Astronomy 2202:
“A Spacecraft Tour of the Solar System”

Lecture 5B:
“MSL to Mars 2020”

Fall 2020
MW 9:55 – 11:10 am, RF203
Current & Future Mars Missions

Operational 2001 - 2014

- Mars Odyssey
- ESA Mars Express (NASA: MARSIS)
- Mars Reconnaissance Orbiter

2016

- MAVEN
- ESA Trace Gas Orbiter (NASA: Electra)

2018

- InSight
- ESA ExoMars Rover (NASA: MOMA)

2020

- Science Rover

2022

- Pre-decisional: for Planning and Discussion Purposes Only

Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

Evolving Mars Science Themes
A Multistep Handoff
NASA AND THE EUROPEAN SPACE AGENCY'S PROPOSED PLAN FOR RETURNING SAMPLES FROM MARS

1. Perseverance deposits samples in sealed tubes

2. Fetch rover picks up tubes and takes them to a lander with a small rocket

3. Rocket blasts canister with samples into orbit to be collected by orbiting spacecraft

4. Orbiter heads back to Earth and jettisons sample canister to surface for collection

Pre-decisional: for Planning and Discussion Purposes Only
Proposed History of Mineral Alteration on Mars

Mars Express OMEGA spectrometer mineral detections from orbit indicate:

- **Phyllosilicates** *(clay minerals)* formed in the earliest aqueous environments,
- The surface environment changed
- **Sulfates** formed from later aqueous environments (e.g., evaporation -> salts)
- **Anhydrous ferric oxides** dominate weathering during the last half of Mars history.

Simplified from Fig. 5 of Bibring et al. (2006) *Science*; 312, 400-404.
The First Billion

• Timing of Basin Formation
• Ancient crust
• Volcanism
• Atmosphere
• Aqueous process
  – Fe/Mg phyllosilicate formation
  – Near surface weathering, surface crust hydrothermal
  – Al phyllosilicate formation
• Surface process
  – Carbonate alteration

Graphics: NASA AMES MARS CLIMATE MODELING CENTER
Picture Perfect Landing!

"10 10 10"

MARS OLYMPICS

"...REALLY STUCK THE LANDING!!"
Heat shield separation captured by Curiosity’s Mars Descent Imager
And Our First View of Curiosity
Without the Engineers....

It never would have happened!
Mars Science Laboratory Entry, Descent, Landing

Distance: 2,635.77 miles
Altitude: 1,298.34 miles
Velocity: 11,301 mph
Time to Entry: -00:10:55.8
Time to Touchdown: -00:18:06.4

CRUISE STAGE SEPARATION
CRUISE STAGE SEPARATION -00:00:59.1
Kicking up dust just prior to landing
And Our First View of Curiosity
Curiosity’s primary scientific goal is to explore and to quantitatively assess a local region of the martian surface in terms of its potential for habitability.

- Investigate the geologic potential for habitable environments
- Investigate the chemical and mineralogical potential for habitability
- Inventory the chemical building blocks of life (C, H, N, O, P, and S)
- Assess the diagenetic history of geologic samples
- Characterize present-day contributions to surface weathering
- Determine the nature and inventory of organic carbon compounds
Target: Gale Crater and Mount Sharp
Curiosity’s landing site of Gale crater was selected after consideration of over 50 other landing sites.
155 km diameter Gale Crater straddles the dichotomy boundary, is a local low area
Curiosity’s primary scientific goal is to explore and quantitatively assess a local region on Mars’ surface as a potential habitat for life, past or present

- Biological potential
- Geology and geochemistry
- Water and weather
- Radiation hazards
REMOTE SENSING
Mastcam (M. Malin, MSSS) - Color and telephoto imaging, video, atmospheric opacity
ChemCam (R. Wiens, LANL/CNES) – Chemical composition; remote micro-imaging

CONTACT INSTRUMENTS (ARM)
MAHLI (K. Edgett, MSSS) – Hand-lens color imaging
APXS (R. Gellert, U. Guelph, Canada) - Chemical composition

ANALYTICAL LABORATORY (ROVER BODY)
SAM (P. Mahaffy, GSFC/CNES) - Chemical and isotopic composition, including organics
CheMin (D. Blake, ARC) - Mineralogy

ENVIRONMENTAL CHARACTERIZATION
MARDI (M. Malin, MSSS) - Descent imaging
REMS (J. Gómez-Elvira, CAB, Spain) - Meteorology / UV
RAD (D. Hassler, SwRI) - High-energy radiation
DAN (I. Mitrofanov, IKI, Russia) - Subsurface hydrogen

Rover Width: 2.8 m
Height of Deck: 1.1 m
Ground Clearance: 0.66 m
Height of Mast: 2.2 m
**Arm Functions:**

- Cleans rock surfaces with a brush
- Places and holds the APXS and MAHLI instruments
- Acquires samples of rock or soil with a powdering drill or scoop
- Sieves the samples (to 150 μm or 1 mm) and delivers them to instruments or an observation tray
- Exchanges spare drill bits
150-km Gale Crater contains a 5-km high mound of stratified rock. Strata in the lower section of the mound vary in mineralogy and texture, suggesting that they may have recorded environmental changes over time.
Ancient river and debris fan on crater floor

Water-Related Geology and Minerals around Mount Sharp
Why Gale Crater?

Strata show evidence for diverse sedimentary environments.
Why Gale Crater?

These varied units represent an unknown expanse of time.
Why Gale Crater?

And interaction among (potentially aqueous) environments
“Sheepbed” rocks contain 1 to 5-mm fractures filled with calcium sulfate minerals that precipitated from fluids at low to moderate temperatures.
“Sheepbed” rocks also contain many spherules suggesting that water percolated though pores
MSL’s Ancient Habitable Environment at Yellowknife Bay, Gale Crater

- The regional geology and fine-grained rock suggest that the John Klein site was at the end of an ancient river system or within an intermittently wet lake bed.

- The mineralogy indicates sustained interaction with liquid water that was not too acidic or alkaline, and low salinity. Further, conditions were not strongly oxidizing.

- Key chemical ingredients for life are present, such as carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur.

- The presence of minerals in various states or oxidation would provide a source of energy for primitive biology.
Success! We’re on our way.
Curiosity’s ultimate goal is to explore the lower reaches of the 5-km high Mount Sharp.
Earth as a bright evening star, from Gale Crater, sol 529, 80 minutes after sunset
It is estimated that both Earth and Moon would be visible from Mars to a human observer with normal vision.
Mars 2020 Looks Like Curiosity

Similar, but different…
Mars 2020 Rover Concept

Stays the Same as MSL
- Avionics
- Power
- GN&C
- Telecom
- Thermal
- Mobility

Changed
- New Science Instrument Suite
- New Sampling Caching System
- Modified Chassis
- Modified Rover Harness
- Modified Surface FSW
- Modified Rover Motor Controller
- Modified Wheels

Expected to Change
- Some Mobility components (to support wheel and/or Rover mass)
Mars 2020

- new science instruments
- new wheels
- new engineering cameras
- enhanced autonomy capabilities
- 5 hour ops timeline
- enhanced EDL cameras
- enhanced EDL capabilities
- helicopter (still being assessed)
Mission Overview

LAUNCH
- Atlas V 541 vehicle
- Launch Readiness Date: July 2020
- Launch window: July/August 2020

CRUISE/APPROACH
- ~7 month cruise
- Arrive Feb 2021

ENTRY, DESCENT & LANDING
- MSL EDL system (+ Range Trigger and Terrain Relative Navigation): guided entry and powered descent/Sky Crane
- 16 x 14 km landing ellipse (range trigger baselined)
- Access to landing sites ±30° latitude, ≤ -0.5 km elevation
- Curiosity-class Rover

SURFACE MISSION
- 20 km traverse distance capability
- Enhanced surface productivity
- Qualified to 1.5 Martian year lifetime
- Seeking signs of past life
- Returnable cache of samples
- Prepare for human exploration of Mars

## Mars 2020 Mission Objectives

### GEOLOGIC EXPLORATION
- Explore an ancient environment on Mars
- Understand processes of formation and alteration

### HABITABILITY AND BIOSIGNATURES
- Assess habitability of ancient environment
- Seek evidence of past life
- Select sampling locations with high biosignature preservation potential

### PREPARE A RETURNABLE CACHE
- Capability to collect ~40 samples and blanks, 20 in prime mission
- Include geologic diversity
- Deposit samples on the surface for possible return

### PREPARE FOR HUMAN EXPLORATION
- Measure temperature, humidity, wind, and dust environment
- Demonstrate In Situ Resource Utilization by converting atmospheric CO\(_2\) to O\(_2\)

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**see backup for formal wording**

The Mars 2020 Mission

A new type of planetary mission in which exploration supports sampling
What Mars 2020 science is not...

MSL exploration + *Mars Sample Return with the same rover and a lower budget

*possible
What Mars 2020 science is...

We will use our payload to explore a new region of Mars, and to support the selection of samples that, if successfully returned to Earth, would provide material for generations of planetary scientists.
For previous (and existing) Mars rover missions, *sampling supported exploration*.

For Mars 2020, the first step towards *Mars sample return*, *exploration supports sampling*.

*This transition is analogous to the evolution of terrestrial geological/geochemical investigations as knowledge of the study area grows*
Balancing exploration and sampling

We must strive to maximize operational efficiencies using innovative and strategic approaches wherever possible.

But… some of the scientific process is incompressible.

As we approach a target (e.g. orbital data > remote science > proximity science), information increases, and interpretations evolve.

The science team must arrive at Mars highly trained, nimble, and disciplined - ready to support extremely rapid data generation and dissemination, and

ready to make hard decisions quickly.
The project system shall have the capability to perform the following Baseline Reference Scenario (BRS) surface mission within 1.25 Mars years (836 sols), which includes the following:

- Conduct the investigations required to meet science objectives A and B and meet technology objective D
- Explore 2 Regions Of Interest (ROI)
  - 6 km of long traverse to achieve
  - 2 science campaigns per ROI
  - 1.5 km of local traverse to explore
  - Acquiring 9 cached samples per ROI, consisting of 7 Mars rock / regolith samples and 2 witness blank samples
- Acquire 2 rock and/or regolith “waypoint” samples
- Single Cache Depot at a location near ROI #2
Sampling & Caching Subsystem (SCS)

- Adaptive Caching Assembly (ACA) (internal to Rover)
- Bit Carousel (part of ACA)
- Robotic Arm
- Turret:
  - Coring drill
  - SHERLOC / WATSON Instrument
  - PIXL Instrument
- Caching Assembly
  ~ 42 sample tubes

Mars 2020 Project

Mars 2020 Payload Family Picture

Instrument Key

- **Mastcam-Z**: Stereo Imager
- **MEDA**: Mars Environmental Measurement
- **MOXIE**: In-Situ Oxygen Production
- **PIXL**: Microfocus X-ray fluorescence spectrometer
- **RIMFAX**: Ground Penetrating Radar
- **SHERLOC**: Fluorescence and Raman spectrometer and Visible context imaging
- **SuperCam**: LIBS and Raman
Mars 2020 Rover

- RIMFAX Electronics
- SHERLOC Electronics
- SuperCam Calibration Target
- Mastcam-Z Calibration Target
- RIMFAX Antenna
- SuperCam Body Unit
- MOXIE
- MEDA Thermal Infrared Sensors
- 3 x MEDA Air Temperature Sensors
- MEDA Electronics & Pressure Sensor
- MEDA Radiation & Dust Sensor
- SuperCam Mast Unit
- 2 x Mastcam-Z Camera
- 2 x MEDA Wind Sensors
- PIXL Sensor
- SHERLOC Sensor
- SHERLOC Calibration Target
- PIXL Calibration Target
- PIXL Electronics
- Mastcam-Z Digital Electronics Assembly
- 2 x MEDA Air Temperature Sensors
Mars 2020

Total cameras: 23
Engineering cameras: 9
Science cameras: 7
Entry, descent and landing cameras: 7
Coring and Sample Tube

Coring Bit

Hermetically sealed sample tube

Core
~ 5 cm long x
~ 1 cm diameter
~ 15 grams

Landing Site Selection

JEZERO
- Deltaic/lacustrine deposition with possible igneous unit and hydrous alteration
- Minerologic diversity including clays and carbonates
- Shallow water carbonates?

NE SYRTIS
- Extremely ancient igneous, hydrothermal, and sedimentary environments
- High mineralogic diversity with phyllosilicates, sulfates, carbonates, olivine
- Possible serpentinization and subsurface habitability

COLUMBIA HILLS
- Carbonate, sulfate, and silica-rich outcrops of possible hydrothermal origin. Hesperian volcanics.
- Potential biosignatures identified
- Previously explored by MER

Go to https://marsnext.jpl.nasa.gov/index.cfm for more information
Isidis Basin
Early/Mid Noachian
(~3.96 Ga, Werner, 2005)

Syrtis Major
Early Hesperian

Syrtis Major Landing Ellipse

Nilli Fossae graben

Jezero Crater

Isidis Basin
Early/Mid Noachian
(~3.96 Ga, Werner, 2005)

after Hogan LSWG ‘16
Meeting Mars 2020 Science Criteria

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

- Paleolake with sedimentary carbonate and Fe/Mg-smectites indicates a likely habitable standing body of water with circumneutral pH conditions [Ehlmann et al., 2008a; Goudge et al., 2015].

- Deltaic and lacustrine sediment is an excellent site for concentration and preservation of organic matter [Summons et al., 2011].
Jezero Crater Paleolake

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

HRSC topography overlain on CTX mosaic.
Jezero Delta Deposits

Inlet Valleys

Outlet Valley

W Delta

N Delta (portion)
LAND ON SCIENCE


Western Delta

Volcanic Floor Unit

Basin Fill

Western Delta Remnants

Basin Fill
Regional Carbonate Unit

• Jezero carbonate is an in situ example of regional unit first mapped by Ehlmann et al. [2008b] [Goudge et al., 2015].

• Carbonate is hypothesized to have formed from aqueous alteration of associated olivine-rich material [e.g., Ehlmann et al., 2008b, 2009; Mustard et al., 2009].

• Hypotheses for origin of protolith olivine unit include:
  • Isidis impact melt sheet [Mustard et al., 2007, 2009].
  • Basaltic lava flows [Hamilton and Christensen, 2005].
  • Exposure of a subsurface layer [Hoefen et al., 2003].
OM Preservation in Delta Deposits

- Organic matter is often highly concentrated and well preserved in offshore deltaic environments [Huc, 1988; Summons et al., 2011].

- Smectite clays have the ability to bind and stabilize organic matter [Wattel-Koekkoek et al., 2001; Kennedy et al., 2002; Ehlmann et al., 2008a].

- Fe/Mg-smectite-rich delta bottomsets at Jezero crater provide ideal location to explore for preserved martian organic carbon.
Jezero Crater Summary

PROS

• Evidence for likely **habitable, lacustrine environment** with preserved volcanic, alteration mineral-bearing (smectite + carbonate), and fluvio-lacustrine units in a **well defined stratigraphy**.

• **Sink for regional sediment** – ability to examine and cache samples from one of the most alteration-mineral-rich regions on Mars.

• Delta exposure at edge of ellipse – well exposed deltaic bottomsets – **excellent accumulation and preservation potential for organics**!

CONS

• Potential terrain issues - dunes abutting delta front may prohibit access, volcanic scarps may be difficult to navigate, etc.

• others....??
NE Syrtis Major
The Key to Unlocking the First 0.5 Gya of Mars’ History

Compelling Mars and Astrobiology Land-on Science

• Bedrock strata in-situ representing four distinct environments of aqueous alteration where reactants and products are together
  – early crustal: creation or distribution by impact? Phyllosilicate formation
  – carbonate/serpentine: surface alteration or hydrothermal?
  – layered phyllosilicates (Al- over Fe/Mg)
  – sedimentary sulfate formation

• A record of aqueous low-T geochemistry preserved in-situ, in mineral-bearing strata, distinct in age, primary mineralogy, and geologic setting well-suited for the M2020 measurements and caching

• Key stratigraphies from Noachian and Hesperian eras

• Hydrothermal, pedogenic and sedimentary environments

• Multiple, diverse igneous units of distinct age
Regional Stratigraphy provides the context for in-ellipse and go-to science

Morphgeologic mapping establishes the local stratigraphy tied to the regional stratigraphy

Ehlmann and Mustard GRL 2013
Mesa Package Stratigraphy

Topographic Profile from CTX DEM
Mesa Package Stratigraphy

Topographic Profile from CTX DEM
Numbered regions of interest corresponding with subsequent slides
Region of Interest

#1
Region of Interest

#2
Region of Interest

#2

- Crater-retaining cap unit
- Linear features and fractures
- Rounded megabreccia
- Olivine-carbonate mesa basal unit
- Crustal knob
- Raised ridge

Scale: 200 m
Region of Interest

#4
Region of Interest

#6

200 m
Region of Interest

- Banded olivine-carbonate mesa basal unit
- Crater-retaining cap unit
- Younger crater
- Crustal units
- Light-toned basement breccia blocks
- Fracturing (some with light-toned edges)
- Recessive linear ridge into crustal units with light-toned internal blocks
- Banded olivine-carbonate mesa basal unit

Scale: 200 m
“Midway”

- Safe landing ellipse featuring NE Syrtis-type terrain located as close as possible to Jezero Crater?
Jezero to Midway traverse

Gusev Crater’s Columbia Hills: A Summary of Key Literature

Bethany Ehlmann for Mars2020 LSWG
7 March 2016
Columbia Hills allow interrogating ~82m of section

http://mars.nasa.gov/mer/gallery/press/spirit/20050901d/SQUYRES_1_Statue-A591R1.jpg
Interesting Materials in the Columbia Hills

• Alkaline volcanic rocks
• Igneous diversity, including likely ashes
• Units likely enriched in Al-clays
• Units with 15-30% Mg-carbonate
• Units with 50-75% silica
• Soils with silica (up to 90%; Kenosha Comets target) and ferric sulfates
Morris et al., 2008, JGR

Fe Mineralogy of Gusev Crater Soils

Fe Mineralogy of Gusev Crater Rocks
### Table 1
List of the martian impact basins, and the resulting ages from this study.

<table>
<thead>
<tr>
<th>Name</th>
<th>Age in Ga (± uncertainty)</th>
<th>Chronology uncertainty</th>
<th>(N(D \geq 1,\text{km}))</th>
<th>(N(D \geq 10,\text{km}))</th>
<th>(N(D \geq 200,\text{km}))</th>
<th>Area in (\text{km}^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gusev</td>
<td>(4.02 \pm 0.02)</td>
<td>4.12</td>
<td>0.0424</td>
<td>6.06e-4</td>
<td>8.90e-7</td>
<td>40957</td>
</tr>
</tbody>
</table>

(Werner, 2009, *Icarus*)
Columbia Hills Comanche Carbonates: The Data

41% olivine \((\text{Mg}_{0.72}\text{Fe}_{0.28})_2\text{SiO}_4\)

16-34% carbonate \((\text{Mg}_{0.62}\text{Fe}_{0.25}\text{Ca}_{0.11}\text{Mn}_{0.02})\text{CO}_3\)

~5% hematite \(\text{Fe}_2\text{O}_3\)

~30% residue (silica-rich, non-crystalline iron bearing phases) (62% SiO\(_2\), 10% Fe\(_2\)O\(_3\), 8% Al\(_2\)O\(_3\), 8% SO\(_3\))

*Morris et al., 2010, Science*
Comanche Carbonate-rich Outcrops

Mg-Fe carbonates up to ~30 wt% are hydrothermal in origin [Morris et al., 2010]

or are lacustrine evaporites [Ruff et al., 2014]

from S. Ruff, 2nd wkshp pres.
Silica rich rocks

Figure 23. MI mosaic (sol 1157) of silica-rich nodular outcrop Elizabeth Mahon. White rectangle indicates an enlarged portion shown in Figure 24. Color inset is a portion of a Pancam approximate true-color image (sol 1160, P2582) with the area of the MI scene outlined in black. Digitate protrusions and porous texture are common features of the silica-rich nodular outcrops. MI scene is ~5 cm across.

Figure 24. Portion of the Elizabeth Mahon MI mosaic shown in Figure 23. Black arrow depicts the apparent motion of a chunk of silica-rich rock after it broke away from the larger mass. It exposes a porous, sponge-like texture on the surface below that probably is more pristine than the digitate protrusions apparently smoothed by aeolian abrasion (white arrows). Scene is ~2.5 cm across.
Sol 1160 Pancam ATC Elizabeth Mahon

Digitate protrusions

Erosional or primary feature?

Primary feature Microbially mediated?

Filamentous bacteria

Diatoms

El Tatio, Chile hot spring discharge channel

from S. Ruff, 2nd wkshp pres.
Columbia Hills, Gusev Crater site

• To what extent do materials accessible represent lake sediments vs. other geologic processes?
  – If evaporite carbonate-rich lake, then preserves alkaline body of water in mid Noachian to early Hesperian
  – If carbonates are instead hydrothermal, then indicate processes related to ground water in mid Noachian to early Hesperian

• To what extent are the forms and structure of silica-rich rocks uniquely indicative of (a) a hydrothermal sinter and (b) a biologically-mediated deposits?
  – What you think about the answer to this question likely directly correlates with how you view the attractiveness of returning to Gusev as Mars2020’s landing site

• To what extent can the context and timing of events in the Columbia Hills to relate to events elsewhere on Mars?
  – Timing constraint is post-Gusev (<4.1 Ga) and pre-Adirondack plains basalt (>3.65 Ga)
  – Stratigraphy is small-scale and cannot be further correlated in time with other globally significant units. If returned, samples could provide absolute dates of different units

• To what extent can Mars2020, with its in situ package of instruments, learn more than MER Spirit vs. science advances waiting for the return of samples?
  – MER: in-situ chemistry (major, minor); IR emission spectrometry for silicates, carbonates, sulfates; microscopic imaging; *Fe-oxidation state*
  – MER: in-situ chemistry (major, minor, trace); IR VSWIR and Raman spectrometry for silicates, carbonates, sulfates (*likely superior mineral discrimination within class; small-scale petrologic relationships*); organics detection
Criterion 1:
The site is an astrobiologically-relevant ancient environment and has geologic diversity that has the potential to yield fundamental scientific discoveries when it is a) characterized for the processes that formed and modified the geologic record; and b) subjected to astrobiologically-relevant investigations (e.g., assessment of habitability and biosignature preservation potential). (scoring: 1=lowest potential, 5=highest potential)

Criterion 2:
A rigorously documented and returnable cache of rock and regolith samples assembled at the site has the potential to yield fundamental scientific discoveries if returned to Earth in the future. (scoring: 1=lowest potential, 5=highest potential)

Criterion 3:
There is high confidence in the assumptions, evidence, and any interpretive models that support the assessments for Criteria 1 and 2 for the site. (scoring: 1=lowest confidence, 5=highest confidence).

Criterion 4:
There is high confidence that the highest-science-value regions of interest at the site can be adequately investigated in pursuit of Criteria 1 and 2 within the prime mission. (scoring: 1=lowest confidence, 5=highest confidence).

Criterion 5:
The site has high potential for significant water resources that may be of use for future exploration—whether in the form of water-rich hydrated minerals, ice/ice regolith or subsurface ice. (scoring: 1=lowest potential, 5=highest potential).
Threshold Geological Criteria

1. Presence of subaqueous sediments or hydrothermal sediments (equal 1st priority), OR
   hydrothermally altered rocks or low-T fluid-altered rocks (equal 2nd priority)
2. Presence of minerals indicative of aqueous phases (e.g., phyllosilicates, carbonates, sulfates, etc.) in outcrop
3. Noachian/Early Hesperian age based on stratigraphic relations and/or crater counts
4. Access to unaltered igneous rocks as float
5. Not a Special Region

Potential Qualifying Geological Criteria:

1. Morphological evidence for standing bodies of water and/or fluvial activity (deltaic deposits, shorelines, etc.).
3. Presence of former water ice, glacial activity or its deposits.
4. Igneous rocks of Noachian age, of known stratigraphic relation, better if including exhumed megabreccia.
5. Volcanic unit of Hesperian or Amazonian age well-defined by crater counts and well-identified by morphology and/or mineralogy.
6. Probability of samples of opportunity (ejecta breccia, mantle xenoliths, etc.).
7. Potential for resources for future human mission.