# Mars Exploration Rovers: Spirit and Opportunity Mission Description

## Mission Overview

The Mars Exploration Rover (MER) mission consisted of two spacecraft, MER-2 hardware, which included the Spirit rover, and MER-1 hardware, which included the Opportunity rover (Crisp et al., 2003; Garvin et al., 2003). Spirit was launched June 10, 2003, on a Delta II 7925 launch vehicle. Opportunity followed 3 weeks later, launching July 7, 2003 on a Delta II 7925 Heavy vehicle. Each spacecraft followed a Type I trajectory from Earth to Mars, with Spirit landing in Gusev Crater on January 4, 2004 UTC and Opportunity landing in Meridiani Planum on January 25, 2004 UTC. The Earth-Mars range was 170.2 million km at the time of Spirit's landing and 198.7 million km at the time of Opportunity's landing.

The spacecraft design was based on the Mars Pathfinder configuration for cruise and entry, descent, and landing. Each MER spacecraft contained a rover that was carried to Mars inside a lander. The lander was packed inside a heatshield and backshell attached to a cruise stage. At Mars arrival, the cruise stage was jettisoned from the entry capsule. The entry capsule entered the Martian atmosphere directly from the Earth-Mars transfer trajectory at a velocity of 5.4 km/s. The lander velocity was reduced from this high entry speed by the application of aerodynamic braking by a parachute and aeroshell, propulsive deceleration using small solid rocket motors, and inflated airbags to reduce the remaining vertical and horizontal velocity components at surface impact (involving significant bouncing). Key engineering status information was collected and returned in near real time to the extent possible during entry and descent. In addition, all engineering data obtained during the critical entry, descent, and landing phase were recorded for later playback during the first week of landed operations.

The two landing sites were selected because of their science potential and safety characteristics (Golombek et al., 2003). The two sites exhibited different types of evidence suggesting past liquid-water activity. For Gusev, the evidence was primarily geomorphologic (possible crater lake) and for Meridiani, it was primarily mineralogic (gray coarse-grained hematite). The navigation team determined the location of the landing sites in inertial space, by fitting direct-to-Earth (DTE) two-way X-band Doppler and two passes of UHF two-way Doppler between each rover and Mars Odyssey. Translated to the MOLA IAU 2000 frame (Seidelmann et al., 2002) these inertial positions are 14.571892 degrees S latitude and 175.47848 degrees E longitude for Spirit, and 1.948282 degrees S latitude, 354.47417 degrees E longitude for Opportunity. The location of the landing sites, with respect to surface features in maps produced in the MOLA IAU 2000 cartographic reference frame, are 14.5692 degrees S latitude, 175.4729 degrees E longitude for Spirit and 1.9462 degrees S latitude, 354.4734 degrees E longitude for Opportunity.

Each of the identical rovers was equipped with a science payload consisting of two remote sensing instruments (Pancam and the Miniature Thermal Emission Spectrometer) at the top of a rotatable mast to survey the surrounding terrain, a robotic arm capable of placing three instruments (Alpha Particle X-Ray Spectrometer, Moessbauer Spectrometer, and Microscopic Imager) and a rock abrasion tool (RAT) on selected rock and soil samples, and several on-board magnets and calibration targets. Engineering sensors and other components on the rovers useful for science investigations included stereo navigation cameras (Navcam) on the top of the mast, stereo hazard cameras in front and rear under the solar panels (Hazcams), wheel motors, the wheels themselves for digging, gyros, accelerometers, and reference solar cells. Mission operations allowed commanding of the rover each martian day, or sol, on the basis of the previous sol's data. Over the 90-sol prime mission lifetime and several mission extensions, the rovers carried out field geology investigations, exploration, and atmospheric characterization. Many extended missions followed the 90-sol primary mission. Brief summaries of the activities in each mission phase are described below. The mission has been described in many papers, including a pre-landing set of papers in the December 2003 special section of Journal of Geophysical Research - Planets, and post- landing special issues of Science in 2004 for Spirit rover (volume 305, number 5685) and Opportunity rover (volume 306, number 5702). Additional special issues were published in 2005 for Earth and Planetary Science Letters (volume 240, number 1) and Nature (volume 436, number 7047). In 2006, the science team published several papers on the Spirit rover in Journal of Geophysical Research - Planets (volume 111, number E02). Another Journal of Geophysical Research - Planets special issue was published in 2008 (volume 113, number E06), with another JGR update in 2010-2011 (volume 115 and vol 116).

## Mission Phases

Development

The development phase began with the start of mission funding in May, 2000. During this phase, the science and technology requirements were developed and analyzed, and the spacecraft and mission were designed. The instruments and spacecraft were fabricated and tested before delivery to Kennedy Space Center. The design of the spacecraft trajectory and mission operations were also determined during this period.

Spacecraft Id : MER2

Mission Phase Start Time : 2000-05-08

Mission Phase Stop Time : 2003-06-10

Spacecraft Id : MER1

Mission Phase Start Time : 2000-05-08

Mission Phase Stop Time : 2003-07-07

Launch

The launch phase for each vehicle began at the final countdown through spacecraft separation from the upper stage. Spirit (MER-2 hardware) was launched June 10, 2003, at 1759 UTC (1359 EDT) from launch complex 17A at Cape Canaveral Air Force Station, Florida. The launch azimuth was 93 degrees. The boost portion of the launch vehicle trajectory took approximately 10 minutes, and was followed by a short coast phase in a parking orbit for approximately 15 minutes. After third stage burnout, the upper stage despun the stack using a yo-yo despin system. Separation of the third stage occurred approximately 36 minutes after launch.

Opportunity (MER-1 hardware) was launched July 8, 2003, at 0318 UTC (July 7, 2003, 2318 EDT) from launch complex 17B at Cape Canaveral Air Force Station, Florida. The launch azimuth was 99 degrees. The boost portion of the launch vehicle trajectory took approximately 9 minutes, and was followed by a long coast phase of approximately 60 minutes in a parking orbit. After third stage burnout, the upper stage despun the stack using a yo-yo despin system. Separation of the third stage occurred approximately 83 minutes after launch.

Spacecraft Id : MER2

Mission Phase Start Time : 2003-06-10

Mission Phase Stop Time : 2003-06-10

Spacecraft Id : MER1

Mission Phase Start Time : 2003-07-07

Mission Phase Stop Time : 2003-07-07

Cruise

The cruise phase for each spacecraft began soon after separation from the third stage and ended 45 days before entry into the Mars atmosphere. The duration of cruise phase was 162 days for Spirit and 156 days for Opportunity. The major activities during this phase included: checkout and maintenance of the spacecraft in its flight configuration, monitoring, characterization and calibration of the spacecraft and payload systems, software parameter updates, attitude correction turns, navigation activities for determining and correcting the vehicle's flight path, and preparation for EDL and surface operations, including EDL X-band communication tests. No science investigations were conducted during cruise, except for instrument health checkouts.

Spacecraft Id : MER2

Mission Phase Start Time : 2003-06-10

Mission Phase Stop Time : 2003-11-19

Spacecraft Id : MER1

Mission Phase Start Time : 2003-07-07

Mission Phase Stop Time : 2003-12-10

Approach

The approach phase was dedicated to the activities necessary to ensure a successful Entry, Descent, and Landing for each spacecraft, beginning 45 days before entry into the Martian atmosphere and ending at the atmospheric entry interface point 3522.2 km from the center of Mars. The main activities during this phase were: acquisition and processing of navigation data to support development of the final trajectory correction maneuvers and activities leading up to the final turn to the entry attitude 70 minutes before entry and separation from the cruise stage 15 minutes before entry.

Spacecraft Id : MER2

Mission Phase Start Time : 2003-11-19

Mission Phase Stop Time : 2004-01-03

Spacecraft Id : MER1

Mission Phase Start Time : 2003-12-10

Mission Phase Stop Time : 2004-01-24

Entry, Descent, and Landing

The entry, descent, and landing (EDL) phase for each spacecraft started six minutes prior to landing. Approximately 20 seconds after parachute deploy, the heatshield separated from each spacecraft, followed approximately 10 seconds later by lander separation on a bridle. This was followed by radar acquisition of the ground, acquisition of three images by the DIMES (Descent Image Motion Estimation System), airbag inflation, RAD/TIRS rocket firing, bridle cut (6.5 m above the surface for Spirit, 8.5 m for Opportunity), and landing. The landing (first impact) occurred at 04:26 UTC on January 4, 2004 for Spirit (1425 Mars local solar time, solar longitude Ls = 327.66) and 04:55 UTC on January 25, 2004 for Opportunity (1323 Mars local solar time, solar longitude Ls = 339.10). Spirit bounced 28 times before coming to rest on the base petal of the lander. After retraction of the airbags and opening of the petals, the base petal was oriented at a tilt of 2 degrees. Opportunity bounced 26 times before coming to rest on a side petal (+Y petal) of the lander. After retraction of the airbags and opening of the petals, the base petal was oriented at a tilt of 5 degrees, with the base petal down on the surface. The entry, descent, and landing phase for each spacecraft was completed once the rover solar panels were opened and the lander was on the surface of Mars in a thermally stable, positive energy balance, in a commandable configuration.

Spacecraft Id : MER2

Mission Phase Start Time : 2004-01-04

Mission Phase Stop Time : 2004-01-04

Spacecraft Id : MER1

Mission Phase Start Time : 2004-01-25

Mission Phase Stop Time : 2004-01-25

Post-Landing Through Egress

The post-landing through egress phase of each mission began after the lander petals and rover solar panels had been opened. This phase ended 12 Martian sols (each sol being 24.66 hours) after landing for Spirit, and 7 Martian sols for Opportunity, when each rover drove off of the lander directly onto the surface of Mars. Data confirming the egress event for Spirit were received at 01:53 PST January 15, 2004 (09:53, January 15, UTC). Engineers received confirmation that Opportunity's six wheels successfully rolled off the lander and onto martian soil at 03:01 PST, January 31, 2004 (11:01 January 31, UTC).

Spacecraft Id : MER2

Mission Phase Start Time : 2004-01-04

Mission Phase Stop Time : 2004-01-15

Spacecraft Id : MER1

Mission Phase Start Time : 2004-01-25

Mission Phase Stop Time : 2004-01-31

Primary Mission

Spirit and Opportunity's primary missions each lasted for 90 Martian sols from time of landing. During this phase and the extended mission phase, a wealth of science and engineering information was collected from the rover and instrument payload. During Spirit's mission, the rover traveled in a primarily northeast direction from its landing site to the 210-meter diameter crater informally called 'Bonneville,' and then headed southeast towards the hills nicknamed 'Columbia Hills,' covering a distance travelled of 635 meters. During that time, Spirit acquired 23810 Pancam images, 2886 Navcam images, 3980 Hazcam images, and 1872 Microscopic Imager images (these image counts include full frames, subsampled frames, downsampled frames, and thumbnails). During Opportunity's prime mission, the rover spent the first two months investigating the surrounding area where it landed, which was a 20- meter diameter crater nicknamed 'Eagle.' After the study of 'Eagle,' it headed east towards the 130-meter diameter crater nicknamed 'Endurance,' covering a distance travelled of 772 meters. During the prime mission, Opportunity acquired 22503 Pancam images, 2343 Navcam images, 4421 Hazcam images, and 1395 Microscopic Imager images.

Spacecraft Id : MER2

Mission Phase Start Time : 2004-01-11

Mission Phase Stop Time : 2004-04-06

Spacecraft Id : MER1

Mission Phase Start Time : 2004-02-01

Mission Phase Stop Time : 2004-04-27

Extended Mission 1

The rovers' operated through several extended missions. Objectives for each of the extended missions are described in the next section.

Spacecraft Id : MER2

Mission Phase Start Time : 2004-04-06

Sol Start Time: 91

Mission Phase Stop Time : 2004-09-30

Sol Stop Time: 264

Spacecraft Id : MER1

Mission Phase Start Time : 2004-04-27

Sol Start Time: 91

Mission Phase Stop Time : 2004-09-30

Sol Stop Time: 243

Extended Mission 2

Spacecraft Id : MER2

Mission Phase Start Time : 2004-10-01

Sol Start Time: 265

Mission Phase Stop Time : 2005-03-31

Sol Stop Time: 441

Spacecraft Id : MER1

Mission Phase Start Time : 2004-10-01

Sol Start Time: 244

Mission Phase Stop Time : 2005-03-31

Sol Stop Time: 420

Extended Mission 3

Spacecraft Id : MER2

Mission Phase Start Time : 2005-04-01

Sol Start Time: 442

Mission Phase Stop Time : 2006-09-30

Sol Stop Time: 974

Spacecraft Id : MER1

Mission Phase Start Time : 2005-04-01

Sol Start Time: 421

Mission Phase Stop Time : 2006-09-30

Sol Stop Time: 954

Extended Mission 4

Spacecraft Id : MER2

Mission Phase Start Time : 2006-10-01

Sol Start Time: 975

Mission Phase Stop Time : 2007-09-28

Sol Stop Time: 1328

Spacecraft Id : MER1

Mission Phase Start Time : 2006-10-01

Sol Start Time: 955

Mission Phase Stop Time : 2007-09-28

Sol Stop Time: 1307

Extended Mission 5

Spacecraft Id : MER2

Mission Phase Start Time : 2007-09-29

Sol Start Time: 1329

Mission Phase Stop Time : 2008-09-28

Sol Stop Time: 1684

Spacecraft Id : MER1

Mission Phase Start Time : 2007-09-29

Sol Start Time: 1308

Mission Phase Stop Time : 2008-09-28

Sol Stop Time: 1663

Extended Mission 6

Spacecraft Id : MER2

Mission Phase Start Time : 2008-09-29

Sol Start Time: 1685

Mission Phase Stop Time : 2010-03-22

Sol Stop Time: 2210

The last communication with Spirit was on Sol 2210 (March 22, 2010). Total odometry was 7,730.5 meters (4.80 miles).

Spacecraft Id : MER1

Mission Phase Start Time : 2008-09-29

Sol Start Time: 1664

Mission Phase Stop Time : 2010-09-26

Sol Stop Time: 2372

Extended Mission 7

Spacecraft Id : MER1

Mission Phase Start Time : 2010-09-27

Sol Start Time: 2373

Mission Phase Stop Time : 2012-09-30

Sol Stop Time: 3087

Extended Mission 8

Spacecraft Id : MER1

Mission Phase Start Time : 2012-10-01

Sol Start Time: 3088

Mission Phase Stop Time : 2014-09-30

Sol Stop Time: 3797

Extended Mission 9

Spacecraft Id : MER1

Mission Phase Start Time : 2014-10-01

Sol Start Time: 3798

Mission Phase Stop Time : 2016-09-30

Sol Stop Time: 4509

Extended Mission 10

Spacecraft Id : MER1

Mission Phase Start Time : 2016-10-01

Sol Start Time: 4510

Mission Phase Stop Time : 2018-09-30

Sol Stop Time: 5219

Extended Mission 11

Spacecraft Id : MER1

Mission Phase Start Time : 2018-10-01

Sol Start Time: 5220

Mission Phase Stop Time : 2019-09-30

Sol Stop Time: 5575

The last communication with Opportunity was on Sol 5111 (June 10, 2018) during a historic global dust storm. Total odometry was 45.16 kilometers (28.06 miles). The remainder of Extended Missions 10 and 11 were devoted to trying to reestablish communication with Opportunity. On February 12, 2019 (Sol 5352) NASA decided to end attempts to communicate with the spacecraft, effectively ending the mission.

Mission Objectives

*Mission Objectives Overview*

The MER mission had a set of science and technology objectives. The science was closely aligned with the Mars Exploration Program objective of determining the degree to which Mars provided conditions necessary for formation and preservation of prebiotic compounds and whether life started and evolved. This objective can be broadly stated as defining habitability of Mars and providing an understanding of roles of tectonic and climatic processes in possibly providing the conditions that led to life. The presence of water and its interaction with crustal materials is of fundamental importance. Thus, three of the MER objectives focused on searching for evidence of water in the past: (1) to investigate landing sites that have a high probability of containing evidence of the action of liquid water, (2) to search for and characterize a diversity of rocks and soils that hold clues to past water activity, and (3) to extract clues related to the environmental conditions when liquid water was present and assess whether those environments were conducive to life.

The other MER science objectives were related to the Mars Exploration Program objective of determining the nature and sequence of the various geologic processes that have created and modified the Martian crust and surface: (4) to determine the spatial distribution and composition of minerals, rocks and soils surrounding the landing sites, (5) to determine the nature of local surface geologic processes from surface morphology and chemistry, (6) to calibrate and validate orbital remote sensing data and assess the amount and scale of heterogeneity at each landing site, (7) for iron-containing minerals, to identify and quantify relative amounts of specific mineral types that contain H2O or OH, or are indicators of formation by an aqueous process, and (8) to characterize the mineral assemblages and textures of different types of rocks and soils and put them in geologic context. These are basic field geology objectives that can be carried out at any landing site, but will provide the basis for addressing the first three objectives related to past water and thus habitability.

Three additional objectives for MER were technology related: (9) to demonstrate long-range traverse capabilities by mobile science platforms to validate long-lived, long-distance rover technologies, (10) to demonstrate complex science operations through the simultaneous use of multiple science-focused mobile laboratories, and (11) to validate the standards, protocols and capabilities of NASA-provided and internationally-provided orbiter-based Mars communications infrastructure. These objectives provided experience, lessons-learned, and technology feed-forward to enable improved Mars science missions in the future. While not part of the formal mission objectives, the rovers' remote sensing instruments were also used to make scientific observations of the martian atmosphere.

*First Extended Mission objectives:*

1) Extend investigation of the water history in Gusev Crater by traversing to the Columbia Hills.

2) Investigate the geologic context of the Opportunity outcrop by traversing to other targets (Endurance crater and the etched region south of the landing site) and conducting in-situ investigations of exposed outcrops.

3) Continue atmospheric measurements at both sites to encompass a longer portion of the Martian seasonal cycle.

4) Calibrate and validate orbital remote sensing data for additional types of soil and rock deposits.

5) Conduct long range traverses (>1 km) to extend Mars surface exploration and demonstrate relevant mobility technologies.

6) Demonstrate long term, sustainable operations of two mobile science platforms on remote planetary surfaces.

7) Characterize solar array performance over long durations of dust depositions at two different landing sites.

*Second Extended Mission objectives:*

1) Continue search for evidence of the role of water in the geological history of Gusev Crater.

2) Extend the geological exploration of the water-lain sedimentary and other outcrops in Meridian Plains into the regions south of Endurance Crater.

3) Continue atmospheric measurements at both sites.

4) Calibrate and validate orbital remote sensing data for additional types of soil and rock deposits.

5) Characterize solar array performance over long durations of dust depositions at two different landing sites.

6) Demonstrate long term, sustainable operations of two mobile science platforms on remote planetary surfaces, with much of the science team participating from their remote home institutions.

*Third Extended Mission objectives:*

1) Continue to search for evidence of the role of water in the geological history of Gusev Crater by exploring a large variety of outcrops found within the Columbia Hills.

2) Extend the geological exploration of water-lain sedimentary and other outcrops in Meridian Planum into the regions south of Endurance Crater, including the expansive Etched Terrain and, if the Etched Terrain can be crossed, Victoria Crater.

3) Continue atmospheric measurements at both sites to encompass a full martian year.

4) Calibrate and validate orbital remote sensing data for additional types of soil and rock deposits.

5) Characterize solar array performance over long durations of dust depositions at two different landing sites.

6) Demonstrate continued long term, sustainable operations of two mobile science platforms on remote planetary surfaces, with most of the science team participating from their remote home institutions.

7) Demonstrate specific improvements in rover capability.

*Fourth Extended Mission objectives:*

1) Continue to search for evidence of the role of water in the geological history of Gusev Crater by exploring a large variety of outcrops and soils found within the Columbia Hills, including unexplored regions south of the Inner Basin.

2) Extend the geological exploration of water-lain sedimentary and other rock outcrops in Meridiani Planum to Victoria Crater. Search for lake-bed sedimentary deposits that have not been transported by wind or water, which would provide key geologic insight into the processes involved in the formation of the evaporate-rich rocks at Eagle, Endurance, and Erebus Craters.

3) Determine the nature of local surface geologic processes at new locations in Gusev Crater and Meridiani Planum.

4) Continue atmospheric measurements at both sites to characterize interannual variations across a second martian year.

5) Calibrate and validate orbital remote sensing data for additional types of soil and rock deposits.

6) Characterize solar array performance over long durations of dust depositions at two different landing sites.

7) Continue to demonstrate long term, sustainable operations of two mobile science platforms on remote planetary surfaces, with most of the science team participating from their remote home institutions.

*Fifth Extended Mission objectives:*

1) Continue to search for evidence of the role of water in the geological history of Gusev Crater by exploring a large variety of outcrops and soils found within the Columbia Hills, including the target-rich Inner Basin.

2) Extend the geological exploration of water-lain sedimentary and other rock outcrops in Cape Victory to Victoria Crater. Search for lake-bed sedimentary deposits that have not been transported by wind or water, which would provide key geologic insight into the processes involved in the formation of the evaporate-rich rocks at Eagle, Endurance, and Erebus Craters.

3) Determine the nature of local surface geologic processes at new locations in Gusev Crater and Victoria Crater.

4) Continue atmospheric measurements at both sites to characterize interannual variations across a second martian year.

5) Calibrate and validate orbital remote sensing data for additional types of soil and rock deposits.

6) Characterize solar array performance over long durations of dust depositions at two different landing sites.

7) Continue to demonstrate long term, sustainable operations of two mobile science platforms on remote planetary surfaces, with most of the science team participating from their remote home institutions.

*Sixth Extended Mission objectives:*

1) Continue to search for evidence of the role of water in the geological history of Gusev Crater by exploring a large variety of outcrops and soils found within the Columbia Hills, including the target-rich Inner Basin.

2) Extend the geological exploration of water-lain sedimentary and other rock outcrops in Victoria Crater to Endeavor Crater. Search for lake-bed sedimentary deposits that have not been transported by wind or water, which would provide key geologic insight into the processes involved in the formation of the evaporate-rich rocks at Eagle, Endurance, and Erebus Craters.

3) Determine the nature of local surface geologic processes at new locations in Gusev Crater and en route to Endeavor Crater.

4) Continue atmospheric measurements at both sites to characterize interannual variations across a second martian year.

5) Calibrate and validate orbital remote sensing data for additional types of soil and rock deposits.

6) Characterize solar array performance over long durations of dust depositions at two different landing sites.

7) Continue to demonstrate long term, sustainable operations of two mobile science platforms on remote planetary surfaces, with most of the science team participating from their remote home institutions.

*Seventh Extended Mission objectives:*

1) Use Spirit to measure two-way X-band Doppler shift over a period of months to years to constrain the moment of inertia of Mars.

2) Use Spirit to monitor surface-atmospheric interactions within the Inner Basin with regular Pancam albedo panoramas to track eolian dynamics on a terrain-level scale and repeated Microscopic Imager imaging of specific soil sites to track eolian dynamics on a soil grain scale.

3) Use Spirit to continue the geologic and geochemical investigations of sulfate deposits in Scamander crater.

4) Use Opportunity to advance toward Endeavor crater with the objective of investigating the phyllosilicate-bearing materials present in Endeavor's rim.

5) Use Opportunity to continue sampling cobbles along the route to Endeavor, with particular emphasis on finding and characterizing rocks that may be representative of the ones that were altered to form the Meridiani sediments.

6) Use Opportunity to continue a comprehensive search for 'wet' sedimentary facies preserved in the bedrock at Meridiani.

7) Continue atmospheric measurements at both sites to extend the characterization of interannual variations for a fourth martian year.

8) Calibrate and validate orbital remote sensing data for both sites for additional types of soil and rock deposits.

9) Characterize solar array performance over long durations of dust deposition at two different landing sites.

10) Continue to demonstrate long-term, sustainable operations of science platforms on remote planetary surfaces with a distributed team participating from their remote locations, and dynamically model rover mobility both post drive and, in a predictive sense, predrive.

*Eighth Extended Mission objectives:*

1) Characterize the Noachian outcrops on Cape York.

2) Investigate the impact ejecta deposit from the Endeavour crater impact and characterize the clasts and matrix of the impact ejecta.

3) Characterize the Burns formation within Botany Bay.

4) Look for evidence of aqueous alteration of the crater rim rocks.

5) Search for dust devils and record detections with on-board imaging systems.

*Ninth Extended Mission objectives:*

1) Characterize the Explore the Murray Ridge and Cape Tribulation rim segments.

2) Use Opportunity to explore Marathon Valley in Cape Tribulation to get stratigraphic, structural, and compositional settings for the exposure of Fe, Mg smectites detected using CRISM observations.

3) Use Opportunity to monitor atmospheric optical depth using Pancam.

4) Search for water ice clouds by imaging the sky, with an emphasis on the annual "aphelion cloud" season.

5) Continue searching for dust devils and record detections with on-board imaging systems.

6) Measure the composition of the atmosphere using APXS to track variations in argon abundance.

*Tenth Extended Mission objectives:*

1) Search for and characterize Matijevic formation rocks at stratigraphic and topographic low points.

2) Characterize nature and extent of aqueous alteration of Shoemaker formation breccias and evaluated the extent of geologic control of aqueous alteration of Endeavour’s rim.

3) Characterize Burns and Grasberg formation rocks on Meridiani plains for comparison to equivalent rocks inside Endeavour.

4) Investigate small impact craters that excavated Burns and/or Grasberg formation rocks.

5) Explore and characterize the morphology, topography, and materials within Perseverance Valley.

6) Test hypotheses for the origin and evolution of Perseverance Valley.

*Eleventh Extended Mission objectives:*

1) Continue exploring and characterizing the morphology, topography, and materials within Perseverance Valley.

2) Continue testing hypotheses for the origin and evolution of Perseverance Valley.  
  
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