A. Cover Page

Date of Final report *October 1, 2019*

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Project Title: *Seismic characteristics of shallow soils on Mars: Ice in soils*
Program Area: LaSPACE REA

Amount Awarded by LaSPACE:
$34,999 (from 115-31-4101 / Award # AWDC-001589)

Amount PI cost shared:
$35,001
Project Period: September 1, 2018 to August 31, 2019

This funding was awarded under National Aeronautics and Space Agency (NASA) grant number NNX15AH82H.

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1 Final Report

1.1 Technical Description

1.1.1 Goals of the Proposal

A. *Theoretical Robust Elastic Soil Models for Mars*
To create a range of robust elastic soil models constrained by properties such as density, porosity, apparent cohesion, grain angularity, mineral bulk modulus and H_20-ice content from which we can validate predicted seismic velocities through the use of a well-established contact theory.

B. *Detection, Interpretation and Characterization of the Seismic Ice-table Boundary*
To use sand tank physical models will evaluate and calibrate models to data. Our high-resolution piezo-sensors (~1 kHz–5 kHz) detect elastic seismic waves (compressional, shear waves) which respond to changes in density and effective elastic moduli between relatively dry and soils containing frozen pore spaces.

1.1.2 Public Science Summary

Water is key for to support future human missions on the Moon as well as Mars, and high-frequency seismic sounding tools have the potential to provide a minimally invasive characterization of the volume and distribution of ice. Unfortunately, for example, as in the case of Mars, current instrumentation either in orbit or on the current rover cannot detect buried ice. Our results indicate that buried ice, a resource critical to human exploration of Mars, may be detectable using miniature, commercial off-the-shelf seismic sensors.

1.1.3 Accomplishments

Scientific: A combination of ground-penetrating radar (GPR) and seismic data suggest that frozen H_2O water in granular materials is readily detectable by changes to the intrinsic attenuation of the media. For the layer thicknesses (10 cm) in our experiments, clear reflections are not detectable. The strongest seismic arrivals are surface waves. We inverted their dispersion characteristics (velocity versus frequency) to obtain Sv -versus-depth models (See Conference Proceedings below: LPSC conference paper and LPSC poster)

Institutional: A Summer Faculty Fellowship at the NASA/Marshall Space Flight, 2019. I produced a NASA technical report, recently submitted for review and publication (Lorenzo and Patterson, in press)

1.1.4 Ongoing Derivative Activities:

- Proposals to NASA (4 are currently pending response from NASA)

- Summary of Most Recent Proposal: Analog studies of lunar regolith

In order to validate the scalability of my laboratory experimental approach into more realistic field conditions during my NASA/Marshall Fellowship I ran a field experiment at their outdoor regolith field. Through contact-theory, on Earth, seismic velocities in the regolith are controlled by the grain-size texture, moisture and gravitational acceleration so that seismic velocity observations both in the field and the lab should be similar. From the two experiments, I derived Vp values ~ 100 m/s and Vs values ~50 m/s. The Vp/Vs ratio is compatible for the same regolith (Figure 1)

- Minority Student Undergraduate Thesis: Jera'Nae Garner-Donald who began her research work funded under the current proposal is continuing this project which will form part of her undergraduate

thesis titled: Foundations in Granulometry and Morphometry in Seismic Imaging, Jera'Nae is an undergraduate candidate for the B.S. in Biology, President of Bio Jags at Southern University and A & M College, an historically black undergraduate college.

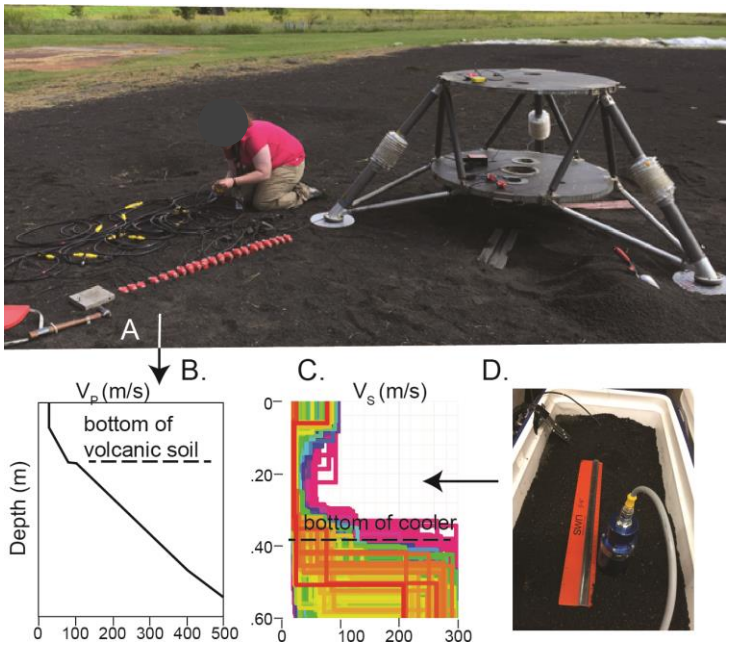

Figure 1. Marshall Space Flight Center Regolith Field geophone seismic experiment adjacent to mock lunar lander; Summer 2019 B. Velocity model derived from refracted seismic arrivals C. A range of seismic inversion results and their RMS misfits (0 .14 --red,to 0.27--blue) against a dispersion curve D. Smaller-scale experiment in the same soil. Signal from a magnetostrictively seismic source (blue) is collected with buried wired sensors (kHz). Ruler is 30 cm. long.

1.1.5 Proposals Submitted (4)

x Pending Title: GANGOTRI mission concept on the glacial key to the Amazonian climate of Mars
Source of Support: NASA
Co-I: 10 % Award Amount: $133,770 Duration: 10/15/2019 - 6/30/2020

X Pending Title: A Short-period Seismic Instrument to Understand Lunar Regolith Processes and Support in-situ Resource Use
Source of Support: NASA
PI: 100% Award Amount: $764,229 : Duration: 1/1/2020 - 12/31/2022

X Pending Title: Conceptual seismic framework to interrogate ground ice depths on Mars
Source of Support: NASA
PI: 100% Award Amount: $414,262 : Duration: 7/1/2019 -6/30/2022

X Pending Title: Analog Lunar Environment for Advancing Seismic Studies (ALEASS)
Co-I:15% Award Amount: $1.5M (sub-contract to NASA/Marshall Space Flight Center)

Photos of Research Activities (See Appendices)

2 Supporting Information

2.1 List of Participants & Description of the Collaboration

Center	Name(s)	Expertise
NASA/ George C. Marshall Space Flight Center, Huntsville, Alabama	Renee Weber	Planetary seismologist
	Caleb Fassett	Planetary surface processes
	Michael Zanetti	
	Heidi Fuqua-Haviland	Electromagnetic planetary fields
University of Central Florida Planetary Sciences Group	Dan Britt	Development of regolith simulants
	Kevin Cannon	Development of regolith simulants
United States Geological Survey, Albuquerque, New Mexico	Robert Anthony	Seismic Instrumentation

2.2 Student Participants

Student	**Home Institution**	**Period of participation**	**Outcomes**
Abah Omale	Louisiana State Univ., Baton Rouge	Aug.-Dec. 2018 $10,000	Current research assistant Graduation expected 2020 (additional grants)
Daniel Locci	Louisiana State Univ., Baton Rouge	May-July 2019 $2,200	Current research assistant Graduation expected 2022 (additional grants)
Jera'Nae Garner-Donald	Southern University HBCU, Baton Rouge	May 2019 – present $850 (supplemented with external awards)	• Research results in professional conference • Undergraduate thesis on "Automated Grain Analysis"

2.2.1 Articles for NASA venues

Lorenzo, J.M., Patterson D.A., in press Evaluation of a Piezo-ceramic sensor *In* Ed. Six, F. NASA Technical Report (number to be assigned) Marshall Space Flight Center Faculty Fellowship Program.

2.2.2 Invited Talks

Lorenzo, J. M., 2019 Seismic properties of soils on Earth and possible applications to Moon and Mar. NASA/Marshall Space Flight Center, and University of Huntsville National Space Science and Technology Center, University of Alabama, Huntsville –August 9, 2019

Lorenzo, J. M., Patterson, D. A., 2018 Seismic properties of soils on Earth and possible applications to Moon and Mar. NASA/Marshall Space Flight Center, and University of Huntsville National Space Science and Technology Center, University of Alabama, Huntsville- October 23, 2018

2.2.3 Conference proceedings

(undergraduate*, and graduate students [1])

Garner-Donald[*], J., **Lorenzo**, J.M., Matherne[1], C. 2019. Foundations in Granulometry and Morphometry in Seismic Imaging. Annual Biomedical Research Conference for Minority Students Anaheim, CA, Nov.13-16, 2019.

Garner-Donald[*], J., **Lorenzo**, J.M., Matherne[1], C. 2019. Foundations in Granulometry and Morphometry in Seismic Imaging. Annual Biomedical Research Conference for Minority Students Anaheim, CA, Nov.13-16, 2019.

Lorenzo, J. M., Patterson, D. A., Karunatillake, S., Weber, R., Haviland, H., and Fassett, C., 2019, Seismic Characteristics of the Shallow (0–1 m) Soils on the Moon and Mars: Ice in Soils, *In* 50th LPSC: Houston, Lunar and Planetary Institute, Abstract #3246. (poster and abstract available upon request to gllore@lsu.edu)

3 Appendices with Photos and Student Demographic Forms

1. Summer Undergraduate Research Presentation

Photo # 1
Jera'Nae Garner-Donald (right) and Daniel Locci-Lopez (left) were two students supported by the current LaSPACE REA grant.

Jera'nae is presenting her poster entitled:
"Foundations in Granulometry and Morphometry in Seismic Imaging" at the 2019 Summer undergraduate Research Form, July 2019. Baton Rouge. Her granulometric analysis was performed on laboratory samples to simulate Mars regolith.

2. Initiation of Collaboration between LSU and Marshall Space Flight Center, Huntsville, AL: on Oct. 23, 2018

Photo #2 of PI presenting research ideas at NASA/Marshall Space Flight Center, Oct. 2018.

Photo #4 of PI (white circle) in the company of fellow NASA/Marshall Faculty Fellows, Huntsville, AL, summer of 2019.

3. Field Experiment at Marshall Space Flight Center: Date: August 14, 2019

Photo #3 of graduate student Deanna Phillips as she lays out LSU geophones adjacent to a mock lunar lander. The lander is constructed to have low weight and strength using titanium honeycomb Aluminum and carbon composites. The lunar regolith field testbed at the Marshall Space Flight Center is built from a lunar regolith simulant from the San Francisco volcanic field in Arizona. R Renee Weber, head of the planetary space science group at Marshall facilitated use of the lander and access to this highly-restricted facility. Marshall NASA participants included R. Weber, M. Zanetti, H. Heidi-Haviland, and the author J. Lorenzo. Logan Kennedy managed the lunar lander.