SLOWLY COOLED VOLCANIC GLASSES IN 74221,2. D. Nyarwaya1, A. Dev1, K. Mueller1, D.C. Barker2, M.R. Martinez1,2, D. Luna1, A.M. Shipman1,4, and J. K. Meen1,4. 1Texas Center for Superconductivity, University of Houston, Houston Science Center, 3201 Cullen Blvd, Rm. 202, Houston, Texas 77204 USA (dnyarwaya@uh.edu), 2Department of Earth and Atmospheric Sciences, University of Houston, Science & Research Building 1, 3507 Cullen Blvd, Rm. 312, Houston, Texas 77204 USA, 3Department of Mechanical Engineering, University of Houston, Cullen College of Engineering, 4722 Calhoun Rd., Houston TX 77204 USA, 4Department of Chemistry, University of Houston, Lamar Fleming Jr. Building, 3507 Cullen Blvd, Houston, Texas 77204 USA (jmeen@uh.edu).

Abstract: Hand-picked clasts from a regolith sample were characterized by optical and electron microscopy and chemical analysis. The exteriors of these grains are mantled in olivine, plagioclase, and ilmenite and some have gas-precipitated encrustations. The internal chemistry of the glass clasts shows significant ranges in refractory oxides that require separation of olivine, plagioclase, and ilmenite from the liquid although the phenocryst population is essentially absent except on the surfaces. Volatile oxide contents are very low – much lower than found in glassy spherules from the same regolith. Apparently these glasses cooled much more slowly than those due to fire fountaining and separation of both minerals and volatile elements was given more time to occur.

Introduction: The regolith that enshrouds the lunar surface has a mode dominated by minerals and rock fragments derived from lunar bedrock by excavation at the sites of major impacts, agglutinates (minerals welded together by glasses interpreted to have formed by in situ melting resulting from the continual micrometeorite bombardment of a billion years), and volcanic glass [1]. Volcanic glass extracted from the regolith defines different liquid lines of descent and each coherent set of samples is considered to have been generated from a batch of magma by fire fountaining [2]. We report part of a study of coherent pieces of glass in regolith collected by Apollo 17. This regolith is rich in volcanic materials and is probably near a center of volcanism in the time interval 3.51 To 3.71 Ga ago [3]. Barker and Snow [4] report the chemical and mineralogic data on green and orange glasses. This paper looks at data for regolith fragments from the same regolith sample but that are less obviously glass; pieces that apparently cooled more slowly but originally were similar in composition and origin. An accompanying paper [5] investigates an aphyric polycrystalline basalt from the same regolith sample.

Sample Preparation and Analysis: Approximately 40 mg of the fine fraction of regolith 74221,2 was spread out and, to the extent possible, composite grains were disaggregated. Visibly distinctive green and orange glass spherules were hand-separated for study [4]. Rounded dark grey to black grains were separated. These typically are 50-150 µm in each direction. Each grain was lightly brushed to remove dust and photographed in reflected plane polarized light. The grain was mounted in thermal wax on an individual scanning electron microscope stub and lightly carbon coated. The surface was imaged and x-ray mapped on a JEOL JSM-6330 scanning electron microscope used EDAX Octane Pro EDS and TEAM software. After full documentation of the surface, most grains were removed from the SEM stub and the thermal wax melted off. Remnant wax was dissolved in acetone and, after drying, the grain was mounted in epoxy in a 1 mm brass tube, exposed and polished to 1 µm relief. The surface was then carbon coated (2.5 nm thick) and studied by JEOL JXA8600 electron microprobe using on-line Geller software to manipulate the x-ray wavelength-dispersive spectrometer results.

Surfaces of Grains: The grains of orange and green glasses are spherules or tear drop shaped and almost-uniformly convex. The surfaces of these black glasses tend to be less regular and are undolose with both concave and convex regions. Most of the surface is smooth although some grains have areas that are rough, as documented below.

X-ray spectrometry here used an accelerating voltage of 15 kV so x-rays leaving the surface are derived from the top ∼700 nm of the grain. Most of the x-ray maps are dominated by Mg, Fe, Si, and O; by Ca, Na, Al, Si, and O; or by Fe, Ti, Mg, and O. This indicates that the surface of the grain is composed of olivine, plagioclase, or ilmenite, respectively. A much smaller area yields a multi-element spectrum that shows that glass occurs at the surface. Portions of these areas have particularly high contents of certain elements consistent with plagioclase or olivine grains at the surface but less than 700 nm in thickness above glass.

Some but not all grains have rough areas that are chemically distinct from the rest of the surface. In all cases, these areas were not sufficiently thick to be solely represented in the x-ray spectrum and the spectrum has significant contributions from the underlying material – almost always basaltic glass. This feature, combined with the submicron heterogeneity of these rough areas, renders SEM characterization of the materials inadequate. It is certain that these areas are enriched in K, Na, Cl, P; the grain size of the material is largely
submicron and several mineral species are intergrown. Further studies are planned to characterize these regions and grains with significant cover of such areas have not been sectioned. The most plausible origin model for such regions is as precipitates from volcanic gases after solidification of the grains and at relatively low temperatures. These magmatic exhalatives differ from vapor-deposited postulated by Martinez et al. [6] to have formed from gases generated by impact melting events in numerous respects: in particular, the latter are coarser-grained and discrete from other species.

**Interiors of Grains:** Sectioned grains are very similar in appearance to the glass spherules from the same regolith [4]. They are dominated by areas of glass with distinctive olivine and ilmenite quench crystals. Despite the presence of plagioclase on the surfaces of the grains, plagioclase crystals were not located in the interiors. Careful examination of the edges of the grains confirms the presence of thin mineral grains around each grain margin although much of these minerals were damaged or delaminated by polishing.

Composition heterogeneity between the two populations of glasses is, however, extremely different. Away from clearly quench-growth-modified regions, each glassy spherule has essentially no compositional variation [4]. The glasses described here, however, have considerable differences in contents of all elements. Each grain shows a definite range in each of SiO₂, TiO₂, Al₂O₃, MgO, and FeO contents. Simple fractional crystallization models show that the compositional variations are broadly explicable by separation of olivine, plagioclase, and ilmenite from the most mafic liquid of each grain. In every case, all three minerals must separate for reasonable modeling.

Other elements tell a different story – K, Na, P, and F all have very low concentrations. Internal variations are, again, quite large. These volatile species were given enough time to effectively separate from much of the glass.

The process by which these glasses were liberated from their parental magmas is unclear but the time that they spent exposed as liquid appears to have been considerable. Minerals crystallized from the liquid, presumably directly on the surfaces of the droplets. This resulted in significant changes in the compositions of the liquids. Simultaneously, the liquids were losing volatile elements from the surface – a process that must have altered the phase relations of the systems.

**References:**