

EXPLORING ORIGINS OF PITTED/VESICULAR ROCKS IN PERSEVERANCE VALLEY, ENDEAVOUR CRATER. A. W. Tait^{1*}, C. Schröder¹, W. H. Farrand², J. W. Ashley³, B. A. Cohen⁴, R. Gellert⁵, J. Rice⁶, L. C. Crumpler⁷, B. Jolliff⁸, ¹Biological and Environmental Sciences, University of Stirling, Stirling, FK9 4LA, UK (alastair.tait@stir.ac.uk), ²Space Science Institute, Boulder, CO, USA, ³Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, ⁴NASA Goddard Space Flight Centre, Greenbelt, MD, USA, ⁵Department of Physics, University of Guelph, Ontario, Canada, ⁶Planetary Science Institute, Tucson, AZ, USA, ⁷NM Museum of Natural History & Science, Albuquerque, NM, USA, ⁸Washington University in St. Louis, MO, USA.

Introduction: Since sol 4780, the NASA Mars Exploration Rover (MER) *Opportunity* has been traversing down *Perseverance Valley* (PV), a linear, negative-relief feature trending perpendicular to the western flank of Endeavour crater. The goal of the current investigation is to understand PVs geomorphology and chemical composition to determine its mode of formation and approximate age. Formation hypotheses include debris or fluid flow, and wind sculpting, all while intersecting possible Noachian lithologies [1]. Rover observations confirms orbital data that there exists a dextral off-set, indicating a structural origin to the valleys formation [2]. This faulting may have allowed for fluids to interact with the rocks [3]. On sol ~5000 *Opportunity* started to investigate a train of dark pitted/vesicular rocks with an unusual morphology, texture, and composition enriched in Al and Si. Here we describe the rock facies, and explore preliminary formation/alteration hypotheses.

Facies Description: An outcrop of pitted/vesicular rocks lines the upper segment of PV, running parallel with the valley itself. The train is approximately ~15 m long and ~1 m wide, it begins in-line with rocks of the lower Shoemaker formation, within the southern fork of PV. The outcrop is a train of pebble to cobble sized fractions (Fig. 1); if these are indeed float rocks, this does not rule out mechanical transport from higher up the slope. However, the larger targets such as *Tomé*, *San Juan Pueblo* and *Allende* all show a planar fabric with strike and dip in rough alignment with each other (Fig. 1B), implying they are part of a single jointed rock mass.

Under Pancam false color imagery the rocks themselves are dark with a bluish surface; however, the coloration is not uniform, with the dark color terminating near the burial horizon becoming pink/cream in color. This, color, however, also exists higher up on some surfaces which may indicate some of the rocks have rotated (Fig 1A, B). Pancam reflectance spectra of the dark surfaces in the near-infrared (754 – 1009 nm) have a strong negative slope with a an absorption feature centered from 904 to 934 nm, potentially caused by low-Ca pyroxene absorptions [4], while the cream material has a 934 – 1009 nm downturn, indicating a potential hydration feature [5]. The dark surfaces exhibit potentially vesicular pitting on their surfaces. It is unknown at this time if they are true vesicles from volatile release or

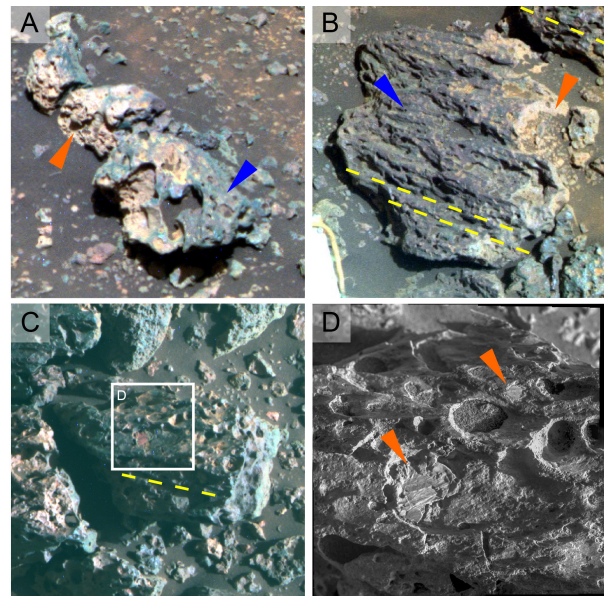


Figure 1. Within these images, orange arrows point to light material associated with ferric reflectance, and blue arrows at the darker pitted/vesicular material of ferrous reflectance. (A) PC Sol 5055 “La Angostura”. Target shows extensive botryoidal textures on the lighter surface. (B) PC Sol 5070 “Allende” this cobble shows a planar fabric (yellow line) through the rock that is parallel to fabric in neighboring rocks (top right). (C) PC Sol 5057 “Nazas”. Cobble shows some planar fabric and two orange spots within pits/vesicles. Insert: (D) MI Sol 5053 “Nazas”. Two orange spots are fine grained, showing aeolian polishing, with raised edges and linear streaks.

pseudo-vesicles. The vesicles are round and show no evidence of shearing, that could have been diagnostic of an extrusive rock. But they do appear to follow a planar fabric through the rock (Fig 1B). The pits/vesicles have rounded edges indicating aeolian processes have exacerbated their cavity. The partially buried target *La Angostura* is lined by pink material which appears botryoidal, with none of the pitting exhibited on the exposed surfaces (Fig 1A). The pink material appears in two locations on rocks within this unit, 1) exposed partially buried rocks, and 2) on the edges of larger cobbles.

On Sol 5060 the rover drove over the rocks easily disturbing and breaking some, which indicates a friable nature. Excavated rocks from this traverse did not show cavities but rather infill with lighter oxidized material. Rocks also exhibited alteration cracks. Microscopic im-

aging (MI) of the surface of *Tomé* revealed a homogeneous fine grained texture of sugary appearance. No clasts could be seen at this scale. During this scuffing, the rover also excavated light colored sediments and orange sands, which are interpreted to be non-ferric evaporitic salts. Inside some of the pits/vesicles of *Tomé* was an orange infill (*Nazas*) that displayed a strong 535 nm band depth indicative of crystalline ferric oxides (Fig. 1C). MI of this feature exhibited a fine grained material that may have been polished through aeolian processes (Fig. 1D). The spot also has a raised rim, which could be due to aeolian sculpting, or it could be zonation.

Formation Hypotheses: *Volcanic origin.* The fine-grained and vesicular textures of the unit is similar to volcanic extrusive and ash-fall deposits. The later having precedent in the Grasberg formation [6]. The material that infills some vesicles is high in alumina, silica and ferric-iron signifying it could be an altered zeolite, indicating fluid alteration (Fig 1D). *Allende* if plotted in total alkali-silica space is a basaltic-andesite in composition, making it evolved over basalt [7].

Impactite. Textures and chemistry of the pitted/vesicular rocks are similar to vesicles terrestrial suevite melt clasts, tektites, and pseudotachylites. Impact melts created by the heat of impact, are characterized by high silica (e.g., glass), with low volatile content (e.g., K, Na, S, H₂O), often contain vesicles, and planar impact fabrics [8]. Similarly, pseudotachylites are melts created by frictional heating from an impact. Direct comparison of terrestrial impactite chemistries to those on Mars is difficult due to different target rock and atmospheric compositions on Earth and Mars. Furthermore the mantle of Mars has undergone volatile depletion during core formation leading to a lower K and Na in crustal composition [9]. We compared elemental ratios within *Allende* to several terrestrial tektites [10,11], suevites melt clasts [12,13], and pseudotachylites [14]. We found that *Allende* had Al/Si, Na/Ca and (K+Na)/Si ratios similar to suevite melt clasts from Chicxulub crater, and pseudotachylites from Vredefort craters. Although sodium was similar for terrestrial pseudotachylites, potassium in *Allende* was considerably lower than potassium found in terrestrial pseudotachylites [8,10]. It should be stated that these rocks have undergone considerable alteration, which could also be masking the original composition (see below). The greater story of impact melt production and subsequent alteration/preservation remains somewhat enigmatic for the Mars case, particularly when compared to the Moon, for which melt production appears to be commonplace for craters small and large. The need to understand such processes enhances interest in impactite candidates found on Mars.

Alteration vein. The enrichment in Si and Al in *Allende* is similar to vein material crosscutting Noachian

material at Endeavour crater predating the impact [15] (this conference). These are interpreted as high water-to-rock ratio alteration veins. The pitted rocks could be similarly altered infilling vein material, potentially facilitated by faulting.

Late Stage Alteration: The reflectance of the pitted rocks indicated that sub-surface alteration has taken place. The light pinker surfaces from the recently exposed rocks are possibly ferric and hydrated, indicating an oxidizing environment. The pits and vesicles align with a planar fabric within the rock, this could be evidence the dissolution of larger clasts with fluid exploiting planes of weakness (e.g., bedding, impact decompression fractures, etc.). Paradoxically, the results from APXS of the pitted rocks show low Cl, despite being surrounded by a light material in the soil (possibly Ca-sulfate, such as those found at Homestake, also in Endeavor crater [16]), which could be a later alteration overprint. The high Al and Si content within the pitted rocks might be residual enrichment as Mg, Fe and other elements are leached from the rocks. Proximity to a proposed fault could provide the source of water needed for this process through a high water-rock interaction or water-vapor leading to cation exchange and the generation of evaporite material [17]. Such increased sub-surface relative humidity would be buffered by clays present within the Noachian units [18]. This could lead to thin films of super-saturated water resulting in reaction driving cracking, fragmenting the rocks apart [19]. Such a process may explain why these rocks are rubble and not a coherent unit.

Take Away Points: Deciphering the protolith of the pitted/vesicular rocks is still unclear, due to an extensive post impact alteration history that is consistent with interaction with fluid masking original compositions. Evidence of such fluids is important to understanding the formational history of *Perseverance Valley*.

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