Selecting a Mars Landing Site – the 0.0003% solution

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The Problem

You have a multi-million (or billion) dollar spacecraft that will soon be launched to Mars. A piece of complex robotics and state-of-the-art scientific analysis equipment that thousands of people are working together to build. A craft that represents up to 20 years of the scientific careers of the primary investigators (PIs) responsible for it…

The big problem is – where do you tell it to land?

Selecting a good landing site on Mars

Mars is smaller than the Earth (6787km in diameter as opposed to 12756km), but when you are landing a craft on it, you still have to look at the whole planet to find a suitable landing site. The designers and engineers tell you that the craft will be able to set down somewhere in a landing area about 20km by 7km (or 439 km^2); Mars is a planet that has a surface area of 144.8 million km^2. Which 0.0003% of the planet do you send your craft to? This has to be determined by what you are looking for.

What is the goal of the mission?

The goal of the mission is to continue the search for evidence of life on Mars. In the most recent cases (the Spirit and Opportunity Mars Exploration Rovers, and the Curiosity Mars Science Laboratory Rover), we have been looking for evidence of a past wetter and habitable environment on Mars. Curiosity is also looking for organic signatures that may have been left by ancient or recent life. Future Mars missions, such as the European Space Agency's 2016 and 2018 ExoMars missions and NASA's 2020 Mars Rover, will not only be searching for life on the surface of Mars, but they will also be drilling metres below the surface to look for traces of organic molecules that may indicate past or present life.

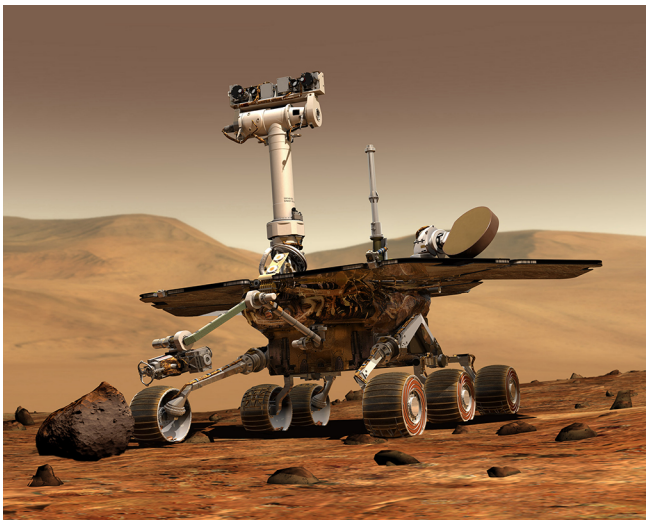


Figure 1: NASA's Spirit Rover – sent to Gusev Crater on Mars in 2004 to look for evidence of water.

Where do you look for life?

Where are these potentially habitable environments? How do we know what Mars was like in the past? Finding the answers to these questions has been the goal of the Mars Missions since the 1970s. We now have evidence from the Phoenix lander and both Spirit and Opportunity rovers that – in the past – Mars was much wetter and warmer than it is today. Phoenix even found layers of water ice where it landed – just below the surface dust. However, Mars today is a very different planet. It is dry and cold, with only a thin atmosphere. Water can only remain in liquid form for about 8 to 10 minutes before it either evaporates into the atmosphere or freezes out onto the surface. If you are looking for life on Mars, you have to think differently to the way you would if you were looking for life on Earth.

Consider the diversity of environments that we have on Earth. Imagine that instead of being from Earth, you are a Martian, and you are sending your first space probe to Earth to find out if there is life here. Where would you land the probe on Earth? As a Martian – assuming that Earth life would be likely to evolve in a Mars-like environment – you would probably send it to places like the Dry Valleys in Antarctica, the Atacama Desert in South America, or Haughton Crater in Canada (Figure 2).

Figure 2: A prototype Mars rover being tested at Haughton Crater, Canada

All of these places are used as Mars-lookalikes (or "analogues") when proposed Mars rovers, or scientific instruments designed to fly to Mars, are being tested on Earth. Fortunately for your career as a Martian scientist you can find life pretty much anywhere on Earth, so your craft will succeed in finding life no matter where it lands. It will, however, take longer to find traces of Earth life in these Mars-like environments, as very few Earth organisms can live there.

Earth-bound scientists have a harder task when looking for landing sites on Mars. There are no truly 'Earth-like' places on Mars: no jungles, no oceans. Mars' oceans dried up or froze billions of years ago and we are pretty sure that Mars never had jungles of any sort.

You need to look at the whole planet and see where life would be most likely to have existed in the past or may still be able to exist today. You are looking for the right types of rocks, landforms and sediments that indicate that Mars was once more 'Earth-like'. Places which were warmer, wetter and would have been friendlier to life, if life as we know it ever evolved on Mars. The ideal rocks to look for evidence of past life are layered ocean or lake mudstones or fine sediments that you find in river delta deposits. These only form in water-rich areas, and indicate the long-term presence of water. In addition, you also can look for evidence of ancient lake shorelines, or meandering river beds. These can be seen in images taken by orbiting spacecraft.

Finding evidence for habitable environments

To detect these mineral and rock types or any environments that may have been habitable in the past, we use pictures taken from Mars orbit by craft like Mars Odyssey, Mars Reconnaissance Orbiter and MarsExpress. These craft are constantly scanning the surface of Mars – taking pictures that allow them to see something the size of this book on the surface of the planet – and also working out what it is made of. In addition to taking photos using visible light (the part of the electromagnetic spectrum we see), they also see into the ultraviolet and infrared wavelengths (Figure 3). This allows us to create synthetic images by overlapping different spectral bands[1] which enhance and identify mineral and rock types, surface roughness, and even surface temperatures at night.

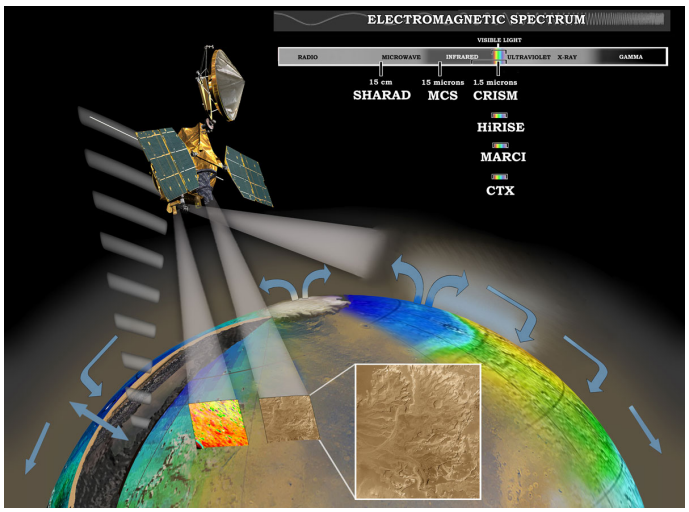


Figure 3: The Mars Reconnaissance Orbiter and its spectral capabilities.

[1] The spectrum can be divided into spectral bands of different wavelength. One remote sensing instrument (spectrometer) can record images across a small range of wavelengths. These images can then be combined digitally.

The photographic data from most of the Mars orbiters are publicly posted on their websites, so anyone can look at it, and analyse it for indications of a potential habitable environment.

Site Selection Process – finding the Curiosity landing site

Once a Mars mission is announced, and a need is identified for a landing site to be selected, a call for sites is made to scientists globally. NASA's Mars landing site selection group is gathered from the members of the Mars Exploration Program Analysis Group. Proposals for landing sites are requested from scientists and engineers from all countries.

The selection of Curiosity's landing site began in 2006, for a proposed 2009 launch date. At the 2006 site selection workshop a total of 33 landing sites were proposed with a total of 94 landing ellipses[2] shared between them. They were flagged as sites of potential geologic interest. More orbiter time was dedicated to obtaining data for these areas of Mars to allow their investigators to research them before the next workshop.

By the end of the second workshop in 2007 – after spending three days discussing 29 sites – the number of potential landing sites had been cut to six. Four factors were rated for each site by a vote from the attendees: the ability to characterise the geology; evidence for a habitable environment; preservation of bio-signatures[3]; and the ability to assess the biological potential of the site. These final six sites did not actually include Gale Crater, the final landing site for Curiosity, as it was voted down and out of the finals because not enough was known at this time about its geologic history and whether it had ever had a habitable environment. Figure 4 shows the results of the site assessments considered in the second landing workshop: including the Gale Crater site.

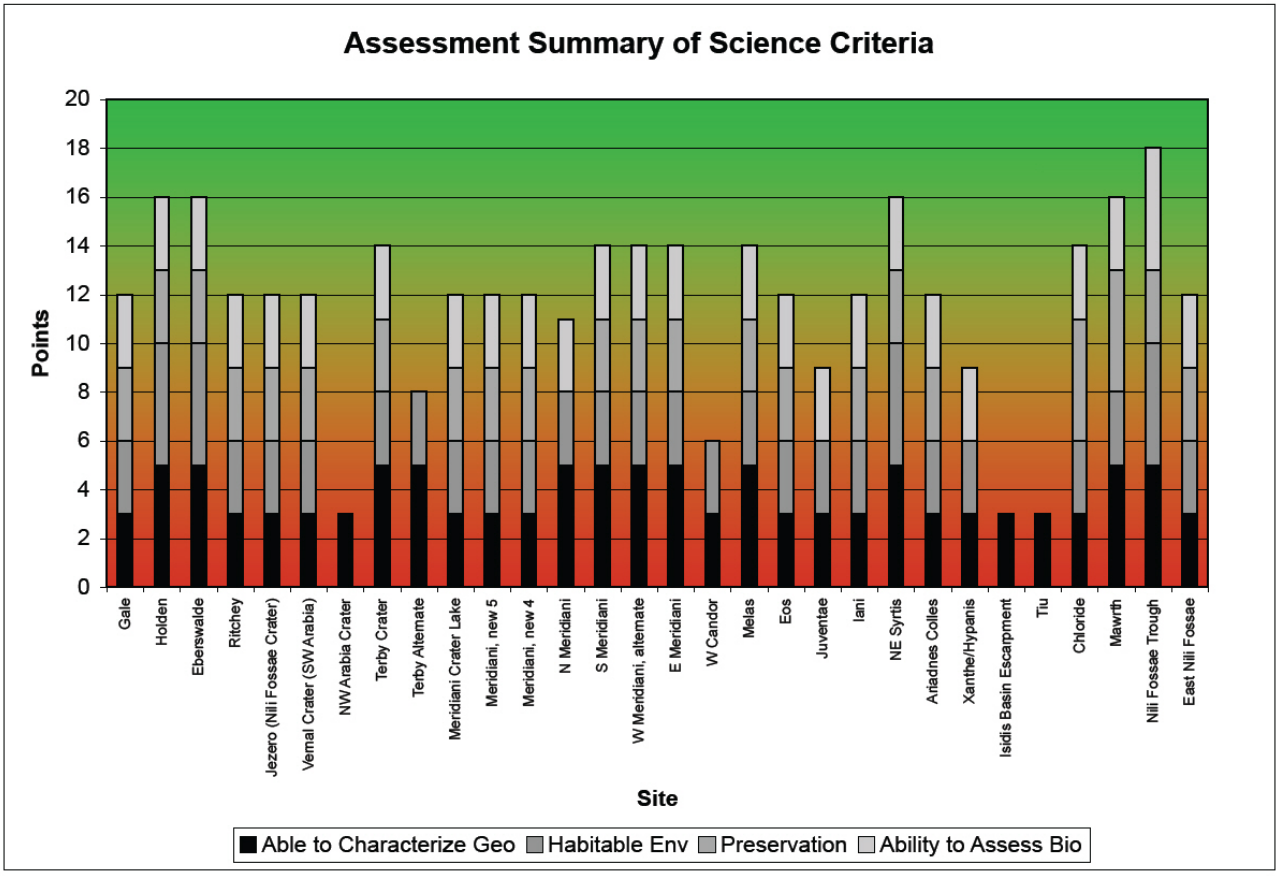


Figure 4: Results of the second landing site workshop for Curiosity.

By the third landing site workshop in 2008, Gale had been added to the list again. The CRISM spectrometer[4] on the Mars Reconnaissance Orbiter had provided some very interesting mineral maps showing detailed changes in mineralogy that suggested that Gale Crater had been a wet and potentially habitable environment in the past. The images and maps showed evidence of lots of clays (smectites) – which can only form in watery environments – and a sequence of layered minerals up the side of the central mountain in Gale crater (now known as Mount Sharp) which hinted at a long-standing lake in the crater gradually drying out over time (Figure 5).

[2] A landing ellipse or footprint is the area required to safely land a spacecraft.

[3] A bio-signature is any substance that provides evidence of life.

[4] See Footnote 1. CRISM – Compact Resolution Imaging Spectrometer for Mars – is one of the instruments carried on the Mars Reconnaissance Orbiter – it is especially good at detecting minerals from orbit.

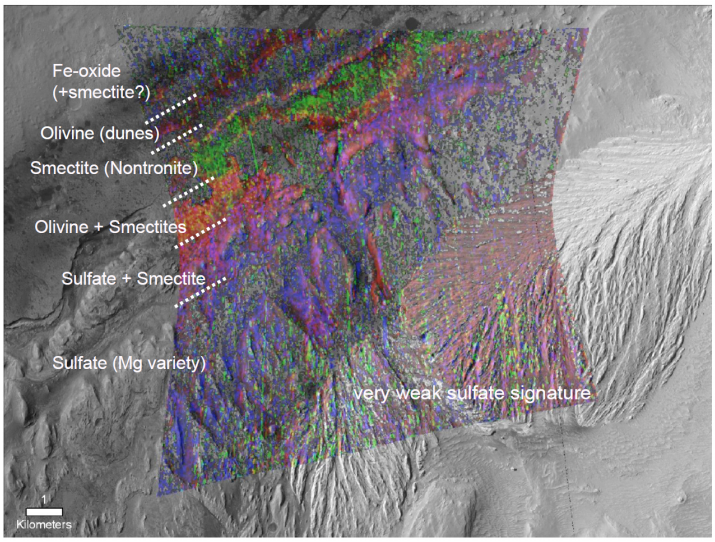


Figure 5: Clays and other minerals in the Gale Crater identified by CRISM spectrometer. Image courtesy Michael Milliken & NASA

Landforms on the floor of Gale Crater also suggested that there had been many floods of water entering the crater, carrying sediments with them down rivers. The 2008 workshop ended with a vote that had seven sites going through to the next round. Again, more orbital data on those seven sites was requested, with more targeted images taken over the next year from the Mars orbiters.

At the time of the third workshop it was still thought that Curiosity would be launched in 2009, but engineering and other problems delayed its launch until 2011, so the next two years were spent accumulating more orbital data.

The final four potential landing sites had been chosen by the time of the fourth site selection workshop in 2010,: Gale Crater, Mawrth Vallis, Holden Crater, and Eberswalde Crater (Figure 6).

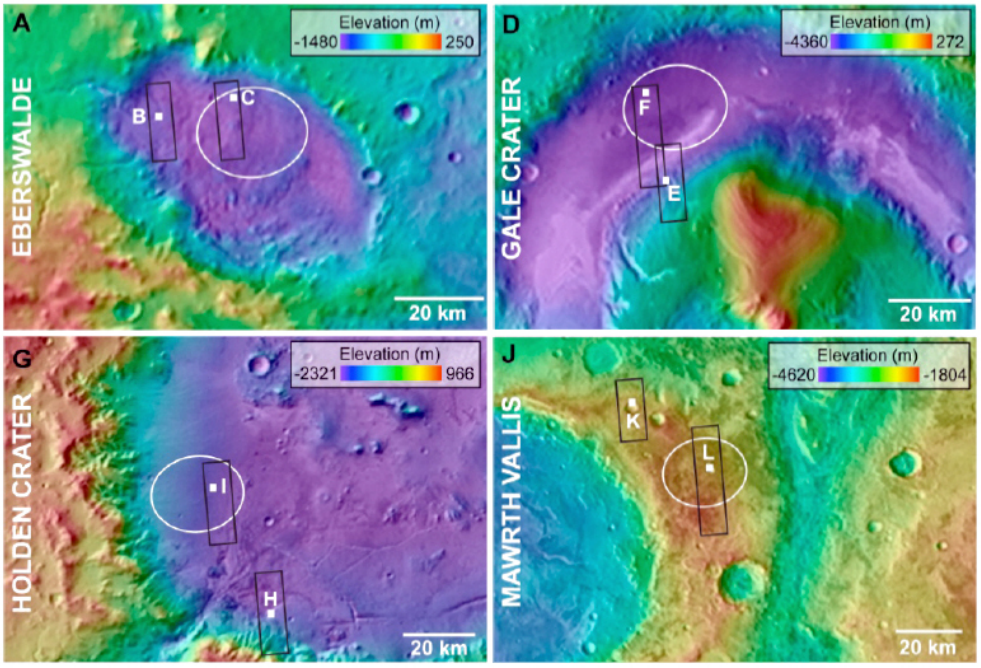


Figure 6: Final four landing sites for Curiosity. Image courtesy John Grant & NASA.

Holden and Eberswalde craters appear to be river delta deposits, where ancient rivers have repeatedly flowed into craters and then drained into the lower northern plains. They both have thick layers of river sediments – now cemented into raised deltas – and some evidence of clays. Mawrth Vallis has what appear to be thick clay layers, suggesting a long term water presence. It is also the flattest (and therefore safest) site of the four. Gale Crater is unusual, as it has a central mountain peak which is higher than the surrounding crater walls. This 5km high mountain is rich in clays and sulphates, both of which require long periods of water to form. It is also the deepest and most risky of the four landing sites, with the landing ellipse barely fitting into the crater floor which lies over 4km below the surrounding plains.

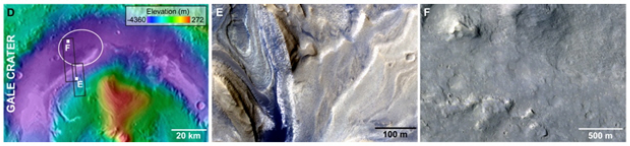
At the fifth and final workshop in 2011, presentations were given by scientists who were now the world experts on these four landing sites. Despite two days of data and discussions, no consensus was reached at the end of the workshop; all four sites were seen by the attending scientists and engineers (who were not specifically proposing a site) as being of equal scientific merit.

At one point the engineers who had designed and built Curiosity were asked by the scientists whether they could in fact guarantee that she would be able to land at Gale, as it seemed to be a bit risky. This was one of the first times that anyone present could remember scientists being more risk averse than engineers – usually it is the other way around! The engineers went to great lengths to assure all present that the rover could land equally safely at all four sites.

Four pieces of paper…

At the end of the fifth workshop **Quad Charts**[5] were formulated for each of these final four sites. This **single page** of information summarising the strengths and weaknesses of each site, along with recommendations of the steering committee that had organised the workshops, went to NASA headquarters for the final selection (Figure 7). In essence, five years of discussions and scientific research were boiled down to only four pages of data.

Gale Crater Site



4.5S, 137.4E

Overarching Hypothesis:

- Strata within the 5 km thick mound of layered sediments within Gale crater record a sequence of aqueous habitable environments over an extended period. These strata contain multiple hydrous minerals (sulfates, phyllosilicates) that indicate varying aqueous environmental conditions.

Specific Pros of Site:

Setting -
•Diverse stratigraphy in a 5 km mound within a 5 km deep Late Noachian crater. Stratigraphy includes well-defined beds of hydrated minerals and the lower mound includes contributions by fluvial processes and likely reflects deposition during changing and possibly global scale wetter-to-drier environmental conditions.
•Alluvial materials and inverted channels in the ellipse record hydrologic conditions when they were emplaced and provide the opportunity to sample materials weathered and eroded from the crater walls.

Diversity -
•Multiple mineralogical and stratigraphic units within the 5 km thick mound sequence with alternating inter-bedded phyllosilicate and sulfate bearing beds in the lower mound. Stratigraphy comprising the mound is continuous over many km and well characterized in places.
•Alluvium in the landing ellipse enables sampling crater rim materials that may record environmental conditions during their emplacement and from before the formation of the north-south dichotomy on Mars.

Preservation –
•The phyllosilicate-bearing units in the lower mound and moat include smectites that would help preserve organics if present. Biosignatures may be best preserved in the sulfate bearing strata in the mound.

Exploration Targets –
•The specific distribution of science targets within and outside of the ellipse is well defined. Preserved organics could occur in a high thermal inertia unit in fan in ellipse, in clay rich layers that may not have sulfates, and in the sulfates.

Possible Cons of Site:

• The original extent and timing of processes responsible for the present mound morphology needs better definition and the regional and global stratigraphic context of the mound is not firmly established and it is unlikely that all depositional aspects of the mound will be understood in advance of landing.
• Science in landing ellipse on and near an alluvial fan is secondary to that outside of the ellipse and observations within the ellipse may be encumbered by dust.

Remaining Uncertainties:

• Although several testable models for mound formation exist, uncertainty remains about the depositional setting for much of the stratigraphy despite a better understanding of the constituent mineralogy. Nevertheless, bed continuity and morphology implies origin of lower section involved deposition onto a wet surface or into standing water and there is evidence for fluvial redistribution of mound materials.
•The source of water associated with deposition remains uncertain, but if sediments were deposited in a lake, the relative paucity of associated valleys suggests groundwater as opposed to meteoric sources.
• The source of the lower mound sediments is unknown but likely from outside of the crater and it is uncertain whether the mound is part of a larger deposit (though it is morphologically similar to deposits seen elsewhere on Mars). Valleys breaching the rim at a stratigraphic level now lost to erosion may have contributed fill to the crater and/or in lake.
• Crater statistics suggest Gale is Late Noachian, whereas floor deposits onlapping the lower mound and including the fan in ellipse are interpreted to be Early Hesperian, thereby bracketing the age of the lower mound. Age of upper mound and total time recorded in the mound is uncertain.
•Preservation potential of organics in the sulfate units may be compromised by the known presence of iron oxides.

Figure 7: Quad Chart for Gale Crater. Image courtesy Matt Golombek & NASA.

Communication is important

The Mars site selection process is a perfect example of the need for clear and concise communication in science. Potential landing sites that had poorly presented or poorly supported scientific arguments at the early workshops were dropped off the list (including Gale, initially). Sites in the final four that were not able to clearly summarise their strengths and weaknesses ended up with poorer quad charts. When a decision of this importance – which may change your career as a scientist and affect the fate of a multi-million dollar piece of machinery – is being made on the basis of a single piece of paper, every word is vitally important.

Did the best site win?

It looks like NASA selected the right landing site. So far, Gale crater has delivered more than any of us had hoped for. At the time of writing (September 2013) Curiosity has discovered evidence of fast flowing ancient streams and shallow lakes at the base of Gale crater – right where she landed – and is now heading to the base of Mount Sharp. There is still so much more to be found. Curiosity still has a few kilometres to go before she reaches the really interesting minerals and rock layers, seen by CRISM from orbit, which were the whole reason that Gale was reinstated in the selection process. Curiosity's journey has only just begun (Figure 8)!

[5] A quad chart is a very useful tool used to provide an overview of a product or an idea. It is divided into four quadrants usually in a landscape orientation. They are typically only one page long. The format promotes succinct communication and is very useful for rapid decision-making.

Figure 8: NASA's Curiosity Rover takes a "selfie" at the John Klein site in Gale Crater on Mars – Sol 117, Feb 3, 2013

Resources for further investigation:

Mars Facts: http://solarsystem.nasa.gov/planets/profile.cfm?Object=Mars

NASA's Spirit and Opportunity Rovers: http://marsrovers.jpl.nasa.gov

NASA's Curiosity Rover: http://mars.jpl.nasa.gov/msl/

ESA's ExoMars Rover and Orbiter: http://exploration.esa.int/mars/

NASA's 2020 Mars Rover: http://mars.jpl.nasa.gov/mars2020/

NASA's Phoenix lander: http://www.nasa.gov/redplanet/phoenix.html

NASA's Mars Orbiters: http://mars.jpl.nasa.gov

Mars Exploration Program Advisory Group: http://mepag.nasa.gov/

Mars Landing Site Resources –includes discussion papers and reports from all the site selection workshops: http://marsoweb.nas.nasa.gov/landingsites/

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* Marion Anderson is a geoscientist with considerable experience in the coordination and delivery of undergraduate Geosciences at Monash University. Her varied career also includes work as a biologist, a mechanical engineer and a palaeontologist. Her research interests in surface processes and the chances of life on Mars led to her involvement in the selection the landing sites for NASA's Opportunity, Spirit, and Curiosity Mars rovers.

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Mars Science Laboratory (MSL) Landing Site Selection Activities – Quad Charts and Landing Sites

Go to the MarsOWeb site: (http://marsoweb.nas.nasa.gov/landingsites/msl/workshops/2nd_workshop/program.html) for the second Mars Science Laboratory landing site workshop (2007).

Split the class into groups, and assign each group one potential Mars Rover landing site.

Recommended sites are:

Nili Fossae Crater (http://marsoweb.nas.nasa.gov/landingsites/msl/workshops/2nd_workshop/talks/Fassett_Nili.pdf)

Terby Crater (http://marsoweb.nas.nasa.gov/landingsites/msl/workshops/2nd_workshop/talks/Wilson_Terby.pdf)

Juventae Chasma (http://marsoweb.nas.nasa.gov/landingsites/msl/workshops/2nd_workshop/talks/Bishop_Juventae.pdf)

Southern Meridiani (http://marsoweb.nas.nasa.gov/landingsites/msl/workshops/2nd_workshop/talks/Wiseman_SMeridiani.pdf)

East Meridiani (http://marsoweb.nas.nasa.gov/landingsites/msl/workshops/2nd_workshop/talks/Hynek-E-Meridiani.pdf)

Note that any of the other presentations can also be used – except for Gale Crater, Eberswalde Crater, Holden Crater, or Mawrth Vallis – as these already have quad charts which were generated at the 2011 MSL site selection workshop.

Tasks:

The task for each group is to examine the data presented for their site, along with the introductory talks about the engineering and science constraints (see the 'Welcome / Introduction' talks and the overview talks in the 'Landing Sites and Habitability' section on the workshop landing site above), and compile a Quad Chart for their site. The four quadrants of their chart should be:

1) Images of a potential landing site and a testable hypothesis about their site

2) Pros – the advantages that their site has.

3) Cons – the disadvantages that their site has.

4) Remaining Uncertainties - what more is needed to be known about their site.

Refer to the quad charts for Gale, Eberswalde, Holden, and Mawrth at http://marsoweb.nas.nasa.gov/landingsites/msl/workshops/5th_workshop/Final_Quad_Charts_for_5th_MSL_Workshop_5-26-11.ppt for examples of what their Quad Charts may look like.

Each site should only have one quad chart generated, and each quad chart should fit on a single A4 sheet of paper (or one PowerPoint slide) with a minimum font size of 12 point.

Once the charts are completed, each group should present the data about their site in a 3 minute oral presentation.

The class as a whole should then vote for the top site, based both on the quality of the data, and the quality of the presentation. Give each student one vote for each of two sites, a first preference and a second preference: use small pieces of coloured card – green for first preference and yellow for second preference. They are NOT permitted to vote for their own site.

Tally the votes, recording the number of preferences for each site and ask the students to display the votes as bar charts showing number of first preference votes and number of second preference votes. Then tally again to get a total vote where two second preference votes = one first preference vote (rounding down). Graph these votes again as bar charts.

Discussion Points:

1) Voting results:

- Did the site with the most first votes win?
- Should a site with more second preferences than first preferences be allowed to win?
- Were there any sites that should not have made it to the voting stage? Why?
- Were there any sites where the quad charts were good, but the presentations let their site down?

- Were there any sites where the presentations were good, but the quad chart let their site down?
- Do the students think that the best site won?

Compare their site data to the final four quad chart data:

- Do they think that any of their sites were better than the final four sites?
- Was Curiosity sent to the 'right place'?
- Would they suggest any of their sites as a possible landing place for Curiosity's "clone", the 2020 NASA Mars Rover?Why or why not?
- Can they think of better places to send the 2020 rover instead?

Possible Follow-Up Activity:

Using data available through the MarsOWeb site (http://marsoweb.nas.nasa.gov/landingsites/index.html) through the links at the bottom of the web page, and data from the USGS PIGWAD Mars Mapping website (http://webgis.wr.usgs.gov/index.html), students can select their own landing site, anywhere on Mars, and gather data to characterise the area in the same way they did for the Quad Chart activity.

If their site looks interesting enough to explore further they can submit it for consideration as a possible Mars Rover or Mars Lander landing site by filling in the 'Call for future landing sites' form available at the MarsOWeb site.

www.tesep.org.au