THE MOBILITY OF VOLATILES IN HIGHLAND ROCKS: MINERALOGIC EVIDENCE. R. H. Hunter and L. A. Taylor, Department of Geological Sciences, The University of Tennessee, Knoxville, Tennessee 37916.

A characteristic of lunar highland rocks is their relative abundance of halogens, P, and volatile metals, Zn, Cd, etc. Some samples eg., 66095, are notably enriched in these volatile elements. In igneous rocks most of the Cl and P are present in apatite and/or whitlockite, and the abundances of these phases reflect high volatile fugacities in the melt stage (1). However, in breccias and impact melt-rocks, ie., the majority of highland rocks, Cl and P are present in lawrencite ($FeCl_2$), now manifest in akaganéite - $\beta FeOOH$, and schreibersite - $(FeNi)_3P$ (Taylor and Hunter, this volume). These phases are often overlooked when interpreting Cl and P data in highland rocks, and their abundances reflect impact and metamorphic processes and meteoritic contamination (1). In order to asess the pervasiveness of volatiles in the highland rocks, a petrographic search was undertaken in Apollo samples for akaganéite and schreibersite. Particular attention was paid to pristine samples and possible correlations between the presence or absence of 'rust' and schreibersite, rock type, and sampling station.

The data-base was restricted by the existence and availability of thin-sections in the Lunar Sample Library. 148 rock-samples were studied. The Ryder and Norman Apollo 16 compilation (2) was found to be invaluable in this study. Of the samples with original weight of less than 20 gms., many had poor representations, and often only one probe-mount or polished thin-section was available. Whenever possible at least two thin-sections of each sample were examined using a high-power objective (40X), and the presence or absence of rust and schreibersite were recorded, and if present their relative abundances. The mass of the samples also was an important consideration. The probability of finding a phase at the 1 modal% abundance level decreases with decreasing sample size; taken to an extreme, a monomineralic grain, eg., of plagioclase, will contain neither rust nor schreibersite. No meaningful method of evaluating these mass data was available, but less emphasis should be placed upon the absence of these phases in samples of less than 20 gms.

The results of the survey are presented in Table 1; a list of the samples checked, their rock-types, presence or absence, and relative abundance of rust and schreibersite, and the weight category of the rock. The data are presented graphically in Figure 1, as a function of sample station and weight category.

Rust and Schreibersite. Of the 99 samples greater than 20 gms., 63 contain rust, 70 contain schreibersite and 52 contain both phases. The presence of rust indicates the former presence of lawrencite (3). This $FeCl_2$ oxyhydrates of FeOOH by contamination with terrestrial water vapor. It is usually associated with native FeNi metal. Indeed the presence of native metal as a scaveger or sink is a requisite for the formation of lawrencite, the precursor of 'rust'. Schreibersite commonly occurs with native metal and, to some extent, indicates the mobility of P. However, this phase is often difficult to detect, especially when is association with the metal. It is often misidentified as troilite. The presence of rust and schreibersite indicates that both Cl and P may have been mobile - probably during impact metamorphism (1). However, some of the schreibersite is undoubtedly of meteoritic origin and no reliable method exists for establishing the meteoritic versus lunar origin of schreibersite or native metal.

Pristinity. The majority of pristine samples are of cataclastic anorthosite and exist as clasts within impact melt rocks or breccia (4.5). Rust and schreibersite are absent from the majority of pristine clasts, the exceptions being 67435 and 67975, both of which contain traces of rust ie., Cl. However, rust and/or schreibersite are present in glassy melt fragments or matrix attached to several of the pristine clasts. One such notable occurence is in 61016. The pristine clasts where the volatile-bearing phases have been identified in attached glass or matrix have been indicated in Table 1 by the addition of G or M to the clast-type description.

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Pristinity is usually judged by low siderophile element content; this, and other criteria, are reviewed in (6). Pristine samples "have retained their bulk-chemistry without contamination by other lunar or non-lunar materials" (4.5). The absence of a scavenger phase - native FeNi metal - in pristine clasts, possibly accounts for the lack of volatile bearing phases; but we have established the pervasive nature of Cl and P throughout the clast-laden matrix. Our observations indicate that care is required when interpreting or extrapolating volatile element data from "pristine" samples.

Rock-type. The majority of observed rust and schreibersite occurs in impact-melt rocks or breccia matrices. In the breccias and cataclastic anorthosites, the volatile-bearing phases are largely absent from the anorthositic clasts themselves, as noted above for the pristine clasts. This is likely a function of the absence of a scavenger or sink phase in the ANT suite clasts. Alternatively a "plumbing" problem may exist. The melt rocks, as well as such clasts in breccias, contain both rust and schreibersite, whereas the anorthositic clasts do not. This suggests that the volatiles were pervasive, not during the melt stage, but subsequent to crystallization. If the volatiles were present during the melt stage, these elements should have near-homogenous distribution throughout the entire rock, matrix and clasts alike. Thus, the pervasiveness of the volatiles is a function of porosity within the sample; the impact-melt rock contains more cracks, voids and avenues for volatile penetration. Many samples contain glassy material and/or thin glassy rinds, indicating quenching from the liquid state. The glass in these samples often contains schreibersite, but no rust, associated with spherical, native FeNi blebs, and these blebs may have a significant meteoritic component.

Sampling station. Figure 1 shows the abundance of rust and schreibersite as a function of sampling station. The stations have been grouped according to general position at the Apollo 16 landing site in order to evaluate any possible control of site stratigraphy on the pervasiveness of the volatiles. No apparent correlations exist; however, this may be a function of our inadequate data-base. A distinct paucity of thin-sections exists for samples from some of the stations, eg., Station 2. In addition, some stations only a few samples were collected, notably Stations 6 and 9.

Conclusions. This study has established the pervasiveness of the volatile elements Cl and P, as indicated by the presence of akaganéite (Rust) and schreibersite. The majority of the 148 rock-samples studied contain either rust or schreibersite. Of the samples greater than 20 gms. original weight, 63% contain rust, 70% contain schreibersite, and 52% contain both phases. Undoubtedly, other volatile elements are similarly pervasive. Positive correlations of Cl with Zn in 66095 clasts and matrix (Wänke *et al*., this volume) indicate that Zn and probably other volatile elements are likely to be enriched in samples containing rust. Indeed, the rust may not be the "red herring" as originally thought.

The origin of the volatiles is still a point of conjecture, as is their mechanism of emplacement. Of the two likely sources; fumarolic activity; metamorphism and volatilization from KREEP, we feel that the latter predominates. Some of the P may have its origin in meteoritic contamination, ie., FeNi metal or schreibersite. Factors controlling the present distribution of volatile elements in lunar highland rocks are: degree of metamorphism (1), mineralogy (Taylor and Hunter, this volume), porosity ('plumbing'), and presence or absence of scavenger or sink phases.

The virginity of certain "pristine samples" may have been violated by the penetrative effect of fugitive volatile elements.

References. (1) Garrison, J. R. Jr. and Taylor, L. A., 1980. Proc. Lun. Highlands Conf. (2) Ryder G. and Norman M., 1980. JSC Publ. 16904. (3) Taylor L. A. *et al*., 1973, PLSC 4th. (4) Ryder G. and Norman M., 1979. JSC Publ. 14565. (5) Ryder G. and Norman M., 1979. JSC Publ. 14603. (6) Warren P. H. and Wasson J. T., 1977. PLSC 8th.

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	Rock type	Rust	Schr.	Wt.		Rock type	Rust	Schr.	Wt.		Rock type	Rust	Schr.	Wt.		Rock type	Rust	Schr.	Wt.
60015*	AG	+	++	1	61548	M	+	++	3	64537	B	+	+++	2	67075*	A	0	0	2
60016	B	++	0	1	61558	G	0	+	4'	64538	B	0	++	3	67095	M	+	++	2
60017	M	0	0	1	61568	M	0	+	4	64559	M	0	++	3	67115	B	+	++	2
60018	M	+++	+	1	61569	M	0	0	4	64567	M	++	++	4	67215	B	+++	+	2
60019	B	++	0	1	61575	M	0	0	4	64576	M	0	++	4	67235	M	++	++	1
60025*	A	0	0	1	62235	M	+	0	2	64579	M	0	++	4'	67415	A	+	+	2
60035	B	+	+	1	62237*	A	0	0	3	64585	M	0	++	4'	67435*	A	+	+++	2
60055*	A	0	0	3	62255*	AG	0	++	1	64586	M	0	++	4'	67455*	AM	+++	0	1
60056	A	0	0	4	62275	A	0	0	1	64815	M	0	0	4	67475	M	+	+	2
60075	B	0	+	2	62295	M	0	+++	1	64816	M	0	++	4'	67565	M	+	0	4
60095	G	0	+++	3	63335	M	0	0	3	64818	B	0	0	4	67605	B	0	0	3
60115	B	+	+	2	63355	M	+++	++	3	65015	M	0	0	1	67638	B	0	0	4
60135	A	0	++	2	63505	M	0	0	4	65016	G	0	++	3	67669	B	0	0	4
60215*	A	0	0	2	63506	M	0	0	4	65035	A	0	++	2	67705	G	0	++	4
60235	M	+++	+++	3	63525	M	0	0	4	65055	M	0	0	1	67729	B	0	++	3
60255	B	++	+	1	63527	M	+++	0	4	65056	M	++	++	3	67735	M	0	0	4
60275	B	+	++	2	63529	M	0	0	3	65075	M	+++	+++	2	67915	B	+	++	1
60315	M	+	+++	1	63535	M	0	0	4	65095	B	+++	++	1	67935	M	++	++	2
60335	M	+	+++	2	63537	M	++	++	4'	65315*	AG	0	++	2	67936	M	+	+	3
60525	M	++	0	4	63538	M	+	0	3	65325*	AM	++	0	3	67937	M	+	+++	3
60615	M	0	++	3	63546	M	0	0	4	65326	A	++	0	3	67955	M	+++	++	2
60618	M	+	+	3	63549	M	+	++	3	65359	B	++	++	4'	67975*	AM	++	0	2
60625	M	+++	+++	4	63559	G	0	0	4	65715	B	+++	+	3	68035	B	0	0	3
60639*	A	0	0	2	63577	B	+	0	4	65759	A	++	0	4'	68115	B	+	+++	1
60665	G	0	+++	3	63579	M	0	0	4	65766	A	++	0	4'	68415	M	0	+	2
60666	M	0	+++	4	63585	M	+++	+++	3	65779	M	++	++	4	68416	M	0	++	2
61015	B	0	++	1	63587	M	0	+	3	66035	B	++	++	2	68505	M	++	0	4'
61016*	AM	+++	+	1	63596	M	++	0	4	66036	B	+	+	4'	68515	B	+++	+++	2
61135	B	++	+++	2	63597	M	0	0	4	66037	B	+	++	4'	68517	B	0	0	4
61155	M	0	0	3	63598	M	++	+	4	66055	B	+++	+++	1	68519	M	++	++	4
61156	M	+	++	3	64435*	AM	+	0	1	66075	B	0	0	2	68525	M	+++	0	3
61175	B	++	++	1	64455	M	++	++	3	66095	M	+++	+++	1	68526	M	0	0	4
61195	B	++	++	1	64475	B	++	+++	1	67015	B	+	0	1	68529	G	0	0	4
61295	B	+	+++	2	64476	B	+++	++	2	67016	B	+++	0	1	68815	B	++	+	1
61536	B	+	++	3	64478	M	0	0	4	67025	M	++	0	4	69935	B	++	+	2
61546	M	0	++	2	64535	B	+	++	2	67035*	A	0	0	2	69945	M	++	++	4
61547	M	0	0	4	64536	B	+++	+++	2	67055	B	0	0	2	69955*	AG	+	+	3

Table 1. Occurrence of "rust" and schreibersite in Apollo 16 samples. Rock-type; A = ANT Suite, B = Breccia, G = Glass, M = Impact-melt rock. Phase abundances; +++ = abundant, ++ = present, + = trace, 0 = absent. * indicates pristine sample. It must be noted that sample numbers beginning 60- are from Station 10, 63- are from Station 13, and 67- are from Station 11. Weight categories; 1 = >500 gms.,2 = 500-100 gms.,3 = 100-20 gms., 4 = 20-5 gms., (4' = samples less than 5 gms.).

FIG. 1