I. Background and Overview

Abstract

This proposed research will address Emphasis Area 2 noted in the Request for Proposals for this research opportunity by using the existing Hyperspectral Imager for the Coastal Ocean (HICO, *Lucke et al*., 2011) on the International Space Station (ISS) to examine a set of playas and ephemeral lakes in the United States and in Australia. We are seeking to assess the utility of HICO for characterizing and mapping minerals associated with playas and mapping their fractional abundance outside of the playa. We also seek to use the remote sensing data to assess the surface state of the playa (wet vs. dry, soft vs. hard). These factors have bearing in that dusts stripped from playa surfaces can affect nearby human communities and agricultural fields. Playas are also used for recreation and sometimes as transportation corridors and their physical state has important bearing for those functions.

HICO, and supporting airborne hyperspectral datasets, will be converted from at-sensor radiance to surface reflectance using commercial radiance transfer-based atmospheric correction software. Spectrally unique (endmember) materials will be identified using commercial and custom programs including spectral mixture analysis, constrained energy minimization, and spectral feature fitting. Associations of the minerals present and the presence or absence of spectral features associated with standing water or wet sediments will be used to characterize the playa type, the nature of its surface and to gauge if dust with salts or other minerals is more or less likely to be subject to stripping by wind and to affect downwind human communities or farms. This study will examine the viability of using HICO or successor instruments as a tool for the monitoring of playa surfaces.

Background

Drainage in closed basins in arid regions empty into ephemeral lakes, also known as playas. While making up only about 5% of arid regions (*Cooke et al*., 1993), playas are significant for a number of reasons. Playas are indicators of environmental conditions and accept effluents eroded from their surrounding basins; thus, playas can act as recorders of the effects of erosion and level of rainfall in recent geologic history. They are also important in that dust stripped from the surfaces of playas can pose hazards to human health both by the fine particulate nature of the dust and since the dusts can sometimes contain hazardous trace metals (*Plumlee and Ziegler*, 2002; *Reynolds et al*., 2007; *Reheis et al*., 2009). Salts stripped from playa surfaces contribute to the surface layer of agricultural areas downwind of playas (*Eckardt et al*., 2001) and salt-affected soils are recognized as an impediment to productive agriculture. Playas are also used for recreational and military transport, and so remote assessment of playa composition and surface state (wet or dry, soft or hard) is valuable. The detailed mineralogic nature of playa surfaces can change from season to season based on the level and type of runoff from the surrounding basin and/or based on the efflorescent minerals that can form as crusts. Playas in even adjacent basins can also display differing mineral assemblages (*Eugster*, 1980). Evaporite minerals formed on some playas can have economic value as sources for sodium carbonate, borate, and other compounds (*Reeves*, 1978). Remote monitoring of playas through orbital or airborne sensors has been the focus of a number of studies (e.g., *Millington et al*., 1989; *Crowley*, 1993; *Crowley and Hook*, 1995; *Bryant*, 1996).

Classification of playas has been based primarily on hydrologic characteristics. For example, *Rosen* (1994) classified playas based on hydrology, dividing them into, primarily, discharge playas (an undrained closed playa where evaporites accumulate), through-flow playas (partly-drained closed basins where evaporites may accumulate), and recharge playas where water input roughly equals output, evaporites generally do not accumulate but the surface is dominated by clastic materials and clays). *Reynolds et al*. (2007) made the more fundamental distinction of "wet" and "dry" playas. "Wet" playas are those where the ground water table is within approximately 5 m of the surface with that water being consistently lost through evaporation or outflow. The water table is much deeper below "Dry" playas with little to no interaction of ground water with the surface.

These different playa types lead also to different types of minerals and surface conditions. Wet playas lose ground water through evaporation leaving behind evaporite minerals (with the type of mineral forming based on the groundwater brine composition). These evaporite mineral surfaces are often porous and friable forming a "soft" playa surface. Dry playas generally have hard surfaces formed of fine-grained clastic sediments including clay minerals. These surfaces also generate less dust than do dried out wet playas (*Gillette et al*., 1980).

The types of minerals that form in wet playas are dictated by the composition of the ground water brines which are, in turn, derived from chemical weathering of the lithologic substrate. While most evaporite minerals form from neutral to alkaline brines there are a number of ephemeral lakes in Australia that have neutral to acidic brines and which in addition to precipitating minerals such as halite and gypsum can also precipitate minerals more typically associated with acid mine drainage environments such as jarosite and alunite. While these lakes have been the subject of a number of studies (e.g., *Teller et al*., 1982; *Long et al*., 1992, *Benison et al*., 2007), the HICO orbital sensor and it's coverage in the visible and near infrared (VNIR) range provides an excellent opportunity to further characterize these features.

Since the hydrologic class of the playa dictates the type of surface minerals, for the purposes of this proposed research we suggest considering playas based largely on the types of sediments that are present and also on the basis of the pH of associated ground and/or surface waters. Thus the types of playas (not a comprehensive listing) considered for this proposal on this basis are listed in **Table 1.**

Table 1. A composition-based classification scheme for playas

Sediment Type	*pH of ground/surface waters*	*Example(s)*
Primarily clastic sediments	Neutral-Alkaline	Ivanpah Playa, Railroad Valley
Primarily chemical sediments	Neutral-Alkaline	Bristol Dry Lake, Bonneville
	Acidic-Neutral	Lake Tyrrell

While playas range in size, some are quite extensive and thus serve as ready targets for remote sensing instruments with moderate resolution such as HICO which is hosted on the International Space Station (ISS). While the primary focus of HICO has been studies of littoral environments, calibration experiments have been performed using several different playas. We propose to use some of these scenes and to collect several new ones to assess the utility of HICO, and potential successor hyperspectral sensors on the ISS, for characterizing playas, assessing their composition and surface state, and assessing their potential as sources of dusts and/or salts which could trouble nearby human communities and farms. The playas that we plan to examine as part of this study are listed in **Table 2**.

Table 2. Playas and ephemeral lakes to be studied in this investigation.

Playa/Ephemeral Lake	*Location*	*Approx. Lat. / Long.*	*Type*
Railroad Valley, Lunar Lake	Nye County, NV	38.50° N, 115.65° W	Detrital, clays; Fe minerals
Ivanpah Playa	Clark County, NV	35.60° N, 115.40° W	Detrital dominated
Bonneville Salt Flats	Tooele County, UT	32.71° N, 106.44° W	Evaporite dominated
White Sands/ Lake Lucero	Dona Ana County, NM	35.60° N, 115.40° W	Evaporite dominated
Lake Tyrrell	Victoria, Australia	35.30° S, 142.80° E	Acid Saline precipitates
Western Australia lakes	West Australia	various	Acid Saline precipitates

HICO is described by *Lucke et al*. (2011). It is a pushbroom type scanner with a grating dispersive element and a silicon CCD. HICO is mounted on the ISS and has a nadir cross-track field of view of 42 km and a nadir ground instantaneous field of view of 90 m. The full spectral range of HICO is 0.35 to 1.08 μm in 128 spectral channels. The nominal range for coastal remote sensing is 0.4 – 0.9 μm and this is the range of data distributed on the HICO web pages (hico.coas.oregonstate.edu). HICO data is also available on the NASA GSFC Ocean Color web pages (oceancolor.gsfc.nasa.gov) and those data have the full complement of 128 channels although the longer wavelength bands have reduced signal-to-noise relative to those in the 0.4 – 0.9 μm range. The VNIR spectral range covered by HICO does not extend into the shortwave infrared (SWIR, 1 to 2.5 μm) where vibrational overtone features of sedimentary minerals such as clays, carbonates and sulfates most commonly occur. However, the VNIR range that HICO does cover, is one in which charge transfer and crystal field absorptions associated with transition metal ions, most prominently iron, occur (*Burns*, 1993). Iron-bearing minerals are associated with many rock-forming minerals that are transported into playas as detrital remnants. Also, evaporite minerals can often have iron as a contaminant in their mineral structure. Several of the playas that we propose to study (Railroad Valley, Ivanpah Playa, Lunar Lake) are noted as being especially rich in Fe-bearing minerals (CEOS IVOS Test Site Catalog, http://calval.cr.usgs.gov/sites_catalog_template.php?site=rrva). The complement of iron-bearing minerals present in playas affects their reflectance spectra and can be used to distinguish playas in different drainage basins (**Fig. 1**). As noted above, iron-bearing minerals are also associated with a number of ephemeral acid-saline lakes in Australia (**Fig. 2**). These lakes precipitate a number of minerals typically associated with acid mine drainage environments (**Fig. 3**). Co-I Bowen has worked with these lakes and has field and local airborne remote sensing data over some of them. We propose to request HICO data acquisitions over these lakes along with a number of North American playas.

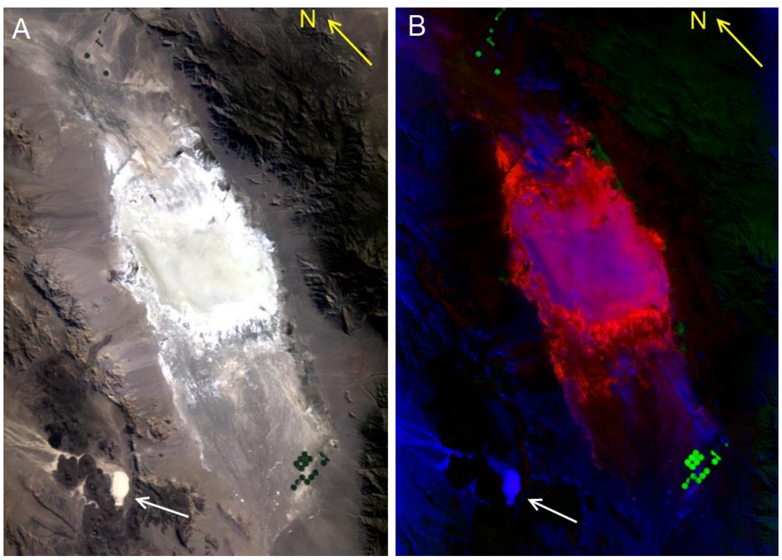

Fig. 1. A. Approximately true color image subsectioned from HICO scene H2012133145735.L1B_ISS centered over Railroad Valley Playa with the smaller Lunar Lake playa indicated by a white arrow. The yellow arrow points north. **B**. Composite of Constrained Energy Minimization (CEM) and modified CEM (MCEM) fraction images. Red is derived from a Railroad Valley playa endmember, green from vegetation, and blue from Lunar Lake.

Fig. 2. Acid-saline ephemeral lake in Lake Cowan basin Australia with reddish Fe^{3+}-bearing sediments and precipitates (from *Benison et al*., 2007).

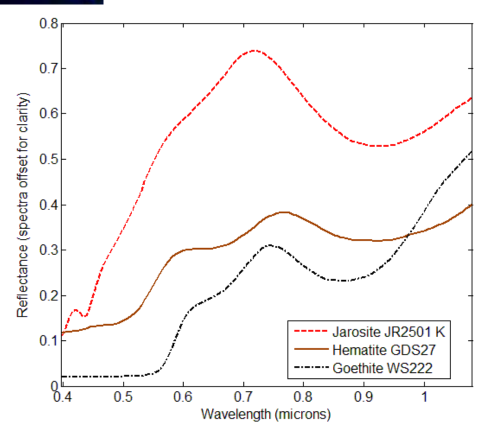

Fig. 3. Iron oxide (hematite), oxyhydroxide (goethite), and ferric sulfate (jarosite) minerals associated with acid-saline lakes. Spectra are from the USGS spectral library (*Clark et al*., 2007) and are at HICO spectral resolution.

II. Project Plan

Research Design and Methodology

Research Questions:

- How well can HICO and other hyperspectral datasets be used to determine minerals present on playa surface and to categorize the study playas on a compositional and on a hydrologic basis (as per *Rosen*, 1994 and *Reynolds et al*., 2007)?
- While supporting hyperspectral datasets will be used to aid in compositional characterization of the study playas, the VNIR range of HICO will be used to map surface types based largely on factors related to Fe-bearing minerals and Fe contamination of evaporite minerals. How strong or weak is the correlation between the VNIR spectral units and those determined based on supporting SWIR datasets?
- How well can the surface state of playas be determined from the orbital and supporting datasets?

Objectives:

1. Use remote sensing data to characterize the compositional character of the study playas and associate them with hydrologic classes.
2. Characterize the surface state of the study playas in terms of physical character (wet vs. dry, hard vs. soft).
3. Use broad scale context provided by HICO to characterize any fractional spread of playa materials in the surrounding basin.
4. Conduct field work of several of the study playas to field check maps and derived compositional and surface state information generated from HICO.
5. Assess the potential for the study playas to be sources of dusts and/or salts that could affect nearby communities or farms; establish criteria for using hyperspectral remote sensing data to make such an assessment for other areas.

Research Strategy

Significance:

This research will make use of a relatively new technology (hyperspectral remote sensing) from a unique platform (the ISS) to address issues related to a major component of the arid region hydrologic cycle (the terminus of waters and sediments in closed basins- playa lakes). In addition to demonstrating a new approach to the mapping and characterization of desert playas, we will also be providing a means of assessing what minerals are present on playa surfaces, whether they are minerals that would contribute to soil salinity in near-by farms or contribute dust to dust storms. Our characterization of playas from remote sensing data will also include assessing the state of playa surfaces (wet vs. dry, soft vs. hard) to provide information that would be of interest to transportation across playa surfaces (recreational activities, military transport). Also, the orbital vantage point of HICO from the ISS allows for the collection of data over remote locations and for the application of hyperspectral analysis to dry and ephemeral lakes from which such data has not previously been acquired (e.g., the Australian acid saline lakes). The study of the Australian acid saline lakes also has significance for work being done in NASA's Planetary Science Division of the Science Mission Directorate on Mars (e.g., *Benison and LaClair*, 2003).

Innovation:

This research applies a relatively new remote sensing resource (HICO on the ISS) to a problem in land remote sensing. We will map playa material classes using commercial and custom-coded software. We will thus extend the functionality of those custom-coded approaches and make them more mature and robust. This application area will also provide a showcase for the utility of these approaches for mapping minerals using hyperspectral data. Also, we expect to demonstrate the utility of using orbital hyperspectral data for monitoring the composition and state of playa surfaces.

Research Approach and Methodology:

For the playas and ephemeral lakes listed in **Table 2**, we will follow the following stages in our analysis. 1) Acquire and perform atmospheric correction on hyperspectral datasets. 2) Detect spectral endmembers and determine what key minerals are represented by those endmembers based on analysis of HICO data and also using supplementary airborne hyperspectral data (AVIRIS, HyMap), where it is available, to use information from the SWIR spectral range to aid in mineral identification. 3) Map the distribution of endmember materials (assumed to be dominated by one or more key minerals) within the study playas and as a fractional component of surrounding basins. 4) Field checking of spectral mapping results for a subset of the study playas. 5) Characterize the study playas in terms of the compositional classification scheme summarized in **Table 1** and relate them to the hydrology-based classification criteria of *Rosen* (1994) and *Reynolds et al*. (2007). 6) Determine the physical state of the playa and map probable differences in surface state. 7) Assess if minerals are present that would be of concern as a component of dust blown off of the playa or minerals that would contribute to increasing the salt content of agricultural fields. 8) Present results at meetings and in a peer-reviewed journal article. Each of these steps is described in more detail below.

<u>1. Acquire and Atmospheric Correction of Hyperspectral Data over Study Playas</u>

Data Acquisition:

HICO data are available through the HICO web pages hosted from Oregon State University (http://hico.coas.oregonstate.edu/) and some of the data is also available through the NASA Goddard Space Flight Center (GSFC) Ocean Color web pages (http://oceancolor.gsfc.nasa.gov/). Supplementary AVIRIS data is available from the Jet Propulsion Lab (JPL) AVIRIS web pages (http://aviris.jpl.nasa.gov/data/index.html). Co-I Bowen also has HyMap data over some Western Australia acid-saline lakes.

Atmospheric Correction:

Data are provided in the form of at-sensor radiance. Data will be converted to reflectance using the FLAASH atmospheric correction, part of the ENVI Atmospheric Correction Module. FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) incorporates the MODTRAN (*Berk et al*., 1989) radiative transfer code and any one of several standard atmospheres can be used to model the atmosphere given the day, time, and geographic coordinates of the data collection. FLAASH can be used to correct for atmospheric water in HICO data since one of the options in FLAASH allows for the 835 nm atmospheric water band to be used to estimate atmospheric water. More details on specifics of the FLAASH method are in *Cooley et al*. (2002).

<u>2. Detect and Identify Endmember Minerals within Study Playas</u>

HICO and supplementary airborne hyperspectral datasets will be used to determine the presence or absence of key minerals within the study playas. This information will be used to help determine the compositional class of the playa being examined. Spectral features associated with these minerals will be associated with spectral endmembers that define the spectral variability of the dataset (*Adams et al*., 1993). A standard ENVI endmember determination sequence (minimum noise fraction transformation, pixel purity index, n-Dimensional visualization; e.g. *Boardman and Kruse*, 1994) will be used to identify image endmember pixel sets. This will be done both on full scenes and on masked out sections covering only the playas. Minerals dominating the spectral endmembers will be determined by comparison to spectral libraries such as the USGS spectral library (*Clark et al*., 2007).

<u>3. Map the Distribution of Spectral Endmembers</u>

A variety of spectral mapping approaches are available within the commercial ENVI software and using customized approaches that the PI has coded. These methods are briefly described below. It is expected that multiple approaches will be used on each dataset in order to determine the optimal mapping method. Determining the best mapping results will be one of the goals of the planned field checking.

Spectral Mixture Analysis:

Spectral mixture analysis (SMA) is a linear methodology that models each spatial element (pixel) of an image as a linear combination of endmember spectra (*Adams et al*., 1993). It has been successfully used for a wide variety of applications (e.g., *Smith et al*., 1990; *Farrand et al*., 2006). SMA is also useful as a means of detecting spectral endmembers that define the spectral variability of the dataset by assembling a root mean square (RMS) error image that summarizes the differences, across all bands, between the measured and modeled data. Areas of high RMS error represent materials that were not well modeled by the existing endmembers and so averages of those image pixel spectra can be used either as additional spectral endmembers (if they are spatially widespread across the scene) or mapped as low abundance materials by some other approach such as Constrained Energy Minimization or Low Probability Material Detection. Both SMA and the methods described next generate fraction images (with data numbers ranging, ideally, between 0 and 1) representing the relative abundance of the endmember materials.

Constrained Energy Minimization/Low Probability Material Detection:

Constrained energy minimization (CEM, *Farrand and Harsanyi*, 1997) and low probability material detection (LPMD, *Farrand and Harsanyi*, 1995) are methods that use the principal eigenvectors of the sample correlation matrix of the dataset to map spatially extensive or somewhat less abundant materials (with CEM) or materials that might be present in only a relatively small fraction of the image (LPMD). While a version of CEM is available with the commercial ENVI software, it is implemented differently than what is described in (*Farrand and Harsanyi*, 1997) and the PI has his own implementation that better fits the original algorithm and provides superior results to the ENVI implementation. Also, implemented is a modified CEM (MCEM) which allows for the input of desired and undesired spectra so that undesired materials, which might be wrongly mapped with high scores in the CEM fraction image, can be nulled out and only the target spectrum is mapped.

An example of mapping out different playa types in adjacent basins, including Railroad Valley playa and Lunar Lake, using CEM and MCEM is shown in **Fig. 1**.

Spectral Feature Fitting:

Minerals can have characteristic absorption bands caused by atomic to molecular level effects in the mineral structure. In many cases, these absorption bands provide a characteristic “fingerprint” of the mineral. *Clark et al*. (1990) defined a methodology for comparing spectral features of library spectra to spectral features observed in hyperspectral data. This method was expanded to be a central component of the USGS “Tetracorder” processing approach (*Clark et al*., 2003). Spectral feature fitting is also a spectral matching algorithm resident within the commercial ENVI software and will be used where appropriate with the spectral mapping of the study playas. An example of mapping gypsum at White Sands, NM using multiple spectral feature fitting from a library spectrum of gypsum is shown in **Fig. 4B**. This figure also demonstrates the ability to map the spread of sediments derived from playas since the gypsum dunes at White Sands are derived from the Lake Lucero playa (to the southwest of the portion of the region shown) and the figure shows that the gypsum sediments have been blown and concentrated in the northeastern portion of the area that overall appears light-toned in the approximate true color representation in **Fig. 4A**.

Reconciliation of Spectral Ranges:

While some work will be done with supplementary datasets covering the extended SWIR spectral range for the purposes of aiding in the identification of minerals on the playa surfaces, we are addressing a study set of playas that have associated iron-bearing minerals and thus mapping of playa sediments is achievable using the VNIR spectral range of HICO. For example, **Fig. 5** shows a mapping of iron-rich and iron-poor run-off sediments and gypsum dunes using both the full AVIRIS spectral range (0.4 – 2.5 μm) and the same analysis using data convolved to the HICO spectral range (0.4 – 1.0 μm). For this example, the sediments mapped, while having diagnostic features in the SWIR, also have associated features due to iron-bearing minerals in the VNIR and so can be mapped using the HICO spectral range with a minimal loss of fidelity.

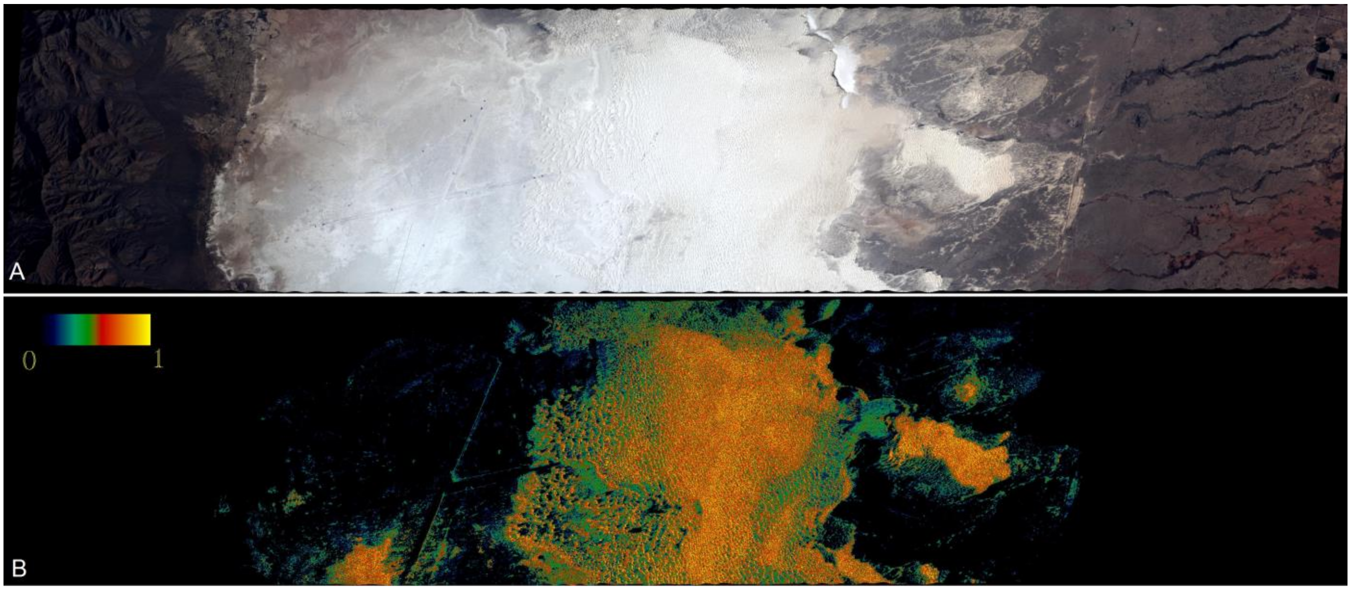

Fig. 4. A. Approximately true color representation of AVIRIS scene f110523t01p00r08rdn_c_sc01 over part of the White Sands region (centered at approximately 32.95°N, 106.36°W). **B**. Pseudo-colored representation of a spectral feature fit image (scaled between 0 and 1) with best matches to the library gypsum in yellow. While a large region is light-toned, gypsum sediments are concentrated in the northeast.

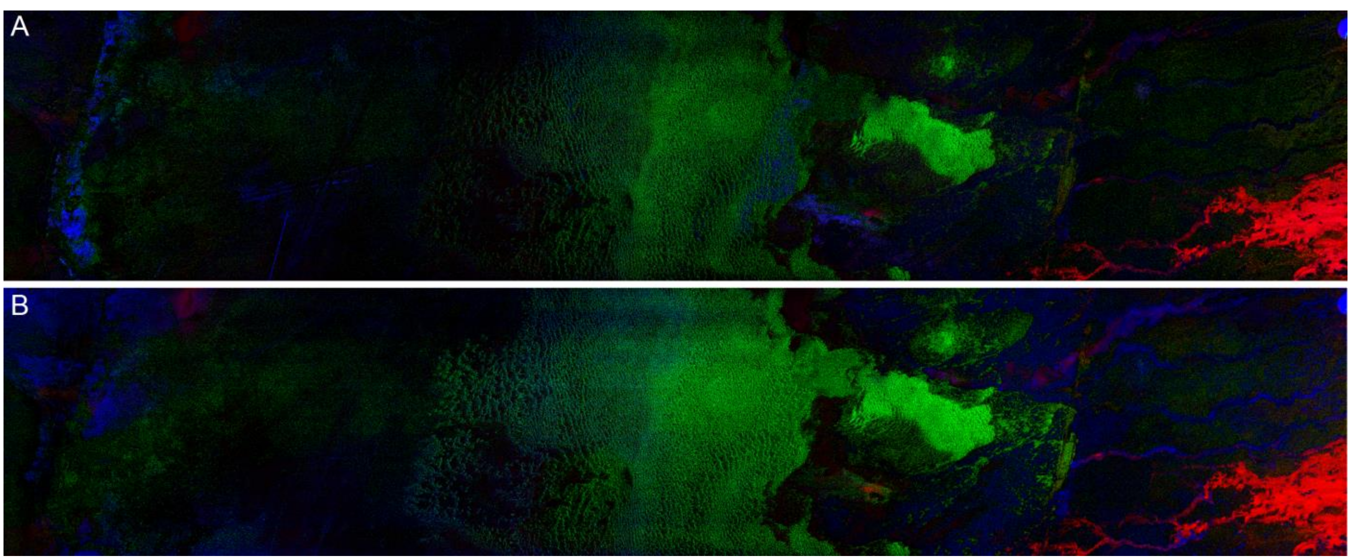

Fig. 5. A. Composite of CEM fraction images of sediment units (Red = iron-rich run-off sediments, Green = gypsum sediments, Blue = iron-poor run-off sediments for the AVIRIS scene f110523t01p00r08rdn_c_sc01 over part of the White Sands region. These images were calculated using the full AVIRIS spectral range (0.4 – 2.5 μm).

B. Composite of CEM fraction images of same endmember, but calculated using target spectra and a dataset convolved to the HICO spectral range (0.4 – 1.0 μm).

4. Field Checking of Mapping Results

We budget for field work to examine several of the study playas (tentatively, Ivanpah, Lunar Lake, Railroad Valley, Bonneville Salt Flats). These areas are too spatially extensive for the team to walk along map contacts as it were; however, we will do spot checking of mapping results with a portable FieldSpec spectroradiometer. Standard field reflectance spectroscopy methodology (e.g., *Deering*, 1989) will be followed. GPS locations of field-checked sites will be logged for comparison to the imagery.

5. Classification of Study Playas

Using the HICO data and supporting datasets, indicators of minerals associated with different playa types will be examined. A preponderance of clay minerals would be associated with playas dominated by clastic minerals and this would be equivalent to the recharge playa type of *Rosen* (1994) and the “dry” playas of *Reynolds et al*. (2007). The detection of evaporite minerals such as gypsum would be indicative of a neutral to alkaline environment and either a discharge or through-flow playa in the hydrologic scheme of *Rosen* (1994) and a “wet” playa as per *Reynolds et al*. (2007). Gypsum and some other hydrated evaporite minerals can be identified even in the VNIR range of HICO based on the presence of a water overtone band at 0.994 μm. For the Australian acid-saline ephemeral lakes, gypsum can also be present, but the presence of additional Fe^{3+}-bearing phases, such as those in **Fig. 3**, can indicate a more acidic groundwater brine.

6. Determination of the Physical State of Playa Surfaces

As noted above, playas with evaporite minerals generally have softer surfaces than dry playas. Thus, the determination of mineralogy aids in the determination of hard vs. soft playa surfaces. Based on the season and the amount of runoff into the playas, either type of playa can have standing water or muddy surfaces. Standing water has a generally low reflectance and a sharp drop-off in reflectance in the near infrared. Wet surfaces show a drop in reflectance which becomes more severe with increasing wavelength and can show the growth of water absorption features near 0.85 and 0.99 μm which is within the HICO spectral range.

7. Assessment of Hazardous Minerals

Previous workers have described certain minerals that can be associated with playas that potentially have a deleterious effect on human health (e.g., *Plumlee and Ziegler*, 2003). These include minerals that can incorporate toxic elements such as arsenic and chromium as has been observed for dust derived from the Owens Lake dry lakebed in California (*Reheis et al*., 2002). In addition, salt minerals are generally deleterious to plant health and thus salts derived from playa surfaces adversely affect nearby agricultural fields. Cataloging minerals observed in the study playas and comparing them against known hazardous minerals, such as those pointed out by *Plumlee and Ziegler* (2003) will be the final research stage of this investigation.

8. Dissemination of Study Results

We will present the results of this research at the HICO Data User’s Meeting (location and time TBD) and at the American Geophysical Union (AGU) annual meeting. In addition, we will assemble the results of this research into a paper to be submitted to a peer-review journal, nominally to *Remote Sensing of Environment*.

Facilities and Other Resources

The Space Science Institute (SSI) and Co-Investigator Bowen’s Department of Geology and Geophysics at the University of Utah have the computing and institutional support required to ensure the success of this proposed investigation. SSI has significant computing capabilities, in addition to several computers with Adobe Flash development software suites, SSI maintains its own web servers and dedicated high speed data connections (T1). SSI also has its own large format banner printer, capable of printing signage for the conferences, poster sessions, and/or workshop components of any project. The PI has a Dell OptiPlex 9020 MiniTower PC with an Intel core i7-4770 processor, 8 GB of memory, and 1 TB hard disk drive with ENVI 5.1, MATLAB, and ArcGIS 10.1. We also request funding for the ENVI Atmospheric Correction Module.

Co-I Bowen has access to a PanAnalytics FieldSpec at the University of Utah's Department of Geology and Geophysics for the proposed field work. We propose to include a University of Utah undergraduate as a summer study student to aid with field work and some data processing.

III. Economic Impact of Project Success

This proposed research will be important to a number of companies and agencies tasked with public health issues, agriculture, and land management. As noted above, playa surfaces can be sources of material that is stripped from the playa surface and incorporated into dust storms. For certain playas, the quantity of dust incorporated into dust clouds can be quite significant. *Plumlee and Ziegler* (2003) state that "during the passage of storm systems, the 24 hour average concentrations of PM10 dust particles (those less than 10 μm in diameter) can exceed 150 $\mu g\ m^{-3}$, more than 10 times the maximum amount allowed under Federal air quality regulations". *Reynolds et al*. (2007) note that "dry" playas (those with surfaces well removed from the top of the water table and composed primarily of clays and clastic sediments) are more resistant to eolian stripping of dust. However, "wet" playas lose ground water through the surface and evaporites can form a porous, "puffy" surface which can be easily stripped by the wind. Thus, the ability to characterize playa surfaces through orbital hyperspectral data, both in terms of the minerals present and the physical state of the playa surfaces, will be valuable in assessing the potential for sediments being stripped from playa surfaces. The approaches and types of data derived from this research could then have an impact for companies and agencies concerned with public health issues that might stem from dust storm impacts.

Likewise, salts stripped from "wet" playa surfaces, when blown onto agricultural fields, increase the salinity of those soils. Salt-affected soils adversely affect agricultural yields. Being able to characterize the amount and types of salts that are stripped from the playa surfaces can thus factor into strategies to mitigate the effects of the salts on nearby agricultural lands. Thus, this work has potential for aiding the agriculture industry in countering soil salinity problems.

Finally, the use of some playas for recreational activities (www.blm.gov/ca/st/en/fo/needles/ivanpah.html) and as corridors for military transport depends on hard, dry surfaces. Vehicular traffic is best done on the "dry" playas of *Reynolds et al.* (2007); however, land speed records have been set on the evaporites of the Bonneville salt flats (*Lines*, 1979) so the dried out surfaces of "wet" playas can also be excellent surfaces for transportation. Thus, groups seeking to use playa surfaces for recreational or transportation purposes need information on the state of the playa surface. As noted above, remote sensing data of the type described in this proposal can be used to provide such information on whether playa surfaces are wet or dry. The broad coverage of the HICO sensor would be especially valuable for this type of characterization of large playas such as Railroad Valley. Thus, this research has potential value for agencies, private groups, and commercial concerns that use playas for vehicular transport.

IV. Budget and Time Frame

Time Frame:

Costs are broken down by month using the template provided in the RFP. In Table 3, we describe tasks based on a quarterly basis.

Table 3. Tasks broken down on a quarterly basis

Quarter	*Task*	*Team Member Involvement*
Oct. – Dec. 2014	Acquire existing data, task HICO for new data collections	Farrand
	Atmospheric correction of data, endmember detection	Farrand
	Present project outline as poster at Fall AGU	Farrand
Jan. – Mar. 2015	Mapping of spectral endmembers, playa minerals	Farrand
	Atmospheric correction of data, endmember detection of new HICO data (data collection time frame is unknown)	Farrand
	Attend HICO data users meeting	Farrand
Apr. – Jun. 2015	Field work at Ivanpah, Railroad Valley, Bonneville playas	Farrand, Bowen, Student intern
	Catalog and analysis of photographs, field spectra	Farrand, Bowen, Student intern
	Comparison of field study to remote sensing maps	Farrand, Bowen, Student intern
Jul. – Sep. 2015	Atmospheric correction of data, endmember detection of new HICO data (data collection time frame is unknown)	Farrand, Student intern
	Assess potential dust hazards for study playas based on mineral detections	Farrand, Bowen, Student intern
Oct. – Dec. 2015	Refine mineral maps based on ground truth	Farrand
	Write paper for *Remote Sensing of Environment*	Farrand, Bowen
	Present project results at Fall AGU	Farrand
Jan. – Mar. 2016	Submit and revise *Remote Sensing of Environment* paper	Farrand, Bowen

Budget Justification:

Direct Costs

Principal Investigator Farrand will be doing the bulk of the work on this proposal including atmospheric correction of the hyperspectral datasets, endmember determinations, and spectral mapping of the endmembers and playa minerals. He will also guide the field work and be the principal author of the proposed Remote Sensing of Environment paper and be the presenter of research at the AGU meetings and the HICO data users meeting. Dr. Farrand is thus requesting 40% coverage of salary time to conduct this work.

The Space Science Institute (SSI) will also directly fund the University of Utah summer study student as an SSI intern. Co-Investigator Bowen is fully funded through her position at the University of Utah and so does not request any coverage for her salary; however, given limited time to devote to the work, the summer study student will be able to conduct work as a field assistant for the proposed field work and to assist Dr. Bowen and to remotely assist Dr. Farrand with tasks such as the cataloging of field photographs, samples and spectra, and preparation of figures for publications. We thus request two work months in both years one and two to support that student.

Other Direct Costs: Materials, Supplies and Publications

- *Materials and Supplies* are requested for SSI at 1.5% of MTDC, based on historical actuals.

- *Software Maintenance*: Given that the PI will be extensively utilizing the IDL/ENVI software for analysis of hyperspectral imagery and spectral analysis, we are requesting maintenance costs for the IDL/ENVI software that is presently priced at $1635 and is budgeted with a 5% per annum increase.
- *Software Purchase*: SSI and the PI do not currently have the ENVI Atmospheric Correction module. The PI has an older version of the ACORN atmospheric correction software, but that software does not allow for the use of the 835 nm atmospheric water band for the correction of atmospheric water effects while the FLAASH program in the ENVI Atmospheric Correction module does allow for the use of that 835 nm band. Thus we budget funds for the purchase of the Atmospheric Correction module in year one with the current price of that software being $2550 and we budget $375 in year two for software maintenance.
- *Communication and Duplication* expenses are requested for SSI at 2% of MTDC, based on historical actuals, as explained in the Proposed Budget Details.
- *Facilities & Administrative Costs:* The SSI rate for a project managed on-site is calculated according to the rate agreement of 9/20/2012. The cognizant Federal agency is NASA, and our contact is Debbie Rafi at the Office of Naval Research, Indirect Cost Branch, 875 N. Randolph St., Rm. 372, Arlington, VA 22203, phone 703-696-5641
- We plan on writing a paper to be submitted to *Remote Sensing of Environment*. That journal does not have page charges; however, in order to accommodate a projected two color pages, we budget $992 in year two (color pages are currently priced at $450 each and thus for year two, we budget for two with inflation at 5% per annum).

Other Direct Costs: Travel

We plan on presenting the results of this research at the Fall meeting of the American Geophysical Union (AGU) and at the HICO data users meeting. In order to field check the remote sensing analyses, we plan on field work at a subset of our study sites with the planned field sites all being accessible by driving from Co-Investigator Bowen's institution in Salt Lake City. Thus we plan for the PI to fly to Salt Lake City and for the Co-I and summer intern to accompany him into the field with the University of Utah FieldSpec reflectance spectrometer in order to examine the Bonneville Salt Flats, Railroad Valley and Lunar Lake playas and the Ivanpah playa.

For the eight days and seven nights of field work, airfare for the PI to travel to Salt Lake City, UT is budgeted at $279 (based on a quote from expedia.com obtained in March 2014). Ground transportation for this trip includes mileage to and from the Denver airport at 33 miles times 2 at $0.56/mile, airport parking at $12/day, and a rental car at $277.71 (based on a quote from expedia.com obtained in March 2014) with three full 13 gallon tanks of gas for a total ground transportation cost of $595. Per diem is estimated based on $92/night for lodging and $71/day meals ($53.25 on travel days), with costs obtained in March 2014 from gsa.gov. Lodging and per diem costs are budgeted for the PI, Co-I Bowen, and the summer intern student so that the total per diem trip cost is $3706.

For the travel to the HICO data users meeting (for three days and two nights), we use a strawman destination of Oregon State University (the home institution of the HICO Principal Investigator) since the location of the 2015 HICO data users meeting has not been set. Airfare for the PI to travel to Corvallis, OR is budgeted at $294 (based on a quote from expedia.com obtained in March 2014). Ground transportation for this trip includes mileage to and from the Denver airport at 33 miles times 2 at $0.56/mile, airport parking at $12/day, and a rental car at $85.27 (based on a quote from expedia.com obtained in March 2014) with a full 13 gallon tank of gas for a total ground transportation cost of $221. Per diem is estimated based on $83/night for lodging and $46/day meals ($34.50 on travel days), with costs obtained in March 2014 from gsa.gov for total per diem trip cost of $295.

To report on the preliminary and final results of the investigation, we budget for travel to San Francisco to attend the American Geophysical Union (AGU) Fall Meeting in December 2015 and 2016. We are budgeting for 3 days of travel with 2 nights of lodging in San Francisco, CA. Air travel is estimated at $326 in 2014 and $342 in 2015 (based on a quote from Expedia.com in March 2014 and inflated at 5% per annum). Ground transportation (including personal car travel to and from the airport at $0.56/mile over the one way distance of 33 miles (times two), and airport parking at $12/day) and an airport shuttle from SFO to downtown San Francisco and back, is budgeted at $140 in 2014 and $147 in 2015. Per diem is budgeted at $71/day for meals ($53.25 for travel days) and $172/night for lodging (with costs obtained from www.gsa.gov in March 2014) so the total meal plus lodging costs (inflated 5% per annum) are $548 in 2014 and $575 in 2015. Registration cost for the AGU meeting is estimated at $530 in 2014 and $557 in 2015 (inflated at 5% per annum).

Indirect Costs:

Indirect costs are based on our negotiated rate with our cognizant federal agency, NASA. This rate is applied to TDC with some exceptions. Costs are recovered only on the first $25K of a subaward.

V. Additional Information

5. No other government or funding agency has reviewed this proposed research.

6. Professional References

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7. We perceive no conflicts of interest.

8. References

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VI. Biographical Sketches of PI and Co-I

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EDUCATION

Ph.D. in Geosciences at the University of Arizona, Tucson, AZ, Spring 1991.
Minor in Remote Sensing
Dissertation Title: Visible and Near Infrared Reflectance of Tuff Rings and Tuff Cones
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M.S. in Geosciences at the University of Arizona, Tucson, AZ, Spring, 1987.
Thesis Title: Highland contamination and minimum basalt thickness in northern Mare Fecunditatis;
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B.S. in Geology at Franklin and Marshall College, Lancaster, PA, Spring 1984.

PROFESSIONAL EXPERIENCE

6/1999 – present: Senior Research Scientist, Space Science Institute, Boulder, CO. Participating Scientist on Mars Exploration Rover mission. Working on NASA Mars Data Analysis and Mars Fundamental Research program projects. Using analog terrestrial sites using AVIRIS, ASTER, and HyMap data and ASD FieldSpec for field reflectance spectrometery. Experience working with Mars Reconnaissance Orbiter CRISM and HiRISE data, MER Pancam and Mini-TES data, Mars Odyssey THEMIS data, Mars Global Surveyor MOC, MOLA, and TES data, and Mars Pathfinder IMP data.

1/1998 - present: Periodic commercial remote sensing consulting work. Analysis of hyper- and multispectral datasets for commercial clients. Teaching workshops on hyperspectral remote sensing phenomenology and processing. Experience with ENVI, IDL, MATLAB, and ArcGIS.

1996 - 1/1998: Senior Research Scientist, Applied Signal and Image Technology, Boulder, CO. Analyzed hyperspectral data sets for purposes of mineral exploration and environmental remediation, integrated remote sensing with other information sources, collected field reflectance spectra, and validated algorithms for hyperspectral data analysis.

1992 - 1995: Research Scientist, Science Applications International Corporation (SAIC), McLean, VA. Worked under contract to Naval Research Laboratory on the Hyperspectral Digital Imagery Collection Experiment (HYDICE). Analyzed hyperspectral data sets for purposes of identification of manmade and natural materials, assisted in planning and conduct of data collections (including collection of ground truth data), represented and gave presentations for program at numerous meetings. Experience with using radiative transfer codes for the atmospheric correction of remote sensing data.

Publications (first author peer-reviewed publications and selected co-author publications):

R.E. Arvidson, S.W. Squyres, J.F. Bell III, J.G. Catalano, B.C. Clark, L.S. Crumpler, P.A. de Souza Jr., A.G. Fairén, **W.H. Farrand**, and 22 others (2014) Ancient aqueous environments at Endeavour Crater, Mars, *Science*, **343**, doi:10.1126/science.1248097.

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Current Grant Funding:

JPL Contract No. 1242887; Mars Exploration Rover (MER) Participating Scientist
Title: Major and Minor Components of the Surface Layer of Mars: An Investigation Using the MER Pancam and mini-TES Instruments
Total Funding: $853,820; Period Covered: 7/23/2002 – 9/28/2014
Principal Investigator: W.H. Farrand

NASA Award NNX12AH92G
Title: Field and Laboratory Studies of Hydrovolcanic Tephras and Impact Ejecta: Applications to Mars Rover Investigations
Total Funding: $195,585; Period Covered: 4/10/2012 – 4/9/2015
Principal Investigator: W.H. Farrand; Co-Is.: S. Wright (Auburn University)

NASA Award NNX11AB25G
Title: Imaging Photometric and Polarimetric Remote Sensing of the Moon
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Total Funding: $297,438; Period Covered: 11/1/2010 – 10/31/2014
Principal Investigator: G. Videen ; Co-Is.: M. Wolff, W. Farrand

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1998- **B.S.** Earth Sciences, *University of California Santa Cruz*, Santa Cruz, CA

<u>B. Professional Experience</u>

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2011 – present	**Associate Research Professor**, Geology and Geophysics, University of Utah
2007 – 2012	**Assistant Professor**, Earth and Atmospheric Sciences, Purdue University
2005 – 2007	**Postdoctoral Research Associate**, Geology, Central Michigan University

<u>C. Publications</u> *(student authors <u>underlined</u>)*

<u>Bell, J.</u> and **Bowen, B.B.**, in press, Fault-focused fluid flow in an acid and redox influenced system: Diageneitc controls on cement mineralogy and geomorphology in the Navajo Sandstone: *Geofluids.*

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D. Current Grant Funding

- Friends of Red Butte Creek: Research, Outreach, and Education Grants: Salt Lake County Watershed Planning and Restoration Program (PI: Bowen), 2013-2014, $15,000.
- U-S^{2}TEM Scholars- Undergraduate Sustainability Science, Technology, Engineering, and Math Scholars: National Science Foundation (Co-PI: Bowen), 2013-2018, $600,000.
- Petrological and Petrophysical Characterization of the Mount Simon Sandstone and Eau Claire Formation in Support of Phase III Sequestration Evaluation: Indiana Geological Survey / U.S. Department of Energy (Co-PI: Bowen), 2008-2014, $172,257.

Synergistic Activities

- Peer Review 2005- present: Reviewer for Science, Geology, Geophysical Research Letters, Geochimica et Cosmochimica Acta, Earth and Planetary Science Letters, Geological Society of America Bulletin, Journal of Sedimentary Research, Palios, Mathmatical Geoscience, Sensors, Rocky Mountain Geology, Applied Geochemistry, NSF- Low Temperature Geochemistry, NSF- Sedimentary Geology and Paleobiology, The International Science and Technology Center (U.S. Civilian Research and Development Foundation), NASA Astrobiology Institute, NASA Education and Outreach, NASA Mars Data Analysis Program, NASA Mars Fundamental Research, NASA Postdoctoral Program, American Chemical Society
- Invited participant in InTeGrate (Interdisciplinary Teaching of Geoscience for a Sustainable Future) workshop (2013)
- Geological Society of America Sedimentary Geology Division Representative, Annual National Meeting Joint Technical Program Committee (2010-2011)
- Member of SEPM Award Nominating Committee (2010)
- Developed interactive museum display at St. Louis Science Center about extreme environments on Earth as analogs for Mars (2006-2013)
- Authored contribution to "Geo-Logic" section of the L.A. Times: Bowen, B.B., 2005, "The Salt of the Earth, Linked to Mars", Los Angeles Times.
- Active in public outreach for Grand Staircase-Escalante National Monument, e.g., featured in interactive "Ask the Experts" geology display at Kanab visitor's center and award-winning film "Traces in Time" by Odyssey Productions, speaker in public summer lecture series (2001-current)