Introduction: Palagonite is a collective term for altered volcanic glass. Rapidly quenched volcanic glasses in a variety of environments ranging from hydrothermal vents, sub marine and sub glacial environments can form palagonite [1]. Palagonite typically contains an assemblage of primary basaltic glass that has been altered into amorphous hydrated silicate ‘gel-palagonite’ and phyllosilicate (usually smectite) [1]. Although the nakhlite martian meteorites and their secondary alteration assemblages may have very different petrogeneses to palagonite, the types of alteration within them, namely the hydrated silicate assemblages (the most abundant form of alteration in the nakhlites), are also found in palagonite. Of particular interest in the nakhlites is the zoned olivine fracture filling material which dominates them - an Fe-Mg-Al hydrated silicate lacking any detectable crystalline structure by electron diffraction and deemed as a gel [2]. A collective term, iddingsite, has been used to describe these olivine based alteration assemblages [3]. As well as ‘iddingsite’ based terrestrial rocks [4], palagonite may also provide insights into the formation mechanisms of the structurally complex, hydrated and perhaps metastable hydrated silicate assemblages in the nakhlites. Furthermore, the identification of similar terrestrial gels to those in martian meteorites will allow us to identify Mars terrestrial analogues, providing an additional sample yield when understanding the properties of gels, which could also be used to calibrate future Mars payloads and laboratory experiments. The interaction of organic material with these hydrated assemblages by possible biotic and abiotic processes could also be investigated, with palagonite shown to have strong affinities with them on Earth [5,6].

Sample & Methods: Icelandic palagonite is sub glacial altered volcanic glass - hyaloclastite. Samples of weathered hyaloclastite were collected from Valafell, from the north-east of Hekla volcano, Iceland [5]. Pieces of palagonite rock were dropped in epoxy resin. The resin blocks were sliced with a diamond saw to expose non polished, flat faces of the palagonite. The sections were coated with carbon to reduce charging effects under SEM/FIB. SEM and EDX analyses were initially performed with the FEI Quanta 3D dual Beam FIB-SEM attached with an EDAX EDX spectrometer at UNM for phase identification. Indentified phases were then further analyzed by TEM using the JEOL 2010F at UNM. TEM samples of different phases in the hyaloclastite were prepared using FIB.

Results: The Icelandic Palagonite sample chemically displays 2 main phases from BSE and SEM-EDX (Fig.1). The first is the primary glass phase - sideromelane (Al,Ca,Mg,Fe) silicate with minor Na and Ti. The second phase is texturally secondary to the glass. This phase typically has lower Ca and Fe contents, lacks Na by qualitative SEM-EDX and resemble gel-palagonite described in previous studies [1,5]. The samples also contain abundant sub mm sized pores containing either a ‘plated’ or ‘smooth’ texture. All of the pits analysed were pores rather than vesicles due to their circular edges and pitted textures as seen when viewed at various tilt angles with the FIB-SEM (Fig. 1c).

Figure 1. BSE Images of Icelandic Palagonite. (a) Low Mag image showing the generic phases. Bright region is sideromelane - primary glass. Darker material is palagonite-gel. (b) Two types of pores in Icelandic palagonite – smooth, unaltered and pores with plated phyllosilicate on the top surface. (c) Pores are mostly spherical rather than vesicular. Note the inset which shows the layers of alteration that were sectioned through with the FIB (See Fig.2).
The plated pores are an ~10 micron thick assemblage of layered zones of silicate. The layers have different cation concentrations (Ti, Fe,Mg) and lack any structure by SAD, except for the top phyllosilicate layer. These layers ascend to an ~2 micron thick phyllosilicate layer. A Ti-rich layer is closest to the glass interface and transitions to an Fe-rich band, which in turn transitions to an Mg-rich layer, finally terminating with the top phyllosilicate layer (Fig 2b). The concentration of Mg follows a gradient which progressively enriches from the bottom layer up to the phyllosilicate (Fig 2b). It is the phyllosilicate top layer which provides the plated texture of these pores. Some dark blebs of carbonaceous material were also identified in the top gel and phyllosilicate layers (e.g. Fig 2a). This entire assemblage is disconnected from the glass substrate in the pores (Fig. 1c inset).

**Figure 2.** TEM of extracted altered pore as in Fig 1c. (a) DF STEM montage. 1-2 µm top phyllosilicate (smectite) layer in pore transitions to gel layers which are Mg rich-Fe rich-Ti rich. Bright bands are rich in the high Z (Fe and Ti) cations. (b) STEM-EDX map of region in red dash rectangle in (a). (c) SAD of gel and phyllosilicate regions. Dark blebs of carbonaceous material under DF are arrowed.

**Discussion:** The alteration assemblages in the plated pores are zoned silicates which line the surface of the pores. Texturally, the assemblages resemble the fracture filling material in some of the nakhlites which contain olivine fractures margined with phyllosilicate and transition to the SAD amorphous hydrated silicate gel, along the direction of the fractures (Fig. 3) [7]. The distinctive banding of gel layers due to varying cation abundances (primarily variation in Fe in the

**Figure 3.** BF TEM image of olivine fracture filled phyllosilicate-gel assemblage in the Lafayette nakhlite [7]. Dark regions in the gel are high Z Fe rich bands. Similar 2:1 phyllosilicate (smectite) fringes were found in palagonite (Fig. 2).

nakhlites) occurs on the submicron scale (e.g. Fig 3). The enrichment in Ti in the bands closest to the sideromelane interface in palagonite suggests that a transport of cations took place from the glass to this alteration layer. Palagonisation has been shown to involve extensive dissolution processes [8]. Assuming this to be the case, the non-crystalline structure of the gel bands may have been due to the saturation of major cations in the contacting dissolving fluid, precipitating the metastable phase. An Mg enriching gradient across the zones from the bottom to the top of the assemblage (Fig. 2) suggests that Mg was mobile across this alteration sequence with the termination of the Mg-rich layer as stable phyllosilicate (smectite). The Lafayette phyllosilicate-gel assemblages differ by containing Fe enriched bands between the gel-phyllosilicate interface (Fig. 3) rather than this Mg gradient. This could be due to the less pervasive alteration conditions experienced the nakhlites which were preferentially remobilizing/dissolving and saturating the Fe3+ cations from the host olivine grains and/or the richer Fe content in the host olivines. The structural/textural similarity between these Icelandic palagonite and nakhlite assemblages demonstrates that gel-phyllosilicate interfaces occur under diverse alteration scenarios. Sub glacial or submarine palagonisation on Mars may have been conducive to similar types of alteration assemblages if volcanism occurred in those environments [9].

In light of this preliminary study, similar types of analyses of terrestrially altered olivine in the form of ‘iddingsite’ would be worthwhile [4] in order to compare the submicron variation of phyllosilicate-gel, silicate-gel interfaces with altered olivine. There is clear distinction between the identified gel phases here and the crystalline, fibrous phyllosilicate layer which line the top of the hyaloclastite pores. This similarity, especially in the gel) with the nakhlites highlights the need to distinguish it from phyllosilicate when reducing the secondary assemblages in martian meteorites to their constituent parts.