'Rusty Rocks' from the Moon: Volatile-element Contributions from Meteorites. M. M. Jean[1], B. Bodnar[2], C. Farley[2], and L. A. Taylor[1], [1]Planetary Geosciences Institute, Dept. Earth and Planetary Sciences, University of Tennessee Knoxville TN 37996-1410. [2]Dept. of Geosciences, Virginia Tech University, Blacksburg VA 24601.

Introduction: The origin of rusty alteration within rocks from Apollo 16 has been the subject of debate, ever since its first description by Taylor [1] and El Goresy [2]. This observation is typified in "Rusty Rock" 66095, a fine-grained, subophitic to ophitic polymict breccia [1]. The alteration specifically hosted within 66095 was shown to exhibit volatile enrichments in ^{204}Pb, Cd, Bi, Br, I, Ge, Sb, Tl, Zn, and Cl [3], similar to the claims of Goldschmidt [4]. Although Rusty Rock 66095 is often used as the type example of rusty alteration for Apollo 16, it is not unique among recovered Apollo 16 rocks and soils. Rocks from every station visited during the EVA's of the Apollo 16 mission contain rust-colored alteration [1]. More importantly, Apollo 16 rocks/soils, typical of the highlands in being older than the maria, contain the highest amounts of meteoritic materials, as exemplified by their PGE contents.

We extend the evidence for hydration and oxidation from Apollo 16 samples, beyond rock 66095, to include samples recovered from all stations visited during the Apollo 16 mission (Table 1). These samples comprise a variety of lithologies ranging from regolith/soil, to impact-melt breccias and basalts.

Table 1. Apollo 16 samples with "rusty" alteration surrounding FeNi metal grains

60016	63585	65359	66036	68505
60255	64455	65759	66055	68841
60625	64567	65766	66095	69935
61135	65095	65779	67455	69941
62241	65326	66035	68501	69961

The origins for volatile enrichments observed in the alteration surrounding metal grains have been attributed to fumarolic-hydrothermal or magmatic processes [3]. However, the pervasive nature of the alteration from Apollo 16 observed here, allows us to investigate a third possiblity: meteoritic contributions [1]. Herein, we demonstrate that the volatile compositions of the rust from lunar rocks are always associated with meteorite fragments – abundant in every Apollo 16 sample.

Methods: Major- and minor-element compositions were analyzed with a Cameca SX-100 electron microprobe at the University of Tennessee. Elemental X-ray maps for Fe, Cl, P, and S were collected for FeNi metals with oxidized rims. Raman Spectroscopy for alteration identification was utilized at Virginia Tech.

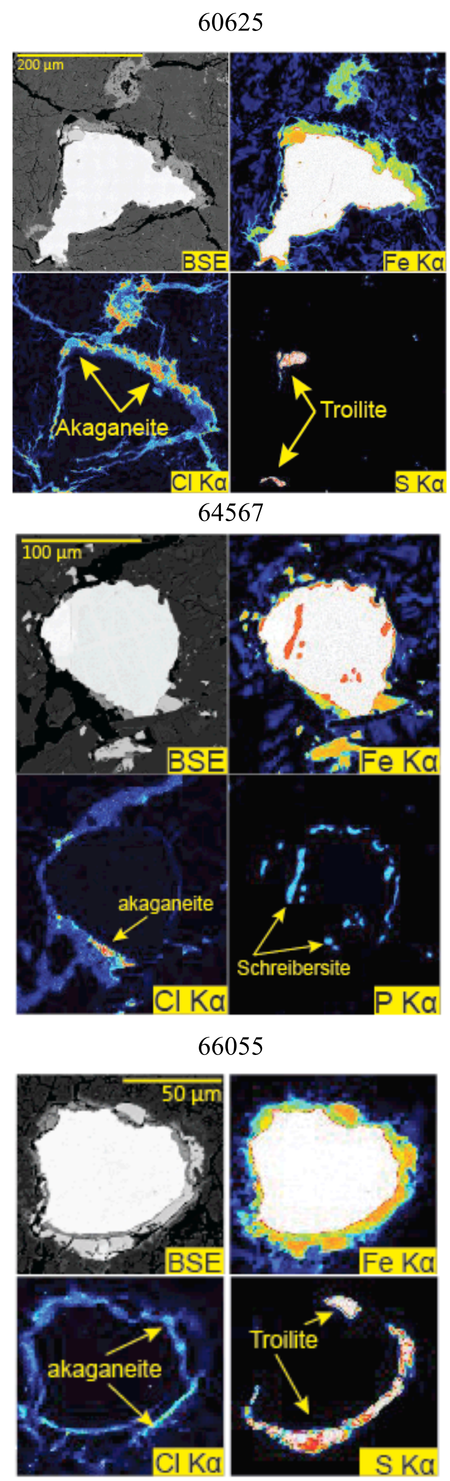

Figure 1. *WDS X-ray maps of rust surrounding FeNi metal grains in Apollo 16 rocks.*

66055

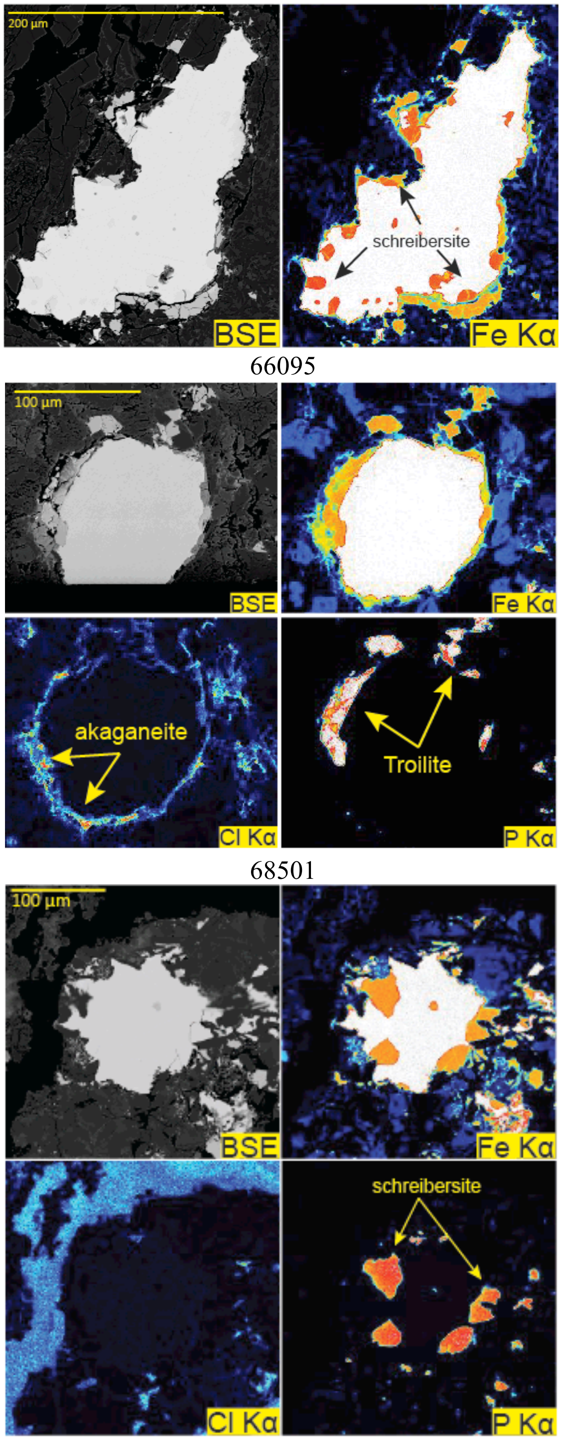

***Figure 1.** continued*

Results: The main phases under investigation, besides the rusty rims, are the FeNi metal, with schreibersite and cohenite, as evidence for meteoritic metal. The FeNi metal grains occur in sub-spherical to elongated shapes, up to several millimeters in diameter (Fig. 1). Schreibersite and cohenite occur as intergrowths within many of the FeNi metal grains (Fig. 1).

The majority of the FeNi metals in these rocks have been oxidized to an FeO(OH) polymorph, e.g., akagaeneite [4], βFeO(OH,Cl), typically producing fritted margins on the metal grains (Fig. 1). Recent studies [3] have focused on chlorine hosted within the alteration in order to examine both the origin of the alteration and the transport of volatiles in the lunar crust and on the lunar surface. We have analyzed the alteration phase akaganeite, adjacent to these large rusty FeNi metal grains, with up to 3.4 wt% Ni, 1.3 wt% Co, and 4.5 wt% Cl, as previously reported by Taylor [1].

Implications for Cl-isotopes: The heavy δ^{37}Cl values observed for 66095 and Apollo 16 soils [3], in general, are interpreted to indicate that Apollo 16 samples are most likely indigenous to the Moon, e.g., degassing of an ejecta blanket or far-less likely degassing of a shallow basalt intrusion, but *not* a product of extra-lunar additions.

Based upon the occurrences of schreibersite and cohenite, in and around the rusty metal grains, as indicative of meteoritic metal, we have identified the rusty grains to be of meteoritic origin. Such metal grains are present in rocks and soils from all sampling sites of Apollo 16. Future investigations of Cl isotopes may help clarify the ongoing debate for the role of extra lunar processes. A real *rusty* meteorite should definitely be analyzed.

Summary: The majority of the Apollo 16 rocks contain rust, and its different phases, associated with FeNi metal. We reaffirm our original interpretation, now four decades old, that the volatile components, particularly the Cl, were introduced into the Apollo 16 soils as meteoritic components. The Cl had effectively reacted with the FeNi metal to form lawrencite ($FeCl_2$), while still in the meteorite. Upon exposure to terrestrial air and water vapor, the lawrencite effectively reacted to βFeO(OH) and HCl, which further oxidized the minerals.

This is depicted by the following reactions:

$$2Cl + Fe\ metal = FeCl_2\ (lawrencite)$$

$$FeCl_2 + \tfrac{1}{2} O_2 + H_2O = \beta FeO(OH,Cl)\ (Ak) + HCl$$

It is our firm opinion that the rust and its volatile components in the Apollo 16 rocks/soils are exogenic, i.e., from meteorites and/or the Earth

References: [1] Taylor, L.A. et al. (1973) *LPS IV*, 829; [2] El Goresy A. et al. (1973) *LPS IV*, 733; [3] Shearer C.K. et al. (2014) *GCA*, 139, 411; [4] Goldschmidt, V.M., 1928, Geochemistry; [5] Taylor L.A. et al. (1974) *Geology*, 2, 429; [6] Hunter R.H and Taylor L.A. (1981) *LPS XXII*, 253.