HyVista CORPORATION

AIRBORNE HYPERSPECTRAL REMOTE SENSING

HyMap SURVEY PROCESSING REPORT

Glass Buttes
Oregon

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Disclaimer: No warranty is given for the accuracy or of any of the products or statements made regarding the HyMap data or derived results, however all processing was done to the best of the author's knowledge.

Executive Summary

HyVista Corporation conducted an airborne hyperspectral scanner imagery, for Oramat INC, over an area in Oregon termed Glass Buttes on the 19 August 2009.

This report describes the processing that has been applied to the HyMap data to produce a number of image products including overview colour composites, decorrelation colour composites, minimum noise fraction (MNF) colour composites, and unmixed end-member mineral map. To produce these products the data first has various processes applied to it that converts the raw data into reflectance imagery which is then geometrically corrected and radiometrically levelled so that seamless image mosaics are produced.

Three (3) "Classes" of imagery have been produced:

1. Overview colour composites and MNF images can be used for photo-interpretation to delineate geological units and structural features. They do not provide information on the mineralogy of geological formations i.e. the same colour may map different rock types in these images.

2. The decorrelation stretch colour composites are derived from selected SWIR and VNIR bands and produce images that map the overall distribution absorption features that characterise Si-OH, Al-OH and iron oxide bearing minerals within the area but not specific mineral species.

3. Specific species mineralogical information is extracted by applying end-member un-mixing processing to the reflectance image mosaic. This requires several procedures that are carried out separately on the Short Wave Infrared bands (SWIR: 2.00 microns to 2.43 microns) and the Visible Near Infrared bands (VNIR: 0.488 microns to 1.12 microns). Processing of the SWIR bands can map the distribution OH bearing minerals (clays, micas, chlorites, hydrated silicates and amphiboles etc), carbonates, sulphates and the VNIR bands iron oxides.

All mineral identification is based on analysis of the spectra and since this is a subjective procedure it requires field confirmation. Some minerals, such as those characterised by Mg-OH / carbonate absorption (~2.30 microns) have very similar spectra, though in this area no such minerals have been located.

A total of 11 spatially coherent mineral units have been identified in the area that map 7 distinct minerals, there are 2 Dickite units and four Opal units. For each mineral the output products are grey scale and rainbow coloured images where the tone or colour depicts the abundance of the mineral mapped (i.e. increasing abundance from dark to light or from blue to red). For the SWIR minerals three RGB colour composite image maps have been produced by assigning differing mineral abundance images to the red, green and blue image bands. Other combinations are possible. Rule classification images have also been produced that combine all of the minerals mapped into one image.

The output images are written ENVI, ER Mapper, and Geotiff formats. The geo-correction applied to the data results in image maps in the UTM/ WGS84 Zone 11 N map projection.

Note the intermediate products are not intended to be used by the customer they are provided for future reference by HyVista staff.

INTRODUCTION

HyVista Corporation was contracted to conduct an airborne hyperspectral scanner imagery over the area termed Glass Buttes on the 19 August 2009 (Figure 1) by Ormat INC.
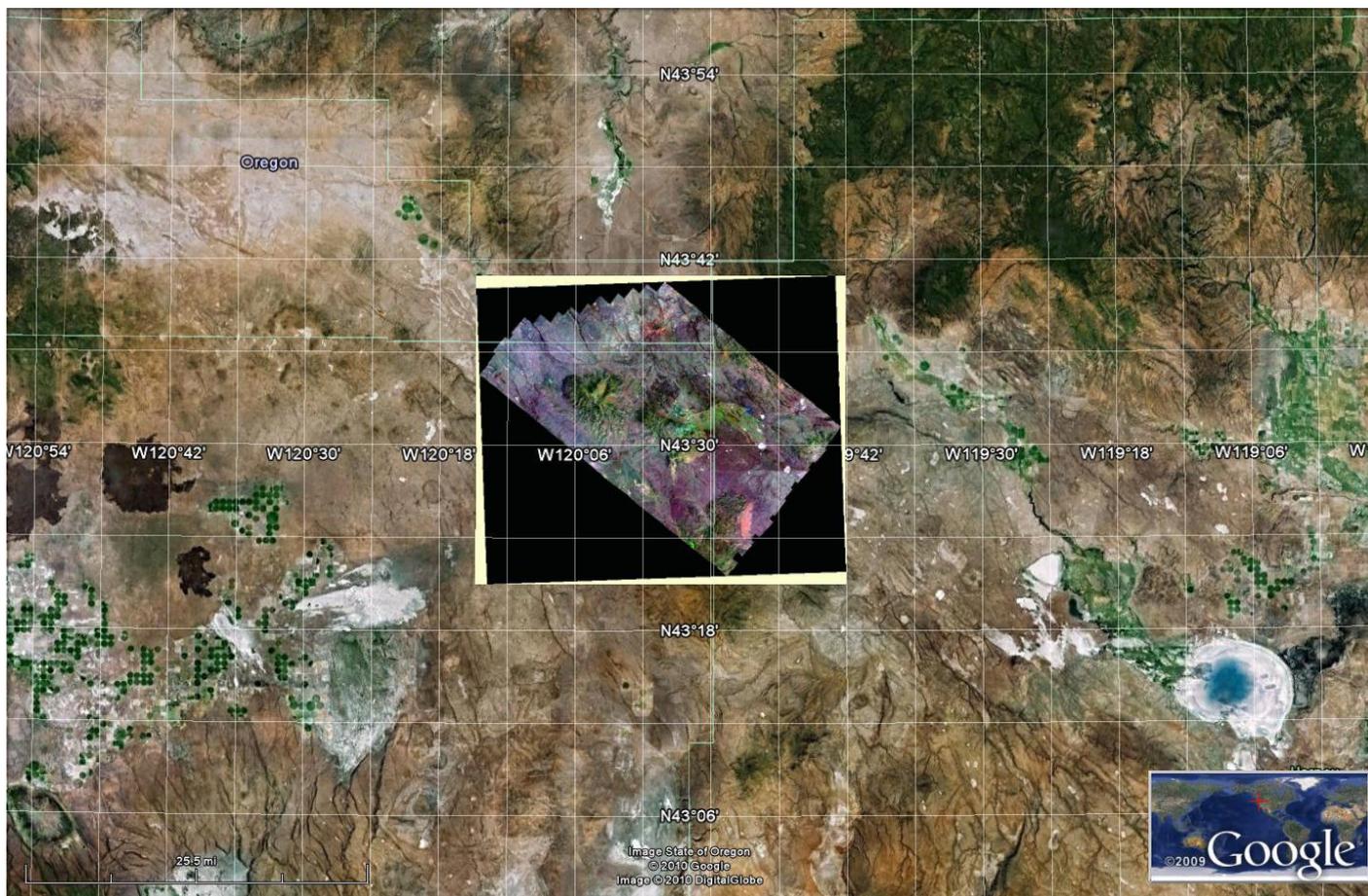
Figure 1: Glass Buttes Survey Area Location.

The HyMap is an airborne hyperspectral scanner delivering 126 bands (approx 18 nm width per band) of imagery over the 450nm to 2500nm spectral interval. The HyMap data pre-processing is carried out on a strip by strip basis, to produce radiance and apparent reflectance, and GLT files for later geometric rectification / mosaicing. The reflectance images are cross track and level corrected, (i.e. solar illumination corrected). These reflectance images are then geo-corrected to position each individual pixel in its accurate geo-location in the UTM/MGA 94 map projection. The corrected strips are them mosaiced to produce a seamless, homogeneous data (map) cube for the whole survey area. This data-cube is then processed to produce various band colour composite, minimum noise fraction (MNF), band ratio index images and image-maps that highlight mineralogical and geological / chemical variations.

Figure 2 is an example image produced from the cross-track illumination and level correction reflectance data; a Red Green Blue (RGB) colour composite in which bands 108, 28, 3 are displayed in red, green, blue respectively. For colour composite images the order of band numbers, wavelengths or mineral names in the file name is always R-G-B.

This document outlines the Level 1c processing and details the Level2 and Level3 processing applied to HyMap data. Further information on the sensor specification, survey planning and data pre-processing is available upon request.
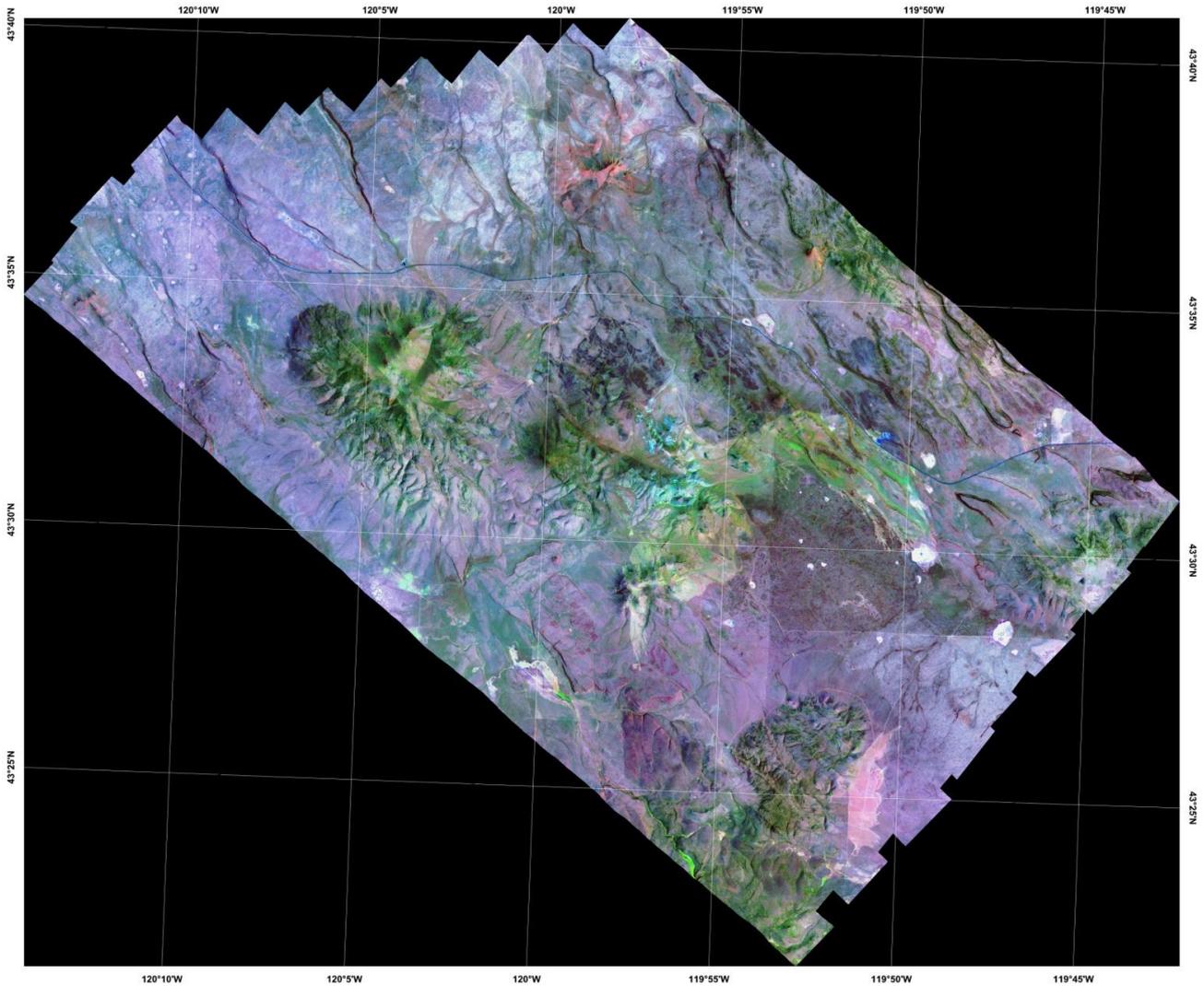
Figure 2: Overview false colour composite, RGB Bands 108-28-3 with grid.

DATA PROCESSING

Three levels of process have been applied to the data for this project and the initial products are stored as intermediate images. These intermediate are analysed, scaled, thresholded, masked and overlain onto background images as required to produce the delivery product images:

LEVEL 1 A&B
Raw and Pre-processed data

LEVEL 1C
Cross track corrected mosaiced reflectance image (Data-Cube)

LEVEL 2
Colour composites, true and false colour
SWIR decorrelation stretch colour composite images
Relative Band Depth index images
SWIR MNF Image from which a Colour Composites was produced

LEVEL 3
Mineral Mapping from SWIR and VNIR data using:
      Un-mixing
      Match Filtering
      Logical Operator Masking

Mineral abundance images have been determined from these processes and are presented as:

> Thresholded greyscale images
> Rainbow colouring of greyscale images
> Mineral Colour Composite images
> Rule classified images

MAP PRODUCTS

The delivered map products are precision geo-rectified mosaic images of products listed above written in ENVI, ER Mapper and Jpeg and Geotiff formats in the UTM/ WGS84 Zone 11 N map projection.

The rainbow coloured, mineral colour composite and rule class images have also been produced with black, white and greyscale image backgrounds. Geographic grids have not been added to the images expect for some example images in this report.

Shape files have also been produced for the mineral mapped.

LEVEL 1 / PRE-PROCESSING OF DATA

The HyMap scanner data is collected and stored on a DLT flight tape and converted to ENVI-compatible image files (16-bit integer, BIL data file with an ASCII header file) during pre-processing of the data, The HyMap stores the intensity of light reflected from the surface of the earth as digital numbers (DN). The intensity recorded is the net effect of the wavelength-dependent atmospheric absorption and scattering, solar irradiance, light scattered back from the earth surface, and background voltages from the scanner electronics. Pre-processing involves two corrections.

Dark Current Subtraction

This correction removes the "zero light" spectrum in all image pixels. The DN values for subtraction are obtained from the scanner while imaging a non-reflecting surface. It represents system voltages and electronic noise. It is additive and band-dependent.

Calibration – Radiometric, Spectral and Scaling

The scanner is calibrated using a standard light source so the response of each detector is known. Every pixel of each band has been scaled_EL23571_S by this band constant and a multiplier has been applied so that the data is stored as a 16-bit integer.

Data Units

When the pre-processing corrections described above have been applied, the data are in radiance units of microwatts/cm^2/steradian/nm before the multiplier of 1000 is applied to convert it to a 16-bit integer.

Atmospheric Correction

Whilst the HyMap's radiance data is spectrally and radiometrically calibrated, the spectra are distorted by atmospheric absorption and scattering. The data has been processed using the HyCorr program that determines a model of a subset of atmospheric properties that are appropriate for the time (UTC), date, latitude/longitude and acquisition height (AGL) for HyMap data that has been radiance corrected. HyCorr uses radiative transfer calculations and the calibrated hyperspectral data (with artefact suppression) to remove and reduce atmospheric and solar illumination effects. The output of HyCorr is an apparent surface reflectance image from which spectra can be compared to relative reflectance library spectra, i.e. the atmospheric over-print has been removed and mineral absorption features are now recognisable HyCorr output is apparent surface reflectance. Reflectance imagery is unit-less.

Cross Track Correction and Strip Levelling

Prior to geometric correction each strip is processed to remove the effect of bi-directional reflectance that results from non uniform illumination across the image when the azimuth is to the side of the flight line. This results in the images being brighter on one side than the other. The levelling correction adjusts each data strip to the same data ranges. These corrections improve processing and ensure that the final mosaic images are seamless.

Geometric Correction

Variations in the aircraft orientation, speed and altitude during image acquisition result in spatial distortions of the images, even though the scanner is mounted in a tri-axial, gyro-stabilised platform that compensates for some of these motion effects. An IMU/GPS unit is attached to the scanner and it provides data that can be used remove these distortions which would otherwise result in positional errors of several hundred metres. Using these data with the appropriate software permits geo-correction to be completed without the need for control point picking and, depending on terrain variation; this can reduce positional errors to below 20m.

Software developed by HyVista is used for to produce a ray traced image (.glt) file from combining the output from the IMU/GPS with a DEM (SRTM 90m image). The glt file is then used to georectify the image products produced to the UTM/MGA94 map projection using proprietary HyVista software.

Level 1C Product

In this survey the cross track corrected and levelled reflectance data have been mosaiced into data cubes for all bands and this mosaic has been split into VNIR and SWIR sub-banded images. The SWIR mosaic has also had a continuum removal applied to it. Subsequent Level 2/3 processing has been carried out using these images.

LEVEL 2 PROCESSING

Colour Composite Mosaics

Overview Colour Composites

Two colour composite images have been produced from the reflectance data consisting of:

Landsat TM 741 equivalent: RGB = 2.208um/0.845um/0.488um (HyMap bands 108, 28, 03 respectively)
True Colour: RGB=0.664um/0.577um/0.488um (HyMap bands 15, 09, 03 respectively)

The contrast in these colour composites has been enhanced by applying the ENVI square root and then Gaussian stretches to the images.

Note all colour composite images (DCS, MNF and Mineral Map) have a naming convention where band numbers or mineral names are given in order Red, Green Blue the same as they are displayed.

Decorrelation Stretch (DCS) Colour Composites

The SWIR bands 109 (2.228um), 114(2.312um) and 29(0.8609um) are combined as a RGB colour composite image and the ENVI decorrelation stretch function applied to it. The resultant image maps the distribution of mineral classes that absorb at these wavelengths i.e. Si-OH/Al-OH, Mg-OH/Carbonates and Iron Oxides respectively. However, since it is absorption being mapped the resultant colours are confusing, for example Mg-OH absorptions (displayed as green) are mapped as not green. However, by taking the negative of the bands (i.e. inverting the RGB colour image planes) an image results in which:

Red = Si-OH/Al-OH bearing minerals (including – illite, opal and tourmaline?)
Green Mg-OH/CO3 bearing minerals (including - amphibole, talc, calcite, dolomite)
Blue = FeOx minerals (hematite and goethite)

Relative Band Depth Index Images

By calculating the relative depths of the absorption features at specific wavelengths it is possible to produce images that show the overall abundance of groups of minerals that have a primary absorption feature at the specified wavelength. In this case the band depths for nine (9) SWIR absorption features were produced and examined mapped to show the distribution of:

0.870um – FeOx (hematite)
0.905um – FeOx (goethite)
1.545um – Sulphate (jarosite gypsum) and Apatite - Epidote
2.173um - Advanced Argillic (AA: alunite, pyrophyllite, dickite, ordered kaolinite)
2.190um - AlOH-short (AlOH: kaolinite, aluminium rich Illite)
2.208um - AlOH-std (AlOH: kaolinite, muscovite / illite, Al-smectite)
2.215um - AlOH-long (AlOH: illite / muscovite / Al smectite)
2.228um - Si-OH (opal)
2.245um – Tourmaline
2.262um - FeOH (FeOH: jarosite, nontronite, chlorite, Fe / Mg smectite)
2.313um - MgOHCO3-shorter (MgOH / CO3: actinolite / talc / dolomite)
2.326um - MgOHCO3-longer (MgOH / CO3: hornblende / biotite / chlorite / calcite)
2.346um –Epidote (CaAlOH: epidote but also chlorite / carbonate)

These images are termed Relative Band Depth Index Images and in this case only the Goethite iron oxide images, which maps the same distribution as the hematite RBD image has been used as a delivery product.

MNF Transform

An MNF transform was applied to the SWIR reflectance and a colour composite has been produced from bands 2, 3 and 4. This images show the greatest variation is surface materials producing an image that highlights geological and regolith variation within the area.

LEVEL 3 PROCESSING

Mineral Mapping

Hyperspectral remote sensing is essentially a mineral mapping technology. Its fundamental principles are based on spectroscopy, so an understanding of the spectral signatures of surface materials is required for its application. Briefly, each pixel of a hyperspectral image contains a spectrum which forms the basis for determining the materials present in a scene. Surface mineralogy and other components are mapped using algorithms which either de-convolve a scene into component end-member signatures (unsupervised un-mixing) or specifically target spectral signatures of known materials (supervised match filtering). A combination of these approaches has been applied in the project.

Spectral End-member Un-mixing

Linear spectral un-mixing is the process of deriving the abundances of component materials in a scene from the individual pixel spectra, given the end-member spectral signatures. To give perfect un-mixing results, the signatures for all end-members present in a scene would need to be known. However, in practice, un-mixing algorithms map the distribution of automatically scene-derived end-member materials. These are especially useful for analysis where signatures of the target(s) are not known and for general geological and regolith mapping.

Un-mixing methods output a set of end-member spectra with corresponding un-mixed images which are, in effect, mineral maps. There are several programs that can be used for this type of processing. ENVI has a selection of mapping methods which generate abundance images notably Matched Filtering and Matched Tuned Filtering. However, HyVista has several proprietary un-mixing programs that can be applied to mosaiced reflectance imagery (as in this case) or allows for the selection of end-member data from multiple strips without the need to mosaic them. Thus, when they are un-mixed, the distribution of end-members matches across images strip boundaries. This software produces mineral maps that can be used for geological and regolith interpretation where there is no a priori knowledge of the minerals present in the area.

Prior to applying the un-mixing algorithm, the data are processed to remove pixels that are of shadow, anomalously bright areas (such as active fires and metal roofs), and surface water, green and dry vegetation. These are effectively noise pixels and affect the image statistics. These pixels are masked out

(i.e. set to zero). In this survey there extensive areas of green and dry vegetation have been removed, Figure 3.
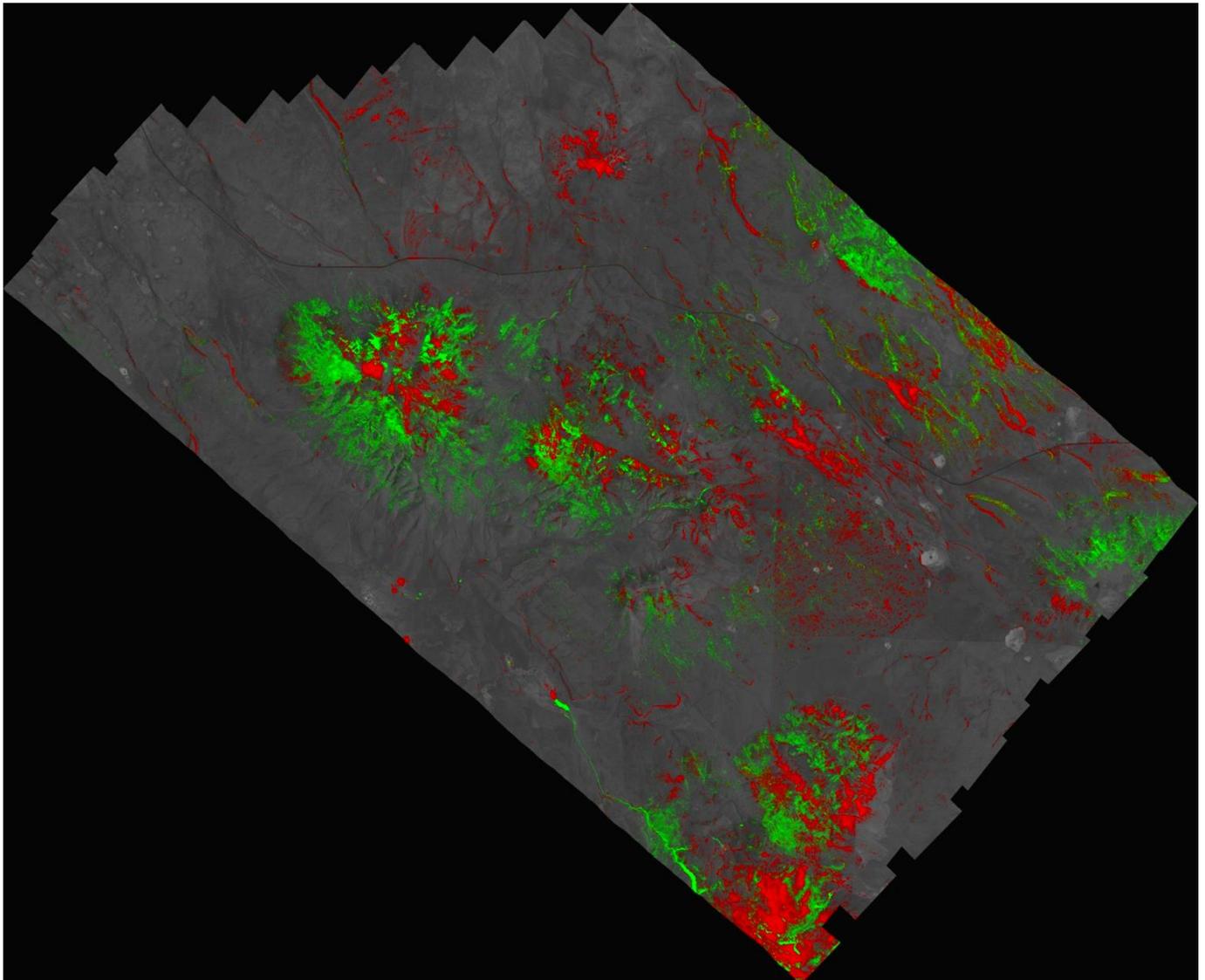
Figure 3: Glass Buttes Green (green) and Dry Vegetation (red) Cover.

Running the un-mixing algorithms produce two outputs; an end-member library that contains the spectra for each spectral end-member detected within the data, including minerals, and a series of abundance images each band of which maps the distribution of a spectral end member. The programs are run separately on the Visible Near Infra Red bands (VNIR 0.5 microns to 1.12 microns) for iron oxides and Short Wave Infrared bands (SWIR 1.95 microns to 2.43 microns) for phyllosilicate, carbonates and etc..

The spectral libraries are examined and end-members recognised as minerals are determined and then mineral species identified. Non mineral spectra may include those from noisy spectra, residual vegetation, spectrally featureless areas and multiple mixed spectra that cannot be identified. The program uses a statistical technique to match each pixel to a spectral end-member and creates the abundance images such that each pixel has a value that is proportional to its closeness of fit to the spectra in question, the higher the value the better the match. In percentage terms, pixels with 0% have no match and the values of 100% have a perfect match and would be "pure" spectra but these will be quite rare within an image as most pixels will contain several different materials. Therefore, in probability terms pixels with percentage values of over 70% have a significant content of the spectral end-member (mineral). In this case the thresholds have been set at ~95%.

The abundance images are examined to determine which minerals they are mapping and where required masking is applied to remove misclassified pixels. Where an abundance image is mapping a mineral that

cannot be separated by un-mixing match filtering or band depth ratios and logical masking may is utilised to optimise the mineral maps.

Mineral Mapping Results

Mineral	Image name abbreviation	Technique	Comments
Iron Oxide	Fe Oxide – Goethite>Hematite	Un-mixing	Iron oxide probably a mixture of hematite and goethite but cannot separate.
Opal	Op (1, 2, 3,4)	Un-mixing	4 spectrally similar units mapped which are spatially distinct admixtures with tourmaline in some pixels.
Dickite	Di	Un-mixing	2 spectrally similar units mapped which are spatially distinct
Alunite	Al	Un-mixing	Closely associated with Dickite
Kaolinite	Ka	Un-mixing	
Tourmaline	To	Un-mixing	
Sericite	Se	Un-mixing	Only white mica (or illite) mapped main wavelength minima < 2.2um suggest Al-)H rich variety

Table 1 – Minerals mapped, see table 3 for file names and spectra.

DATA DELIVERY

The data are delivered on a disk with the following folders and sub-folders:

GLASS BUTTES SURVEY

   Glass Buttes Level 1 Data

           Strips 1-13 Raw DN, Radiance, Reflectance, and Geocorrection (glt) data

Glass Buttes Processing

           <u>**Intermediate Processing (Level 1c,2 and 3)**</u>
           Decorrelation Stretch
           Masking
           Mineral Map Colour Composites
           Mineral Maps Grey Scale
           Mineral Maps Rainbow
           MNF Colour Composites
           Overview Colour Composites
           RBD Index Images
           Reflectance Data Cubes
           Mineral Maps Rule Classification
           Unmixing

As the intermediate products are not intended to be used by the customer and are included on the delivery disk as a backup for future reference by HyVista staff. They are not documented in this report.

           <u>**Delivery Products**</u>
           Decorrelation Stretch
           Mineral Map Colour Composites
           Mineral Maps Grey Scale
           Mineral Maps Rainbow
           MNF Colour Composites
           Overview Colour Composites
           Mineral Maps Rule Classification
           Spectra (as jpegs)
           Minerals Shape Files

   See *table 3 for file details, comments, spectra, legends and threshold values for mineral map products.*

Data Formats

The delivery image products are written in ENVI, ER Mapper and Geotiff formats, jpegs have been produced for images use as inclusion in this report.

All images have been geo-corrected using the UTM WGS84 Zone 11 North projection. Pixel size is 3.3m.

Each image type has the map info included in its header or world file (jpw-tfw).

Table 3 lists all of the files produced in the Level 2 and Level 3 processing

Examples of the images products are presented in Appendix I.

AB#	Abundance Band Number Of Un-mixing Image
AMAP	Un-mixed Output
BG	Background Image – colour image overlain on background image
CC	Colour Composite
CR	Continuum remove applied
DB	Band Depth
DCS	Decorrelation Stretch
DV	Dry Vegetation
EQUALISE OR HE	Histogram Equalize Contrast Stretch
FPL	Un-mixed Output
GEO	Geo-Corrected Data Using A HyMap glt (Geometric Lookup Table) File
GUASS or GU	Histogram Gaussian Contrast Stretch
GSBG	Grayscale background added to image
GV	Green Vegetation
HT	High Threshold > 95%
INDEX	Image That Has Been Thresholded To Highlight A Specific Mineral Group
INVERTED	Negative Image
MASK or MSKD	Mask image or Mask applied to image
MF	Match Filter
MNF	Minimum Noise Fraction Transform Image
MOS	Mosaic Of All Survey Strips That Have Been Cross Track Corrected And Leveled
LT	Low Threshold > 72%
RAINBOW	ENVI Colour Look Up Table Applied To Image Such Grey Tones Are Coloured Dark To Light From Blue To Red.
RGB	Red Green Blue order of colour composite images e.g. RGB 2-3-4 bands = R2-G3-B4
REF	Reflectance Data – Atmospherically Corrected
Rule Class	ENVI Rule Class Transform that combines n images into n coloured image
Stack	Greyscale mineral images combined into single image for input into Rule Class
SGA	Un-mixed Output
SR	Square Root Contrast Stretch
SWIR OR SW2	Derived From Processing 25 Selected Shortwave Infrared Bands
TH	Threshold Applied
VNIR	Derived From Processing 35 Selected Visible And Near Infrared Bands
WBG	White background added to image
WVL	Wavelength Shift Image

Table 2: Abbreviations used in file name

Table 3: Image Delivery Product Table

Folder	Image and Comment	Threshold	End-member Spectra & Legends
Overview Colour Composites			
	glass_buttes_ref_MOS_RGB_15_9_3_SR_GU		
	glass_buttes_ref_MOS_RGB_108_28_3_SR_GU		
Decorrelation Stretch			
	glass_buttes_ref_MOSM_DCS_RGB_109_105_30_INVERT_TH_MSKD		
	glass_buttes_ref_MOSM_DCS_RGB_109_105_107_INVERT_TH_MSKD		
Minerals Maps Grey Scale			
	glass_buttes_ref_MOSM_MM_AMAP_AB7_Al_TH	3.221-3.679	
	glass_buttes_ref_MOSM_MM_AMAP_AB8_Di2_TH	2.9-5.49	

	glass_buttes_ref_MOSM_MM_AMAP_AB10_Ka_TH	2.107-3.357	
	glass_buttes_ref_MOSM_MM_AMAP_AB12_Op4_TH	O.821-1.607	
	glass_buttes_ref_MOSM_MM_FPL15_AB1_Op1_TH	0.84-0.92	
	glass_buttes_ref_MOSM_MM_FPL15_AB2_Op2_TH	0.278-.549	

	glass_buttes_ref_MOSM_MM_FPL15_AB15_Op3_TH	0.105-0.148	
	glass_buttes_ref_MOSM_MM_FPL15_AB4_To_TH	0.159-0.272	
	glass_buttes_ref_MOSM_MM_FPL15_AB13_Di_TH	0.528-0.253	
	glass_buttes_ref_MOSM_MM_FPL15_AB14_Se_TH	0.11-0.23	
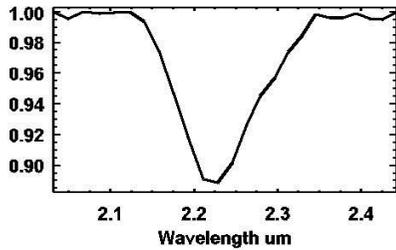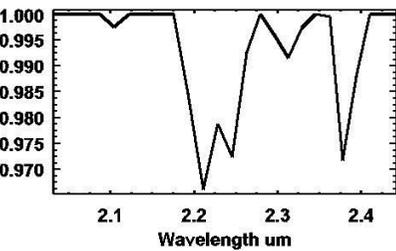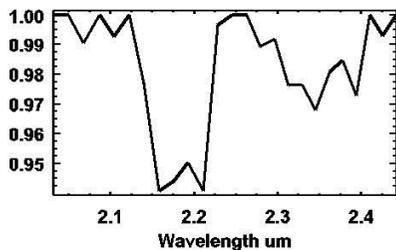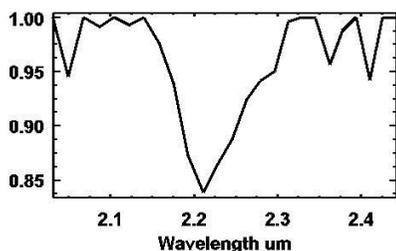
	glass_buttes_ref_MOSM_MM_RBD_FeOx_TH	1.031-1.047	
Minerals Rainbow Coloured			
	Same image as Grey Scale but with ENVI Rainbow colour Look Up Table applied, see below for Legend. Image name has R suffix.		
Mineral Maps Colour Composite			
	glass_buttes_ref_MOSM_MM_RGB_Di_Al_OP1	As Above	
	glass_buttes_ref_MOSM_MM_RGB_Ka_Se_To	As Above	
	glass_buttes_ref_MOSM_MM_RGB_OP3_OP4_OP2	As Above	
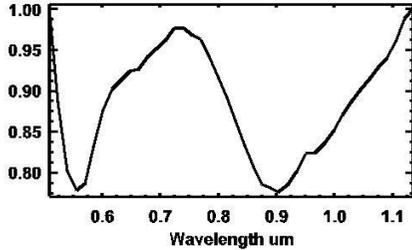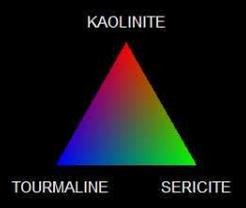
MNF Colour Composite	glass_buttes_ref_MOS_MNF_RGB_2_3_4_HE		
Rule Classification Mineral Map			
	glass_buttes_ref_MOS_MM_ST3_RC_RGB	As Above	

Legend (colour key):
- DICKITE
- ALUNITE
- KAOLINITE
- SERICITE
- OPAL 1
- OPAL 4
- OPAL 2
- OPAL 3
- Fe OXIDE - GOETHITE
- TOURMALINE

LEGEND RAINBOW COLOUR WEDGE

95%	Mineral abundance Images	>99%

Appendix I
Example Image Gallery
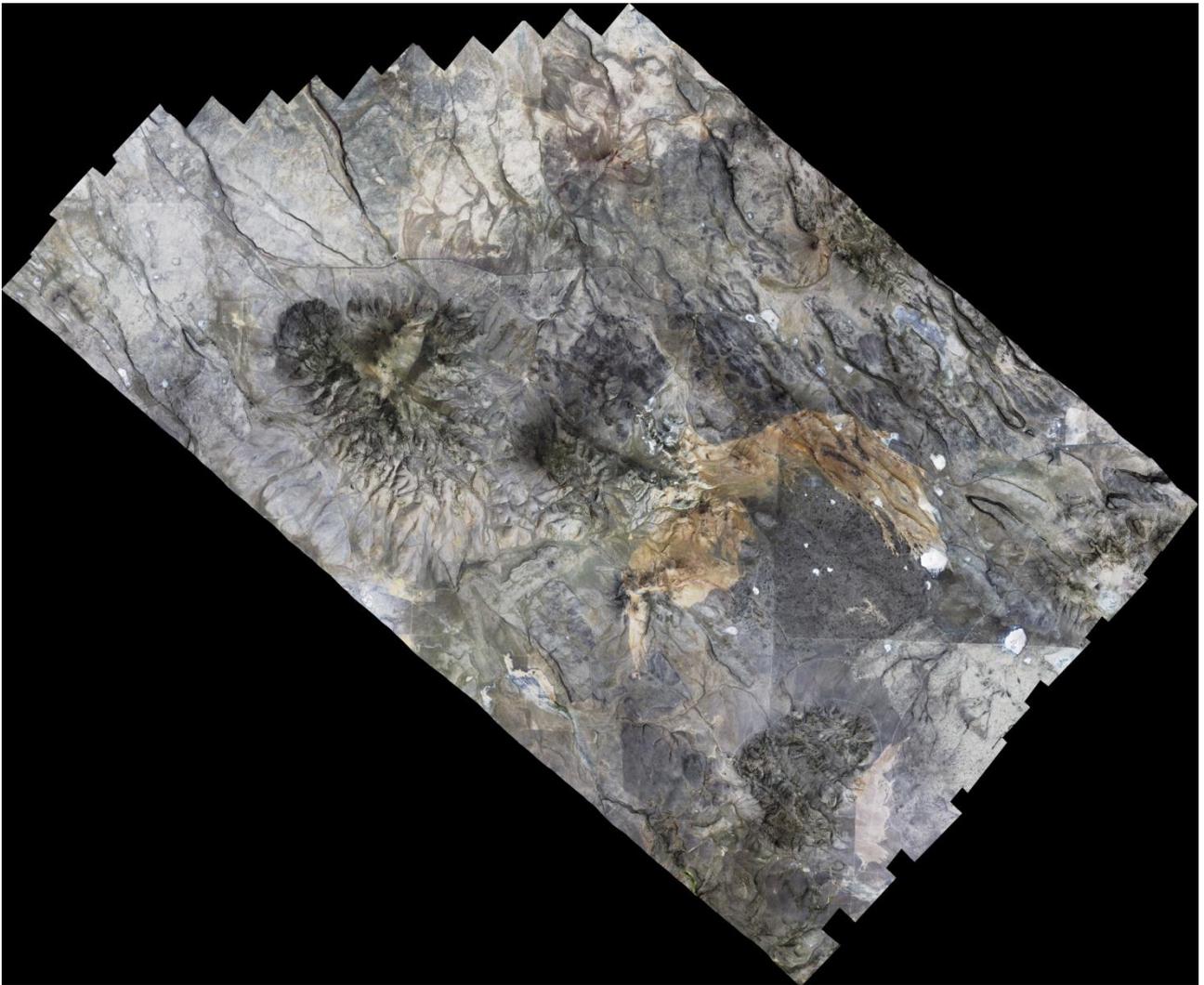
Plate 1: True Colour Composite Image:
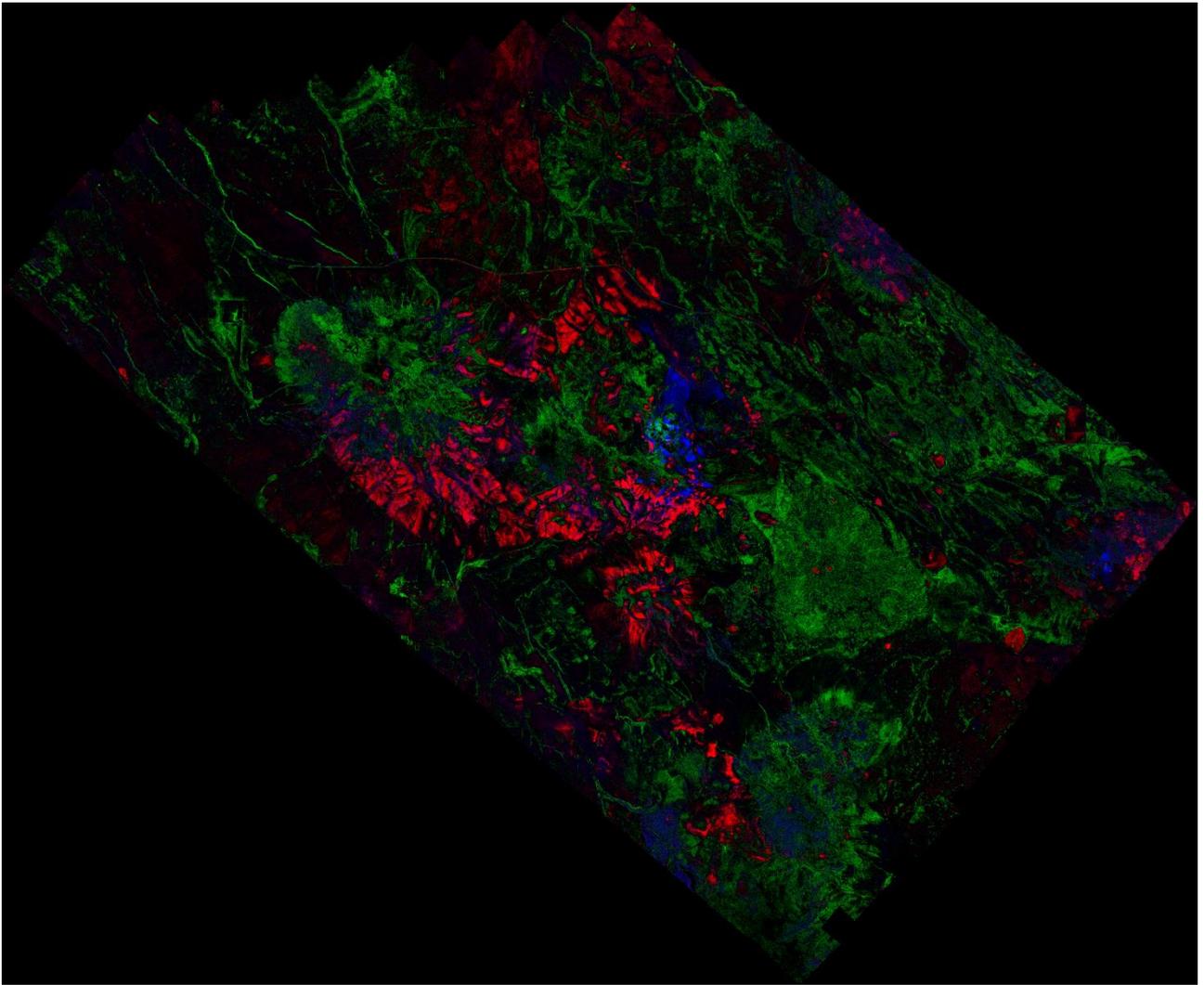
Plate 2: SWIR Decorrelation Stretched Colour Composite:
glass_buttes_ref_MOSM_DCS_RGB_109_105_107_INVERT_TH_MSKD
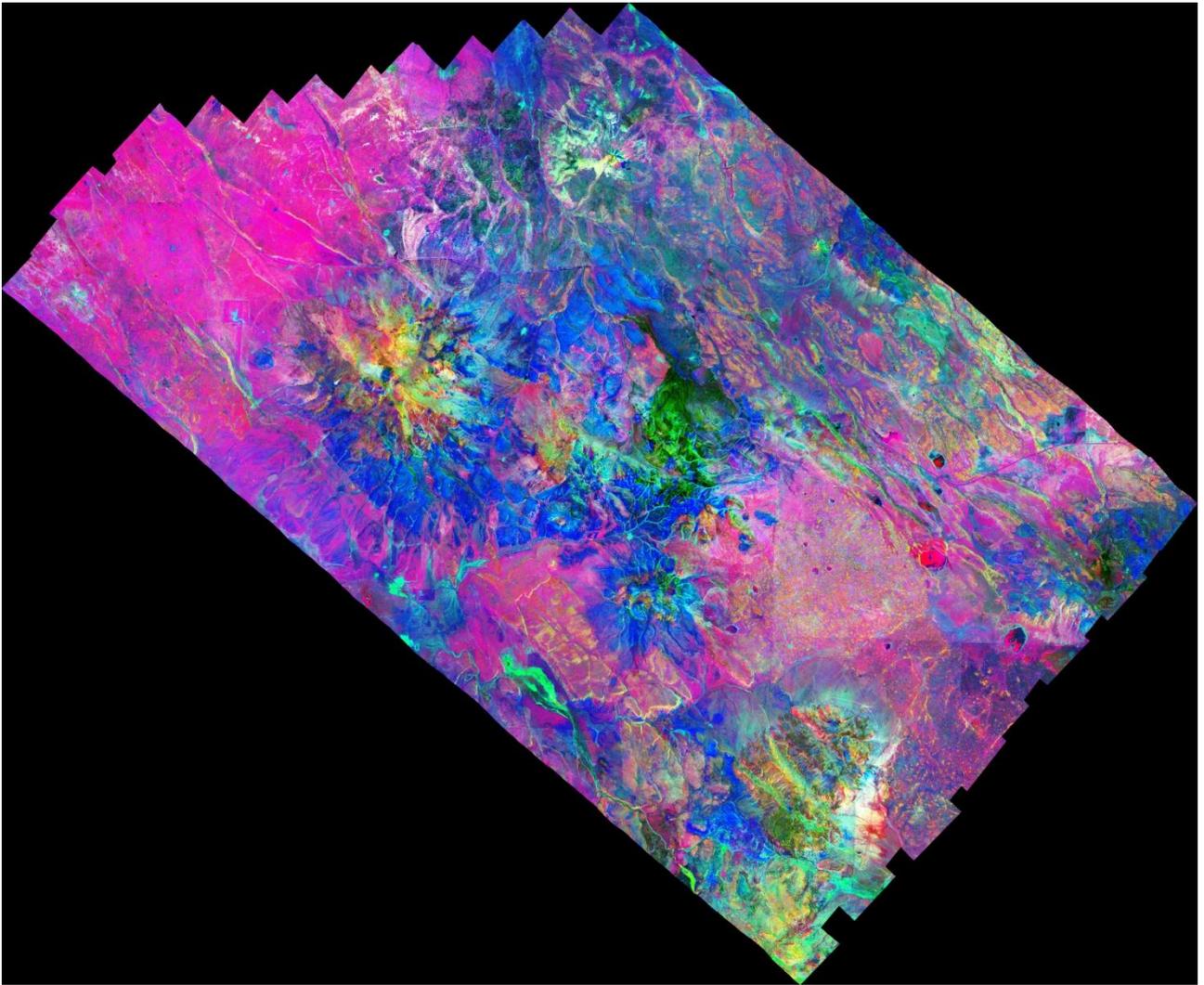
Plate 3: MNF Colour Composite RGB 2, 3, 4: glass_buttes_ref_MOS_MNF_RGB_2_3_4_HE_MSKD

Plate 4: Grey Scale Mineral Map of Dickite: glass_buttes_ref_MOSM_MM_FPL15_AB13_Di_TH

Plate 5: Rainbow Coloured Grey Scale Mineral Map of Dickite:
glass_buttes_ref_MOSM_MM_FPL15_AB13_Di_TH
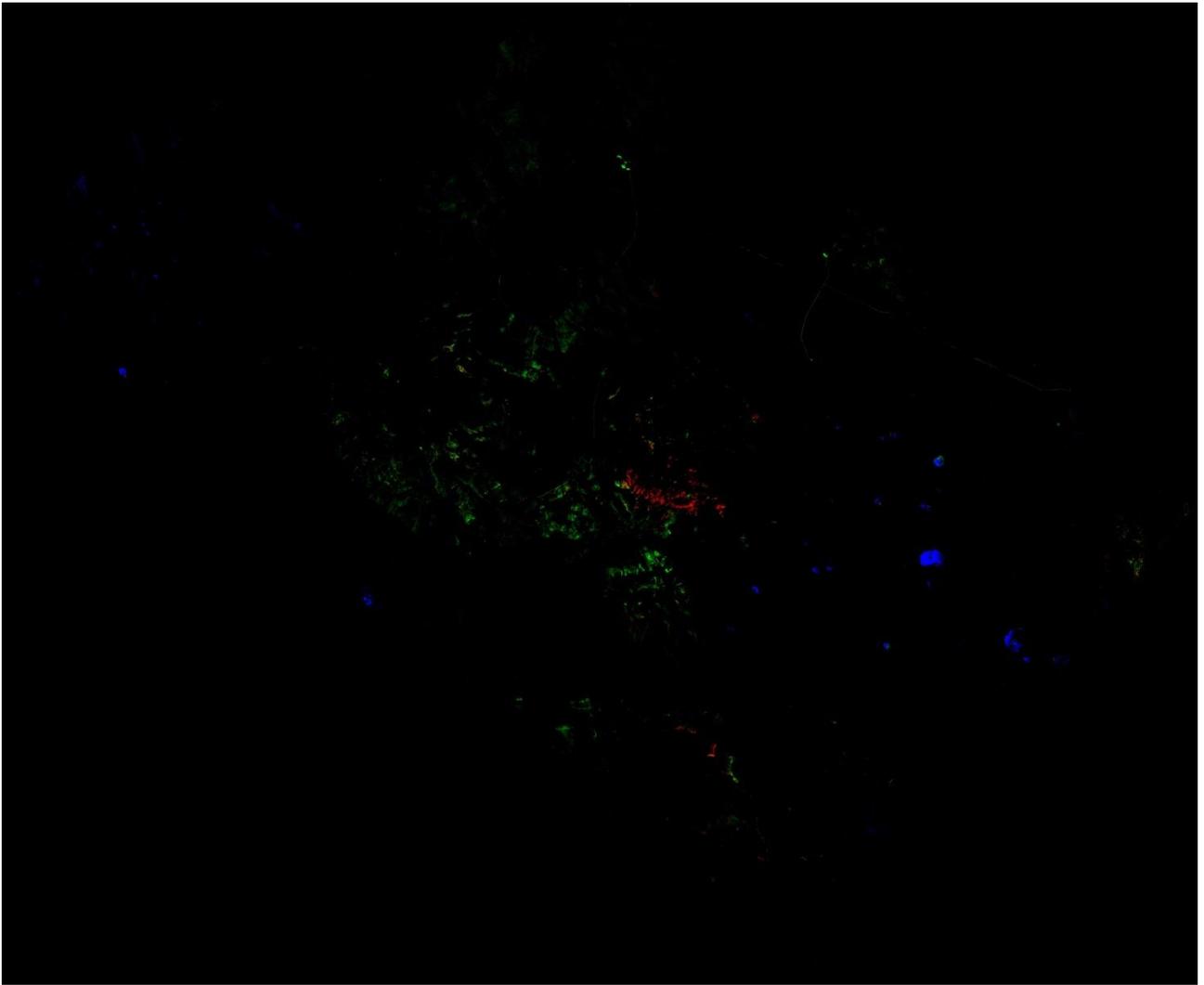
Plate 6: Mineral Map colour composite of Opal: glass_buttes_ref_MOSM_MM_RGB_OP3_OP4_OP2
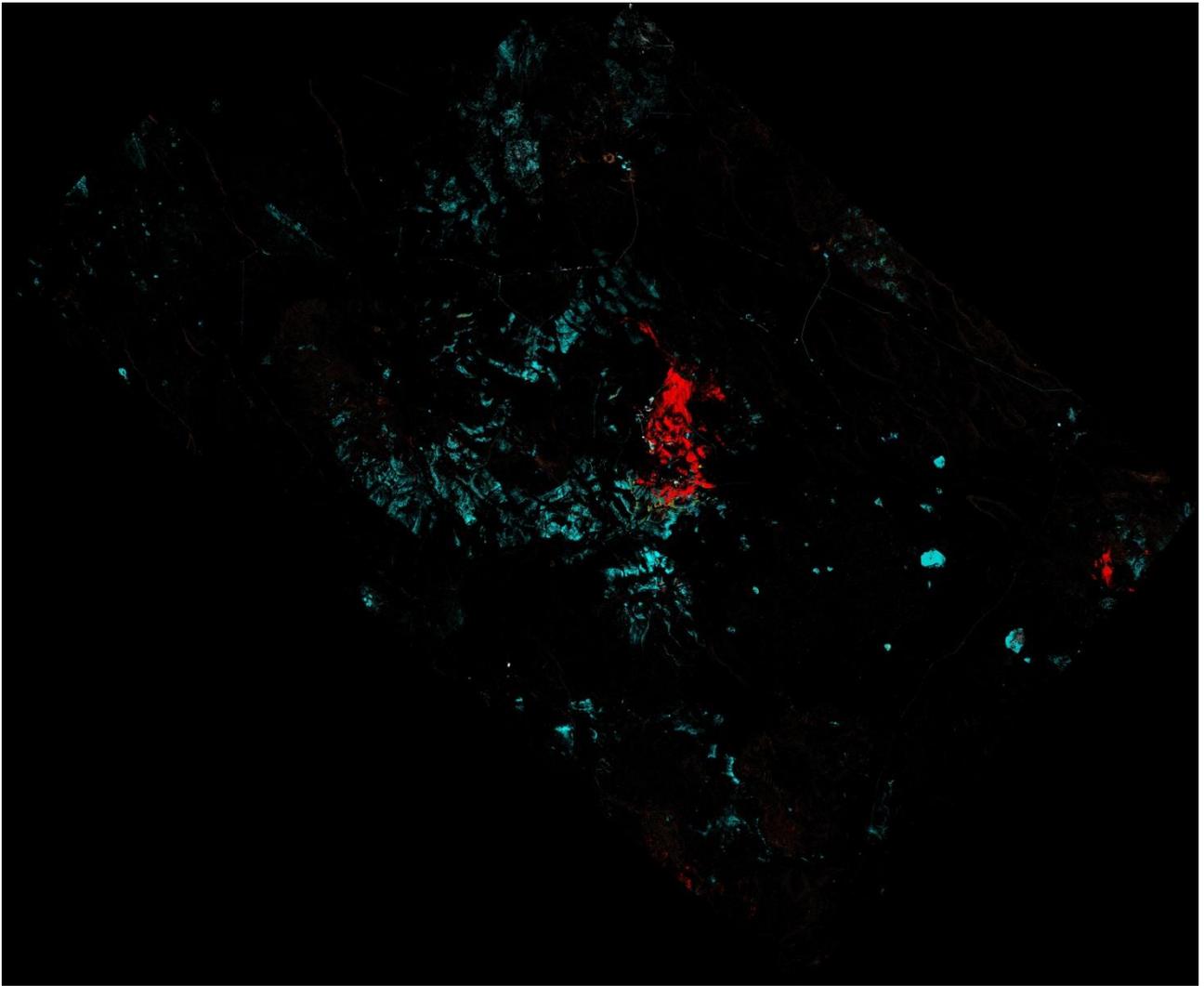
Plate7: Rule Class Image, see table 3 for legend: glass_buttes_ref_MOS_MM_ST3_RC_RGB

Appendix 2

Survey Planning and Specifications

For survey operations and flight logistics and planning, HyVista utilises two integrated software and hardware packages.

The first is Flitemap (Jeppesen - www.jeppesen.com) which is a high resolution moving map and flight planning application. Using HyVista propriety software, flight line information is plotted as user waypoints and entered to the FliteMap database. This information then can be used to plan day to day flight logistics and flight logging and reporting. Another important feature of Flitemap is the ability to log the GPS signal from the HyMap system while in flight. A GPS signal is transmitted from the HyMap system via the Omnistar 3000LR DGPS as RTCM. This signal is recorded every second and plotted on the Flitemap display and can also be saved for archiving and reporting purposes to easily and quickly show terrain coverage and target acquisition completion.

The second and most important survey operation software/hardware package is Eztrack Aerial Survey System (TRACK'AIR – www.trackair.com). The system is a combination of specially developed software and hardware tools integrated to streamline airborne survey operations. The system consists of an equipment kit and the TRACKER planning and reporting software. This includes the TECI (Tracker External Camera Interface), snapSHOT software running on a laptop, a panel display for pilot viewing and a complementary cross track indicator (CTI) for the pilot. The Eztrack is a complete Aerial Survey System which starts at the planning stages of a survey mission. Utilising snapXYZ and snapPLAN a survey area consisting of flight lines can be planned in minutes from any waypoint or polygon coordinates. Flight lines are stored in a database system making it easy to archive and report survey missions. Tracker also accepts many different projections and datums making it easy to use with different client needs. Actual flight operation utilises the Eztrack hardware and snapSHOT software. The Eztrack receives a GPS signal transmitted from the HyMap system via the Omnistar 3000LR DGPS as RTCM. This increases the accuracy of flight line operations.