ABSTRACT

The twin rovers, Spirit and Opportunity, of the Mars Exploration Rover Project successfully landed on the surface of Mars in January 2004, and began an unprecedented period of surface exploration. Spirit’s landing in Gusev crater, and its subsequent journeys to the Columbia Hills provided ample evidence for the advantages of mobile rovers over fixed landers. Opportunity’s “hole in one” landing in the 20-meter Eagle crater with the essential evidence to answer the science questions for Meridiani lying meters away underscored the advantage of surface mobility. The project skillfully dealt with a host of challenges after landing, including Flash memory problems and the cold and dim light of Martian winter, to successfully extend the reach of Earth-bound scientists to two new locations on Mars. With the overwhelming success of the prime mission, NASA’s decision to continue the MER journey of exploration has achieved results undreamed of before launch.

1.0 INTRODUCTION

The twin Mars Exploration Rovers (MER) began as a dream in Dr. Mark Adler’s eyes in April of 2000. After NASA Headquarters granted approval in May 2000, the project went quickly to work. The successful launches in June and July of 2003 capped off a grueling 35-month development program. After the 7-month cruise period [1], the twin landings led to a planned 90-day surface mission — one that has already been exceeded by a factor of 5. The tremendous scientific findings include incontrovertible evidence for past liquid water at both landing sites. After the nominal 90-day mission, the twin rovers continued to outlive everyone’s expectations, including the MER team itself. The Project has received authorization from NASA Headquarters to continue operations through 10/1/2006 — for a total surface lifetime of over 32 months! If the flight team is successful in stretching the vehicles survival out to that date, the mission will be over ten times the originally planned lifetime. The intent of this paper is to provide the aerospace community a status report of the progress of the Mars Rovers exploration of the Martian surface, picking up after the landings and continuing through fiscal year 2005.

2.0 SPIRIT’S JOURNEY

The phrase “disappointment to triumph,” would have to be Spirit’s story in a nutshell. The vehicle’s surface journey began with the egress from the lander onto a sand covered plain strewn with common basaltic rocks, but struggled through to literally the pinnacle of success with its exploration of the Columbia hills. Its chronicles, as shown in Figure 1, are reviewed below.
2.1 Timeline of Spirit Events

Spirit launched towards Mars from the Cape Canaveral Air Station aboard a Boeing Delta II 7925 rocket on June 10, 2003. After an approximate 7-month interplanetary cruise safely enclosed inside the saucer-like cruise spacecraft, Spirit arrived at Mars on January 4, 2004 and began her dynamic metamorphosis from an interplanetary vehicle, to an entry, descent and landing (EDL) system, to ultimately a freely-roving surface vehicle.

Prior to entering the atmosphere of Mars, the cruise stage assembly separated from the atmospheric entry capsule containing the rover folded inside her lander. The entry capsule, or aero shell, decelerates the vehicle using the atmospheric drag from the tenuous Martian atmosphere against its fore body heat shield. Then, a parachute is deployed to slow the vehicle further while the heat shield is then jettisoned. Prior to surface impact, retro-rockets are fired to slow the lander’s speed of descent, and airbags are inflated to cushion the lander at surface impact. After its initial impact, the lander bounces along the Martian surface until it rolls to a stop. The airbags are then deflated and retracted, and the lander petals and rover egress aids are deployed. Once the petals have opened, the rover deploys its solar arrays, and places the system in a safe state. Spirit bounced 28 times on Mars before coming to a stop.

Early on the morning of January 4, 2004, after initial deployments, Spirit sent her first images from the surface of Mars through the Mars Odyssey orbiting spacecraft. These first images revealed a healthy spacecraft and an exciting environment on the surface to explore. Over the next few sols, Spirit completed her deployments including standing up on her wheels and cutting the cables that had connected her to the lander. At this point she is a free vehicle but still atop the lander.

Because substantial airbag material remained exposed directly in front of the rover, even after several air bag retraction attempts, it was decided to perform a turn in place on the lander and egress off in a different direction. On Sol 10, Spirit moved for the first time and backed up 25 cm and turned 45°. On the next sol she performed two more turns reaching a total turn azimuth of 115° to enable her to egress off in the +X+Y direction from the lander. On Sol 12, Spirit put six wheels safely on the surface of Mars.

Once off the lander, Spirit began her exploration of the surface. She deployed her robotic arm and began in situ measurements of soils next to the lander. On Sol 15, she retracted her arm and performed a 2-meter drive towards the rock named Adirondack. Two days later on Sol 17 Spirit’s robotic arm was deployed to place her in situ instruments on the rock. However, problems started for Spirit on the next sol.

On Sol 18, the first surface anomaly occurred [2]. Spirit became unresponsive to communication attempts. An investigation team was assembled to begin looking into the situation. Over the next several sols, attempts were made to establish communications with the rover with limited success. The biggest concern was that Spirit was staying awake too long and would be draining her batteries. Adding to this...
critical situation was Opportunity’s arrival and EDL in a few days.

The flight software team developed a strategy to have Spirit restart without using the Flash memory onboard. This was radiated to Spirit on Sol 21 and resulted in return of control of the rover to a known and stable state. From there, Spirit was recovered and the problem fully diagnosed. The problem was found to be associated with how the rover manages files in the Flash memory. A change to the flight software has since corrected the problem. Spirit return to conducting her science mission around Sol 30.

Once fully operational again, Spirit was very efficient at conducting remote sensing and in situ campaigns. Within roughly 34 sols, Spirit traversed approximately 300 meters to Bonneville Crater, an approximately 100 meter impact crater. Spirit did not enter the crater but spent several sols exploring the ejecta blanket around a portion of the crater.

Sol 90 represented the completion of the prime mission for Spirit satisfying the full mission success criteria, although programmatically the prime mission was declared complete when Opportunity passed 90 sols. At sol 90, Spirit had traversed 635 meters, exceeding the mission success requirement of one rover achieving 600 meters. Shortly thereafter, the flight software was updated on the rover adding some enhancements.

From Bonneville Crater, Spirit pushed on Southeast heading toward the Columbia Hills some 2.5 km distant. The Columbia Hills were named in honor of the Space Shuttle Columbia astronauts that lost their lives in the Columbia accident. Obviously, the drive to the Columbia Hills presented many opportunities for Spirit to conduct both remote sensing and in situ science campaigns, including the use of the rover wheel to dig shallow trenches.

Spirit arrived at the base of the Columbia Hills on Sol 156 and began her ascent of what is called West Spur. The ascent of the hills presented new mobility challenges for the rover. The engineers responsible for rover driving had to contend with many of the same issues that mountain climbers face. The rover experienced slippage up steep slopes. There were occasions where the direct ascent had to be abandoned for more lateral traverses. At one point a rock became embedded in the left rear wheel. Several sols were spent ejecting the rock from the wheel. One of the upward paths had to be abandoned altogether and the rover backtracked down. However, as a result of that backtrack, Spirit discovered some unique geology that would have otherwise been missed.

The ascent of the Columbia Hills towards Husband Hill, the tallest peak, presented the science team with some of the most exciting findings, in addition to some of the most spectacular views of the mission. At these new elevations the giant crater walls of Gusev Crater are visible in the distance. Dust devils are observed with some regularity out on the plains.

Spirit reached the summit of Husband Hill on Sol 581. She is now poised to capture some of the most spectacular vistas from this great vantage point. Additionally, she will use this vantage point to plot her route south into the, so-called, Inner Basin.

### 2.2 Spirit Science Results

The Gusev Crater landing site of Spirit was selected because its geologic setting, as viewed from orbit, suggested that floodwaters once descended Ma’adim Valles and flowed into Gusev where they ponded to form a lake prior to flowing out of the crater to the north at a level higher than the mouth of the channel in the southern rim. This sequence of events was assumed to have taken place early in Martian history and to be masked by some amount of change on the surface due to the intervening billions of years, but the team hoped to uncover evidence of the lacustrine past. Spirit’s initial science results demonstrated however how well Mars holds onto its secrets.

At the Columbia Memorial Station landing site, Spirit’s first panorama showed a volcanic plain that would be her home for her first five months of exploration. The science results from that phase of the mission were unsurprisingly consistent with the exploration of that volcanic plain. Spirit characterized the geology of the landing site and of Bonneville Crater to the north east, where the images showed a landscape of impact disrupted volcanic rocks that had subsequently been modified by eolian action. The dark, fine-grained, vesicular rocks appeared to be from a single population of lavas, as evidenced by Pancam and Mini-TES spectra. So Spirit investigated the similarities and differences among these rocks. The spectral observations did indicate variations in the coatings and dust mantles on the rocks. Images with the MI of brushed surfaces and abraded rock interiors showed alteration rinds and even veins. The interior rocks surfaces polished by the RAT (5 mm depth) did contain identifiable
crystals. The elemental compositions observed with the APXS were all consistent with basalts containing olivine, pyroxene, plagioclase, and accessory iron- and titanium-oxides. The Mössbauer spectra, and those of Pancam and Mini-TES confirmed the olivine, and added magnetite and pyroxene. The observed compositions were such that, when compared to previous surface observations by Viking and Pathfinder and analyses of Martian SNC meteorites, Spirit’s basalts extended the known range of Martian crustal rock composition.

As the mission progressed however, as Spirit drove towards the Columbia Hills, the sum of all the evidence she collected began to reveal the first subtle indications to the trail of past water. Among the basaltic rocks high sulphur, chlorine, and bromine concentrations, as compared with terrestrial basalts and Martian meteorites were measured with the APXS. Mineral-filling in fractures and in voids viewed by the MI correlated with high bromine. The light-toned rock Mazatzal had multiple thin surface coatings, viewed with MI and Pancam, along with enrichments in sulphur, chlorine and ferric iron. These observations all pointed to trace amounts of water having altered the Gusev plains volcanic rocks.

Figure 2. Mosaic of four images taken by the Microscopic Imager (merged with Pancam colour data), 45mm across. A circular subsurface exposure was ground by the second abrasion. The dark strip (centre right, 10% area) is a remnant of the dark-toned coating. The light-toned rock Mazatzal had multiple thin surface coatings, viewed with MI and Pancam, along with enrichments in sulphur, chlorine and ferric iron. These observations all pointed to trace amounts of water having altered the Gusev plains volcanic rocks.

The soils that share the volcanic surface with the rocks also began to reveal a water story, although it is not straightforward. The regolith is composed of olivine-rich basaltic fines and ‘global’ Martian windblown dust. The presence of olivine, a relatively easily chemically-altered mineral is a little surprising as it suggests that physical weathering has been more important than chemical weathering (aided by water) for some long period of time. However, in trenches that Spirit dug with her wheels positive correlations between magnesium, sulphur and other salt components were found with the APXS, in particular in a trench that Spirit dug as she neared the Columbia Hills. Furthermore, sulphur, chlorine and bromine concentrations in the trench soils decoupled from one another as compared with the surface soils, indicative of chemical mobility and separation. Mössbauer observations in the trenches found more oxidized iron than at the surface.

Taken altogether, the basaltic rocks with evidence of some weathering, surrounded by a basaltic regolith with a pattern of alteration of the igneous minerals and transport of soluble materials with depth points to interaction with water. It does not imply standing bodies of water on the surface, nor vast amounts of ground water or hydrothermal action. Rather it points to small quantities of transient water, possibly due to ground ice or even condensation from the atmosphere. Still, the nature of the coatings, and the amounts of salts in the subsurface require more water than is in the present Martian atmosphere to mobilize the soluble sulphur-rich components. Spirit’s evidence in Gusev’s plains supports past conditions that were wetter than modern Mars.
The Columbia Hills are where Spirit’s scientific payoff has really come into its own. Soon after arriving at the Columbia Hills, Spirit found hematite in odd-shaped rocks, one of which was dubbed “Pot-of-Gold”. These rocks appear to be the more resistant remains of water-altered portions of rocks whose unaltered softer parts were eroded away. Following a circuitous route from the base of the hills to reach a suspicious target on the West Spur spotted from below, Spirit found outcrop: the first large patches of rock in place where it formed observed by Spirit were nicknamed ‘Longhorn’, but in-place rock has turned out to be somewhat abundant in the Columbia Hills. These West Spur rocks are rather different from the volcanic rocks on the plains. Some of the rock appears is layered as shown by Pancam images; the layers range from fine, or <1 cm thick, to massive. The nature of the layering remains enigmatic. The layering is such that it could have been deposited in either air or water. Clasts up to several millimeters in size are apparent in MI images that show that these granular rocks are poorly sorted. This poor size-sorting and the large maximum grain sizes indicate deposition in a high-energy environment. A mineral mix that includes basaltic glass best explains mini-TES spectra of these West Spur rocks. Elemental data from the APXS indicate elevated bromine, chlorine, sulphur and phosphorus, which, like on the plains, suggest that liquid water was involved in mobilizing their salts. The Mössbauer observations of these rocks show impressive evidence for weathering, first in the absence of primary igneous minerals, and secondly, and in particular in the outcrop nicknamed “Clovis”, in the form of the hydrated iron oxide mineral goethite. Goethite can only form in the presence of water. The softness of all these West Spur rocks as measured by ease of grinding with the RAT adds to an overall story for the rocks, deposited energetically either by impact or volcanism and then greatly altered by interaction with water, more water than suggested by the evidence from the Gusev plains. Discoveries in the Columbia Hills in the second and third extended missions have continued to expand the different rock types in the hills, have provided further evidence for the alteration of Columbia Hills rocks by water, and have provided evidence for a wider range of Martian crustal chemistry than was known from the Martian SNC meteorites. As she moved from the West Spur onto the northwest flank of Husband Hill, Spirit found a new lithology, typified by rocks dubbed “Wishstone” and “Champagne”. These were also poorly sorted granular rocks, but less oxidized and containing notably high levels of phosphorous. Again, aqueous alteration of explosively emplaced materials may be implicated, but both the primary material and the conditions of alteration are likely to have been different than for the rocks of the West Spur. Further up the northwest flank of Husband Hill Spirit found another rock type in late January 2005. This time the new variety appeared to be in the form of bedrock. “Peace” and “Alligator” rocks define the new type, and are granular rocks, with some finely layering, and apparently composed of sand-sized grains of basalt cemented by large quantities of magnesium sulfate salt. The Peace/Alligator basalt is again different in composition from any previously observed, in particular because of high abundances of olivine and magnetite. The salt abundance at about 20% by mass far exceeded that in any other Gusev rock up to that
point, pointing to either pervasive acid sulfate weathering of the initial basaltic grains, or to evaporation of groundwater or surface water. Spirit reached the summit of Husband Hill on

Spirit reached the summit of Husband Hill on

ascent. The science team will certainly add to that engineering feat by pursuing in the months to come the compounding, subtle, and even contradictory evidence for the role of water in

Mars’ past that is manifest in the rocks of the Columbia Hills.

Figure 4. Opportunity Surface Operations Timeline

3.0 OPPORTUNITY’S ADVENTURES

Opportunity would likely be characterized as the “lucky rover”. From the time of landing until the end of extended mission 2, everything seemingly broke her way. Opportunity followed a similar series of events during its egress period as Spirit, with the small differences of taking only seven days to roll off the lander, and performing a direct forward egress without turning.

3.1 Timeline of Opportunity Events

On the other side of the planet, Opportunity shot a “hole in one” during its landing. The rover rolled into a small crater containing the geologist’s dream – clearly evident outcrops of bedrock. As shown in figure 4, the science team spent two months ensuring that the history of water in Eagle Crater was definitively studied. The only dark cloud on Opportunity’s horizon was the discovery of a stuck-on shoulder joint heater. Powered off automatically during the day by a thermostat in series with the failed switch, the heater was designed to warm up the shoulder joint of the instrument arm to allow movement during the cold Martian nights. The major impact of this anomaly was the consumption of additional power. A plan to work around this problem was developed, which involved putting the entire rover to sleep at night, precluding nighttime telemetry passes with the overhead Mars Orbiters (MGS and Odyssey). This change was implemented later, with our first flight software update on the surface shortly after the end of the prime mission. Before then the rover had already moved on to a real challenge – Endurance Crater.

Endurance Crater was larger than Eagle Crater, about 160 meters wide vice 20 meters. It also was about 20 meters deep, with walls varying from 17 degrees of slope up to sheer overhangs. The slope posed the real problem. The rovers were designed for flat, plains – safe, flat, plains. We knew that in sand, we couldn’t drive once we reached slopes between 10 and 17 degrees, depending on sand grain size and cohesiveness. As usual, the flight team took every risk mitigation action available, choosing to institute a series of tests to validate the rovers’ abilities to successfully climb down, around, and up rocky slopes such as Endurance Crater posed. When the slope traverse envelope was characterized, the team sent Opportunity into the crater and began intensive study of each layer of bedrock exposed by the crater formation event. This exploration occupied the remainder of the Prime Mission and all of Extended Mission 1,
culminating in the close up observations of the heat shield that had protected the lander with Opportunity inside during the supersonic entry into the Martian atmosphere. Opportunity then began a trek south, towards unexplored territory, called “etched terrain” due to its appearance from orbit. During the trek, the rover discovered yet another pitfall of Mars—a section of the rolling dunes where the rover experienced significantly reduced traction and actually dug into the dune past it’s “hubcaps.” It took over five weeks to carefully examine the soil, build a test facility to simulate the dune and the soil, test possible extrication techniques, successfully drive out of “Purgatory” dune and back onto the plain. At that point, the rover, was asked to return to Purgatory and study it in detail. As of this writing, Opportunity has resumed its journey south, through the etched terrain and on to first Erebus crater and, with luck, Victoria crater.

3.2 Opportunity Science Results

Opportunity’s science began with the fulfillment of the MER Athena Science Team’s wildest dreams: not only did she land in view of outcrop, but that outcrop was layered, and upon closer examination, soft and made up of evaporitic minerals. Opportunity had landed right next to rocks that would tell a story of abundant liquid water in Mars’ past, and because those rocks were outcrop, the story they told described events that had happened right where they stood. More generally, Opportunity’s story at Meridiani Planum began with the selection of that landing site. The selection was based upon orbital data from the Thermal Emission Spectrometer (TES) on the Mars Global Surveyor (MGS) spacecraft. The MGS TES data showed only one region of Mars where the surface composition differed in a significant way from the rest of the mostly-basaltic surface. That place was Meridiani Planum where the TES spectra showed crystalline grey hematite covering about 10% of the surface, and hematite is a mineral that, on Earth, commonly forms in the presence of liquid water. Thus, sending Opportunity to Meridiani Planum would test the scientific hypothesis of whether Meridiani’s hematite formed in the presence of liquid water, or was formed by a high-temperature volcanic process.

With the outcrop in her sights, Opportunity’s first order of scientific business was to find the hematite. She wasted no time in that regard, as the mineral was quite apparent in Mini-TES spectra, and was apparently littering the ground all around the landing area, and was even more concentrated outside of Eagle crater in which Opportunity had come to rest. Curiously, where the airbags had pressed the surface, the hematite was missing. The hematite was also very low in the outcrop rock. Closer inspection of the surface regolith inside Eagle revealed a soil-like material littered with small spherules that were dubbed ‘blueberries.’

![Figure 5. Left: Opportunity Mini-TES hematite map where red is high hematite and blue is no hematite. Notice that the blue areas are airbag imprints and that the light-toned outcrop is low in hematite compared to the granular regolith surface. Right: blueberries eroding out of the layered Eagle Crater outcrop.](image)

Experiments with the Mössbauer, pressing its contact plate into the surface showed that the larger, 3-5 mm blueberries and other fragments would disappear if pressed into the surrounding sand-sized (<0.1 mm) materials. Thus the blueberries were quickly postulated to contain at least some of the hematite. That they were made up almost entirely of hematite was demonstrated.
with a side-by-side comparison of a pile of blueberries that had collected inside a small depression in the outcrop with the undecorated rock surface nearby. While the blueberries litter the surface regolith, they do also occur in the outcrop, although filling only about 1% by volume of the rock.

The test of the hematite formation hypothesis required the characterization of the geology of Eagle Crater. Several lines of evidence were joined together to conclude that "Eagle Crater" outcrop was evidence of past liquid water. First, high sulphate, bromine and chlorine, all highly soluble constituents, were detected by the APXS. Second, the Mössbauer found jarosite, an iron sulphate, which has to be a water-emplaced mineral. Third, the Pancam and the MI observed cross-bedding, which requires deposition of the sediments in a moving fluid. The more obvious layering is not enough to identify the deposition of the sedimentary outcrop in water. Fourth, the blueberry morphology observed by Pancam and MI show evidence of being concretions that form by water flow through rock. Fifth, the "blueberries" hematite content is consistent with their being concretions. Sixth, Pancam and MI images show possible vugs or crystal molds, which suggest later re-mineralization of the deposits in the rocks by water, with still later dissolution or erosion. In summary, the Eagle Crater outcrop was found to be water-lain evaporite sedimentary deposits that were, at least in part, laid down in flowing liquid water on the surface of Mars.

With sedimentary rocks exposed in a small crater having produced such a plentiful record of the Martian past, a deeper crater, it was hoped, would provide even deeper understanding. So Opportunity’s scientists set their sights on crossing some 750 m of open, flat plains to get to Endurance Crater. On the way they explored the blueberry strewn basaltic plains; the abundant hematite-rich concretions littering the surface form a lag deposit after erosion of the softer rock materials. Across the plains, Opportunity found an SNC-like volcanic rock called “Bounce Rock”, and imaged the rocks at Anatolia “fracture”. The rocks at 10 m wide Fram Crater proved similar to those in Eagle Crater, extending the minimum areal extent of the water body that deposited these sulphate-rich rocks. Arriving at Endurance itself, Opportunity proceeded to characterize the 150 m crater from different vantage points along the rim and then by driving down inside the crater to examine the stratigraphic section exposed in the crater’s walls.

The rocks in Endurance proved similar to those at Eagle Crater, but with a much thicker stratigraphic column exposed that documents a longer geologic period of standing liquid water on Mars. Descending into Endurance, Opportunity observed subtle variations in chemistry, texture, and color. The most important change was in the chlorine content, which increased with depth into the crater. Other evidence of water-alteration were mineral-filled cracks that decorate rock fractures below the rim of Endurance. The thickness of the stratigraphic column exposed at Endurance allowed for a more complete model of the environment when the sediments were deposited. The outcrop exposures together form a related set of strata that are defined as the Burns formation, which is subdivided into lower, middle and upper units. The three units as a group are at least 7 meters thick that record a “wetting-upward” progression recording the increasing influence of groundwater and then surface water in controlling the depositional processes. The Burns lower unit is interpreted as a dry dune field preserved by a record of large-scale cross-beded sandstones. The Burns middle unit is a planar, finer scale sandstone that was deposited after the dunes of the lower unit had been eroded down to the capillary fringe of the water table. On Earth, a sand sheet like the Burns middle unit could form between elevated dune fields and topographically depressed inter-dune or playa surfaces. The upper unit of the Burns formation is a mixture of sand sheet facies and inter-dune facies. It is in the latter rock facies that the ripples found in Eagle Crater can occur, formed by shallow sub aqueous flows with currents of a few tens of centimeters per seconds. Endurance provided the evidence for a more complete, and a little more complicated history of water at Meridiani Planum, wherein the sub aqueous as well as the eolian deposits of the Burns upper unit were formed with granular materials from an evaporitic source process. Endurance Crater’s evidence reduced the significance of the surface water, but confirmed the large volumes of ground water necessarily flowing through the system to produce the observed evaporitic mineral rocks.

After exiting Endurance Crater on Sol 315, Opportunity drove about 200 meters south, to investigate the vicinity of the heat shield impact. While most of the investigation was of the heat shield itself, Opportunity also made an
bedded strata. The middle unit is the regular finely laminated sandstone in the middle and the upper unit is above the dark band in the top right of the image.

Figure 6. Burns Cliff in Endurance Crater. The lower unit is on the left with cross-bedded strata. The middle unit is the regular finely laminated sandstone in the middle and the upper unit is above the dark band in the top right of the image.

unexpected discovery: a nickel-iron meteorite, about 25 cm across, was found adjacent to the heat shield and subsequently confirmed as the first meteorite discovered on another planet by the APXS and Mössbauer. That the meteorite was found lying loose on the surface, without a clear crater, suggests that significant regolith has eroded since the meteorite fell.

As of this writing, Opportunity has entered the “Etched Terrain”. This is an area that was hoped

Figure 7. Heat Shield rock sitting alone near the impact point of Opportunity’s heat shield is the first meteorite identified on the surface of another planet. It sits on the basaltic sands of Meridiani Planum among the blueberries, having been identified by its high reflectivity in Mini-TES, it’s shiny appearance in Pancam (image shown), its metallic iron in Mössbauer, and it’s iron and nickel composition in APXS spectra.
to offer exposed sections of undisturbed (by craters) layers of the sulphate sediments. After crossing the dune fields, Opportunity has indeed found exposures of Meridiani sediments, but they are flat lying making horizontal correlation of the layers more complicated than hoped. Using Mars’ natural drill holes (craters) still may offer the best access to the stratigraphic column. The most attractive target of all lies just beyond the Etched Terrain: Victoria crater. This 800 meter diameter crater which could expose 30 to 50 meters of strata will be the future of Opportunity’s scientific exploration.

4.0 CONCLUSION

The surface operations of the MER rovers have amazed the world with astounding vistas and a wealth of scientific discovery. People from around the world have followed the chronicles of the twin rovers as they continue their voyages of discovery. This is truly a mission relevant to the full spectrum of the population, from scientists to school children.

One of the keys to the popularity of the rovers is that they are really exploring new territory, in a manner that ordinary people can relate to. As the rovers continue to bring back images of new areas of Mars, people will continue to follow along with their exploits.

The mobility of these rovers was the key to their scientific return. Without the ability to drive, even the return from the Opportunity landing site would have been reduced to remote sensing only. The key in-situ observations would have been out of reach. And the Spirit discoveries at the Columbia Hills would never have been dreamed of.

Headquarters has already approved continued operations of the rovers into September 2006, with every expectation that they will be allowed to continue thereafter – provided the rovers remain healthy and continue to be scientifically productive.

No one can predict the lifetime of these vehicles. The original concern that the solar panels would decrease their electricity production due to being coated in dust has not proven to be a death sentence. The periodic cleaning events (likely wind induced) have kept the solar panels producing at good levels (currently as much for Spirit as on day 6 of the mission). Mechanical parts may wear out in time, or the continued thermal cycles from the 100 degree Celsius day to night temperature difference may cause a catastrophic failure tomorrow. The flight team (engineers and scientists) will continue to do their best to get world-class science from the vehicles every day.

5.0 ACKNOWLEDGMENTS

Successfully landing the twin rovers on Mars, and operating them for the past 18 months was a tremendous scientific and engineering feat. It would not have been possible without the dedicated efforts put forth by the women and men of the Mars Exploration Rover Project, including development and operations; NASA, Jet Propulsion Laboratory, and contractor personnel; engineering teams and science teams. All of the above personnel sacrificed weekends, nights, and holidays to make the original dream in Dr. Adler’s eyes a reality.

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6.0 REFERENCES
