National Aeronautics and
Space Administration

Mars Sample Return (MSR)
Independent Review Board-2 Final Report
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Orlando Figueroa - IRB Chair
Shea Kearns – Review Manager
Nathan Boll – Review Manager
Jeffrey Elbel – Technical Editor

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MSR IRB-2 Members

Orlando Figueroa, Chair
Steve Battel
Jon Bryson
Anders Elfving
Vicky Hamilton
Michele King*
Gentry Lee
Daniel Limonadi

Jonathan Lunine
Todd May*
Heather McDonald
Adm. Mike Mullen
Keith Parrish*
Lisa Pratt*
Gary Rawitscher
Janet Vertesi

Programmatic Consultants

- Louis Fussell
- Mark Jacobs
- Andy Prince
- Jahi Wartts

* IRB Subpanel Leads

MSR IRB-2 Charter

- Are the scope and cost/schedule understood and aligned?
  - What is the likely range of probable cost and schedule, drivers, and risks?
  - What is the funding profile required for the execution of the mission, and how sensitive is the mission to less than optimal funding profile guidelines?
  - Are there outsourcing, descope, or architectural options that should be considered in order to reduce technical risks, and/or to improve schedule and/or cost margins?
- Does the current distribution of work across NASA centers best position the program for technical/schedule/cost success?
- Are the management approach and structure adequate, including the international partnership for a program of this scope and complexity?
- Are lessons from Mars 2020, JWST, or other flagship missions of comparable scope being considered and applied?

Review Methodology

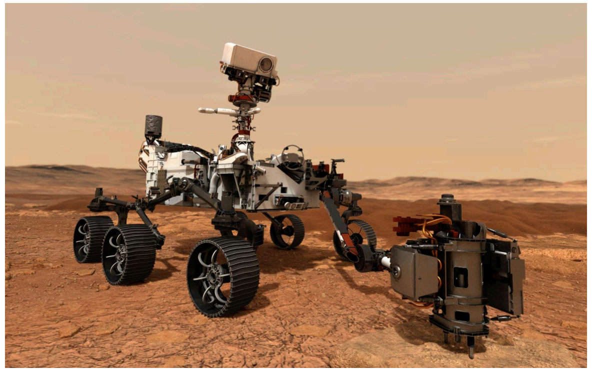
- Full IRB meetings or "plenaries"
- Interviews with stakeholders, key personnel, and community members
- Meetings of IRB subpanels
  - Programmatic/Implementation Strategy
  - Present End-to-End System Design/Architecture
  - Planetary Protection/Sample Science
  - Governance/Risks and Opportunities
- Follow-up discussions with Program and Project personnel
- IRB deliberations and discussions
- IRB period of performance: May to Aug 2023
  - See detailed timeline in Appendix

MSR Background: Pre-Phase A to Present

- NASA acquisition strategies included multiple NASA Centers and a European Space Agency (ESA) partnership from the beginning of pre-Phase A, with ESA providing a Sample Fetch Rover (SFR)/Sample Transfer Arm and the Earth Return Orbiter (ERO)/Ariane launch vehicle. *The US cost was constrained to less than $3B.*
- Industrial pre-development contracts for ERO, the SFR, and the Ariane Launch Vehicle began shortly after the first (2019) of two NASA acquisition strategy meetings.
- NASA/SMD chartered an MSR IRB-1 in 2020 to inform Key Decision Point A (KDP-A). The IRB found the total program plans to be virtually non-executable.
- Re-baselining MSR to deal with mass and other issues highlighted by IRB-1 included consideration for a second lander for the SFR. This option was eventually rejected because of added complexity/cost.
- An opportunity for Italy to contribute a second lander was eliminated because of the need to re-baseline the ESA Rosalind Franklin Mars mission due to the Russian invasion of Ukraine.
- The success of the Ingenuity helicopter on Mars resulted in the baseline placing higher reliance on the Perseverance rover, with support by helicopters as backups. The SFR was descoped.
- A variety of mounting issues with the evolving baseline including technical, schedule, and cost concerns led to the creation of IRB-2.

The MSR Campaign

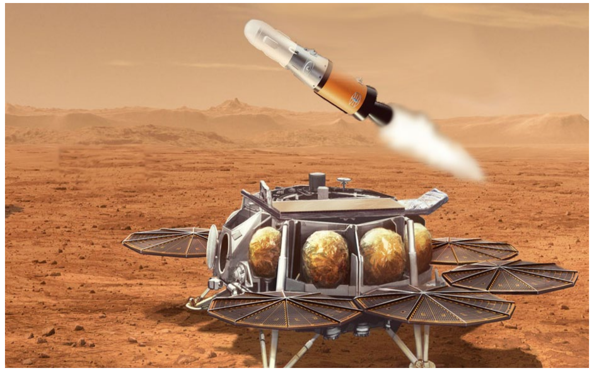
MEP



Mars 2020/Perseverance

- *Collect samples of rock, regolith, and atmosphere*
- *Cache samples on the surface for retrieval*

MSR



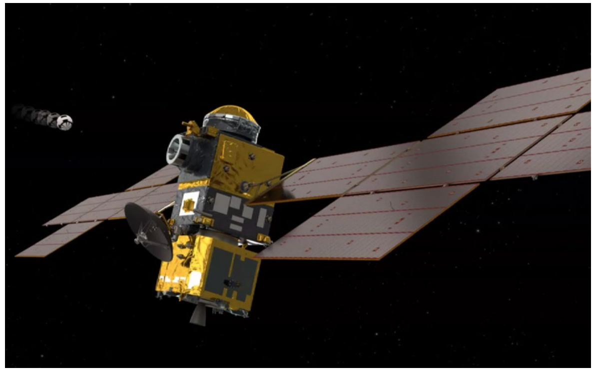
Sample Retrieval Lander (SRL)

and

Mars Ascent Vehicle (MAV)

- Retrieve samples cached onboard Mars 2020 rover or from sample depot
- *Launch samples into orbit around Mars*

MSR



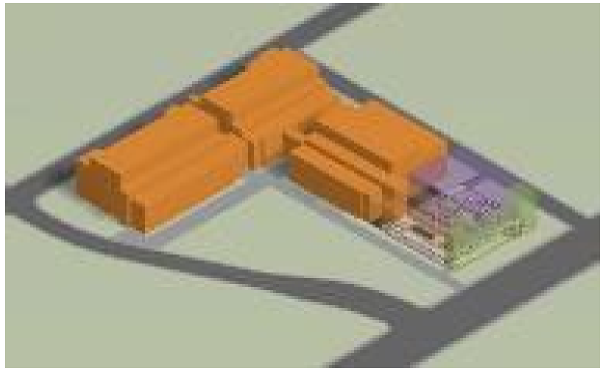
Earth Return Orbiter (ERO)

and

Capture Containment and Return System (CCRS)

- *Capture and contain samples in Mars orbit*
- *Decontamination, Back Planetary Protection (BPP)*
- *Safely return samples to Earth for recovery at landing site*

MEP



Sample Receiving Project

- *Recover and transport contained samples to receiving facility*
- *Safety assessment and sample containment*
- *Initial sample science and curation*

MEP – Mars Exploration Program

MSR – Mars Sample Return

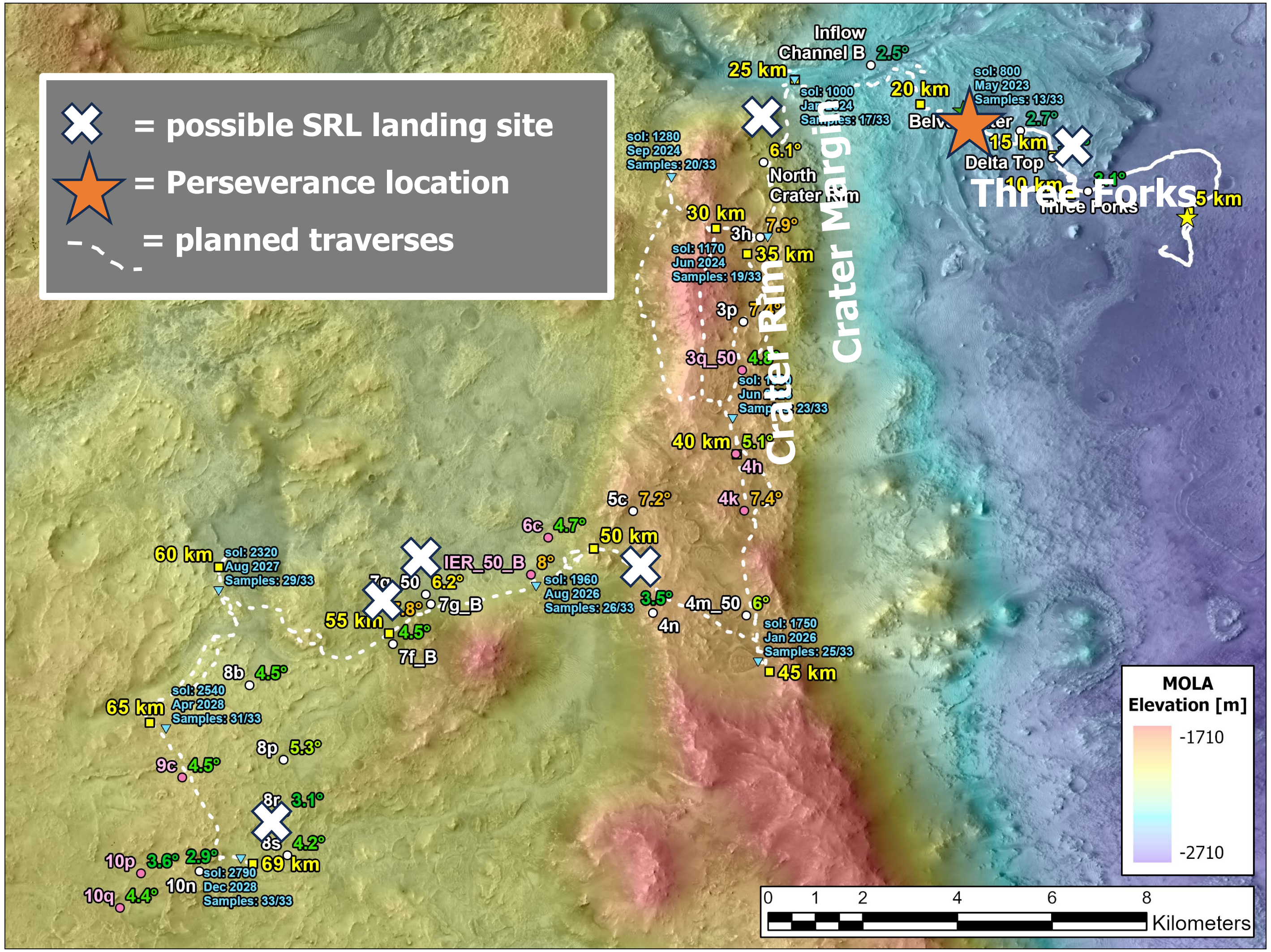
The Imperative of Mars Sample Return

- **MSR represents the critical next step in a strategic program of Mars Exploration** spanning the past four decades. US and European orbiters and US rovers have found promising sites where life might once have existed. Samples are now being collected from one of those promising sites for return to Earth.
- **MSR returns scientifically-selected samples of Mars to address key scientific and existential questions using our most sensitive laboratories**: Did Mars harbor life in the past and if so, when? Mars was once the most Earth-like planet in the Solar System; what transformed it into the uninhabitable world that it is today?
- **MSR is a top priority of the last two surveys of the National Academies Decadal Survey of Planetary Science**, a consensus report that is respected and followed by Congress and the President.
- **MSR will inform the USA's Moon-to-Mars strategy** by characterizing environmental conditions, by validating backward planetary protection assurance, and by demonstrating launch from the surface of Mars.
- **Leadership in space exploration is a hallmark of USA's soft power in the world**. Peaceful exploration of space serves to demonstrate US technological expertise and willingness to complete what it sets out to accomplish, no matter how difficult. *NASA is succeeding at doing the seemingly impossible.*
- **China has announced plans for a Mars sample return mission** (Tianwen-3) that they claim will be launched in 2028 or 2030. These plans challenge the USA's technical, engineering, and scientific leadership in Mars exploration.
- **Mars has engaged human imagination for centuries**. It is time "to organize and measure the best of our energies and skills" (JFK, 1962) for the next giant leap to return samples now.

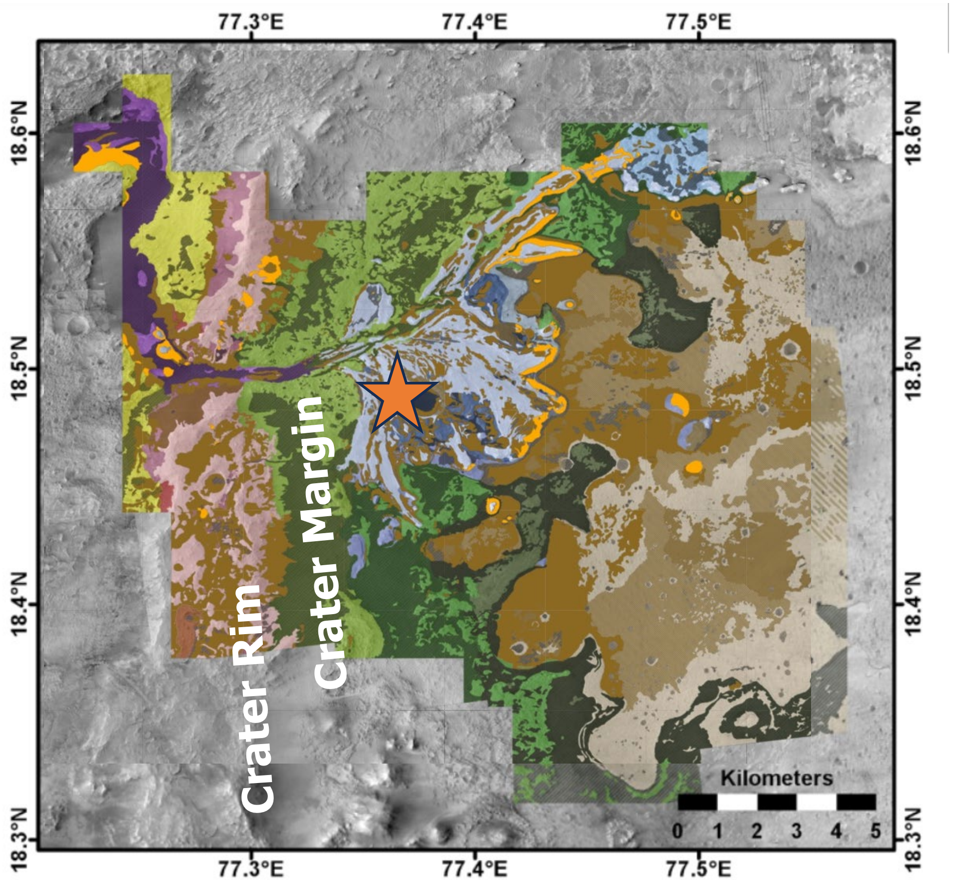
The Value of Returned Samples from Mars

- Return of lunar samples during Apollo established the present paradigm of an impact-dominated early solar system and provided an absolute chronology for early events in the vicinity of Earth. ***MSR will similarly revolutionize our understanding of the inner solar system from a vantage point beyond Earth.***
- Mars Sample Return is the next step in a ***carefully crafted, science-based strategy*** for Mars Exploration: ***"Follow the Water – Habitability – Search for Life."***
- ***Whether there was or is life elsewhere in our solar system is one of the most important scientific questions we can answer***. This question is the pinnacle of a decades-long NASA program of strategic Mars exploration. The question has informed the highest scientific priority flagship mission in the last two planetary science decadal surveys.
- The samples currently being collected by the Perseverance rover are from a delta/lake deposit that is thought to have formed in an Earth-like environment early in Mars' history. ***This makes the samples of very high value in the search for ancient life beyond Earth***.
- ***State-of-the-art laboratory facilities are needed*** in order to engage the best technological and scientific capability to detect faint, difficult-to-detect signatures. ***This work is impossible to do on Mars*** with the limitations in mass and power of robotic instruments that can be brought to the Martian surface.
- China is planning to return Mars samples on a similar timetable, but lack similar scientific rigor. ***MSR will bring back carefully-selected samples that the international Mars science community has deemed are of the greatest value.***

Diversity of Geologic Units on Crater Margin and Rim



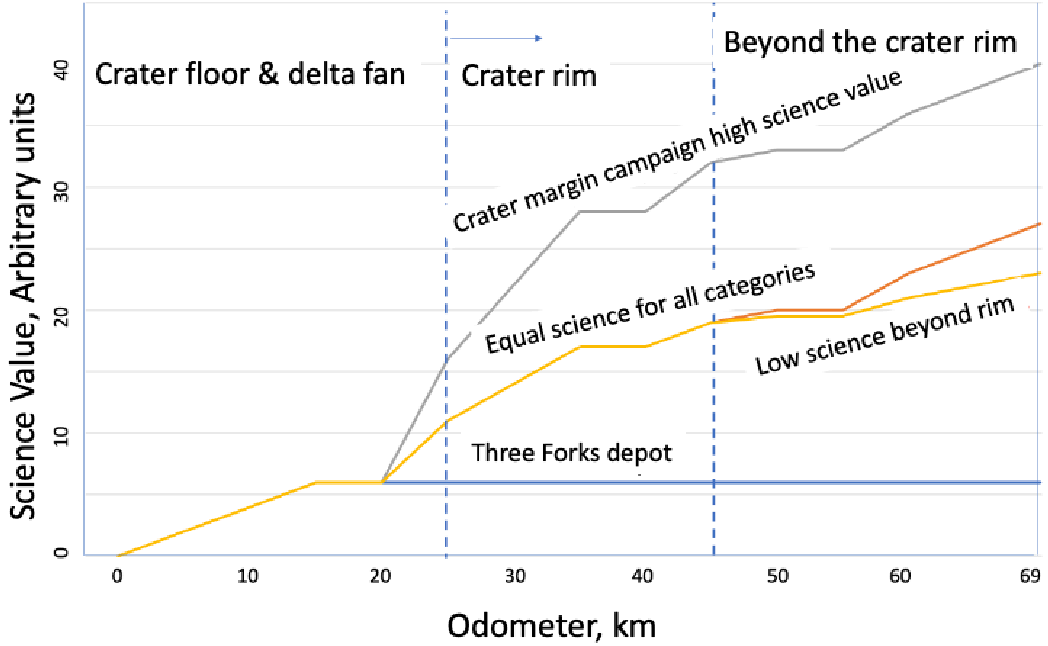
Region of crater margin and rim, with possible landing sites (low slopes, few rocks) for SRL, identified from orbit for future certification by Perseverance.

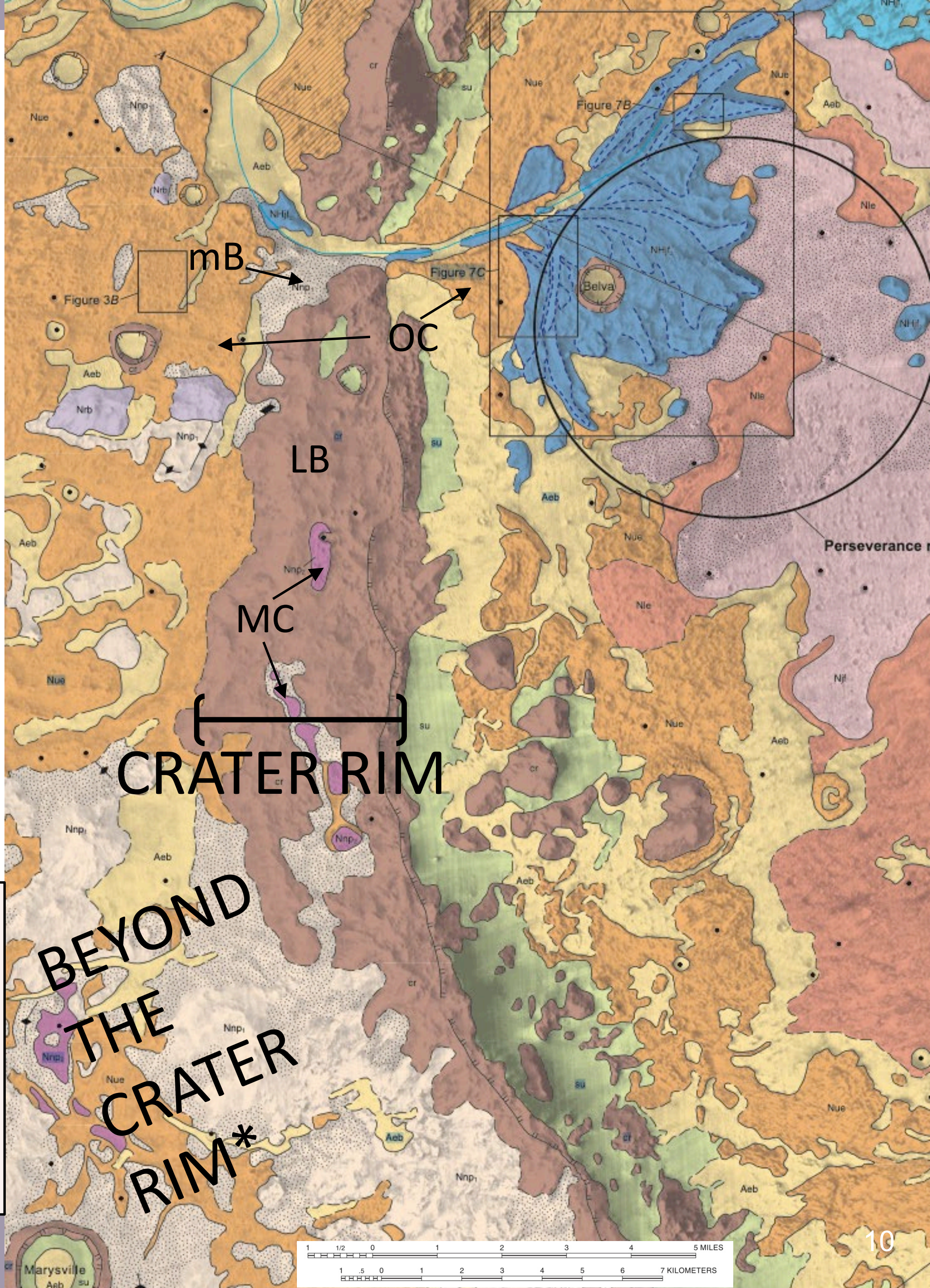


Geologic map from orbit data for the Jezero Crater field site (Stack et al., [2020]). Each color indicates a distinct geologic unit.

Why is the Crater Rim So Exciting?

Notional Science Value Versus Distance Traveled





Map Legend

LB **Layered Basement** – material in which the crater was formed that has been lifted and folded over to create the rim

mB **megaBreccias** – possibly from before the formation of the regional basin within which Jezero lies; some may even be mantle material (the bulk interior lying below Mars' crust)

MC **Mafic Caprock** – remnants of an eruption that covered a region of Mars five times the size of the Yellowstone super-eruption in North America

OC **Olivine-Carbonate** – the North end of the rim hosts a possible remnant of a beach

** Beyond the crater rim requires additional mileage and contains additional exposures of the above units*

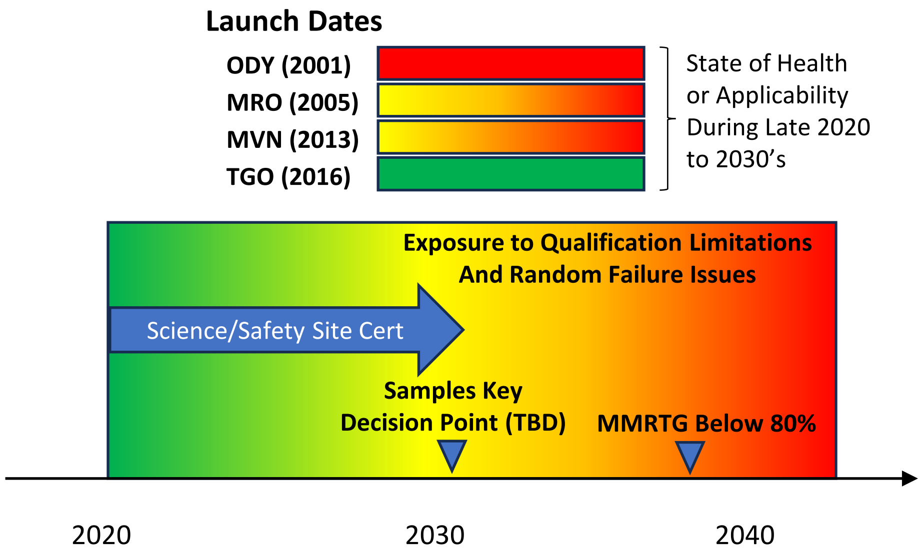
Recognition of Strengths

- 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.

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.

Qualitative State of M2020 and Mars Telecom Assets



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

Key Takeaways From All Findings (1 of 2)

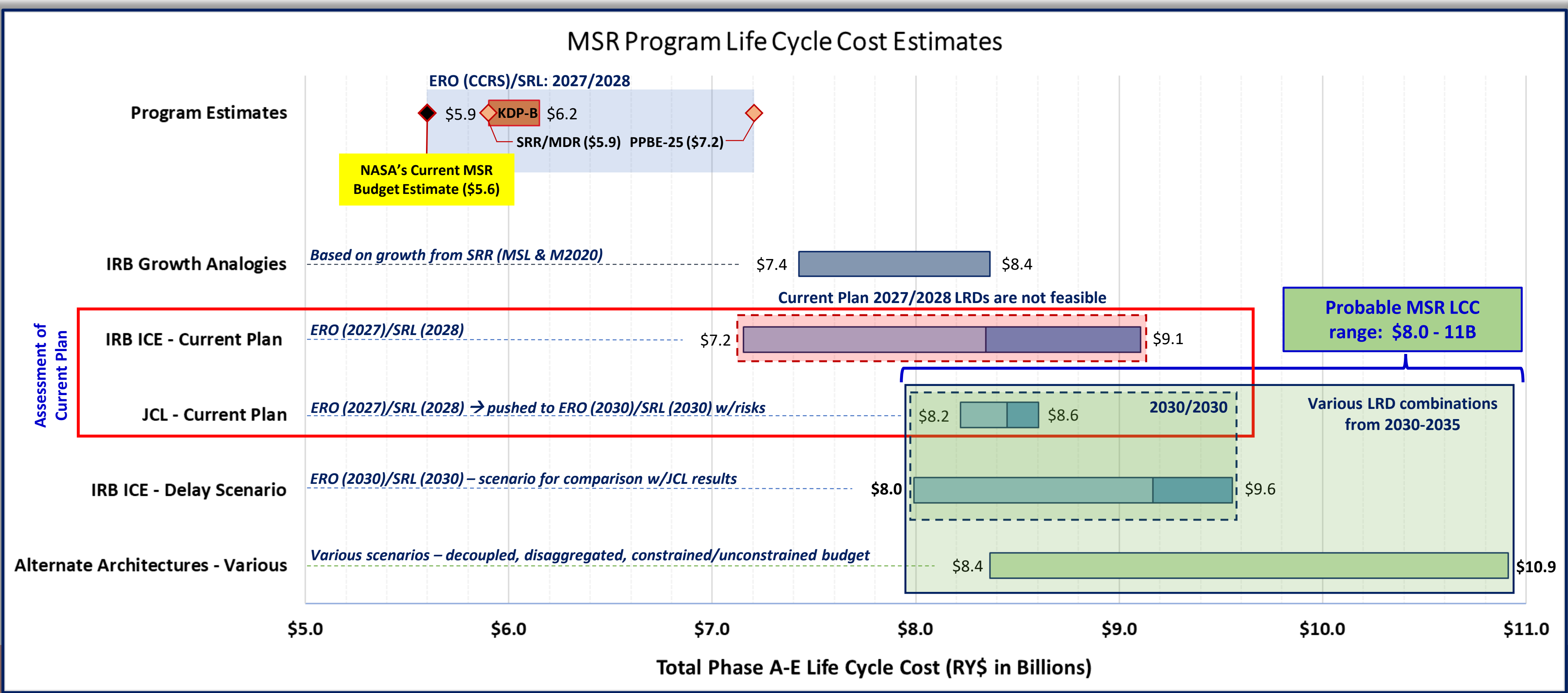
- The strategic and high scientific value of MSR is not being communicated appropriately.
- MSR is a deep-space exploration priority for NASA, in collaboration with ESA. However, MSR was established with unrealistic budget and schedule expectations from the beginning. MSR was also organized under an 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.

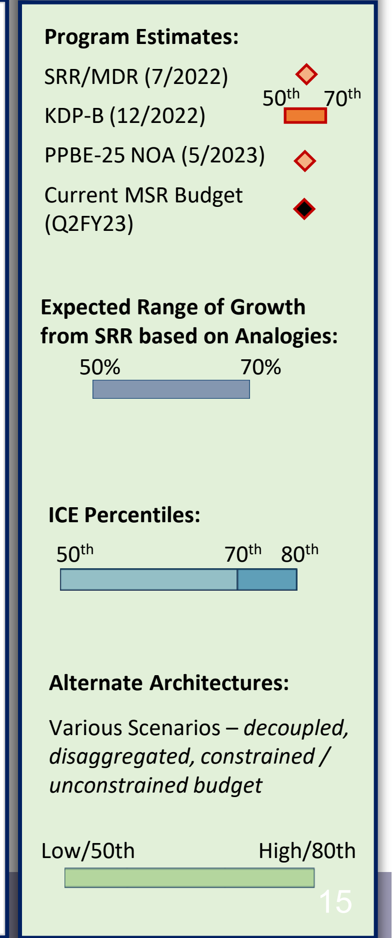
Key Takeaways From All Findings (2 of 2)

- 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.





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]

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]

Organization of Findings and Recommendations

Findings and Recommendations

- F1 Collecting the Right Samples
- F2 Communicating the Importance of MSR
- F3 Overall Organizational Structure
- F4 Agency-level Leadership and Engagement
- F5 ERO/CCRS and the NASA/ESA Partnership
- F6 OS Impact Across MSR Elements
- F7 UV Decontamination of Possible Biohazards on the OS Exterior
- F8 NASA Coordination with US Regulatory Agencies on Backward Planetary Protection
- F9 Architectural Robustness and Resiliency
- F10 Programmatic Assessment
- F11 Independent Review Structure
- F12 Culture and Communication

Additional Important Findings and Recommendations

- F13 Verification and Validation
- F14 Cross-Organization Engineering Management
- F15 Telecommunications Infrastructure
- F16 Helicopter Accommodation Risk Balance
- F17 Technical Baseline Management and Change Control
- F18 Launch Vehicles
- F19 Workforce Capacity and Expectations Post COVID-19
- F20 Supply Chain