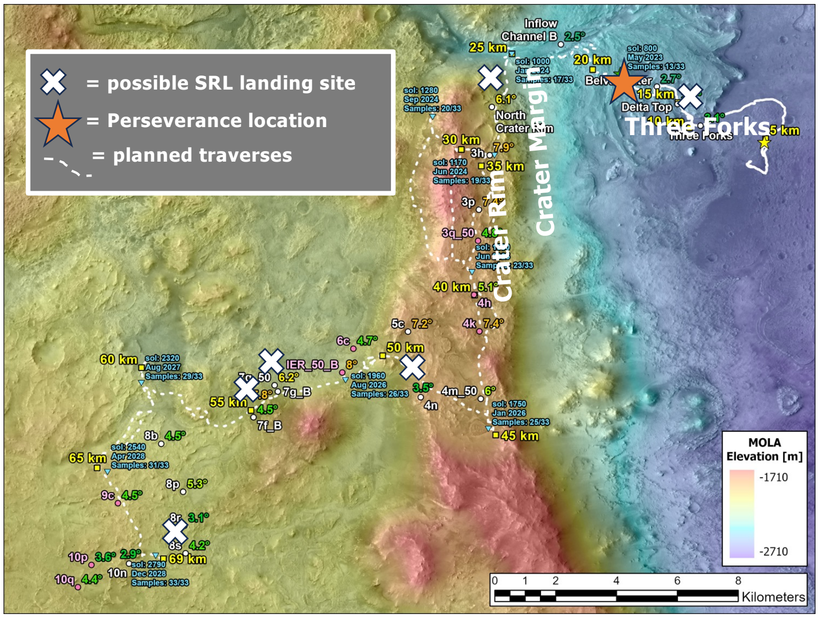
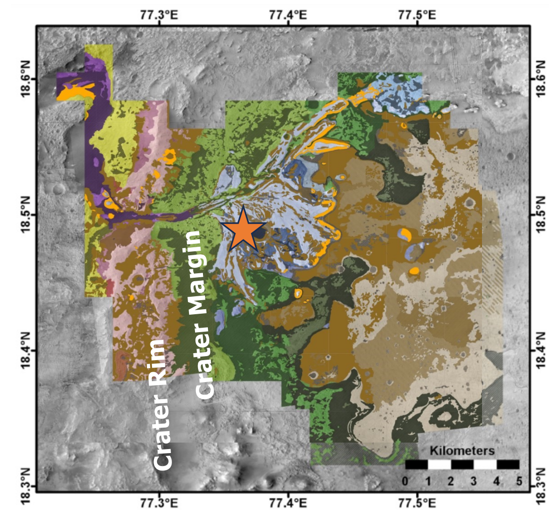
Diversity of Geologic Units on Crater Margin and Rim



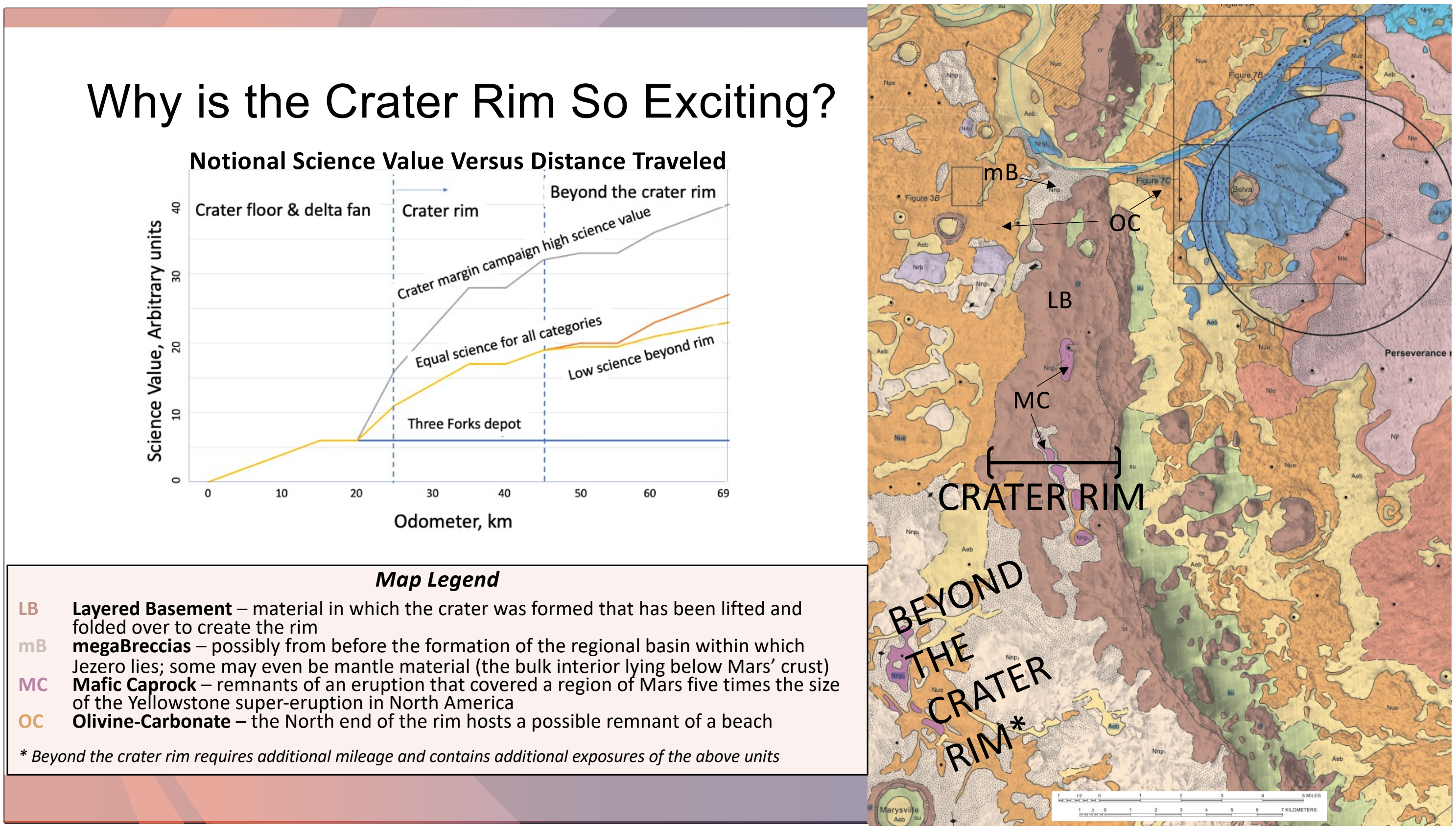
Region of crater margin and rim, with possible landing sites (low slopes, few rocks) for SRL, identified from orbit for future certification by Perseverance.



Geologic map from orbit data for the Jezero Crater field site (Stack et al., [2020]). Each color indicates a distinct geologic unit.

The image on the left is colorized by elevation (red = high, blue = low) around the western rim of Jezero crater. The delta fan, Perseverance's approximate current location, and the Three Forks depot are located at top right. White dotted lines and "X"s indicate possible future drive paths and SRL landing sites.

A zoomed-in view of the delta fan and adjacent crater margin and rim is shown at right. The image is colorized according to the different geologic units that have been mapped in the area, revealing the tremendous diversity available for Perseverance to sample as it continues driving towards the west. The orange star indicates Perseverance's location.



This slide shows the relative scientific value of the Martian samples that would be returned to Earth based on the distance traveled by Mars 2020's Perseverance rover, categorized as: on the crater floor and delta fan, on the crater rim, and beyond the crater rim.

The 10 samples deposited at the Three Forks depot, which represent only the geology of the crater floor and front of the delta, are the only samples that would be returned to Earth in the first scenario. In this scenario, no additional value to Mars Sample Return is achieved from the continued exploration and collection of samples by Perseverance.

In all other scenarios, the samples to be returned to Earth are the ones that are already onboard and yet to be secured by Perseverance. The collection of additional samples yields increasing science value as Perseverance continues its trek along the delta top, across the crater margin, and then out of Jezero onto the crater rim. The differences in the lines on the graph lie in the scientific value assigned to each new sample — whether the value is equivalent to ("equal science") or greater ("high science value") than the samples already collected. Mars scientists suspect that the crater margin and rim contain material of exceptional diversity. The science value may hence increase more substantially in that part of the mission.

Once Perseverance reaches the region beyond the crater rim, there are ambiguities in our understanding of what Perseverance will encounter. The increase in science value may therefore be less than expected, but we will not know this until Perseverance gets there.

Recognition of Strengths

- Interviews with NASA and ESA personnel reflected a strong commitment to a partnership of world leadership in Mars exploration and to mission success.
- The campaign has made substantial progress since the start of formulation in 2020, despite the many external constraints and the challenging pandemic and geo-political circumstances.
- Progress and maturity from the concept reviewed by IRB-1 demonstrates an impressive level of commitment by a team with world-class talent.
- The team has recognized the challenge of a program with such diverse partners and is developing the cross-cultural understanding necessary to accomplish the program.
- The Mars 2020 science team has done an excellent job of operating the Perseverance rover as the fundamental first element of MSR.
  - An early depot of returnable samples has been placed on the crater floor at Three Forks.
  - Additional samples from the delta top have been collected by Perseverance. Samples from the margin and rim of Jezero Crater are anticipated. These samples significantly increase the scientific value above the samples at Three Forks.

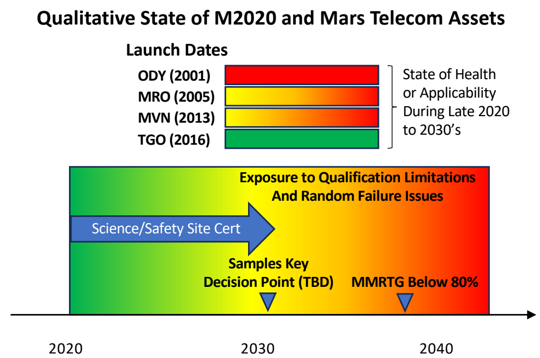
Two key lessons learned from JWST and other efforts of similar magnitude point to two crucial factors for mission success:

- World class talent
- Strong systems engineering

The MSR program showed strong irrefutable evidence of both factors.

MSR: A Highly Constrained and Challenging Campaign

- Unrealistic budget and schedule expectations from the beginning
- Tight mass margins, uncertainties in launch vehicles' performance and/or contracts
- Restricted launch period opportunities/Mars arrival times
- Dust storm season complicates launch periods
- Time limitations for surface operations and safe launch of the MAV
- Orbiting Sample (OS) design/requirements, orbital detection/retrieval, protection of samples
- Certification of safe landing sites beyond Three Forks
- Longevity and reliability of Perseverance as the primary sample transfer vehicle
- Backward Planetary Protection requirements
- Aging Mars telecommunications infrastructure
- Multiple system handoffs to return samples from Mars to Earth
- Expertise to meet these challenges is spread among multiple organizations, technical elements, and cultures.



Sustained science community and Agency support will be needed for success.

MSR an exceptionally challenging campaign due to the many intrinsic and extrinsic constraints that need to be simultaneously balanced for the technical and programmatic solutions to close.

The qualitative assessment related to the orbital assets and M2020 shown on the slide are consistent with NASA practice for assessment of risk:

Green (G) - Status is Satisfactory
Yellow (Y) - Status is Cautionary
Red (R) - Status is Unsatisfactory

Key Takeaways From All Findings (1 of 2)

- The strategic and high scientific value of MSR is not being communicated appropriately.
- MSR is a deep-space exploration priority for NASA, in collaboration with ESA. However, MSR was established with unrealistic budget and schedule expectations from the beginning. MSR was also organized under an unwieldy structure.
- As a result, there is currently no credible, congruent technical, nor properly margined schedule, cost, and technical baseline that can be accomplished with the likely available funding.
  - Technical issues, risks, and performance-to-date indicate a near zero probability of ERO/CCRS or SRL/MAV meeting the 2027/2028 Launch Readiness Dates (LRDs). Potential LRDs exist in 2030, given adequate funding and timely resolution of issues.
  - The projected overall budget for MSR in the FY24 President's Budget Request is not adequate to accomplish the current program of record.
  - A 2030 LRD for both SRL and ERO is estimated to require ~$8.0-9.6B, with funding in excess of $1B per year to be required for three or more years starting in 2025.
- Decoupling the LRDs of SRL and ERO, as well as consideration of alternate architectures in combination with later LRDs, can yield an MSR Program that is potentially able to fit within the likely annual funding constraints.

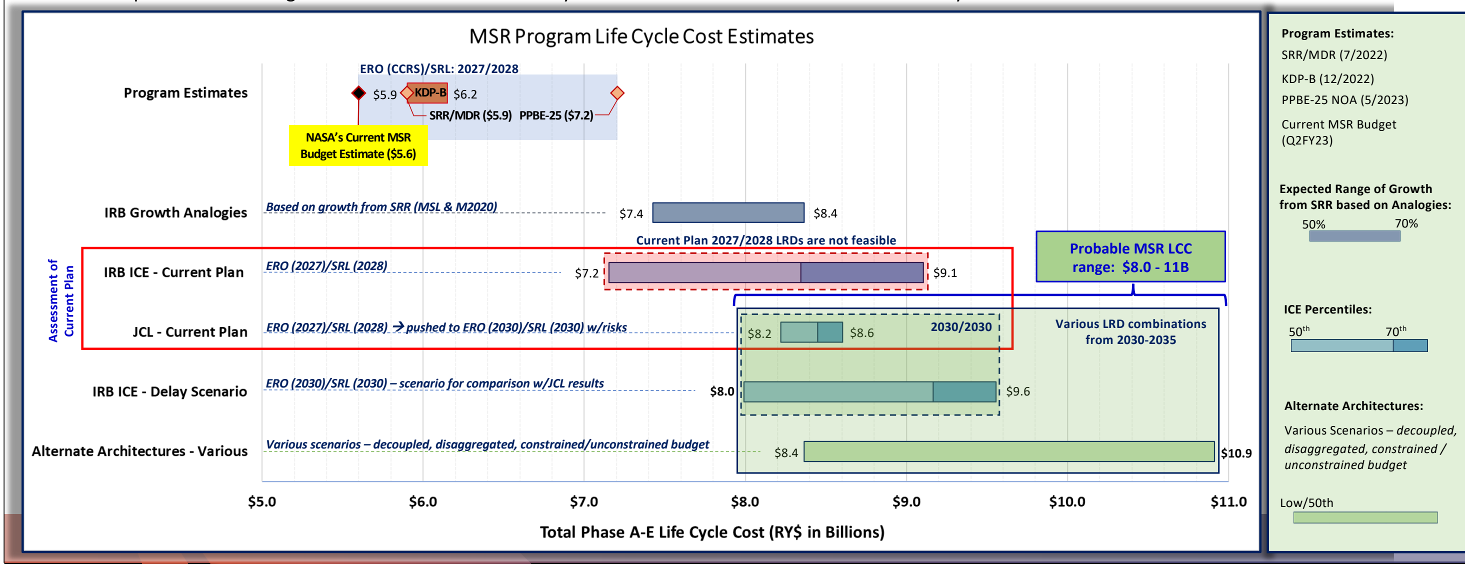
The focus of the IRB was to explore broadly and deeply in keeping with its charter, in order to increase the probability of mission success. The IRB arrived at a total of twenty findings reflecting the areas of greatest concern. In most cases more than one finding will be traceable to the Key Takeaways. The intent of the Key Takeaways is to summarize where the biggest challenges exist for the MSR Program.

Key Takeaways From All Findings (2 of 2)

- MSR is a very complex Program and campaign with multiple parallel developments, interfaces, and complexities that are beyond the experience base of the Science Mission Directorate and the participants.
    - The organizational arrangement greatly amplifies cultural differences and dynamics.
- The MSR campaign (i.e., MEP and MSR) is not arranged to be led effectively.
- Program management is impeded by the following:
    - The structure of MSR as a hybrid Single-Program/Tightly-Coupled Program
    - Deficiencies in the organizational and programmatic oversight structure
    - Unclear roles, accountability, and authority
- Mars 2020 has been successful in acquiring samples of high scientific value, with a potentially substantial increase in science value in the samples that are yet to be collected on the crater margin and rim.
- The lack of a well-defined Orbiting Sample (OS) design continues to impact and constrain many MSR systems, with implications that affect UltraViolet (UV) decontamination and robust containment for backward planetary protection.

Summary of Programmatic Assessment

- The IRB's independent programmatic assessment shows that **$8-11B** is the probable range (50%-80% confidence level) for the total MSR Program Life Cycle Cost (LCC) – *range for IRB ICE ERO (2030)/SRL (2030) and various alternate architectures*
  - The IRB's independent programmatic assessment shows that **$8.0-9.6B** is the probable range (50%-80% confidence level) for the total MSR Program LCC, with the earliest probable Launch Readiness Dates (LRDs) for both ERO and SRL in 2030.
  - There exist a variety of potential alternate architectures that the program may choose to consider in order to add robustness and resiliency to the Program and/or operate within the constraints of a fiscal year budget cap. IRB analysis suggests the alternate architecture solution space has an LCC range of **$8.4-10.9B,** with various LRD combinations in the 2030-2035 timeframe.
- The probable cost range demonstrates the uncertainty based on the various scenarios estimated by the IRB.



The IRB performed an independent programmatic assessment of MSR's current plan that reflects the ERO/CCRS 2027 and SRL/MAV 2028 Launch Readiness Dates (LRDs). Several different methodologies were used including analogous growth factors, Independent Cost Estimating (ICE), and Joint Confidence Level (JCL) analysis. The JCL analysis indicates that the currently planned LRDs are not feasible, with the earliest probable LRDs for both ERO and SRL in 2030. The ICE for the delayed 2030/2030 LRD scenario combined with the JCL results suggest a probable $8B-9.6B lifecycle cost range. The IRB also analyzed a range of alternate architectures with varied launch scenarios to cover the potential solution space for a replanned, robust and resilient MSR program, with several options constrained to fiscal year costs of $850M to $1B. The alternate architecture analysis estimates the probable lifecycle cost range of alternative architectures to be approximately $8.4-10.9B. Overall, the IRB analysis suggests the alternate architecture solution space has an LCC range of $8.4-10.9B, with various LRD combinations in the 2030-2035 timeframe.

Key Takeaways From All Recommendations (1 of 2)

- NASA must do a much better job at engaging and communicating the importance of MSR as a priority for the nation, and as the culmination of a long-term Mars exploration strategy in partnership with ESA. [R2, R4, R5]
- Leadership at NASA HQ must properly organize and staff the Mars Exploration Program and the MSR Campaign with a clear and unified reporting structure and a well-defined chain of command. Leadership must also strengthen community and stakeholder engagement and provide the expertise necessary for proper programmatic control and assessment. [R2, R3, R4, R12, R18, R19, R20]
- The entire management and organizational structure for MSR should be revisited in order to reduce overhead and to delegate authority and accountability to key contributing partners and Project elements. This effort should include reintegrating the MEP and MSR into a single office that reports to the SMD Associate Administrator (SMD AA) and NASA Associate Administrator (NASA AA) and retaining integrative engineering leadership at the Jet Propulsion Laboratory (JPL) through effective cross-functional teaming. [R3, R15, R16, R17, R19, R20]
- The OS needs immediate attention in order to finalize its design. Design should include more focus on concerns about UV decontamination and robust containment for backward planetary protection. [R6, R7, R8, R9, R10, R16, R17]

In most cases, more than one finding will be traceable to the Key Takeaways in a similar fashion to the Key Takeaways from All Findings.

Key Takeaways From All Recommendations (2 of 2)

- The most important sample science may lie ahead on the crater rim, and this material should be included in the returned sample set. [R1]
- NASA should establish MSR as a Tightly-Coupled Program with separate Standing Review Boards (SRBs) for SRL, MAV, and CCRS. This approach should include in-depth programmatic assessment (including JCLs) to be reconciled at the Program level by an SRB similarly to what the IRB did. [R3, R4, R9, R10, R11]
- NASA and ESA should collaborate more closely in order to better integrate the ERO spacecraft and CCRS teams into a one-team approach wherein ESA plays a larger role in order to provide greater programmatic resilience to the overall campaign. [R3, R5, R6, R7, R8, R9, R10]
- Alternate architectures should be examined under clear guidelines provided by NASA HQ for yearly budget constraints, while acknowledging that the lifecycle cost will likely be in the $8 to $11B range regardless of architectural choices. [R9, R10, R13, R14]
- NASA should not baseline the MSR campaign until credible congruent technical and programmatic plans are developed with demonstration of proper technical margins, robustness, and resilience. These values should be consistent with plans for an annual budget that ensures mission success. [R1 to R20]