EXPLOSIVE VOLCANISM ASSOCIATED WITH THE SILICIC COMPTON-BELKOVICH VOLCANIC COMPLEX: IMPLICATIONS FOR MAGMA WATER CONTENT. L. Wilson[1,2] and J. W.Head[2] [1]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK, l.wilson@lancaster.ac.uk, [2]Dept. of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912 USA, James_Head@brown.edu

Introduction: The edifices that form the Compton-Belkovich complex on the lunar farside have been interpreted as volcanic extrusions of high-silica (rhyolite) composition based on their albedo [1], mineralogy and Th content [2]. Surrounding the high albedo, positive topography of the extruded features, occupying a 25 × 35 km (~690 km^2) area, is a larger area of high Th content measured by the Lunar Prospector Gamma Ray Spectrometer. This thorium distribution is interpreted to define the extent of a pyroclastic blanket surrounding the extrusive volcanic complex [3], including an inner blanket with a radius of ~33 to 44 km (~900 km^2) and a Th content of ~20 ppm and an outer blanket extending up to 300 km to the east of the complex (covering ~60,000 km^2) with a Th content of ~2 ppm. Mini-RF data from LRO support the idea that these areas are poor in blocks and dominated by (possibly pyroclastic) fines down to depths of at least 10s of cm [4]. We support the interpretation of the Compton-Belkovich volcanic complex (CBVC) as a high-silica eruption site with effusive and pyroclastic components, and use the spatial distribution of albedo and Th to estimate 1) the nature of the explosive eruptions, 2) the distribution of the pyroclasts, and 3) the equivalent water content of the magma that erupted explosively, all from first principles [5-10].

Theory: Rhyolitic eruptions commonly involve the explosive eruption of magma enriched in volatiles concentrated into the upper part of the magma reservoir followed by extrusion of the more volatile-poor magma below. Any explosive eruption derives the kinetic energy of the ejected gas and pyroclasts, and hence the velocity of the pyroclasts, from expansion of the gas component. How the gas expands (adiabatically or nearly isothermally) is controlled by the extent to which it stays in good thermal contact with the magmatic liquid forming the pyroclasts. Where the gas mass fraction is small compared with the liquid fraction, it is common to assume that the system is isothermal, especially if not much gas expansion occurs. Under more general conditions a better approximation is to treat the mixture as a pseudo-gas expanding adiabatically with bulk thermodynamic properties that are weighted composites of the properties of the components. The most detailed option is to track the gas-pyroclast thermal interactions via the optical depth of the jet of material that leaves the vent, thus allowing for a change from isothermal to adiabatic gas behavior.

Under lunar conditions, i.e. no atmosphere, gas eventually expands to zero pressure (whereas on bodies with atmospheres gas expansion stops when atmospheric pressure is reached). This means that the flow of gas and entrained pyroclasts in the surface vent is almost always choked, i.e. the speed is limited to the speed of sound waves in the mixture. Further gas decompression above the vent is via a system of shocks. Continued gas expansion toward zero pressure eventually causes the system to enter the Knudsen regime where collisions between gas molecules are less frequent than collisions between gas molecules and pyroclasts. The normal drag force interaction between particles and gas ceases to apply and pyroclasts then travel on independently of the gas to follow truly ballistic trajectories under gravity. The above principles have been used in a series of papers analyzing explosive eruptions into a vacuum [5-10]. We now apply these principles to the nature of pyroclastic eruptions in the CBVC.

Modeling: A consequence of the very large amounts of gas expansion into the lunar vacuum is that every tiny gas bubble that nucleates as the pressure in the magmatic fluid decreases on approaching the surface will expand indefinitely - at least until cooling causes the host liquid to become so viscous that expansion is resisted. The result is that a magmatic foam is formed, the disintegration of which tears the magmatic liquid apart into pyroclasts that are expected to be systematically much smaller in lunar eruptions than in otherwise similar terrestrial ones. Lunar basaltic pyroclasts, e.g. in Apollo 17 samples, range in size mainly from ~30 to ~400 μm [11]. Basaltic pyroclasts on Earth generally range up to much coarser sizes, spanning tens of μm to at least tens of cm [12]. Silicic eruptions on Earth involve a very wide range of clast sizes, with the bulk of particles typically in the range 1 μm to a few tens of mm [13], though some pumice clasts up to ~1 m in size can occur [12]. Given the likely greater propensity for gas bubble expansion in lunar conditions, we expect the size distribution of pyroclasts in lunar silicic eruptions from the CBVC vents to be mainly in the range 1 μm to 1 mm.

We have simulated explosive eruptions on the Moon [10] in which either (a) all of the pyroclasts were ~300 μm in size (approximately the median size for mafic clasts) and were accelerated by the expanding volcanic gas (assumed to be dominated by CO) in accordance with the progressive detailed gas expansion scheme described above, or (b) 80% by mass of the pyroclasts

were much coarser than 1 mm and decoupled rapidly from the gas flow, leaving the remaining 20% of the erupted pyroclasts with ~300 μm sizes to accelerate as before. The distribution of pyroclasts inferred from the Th data at the CBVC could be explained by just this kind of size sorting. Table 1 is based on data from our Table 12 in [10] but has been expanded to include larger amounts of the gas component and hence greater maximum pyroclast ranges. The data have also been modified by changing the assumed gas composition from CO to H_2O since this is the commonest volatile in high-silica melts. The result can only be an approximate simulation of the CBVC case because (a) it deals with a bimodal distribution of clast sizes rather than a continuous distribution, (b) we do not know the distribution of pyroclast sizes at the CBVC, and (c) we are not sure that H_2O is the dominant volatile. However, it serves to illustrate the proposed scenario. In Table 1 the total volatile content, n, is given in both ppm and wt.% for ease of reading; R_{mono} is the implied maximum range of pyroclasts when all of the clast have the median 300 μm size; R_{coarse} and R_{fine} are the maximum ranges of the coarse and fine fractions when the bimodal size distribution is assumed, as seems applicable here. In a previous analysis by others [3], CBVC explosion products were treated as a single phase in which all pyroclasts acquire the same speed as the gas, that speed being the result of the conversion of all of the initial internal energy of the (assumed) single-phase fluid to kinetic energy. These assumptions ignore many important components of the processes involved (as outlined above), and result in underestimates of the ejection speeds and dispersal values for equivalent initial temperatures and gas phase compositions.

Results: If we interpret the 33 to 44 km radius of the inner pyroclastic deposit identified by [3] at the CBVC as the coarse component radius, R_{coarse} in Table 1, this implies that the magmatic water content, n, was ~2.5-3.5 wt.%. Similarly the ~300 km maximum extent of the outer pyroclastic deposit implies n = ~2 wt.%. Taken together these results imply an H_2O content of ~2-2.5 wt.%. This would not be a high water content in a terrestrial andesite or rhyolite. Using solubility data for water in rhyolite of [14], a magma reservoir top would have to be at a depth of at least ~7-10 km in the lunar crust to retain this amount of water. [15] have estimated that the CBVC extrusives contain ~0.55 wt.% residual water, making the pre-eruption total 2.5-3 wt.%. This would require the magma top to be at depths of at least 10-15 km. Note that these depths are very much minimum values, and are entirely consistent with the suggestion that these magma reservoirs were located at the density trap at the base of the crust [10].

Using topographic data [2] we estimate the volume of the CBVC extrusives to be ~160 km^3. Against a background regolith Th content of ~1 ppm, the inner and outer pyroclastic blanket Th contents of 20 ppm and 2 ppm, respectively, imply that up to 50% of the outer blanket (~60,000 km^2) and essentially all of the inner blanket (~900 km^2) consist of pyroclasts down to depth suggested by the mini-RF data of [4] to be at least of order 0.5 m. These values imply a total pyroclast volume of ~12 km^3, ~7% of a total erupted volume of ~172 km^3. The pyroclast blanket does not retain impact craters well [16-17], suggesting that it may be much thicker, say 5 m; this would make the total pyroclast volume ~80 km^3, ~30% of a total erupted volume of ~240 km^3. If the underlying magma reservoir had the same ~690 km^2 plan-view area as the topographic and albedo feature, the erupted magma would have occupied the upper ~350 m of the reservoir. The physical nature of such regional pyroclastic deposits could readily explain the young and unusual crater retention ages reported [2,16-17], suggesting instead a much older age for the deposit that previously reported [2].

Table 1: Pyroclast ranges as a function of magma water content, n, for a monodisperse (R_{mono}) and a bimodal (R_{coarse} and R_{fine}) pyroclast size distribution.

n /ppm	n /%	R_{mono} /km	R_{coarse} /km	R_{fine} /km
500	0.05	2.8	0.7	8.0
1000	0.1	5.3	1.3	16
2000	0.2	11	2.7	32
5000	0.5	27	6.7	81
10000	1	55	13	161
20000	2	109	27	322
30000	3	163	40	482
40000	4	218	53	643
50000	5	272	67	804

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