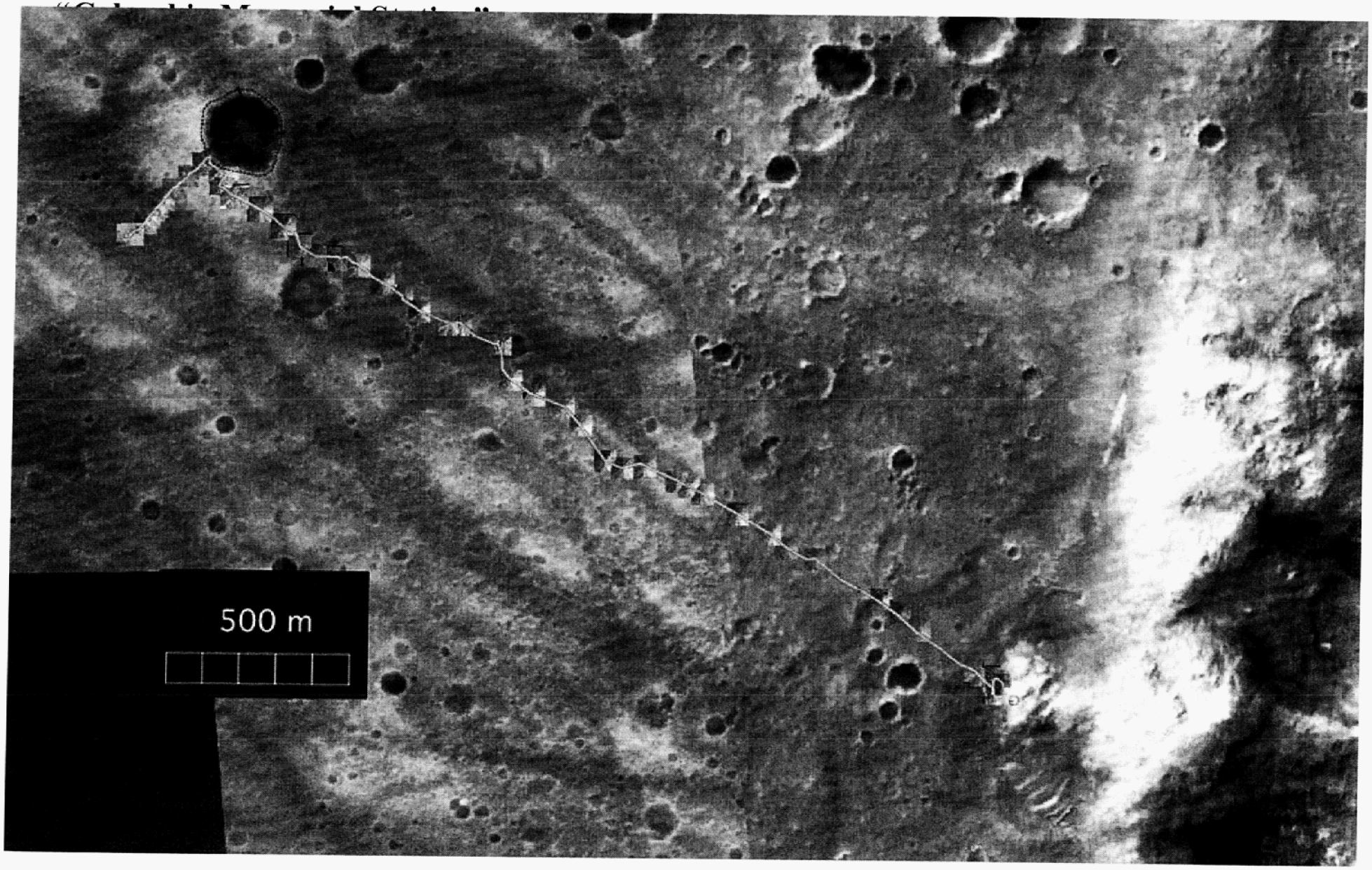


Spirit Landing Site
"Columbia Memorial Station"

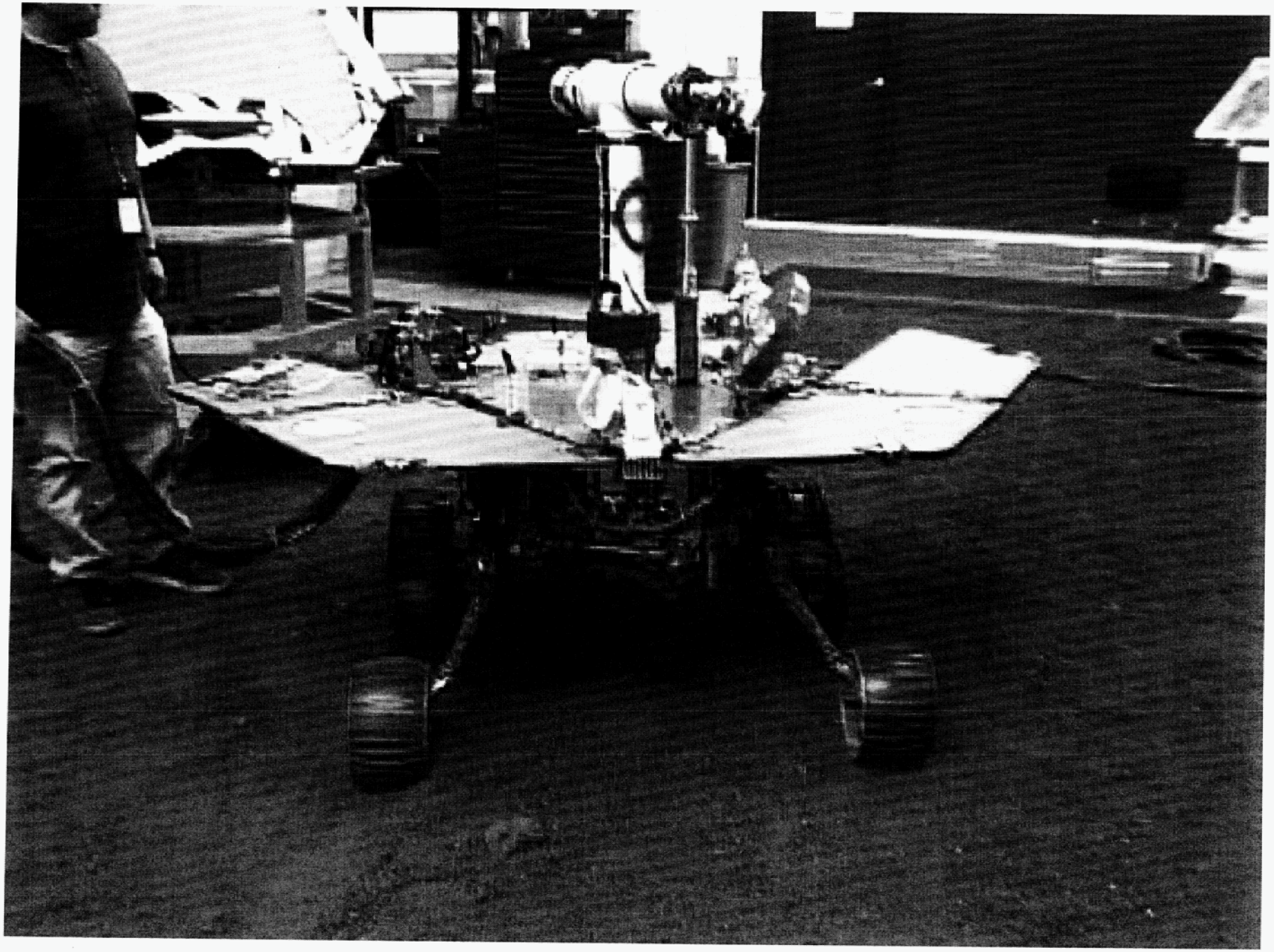


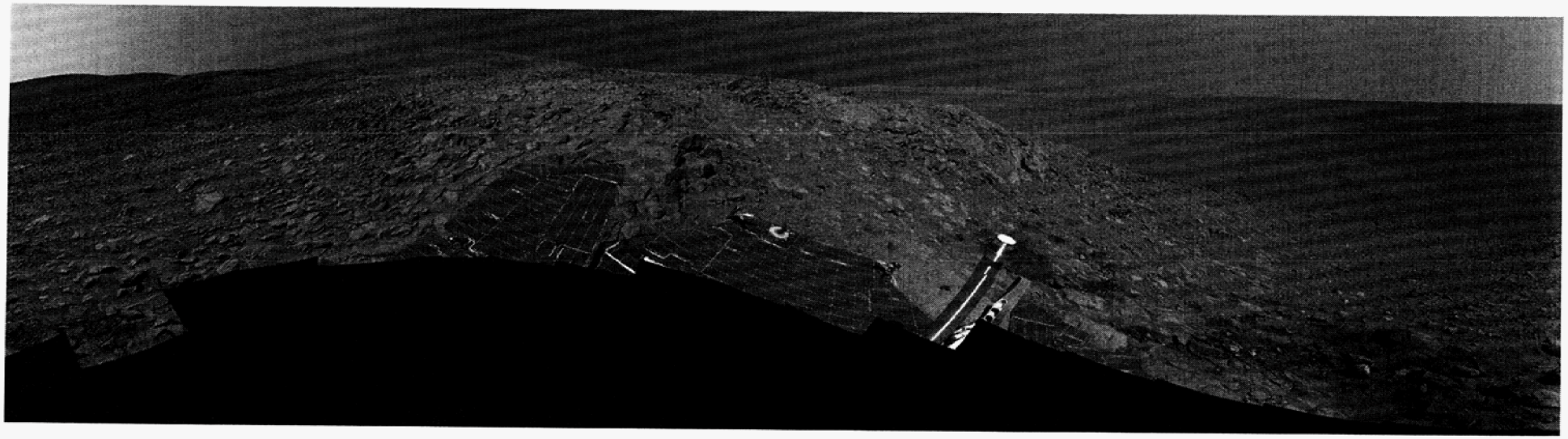


Spirit Landing Site

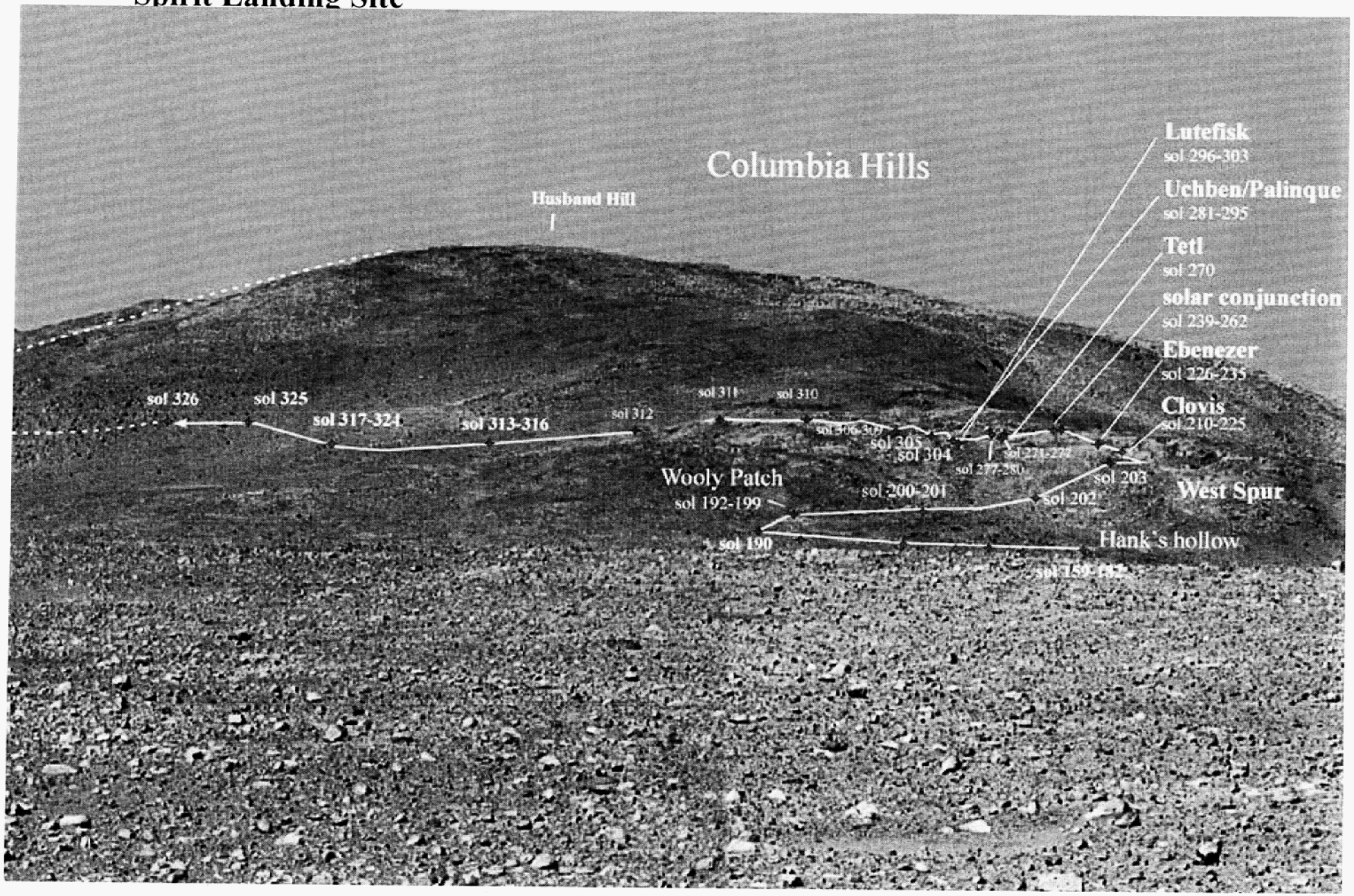


Spirit
Sol 135

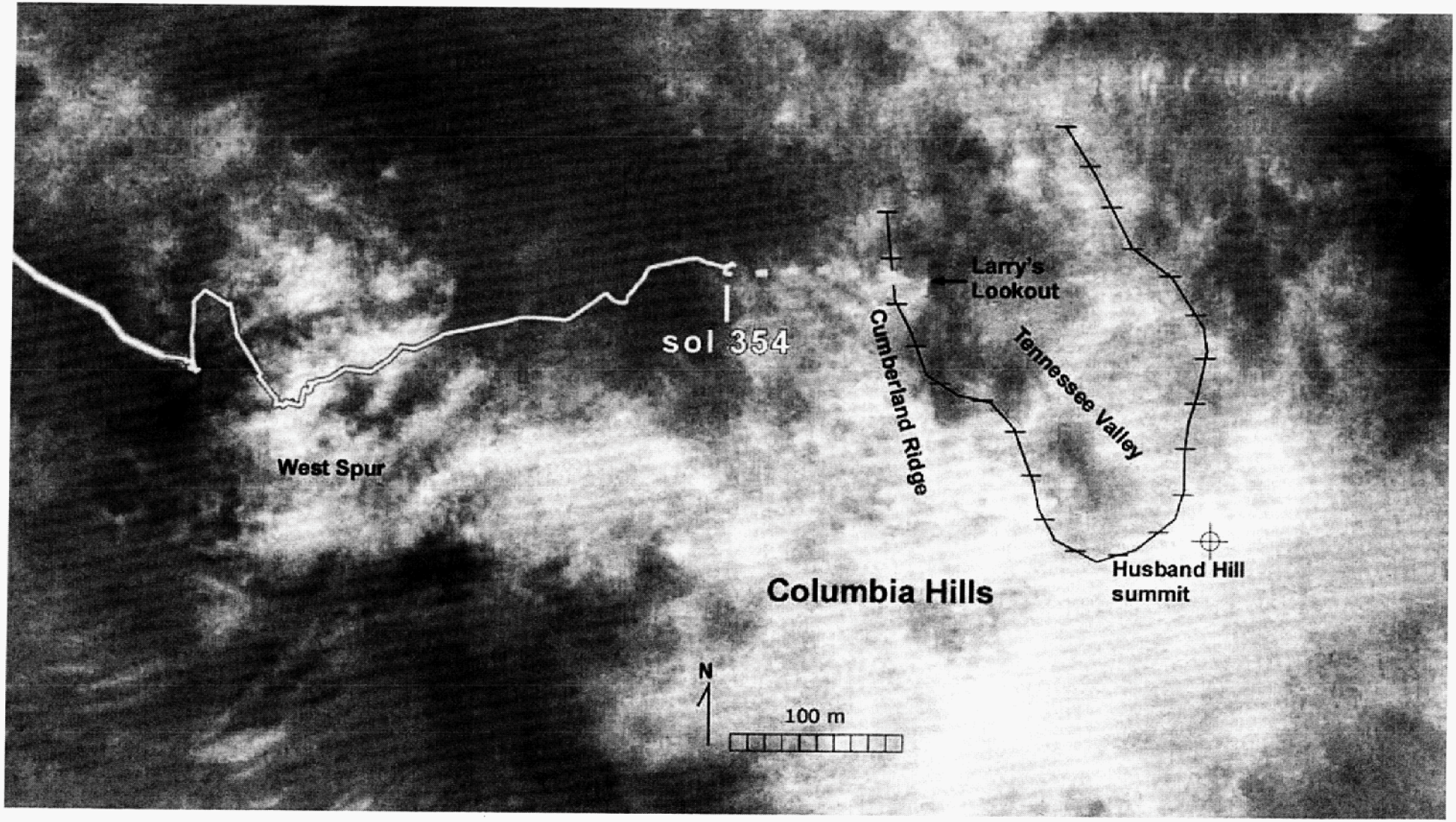




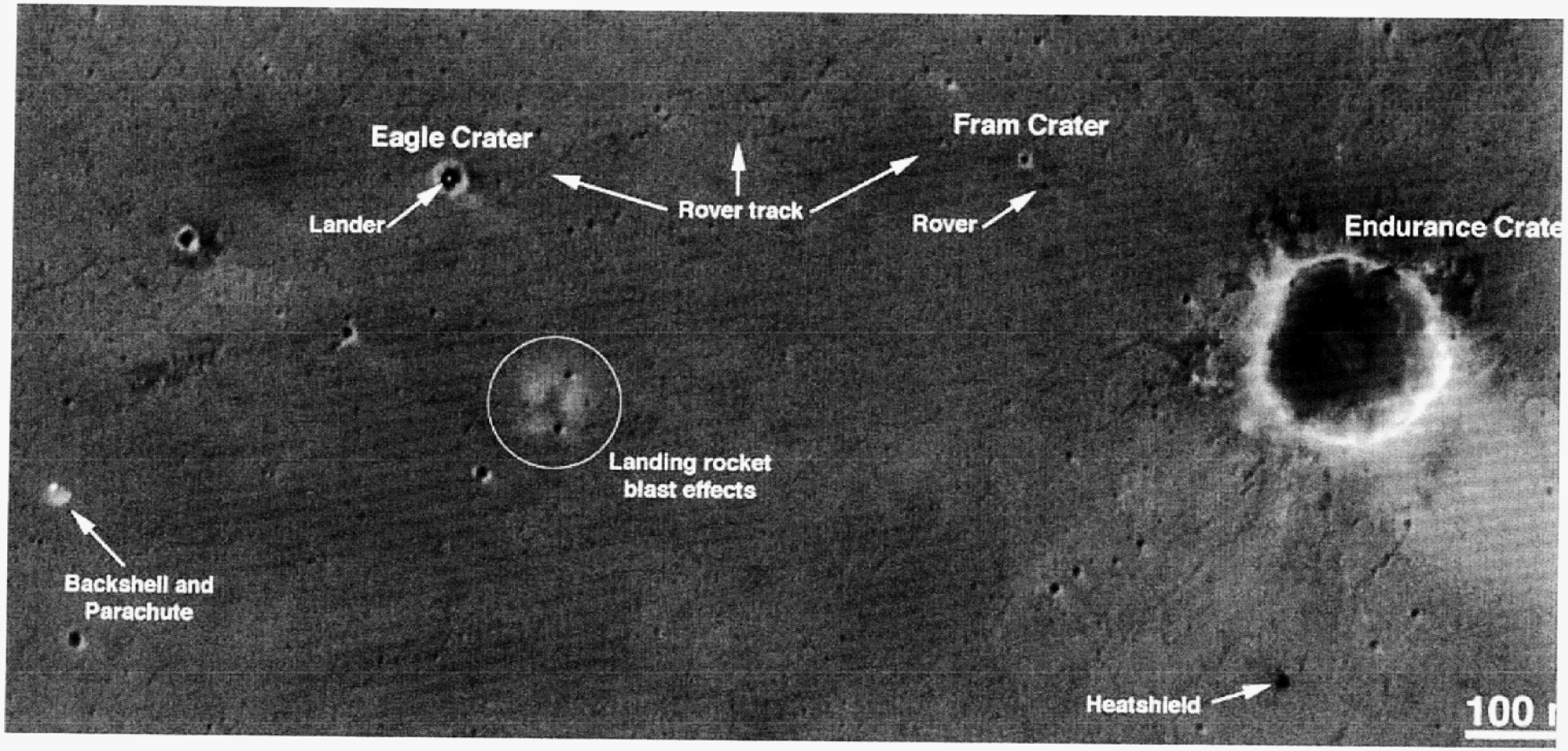
Spirit Landing Site

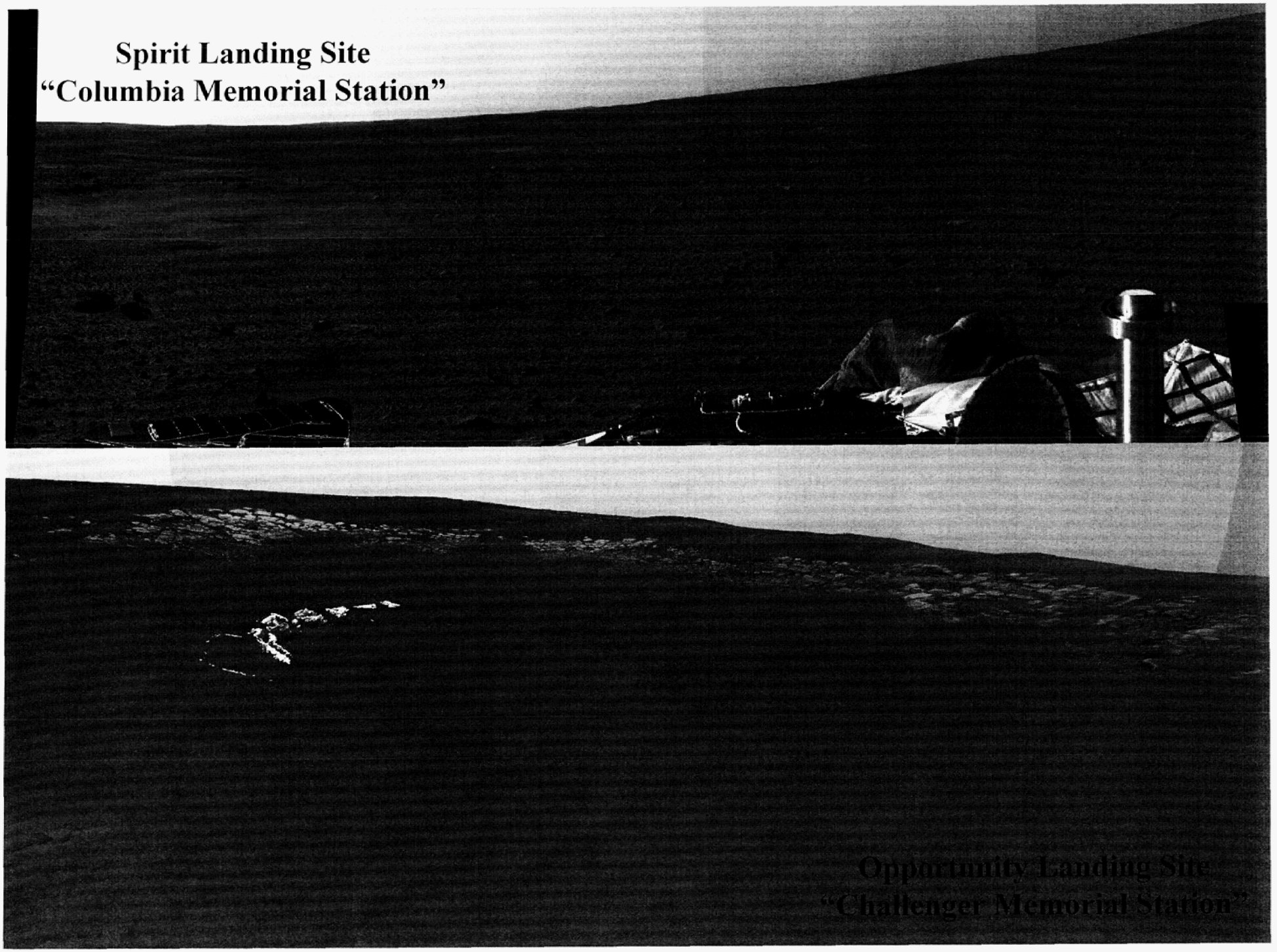


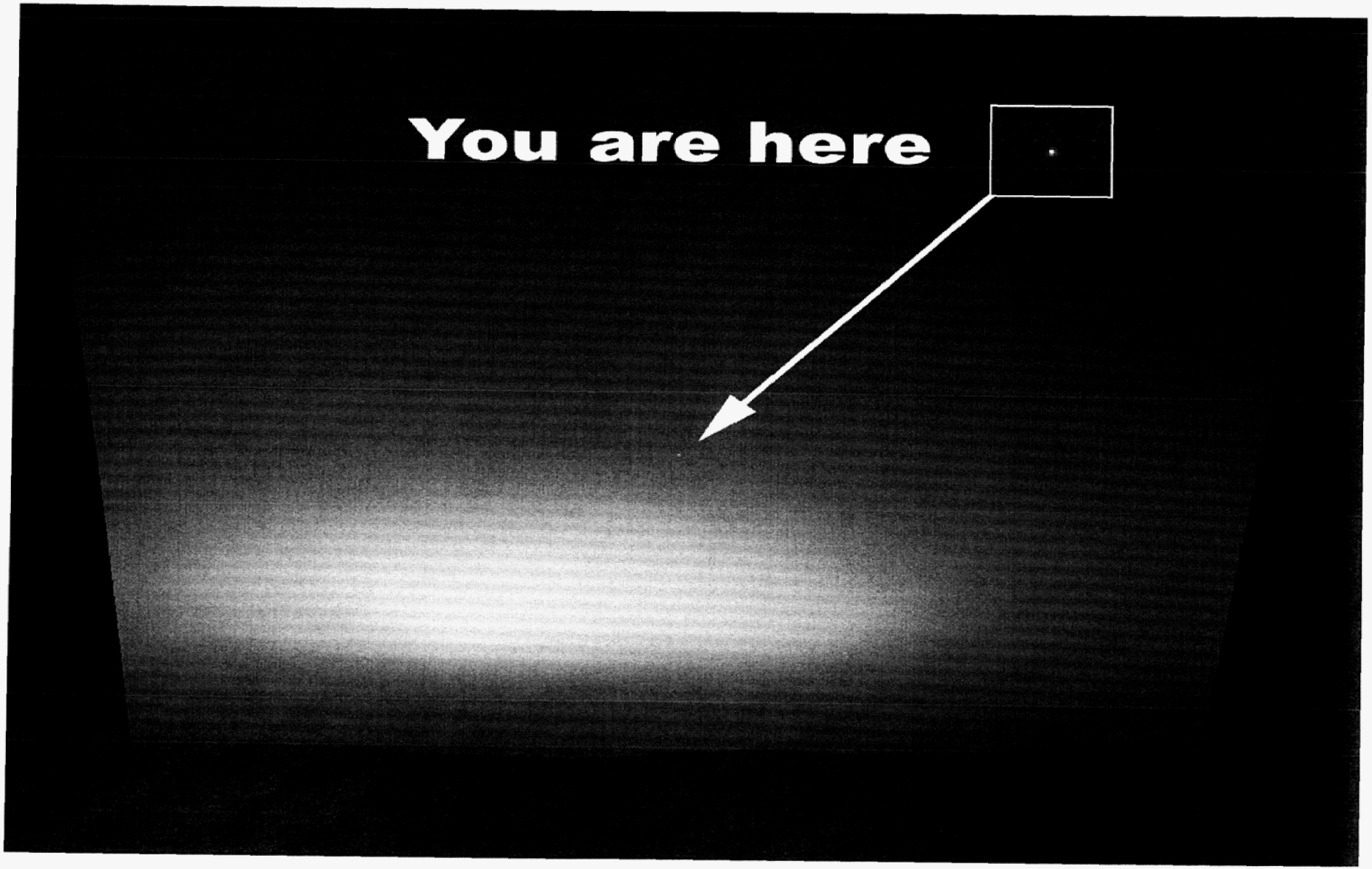
Spirit Landing Site
"Columbia Memorial Station"



Spirit Landing Site
"Columbia Memorial Station"




Spirit Landing Site
"Columbia Memorial Station"
Opportunity Landing Site
"Challenger Memorial Station"

ONE YEAR
ON MARS
MARS EXPLORATION ROVERS

View of Earth from Mars