SAO Essay Cover Page

Essay Title Mars Science: Pre- and Post- Rovers

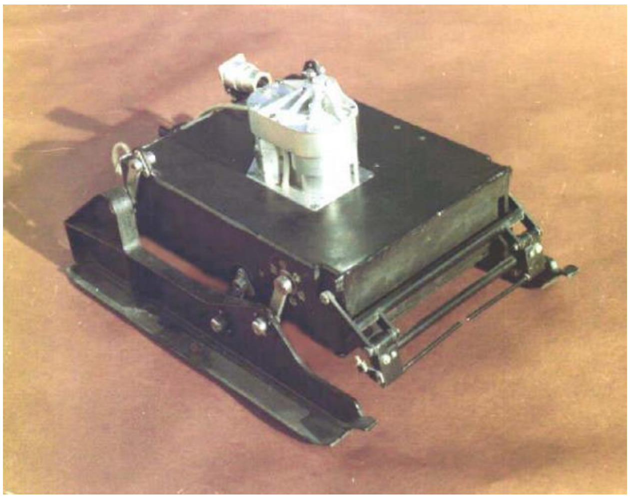

Fig. 1 The first Martian 'rover', PROP-M
Credit: http://nssdc.gsfc.nasa.gov/planetary/image/mars_propm_rover.jpg

Introduction

Recent outcomes of rover missions to Mars should be taken in context as extensions of, and supplements to, previous and existing data from missions to the red planet.

Missions specifically to Mars began with the USSR's failed Marsnik 1 flyby of 1960 (Cornellweb). Subsequent missions such as NASA's early Mariner craft were also designed as flybys to gather pictorial information (Mariner34web), and from the early 70's, probes could be sent to Mars to make studies on a global scale from orbit, the most recent orbiter being NASA's Mars Reconnaissance Orbiter, launched in 2005 to study the history of water on Mars (MROweb). From the mid 70's, probes were also sent to *land* on Mars to conduct experiments, the first success being NASA's Viking 1 in 1975 (Vikingweb).

Although the USSR was first to put a (tethered) 'rover' on Mars in 1971, with a densitometer and penetrometer, (Fig. 1), it failed, so in 1997 aboard Mars Pathfinder, NASA's Sojourner became the first mobile science station to land on Mars (Pathfinderweb). This, and subsequent rover missions, support a huge step forward in planetary science, but since so much of each mission's science overlaps, it's appropriate to compare our pre-, and post- rover results from Mars missions.

Pre-rover Science

NASA built ten small probes in their Mariner series, to fly past the inner terrestrial planets and collect bulk data on those planets. In 1965 Mariner 4 carried a magnetometer to measure magnetic fields; an ionization chamber to measure charged particles; a radiation detector to detect low-energy particles, protons and alpha particles; a solar plasma probe to measure charged particles from the Sun; a cosmic dust detector, and a TV camera. It took the first close-up pictures of another planet, showing impact craters and frost on crater edges (Anderson 1965).

Resultant science from the Mariner 4 mission was largely focussed on 'bulk' specifications, such as re-calculating the radius of Mars to 3,390 Km and commenting on Mars' ellipticity (Bullen 1966), postulation of a magnetic field no more than $3x10^{-4}$ of Earth's (Smith et al 1965), concluding that the age of large craters cannot be the sole source of data for describing erosion on Mars (Hartmann 1966), and disputing claims that cratering on Mars implied our Moon's craters were caused by impacts rather than volcanic activity (McCall, 1966).

In 1969, Mariners 6 and 7 flew over Mars' South Pole and equatorial regions, taking pictures and analysing the atmosphere and surface remotely. They dispelled the myth of artificial canals on Mars, and TV pictures helped the public to understand Mars better (Leighton 1969). With sensors onboard like infrared & ultra-violet spectrometers, radiometers to measure Mars' surface and atmospheric temperatures, radio wave occultation equipment to quantify the lower atmosphere and the Martian ionosphere, and sensors for measurement of General Relativity (WikiMarinerweb), this pair of probes provided even more detail and data on the Martian atmosphere as well as orbital mechanics.

Some science to come out of these voyages includes a suggestion from infrared spectral data, that there was solid Carbon Dioxide in Mars' atmosphere (Herr & Pimental 1970), and establishment of an atmospheric temperature profile (Rasool et al 1970).

Mariner 9 became the first craft inserted into orbit around Mars, lasting a year until 1972. After waiting a month for a global dust storm to settle, it returned pictures of a Martian terrain covered with huge volcanoes, canyons, and old riverbeds – pictures covering every part of Mars' surface. It also sent back images of Mars' two moons Phobos and Deimos (Mariner9web). Data from Mariner 9 was used to do a wide variety of science: surface photos were used to verify a theory of planetary energy distribution (Pines & Shahan 1972), radiometry allowed more accurate calculation of Mars' magnetic field and rotation axis (Lorell 1972), IR spectroscopy gave an insight into Mars' geological differentiation and atmospheric temperature profiles (Hanel et al 1972), and much other work on atmospheric water and oxygen, gravity fields, mapping, celestial mechanics, tectonics etc.

Landers came next, with the first successful US craft to return data from the Martian surface being Viking 1 which landed at the Plains of Gold (Chryse Planitia) in mid 1976. With their flight-partners in orbit and twin landers on Mars, Vikings 1 & 2 carried science tools for biological experiments, chromatography, mass spectrometry, X-Ray spectrometry, seismometry, meteorology, colour photography, as well as equipment to test the physical and magnetic properties of Martian soil and atmosphere. The biological experiments returned inconclusive results about the existence of life, and both landers continued to transmit till the early 80's, thanks in part to their new nuclear power technology (Vikingweb).

Orbiters still have an important role over landers, and NASA's Mars Global Surveyor (1999) and Mars Odyssey (2001) make atmospheric and surface discoveries of the Martian seasons, dynamic weather patterns, active erosion evidence, patchy magnetic field, geochemical makeup, existence of sub-surface water, and moons. 3D maps are built up from altimeter readings, planetary formation theory is fortified with gravity calculations, and information about conditions for other probes is relayed by these orbiting satellites (GlobalSurveyorweb, MarsOdysseyweb).

Two other orbiters are still performing much important science: Mars Express (since 2003) and Mars Reconnaissance Orbiter (since 2005). The former has the mission task of looking for sub-surface water on Mars, and can also detect sub-surface craters, ancient glacial activity, and also is part of the radio transmission network around the planet. The latter has a high resolution camera onboard, and will also contribute to an "interplanetary Internet" (HiRISEweb).

NASA's Phoenix Mars lander arrived at a high 'Arctic' latitude in 2008, and was "…designed to study the history of water and search for complex organic molecules in the ice-rich soil of the Martian arctic…" (Phoenixweb). It is looking at promising locations found by Mars Odyssey, and has a robotic arm for collecting samples which can be pre-heated in small, onboard ovens. Phoenix has a 2m tall mast with camera atop, for high resolution photography of local geology, spectroscopes, and scanners to study the fog, dust and clouds up to an altitude of 20 Km (Phoenixweb).

Rover Science

Delivering mobile science laboratories to the surface of Mars means that geographical exploration and physical interaction with the surface and atmosphere can be undertaken, another step in the extension of human exploration. Mars Pathfinder was the first mission to deliver a roving science laboratory. It was targeted for a rocky flood plain in the Northern Hemisphere where good geological samples could be found. As well as many weather observations, this mission returned billions of bits of information, over 16,500 images from the lander, and 550 images from it's rover named Sojourner. On it's 100m travels, Sojourner covered about 250 m^2 of Martian ground (Darlingweb), made 15 rock/soil analyses for chemical composition, and overall results show Mars to once have had liquid water on it's surface and a warmer, thicker atmosphere (Pathfinderweb).

In the next successful mission to Mars, NASA sent two rovers named Spirit and Opportunity, to opposite sides of the planet. Arriving within weeks of each other in 2004, Spirit landed at Gusev Crater, a large impact crater which may have been flooded in the past, and Opportunity landed in a small, equatorial crater on Meridiani Planum, (SpiritOppweb, UCARGusevweb, UCARMeridianiweb).

The main tools onboard Spirit and Opportunity, which have provided hundreds of thousands of pictures, thousands of spectra, and allowed scientists to formulate theories about how Martian geology developed, are the panoramic camera, a thermal emission spectrometer to take an atmospheric temperature profile, a Mössbauer spectrometer to look at rocks/soils with Iron content, an Alpha particle X-Ray spectrometer to look at elemental rock makeup, magnets to collect particles for analysis by the spectrometers, a camera for high resolution, microscopic close-ups of rocks and soil, and an abrasion tool for grinding away rock surfaces for inspection (MERMissionweb).

A tiny selection of the science provided by rovers shows the diversity of results. Stoker et al (1999) developed 3D virtual reality software to interpret the images sent from Sojourner and thereby resolve millimetre-sized targets on Martian rocks. Allen et al (2001) had emphasised the importance of rovers' landing sites being near hematite, an Iron oxide associated with water deposits and bio-indicators. A 2004 NASA view of Mars is a planet of basaltic rock, with sulphuric acid groundwater which interacts with the rock, dissolving things out of it, which then evaporate, leaving sulphate salts like Magnesium Sulphate, behind, sometimes resulting in sulphate-rich evaporate beds such as those at Meridiani (Spaceweb). Squyres et al (2007) reported on sulphate rich sandstone and bedrock, and wind erosion around Victoria crater, observed by Opportunity, and eroded basalt and silica-rich soils at Home Plate by Spirit, speculating that life may have existed. Geissler et al (2008) were able to take images from Mars Global Surveyor and Mars Reconnaissance Orbiter, combined with images of their own tracks left by Spirit and Opportunity, over two years, and improve our understanding of the wind patterns in different seasons and hemispheres. One of Spirit's wheels jammed four years ago, and dragged across the soil, revealing salts just beneath the surface, which were formed in the presence of water, so scientists think Mars once had lots of water which evaporated and left these salts. The soft, powdery topsoil eventually bogged Spirit which is now a stationary science platform (Spiritvidweb).

Opportunity and Spirit have been on Mars for six years, and have travelled over 20 Km and 7.7 Km respectively (MERMissionweb, MERSpiritweb). The ability to traverse the surface shaped the design of some of the science carried out. For example, studying landing sites, rocks and soils showing potential liquid water chemistry and/or pre-biotic activity as well as the types, morphologies, textures, distributions and chemistry of rocks and soils. Also, as the missions surpassed their expected lifespan, atmospheric telemetry was able to describe the Martian seasons over several years (Starbrightweb).

It's misleading to draw a line between pre-, and post- rover science, because rovers have 'merely' been a refinement of our technology towards being more like a human body. To be able to identify, move to, and manipulate various parts of the environment on Mars is clearly advantageous. But, good, theory-building science is still performed even from Earth bound telescopes, such as Mumma et al (2009) who inferred from IR results from the Keck Observatory, that Methane production was still active on Mars.

From flyby observations which allowed calculations of ephemera and 'bulk' qualities, to, for example, Economou & Pierrehumbert's (2010) most recent use of X-Ray spectrometer ratios of Argon and Carbon Dioxide from the MER rovers, there has been a progression of sophistication over the last 50 years, from basic attempts to get the communications sorted out, to mobile, high quality, on-site investigations by rovers. And while the amount of data and subsequent science that the rovers are responsible for, is staggering, it seems clear that more and more will be learnt about Mars as future missions do more science on more of the red planet.

There's not a huge amount of *scientific* merit in sending humans to Mars, when robotic exploration can achieve so much (Rees 2010). And the overlap with, and refinement of, pre-rover science, shouldn't be neglected when considering the new revelations of rover missions.

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