Combined SWIR and LWIR Mineral Mapping Using MASTER/ASTER

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Abstract—This research uses multispectral short-wave-infrared (SWIR) and long-wave-infrared (LWIR) remote sensing to map mineralogy associated with hot springs and epithermal mineral deposits. Selected sites around the world covering a range of active/inactive hot springs and deposit types are being studied using the MODIS/ASTER airborne simulator (MASTER) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). MASTER and ASTER data analysis contribute to mineral mapping in the VNIR/SWIR, however, their main contribution is improved mapping of siliceous sinter utilizing LWIR signatures. Integrated study using these VNIR/SWIR/LWIR remote sensing datasets is in progress.

I. Introduction

There are thousands of active hot springs around the world occurring predominantly in association with volcanically active areas. Because these areas exhibit high variability in rock composition and available surface water, a wide range of surface materials occur. Active hot springs systems (and by inference, inactive and fossil systems), can be simplistically divided into three general types based on water chemistry and the types of mineral deposits formed[1]. These are 1) alkaline, siliceous-sinter- dominated systems, 2) travertine carbonate dominated systems, and 3) acid sulfate systems. Mixed types are also common within individual hot springs systems, indicating subsurface mixtures of different waters.

ASTER and MASTER provide unique combined SWIR and LWIR multispectral data that deliver new views of these deposits. Selected examples demonstrating MASTER/ASTER analysis and mineral mapping are presented here.

II. Master

The MODIS/ASTER airborne simulator (MASTER) instrument was developed by NASA Ames Research Center in conjunction with the Jet Propulsion Laboratory. Its purpose is to collect ASTER-like and MODIS-like data sets in support of NASA's Terra satellite launched in December 1999 as part of NASA's Earth Observing System (EOS)[2]. MASTER has 50 spectral bands covering the approximately 0.46–12.9 μm range, including 14 bands in the SWIR (~1.0–2.5 μm) and 10 bands in the LWIR (~8–14 μm). MASTER's spatial resolution ranges from approximately 4 – 50m depending on aircraft platform and flight altitude. MASTER data were acquired in support of this project for various sites in the USA during 1999[3]. Additional MASTER data were acquired for sites in New Zealand during August 2000 as part of the NASA PACRIM II campaign[4].

III. Aster

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), one of the principal instruments on Terra, covers the approximately 0.55 – 11.3 μm range (4 VNIR bands, 6 SWIR bands, and 5 LWIR bands) [5, 6]. ASTER spatial resolution is 15m (VNIR), 30m (SWIR), and 90m (LWIR). ASTER Level 1B archive data acquired for selected sites during 2000 and 2001 and available from the U.S. Geological Survey were used for this study.

IV. Methods

The same procedures were followed for processing and analysis of both the MASTER and ASTER data. Data were first split into the VNIR-SWIR and LWIR spectral ranges. VNIR-SWIR data were converted to apparent reflectance using the commercially available "ACORN" atmospheric correction software[7] and the appropriate instrument spectral response curves[8, 9]. LWIR data were atmospherically corrected using the "ISACS" approach[10] and then converted to temperature and emissivity using the normalized emissivity method[11].

Standardized analysis methods developed by Analytical Imaging and Geophysics LLC (AIG) for hyperspectral data were used to analyze each multispectral dataset[12]. These include 1) linear transformation of either the reflectance data (VNIR/SWIR) or emissivity data (LWIR) to minimize noise and determine data dimensionality[13, 14], 2) location of the most spectrally pure pixels[14], 3) extraction of endmember spectra[14], and 4) spatial mapping of specific image spectral endmembers[15]. These methods derive the maximum information from the data themselves, minimizing the reliance on *a priori* or outside information. Many of these methods are incorporated in the commercial software package "ENVI™".

V. RESULTS

Analysis of the SWIR MASTER/ASTER data allow mapping of characteristic minerals associated with hot springs/mineral deposits, including carbonate, kaolinite, alunite, buddingtonite, muscovite, and hydrothermal silica. Mineral identification and the general distribution of specific minerals were verified utilizing ground spectral measurements and mineral maps produced from AVIRIS hyperspectral data[16]. Selected SWIR spectra are shown in Figures 1 and 2.

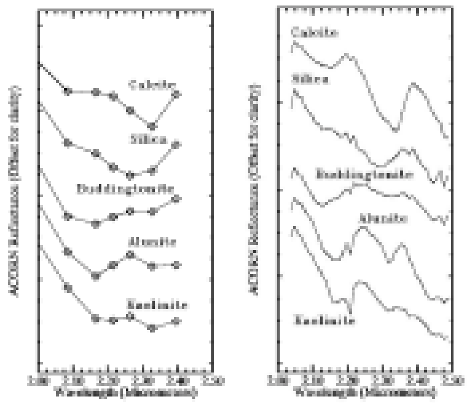

Figure 1: Selected MASTER SWIR mineral spectra (left) compared to AVIRIS mineral spectra (right), Cuprite, Nevada.

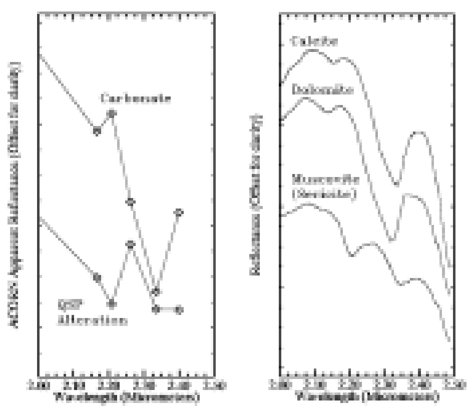

Figure 2: Selected ASTER SWIR mineral spectra (left) compared to AVIRIS mineral spectra (right), N. Death Valley, CA.

Note that MASTER/ASTER SWIR spectra don't fully resolve the SWIR molecular absorption features present for these minerals, however, the bands are adequately positioned to determine general shape and feature differences that allow identification of some important minerals. There may be some confusion using MASTER/ASTER between minerals that are distinctly separated using AVIRIS, particularly when mixtures occur (eg: calcite, dolomite; kaolinite, alunite, buddingtonite)[16].

MASTER and ASTER LWIR spectral signatures principally allow improved mapping of the distribution of siliceous sinter and alteration associated with these deposits. Figure 3a shows a comparison of a MASTER spectrum for the silica cap at Cuprite, Nevada to a laboratory quartz spectrum[17]. Figure 3b shows LWIR emissivity spectra for the same Cuprite, NV endmembers shown in Figure 1.

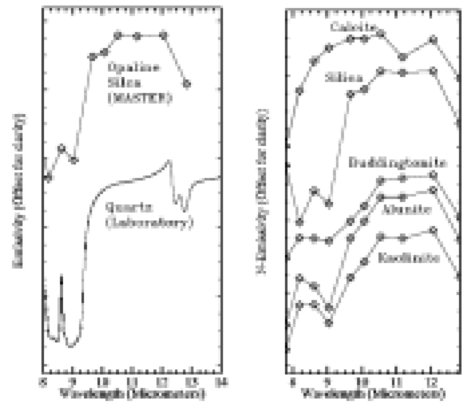

Figure 3: A. Comparison of opaline silica MASTER emissivity signature from Cuprite, NV to laboratory spectrum of quartz. B. LWIR spectra for Cuprite SWIR endmembers.

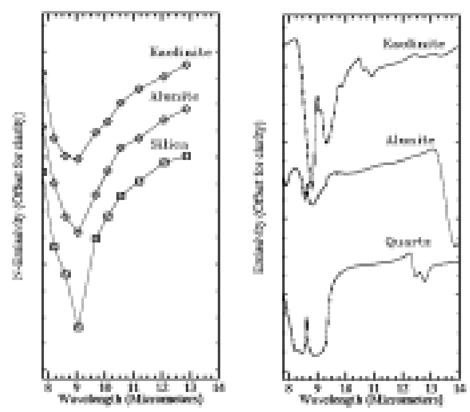

Figure 4: Comparison of MASTER emissivity spectra for Steamboat Springs, NV (left) versus mineral library spectra. (right).

At Steamboat Springs, Nevada, extraction of mean MASTER LWIR spectra for areas of known mineralogy[3] shows that there are only very small differences between the emissivity spectra (Figure 4). These spectra principally exhibit spectral features near 9.0 μm characteristic of silica and these areas were observed in the field to be silicified in addition to having the alteration minerals kaolinite and alunite present. There is no clear indication of mineralogy other than silica. At a site in northern Death Valley, CA[14], ASTER emissivity spectra demonstrate the separability of silicification (Quartz-Sericite-Pyrite [QSP] alteration) and limestone (calcite)(Figure 5).

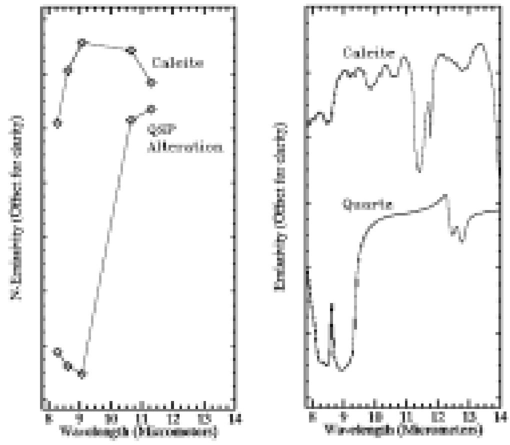

Figure 5: Comparison of ASTER emissivity spectra for northern Death Valley, CA (left) versus mineral library spectra. (right).

VI. CONCLUSIONS

SWIR spectral signatures and mineral maps derived from MASTER and ASTER data generally agree with those extracted from higher spectral resolution hyperspectral data, thus validating the multispectral instruments' performances. Analysis of the SWIR MASTER/ASTER data allow mapping of characteristic minerals associated with hot springs/mineral deposits, including carbonates, kaolinite, alunite, buddingtonite, muscovite, and hydrothermal silica. Mineral identification and distribution was verified utilizing ground spectral measurements and mineral maps produced from AVIRIS hyperspectral data. LWIR spectral signatures principally allowed improved mapping of the distribution of siliceous sinter associated with these deposits. Integrated analysis of the MASTER/ASTER data using both the SWIR and LWIR spectral data is in progress with the goal of refining maps showing the distribution of key minerals associated with active and fossil hot springs and epithermal mineral deposits.

VII. ACKNOWLEDGMENTS

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VIII. REFERENCES

1] White, D. E., 1981, Active Geothermal Systems and Hydrothermal Ore Deposits. *Econ Geol. 75th Ann. Vol*: p. 392-423.

2] Hook, S. J., Myers, J.J., Thome, K.J., Fitzgerald, M., and Kahle, A. B., 2001, The MODIS/ASTER airborne simulator (MASTER) – a new instrument for earth science studies: *Rem Sens. Env*., v. 76, p. 93-102.

3] Kruse, F. A., 2000, Mapping Active and Fossil Hot Springs Systems Using AVIRIS, HYMAP, TIMS and MASTER (Abst): in *Proceedings, 14th Thematic Conference, Applied Geologic Remote Sensing*, ERIM, Ann Arbor, MI, p. 122.

4] Milne, T., and Tapley, I., 2002, A Decade of PacRim with AIRSAR: Science and Applications: in *Proceedings JPL AIRSAR Workshop*, JPL, Pasadena, CA (in press)

5] Yamaguchi, Y., Kahle, A. B., Tsu, H., Kawakami, T., and Pniel, M., 1998, Overview of advanced spaceborne thermal emission reflectance radiometer: *IEEE TGARS*, v. 36, p. 1062 – 1071.

6] ERSDAC, 2001, *ASTER User's Guide, Part I, General (ver 3.1)*, March 2001, ERSDAC, 101 p.

7] AIG, 2001, *ACORN User's Guide, Stand Alone Version:* Analytical Imaging and Geophysics *LLC*, 64 p.

8] JPL, 2002, ASTER spectral response curves available at *http://asterweb.jpl.nasa.gov/instrument/character.htm*.

9] JPL, 2002, MASTER spectral response curves available at *ftp://asapdata.arc.nasa.gov/master/srf/*

10] Johnson, B.R., 1998, In-scene Atmospheric Compensation: Application to SEBASS Data Collected at the ARM Site. *Part I Technical Report, Space and Environment Technology Center*, The Aerospace Corporation, May, 1998.

11] Hook, S. J., Gabell, A. R., Green, A. A., and P. S. Kealy, 1992. A Comparison of Techniques for Extracting Emissivity Information from Thermal Infrared Data for Geologic Studies. *Rem. Sens. Env.*, vol. 42, pp.123-135.

12] Kruse, F. A., and Boardman, J. W., 2000, Characterization and Mapping of Kimberlites and Related Diatremes Using Hyperspectral Remote Sensing: in *Proceedings, 2000 IEEE AeroSpace Conference*.

13] Green, A. A., Berman, M., Switzer, B., and Craig, M. D., 1988, A transformation for ordering multispectral data in terms of image quality with implications for noise removal: *IEEE TGARS*, v. 26, no. 1, p. 65 - 74.

14] Boardman J. W., and Kruse, F. A., 1994, Automated spectral analysis: A geologic example using AVIRIS data, north Grapevine Mountains, Nevada: in *Proceedings, Tenth Thematic Conference on Geologic Remote Sensing*, ERIM, Ann Arbor, MI, p. I-407 - I-418.

15] Boardman, J. W., 1998, Leveraging the high dimensionality of AVIRIS data for improved sub-pixel target unmixing and rejection of false positives: mixture tuned matched filtering, in: *Summaries of the Seventh Annual JPL Airborne Geoscience Workshop*, Pasadena, CA, p. 55.

16] Kruse, F. A., Boardman, J. W., and Huntington, J. F., 2002, Comparison of Airborne and Satellite Hyperspectral Data for Geologic Mapping: in Proceedings, SPIE International Symposium on AeroSense, 1-5 April 2002, Orlando, FL (in press).

17] Salisbury, J. W., Walter, L. S., Vergo, N., and D'Aria, D. M., 1991b, Infrared (2.1- 25 micrometers) *Spectra of Minerals*: Johns Hopkins University Press, 294 p.