WORKSHOP ON

SPECTROSCOPY OF THE MARTIAN SURFACE: WHAT NEXT?

Held at
Lunar and Planetary Institute, Houston, TX
June 10-11, 1999

Edited by

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R. Clark, P. Lucey, and S. Murchie

Sponsored by

Lunar and Planetary Institute
JPL Mars Program Office

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CONTENTS

INTRODUCTION

Mineralogy is an essential tool to assess environments on Mars that may have been conducive to the support and preservation of life and biomarkers, and reflectance and emission spectroscopy remain the most capable method for remote mineral identification. On June 10 - 11, leaders of the planetary community with expertise in spectroscopy and remote mineral identification met to discuss the state of understanding of Mars surface composition, and to assess what critical gaps may exist in planned spectral measurements of Mars. Participants also discussed what critical gaps may exist in research programs to support investigations of the current and planned data sets, and the proposed Mars airplane. It was felt these issues needed to be addressed, given the shift of the NASA Mars program toward a search for regions conducive to the preservation of biomarkers, and the desire for sample return. This report summarizes our consensus.

To support the selection of landing sites that may preserve biomarkers, participants agreed that the most critical gap that will remain is a spectral data set of Mars that contains very high information content spectra of targeted regions. Experience gained from spectral data sets of Mars and Earth has shown that an unambiguous interpretation requires spectra with both high spatial resolution and very high information content. High information content is obtained by measuring with broad spectral range, high spectral resolution, and high signal to noise ratio. Targeted rather than global coverage will allow the return of this type of data set. The first workshop Letter summarizes the consensus.

Participants also discussed the ability of the community to interpret current and planned spectral data sets. Some participants stated a need for: 1) an expansion of publicly available spectral libraries to include a wider range of materials, such as coatings and poorly crystalline materials, that may be present on Mars; 2) public archiving of data measured under current programs; 3) upgrading the community laboratory facility to measure the full wavelength range of current and planned data sets (0.4 - 50 μm); and 4) testing and evaluation of currently available methods for quantitative spectral analysis, and evaluating similar methods developed by Department of Defense and Intelligence Agencies. The workshop did not have the goal of addressing these issues, and no consensus was reached, but these issues were felt to be of sufficient importance to warrant further discussion. The majority of participants did agree that there is a need for spectral measurements over the full wavelength range of current or planned data sets, and that there is a need for testing of currently available quantitative analysis methods. The second workshop Letter summarizes the majority recommendations.

Selecting among potential landing and sample return sites will be aided by a clear, unambiguous interpretation of spectra measured from orbit. To provide adequate support for the landing site selection process, we recommend the measurement from orbit of high information content spectra of targeted regions, and further discussion of what is needed for supporting laboratory measurements and evaluation of quantitative methods of examining the spectra. This will provide essential tools in the phased approach to Mars exploration that NASA has developed. Additional details on workshop recommendations are contained in the Letters within this report. We strongly encourage NASA and the Mars community to consider these recommendations in planning for future research programs.

HISTORICAL NOTE

This workshop had an unusual breadth of researchers present, and included expertise in spectroscopy of Mars, Earth, and the moon; from the both NASA and the DOD/Intelligence community; and in laboratory spectral research and computational spectral analysis.

However, an interesting historical note was the presence of all three builders of the only thermal infrared spectrometers ever sent to Mars. It is the first, and will perhaps be the only time, that all three have met:

Kenneth C. Herr (1969 Mariner Mars 6/7 Infrared Spectrometer, *IRS*)
Rudolf A. Hanel (1971 Mariner Mars 9 Infrared Interferometer Spectrometer, *IRIS*)
Philip R. Christensen (1997 Global Surveyor Thermal Emission Spectrometer, *TES*)

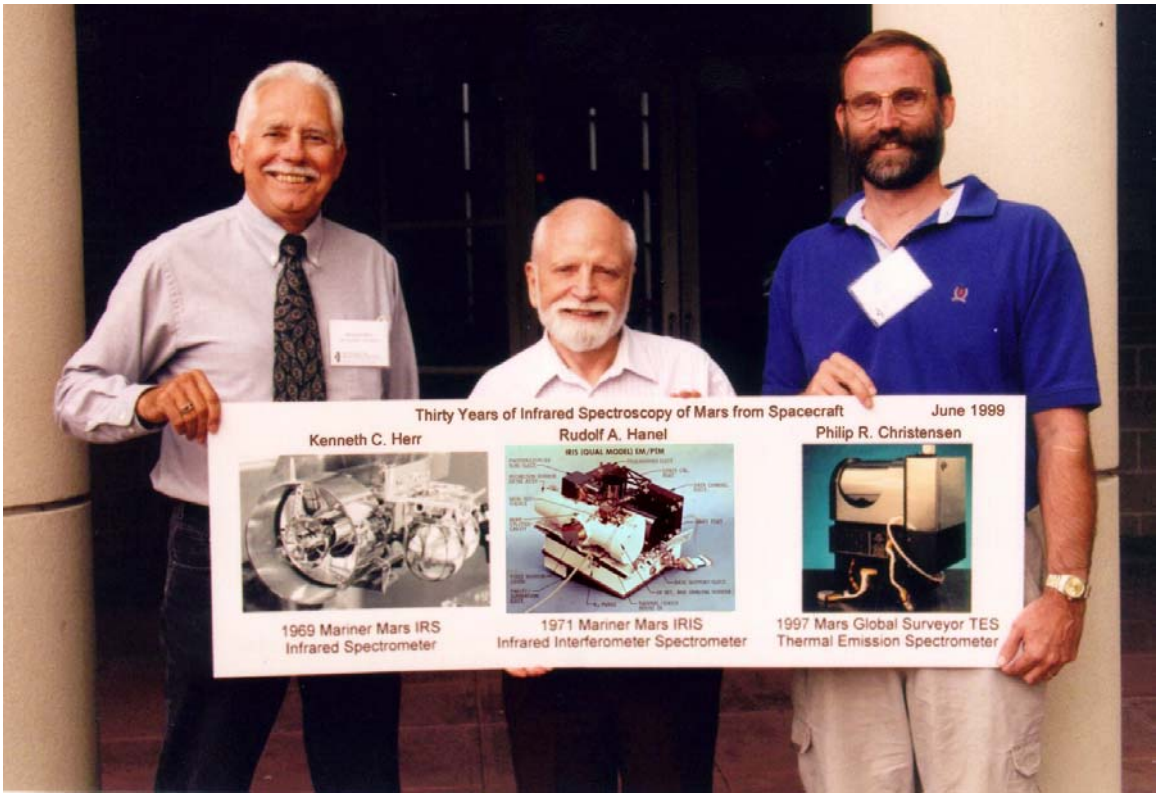

Photo Credit: Debra Rueb, LPI Staff Photographer
Taken during the workshop, at the entry to the LPI

RECOMMENDATIONS: NEXT SPECTRAL DATA SET

Summary Recommendations: High resolution spectroscopy will be of great importance for future Mars exploration and is particularly important for assessing present and past environments in the search for evidence of life. After the successful return of planned data sets, the next orbited instrument should emphasize hyperspectral measurements that:

1) are targeted to regions of interest rather than global.
2) have very high information content (high signal to noise ratio, high spectral resolution, and cover both the reflectance and emission spectral regions).
3) have high spatial resolution.

This information will allow the best opportunity to select the most desirable landing sites for missions focused on life detection and biomarkers.

Background. On June 10 - 11, 1999 the workshop "*Spectroscopy of the Martian Surface: What Next?*" was held at the Lunar and Planetary Institute in Houston, TX. At this workshop, leaders of the science community with expertise in spectroscopy and remote mineral identification met to discuss the state of understanding of Mars surface composition, and to assess what critical gaps may exist after the successful completion of currently planned Mars missions. Participants agreed that the most critical gap that will remain is a spectral data set containing targeted, very high information content measurements to support the selection of landing sites that may preserve biomarkers. This information will enable sample return missions focused on life detection the best opportunity to bring back definitive samples. This letter summarizes the consensus of the participants.

Planned data sets. Should the currently planned instruments complete their objectives, then we feel that the global reconnaissance mapping of Mars will be completed. The Global Surveyor TES will provide global measurements of Mars using emission spectroscopy (6 - 50 μm) at 3 km spatial resolution. This will be complemented in 2001 by multispectral visible and thermal infrared imaging at <100 m/pixel (MARCI and THEMIS). Equally important, the 2003 Mars Express OMEGA will obtain hyperspectral visible and near-infrared imaging (0.4 to 5.0 μm) at 2 km/pixel, filling a critical gap in the type of data available for mineralogical analysis.

Next data set. The next instrument should collect high spatial resolution, high information content spectra of targeted regions. Mineralogy is an essential tool to assess ancient and modern environments on Mars that may have been conducive to the support and preservation of life and biomarkers, and reflectance and emission spectroscopy remain the most capable method for remote mineral identification. It is likely that the global data sets (TES, THEMIS, MARCI, OMEGA) can be used to identify many potential sites for lander science measurements and sample return. Experience gained from spectral data sets of Mars and Earth has shown that an unambiguous interpretation of a complex region requires spectra with both high spatial resolution and very high information content. Such data will be important for selecting the most desirable among the potential landing sites. It will also greatly facilitate traverse planning, and lead to maximal return from landed science and sample return missions.

High information content is obtained by measuring with broad spectral range, high spectral resolution, and most importantly high signal to noise ratio (SNR). Spectral

resolution should be coupled with SNR, so that lower spectral resolution requires higher SNR. The data set should not be global, but should focus on the most promising sites identified from the global data sets. The currently proposed Ariane piggyback micromissions will lack the payload for an instrument capable of making these measurements.

Neither reflectance nor emission spectroscopy alone is sufficient to uniquely determine the full range of minerals that may be present, as each method is sensitive to different physical processes. Together they provide the best capability to identify the surface mineralogy. The broader the spectral range, the less ambiguous the interpretations, and the more technical the justification for selecting a particular landing site.

Accurate interpretations of mineralogy require a strong analytical and laboratory foundation. Although much progress has been made, the program would be considerably strengthened by coordinated testing and integration of analytical approaches; identification and mitigation of gaps in community spectral libraries and facilities; and an explicit means to make existing and future laboratory measurements readily available to the entire community.

On the basis of our extensive experience with laboratory, planetary, and terrestrial spectroscopy, the workshop participants identified the following instrument characteristics required to best determine the minerals present and to best select among potential landing sites:

--Targeted coverage.
--Spectral resolution of <10nm for 0.4 - 2.5 μm region; $\lambda / \lambda\Delta > 250$ for 2.5 - 50 μm.
--SNR >500rms for 30% albedo at 2 μm, and >500 to 1000rms for thermal for 270K.
--Spatial resolution of <100 m/pixel.
--As broad a wavelength range as possible.
--Continuous spectra sampled >1 to 2 measurements per spectral resolution element.
--High quality calibration.

Such an instrument would provide an essential tool in the phased approach to Mars exploration that NASA has developed. We strongly encourage NASA and the Mars community to consider these recommendations in planning for future missions.

Sincerely,
Participants of the workshop, "*Spectroscopy of the Martian Surface: What Next?*"

Jim Bell	Diana Blaney	Phil Christensen	Ben Clark
Roger Clark	Stéphane Erard	Jack Farmer	William Farrand
Rudy Hanel	Gary Hansen	Ken Herr	Eric Keim
Laurel Kirkland	Melissa Lane	Paul Lucey	Richard Morris
Scott Murchie	John Mustard	Carlé Pieters	Jack Salisbury
Steve Saunders	Allan Treiman	Steve Young	

RECOMMENDATIONS: SUPPORTING RESEARCH

Summary Recommendations: Spectroscopic remote sensing of surface composition has been of critical importance to our current understanding of Mars, as well as other planets. Spectroscopy, especially high resolution spectroscopy, will continue to be of great importance for future Mars exploration and is particularly important for assessing present and past environments in the search for evidence of life. There are two areas that need more emphasis by Research and Analysis Programs: 1) Measurement and public archiving of spectra covering the range 0.4 - 50 μm; and 2) Testing of quantitative mineral analysis methods. Participants also felt there should be additional discussion of what materials should be measured, and how the data should be archived.

Background. On June 10 - 11, 1999 the workshop "*Spectroscopy of the Martian Surface: What Next?*" was held at the Lunar and Planetary Institute in Houston, TX. At this workshop, leaders of the planetary community with expertise in spectroscopy and remote mineral identification met to discuss the state of understanding of Mars surface composition, and to assess what critical gaps may exist in planned measurements of Mars and supporting research programs. This letter summarizes our consensus about the supporting research programs.

Knowledge of surface composition is an essential tool to assess ancient and modern environments on Mars that may have been conducive to the support and preservation of life and biomarkers. Reflectance and emission spectroscopy are the most capable method for remote compositional mapping. Participants concluded that there remain several critical needs in the ability of the community in order to reliably interpret current and planned spectral data sets. One is the unavailability of supporting spectral libraries that contain diverse measurements over the entire wavelength range measured by current and planned spectrometers (0.4 - 50 μm). Another is the need to test and compare currently available analytical methods that are used to quantitatively examine remotely sensed spectra.

Laboratory spectra. Two factors are essential for detection and quantification of surface materials: high information content spectra of Mars, and high quality laboratory spectra. Participants concluded that a lack of access by the entire community to measurements over the full wavelength range measured by current and planned spectrometers (0.4 - 50 μm) seriously impedes interpretations. Measurement of diverse materials relevant to active processes and the environment of Mars over the full wavelength range should be encouraged by current Research and Analysis Programs. This community effort will be strongly aided by insuring that there is a community measurement facility capable of measuring the entire 0.4 - 50 μm range. It is essential to the success of this integrated approach that spectral data measured under this program are publicly archived, and that the materials measured are well-characterized.

Quantitative methods. Workshop participants concluded that there is a strong need to test and evaluate currently available identification and unmixing algorithms. An important baseline could be established through blind measurements by different algorithm proponents of prepared samples representing increasing degrees of difficulty.

Participants also felt quantitative methods will be advanced by the development of liaisons to similar research programs, such as those developed by Department of Defense and

Intelligence agencies. One goal should be to test and incorporate knowledge from these other programs into the NASA community, perhaps by inviting them to participate in the blind measurement program.

Additional discussions. Participants concluded there should be additional public discussion of what materials should be measured, and how the data should be archived. Materials discussed included weathering materials and coatings, and poorly crystalline materials that may be present on Mars. The workshop did not have the goal of addressing these issues, and no consensus was reached, but these issues were felt to be of sufficient importance to warrant further discussion.

Recommendations. Selecting among potential landing sites will be aided by measuring targeted, high information content spectra from orbit, followed by clear, unambiguous interpretations of the spectra. Community access to measurements over the full wavelength range covered by current and planned instruments, and the development and testing of quantitative analysis methods will provide the enabling foundation and data analysis tools that are essential to the phased approach to Mars exploration that NASA has developed. We strongly encourage NASA and the Mars community to consider these recommendations in planning for future research programs.

Sincerely,
Participants of the workshop, "*Spectroscopy of the Martian Surface: What Next?*"

Jim Bell	Phil Christensen	Ben Clark	Roger Clark
Stéphane Erard	Jack Farmer	William Farrand	Rudy Hanel
Gary Hansen	Ken Herr	Eric Keim	Laurel Kirkland
Melissa Lane	Paul Lucey	Scott Murchie	John Mustard
Carlé Pieters	Jack Salisbury	Steve Saunders	Allan Treiman
Steve Young			

RECOMMENDATIONS: MARS AIRPLANE

Participants felt that with the successful completion of the currently planned remote sensing instruments (TES on Mars Global Surveyor, THEMIS on Mars '01, and OMEGA on Mars Express '03), the next step for Mars surface spectroscopy is targeted imaging spectroscopy at spatial scales < 100 m.

Participants recognized that the Mars Airplane could act as a science and technology demonstration mission, paving the way for the next generation of observation, provided an appropriate instrument was flown at a good location. This instrument would need to have spatial resolution of a few 10's of meters. The instrument should cover a wavelength range at sufficient spectral resolution ($\lambda / \lambda\Delta > 250$) and signal to noise ratio (>500) to be able to identify specific diagnostic mineral spectral features. High spectral resolution is needed for definitive mineralogic characterization, because the currently planned global survey products will likely be sufficient to identify candidate locations that may contain mineral deposits conducive to preservation of a fossil record. However, a data product capable of prioritizing and characterizing in more detail an interesting site at higher spatial and spectral resolution than is currently planned is of high interest to the community.

While imaging spectroscopy is desirable, a profiling spectrometer taking spectra along the airplane track would also return scientifically useful data, provided it was registered to images. However, a poorly chosen instrument or one flown to a location where the geologic setting would not predict mineralogical variations could be a serious setback in the overall goal of exploring Martian mineralogy at these spatial scales.

Sincerely,
Participants of the workshop, "*Spectroscopy of the Martian Surface: What Next?*"

Jim Bell	Diana Blaney	Phil Christensen	Ben Clark
Roger Clark	Stéphane Erard	Jack Farmer	William Farrand
Rudy Hanel	Gary Hansen	Ken Herr	Eric Keim
Laurel Kirkland	Melissa Lane	Paul Lucey	Richard Morris
Scott Murchie	John Mustard	Carlé Pieters	Jack Salisbury
Steve Saunders	Allan Treiman	Steve Young	

MEETING PROGRAM

* = presenter

Thursday, June 10, 1999
7:45 Registration
8:15 Welcome, Introductory remarks

PRESENTATIONS I
8:30 a.m.
Chair: Carlé Pieters

Format: Each talk is 15-20 minutes, followed by a 15-10 minute discussion/questions period.

Mars program + sample return
8:30 Steve Saunders*, Spectroscopy for Mars Exploration
9:00 Jack Farmer*, Environmental and Mineralogical Controls on Fossilization: Key Elements in a Strategy for Mars Exopaleontology

Past/Current data sets
9:30 Jim Bell*, Fifty Years Of Mars Surface and Atmospheric Composition from Telescopes: Highlights and Implications For Spacecraft Studies
10:00 Ken Herr*, 1969 Mariner Mars Infrared Spectrometer (IRS): Lessons for Future Exploration
10:30 BREAK
10:45 Rudy Hanel*, 1971 Mariner Mars Infrared Interferometer Spectrometer (IRIS)
11:15 John Mustard*, Review of the 1989 ISM Instrument and Results
11:45 Phil Christensen*, Mars Surface Mineralogy and Petrology from 1997 MGS TES Data

LUNCH
12:15

PRESENTATIONS II
1:30 p.m.
Chair: John Salisbury

Format: 15 minute talk + 10 minute questions/discussion. The combined Mini-TES/THEMIS talk is 25 minutes +15 for questions/discussion.

Planned and terrestrial data sets

1:40 Carlé Pieters*, J. F. Mustard, and S. L. Murchie, Aladdin Instruments at Mars
2:05 Phil Christensen*, Overview of the Mini-TES and THEMIS Instruments for the Mars 2001 Surveyor Mission
2:45 Paul Lucey*, A Strategy for Future Mars Spectral Remote Sensing: An Outsider's Opinion
3:10 BREAK

MODERATED PANEL DISCUSSION
3:25 p.m.
Moderator: John Mustard

Format: Each panelist has a 10 minute talk, and 5 minute questions/discussion. Followed by 60 minute discussion.

3:25 Visible/Near-IR: Roger Clark
3:40 Thermal IR: Phil Christensen
3:55 Both: Jack Salisbury
4:10 "Outside the community" spectroscopist: Paul Lucey
4:25 Surface studies: Ben Clark
4:40 Discussion (60 minutes)

GROUP DINNER
6:30
The Italian Café

Friday, June 10, 1999

PRESENTATIONS III
8:15 a.m.
Chair: Allan Treiman

8:15 Introductory remarks.

Format: 15 minute talk, then 10 minute discussion/questions.

8:25 Diana Blaney* and D. Glenar, In Situ Spectrometers for Martian Mineralogy
8:50 Roger Clark* Mapping the Surface Mineralogy of Hydrothermal Alteration Systems: Applications to the Geologic History of Mars and the Search for Past Life
9:15 William Farrand*, Sub-pixel Detection and Mapping of Spectrally Unique Materials on Mars using ISM Data
9:40 Gary Hansen*, Remote Sensing Spectroscopy of the Polar Regions of Mars
10:05 BREAK
10:20 Eric Keim*, The SEBASS Hyperspectral Imaging Spectrograph: Instrument Description and Sample Thermal Images Obtained Near Flagstaff, Arizona and Mesquite, Nevada (15 minutes + 5 for questions)
10:40 Steve Young*, Use of Thermal Hyperspectral Imagery in Terrestrial Surface Characterization (15 minutes + 5 for questions)

LUNCH (brought in)
11:00

WORKSHOP REPORT MODERATED DISCUSSION
11:45 p.m.
Moderator: Paul Lucey

11:45 Discussion

The discussion will begin with any major issues left unresolved from the panel discussion, and then will address submitted questions.

ADJOURN
2:45

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