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COLLEGE

SOJOURNING AND SURVEYING ON MARS

A Lecture by

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Sojourning and surveying on Mars

After an absence of twenty one years, 1997 saw the return of space explorers to the planet Mars. The hiatus was not for the want of trying: since the shut down of the second Viking mission at the end of the 1970s, three spacecraft, two Russian and one American, destined for the Mars system had been tragically lost before they could contribute to the sum of our scientific knowledge. In the meantime however we have been learning much about Mars, benefiting from the fact that Viking had led us to realise that we had twelve samples of martian rock on Earth. Now we have many informed questions to ask about the most Earth-like object we know about in space; not least we require a full enquiry into the controversy whether it once supported life.

To address this and many other problems, NASA has established a programme of flights at two year intervals to cross the fifty million miles or so to our near neighbour. Each time Mars comes close to us (its period is almost exactly twice that of our own planet), during the decade upto 2005, and probably beyond, a mixture of orbiters and landers will make the journey as part of the USA's new policy of launching smaller, faster, cheaper space vehicles. USA is not alone it its ambitions for Mars; Japan has a mission (Planet B) already being built and Europe hopes to get in on the act, in 2003, with the Mars Express orbiting mission, taking along the UK's Beagle 2 to join the flotilla of landers.

The NASA programme is one which has been carefully and sequentially planned. In 1997, a new technology landing feasibility study (Pathfinder) and a global survey for the purpose of choosing future landing sites were implemented; both arrived safely. They will be followed in 1998 by a high latitude lander; in 2001 another technology demonstrator considering environment conditions and the feasibility of making oxygen for propellent from martian raw materials is under construction. It will also carry a Rover which is to collect rock samples for a possible later return to Earth; the year 2003 will see more technology to verify whether a rocket motor, using the locally prepared fuel, can be fired on the martian surface, with a second rover undertaking more sample collection. Then 2005 is the year chosen when a sample return mission will take place; a decision will have to be taken concerning which of the two caches stored in 2001 and 2003 will be selected for transport back to eagerly awaiting Earth based labs. If all goes according to plan by 2015 the programme could culminate with men walking on another body in space some forty odd years after Neil Armstrong's "one small step".

With such an enormous program hinging on the outcome of the Mars Pathfinder and Global Surveyor Missions, it was hardly surprising that the World's Planetary Sciences community held its collective breath on July 4th and again in September 1997. Pathfinder was testing the new concept of 'bouncing' a lander to rest on the Plains of Chryse, whilst the Surveyor would go into orbit by using Mars's thin atmosphere as an aerobrake. Both ideas, which save on the most precious commodity in space travel - fuel - were an unreserved success. The lander made it into its 200x50km target ellipse and, after a minor hiccup when its deflated protecting airbags appeared to have snagged the unloading ramps, its 12kg rover Sojourner rolled out onto Mars. Man's preoccupation with wheeled transport has enabled him to roam around another planetary body to part satisfy, part stimulate, his curiosity. Such was the interest in Pathfinder's success that the Open University's Saturday morning magazine programme Open Saturday captured about 20% of the TV viewing audience - nearly a million viewers checked to see what was happening. That weekend NASA's World Wide Web site recorded a staggering 500 million hits, more than the Olympic Games computer information page during an equivalent period.

Global Surveyor was equally accurate in its rendez-vous with Mars. The objective after the breaking manoeuvre was for an highly elliptical orbit with a period of 45±3 hours; when the spacecraft was recovered, after its communication blackout, it was found to have an orbit taking 44hrs 59mins 34secs. According to the plan the ellipse should have decayed over the next hundred days using the solar power panels as a slowing down mechanism to give a circular two hour orbit passing nearly over the poles so that the orbiter would be capable of totally surveying the planet rotating beneath it. As the orbit precessed, every 88th day, the spacecraft should pass over the same track. Unfortunately due to a problem with the panels the orbit has not decayed as hoped; although Global Surveyor could be slowed further, by a rocket motor burn, there is no necessity to make the correction and NASA are content to wait a little longer for the bulk of the data. Some however have already started to come in; for example laser altimetry has measured the topography and microwave sounding has acquired surface temperature measurements. Most information will infact be gleaned when the spacecraft is close to the planet throughout its orbit; it is envisaged that mapping the surface will be achieved with 1-2 metre resolution.

The new philosophy of smaller, faster, cheaper means that NASA spacecraft no longer are crammed with huge payloads. Each separate mission will have specific tasks to achieve. Although Pathfinder was a technology demonstrator to show the feasibility of high velocity entry, and once down on the surface the possibility of mobility, it also carried a small package of instrumentation: a camera, an atmospheric monitor and a chemical analysis device.

The effectiveness of the new approach can be seen from the data returned by the mission; all told there were: 1.2 Gbits of information, over a period of thirty days, made up of 9669 lander images, 384 rover photographs and 4 million temperature, wind and pressure measurements;

the rover Sojourner travelled 52 metres with 114 course changes to analyse five rocks and six soils. To see what was achieved in more detail we can look at the various experiments.

The atmospheric monitor was active during the decent when it measured temperatures of -175°C at altitudes of 60 to 80 kms. Although these were some 30°C colder than Viking, they were not as low as some meteorologists had expected, leading to the conclusion that Mars was experiencing a brief "heat wave". Once on the surface, temperature was continuously monitored by three thermocouples at 1m, 50 cms and 25 cms above the ground. Over a thirty day period the maxima and minima were very constant. Typically, the mid-afternoon temperature nearest the ground was a balmy 263K (-13°C) whereas just before dawn it fell to a chilly 197K (-76°C). At the top of the mast, it was some eight degrees colder during the day but four degrees warmer at night. Pressure also varied on a diurnal cycle. It was confirmed that the atmosphere is some hundred times less thick than on Earth with an average pressure of 6.7mb, slightly lower in the early evening and just before dawn. This pressure fluctuation could be correlated with winds that at night tend to blow from the south but during the day from the north. The time averaged wind speed was <6m/sec. On the whole Pathfinder did not experience much in the way of weather.

The spacecraft chose to land in the Ares Valley for the specific reason that it might represent a site which had experienced a major flood in the long distant past. Under such circumstances, it could be envisaged that the rock types encountered at the location might be a diverse collection of materials. That the landing station (named Sagan Memorial Station for the famous astronomer and planetary scientist who died early in 1997) had been an area of castastrophic floods and continuous aqueous activity was confirmed by the presence of rocks upto a meter in size covering 16% of the surface area. On a smaller scale the depositional plain is covered with rounded to sub-rounded pebbles, as would be expected from erosional water polishing. Many of the rocks appear to be 'perched' on mounds of soil suggesting a wash-out. Evidence for aeolian activity, stripping away the soil, can be seen from wind tails behind rocks and small dune fields which have been recognised. The rocks themselves are dark grey and almost entirely covered with continuous layers of red dust but underneath appear 'weathered' and possessing a rind. The soil is red in colour, as found by Viking, suggesting severe oxidation of the iron to the ferric valence state. Undisturbed soil in some of the images shows as very dark or even black; whether this is an indication that the oxidation layer is not total is unknown. At least one rock, called Scooby Doo, is bright red and may be an indurated or compacted soil; others show signs of vesicles and could be volcanic.

To learn more about the origin of the rocks and soil, they were subjected to chemical analysis by alpha, proton, x-ray (APX) spectometry. This technique, developed by a group at the Max

Planck Institut fur Chemie at Mainz, involves bombarding mineralogical samples with alpha particle radiation from a Curium-244 source. Three nuclear reactions take place:

alpha → sample → X
alpha → sample → protons
alpha → sample → X radiation

Each of the scattered fluxes has an energy spectrum which is characteristic of the elements in the target and can be measured by an instrument weighing around 500 grams using 300mw of power. APX is a particularly good technique for the major rock forming species and hence is very valuable for making a first guess to identify rock types from a simple mode of study. It is not really the most suitable method for elements heavier than silicon and not especially sensitive to light elements e.g. carbon. Other problems are that the radiation only penetrates a few microns and there is no true mineralogical information. One of the beauties of running APX on Mars is that the signals are of the best quality when the detectors are cooled. Therefore Sojourner's movements were carried out during the day to place the APX against appropriate samples; the data acquisition was carried out with the vehicle parked-up for the night.

The APX instrument analysed the soil at the Pathfinder landing site at six locations. They were found to be almost identical and the results were similar to those obtained twenty years ago by the two Viking missions. Sojourner's APX (unlike Viking's, which could not reach rocks even very close ones) was designed with the specific aim of getting at the rock compositions in the hope that they were representative of many sorts of material brought by water from far away. It was only when the little robot tried to do this that the scientists realised that they had made their first mistake. Actually, it was not so much a mistake, more an oversight. The rocks were coated with fine soil so that the true composition was being hidden because the alpha particles, with their short penetration distance, could not 'see' through the obscuring dust. Here however ingenuity came to the fore; the APX team realised that the soil had a common homogenous composition and because it had been weathered from rocks it was different in composition. The element which was most diagnostic in this respect was sulphur. The soils contained two or three percent sulphur, probably from reaction of SO_3^{2-} containing acid vapours emitted from volcanic vents. A way was conceived to nomalise the soil coating out of the rock results. This was achieved by plotting data for each element against the sulphur content. The information is found to describe a straight line relationship to confirm not only that the idea works, but to afford three other pieces of information (i) that four of the five rocks analysed are of the same composition, (ii) an average compostion for the rock type can be calculated from the intercept at zero concentration sulphur and (iii) one of the rocks Scooby Doo is in fact a soil clod as suggested by the camera observations (it has the end-member composition in a two component mixture).

From the data it is possible to calculate a hypothetical soil-free rock composition of

Element	wt%
MgO	2.0
Al_2O_3	10.6
FIO	12.0
CaO	7.3
SiO_2	62.0
Na_2O	2.6
TiO_2	0.7
K_2O	0.7
	97.9

The nearest rock to the mathematical derived composition had already been named Barnacle Bill and was the first one which the team had investigated.

Such a rock on Earth would be called an andesite, after the place where it is a common component - the Andes. This should not be taken to mean that processes similar to those which formed the Andes (Plate tectonics) are happening on Mars. What it does however say is that perhaps a two stage differentiation process is going on since rocks of high SiO_2 content can only be formed with great difficulty direct from a mantle source.

There is an alternative solution since rocks with high SiO_2 contents on Earth are sometimes sedimentary. An enormous desire exists to locate rocks of sedimentary origin on Mars, because these are formed under water and therefore also contain the detritus of life - fractions of a percent of organic debris deposited and surviving from the death of living organisms. On the basis of the few Pathfinder analyses, no one is yet prepared to stick their necks out and argue for a sedimentary provenance.

In anticipation of sedimentary samples Sojourner's APX can detect carbon in rocks at about the 1% level; one of the aims and hopes of various missions is to find carbon-rich carbonates which ought to be abundant given that the atmosphere of Mars is over 95% carbon dioxide. The search for carbonate or carbon in the rocks by Pathfinder has proven impractical because contact between the APX sensor and the rocks was not good. Thus the atmosphere leaks infront of the detectors and a signal for carbon is obtained from the gas which the instrument can not avoid analysing. All that can be said so far is that Sojourner did not encounter any pure (or very rich) carbonate rocks, since a signal from a 12wt % C (the C content of $CaCO_3$) rock would have undoubtedly have been seen.

Whilst the calculated soil free rock composition argues that SiO_2 rich rocks are common at the Sagan base, it cannot be the only rock type because it is impossible to derive the soil composition from weathering an andesite. The soil is much higher in MgO and FeO, but lower in SiO_2, demonstrating that elsewhere on Mars there is a source of what is called mafic material. It need not necessarily be local because it could be wind blown to the site. Something close to or the equivalent of martian meteorites (which are a deep seated mantle-like rock type) could be the missing component.

Perhaps the most important things that Pathfinder has proved are that it is possible to take instruments to the surface of a planetary body and have them survive the equivalent of being dropped off a ten storey building. With the concept of mobility also demonstrated, for the purposes of exploring and collecting material, the prospects for learning more about Mars and other solid objects in the solar system, during the first years of the new millenium, look rosey. It is very encouraging for scientists taking the lead in the proposal to ESA that the Agency launch a mission dedicated to the search for past life on Mars in 2003. We intend to ensure Britian plays a full role in these exciting events, which Sir Thomas Gresham, with his eye for a chance to trade, would surely endorse.

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