Mechanisms for Planetary Spherules Formation and Alteration: Salar Grande, Chile – An example of volcanic/aqueous processes interactions. I. Ukstins Peate[1], N. A. Cabrol[2 & 3], E. A. Grin[2 & 3], R. French[4], C. Dressing[5], T. Franklin[6], K. Parsons[1], J. Piatek[7], and G. Chong[8]. [1]Department of Geoscience, University of Iowa, 121 Trowbridge Hall, Iowa City IA 52242. Email: Ingrid-Peate@uiowa.edu; [2]NASA Ames Research Center, CA; [3]SETI Carl Sagan Center, CA; [4]University of California, Santa Cruz, CA; [5]Princeton University, NJ; [6]Massachussetts Institute of Technology, Cambridge, MA; [7]Central Comnnecticut State University, CT; [8]Universidad Catolica del Norte, Centro de Biotechnologia, Antofagasta, Chile.

Project Overview: Silica nodules and hematite spherules are observed in the Atacama desert of Chile at Salar Grande and Monturaqui. The Planetary Spherules Project (PSP) investigates their formation, deposition, and alteration processes as potential analogs to the silica nodules found in Gusev crater and the hematite spherules discovered at Meridiani on Mars.

One of the intriguing early discoveries of the Mars Exploration Rover mission is the observation of spherules, nicknamed 'blueberries', found as lag deposits on the planetary surface sediments and embedded in lithified rocks of Endurance Crater. These spherules are dominantly composed of iron oxides such as hematite and consist of 500 µm – 10 mm spherical solitary spheres with rare occurrences of doublets and triplets [1]. The investigation of the internal morphology of the blueberries using exposed fractured spherules and RAT-abraded spherules embedded in lithified outcrop did not identify the presence of any internal textures. Their mineralogy, texture, composition, distribution, and morphology are consistent with the spherules being secondary-cemented concretions formed in a sedimentary sequence by precipitation from aqueous fluids within the rock some time after the sediments were deposited [2-6]. Several other different formation mechanisms for the blueberries on Mars have been proposed, including meteorite impact into a hematite-rich target terrain generating impactite spherules [7], deposition in volcanic sedimentary rock as a product of fluid flow [8], and formation in a volcanic hydrothermal environment [9]. More recently, silica-rich soils and nodules were discovered at Gusev crater and have been related to past hydrothermal activity [10].

PSP has identified Earth-analog locations of spherules in the Atacama Desert which represent the variation in proposed mechanisms of formation for Martian blueberries and silica nodules. The goal of the project is to better constrain the formation mechanisms of spherules and also examine the effects of weathering, erosion and redistribution on the formation of surface spherule lag deposits. We will apply this information to both *in situ* Mars spherules and lags in order to provide a field-based quantitative assessment of spherule morphology and texture. This will allow critical evaluation of formation mechanisms and lag deposit density and distribution to assess surficial processes responsible for remobilization. Here we present preliminary results of a 2-year field campaign at Salar Grande, Chile, which contains a ~15 km^2 surficial spherule lag deposit and provides our end-member field analog for volcanically-derived spherule formation mechanisms.

Geologic background: The spherules found at Salar Grande form a widely dispersed field along an eastward-sloping fan of debris deposits. The field is bounded to the east by Salar Grande, a currently inactive salar which contains up to 70 m thickness of >99 % pure NaCl. The spherule lag field is bounded to the west by a prominent oblique fault forming the western edge of a fault-bounded graben with fault scarp relief of ~50-70 m. The northern and southern edges of the lag field are not defined by geologic boundaries but occur where the spherule density drops to zero. The eastern edge of the fault graben is part of the Coastal range, and is composed of a sequence of Jurassic intermediate subaerial extrusive volcanic rocks which in southern localities near Antofagasta total approximately 4000 m in thickness. The Jurassic sequence contains small amounts of explosive volcanic deposits and intercalated marine limestones. The extrusive volcanic lava flows serve as the host formation for the spherules observed in lag deposits to the east, and are observed *in situ* as silica-rich anygdules formed by fluid flow in variably altered andesitic sparsely to moderately vesicular lava flows. Once liberated from the lava by weathering processes, the spherules have an outer shell ranging in color from light mustard yellow to rusty red, with rare spherules of green and also rare spherules with a milky white outer surface color. Fractured spherules are milky white to translucent, and display intricate internal banding structures. Some do not display any internal structure.

Results: *Spherule-Size Distribution.* We establish the distribution and density of spherules as clues to their origin, emplacement, and alteration processes. We collected 2,852 spherules in 111 survey points from 5 topographic and sedimentologic profiles located between 668 m-830 m. Several-kilometer long profiles (1.3-2.8 km) were generated by collecting survey points every 100 meters. Three east/west profiles were completed from Salar Grande to the western fault at characteristics locations across the field; one north/south profile was completed across the main debris aprons that appears to be releasing the silica nodule; another north/south profile was completed off the main field, in a perched valley characterized by localized and larger than average silica nodules. Spherules were collected within a 1 m^2 frame at each survey point. They were then sieved and counted in order to understand the changes in density as a function of the source region, if any; their size distribution; and their composition. Results show a 0.5->16 mm size range with most of the population included between 0.5-4 mm. Particle-size distributions are multimodal for all profiles (Figure 1) suggesting either multiple physical (source) or temporal origins for the spherules.

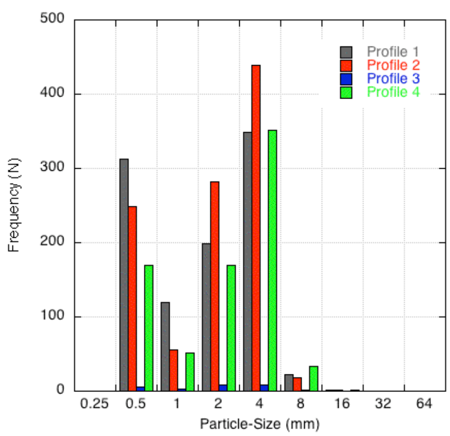

Fig. 1: Spherule-size distribution.

Spherules density and size vary along the slope. Larger diameters are observed at highest elevation; highest densities are observed at the front of gully deposits, suggesting that deposition is related to local gully activation over time.

Spherule Petrology. Spherules are composed of silica (SiO_2) with rare and restricted occurrences of calcite ($CaCO_3$). The internal structure of spherules is defined by complex banding ranging from <10 to >100 microns in thickness. Bands are defined by slight changes in color of the silica from milky opaque to more clear, and also by the presence of scattered iron oxide microcrystals occurring on boundary layers. Color change may be related to cyclic variations in geochemistry of fluids during precipitation of amygdules, or to crystallographic changes in the silicate mineralogy related to temperature of formation. All amygdules, regardless of size, share a common outer (primary) shell of well-defined, smooth silica bands. Internal textures vary, ranging from smooth bands to bulbous clusters and fans nucleating on the inside of the primary shell (Figure 2).

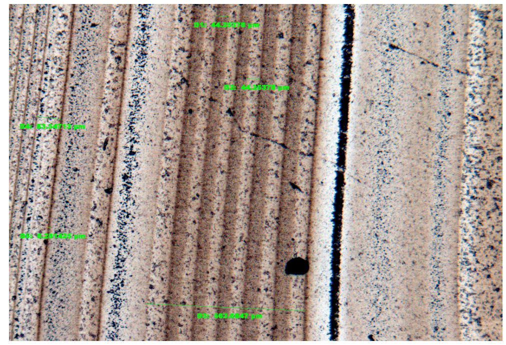

Fig. 2: Thin-section of a banded spherule. The image is 650 µm across.

Micro-stratigraphic banding relationships indicate textural changes occurred during amygdule growth, which could change from regular phases of shell growth to irregular internal growth, back to regular shell growth. These textural changes could be related to variations in fluid chemistry or volume during deposition, or pauses in amygdule growth during formation. Future work targeting geochemical study of the trace element compositions and isotopic variations in the complex spherule banding will allow more detailed evaluation of the petrogenetic evolution of amygdule growth.

Conclusions: The Salar Grande spherule lag field provides an analogy to Mars spherule lag deposits and also provides the opportunity to evaluate volcanic methods of spherule formation, weathering and redistribution processes which may have created fields similar to those currently found on Mars. Salar Grande spherules are formed as amygdules in intermediate composition vesicular effusive lava flows and are dominantly silica in composition with minor amounts of calcite. Spherules are sourced from the Jurassic volcanics of the coastal range and were emplaced in debris flows from the coastal range. Secondary weathering of the debris deposits liberated the spherules from the volcanic matrix and remobilized the spherules to redeposit them on the surface of the debris fan.

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