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Trip to Mars Part 2

Introduction

Mars has been the focus point of the search for life beyond Earth for many years and the possibility of collecting and returning samples from Mars has long been desired by NASA scientists. NASA has sent a variety of missions to Mars, involving orbiters equipped with advanced forms of geology, mineral, topography and climatic data collection technology, on ground stations and rovers and conducts Earth based observations (1). Orbiters, such as Mars Odyssey and Mars Reconnaissance Orbiter of Mars have used CRISM, HIRISE, THERMIS, GRS and MARIE collectors to collect topography, mineral light exposures, climatic conditions, radiation levels, surface conditions and water and ice presence remotely, more specifics of mission technology and direct findings can be found in Part 1 (1).

The collections of data from these orbiters showed present day Mars has a large range of surface temperatures and extremes in weather storms due to having a thin atmosphere (2). Water is not present today in liquid form, but ice exists on the planet and geological formations left behind indicate a former presence of liquid water behavior determined from collected topographic profiles of the planet (2). Additionally, the Insight stationary station on Mars has added to climate data and increased geological information (1). Mars is tectonically sound but has volcanic remnants and seismic activity (2). Lastly, former missions like the Curiosity Rover in Gale Crater have explored the ground doing on site sampling and analysis which has located organic molecules and minerals used by, for and from life (1-2). On Earth analysis of this data allows for climate and land reconstruction to understand what the conditions on Mars are.

While no life or definitive traces of life on Mars have been found, conditions matching Earth presumptions of the requirements for life to have once existed on Mars have been found. Astrobiologists are now fueling time and energy into locating the most ideal places on Mars to find traces of life, in an attempt to understand how life off Earth could have existed, may possibly exist today and challenge our perceptions on how and where life survives.

Presently the newest mission to Mars is the Perseverance Rover which is exploring the Jezero Crater due to its perceived ideal conditions for life to have once been present (3). Jezero was chosen from over 60 other strong candidates after five years of site studies and is thought to have once had a river formation that flooded the crater and continual water and mineral deposit periods that could have been life containing (3). Jezero Crater is 45 km in diameter, and on the edge of the near equatorial plain, Isidis Planitia, coordinates are 18.4º N / 77.5º E (3). Jezero Crater was formed by the impact of two meteorites in the region and formed geographic environments that could be ideal for life and life presence to have occurred (3). A river delta environment within the crater is highly probable, as topographic profiling suggests alluvial or deltic fanning and Reconnaissance Orbiter has used CRISM to locate clay found within the crater and proposed deposits (3). This makes the possibility of life within the sediments having been probable based on Earth features of similar nature that have supported life and other studies have underground investigation of the Earth, water atmosphere interface in terms of life supporting conditions (4). By looking at mineral presence and the indication of water and life supporting conditions they provide it can be expected the most probably locations on Mars to send a rover to possibly find life would be within the North West corner of the Jezero crater where the highest amount of minerals requiring water and could form with water are located.

Methods

The morphology of Jezero

To understand and visually recreate the topography and geography of Mars and Jezero Crater photographic and topographic mapping were created using data obtained from Reconnaissance Orbiter using HIRISE technology (5-6). Reconnaissance Orbiter collected and targeted locations for detailed imagery, based on THERMIS, GRS, MARIE and additional information gathered from the already launched Mars Odyssey Orbiter to determine locations of interest for further analysis (1, 5-6). Images and elevation data were collected with HIRISE using visible and near infrared wavelengths and telescopic lenses and were processed to form topographic maps of the targeted sites, including Jezero Crater as exhibited in Figure 1a and Figure 2. To further visualize the shape of the Jezero Crater a cross sectional elevation profile was made using trek.nasa.gov tools and software (7). Points from the Northwest and Southeast rims of the crater were used, and a straight line was drawn between them using the website's tools (7). A create elevation profile option was selected and the cross sectional graph between points a and a’ was created and is exhibited in Figure 1b to see the side profile of the crater elevations (7).

Evidence of flowing liquids in the crater

To look into the possibility of historically flowing liquids within Jezero Crater, HIRISE technology onboard the Reconnaissance Orbiter was used to obtain detailed photographic and elevational data of a specific target location (3, 5-6). The northwest rim of the crater was selected for detailed imagery analysis due to visible geographic rock formations analogous to river systems or volcanic deposits seen on Earth (3). HIRISE data was used to map the topography of the potential former river and deposit sites to determine the topographic likelihood of this geographic feature and can be seen in Figure 2. Additionally, the topographic profiling of the rest of the crater are also used to see cross references to layers of deposits or potential flows for investigation into liquids Mars formerly contained and put in elevation profiles and stand alone topographic maps or with overlays of other data.

Mineralogy and chemistry of Jezero

In order to collect the mineralogy of the crater the use of CRISM technology on board the Reconnaissance Orbiter was collected and analyzed (5-6). Based on data collected from technology already described onboard the Mars Odyssey and topographic profiling from HIRISE data on the Reconnaissance Orbiter the location and panel for CRISM mineral wavelength data collection to occur was chosen (5-6). CRISM uses visible, infrared and near-infrared wavelengths from the ground coverage to determine surface composition based on wavelength reflection (5-6). The orbiter collected data which was then overlain on topographic maps of the crater to get visual understandings of where these minerals were located. Coloring levels were done to group the minerals together by type, size and chemical composition. Figure 3 only shows the presence of hydroxylated minerals that contain both O and H atoms in their chemical formula, but do not require water for formation. While figure 4 shows the distribution of hydrated minerals containing H_2O that required water to be present. The distinguishing and separation of these mineral types is important, and each figure also displays the differences within each type of size, specific mineral and structure.

Surface path

To generate a proposed path for rover mobility, the topographic and mineral data components were combined to best evaluate conditions that could be ideal to find traces of life. Cross sections along the topographic map of the northwest portion of the crater (seen in Figure 2) were selected and elevation profiles of these cross sections were generated using trek.nasa.gov tools and software (7). Once the elevation profiles were made coloring was done overtop of them to correlate with mineral distribution to formulate Figure 5 from elevation and select mineral analysis. The presence of Fe-OH and Mg-OH shown in red in Figure 3 are overlaid in red, and the presence of bound water with the "Sulfate" index also shown in red but in Figure 4 were overlaid on top in blue, and the 1900 nm bound water hydroxylated minerals shown in blue in Figure 3 are in purple. From the analysis and correlation of hydroxylated and hydrated mineral pressences and elevation profiles for rover movement, a proposed path for the rover to travel and sample along was created with the best conditions for life and overlain on the topographic profile of Figure 2 and the cross sections shown in Figure 5 to create Figure 6. Figure 6 shows the rover path presented based on the search for life that hydroxylated and hydrated minerals in higher values, larger size, and of specific iron/magnesium composition suggests could be ideal locations. The path was created by sorting ideal locations for sampling and elevational paths to travel between to acquire them. Sampling will involve drilling to collect rock, particle and dust samples like has been seen with the Curiosity Rover and ideally be returned to Earth as is the goal with the Perseverance Rover (1).

Data and Results

Previous Mars missions have collected data through multiple forms of advanced technology that have allowed for many elements of Mars to be analyzed remotely to best evaluate locations and conditions on the planet for rover movement and that could potentially support life. The Jezero Crater spans great diversity in elevation, but this is not uniform across the crater from the North to South or the East to West as is shown in the elevation profiles of Figure 1b and Figure 5 with some cross sections having steep slopes while others are more stepped and gradual. Additionally the Crater has a more ideal region geographically, the Northwest, due to formerly visually observed and hypothesized landform deposits from a delta, making this region the focus of analysis for water and mineral contents and the most probable candidate within the crater for life traces and landing a rover. The northwest region of the crater also contains mineral contents that can be used to understand the likelihood or requirement of water in areas based on chemical structure and mineral signature; the delta region is rich in mineral content, but varies in type, individual minerals and mineral molecular structure. This can be compared to the likely delta deposit landforms for a history of or traces of water, which would make suitable conditions for life. Individual aspects of this data was analyzed separately before being put in conversation together and comprehensively towards the conditions of the crater as a whole.

The morphology of Jezero

Jezero is a crater with unequal maximum heights surrounding the rims. The southwest rim and southeast rims have the highest elevations of the edge, while the northeast and center north rim has the lowest elevation of rim. The northwest has middle elevations, and several cuts through the rim into the crater. The middle of the crater drops in elevation, and relatively flat in slope once not immediately at the rims. One significant and notable morphological feature in the base of the crater is a further but smaller circular hole that declines further and steeply in elevation, but is small on total circumference. A cross sectional elevation profile of the crater displays the type of elevation changes in the crater and a topographic contoured and colored map shows the entire crater in Figure 1a and Figure 1b.

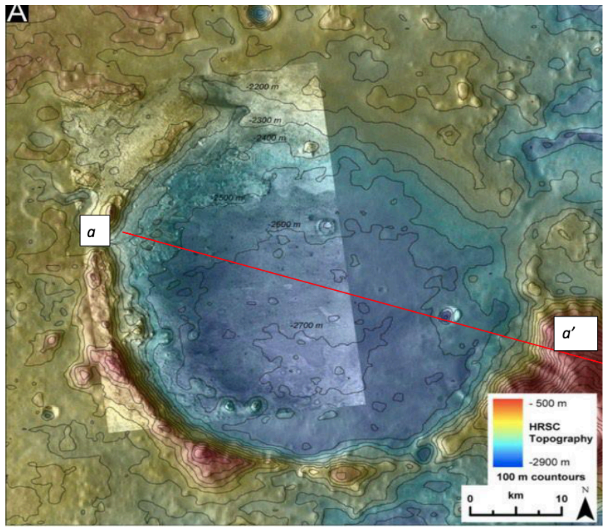


Figure 1a. Topography of the Jezero crater from HIRISE collected data with altitudinal contours and coloring. Contour lines and coloring are used to indicate elevation, with the highest elevations being in red and browns around the outside of the crater, and the lowest elevations being in blues in the center of the crater. Altitude varies from the lowest point inside the crater to various high spots around the edges.

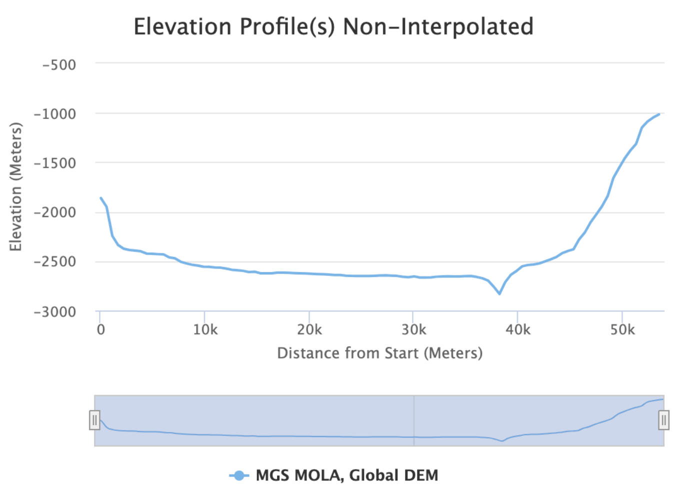


Figure 1b. Cross section elevation profile of the Jezero crater along cross section a to a' from Figure 1a. The north west side of the crater had a lower elevation rim than the south east side with around 800 m difference in max rim height. The slope of the northwest side is steeper but changes less in elevation, while the southwest has a more gradual and less steep slope into the crater. The south west side of the crater also contains a further and brief drop in elevation

than the rest of the bottom crater. This cross section elevation profile graph was made using trek.nasa.gov tools (7).

Evidence of flowing liquids in the crater

In the northwest section of Jezero Crater landform deposits are of interest for further investigation towards life sustaining conditions. Landforms that scientists have determined look similar to alluvial or deltic deposits and of interest for study are visible fanning out of the cut in the ridge and extending along and into the base of the crater. These deposits have layers visible in the topography of the deposit plain, retreating and staking gradually into the ridge cut analogous to deltic or alluvial river deposits found in delta systems on Earth. The topography contours and elevational coloring of these retracting deposits are displayed in Figure 2.

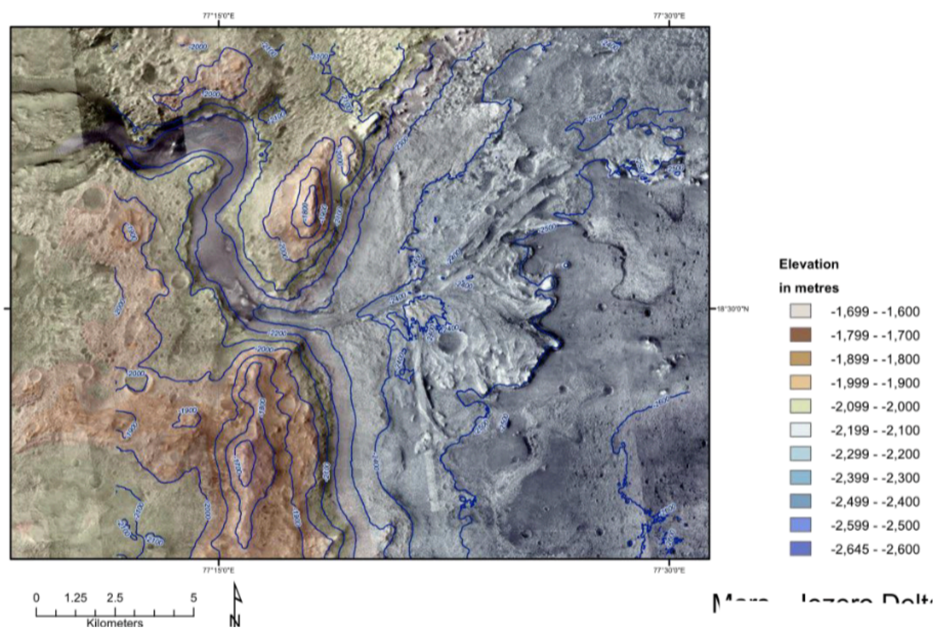
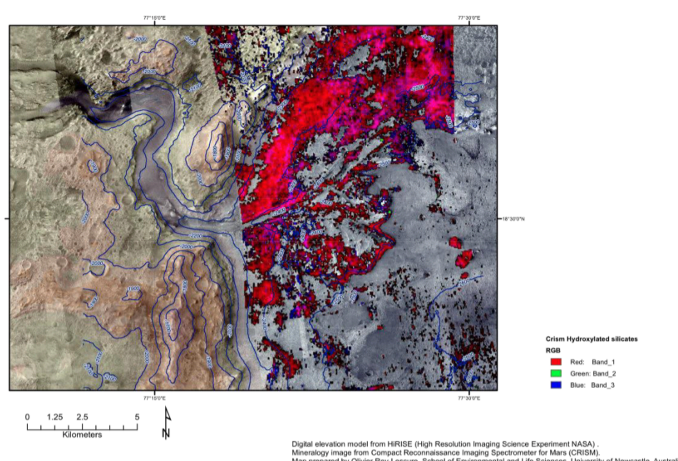


Figure 2. Topography of Jezero Crater North West rim using HIRISE collected data with contours and coloring. Elevation of the rim of the crater is higher and shown in oranges, while the base level of the crater and feature entering the crater from the north west is lower in grays. Geological features entering into the crater, with similar profiles to river and delta systems on Earth. Region is located at point a from Figure 1.

Mineralogy and chemistry of Jezero

Mineral content and distribution in the northwest region is crucial for understanding the conditions present for expeditions. Hydroxylated minerals are present in the northwest section of the crater, in the form of Fe-OH and or Mg-OH containing minerals which are of larger particle size. These predominantly follow several elevation boundaries, particularly extending northeast of the band CRISM data was collected on. Minimal Al-OH and Si-OH hydroxylated minerals are present and medium amounts of larger hydrated minerals than those, and appear along elevation change boundaries and at the edge of Fe-OH and Mg-OH regions in red. Hydroxylated mineral content is displayed in Figure 3.

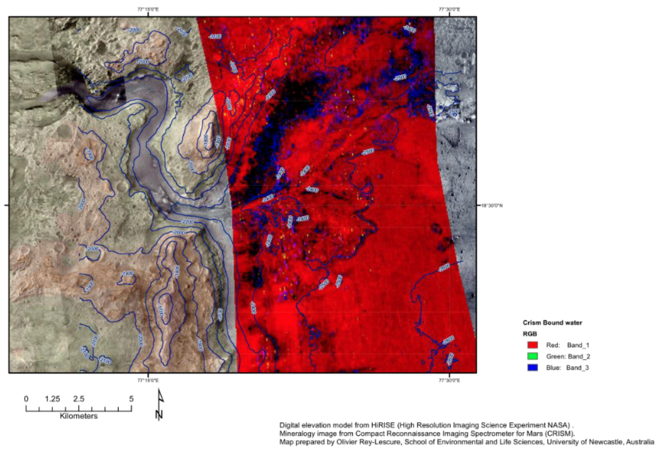
Hydrated minerals with larger particle size, bound, dissolved or absorbed molecular water and sulfates are present throughout most of the entirety of the band CRISM data was collected on. No monohydrated sulfates were found in significant quantities. Larger particle size hydrated minerals are scattered within the region, particularly along marked elevation boundaries. Hydrated mineral distribution is shown in Figure 4.



Channel	Parameter Descriptionand Name	Scaling	Significance	Cautions
Red	Index for presence of Fe-OH and Mg-OH containing brightness around 2320 nm relative to 2170 nm (0 2300•)	0.005-0.020 to 0-250	Higher values indicate greater content or larger particle size of iron/magnesium phyllosilicates	Weakly sensitive to shaded slopes and strong brightnessboundaries. Intermiment detector artifacts at edges of images
Green	Depth of 2210-nm band due to Al-OH or Si-OH in minerals; relative to a continuum between 2140and 2250 nm (8 D2210' }	0.005-0.020 to 0-250	Higher values indicate greater content or larger particle size of aluminium phyllosilicates or hydrated silica	Weakly sensitive to shaded slopes and strong brightness boundaries. Intermiment detector artifacts at edges of images
Blue	Depth of 1900-nm band due to bound water; relative to a continuum between 1874 and 2006 nm (8D1900*}	0 01 -0.04 to 0-250	Higher values indicate greater content or larger particle size of hydrated minerals	Also sensitive to water ice surface frost or atmospheric hazes that are accentuated at low solar incidence angles

Figure 3 and Key to Figure 3. Hydroxylated mineral distribution and topographic map of the North West rim of Jezero Crater using CRISM and HIRISE data. Ranges minerals are found in are predominantly in the flat areas and span topographic profile changes. Highest presence of minerals found are deep red containing some of or one of Fe-OH and Mg-OH. Green shows up weakest on the CRISM data and indicates low amounts of Al-OH and Si-OH.

Hydroxylated minerals have both O and H in their chemical formulas, but do not require or guarantee the presence of water for their formation.



The fourth IR browse product (**ir_hyd**) shows information related to bound water in minerals, usually sulfates but in some cases phyllosilicates, hydrated glass, or other minerals. It is also derived from spectral data corrected for atmospheric and photometric effects, and has been filtered.

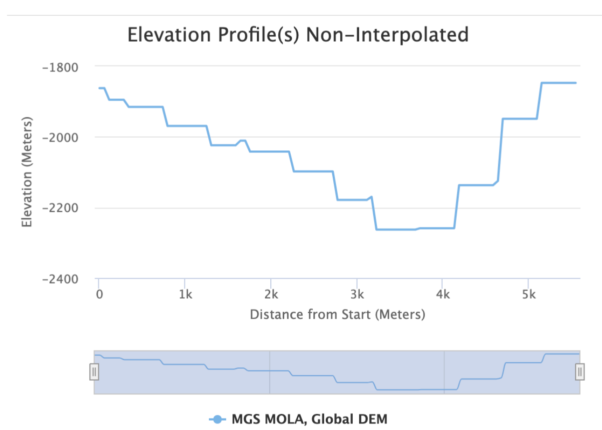
Channel	Parameter Description and Name	Scaling	Significance	Cautions
Red	"Sulfate" index, a measure of bound water or ice; measures the drop in reflectance from near 2300 nm to near 2400 nm (SINDEX*)	0.00-0.03 to 0-250	Higher values indicate greater content or larger particle size of minerals or glasses with bound, dissolved, or adsorbed molecular water, especially sulfates	This parameter is sensitive to water ice and to dust and atmospheric ice hazes that are accentuated at low solar incidence angles
Green	Depth of 2100-nm band in monohydrated sulfates; relative to a continuum between 1930 and 2250 nm (BD2100*)	0.01-0.04 to 0-250	Higher values indicate greater content or larger particle size of monohydrated sulfates	Also sensitive to water ice surface frost or atmospheric hazes that are accentuated at low solar incidence angles
Blue	Depth of 1900-nm band due to bound water; relative to a continuum between 1874 and 2006 nm (BD1900*)	0.01-0.04 to 0-250	Higher values indicate greater content or larger particle size of hydrated minerals	Also sensitive to water ice surface frost or atmospheric hazes that are accentuated at low solar incidence angles

Figure 4 and Key to Figure 4. Hydrated mineral distribution and topographic map of the North West rim of Jezero Crater using CRISM and HIRISE data. Red is indicative of high presence of minerals with bond water molecules and sulfates, particularly gypsum, and spans the majority of the CRISM data band in varying intensity of color, deeper color indicating stronger presence. Green is indicative of monohydrated sulfates. Blue represents amounts of larger particle hydrated minerals. Hydrated minerals contain H2O in their chemical formula and can not form without water present, unlike hydroxylated minerals displayed in Figure 3.

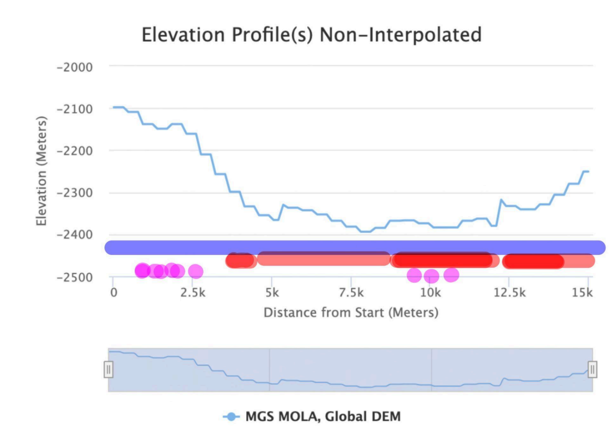
<u>Surface path</u>

Five cross section elevation profiles were created and overlaid with selected mineral data. Cross section A along the ridge opening has no mineral data, but does dip in elevation in the center. Cross sections B, C, D and E all contain full data of Sulfate index measurement for hydrated minerals (Figure 5). Cross section B has elevation decreases north, that level out some in the middle of the cross section but then increases again towards the south of the cross section distance. Cross section B minerals involved areas of just Fe or Mg -OH minerals and areas of just Hydroxylated 1900nm bound minerals, as well as select areas containing both. Cross section C continually decreases in elevation along the cross section distance, with a steeper slope north. Minerals in Cross section C vary in intensity greatly between bands and mineral type, and have many areas containing all mineral types. Cross section D starts at a high elevation with a dip and then mildly steep decrease and the cross section ends on a flatter but higher plain. Minerals in Cross section D include minimal 1900 nm bound water minerals, and Fe or Mg-OH is well spaced across the section and in varying intensities, but both contain a high density pocket south.. Cross section E starts high and flat then dips and re-elevates before steeply dropping and flattening at the south of the cross section. Cross section E minerals include low levels of 1900 nm, along with high density and low pockets of Fe or Mg-OH there and mixed presence along the cross section. The proposed path moves between and along the cross sections with 13 targeted sample locations. Most locations contain all types of mineral indication but some on the north do not have all, and the sample in A lacks data so it is unsure what will be collected in the ridge base. The southern end is expedited to have all minerals which are all expected to be at the lower elevations within the cross sections.

CRISM Mineral Overlay Key
Red- Fe-OH and Mg-OH containing Hydroxylated minerals (Figure 3)
Purple- 1900 nm bound water Hydroxylated minerals (Figure 3)
Blue- "Sulfate" index measurement of water bound or ice Hydrated minerals (Figure 4)
No Color- No mineral data or minerals present



Cross Section A. Contains no mineral data, as no CRISM recordings were picked up or presented along the cross section. Has uniform and organized step-like drops in



Cross Section B. Contains several intensities of all mineral types from CRISM data. Elevation drops in from both ends in mixed levels of slope intensity.

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<td>elevation throughout the north-south arrangement of the cross section.</td>
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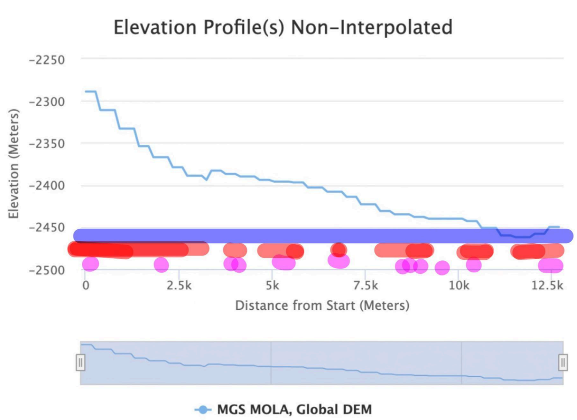

Cross Section C. Minerals from CRISM data overlaid in varying intensities, with several locations of overlap of all minerals. Elevation gently decreases from north to south.
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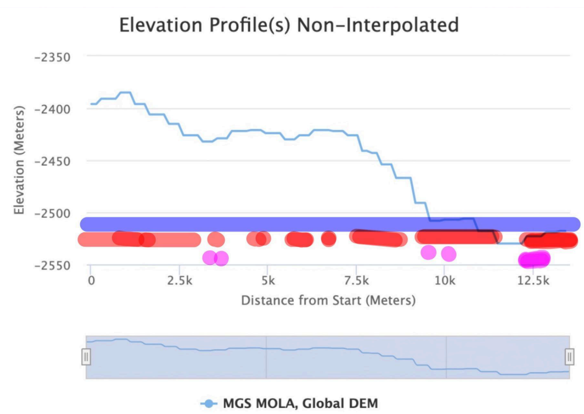

Cross Section D. Minerals from CRISM data indicate the southern portion is rich in all three types. High intensities of them at the bottom low elevation. Elevation gradually decreases and levels.
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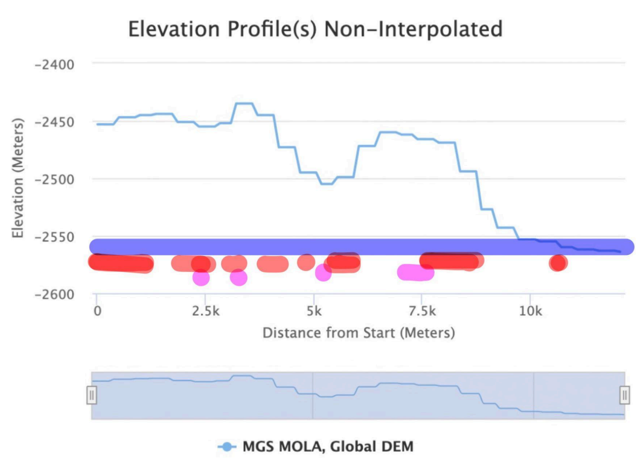

Cross Section E. Minerals from CRISM low over cross section, but have overlapping areas of higher intensity. Elevation higher and rises and falls before steep decrease.
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Figure 5. Cross Sections and Mineral Presence Within Jezero Crater Delta using HIRISE, CRISM and Topographic Data. Five cross section elevation profiles throughout the proposed landing site in Jezero Crater, with CRISM mineral data overlay of Fe-OH and Mg-OH Hydroxylated Minerals, 1900 nm bound water hydroxylated minerals and sulfate index measurement on elevation profile. Mineral overlay corresponds with length along cross section of elevation, deeper color corresponds to stronger amount of minerals present. Mineral data from Figures 3 & 4, topographic data from Figure 2.

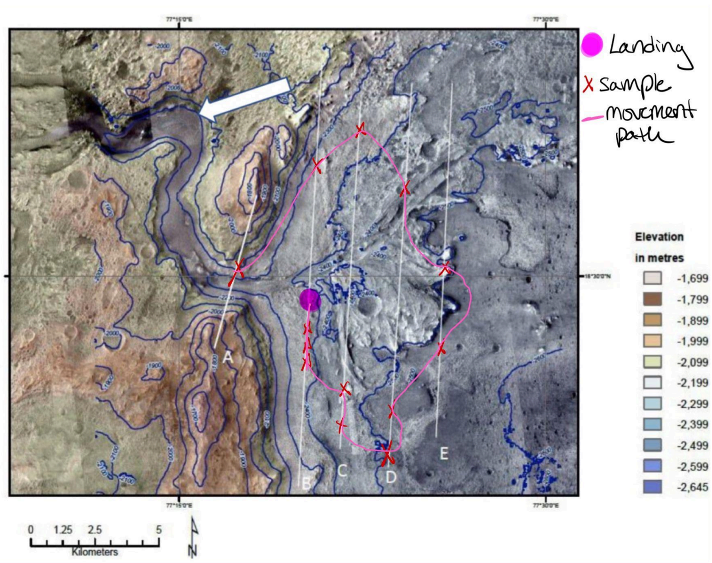

Figure 6. Proposed Path of Rover Sample Collection within Jezero Crater. Rover would land in the center of northwest area, move south along the B transect for three sample sites, over to southern C for 2 sample sites, to D for 2 sample sites, up north along E for 2 spread out samples, and then up to north D for one sample, one north C and one North B before over to center of ridge on A. Most sampled will expect to collect all mineral types looked at, but some on the northern ends will only collect one or two, and the collection in A is unknown what will be found.

Discussion

Taking all the topographic and mineral data collected from Jezero, it is more likely for the crater to be the remains of an alluvial fan deposit as opposed to that of a deltaic environment, however the crater morphology does also share traits of a deltaic environment. This is due to several defining factors of the morphology that connect with both and other research from scientists into Jezero Crater (4). While deltaic environments typically have flat beginnings and form on a raised plane, this does not occur in Jezero and instead the entrance cuts through a ridge and into the crater through elevated peaks as Cross section A displayed in Figure 5. Additionally, the debris and minerals seem to be spaced out and left in bands that follow elevation markings and contours as all Figure 3, Figure 4 and Figure 5 can indicate. This suggests the deposits of minerals were funneled into the crater in waves of flooding or water movement. However, the shape some of this minerals, particularly those in blue in Figure 4, and the shape of land deposits in Figure 1 and Figure 2 creates are representative more of a deltic formation and not a fanning typically seen from an alluvial fan. This could be due to post water drying up atmospheric erosion, or another unknown phenomena occurring. Additionally the complete coverage of the sulfate index of hydrated minerals suggest that the entire crater area was once underwater, which could be more indicative of a delta, or just sustained and repetitive complete flooding of alluvials. Lastly the types of minerals, particularly gypsum and those in blue in Figure 4, would indicate the drying up of minerals in bands and not full coverage of a water body. Additionally it is possible that over ancient time the Jezero crater experienced conditions of both a delta and alluvial that changed over time to leave traces of both characteristics depending on water availability.

The minerals found present do mean there was a large presence of water on the surface of Mars in the past, but don't indicate how sustained this was or what the conditions of this were. However, the entire region sampled with CRISM data within the northwest region and where the cross sections were, was covered in hydrated minerals according to the "sulfur index" as shown in red in Figure 4 and in blue in Figure 5 overlays. Hydrated minerals require water to form and therefore suggests the entire region of the crater was at some point in time likely flooded with water from the northwest region. This indicates that Cross section A and the river basin in which it outflows was also probable to have had water, meaning a sample along this cross section could confirm this and further provide insight into the life of this water system. The mineral gypsum shown in blue of Figure 3 is an evaporite and suggests that water evaporated where it was found, indicating water could have, at some point, retreated in the crater back towards the outflow of Cross section A or was disturbed by something else, possibly biological processes. The presence of other hydroxylated minerals across the crater shown in Figure 3, such as hydrated silica and hydrated minerals don't mean water had to have been present, but could have been. They also suggest the most probable place for life to have been, especially since where hydroxylated minerals were present, so are hydrated minerals, meaning regardless of the need for water for hydroxylated minerals to form, water was present there at some point. This means the most probable places for life to have been were the locations of hydroxylated minerals, and in these places it could be hypothesized that the life that could be found would be cyanobacteria or another microbial capable of forming and living in silica, clay sediments like seen on Earth within stromatolites (4). Life on Mars would not have to be exactly like life on Earth, however, the properties cyanobacteria have in this way and with the minerals found could suggest life in these locations and of a similar niche or microbial structure (4).

Based on the synthesis of mineral data presented in Figure 5, cyanobacteria that are chemolithotrophs would be a strong candidate for life or key characteristics of life that was once on Mars. Since there are bands of evaporated gypsum, this suggests microbial communities could have lived in these for shelter towards Mar's harsh climate, since Earth cyanobacteria can produce Ca waste. Additionally the high presence of iron oxides suggest they could be in such high amounts due to being cyanobacteria waste or protective products. The locations in which high levels of gypsum and high levels of Fe-OH or Mg-OH are present would therefore be strong candidates for sampling sites to contain the highest chances for life to exist and be ideal characteristics biologically for sites. These conditions were all used when picking the 13 sample sites and paths shown in Figure 6. While not all the sample sites have all characteristics, most do or have high levels or intensity of one of the candidate conditions to understand differences between conditions, especially if life were to be located at any of them. Additionally the path was made in attempts for easy mobility of elevation.

Other research into Jezero Crater has had scientists hypothesize the crater was a deltic formation, which as discussed above, the crater seems to share characteristics of both a deltic and alluvial formation (4). Other research has also looked into the presence and efforts to locate organic molecules and materials, something this data does not explicitly cover or utilize, beyond OH hydroxylated groups (4). Earth analysis and potential onsite rover testing of samples collected could however test comprehensively for organic molecules once samples are collected. However, the use of organic molecules for finding life is crucial and a limitation of this data, but also a subjective anthropological bias of the ideas of life as we know on Earth being the only structure and context for life searches. Further studies into life on Mars could be done in other areas of Jezero assuming water presence once encapsulated the crater, the smaller further dip in the crater along the cross section of Figure 1a and Figure 1b could be of interest due to its isolated depth that could have sheltered life there or maintained water differently than the rest of the crater. Additionally a look into the potential of life in ice caps on Mars could be a further mission due to the ability of life to survive on snowball Earth.

Conclusion

Through mineral and topographic analysis of Jezero through HIRISE and CRISM technology, the direction of possible locations for life to exist can be targeted. The topography of the crater shows a cut through the rim and the basin of the crater shows layers of deposits within the crater. These topographic features point to the former presence of water moving into the crater and expanding into it with characteristics of alluvial fans and deltic systems. The mineral composition collected from CRISM data gives further insight into the water presence theory.

With sulfate hydrated minerals found along all of the crater, the presence of water there is true, and locations of hydroxylated minerals that are used by cyanobacteria microbial life as seen on Earth suggests locations of strong possibility of finding life if it ever existed on Mars. Mineral samples would be expected to contain hydrated and hydroxylated minerals and if life were present in the past possibly stromatolites due to silica and life content and sample sites were therefore chosen due to CRISM data indicating they contained mineral levels.

The results found suggest possible places that would be ideal to sample in an effort to find life traces on Mars due to chemically and topographically formulating places hypothesized to be best suited for microbial life based on understanding of extreme conditions life can survive in on Earth. This gives specialized targets for sampling into the search of life on Mars with areas located of high mineral content and potential correct diversity being the probable best locations to find life on current missions or give understanding for a new direction in the future. While the search for life on Mars and outside of Earth continues and may be a long path ahead, every step forward increases human knowledge of the universe and continues to challenge our perceptions of what, where and how life can exist.

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