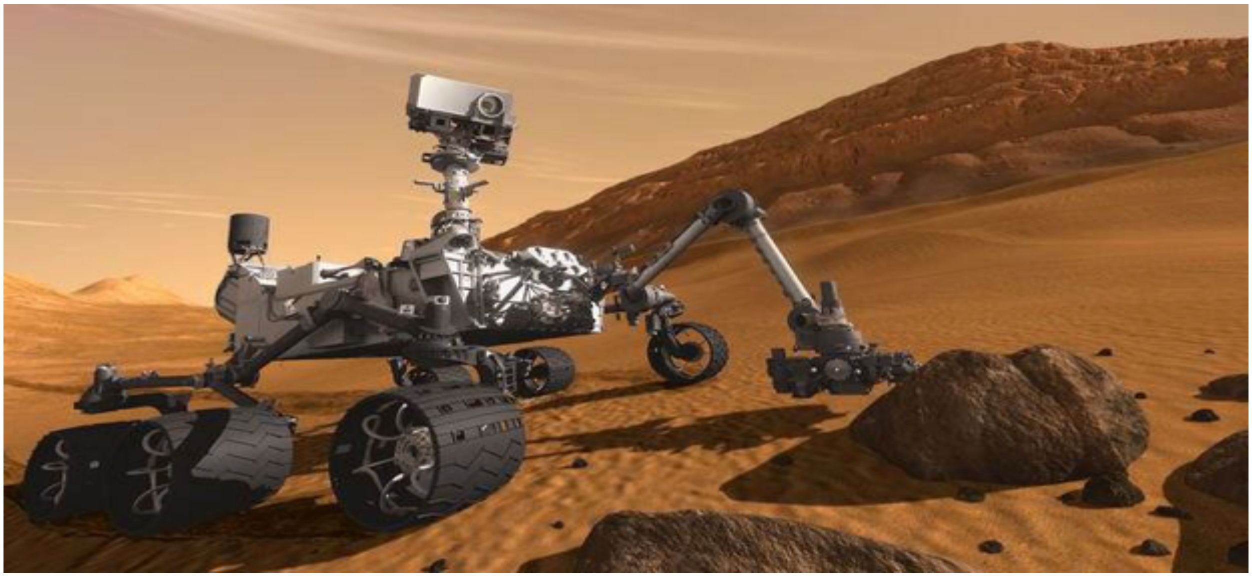
National Aeronautics and Space Administration

Mars Activity

Curiosity Landing Site Selection

Grades: 6-12 Prep Time: ~10 Minutes Lesson Time: ~100 Minutes



WHAT STUDENTS DO: Investigate Curiosity Landing Sites

In this activity, students investigate the four proposed landing sites for Curiosity rover as one of three experts: Mineralogist, Geomorphologist, or Engineer. Through individual and group work, discussions, and debate, teams propose which landing site is the best site for landing the rover safely and for the best scientific yield.

NRC CORE & COMPONENT QUESTIONS	INSTRUCTIONAL OBJECTIVES
HOW DO ENGINEERS SOLVE PROBLEMS? *NRC Core Question: ETS1: Engineering Design*	*Students will be able*
HOW ARE ENGINEERING, TECHNOLOGY, SCIENCE, AND SOCIETY INTERCONNECTED? *NRC Core Question: ETS:2 Links Among Engineering, Technology, Science, and Society*	
What Is a Design for? What are the criteria and constraints of a successful solution? *NRC ETS1.A: Defining & Delimiting an Engineering Problem*	**IO1: to evaluate** proposed landing sites using criteria
What Is the Process for Developing Potential Design Solutions? *NRC ETS1.B: Developing Possible Solutions*	

What are the relationships among science, engineering, and technology?

NRC Component Question: ETS2A: Interdependence of Science, Engineering, and Technology

1.0 About This Activity

Mars lessons leverage *A Taxonomy for Learning, Teaching, and Assessing* by Anderson and Krathwohl (2001) (see *Section 4* and *Teacher Guide* at the end of this document). This taxonomy provides a framework to help organize and align learning objectives, activities, and assessments. The taxonomy has two dimensions. The first dimension, cognitive process, provides categories for classifying lesson objectives along a continuum, at increasingly higher levels of thinking; these verbs allow educators to align their instructional objectives and assessments of learning outcomes to an appropriate level in the framework in order to build and support student cognitive processes. The second dimension, knowledge, allows educators to place objectives along a scale from concrete to abstract. By employing Anderson and Krathwohl's (2001) taxonomy, educators can better understand the construction of instructional objectives and learning outcomes in terms of the types of student knowledge and cognitive processes they intend to support. All activities provide a mapping to this taxonomy in the Teacher Guide (at the end of this lesson), which carries additional educator resources. Combined with the aforementioned taxonomy, the lesson design also draws upon Miller, Linn, and Gronlund's (2009) methods for (a) constructing a general, overarching, instructional objective with specific, supporting, and measurable learning outcomes that help assure the instructional objective is met, and (b) appropriately assessing student performance in the intended learning-outcome areas through rubrics and other measures. Construction of rubrics also draws upon Lanz's (2004) guidance, designed to measure science achievement.

How Students Learn: Science in the Classroom (Donovan & Bransford, 2005) advocates the use of a research-based instructional model for improving students' grasp of central science concepts. Based on conceptual-change theory in science education, the 5E Instructional Model (BSCS, 2006) includes five steps for teaching and learning: Engage, Explore, Explain, Elaborate, and Evaluate. The Engage stage is used like a traditional warm-up to pique student curiosity, interest, and other motivation-related behaviors and to assess students' prior knowledge. The Explore step allows students to deepen their understanding and challenges existing preconceptions and misconceptions, offering alternative explanations that help them form new schemata. In Explain, students communicate what they have learned, illustrating initial conceptual change. The Elaborate phase gives students the opportunity to apply their newfound knowledge to novel situations and supports the reinforcement of new schemata or its transfer. Finally, the Evaluate stage serves as a time for students' own formative assessment, as well as for educators' diagnosis of areas of confusion and differentiation of further instruction. This five-part sequence is the organizing tool for the Mars instructional series. The 5E stages can be cyclical and iterative.

2.0 Materials

Required Materials

Print and Laminate:

From Student Guide:

(A) Expert Cards	1 per team of 6
(B) Landing Site Selection Guides Site 1	1 per team of 6
(C) Landing Site Selection Guides Site 2	1 per team of 6
(D) Landing Site Selection Guides Site 3	1 per team of 6
(E) Landing Site Selection Guides Site 4	1 per team of 6

Print from Student Guide:

(F) Landing Site Selection Sheet	1 per student
(G) Expert Group Meeting Sheet	1 per student
(H) Reflection	1 per student

3.0 Vocabulary

***Please Note!** Many of the terms listed here are also defined on the *(A) Expert Cards* for students to use during the lesson.

Alluvial Fan landform. A fan-shaped collection of sediment deposited by a river when its flow is suddenly slowed.

Anhydrous a substance that does not contain any water

Aqueous containing water

Biosignature a physical and/or chemical marker of life that does not occur through random processes or human intervention

Canyon landform. A long tube or ravine, usually formed by a river that erodes the sides of a valley

Clay often indicates the past presence of water, since clay frequently forms in a water-rich environment

Climate Conditions a summary of weather conditions over time, includes items such as temperature, humidity, rainfall, etc.

Context Image a picture of the area around the possible landing site that provides a more regional view than the **zoom image**

Crater a circular depression (hole in the ground) with a raised rim, formed by a meteoroid hitting a planet

Delta landform. A collection of sediment, formed when a river flows into standing water, like a lake

Density	the amount of a substance in a given area, compactness. High density means a lot of rock in a relatively small area
Deposit	an accumulation (build up) of sediments, minerals, rocks, etc.
Diverse & diversity	variety; many different kinds of minerals are present
Ejecta	substances (rocks & minerals) thrown out of a crater during a meteorite impact
Elevation	the height of an area
Eroded or erode	worn down or slowly destroyed by wind, water, or natural processes. For example, canyons are often formed by water grinding down and washing away rock
Fe	iron: a mineral, silver-white in color. Iron is also a phyllosilicate mineral. If ever there was a time when Mars was habitable, it was at a time phyllosilicates formed.
Fe3 – oxyhydroxide	Iron oxide that is hydrated
Geologic History	an explanation of all of the geologic processes that have occurred in a region based on empirical evidence
Geologist	scientists who study the Earth. They look at the Earth as it is today and wonder how it got to look the way it does, what it looked like in the past, and what it might look like in the future
Geomorphologist	a type of geologist who studies the planet's surface features and how the surface changes over time. They are interested in what causes the changes and how quickly they occur.
"Go to" site	this type of target site is a place outside of the landing ellipse where Curiosity's mission team wants the rover to go investigate. It means more travel for the rover. More driving will use more precious energy and time.
Ground Engineer	the major goal of engineering is to solve problems that arise from a specific human need or desire. In this task, an engineer's primary responsibility is to make sure Curiosity can safely land and drive to points of scientific interest in
Ground Water	water below the surface of the planet
Habitable	an area capable of supporting life. Signs of long-lasting water and presence of organics are conditions associated with a habitable environment.
Hydrated	a substance that was formed with water; it is water bound in its structure
Hydrologic	water processes
Hydrothermal	minerals or rocks produced by hot water, often heated underground by a planet's internal heat

"In place" site	this type of target site is a place where Curiosity can stay within the landing ellipse to investigate. It means less travel for the rover. Less travel will use less precious energy and take less time. It is safer to move Curiosity as little as possible.
Iron Oxide	iron oxides may negatively impact the preservation of organics
Lake Bed	landform. The bottom of a lake
Landing Ellipse	the area where Curiosity is likely to land
Martian Crust	the outermost layer of the planet, Mars
Mg	magnesium: a mineral, silver-white in color and metallic. It is also a phyllosilicate mineral. If ever there was a time when Mars was habitable, it was at a time phyllosilicates formed
Mineral	an inorganic substance, not vegetable or animal. Minerals make up rocks
Mineralogist	a type of geologist who studies minerals.
Mosaic	a picture composed of two or more images(the image credits often mention that the image is 'mosaic")
Mound	landform. A naturally occurring raised area or elevation
Orbital Detection	something that can be discovered from instruments on spacecraft such as NASA's Mars Reconnaissance Orbiter
Organic or organics	carbon-based molecules that are the chemical building blocks of life as we know it
Phyllosilicate	a special type of clay (a sedimentary rock) that can preserve signs of organics.
Proximity	how close or near an object is to a given point
Sediment	substances such as silt, sand, gravel that are deposited by ice, water, or wind
Sedimentary	a type of rock formed by the accumulation of sediments on the surface (e.g., volcanic ash) or in bodies of water
Slope	an inclined or slanted surface; the steepness of an area
Strata	layers of rock materials formed in a specific time in geologic history; older layers are beneath younger layers, allowing a planet's history of environmental conditions to be traced through the rock record ice, water, or wind
Sulfate	minerals that indicate a presence of water. Because Sulfates are hydrated, their presence suggests water was once in the environment.

Target the area where Curiosity aims to go

Zoom Image a picture that shows the landing site at an increased magnification in relationship to the **context image**

4.0 Instructional Objectives, Learning Outcomes, Standards, & Rubrics

Instructional objectives, standards, and learning outcomes are aligned with the National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, which serves as a basis for upcoming "Next-generation Science Standards." Current National Science Education Standards (NSES) and other relevant standards are listed for now, but will be updated when the new standards are available.

The following chart provides details on alignment among the core and component NRC questions, instructional objectives, learning outcomes, and educational standards.

- Your **instructional objectives (IO)** for this lesson align with the NRC Framework and education standards.
- You will know that you have achieved these instructional objectives if students demonstrate the related **learning outcomes (LO)**.
- You will know the level to which your students have achieved the learning outcomes by using the suggested **rubrics** (see Teacher Guide at the end of this lesson).

Quick View of Standards Alignment:

The Teacher Guide at the end of this lesson provides full details of standards alignment, rubrics, and the way in which instructional objectives, learning outcomes, 5E activity procedures, and assessments were derived through, and align with, Anderson and Krathwohl's (2001) taxonomy of knowledge and cognitive process types. For convenience, a quick view follows:

HOW DO ENGINEERS SOLVE PROBLEMS?

NRC Core Question: ETS1: Engineering Design

HOW ARE ENGINEERING, TECHNOLOGY, SCIENCE, AND SOCIETY INTERCONNECTED?

NRC Core Question: ETS:2 Links Among Engineering, Technology, Science, and Society

What Is a Design for? What are the criteria and constraints of a successful solution?

NRC Component Question ETS1.A: Defining & Delimiting an Engineering Problem

What are the relationships among science, engineering, and technology?

NRC Component Question: ETS2A: Interdependence of Science, Engineering, and Technology

Instructional Objective *Students will be able*	**Learning Outcomes** *Students will demonstrate the measurable abilities*	**Standards** *Students will address*	
IO1: **to evaluate** proposed landing sites using criteria	**LO1a. to identify** landing site requirements given a specific perspective **LO1b. to develop** acceptable criteria **LO1c. to judge** proposed landing sites using criteria **LO1d. to instantiate** landing site conclusions using data **LO1e. to find coherence** among the experts to successfully reach a consensus in selecting a landing site	**NSES (E): SCIENCE & TECHNOLOGY: Abilities of Technological Design** **Grades 5-8:** E1b, E1d **NSES (E): SCIENCE AND TECHNOLOGY: Understandings about Science and Technology** **Grades 5-8:** E2a, E2d **Grades 9-12:** E2a, E2d	**Rubrics in Teacher Guide**

This activity also aligns with:

21ST CENTURY SKILLS

- Critical Thinking and Problem Solving
- Communication
- Collaboration
- Initiative and Self-Direction

5.0 Procedures

PREPARATION (~20 minutes)

Print and Laminate:

From Student Guide:

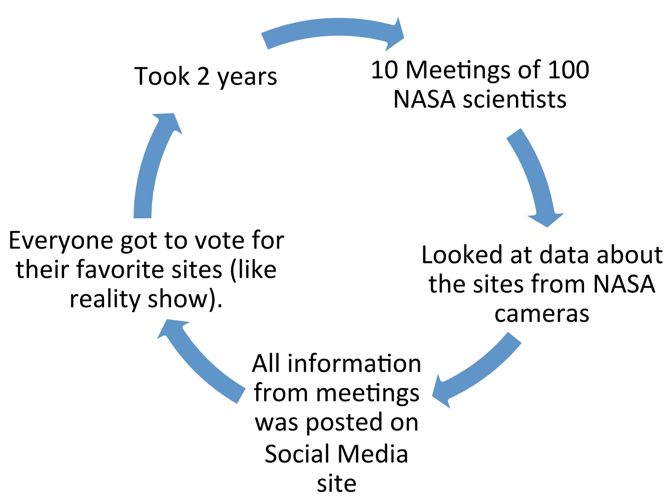
(A) Expert Cards	1 per team of 6
(B) Landing Site Selection Guides Site 1	1 per team of 6
(C) Landing Site Selection Guides Site 2	1 per team of 6
(D) Landing Site Selection Guides Site 3	1 per team of 6
(E) Landing Site Selection Guides Site 4	1 per team of 6

Print from Student Guide:

(F) Landing Site Selection Sheet	1 per student
(G) Expert Group Meeting Sheet	1 per student
(H) Reflection	1 per student

STEP 1: ENGAGE (~10 minutes)

A. Direct students to create a process map of the steps they think were taken to choose a landing site for the Curiosity rover. The process map should include:
   a. Who was involved?
   b. What information did they need?
   c. How did they get the information?
   d. How long did it take?
   e. How did they make the final decision?
   *Student example below:



B. Ask students to share ideas with the class

C. Explain to students that they are going to go through the process of choosing a landing site for the Curiosity Rover.

D. Share the mission goal to the class:

- NASA's Mars Science Laboratory mission will study whether the target area of Mars has evidence of past and present habitable environments. A habitable environment is an area capable of supporting life. Signs of long-lasting water and presence of organics are conditions associated with a habitable environment. – Adapted from Jet Propulsion Laboratory Press Kit

E. Explain to students that if we know the goal for the mission, then we can use this goal to define the landing site for the mission.

F. Read the following:
"In this activity, you will be selecting an Expert Role to participate in the landing site selection for NASA's Mars rover Curiosity. As a team, you will be working together to determine which landing site would be the safest to land in and would give the greatest amount of science return. The science return we are looking for is related to possible past or present habitable environments on Mars. Your goal for Mars exploration is looking for both long-lasting water and organics; these are necessary preconditions for life as we know it."
Teacher Tip: Please emphasize that Curiosity is looking for habitable environments, not searching for life.

STEP 2: EXPLORE (~30 minutes)
Selecting Experts and Analyzing Landing Sites

A. Explain to students that scientists and engineers often work together. Let them know that they will be taking on different roles as scientists and engineers. Read the National Research Council (2012) Framework's explanation of the relationship between science and engineering:

a. "Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements—knowledge and practice—are essential. In science, knowledge, based on evidence from many investigations, is integrated into highly developed and well-tested theories that can explain bodies of data and predict outcomes of further investigations" (p. 26).

b. "Similarly, engineering involves both knowledge and a set of practices. The major goal of engineering is to solve problems that arise from a specific human need or desire. To do this, engineers rely on their knowledge of science and mathematics as well as their understanding of the engineering design process" (p. 27).

c. "Engineering and science are similar in that both involve creative processes, and neither uses just one method…. Like scientific investigations, engineering design is both iterative and systematic. It is iterative in that each new version of the design is tested and then modified, based on what has been learned up to that point. It is systematic in that a number of characteristic steps must be undertaken" (p. 46).

B. Break students up into groups of three. Each group will be a Landing Site Selection Team. Hand 1 set of *(A) Expert Cards* to each landing-site-selection team.

C. Explain to the students: "For this activity, we will have three primary Experts for each Landing Site Selection Team."

D. Provide the following explanations regarding each Expert:

Mineralogist -
Mineralogists are geologists who study minerals. The Department of Labor and Statistics (2012) defines geologists as scientists who "study the physical aspects of the Earth, such as its composition, structure, and processes, to learn about its past, present, and future." They study the Earth as it is today and wonder how it got to be the way it is, what it was like in the past, and what it might be like in the future.

Overall, the goal of this exploration mission is to look for long-lasting water and organics; both are requirements for life as we know it. As the mineralogist, you will look at the minerals of each landing site to find evidence of water and organics. You would like to land in a location that has several different kinds of minerals. Pay special attention to sites with:

- as many different locations as possible
- a diversity of minerals
- minerals most likely to hold evidence of the environment's habitability (minerals formed in the presence of water)
- minerals that may have preserved carbon-based molecules called organics, the chemical building blocks of life

Geomorphologist -
A Geomorphologist is a type of geologist who studies a planet's surface and how it changes over time. You are interested in what causes the changes and how quickly they occur.

Overall, the goal of this exploration mission is to look for long-lasting water and organics; both are requirements for life as we know it. You will look at the type of rocks, landforms, and geologic history of each landing site. You will question what geologic processes formed the site, when the site was formed, and how it changed over time. This information might help reveal evidence of past water; for example, you might find a channel carved by a river millions of years ago. Certain types of rocks are only formed in the presence of water. Other rocks may better preserve evidence of organics, if any were present. You would like to land in a location that is geologically diverse with many landforms and a record of planetary history. Pay special attention to:

- the number and diversity of landforms
- the diversity of rocks formed by different geologic processes, especially those involving heat and water
- landforms and rocks most likely to hold evidence of the environment's habitability (rocks that likely formed in the presence of water)
- areas that have not been negatively affected by environmental conditions
- environments that may geologically record different time periods on Mars
- the density of rocks, especially sedimentary rocks

Ground Engineer –
In this task, a Ground Engineer's primary responsibility is to make sure Curiosity can safely drive to points of scientific interest in and around the selected landing site.

Overall, the goal of this exploration mission is to look for long-lasting water and organics; both are requirements for life as we know it. You must help decide whether Curiosity would be able to achieve the mission's scientific goals at each of the landing sites. You must be aware of large boulders, steep slopes, and thick dust deposits: anything that could cause the rover to get stuck or damaged while driving. You might consider:

- the size of the landing ellipses
- the slope of the site
- the distance Curiosity will have to travel
- the elevation of the landing ellipse; the lower the elevation, the better

E. Ask each Landing Site Selection Team to review the *(A) Expert Cards* and choose Expert roles.

F. Students will work independently for the first phase in their selected Expert role. Students will use the *(A) Expert Cards* as a guide.

G. Students will complete the *(F) Landing Site Selection Sheet* for their Expert Role using the *(B- E) Landing Site Guides 1-4.*

Teacher Tip: You may want to review the terms defined in the vocabulary section of this lesson as students review *(B- E) Landing Site Guides 1-4.*

H. The *(B- E) Landing Site Guides* contain all of the important information about each of the landing sites. The students will use this information to make observations and collect information important to their Expert Role on the *(F) Landing Site Selection Sheet.*

 Teacher Tip: Print classroom copies of the landing site information into individual packets. One set per team should suffice. Students in each team can then share the packets. Reusable classroom sets (possibly laminated) can be printed in color once and reused each year.

STEP 3: EXPLAIN (~20 minutes)

Establishing Criteria

A. Once the students have written observations for each landing site, they will then rank each site from 1-4 stars, 1 star being the favorite landing site, 4 star being the least favorite.

B. Students will need to provide an explanation as a defense for their ranking. These rankings will be shared with others who are playing the same Expert Role on other teams.

C. Move students into groups consisting only of the same type of Expert. All Ground Engineers meet together, all Mineralogists meet together, and all Geomorphologists meet together.

D. In these Expert groups, students will share their top Landing Site choice, giving an explanation for why it was chosen.

E. Each group member will note the landing site selected and the reasons it was chosen on the *(G) Expert Group Meeting Sheet*. This collection of ideas should also lead to some tension.

STEP 4: ELABORATE (~15 minutes)

Landing Site Selection Team Meeting

A. Not all students will agree on the best landing site. Therefore, the Expert groups may need to establish some criteria they plan to use in ranking their landing site selections. These criteria will be listed on their *(G) Expert Group Meeting Sheet*.

 Teacher Tip: These groups do not need to reach consensus. That is authentic to the scientific process. Mission teams often take a few years to make these kinds of critical decisions, with many individuals and teams engaging in this rich interaction. If students are having difficulty, you can convey that considering all perspectives is very important for uncovering all of the potential issues, which ensures long-term mission success.

B. Students will then work individually to apply the newly identified criteria and to finalize their landing site selection ranks. These are the ranks. The student will present the defense of these ranks to their Landing Site Selection Team (the original group of three).

C. Move students to their Landing Site Selection Team location. Here, each expert will share the ranking they have established and explain the reason for their Landing Site choice.

D. As a team of experts, students must debate and defend their landing site selection.

E. Upon debate completion, the Landing Site Selection Team will rank their landing site preferences with an explanation for their choice. Each team must reach consensus to make one landing site recommendation.

STEP 5: EVALUATE (~20 minutes)
Defend and Reflect

A. Assign the Landing Site numbers to each of the four corners of the classroom (1, 2, 3, and 4). Ask all of the Landing Site Selection Teams to stand at the number of the Landing Site they have chosen.

B. The goal at the end of this exercise is to have the majority of the Landing Site Selection Teams in agreement on a final landing site.

C. As a class, each Landing Site Selection Team will share the reasons for their selections.

D. As teams change their minds based on new reasons and explanations from other Landing Site Selection Teams, they may move to the new Landing Site number.

E. Hand out *(H) Reflection* - 1 per student

F. Based on classroom conversation and experiences, students should apply what they have learned to reflect on the how these Experts worked together to make a decision. Students should find:

a. "The fields of science and engineering are mutually supportive, and scientists and engineers often work together in teams, especially in fields at the borders of science and engineering." (A Framework for K-12 Science Education, pg. 210-211)

6.0 Extensions

As a homework activity, ask students to follow their curiosity about Mars. Ask them to go online (with the parents, if their age suggests it), and ask "Dr. C" at least 3 questions about Mars. Have them write down the following URL: http://mars.jpl.nasa.gov/drc/

7.0 Evaluation/Assessment

Use the *(I) "Landing Site Selection" Rubric* as a formative and summative assessment, allowing students to improve their work and learn from mistakes during class. The rubric evaluates the activities using National Science Education Standards.

8.0 References

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This lesson adapted from *The Mars Science Laboratory Curiosity Rover Landing Site Selection Activity – Facilitator Guide,* Goddard Space Flight Facility.

(A) Expert Card - Mineralogist (1 of 3)

Mineralogists are geologists who study minerals. The Department of Labor and Statistics (2012) defines geologists as scientists who "study the physical aspects of the Earth, such as its composition, structure, and processes, to learn about its past, present, and future." They study the Earth as it is today and wonder how it got to be the way it is, what it was like in the past, and what it might be like in the future.

A primary goal of this exploration mission is to look for long-lasting water and organics; both are requirements for life as we know it. As the mineralogist, you will look at the minerals of each landing site to find evidence of water and organics. You would like to land in a location that has several different kinds of minerals. Pay special attention to sites with:

- as many different locations as possible
- a diversity of minerals
- minerals most likely to hold evidence of the environment's habitability (minerals formed in the presence of water)
- minerals that may have preserved carbon-based molecules called organics, the chemical building blocks of life

Term	Definition or Importance
Anhydrous	A substance that does not contain any water
Aqueous	Containing water
Biosignature	A physical and/or chemical marker of life that does not occur through random processes or human intervention
Clay, clay-rich, & clay abundance	Often indicates the past presence of water, since clay frequently forms in a water-rich environment
Crater, impact crater, or meteorite crater	A circular depression (hole in the ground) with a raised rim, formed by a meteoroid hitting a planet
Deposit	An accumulation (build up) of sediments, minerals, rocks, etc.
Diverse & diversity	Variety; many different kinds of minerals are present
Ejecta	Substances (rocks & minerals) thrown out of a crater during a meteorite impact
Fe	Iron: a mineral, silver-white in color and metallic. It is also a **phyllosilicate** mineral. If ever there was a time when Mars was habitable, it was at a time phyllosilicates formed.

(A) Expert Card - Mineralogist (2 of 3)

Fe^3 – oxyhydroxide	Iron oxide that is **hydrated**
Habitable	An area capable of supporting life. Signs of long-lasting water and presence of organics are conditions associated with a habitable environment.
Hydrated	A substance that was formed with water and is bound in its structure
Hydrothermal	Minerals or rocks produced by hot water, often heated underground by a planet's internal heat
Iron Oxide	Iron Oxides may negatively impact the preservation of organics
Landing Ellipse	The area where Curiosity is likely to land
Mg	Magnesium: a mineral, silver-white in color and metallic. It is also a phyllosilicate mineral. If ever there was a time when Mars was habitable, it was at a time phyllosilicates formed
Mineral	An inorganic substance, not vegetable or animal. Minerals make up rocks
Orbital Detection	Something that can be discovered from instruments on spacecraft such as NASA's Mars Reconnaissance Orbiter
Organic or organics	Carbon-based molecules that are the chemical building blocks of life as we know it
Phyllosilicate	A special type of clay (a sedimentary rock) that can preserve signs of organics.
Sediment	Substances such as silt, sand, gravel that are deposited by ice, water, or wind
Sulfate	Minerals that indicate a presence of water. Because Sulfates are hydrated, their presence suggests water was once in the environment.
Volcanic	a rock formed from magma that erupted from a volcano and cooled on the surface (also igneous rock, and often basalt)

(A) Expert Card - Mineralogist (3 of 3)

A primary mission goal for NASA's Mars rover Curiosity is to search for signs of past habitable environments on Mars that could have supported small life forms called microbes. Your responsibility is to help provide a geologic context for these environments. By learning about the minerals at a landing site, finding out how and when they formed and what has happened to them since they formed, you can help piece together the geologic history of the area - and the planet Mars!

(A) Expert Card – Geomorphologist (1 of 3)

You are a Geomorphologist, a type of geologist who studies a planet's surface and how it changes over time. The Department of Labor and Statistics (2012) defines geologists as scientists who "study the physical aspects of the Earth, such as its composition, structure, and processes, to learn about its past, present, and future." They study the Earth as it is today and wonder how it got to be the way it is, what it was like in the past, and what it might be like in the future. You are interested in what causes the changes and how quickly they occur.

A primary goal of this exploration mission is to look for long-lasting water and organics; both are requirements for life as we know it. You will look at the type of rocks, landforms, and geologic history of each landing site. You will question what geologic processes formed the site, when the site was formed, and how it changed over time. This could help reveal evidence of past water; for example, you might find evidence of a channel carved by a river millions of years ago. Certain types of rocks may better preserve evidence of organics, if any were present. You would like to land in a location that is geologically diverse. Pay special attention to:

- the number and diversity of landforms
- the diversity of rocks formed by different geologic processes, especially those involving heat and water
- landforms and rocks most likely to hold evidence of the environment's habitability (rocks that likely formed in the presence of water)
- areas that have not been negatively affected by environmental conditions
- environments that may geologically record different time periods on Mars
- the density of rocks, especially sedimentary rocks

Term	Definition or Importance
Alluvial Fan	Landform. A fan-shaped collection of sediment deposited by a river when its flow is suddenly slowed.
Aqueous	Containing water
Canyon	Landform. A long tube or ravine, usually formed by a river that erodes the sides of a valley
Climate Conditions	A summary of weather conditions over time, includes items such as temperature, humidity, rainfall, etc.
Crater, impact crater, or meteorite crater	Landform. A circular depression (hole in the ground) with a raised rim, formed by a meteoroid hitting a planet
Delta	Landform. A collection of sediment, formed when a river flows into standing water, like a lake
Deposit	An accumulation (build up) of sediments, minerals, rocks, etc.

(A) Expert Card – Geomorphologist (2 of 3)

Density	The amount of a substance in a given area, compactness. High density means a lot of rock in a relatively small area
Diverse & diversity	Variety; many different kinds of minerals are present
Ejecta	Substances (rocks & minerals) thrown out of a crater during a meteorite impact
Eroded or erode	Worn down or slowly destroyed by wind, water, or natural processes. For example, canyons are often formed by water grinding down and washing away rock
Geologic History	An explanation of all of the geologic processes that have occurred in a region based on empirical evidence
Ground Water	Water below the surface of the planet
Habitable	An area capable of supporting life. Signs of long-lasting water and presence of organics are associated with a habitable environment.
Hydrated	A substance that was formed with water
Hydrologic	Water processes
Hydrothermal	Minerals or rocks produced by hot water, often heated underground by a planet's internal heat
Lake Bed	Landform. The bottom of a lake
Landing Ellipse	The area where Curiosity is likely to land
Martian Crust	The outermost layer of the planet, Mars
Mound	Landform. A naturally occurring raised area or elevation
Orbital Detection	Something that can be discovered from instruments in space, such as Mars Reconnaissance Orbiter
Sediment	Substances, such as silt, sand, gravel, that is deposited by ice, water, or wind
Sedimentary	A type of rock formed by the accumulation of sediments on the surface (e.g., volcanic ash) or in bodies of water

(A) Expert Card – Geomorphologist (3 of 3)

Strata	Layers of rock materials formed in a specific time in geologic history; older layers are beneath younger layers, allowing a planet's history of environmental conditions to be traced through the rock record

A primary mission goal for Curiosity is to search for habitable environments on Mars. Your responsibility is to interpret the data and develop criteria to analyze potential landing sites. You will need to share your findings with the Landing Site Team and listen to their input to choose a final landing site. You want to try to understand what the environment was like where organisms may have once lived.

(A) Expert Card - Ground Engineer (1 of 2)

You are a Ground Engineer; in this task, your primary responsibility is to make sure Curiosity can safely drive to points of scientific interest in and around the selected landing site.

A primary goal of this exploration mission is to look for long-lasting water and organics; both are requirements for life as we know it. You must help decide whether Curiosity would be able to achieve the mission's scientific goals at each of the landing sites. You must be aware of large boulders, steep slopes, and thick dust deposits: anything that could cause the rover to get stuck or damaged while driving. You might consider:

- the size of the landing ellipses
- the rock density
- the slope of the site
- the distance Curiosity will have to travel
- the elevation of the landing ellipse; the lower the elevation, the better

Term	Definition or Importance
Crater, impact crater, or meteorite crater	A circular depression (hole in the ground) with a raised rim, formed a meteoroid hitting a planet
Delta	A collection of **sediment**, formed when a river flows into standing water, like a lake
Elevation	The height of an area
"Go to" site	This type of **target** site is a place outside of the landing ellipse where Curiosity's mission team wants the rover to investigate. It means more travel for the rover. More driving will use more precious energy and time.
In place	This type of **target** site is a place where Curiosity can stay within the landing ellipse to investigate. It means less travel for the rover. Less travel will use less precious energy and take less time. It is safer to move Curiosity as little as possible.
Landing Ellipse	The area where Curiosity is likely to land
Mound	A naturally occurring raised area or elevation
Proximity	How close or near an object is to a given point
Rock Density	the amount of a rock in a given area, compactness. High density means a lot of rock in a relatively small area

(A) Expert Card - Ground Engineer (2 of 2)

Sediment	Substances, such as silt, sand, gravel, that is deposited by ice, water, or wind
Slope	An inclined or slanted surface; the steepness of an area
Target	The area where Curiosity aims to go

Information about Curiosity:

Approximate Size:

- 3 m (or 10 ft.) long
- 2.8 m (9 ft.) wide
- 2.1 m (7 ft.) tall

Wheels

- 6 wheels, capable of driving over obstacles up to 65 cm (25 in) high,
- Can drive on slopes up to 30° on solid rock or 15° on loose material (like a sand dune)

Mass

- 899 kg. (1,982 lbs.)

Distance:

- Can travel up to 200 m (660 ft.) per day,
- Top speed of up to 4 cm/s (meaning it could drive across a football field in about 40 minutes)
- Designed to be able to drive 20 km (12 miles) total

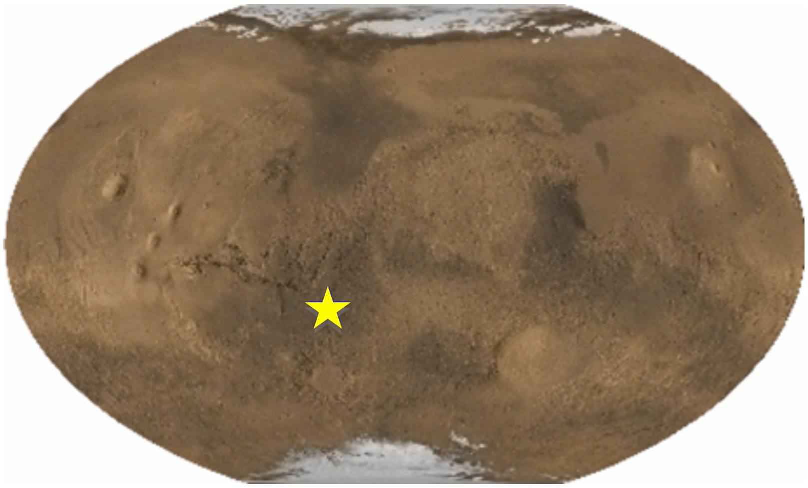
Lifespan:

- Designed to last a full Mars year (687 Earth days) or more

A primary mission goal for Curiosity is to search for habitable environments on Mars. Your responsibility is to interpret the data and develop criteria to analyze potential landing sites. You will need to share your findings with the Landing Site Team and listen to their input to choose a final landing site. You want to achieve science goals, while ensuring the safety of Curiosity!

Courtesy NASA/ JPL-Caltech

(B) Landing Site Selection Guide - Landing Site 1 (1 of 10)



Location: (24ºS, 327ºE)

Elevation: -1.5 km (-0.9 mi)

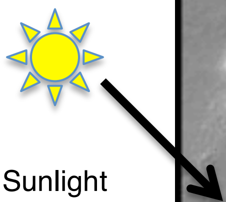
Courtesy NASA/JPL-Caltech

Overarching Hypothesis:
Landing Site 1's rock layers, geomorphology, and mineralogy record:

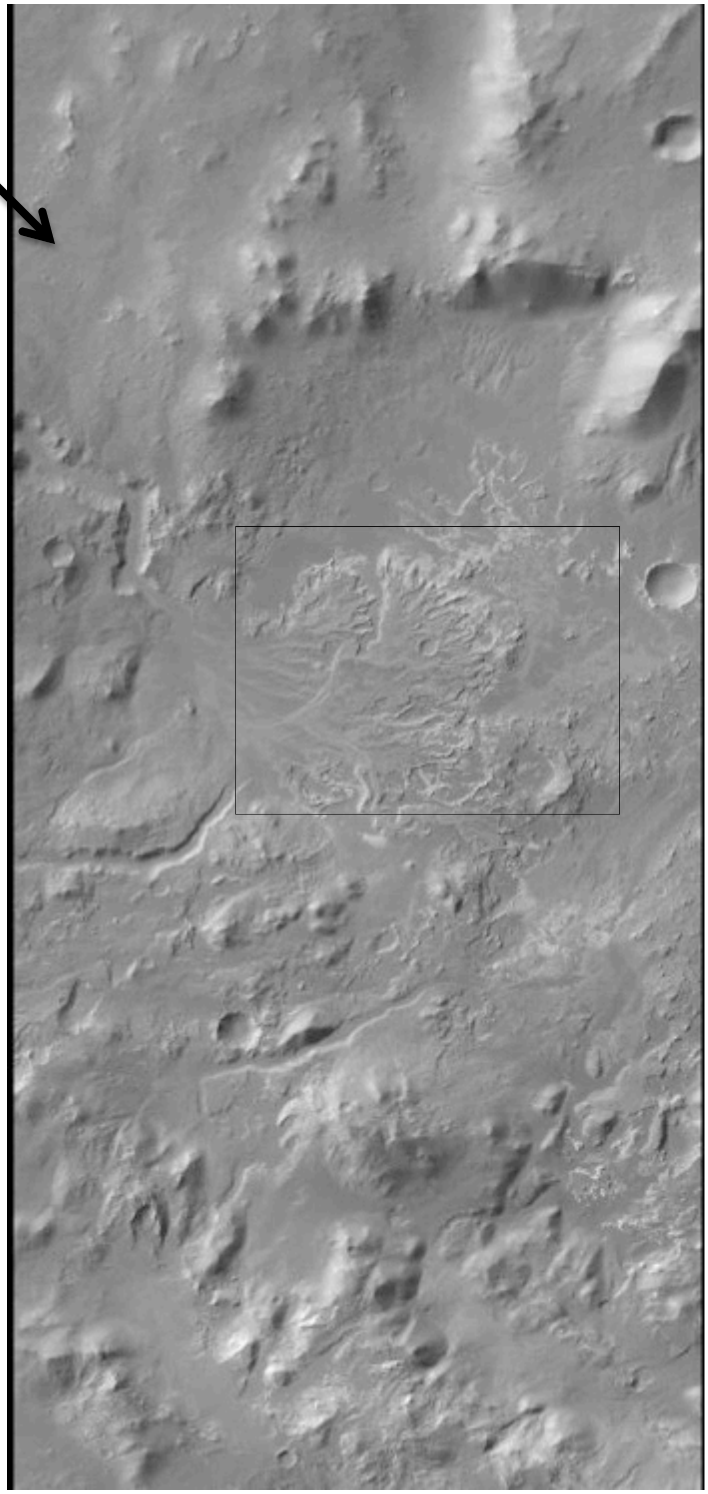
- evolution of a crater lake,
- history of water and climatic changes resulting in the formation of landforms & deposits from rivers,
- sediments that might have been favorable to the preservation of organic materials and/or other kinds of bio signatures.

(B) Landing Site Selection Guide - Landing Site 1 (2 of 10)

Context Image of Landing Site 1



Sunlight comes from the Northwest direction.



Rectangle indicates approximate location of Zoom Image #1.

Image Credit: NASA/JPL-Caltech/Malin Space Science Systems

(B) Landing Site Selection Guide - Landing Site 1 (3 of 10)

Landing Site 1: Zoom

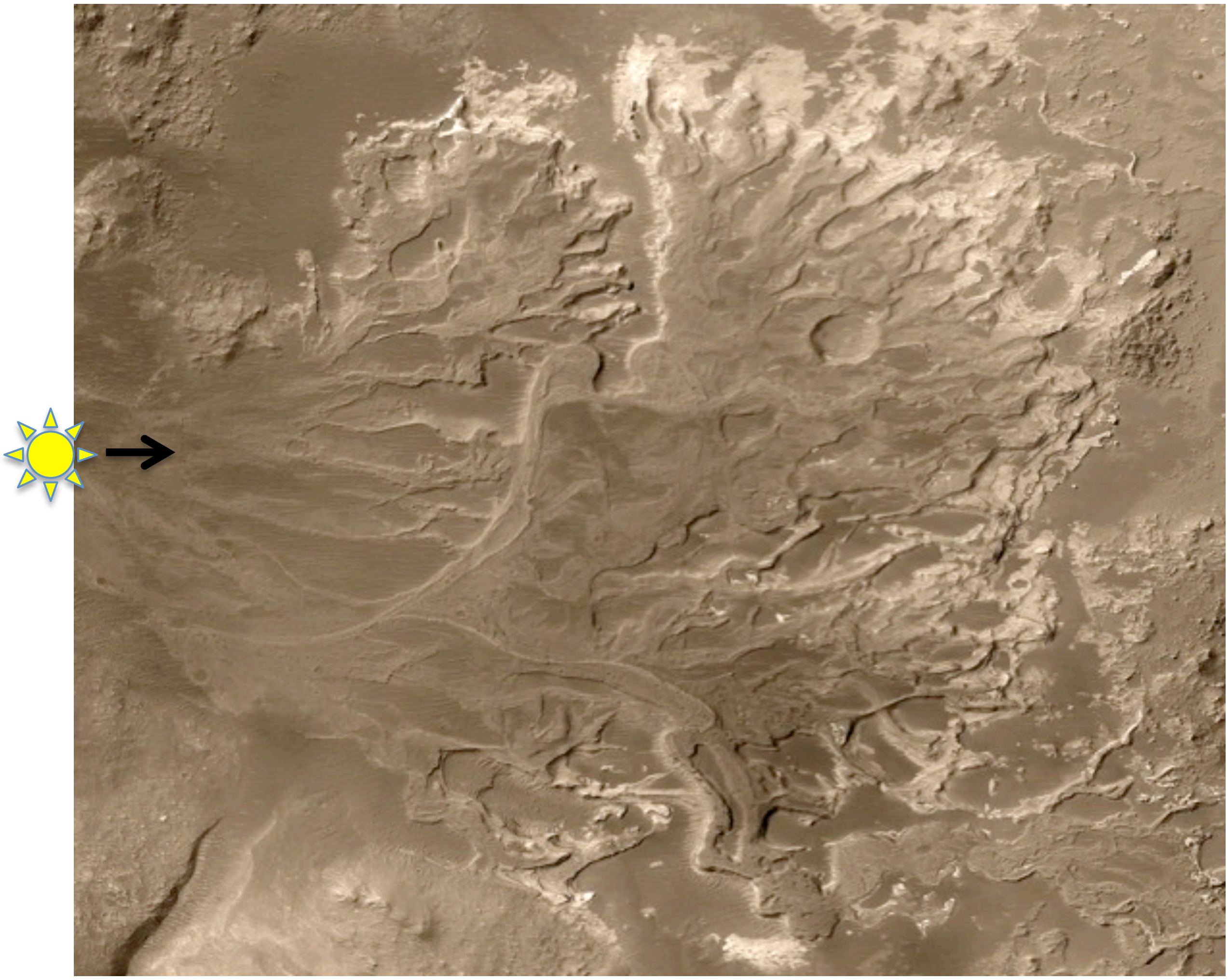


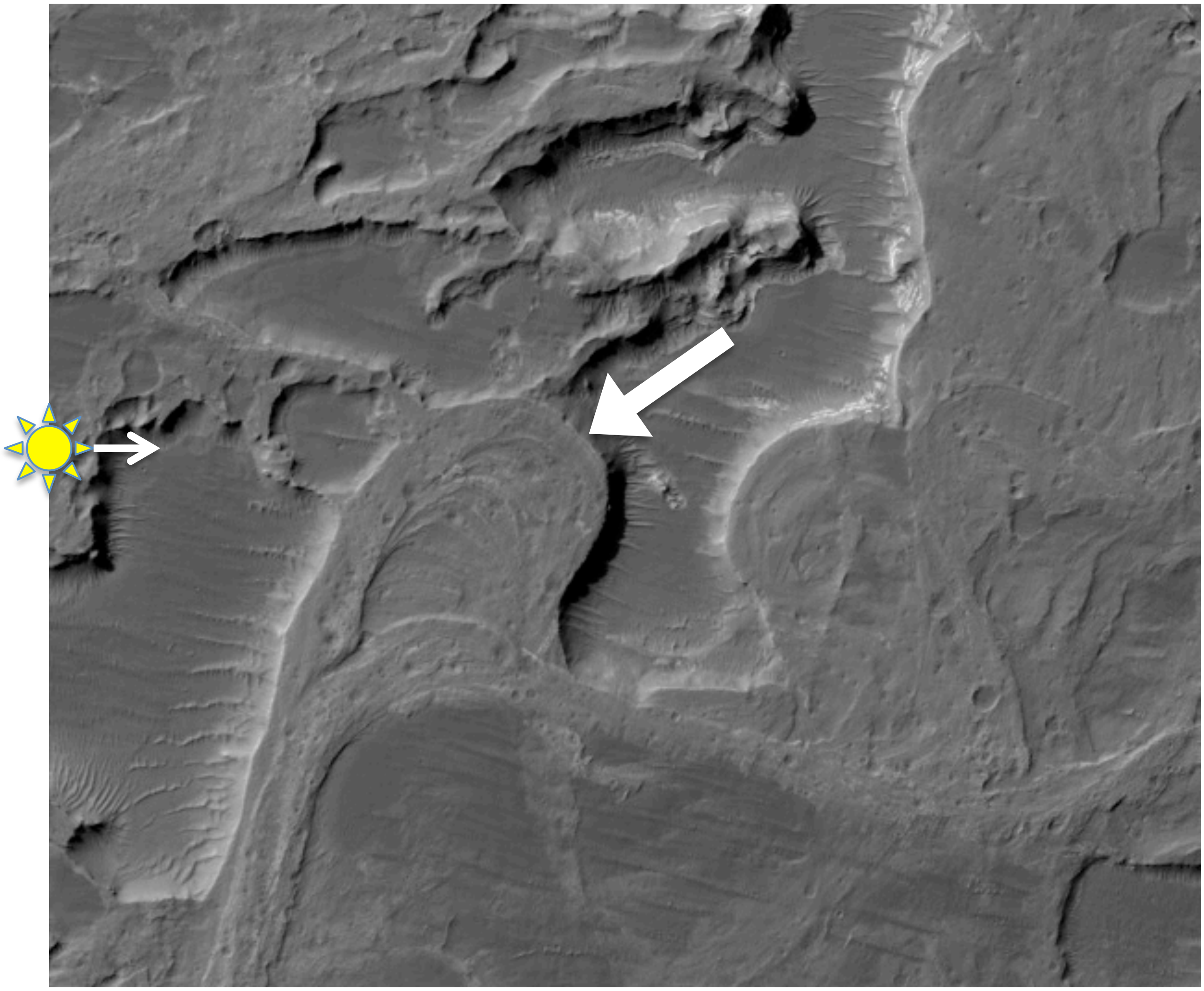
Image Credit: NASA/JPL-Caltech/Malin Space Science Systems

Image #1

- Close-up view of Landing Site 1 delta
- Delta is positive-relief feature (It sticks out relative to land around it)
- Scientists believe sediment deposited in the delta sticks out because it is coarse-grained (possibly containing sand-sized grains or pebbles) and does not wear away as easily as finer-grained material (like dust)
- Rectangle indicates location of Landing Site 1 Zoom Image #2

(B) Landing Site Selection Guide - Landing Site 1 (4 of 10)

Landing Site 1: Zoom Image #2



NASA/JPL/University of Arizona

- Close-up view of one of the most interesting features in Landing Site 1
- Shows what appears to be a river channel
- If you look closely, you can see several curved lines within the larger curve, which might record evidence of the carving of the channel as it moved closer and closer to the where the white arrow is located
- This process would take a long time, so liquid water may have been stable in this location for fairly long time during formation of the delta

(B) Landing Site Selection Guide - Landing Site 1 (5 of 10)

Geomorphologist

Basic geology and geologic history is understood (river deposited sediment into a lake to form delta).

Pros	Cons
Excellent preservation of delta & river	Limited variety of minerals known to preserve organics detected from orbit
Smaller river systems & possible lake deposits are present	Not certain if area was ice-covered (no deformation of the delta as would be expected)
Opportunity to determine the sedimentary, hydrologic, & climate conditions from a time when the rocks and landforms were formed	Delta was formed 1,800 to 3,700 million years ago, perhaps too young to provide evidence of a habitable environment
Estimates suggest the sediment is a hundred thousand years old or more	Sediment contributions from Holden ejecta are uncertain
Holden crater ejecta	

(B) Landing Site Selection Guide - Landing Site 1 (6 of 10)

Geomorphologist

Rock Density in Landing Site 1

Map showing rock density in and around the Landing Site 1 landing ellipse

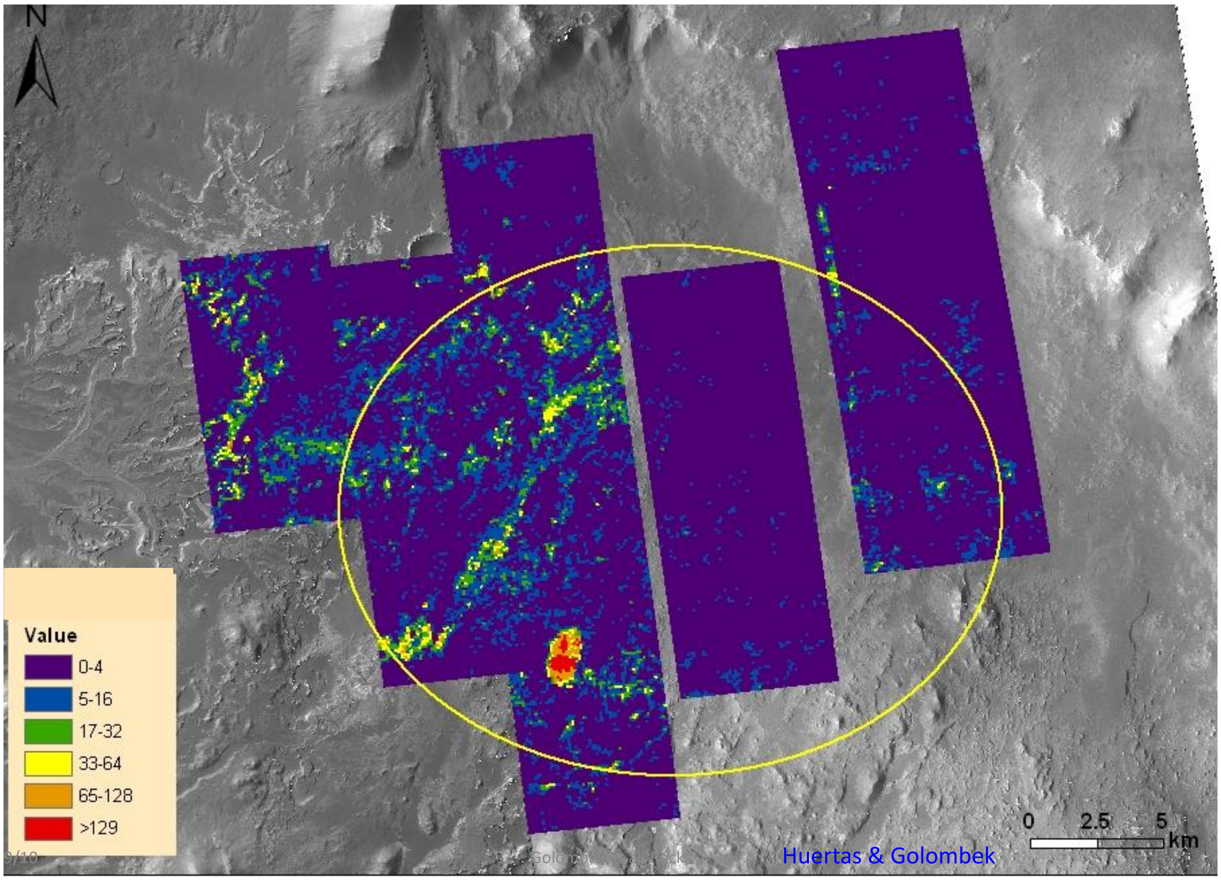


Image Credit: Huertas & Golombek

- Purple & blue areas = lower rock densities
- Red & orange areas = higher rock densities

*Please share this map with the Ground Engineer in your group

(B) Landing Site Selection Guide - Landing Site 1 (7 of 10)

Mineralogist

At least 3 distinct types of minerals present, including clay minerals.

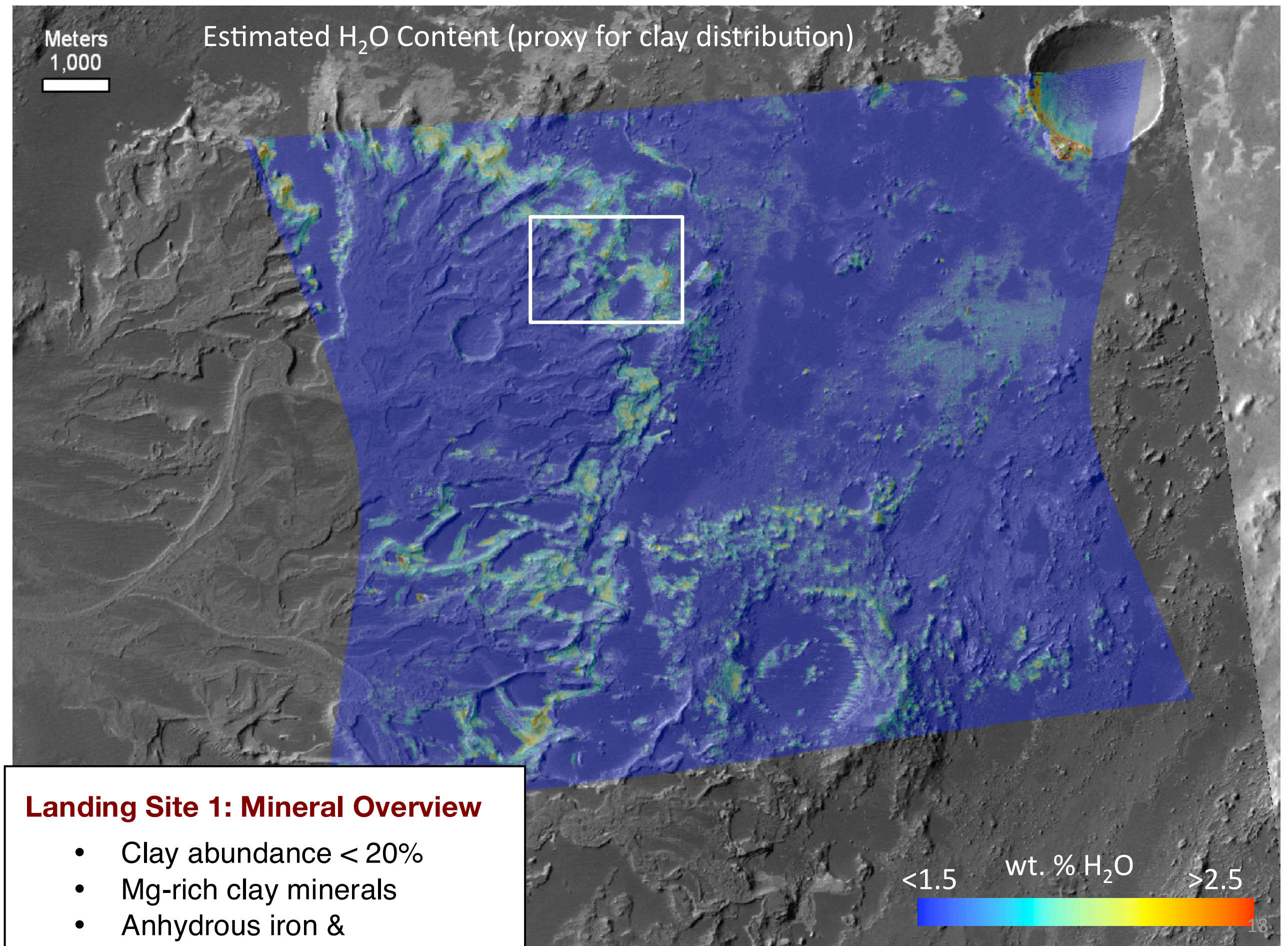
Pros	Cons
Materials in the landing ellipse & delta include clay minerals *(Places where clay minerals are found are excellent to search for habitable environments or signs of past life)*	Limited variety of minerals known to preserve organics detected from orbit
Mineral diversity within & outside of the landing ellipse	Sediment contributions from Holden ejecta are uncertain
Orbital detection of clay minerals make a well-defined target	
Some material may show a relation to hydrothermal activity	

(B) Landing Site Selection Guide - Landing Site 1 (7 of 10)

Mineralogist

Mineralogy of the Landing Site 1

Image shows where clay minerals are likely located around edge of Landing Site 1



Landing Site 1: Mineral Overview

- Clay abundance < 20%
- Mg-rich clay minerals
- Anhydrous iron & magnesium minerals are the dominant phases (> 80%)

Image Credit: NASA/JPL/JHUAPL

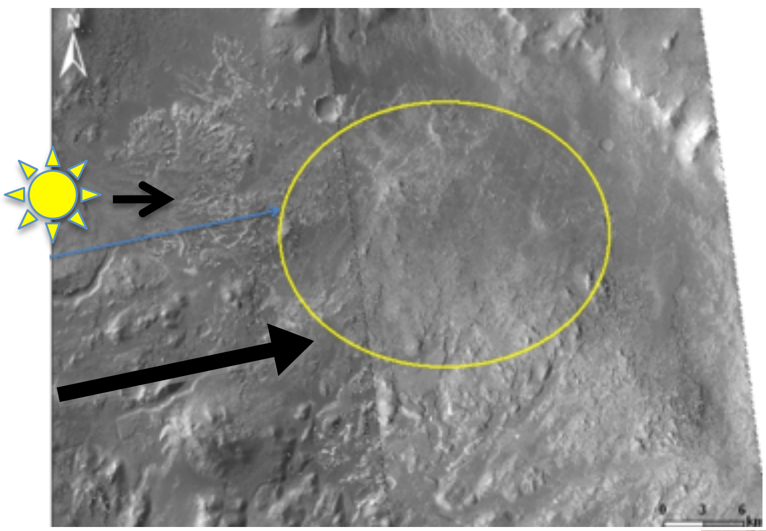
- Yellow and red = more clay minerals
- Blue and green = fewer clay minerals
- See range in lower, right-hand corner

(B) Landing Site Selection Guide - Landing Site 1 (8 of 10)

Ground Engineer

Location of Landing Site 1 Landing Ellipse

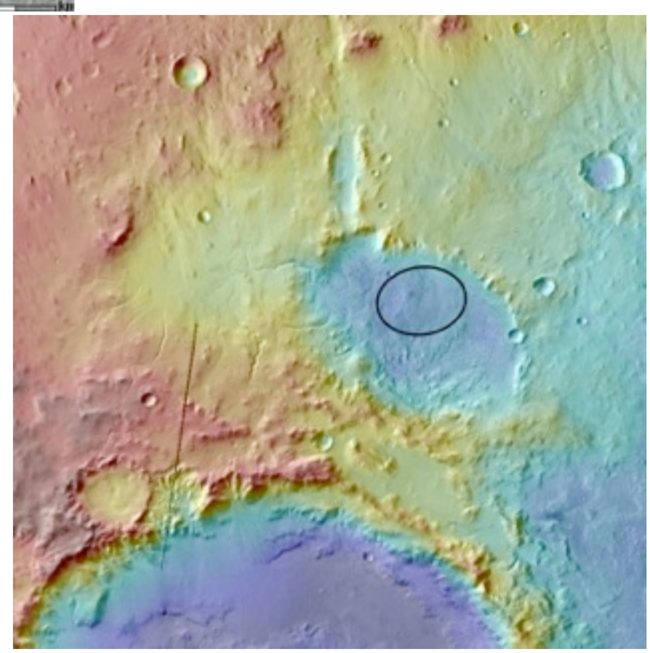
- Ellipse is 25 km (~15 miles) long and 20 km (~12 miles) wide
- Delta is located just outside landing ellipse
- Arrow points to edge of the delta closest to landing ellipse



NASA/JPL-Caltech/Malin Space Science Systems

Location of Landing Site 1 Landing Ellipse: Elevation

- Image shows elevation of landing site in and around the crater landing ellipse (25 - 20 km)
- Dark blue & green areas = lower elevations
- Brown & red areas = higher elevations
- Arrow indicates approximate location of edge of Landing Site 1 delta



NASA/JPL-Caltech/UA

(B) Landing Site Selection Guide - Landing Site 1 (9 of 10)

Ground Engineer

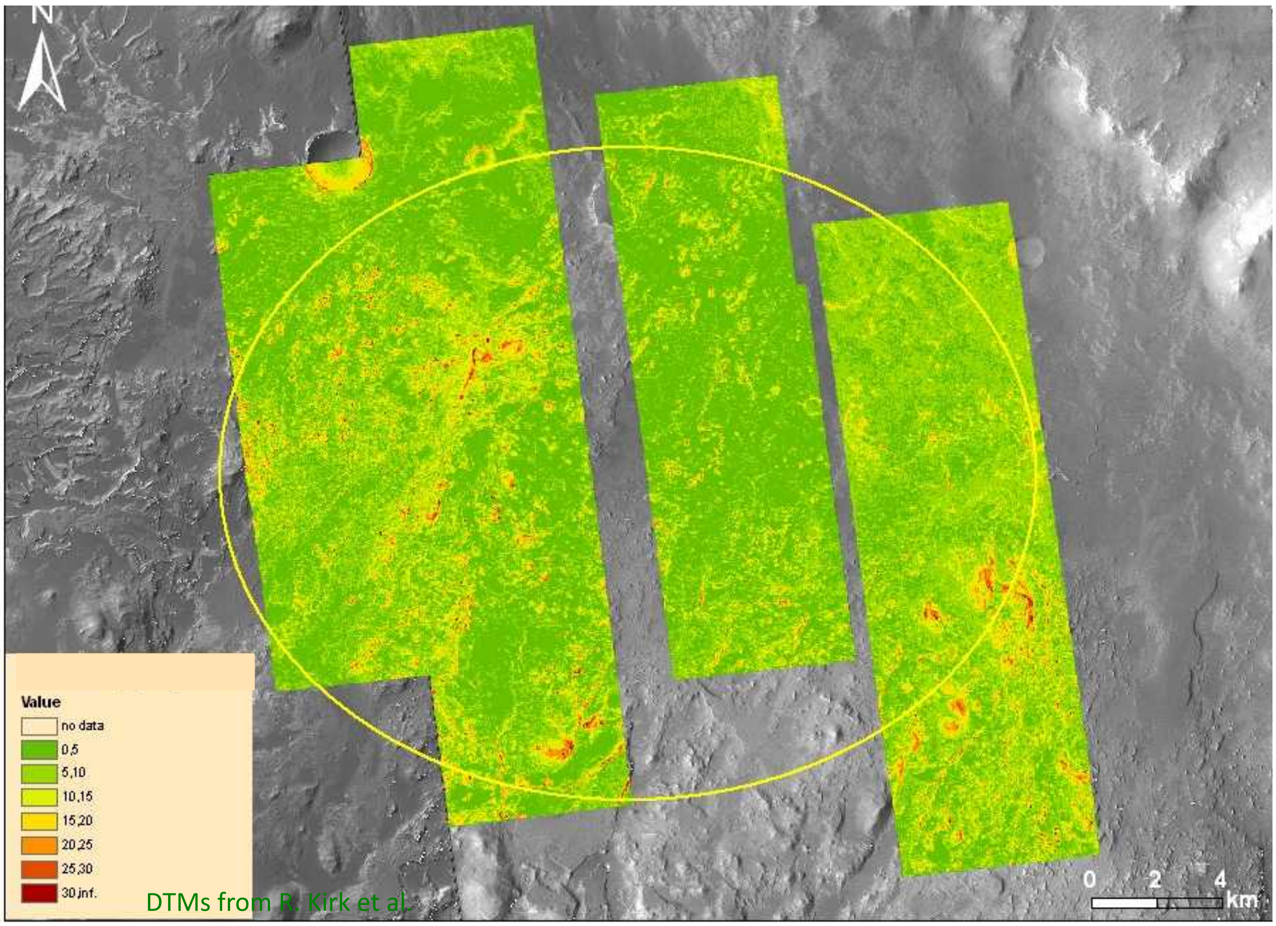
Pros	Cons
In place site means CURIOSITY may not have to travel	Science in landing ellipse is secondary to that outside of the ellipse
Offers both *in place* and *go to* opportunities for investigation	
Mineral diversity within and outside the landing ellipse	

(B) Landing Site Selection Guide - Landing Site 1 (10 of 10)

Ground Engineer

Slopes in Landing Site 1

Map showing slopes of the landscape in and around the Landing Site 1 landing ellipse



- White and dark green areas = shallower slopes
- Red and orange areas = steeper slopes

(C) Landing Site Selection Guide - Landing Site 2 (1 of 10)

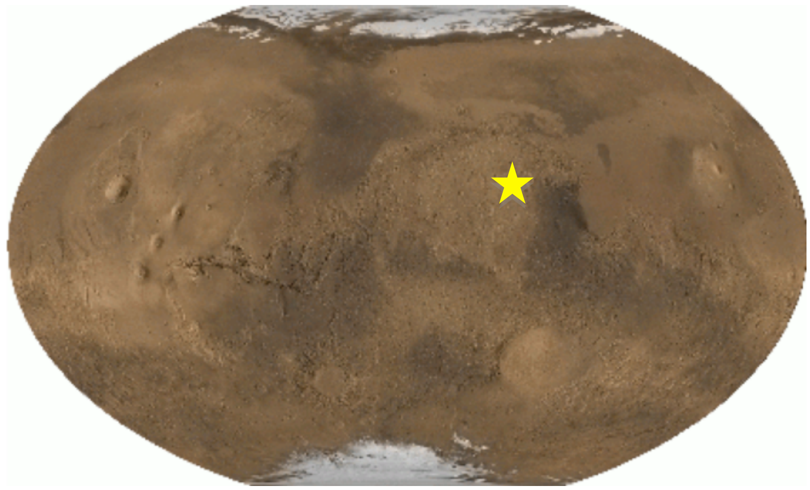


Image: Courtesy NASA/JPL-Caltech

Location: (4.5°S, 137°E)

Elevation: -4.5 km (-2.8 mi)

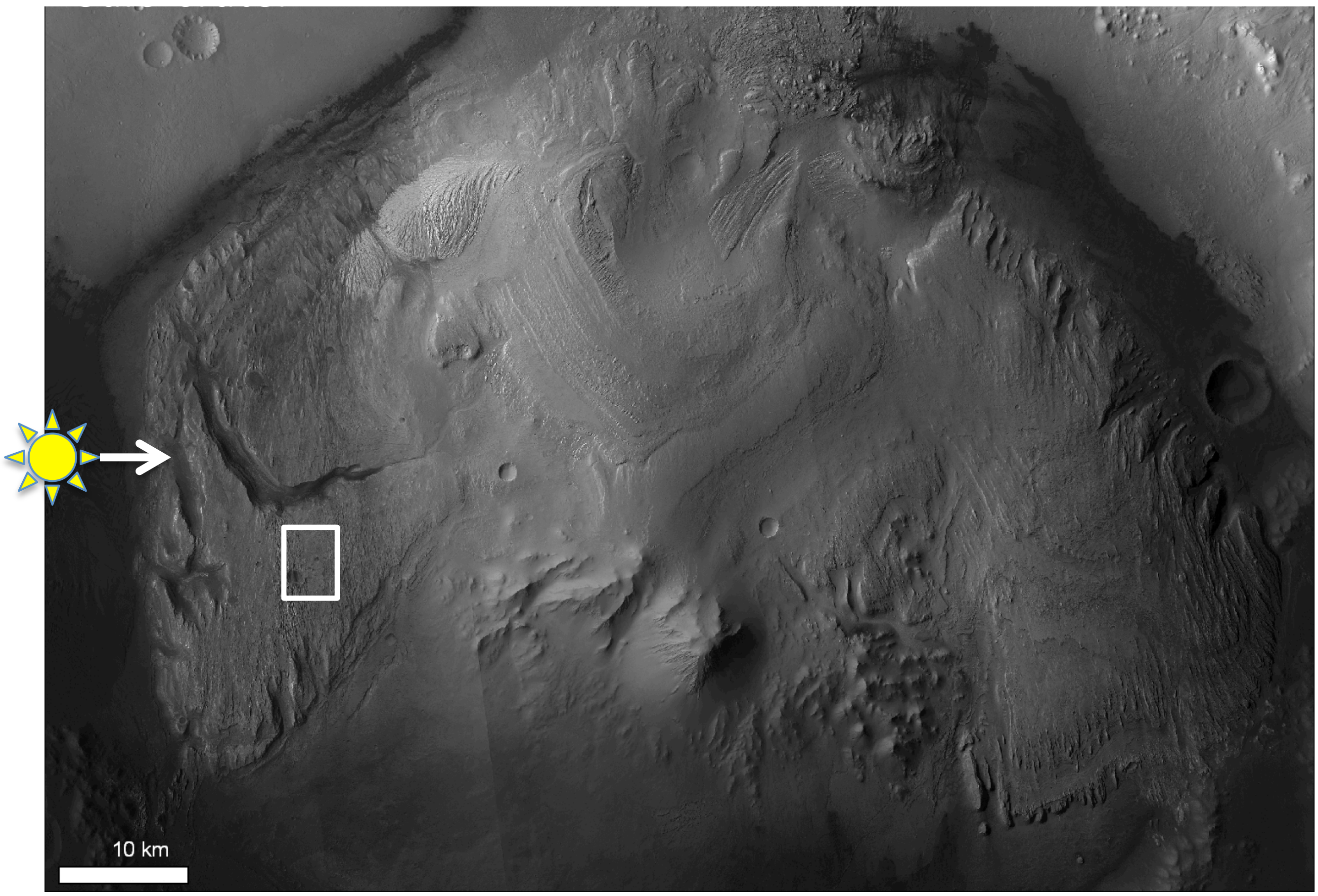
Overarching Hypothesis:

- 5-km-thick (just over 3 miles) stacks of sedimentary rock within Landing Site 2 record a sequence of aqueous habitable environments over an extended period.
- These strata contain multiple hydrous minerals (sulfates, phyllosilicates) that indicate varying water-based environmental conditions.

(C) Landing Site Selection Guide - Landing Site 2 (2 of 10)

Landing Site 2 Mound: Zoom Image #1

- Close-up view of Landing Site 2 mound
- White box indicates approximate location of Landing Site 2 Zoom Image #2



Courtesy NASA/JPL/University of Arizona

Sunlight comes from the West direction.

(C) Landing Site Selection Guide - Landing Site 2 (3 of 10)

The "Grand Canyon" of Landing Site 2: Zoom Image #2

- Close-up view of a canyon carved into the sedimentary rocks that make up the Landing Site 2 mound.
- If you look closely, you can see some of the light- and dark-colored layers of rock on the walls of the canyon.

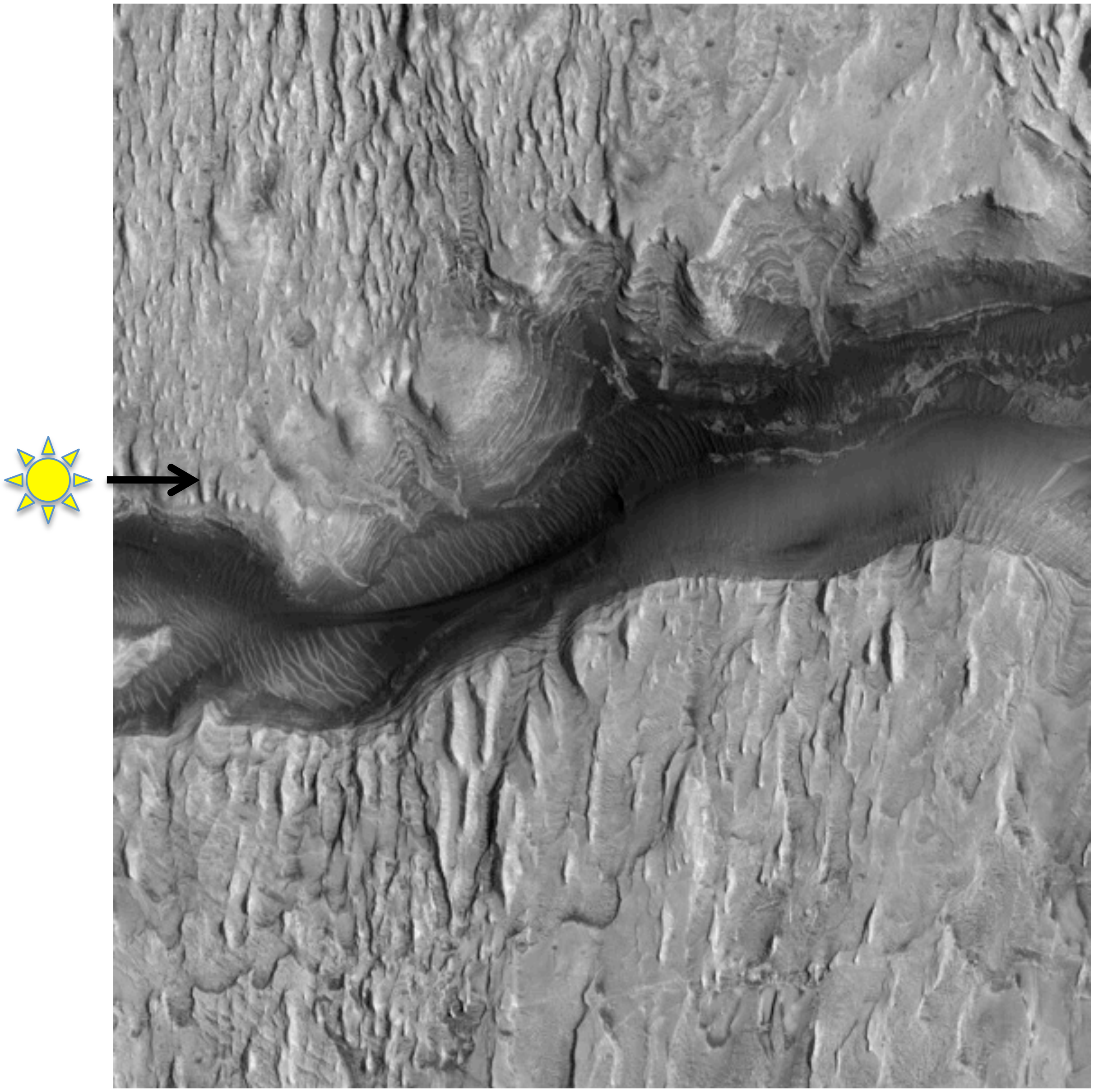


Image Credite: Courtesy NASA/JPL/University of Arizona

(C) Landing Site Selection Guide - Landing Site 2 (4 of 10)

Geomorphologist

Basic geology is understood (thick stack of sedimentary rocks; likely once filled crater and are now being eroded)

Past environments of the Landing Site 1 are not well understood (unknown where the sediment in the sedimentary rocks came from or how it was deposited).

Pros	Cons
Diverse rock layers in a 5 km (over 3 miles) deep crater	Observations within the landing ellipse may be encumbered by dust
Crater created about 4,000 million years ago, although the exact time is not known	It is unlikely that all aspects of the rock & minerals formation will be understood before landing.
Probably shows rocks and minerals during climate changing, wetter-to-drier environmental conditions.	The processes responsible for the present landform development needs better definition
Includes rock and mineral deposits from a river	The source of water associated with the crater remains uncertain
Materials record hydrologic conditions and provide the opportunity to sample materials weathered and eroded from the crater walls.	The source of the lower mound sediments is unknown
Ability to investigate crater rim materials that have fallen inside the crater (some of the top of the crater has fallen to lower areas where Curiosity can reach it)	Some of the rocks and minerals were created approximately 4,000 million years ago, while others are younger and were created approximately 1,800 million years ago. Older rocks record more information.
	It is difficult to tell the exact age of the rocks and minerals in the crater.

(C) Landing Site Selection Guide - Landing Site 2 (5 of 10)

Geomorphologist

Rock Density in Landing Site 2

Map showing rock density in selected locations in and around the Landing Site 2 landing ellipse

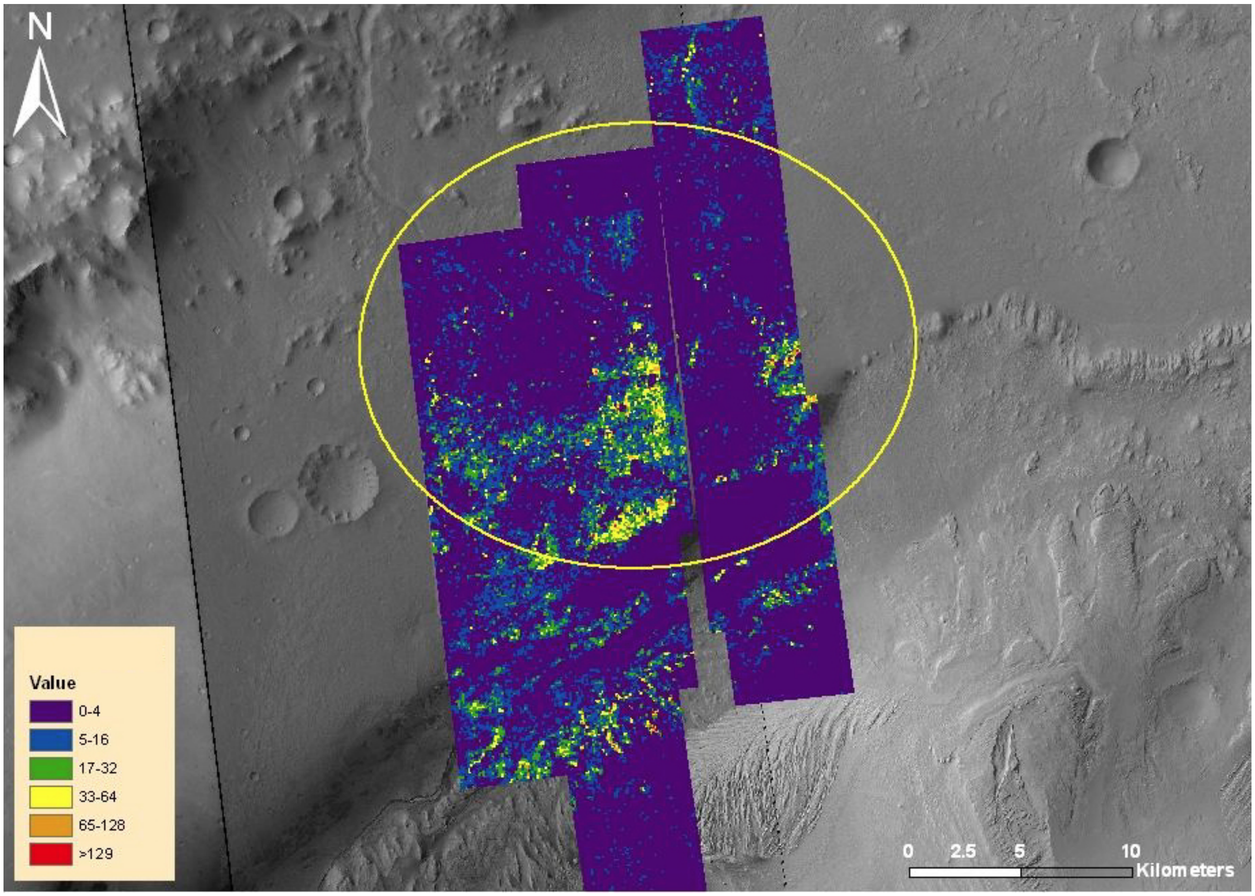


Image Credit: Huertas & Golombeck

- Purple and blue areas = lower rock densities
- Red and orange areas = higher rock densities

*Please share this map with the Ground Engineer in your group

(C) Landing Site Selection Guide - Landing Site 2 (6 of 10)

Mineralogist

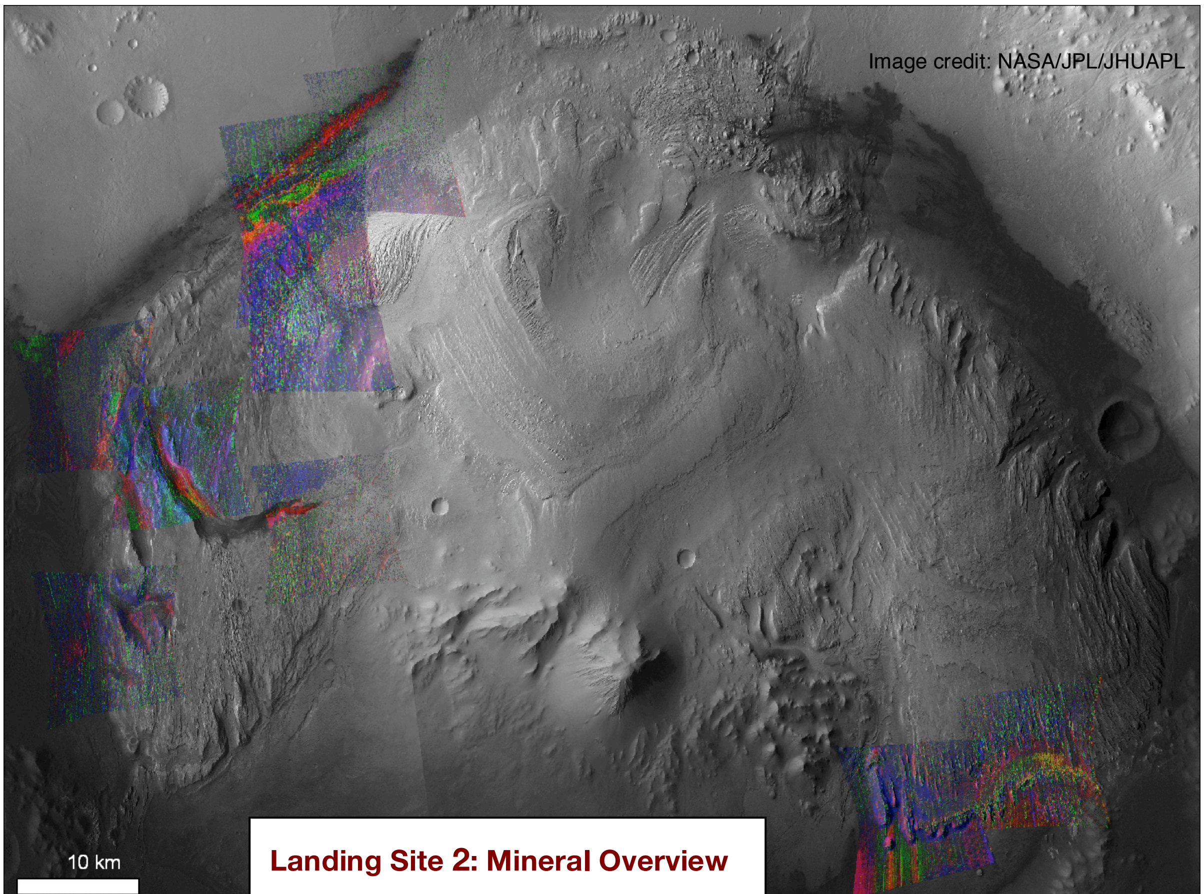
Orbiters have identified several different types of minerals within the different layers of sedimentary rock, including clay minerals and sulfate salts.

Pros	Cons
Includes well defined beds of hydrated minerals	The site is known to have iron oxides present. The preservation of organics may be negatively impacted by iron oxides.
Includes rock and mineral deposits from a river	
Multiple mineralogical and rock units with alternating phyllosilicate and sulfate bearing beds.	
The phyllosilicates include materials that would help preserve organics if present.	
Biosignatures may be best preserved in the sulfates in the mound	
Preserved organics could occur in clay rich layers and in the sulfates.	

(C) Landing Site Selection Guide - Landing Site 2 (7 of 10)

Mineralogist

Mineralogy of the Landing Site 2 Mound



Landing Site 2: Mineral Overview

- Clay abundance < 30%
- Fe-rich clay minerals
- Anhydrous iron & magnesium minerals are the dominant phases (> 45 - 70%)

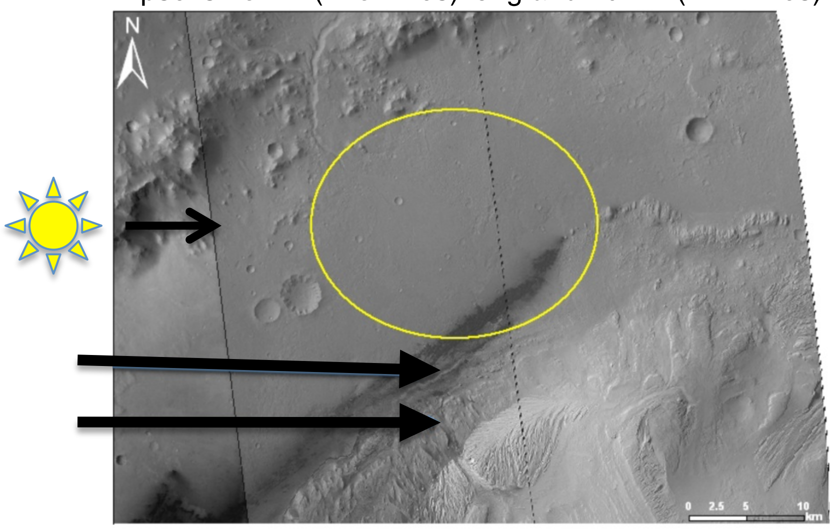
- Green & orange = clay minerals
- Blue & pink = sulfate salts
- Lack of color = lack of CRISM data

(C) Landing Site Selection Guide - Landing Site 2 (8 of 10)

Ground Engineer

Location of Landing Site 2 Landing Ellipse

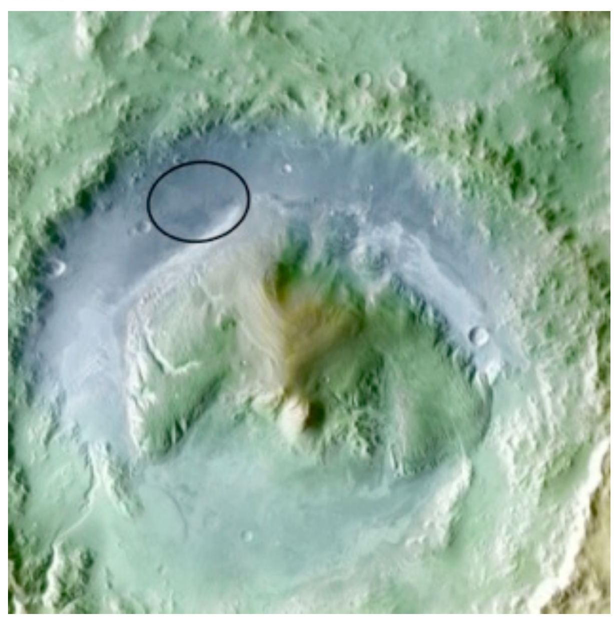
- Target is the very large stack of sedimentary rocks that form a mound inside the crater (lower left in image)
- Top arrow points to one location where Curiosity could sample and analyze interesting rocks in the mound
- Lower arrow points to canyon in the mound that Curiosity could drive up to reach more sedimentary rocks in the stack
- Ellipse is 25 km (~15 miles) long and 20 km (~12 miles) wide



NASA/JPL/Arizona State University

Location of Landing Site 2 Landing Ellipse: Elevation

- Image shows elevations of site in and around the Landing Site 2 landing ellipse (25 x 20 km)
- Dark blue areas = lowest elevations
- Brown areas = highest elevations
- Curiosity's target is large 5-km-thick mound of sedimentary rocks located southeast of landing ellipse (in the center of the image)



NASA/JPL-Caltech

(C) Landing Site Selection Guide - Landing Site 2 (9 of 10)

Ground Engineer

Pros	Cons
The specific distribution of science targets within and outside of the ellipse is well defined.	Observations within the ellipse may be hidden or affected by dust
Preserved organics could occur in landing ellipse, in clay rich layers and in the sulfates.	Science in landing ellipse is secondary to that outside of the ellipse
	Go to site means Curiosity will have to travel

(C) Landing Site Selection Guide - Landing Site 2 (10 of 10)

Ground Engineer

Slopes in Landing Site 2

Map showing slopes of the landscape in selected locations in the Landing Site 2 landing ellipse and the target destination of Landing Site 2's mound

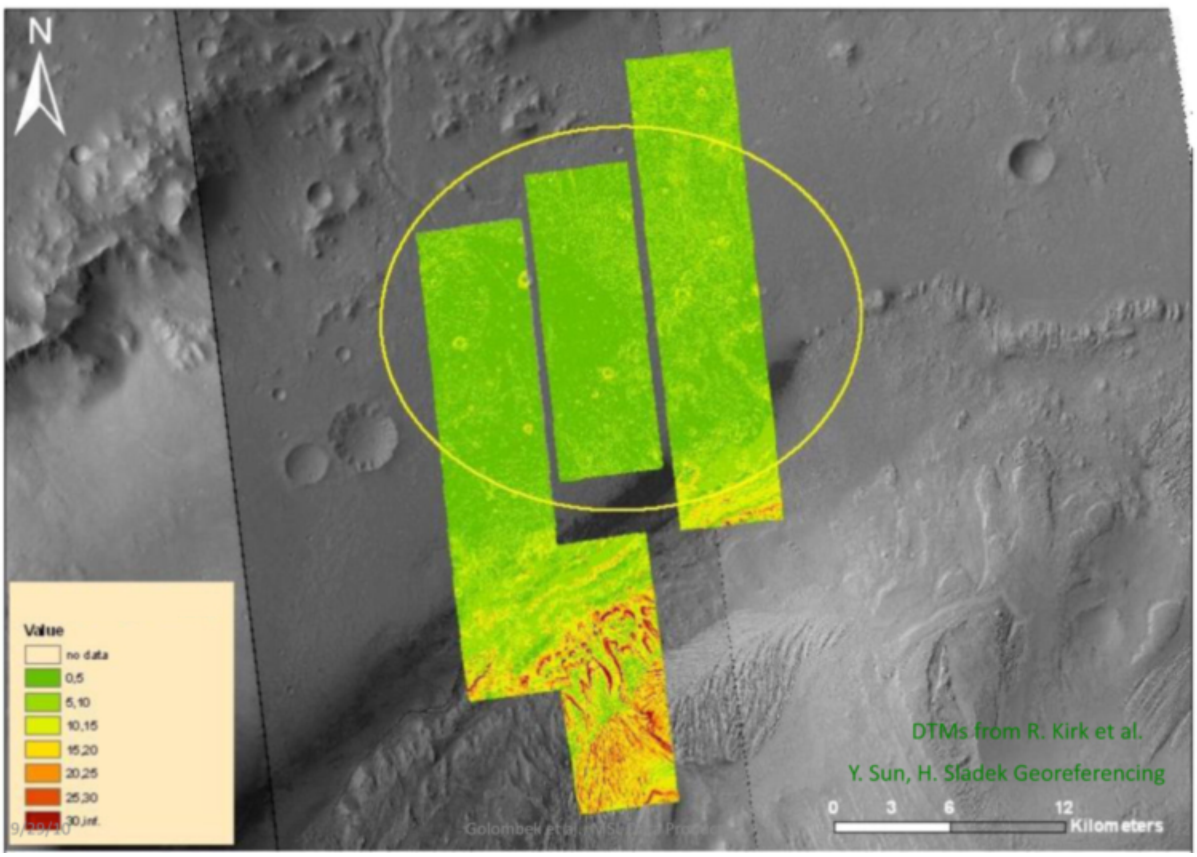
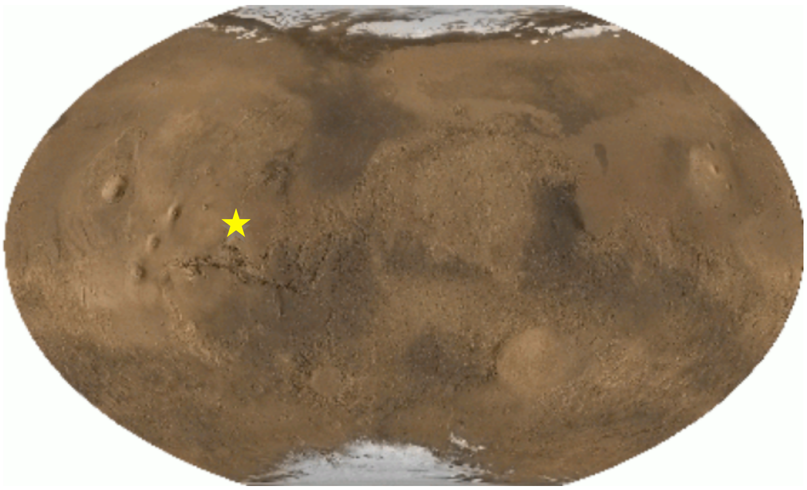


Image Credit: DTMs from Kirk et al. Y. Sum, H. Sladek Georeferencing

- White and dark green areas = shallower slopes
- Red and orange areas = steeper slopes

(D) Landing Site Selection Guide - Landing Site 3 (1 of 10)



Location: (26°S, 325°E)

Elevation: -1.9 km (-1.2 mi)

Courtesy NASA/JPL-Caltech

Overarching Hypothesis:

- Landing Site 3 preserves evidence of a river and lake system
- Contains alluvial fans, deposits from huge floods, possible lake beds, areas with clay minerals, and blocks of ancient Martian crust broken apart by impact events early in the planet's history.
- Provides the opportunity to evaluate and preserving evidence of a sustained, habitable environment.

(D) Landing Site Selection Guide - Landing Site 3 (2 of 10)

Landing Site 3 Context Image

- Closer view of diverse geology within Landing Site 3, including alluvial fans, bedrock, flood deposits, and clay-rich light-toned layered deposits (Light-toned-layered deposits)
- "Rim breach" is a location where a flood from came over Landing Site 3's rim
- Large white rectangle outlines a region with exposed Light-toned-layered deposits
- Red arrows show a possible route Curiosity could take to study Light-toned-layered deposits
- Small white box indicates approximate location of Landing Site 3 Zoom Image

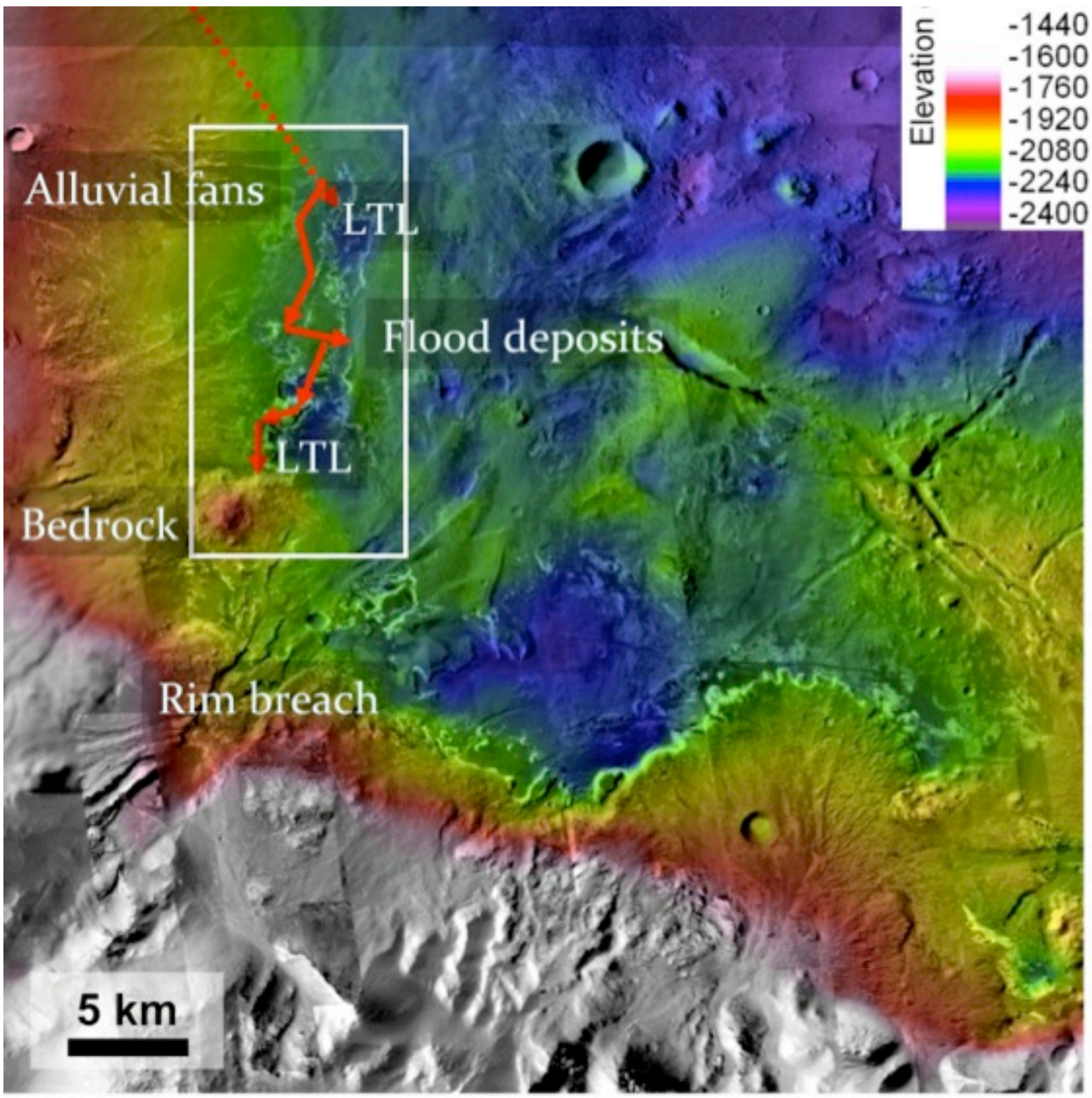


Image Credit: Courtesy of Ross Irwin and the Smithsonian Institution

(D) Landing Site Selection Guide - Landing Site 3 (3 of 10)

Landing Site 3: Zoom Image

- Close-up view of light-toned-layered depositsLight-toned-layered deposits located south of Landing Site 3's landing ellipse
- Light-toned-layered deposits contain lots of clay minerals
- Light-toned-layered deposits would be prime targets for Curiosity at this landing site

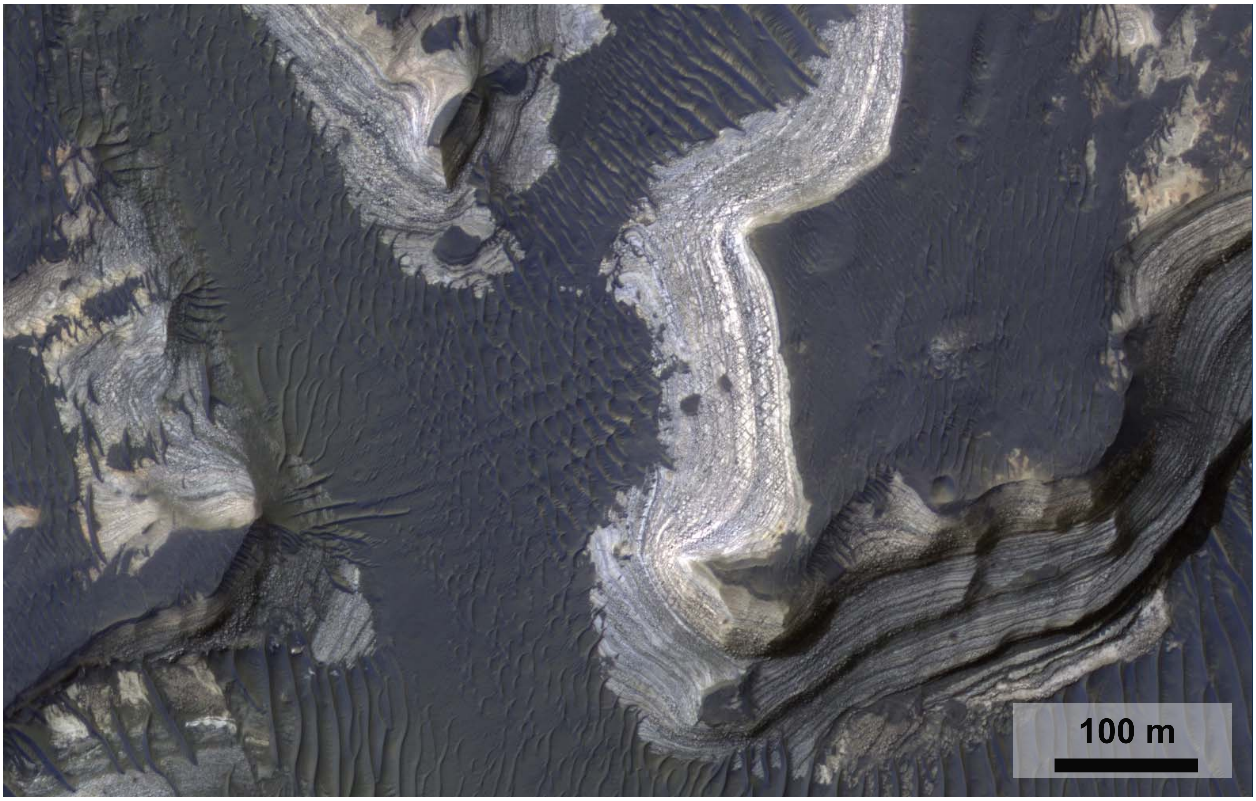


Image Credit: NASA/JPL-Caltech/University of Arizona

(D) Landing Site Selection Guide - Landing Site 3 (4 of 10)

Geomorphologist

- Complex geology
- Several different environments recorded in the area; how they interacted is not very well understood

Pros	Cons
Comprises one of the largest and best preserved alluvial systems on Mars	Origin of stratified light-toned (Light-toned-layered deposits) materials remains uncertain
Channel enters crater south of landing ellipse, called Uzboi Valles. Uzboi Valles is thought to have flooded Landing Site 3 and formed a lake, leaving flood deposits	Most of the rocks and minerals are fairly young, formed between 1,800 and 3,700 million years ago. Older rocks preserve more history of the planet.
Diverse and potentially weathered sediments likely record the environmental conditions responsible for their formation	
Some rocks & minerals from the impact crater provide a diverse age range from approximately 4,100 to 1,800 million years old	
Includes sediments, flood deposits, & impact crater rocks in the crater walls and floor	
There are targets for evaluating any preserved organics	

(D) Landing Site Selection Guide - Landing Site 3 (5 of 10)

Geomorphologist

Rock Density in Landing Site 3

Map showing rock density in and around the Landing Site 3 landing ellipse

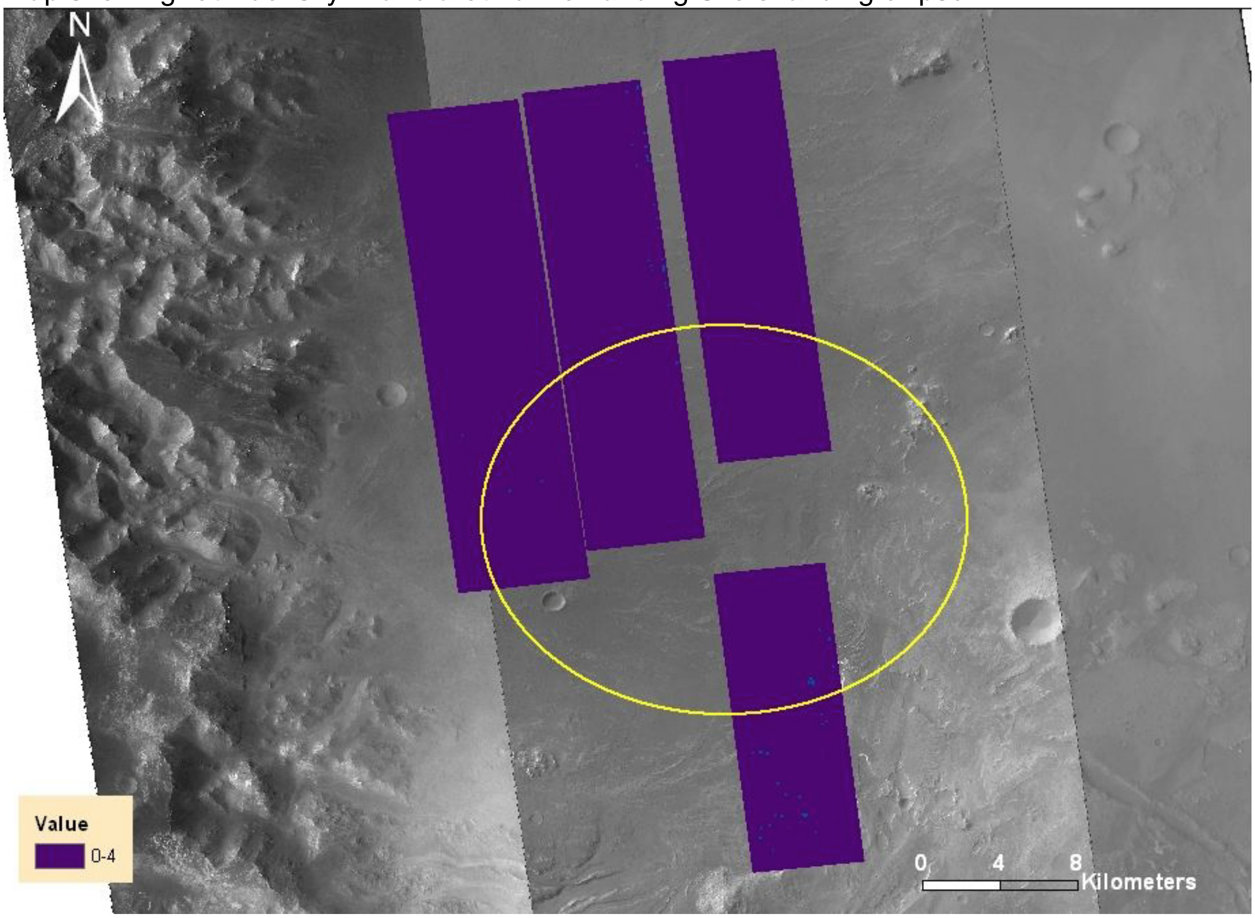


Image Credit: Huertas & Golombek

- Purple & blue = lower rock densities
- Red & orange = higher rock densities

(D) Landing Site Selection Guide - Landing Site 3 (6 of 10)

Mineralogist

Pros	Cons
Many different kinds of minerals are found in the deposits inside the crater, as well as in the crater walls and floor	A limited variety of clay minerals known to preserve past signs of life have been detected here
Diverse and potentially weathered sediments likely record the environmental conditions responsible for their formation	Relatively limited variety of phyllosilicate minerals known to preserve organics detected from orbit.
Mineral diversity in the light-toned layered deposits and crater walls/floor	
Includes sediments, phyllosilicates, flood deposits, & impact crater rocks in the crater walls and floor	
There are targets for evaluating any preserved organics	

(D) Landing Site Selection Guide - Landing Site 3 (7 of 10)

Mineralogist

Mineralogy in Landing Site 3

Image shows a diversity of minerals located just outside the landing ellipse, inside the southwestern wall of Landing Site 3

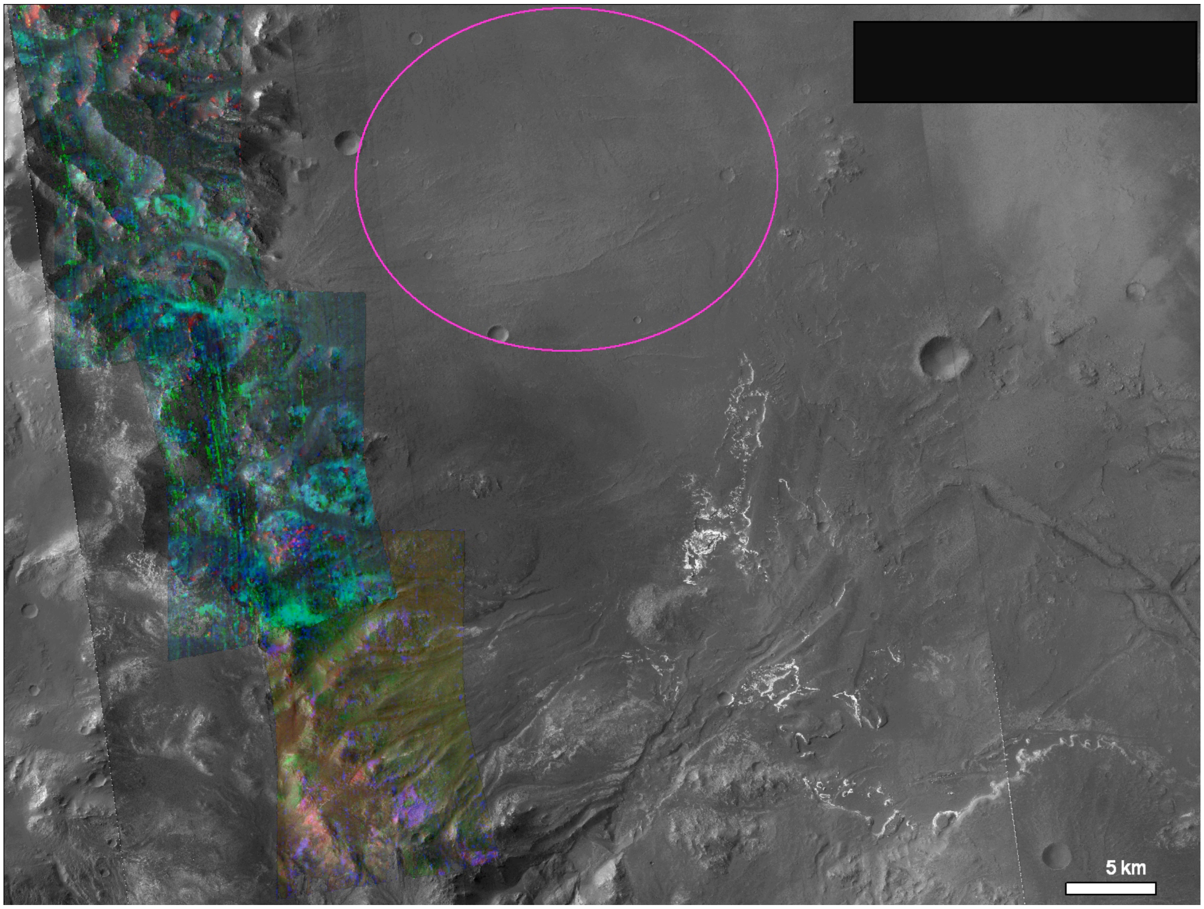


Image Credit: NASA/JPL-Caltech/JHUAPL/University of Arizona

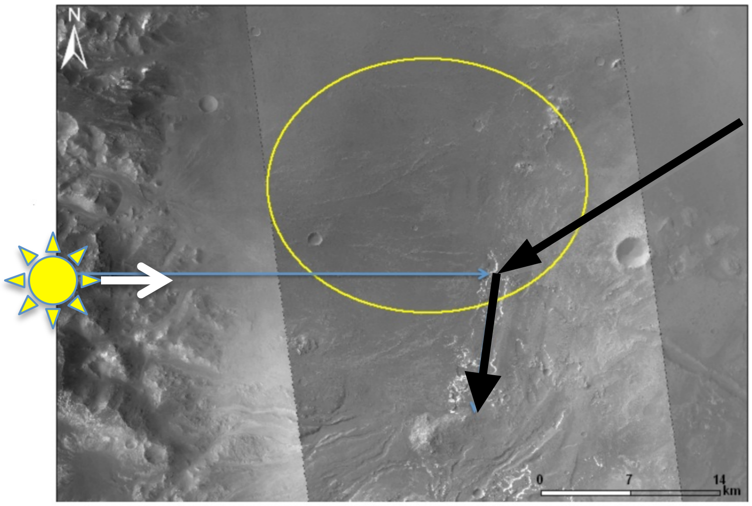
CRISM with HiRISE overlay:
Different colors indicate the presence of different types of minerals

Blue/green tones = a variety of volcanic (igneous) rock
Reddish/pinkish/purple tones = Fe/Mg-bearing clay minerals

(D) Landing Site Selection Guide - Landing Site 3 (8 of 10)

Ground Engineer

Location of Landing Site 3 Landing Ellipse



Landing ellipse is 25 km (~15 miles) long and 20 km (~12 miles) wide

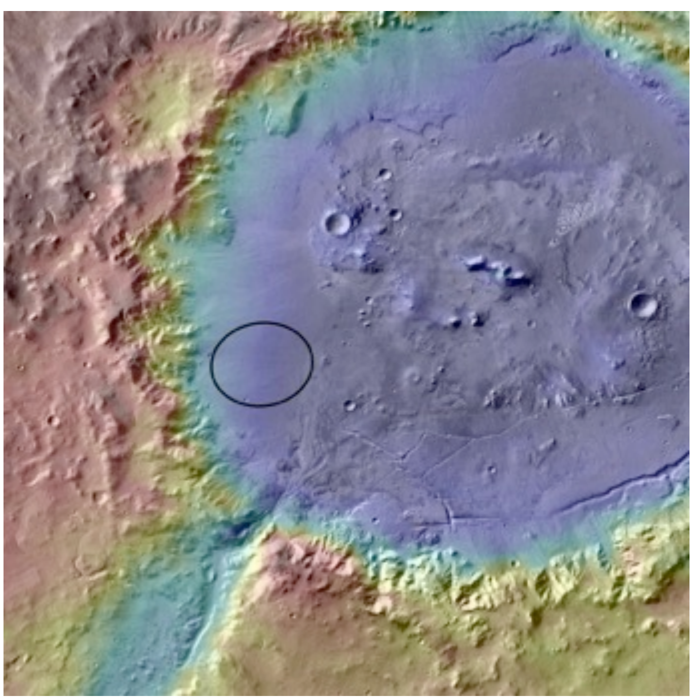
Long arrow points to interesting geologic unit in Landing Site 3 that Curiosity could investigate (Light-toned-layered deposits)

Shorter arrow is route Curiosity could take to learn more about this light-colored unit

Sunlight comes from the West direction.

Image Credit: NASA/JPL/Arizona

Location of Landing Site 3 Landing Ellipse: Elevation



Elevations of the Landing Site 3 landing ellipse (25 × 20 km)

Dark blue and green areas = lower elevations

Brown and red areas = higher elevations

Channel that enters crater south of landing ellipse is called Uzboi Valles

Uzboi Valles is thought to have flooded Landing Site 3 and formed a lake, leaving flood deposits

Image Credit: Courtesy NASA/JPL-Caltech/UA

(D) Landing Site Selection Guide - Landing Site 3 (9 of 10)

Ground Engineer

Pros	Cons
In place site means CURIOSITY may not have to travel very far	*Go to* sites require CURIOSITY to travel
Includes both *in place* and *go to* exploration	
Well-defined exploration targets exist inside and outside the landing ellipse.	
Targets within the ellipse offer access to all major units for interrogation	

(D) Landing Site Selection Guide - Landing Site 3 (10 of 10)

Ground Engineer

Slopes in Landing Site 3

Map showing slopes of the landscape in and around the Landing Site 3 landing ellipse

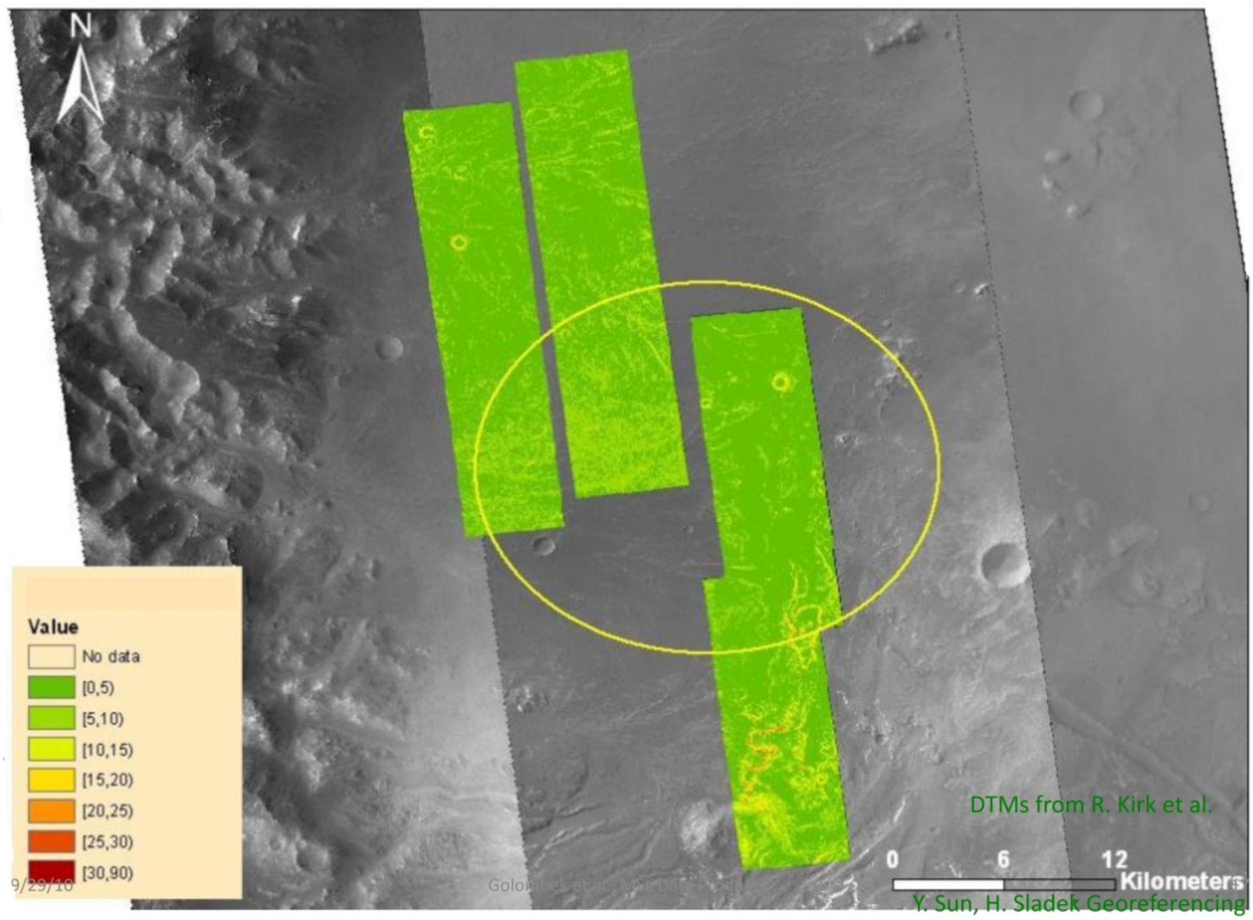


Image Credit: DTMs from Kirk et al.
Y. Sum, H. Sladek Georeferencing

- White and dark green = shallower slopes
- Red and orange = steeper slopes

(E) Landing Site Selection Guide - Landing Site 4 (1 of 12)

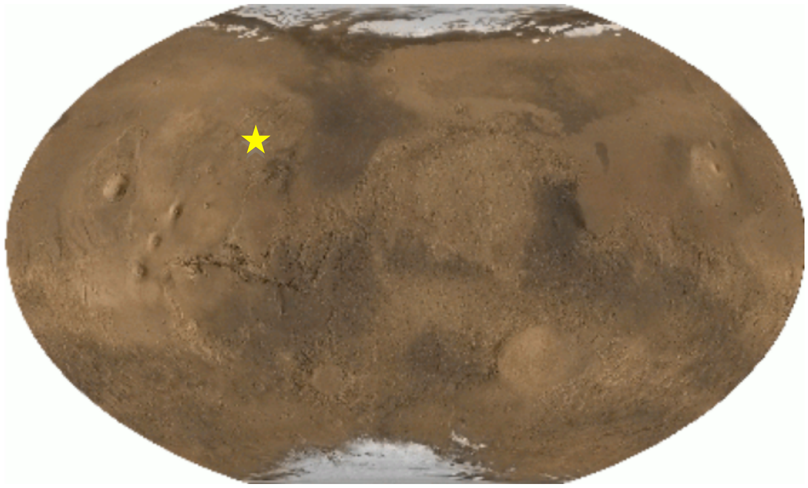


Image Credit: NASA/JPL-Caltech

Location: (24°N, 341°E)

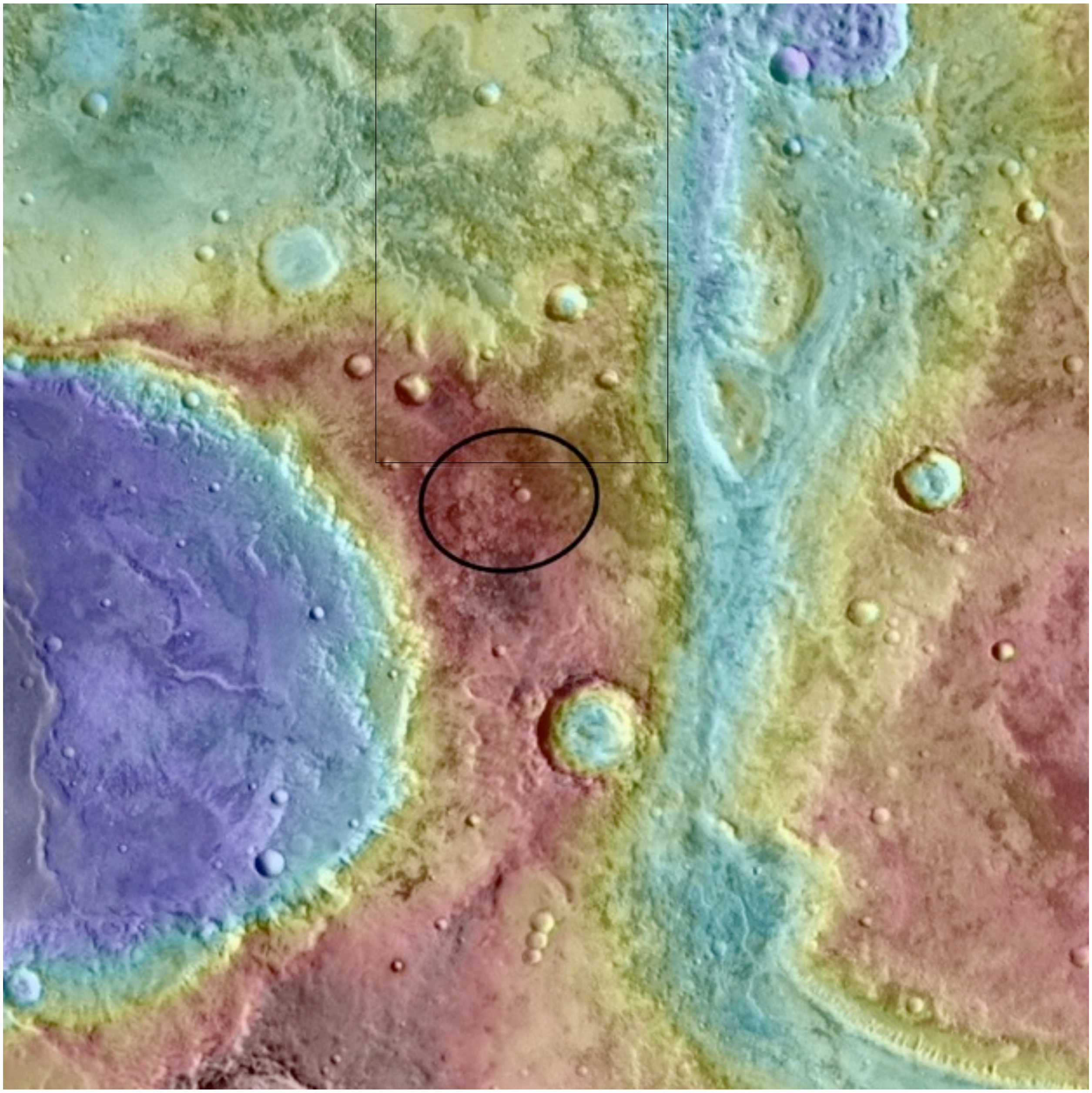
Elevation: -2.2 km (-1.4 mi)

Overarching Hypothesis:

- Landing Site 4 records geologic processes during early Martian history
    - A time when water bound minerals and rocks were being formed
- Provides the opportunity to understand the potential for early habitability on the planet
- May be representative of global conditions on Mars.

(E) Landing Site Selection Guide - Landing Site 4 (2 of 12)

Location of Landing Site 4 Landing Ellipse: Context Image



Courtesy NASA/JPL-Caltech/UA

- Black box indicates approximate location of bottom of Landing Site 4 Zoom Image #1, which extends beyond the top of this image

(E) Landing Site Selection Guide - Landing Site 4 (3 of 12)

Location of Landing Site 4 Landing Ellipse: Context Image

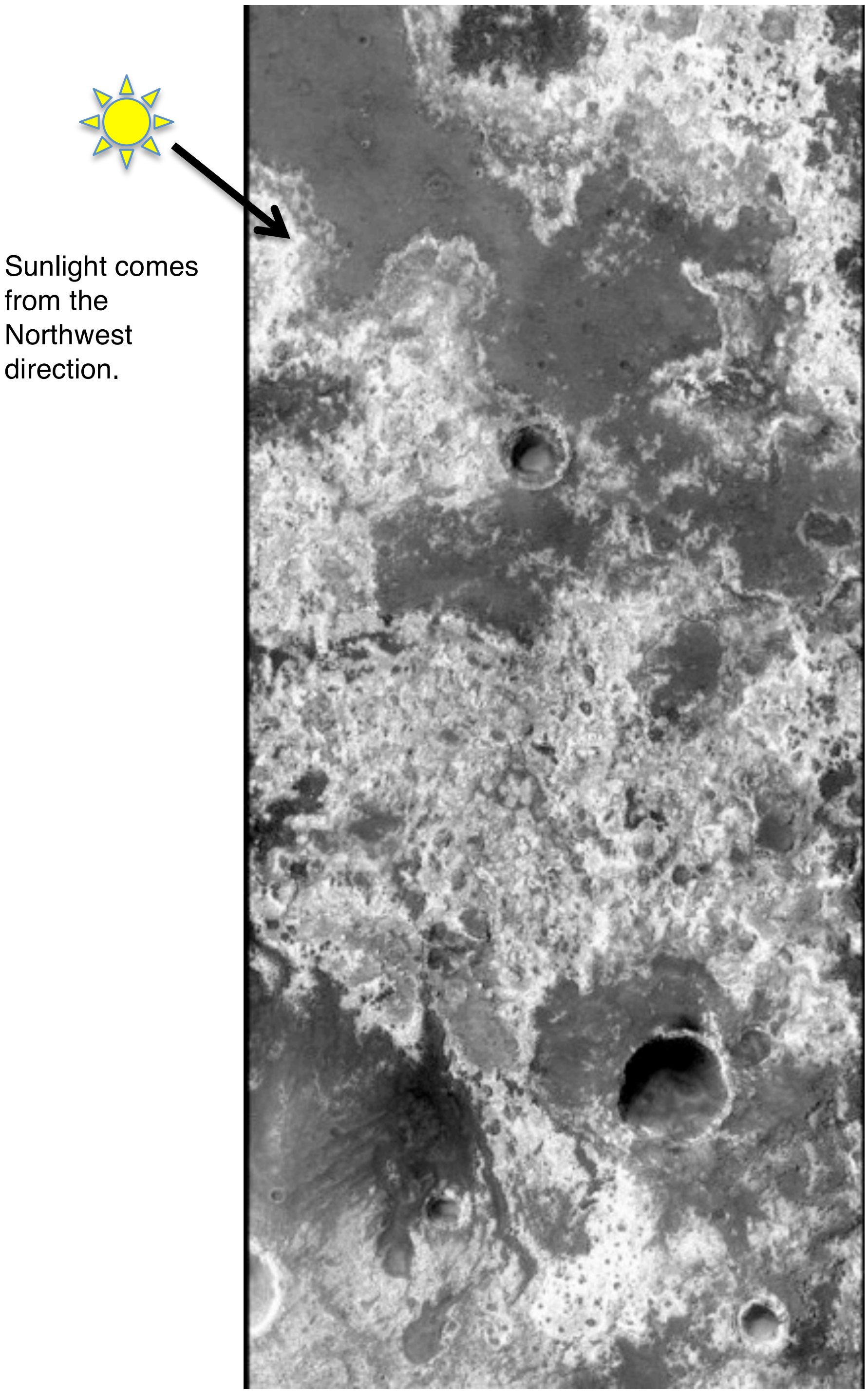


Image Credit: NASA/JPL-Caltech/MSSS

(E) Landing Site Selection Guide - Landing Site 4 (4 of 12)

Location of Landing Site 4 Landing Ellipse: Context Image

Image Credit: NASA/JPL-Caltech/MSSS

- Close-up view of 3-km-diameter (1.9-mile-diameter) impact crater near the Landing Site 4 landing ellipse
- When this impact crater formed, it exposed layers in sedimentary rock; some layers are harder than others, and appear to “stick out” more than other layers, forming ledges in the crater walls
- Much of the image area is covered with dark sand; lines on crater floor are sand dunes

(E) Landing Site Selection Guide - Landing Site 4 (5 of 12)

Geomorphologist

- Complex geology that is not very well understood
- Past environments of the area are not very well understood

Pros	Cons
Home to the oldest preserved rocks of the four candidate sites, approximately 4,000 million years old	The history & process of the formation of the rocks at Landing Site 4 remains uncertain
Some of the rocks appear to have been altered by groundwater	The amount, source, and duration of interaction with water in development of the units remain uncertain.
Allows investigation of information about the geologic processes active on early Mars.	Affected by the Heavy Bombardment period on Mars (when many asteroids impacted the planet)
The rocks are so old that they might be from a period not recorded in the rock record on Earth	Area has exposure to radiation, which could alter rocks
Younger rocks exist that would allow for exploration of more recent time periods on Mars	Some evidence that the rocks have been chemically altered since they formed.
Variety of rocks to help define the early period of time when water was present	
Variety of rocks to help define determine whether the environment was habitable	

(E) Landing Site Selection Guide - Landing Site 4 (6 of 12)

Geomorphologist

Rock Density in Landing Site 4

Map showing rock density in selected locations in and around the Landing Site 4 landing ellipse

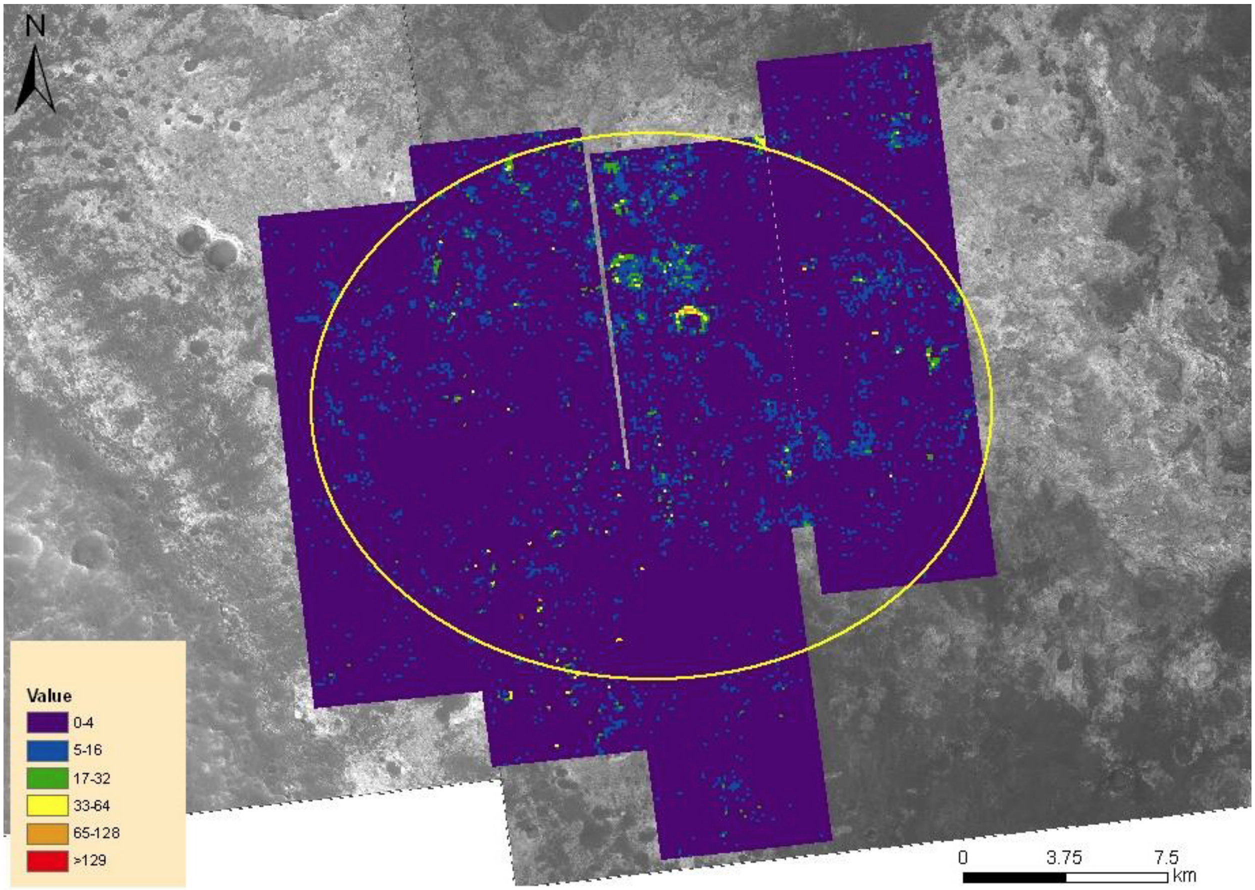


Image Credit: DTMs from Kirk et al.
Y. Sum, H. Sladek Georeferencing

- Purple and blue areas = lower rock densities
- Red and orange areas = higher rock densities

(E) Landing Site Selection Guide - Landing Site 4 (7 of 12)

Geomorphologist

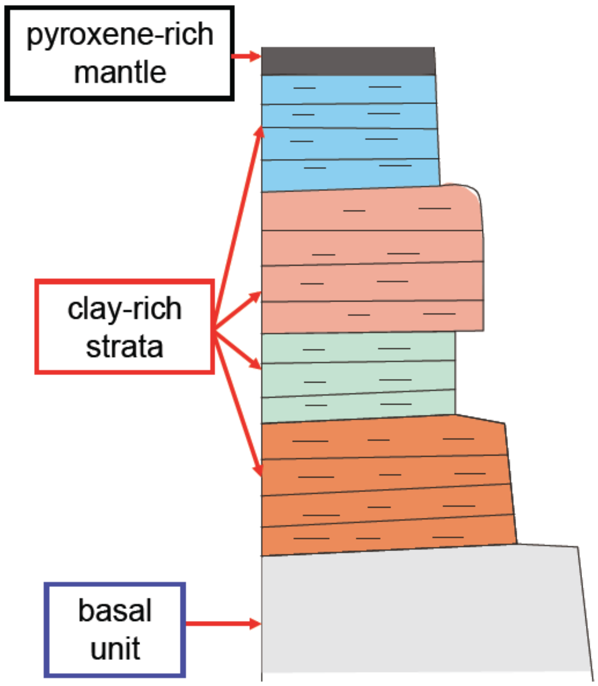


Image Credit: Bibring and Institute d'Astrophysique Spatiale

Pyroxene: silicate minerals found in igneous or metamorphic rock

- Silica is a good preservation agent for fossils (fossils on Earth; on Mars, we expect microbial life and not complex, multicellular organisms) and organic bio signatures

Clay minerals

- Some of the best materials to preserve evidence of life.
- Often indicate the past presence of water, since they frequently form in a water-rich environment.

Basal unit:

- Used to study aqueous history of the area

(E) Landing Site Selection Guide - Landing Site 4 (8 of 12)

Mineralogist

- Diverse mineralogy at this landing site, including at least two types of clay minerals

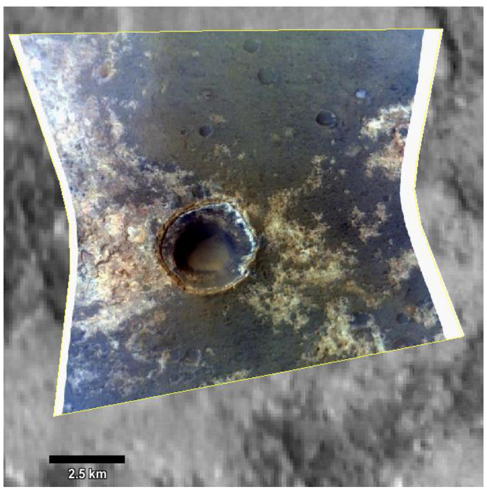
Pros	Cons
Several different types of minerals (including clay minerals) found within the landing ellipse	The history & process of the formation of the rocks and minerals at Landing Site 4 remains uncertain
More hydrated minerals are present than any of the other sites. These minerals formed in water-rich environments	The amount, source, and duration of interaction with water in development of the units remain uncertain.
Multiple phyllosilicates and sulfates which record varying aqueous (water) environmental conditions	
Phyllosilicates may contain/help preserve organics	
High level of sulfates	
Mg/Fe and Al- bearing phyllosilicate may show distribution of any organics	
Phyllosilicate abundance is over 50%, the highest on the planet	
Silicate minerals rich in magnesium and iron	
Hydrated phyllosilicate-rich site. If ever there was a time when Mars was habitable, it was at a time phyllosilicates formed	

(E) Landing Site Selection Guide - Landing Site 4 (9 of 12)

Mineralogist

- Different colors in the images represent different amounts of minerals
- The types of minerals near the surface in and around Mawrth Vallis are different than types of minerals found below the surface (For more detail, see *Geology of Landing Site 4* graphic, located in the geomorphologist's information)
- Blue outline in the bottom image shows the location of the CRISM images relative to the Landing Site 4 landing ellipse (both images are from the same location)

Image Credit: NASA/JPL-Caltech/JHUAPL



Craters shows hydroxilated silicates changes with depth.

Blue = water rich clays
Red = Fe/Mg clay
Green = Al clay

Image ID: FRT0000C596

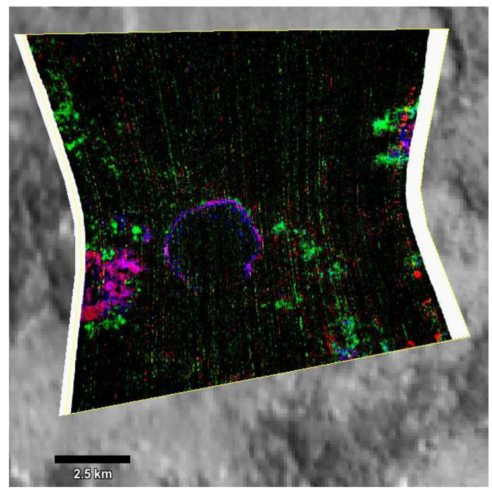


Image Credit: NASA/JPL-Caltech/JHUAPL

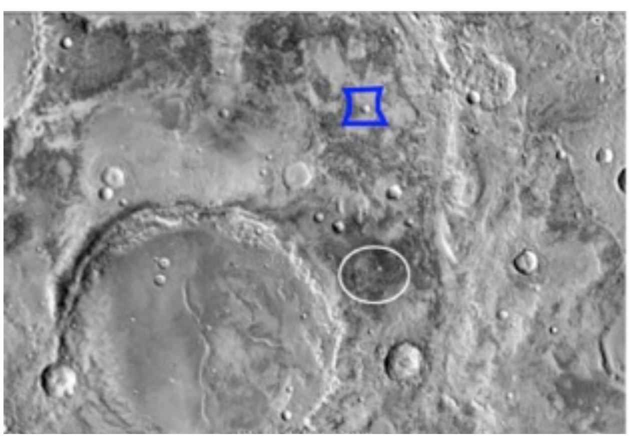


Image Credit: NASA/JPL-Caltech/Arizona State University

Landing Site 4: Mineral Overview

- Clay abundance ~30 - 70%
- Fe-rich clay minerals
- Fe/Mg-mica in Fe-rich clay
- Fe3 - oxyhydroxide
- Anhydrous iron & magnesium minerals are the dominant phases (< 30%)

(E) Landing Site Selection Guide - Landing Site 4 (10 of 12)

Ground Engineer

Pros	Cons
In place site means Curiosity may not have to travel very far	*Go to* sites require Curiosity to travel
The site is so large that a number of ellipses can be considered for *Go-To* and *In-Place*	
Several different types of minerals (including clay minerals) found within the landing ellipse	
Several locations in close proximity and within the ellipse	
Prioritized targets within the ellipse has been identified and targets outside the ellipse	

The most highly recommended landing ellipse is shown below.

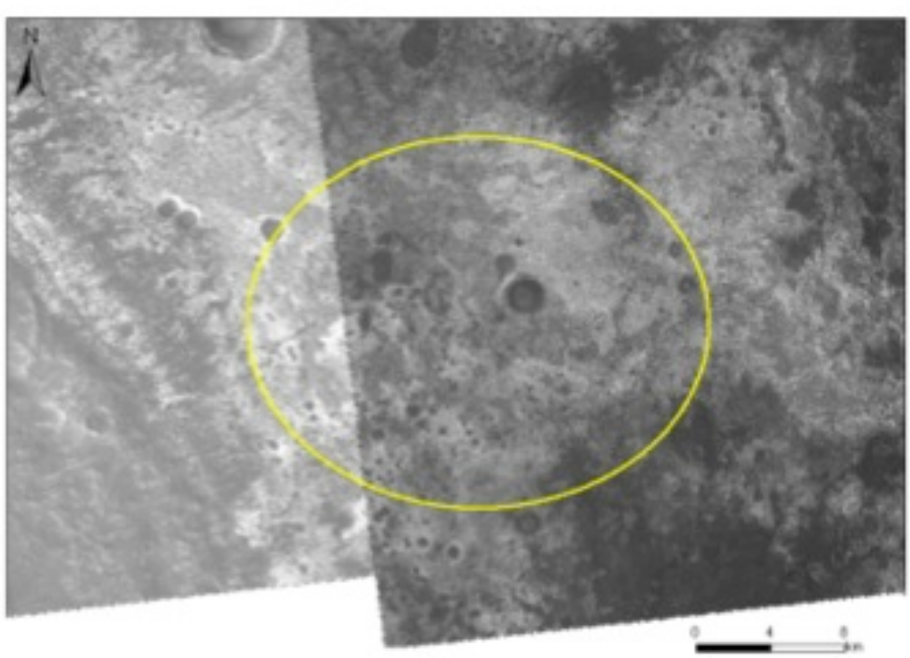
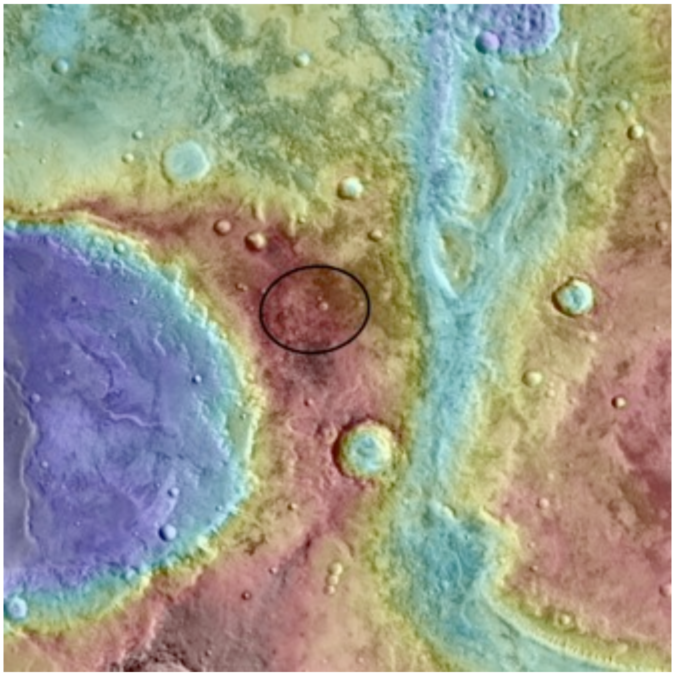


Image Credit: NASA/JPL-Caltech/Arizona State University

(E) Landing Site Selection Guide - Landing Site 4 (11 of 12)

Ground Engineer

Location of Landing Site 4 Landing Ellipse



Courtesy NASA/JPL-Caltech

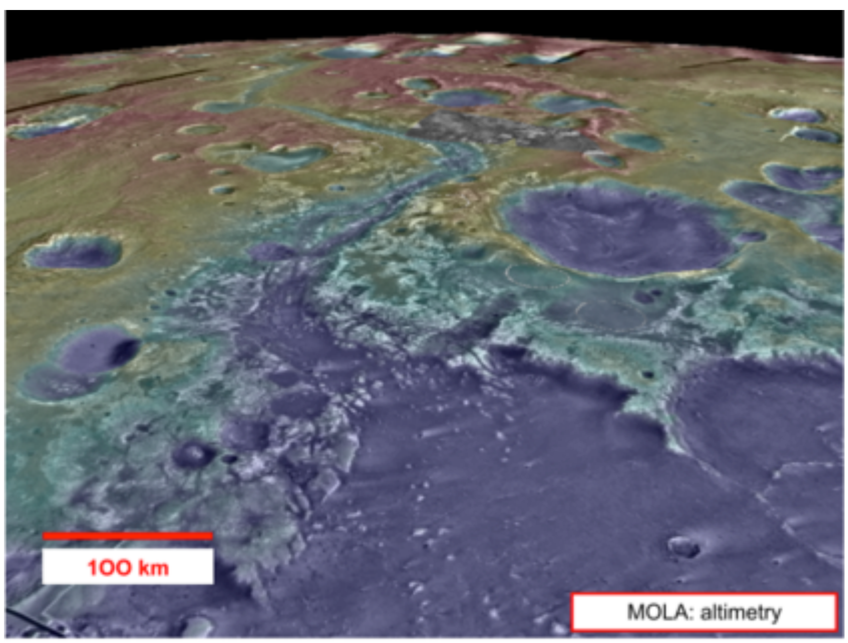
Ellipse is 25 km (~15 miles) long and 20 km (~12 miles) wide

Location of Landing Site 4 Landing Ellipse: Elevation

Image shows elevation in and around Landing Site 4 landing ellipse (25 × 20 km)

Dark blue and green areas = lower elevations

Brown and red areas = higher elevations



Courtesy NASA/JPL-Caltech

(E) Landing Site Selection Guide - Landing Site 4 (12 of 12)

Ground Engineer

Slopes in Landing Site 4

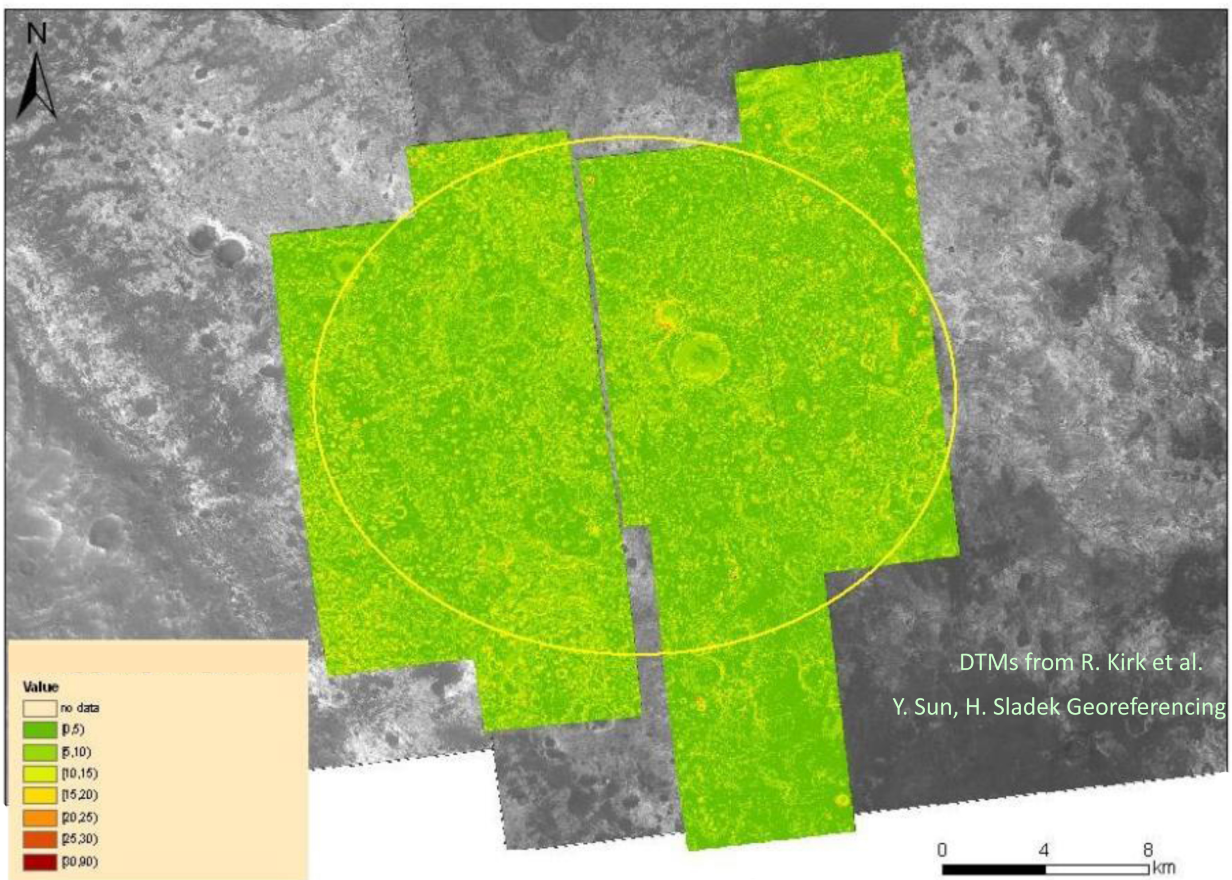


Image Credit: DTMs from Kirk et al.
Y. Sum, H. Sladek Georeferencing

- Map showing slopes of the landscape in selected locations in and around the Landing Site 4 landing ellipse, based on high-resolution digital elevation models (5 meters/pixel)
- White and dark green areas = shallower slopes
- Red and orange areas = steeper slopes

(F) Landing Site Selection Sheet (1 of 2)

NAME: ________________________________

Use the Expert Cards and Landing Site Guides to make observations (important details) about each landing site. You will use these observations to rank your choice of landing site. The better your observations, the better your rankings will be. Explain your ranking.

★★★★ (4 stars) = your favorite site

★★★ (3 stars) = your 2nd choice

★★ (2 stars) = your 3rd choice

★ (1 star) = your least favorite site

Landing Site	Observations	Rank (1-4) & Explanation
1		
2		

(F) Landing Site Selection Sheet (2 of 2)

Landing Site	Observations	Rank (1-4) & Explanation
3		
4		

(G) Expert Group Meeting Sheet (1 of 2)

NAME: ________________________________

During your Expert Group Meeting, complete the table below. In this table, you will record the reasons each person chose his or her landing site. These reasons may or may not persuade you to change your ranking for site selection. At the end of your Expert Group Meeting, make changes to your rankings on the *(F) Landing Site Selection Sheet*. You will be reporting to your Landing Site Selection Team, so be prepared to explain why you chose those rankings.

Landing Site	Reasons the Landing Site was chosen
1	
2	
3	
4	

(G) Expert Group Meeting Sheet (2 of 2)

As an expert group, you may have found you all did not agree on your observations. This disagreement probably occurs because you don't have a common set of criteria in place for how you would measure or observe objects. For example, how much "red" area is considered "a lot?" How big is "big?" As a group, you will want to establish precise criteria so that you are all comparing the data similarly. Below, identify some of the areas your expert group had difficulty agreeing on. Then, create a list of rules you will all follow. An example has been provided for you.

Area of Difficulty	***Criteria***
Ex. How much is "a lot"?	***Ex. When more than half of the image is that same color.***

(H) Reflection (1 of 3)

NAME: ______________________________

Answer the following questions on your own.

1. Refer back to your process map from the beginning of this activity. Are there any additions you can make to this diagram now that you have completed this activity? Go ahead and add those to the map.

2. Did everyone in your Landing Site Selection Team get the landing site they wanted for the rover? ____________ Why or why not?

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3. Describe an example of how a member of the Landing Site Selection Team needed to compromise with the other team members to pick a rover landing site.

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(H) Identifying Science and Engineering Relationships (2 of 3)

4. Describe how the criteria were helpful and necessary in the decision-making process for the landing site.

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5. After this activity, what do you now understand about the way scientists and engineers work to identify a landing site for a mission such as the Mars Science Laboratory?

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6. Is there one right answer to a correct landing site? ________________ Why or Why not?

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7. Which landing site did your group choose? ____________________________________

Explain why this landing site was chosen using data and criteria to support your reasoning.

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(I) Teacher Background Information (1 of 2)

Information below may be some of the observations students will make during this process. Reminding students that higher rock densities and rougher surfaces will be more difficult to land on or even rove over because of the number of rocks on the terrain. Steep slopes should also be avoided since they could cause the rover to tumble down the slope or even be unable to drive back out.

Landing Site 1 (Eberswalde Crater)

- **Preservation Potential:** Life on Earth thrives in river, delta, and lake environments. The layered, clay-rich rocks in the delta may contain evidence of habitable environments and/or life, if it ever existed in the environment.
- **Geomorphologist:** Eberswalde Crater has highest rock density of the four landing sites
- **Ground Engineer:** Roughest surface of all of the landing sites
- **Ground Engineer:** Eberswalde Crater landing ellipse contains steepest slopes of the four landing sites

Landing Site 2 (Gale Crater)

- **Preservation Potential:** Gale has a very thick deposit of sedimentary rocks that includes clay minerals and sulfate salts. The rocks appear to have once filled in the crater and are now being eroded. Within the thick stack of rocks, there is some evidence of erosion between layers, meaning that there are gaps in the geologic record chronicled in this sequence. However, there are still a very large number of layers preserved, and, in general, the layers that are present appear to be relatively flat and fairly undisturbed. This might have helped them hold on to evidence of habitable environments if they ever existed in that area.
- **Ground Engineer:** Very smooth landing site

Landing Site 3 (Holden Crater)

- **Preservation Potential:** Holden Crater would provide the opportunity to investigate the habitability of several types of environments, including alluvial fans, flood deposits, and possible lake beds. The light-toned-layered deposits (Light-toned-layered deposits) at this site contain a lot of clay minerals. They would be a good rock type to test for evidence of past habitable environments.
- **Geomorphologist:** Holden Crater has lowest rock density of the four landing sites (though it is just slightly below the rock density found in Mawrth Vallis)
- **Ground Engineer:** Very smooth landing site

(I) Teacher Background Information (2 of 2)

Landing Site 4 (Mawrth Vallis)

- **Preservation Potential:**
    - Positive: Mawrth Vallis contains clay minerals, which are some of the best materials to preserve evidence of life. Most evidence of past life on Earth was preserved in clay that became rock. Clay minerals also often indicate the past presence of water, since they are often form in a water-rich environment.
    - Negative: Mawrth Vallis has very old sedimentary rocks. They have been around for a long time, and have experienced things like lots of impact events and exposure to radiation. There is also evidence that the rocks have been chemically altered since they formed.
- **Ground Engineer:** Mawrth Vallis has an intermediate surface roughness

(J) Teacher Resource – Landing Site Selection Rubric

You will know the level to which your students have achieved the **Learning Outcomes**, and thus the **Instructional Objective(s)**, by using the suggested **Rubrics** below.

Instructional Objective 1: to evaluate proposed landing sites using criteria

Related Standard(s) (will be replaced when new NRC Framework-based science standards are released):

National Science Education Standards (NSES)
(E) Science and Technology: Understandings about science and technology

Scientific inquiry and technological design have similarities and differences. Scientists propose explanations for questions about the natural world, and engineers propose solutions relating to human problems, needs, and aspirations. Technological solutions are temporary; technologies exist within nature and so they cannot contravene physical or biological principles; technological solutions have side effects; and technologies cost, carry risks, and provide benefits. (Grades 5-8: E2a).

Perfectly designed solutions do not exist. All technological solutions have tradeoffs, such as safety, cost, efficiency, and appearance. Engineers often build in back-up systems to provide safety. Risk is part of living in a highly technological world. Reducing risk often results in new technology. (Grades 5-8: E2d).

Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations. Many scientific investigations require the contributions of individuals from different disciplines, including engineering. New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines. (Grades 9-12: E2a)

Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human aspirations. Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world. (Grades 9-12: E2d)

National Science Education Standards (NSES)
(E) Science and Technology: Abilities of Technological Design

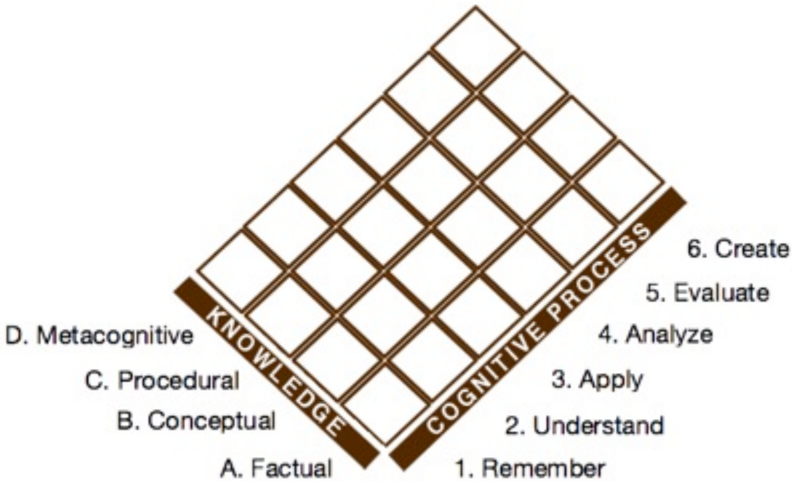
Design a solution or product. Students should make and compare different proposals in the light of the criteria they have selected. They must consider constraints—such as cost, time, trade-offs, and materials needed—and communicate ideas with drawings and simple models. (Grades 5-8: E1b)

Evaluate completed technological designs or products. Students should use criteria relevant to the original purpose or need, consider a variety of factors that might affect acceptability and suitability for intended users or beneficiaries, and develop measures of quality with respect to such criteria and factors; they should also suggest improvements and, for their own products, try proposed modifications. (Grades 5-8: E1d)

Related Rubrics for the Assessment of Learning Outcomes Associated with the Above Standard(s):

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1a. to identify landing site requirements given a specific perspective	Initial landing site selection is comprehensively based on the expert role and choice is thoughtful.	Initial landing site selection is strongly based on the expert role and choice is thoughtful.	Initial landing site selection is somewhat based on the expert role and choice is thoughtful.	Initial landing site selection is not based on the expert role.
LO1b. to develop acceptable criteria	Criteria are thoughtful, detailed, and comprehensive.	Criteria contains strong details and appear thoughtful.	Criteria have some details and appear thoughtful.	Criteria have few details with little thought put into them.
LO1c. to judge proposed landing sites using criteria	The use of criteria is evident in landing site selection and used as evidence for the selection.	The use of criteria is somewhat evident in landing site selection and used as evidence for selection.	The use of criteria is somewhat evident, but not used as evident.	Criteria were not used in landing site selection.
LO1d. to instantiate landing site conclusions using data	Landing site selected is accurately and completely supported by data collected.	Landing site selected is supported by data collected.	Landing site selected is support by some data collected.	Landing site selected is not supported by data.
LO1e. to find coherence among the experts to successfully reach a consensus in selecting a landing site	Group successfully chooses a landing site based on information from all members of the team using effective communication and accurate information.	Group chooses a landing site based on information from 3 team members.	Group chooses a landing site based on information from 2 team members.	Team is unable to work collaboratively.

(K) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (1 of 3)



This lesson adapts Anderson and Krathwohl's (2001) taxonomy, which has two domains: Knowledge and Cognitive Process, each with types and subtypes (listed below). Verbs for objectives and outcomes in this lesson align with the suggested knowledge and cognitive process area and are mapped on the next page(s). Activity procedures and assessments are designed to support the target knowledge/cognitive process.

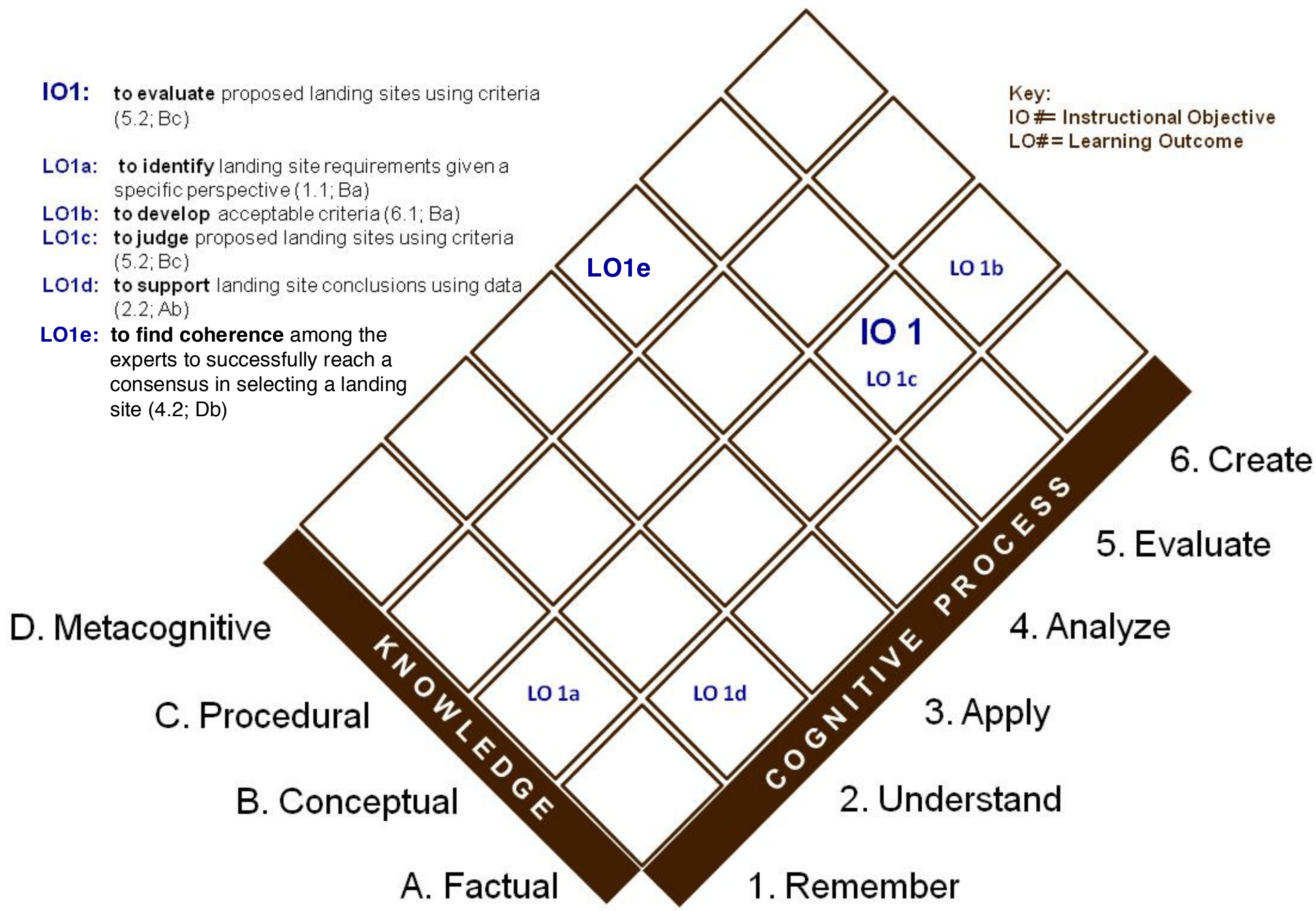
Knowledge	Cognitive Process
A. Factual **Aa:** Knowledge of Terminology **Ab:** Knowledge of Specific Details & Elements **B. Conceptual** **Ba:** Knowledge of classifications and categories **Bb:** Knowledge of principles and generalizations **Bc:** Knowledge of theories, models, and structures **C. Procedural** **Ca:** Knowledge of subject-specific skills and algorithms **Cb:** Knowledge of subject-specific techniques and methods **Cc:** Knowledge of criteria for determining when to use appropriate procedures **D. Metacognitive** **Da:** Strategic Knowledge **Db:** Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge **Dc:** Self-knowledge	**1. Remember** **1.1** Recognizing (Identifying) **1.2** Recalling (Retrieving) **2. Understand** **2.1** Interpreting (Clarifying, Paraphrasing, Representing, Translating) **2.2** Exemplifying (Illustrating, Instantiating) **2.3** Classifying (Categorizing, Subsuming) **2.4** Summarizing (Abstracting, Generalizing) **2.5** Inferring (Concluding, Extrapolating, Interpolating, Predicting) **2.6** Comparing (Contrasting, Mapping, Matching **2.7** Explaining (Constructing models) **3. Apply** **3.1** Executing (Carrying out) **3.2** Implementing (Using) **4. Analyze** **4.1** Differentiating (Discriminating, distinguishing, focusing, selecting) **4.2** Organizing (Finding coherence, integrating, outlining, parsing, structuring) **4.3** Attributing (Deconstructing) **5. Evaluate** **5.1** Checking (Coordinating, Detecting, Monitoring, Testing) **5.2** Critiquing (Judging) **6. Create** **6.1** Generating (Hypothesizing) **6.2** Planning (Designing) **6.3** Producing (Constructing)

(K) Alignment of Instructional Objective(s) and Learning Outcomes with Knowledge & Cognitive Process Types (2 of 3)

The design of this activity leverages Anderson & Krathwohl's (2001) taxonomy as a framework. Pedagogically, it is important to ensure that objectives and outcomes are written to match the knowledge and cognitive process students are intended to acquire.

IO1: **to evaluate** proposed landing sites using criteria (5.2; Bc)

LO1a: **to identify** landing site requirements given a specific perspective (1.1; Ba)
LO1b: **to develop** acceptable criteria (6.1; Ba)
LO1c: **to judge** proposed landing sites using criteria (5.2; Bc)
LO1d: **to support** landing site conclusions using data (2.2; Ab)
LO1e: **to find coherence** among the experts to successfully reach a consensus in selecting a landing site (4.2; Db)



(K) Alignment of Instructional Objective(s) and Learning Outcomes with Knowledge & Cognitive Process Types (3 of 3)

The design of this activity leverages Anderson & Krathwohl's (2001) taxonomy as a framework. Below are the knowledge and cognitive process types students are intended to acquire per the instructional objective(s) and learning outcomes written for this lesson. The specific, scaffolded 5E steps in this lesson (see 5.0 Procedures) and the formative assessments (worksheets in the Student Guide and rubrics in the Teacher Guide) are written to support those objective(s) and learning outcomes. Refer to (K, 1 of 3) for the full list of categories in the taxonomy from which the following were selected. The prior page (K, 2 of 3) provides a visual description of the placement of learning outcomes that enable the overall instructional objective(s) to be met.

At the end of the lesson, students will be able

IO1: to evaluate landing sites using criteria

5.2: to evaluate
Bc: knowledge of theories, models, and structures

To meet that instructional objective, students will demonstrate the abilities:

LO1a: to identify landing site requirements

1.1: to identify
Ba: knowledge of classifications and categories

LO1b: to develop acceptable criteria

6.1: to develop
Ba: knowledge of classifications and categories

LO1c: to judge landing sites using criteria

5.2: to judge
Bc: knowledge of theories, models, and structures

LO1d: to support conclusions with data

2.2: to instantiate
Ab: knowledge of specific details and elements

LO1e. to find coherence among the experts

4.2: to organize
Db: Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge