Final Report: Year Four of Four (March 2003 - August 2004)
Monitoring the Hazards of Silicic Volcanoes with Remote Sensing
Grant Number: NAG5-9070 (ASU PVA6597/TE)

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I. Background

This report details the final progress on the Solid Earth and Natural Hazards project: *Monitoring of Hazards of Silicic Volcanoes with Remote Sensing (SENH99-0000-0159).* The original award went to Arizona State University (ASU) with Dr. Jonathan Fink as the P.I. and Dr. Michael Ramsey as the Co-I. In May 2000, Dr. Ramsey left ASU to take a tenure-track faculty position at the University of Pittsburgh. The principle investigators and NASA Headquarters agreed to split the grant award at the HQ level and therefore avoid the double overhead charges that would arise from a university subcontract. The objectives of the science were divided, and coordinated yearly progress reports have been submitted from each University. **This report details the final progress on work carried out at Arizona State.** A report by Dr. Ramsey at the University of Pittsburgh has already been submitted. The work from both institutions is closely related and this report will reflect that connection.

Of the original proposed tasks, Arizona State University spent the final award years completing work related to the mapping of petrologic variations in silicic lavas and data fusion techniques. Methods developed for this research are being refined for use in hazard monitoring and assessment of active domes and lavas. Situations like the recent dome eruptions at Mt. St. Helens and Montserrat Volcano have demonstrated how remote sensing can be used as an important monitoring tool. Measuring volatile content is particularly important for understanding the potential explosivity of an erupting silicic volcano. Higher volatile contents, as determined from remote observations, can signal a more hazardous lava dome or flow. Previous research has shown that mapping surface textures combined with knowledge of composition and crystal content, can serve as a good indicator of a system's volatile content, and subsequently its potential for explosive activity. For this project, an overarching goal at ASU has been to develop robust methods for fully characterizing surface texture, composition, and crystallinity on active volcanoes using remotely sensed data. In conjunction with work done by Dr. Ramsey's group at University of Pittsburgh we were able to accomplish this goal.

At Arizona State, this SENH grant has partially funded one of the primary investigators (Fink), a post-doctoral researcher (Wessels) for ~20% of his salary (for two years), and a graduate student researcher (Eisinger) for ~60% of his salary. Additionally some funding has been allocated to a graduate student (Kuhn) at the University of Pittsburgh. ASU publications resulting from this work include a book chapter, one thesis, and four conference abstracts. Two papers are still in preparation.

II. Results

Of five theme areas originally proposed, three have been the focus of ASU efforts:

(1) Mapping Petrologic Variations in Domes (shared with University of Pittsburgh)
(2) SAR Applications
(3) Data Fusion

1. Mapping Petrologic Variations in Domes

An important goal of this project was to understand how thermal infrared imagery can be used to discriminate compositional variations in glassy rhyolites for hazard assessment of active silicic domes and lavas. Using spectral data from the airborne MODIS ASTER simulator (MASTER) and the space-borne ASTER sensor, Chris Eisinger attempted to characterize the phenocryst content of glassy lavas for the compositionally zoned Glass Mountain flow at Medicine Lake Volcano in northern California (Figure 1). This was only possible after a thorough laboratory study of thermal infrared spectra for numerous high silica glassy lavas and the application of a linear deconvolution model (Ramsey and Fink, 1999). Key results show that (1) characterizing the nature of glassy lavas is critical for interpreting spectral features, (2) thermal infrared spectroscopy appears to be an especially sensitive method for determining the microcrystalline nature of a glassy lava, (3) phenocryst end-member deconvolutions may serve as an effective proxy for evaluating bulk silica composition from laboratory spectra (Figure 2), and that (4) bulk chemical differentiation of in-situ glassy lavas is a possibility if high spectral and spatial resolution thermal infrared sensors are available. Unfortunately, MASTER and ASTER image data have a low spectral resolution, and this severely limits the deconvolution accuracy for composition of rhyolite glasses. Qualitatively, deconvolved images from these sensors provide useful information. For example, mixing patterns on the Glass Mountain flow (Figure 1) clearly show fingers of a less silica rich lava that erupted simultaneously or prior to the more dominant rhyolite.

Eisinger completed his M.S. thesis and graduated in August, 2002. A publication from his work is still in preparation. At the University of Pittsburgh, more recent work exploring how the addition of phenocrysts affects vesicularity estimations was completed by Ramsey/Kuhn (Kuhn, 2003). Mapping vesicularity and composition (in conjunction with temperature and block size), has provided nearly every major parameter needed for monitoring and modeling volcanic dome eruptions.

2. SAR Applications

Lava surface textures were evaluated using SIR-C/XSAR, AIRSAR, ERS data, and small-scale (cm) terrain measurements. Measurements taken of flow surfaces at Unzen Volcano in Japan, the Inyo domes, and Medicine Lake Volcano helped to constrain different instrument responses to a variety of silicic dome and flow surface textures. Notably, patterns recognizable in SIR-C/XSAR data were not as apparent in the higher spatial resolution AIRSAR data. Block size distributions measured using a Laser Range Finder/GPS system for this project, along with observations by Anderson and others (1998) are not readily apparent in any of the AIRSAR bands over the Inyo Domes. For example, the coarsely vesicular pumice (CVP) areas mapped on Obsidian dome tend to lie in areas of lower backscatter in the P-band, but bright returns occur almost randomly over the image. These abundant bright areas are most likely caused by large blocks that act as 'corner reflectors' at the radar scale. This effect is also present at Medicine Lake, but the higher degree of vesicularity within those lava flows attenuates the signal, especially over coarsely vesicular areas.

Our analysis of SAR data over silicic domes and flows has shown that high resolution multiwavelength, cross-polarized might often distinguish the coarsest lava textures from the smoothest portions. However, the TIR texture extraction does a better job of differentiating over a wide range of mm-scale textural features. Therefore multicomponent SAR data, combined with TIR derived texture and chemistry maps, should provide an enhanced method for monitoring active lava domes and flows using satellite-based sensors such as ASTER.

3. Data Fusion

In order to accurately detect chemical, textural, or thermal variations on active lava surfaces using TIR bands, it is critical to have accurate co-registration of images over the extremely rough terrain of silicic volcanoes. Locating sub-pixel vesicularity variations or thermal anomalies, for example, is an important concern when monitoring an active dome surface with the 90m TIR bands of ASTER. For high spatial resolution data from the MASTER instrument, for example, topography induced geometric distortions were also a problem. By using highly detailed DEMs, such as 10m TOPSAR or 1 to 2m stereo-pair derived data, we found that we could successfully coregister unique datasets (Figure 3). Further, a GPS based Laser Range Finder combined with high resolution DEMs and ortho-rectified aerial photographs can be used to adequately fuse SAR and optical data for spectral comparisons of different surface materials.

III. Summary

In conjunction with efforts at the University of Pittsburgh, this SENH research project has produced a dozen publications and assisted three graduate students in the successful completion of their degrees. For Arizona State, work was primarily on non-active volcanic features using airborne thermal imagery and SAR data acquired over Medicine Lake Volcano (CA), Inyo Domes (CA), and Unzen Volcano (Japan). Our work in petrologic mapping and data fusion techniques using these data sets established some important guidelines utilizing satellite based ASTER images to monitor hazardous active volcanoes such as Soufrière Hills, Montserrat and Bezymianny, Russia. While it has been a challenge to maintain the project focus having a physical separation of scientists, none of the original elements of research were sacrificed and the proposal funding has been fully utilized to meet most of the original objectives while adding new objectives and results. The research made possible by this award has formed the foundation for new NASA and NSF projects by Dr. Ramsey at the University of Pittsburgh.

IV. Presentations and Publications

1. *Books:*

Mouginis-Mark, P.J., Crisp, J.A. and Fink, J.H. 2000. Remote sensing of active volcanoes. *American Geophysical Union Monograph 116.*

2. *Publications:*

Wessels, R.L. and M.S. Ramsey, Multi-sensor/multi-wavelength data fusion over steep volcanic terrain: Analysis challenges in the next era of remote sensing, *Rem. Sens. Environ. (in prep)*, 2005.

Eisinger, C., Ramsey, M., and Fink, J., Characterizing the Composition of Glass Mountain, California, using Infrared Remote Sensing, *Bull. Volc. (in prep)*, 2005.

3. *Thesis:*

Eisinger, C., Characterizing the composition of silicic lavas using infrared remote sensing, *Arizona State University*, 57 pp., 2002.

4. *Abstracts:*

Eisinger, C.L., M.S. Ramsey, R.L. Wessels and J.H. Fink, Discriminating Compositional Variations on the Silicic Domes of Medicine Lake Volcano, CA, with the New Airborne Hyperspectral MODIS/ASTER Simulator, in *Abstr. of the Gen. Assembly IAVCEI*, p. 158, 2000.

Eisinger, C., J. Fink and M.S. Ramsey, Determining Crystal Abundance in Glassy Lavas: Combining Laboratory Infrared Spectroscopy With Remote Sensing, *Am. Geophys. Union Fall Meeting (abs. P72A-0484),* 2002.

Fink, J.H., Anderson, S.W., 2004. Mount St. Helens lava domes, then and now, *EOS Trans. Amer. Geophys. Un. 85 (47)*, Fall Meet. Suppl., Abstract V53D-08A.

Ramsey, M.S. and J.H. Fink, Hazard Mitigation Associated with Silicic Dome Emplacement: Monitoring Surface Textural Variations Using Remote Sensing, in *Abstr. of the Gen. Assembly IAVCEI*, p. 234, 2000.

Wessels, R. and M.S. Ramsey, Multi-sensor/Multi-wavelength Data Fusion Over Steep Volcanic Terrain: Analysis Challenges in the Next Era of Remote Sensing, *Am. Geophys. Union EOS Transactions*, 81:48, p. F1255, 2000.

Glass Abundance **Phenocryst Abundance (Plag + Opx)**

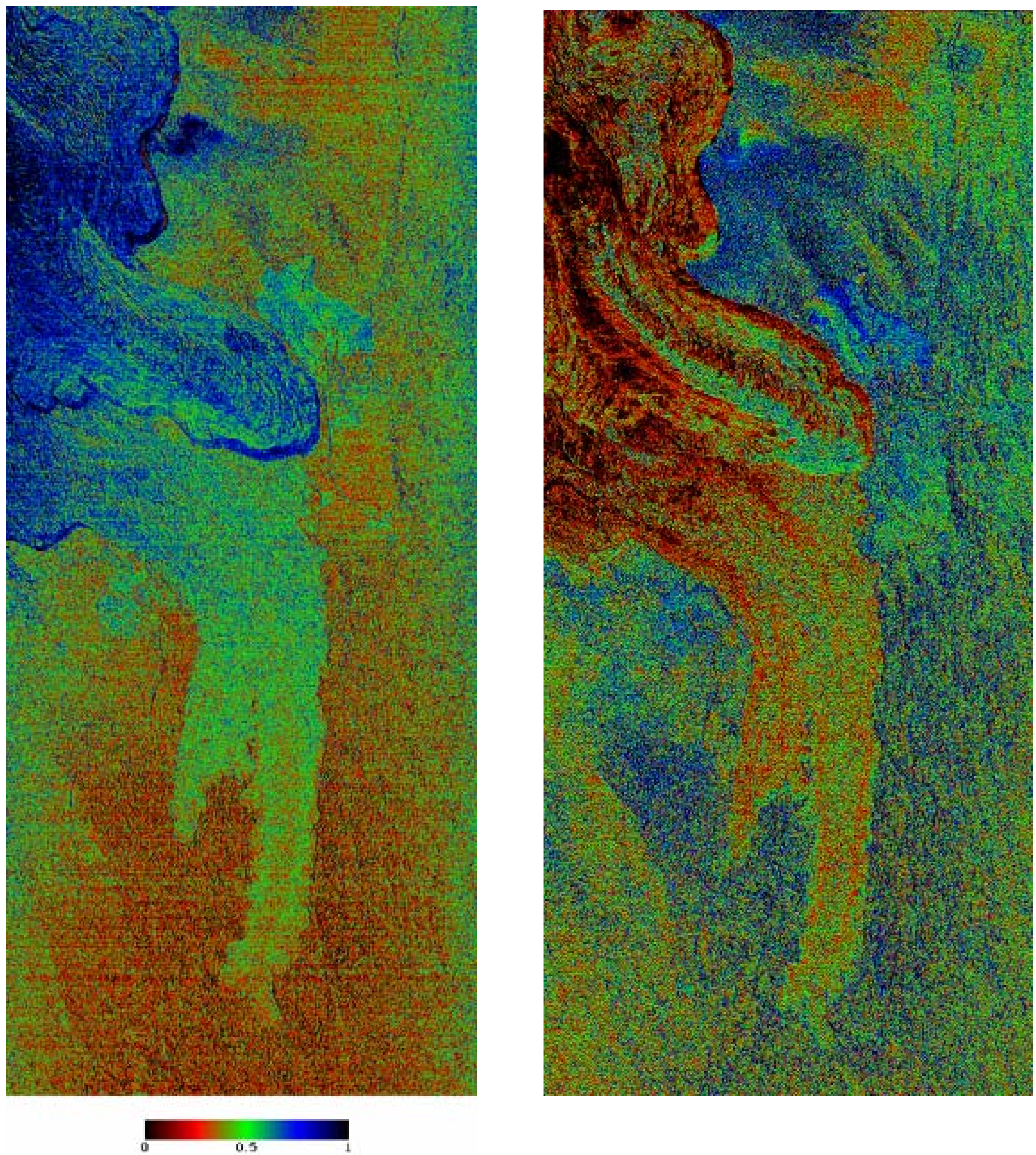
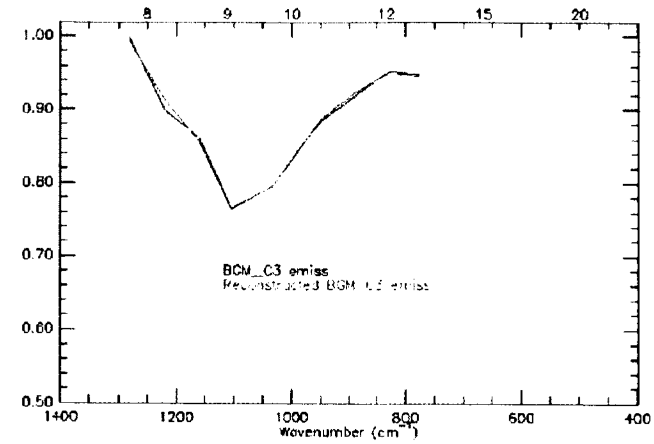


Figure 1. Abundance images using mineral endmembers. A color scale has been applied to highlight variations. Phenocryst abundance image (on right) is a sum of modeled plagioclase and orthopyroxene.

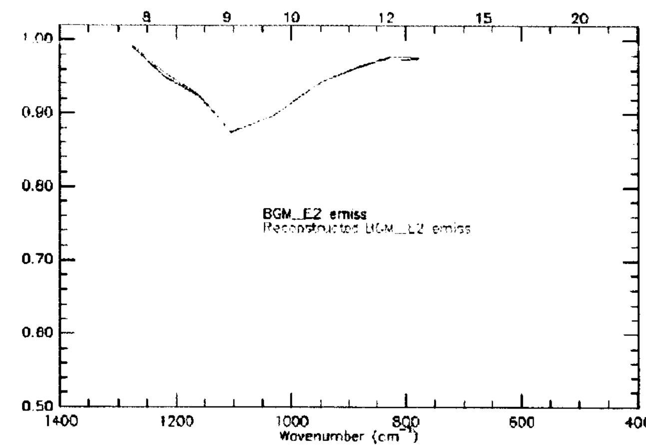
Sample	Modeled Endmember Abundances (Normalized) %

C3
Glassy Obsidian
SiO_2 - 74.23%



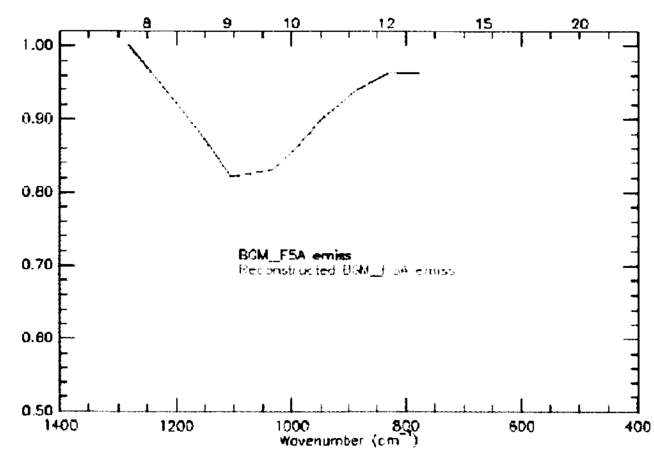
Rhyolite Glass - 97.4
Plagioclase - 2.4

E2
CVP
SiO_2 - 70.05%



Rhyolite Glass - 85.2
Plagioclase - 9.5
Orthopyroxene - 4.8

F5A
Dacite
SiO_2 - 66.96%



Rhyolite Glass - 52.8
Plagioclase - 41.6
Orthopyroxene - 6.1

Figure 2. Laboratory emission spectra of three Glass Mountain samples degraded to the resolution of the MASTER thermal channels and then deconvolved. Bulk SiO_2 values obtained through XRF. Modeled spectra are shown in grey.

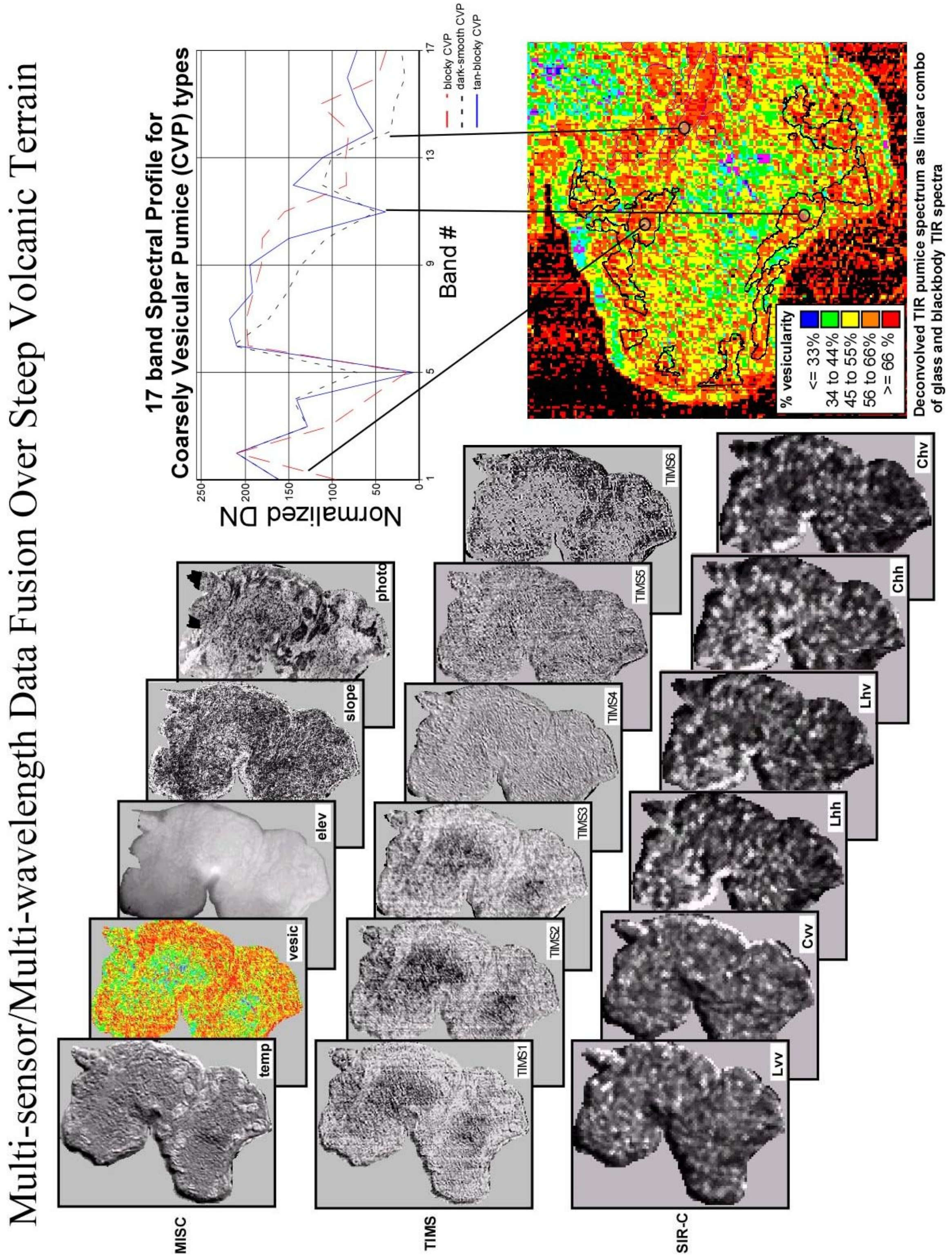


Figure 3. Sixteen images of Crater Glass Flow (CGF) georectified and stacked into one data set. Resultant merged spectra is show for several texture types on CGF. Each image area is one kilometer wide.