SHOCK-INDUCED GEOCHEMICAL VARIATIONS IN THE KEPLERITE-BEARING ASSEMBLAGES OF TISSINT AND INTERGROWN APATITE-MERRILLITE ASSEMBLAGES OF ALH 84001,146

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Dedication

To Baba, Dide, Mama, and Tata.

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ABSTRACT SHOCK-INDUCED GEOCHEMICAL VARIATIONS IN THE KEPLERITE-BEARING ASSEMBLAGES OF TISSINT AND INTERGROWN APATITE-MERRILLITE ASSEMBLAGES OF ALH 84001,146

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Shock metamorphism describes changes (physical, chemical) that occur to materials (structures, rocks, minerals) as a result of shock wave deformation. All Martian meteorites have been subjected to shock, though the degree of shock, and subsequent changes to the physical and chemical characteristics of these rocks, is highly variable. Extensive chemical and structural heterogeneities may occur as a result of shock metamorphism; however, the way in which phosphate minerals respond to shockmetamorphism is not well constrained. Here we present new evidence of shock-induced chemical variations in the keplerite-bearing assemblages of Tissint and the apatitemerrillite assemblages of ALH 84001. Geochemical and structural studies of phosphate phases were investigated using Electron Probe MicroAnalyzer (EMPA), Raman Spectroscopy, Scanning Electron Microscopy (SEM), and Electron Backscatter Diffraction (EBSD) analytical techniques. Phosphates identified included *Low-Na* (Na# = 2.3) keplerite in Tissint and intergrown Cl-rich-apatite with *High-Na* merrillite (Na# = 8.3) in ALH 84001. Na-number is the calculated atomic ratio of sodium to the sum of sodium and calcium ([Na_{atomic}/(Na_{atomic}+Ca_{atmoic})]*100). Presence of keplerite (a newly defined, high-temperature, Na-deficient, phosphate) in Tissint suggests it may be common and occur in a broader range of environments (i.e., meteorite groups) than initially established. ALH 84001 apatite was found to be heterogeneously enriched in halogens with Cl between 3.85 and 5.05 wt% and F between 0.30 and 0.92 wt%. Assuming F + Cl + OH = 1.0 structural formula unit (sfu); average atoms per formula unit (apfu) of F = 0.16, while apfu of Cl = 0.63. Therefore, water content of apatite in ALH 84001 is estimated at 0.21 sfu or, ~21% hydroxyl apatite component. Thus, indicating that parental magmas were Cl-rich and OH-poor. Intergrown apatite-merrillite phases were observed as well, with textures suggesting the replacement of magmatic apatite by merrillite in the solid-state following a shock-metamorphic event.

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CHAPTER 1:

INTRODUCTION

At current, the only source for Martian material exists in the form of Martian meteorites. Fundamental insight regarding the source, evolution, and concentration of Martian volatile species (Darling et al., 2021; Filiberto et al., 2016), the petrogenesis of Martian magma systems (Howarth et al., 2015), and the dynamics of ejection events on Mars (Min et al., 2017) can be gained by studying minerals, such as phosphate phases, contained within these meteoritic rocks. However, due to a long geologic history of collisions with other solar system bodies (Treiman, 1995, 1998, 2021; Udry et al., 2020), all Martian meteorites have experienced shock metamorphism and therefore have undergone some degree of physical and/or chemical change. Despite this fact, the effect of shock on the chemistry of phosphate minerals is not well constrained (Darling et al., 2021).

1.1 Meteorite Classification

Meteorites are rocky and, sometimes, metallic objects which, after being ejected from their parent bodies, travel through space and eventually collide with the surfaces of Earth, the Moon, and other solar system bodies. If a meteorite is successfully recovered after an individual witnesses it traveling through the earth's atmosphere, then the recovered meteorite is considered to be a *fall*; if a meteorite is recovered but cannot be linked to an observed fall, then it is considered to be a *find*.

Meteorite nomenclature is based on the geographic location where a meteorite was recovered and can include a numbering system as well (with 3-6 digits, depending on the information that is recorded), if the location in question has a high meteorite recovery rate (e.g., MIL 03346 was the 346th sample to be classified from Antarctica's Miller Range during the 2003 – 2004 field season). The Meteoritical Bulletin Database maintains a comprehensive list of all formally recognized and officially classified meteorites; as of 22

October 2022, a total of 70,386 valid meteorite names were recognized. Once a meteorite is recovered and named, it can then be broadly classified as either an undifferentiated chondritic meteorite or differentiated achondritic meteorite, as based on the texture and bulk composition of the sample in question.

1.2 Classification of Undifferentiated Meteorites: Chondrites

Undifferentiated chondritic meteorites are derived from unaltered, primitive, solar system materials, whose components were formed in the solar nebula by high-temperature processes, such as condensation and evaporation (Krot et al., 2014). There are four major components contained within chondritic meteorites which include: chondrules, refractory inclusions (Ca-Al-rich inclusions, CAIs) and amoeboid olivine aggregates (AOAs), FeNimetal, and fine-grained matrix material (Krot et al., 2014). The classification of chondritic meteorites is based on bulk chemistry, bulk oxygen isotopic compositions, mineralogy, petrology, and the overall proportion of components (Krot et al., 2014). Figure 1 summarizes the major classes, groups, petrological types, and subgroups of chondrites.

	Undifferentiated Meteorites: Chondrites														
Class \rightarrow		Carbonaceous)rdina	ry	Enst	tatite	Addit	ional
Group \rightarrow	CI	СМ	CO	CR	СВ	СН	CV	СК	Н	L	LL	EH	EL	R	Κ
Petr. Type \rightarrow	1	1-2	3-4	1-2	3	3	3-4	3-6		3-6		3-5	3-6	3-6	3
Subgroup \rightarrow					Cb_{a}		$\mathrm{CV}_{\mathrm{OxA}}$								
					CB_{b}		$\mathrm{CV}_{\mathrm{OxB}}$								
							CV_R								

Figure 1. Classification of Chondrites. Modified after Krot et al. (2014). Petr. Type = Petrological Type. Chondrites can be classified as being: carbonaceous, ordinary, enstatite, or an additional type (R and K).

1.3 Classification of Differentiated Meteorites: Achondrites

Differentiated non-chondritic meteorites lack the major components found in chondrites (therefore, non-chondritic meteorites are referred to as achondrites), are derived from differentiated planetary bodies (i.e., the Moon, Mars, asteroids), and were affected by partial or complete melting, either as melt products or as residues after melt removal (Krot et al., 2014). Nonchondritic meteorites are commonly classified on the basis of their FeNimetal abundances as either achondrites (metal poor), stony irons, or iron meteorites (Krot et al., 2014). These types of nonchondritic meteorites and their associated groups are summarized in Figure 2. Achondrites can then be further divided into two separate categories, primitive and differentiated, as based on the degree of igneous processing that took place (Krot et al., 2014).

Differentiated Meteorites: Achondrites & Other Igneous Meteorites								
Primitive achondrites	Differentiated achondrites	Irons and stony irons	Planetary					
Winonaites	Angrites	Mesosiderites	Martian					
Acapodranites	Aubrites	Pallasites	Shergottites					
Acapulcoites	Ureilites	Main group	Nakhlites					
Lodranites	HED	Eagle Station	Chassignites					
Brachinites	Howardites	IAB irons	Orthopyroxenite					
	Eucrites	IC irons	Lunar					
	Diogenites	IIAB irons						
	-	IIC irons						
		IID irons						
		IIE irons						
		IIG irons						
		IIIAB irons						
		IIICD irons						
		IIIE irons						
		IIIF irons						
		IVA irons						
		IVB irons						

Figure 2. Classification of Differentiated Meteorites. Modified after Krot et al. (2014). Achondrites can be classified as being: primitive achondrites, differentiated achondrites, irons, stony irons, or planetary.

Primitive achondrites are considered to be either (1) the products of ultrametamorphosed chondrites or (2) the residual products created as a result of extremely low degrees of partial melting (Krot et al., 2014). Generally speaking, primitive achondrites exhibit igneous and/or metamorphic textures, with compositions that are moderately

fractionated from the range of chondritic materials (i.e., their bulk compositions are 'nearchondritic') (Krot et al., 2014; Mittlefehldt, 2014; Morlok et al., 2012).

Differentiated achondrites are the products of high degrees of partial, or complete, melting and recrystallization; they exhibit igneous textures with compositions that are highly fractionated from the range of chondritic materials (i.e., their bulk compositions are much different than chondrites) (Mittlefehldt, 2014). Within the achondritic group of meteorites, exists a subgroup which is linked to larger planetary bodies; these *Planetary Meteorites*, as they are called, include materials derived from the Moon (Lunar Meteorites) and Mars (Martian Meteorites).

1.4 Martian Meteorite Classification

All of the Martian meteorites (excluding one polymict breccia), which have been studied thus far show evidence of magmatic origins (Udry et al., 2020). As with terrestrial igneous rocks, these igneous Martian rocks have a range in textures (aphanitic, porphyritic, diabasic, oikocrystic) and compositions (mafic to ultramafic) (Udry et al., 2020). Martian meteorites are divided into four groups based on their: elemental geochemistry and radiogenic isotopic compositions; emplacement histories; and crystallization and ejection ages. These groups are the: Shergottites, Nakhlites, and Chassignites (SNCs); Orthopyroxenites; and Regolith breccias (Udry et al., 2020).

The most abundant Martian meteorite group by mass (82%) and total collection by number (89%) are the shergottite type meteorites (Udry et al., 2020) (Figure 3, Figure 4). The geochemical classification of shergottites is based on incompatible trace element (ITE) enrichments or depletions, as ITE compositions reflect unique source (i.e., parent melt) compositions (Udry et al., 2020). Large variations in ITE compositions (and radiogenic isotopic compositions: Lu-Hf, Sm-Nd, and Rb-Sr) are exhibited in shergottites and are believed to have formed during silicate planetary differentiation and crystallization following an early magma ocean phase (Suarez et al., 2022; Udry et al., 2020). Therefore, shergottites derived from compositionally-variable, partially-melted, mantle sources, will inherit unique isotopic compositions which are reflections of original mantle source compositions (Suarez et al., 2022; Udry et al., 2020) (Figure 4).



Figure 3. Representation of all Martian Meteorite types. Taken after Udry et al. (2020). Greyscale photos are backscattered electron (BSE) images, while colored photos are photomicrographs, under crossed polarized light (XPL). (a) Basaltic shergottite NWA 8657; sample contains pyroxene and maskelynite and is absent of olivine phenocrysts and megacrysts. (b) Olivine-phyric shergottite LAR 06319; sample contains olivine phenocrysts along with olivine, pyroxene, and maskelynite which crystalized later on. (c) Poikilitic shergottite NWA 4468; sample contains olivine chadacrysts that are enclosed by larger pyroxene oikocrysts along with olivine, pyroxene, and maskelynite which crystalized later on. (d) Gabbroic shergottite NWA 6369; sample contains cumulate pyroxene or plagioclase. (e) Augite-rich shergottite NWA 8159; sample contains intergranular plagioclase, augite, olivine; sample lacks pigeonite. (f) Nakhlite MIL 090030; sample is clinopyroxene-rich and contains cumulus pyroxene and olivine. (g) Chassignite NWA 2737; sample contains olivine cumulates with inclusions of chromite; and interstitial plagioclase, orthopyroxene, and phosphates. (h) Orthopyroxenite ALH 84001; sample contains mosaic-grained orthopyroxene; minor amounts of chromite, augite, glass, olivine, apatite; and secondary phases (e.g., Fe-Mn-Mg carbonate). (i) Regolith breccia NWA 7034; sample contains igneous clasts (basalt, mugearite, trachyandesite, norite, gabbro, monzonite). Scale bars = 500 µm length.



Figure 4. Plot of isotopic source rations (¹⁷⁶Lu/¹⁷⁷Hf and ¹⁴⁷Sm/¹⁴⁴Nd) of enriched, intermediate, and depleted shergottites, and ALH 84001 against an assumed end-member mixing array (shown by underlying grid) that was generated using end-member compositions (indicated by green circles). Taken after Suarez et al. (2022).

Along with geochemical variations, variations in texture (i.e., grain size, shape, modal abundance of minerals) exist as well, which aid in shergottite classification (Udry et al., 2020) (Figure 3). Texturally, shergottites can be divided into five groups: (1) basaltic (2) olivine-phyric (3) poikilitic (4) gabbroic and (5) augite-rich shergottites. Through textural and geochemical investigations of Martian meteorites, numerous fundamental planetary processes can be uncovered, including: the timing of magmatic rock formation and emplacement (along with what conditions were present at the time of these events); planetary accretion and differentiation; timing of secondary processes, such as alteration and weathering; and impact events in the Martian past (Udry et al., 2020) (Figure 5).



Figure 5. Information to be gained by studying Martian Meteorites. Taken after Udry et al. (2020). Highly volatile compounds (i.e., OH, H₂O, CO₂, Cl, S) are represented by blue bubbles.

The Martian meteorites Nakhlites and Chassignites are geochemically and texturally distinct from shergottites and constitute ~17% of all Martian meteorites by mass and ~10% by total collection number (Udry et al., 2020). Nakhlite and Chassignite meteorites share many similarities (e.g., ~1.3 Ga crystallization age; ~11 Ma ejection age; depleted radiogenic isotope compositions) and are thought to be derived from the same location and volcanic system on Mars (Udry et al., 2020). Nakhlites are igneous rocks that contain: abundant clinopyroxene; cumulus pyroxene and olivine; minor glass, plagioclase, phosphates, iron-rich olivine in mesostasis, titanomagnetite, and sulfides (Udry et al., 2020) (Figure 3f). Lastly, chassignites are dunitic igneous rocks that contain: cumulus olivine; chromite inclusions; interstitial plagioclase; orthopyroxene; and phosphates (Figure 3g).

1.5 Phosphate Phases in Extraterrestrial Systems

Calcium (Ca-) phosphates, notably apatite group minerals Ca₅[PO₄]₃[F,Cl,OH] and merrillite Ca₉Na(Fe,Mg)(PO₄)₇, are among the most important minerals investigated in Martian meteorites (Darling et al., 2021; Kenny et al., 2019; Udry et al., 2020). Their significance lies in the fact that phosphate minerals are enriched in volatiles (i.e., apatite group minerals incorporate volatile species such as chlorine, fluorine, and lead) and trace elements (i.e., Ca-phosphates are the primary carriers of REEs in Martian meteorites) (Cox et al., 2020; Darling et al., 2021; Kenny et al., 2019; Walton et al., 2012). Given these elemental enrichments, apatite and merrillite are often targeted for geochemical analyses.

The applicability of phosphate geochemistry is far reaching; phosphates are readily used for (1) evaluating the origin, abundance, and evolution of volatile species contained in Martian systems (2) providing constraints on endogenic and exogenic thermochronological processes (3) geochronological purposes and (4) providing information on the genesis and evolution of magmas through application of trace element and isotopic studies (Cox et al., 2020; Darling et al., 2021; Kenny et al., 2019; Udry et al., 2020). Though phosphate minerals are often targeted for geochemical work, the effect of shock metamorphism on the chemical and isotopic records of these minerals is not well understood (Cox et al., 2020; Darling et al., 2021; Kenny et al., 2019).

1.5.1 Apatite-group Minerals

Apatite is the most abundant, volatile-bearing, phosphate found on Earth and in Martian meteorites (Darling et al., 2021). Apatite occurs in both biological (i.e., as the main inorganic component of bones and teeth) and geological systems (i.e., as an accessory mineral in all geologic environments) and thus is of interest to many scientific fields (Hughes and Rakovan, 2002; Liu et al., 2013; McCubbin and Jones, 2015) (Figure 6). Thus, the variable chemistry and robust structure of apatite allow it to accommodate a wide scope of trace metals, radionuclide species, and volatiles (Hughes and Rakovan, 2002). Therefore, the presence of apatite in the geologic environment strongly influences the evolution and signature of trace elements and volatile contents in any given system which supports apatite formation (Hughes and Rakovan, 2002).

Apatite formation, particularly in the geologic environment, may occur from crystallizing melt, concentrated hydrothermal brines, aqueous solutions at low temperatures, or vapor phases (Rakovan, 2002). The general apatite formula is as follows: $A_5(XO_4)_3Z$, where A is a generally a large divalent cation (e.g., Ca^{2+}), X is a pentavalent cation (P^{5+}), and Z is an anion (F^- , CI^- , OH^- , O^{2-}) or rarely a vacancy. The atomic arrangement of apatite-group minerals allows for structural variants which accommodate numerous cation substitutions for Ca at the A-site (i.e., Na⁺, Sr²⁺, Pb²⁺, Ba²⁺, REE³⁺, Y³⁺, Th⁴⁺, U⁴⁺, U⁶⁺, \Box , etc.), alongside replacement of the PO₄³⁻ group for various anionic complexes at the X-site (i.e., AsO₄³⁻, VO₄³⁻, SO₄²⁻, SiO₄⁴⁻, CO₃²⁻, etc.) (Pan and Fleet, 2002); note Figure 7. Crystal lattice vacancies are represented by an open square (i.e., \Box). Ternary plots may be constructed to aid in illustrating the relative abundances of halogens, which are strongly influenced by original source compositions; note Figure 8 and Figure 9 (Filiberto and Treiman, 2009; McCubbin and Jones, 2015).



Figure 6. Apatite backscattered electron (BSE) images and photographs as sourced from various environments (i.e., asteroidal and planetary bodies). Taken after McCubbin and Jones (2015). (a) BSE image of apatite in the LL Chondrite (low-iron, low metal ordinary chondrite) Chelyabinsk. Note that apatite exhibits a vein-like texture; this texture is indicative of fluid-deposited apatites. (b) BSE image of apatite in the Eucrite (achondritic stony meteorite) Bates Nunataks 00300. Note apatite occurrence with late-stage crystallization products (tridymite, troilite). (c) BSE image of apatite in the Lunar sample 76535 (lunar highlands magnesian-suite troctolite). Note the intergrown texture of apatite and merrillite. (d) BSE image of apatite in the Martian breccia NWA 7034. Apatite-bearing basaltic clasts are rich in chlorine (not shown) and show evidence of secondary alteration due to fluids. (e) Photograph of terrestrial apatite (blue) occurring with calcite (orange) from Lake Baikal, Russia. Secondary ion mass spectrometry standards are routinely created using apatite derived from Baikal, Russia in order to study extraterrestrial apatite. Ap = apatite; Bdy = baddeleyite; Cpx = clinopyroxene; Fe = Fe-rich metal; Ilm = ilmenite; Mer = merrillite; Opx = orthopyroxene; Pl = plagioclase; Trd = tridymite; Tro = troilite.

1																	2
H																	He
Hydrogen 1.00794																	Helium 4.003
3	4	1										5	6	7	8	9	10
Li	Be											В	С	N	0	F	Ne
Lishium	Beryllium											Boron	Carbon	Nitrogen	Oxygen	Fluorine	Neen
6.941	9.012182											10.811	12.0107	14.00674	15.9994	18.9984032	20.1797
N	Ma											15	14 C:	D D	10	C	10
Sodium	Manosium											Al	Silicon	Phosphorus	Sulfar	Chlorine	Area
22.989770	24.3050	-										26.981538	28.0855	30.973761	32.066	35.4527	39.948
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Potassium 39.0983	Calcium 40.078	Scandium 44.955910	Titanium 47.867	Vanadium 50.9415	Chromium 51,9961	Manganese 54,938049	Iron 55.845	Cobalt 58.933200	Nickel 58.6934	Copper 63.546	Zinc 65.39	Gallrum 69.723	Germanium 72.61	Arsenic 74.92160	Selenium 78.96	Bromine 79.904	Krypton 83.80
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Mo	Te	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Те	I	Xe
Rubidrum	Strontrum	Ymnum	Zirconium	Niobium	Molybdonum	Technetium	Ruthenium	Rhodium	Palladium	Saber	Cadmium	Indium	Tm	Antimony	Tellurium	lodine	Xenon
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Ce	Ro	In	Цf	Ta	w	Do	O.	In	Dt	A.u.	Ца	TI	Ph	D;	Po	At	Dn
Cesium	Barium	Lanthanum	Hafnium	Tantalum	Tungsten	Rhenium	Osmam	Indexem	Platinum	Gold	Mercury	Thallium	Lead	Bismuth	Polonium	Astatine	Radon
132.90545	137.327	138.9055	178.49	180.9479	183.84	186.207	190.23	192.217	195.078	196.96655	200.59	204.3833	207.2	208.98038	(209)	(210)	(222)
87	88	89	104	105	106	107	108	109	110	111	112	113	114				
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt									
(223)	(226)	(227)	(261)	(262)	(263)	(262)	(265)	(266)	(269)	(272)	(277)						
				58	59	60	61	62	63	64	65	66	67	68	69	70	71
				Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
				Cerium 140.116	Prasoody mium 140.90765	Neodymium 144.24	Promethium (145)	Samarium 150.36	Europium 151.964	Gadolinium 157.25	Terbium 158.92534	Dysprosrum 162.50	Holmium 164.93032	Erbium 167.26	Thulium 168.93421	Ytterbium 173.04	Lutetium 174.967
				90	91	92	93	94	95	96	97	98	99	100	101	102	103
				Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
				Thorum 222.0281	Protactinium	Uranium	Neptanium (237)	Platonium (244)	Americium (243)	Curium (247)	Berkelium (247)	Californium (251)	Einsteinium (252)	Fermium (257)	Mendelevium (258)	Nobelium (250)	Lawrencium (262)

Figure 7. Schematic diagram of the periodic table illustrating elements which occur in apatite super-group minerals (shaded in red). Taken after Hughes and Rakovan (2015). The concentration of these elements in apatite ranges from parts per million (ppm), to tens of weight percent.



Figure 8. Ternary plots of apatite F-Cl-OH chemistries as they are related to asteroidal parent bodies, lunar samples, and Martian meteorite sources. Taken after McCubbin and Jones (2015). (a) Apatite volatile chemistry as related to differentiated and undifferentiated asteroidal parent bodies. Differentiated parent bodies are represented by eucrites (achondritic stony meteorites) and the anomalous achondrite GRA06128/9 (ancient cumulate lithology which underwent metasomatism). Undifferentiated bodies are represented by LL chondrites (low-iron, low metal ordinary chondrites). (b) Apatite volatile chemistry as related to lunar samples. Mare basalts represent unaltered Lunar basalts, while lunar highlands represent altered crustal materials. (c) Apatite volatile chemistry as related to Martian meteorite sources. Basaltic shergottites represent altered crustal materials.



Figure 9. Ternary plot of apatite F-Cl-OH chemistries as they are related to Terrestrial (basaltic rocks of Earth) and Martian sources. Taken after Filiberto and Treiman (2009). Data collected in this study for ALH 84001 apatite are superimposed on the plot. ALH 84001 apatite data plotted are the average of 13 analyses. Assuming that F (fluorine) + Cl (chlorine) + OH (hydroxyl) = 1.0 structural formula unit (sfu), an indirect calculation can be made which estimates the water content of apatite. Average atoms per formula unit (apfu) F = 0.164; average apfu Cl = 0.630 \therefore average estimated water content in ALH 84001 apatite = 0.206 sfu or ~20% hydroxyl apatite component. Blue squares illustrate terrestrial samples while red circles illustrate Martian samples. Martian rocks analyzed included: shergottites, nakhlites, chassignites, and orthopyroxenites (ALH 84001). Mars outliers are highlighted by a dashed red circle and include apatite compositions which contain significant proportions of F. Terrestrial sample analyses shown are of unaltered rocks which did not undergo metasomatism. Note that Martian samples are enriched in Cl and contain low abundances of water (OH) while terrestrial basalts are Cl-poor and contain variable OH:F ratios. Data presented in this study are in general agreement with Martian apatite data; however, apatite analyzed in ALH 84001 are slightly more enriched in Cl relative to other meteorites.

The ability for apatite to readily incorporate halogens from magmatic systems allow the mineral to be used as a tool to constrain preeruptive volatile contents of parent magmas (Filiberto and Treiman, 2009). Therefore, the abundance of volatiles in magmas derived from different planetary bodies can be compared (Filiberto and Treiman, 2009). McCubbin and Jones (2015) found that, while apatite derived from undifferentiated, chondritic, meteorite bodies were Cl-rich (Figure 8A), those apatites derived from differentiated bodies had highly variable volatile chemistries (Figure 8C). Although some variability was reported in the Martian meteorites of Filiberto and Treiman (2009) as well, their results found apatite to be Cl-rich and OH-poor thus indicating that Martian parental magmas were likely dominated by chlorine and contained little water (Figure 9).

1.5.2 Whitlockite-group Minerals

As with apatite-group minerals, the whitlockite-group of minerals comprises both biologically and geologically significant phosphate phases (Britvin et al., 2021; Capitelli et al., 2021). The Commission on New Minerals, Nomenclature and Classification (CNMNC) of the International Mineralogical Association (IMA) currently recognizes eight phosphate phases as members of the whitlockite-group of minerals. Table 1 summarizes ideal formulas and species-defining constituents of these members. Whitlockite-group minerals follow the general chemical formula of A₉BM(PO₃X)₄(PO₄)₃, where: A-site = Ca or Sr; B-site = Na, Ca, or \Box (vacancy; a point defect in crystal lattice); M-site = Mg, Fe²⁺, or Mn²⁺; X-site = O²⁻ or OH (Britvin et al., 2021). As such, whitlockite-group minerals can be further divided into two groups: *anhydrous* (e.g., merrillite, keplerite) and *hydrous* (e.g., whitlockite) members.

Table 1. Whitlockite-group minerals that have been approved by The Commission on New Minerals, Nomenclature and Classification (CNMNC) of the International Mineralogical Association (IMA). Adapted after Britvin et al. (2021) and Capitelli et al. (2021). Note that members of the Merrillite subgroup contain only anhydrous minerals while the Whitlockite subgroup contains only hydrous minerals. *Hedegaardite has not been characterized in full and so information regarding its crystal structure are not yet available.

Mineral Phase	Ideal Formula	Species-defining Constituents								
		А	В	М	Х					
Merrillite subgroup (Anhydrous members)										
Merrillite	Ca ₉ NaMg(PO ₄) ₇	Ca	Na	Mg	Ο					
Keplerite	$Ca_9(Ca_{0.5}\Box_{0.5})Mg(PO_4)_7$	Ca	$Ca_{0.5}\square_{0.5}$	Mg	Ο					
Ferromerrillite	$Ca_9NaFe^{2+}(PO_4)_7$	Ca	Na	Fe ²⁺	Ο					
Matyhite	$Ca_9(Ca_{0.5}\Box_{0.5})Fe^{2+}(PO_4)_7$	Ca	Ca _{0.5} □ _{0.5}	Fe ²⁺	Ο					
	Whitlockite subgroup (Hydrogen-bea	ring men	nbers)							
Whitlockite	Ca ₉ Mg(PO ₃ OH)(PO ₄) ₆	Ca		Mg	OH					
Strontiowhitlockite	Sr ₉ Mg(PO ₃ OH)(PO ₄) ₆	Sr		Mg	OH					
Wopmayite	$Ca_6Na_3\Box Mn^{2+}(PO_4)_3(PO_3OH)_4$	Ca		Mn^{2+}	OH					
*Hedegaardite	(Ca,Na) ₉ (Ca,Na)Mg(PO ₃ OH)(PO ₄) ₆									

Structural distinctions between hydrous and anhydrous members of the whitlockitegroup of minerals can be made based on the location of [P(1)O4] tetrahedra relative to the truncated apex of the B-site of the crystal (Figure 10) (Britvin et al., 2021). Careful distinction between *hydrous* and *anhydrous* members of the whitlockite-group of minerals is warranted, as nomenclature confusion exists in the literature; this is due partially to early works who equated merrillite to whitlockite (Jolliff et al., 1996). This early confusion may be excused though, as analyses conducted by electron microprobe methods are not able to detect hydrogen. Although merrillite and keplerite are anhydrous mineral phases, their occurrence in a rock does not signify a low-volatile content for its associated parental magma (Shearer et al., 2015). Rather, low-volatile content (i.e., -OH) in these phases may then indicate that their associated rock has not been subjected to hydrothermal fluids or aqueous alteration (Shearer et al., 2015). Merrillite and keplerite are related by the coupled charge-balanced substitution Na⁺ $\Leftrightarrow \frac{1}{2} Ca^{2+} + \frac{1}{2} \Box$ at the B-site of the crystal structure (Britvin et al., 2021) (Table 1). There is a complete solid-solution series between the two compositions (Britvin et al., 2021). Keplerite (*as an end-member*) is defined as the sodium-free, Ca-analogue to merrillite (Britvin et al., 2021). Similarly, end-member merrillite is defined as the Na-analogue to keplerite. A characteristic structural feature of keplerite is a half-vacant occupancy of the sixfold-coordinated B-site (Figure 10), which has been referred to as Ca(IIA) in previous works (Britvin et al., 2021; Dowty, 1977). Though similarities exist between these two minerals, they are chemically distinct; further descriptions of merrillite and keplerite are noted in the sections which follow.



Figure 10. B-site environments of keplerite and whitlockite. Taken after Britvin et al. (2021). (a) B-site of keplerite: $Ca_9(Ca_{0.5}\Box_{0.5})Mg(PO_4)_7$. Note that the B-site is half-occupied with Ca^{2+} . Also note that the apex-truncated trigonal pyramid [BO6] is related to the hydrogen-free [P(1)O4] tetrahedra by a common face. (b) B-site of whitlockite-type mineral: $Ca_9FeD(PO_4)_7$. Note that the B-site contains a P-O paired inverted [P(1')O4] tetrahedron (i.e., the B-site in hydrogen-bearing whitlockite is not vacant) and is free of cations. Also note the presence of a triply split proton (deuteron, shown as blue spheres) which connects the apexes of all four [PO4] tetrahedra through hydrogen bonding (shown as blue dashes).

1.5.2.1 Merrillite in the Literature

Shearer et al. (2015) provide a robust and comprehensive review of the chemical and structural characteristics of end-member merrillite. As discussed, phosphate minerals such as merrillite, keplerite, and apatite are ubiquitous accessory phases in extraterrestrial magmatic systems. These phases are typically amongst the last minerals to crystalize from a magma and thus, commonly occur with other late-stage phases such as silica, sulfides, and oxides (McCubbin et al., 2014; Shearer et al., 2015). Large variations in the chemical composition of Martian merrillite has been well documented in the literature; these variations exist not only within individual samples (e.g., note chemical zonation of sodium in merrillite; Figure 11), but between them as well (e.g., note Martian merrillite compositions vary widely between groups; Figure 12 through Figure 15) (Liu et al., 2018; Shearer et al., 2011). This large range in compositions likely reflects intermediate merrillite-keplerite chemistries.



Figure 11. Backscattered electron (BSE) images and X-ray element maps of phosphate grains from the Elephant Moraine (EETA) 79001 shergottite. Taken after Liu et al. (2018). Note that phosphate grains #20 and #5 are in direct contact with impact melt while grain #38 is not. Also note circumferential chemical zonation of Na and moderate zonation of Mg in phosphate grains that directly contact impact melt. Numbers given in red on X-ray maps are Na₂O and MgO contents, given as weight percent (wt%).



Figure 12.Compositional variations in Martian merrillite. Taken after Liu et al. (2016). Data collected in this study for Tissint keplerite and ALH 84001 merrillite are superimposed on the plot. Na and Mn are given as atoms per formula unit (apfu); formula amounts normalized to 56 oxygen atoms. Mg-numbers are the calculated atomic ratio of magnesium to the sum of magnesium and iron ([Mg_{atomic}/(Mg_{atomic}+Fe_{atmoic})]*100). Tissint keplerite data plotted are the average of 35 analyses. Representative average formula amounts (per 56 O) for keplerite analyzed in this study is 0.43 Na and 0.04 Mn apfu with Mg# 63.2. ALH 84001 merrillite data plotted are the average of 95 analyses. Representative average formula amounts (per 56 O) for merrillite analyzed in this study is 1.63 Na and 0.01 Mn apfu with Mg# 87.6. Meteorites include shergottites (olivine-phyric, basaltic, lherzolitic), and an orthopyroxenite (ALH 84001), and a regolith breccia (NWA 7034). Color classification used to distinguish between depleted, intermediate, and enriched chemical groups.



Figure 13. Plot of Na (a.f.u.) versus Mg# in Martian merrillite. Taken after Shearer et al. (2015). Na given as atoms per formula unit (a.f.u); formula amounts normalized to 56 oxygen atoms. Mg-numbers are the calculated atomic ratio of magnesium to the sum of magnesium and iron $([Mg_{atomic}/(Mg_{atomic}+Fe_{atmoic})]*100)$. Tissint keplerite data plotted are the average of 35 analyses. Representative average formula amounts (per 56 O) for keplerite analyzed in this study is 0.43 Na and 0.04 Mn apfu with Mg# 63.2. ALH 84001 merrillite data plotted are the average of 95 analyses. Representative average formula amounts (per 56 O) for merrillite analyzed in this study is 1.63 Na and 0.01 Mn apfu with Mg# 87.6.



Figure 14. Plot of Mn (a.f.u.) versus Mg# in Martian merrillite. Taken after Shearer et al. (2015). Mn given as atoms per formula unit (a.f.u); formula amounts normalized to 56 oxygen atoms. Mg-numbers are the calculated atomic ratio of magnesium to the sum of magnesium and iron $([Mg_{atomic}/(Mg_{atomic}+Fe_{atmoic})]^*100)$. Tissint keplerite data plotted are the average of 35 analyses. Representative average formula amounts (per 56 O) for keplerite analyzed in this study is 0.43 Na and 0.04 Mn apfu with Mg# 63.2. ALH 84001 merrillite data plotted are the average of 95 analyses. Representative average formula amounts (per 56 O) for merrillite analyzed in this study is 1.63 Na and 0.01 Mn apfu with Mg# 87.6. Note that the 1 σ precision for Mn at plotted concentrations is \leq 0.01 wt%. Therefore, significance of Mn variation must be handled with care.



Figure 15. Ternary plot of Martian and Lunar merrillite. Taken after Shearer et al. (2015). Each vertex of the triangle corresponds to one of the three Ca- and Na-site substitutions attributed to merrillite-type minerals. These substitutions include: (1) Ca+ \Box ⇔2Na, (2) 3Ca⇔2REE+ \Box , and (3) Ca+Na⇔REE+ \Box . Note that P-site and Ca-site substitutions (e.g., P + Ca⇔Si + REE) are not plotted here. The most significant substitution observed in Martian merrillite phases can be described by variance in vacancies, Ca, and Na within the Na-site of the crystal (i.e., Ca+ \Box ⇔2Na). The most significant substitution observed in Lunar merrillite phases is the coupled substitution of (a) REE³⁺ for Ca in the Ca-site with (b) a vacancy in the Na-site (Shearer et al., 2015).

The most common cations found in each of the four structural sites (i.e., P-, Na-, Mg-, and Ca(1,2,3)-sites) of merrillite are shown in Figure 16. Merrillite is trigonal, R3c space group, and has unit cell parameters a = 10.362 Å, c = 37.106 Å (Shearer et al., 2015; Xie et al., 2015) (Figure 17). Texture, as with chemical composition, has been documented to vary considerably in merrillite as well (Howarth et al., 2015; Shearer et al., 2015; Shearer et al., 2011) (Figure 18 through Figure 21). Merrillite grains can range in size from a few microns in diameter to 100s of microns in length (Shearer et al., 2015). Crystal faces can range from anhedral to euhedral and can be deformed, resorbed, and/or rimmed by, or intergrown with, apatite (Bellucci et al., 2017; Greenwood et al., 2008; Howarth et al., 2015; Shearer et al., 2017; Greenwood et al., 2008; Howarth et al., 2015; Shearer et al., 2015; Shearer et al., 2011; Walton et al., 2014).



Ionic Radii (Angstroms)

Figure 16. Cations commonly found in merrillite. Taken after Shearer et al. (2015). Figure colors corresponded to Figure 17; P-sites (tetrahedral sites) are shown in red; Mg-sites (octahedral sites) are shown in blue; Na-sites are shown in yellow; and Ca(1,2,3)-sites are shown in green. VIII, VI, and IV correspond to 8-, 6-, and 4-fold coordinated sites.


Figure 17. Representative section of merrillite crystal structure, looking down the c-axis. Taken after Shearer et al. (2015). (A) Section of merrillite crystal structure, looking down the c-axis. (B) Magnified knockout of (A). The ball and stick diagram of (B) demonstrates the relationship between Na 6-fold polyhedra, Ca(1) 8-fold polyhedra, and P-tetrahedra. The tetrahedral sites (P-sites) are shown in red while the octahedral sites (Mg-sites) are shown in blue. Na atoms (Na-site) are shown in yellow; Ca atoms (Ca(1,2,3)-sites) are shown in green; and O atoms are shown in purple. A triangular symbol is used to denote the location of the 3-fold axes. Numbers represent symmetrically unique sites.



Figure 18. Backscattered electron (BSE) images and X-ray maps of merrillite-bearing and apatitebearing assemblages in Martian meteorites. Taken after Shearer et al. (2015). (A) BSE image of merrillite in EETA79001 lithology A (olivine-phyric shergottite). (B) Ca X-ray map of the BSE image A. (C) BSE image of merrillite in Los Angeles (basaltic shergottite). (D) Ca X-ray map of the BSE image C. (E) BSE image of merrillite in ALH 84001 (orthopyroxenite). (F) Ca X-ray map of BSE image E. (G) BSE image of merrillite in NWA 7034 (regolith breccia). (H) Ca X-ray map of BSE image G. Mineral abbreviations: m = merrillite; p = plagioclase; cpx = clinopyroxene; opx =orthopyroxene; ol = olivine; a = apatite; g = glass. X-ray maps expressed qualitatively; high Cacounts are indicated by warm colors while low Ca counts are indicated by cool colors.



Figure 19. Backscattered electron (BSE) image and X-ray maps of intergrown apatite-merrillite texture of NWA 7034 (regolith breccia). Taken after Shearer et al. (2015). Mineral abbreviations: m = merrillite; p = plagioclase; a = apatite. X-ray maps expressed qualitatively; high Ca counts are indicated by warm colors while low Ca counts are indicated by cool colors.



Figure 20. Backscattered electron (BSE) image and X-ray maps of the apatite and merrillite phases of Northwest Africa 7755 (enriched lherzolitic shergottite). Taken after Howarth et al. (2015). Mineral abbreviations: Msk = maskelynite; Ap = apatite; Pyx = pyroxene; Ol = olivine; S = sulfide. X-ray maps expressed qualitatively; high Ca and Cl counts are indicated by warm colors while low Ca and Cl counts are indicated by cool colors. Note the presence of shock melt in apatite and its associated chemical signatures (i.e., Cl-enrichment in presence of shock melt).



Figure 21. Backscattered electron (BSE) image and X-ray maps of the intergrown apatite-merrillite assemblages of Northwest Africa 7755 (enriched lherzolitic shergottite). Taken after Howarth et al. (2015). Mineral abbreviations: Msk = maskelynite; Ap = apatite; Pyx = pyroxene; Ol = olivine. X-ray maps expressed qualitatively; high Ca and Cl counts are indicated by warm colors while low Ca and Cl counts are indicated by cool colors. Note the presence of shock melt in apatite and its associated chemical signatures (i.e., Cl-enrichment in presence of shock melt). Also note occurrence of merrillite along margin of apatite grains.

1.5.2.2 Keplerite in the Literature

Keplerite, $Ca_9(Ca_{0.5}\Box_{0.5})Mg(PO_4)_7$, is a newly defined phosphate mineral (Britvin et al., 2021). Therefore, research discussing keplerite (particularly, end-member keplerite) are currently limited. Britvin et al. (2021) found meteoritic keplerite to occur in the maingroup pallasites and angrites (i.e., extremely Na-deficient rocks) (Table 2). Terrestrial keplerite, on the other hand, was found to occur in pyrometamorphic rocks of the Hatrurim Basin, Israel (Britvin et al., 2021). Keplerite is described by Britvin et al. (2021) as an indicator of high-temperature environments that are depleted in sodium and water; presence of sodium in the mineral system promotes intermediate merrillite-keplerite phases to crystallize, while the presence of water promotes whitlockite crystallization. Structurally, keplerite is trigonal, R3c space group, and has unit cell parameters a = 10.3330 Å, c = 37.0668 Å (Britvin et al., 2021).

Table 2. Summarized meteoritic keplerite chemical compositions. Taken and adapted after Britvin et al. (2021). References: [1] (Britvin et al., 2021); [2] (Buseck and Holdsworth, 1977); [3] (Keil et al., 1976); [4] (Crozaz and McKay, 1990). Dashed fields indicate below detection limit.

Meteorite:	Marjalahti	Marjalahti	Ahumada	Lew 86010	Imilac	Angra dos Reis	Somervell County				
Group:	Pallasite	Pallasite	Pallasite	Angrite	Angrite	Pallasite					
Reference:	[1]	[2]	[2]	[4]	[2]	[3]	[2]				
wt%											
Na2O	_	_	0.1	0.4	0.52	0.67	0.68				
CaO	48.87	48.8	49.1	50.7	50.2	50.2 49.4					
MgO	3.9	4.52	3.32	2.68	3.62	2.82	3.76				
FeO	1.33	0.88	1.85	1.62	0.36	1.29	0.5				
P2O5	46.24	45.2	45.6	44.6	45.9	45.1	46.8				
SiO2	_	_	0.32	0.68	_	0.08					
Total	100.34	99.4	100.29	100.7	100.6	99.95	100.52				
	Fo	rmula amoun	ts (O = 28 at	oms per form	ula unit; ap	ofu)					
Na	—	—	0.03	0.14	0.18	0.24	0.23				
Ca	9.33	9.42	9.42	9.76	9.58	9.52	9.24				
$\Sigma(Ca,Na)$	9.33	9.42	9.45	9.9	9.76	9.76	9.48				
Mg	1.04	1.21	0.89	0.72	0.96	0.76	0.99				
Fe2+	0.2	0.13	0.28	0.24	0.05	0.19	0.07				
$\Sigma(Mg,Fe)$	1.24	1.34	1.17	0.96	1.01	0.95	1.06				
Р	6.97	6.89	6.91	6.79	6.92	6.87	7.02				
Si	—	—	0.06	0.12	_	0.12	0.01				
$\Sigma(P,Si)$	6.97	6.89	6.97	6.91	6.92	6.99	7.03				
Mg-number	84	90	76	75	94	80	93				
Na-number	0	0	0.4	1.4	1.8	2.4	2.5				



Figure 22. Representative section of keplerite crystal structure, looking down the c-axis. Taken after (Britvin et al., 2021). Species-defining constituents include : $[MO_6]$ octahedra (shown in red); $[BO_6]$ polyhedra (shown in green); and $[PO_4]$ tetrahedra (shown in yellow). Note that $[AO_8]$ polyhedra not shown. Orientation of figure is shown as a parallel slice along the (0001) plane.

Raman spectra of keplerite and merrillite (*along with ferromerrillite*) are given in Figure 23, Figure 24, and Table 3. Raman spectra are emphasized here as they can provide diagnostic information regarding structural and chemical characteristics of phases investigated. Three key features from these figures are noted: 1) as is anticipated for minerals of the merrillite subgroup, doublets (or, "duplets") located in the ~960 cm⁻¹ region are observed for both keplerite and merrillite (Britvin et al., 2021; Jolliff et al., 2006; Xie et al., 2015). 2) Though both minerals demonstrate similar spectral characteristics between 400 and 1080 cm⁻¹, keplerite exhibits additional bands ("shoulder") in the ~960 cm⁻¹ region while merrillite does not (Britvin et al., 2021) (Figure 24). The reason for this spectral feature in keplerite may be related to bonding-environment distortions caused by the

bonding of the half-vacant B-site with adjacent [PO₄] tetrahedra (Britvin et al., 2021) (Figure 10, Figure 22). 3) Neither keplerite nor merrillite exhibit bands at 923 cm⁻¹; this is consistent for HPO_4^{2-} groups which lack essential hydrogen in their crystal structure (as compared to H-bearing phosphates, such as whitlockite, which exhibit a peak at 923 cm⁻¹) (Britvin et al., 2021; Jolliff et al., 1996)



Figure 23. Raman spectra of keplerite, merrillite, and ferromerrillite over the 0 to 1200 cm^{-1} range. Taken after Britvin et al. (2021). Keplerite spectra derived from the Marjalahti pallasite are shown in blue (a); merrillite spectra derived from the Brahin pallasite are shown in black (b); and ferromerrillite spectra derived from the Los Angeles shergottite are shown in red (c). Note that spectra (b) and (c) are offset by 100 cm⁻¹ along the x-axis.



Figure 24. Raman spectra of keplerite, merrillite, and ferromerrillite over the 900 to 1000 cm⁻¹ range. Taken after Britvin et al. (2021). Keplerite spectra derived from the Marjalahti pallasite are shown in blue (a); merrillite spectra derived from the Brahin pallasite are shown in black (b); and ferromerrillite spectra derived from the Los Angeles shergottite are shown in red (c). Note that keplerite displays visually resolved shoulders located at 950 and 958 cm⁻¹ which cause peak broadening.

Table 3. Measured frequencies of (PO ₄) vibration modes (cm^{-1}) for Raman spectra in Fi	gure 23
and Figure 24. Taken and adapted after Britvin et al. (2021). Note that visually resolved sh	noulders
are highlighted in yellow.	

1. .

Mineral:	Keplerite	Merrillite	Ferromerrillite
Meteorite:	Marjalahti	Brahin	Los Angeles
Band Assignmnet:			
$v_2(\delta_s)$	407	409	403
	442	446	445
$v_4(\delta_{as})$	551	551	548
		593	591
	601	603	606
	622	618	620
		756	752
$v_1 (v_s)$	*950		
	954	957	954
	*958		
	971	973	970
$v_3 (v_{as})$	1016	1015	1012
	1078	1080	1080

It is important to emphasize that although keplerite is a newly *defined* mineral, it is not a newly *discovered* mineral. As is discussed in Britvin et al. (2021), the first documented occurrence of a Ca-enriched, Na-deficient, "whitlockite" phase was by Dowty (1977) in the Angra dos Reis meteorite (angrite group). Similar findings were documented by Buseck and Holdsworth (1977) who conducted a comprehensive study of phosphate phases in pallasite meteorites. Buseck and Holdsworth (1977) demonstrated a wide range of Ca-phosphate compositions, with notable Na-deficiencies, in the Ahumada, Mt. Vernon, and Antofagasta meteorites. Likewise, analyses of 'merrillite' in the Marjalahti pallasite show a total absence of Na (Buseck and Holdsworth, 1977), see Table 2 (Buseck and Holdsworth, 1977). Further, distinctions between merrillite subgroup members (e.g., Na-merrillite, Ca-merrillite, REE-merrillite) has been well documented in the literature (Adcock et al., 2014; Jolliff et al., 2006; Liu et al., 2016; Shearer et al., 2015; Xie et al., 2015).

1.6 Shock Metamorphic Effects in Rocks and Minerals

Shock metamorphism, often used interchangeably with *impact* metamorphism, describes the physical and chemical changes that occur to structures, rocks, and minerals that have been subjected to hyper-velocity impact events (DeCarli, 2005; Ferrière and Osinski, 2013). Although impact events can involve the ejecta of material into space, various degrees of shock deformation can occur to a planet as a result of impact metamorphism. For example, shock-related deformation may occur to a planet without any material leaving said planet's surface. Further, impact events may cause materials to temporarily leave their planetary surface, only to fall back to a new location on their parent body later on (e.g., NWA 7034: Udry et al. (2020)). Finally, multiple impact deformation events may occur to a target planet before any material is ejected from its surface (e.g., ALH 84001: Treiman (1995, 1998, 2021). In any case, although impact events are punctuated in nature, they are characterized by extreme temperature (i.e., 100s to 1,000s °C) and pressure (i.e., 10s to 100s GPa) spikes, along with extreme rates of quenching and strain, which can produce shock features (Dasgupta and Bhowmik, 2021; Langenhorst and Deutsch, 2012) (Figure 25).



Figure 25. Pressure-temperature (P-T) diagram of metamorphic conditions. Taken after French (1998). The plot above shows the differences in pressure and temperature regimes for terrestrial metamorphic conditions (shaded region, to the bottom left) and shock metamorphic conditions ("shock metamorphism" curve, to the right). Shock pressures exceeding 50 GPa can produce extreme heat and thus can cause melting and vaporization to occur. Shock metamorphic features (i.e., planar deformation features, diaplectic glasses, melting, etc.) are noted along the shock metamorphism curve with approximate P-T regimes (dashed vertical lines). Mineral decomposition reactions for sphene, quartz, and zircon are noted along the temperature axis to the left; note that extreme temperatures are also associated with extreme pressures of shock metamorphism. At center are stability curves for coesite, diamond, and stishovite – at equilibrium conditions for each respective mineral.

The effects of shock on Martian meteorites are highly variable (both between different meteorite types and within individual specimens as well) (Fritz et al., 2005; Udry et al., 2020). Fritz et al. (2005) determined that the minimum shock pressures required for Martian material to be ejected from the surface of Mars and into space to be at least ~5 GPa. Thus, all Martian meteorites have been subjected to shock; though the degree of shock, and subsequent changes to the physical and chemical characteristics of these rocks, is highly variable. As an example: shergottites, the most abundant of all Martian meteorite types by both mass (82%) and total number of collected meteorites (89%), generally show

shock pressures of >19 GPa (Fritz et al., 2005; Udry et al., 2020) with the rare occurrence of highly shocked samples exhibiting shock levels of 75-90 GPa (the highest shock level possible before complete melting occurs) (Kizovski et al., 2019).

Evidence of shock-metamorphism in rocks and minerals include 1) deformation features: planar fractures (PFs), planar deformation features (PDFs), dislocations, mechanical twins, kink bands, and mosaicism, 2) phase transformations: such as the formation of amorphous glasses (i.e., diaplectic glass formed from the transformation of plagioclase into maskelynite) and mineral phase transformations (i.e., the formation of high-pressure polymorphs such as coesite and stishovite), and 3) partial-to-complete: melting, decomposition, and vaporization (i.e., formation of impact melt) (DeCarli, 2005; Ferrière and Osinski, 2013; French, 1998; Langenhorst and Deutsch, 2012). Note, those minerals which show evidence of being subjected to shock metamorphism are then termed "shocked" (e.g., shocked quartz, shocked apatite, etc.).

A wide range of shock-metamorphic effects are observed in rocks and minerals due to impact events. Transient shock compressions (i.e., sudden *pressure* spikes) are often the driving force which cause deformation and phase transformation features in minerals (Langenhorst and Deutsch, 2012). Melting, decomposition, and vaporization are shockmetamorphic effects which are often driven by temperature (Langenhorst and Deutsch, 2012). Figure 25 summarizes the pressure and temperature regimes required for the aforementioned shock-induced features to form. Shock-metamorphic features exhibited in quartz, feldspar, olivine and pyroxene have been extensively studied and described, while the general understanding of how nesosilicates, double-chain inosilicates, phyllosilicates, carbonate, sulfate, and phosphate minerals are affected by (and respond to) shock is not as well constrained (Cox et al., 2020; Darling et al., 2021; Ferrière and Osinski, 2013; Kenny et al., 2019).

1.7 Objective

The focus of this study is to investigate shock-induced geochemical variations in Martian phosphate phases. The keplerite-bearing assemblages of Tissint and intergrown apatite-merrillite assemblages of ALH 84001,146 were targeted for further investigation. The two meteorites chosen for this study are both highly-shocked in state and contain chemically distinct phosphate phases. Phosphates were distinguished geochemically; by Electron Probe MicroAnalyzer (EMPA) techniques, Raman Spectroscopy, and Scanning Electron Microscopy (SEM) and structurally; by Electron Backscatter Diffraction (EBSD) analytical techniques.

CHAPTER 2:

MATERIALS

2.1 Tissint

The Tissint meteorite (Figure 26) was observed to fall as a meteor shower over the Moroccan desert on July 18, 2011 (Aoudjehane et al., 2012; Irving et al., 2012). Tissint is now the fifth observed fall which has origins connected to Mars. Estimates for the total sample mass recovered from the Tissint fall range from ~ 12 kg (Udry et al., 2020) to ~ 17 kg (Schulz et al., 2020). Subtle heterogeneities between subsamples and fragments of Tissint may therefore be anticipated, due to the large mass of material recovered (Schulz et al., 2020). The first samples of Tissint were collected at the end of October 2011; three months after its fall (Balta et al., 2015). As such, the residence time of Tissint on the surface of earth was limited, as was the exposure of Tissint to terrestrial weathering processes and terrestrial contamination (Balta et al., 2015; Schulz et al., 2020). However, as demonstrated by Barrat et al. (2014), terrestrial contamination cannot be ruled out entirely simply due to Tissint's short residency time on Earth, as was previously proposed by Aoudjehane et al. (2012). Barrat et al. (2014) assert that the interaction between Tissint meteorite fragments with surrounding desert soils on earth may account for the Ce anomaly and enrichments of Ba, Sr, Th, U, and light rare earth elements (LREE) which were observed in impact-melts by Aoudjehane et al. (2012). Therefore, careful consideration must be made when analyzing Martian meteorites: it is suggested that small fragments of the Tissint meteorite be either avoided entirely or analyzed with caution (Barrat et al., 2014).



Figure 26. Photograph of a typical fragment of Tissint (Natural History Museum, London: BM.2012,M1). Taken after Aoudjehane et al. (2012). The exterior of the meteorite is covered in a black fusion crust with a predominately pale grey interior which is composed of light-green olivine macrocrysts and black shock melted regions (veins, pockets). The rock fragment shown is 1.1 kg in mass. The scale bar at the bottom is given in centimeters.

Tissint is an olivine-phyric shergottite with abundant subhedral to euhedral olivine grains of variable size (up to 3.0 mm) which are set in a finer-grained groundmass (Baziotis et al., 2013; Irving et al., 2012; Schulz et al., 2020) (Figure 27). Olivine grains in Tissint are often compositionally zoned, with Mg-rich cores and Fe-rich rims, and commonly contain numerous mineral and melt inclusions (Baziotis et al., 2013; Schulz et al., 2020). The groundmass of Tissint is predominately composed of pyroxene and maskelynite (diaplectic plagioclase glass) with minor olivine, pyroxene-composition glass, Ti-chromite to ulvöspinel, ilmenite, pyrrhotite, merrillite, and shock-induced melt pockets and veins (Balta et al., 2015; Baziotis et al., 2013; Irving et al., 2012). A multitude of high-pressure (HP) minerals and phases have been identified as well (e.g., ringwoodite, akimotoite, majorite, lingunite, hollandite, tuite, stishovite, perovskite, tissintite), which reflect the complex shock history of Tissint (Baziotis et al., 2013; Ma et al., 2015; Walton et al., 2014).



Figure 27. Backscattered electron (BSE) image of Tissint thin section investigated in this study. Tissint is composed of olivine macrocrysts ($\leq 2.0 \text{ mm}$) & microphenocrysts ($\leq 0.4 \text{ mm}$); olivine grains are set in a finer-grained groundmass of pyroxene, maskelynite, ilmenite, troilite, chromite, and phosphates (i.e., keplerite). Sample is approximately 1" in diameter. Scale bar is 1 mm in total length; each individual box is 100 µm in length. Colored boxes represent the location of identified grains; red = grain 1; orange = grain 2; yellow = grain 3; light green = grain 4; dark green = grain 5; dark blue = grains 7-12; purple; grains 13-16. Mineral abbreviations of select phases: Pgt = pigeonite; Tro = troilite; Ol = olivine; Msk = maskelynite.

2.2 ALH 84001

The ALH 84001 meteorite was collected in the Far Western Icefield of Allan Hills (ALH), Antarctica, during the 1984-85 Antarctic Search for Meteorites (ANSMET) Field Season; it was the first rock to be processed and classified from that field season (hence "84001") (Meyer, 2012). The sample was quickly identified as being unique given its size, composition (achondrite), and perceived green color (e.g., Figure 28, Figure 29). Figure 29 shows how the meteorite was cut and sectioned; the thin section studied here is ALH 84001,146. The meteorite caught international headlines in 1996 when (McKay et al.) proposed that ALH 84001 recorded evidence of past Martian life. Although habitable environments may have existed in its past, the scientific community still has not found any evidence directly linking the ALH 84001 meteorite to life on Mars (Treiman, 2021; Udry et al., 2020).

Aside from its potential link to biological processes, ALH 84001 is unique in the sense that it is the oldest known igneous rock from Mars, having crystallized from magma at 4.091 \pm 0.030 billion years (Lapen et al., 2010). Further, the rock underwent a complex postcrystallization history of aqueous-carbonate alteration and multiple shock-induced metamorphic events (Lapen et al., 2010; Treiman, 1998). ALH 84001 is an igneous cumulate rock, an orthopyroxenite, composed of mosaic-grained orthopyroxene (4-5 mm diameter) which enclose subhedral to euhedral grains of chromite (occurring within recrystallized granular bands) (Lapen et al., 2010; Treiman, 1998). Other igneous minerals include chromite, maskelynite (after plagioclase), apatite, merrillite, augite, olivine, and amorphous SiO₂. Aqueous alteration materials (affected or not by shock) include Mg-Fe-Ca carbonates, magnetite, Fe-sulfide(s), and rare phyllosilicates (Jolliff et al., 2006; Lapen et al., 2010; Treiman, 1995, 1998, 2021). Figure 30 is a backscattered electron (BSE) image of the ALH 84001 thin section used in this study.



Figure 28. Representative photograph of ALH 84001(NASA \# S94-32547). Taken after McKay et al. (1996). The photograph exemplifies the porosity of the interior of ALH 84001. Note that the exterior of the meteorite is covered in a dark black, fusion crust. Scale bar given on the bottom right.





C Meyer 1996

Figure 29. Photograph and schematic drawing of ALH 84001 after it was sawn in 1994. Taken after McKay et al. (1996). Note that sample investigated in this study is ALH 84001,146. Scale bar given on the bottom right.



Figure 30. Backscattered electron (BSE) image of ALH 84001,146 thin section investigated in this study. ALH 84001 is composed of mosaic-grained orthopyroxene crystals (0.5 to 1.5 mm diameter), chromite, interstitial plagioclase, apatite, merrillite, clinopyroxene, and SiO₂ phases. Sample is approximately 1" x 2". Scale bar is 0.5 mm in total length; each individual box is 100 μ m in length. Location of apatite-merrillite intergrown grains #1-3 noted by red box; apatite-merrillite intergrown grains #4-6 noted by yellow box; individual merrillite grain #8 noted by green box. Mineral abbreviations of select phases: OPX = orthopyroxene; Chr = chromite; Plag = plagioclase.

CHAPTER 3:

METHODS

3.1 JEOL JXA-8530F Hyperprobe: Tissint and ALH 84001

3.1.1 Energy Dispersive Spectrometry (EDS)

The fast identification of minerals by EDS analysis was performed at Rice University EMPA Laboratory (Department of Earth, Environmental and Planetary Sciences) using a JEOL Silicon Drift (SD) X-ray Detector with 10mm² active area and 133eV resolution. The detector is attached to a JEOL JXA 8530F Hyperprobe. The analytical conditions used for EDS analysis were: 15 kV accelerating voltage, 20 nA beam current, and a live time of 20 seconds. DeadTime (DT) during the analysis was 35-40%. The beam diameter size used was "spot" (~300 nm). The EDS spectra were compared to spectra of known minerals, whereas the semi-quantitative EDS analyses were normalized to appropriate numbers of oxygen atoms to easily recognize minerals by stoichiometry.

3.1.2 Electron MicroProbe Analysis (EMPA)

Electron Probe Micro-Analysis (EMPA) of Tissint and ALH 84001 employed BackScattered Electron (BSE) imaging, quantitative point analysis, and Wavelength Dispersive Spectrometry (WDS) quantitative mapping. Data were acquired at the EMPA Laboratory at Rice University, using a JEOL JXA 8530F Hyperprobe equipped with a field emission (Schottky) emitter and five WDS spectrometers.

3.1.3 Phosphate Analysis

The analytical conditions used were 15 kV accelerating voltage, 20 nA beam current, 3-micron beam diameter. The analyzed x-ray lines, diffracting crystal, peak position (L-value in mm), and lower and upper background offsets (BG_L and BK-U) are shown in Supplementary Table 1. The counting times and detector settings are given in

Supplementary Table 2. The PhiRoZ (JEOL) matrix correction was employed for quantification.

Because phosphate minerals can contain significant proportions of rare earth elements (REE), there are potential interferences between K X-ray lines of transition elements and L X-ray lines of the REE, and among L lines of different REE. The interferences between the interfered and interfering elements (La L α and Nd L α ; F k α and Ce L α ; Nd L α and Ce L α , respectively) were corrected by applying an empirically determined correction coefficient k, as follows: (Net intensity of corrected interfering element) = (Net intensity of measured interfered element) – k*(Net intensity of measured interfering element), where the measurements were done on pure REE phosphate standards. The coefficient k is the ratio between the net counts of an interfered element divided by the net counts of the measured interfering element. For example, for the correction for F which is drastically interfered with by Ce, F was analyzed on CePO₄ standard (net intensity of interfered element) divided by the net counts of Ce (interfering element) was used as k correction coefficient for F. The interference corrections applied are presented below (where "cps" stands for "counts per second"):

 $(La cps)_{corrected} = (La Net)_{measured} - 0.030739 x - (Nd Net)_{measured}$

 $(F cps)_{corrected} = (F Net)_{measured} - 0.14098 x (Ce Net)_{measured}$

 $(Nd cps)_{corrected} = -0.7 (Nd Net)_{measured} - 0.00223 x (Ce Net)_{measured}$

3.1.4 WDS quantitative maps

To evaluate chemical compositions and potential chemical zonation of materials, Wavelength Dispersive Spectrometry (WDS) element mapping were acquired using 15 kV accelerating voltage, 50 nA beam current, using stage mode scanning and 30 ms dwell time for larger maps (< x 3000 magnification) and beam mode and 50 ms dwell time for small maps (> x 3000 magnification). Deadtime correction was applied for every mapped element. Each element map was subsequently quantified employing the same standards used in the phosphate analysis and corrected for dead time.

3.2 JEOL JXA-8530F Field Emission Electron Probe: Tissint

All procedures followed for JEOL JXA-8530F Hyperprobe data collection (i.e., Analytical Conditions for EDS and EMPA) were applied to JEOL JXA-8530F Field Emission Electron Probe analyses. The analysis of phosphate phases contained within Tissint was performed in the Astromaterials Research and Exploration Science (ARES) Electron Beam (EB) Laboratory at Johnson Space Center (JSC).

3.2.1 Energy Dispersive Spectrometry (EDS)

The fast identification of minerals by EDS analysis was performed using a Thermo Scientific UltraDry silicon drift X-Ray Detector with $10mm^2$ active area and 133eV resolution. The detector is attached to a JEOL JXA-8530F Electron Microprobe. The analytical conditions used for EDS analysis were: 15 kV accelerating voltage, 20 nA beam current, and a live time of 10 to 30 seconds. The beam diameter size used was "circle" (3.0 μ m).

3.2.2 Electron MicroProbe Analysis (EMPA)

To evaluate chemical composition of materials, Electron Probe Micro-Analysis (EMPA) of Tissint employed BackScattered Electron (BSE) imaging and quantitative point analysis. Data were acquired using a JEOL JXA-8530F Microprobe equipped with a field emission (Schottky) emitter and five WDS spectrometers. The ZAF correction was employed for quantification.

3.3 WITec alpha300R Raman Microscope: Tissint

To evaluate chemical composition of materials, Raman spectra of keplerite in Tissint were acquired on a WITec alpha300R Raman Microscope with a WITec Diode laser and a 50x / 0.75 Zeiss EC Epiplan objective. Integration times of 30 s with an accumulation of 10–20 scans were selected at a spectral resolution of approximately 2.8 cm⁻¹/pixel. Two Raman spectra were collected for two keplerite grains: #1 and #2. Raman spectra were fitted to a Lorentz function fitting profile. Additional figures and tables pertaining to individual analyses and analytical conditions can be found in the Appendix (e.g., Supplementary Table 13 and Supplementary Table 14).

3.4 JEOL 7900F Field Emission Gun SEM: Tissint

Crystallographic orientations of select keplerite grains in Tissint were studied by Electron backscattered diffraction (EBSD). Data were acquired on a JEOL 7900F Field Emission Gun Scanning Electron Microscope (SEM) coupled to an Oxford Instruments Symmetry detector. A voltage of 20 kV, beam current of 9 nA, and tilt of 70° were used for all analyzed grains. Data collected included Inverse Pole Figures (IPFs), band contrast (BC), grain boundaries (GB), and phase (Ph) maps of analyzed keplerite grains. Electron backscatter patterns (EBSP) (i.e., Kikuchi bands; crystal lattice projections) were collected for both keplerite gains and the phases which surrounded them (i.e., clinopyroxene, ilmenite, maskelynite, troilite, olivine, Cr-spinel) to aid in phase identification.

CHAPTER 4:

TISSINT

4.1 Results

A total of 16 phosphate grains were identified in Tissint (Figure 31 and Figure 32). Identified phosphates typically occur with maskelynite, troilite, ilmenite, pigeonite, and olivine. They had either an elongated or "finger-like" texture (e.g., Figure 31a), or occurred as inclusions (e.g., Figure 32d) with subhedral to anhedral crystal faces. Sizes of grains ranged from a few microns in length (or diameter) to 10s of microns in maximum length. Grains which were only a few microns in total length (or in maximum diameter) were not targeted for geochemical or structural work.

4.1.1 Phosphate Discrimination

Discriminating among possible phosphate minerals relies on the three key differences between apatite, merrillite and keplerite. First, Apatite contains Cl and F while merrillite and keplerite are devoid of all halogens (Table 5). Second, both merrillite and keplerite contain higher P₂O₅, Na₂O, and MgO contents along with lower CaO contents, when compared to apatite (Table 4 and

Table 6). Third, merrillite (Ca₉NaMg(PO₄)₇) contains appreciable Na₂O contents when compared to keplerite (Ca₉(Ca_{0.5} $\Box_{0.5}$)Mg(PO₄)₇). All phosphate grains identified in Tissint are Na-deficient with respect to ideal merrillite compositions. Although apatite was not identified in Tissint, it has been reported in other works (Aoudjehane et al., 2012; Mari et al., 2019).

4.1.2 Keplerite Chemical Composition

A total of 7 keplerite grains were targeted for quantitative analysis and 35 individual points were collected. A comprehensive summary of keplerite chemical composition data is given in Table 4. Normalized formula amounts were calculated from measured oxide weight percentages. Datapoints which measured abnormal oxide concentrations (e.g., low phosphorus content, like 30 wt% P_2O_5) or total percentages (e.g., total wt% \leq 98.5%) were excluded from calculations.

Variations in chemical compositions were noted for analyzed keplerite grains (Supplementary Table 4). Na₂O contents ranged from 0.29 to 0.98 wt% with an average of 0.61 wt% ($1\sigma = 0.20$). CaO contents ranged from 44.53 to 47.58 wt% with an average of 46.73 wt% ($1\sigma = 0.68$). MgO contents ranged from 2.57 to 3.32 wt% with an average of 2.88 wt% ($1\sigma = 0.27$). P₂O₅ contents ranged from 43.39 to 46.77 wt% with an average of 45.53 wt% ($1\sigma = 0.80$).

Calculated formula amounts (normalized to 28 oxygens), likewise, varied as well. The lowest calculated formula amount for Na was found to be 0.10 atoms per formula unit (i.e., the calculation was based on datapoint with lowest measured Na₂O contents) (Supplementary Table 9). The highest calculated formula amount for Na was found to be 0.34 atoms per formula unit (i.e., the calculation was based on datapoint with highest measured Na₂O contents) (Supplementary Table 10).

The magnesium# ([Mg_{atomic}/(Mg_{atomic}+Fe_{atmoic})]*100) of the analyzed phosphate minerals is 63.2. The sodium# ([Na_{atomic}/(Na_{atomic}+Ca_{atmoic})]*100) is 2.3. Cation-site occupancies are: Ca-site = 9.26; Mg-site = 1.22; P-site = 7.05 (Figure 33). To the Ca site, we assigned Ca, Na, K., Mn, and the rare earth elements (La, Ce, Nd); to the Mg site, we assigned Mg and Fe; and to the P sites we assigned P, Si, and S. To satisfy ideal keplerite compositions, site occupancies would be assigned as follows: Ca-site = 9.50; Mg-site = 1.00; P-site = 7.00. Note that the Ca-site in analyzed keplerite grains is too low while the Mg-site is too high. This may indicate that the Ca-site in keplerite contains some Fe+Mg+Mn (Table 4). Maps of element distributions (Na, Ca, Cl, F, S, Si, K, Fe, Mg, and P) in two keplerite-bearing assemblages were obtained by Wavelength Dispersive Spectrometry (WDS) on the EPMAs, see Figure 34 and Figure 35. Shock-melt veins were not observed or identified during analyses and therefore no phosphates were found to occur in shock-melted zones. None of the grains analyzed here showed any chemical zoning in any orientation (Figure 34 and Figure 35).



Figure 31. Backscattered electron (BSE) images of keplerite grains #1-2 *in Tissint.* (a) Keplerite grain #1 in Tissint and (b) Keplerite grain #2 in Tissint. Mineral abbreviations: Pgt = pigeonite; Tro = troilite; Ol = olivine; Msk = maskelynite; Ilm = ilmenite; Kep = keplerite; Chr = chromite. Scale bar is 10 µm in length. Note Figure 27 for location of analyzed points.



Figure 32. Backscattered electron (BSE) images of keplerite grains #3-16 in Tissint. Grains denoted in green (1, 2, 5, 8, 9, 10, 12) were used in quantitative point analysis calculations. Note occurrence of keplerite grains with symplectite in figure (f). Scale bar is 1 to 10 µm in length.

Chemical composition of Keplerite in Tissint										
	wt%a	$1\sigma^{a}$	To 28 c	oxygens						
Al ₂ O ₃	0.140	0.17	Al	0.003						
Ce ₂ O ₃	0.034	0.03	Ce	0.002						
La ₂ O ₃	0.036	0.10	La	0.002						
Nd ₂ O ₃	0.035	0.07	Nd	0.002						
FeO	2.980	0.54	Fe	0.449						
MnO	0.142	0.03	Mn	0.022						
MgO	2.876	0.27	Mg	0.771						
CaO	46.726	0.68	Ca	9.010						
Na ₂ O	0.614	0.20	Na	0.214						
K ₂ O	0.048	0.02	K	0.011						
P ₂ O ₅	45.528	0.80	Р	6.937						
SiO ₂	0.544	0.60	Si	0.098						
SO ₃	0.090	0.13	S	0.012						
* <i>TiO</i> ₂	0.023	0.02	*Ti	0.003						
F	0.000	0.00	F	0.000						
Cl	0.009	0.01	Cl	0.003						
O=F,Cl	-0.002									
Total	99.823									

Table 4. Average composition of keplerite in Tissint.

^a Oxide concentrations; EPMA analyses by mass. Average of 35 analyses. *TiO₂ was not analyzed via JEOL JXA-8530F Hyperprobe at Rice University. Therefore, weight percent and normalized formula amounts are the average of 35 analyses collected via JEOL JXA-8530F Microprobe at NASA-JSC-ARES.

Ca-site	9.264
Mg-site	1.220
P-site	7.046

Includes: Na, La, K, Ca, Mn, Ce, Nd Includes: Fe, Mg

	Inclu	udes:	Si,	P,	S
--	-------	-------	-----	----	---

Mg#	63.24	
Na#	2.32	

Mg ratio = 100 x Mg / (Mg + Fe) Na ratio = 100 x Na / (Na + Ca)

Keplerite Formula	$Ca_9(Ca_{0.5}\square_{0.5})Mg(PO_4)_7$
----------------------	---

1 IA																	18 VIIIA
1						Perio	odic T	able	of the	e Eler	nents						^{8A}
Hydrogen	2 11A							Atomic	_			13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	Heium
1.008	2A	1						Number	- 1			3A	4A	5A	6A	7A	<u>4.003</u>
Ľ	Be							Syr	nbol			B	C	N	° O	F	Ne
6.941	3.012							Na Atomi	ame c Moss			10.811	12.011	14 (037	15.000	Fillerine 18.318	20.180
'Na	Ma	3	4	5	6	7	8	9	10	11	12	AI	^{¹₄} Si	[™] P	l [™] S	ľ′ci	"Ar
Sectium 22.990	Magnesium 24,505	111B 38	IVB 4B	VB 58	VIB 6B	VIIB 7B	$-\epsilon$	VIII		1B 1B	11B 2B	Aluminum 26.982	Silicen 28.080	Phospherus 36,974	Sultur 32.000	Chlorine 35.453	Argen 38.948
¹⁹ K	20	21 Sc	²² Ti	²³ V		²⁵ Mn	26 Fo	27 Co	28 Ni	29	30 7 n	31 Ga	32 Go	³³ Δe	34 Sa	³⁵ Br	³⁶ Kr
Potassiara 39.098	Calcium 40.078	Scandium 44.956	Titanium 47.88	Vanadium 50.912	Chronnium 51.996	Manganese 54,938	Iron 55.815	Cabalt 58.933	Nickel 58.593	Copper 63.545	Zinc 65.38	Gellium 69.723	Germanium 72.631	Arsenic 74.922	Selenium 78.971	Bromine 79.314	Krypton 84.798
37 Dh	³⁸ Cr	³⁹ V	40 7 r				44 Du	45 Dh		47 • • •		49 1 m	50 6 n	51 Ch	52 To	53	54
Rubidium 85.458	Strantium 87.62	Yttrium 88.325	Zirconium 91.224	Niobium 12,995	Molybdenum 15:35	Technetium 58.907	Ruthenium 101.07	Rhedum 102.905	Palladium 108.42	Novar 107.808	Codmium 112.414	Influm 114 818		Antimony 121.760	Tellarium 127.6	lodine 125.904	Xanon 131/294
55	56	57-71	72.0	73	74	75	76	77.	78	79	80.	81	82	83	84	85	86
CCS	Barium		HT	I a Tantalum	W Tungsten	Rhenium	US Osmium	Iridium	Platinum	AU	Hg	Thallium	PD	Bismath	Polonium	Astatine	Radon
87	88	89-103	178.49	180,548	163.85	186.207	190.23	192.22	195.08	135.967	112	204.383	114	1115	1116	117	118
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mathematika	Darpstedium	Rg	Cn	Nh	FI	Monorellution	Lv	Ts	Og
223.020	228.028		[261]	[282]	[266]	264	[263]	[268]	[278]	[280]	1285	[285]	1280	[283]	203	[204]	1204
	Lanth	anide 57	58	59	0r 60		62 C	m 63	64	Ed 65	г ь 66	67	68	=r 69	-m ⁷⁰	/h 71	
	Ser	ies Lanti	hanum Ce 14	rium U110 Prasec 140	dymiam Neod	ymium 1,243 Prom	nethium Sam 4.913 15	tarium Eur	opium Gad	olinium Te 57.25 16	ebium Dysp 18.925 16	rosium Hol	10 E mium 4,902 16	toium Th 17.259 10	ulium Ytte 38.934 17	stbium Lute 3,055 174	tium 1.957
	6 et 1	89	90	. 191	92	. 93	. 194	95		97			- 100	101	102	103	=
	Ser	ies Acti		rium Prote	a Ura	nium Neg	tunium Plut		risium C	rium B+r	SK Calif	JT Eins	teitium	mium Meno	AC Not	10 Lawr	Inclum
		22		28	<u>930</u> (<u>23</u>	23	2.940 24	1.001 24	3,851 24	1.970 24	25			N.386 2			<u>84</u>

Figure 33. Periodic table of elements with Ca-Site (green), Mg-site (blue), and P-site (red) assignments filled in for keplerite. Source of periodic table: <u>https://sciencenotes.org/</u>. Data corresponds to Table 4. Opacity of colors varies with respect to relative abundances (i.e., 0.001 to 0.250 cations = 20% opacity; 0.251 to 0.500 cations = 40% opacity; 0.501 to 0.750 cations = 60% opacity; 0.751 to 1.000 cations = 80% opacity; >1.001 cations = 100% opacity).



Figure 34. Quantitative WDS (Wavelength Dispersive Spectrometry) element map distribution and BSE (BackScattered Electron) image of phosphate keplerite grain #1 in Tissint. WDS element maps illustrate elemental distributions in phosphates and surrounding phases; maps are given in weight percent (wt%). WDS element maps correspond to BSE image in the bottom right-hand corner. Mineral abbreviations: Pgt = pigeonite; Tro = troilite; Ol = olivine; Msk = maskelynite; Ilm = ilmenite; Kep = keplerite. Scale bar is 10 μ m in length.



Figure 35. Quantitative WDS (Wavelength Dispersive Spectrometry) element map distribution and BSE (BackScattered Electron) image of phosphate keplerite grain #2 in Tissint. WDS element maps illustrate elemental distributions in phosphates and surrounding phases; maps are given in weight percent (wt%). WDS element maps correspond to BSE image in the bottom right-hand corner. Mineral abbreviations: Pgt = pigeonite; Tro = troilite; Ol = olivine; Msk = maskelynite; Ilm = ilmenite; Kep = keplerite; Chr = chromite. Scale bar is 10 µm in length.

4.1.3 Raman Spectroscopy

A total of four scans were collected for Raman phosphate phase analysis in Tissint: two spectra were collected for keplerite grain #1 and two were collected for keplerite grain #2. A representative scan of keplerite in Tissint are shown in Figure 36 and Figure 37; a backscattered electron (BSE) image of the analyzed keplerite grain are shown in Supplementary Figure 92. Additional information regarding each individual Raman scan can be found in the Appendix (e.g., Supplementary Figure 93; Supplementary Table 13). All scans collected exhibited comparable spectral features (i.e., peak locations). As such, the four collected scans were averaged. Averaged spectra are shown in Figure 38 and Figure 39.

Three key features were observed in measured spectra. First, doublets (i.e., "duplets"), characteristic of merrillite-subgroup members, were observed to occur at 955.7 to 958.7 cm⁻¹ and 970.0 to 972.8 cm⁻¹ (Figure 37, Figure 39). Second, visually resolved shoulders located at 947.5, 952.0, and 955.7 cm⁻¹ were exhibited in spectra. The occurrence of these bands was associated with general peak-broadening. Third, the 923 cm⁻¹ band, characteristic of HPO₄²⁻ groups (e.g., whitlockite), was not observed in any of the collected Raman spectra.



Figure 36. Representative analysis of measured Raman spectra for keplerite (grain #2) in Tissint over the 700 to 1700 cm⁻¹ range. Spectrum 214. Note doublets located at 958.7 and 973.6 cm⁻¹; missing 923 cm⁻¹ band (i.e., characteristic signature of HPO₄²⁻ groups); and visually resolved shoulders located in the 947.5 to 955.7 cm⁻¹ region.



Figure 37. Representative analysis of measured Raman spectra for keplerite (grain #2) in Tissint over the 870 to 1080 cm⁻¹ range. Spectrum 214. Note that keplerite displays visually resolved shoulders located at 947.5, 952.0 and 955.7 cm⁻¹ which cause peak broadening. Also note the missing 923 cm⁻¹ band, which is a characteristic signature of HPO₄²⁻ groups.



Figure 38. Averaged analysis of measured Raman spectra for keplerite grains #1 and #2 in Tissint over the 600 to 1200 cm-1 range.



Figure 39. Averaged analysis of measured Raman spectra for keplerite grains #1 and #2 in Tissint over the 900 to 1000 cm-1 range. Note the visually resolved shoulders located at 947.5, 952.0, and 955.7 cm⁻¹. Given a local minima of 964.7 cm⁻¹; the left-most end of the curve is a distance of 17.2 cm⁻¹ away from the local minima (i.e., 946.7 cm⁻¹ – 957.5 cm⁻¹ = 17.2 cm⁻¹). Given the same local minima of 964.7 cm⁻¹; the right-most end of the curve is a distance of 15.6 cm⁻¹ away from the local minima (i.e., 946.7 cm⁻¹ = 15.6 cm⁻¹). As such, the left-most portion of the curve is more bulbous (i.e., due to the accented shoulder) than the right-most portion of the curve.
4.1.4 Electron Backscattered Diffraction (EBSD)

Keplerite grains #1 and #2 were targeted for EBSD structural analysis. Inverse pole figure (IPF) maps and electron backscatter patterns (EBSPs) (i.e., Kikuchi bands; crystal lattice projections) were collected for both keplerite grains. A total of 6 EBSPs were collected; 2 for grain #1 and 4 for grain #2.

Measured IPFs are shown in Figure 40 and Figure 41 while a representative EBSP are shown in Figure 42. Phase maps of analyzed sections can be found in the Appendix (e.g., Supplementary Figure 99). Coloring schemes used an IPF z-scheme (parallel to the z-direction) for orientation maps produced. In other words, each point on the map is colored according to which crystal direction is measured to be parallel to the z-direction of the map. Analyzed grains were found to have a merrillite-type crystal structure. Both grains exhibited similar crystal orientations as well, with the 10-10 crystal face being roughly parallel to the map surface.



Figure 40. Backscattered electron (BSE) image and inverse pole figure (IPF) z-scheme (i.e., IPF map relative to the z direction of the image) of keplerite grain #1 in Tissint. Keplerite grain analyzed outlined in red. Note that the 10-10 face is roughly parallel to the map surface in the analyzed keplerite grain (denoted by "Merrillite Xie").



Figure 41. Backscattered electron (BSE) image and inverse pole figure (IPF) z-scheme (i.e., IPF map relative to the z direction of the image) of keplerite grain #2 in Tissint. Keplerite grain analyzed outlined in red. Note that the 10-10 face is roughly parallel to the map surface in the analyzed keplerite grain (denoted by "Merrillite Xie").



Figure 42. Backscattered electron (BSE) image and electron backscatter patterns (EBSPs) of keplerite grain #2 in Tissint. (a) BSE image of keplerite grain #2. (b) EBSP of keplerite grain #2. (c) Kikuchi bands and associated crystallographic planes superimposed on EBSP of keplerite grain #2. Yellow star denotes the location of spot analysis. Kikuchi bands are geometrical projections of crystal lattice planes.

4.2 Discussion

Through combined geochemical and structural characterization, phosphate phases in Tissint were found to have 1) compositions typical of Tissint phosphates, 2) crystal structures analogous to merrillite-subgroup members, 3) sodium deficiencies relative to that of ideal merrillite compositions (Ca₉NaMg(PO₄)₇), and 4) sodium deficiencies relative to merrillite-subgroup members of other meteorite groups.

As can be expected for minerals which are members of a solid-solution series, a range in measured phosphate compositions was documented in Tissint (e.g., Na₂O ranged

from 0.29 to 0.98 wt%) (Supplementary Table 4). Analyzed grains were found to be moderately heterogeneous; the average sodium content of all analyzed grains was 0.61 wt% for Na₂O ($1\sigma = 0.19$, n = 35). However so, individual phosphate grains were generally found to be homogenous at the mineral-scale. Further, no chemical zoning was found in any of the analyzed phosphate grains (Figure 34 and Figure 35). Although shock-melt zones were not observed in this study, their influence on phosphate chemistry should not be discounted (Liu et al., 2018). Note Appendix for element-specific WDS maps.

All analyzed phosphate phases contained considerably less sodium in their structure when compared to end-member merrillite. Ideally, merrillite should accommodate 1.0 formula unit of sodium in its crystal structure for every 28 oxygens present (Xie et al., 2015). At most, the highest measured (Tissint phosphate) Na content was found to be 0.98 wt%, which corresponds to 0.34 formula units of sodium (Supplementary Table 10). Therefore, even at the highest measured value, phosphates analyzed in this study contain far too little sodium to satisfy end-member merrillite compositions.

This deficiency in sodium is reflected in the Na# as well, which was averaged at 2.32 for all analyzed phosphate grains (Table 4). When compared to end-member merrillite (which is described by an Na# of 10), it is quite clear that an intermediate merrillite-keplerite phase is present in Tissint. The following additional qualifiers are suggested to be used in conjunction with Na# to better describe intermediate merrillite-keplerite phases:

- <u>End-member keplerite</u>: for Na-number = 0.00.
- Low-Na keplerite: for Na-numbers between 0.01 and 2.50
- <u>High-Na keplerite</u>: for Na-numbers between 2.51 and 5.00
- Low-Na merrillite: for Na-numbers between 5.01 and 7.50
- <u>High-Na merrillite</u>: for Na-numbers between 7.51 and 9.99
- <u>End-member merrillite</u>: for Na-number = 10.00.

An example of the proposed Keplerite-Merrillite classification system can be given from the results of this study. The lowest Na₂O content measured in analyzed phosphates was 0.29 wt%, while the highest measured at 0.98 wt%. Using these data (along with associated chemical data; CaO, FeO, P₂O₅ wt%, etc.), normalized formula amounts (i.e., atoms per formula unit) can be calculated and then applied to the Na# equation: $([Na_{atomic}/(Na_{atomic}+Ca_{atmoic})]*100)$ (Supplementary Table 9; Supplementary Table 10).

At the lowest, sodium contents measured (0.29 wt% Na₂O), 0.10 Na atoms and 9.09 Ca atoms in analyzed grains (i.e., Point 22). Therefore, using these data the Na# is $[Na_{0.10}/(Na_{0.10}+Ca_{9.09})]^*100 = 1.01$. At the highest, sodium content measured (0.98 wt% Na₂O), 0.34 Na atoms and 8.91 Ca atoms in analyzed grains (i.e., Point 210). Therefore, using these data the Na# is $[Na_{0.34}/(Na_{0.34}+Ca_{8.91})]^*100 = 3.68$. At an average Na# of 2.32 (Table 4), low-end Na# of 1.01, and high-end Na# of 3.68, phosphates in Tissint were found to be generally composed of low-Na keplerite, however a few high-Na keplerite grains were found to occur as well (Supplementary Table 4). It should be noted that incorporation of sodium into the crystal structure of Tissint phosphates should be expected, simply given their occurrence with late-stage, Na-rich phases, such as maskelynite (i.e., feldspathic glass, (Na,Ca)[(Si,Al)AlSi₂]O₈)) (e.g., Figure 34 and Figure 35).

Likewise, Mg#, $[Mg_{atomic}/(Mg_{atomic}+Fe_{atmoic})]*100$, extrema can be calculated as well. At the lowest, magnesium contents measured (2.57 wt% MgO), 0.70 Mg atoms, 0.45 Fe atoms, and 0.16 Na atoms in analyzed grains (i.e., Point 15). Therefore, using these data the Mg# is $[Mg_{0.70}/(Mg_{0.70}+Fe_{0.45})]*100 = 60.87$ (Supplementary Table 11). At the highest, magnesium contents measured (3.32 wt% MgO), 0.90 Mg atoms, 0.27 Fe atoms, and 0.23 Na atoms in analyzed grains (i.e., Point 211) (Supplementary Table 12). Therefore, using these data the Mg# is $[Mg_{0.90}/(Mg_{0.90}+Fe_{0.27})]*100 = 76.9$. The average for the 35 analyzed points in Tissint were found to have Mg# = 63.2 with 0.21 Na atoms and 0.02 Mn atoms (per 28 O) (Table 4).

When these data are compared to the olivine-phyric phosphates of Liu et al. (2016) and the Martian phosphates of Shearer et al. (2015), it was found that all phosphates analyzed in this study exhibited chemical compositions typical of Tissint (Figure 12) with notable deficiencies in Na₂O contents when compared to phosphates in other meteorite groups (Figure 13). Additionally, when considering site-specific occupancies, analyzed phosphate grains in Tissint were found to contain excess calcium (i.e., 9.3 atoms) relative to ideal merrillite compositions (i.e., 9.0 atoms; Ca₉NaMg(PO₄)₇) (Table 4).

Raman spectra collected of Tissint phosphate grains also reflect intermediate merrillite–keplerite characteristics. Overall, spectra collected in this study were found to be in close approximation to the meteoritic keplerite grains analyzed in Britvin et al. (2021) (e.g., Figure 23, Figure 24). The most robust similarity between this study and that of Britvin et al. (2021) is the presence of visually-resolved shoulders and associated peak-width-broadening in all collected Raman spectra (e.g., Figure 37, Figure 39). An important note to be made here is that such visually-resolved shoulders (i.e., located at 950 and 958 cm⁻¹) have not been reported in earlier works for end-member merrillite (Britvin et al., 2021; Xie et al., 2015). As such, the presence of these additional bands further supports the presence of intermediate merrillite-keplerite phases in Tissint.

As is discussed by Britvin et al. (2021), peak width-broadening in keplerite may be attributed to phase-specific structural distortions associated with the selective bonding of [PO₄] tetrahedra to the half-occupied B-site of the crystal system (Figure 10). In a more general sense, peak-width broadening of Raman spectra could also be caused by (1) general compositional variations in minerals (e.g., ionic substitutions), and (2) analyzing internally

damaged minerals that have undergone shock-metamorphic alterations (e.g., due to shockcompression and mechanical stress) (Ruschel et al., 2012; Zhang et al., 2018).

The widened peaks measured in Tissint could provide diagnostic phase-specific information. The distinction between end-member merrillite and end-member keplerite can be made by taking note of two unique spectral signatures recorded in Tissint Raman spectra. First, Tissint phosphate-phase spectra recorded the presence of a visually resolved shoulder occurring between the frequencies of 950 and 958 cm⁻¹; these frequencies noted describe the shoulder locations of end-member keplerite (Britvin et al., 2021). The occurrence of a shoulder in the correct spectral range (for all measured spectra) indicates that the phosphate phase identified in Tissint is likely keplerite. Second, although collected Tissint spectra are in agreement with the general spectral properties of keplerite-type phases (e.g., observable shoulder), they do not adequately describe end-member keplerite (i.e., analyzed Tissint phosphates have additional bands at 947.5, 952.0, and 955.7 cm⁻¹). These data do, however, indicate that compositional variation in minerals (e.g., merrillitekeplerite solid solution series) can cause unique spectral signals to result in intermediate phases (e.g., peak-broadening); as was observed in Tissint phosphates. The occurrence of a skewed shoulder in the approximate spectral range then indicates that the phosphate phase identified in Tissint is actually of intermediate merrillite-keplerite composition. Therefore, Raman spectroscopic techniques explored through this study proved useful as a method to distinguish between minerals of the merrillite-keplerite solid solution series.

Along with the aforementioned geochemical and spectral analyses, a structural analysis of phosphate grains in Tissint was conducted as well by collecting inverse pole figures (IPFs) and electron backscatter patterns (EBSPs). IPFs and diffraction patterns were collected as they provide information specific to the crystallographic orientation of individual mineral grains (Černok et al., 2019). All orientation maps and diffraction

patterns produced were in good agreement with one another (i.e., data were consistent between mineral grains). Orientation maps demonstrate a preference for both keplerite grains to align with the 10-10 plane. As anticipated, all keplerite grains analyzed exhibited a merrillite-type crystal structure (i.e., note Figure 17 and Figure 42). Further distinctions between merrillite and keplerite in collected EBSP data were not observed.

4.3 Implications

It is important to stay up-to-date with current nomenclature and classification schemes, as it allows for comprehensive communication between communities. As discussed, though keplerite is not a newly discovered mineral, it is a newly defined mineral. As a result of its novelty, there exists within the literature several key examples where keplerite (particularly end-member keplerite) likely existed, instead of merrillite. These examples are explored further to illustrate the implications of having a keplerite-bearing rock.

Keplerite presence in Tissint may provide insight to the conditions that might have existed at the time of phosphate crystallization (e.g., Udry et al. (2020); Figure 5). As was demonstrated by Adcock et al. (2014), stoichiometric keplerite (i.e., Ca_{9.4}Mg_{1.1}(PO₄)_{7.0}) was produced through the devolatilization of whitlockite (i.e., heating of whitlockite to ~1,000 °C). Further, the shock experiments of Adcock et al. (2017) demonstrated that the likely driver of phosphate transformation from OH-rich (e.g., whitlockite) to OH-poor phases (e.g., keplerite) is facilitated by extreme, localized, temperature spikes. These formation conditions (i.e., punctuated heating events) are consistent with the proposed formation environment of keplerite (Britvin et al., 2021). This is important considering that merrillite subgroup minerals are late-stage, volatile-rich, phases that are often used to estimate the volatile histories of magmas (Baziotis et al., 2013). Therefore, rocks which

contain end-member keplerite may have originally formed in volatile-rich, hydrous environments, if shock-transformed from whitlockite (Adcock et al., 2017).

Further, if it is indeed keplerite that forms as a result of shock-related processes and not merrillite, then Na-deficiencies in analyzed Tissint grains are to be expected as keplerite itself is a Na-free mineral. However, due to its association with other late-stage phases that are Na-rich (e.g., maskelynite; Figure 34 and Figure 35), it is also not surprising that analyzed keplerite grains in Tissint accommodated variable amounts of sodium (Table 4). Additionally, chemical zonation of sodium in intermediate merrillite-keplerite phases has been observed in grains which contact impact melt (i.e., a shock metamorphic feature) (Liu et al., 2018). Therefore, shock-metamorphic conditions (i.e., elevated temperatures) and features (e.g., impact melt) can cause geochemical variations in the merrillite-keplerite mineral series.

4.4 Conclusions

Keplerite is a newly recognized phosphate mineral that forms a solid solution with merrillite. Here we show the first documented occurrence of (low-Na) keplerite in Tissint. The presence of keplerite in Tissint suggests it likely common and occurs in broader range environments (i.e., meteorite groups) than initially established (Britvin et al., 2021). Endmember keplerite may be produced through the devolatilization of whitlockite (Adcock et al., 2014). Formation of keplerite from whitlockite may then indicate the presence of a volatile-rich, hydrous, source environment for those rocks which contain keplerite-bearing mineral assemblages (Adcock et al., 2017). However, care must be taken when analyzing phosphate phases, as proximity to impact melt (i.e., shock-metamorphic features) can cause compositional zonation in the merrillite-keplerite mineral series (e.g., Liu et al., 2018).

CHAPTER 5:

ALH 84001

5.1 Results

A total of 11 phosphate grains were identified in ALH 84001: two grains of Cl-rich apatite, and 9 grains of merrillite. Backscattered electron (BSE) images of all identified grains can be seen in Figure 43. All phosphates identified in ALH 84001 were associated with interstitial plagioclase and/or orthopyroxene. Two of the merrillite grains were intergrown with apatite grains; specifically, merrillite mantles a core of apatite (Figure 43ab). Merrillite-included apatite grains were approximately 40-50 microns in diameter. The other merrillite grains are single, discrete grains associated with orthopyroxene and interstitial plagioclase (Figure 43c-d). The merrillite grains are anhedral (and irregular) to euhedral and ranged in size from 10s of microns in length (or diameter) to 100s of microns in maximum dimension. No Na-deficient merrillite (i.e., keplerite) grains were identified. Apatite and Merrillite Chemical Composition

All 9 identified merrillite grains were targeted for quantitative analysis and 95 individual points were collected (Supplementary Table 5). Further, both identified apatite grains were targeted for quantitative analysis as well; 13 individual points were collected (Supplementary Table 7). A comprehensive summary of apatite chemical composition data is given in Table 5, while merrillite chemical composition data is given in Table 6. Normalized formula amounts were calculated from measured oxide weight percentages. Datapoints which measured abnormal oxide concentrations (e.g., low phosphorus content, like 30 wt% P₂O₅) or total percentages (e.g., total wt% \leq 98.5%) were excluded from calculations.



Figure 43. Backscattered electron (BSE) images of apatite grains #1-2 and merrillite grains #1-9 in ALH 84001. Mineral abbreviations: Plag = plagioclase; OPX = orthopyroxene; Ap = apatite; Mer = merrillite. Note intergrown apatite-merrillite textures and occurrence of phosphates with interstitial plagioclase and orthopyroxene. Scale bar is 10 μ m in length. Note Figure 30 for location of analyzed points.

Chemical composition of Apatite in ALH84001,146										
	wt% ^a	$1\sigma^{a}$	To 8 c	ations						
Al ₂ O ₃	0.04	0.06	Al	0.005						
Ce ₂ O ₃	0.02	0.02	Ce	0.001						
La ₂ O ₃	0.01	0.03	La	0.000						
Nd ₂ O ₃	0.11	0.13	Nd	0.003						
FeO	0.17	0.05	Fe	0.012						
MnO	0.03	0.02	Mn	0.002						
MgO	0.03	0.01	Mg	0.004						
CaO	53.79	0.61	Ca	4.911						
Na ₂ O	0.26	0.04	Na	0.043						
K ₂ O	0.01	0.01	K	0.001						
P ₂ O ₅	41.50	0.38	Р	2.994						
SiO ₂	0.19	0.05	Si	0.016						
SO ₃	0.12	0.01	S	0.008						
F	0.61	0.17	F	0.164						
Cl	4.36	0.42	Cl	0.630						
O=F,Cl	-1.24	0.11	Charge	0.215						
Total	100.02		Sum	0.213						

 Table 5. Average chemical composition of apatite in ALH 84001.

^a Oxide concentrations; EPMA analyses by mass. Average of 13 analyses.

Ca-site	4.982	Includes: Al, Ce, La, Nd, Fe, Mn, Mg, Ca, Na, K
P-site	3.018	Includes: Si, P, S

Mg#	25.07	Mg ratio = 100 x Mg / (Mg + Fe)
Na#	0.88	Na ratio = $100 \times Na / (Na + Ca)$

Apatite	C_{2} (PO ₂). (OH E C ¹)
Formula	Ca5(1 O4)3(O11,1,C1)

1 IA																	18 VIIIA
						Perio	T aibe	able	of the	Flen	nents						8A
H	2					1 011						13	14	15	16	17	He
Hydrogen 1.008	2A							Atomic Number						5A			4.003
³ Li	^⁴ Be							Syr	nbol			⁵B	° C	⁷ N	° o	°г	¹⁰ Ne
Uthlum 6.941	Beryllum 3.012	ļ						Na	ime			Beron 10.811	Cerbon 12.011	Nitrogen 14.037	0xygen 15.000	Fluorine 18.938	Neon 20.180
	12 Ma			_		_							¹⁴ ei	15	16 c		
Sedum 22,990	Magnosium 24,305	3 111B	4 IVB	VB	VIB	7 VIIB	ĉ	— viii —		11 IB	12	Atuminum 20.982	Silicen 28.080	Phosphorus 10,974	Sultur 32,000	Chlorine 35.453	Argen 30.948
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Potasolarn 39.038	Catcium 40.074	SC Scandium	Titanium 47.88	Vanadium 50.912	Chrornium 51.995	Manganese Manganese	Fe 1000	Co Cabalt 55 833	Nickel 56 033	Copper		Gallum 68 723	Germanium 72 631	AS Arsenic 74.922	Se Selenium 78.971	Bromine 79.834	Kr Krypton 84 798
37	38	39	40	41	42	43	44	45	46	47	48	49.	50	51	52	53	54
Rubidium	Sr	Yttrium		Nobium	MO	Technetium	Ruthenium	Rh	Pd	Ag	Cd	In	Sn	SD	Tellurium	lodine 156 Bod	Xe
55	56	57-71	72	73	74	75	76_	77	78_	79	80	81	82	83	84	85	86
	Ba		Hf	Та	W	Re	Os	Ir	Pt	Au	Hg	TI	Pb	Bi	Po	At	Rn
152.305	137.328	80.102	178.49	180,948	163.85	188,207	190.23	192.22	195.08	195.967	200.59	204.383	207.2	208.980	[208.982]	2(9.387	222.018
^{°′} Fr	Ra	08-103	Î [™] Rf	Ďb	Ŝg	Bh	Hs	Mt	Ds	Ŕg	ľČn	Ňh	FI	Mc	Ľv	Ϊ Τs	'Ög
Prenclum 223.020	Radium 225.025		Rutherfordium [261]	Dubnium 282	Seatorgium [295]	Bohrium 264	Hassium [263]	Meltnerium 268	Darmstedtium [278]	Roentgenium [280]	Copernicium [285]	Nihonium [285]	Flørovium 289	Moscosłum [283]	Livermorium 203	Termessine [234]	Oganesson 294
		57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	
	Lanth Ser	anide L	.a C		Pr N	Id P	m S	m E		d T	-b D)y H			`m Y	′b L	.u
				0,110 14			4.913	0.35 15	1.304	17.25 15	8.925	.500 10	100	7.259 10	8.934 17	102	1967
	Acti	nide ries	\c ∥ຶT	⁻h ∥ຶF	'a∥‴l	J∥ĩN	lp∥"F	²u∥"Ă	∖m∥‴C	∶m∥ຶΈ	3k∥ຶC	Cf∥"Ē	:s∥ ÏF	m Ň	/ld 🛛 🕅	lo∥″ĭ	.r
	50	Act 22	Inium Th 7.028 23	2.038 Prote 2.038 23	otinium Un 1.036 23	nium Nep 8.023 23	tunium Plut 7.548 24	Anie 4.054 Z4	erisium Cu 3.261 24	rium Ber 7.070 24	kelium Celife 7.070 251	Einst	əltium Fər 1541 25	mium Mend 7.008 2	elevium Nob	əlium Lawre	enclum 1621

Figure 44. Periodic table of elements with Ca-Site (green) and P-site (red) assignments filled in for apatite. Source of periodic table: <u>https://sciencenotes.org/</u>. Data corresponds to Table 5. Opacity of colors varies with respect to relative abundances (i.e., 0.001 to 0.250 cations = 20% opacity; 0.251 to 0.500 cations = 40% opacity; 0.501 to 0.750 cations = 60% opacity; 0.751 to 1.000 cations = 80% opacity; >1.001 cations = 100% opacity).

Chemical composition of Merrillite in ALH84001,146											
	wt% ^a	$1\sigma^{a}$	To 28 o	oxygens							
Al ₂ O ₃	0.014	0.03	Al	0.003							
Ce ₂ O ₃	0.092	0.11	Ce	0.006							
La ₂ O ₃	0.094	0.18	La	0.006							
Nd ₂ O ₃	0.053	0.08	Nd	0.003							
FeO	0.861	0.18	Fe	0.129							
MnO	0.031	0.02	Mn	0.005							
MgO	3.421	0.06	Mg	0.911							
CaO	46.715	0.41	Ca	8.946							
Na ₂ O	2.348	0.08	Na	0.814							
K ₂ O	0.089	0.01	K	0.020							
P ₂ O ₅	46.399	0.38	Р	7.021							
SiO ₂	0.026	0.12	Si	0.005							
SO ₃	0.009	0.01	S	0.001							
F	0.000	0.00	F	0.000							
Cl	0.004	0.00	Cl	0.001							
O=F,Cl	-0.001	0.00									
Total	100.155										

Table 6. Average chemical composition of merrillite in ALH 84001.

^a Oxide concentrations; EPMA analyses by mass. Average of 95 analyses.

Ca-site	8.966	Includes: La, Ca, Mn, Ce, Nd
Na-site	0.834	Includes: Na, K
Mg-site	1.040	Includes: Fe, Mg
P-site	7.026	Includes: Si, P, S

Mg#	87.62	Mg ratio = 100 x Mg / (Mg + Fe)
Na#	8.34	Na ratio = $100 \times Na / (Na + Ca)$

Merrillite	$C_{2} M_{2} M_{2} (DO)$
Formula	Ca9INalVig(PO4)7

1 IA																	18 VIIIA
	1					Perio	odic T	able	of the	Elen	nents						2
H	2							_	_			13	14	15 VA	16 VIA	17 VIIA	He
1.008	2A							Number				3A	44	5A	6A	7A	4.000
Li	Be							Syr	nbol			°в	°с	ľΝ	° o	F	Ne
E341	Beryflum 3.012							Na	me : Miss			Boron 10.811	Cerbon 12.011	Nitrogen 14/037	Oxygen 15.000	Fluorine 18.018	Neon 20.180
¹¹ Na	¹² Ma	3	4	5	6	7	8	<u> </u>	10	11	12		¹⁴ Si	15 P	¹⁶ S		¹⁸ Ar
Sadium 22.980	Magnesium 24,505	IIIB 3B	іVВ 4В	VB 5B	VIB 6B	VIIB 78	- -	— vill —		1B 1B	11B 2B	Alumisum 26.982	Silicen 28.086	Phosphorus 16,974	Sultur 32.008	Chlorine 35.453	Argen 38.948
19	20	²¹	²² T i	²³ V	²⁴	25	26 F O	27	28 Ni	29	³⁰ 7 n	³¹	³²	33	34	35 Br	³⁶
Potassiarn 39.038	Calcium 40.078	Scandium 44.856	Titankum 47.88	Vanadium 50.912	Chrornium 51.996	Manganese 84,938	Iron 55.815	Cabalt 58,933	Nickel 58.593	Copper 63.548	Zinc 65.38	Gellium 69.723	Germanium 72.631	Arsenic 74.922	Selenium 78.971	Di Bromine 79,314	Krypton 84.798
37 Dh	38	³⁹	⁴⁰ 7-		42	43 T o	44 D.1	45 Dh		47		⁴⁹ Lm	50	51 Ch	52 T a	53	54
Rubidium 85.458	Strantium 87.62	Yttrium 88.335	ZI Zireonium 91.224	Niobium B2.906	Molybdenum 15-15	Technetium 58.907	Ruthenium 101.07	Rhodum 102.905	Palladium 10642	Novar 107.858	Codmium 112.414	Influm 114.818		Antimony 121.750	Tellurium 127.6	lodine 125.904	Xenon 131.254
55	56	57-71	72.00	73	74	75	76	77	78	79	80	81-1	82	83	84	85	86
CCS	Barium		HT	Tantalum	Tungsten	Rhenium	US Osmium	Iridium	Platinum	Gold	Hg	Thallium	PD	Bisruth	Polonium	Atatatine	Radon
87	88	89-103	1/8.42	105	106	180.207	190.25	192.22	190.08	111	112	113	114	115	116	117	118
Fr	Ra		Rf	Db	Seatorgum	Bh	Hs	Metherium	Darmstedtium	Rg	Cn	Nh	FI	Moscowlum	LV	TS	
223.020	225.025		[261]	282	[205]	264	[263]	268	278	12801	285	289	289	[283]	[203]	, [204]	204
	Lanth	anide 57	a 58	1 59		IA 61		m 63		24 65	г ь 66	67	<u>ام ا</u>	=r 69	-m ⁷⁰	/h 71	
	Ser	ies Lanti 138	hanum Ce 1.905 14	rium 0,116 Prases	dymiam Neod	ymium 4.243 Prom 14	ethium Sam 4.913	arium Eur 0.35 15	opium 1,964 15	olinium 57.25	rbiurn Dysp 8.925 16	Hol	inium Er 4,903 16	bium Th 7.259 10	uliurn Ytte 8.904 17	rbium Lute 3,055 17/	tium 1.967
	Actir	aide 89	90	- h 91	92	93	Jan 194	95		97	1	1 99		101	102	103	_
	Ser	ies Acti	Inium The	orium Prote	ctinium Ura	nium Nep	tunium Plut	onium Ame	risium Cu	atium B+ri 7 070 24	kelium Celifi 7 (70) 25	rnium Einst	LS For	mium Meno	Jelevium Nob	silum Lawre	inclum
		20													<u> </u>		<u> </u>

Figure 45. Periodic table of elements with Ca-Site (green), Na-site (yellow), Mg-site (blue), and P-site (red) assignments filled in for merrillite. Source of periodic table: <u>https://sciencenotes.org/</u>. Data corresponds to Table 6. Opacity of colors varies with respect to relative abundances (i.e., 0.001 to 0.250 cations = 20% opacity; 0.251 to 0.500 cations = 40% opacity; 0.501 to 0.750 cations = 60% opacity; 0.751 to 1.000 cations = 80% opacity; >1.001 cations = 100% opacity).

Quantitative Wavelength Dispersive Spectrometry (WDS) element map distributions of the apatite- and merrillite-bearing assemblages of ALH 84001 can be seen in Figure 46, Figure 47, and Figure 48. WDS element maps were generated for Na, Ca, Cl, F, S, Si, K, Fe, Mg, and P. Moderate Cl enrichments were observed to occur in some apatite grains (e.g., Figure 47) but not others (e.g., Figure 46). Further, isolated merrillite grains show evidence of chemical mobility; Cl-rich mineral grain fractures were observed (e.g., Figure 48). Slight chemical zoning can be seen in plagioclase (e.g., note K element map of Figure 48).

An example of homogenous mineral-assemblages can be seen in the WDS element maps of Na, Cl, and F of apatite and merrillite grains #1-3 (Figure 50, Figure 51, and Figure 52, respectively). An example of heterogenous mineral-assemblages can be seen in the WDS element maps of Na, Cl, and F of apatite and merrillite grains #4-6 (Figure 54, Figure 55, and Figure 56, respectively). Lastly, an example of selective mineral-grain enrichments be seen in the WDS element maps of Na, Cl, and F in merrillite grain #8 (Figure 58, Figure 59, and Figure 60, respectively). Note Appendix for supplementary element-specific WDS maps.

Overall, however, apatite and merrillite grains were found to be largely homogenous in composition (Table 5 and Table 6). To compare chemistries with the keplerite-bearing assemblages of Tissint, weight percentages (wt%) of select oxides for analyzed ALH 84001 merrillite grains are given. Na₂O contents ranged from 2.15 to 2.50 wt%; average = 2.35 wt% ($1\sigma = 0.08$). CaO contents ranged from 45.00 to 47.48 wt%; average = 46.72 wt% ($1\sigma = 0.41$). MgO contents ranged from 3.30 to 3.83 wt%; average = 3.42 wt% (1σ = 0.06). P₂O₅ contents ranged from 44.51 to 47.03 wt%; average = 46.40 wt% ($1\sigma = 0.38$) (Supplementary Table 5). When compared to average Tissint phosphate compositions, ALH 84001 phosphates are enriched in sodium and magnesium.



Figure 46. Quantitative WDS (Wavelength Dispersive Spectrometry) element map distribution and BSE (BackScattered Electron) image of apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps illustrate elemental distributions in phosphates and surrounding phases; maps are given in weight percent (wt%). WDS element maps correspond to BSE image in the bottom right-hand corner. Mineral abbreviations: Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Note intergrown texture between apatite and merrillite (i.e., merrillite overgrowths on apatite grains) and highly fractured mineral grains. Scale bar is 10 μ m in length.



Figure 47. Quantitative WDS (Wavelength Dispersive Spectrometry) element map distribution and BSE (BackScattered Electron) image of apatite-merrillite intergrown grains #4-6 in ALH 84001. WDS element maps illustrate elemental distributions in phosphates and surrounding phases; maps are given in weight percent (wt%). WDS element maps correspond to BSE image in the bottom right-hand corner. Mineral abbreviations: Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Note intergrown texture between apatite and merrillite (i.e., merrillite overgrowths on apatite grains) and highly fractured mineral grains. Scale bar is 10 μ m in length.



Figure 48. Quantitative WDS (Wavelength Dispersive Spectrometry) element map distribution and BSE (BackScattered Electron) image of isolated merrillite grain #8 in ALH 84001. WDS element maps illustrate elemental distributions in phosphates and surrounding phases; maps are given in weight percent (wt%). WDS element maps correspond to BSE image in the bottom right-hand corner. Mineral abbreviations: Plag = plagioclase; Mer = merrillite; OPX = orthopyroxene. Scale bar is 10 μ m in length.



Figure 49. Detailed view of BSE (BackScattered Electron) image of apatite-merrillite intergrown grains #1-3 in ALH 84001. Mineral abbreviations: Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 10 μ m in length.



Figure 50. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sodium (Na) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length. Note that all minerals exhibit homogenous compositions (i.e., homogeneity based on low variance in chemical measurements).



Figure 51. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chlorine (Cl) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length. Note that all minerals exhibit homogenous compositions.



Figure 52. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of fluorine (F) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length. Note that only apatite and orthopyroxene accommodate F incorporation. Although slight "peaks" is fluorine content is observed (i.e., bright patches), minerals shown here exhibit approximately homogenous compositions.



Figure 53. Detailed view of BSE (BackScattered Electron) image of apatite-merrillite intergrown grains #4-6 in ALH 84001. Mineral abbreviations: Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 10 μ m in length.



Figure 54. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sodium (Na) in apatite-merrillite intergrown grains #4-6 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 53. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length. Note that all minerals exhibit homogenous compositions.



Figure 55. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chlorine (Cl) in apatite-merrillite intergrown grains #4-6 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 53. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length. Note heterogenous incorporation of chlorine into the apatite structure. There was no observed relationship between mineral fractures and variance in chemical composition (i.e., fractures were not associated with apparent loss or gain in chlorine).



Figure 56. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of fluorine (F) in apatite-merrillite intergrown grains #4-6 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 53. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length. Although very minimal, there is a slight enrichment in F associated with the large mineral fracture which cuts the apatite grain diagonally. Note that the F-rich "phase" to the right-end of the map is the result of epoxy, and thus not a reflection of the meteorite itself.



Figure 57. Detailed view of BSE (BackScattered Electron) image of merrillite grain #8 in ALH 84001. Mineral abbreviations: Plag = plagioclase; Mer = merrillite; OPX = orthopyroxene. Scale bar is 10 μ m in length



Figure 58. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sodium (Na) in merrillite grain #8 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 57. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length. Note that all minerals exhibit homogenous compositions.



Figure 59. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chlorine (Cl) in merrillite grain #8 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 57. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length. Note that there is a moderate enrichment in Cl that is directly associated with mineral (i.e., merrillite) fractures.



Figure 60. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of fluorine (F) in merrillite grain #8 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 57. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length. Note that all (major) minerals exhibit homogenous compositions.

However, unlike phosphates found in Tissint, the mineral assemblage of ALH 84001 contains volatile-bearing phases (i.e., apatite). Apatite Cl and F contents in ALH 84001 grains were moderately heterogeneous in composition with Cl concentrations ranging from 3.85 - 5.05 wt% (average = 4.36 wt%; $1\sigma = 0.42$) and F concentrations ranging from 0.30 - 0.92 wt% (average = 0.61 wt%; $1\sigma = 0.17$) (Supplementary Table 6).

Assuming that F + Cl + OH = 1.0 structural formula unit (sfu), an indirect calculation can be made which estimates the water content of apatite. Average atoms per

formula unit (apfu) of F in apatite was calculated at 0.16 while the average apfu Cl was calculated to be 0.63. Therefore, the water content of apatite is estimated at 0.21 sfu or \sim 21% hydroxyl apatite component (Table 5).

Magnesium# for analyzed apatite, $Ca_5(PO_4)_3(OH,F,Cl)$, grains was calculated to be 25.1 ([Mg_{atomic}/(Mg_{atomic}+Fe_{atmoic})]*100). Site-specific element designations were: Ca-site = 4.98; P-site = 3.02. Site designations included the following: Ca-site included Al, Ce, La, Nd, Fe, Mn, Mg, ca, Na, K; P-site included Si, P, S (Figure 44).

Magnesium# for analyzed merrillite, Ca₉NaMg(PO₄)₇, grains was calculated to be 87.6 $([Mg_{atomic}/(Mg_{atomic}+Fe_{atmoic})]*100).$ Sodium# was calculated to be 8.3 ([Naatomic/(Naatomic+Caatmoic)]*100). Site-specific element designations were: Ca-site = 8.97; Na-site = 0.83; Mg-site = 1.04; P-site = 7.03. Site designations included the following: Casite included La, Ca, Mn, Ce, Nd; Na-site included Na, K; Mg-site included Fe, Mg; P-site included Si, P, S (Figure 45). Finally, although granular bands are a well-documented feature in ALH 84001 (Treiman, 1995, 1998, 2021), they were not identified in the analyzed section. Therefore, no phosphates were identified or analyzed from the granular zones within ALH 84001.

5.2 Discussion

A geochemical investigation of ALH 84001 phosphate phases revealed 1) intergrown apatite-merrillite textures, 2) Cl-rich, OH-poor, apatite grains, 3) moderate Cl-enrichment in merrillite mineral fractures, and 4) moderate Cl-enrichment in select apatite grains. When compared to end-member merrillite compositions (Ca₉NaMg(PO₄)₇), merrillite in ALH 84001 was found to have slight deficiencies in sodium. Average Na₂O contents measured 2.35 wt% ($1\sigma = 0.08$) and 0.81 formula amounts (per 28 O) (

Table 6). When the chemical composition (i.e., Na apfu; Mn apfu; Mg#) of merrillite in ALH 84001 was compared to the olivine-phyric phosphates of Liu et al. (2016)

and the Martian phosphates of Shearer et al. (2015), all analyzed phosphates in this study exhibited chemical signatures characteristic of ALH 84001 (e.g., Na- and Mg-contents: Figure 12, Figure 13, Figure 14).

Analyzed apatite grains also reflect typical chemical compositions measured in Martian meteorites (Figure 9); however, grains analyzed in ALH 84001 exhibited slightly higher Cl contents. At 0.16 apfu F and 0.63 apfu Cl, the hydroxyl component calculated in apatite accounted for 0.21 sfu or ~21%. These results are consistent with that of Filiberto and Treiman (2009) who propose that Martian magmas are depleted in water but enriched in chlorine.

Textural relationships observed between apatite and merrillite (Figure 46, Figure 47) suggest that processes related to shock-metamorphism (e.g., punctuated pressure spikes) likely played an important role in the chemical evolution of ALH 84001 phosphates. Crystallization sequences of apatite-merrillite intergrowths are oftentimes ambiguous in Martian meteorites, as the textural relationship between the two phases can be complex (i.e., inclusions and intergrowths of one phase in the other) (Bellucci et al., 2017; Darling et al., 2021; Greenwood et al., 2003; Greenwood et al., 2008; Howarth et al., 2015; Hwang et al., 2019; Shearer et al., 2011) (Figure 21). However, it is proposed that ALH 84001 results provide clear textural evidence for the following crystallization sequence:

- 1. Magmatic apatite crystallizes first from a Cl-rich, late-stage, melt or fluid.
- 2. Devolatilization of apatite grains occurs following multiple cataclysmic shock events.
- 3. Volatile-free merrillite replaces shocked, devolatilized, apatite grains.
- 4. Mobilized volatiles (i.e., chlorine) move from the apatite system to concentrate in:

- i. *the mineral fractures of merrillite* (e.g., Figure 59). In this scenario, the entire apatite system has been devolatilized due to a shock event; chlorine is mobilized, and becomes concentrated along newly generated (shock-induced) cracks and fractures of the original apatite grain. The recrystallization of apatite to merrillite proceeds to completion (i.e., complete transformation from apatite to merrillite occurs), and residual chlorine becomes concentrated in the fractures of merrillite (i.e., a volatile-free phase).
- ii. *low-fracture zones within apatite* (e.g., Figure 55). In this scenario, the apatite system has been partially devolatilized due to a shock event; chlorine is mobilized, and becomes concentrated in "pockets" within the apatite mineral system. The recrystallization of apatite to merrillite proceeds and mobilized chlorine becomes enriched in the apatite mineral system present.

The counterargument for this scenario would be one in which merrillite was the magmatic phase (instead of apatite). In this counter case, the observed texture produced would be created predominately through interaction with Cl-rich fluids or melt, instead of resulting from shock-metamorphism. This scenario seems unlikely for ALH 84001 though, which has had an extensive shock history (i.e., granular bands in ALH formed between 45-50 GPa; carbonates in ALH fractured at 25-45 GPa; ALH underwent a maximum of 16 GPa when it was ejected from Mars) (North et al., 2023). As such, although there may have been some alteration related to fluid-based interactions, it is proposed that the chemical variation observed in the intergrown texture of apatite and merrillite in ALH 84001 formed as a result of extensive devolatilization related to extensive shock-metamorphic processes.

5.3 Implications

The Cl-rich nature of apatite in ALH 84001 supports the interpretation that Martian parental magmas contained little water but were enriched in other volatiles, such as chlorine (Filiberto and Treiman, 2009). The major implication of these findings is that ancient eruptions of Cl-rich, OH-poor, magmas contributed very little water to the Martian surface (Filiberto and Treiman, 2009). Further, shock-induced chemical variations were found to occur in the magmatic (e.g., apatite devolatilization) and nonmagmatic (e.g., chlorine enrichment in merrillite fractures) phosphate phases of ALH 84001. Therefore, careful consideration must be taken when investigating phosphates that have undergone physical and chemical changes resulting from shock-metamorphism.

5.4 Conclusions

Intergrown merrillite-apatite phases were found to occur in ALH 84001. Analyzed apatite grains contain variable volatile contents but are generally enriched in Cl, while merrillite grains are largely homogenous in composition. In contrast to previous reports (Howarth et al., 2015; Shearer et al., 2011), textures observed in this study provide unambiguous support for a proposed phosphate crystallization history involving magmatic apatite and merrillite recrystallization. Evidence of shock-induced chemical alterations was observed in the fractures of merrillite grains (i.e., Cl-rich fractures) and within unfractured regions of apatite grains. Chemical variations are linked to shock-induced metamorphic events (i.e., meteorite impacts). As was concluded for Tissint, careful consideration must be taken when analyzing grains that show evidence of alteration by shock, as shock metamorphism can drive element mobility in phosphate phases.
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APPENDIX A:

INSTRUMENT CONDITIONS

JEOL JXA-8530F Hyperprobe

Supplementary Table 1. JEOL JXA 8530F Hyperprobe spectrometer settings, and average standard deviation SD (1σ) and detection limits DL (in ppm).

Element	X-ray	Crystal	Peak Pos.	BG_L	BG_U	SD	DL
			(mm)				
Na	Ka	TAP	129.771	5	5	12.657	138.729
Si	Ka	TAP	77.987	6	6	103.990	105.793
La	La	PETJ	85.483	5	5	46.563	1706.268
K	Ka	PETJ	119.993	5	5.5	467.067	101.278
Ca	Ka	PETJ	107.771	5	6	0.350	104.818
Fe	Ka	LIF	134.833	5	5	189.667	310.395
Cl	Ka	PETH	151.477	5.5	5	63.803	61.667
Р	Ka	PETH	197.081	6	6	0.490	65.173
S	Ka	PETH	172.102	5	5	3.220	30.034
F	Ka	LDE1	85.61	5	5	1.737	307.000
Mg	Ka	TAP	107.491	6	6	100.000	45.831
Al	Ka	TAP	90.635	5	5	189.110	84.152
Mn	Ka	LIFL	145.493	5	5	49.100	127.269
Ce	La	LIFL	177.428	3	5	12.873	177.015
Nd	La	LIFL	164.888	5.3	5	273.017	1297.458

Supplementary Table 2. JEOL JXA 8530F Hyperprobe counting times and detector settings. *Source of the standards: SPI: SPI Sullpies; Smth: Smithsonian standards; Mode**: Int=integral; Dif=differential

		Cour time	Counting time (sec) Detector setting								
Element	Standard	Peak	Back	Gain	High.V	Base.Line	Window (V)	Mode**			
Na	Plagioclase_SPI*	10	5	32	1651	0.7	0	Int			
Si	Olivine_SPI	10	5	32	1651	0.7	9.3	Dif			
La	Monazite_SPI	30	20	16	1700	0.7	0	Int			
К	Biotite_SPI	10	5	64	1676	0.7	0	Int			
Са	Apatite_SPI	10	5	64	1676	0.7	0	Int			
Fe	Olivine_SPI	10	5	32	1716	0.7	0	Int			
Cl	Tugtupite_SPI	10	5	64	1660	0.7	0	Int			
Р	Apatite_SPI	10	5	64	1660	0.7	0	Int			
S	Apatite_SPI	30	20	64	1660	0.7	0	Int			
F	Apatite_SPI	10	5	64	1690	0.7	9.3	Dif			
Mg	Biotite_SPI	30	20	32	1644	0.7	0	Int			
Al	Plagioclase_SPI	10	5	32	1644	0.7	0	Int			
Mn	Rhodonite_SPI	10	5	32	1700	0.5	0	Int			
Ce	CePO4_Smth*	30	20	32	1700	0.5	0	Int			
Nd	NdPO4_Smth	30	20	32	1700	700 0.5 0 In					

Mafic silicates

The analytical conditions used were 15 kV accelerating voltage, 20 nA beam current, spot beam (~300 nm diameter). The standards used are shown in Supplementary Table 3. The counting time was 20 seconds for each element (10 sec per peak and 5 sec per each lower and upper background, respectively), except for Ni, where the counting time was 70 sec (30 per peak and 20 sec per each lower and upper background, respectively). PRZ (JEOL) matrix correction was employed for quantification.

Element	Standard
Na	Jadeite_SPI
Si	Olivine SPI
K	Biotite SPI
Са	Plagioclase_SPI
Fe	Almandine SPI
Ti	Rutile SPI
Ni	Olivine SPI
Al	Almandine SPI
Mg	Olivine SPI
Cr	Chromite_SPI
Mn	Rhodonite_SPI

Supplementary Table 3. JEOL JXA 8530F Hyperprobe standards used in mafic silicate analysis.

Trace elements analysis in phosphates

The analytical conditions used were 15 kV accelerating voltage, 150 nA beam current, and a 3-micron beam diameter. The analyzed X-ray line analyzed was L α X-ray for Sm, Eu, Ce, Nd, Gd, and the M α X for U and Th. The standards used were Smithsonian REE phosphate standards. For U and Th, pure metal and monazite standards were used, respectively. The counting time for each element was 200 sec (80 sec per peak and 60 sec per each lower and upper background, respectively). The PRZ (JEOL) matrix correction was used for quantification). The average detection limits were 30 ppm for Sm, 40 ppm for Eu, 34 ppm for Ce, 19 ppm for Gd, 25 ppm for Th, and 19 ppm for U. Gd, Th and U show analytical standard deviation mostly above 100%, showing that the concentration of these elements is below the detection limit, except for few analyses. For details regarding the

standard deviation for each element/analysis see Table X (Trace Element Analysis) in Appendix Y. The interference between Nd and Ce was corrected as follows:

(Nd cps)_{corrected} = (Nd Net)*measured* - k x (Ce Net)*measured*

Where the "fake" Nd counts produced by the interference of Ce were first counted on pure CePO₄ standard, then the correction coefficient k (=0.00223) was calculated and applied in the correction of Nd in the trace element analysis of the Martian phosphates.

APPENDIX B:

QUANTITATIVE POINT ANALYSES

Supplementary Table 4. Summarized quantitative point analyses for keplerite in Tissint. Data used to calculate average wt% (weight percent) and formula amounts included data collected at Rice University (JEOL JXA-8530F Hyperprobe) and JSC (JEOL JXA-8530F Field Emission Electron Probe). Note that TiO2 was not analyzed at Rice University; these data were only collected at JSC. Comments denote mineral names given at time of data collection.

Data Collection	Point	Comment	Na2O	SiO2	La2O3	K2O	CaO	FeO	Cl	P2O5	SO3	F
Rice Uni.	207	Tissint_merr1_1	0.660	0.054	0.000	0.008	47.482	2.338	0.008	46.127	0.031	0.000
Rice Uni.	208	Tissint merr1 2	0.720	0.128	0.000	0.033	47.136	2.234	0.003	45.922	0.019	0.000
Rice Uni.	209	Tissint_merr1_3	0.652	0.110	0.423	0.011	47.170	2.398	0.004	46.227	0.028	0.000
Rice Uni.	210	Tissint_merr1_4	0.981	0.618	0.000	0.050	46.423	2.387	0.003	46.127	0.147	0.000
Rice Uni.	211	Tissint_merr1_5	0.638	0.011	0.000	0.062	47.111	1.763	0.017	45.387	0.040	0.000
Rice Uni.	212	Tissint_merr1_6	0.688	0.021	0.000	0.027	46.713	2.201	0.019	45.352	0.032	0.000
Rice Uni.	213	Tissint_merr1_7	0.824	0.047	0.187	0.020	47.433	2.660	0.010	46.502	0.023	0.000
Rice Uni.	214	Tissint_merr1_8	0.816	0.266	0.000	0.034	47.387	2.556	0.001	46.773	0.034	0.000
Rice Uni.	215	Tissint_merr1_9	0.880	0.662	0.000	0.050	47.187	2.551	0.006	46.600	0.011	0.000
Rice Uni.	217	Tissint merr2 1	0.777	0.276	0.000	0.052	47.527	2.888	0.008	46.712	0.076	0.000
Rice Uni.	218	Tissint_merr2_2	0.855	1.336	0.331	0.074	46.609	2.843	0.005	46.250	0.043	0.000
Rice Uni.	219	Tissint_merr2_3	0.871	0.386	0.000	0.055	47.542	2.711	0.013	46.505	0.044	0.000
Rice Uni.	220	Tissint_merr2_4	0.887	0.885	0.000	0.093	47.060	3.017	0.017	46.432	0.687	0.000
Rice Uni.	221	Tissint_merr2_5	0.830	1.428	0.263	0.104	47.579	2.816	0.008	46.126	0.060	0.000
Rice Uni.	223	Tissint_merr2_7	0.772	0.583	0.000	0.066	47.191	2.701	0.047	45.673	0.166	0.000
JSC-ARES	10	Kep5a	0.520	0.347	0.000	0.035	46.814	3.005	0.021	45.198	0.053	0.000
JSC-ARES	11	Kep5b	0.458	0.338	0.000	0.031	47.120	2.879	0.000	45.273	0.046	0.000
JSC-ARES	12	Kep5c	0.542	0.303	0.000	0.059	46.511	3.031	0.006	45.200	0.036	0.000
JSC-ARES	13	Kep5d	0.440	0.344	0.000	0.053	47.099	3.044	0.004	45.136	0.061	0.000
JSC-ARES	14	Kep5e	0.512	0.365	0.000	0.057	46.907	2.929	0.016	45.289	0.208	0.000
JSC-ARES	15	Kep5f	0.453	0.352	0.000	0.053	46.960	2.931	0.000	45.001	0.015	0.000
JSC-ARES	18	Kep8a	0.787	1.701	0.011	0.044	45.078	2.992	0.019	44.002	0.428	0.000
JSC-ARES	19	Kep8b	0.530	0.075	0.023	0.043	46.994	2.959	0.013	45.513	0.040	0.000
JSC-ARES	20	Kep8c	0.837	1.513	0.019	0.077	45.861	3.018	0.017	44.208	0.147	0.000
JSC-ARES	21	Kep8d	0.692	1.063	0.000	0.050	46.284	2.888	0.000	44.605	0.070	0.000
JSC-ARES	22	Kep9a	0.291	0.119	0.000	0.019	46.381	3.583	0.000	45.353	0.034	0.000
JSC-ARES	23	Kep9b	0.350	0.135	0.000	0.038	46.794	3.582	0.000	45.917	0.024	0.000
JSC-ARES	24	Kep9c	0.385	0.310	0.016	0.068	46.369	3.470	0.001	45.218	0.031	0.000
JSC-ARES	25	Kep9d	0.415	0.722	0.000	0.049	46.627	3.464	0.013	45.294	0.023	0.000
JSC-ARES	33	Kep10b	0.383	2.668	0.000	0.026	44.529	4.561	0.012	43.385	0.110	0.000
JSC-ARES	32	Kep10a	0.389	0.188	0.000	0.029	46.442	3.579	0.005	45.969	0.081	0.000
JSC-ARES	26	Kep12a	0.469	0.056	0.000	0.049	46.567	3.484	0.000	45.287	0.066	0.000
JSC-ARES	27	Kep12b	0.400	0.232	0.000	0.024	46.443	3.536	0.007	44.985	0.134	0.000
JSC-ARES	28	Kep12c	0.325	0.129	0.000	0.053	46.575	3.581	0.003	45.557	0.037	0.000
JSC-ARES	31	Kep12f	0.475	1.253	0.000	0.094	45.499	3.722	0.005	44.368	0.052	0.000
		Average	0.614	0.544	0.036	0.048	46.726	2.980	0.009	45.528	0.090	0.000
		Min	0.291	0.011	0.000	0.008	44.529	1.763	0.000	43.385	0.011	0.000
		Max	0.981	2.668	0.423	0.104	47.579	4.561	0.047	46.773	0.687	0.000
		StDev	0.199	0.600	0.101	0.023	0.679	0.542	0.009	0.798	0.130	0.000

Data Collection	Point	Comment	MgO	Al2O3	MnO	Ce2O3	Nd2O3	TiO2	Total	O=F,Cl	-O=F2	-O=Cl2	Total recalc
Rice Uni.	207	Tissint_merr1_1	3.192	0.001	0.143	0.050	0.000	*	100.094	0.002	0.000	0.002	100.092
Rice Uni.	208	Tissint_merr1_2	3.149	0.063	0.140	0.036	0.000	*	99.583	0.001	0.000	0.001	99.582
Rice Uni.	209	Tissint_merr1_3	3.217	0.073	0.119	0.000	0.000	*	100.432	0.001	0.000	0.001	100.431
Rice Uni.	210	Tissint_merr1_4	3.196	0.361	0.115	0.000	0.192	*	100.600	0.001	0.000	0.001	100.599
Rice Uni.	211	Tissint_merr1_5	3.323	0.061	0.104	0.000	0.133	*	98.650	0.004	0.000	0.004	98.646
Rice Uni.	212	Tissint_merr1_6	3.270	0.070	0.176	0.097	0.114	*	98.780	0.004	0.000	0.004	98.776
Rice Uni.	213	Tissint merr1 7	2.962	0.032	0.131	0.023	0.000	*	100.854	0.002	0.000	0.002	100.852
Rice Uni.	214	Tissint_merr1_8	3.033	0.120	0.149	0.053	0.213	*	101.435	0.000	0.000	0.000	101.435
Rice Uni.	215	Tissint_merr1_9	3.039	0.382	0.159	0.008	0.066	*	101.601	0.001	0.000	0.001	101.600
Rice Uni.	217	Tissint_merr2_1	3.215	0.083	0.141	0.053	0.000	*	101.808	0.002	0.000	0.002	101.806
Rice Uni.	218	Tissint_merr2_2	3.203	0.301	0.157	0.031	0.052	*	102.090	0.001	0.000	0.001	102.089
Rice Uni.	219	Tissint_merr2_3	3.200	0.058	0.109	0.076	0.023	*	101.593	0.003	0.000	0.003	101.590
Rice Uni.	220	Tissint_merr2_4	3.135	0.229	0.096	0.041	0.000	*	102.579	0.004	0.000	0.004	102.575
Rice Uni.	221	Tissint merr2 5	3.213	0.284	0.118	0.023	0.253	*	103.105	0.002	0.000	0.002	103.103
Rice Uni.	223	Tissint_merr2_7	3.192	0.237	0.176	0.012	0.000	*	100.816	0.011	0.000	0.011	100.805
JSC-ARES	10	Kep5a	2.625	0.035	0.087	0.000	0.000	0.023	98.763	0.005	0.000	0.005	98.758
JSC-ARES	11	Kep5b	2.672	0.013	0.122	0.055	0.042	0.086	99.135	0.000	0.000	0.000	99.135
JSC-ARES	12	Kep5c	2.611	0.037	0.141	0.041	0.000	0.000	98.518	0.001	0.000	0.001	98.517
JSC-ARES	13	Kep5d	2.613	0.059	0.123	0.016	0.000	0.027	99.019	0.001	0.000	0.001	99.018
JSC-ARES	14	Kep5e	2.704	0.068	0.117	0.032	0.000	0.059	99.263	0.004	0.000	0.004	99.259
JSC-ARES	15	Kep5f	2.567	0.021	0.158	0.063	0.010	0.029	98.613	0.000	0.000	0.000	98.613
JSC-ARES	18	Kep8a	2.697	0.753	0.130	0.069	0.000	0.001	98.712	0.004	0.000	0.004	98.708
JSC-ARES	19	Kep8b	2.781	0.024	0.149	0.000	0.058	0.008	99.210	0.003	0.000	0.003	99.207
JSC-ARES	20	Kep8c	2.815	0.226	0.137	0.062	0.033	0.030	99.000	0.004	0.000	0.004	98.996
JSC-ARES	21	Kep8d	2.642	0.550	0.155	0.058	0.000	0.018	99.075	0.000	0.000	0.000	99.075
JSC-ARES	22	Kep9a	2.583	0.022	0.168	0.002	0.029	0.000	98.584	0.000	0.000	0.000	98.584
JSC-ARES	23	Kep9b	2.633	0.028	0.155	0.039	0.000	0.000	99.695	0.000	0.000	0.000	99.695
JSC-ARES	24	Kep9c	2.572	0.082	0.184	0.029	0.001	0.030	98.766	0.000	0.000	0.000	98.766
JSC-ARES	25	Kep9d	2.595	0.323	0.106	0.048	0.000	0.000	99.679	0.003	0.000	0.003	99.676
JSC-ARES	33	Kep10b	2.950	0.062	0.175	0.028	0.000	0.052	98.941	0.003	0.000	0.003	98.938
JSC-ARES	32	Kep10a	2.616	0.000	0.190	0.029	0.000	0.005	99.522	0.001	0.000	0.001	99.521
JSC-ARES	26	Kep12a	2.579	0.030	0.173	0.004	0.000	0.008	98.772	0.000	0.000	0.000	98.772
JSC-ARES	27	Kep12b	2.628	0.049	0.118	0.043	0.000	0.042	98.641	0.002	0.000	0.002	98.639
JSC-ARES	28	Kep12c	2.621	0.010	0.164	0.006	0.007	0.000	99.068	0.001	0.000	0.001	99.067
JSC-ARES	31	Kep12f	2.607	0.165	0.191	0.069	0.015	0.035	98.550	0.001	0.000	0.001	98.549
		Average	2.876	0.140	0.142	0.034	0.035	0.023	99.816	0.002	0.000	0.002	99.814
		Min	2.567	0.000	0.087	0.000	0.000	0.000	98.518	0.000	0.000	0.000	98.517
		Max	3.323	0.753	0.191	0.097	0.253	0.086	103.105	0.011	0.000	0.011	103.103
		StDev	0.274	0.171	0.028	0.026	0.066	0.024	1.315	0.002	0.000	0.002	1.315

Supplementary Table 5. Summarized quantitative point analyses for merrillite in ALH 84001. Data used to calculate average wt% and formula amounts were collected at Rice University (JEOL JXA-8530F Hyperprobe). Comments denote mineral names given at time of data collection.

Data Collection	Point	Comment	Na2O	SiO2	La2O3	K20	CaO	FeO	C	P205	503	F
Rice Uni	92	ALH84001 Ap1 gray 7	2 317	0.000	0.000	0.087	46 709	0.786	0.002	46 583	0.011	0.000
Rice Uni.	93	ALH84001 Ap1 gray 8	2.268	0.000	0.052	0.080	46.670	0.748	0.004	46.563	0.009	0.000
Rice Uni.	94	ALH84001 Ap1 gray 9	2.429	0.000	0.000	0.103	47.106	0.765	0.000	46.760	0.000	0.000
Rice Uni.	95	ALH84001 Ap1 gray 10	2.254	0.000	0.000	0.093	47.261	0.769	0.000	46.412	0.007	0.000
Rice Uni.	96	ALH84001 Ap1 gray 11	2.331	0.000	0.000	0.084	46.364	0.795	0.002	46.471	0.007	0.000
Rice Uni.	97	ALH84001_Ap1_gray_12	2.409	0.000	0.000	0.077	46.898	0.625	0.000	46.880	0.000	0.000
Rice Uni.	98	ALH84001 Ap1 gray 13	2.296	0.000	0.000	0.085	46.444	0.782	0.005	46.191	0.011	0.000
Rice Uni.	99	ALH84001_Ap1_gray_14	2.378	0.000	0.000	0.102	47.125	0.685	0.000	46.852	0.029	0.000
Rice Uni.	100	ALH84001_Ap1_gray_15	2.326	0.045	0.000	0.099	46.939	0.711	0.000	46.268	0.015	0.000
Rice Uni.	101	ALH84001_Ap1_gray_16	2.382	0.000	0.000	0.111	47.050	0.662	0.000	46.308	0.003	0.000
Rice Uni.	102	ALH84001_Ap2_gray_1	2.296	0.026	0.000	0.098	46.719	0.725	0.009	46.177	0.004	0.000
Rice Uni.	103	ALH84001_Ap2_gray_2	2.291	0.000	0.112	0.100	46.600	0.618	0.002	46.403	0.001	0.000
Rice Uni.	104	ALH84001_Ap2_gray_3	2.189	0.016	0.000	0.084	46.437	0.662	0.000	46.222	0.003	0.000
Rice Uni.	105	ALH84001_Ap2_gray_4	2.323	0.000	0.000	0.090	47.199	0.809	0.005	46.571	0.000	0.000
Rice Uni.	106	ALH84001_Ap2_gray_5	2.422	0.000	0.000	0.093	47.021	0.715	0.000	46.518	0.009	0.000
Rice Uni.	107	ALH84001_Ap2_gray_6	2.429	0.000	0.000	0.083	47.019	0.785	0.006	46.964	0.000	0.000
Rice Uni.	108	ALH84001_Ap2_gray_7	2.360	0.000	0.000	0.083	47.050	0.785	0.002	46.118	0.008	0.000
Rice Uni.	109	ALH84001_Ap3_1	2.416	0.000	0.000	0.098	46.971	0.846	0.001	46.342	0.016	0.000
Rice Uni.	110	ALH84001_Ap3_2	2.388	0.000	0.000	0.087	46.809	0.728	0.000	46.391	0.012	0.000
Rice Uni.	111	ALH84001_Ap3_3	2.275	0.000	0.000	0.085	46.724	0.688	0.000	46.392	0.008	0.000
Rice Uni.	112	ALH84001_Ap3_4	2.353	0.000	0.000	0.092	46.620	0.652	0.006	46.637	0.021	0.000
Rice Uni.	113	ALH84001_Ap3_5	2.394	0.000	0.000	0.076	47.127	0.789	0.008	46.735	0.014	0.000
Rice Uni.	114	ALH84001_Ap3_6	2.350	0.000	0.194	0.059	46.929	0.682	0.003	46.373	0.000	0.000
Rice Uni.	116	ALH84001_Ap3_8	2.407	0.000	0.000	0.112	46.181	0.942	0.001	46.547	0.011	0.000
Rice Uni.	117	ALH84001_Ap3_9	2.325	0.036	0.000	0.105	46.974	0.955	0.004	46.333	0.014	0.000
Rice Uni.	118	ALH84001_Ap3_10	2.386	0.000	0.175	0.090	46.949	0.808	0.006	46.590	0.000	0.000
Rice Uni.	119	ALH84001_Ap3_11	2.425	0.000	0.000	0.089	46.676	0.752	0.000	46.545	0.011	0.000
Rice Uni.	120	ALH84001_Ap3_12	2.149	0.000	0.000	0.077	46.968	0.649	0.001	46.471	0.005	0.000
Rice Uni.	121	ALH84001_Ap3_13	2.346	0.000	0.000	0.077	46.626	0.649	0.006	46.076	0.015	0.000
Rice Uni.	122	ALH84001_Ap3_14	2.395	0.000	0.332	0.110	47.083	0.843	0.011	46.320	0.000	0.000
Rice Uni.	123	ALH84001_Ap3_15	2.368	0.000	0.000	0.071	46.944	0.799	0.000	46.530	0.018	0.000
Rice Uni.	124	ALH84001_Ap3_trail_1	2.304	0.000	0.000	0.072	46.132	0.852	0.006	45.150	0.016	0.000
Rice Uni.	125	ALH84001_Ap3_trail_2	2.375	0.021	0.000	0.085	46.770	0.943	0.000	46.431	0.001	0.000

Data Collection	Point	Comment	Na2O	SiO2	La2O3	K2O	CaO	FeO	Cl	P2O5	SO3	F
Rice Uni.	126	ALH84001_Ap3_trail_3	2.423	0.037	0.000	0.101	46.960	1.096	0.011	46.385	0.014	0.000
Rice Uni.	127	ALH84001_Ap3_trail_4	2.367	0.068	0.140	0.080	46.662	0.949	0.007	46.865	0.001	0.000
Rice Uni.	128	ALH84001_Ap3_trail_5	2.329	0.095	0.318	0.096	46.837	0.946	0.004	46.483	0.012	0.000
Rice Uni.	129	ALH84001_Ap3_trail_6	2.389	0.089	0.000	0.115	46.901	0.809	0.000	45.765	0.000	0.000
Rice Uni.	139	ALH84001_Ap4_gray_3	2.361	0.000	0.000	0.106	46.757	0.782	0.008	46.346	0.019	0.000
Rice Uni.	140	ALH84001_Ap4_gray_4	2.444	0.000	0.000	0.100	46.922	0.646	0.004	46.691	0.000	0.000
Rice Uni.	142	ALH84001_Ap4_gray_6	2.433	0.000	0.000	0.091	46.620	0.836	0.007	46.731	0.008	0.000
Rice Uni.	143	ALH84001_Ap4_gray_7	2.396	0.000	0.000	0.072	46.755	0.655	0.005	46.328	0.012	0.000
Rice Uni.	144	ALH84001_Ap4_gray_8	2.248	0.000	0.000	0.083	46.605	0.776	0.003	46.291	0.019	0.000
Rice Uni.	145	ALH84001 Ap4 gray 9	2.337	0.000	0.180	0.095	46.355	0.769	0.000	46.275	0.002	0.000
Rice Uni.	146	ALH84001_Ap4_gray_10	2.240	0.024	0.000	0.088	45.812	0.682	0.010	45.335	0.026	0.000
Rice Uni.	147	ALH84001_Ap4_gray_11	2.449	0.000	0.000	0.105	47.013	0.672	0.017	46.766	0.005	0.000
Rice Uni.	148	ALH84001_Ap4_gray_12	2.477	0.009	0.405	0.094	46.813	0.879	0.014	46.864	0.006	0.000
Rice Uni.	149	ALH84001_Ap5_1	2.504	0.019	0.000	0.090	46.805	0.898	0.000	46.211	0.002	0.000
Rice Uni.	150	ALH84001_Ap5_2	2.282	0.000	0.000	0.103	46.756	0.792	0.009	46.576	0.006	0.000
Rice Uni.	151	ALH84001_Ap5_3	2.431	0.001	0.000	0.096	46.618	0.802	0.000	46.451	0.011	0.000
Rice Uni.	152	ALH84001_Ap5_4	2.399	0.000	0.000	0.106	46.864	1.102	0.003	46.159	0.014	0.000
Rice Uni.	153	ALH84001_Ap5_5	2.429	0.000	0.000	0.078	46.623	0.959	0.010	46.286	0.013	0.000
Rice Uni.	154	ALH84001_Ap5_6	2.338	0.031	0.000	0.080	46.736	1.015	0.005	46.377	0.003	0.000
Rice Uni.	155	ALH84001 Ap5 /	2.340	0.000	0.000	0.0/4	46.730	0.865	0.006	46.498	0.004	0.000
Rice Uni.	156	ALH84001_Ap5_8	2.362	0.000	0.049	0.107	46.594	0.995	0.000	46.446	0.000	0.000
Rice Uni.	157	ALH84001 Ap6 1	2.404	0.000	0.000	0.102	4/.1/0	1.108	0.000	46.859	0.000	0.000
Rice Uni.	158	ALH84001 Ap6 2	2.318	0.000	0.000	0.094	47.055	1.019	0.001	46.397	0.003	0.000
Rice Uni.	159	ALH84001_Ap6_5	2.302	0.000	0.034	0.107	47.020	0.929	0.000	46.465	0.004	0.000
Rice Uni.	160	ALH84001 Ap6 4	2.391	0.000	0.215	0.083	47.249	0.878	0.009	46.750	0.011	0.000
Rice Uni.	164	ALH84001_Ap6_/	2.355	0.000	0.000	0.095	47.300	0.859	0.002	40.800	0.011	0.000
Rice Uni.	164	ALH84001_Ap0_8	2.408	0.000	0.000	0.084	40.744	0.955	0.000	46.303	0.010	0.000
Rice Uni.	165	ALH84001_Ap6_9	2.512	0.007	0.000	0.082	47.000	0.992	0.007	40.282	0.017	0.000
Rice Uni	167	ALH84001_Ap0_10	2.407	0.000	0.000	0.098	47.112	0.849	0.007	46.817	0.021	0.000
Rice Uni	168	ALH84001_Ap7_1	2.407	0.000	0.000	0.055	46.025	0.825	0.000	46.602	0.002	0.000
Rice Uni	160	ALH84001_Ap7_2	2.557	0.000	0.000	0.000	40.925	0.023	0.000	46.002	0.003	0.000
Rice Uni	170	AL H84001 Ap7 4	2 323	0.000	0.496	0.101	47.107	0.784	0.005	46 585	0.000	0.000
Data Collection	Doint	Commont	No2O	5:02	1.0202	K20	47.100	E	Cl	P205	503	0.000
Data Collection Rice Uni	Point	Comment ALH84001 Ap7 5	Na2O 2 402	SiO2	La2O3	K2O 0.087	47.100 CaO 47.477	FeO 0.919	Cl 0.004	P2O5	SO3	F 0.000
Data Collection Rice Uni.	Point 171 172	Comment ALH84001_Ap7_5 ALH84001_Ap7_6	Na2O 2.402 2.358	SiO2 0.000 0.000	La2O3 0.000 0.087	K2O 0.087 0.098	CaO 47.477 47.005	FeO 0.919 0.775	Cl 0.004 0.007	P2O5 46.808 46.859	SO3 0.002 0.009	F 0.000 0.000
Data Collection Rice Uni. Rice Uni.	Point 171 172 173	Comment ALH84001_Ap7_5 ALH84001_Ap7_6 ALH84001_Ap7_7	Na2O 2.402 2.358 2.273	SiO2 0.000 0.000 0.000	La2O3 0.000 0.087 0.239	K2O 0.087 0.098 0.089	CaO 47.477 47.005 46.975	FeO 0.919 0.775 0.838	Cl 0.004 0.007 0.004	P2O5 46.808 46.859 45.913	SO3 0.002 0.009 0.015	F 0.000 0.000 0.000
Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 171 172 173 174	Comment ALH84001_Ap7_5 ALH84001_Ap7_6 ALH84001_Ap7_7 ALH84001_Ap7_8	Na2O 2.402 2.358 2.273 2.431	SiO2 0.000 0.000 0.000 0.000	La2O3 0.000 0.087 0.239 0.000	K2O 0.087 0.098 0.089 0.091	CaO 47.477 47.005 46.975 46.910	FeO 0.919 0.775 0.838 0.859	Cl 0.004 0.007 0.004 0.000	P2O5 46.808 46.859 45.913 46.502	SO3 0.002 0.009 0.015 0.016	F 0.000 0.000 0.000 0.000 0.000
Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 171 172 173 174	Comment ALH84001_Ap7_5 ALH84001_Ap7_6 ALH84001_Ap7_7 ALH84001_Ap7_8 ALH84001_Ap7_9	Na2O 2.402 2.358 2.273 2.431 2.328	SiO2 0.000 0.000 0.000 0.000 0.000 0.000 0.000	La2O3 0.000 0.087 0.239 0.000 0.000	K2O 0.087 0.098 0.089 0.091	CaO 47.477 47.005 46.975 46.910 46.329	FeO 0.919 0.775 0.838 0.859 0.911	Cl 0.004 0.007 0.004 0.000 0.000	P205 46.808 46.859 45.913 46.502 45.940	SO3 0.002 0.009 0.015 0.016 0.030	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 171 172 173 174 175	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7	Na2O 2.402 2.358 2.273 2.431 2.328 2.480	SiO2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002	La2O3 0.000 0.087 0.239 0.000 0.000 0.000	K2O 0.087 0.098 0.089 0.091 0.079 0.103	CaO 47.477 47.005 46.975 46.910 46.329 46.263	FeO 0.919 0.775 0.838 0.859 0.911 0.958	Cl 0.004 0.007 0.004 0.000 0.000 0.000	P205 46.808 45.913 46.502 45.940 47.031	SO3 0.002 0.009 0.015 0.016 0.030 0.005	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 171 172 173 174 175 176	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 9 ALH84001 Ap7 10 ALH84001 Ap7 11	Na2O 2.402 2.358 2.273 2.431 2.328 2.480 2.382	SiO2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.0025 0.000	La2O3 0.000 0.087 0.239 0.000 0.000 0.000 0.000	K2O 0.087 0.098 0.099 0.091 0.079 0.103 0.097	CaO 47.477 47.005 46.975 46.910 46.329 46.263 46.831	FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.638	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.004	P205 46.808 46.859 45.913 46.502 45.940 47.031 46.848	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Rice Uni.	Point 171 172 173 174 175 176 177	Comment ALH84001_Ap7_5 ALH84001_Ap7_6 ALH84001_Ap7_7 ALH84001_Ap7_7 ALH84001_Ap7_8 ALH84001_Ap7_9 ALH84001_Ap7_10 ALH84001_Ap7_11 ALH84001_Ap7_12	Na2O 2.402 2.358 2.273 2.431 2.328 2.480 2.382 2.406	SiO2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.002	La2O3 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.227	K2O 0.087 0.098 0.099 0.091 0.079 0.103 0.097 0.094	47.188 CaO 47.477 47.005 46.975 46.910 46.329 46.263 46.831 46.798	FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.004 0.000 0.008	P205 46.808 46.859 45.913 46.502 45.940 47.031 46.848 46.814	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 171 172 173 174 175 176 177 178 179	Comment ALH84001_Ap7_5 ALH84001_Ap7_6 ALH84001_Ap7_7 ALH84001_Ap7_8 ALH84001_Ap7_9 ALH84001_Ap7_10 ALH84001_Ap7_11 ALH84001_Ap7_12 ALH84001_Ap7_13	Na2O 2.402 2.358 2.273 2.431 2.328 2.480 2.382 2.406 2.345	SiO2 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.000 0.000 0.000 0.000	La2O3 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.227 0.230	K2O 0.087 0.098 0.099 0.091 0.079 0.103 0.097 0.094	47.188 CaO 47.477 47.005 46.975 46.910 46.329 46.263 46.798 46.985	FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818 0.864	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.004 0.000 0.008 0.003	P205 46.808 46.859 45.913 46.502 45.940 47.031 46.848 46.814 46.092	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.019 0.007	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 171 172 173 174 175 176 177 180	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14	Na2O 2.402 2.358 2.273 2.431 2.328 2.480 2.382 2.406 2.345 2.432	SiO2 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.000 0.001 0.002 0.000 0.000 0.000 0.000 0.000 0.000 0.000	La2O3 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.227 0.230 0.000	K20 0.087 0.098 0.099 0.091 0.079 0.103 0.097 0.094 0.082	47.188 CaO 47.477 47.005 46.975 46.910 46.329 46.263 46.831 46.798 46.985 46.939	FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818 0.864 0.865	Cl 0.004 0.007 0.004 0.000 0.000 0.004 0.000 0.008 0.003 0.000	P205 46.808 46.859 45.913 46.502 45.940 47.031 46.848 46.814 46.092 46.520	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.019 0.007 0.000	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Rice Uni. Rice Uni.	Point 171 171 172 173 174 175 176 177 178 179 180 181	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 8 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14	Na2O 2.402 2.358 2.273 2.431 2.328 2.480 2.382 2.406 2.345 2.432 2.366	SiO2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.039	La2O3 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.000	0.181 K2O 0.087 0.098 0.091 0.079 0.103 0.097 0.094 0.082 0.077 0.113	47.188 CaO 47.477 47.005 46.975 46.975 46.263 46.831 46.798 46.985 46.939 47.144	FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818 0.864 0.865 0.812	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.000 0.008 0.003 0.000 0.000	P205 46.808 46.859 45.913 46.502 45.940 47.031 46.848 46.814 46.6092 46.520 46.463	SO3 0.002 0.009 0.015 0.016 0.030 0.004 0.007 0.000 0.004	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Rice Uni.	Point 171 171 172 173 174 175 176 177 178 179 180 181	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 8 ALH84001 Ap7 8 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 12 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap7 15 ALH84001 Ap7 15	Na2O 2.402 2.358 2.273 2.431 2.328 2.480 2.382 2.406 2.345 2.432 2.366 2.234	SiO2 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.039 0.000	La2O3 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.000	b:181 K2O 0.087 0.098 0.099 0.091 0.079 0.103 0.097 0.094 0.082 0.077 0.113 0.095	47.188 CaO 47.477 47.005 46.975 46.910 46.329 46.263 46.831 46.798 46.985 46.939 47.144	FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818 0.864 0.865 0.812	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.000 0.000 0.003 0.000 0.000 0.000	P205 46.808 46.859 45.913 46.502 45.940 47.031 46.848 46.814 46.092 46.520 46.463 46.147	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.007 0.000 0.004 0.003	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Data Collection Rice Uni. Rice Uni.	Point 171 172 173 174 175 176 177 178 179 180 181 182 183	Comment ALH84001_Ap7_5 ALH84001_Ap7_6 ALH84001_Ap7_6 ALH84001_Ap7_7 ALH84001_Ap7_8 ALH84001_Ap7_9 ALH84001_Ap7_10 ALH84001_Ap7_11 ALH84001_Ap7_12 ALH84001_Ap7_12 ALH84001_Ap7_13 ALH84001_Ap7_14 ALH84001_Ap7_15 ALH84001_Ap8_1 ALH84001_Ap8_2	Na2O 2.402 2.358 2.273 2.431 2.328 2.480 2.382 2.406 2.345 2.366 2.234 2.335	SiO2 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.0025 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	La2O3 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.000 0.000 0.000 0.207 0.017	K2O 0.087 0.098 0.099 0.091 0.079 0.097 0.094 0.082 0.077 0.113 0.095 0.090	CaO 47.477 47.005 46.975 46.910 46.329 46.263 46.831 46.985 46.939 47.144 46.077	FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818 0.864 0.865 0.812 0.834 0.737	CI 0.004 0.007 0.004 0.000 0.000 0.000 0.000 0.000 0.003 0.000 0.000 0.000 0.000 0.000 0.000 0.0014 0.005	P205 46.808 46.859 45.913 46.502 45.940 47.031 46.848 46.814 46.092 46.520 46.463 46.147 45.346	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.007 0.000 0.004 0.003 0.004	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Rice Uni.	Point 171 171 172 173 174 175 176 177 178 179 180 181 182 183 186	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 9 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 2 ALH84001 Ap8 5	Na2O 2.402 2.358 2.273 2.431 2.328 2.480 2.382 2.406 2.345 2.432 2.366 2.234 2.335 2.212	SiO2 SiO2 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	La2O3 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.207 0.017 0.512	K20 0.087 0.087 0.089 0.091 0.079 0.103 0.097 0.097 0.094 0.082 0.077 0.113 0.090 0.056	CaO 47.477 47.005 46.975 46.910 46.263 46.831 46.985 46.985 46.939 47.144 46.244 46.077	FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818 0.864 0.865 0.812 0.737 0.874	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.000 0.003 0.000 0.000 0.003 0.000 0.0014 0.000 0.0014 0.005 0.007	P205 46.808 46.859 45.913 46.502 45.940 47.031 46.848 46.814 46.092 46.520 46.463 46.4203	SO3 0.002 0.009 0.015 0.016 0.005 0.004 0.019 0.0007 0.000 0.0004 0.003 0.0018 0.027	F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Rice Uni.	Point 171 171 172 173 174 175 176 177 178 179 180 181 182 183 186 187	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 9 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 15 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 5 ALH84001 Ap8 6	Na2O 2.402 2.358 2.773 2.431 2.328 2.480 2.382 2.480 2.382 2.432 2.345 2.324 2.324 2.324 2.212 2.239	0.000 SiO2 0.000 0.000 0.000 0.000 0.001 0.002 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	In203 La203 0.000 0.087 0.239 0.000 0.017 0.512 0.288	K20 0.087 0.087 0.098 0.098 0.091 0.079 0.103 0.097 0.103 0.097 0.103 0.097 0.095 0.077 0.113 0.095 0.095 0.095 0.085	47.136 CaO 47.477 47.005 46.975 46.910 46.263 46.831 46.98 46.939 47.144 46.244 46.751 46.164	FeO 0.919 0.775 0.838 0.911 0.958 0.638 0.864 0.865 0.812 0.834 0.737 0.874 0.831	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.000 0.003 0.000 0.003 0.000 0.003 0.003 0.000 0.0014 0.002 0.003 0.000 0.0014 0.002 0.0014	P205 46.808 46.859 45.913 46.502 46.504 47.031 46.848 46.814 46.520 46.463 46.147 45.346 46.203 46.581	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.019 0.003 0.004 0.003 0.004 0.007 0.000 0.004 0.003 0.016 0.027 0.019	F 0.000
Rice Uni.	Point 171 172 173 174 175 176 177 177 178 179 180 181 182 183 186 187 189	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 8 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 9 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 2 ALH84001 Ap8 5 ALH84001 Ap8 6 ALH84001 Ap8 8	Na2O 2.402 2.358 2.235 2.431 2.328 2.430 2.342 2.480 2.345 2.440 2.345 2.345 2.346 2.335 2.234 2.239 2.291	siO2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.041 0.025 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	0.000 1.a203 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.207 0.217 0.512 0.288 0.347	K20 0.087 0.087 0.098 0.089 0.091 0.079 0.103 0.097 0.103 0.097 0.103 0.097 0.082 0.077 0.113 0.095 0.090 0.056 0.085 0.064 0.064	47.133 CaO 47.477 47.005 46.910 46.329 46.329 46.329 46.831 46.985 46.939 47.144 46.244 46.077 45.751 46.164 46.197	0.735 FeO 0.919 0.775 0.859 0.911 0.958 0.859 0.911 0.958 0.818 0.864 0.865 0.812 0.834 0.737 0.874 0.831 0.857 0.857	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.0014 0.005 0.007 0.0007	P205 46.808 46.808 46.809 45.913 46.502 45.940 47.031 46.848 46.848 46.848 46.620 46.463 46.147 45.346 46.203 46.561	SO3 0.002 0.009 0.016 0.030 0.005 0.004 0.005 0.004 0.007 0.000 0.004 0.003 0.018 0.027 0.019 0.017	F 0.000
Nete Uni. Rice Uni.	Point 171 172 173 174 175 176 177 178 179 180 181 182 183 186 187 189 190	Comment ALH84001 Ap7 5 ALH84001 Ap7 5 ALH84001 Ap7 7 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 2 ALH84001 Ap8 2 ALH84001 Ap8 3 ALH84001 Ap8 4 ALH84001 Ap8 4 ALH84001 Ap8 5 ALH84001 Ap8 8 ALH84001 Ap8 8 ALH84001 Ap8 8 ALH84001 Ap8 8	Na2O 2.402 2.358 2.233 2.431 2.328 2.431 2.328 2.440 2.345 2.432 2.345 2.345 2.345 2.345 2.234 2.335 2.212 2.291 2.190	siO2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	0.000 1.a203 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.027 0.230 0.001 0.001 0.001 0.001 0.017 0.312 0.347 0.347 0.347 0.347 0.311 0	0.181 K20 0.087 0.098 0.098 0.091 0.079 0.103 0.097 0.094 0.082 0.077 0.113 0.097 0.082 0.077 0.113 0.095 0.090 0.056 0.064 0.078	47.103 CaO 47.477 47.005 46.975 46.910 46.329 46.831 46.788 46.985 46.983 46.985 46.985 46.971 46.714 46.724 46.077 45.751 46.164 46.386	6/13 FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.911 0.958 0.818 0.864 0.865 0.812 0.834 0.737 0.874 0.837 0.857 0.800	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.004 0.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000000	P205 46.808 46.808 46.809 45.913 46.502 45.940 47.031 46.848 46.814 46.092 46.520 46.463 46.147 45.346 46.203 46.581 46.521	SO3 0.002 0.009 0.016 0.030 0.005 0.004 0.007 0.000 0.003 0.018 0.027 0.017 0.008	F 0.000
Nete Uni. Rice Uni.	Point Point 171 172 173 174 175 176 177 178 179 180 181 182 183 186 187 189 190 192	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap8 1 ALH84001 Ap8 2 ALH84001 Ap8 5 ALH84001 Ap8 6 ALH84001 Ap8 9 ALH84001 Ap8 9 ALH84001 Ap8 11	Na2O 2.402 2.358 2.273 2.431 2.328 2.431 2.328 2.431 2.328 2.432 2.466 2.342 2.366 2.234 2.336 2.212 2.239 2.190 2.156	siO2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	0.103 0.000 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.000 0.207 0.017 0.512 0.288 0.347 0.931 0.411	K20 0.087 0.087 0.098 0.098 0.091 0.079 0.091 0.079 0.094 0.094 0.082 0.070 0.113 0.095 0.095 0.056 0.085 0.064 0.078 0.078 0.078	47.133 CaO 47.477 47.005 46.975 46.975 46.910 46.329 46.263 46.831 46.798 46.885 46.985 46.939 47.144 46.244 46.771 45.751 46.164 46.197 46.386 46.322	Fe0 0.919 0.775 0.838 0.859 0.911 0.958 0.818 0.838 0.838 0.838 0.818 0.864 0.834 0.737 0.874 0.831 0.857 0.800 0.847	Cl 0.004 0.007 0.004 0.000 0.000 0.004 0.000 0.004 0.003 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.004 0.004 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0000 00	P205 46.808 46.808 46.859 45.913 46.502 45.940 47.031 46.814 46.814 46.814 46.52 46.463 46.534 46.534 46.534 46.561 46.561 46.237 46.080	SO3 0.002 0.009 0.015 0.016 0.030 0.004 0.019 0.000 0.004 0.0030 0.004 0.004 0.003 0.004 0.004 0.003 0.004 0.003 0.017 0.008 0.0000	F 0.000
Rice Uni.	Point Point 171 172 173 174 175 176 177 178 179 180 181 182 183 186 187 190 192 194	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 8 ALH84001 Ap7 9 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 15 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 4 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 8 ALH84001 Ap8 9 ALH84001 Ap8 11 ALH84001 Ap8 11	Na2O 2.402 2.358 2.273 2.431 2.328 2.431 2.328 2.406 2.345 2.436 2.345 2.366 2.234 2.325 2.291 2.156 2.205	siO2 0.000	0.000 1.a203 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.017 0.512 0.411 0.411 0.411 0.412 0	0.181 K20 0.087 0.098 0.099 0.091 0.079 0.091 0.079 0.094 0.082 0.071 0.113 0.095 0.056 0.085 0.064 0.078 0.064	47.133 CaO 47.477 47.005 46.975 46.910 46.329 46.263 46.788 46.984 46.985 46.985 46.984 46.985 46.985 46.164 46.197 46.164 46.197 46.322 46.164 46.197 46.326 46.134	FeO 0.919 0.775 0.859 0.911 0.958 0.638 0.818 0.864 0.812 0.834 0.831 0.857 0.8047 0.947	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.0014 0.000 0.000 0.0014 0.0007 0.0007 0.0007 0.0000 0.0000 0.0000 0.0000	P205 46.808 46.808 46.809 45.913 46.502 45.940 47.031 46.814 46.814 46.814 46.520 46.463 46.463 46.463 46.581 46.581 46.561 46.561 46.094	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.007 0.004 0.003 0.004 0.004 0.018 0.027 0.019 0.017 0.019 0.017 0.008 0.000	F 0.000
Rice Uni.	Point Point 171 171 172 173 174 175 176 177 178 179 180 181 182 183 186 187 189 190 192 194 195	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 8 ALH84001 Ap7 8 ALH84001 Ap7 9 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 15 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 2 ALH84001 Ap8 4 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 6 ALH84001 Ap8 8 ALH84001 Ap8 8 ALH84001 Ap8 18 ALH84001 Ap8 13 ALH84001 Ap8 13 ALH84001 Ap8 13	Na2O 2.402 2.358 2.273 2.431 2.328 2.431 2.328 2.480 2.345 2.345 2.346 2.335 2.234 2.239 2.291 2.190 2.190 2.205 2.223	0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	0.100 0.200 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.001 0.128 0.347 0.438 0.	0.081 K20 0.087 0.098 0.099 0.099 0.091 0.079 0.103 0.094 0.082 0.094 0.082 0.094 0.082 0.095 0.090 0.056 0.095 0.064 0.078 0.064 0.078 0.064 0.078 0.064 0.078 0.064 0.078 0.064 0.078 0.064 0.078 0.064 0.078 0.095 0.095 0.095 0.095 0.095 0.094 0.094 0.095 0.095 0.095 0.095 0.094 0.094 0.095 0.095 0.095 0.095 0.095 0.094 0.095 0.005 0.095 0.095 0.095 0.005 0.095 0.095 0.005 0.095 0.005 0.095 0.005 0.095 0.005 0.005 0.005 0.005 0.095 0.005 0.	47.183 CaO 47.477 47.005 46.910 46.329 46.329 46.329 46.831 46.985 46.939 47.144 46.244 46.077 45.751 46.164 46.197 46.386 46.324 46.197 46.386 46.386 46.384 46.334 46.484 46.484	0.859 0.919 0.775 0.859 0.911 0.958 0.958 0.911 0.958 0.818 0.864 0.862 0.834 0.737 0.834 0.831 0.857 0.800 0.857 0.9064 0.868 0.964	Cl 0.004 0.007 0.004 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0000 00	P205 46.808 46.808 46.809 45.913 46.502 45.940 47.031 46.848 46.848 46.848 46.848 46.623 46.147 45.346 46.581 46.561 46.561 46.237 46.094 46.094 46.400	SO3 0.002 0.009 0.016 0.030 0.005 0.004 0.005 0.004 0.005 0.004 0.005 0.004 0.007 0.000 0.004 0.003 0.018 0.017 0.008 0.011 0.003	F 0.000
Nate Collection Pata Collection Rice Uni.	170 Point 171 172 173 174 175 176 177 178 179 180 181 182 183 186 187 190 192 194 196 197	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap8 14 ALH84001 Ap8 2 ALH84001 Ap8 2 ALH84001 Ap8 4 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 8 ALH84001 Ap8 8 ALH84001 Ap8 1 ALH84001 Ap8 18 ALH84001 Ap8 13 ALH84001 Ap8 14 ALH84001 Ap8 14 ALH84001 Ap8 15	Na2O 2.402 2.358 2.273 2.431 2.328 2.431 2.328 2.440 2.382 2.406 2.342 2.432 2.366 2.239 2.212 2.239 2.190 2.156 2.223 2.223 2.223	sio2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.000	0.100 0.200 0.001 0.017 0.512 0.331 0.411 0.438 0.187 0.390 0.0390 0.0390 0.0390 0.031 0.031 0.0331 0.031 0.031 0.0331 0.031 0.0331 0.0390 0.0331 0.0390 0.031 0.0331 0.0311 0.0331 0.0331 0.0330 0.0390 0.0390 0.0390 0.0311 0.0331 0.0331 0.0331 0.0331 0.0331 0.0331 0.0331 0.0331 0.0331 0.0331 0.0330 0.0350 0.035	K20 K20 0.087 0.098 0.098 0.099 0.079 0.038 0.097 0.094 0.097 0.094 0.077 0.113 0.095 0.095 0.085 0.066 0.078 0.073	47.133 CaO 47.477 47.005 46.975 46.910 46.329 46.263 46.329 46.885 46.985 46.985 46.985 46.985 46.985 46.971 45.751 46.197 46.384 46.022 46.126	Fe0 0.919 0.775 0.838 0.859 0.911 0.958 0.818 0.864 0.864 0.831 0.874 0.831 0.847 0.864 0.800 0.847 0.864	Cl 0.004 0.007 0.004 0.0000 0.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.0000000 0.00000000	P205 46.808 46.808 46.859 45.913 46.502 45.940 47.031 46.848 46.814 46.848 46.848 46.463 46.203 46.581 46.203 46.581 46.203 46.203 46.203 46.203 46.203 46.094 46.047 46.047	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.016 0.030 0.005 0.016 0.005 0.006 0.007 0.000 0.004 0.003 0.004 0.018 0.027 0.019 0.019 0.010 0.000 0.011 0.000	B B F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Rice Uni.	170 Point 171 172 173 174 175 176 177 178 179 180 181 182 183 186 187 189 190 192 194 196 197 198	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap8 1 ALH84001 Ap8 1 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 8 ALH84001 Ap8 9 ALH84001 Ap8 11 ALH84001 Ap8 13 ALH84001 Ap8 14 ALH84001 Ap8 13 ALH84001 Ap8 14 ALH84001 Ap8 13 ALH84001 Ap8 16 ALH84001 Ap8 16 ALH84001 Ap8 17	Na2O 2.402 2.358 2.273 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.382 2.406 2.342 2.366 2.234 2.336 2.239 2.291 2.156 2.205 2.230 2.204	siO2 0.000	0.100 0.000 0.000 0.087 0.239 0.200 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.200 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.017 0.512 0.288 0.347 0.931 0.411 0.438 0.390 0.390 0.917	K20 0.087 0.087 0.098 0.089 0.091 0.079 0.091 0.079 0.094 0.094 0.082 0.077 0.113 0.095 0.095 0.095 0.064 0.078 0.078 0.073 0.119	47.133 CaO 47.477 47.005 46.975 46.971 46.972 46.329 46.329 46.329 46.329 46.329 46.329 46.329 46.329 46.385 46.939 46.385 46.164 46.184 46.386 46.022 46.134 46.124 46.134 46.134 46.134 46.125 46.134 46.134 46.134 46.134 46.134 46.134	Fe0 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818 0.864 0.834 0.834 0.834 0.831 0.857 0.800 0.847 0.964 0.805 1.005 1.010	Cl 0.004 0.007 0.004 0.000	P205 46.808 46.808 46.859 45.913 46.502 45.940 47.031 46.844 46.814 46.814 46.602 46.463 46.463 46.521 46.531 46.561 46.233 46.561 46.080 46.047 46.4047 46.240 46.240	SO3 0.002 0.009 0.015 0.016 0.030 0.004 0.004 0.007 0.000 0.004 0.003 0.004 0.003 0.004 0.003 0.004 0.003 0.018 0.0027 0.019 0.017 0.0017	F 0.000
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Nete Uni. Rice Uni.	Proint Point 171 172 173 174 175 177 176 177 178 179 180 181 182 183 186 187 189 190 192 194 196 197 198 200 201	Comment ALH84001 Ap7 5 ALH84001 Ap7 5 ALH84001 Ap7 7 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 2 ALH84001 Ap8 4 ALH84001 Ap8 5 ALH84001 Ap8 8 ALH84001 Ap8 8 ALH84001 Ap8 8 ALH84001 Ap8 13 ALH84001 Ap8 14 ALH84001 Ap8 15 ALH84001 Ap8 15 ALH84001 Ap8 16 ALH84001 Ap8 17 ALH84001 Ap9 in OPX 1 ALH84001 Ap9 in OPX 1 ALH84001 Ap9 in OPX 1	Na2O 2.402 2.358 2.273 2.431 2.328 2.430 2.382 2.406 2.382 2.406 2.382 2.406 2.3432 2.366 2.231 2.335 2.212 2.391 2.190 2.156 2.223 2.230 2.201 2.422 2.342	siO2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.000 0.001	0.102 0.212 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.237 0.230 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.0017 0.512 0.288 0.347 0.931 0.411 0.438 0.187 0.390 0.917 0.120 0.218	K20 0.087 0.098 0.098 0.099 0.079 0.0097 0.097 0.097 0.094 0.097 0.094 0.097 0.094 0.097 0.094 0.097 0.094 0.095 0.095 0.095 0.056 0.064 0.078 0.078 0.073 0.1092 0.092 0.092 0.092	47.103 CaO 47.477 47.005 46.975 46.910 46.329 46.831 46.788 46.985 46.985 46.985 46.985 46.985 46.985 46.985 46.971 45.751 46.164 46.072 46.184 46.126 45.751 46.126 46.126 46.261 46.262 46.263 46.264 46.271 46.262 46.263 46.264 46.264 46.264 46.264 46.264 46.264 46.264 46.264 46.264 46.264 46.264 46.261 46.262	sre0 0.919 0.775 0.838 0.859 0.911 0.958 0.859 0.818 0.865 0.818 0.865 0.812 0.834 0.737 0.874 0.837 0.800 0.847 0.964 1.005 1.005 1.235 1.181	Cl 0.004 0.007 0.004 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.003	P205 46.808 46.808 46.809 45.913 46.502 45.940 47.031 46.848 46.814 46.992 46.463 46.463 46.463 46.203 46.581 46.237 46.080 46.4047 46.240 46.541 46.344	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.019 0.000 0.004 0.019 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.003 0.019 0.017 0.000 0.0000 0.00017	F 0.000
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Nete Uni. Rice Uni.	173 Point 171 172 173 174 175 174 175 174 175 174 175 176 177 178 177 178 179 181 182 183 186 187 188 187 198 200 201 202 203	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 8 ALH84001 Ap8 13 ALH84001 Ap8 13 ALH84001 Ap8 16 ALH84001 Ap8 16 ALH84001 Ap8 16 ALH84001 Ap8 10 AP1 1 ALH84001 Ap8 10 AP1 10 ALH84001 Ap8 15 ALH84001 Ap9 10 OPX 1 ALH84001 Ap9 10 OPX 2 ALH84001 Ap9 10 OPX 2 ALH84001 Ap9 10 OPX 3 ALH84001 Ap9 10 OPX 4	Na2O 2.402 2.358 2.273 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.406 2.341 2.352 2.432 2.345 2.234 2.239 2.201 2.156 2.205 2.230 2.204 2.4329 2.446 2.324 2.446 2.327	siO2 0.000 0.001 0.002	0.102 0.230 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.207 0.230 0.000 0.207 0.017 0.512 0.288 0.347 0.931 0.411 0.438 0.187 0.390 0.917 0.120 0.218 0.139 0.300	K20 0.087 0.098 0.099 0.099 0.091 0.079 0.091 0.079 0.094 0.094 0.095 0.097 0.094 0.095 0.070 0.095 0.095 0.095 0.0964 0.078 0.0666 0.073 0.109 0.092 0.087 0.0667 0.089	47.133 CaO 47.477 47.005 46.975 46.975 46.329 46.329 46.329 46.329 46.329 46.788 46.985 46.985 46.984 46.985 46.164 46.171 45.751 46.164 46.184 46.224 46.134 46.202 46.134 46.204 46.521 45.781 46.204 46.521 45.980 46.521 46.54 46.934	Site FeO 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818 0.858 0.818 0.864 0.864 0.834 0.834 0.834 0.834 0.874 0.831 0.857 0.800 0.847 0.866 1.005 1.010 1.235 1.181 1.241 1.065	Cl 0.004 0.007 0.004 0.000 0.001 0.002 0.004	P205 46.808 46.808 46.809 45.913 46.502 45.940 47.031 46.814 46.814 46.814 46.814 46.620 46.463 46.463 46.521 46.561 46.237 46.080 46.240 46.240 46.511 46.344 46.108 46.598 46.598	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.007 0.000 0.004 0.003 0.004 0.003 0.004 0.003 0.017 0.019 0.017 0.003 0.011 0.000 0.017 0.000 0.017 0.000 0.017 0.000 0.017 0.000 0.017 0.000 0.017 0.000 0.009 0.009	$\begin{array}{c} 0.000\\ \hline F\\ 0.000\\ 0.00$
Rice Uni.	173 171 172 173 174 175 176 177 178 177 178 177 178 179 181 182 183 184 187 190 192 194 196 197 198 200 201 202 203 204	Comment ALH84001 Ap7 5 ALH84001 Ap7 5 ALH84001 Ap7 7 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 2 ALH84001 Ap8 4 ALH84001 Ap8 5 ALH84001 Ap8 8 ALH84001 Ap8 8 ALH84001 Ap8 13 ALH84001 Ap8 13 ALH84001 Ap8 14 ALH84001 Ap8 15 ALH84001 Ap8 16 ALH84001 Ap8 17 ALH84001 Ap9 in OPX 1 ALH84001 Ap9 in OPX 2 ALH84001 Ap9 in OPX 3 ALH84001 Ap9 in OPX 4 ALH84001 Ap9 in OPX 4 ALH84001 Ap9 in OPX 4	Na2O 2.402 2.431 2.273 2.431 2.382 2.406 2.382 2.406 2.382 2.406 2.3432 2.366 2.231 2.320 2.291 2.190 2.190 2.205 2.205 2.204 2.349 2.442 2.324 2.324 2.324 2.324	siO2 0.000 0.001 0.002 0.003 0.004 0.370	0.100 La203 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.207 0.117 0.512 0.288 0.347 0.411 0.438 0.187 0.917 0.120 0.218 0.139 0.180 0.007	0.181 K20 0.087 0.098 0.099 0.091 0.079 0.094 0.094 0.095 0.097 0.094 0.095 0.095 0.095 0.095 0.095 0.095 0.095 0.095 0.0964 0.078 0.0666 0.092 0.087 0.0667 0.087 0.0667 0.087 0.067	47:133 CaO 47.477 47.005 46.910 46.329 46.210 46.329 46.231 46.329 46.329 46.788 46.985 46.984 46.985 46.984 46.985 46.124 46.107 46.164 46.197 46.386 46.122 46.134 46.204 46.204 46.521 45.5980 46.454 46.829	Site FeO 0.919 0.775 0.859 0.911 0.958 0.638 0.859 0.911 0.958 0.638 0.818 0.864 0.852 0.812 0.834 0.831 0.857 0.800 0.841 0.964 0.868 1.010 1.235 1.181 1.241 1.066 1.265 1.955	Cl 0.004 0.007 0.004 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0000 0.0000 0	P205 46.808 46.808 46.809 45.913 46.502 45.940 47.031 46.814 46.814 46.814 46.620 46.814 46.621 46.463 46.147 46.520 46.641 46.581 46.581 46.561 46.694 46.410 46.511 46.598 46.598 46.598 46.598 46.598	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.019 0.000 0.004 0.019 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.005 0.001 0.001 0.002 0.003 0.004 0.005 0.006 0.009 0.001	$\begin{array}{c} 0.000\\ \hline F\\ 0.000\\ 0.00$
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Rice Uni.	130 171 171 171 172 173 174 175 174 175 174 175 176 177 178 179 178 179 180 181 182 183 186 187 189 190 192 194 201 202 203 204 205 206	Comment ALH84001 Ap7 5 ALH84001 Ap7 7 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap8 1 ALH84001 Ap8 2 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 6 ALH84001 Ap8 13 ALH84001 Ap8 14 ALH84001 Ap8 15 ALH84001 Ap8 16 ALH84001 Ap8 16 ALH84001 Ap8 16 ALH84001 Ap9 in OPX 1 ALH84001 Ap9 in OPX 1 ALH84001 Ap9 in OPX 3 ALH84001 Ap9 in OPX 3 ALH84001 Ap9 in OPX 3 ALH84001 Ap9 in OPX 4 ALH84001 Ap9 in OPX 5 ALH84001 Ap9 in OPX 6 ALH84001 Ap9 in OPX 6 ALH84001 Ap9 in OPX 7 ALH84001 Ap9 in OPX 6 ALH8	Na2O 2.402 2.358 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.432 2.366 2.234 2.334 2.239 2.291 2.190 2.156 2.204 2.432 2.349 2.466 2.324 2.291 2.349 2.4466 2.324 2.291 2.349 2.466 2.324 2.291 2.216 2.426	siO2 0.000 0.001 0.002 0.003 0.0047 0.0370 0.024 0.025	0.100 La203 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.000 0.000 0.000 0.017 0.187 0.390 0.917 0.120 0.218 0.139 0.180 0.007 0.151 0.004	K20 0.087 0.098 0.098 0.099 0.099 0.091 0.079 0.091 0.097 0.091 0.097 0.094 0.092 0.094 0.095 0.095 0.0956 0.085 0.0664 0.092 0.087 0.0667 0.089 0.113 0.0992 0.0172	47.133 CaO 47.477 47.005 46.971 46.971 46.971 46.971 46.971 46.329 46.329 46.788 46.798 46.798 46.714 46.714 46.244 46.77 45.751 46.164 46.126 46.386 46.126 46.384 46.204 46.571 46.521 45.980 46.454 46.521 45.980 46.454 46.521 45.980 46.454 46.829 45.001 46.3913 46.713	sred 0.919 0.775 0.838 0.859 0.911 0.958 0.859 0.911 0.958 0.838 0.859 0.818 0.864 0.864 0.864 0.834 0.737 0.874 0.831 0.857 0.800 0.847 0.864 0.864 0.857 0.800 0.847 0.864 0.864 0.864 0.864 0.864 0.864 0.864 0.864 0.864 0.864 0.864 0.864 0.864 0.864 0.865 1.010 1.225 1.853 1.251	Cl 0.004 0.007 0.004 0.000 0.001 0.001 0.004	P205 46.808 46.808 46.859 45.913 46.502 45.913 46.502 46.814 46.814 46.814 46.62 46.463 46.52 46.534 46.534 46.561 46.237 46.080 46.047 46.344 46.108 46.538 46.538 46.511 46.344 46.108 46.344 46.344 46.344 46.311 46.342 46.314 46.314 46.314 46.314 46.314 46.314 46.314 46.314 46.314 46.314 46.314 46.314 46.314 46.314 46.314 46.314	SO3 0.002 0.009 0.015 0.016 0.030 0.004 0.019 0.007 0.000 0.004 0.019 0.000 0.004 0.003 0.004 0.003 0.019 0.017 0.008 0.000 0.011 0.006 0.009 0.009 0.0001 0.0015	B C F 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Rice Uni.	173 Point 171 172 173 174 175 174 175 174 175 174 175 174 175 176 177 178 179 181 182 183 186 187 188 187 198 200 201 202 203 204 205 206	Comment ALH84001 Ap7 5 ALH84001 Ap7 6 ALH84001 Ap7 7 ALH84001 Ap7 8 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap8 1 ALH84001 Ap8 1 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 5 ALH84001 Ap8 13 ALH84001 Ap8 13 ALH84001 Ap8 15 ALH84001 Ap8 16 ALH84001 Ap8 16 ALH84001 Ap8 10 OPX 1 ALH84001 Ap9 in OPX 2 ALH84001 Ap9 in OPX 2 ALH84001 Ap9 in OPX 3 ALH84001 Ap9 in OPX 4 ALH84001 Ap9 in OPX 4 ALH84001 Ap9 in OPX 4 ALH84001 Ap9 in OPX 5 ALH84001 Ap9 in OPX 6 ALH84001 Ap9 in OPX 7 ALH84001 Ap9 in OPX 7 ALH84001 Ap9 in OPX 7	Na2O 2.402 2.358 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.382 2.406 2.343 2.366 2.234 2.324 2.239 2.291 2.190 2.156 2.205 2.230 2.204 2.4242 2.324 2.324 2.324 2.324 2.324 2.216 2.426 2.426 2.426 2.426 2.426	siO2 0.000 0.001 0.002 0.002 0.00370 1.094 0.090 0.026	0.102 0.203 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.227 0.230 0.000 0.207 0.230 0.317 0.512 0.288 0.347 0.931 0.411 0.438 0.187 0.390 0.917 0.120 0.218 0.180 0.007 0.151 0.000 0.094 0.004	K20 0.087 0.098 0.099 0.091 0.079 0.091 0.079 0.094 0.094 0.095 0.097 0.094 0.095 0.095 0.096 0.095 0.095 0.0964 0.078 0.0664 0.078 0.0666 0.092 0.087 0.0667 0.089 0.113 0.092 0.087 0.089 0.113 0.092 0.072 0.089	47.103 CaO 47.477 47.005 46.910 46.975 46.329 46.329 46.329 46.329 46.329 46.798 46.798 46.798 46.798 46.798 46.798 46.798 46.798 46.798 46.798 46.164 46.197 46.164 46.122 46.134 46.204 46.521 45.791 46.454 45.980 46.454 45.901 46.913 46.913	sred 0.919 0.775 0.838 0.859 0.911 0.958 0.638 0.818 0.864 0.864 0.864 0.834 0.834 0.834 0.834 0.874 0.831 0.857 0.800 0.847 0.866 1.005 1.010 1.235 1.181 1.265 1.853 1.215 0.861	Cl 0.004 0.007 0.004 0.000 0.001 0.002 0.003 0.007 0.004 0.001 0.000	P205 46.808 46.808 46.809 45.913 46.502 45.940 47.031 46.814 46.814 46.814 46.602 46.463 46.463 46.521 46.561 46.203 46.561 46.240 46.463 46.511 46.4598 46.034 46.511 46.473 46.473 46.473 46.473	SO3 0.002 0.009 0.015 0.016 0.030 0.004 0.019 0.007 0.004 0.003 0.004 0.003 0.004 0.003 0.004 0.003 0.018 0.027 0.019 0.017 0.008 0.000 0.011 0.003 0.001 0.017 0.000 0.017 0.000 0.0017 0.000 0.0017 0.000 0.0017 0.0009 0.0001 0.015 0.0099	$\begin{array}{c} 0.000\\ \hline {\bf F}\\ \hline 0.000\\ 0.000$
Nate Collection Parta Collection Rice Uni.	1:3 Point 171 172 173 174 173 174 175 176 177 176 177 180 181 182 183 186 187 188 190 192 192 192 201 202 203 204 205 206	Comment ALH84001 Ap7 5 ALH84001 Ap7 5 ALH84001 Ap7 7 ALH84001 Ap7 10 ALH84001 Ap7 11 ALH84001 Ap7 12 ALH84001 Ap7 13 ALH84001 Ap7 14 ALH84001 Ap7 15 ALH84001 Ap8 1 ALH84001 Ap8 2 ALH84001 Ap8 4 ALH84001 Ap8 5 ALH84001 Ap8 8 ALH84001 Ap8 8 ALH84001 Ap8 8 ALH84001 Ap8 13 ALH84001 Ap8 14 ALH84001 Ap8 15 ALH84001 Ap8 16 ALH84001 Ap9 in OPX 1 ALH84001 Ap9 in OPX 2 ALH84001 Ap9 in OPX 3 ALH84001 Ap9 in OPX 4 ALH84001 Ap9 in OPX 4 ALH84001 Ap9 in OPX 5 ALH84001 Ap9 in OPX 7 ALH84	Na2O 2.402 2.402 2.352 2.431 2.328 2.431 2.328 2.431 2.328 2.431 2.382 2.406 2.382 2.406 2.342 2.355 2.212 2.355 2.221 2.190 2.150 2.205 2.205 2.204 2.304 2.422 2.349 2.422 2.349 2.426 2.324 2.426 2.348 2.149	sio2 0.000 0.001 0.002 0.0047 0.055 0.0764 0.370 1.094 0.090 0.000 1.094	0.103 La203 0.000 0.087 0.239 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.017 0.512 0.347 0.3347 0.3347 0.3347 0.3347 0.3390 0.917 0.120 0.218 0.139 0.180 0.0007 0.151 0.0001 0.094	K101 K20 0.087 0.098 0.098 0.099 0.079 0.091 0.079 0.097 0.094 0.077 0.113 0.095 0.095 0.095 0.095 0.056 0.0685 0.064 0.078 0.066 0.085 0.067 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.087 0.089 0.113 0.089 0.056 0.115	47.103 CaO 47.477 47.005 46.910 46.921 46.329 46.263 46.329 46.329 46.329 46.781 46.985 46.985 46.984 46.985 46.985 46.984 46.985 46.124 46.071 45.751 46.164 46.197 46.386 46.124 46.124 46.124 46.124 46.124 46.204 46.521 45.980 46.454 46.829 45.901 46.715 45.001 46.715	sre0 0.919 0.775 0.838 0.859 0.638 0.859 0.638 0.859 0.638 0.859 0.638 0.859 0.638 0.859 0.638 0.865 0.812 0.837 0.874 0.865 0.800 0.847 0.964 1.005 1.010 1.235 1.181 1.241 1.065 0.861 0.618 1.255	Cl 0.004 0.007 0.004 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0000 0.0000 0.00000000	P205 46.808 46.859 46.808 45.913 46.502 45.940 47.031 46.848 46.814 46.848 46.848 46.848 46.620 46.621 46.463 46.237 46.6237 46.6410 46.6410 46.6410 46.6410 46.634 46.034 46.034 46.034 46.7511 46.371 46.399 44.511 46.371 46.399	SO3 0.002 0.009 0.015 0.016 0.030 0.005 0.004 0.019 0.000 0.004 0.019 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.005 0.006 0.007 0.008 0.009 0.0001 0.001 0.002 0.003 0.004	F 0.000

BRECKIM 92 ALTHR01 (Ap) gray 3.33 0.00 0.001 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.001 0.000 0.001 0.001 0.000 0.001	Data Collection	Point	Comment	MgO	Al2O3	MnO	Ce2O3	Nd2O3	Total	O=F,Cl	-O=F2	-O=Cl2	Total recalc
Base Dim. 91 AL188801 Apl gays 3384 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000	Rice Uni.	92	ALH84001_Ap1_gray_7	3.383	0.000	0.063	0.029	0.000	99.970	0.000	0.000	0.000	99.970
Base Usi 94 ALTBASED ApI gray 3.440 0.000 0.037 0.005 0.011 0.000 </td <td>Rice Uni.</td> <td>93</td> <td>ALH84001_Ap1_gray_8</td> <td>3.384</td> <td>0.000</td> <td>0.047</td> <td>0.056</td> <td>0.000</td> <td>99.881</td> <td>0.001</td> <td>0.000</td> <td>0.001</td> <td>99.880</td>	Rice Uni.	93	ALH84001_Ap1_gray_8	3.384	0.000	0.047	0.056	0.000	99.881	0.001	0.000	0.001	99.880
Base Um. 95 AL184801. Ap] gro 10 3.316 0.000 0.015 0.005 0.000 </td <td>Rice Uni.</td> <td>94</td> <td>ALH84001_Ap1_gray_9</td> <td>3.430</td> <td>0.000</td> <td>0.039</td> <td>0.065</td> <td>0.436</td> <td>101.133</td> <td>0.000</td> <td>0.000</td> <td>0.000</td> <td>101.133</td>	Rice Uni.	94	ALH84001_Ap1_gray_9	3.430	0.000	0.039	0.065	0.436	101.133	0.000	0.000	0.000	101.133
Base Unit. 0 AL184800. ApI grap 11 3.365 0.021 0.025 0.000	Rice Uni.	95	ALH84001_Ap1_gray_10	3.316	0.000	0.018	0.043	0.016	100.189	0.000	0.000	0.000	100.189
Rice Unit. 97 AL184001 ApJ grsl 13.341 0.000	Rice Uni.	96	ALH84001_Ap1_gray_11	3.365	0.021	0.050	0.025	0.000	99.515	0.000	0.000	0.000	99.515
Rice Uni. 98 A.L.1184001 Appl. ppy 13 3.380 0.026 0.041 0.040 9.309 0.000 <td>Rice Uni.</td> <td>97</td> <td>ALH84001_Ap1_gray_12</td> <td>3.341</td> <td>0.000</td> <td>0.000</td> <td>0.080</td> <td>0.000</td> <td>100.310</td> <td>0.000</td> <td>0.000</td> <td>0.000</td> <td>100.310</td>	Rice Uni.	97	ALH84001_Ap1_gray_12	3.341	0.000	0.000	0.080	0.000	100.310	0.000	0.000	0.000	100.310
Rice Uni. 99 ALTIB4001 Apl gray 14 3.415 0.000 0.000 100.000 0.0	Rice Uni.	98	ALH84001_Ap1_gray_13	3.380	0.026	0.046	0.043	0.000	99.309	0.001	0.000	0.001	99.308
Rice Uni. 100 ALIH84001 ApJ gray 15 3.455 0.002 0.003 0.000 0.00	Rice Uni.	99	ALH84001_Ap1_gray_14	3.415	0.000	0.061	0.046	0.000	100.693	0.000	0.000	0.000	100.693
Rice Uni. 101 ALLIB4001 ApJ gay 16 3.447 0.002 0.002 0.002 0.002 0.000 0.000 0.000 0.9557 Rice Uni. 103 ALLIB4001 ApJ gay 2 3.447 0.000 0.001 0.002 0.001 0.000 0.000 0.9557 Rice Uni. 105 ALLIB4001 ApJ gay 2. 3.446 0.000 0.021 0.001 0.000 0.000 0.001 0	Rice Uni.	100	ALH84001_Ap1_gray_15	3.455	0.002	0.025	0.058	0.000	99.943	0.000	0.000	0.000	99.943
Rice Uni. 102 ALL184001 Ap2 gray 1 3.447 0.000 0.003 0.925 0.000	Rice Uni.	101	ALH84001_Ap1_gray_16	3.444	0.020	0.001	0.057	0.046	100.084	0.000	0.000	0.000	100.084
Rike Uni. 101 ALL184001 App. 23:40 0.000	Rice Uni.	102	ALH84001_Ap2_gray_1	3.447	0.000	0.022	0.041	0.033	99.597	0.002	0.000	0.002	99.595
Rice Uni. 104 AL184001 Ap2 gray J 3.398 0.000 0.002 0.000	Rice Uni.	103	ALH84001_Ap2_gray_2	3.416	0.000	0.030	0.010	0.000	99.583	0.000	0.000	0.000	99.583
Rice Uni. 105 ALLIS&001 Ap2 gray 4 3.349 0.000 0.040 0.040 0.000	Rice Uni.	104	ALH84001_Ap2_gray_3	3.496	0.205	0.007	0.032	0.000	99.353	0.000	0.000	0.000	99.353
Rice Uni. 106 ALH184001 Ap2 gray 5 3.485 0.001 0.024 0.007 0.000 10.000 0.000 10.0251 Rise Uni. 107 ALH184001 Ap2 gray 7 3.437 0.000 0.001 0.001 0.000 0.000 0.001 0.001 0.000	Rice Uni.	105	ALH84001_Ap2_gray_4	3.393	0.000	0.040	0.046	0.000	100.476	0.001	0.000	0.001	100.475
Rice Uni. 107 ALLB4001 Ap2 gray 6 3.32 0.009 0.026 0.000 0.234 100.947 0.001 0.000	Rice Uni.	106	ALH84001_Ap2_gray_5	3.405	0.001	0.040	0.027	0.000	100.251	0.000	0.000	0.000	100.251
Rice Uni. 108 ALH24001 Ap2 args 7 3.4.17 0.000 0.001 9.002 0.000 0.001 0.000 0.001 0.000 0.001	Rice Uni.	107	ALH84001_Ap2_gray_6	3.392	0.009	0.026	0.000	0.234	100.947	0.001	0.000	0.001	100.946
Rice Uni. 109 ALLB4001 Ap3 1 3.363 0.001 0.005 0.004 0.000	Rice Uni.	108	ALH84001_Ap2_gray_7	3.417	0.000	0.008	0.071	0.000	99.902	0.000	0.000	0.000	99.902
Rice Uni. 110 ALTRMOD Ap3 2 3.452 0.000 0.001 0.000 0.000 0.001 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.000 0.001 0.000	Rice Uni.	109	ALH84001_Ap3_1	3.363	0.001	0.005	0.040	0.000	100.099	0.000	0.000	0.000	100.099
Rice Uni. 111 ALTRMOD. Ap3.3 3.416 0.050 0.020 0.006 0.000 0.000 9.9733 Rice Uni. 112 ALTRMOD. Ap3.5 3.349 0.000 0.005 0.001 0.000 0.0	Rice Uni.	110	ALH84001_Ap3_2	3.452	0.000	0.000	0.048	0.160	100.075	0.000	0.000	0.000	100.075
Rice Uni. 112 ALFR4001 Ap3 4 3.388 0.000 0.022 0.001 0.001 9.99.99 Rice Uni. 113 ALFR4001 Ap3 6 3.439 0.000 0.002 0.000 0.002 0.000 0.002 0.000 0.002 0.000 0.001 0.002 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 100.103 Rice Uni. 118 ALFR4001 Ap3 11 3.484 0.002 0.002 0.000	Rice Uni.	111	ALH84001_Ap3_3	3.416	0.050	0.029	0.066	0.000	99.733	0.000	0.000	0.000	99.733
Rice Uni. 113 ALH84001 Ap3 5 3.439 0.000 0.052 0.030 0.097 0.000 0.000 0.000 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001	Rice Uni.	112	ALH84001_Ap3_4	3.398	0.000	0.020	0.010	0.111	99.920	0.001	0.000	0.001	99.919
Rice Uni. 114 ALH8401 Ap3 6 3.502 0.000 0.001 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000	Rice Uni.	113	ALH84001_Ap3_5	3.439	0.000	0.052	0.030	0.059	100.723	0.002	0.000	0.002	100.721
Rice Uni: 116 ALH84001 Ap3 8 3.454 0.026 0.024 0.049 0.000	Rice Uni.	114	ALH84001_Ap3_6	3.502	0.000	0.000	0.012	0.000	100.104	0.001	0.000	0.001	100.103
Rice Uni. 117 ALLH84001 Ap3 9 3.499 0.038 0.049 0.029 0.001 10.001 0.000 0.001 100.409 Rice Uni. 118 ALLH84001 Ap3 11 3.484 0.006 0.0027 0.000 99.994 0.000	Rice Uni.	116	ALH84001_Ap3_8	3.454	0.026	0.024	0.050	0.000	99.755	0.000	0.000	0.000	99.755
Rec Uni. 118 ALLB4001 Ap3 10 3.457 0.028 0.028 0.009 100.546 0.001 0.000 <td>Rice Uni.</td> <td>117</td> <td>ALH84001_Ap3_9</td> <td>3.499</td> <td>0.038</td> <td>0.049</td> <td>0.029</td> <td>0.049</td> <td>100.410</td> <td>0.001</td> <td>0.000</td> <td>0.001</td> <td>100.409</td>	Rice Uni.	117	ALH84001_Ap3_9	3.499	0.038	0.049	0.029	0.049	100.410	0.001	0.000	0.001	100.409
Rice Uni. 119 ALLB4001 Ap3 11 3.484 0.006 0.000 0.000 99.994 0.000 0.000 99.994 Rice Uni. 120 ALLB4001 Ap3 13 3.489 0.000 0.033 0.011 0.000 0.000 0.000 99.328 Rice Uni. 122 ALLB4001 Ap3 14 3.420 0.004 0.033 0.014 0.002 0.0000 0.000 0.000	Rice Uni.	118	ALH84001_Ap3_10	3.457	0.028	0.028	0.029	0.000	100.546	0.001	0.000	0.001	100.545
Rice Uni. 120 ALH84001 Ap3 12 3.469 0.000 0.027 0.006 99.849 0.000 0.000 99.849 Rice Uni. 121 ALH84001 Ap3 14 3.420 0.004 0.033 0.011 99.328 0.000 0.000 1.000 <td< td=""><td>Rice Uni.</td><td>119</td><td>ALH84001_Ap3_11</td><td>3.484</td><td>0.006</td><td>0.006</td><td>0.000</td><td>0.000</td><td>99.994</td><td>0.000</td><td>0.000</td><td>0.000</td><td>99.994</td></td<>	Rice Uni.	119	ALH84001_Ap3_11	3.484	0.006	0.006	0.000	0.000	99.994	0.000	0.000	0.000	99.994
Rice Uni. 121 ALH84001 Ap3 14 3.489 0.000 0.033 0.015 0.000 9.329 0.001 0.000 0.002 100779 Rice Uni. 122 ALH84001 Ap3 15 3.403 0.000 0.022 0.001 0.000 0.000 1.00228 0.000 0.000 0.000 0.000 0.000 1.0002 1.00228 Rice Uni. 124 ALH84001 Ap3 trail 3.317 0.013 0.000 1.00.090 0.000 0.000 0.000 1.0009 0.000 1.00.090 0.000 0.000 1.00.091 1.00.090 0.000 0.000 1.00.091 1.00.090 0.000 0.000 1.00.091 1.00.091 1.00.187 0.000 0.000 1.00.247 0.000 0.000 0.000 1.00.247 0.000 0.000 0.000 1.00.62 0.000 1.00.62 0.000 1.00.62 0.000 0.000 0.000 1.00.67 1.00.09 0.000 0.000 0.000 1.00.61 1.00.413 XLH84001 Ap4 gray 1.33	Rice Uni.	120	ALH84001_Ap3_12	3.469	0.000	0.027	0.027	0.006	99.849	0.000	0.000	0.000	99.849
Rice Uni. 122 ALH84001 Ap3 15 3.420 0.004 0.033 0.041 0.089 100.781 0.002 0.000 0.001 0.002 0.000 0.002 0.000 0.002 0.000 0.002 0.000 0.002 0.000 0.001 0.002 0.000 0.001 0.002 0.001 0.002 0.001 0.002 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 <td>Rice Uni.</td> <td>121</td> <td>ALH84001_Ap3_13</td> <td>3.489</td> <td>0.000</td> <td>0.030</td> <td>0.015</td> <td>0.000</td> <td>99.329</td> <td>0.001</td> <td>0.000</td> <td>0.001</td> <td>99.328</td>	Rice Uni.	121	ALH84001_Ap3_13	3.489	0.000	0.030	0.015	0.000	99.329	0.001	0.000	0.001	99.328
Rice Uni. 123 ALH84001 Ap3 Itmil 1 3.403 0.000 0.022 0.047 0.026 100.228 0.000 0.000 0.000 1.0002 Rice Uni. 124 ALH84001 Ap3 tmil 2 3.414 0.009 0.028 0.013 0.000 100.090 0.000 0.000 100.090 0.000 100.090 0.000 100.090 0.000 100.090 0.000 100.090 0.000 100.090 0.000 100.090 0.000 100.022 0.000 100.022 0.000 100.022 0.000 100.022 0.000 0.002 100.022 100.0545 Rice Uni. 127 ALH84001 Ap3 tmil 5 3.399 0.000 0.011 0.002 0.000 0.000 100.059 0.000 0.000 100.059 0.000 0.000 100.059 0.000 0.000 9.856 0.000 0.000 9.854 0.000 0.000 9.854 0.000 0.000 100.413 Rice Uni. 142 ALH84001 Ap4 gmy 7 3.446 0.000	Rice Uni.	122	ALH84001_Ap3_14	3.420	0.004	0.033	0.041	0.189	100.781	0.002	0.000	0.002	100.779
Rice Uni. 124 ALH84001 Ap3 trail 3.375 0.013 0.009 0.024 98.003 0.000 0.001 0.002 0.000 0.001 0.002 0.000 0.001 0.002 0.000 0.001 0.002 0.000 0.001 0.002 0.000 0.001 0.002 0.000 0.001 0.002 0.000 0.001 0.002 0.000 0.001 0.001 0.002 0.000 0.001 0.001 0.001 0.001 0.001 0.002 0.000 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001<	Rice Uni.	123	ALH84001_Ap3_15	3.403	0.000	0.022	0.047	0.026	100.228	0.000	0.000	0.000	100.228
Rice Uni. 125 ALH84001 Ap3 trail 2 3.414 0.009 0.028 0.013 0.0000 10.000 0.000 10.000 100.090 Data Collection Point Camment MgO AL23 MgO C2203 NdO23 Total 0.002 0.000 0.002 100.090 Rice Uni. 127 ALH84001 Ap3 trail 4 3.377 0.000 0.031 0.062 0.000 100.699 0.002 100.000 100.021 Rice Uni. 128 ALH84001 Ap3 trail 5 3.399 0.000 0.011 0.062 0.000 100.591 Rice Uni. 139 ALH84001 Ap4 gray 4 3.465 0.075 0.067 0.000 100.251 0.000 0.000 100.021 100.01 100.00 0.001 100.01 100.00 100.243 Rice Uni. 143 ALH84001 Ap4 gray 7 3.416 0.000 0.023 0.001 0.000 0.002 0.000 0.000 100.251 Rice Uni. 144 ALH84001 Ap4 gray 7	Rice Uni.	124	ALH84001_Ap3_trail_1	3.375	0.013	0.039	0.000	0.044	98.003	0.001	0.000	0.001	98.002
Data Collection Point Comment MgO Al203 NnO Cc203 Nd203 Total O=FC1 O=C12 Total recalc Rice Uni. 127 ALH84001 Ap3 trail 4 3.377 0.000 0.001 0.002 0.000 0.002 100.607 Rice Uni. 128 ALH84001 Ap3 trail 6 3.399 0.000 0.011 0.062 0.000 100.922 0.000 0.000 100.001 100.591 Rice Uni. 139 ALH84001 Ap4 gray 3 3.373 0.001 0.005 0.000 100.000 0.000 0.000 9.9835 0.000 0.000 9.9835 0.000 0.000 100.011 100.23 0.000 0.001 100.013 Rice Uni. 142 ALH84001 Ap4 gray 7 3.416 0.031 0.042 0.035 0.000 100.026 0.000 0.001 100.013 Rice Uni. 144 ALH84001 Ap4 gray 9 3.486 0.042 0.035 0.000 0.000 0.000 0.000 0.000 0.000 0.000 <td>Digg Uni</td> <td>125</td> <td>ALHS4001 Ap3 trail 2</td> <td>2 414</td> <td>0.000</td> <td>0.028</td> <td>0.012</td> <td>0 000</td> <td>100 000</td> <td>0.000</td> <td>0.000</td> <td>0.000</td> <td>100 000</td>	Digg Uni	125	ALHS4001 Ap3 trail 2	2 414	0.000	0.028	0.012	0 000	100 000	0.000	0.000	0.000	100 000
Rice Uni. 126 ALH84001 Ap3 trail 3 3.432 0.014 0.022 0.000 100.547 0.002 100.01 100.02 100.01 100.02 100.01 100.02 100.01 100.02 100.01 100.02 <	Kice Ulli.	123	ALII04001_Ap5_trait_2	3.414	0.009	0.028	0.015	0.000	100.090	0.000	0.000	0.000	100.090
Rice Uni. 127 ALH84001 Ap3 trail 4 3.377 0.000 0.031 0.062 0.000 100.607 Rice Uni. 128 ALH84001 Ap3 trail 6 3.399 0.000 100.658 0.135 99.833 0.000 0.000 99.854 Rice Uni. 139 ALH84001 Ap4 gray 3 3.373 0.001 0.056 0.047 0.000 100.414 0.000 0.000 0.002 99.854 Rice Uni. 140 ALH84001 Ap4 gray 4 3.4465 0.075 0.067 0.000 100.2414 0.000 0.001 100.413 Rice Uni. 142 ALH84001 Ap4 gray 6 3.446 0.000 0.025 19.9998 0.001 0.000 100.255 0.000 0.001 100.265 0.000 0.001 9.997 Rice Uni. 144 ALH84001 Ap4 gray 9 3.448 0.042 0.035 0.000 0.000 0.001 9.973 0.000 0.000 9.933 0.000 0.000 9.934 0.000 0.000 10.023	Data Collection	Point	Comment	MgO	Al2O3	MnO	Ce2O3	0.000 Nd2O3	Total	0.000 O=F,Cl	-O=F2	-O=Cl2	Total recalc
Rice Uni. 128 ALH84001 Ap3 trail 5 3.399 0.000 0.011 0.062 0.000 100.592 0.000 0.000 0.9833 Rice Uni. 139 ALH84001 Ap4 gray 3 3.373 0.001 0.056 0.047 0.000 99.856 0.000 0.000 99.854 Rice Uni. 140 ALH84001 Ap4 gray 4 3.445 0.0075 0.067 0.000 100.215 0.000 0.000 100.265 0.000 0.000 100.265 0.000 0.000 100.265 0.000 0.001 100.265 0.000 0.001 100.265 0.000 0.001 100.265 0.000 0.002 100.00 0.001 100.265 0.000 0.001 100.265 0.000 0.001 100.265 0.000 0.001 100.265 0.000 0.001 100.265 0.000 0.001 100.275 Rice Uni. 144 ALH84001 Ap4 gray 13 3.446 0.042 0.030 0.021 0.000 0.002 100.235 Rice Uni. 144	Data Collection Rice Uni.	125 Point 126	Comment ALH84001_Ap3_trail_3	MgO 3.432	Al2O3 0.014	0.028 MnO 0.028	0.013 Ce2O3 0.046	0.000 Nd2O3 0.000	Total 100.547	0.000 0=F,Cl 0.002	-O=F2 0.000	-O=Cl2 0.002	Total recalc 100.545
Rice Uni. 129 ALH84001 Ap4 gray 3 3.373 0.005 0.038 0.038 0.000 1.000 0.000 0.000 9.833 Rice Uni. 140 ALH84001 Ap4 gray 4 3.465 0.0075 0.007 0.000 100.01414 0.000 0.000 100.1413 Rice Uni. 142 ALH84001 Ap4 gray 6 3.446 0.000 0.023 0.070 0.000 100.265 0.000 0.000 100.2163 Rice Uni. 144 ALH84001 Ap4 gray 7 3.416 0.031 0.042 0.035 0.001 0.000 0.001 9.997 Rice Uni. 144 ALH84001 Ap4 gray 7 3.446 0.042 0.035 0.000 9.9453 0.000 0.000 0.000 0.001 9.997 Rice Uni. 144 ALH84001 Ap4 gray 10 3.449 0.052 0.000 0.002 9.958 0.000 0.000 0.002 9.9558 0.000 0.000 100.2121 Rice Uni. 147 ALH84001 Ap4 gray 112 3.366	Data Collection Rice Uni. Rice Uni.	Point 126 127	Comment ALH84001_Ap3_trail_3 ALH84001_Ap3_trail_4	3.414 MgO 3.432 3.377	Al2O3 0.014 0.000	0.028 MnO 0.028 0.031	0.013 Ce2O3 0.046 0.062	0.000 Nd2O3 0.000 0.000	Total 100.547 100.609	0.000 O=F,Cl 0.002 0.002	-O=F2 0.000 0.000	-O=Cl2 0.002 0.002	Total recalc 100.545 100.607
Rice Uni. 139 ALH84001 Ap4 gray 3 3.373 0.001 0.035 0.047 0.000 99.856 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 100.413 Rice Uni. 142 ALH84001 Ap4 gray 6 3.446 0.000 0.023 0.070 0.000 100.265 0.000 0.000 0.001 99.953 Rice Uni. 144 ALH84001 Ap4 gray 7 3.446 0.002 0.033 0.021 99.958 0.001 0.000 0.001 99.452 Rice Uni. 145 ALH84001 Ap4 gray 9 3.448 0.052 0.000 0.053 0.163 97.934 0.000 0.002 97.932 Rice Uni. 146 ALH84001 Ap4 gray 11 3.366 0.044 0.012 10.121 0.000 0.000 100.35 Rice Uni. 148 ALH84001 Ap5 1 3.427 0.007 0.018 0.098 100.35 0.000<	Data Collection Rice Uni. Rice Uni. Rice Uni.	Point 126 127 128	Comment ALH84001_Ap3_trail_3 ALH84001_Ap3_trail_4 ALH84001_Ap3_trail_5	MgO 3.432 3.377 3.399	Al2O3 0.014 0.000	0.028 0.028 0.031 0.011	0.013 Ce2O3 0.046 0.062 0.062	0.000 Nd2O3 0.000 0.000 0.000	Total 100.547 100.609 100.592	0.000 O=F,Cl 0.002 0.002 0.001	-O=F2 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001	Total recalc 100.545 100.607 100.591
Rice Uni. 140 ALH84001 Apf gray 4 3.465 0.075 0.067 0.000 100.01 0.000 0.000 100.01 100.013 Rice Uni. 143 ALH84001 Apf gray 6 3.446 0.001 0.023 0.070 0.000 100.263 0.000 0.000 0.001 99.997 Rice Uni. 144 ALH84001 Ap4 gray 8 3.368 0.022 0.000 0.001 0.000 0.001 99.453 Rice Uni. 144 ALH84001 Ap4 gray 10 3.449 0.052 0.000 0.002 99.558 0.000 0.000 0.000 99.558 Rice Uni. 147 ALH84001 Ap4 gray 12 3.366 0.025 0.000 0.163 97.934 0.002 0.000 0.002 97.932 Rice Uni. 147 ALH84001 Ap5 1 3.427 0.007 0.18 0.098 0.286 100.365 0.000 0.000 100.35 Rice Uni. 150 ALH84001 Ap5 1 3.3427 0.007 0.018 <td>Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni.</td> <td>Point 126 127 128 129</td> <td>ALH84001_Ap3_trail_3 ALH84001_Ap3_trail_4 ALH84001_Ap3_trail_5 ALH84001_Ap3_trail_6</td> <td>MgO 3.432 3.377 3.399 3.490</td> <td>Al2O3 0.014 0.000 0.000 0.046</td> <td>0.028 0.028 0.031 0.011 0.036</td> <td>0.013 Ce2O3 0.046 0.062 0.062 0.058</td> <td>0.000 Nd2O3 0.000 0.000 0.000 0.135</td> <td>Total 100.547 100.609 100.592 99.833</td> <td>0.000 0=F,Cl 0.002 0.002 0.001 0.000</td> <td>-O=F2 0.000 0.000 0.000 0.000</td> <td>-O=Cl2 0.002 0.002 0.001 0.000</td> <td>Total recalc 100.545 100.607 100.591 99.833</td>	Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 126 127 128 129	ALH84001_Ap3_trail_3 ALH84001_Ap3_trail_4 ALH84001_Ap3_trail_5 ALH84001_Ap3_trail_6	MgO 3.432 3.377 3.399 3.490	Al2O3 0.014 0.000 0.000 0.046	0.028 0.028 0.031 0.011 0.036	0.013 Ce2O3 0.046 0.062 0.062 0.058	0.000 Nd2O3 0.000 0.000 0.000 0.135	Total 100.547 100.609 100.592 99.833	0.000 0=F,Cl 0.002 0.002 0.001 0.000	-O=F2 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001 0.000	Total recalc 100.545 100.607 100.591 99.833
Rice Uni. 142 ALH84001 Ap4 gray 6 3.446 0.000 0.002 0.002 0.000 0.002 1.002.65 Rice Uni. 144 ALH84001 Ap4 gray 8 3.368 0.025 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 99.97 Rice Uni. 145 ALH84001 Ap4 gray 9 3.408 0.040 0.042 0.035 0.016 9.958 0.000 <	Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 126 127 128 129 139	ALH84001_Ap3_trail_3 ALH84001_Ap3_trail_3 ALH84001_Ap3_trail_4 ALH84001_Ap3_trail_5 ALH84001_Ap3_trail_6 ALH84001_Ap3_trail_7	MgO 3.432 3.377 3.399 3.490 3.373	Al2O3 0.014 0.000 0.000 0.046 0.001	0.028 0.028 0.031 0.011 0.036 0.056	0.013 Ce2O3 0.046 0.062 0.062 0.058 0.047	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.135 0.000	Total 100.547 100.609 100.592 99.833 99.856	0.000 0=F,Cl 0.002 0.001 0.000 0.002	-O=F2 0.000 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001 0.000 0.000	Total recalc 100.545 100.607 100.591 99.833 99.854
Rice Uni. 143 ALH84001 Ap4 gray 7 3.416 0.031 0.042 0.035 0.021 0.000 0.000 0.001 99.997 Rice Uni. 145 ALH84001 Ap4 gray 9 3.408 0.042 0.035 0.000 99.558 0.000 0.000 99.558 Rice Uni. 145 ALH84001 Ap4 gray 10 3.449 0.052 0.000 0.025 99.558 0.000 0.000 0.000 0.000 99.558 Rice Uni. 147 ALH84001 Ap4 gray 11 3.466 0.004 0.028 0.078 0.113 100.616 0.004 0.000 0.001 0.002 97.932 Rice Uni. 148 ALH84001 Ap4 gray 12 3.409 0.016 0.085 0.040 0.102 101.213 0.000 0.000 0.004 0.313 100.371 0.002 0.000 100.355 0.000 0.000 0.054 0.210 100.035 0.000 0.000 100.35 0.000 0.000 100.35 0.000 0.000 100.3	Rice Uni. Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 126 127 128 129 139 140	ALI164001 Ap3_trail 2 Comment ALH84001 Ap3_trail 3 ALH84001 Ap3_trail 4 ALH84001 Ap3_trail 5 ALH84001 Ap3_trail 6 ALH84001 Ap4_gray 3 ALH84001 Ap4_gray 3 ALH84001 Ap4_gray 3	MgO 3.432 3.377 3.399 3.490 3.373 3.465	Al2O3 0.014 0.000 0.000 0.046 0.001 0.075	0.028 MnO 0.028 0.031 0.011 0.036 0.056 0.067	0.013 Ce2O3 0.046 0.062 0.062 0.058 0.047 0.000	0.000 Nd2O3 0.000 0.000 0.135 0.000 0.000	Total 100.590 Total 100.547 100.609 100.592 99.833 99.856 100.414	0.000 0=F,Cl 0.002 0.001 0.000 0.002 0.001	-O=F2 0.000 0.000 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001 0.000 0.002 0.001	Total recalc 100.545 100.607 100.591 99.833 99.854 100.413
Rice Uni. 144 ALH84001 Ap4 gray 8 3.568 0.002 0.003 9.43.5 0.001 0.000 0.001 99.43.2 Rice Uni. 146 ALH84001 Ap4 gray 10 3.449 0.052 0.002 0.9558 0.000 0.000 0.000 99.558 Rice Uni. 147 ALH84001 Ap4 gray 11 3.366 0.004 0.028 0.078 0.113 100.616 0.000 0.000 0.000 100.612 Rice Uni. 149 ALH84001 Ap4 gray 12 3.409 0.016 0.085 0.040 0.102 101.213 0.000 0.000 100.612 Rice Uni. 149 ALH84001 Ap5 1 3.427 0.007 0.018 0.098 0.286 100.355 0.000 0.000 100.35 0.000 100.35 0.000 100.35 0.000 100.35 0.000 100.35 0.000 1.002 1.0000 0.000 1.0035 0.000 1.0035 0.000 1.0035 0.000 1.00035 0.000 1.0035 0.	Rice Uni. Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	123 Point 126 127 128 129 139 140 142	ALH84001 Ap3 trail 2 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 3 ALH84001 Ap4 gray 4 3 ALH84001 Ap4 gray 4 3 ALH84001 Ap4 gray 4 3	MgO 3.432 3.377 3.399 3.490 3.373 3.465 3.446	0.009 Al2O3 0.014 0.000 0.000 0.046 0.001 0.075 0.000	0.028 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023	0.013 Ce2O3 0.046 0.062 0.062 0.058 0.047 0.000 0.070	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.135 0.000 0.000 0.000 0.000 0.000	Total 100.590 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265	0.000 0=F,Cl 0.002 0.001 0.000 0.002 0.001 0.002 0.001 0.002	-O=F2 0.000 0.000 0.000 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.001 0.000 0.000 0.002 0.001 0.002	Total recalc 100.545 100.607 100.591 99.833 99.854 100.413 100.263
Rice Uni. 145 ALH84001 Ap4 gray 9 3.408 0.040 0.042 0.042 0.042 99.538 0.000 0.000 99.538 Rice Uni. 147 ALH84001 Ap4 gray 10 3.366 0.004 0.025 0.0163 97.934 0.002 0.000 0.002 0.7932 Rice Uni. 147 ALH84001 Ap4 gray 12 3.409 0.016 0.085 0.040 0.113 100.616 0.004 0.000 0.000 0.000 0.000 0.001 107.612 Rice Uni. 148 ALH84001 Ap5 gray 12 3.409 0.016 0.088 0.040 0.113 100.616 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.000 0.000 0.001 0.002 0.000 0.000 0.001 0.002 0.000 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.	Rice Uni. Data Collection Rice Uni.	Point 126 127 128 129 139 140 142 143	ALH84001 Ap3 trail 2 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap4 trail 6 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 6 ALH84001 Ap4 gray 6 ALH84001 Ap4 gray 6	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.465 3.446 3.416 3.416	Al2O3 0.014 0.000 0.000 0.046 0.001 0.075 0.000 0.031	0.028 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042	0.013 Cc2O3 0.046 0.062 0.062 0.058 0.047 0.000 0.070 0.035	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.135 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251	Total 100.590 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 20.452	0.000 0=F,Cl 0.002 0.001 0.000 0.002 0.001 0.002 0.001 0.001	-O=F2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001 0.000 0.002 0.001 0.002 0.001 0.002	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 92.92
Rice Uni. 146 ALH84001 Ap4 gray 10 3.449 0.052 0.000 0.053 0.163 97.934 0.002 0.000 0.002 97.932 Rice Uni. 148 ALH84001 Ap4 gray 11 3.366 0.004 0.028 0.078 0.113 100.616 0.004 0.000 0.004 100.014 100.01 Rice Uni. 149 ALH84001 Ap5 gray 12 3.409 0.016 0.085 0.040 0.102 101.213 0.000 0.000 0.000 100.612 Rice Uni. 150 ALH84001 Ap5 gray 13 3.427 0.007 0.018 0.098 0.286 100.355 0.000 0.000 100.371 0.002 0.000 0.000 100.356 Rice Uni. 151 ALH8401 Ap5 3 3.361 0.000 0.002 0.001 0.003 0.001 0.000 0.001 0.003 0.000 0.000 0.000 0.000 0.000 0.001 0.000 0.001 0.000 0.001 0.0002 0.001 0.000	Acce Uni. Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 126 127 128 129 139 140 142 143 144	ALI184001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 trail 4 ALH84001 Ap3 trail 4 trail 4 trail 4 ALH84001 Ap3 trail 6 trail 4 trail 6 ALH84001 Ap4 gray 3 trail 6 trail 4 trail 4 trail 6 trail 4 trail 4 trail 6 trail 4 trail 6 trail 6 trail 4 4 trail 6 trail 4 trail 4 trail 4 <	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.465 3.446 3.416 3.468	0.009 Al2O3 0.014 0.000 0.000 0.046 0.001 0.075 0.000 0.031 0.025 0.046	0.028 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000	0.013 Cc2O3 0.046 0.062 0.062 0.058 0.047 0.000 0.070 0.035 0.035	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.135 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000	Total 100.590 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 99.453 20.550	0.000 0=F,Cl 0.002 0.001 0.000 0.002 0.001 0.002 0.001 0.001 0.001 0.001	-O=F2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001 0.000 0.002 0.001 0.002 0.001 0.002	100.050 Total recale 100.545 100.607 100.591 99.853 99.854 100.263 99.997 99.452
Rice Uni. 147 ALH84001 Ap4 gray 11 3.366 0.004 0.028 0.018 0.018 101.616 0.004 0.004 0.004 100.612 Rice Uni. 149 ALH84001 Ap5 gray 12 3.409 0.016 0.088 0.040 0.102 101.213 0.000 0.000 0.000 100.365 Rice Uni. 150 ALH84001 Ap5 1 3.427 0.007 0.018 0.098 0.286 100.365 0.000 0.000 100.355 Rice Uni. 151 ALH84001 Ap5 4 3.357 0.019 0.022 0.044 0.000 100.035 0.000 0.000 100.035 Rice Uni. 153 ALH84001 Ap5 5 3.404 0.001 0.003 0.010 0.000 99.816 0.001 0.000 0.001 0.000 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.001 0.001 0.000 0.001 0.000 0.001 0.001 0.000 0.001 0.000	Rice Uni. Rice Uni.	Point 126 127 128 129 139 140 142 143 144 145	ALH84001 Ap3 trail 2 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 6 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 8 ALH84001 Ap4 gray 8 ALH84001 Ap4 gray 8 ALH84001 Ap4 gray 8	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.465 3.446 3.416 3.368 3.408	0.009 Al2O3 0.014 0.000 0.000 0.046 0.001 0.075 0.000 0.031 0.025 0.040	0.028 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042	0.013 Ce2O3 0.046 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.030	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.025	Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 99.453 99.558 20.414	0.000 0=F,Cl 0.002 0.001 0.000 0.002 0.001 0.002 0.001 0.001 0.000 0.001 0.000	-O=F2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001 0.000 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.000 0.000	100.090 Total recalc 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 99.452 99.558
Rice Uni. 146 ALTROVID_APP gray 12 3.407 0.016 0.085 0.040 0.102 101.215 0.003 0.000 0.003 101.210 Rice Uni. 150 ALH84001 Ap5 1 3.427 0.007 0.018 0.098 0.286 100.355 0.000 0.000 100.355 Rice Uni. 151 ALH84001 Ap5 3 3.361 0.000 0.000 0.004 0.003 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001<	Data Collection Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni. Rice Uni.	Point 126 127 128 129 139 140 142 143 144 145 146	ALH84001 Ap3 trail 2 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 6 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.465 3.446 3.416 3.368 3.408 3.449	0.009 Al2O3 0.014 0.000 0.000 0.000 0.046 0.001 0.075 0.000 0.031 0.025 0.040 0.052 0.040	0.028 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.042	0.013 Cc2O3 0.046 0.062 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.035 0.035 0.053	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.025 0.163 0.112	Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.983 99.453 99.558 97.934	0.000 0=F,Cl 0.002 0.001 0.000 0.001 0.002 0.001 0.001 0.000 0.000 0.002 0.001	-O=F2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001 0.000 0.001 0.001 0.001 0.001 0.000 0.001 0.000 0.002 0.001	100.050 Total recale 100.545 100.607 100.591 99.833 99.854 100.263 99.997 99.452 99.558 97.932
Rice Uni. 147 ALL194001 Ap5 1 3.427 0.007 0.018 0.098 0.286 100.355 0.000 0.000 0.000 100.365 Rice Uni. 151 ALH84001 Ap5 3 3.361 0.000 0.000 0.0313 100.355 0.000	Data Collection Rice Uni. Rice Uni.	Point 126 127 128 129 139 140 142 143 144 145 146 147	ALH84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 trail 3 ALH84001 Ap3 trail 4 trail 4 ALH84001 Ap3 trail 5 trail 6 ALH84001 Ap4 gray 3 aLH84001 Ap4 gray 4 ALH84001 Ap4 gray 6 ALH84001 Ap4 gray 6 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 11	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.465 3.446 3.416 3.368 3.408 3.449 3.366 3.409	0.009 Al2O3 0.014 0.000 0.000 0.046 0.001 0.075 0.000 0.031 0.025 0.040 0.052 0.004 0.052 0.004 0.051	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.028 0.0295	0.013 Cc2O3 0.046 0.062 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.035 0.035 0.030 0.053 0.078 0.078	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.135 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.025 0.163 0.113	Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.985 99.453 99.558 97.934 100.616	0.000 0=F,Cl 0.002 0.001 0.000 0.001 0.002 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	-O=F2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001 0.000 0.002 0.001 0.001 0.000 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	100.090 Total recalc 100.545 100.607 100.591 99.853 99.854 100.413 100.263 99.9558 97.932 100.612
Rice Uni. 150 ALH84001 Ap5 2 3-8-0 0.000 0.004 0.044 0.044 0.013 100.371 0.002 0.000 0.000 100.350 Rice Uni. 152 ALH84001 Ap5 4 3.357 0.019 0.022 0.048 0.000 100.035 0.000 0.001 100.035 0.000 0.000 0.001 0.001 0.002 99.816 0.001 0.000 0.002 99.814 Rice Uni. 155 ALH84001 Ap5 6 3.402 0.000 0.058 0.083 0.000 100.128 0.001 0.000 0.001 100.177 Rice Uni. 156 ALH84001 Ap5 8 3.461 0.000 0.052 0.031 0.025 0.000 100.142 0.000 0.000 100.257 0.031 0.0046	Data Collection Rice Uni. Rice Uni.	Point 126 127 128 129 139 140 142 143 144 145 146 147 148	ALH84001 Ap3 trail 2 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 6 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 1 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 11 ALH84001 Ap4 gray 12	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.465 3.446 3.446 3.368 3.408 3.449 3.366 3.408 3.449	0.009 Al2O3 0.014 0.000 0.0046 0.001 0.075 0.000 0.031 0.025 0.0040 0.052 0.0040 0.052 0.0040 0.016 0.027	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.004 0.042 0.000 0.042 0.000 0.028 0.028 0.028	0.013 Ce2O3 0.046 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.035 0.035 0.035 0.030 0.053 0.070	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.135 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.025 0.163 0.113 0.102 0.296	Total 100.547 100.592 99.833 99.856 100.265 99.998 99.453 99.558 97.934 100.616 101.213	0.000 0=F,Cl 0.002 0.001 0.000 0.002 0.001 0.002 0.001 0.001 0.000 0.002 0.001 0.000 0.002 0.004 0.003 0.003	-O=F2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	-O=Cl2 0.002 0.002 0.001 0.000 0.002 0.001 0.001 0.001 0.001 0.000 0.002 0.001 0.000 0.002 0.001 0.000 0.002 0.001 0.000 0.002 0.000 0.002 0.000 0.002 0.002 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	100.050 Total recale 100.545 100.607 100.591 99.853 99.854 100.263 99.997 99.452 99.558 97.932 100.612 100.265
Rice Uni. 151 ALListouri Ap3 3 3.301 0.000 0.001 0.000 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.001 <td>Nice Uni. Rice Uni.</td> <td>Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149</td> <td>ALI184001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 11 ALH84001 Ap4 gray 12 ALH84001 Ap5 1</td> <td>3.414 MgO 3.432 3.377 3.399 3.490 3.377 3.399 3.490 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.466 3.440 3.366 3.409 3.427 2.450</td> <td>0.009 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.001 0.075 0.000 0.031 0.025 0.040 0.052 0.004 0.016 0.007</td> <td>0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.057 0.023 0.042 0.000 0.042 0.000 0.028 0.008 0.085 0.018</td> <td>0.013 0.046 0.046 0.062 0.058 0.047 0.040 0.003 0.035 0.035 0.035 0.035 0.035 0.030 0.078 0.040 0.098 0.040</td> <td>0.000 Nd2O3 0.000 0.000 0.135 0.000 0.251 0.000 0.251 0.000 0.251 0.163 0.113 0.113 0.112</td> <td>100.099 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 99.453 99.558 97.934 100.616 101.213 100.365</td> <td>0.000 0=F,Cl 0.002 0.001 0.000 0.001 0.000 0.001 0.001 0.001 0.000 0.001 0.000 0.000 0.000 0.000 0.002 0.001 0.002 0.0000 0.00000 0.00000 0.0000 0.0000 0.00</td> <td>-O=F2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000</td> <td>0.000 -O=C12 0.002 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.002 0.001 0.002 0.004 0.003 0.002</td> <td>100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.263 99.997 99.452 99.558 97.932 100.612 101.210 100.365</td>	Nice Uni. Rice Uni.	Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149	ALI184001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 11 ALH84001 Ap4 gray 12 ALH84001 Ap5 1	3.414 MgO 3.432 3.377 3.399 3.490 3.377 3.399 3.490 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.466 3.440 3.366 3.409 3.427 2.450	0.009 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.001 0.075 0.000 0.031 0.025 0.040 0.052 0.004 0.016 0.007	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.057 0.023 0.042 0.000 0.042 0.000 0.028 0.008 0.085 0.018	0.013 0.046 0.046 0.062 0.058 0.047 0.040 0.003 0.035 0.035 0.035 0.035 0.035 0.030 0.078 0.040 0.098 0.040	0.000 Nd2O3 0.000 0.000 0.135 0.000 0.251 0.000 0.251 0.000 0.251 0.163 0.113 0.113 0.112	100.099 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 99.453 99.558 97.934 100.616 101.213 100.365	0.000 0=F,Cl 0.002 0.001 0.000 0.001 0.000 0.001 0.001 0.001 0.000 0.001 0.000 0.000 0.000 0.000 0.002 0.001 0.002 0.0000 0.00000 0.00000 0.0000 0.0000 0.00	-O=F2 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	0.000 -O=C12 0.002 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.002 0.001 0.002 0.004 0.003 0.002	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.263 99.997 99.452 99.558 97.932 100.612 101.210 100.365
Rice Uni. 152 ALLibroid ApJ 4 3.337 0.017 0.002 0.000 100.092 0.001 100.092 Rice Uni. 153 ALH84001 Ap5 5 3.404 0.001 0.002 0.000 100.092 0.001 100.092 Rice Uni. 154 ALH84001 Ap5 6 3.402 0.000 0.058 0.083 0.000 100.128 0.001 0.000 0.002 0.000 0.001 100.092 9.814 Rice Uni. 155 ALH84001 Ap5 8 3.461 0.000 0.058 0.018 10.0250 0.000 0.000 0.000 100.250 Rice Uni. 157 ALH8401 Ap5 8 3.461 0.000 0.043 0.046 0.000 101.155 0.000 0.000 100.4250 0.000 0.000 100.250 Rice Uni. 158 ALH8401 Ap6 1 3.433 0.000 0.042 0.063 0.035 100.446 0.000 0.000 100.442 Rice Uni. 160 ALH8401 Ap6 3 3.4445	Data Collection Rice Uni. Rice Uni.	Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149 150 151	ALH84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 atall 3 ALH84001 Ap3 trail 5 atall 3 3 atall 3 atall 3 atall 3 3 3 3 <	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.465 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.440 3.449 3.469 3.427 3.427 3.421	0.009 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.075 0.000 0.031 0.025 0.040 0.052 0.040 0.016 0.016 0.007 0.000	MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.0085 0.018 0.044	0.013 0.046 0.046 0.062 0.062 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.030 0.053 0.040 0.098 0.040 0.054	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.025 0.163 0.102 0.286 0.313	100.590 Total 100.547 100.547 100.592 99.836 100.414 100.265 99.955 97.934 100.616 101.213 100.365 100.371	0.000 0.002 0.002 0.001 0.000 0.001 0.000 0.001 0.001 0.001 0.001 0.000 0.001 0.000 0.002 0.004 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.002 0.004 0.002 0.	-O=F2 0.0000 0.00000 0.00000 0.00000 0.00000 0.000000 0.00000000	-0-000 -0-C12 0.002 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.000 0.001 0.000 0.001 0.000 0.002 0.001 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.0000 0.00000 0.0000 0.0000 0.0000 0.00000 0.00000 0.000	100.050 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 99.452 99.558 97.932 100.612 101.210 100.365 100.365
Rice Uni. 155 ALH84001 Ap5 3 3-004 0.001 0.003 0.010 0.000 99.816 0.002 0.000 0.002 99.814 Rice Uni. 155 ALH84001 Ap5 6 3.402 0.000 0.003 0.000 100.128 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 100.0127 Rice Uni. 156 ALH84001 Ap5 8 3.461 0.000 0.058 0.128 100.250 0.000 0.000 100.250 Rice Uni. 157 ALH84001 Ap6 1 3.433 0.000 0.022 0.031 0.000 101.165 0.000 0.000 100.442 Rice Uni. 158 ALH84001 Ap6 3 3.445 0.000 0.031 0.035 100.446 0.000 0.000 100.442 Rice Uni. 163 ALH84001 Ap6 7 3.442 0.000 0.031 0.033 0.000 101.14 0.000 0.000 10	Data Collection Rice Uni. Rice Uni.	123 Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149 150 151	ALH84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 11 ALH84001 Ap4 gray 11 ALH84001 Ap5 1 ALH84001 Ap5 2 ALH84001 Ap5 3 ALH84001 Ap5 3 ALH84001	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.465 3.446 3.446 3.446 3.446 3.465 3.446 3.465 3.446 3.465 3.446 3.465 3.446 3.465 3.446 3.465 3.446 3.465 3.446 3.446 3.449 3.469 3.427 3.450 3.361 3.351	0.000 AI2O3 0.014 0.000 0.000 0.046 0.001 0.075 0.000 0.001 0.025 0.040 0.052 0.040 0.052 0.004 0.016 0.007 0.000 0.000 0.000	MnO 0.028 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.018 0.044 0.002	0.013 Ce203 0.046 0.062 0.062 0.062 0.047 0.000 0.070 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.040 0.058 0.040	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.025 0.163 0.113 0.102 0.286 0.286 0.286 0.286	100.590 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 97.934 100.616 101.213 100.351 100.351	0.000 0.002 0.002 0.001 0.000 0.000 0.000 0.001 0.000 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.002		0.000 -O-C12 0.002 0.001 0.000 0.000 0.000 0.001 0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.0000 0.00000 0.00000 0.0000 0.0000 0.0000000 0.00000 0.00000000	100.090 Total recalc 100.545 100.607 100.591 99.853 99.854 100.413 100.263 99.997 99.452 99.558 97.932 100.612 100.365 100.365 100.365 100.035
Rice Uni. 157 ALLISTON ApJ 0 3-802 0.000 0.038 0.038 0.000 100.128 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.000 0.001 0.000 0.001 0.000 0.001 0.000 0.001 0.001 0.000 <td>Nice Uni. Rice Vi. Rice Vi. Rice Vi. Rice Vi. Rice Vi. Rice</td> <td>123 Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149 150 151 152</td> <td>ALH84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 trail 6 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 ALH84001 Ap5 1 ALH84001 Ap5 3 ALH84001 Ap5 3 ALH84001 Ap5 4</td> <td>3.414 MgO 3.432 3.377 3.399 3.400 3.373 3.465 3.446 3.368 3.416 3.368 3.408 3.446 3.366 3.409 3.429 3.366 3.409 3.420 3.361 3.361 3.357</td> <td>0.009 Al2O3 0.014 0.000 0.000 0.046 0.001 0.075 0.000 0.031 0.025 0.040 0.052 0.040 0.052 0.004 0.016 0.007 0.000 0.000 0.000 0.000</td> <td>0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.028 0.085 0.018 0.024 0.000 0.024</td> <td>0.013 Cc2O3 0.046 0.062 0.062 0.058 0.047 0.000 0.075 0.035 0.035 0.035 0.035 0.035 0.078 0.040 0.054 0.040</td> <td>0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.251 0.000 0.251 0.163 0.113 0.112 0.163 0.113 0.102 0.210 0.020</td> <td>100.690 Total 100.547 100.609 100.592 99.835 100.414 100.265 99.9853 99.558 97.934 100.616 101.213 100.365 100.311 100.325</td> <td>0.000 0.002 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.000 0.000 0.002 0.000 0.002 0.000 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.002 0.001 0.002 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.0000 0.00000 0.0000 0.0000 0.0000 0.00000 0.00000 0.00000 0.000</td> <td>0=F2 0.000</td> <td>0.000 -O-C12 0.002 0.001 0.000 0.000 0.000 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000000</td> <td>100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 99.452 99.358 97.332 100.612 101.210 100.365 100.355 100.035 100.035</td>	Nice Uni. Rice Vi. Rice Vi. Rice Vi. Rice Vi. Rice Vi. Rice	123 Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149 150 151 152	ALH84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 trail 6 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 ALH84001 Ap5 1 ALH84001 Ap5 3 ALH84001 Ap5 3 ALH84001 Ap5 4	3.414 MgO 3.432 3.377 3.399 3.400 3.373 3.465 3.446 3.368 3.416 3.368 3.408 3.446 3.366 3.409 3.429 3.366 3.409 3.420 3.361 3.361 3.357	0.009 Al2O3 0.014 0.000 0.000 0.046 0.001 0.075 0.000 0.031 0.025 0.040 0.052 0.040 0.052 0.004 0.016 0.007 0.000 0.000 0.000 0.000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.028 0.085 0.018 0.024 0.000 0.024	0.013 Cc2O3 0.046 0.062 0.062 0.058 0.047 0.000 0.075 0.035 0.035 0.035 0.035 0.035 0.078 0.040 0.054 0.040	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.251 0.000 0.251 0.163 0.113 0.112 0.163 0.113 0.102 0.210 0.020	100.690 Total 100.547 100.609 100.592 99.835 100.414 100.265 99.9853 99.558 97.934 100.616 101.213 100.365 100.311 100.325	0.000 0.002 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.000 0.000 0.002 0.000 0.002 0.000 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.002 0.001 0.002 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.0000 0.00000 0.0000 0.0000 0.0000 0.00000 0.00000 0.00000 0.000	0=F2 0.000	0.000 -O-C12 0.002 0.001 0.000 0.000 0.000 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.002 0.002 0.001 0.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000000	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 99.452 99.358 97.332 100.612 101.210 100.365 100.355 100.035 100.035
Rice Uni. 153 ALH84001 Ap5 / 3.533 0.017 0.0000 0.0015 0.0001 0.0011 0.0000 0.0011 0.0000 0.0011 0.0000 0.0011 0.0001 0.0011 0.0001 0.0011 0.0001 0	Data Collection Rice Uni. Rice Uni.	123 Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149 150 151 152 153 154	ALH84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 atal 3 ALH84001 Ap3 trail 5 atal 3 ALH84001 Ap3 trail 5 atal 3 a	3.414 MgO 3.432 3.377 3.399 3.446 3.445 3.446 3.449 3.427 3.450 3.357 3.404 3.402	0.003 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.075 0.000 0.031 0.025 0.004 0.052 0.004 0.016 0.007 0.000 0.001 0.001 0.000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.028 0.018 0.044 0.000 0.022 0.003	0.013 Ce203 0.046 0.062 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.035 0.035 0.035 0.035 0.030 0.053 0.040 0.040 0.040 0.044 0.044 0.048	0.000 Nd203 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.025 0.163 0.113 0.002 0.226 0.313 0.200 0.028 0.313 0.210 0.000	100.590 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 99.453 99.558 97.934 100.616 100.213 100.365 100.371 100.033 100.093 99.816 100.093 100.191 100.191 100.591 100.592 100.265 100.265 100.0371 100.093 100.095 100.095 100.095 100.095 100.095 100.095 100.095 100.095 100.095 10	0.000 0.000 0.002 0.001 0.000 0.000 0.000 0.001 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	0.000 -O=F2 0.000	0.000 -O-Cl2 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.002 0.001 0.002 0.001 0.002 0.004 0.003 0.000 0.001 0.001 0.001	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 99.452 99.558 97.932 100.612 100.365 100.365 100.035 100.035 100.02 99.814 100.727
Rice Uni. 150 ALH84001 ApC 3.401 0.000 0.003 0.003 0.002 0.000	Data Collection Rice Uni. Rice Uni.	123 Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149 150 151 152 153 154	ALH84001 Apj tail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 ALH84001 Ap5 1 ALH84001 Ap5 2 ALH84001 Ap5 3 ALH84001 Ap5 5 ALH84001 Ap5 5 ALH84001 Ap5 5	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.449 3.368 3.449 3.366 3.449 3.449 3.366 3.449 3.366 3.449 3.366 3.449 3.366 3.449 3.449 3.366 3.449 3.366 3.449 3.366 3.449 3.449 3.366 3.449 3.366 3.449 3.449 3.367 3.449 3.367 3.449 3.449 3.367 3.490 3.4000 3.4000 3.400 3.400 3.400 3.400 3.400 3.	0.003 Al2O3 0.014 0.000 0.000 0.000 0.0046 0.0046 0.0046 0.0046 0.0046 0.001 0.075 0.000 0.031 0.025 0.004 0.016 0.007 0.001 0.001 0.001	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.028 0.042 0.000 0.028 0.085 0.018 0.044 0.000 0.022 0.003 0.058	0.013 Cc203 0.046 0.062 0.062 0.063 0.047 0.000 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.040 0.054 0.040 0.044 0.044 0.044 0.044 0.044 0.044 0.044 0.044 0.044 0.044 0.044 0.044	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.025 0.113 0.102 0.286 0.313 0.210 0.000 0.000 0.000 0.000 0.000	100.590 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 99.453 99.558 97.934 100.616 101.213 100.365 100.371 100.035 100.371 100.035 100.035 100.035 100.031 100.035	0.000 0.002 0.002 0.001 0.000 0.000 0.000 0.002 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.000 0.002 0.000 0.002 0.000 0.002 0.000 0.002 0.0000 0.00000 0.0000 0.0000 0.0000000 0.00000 0.00000000	0.000 -O=F2 0.000	0.0002 -O-Cl2 0.002 0.001 0.001 0.000 0.001 0.002 0.001 0.002 0.001 0.002 0.004 0.002 0.004 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002 0.002 0.001 0.002 0.002 0.002 0.002 0.002 0.002 0.000 0.002 0.000 0.002 0.000 0.002 0.000 0.002 0.000 0.002 0.000 0.002 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0000 0.0000 0.0000 0.00000 0.00000 0.000	100.090 Total recalc 100.545 100.607 100.591 99.853 99.854 100.413 100.263 99.9558 97.932 100.612 100.365 100.365 100.035 100.035 100.022 99.814 100.127 100.000
Rice Uni. 157 ALH84001 Ap6 1 3.433 0.000 0.003 0.000 101.103 0.000 0.000 101.103 Rice Uni. 158 ALH84001 Ap6 1 3.439 0.000 0.025 0.031 0.000 100.442 0.000 0.000 100.442 Rice Uni. 159 ALH84001 Ap6 3 3.445 0.000 0.025 0.031 0.000 100.442 0.000 0.000 100.442 Rice Uni. 160 ALH84001 Ap6 4 3.438 0.000 0.031 0.055 0.000 101.144 0.000 0.000 100.442 Rice Uni. 163 ALH84001 Ap6 7 3.442 0.000 0.031 0.033 0.000 101.70 0.000 0.000 0.000 100.70 Rice Uni. 164 ALH84001 Ap6 8 3.423 0.000 0.021 0.027 0.144 100.367 0.000 0.000 100.367 Rice Uni. 165 ALH84001 Ap6 9 3.407 0.006 0.042 0.010	Nice Uni. Rice Uni.	123 Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149 150 151 152 153 154 155	ALII64001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 11 ALH84001 Ap5 1 ALH84001 Ap5 3 ALH84001 Ap5 3 ALH84001 Ap5 4 ALH84001 Ap5 6 ALH84001 Ap5	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.446 3.446 3.446 3.446 3.446 3.448 3.449 3.449 3.449 3.449 3.449 3.449 3.449 3.449 3.449 3.449 3.440 3.449 3.440 3.400 3.440 3.400 3.440 3.400 3.400 3.401 3.400 3.401 3.400 3.401 3.402 3.402 3.402 3.402 3.402 3.402 3.402 3.402 3.401 3.402 3.402 3.401 3.402 3.402 3.401 3.402 3.401 3.402 3.401 3.402 3.401 3.402 3.401 3.402 3.401 3.401 3.402 3.401 3.401 3.402 3.401 3.401 3.402 3.401 3.401 3.401 3.402 3.401 3.401 3.401 3.402 3.401 3.401 3.401 3.401 3.401 3.402 3.4011 3.401 3.4	0.003 0.014 0.000 0.000 0.000 0.000 0.000 0.046 0.001 0.075 0.000 0.031 0.025 0.0040 0.040 0.052 0.000 0.016 0.000 0.019 0.000 0.017	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.028 0.042 0.000 0.028 0.018 0.000 0.022 0.003 0.058 0.058 0.058 0.059	0.013 Ce203 0.046 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.035 0.035 0.030 0.035 0.030 0.035 0.040 0.040 0.040 0.054 0.054 0.054 0.048 0.0054 0.0054 0.0054 0.0054 0.0054 0.0054 0.0054 0.0054 0.0054 0.0054 0.0054 0.0055 0.0055 0.0055 0.00570000000000	0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.025 0.163 0.102 0.286 0.313 0.102 0.286 0.210 0.000	100.591 Total 100.547 100.609 100.547 100.609 100.547 100.592 99.833 99.836 100.414 100.265 99.998 99.453 99.558 97.934 100.610 100.365 100.375 100.375 100.375 100.365 100.316 100.355 100.316 100.355 100.316 100.355 100.316 100.355 100.316 100.355 100.316 10	0.000 0.002 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.0000 0.00000 0.0000 0.0000 0.0000 0.00000 0.00000 0.00000 0.00000000	0.000 -O=F2 0.000	0.000 0.002 0.002 0.001 0.000 0.000 0.000 0.001 0.0000 0.00000 0.0000 0.0000 0.00000000	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 99.452 99.358 97.332 100.612 101.210 100.365 100.035 100.035 100.022 99.814 100.127 100.026
Rice Uni. 150 ALH84001 Ap6 2 3.425 0.000 0.021 0.035 100.442 0.000 0.000 100.442 Rice Uni. 160 ALH84001 Ap6 4 3.435 0.000 0.021 0.035 100.446 0.000 0.000 0.000 0.000 100.442 Rice Uni. 160 ALH84001 Ap6 4 3.438 0.000 0.035 100.446 0.000 0.000 100.446 Rice Uni. 163 ALH84001 Ap6 8 3.424 0.000 0.027 0.144 10.0367 0.000 0.000 101.70 Rice Uni. 164 ALH84001 Ap6 8 3.423 0.000 0.027 0.144 100.367 0.000 100.367 Rice Uni. 165 ALH8401 Ap6 9 3.407 0.006 0.042 0.010 0.108 100.272 0.002 0.000 100.367 Rice Uni. 166 ALH8401 Ap7 1 3.394 0.000 0.025 0.058 0.000 0.000 100.632 Rice Uni.	Data Collection Rice Uni. Rice Uni.	125 Point 126 127 128 129 139 142 143 144 145 147 148 149 150 151 153 154 155 156	ALH84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 ALH84001 Ap5 1 ALH84001 Ap5 1 ALH84001 Ap5 3 ALH84001 Ap5 4 ALH84001 Ap5 6 ALH84001 Ap5 7 ALH84001 Ap	3.414 MgO 3.432 3.377 3.399 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.440 3.427 3.361 3.357 3.404 3.401 3.393 3.461	0.003 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.075 0.001 0.075 0.001 0.075 0.001 0.075 0.004 0.052 0.004 0.016 0.000 0.000 0.000 0.019 0.0001 0.000 0.017 0.000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.028 0.018 0.018 0.003 0.022 0.003 0.058 0.000 0.050	0.013 Ce203 0.046 0.062 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.035 0.035 0.035 0.040 0.098 0.040 0.098 0.040 0.058 0.040 0.053 0.040 0.058 0.053 0.040 0.058 0.053 0.040 0.058 0.053 0.055 0.	0.000 Nd2O3 0.000 0.000 0.000 0.135 0.000 0.251 0.000 0.251 0.000 0.2251 0.163 0.113 0.226 0.313 0.220 0.226 0.313 0.220 0.000 0.0251 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.000000	100.590 Total 100.547 100.609 100.597 100.699 99.833 99.856 100.414 100.265 99.998 97.934 100.616 101.213 100.365 100.371 100.365 100.093 99.816 100.128 100.0128 100	0.000 0.000 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.002 0.001 0.000 0.002 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000000	0.000 -O=F2 0.000	0.0002 -O=Cl2 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.001 0.001 0.002 0.001 0.002 0.004 0.003 0.0001 0.0001 0.001 0.001 0.001 0.001	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.957 99.452 99.558 97.932 100.612 100.365 100.365 100.035 100.023 99.814 100.127 100.009 100.250 101.165
Rice Uni. 160 ALH84001 Ap6 3.443 0.000 0.032 0.033 100.740 0.000 0.000 100.740 Rice Uni. 163 ALH84001 Ap6 4 3.438 0.000 0.031 0.059 0.000 101.114 0.000 0.000 0.000 101.112 Rice Uni. 163 ALH84001 Ap6 3.424 0.000 0.021 0.027 0.144 100.367 0.000 0.000 101.070 0.000 100.770 Rice Uni. 164 ALH84001 Ap6 3.423 0.000 0.021 0.027 0.144 100.367 0.000 0.000 100.367 Rice Uni. 165 ALH84001 Ap6 3.407 0.006 0.042 0.010 0.108 100.272 0.002 0.000 100.367 Rice Uni. 166 ALH84001 Ap7 1 3.394 0.000 0.025 0.058 0.000 100.663 0.000 0.000 100.852 Rice Uni. 168 ALH84001 Ap7 2 3.415 0.0	Data Collection Rice Uni. Rice Uni.	125 Point 126 127 128 129 139 142 143 144 145 144 145 150 151 152 153 154 155 156 157 158	ALH84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 6 ALH84001 Ap4 gray 6 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 11 ALH84001 Ap5 1 ALH84001 Ap5 1 ALH84001 Ap5 2 ALH84001 Ap5 2 ALH84001 Ap5 4 ALH84001 Ap5 5 ALH84001 Ap5 5	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.449 3.368 3.449 3.346 3.449 3.346 3.427 3.450 3.427 3.450 3.427 3.450 3.427 3.450 3.427 3.327 3.427 3.327 3.427 3.327 3.327 3.427 3.327 3.327 3.327 3.327 3.327 3.327 3.327 3.327 3.327 3.327 3.327 3.327 3.327 3.327 3.327 3.461 3.327 3.409 3.40	0.009 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.004 0.016 0.001 0.000 0.001 0.000 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.028 0.018 0.018 0.002 0.003 0.025 0.003 0.058 0.050 0.043	0.013 Cc203 0.046 0.062 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.035 0.035 0.035 0.035 0.040 0.098 0.040 0.054 0.040 0.054 0.046 0.054 0.046 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.055 0.	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.025 0.113 0.126 0.313 0.210 0.000 0.000 0.000 0.000 0.006 0.128 0.0000	100.591 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 99.453 99.9558 97.934 100.616 101.213 100.365 100.371 100.035 100.371 100.035 100.035 100.035 100.281 100.250 101.165 100.443 100.250 100.445 100.547 100.592 100.605 100.245 100.265 100.265 100.215 100.255 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.125 100.055 100.125 100.125 100.125 100.125 100.125 100.125 100.455 100.455 100.255 100.455 1	0.000 0.002 0.002 0.001 0.000 0.000 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.0000000 0.00000000		0.000 0.002 0.002 0.001 0.001 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000	100.090 Total recalc 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.958 97.932 100.612 101.210 100.365 100.035 100.092 99.814 100.250 100.1250 100.165
Rice Uni. 163 ALH84001 ApC 3.424 0.000 0.071 0.032 0.000 101.112 Rice Uni. 164 ALH84001 ApC 3.424 0.000 0.031 0.030 101.117 0.002 0.000 0.002 101.112 Rice Uni. 164 ALH84001 ApC 3.423 0.000 0.021 0.027 0.144 100.367 0.000 0.000 100.000 0.000 100.000 0.000 100.367 Rice Uni. 165 ALH8401 ApC 9 3.407 0.006 0.042 0.010 0.108 100.272 0.000 0.000 100.367 Rice Uni. 166 ALH84001 ApC 1 3.442 0.000 0.012 0.044 0.000 100.663 0.002 0.000 100.270 Rice Uni. 167 ALH84001 Ap7 1 3.394 0.000 0.022 0.058 0.000 100.852 0.000 100.0852 0.000 100.0852 0.000 100.377 Rice Uni. 168 ALH84001 Ap7 2	Nice Uni. Rice Uni. Ri	125 Point 126 127 128 129 139 140 142 143 144 145 146 147 148 149 150 151 152 153 156 157 158	ALII04001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 1 ALH84001 Ap4 gray 1 ALH84001 Ap4 gray 1 ALH84001 Ap5 1 ALH84001 ALH84001 Ap5 3 ALH84001 ALH84001 Ap5 4 ALH84001 ALH84001 Ap5 6 ALH84001 ALH84001 Ap5 6 ALH84001 ALH84001	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.449 3.368 3.449 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.340 3.440 3.440 3.361 3.357 3.440 3.361 3.361 3.361 3.361 3.402 3.393 3.440 3.44	0.003 0.014 0.000 0.000 0.000 0.000 0.001 0.002 0.0031 0.025 0.040 0.016 0.007 0.000 0.016 0.000 0.019 0.000 0.017 0.000 0.000 0.000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.028 0.018 0.040 0.000 0.058 0.0058 0.043 0.025	0.013 Ce203 0.046 0.062 0.062 0.058 0.047 0.000 0.070 0.035 0.035 0.035 0.030 0.035 0.030 0.035 0.040 0.040 0.098 0.040 0.054 0.048 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.055 0.055 0.055 0.040 0.055 0.	0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.025 0.163 0.000 0.025 0.163 0.102 0.286 0.210 0.000	100.591 Total 100.547 100.609 100.547 100.609 100.547 100.592 99.833 99.836 100.414 100.265 99.998 99.9558 97.934 100.616 101.213 100.365 100.365 100.375 100.375 100.375 100.309 100.365 100.316 100.316 100.325 100.325 100.325 100.325 100.325 100.325 100.325 100.316 100.325 100.422 100.442	0.000 0.002 0.002 0.001 0.000 0.001 0.001 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.00000 0.000000 0.000000 0.00000000	0.000 -O=F2 0.000	0.000 0.002 0.002 0.001 0.000 0.000 0.000 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.00000 0.00	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.263 99.997 99.452 99.558 97.932 100.612 101.210 100.365 100.035 100.035 100.025 99.814 100.127 100.250 101.165 100.446
Rice Uni. 165 AL1104001 Ap6 1 3.747 0.000 0.017 0.002 101.070 0.000 0.000 101.070 Rice Uni. 165 AL184001 Ap6 8 3.423 0.000 0.021 0.027 0.144 100.367 0.000 0.000 0.000 100.367 Rice Uni. 165 AL184001 Ap6 9 3.407 0.006 0.042 0.010 0.108 100.272 0.002 0.000 0.000 100.367 Rice Uni. 166 AL184001 Ap6 10 3.462 0.000 0.012 0.044 0.000 100.633 0.000 100.637 100.637 100.637 100.637 100.637 100.637 100.637 100.637 100.631 100.377 100.641 100.352 0.000 100.852 100.000 100.852 100.000 100.377 100.852 100.000 100.377 Rice Uni. 168 AL184001 Ap7 2 3.415 0.016 0.033 0.0021 0.138 100.799 0.000 0.000 100.377 Rice Uni.<	Data Collection Rice Uni. Rice Uni.	125 Point 126 127 128 129 129 129 129 129 129 129 129 129 129 120 121 122 139 140 142 143 144 145 144 145 144 145 150 151 152 153 154 155 156 157 158 159	ALII84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 ALH84001 Ap5 2 ALH84001 Ap5 3 ALH84001 Ap5 5 ALH84001	3.414 MgO 3.432 3.377 3.399 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.440 3.361 3.357 3.401 3.393 3.461 3.499 3.445 3.445	0.003 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.005 0.001 0.005 0.001 0.005 0.001 0.016 0.004 0.052 0.004 0.016 0.000 0.019 0.001 0.000 0.017 0.000 0.000 0.000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.023 0.042 0.000 0.028 0.000 0.028 0.0018 0.0028 0.003 0.0058 0.0050 0.042 0.000 0.0550 0.042 0.0042	$\begin{array}{c} 0.013\\ \hline 0.0203\\ \hline 0.046\\ 0.062\\ 0.062\\ 0.058\\ 0.047\\ \hline 0.000\\ 0.035\\ 0.047\\ 0.000\\ 0.035\\ 0.035\\ 0.035\\ 0.035\\ 0.035\\ 0.035\\ 0.035\\ 0.040\\ 0.098\\ 0.040\\ 0.098\\ 0.040\\ 0.058\\ 0.048\\ 0.015\\ 0.058\\ 0.046\\ 0.031\\ 0.063\\ 0.058\\ 0.066\\ 0.031\\ 0.066\\ 0.031\\ 0.065\\ 0.058\\ 0.066\\ 0.031\\ 0.065\\ 0.058\\ 0.066\\ 0.031\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.066\\ 0.031\\ 0.065\\ 0.058\\ 0.058\\ 0.066\\ 0.031\\ 0.065\\ 0.058\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.058\\ 0.065\\ 0.005\\ 0.$	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.002 0.163 0.102 0.286 0.313 0.210 0.000 0.000 0.000 0.000 0.068 0.128 0.000 0.000 0.000	100.590 Total 100.547 100.609 100.547 100.609 100.547 100.609 100.414 100.265 99.998 99.9558 97.934 100.616 101.213 100.365 100.0371 100.035 100.093 99.816 100.010 100.250 101.165 100.442 100.442 100.446 101.114	0.000 0.000 0.002 0.000	0.000 -O=F2 0.000	0.0002 -O=Cl2 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.002 0.003 0.004 0.0001 0.0001 0.0001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.000 0.000	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.263 99.977 99.452 99.558 97.932 100.612 101.120 100.365 100.035 100.035 100.092 99.814 100.127 100.009 100.250 101.165 100.442 100.442 100.442
Rice Uni. 165 ALH84001 Ap6 9 3.407 0.006 0.041 0.021 0.0107 0.000 0.000 0.000 100.307 Rice Uni. 166 ALH84001 Ap6 10 3.462 0.000 0.012 0.014 0.0100 100.272 0.000 0.000 0.002 100.270 Rice Uni. 166 ALH84001 Ap7 1 3.342 0.000 0.025 0.058 0.000 100.822 0.000 0.000 100.270 Rice Uni. 167 ALH84001 Ap7 1 3.394 0.000 0.025 0.058 0.000 100.822 0.000 0.000 100.852 Rice Uni. 168 ALH84001 Ap7 2 3.415 0.016 0.033 0.000 0.143 100.377 0.000 0.000 100.377 Rice Uni. 169 ALH84001 Ap7 3 3.393 0.009 0.033 0.021 0.138 100.379 0.000 0.000 100.799 Rice Uni. 170 ALH84001 Ap7 4 3.374 0.000 0.044	Data Collection Rice Uni. Rice Uni.	125 Point 126 127 128 129 129 140 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160	ALH84001 Apj tail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 ALH84001 Ap5 1 ALH84001 Ap5 2 ALH84001 Ap5 5 ALH84001 Ap5 2 ALH84001 Ap5 7 ALH84001 Ap5 8	3.414 MgO 3.432 3.377 3.399 3.446 3.473 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.449 3.446 3.449 3.445 3.445 3.450 3.451 3.452 3.450 3.451 3.452 3.450 3.451 3.450 3.461 3.499 3.445 3.445 3.445 3.445	0.009 Al2O3 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.0046 0.001 0.075 0.000 0.031 0.025 0.004 0.052 0.004 0.016 0.007 0.000 0.001 0.000 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.023 0.042 0.000 0.042 0.000 0.042 0.0085 0.018 0.023 0.024 0.020 0.024 0.025 0.026 0.023 0.025 0.0031 0.073	0.013 Ce203 0.046 0.062 0.062 0.058 0.047 0.000 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.040 0.054 0.040 0.054 0.055 0.058 0.046 0.031 0.063 0.059	0.000 Nd203 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.000 0.2251 0.002 0.113 0.126 0.286 0.313 0.210 0.000 0.000 0.000 0.000 0.0268 0.128 0.0000 0.035 0.0000	100.590 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.998 99.453 99.9453 99.558 97.934 100.616 101.213 100.365 100.371 100.035 100.391 100.280 100.128 100.128 100.128 100.128 100.128 100.128 100.128 100.128 100.128 100.446 101.114 100.246 101.114 100.247 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.592 100.609 100.250 100.245 100.245 100.255 100.245 100.255 100.245 100.255 100.245 100.255 100.255 100.255 100.245 100.255 100.255 100.255 100.255 100.255 100.445 100.255 100.445 100.445 100.255 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.445 100.455 100.445 100.455 100.455 100.455 100.455 100.455 100.455 100.455 100.445 100.445 100.145 100.455 100.445 100.455 10	0.000 0.000 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.004 0.002 0.004 0.002 0.000	0.000 -O=F2 0.000	0.000 0.002 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.002 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000	100.090 Total recalc 100.545 100.607 100.591 99.833 99.854 100.263 99.997 99.452 99.58 97.932 100.612 101.210 100.365 100.035 100.035 100.020 99.814 100.250 101.165 100.442 100.446 101.120
Rice Uni. 166 ALH84001 Ap7 10 3.407 0.000 0.012 0.004 0.000 100.272 0.000 0.002 100.270 Rice Uni. 167 ALH84001 Ap7 1 3.394 0.000 0.025 0.058 0.000 100.663 0.000 0.000 100.661 Rice Uni. 167 ALH84001 Ap7 1 3.394 0.000 0.025 0.058 0.000 100.663 0.000 0.000 100.661 Rice Uni. 168 ALH84001 Ap7 2 3.415 0.016 0.033 0.000 104.852 0.000 0.000 100.377 Rice Uni. 169 ALH84001 Ap7 3 3.393 0.009 0.033 0.001 0.138 100.799 0.000 0.000 100.799 Rice Uni. 170 ALH84001 Ap7 4 3.374 0.000 0.044 0.093 101.038 0.001 0.000 100.799	Nice Unit. Rice Unit. Ric	125 Point 126 127 128 129 139 140 142 143 144 145 144 145 146 147 151 152 153 156 157 158 159 160 163	ALII84001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap5 2 ALH84001 Ap5 3 ALH84001 Ap5 4 ALH84001 Ap5 6 ALH84001 Ap5 6 ALH84001 Ap5 8 ALH84001 Ap5 8 ALH84001 Ap5 8	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.448 3.449 3.368 3.409 3.449 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.440 3.445 3.445 3.445 3.445 3.446 3.448 3.4427 3.446 3.448 3.4427 3.446 3.448 3.4427 3.448 3.4427 3.448 3.4427 3.448 3.4427 3.446 3.448 3.4427 3.446 3.448 3.4427 3.446 3.4	0.000 Al2O3 0.014 0.000 0.000 0.000 0.001 0.002 0.014 0.000 0.046 0.001 0.075 0.000 0.031 0.025 0.040 0.052 0.004 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	0.023 0.028 0.031 0.011 0.036 0.056 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.003 0.044 0.004 0.005 0.004 0.005 0.043 0.043 0.025 0.031 0.073	0.013 Cc203 0.046 0.062 0.062 0.058 0.047 0.0047 0.003 0.070 0.035 0.035 0.035 0.030 0.053 0.030 0.053 0.040 0.098 0.040 0.054 0.048 0.015 0.054 0.046 0.054 0.054 0.048 0.015 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.054 0.055 0.055 0.047 0.055 0.055 0.047 0.035 0.035 0.035 0.040 0.055 0.040 0.035 0.035 0.040 0.055 0.055 0.040 0.055 0.040 0.055 0.055 0.040 0.055 0.055 0.040 0.055 0	0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.025 0.163 0.102 0.286 0.210 0.000 0.025 0.163 0.102 0.286 0.210 0.000	100.597 Total 100.547 100.609 100.547 100.609 100.547 100.592 99.833 99.836 100.214 100.265 99.998 99.9558 97.934 100.265 100.616 100.213 100.365 100.375 100.375 100.375 100.375 100.309 99.816 100.128 100.128 100.128 100.142 100.442 1	0.000 0.002 0.002 0.001 0.000 0.001 0.001 0.001 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000 0.0000 0.00000 0.000000 0.00000 0.00000000	0.000 -O=F2 0.000	0.000 0.002 0.002 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.000	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.263 99.997 99.955 97.932 99.558 97.932 100.413 100.365 100.365 100.035 100.035 100.0250 101.165 100.442 100.146 101.112 101.070
Rice Uni. 167 ALH84001 Ap7 1 3.394 0.000 0.021 0.058 0.000 100.852 0.000 0.000 100.852 Rice Uni. 168 ALH84001 Ap7 1 3.394 0.000 0.025 0.058 0.000 0.000 0.000 100.852 Rice Uni. 168 ALH84001 Ap7 2 3.415 0.016 0.033 0.000 0.143 100.377 0.000 0.000 100.377 Rice Uni. 169 ALH84001 Ap7 3 3.393 0.009 0.023 0.212 0.138 100.799 0.000 0.000 100.799 Rice Uni. 170 ALH84001 Ap7 4 3.374 0.000 0.093 10.038 0.001 0.000 100.799	Data Collection Rice Uni. Rice Uni.	125 Point 126 127 128 129 129 129 129 129 129 129 129 129 121 139 140 142 143 144 145 144 145 144 145 148 149 150 151 152 153 154 155 156 157 158 159 160 163 164	ALI164001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 ALH84001 Ap5 2 ALH84001 Ap5 3 ALH84001 Ap5 6 ALH84001 Ap5 6 ALH84001 Ap5 6 ALH84001 Ap5 6 ALH84001 Ap6 1 ALH84001	3.414 MgO 3.432 3.377 3.399 3.446 3.449 3.440 3.427 3.361 3.357 3.401 3.420 3.933 3.4461 3.433 3.433 3.435 3.435 3.435 3.435 3.424 3.421	0.003 Al2O3 Al2O3 0.014 0.000 0.000 0.000 0.001 0.0046 0.001 0.075 0.0025 0.004 0.025 0.004 0.016 0.007 0.000 0.016 0.000 0.019 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.028 0.000 0.028 0.018 0.000 0.022 0.003 0.058 0.000 0.052 0.003 0.050 0.042 0.031 0.025 0.031 0.073 0.021	0.013 Ce203 0.046 0.062 0.058 0.047 0.000 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.040 0.098 0.040 0.054 0.045 0.058 0.015 0.058 0.046 0.031 0.063 0.052	0.000 Nd2O3 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.251 0.163 0.102 0.286 0.313 0.210 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.108	100.591 Total 100.547 100.609 100.547 100.592 99.833 99.856 100.414 100.255 99.998 99.453 99.558 97.934 100.616 101.213 100.365 100.035 100.035 100.010 100.250 100.116 100.442 100.444 101.101 100.367 100.367	0.000 0.002 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0000 0.0000	0.000 -O=F2 0.000	0.000 -O-Cl2 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.002 0.003 0.004 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.263 99.997 99.452 99.558 97.932 100.612 101.210 100.365 100.035 100.025 100.025 100.025 100.025 100.127 100.042 100.442 100.446 101.112 101.070 100.367
Rice Uni. 168 ALH84001 Ap7_2 3.415 0.016 0.033 0.000 0.143 100.377 0.000 0.000 100.032 Rice Uni. 169 ALH84001 Ap7_3 3.393 0.009 0.033 0.000 0.143 100.377 0.000 0.000 100.377 Rice Uni. 169 ALH84001 Ap7_3 3.393 0.009 0.043 10138 100.799 0.000 0.000 100.377 Rice Uni. 170 ALH84001 Ap7_4 3.374 0.000 0.046 0.043 0.093 101.038 0.001 0.000 101.037	Data Collection Rice Uni. Rice Uni.	123 Point 126 127 128 129 139 140 142 143 144 145 144 145 146 147 148 149 150 151 152 153 154 155 166 164 165 164 165	ALH84001 Apj tail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 5 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 ALH84001 Ap5 2 ALH84001 Ap5 3 ALH84001 Ap5 5 ALH84001 Ap5 4 ALH84001 Ap5 8 ALH84001 Ap5 8 ALH84001 Ap6	3.414 MgO 3.432 3.377 3.390 3.446 3.465 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.449 3.449 3.449 3.427 3.450 3.357 3.404 3.427 3.450 3.323 3.401 3.323 3.441 3.420 3.421 3.423 3.429 3.445 3.428 3.424 3.423 3.424 3.423	0.003 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.0046 0.001 0.075 0.0031 0.025 0.004 0.052 0.004 0.016 0.007 0.000 0.001 0.001 0.000 0.001 0.001 0.000 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.0085 0.018 0.002 0.003 0.058 0.0050 0.043 0.021 0.021	0.013 Ce203 0.046 0.062 0.063 0.047 0.000 0.035 0.035 0.035 0.035 0.035 0.035 0.030 0.053 0.040 0.098 0.040 0.040 0.058 0.046 0.031 0.058 0.046 0.031 0.063 0.059 0.033 0.027 0.010	0.000 Nd203 0.000 0.000 0.000 0.000 0.135 0.000 0.135 0.000 0.000 0.135 0.000 0.251 0.002 0.025 0.163 0.112 0.286 0.313 0.200 0.000 0.000 0.000 0.000 0.000 0.035 0.0000 0.124 0.0000	100.591 Total 100.547 100.609 100.582 99.833 99.856 100.414 100.265 99.993 99.453 99.558 97.934 100.265 100.371 100.365 100.035 100.035 100.035 100.128 100.128 100.124 100.446 101.114 100.367 100.367 100.367 100.367	0.000 0.000 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.004 0.002 0.004 0.002 0.000	0.000 -O=F2 0.000	0.0002 -O=Cl2 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.004 0.003 0.000 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 99.452 99.958 97.932 100.612 101.210 100.365 100.035 100.035 100.092 99.814 100.127 100.009 100.442 100.442 100.442 100.367 100.367 100.270
Rice Uni. 169 ALH84001 Ap7_3 3.393 0.009 0.033 0.021 0.138 100.799 0.000 0.000 100.799 Rice Uni. 170 ALH84001 Ap7_4 3.374 0.000 0.004 0.003 0.003 0.021 0.138 100.799 0.000 0.000 100.799 Rice Uni. 170 ALH84001 Ap7_4 3.374 0.000 0.043 0.093 101.038 0.001 0.000 100.799	Nice Uni. Rice Uni. Ric	125 Point 126 127 128 127 128 129 139 140 142 143 144 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 163 164 165 166 167	ALII64001 Ap3 trail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 5 ALH84001 Ap4 trail 5 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 1 ALH84001 Ap5 2 1 ALH84001 Ap5 4 1 ALH84001 Ap5 6 1 ALH84001 Ap5 8 1 ALH84001 Ap5	3.414 MgO 3.432 3.377 3.399 3.490 3.373 3.446 3.446 3.446 3.446 3.446 3.448 3.449 3.368 3.409 3.449 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.361 3.357 3.440 3.340 3.440 3.361 3.357 3.440 3.440 3.440 3.361 3.357 3.4400 3.440 3.4	0.003 0.014 0.000 0.000 0.000 0.000 0.001 0.002 0.0031 0.025 0.0040 0.0152 0.0040 0.016 0.000 0.010 0.000 0.016 0.000	0.023 0.028 0.031 0.011 0.036 0.056 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.000 0.042 0.003 0.044 0.004 0.004 0.005 0.005 0.043 0.043 0.041 0.042 0.031 0.042 0.042	0.013 Cc203 0.046 0.062 0.062 0.058 0.047 0.040 0.035 0.035 0.035 0.035 0.035 0.035 0.035 0.030 0.053 0.070 0.040 0.098 0.040 0.054 0.054 0.054 0.046 0.031 0.059 0.033 0.025 0.033 0.025	0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.025 0.163 0.000 0.025 0.163 0.102 0.286 0.210 0.000	100.591 Total 100,547 100,609 100,547 100,609 100,547 100,547 100,547 100,549 99,833 99,856 100,414 100,255 99,993 99,855 100,616 100,616 100,355 100,365 100,365 100,365 100,365 100,365 100,128 100,128 100,128 100,442 100,141 101,126 100,442 100,442 100,442 100,442 100,272 100,663 100,853	0.000 0.002 0.002 0.001 0.000 0.001 0.000 0.001 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000	0.000 -O=F2 0.000	0.000 0.002 0.002 0.001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 99.955 97.932 100.413 100.263 99.977 99.452 99.558 97.932 100.121 101.210 100.365 100.365 100.035 100.035 100.127 100.109 100.250 101.115 100.442 100.146 101.112 101.070 100.367 100.270 100.661
Rice Uni. 170 ALH84001 Ap7 4 3.374 0.000 0.046 0.043 0.093 101.038 0.001 0.000 0.000 100/77	Data Collection Rice Uni. Rice Uni.	125 Point 126 127 128 127 128 129 139 140 141 145 144 145 144 145 150 151 152 153 154 155 157 158 150 163 164 165 166 166 166 166 166 166 166 166 166 167	ALII84001 Ap3 tial 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 6 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 9 ALH84001 Ap5 gray 10 ALH84001 Ap5 gray 11 ALH84001 Ap5 gray 12 ALH84001 Ap5 gray 12 ALH84001 Ap5 gray 12 ALH84001 Ap5 gray 12 <td>3.414 MgO 3.432 3.377 3.399 3.373 3.465 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.449 3.449 3.449 3.449 3.427 3.420 3.357 3.402 3.393 3.442 3.433 3.499 3.445 3.424 3.423 3.407 3.424 3.423 3.4462 3.391</td> <td>0.003 Al2O3 Al2O3 0.014 0.000 0.000 0.000 0.001 0.0046 0.001 0.075 0.000 0.031 0.025 0.004 0.016 0.007 0.000 0.0016 0.000 0.0016 0.000 0.0017 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000</td> <td>0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.023 0.042 0.000 0.028 0.018 0.018 0.002 0.028 0.003 0.058 0.000 0.050 0.042 0.043 0.025 0.043 0.025 0.041 0.073 0.021 0.025 0.031</td> <td>0.013 Ce203 0.046 0.062 0.062 0.058 0.047 0.0070 0.035 0.047 0.0070 0.035 0.035 0.035 0.035 0.035 0.036 0.0378 0.040 0.098 0.040 0.054 0.045 0.058 0.046 0.031 0.058 0.033 0.027 0.010 0.044 0.058 0.027 0.010</td> <td>0.000 Nd203 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.025 0.163 0.102 0.286 0.210 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.1144 0.103</td> <td>100.591 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.933 99.856 99.9453 99.558 97.934 100.616 101.213 100.365 100.035 100.035 100.0250 100.110 100.251 100.442 100.444 101.070 100.367 100.272 100.631 100.852</td> <td>0.000 0.001 0.002 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.002 0.001 0.002 0.004 0.003 0.000</td> <td>0.000 -O=F2 0.000</td> <td>0.000 -O-Cl2 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.002 0.004 0.002 0.000 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.002 0.002 0.002 0.002</td> <td>100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.263 99.977 99.452 99.558 97.932 100.612 100.365 100.365 100.365 100.035 100.020 99.814 100.127 100.009 100.442 100.446 101.112 101.070 100.367 100.367 100.661 100.852</td>	3.414 MgO 3.432 3.377 3.399 3.373 3.465 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.449 3.449 3.449 3.449 3.427 3.420 3.357 3.402 3.393 3.442 3.433 3.499 3.445 3.424 3.423 3.407 3.424 3.423 3.4462 3.391	0.003 Al2O3 Al2O3 0.014 0.000 0.000 0.000 0.001 0.0046 0.001 0.075 0.000 0.031 0.025 0.004 0.016 0.007 0.000 0.0016 0.000 0.0016 0.000 0.0017 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.023 0.042 0.000 0.028 0.018 0.018 0.002 0.028 0.003 0.058 0.000 0.050 0.042 0.043 0.025 0.043 0.025 0.041 0.073 0.021 0.025 0.031	0.013 Ce203 0.046 0.062 0.062 0.058 0.047 0.0070 0.035 0.047 0.0070 0.035 0.035 0.035 0.035 0.035 0.036 0.0378 0.040 0.098 0.040 0.054 0.045 0.058 0.046 0.031 0.058 0.033 0.027 0.010 0.044 0.058 0.027 0.010	0.000 Nd203 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.025 0.163 0.102 0.286 0.210 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.1144 0.103	100.591 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.265 99.933 99.856 99.9453 99.558 97.934 100.616 101.213 100.365 100.035 100.035 100.0250 100.110 100.251 100.442 100.444 101.070 100.367 100.272 100.631 100.852	0.000 0.001 0.002 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.002 0.001 0.002 0.004 0.003 0.000	0.000 -O=F2 0.000	0.000 -O-Cl2 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.002 0.004 0.002 0.000 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.002 0.002 0.002 0.002	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.263 99.977 99.452 99.558 97.932 100.612 100.365 100.365 100.365 100.035 100.020 99.814 100.127 100.009 100.442 100.446 101.112 101.070 100.367 100.367 100.661 100.852
	Data Collection Rice Uni. Rice Uni.	123 Point 126 127 128 129 139 140 142 143 144 143 144 143 144 143 144 143 144 143 144 143 144 143 144 145 151 152 153 155 156 157 158 159 160 163 164 165 167 168 166 167 168 169	ALII04001 ADJ Iail 2 Comment ALH84001 Ap3 trail 3 ALH84001 Ap3 trail 4 ALH84001 Ap3 trail 5 ALH84001 Ap3 trail 6 ALH84001 Ap4 gray 3 ALH84001 Ap4 gray 4 ALH84001 Ap4 gray 7 ALH84001 Ap4 gray 9 ALH84001 Ap4 gray 10 ALH84001 Ap5 1 ALH84001 Ap5 1 ALH84001 Ap5 3 ALH84001 Ap5 4 ALH84001 Ap5 5 ALH84001 Ap5 7 ALH84001 Ap5 3 ALH84001 Ap5 3 ALH84001	3.414 Mg0 3.432 3.377 3.399 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.446 3.440 3.427 3.450 3.357 3.404 3.420 3.493 3.461 3.439 3.445 3.439 3.445 3.423 3.424 3.423 3.423 3.424 3.423 3.423 3.424 3.423 3.424 3.423 3.424 3.423 3.424 3.424 3.423	0.003 Al2O3 Al2O3 0.014 0.000 0.000 0.000 0.000 0.001 0.0046 0.001 0.075 0.001 0.075 0.001 0.075 0.004 0.052 0.004 0.016 0.000	0.023 MnO 0.028 0.031 0.011 0.036 0.056 0.067 0.023 0.042 0.000 0.042 0.000 0.042 0.000 0.028 0.0042 0.000 0.028 0.018 0.018 0.002 0.003 0.050 0.042 0.042 0.042 0.043 0.025 0.042 0.021 0.025 0.021 0.025 0.033 0.033	0.013 Ce203 0.046 0.062 0.058 0.047 0.000 0.035 0.035 0.035 0.035 0.035 0.035 0.030 0.053 0.040 0.098 0.040 0.054 0.054 0.053 0.040 0.058 0.0415 0.058 0.0431 0.0633 0.027 0.010 0.044 0.058 0.027 0.010 0.044 0.058 0.021	0.000 Nd203 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.2251 0.163 0.102 0.286 0.313 0.210 0.000<	100.591 Total 100.547 100.609 100.592 99.833 99.856 100.414 100.262 99.993 99.934 100.616 101.213 100.365 100.0355 100.0355 100.041 100.260 100.128 100.128 100.442 100.442 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.367 100.377 100.377	0.000 0.000 0.001 0.002 0.001 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.000 0.002 0.001 0.000	0.000 -O=F2 0.000	0.0002 -O=Cl2 0.002 0.001 0.002 0.001 0.002 0.001 0.002 0.001 0.001 0.001 0.001 0.001 0.001 0.002 0.001 0.002 0.003 0.004 0.002 0.000 0.001 0.001 0.001 0.000 0.001 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	100.090 Total recale 100.545 100.607 100.591 99.833 99.854 100.413 100.263 99.997 99.452 99.958 97.932 100.612 101.1210 100.365 100.035 100.092 99.814 100.0250 101.127 100.0442 100.442 100.442 100.367 100.367 100.367 100.367 100.367 100.367 100.377 100.799

Data Collection	Point	Comment	MgO	Al2O3	MnO	Ce2O3	Nd2O3	Total	O=F,Cl	-O=F2	-O=Cl2	Total recalc
Rice Uni.	171	ALH84001_Ap7_5	3.397	0.000	0.028	0.051	0.000	101.175	0.001	0.000	0.001	101.174
Rice Uni.	172	ALH84001_Ap7_6	3.408	0.000	0.010	0.026	0.000	100.642	0.002	0.000	0.002	100.640
Rice Uni.	173	ALH84001_Ap7_7	3.433	0.000	0.017	0.065	0.000	99.861	0.001	0.000	0.001	99.860
Rice Uni.	174	ALH84001_Ap7_8	3.398	0.004	0.029	0.046	0.093	100.379	0.000	0.000	0.000	100.379
Rice Uni.	175	ALH84001_Ap7_9	3.348	0.213	0.026	0.060	0.000	99.305	0.000	0.000	0.000	99.305
Rice Uni.	176	ALH84001_Ap7_10	3.431	0.021	0.071	0.046	0.000	100.438	0.001	0.000	0.001	100.437
Rice Uni.	177	ALH84001_Ap7_11	3.362	0.000	0.054	0.084	0.117	100.417	0.000	0.000	0.000	100.417
Rice Uni.	178	ALH84001_Ap7_12	3.405	0.003	0.017	0.010	0.149	100.768	0.002	0.000	0.002	100.766
Rice Uni.	179	ALH84001_Ap7_13	3.385	0.022	0.038	0.058	0.200	100.311	0.001	0.000	0.001	100.310
Rice Uni.	180	ALH84001_Ap7_14	3.369	0.031	0.025	0.069	0.000	100.327	0.000	0.000	0.000	100.327
Rice Uni.	181	ALH84001_Ap7_15	3.432	0.018	0.000	0.021	0.000	100.412	0.000	0.000	0.000	100.412
Rice Uni.	182	ALH84001_Ap8_1	3.361	0.016	0.026	0.356	0.158	99.695	0.003	0.000	0.003	99.692
Rice Uni.	183	ALH84001_Ap8_2	3.367	0.025	0.073	0.387	0.000	98.477	0.001	0.000	0.001	98.476
Rice Uni.	186	ALH84001_Ap8_5	3.349	0.001	0.026	0.443	0.000	99.461	0.002	0.000	0.002	99.459
Rice Uni.	187	ALH84001_Ap8_6	3.456	0.000	0.047	0.363	0.000	100.080	0.002	0.000	0.002	100.078
Rice Uni.	189	ALH84001_Ap8_8	3.362	0.004	0.000	0.343	0.000	100.043	0.000	0.000	0.000	100.043
Rice Uni.	190	ALH84001_Ap8_9	3.403	0.000	0.001	0.319	0.000	100.353	0.000	0.000	0.000	100.353
Rice Uni.	192	ALH84001_Ap8_11	3.404	0.008	0.025	0.393	0.000	99.424	0.000	0.000	0.000	99.424
Rice Uni.	194	ALH84001_Ap8_13	3.458	0.000	0.018	0.382	0.055	99.828	0.001	0.000	0.001	99.827
Rice Uni.	196	ALH84001_Ap8_15	3.416	0.000	0.028	0.376	0.112	100.206	0.002	0.000	0.002	100.204
Rice Uni.	197	ALH84001_Ap8_16	3.374	0.032	0.032	0.329	0.000	99.647	0.000	0.000	0.000	99.647
Rice Uni.	198	ALH84001_Ap8_17	3.296	0.011	0.037	0.398	0.000	100.037	0.002	0.000	0.002	100.035
Rice Uni.	200	ALH84001 Ap9 in OPX 1	3.442	0.000	0.026	0.180	0.000	100.287	0.000	0.000	0.000	100.287
Rice Uni.	201	ALH84001_Ap9_in_OPX_2	3.456	0.000	0.069	0.231	0.000	100.514	0.001	0.000	0.001	100.513
Rice Uni.	202	ALH84001_Ap9_in_OPX_3	3.453	0.009	0.016	0.241	0.000	99.811	0.002	0.000	0.002	99.809
Rice Uni.	203	ALH84001_Ap9_in_OPX_4	3.497	0.000	0.072	0.199	0.095	100.653	0.001	0.000	0.001	100.652
Rice Uni.	204	ALH84001_Ap9_in_OPX_5	3.542	0.000	0.043	0.197	0.062	100.769	0.002	0.000	0.002	100.767
Rice Uni.	205	ALH84001_Ap9_in_OPX_6	3.827	0.119	0.039	0.241	0.140	99.293	0.000	0.000	0.000	99.293
Rice Uni.	206	ALH84001_Ap9_in_OPX_7	3.456	0.000	0.032	0.202	0.000	100.894	0.000	0.000	0.000	100.894
		Average	3.421	0.014	0.031	0.092	0.053	100.156	0.001	0.000	0.001	100.155
		Min	3.296	0.000	0.000	0.000	0.000	97.934	0.000	0.000	0.000	97.932
		Max	3.827	0.213	0.085	0.443	0.436	101.213	0.004	0.000	0.004	101.210
	I	StDev	0.061	0.034	0.020	0.114	0.085	0.602	0.001	0.000	0.001	0.602

Supplementary Table 6. Summarized quantitative point analyses for apatite in ALH 84001. Data used to calculate average wt% and formula amounts were collected at Rice University (JEOL JXA-8530F Hyperprobe). Comments denote mineral names given at time of data collection.

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Data Collection	Point	Comment	Na2C	SiO2	La2C	03 K2	0	CaO	FeO		Cl	P2O5	SO3	F
Rice Uni.	86	ALH84001 Ap1 bright 1	0.287	0.162	0.00	0 0.0	22	53.897	0.233	4	.797	41.527	0.150	0.669
Rice Uni.	87	ALH84001 Ap1 bright 2	0.259	0.240	0.00	0.0	06	53.819	0.230	4	.165	41.290	0.121	0.553
Rice Uni.	88	ALH84001_Ap1_bright_3	0.248	0.224	0.00	0.0	03	54.872	0.18	3	.884	41.612	0.142	0.339
Rice Uni.	89	ALH84001 Ap1 bright 4	0.276	0.249	0.00	0 0.0	00	54.203	0.170) 4	.337	41.292	0.135	0.488
Rice Uni.	90	ALH84001 Ap1 bright 5	0.211	0.186	0.00	0 0.0	13	53.595	0.10	5	.045	41.071	0.112	0.573
Rice Uni.	91	ALH84001 Ap1 bright 6	0.331	0.305	0.00	0 0.0	25	52.733	0.194	4	.953	40.613	0.124	0.300
Rice Uni.	130	ALH84001 Ap4 bright 1	0.319	0.128	0.00	0.0	00	54.656	0.073	3	.904	41.798	0.120	0.548
Rice Uni.	131	ALH84001 Ap4 bright 2	0.256	0.161	0.00	0 0.0	39	54.358	0.20	3	.848	42.127	0.111	0.685
Rice Uni.	132	ALH84001 Ap4 bright 3	0.268	0.148	0.00	0 0.0	15	53.263	0.130	4	.252	41.654	0.118	0.763
Rice Uni.	133	ALH84001 Ap4 bright 4	0.234	0.212	0.10	2 0.0	08	53.254	0.164	4	.724	41.477	0.108	0.666
Rice Uni.	134	ALH84001 Ap4 bright 5	0.184	0.155	0.00	0.0	00	53.513	0.16	4	.005	41.477	0.115	0.787
Rice Uni.	135	ALH84001 Ap4 bright 6	0.283	0.183	0.00	0.0	00	53.232	0.19	4	.232	41.708	0.106	0.919
Rice Uni.	136	ALH84001 Ap4 bright 7	0.259	0.126	0.00	0 0.0	17	53.815	0.110) 4	.569	41.796	0.140	0.606
		Average	0.263	0.191	0.00	8 0.0	11	53.785	0.16	4	.363	41.496	0.123	0.607
		Min	0.184	0.126	0.00	0 0.0	90	52.733	0.073	3.	848	40.613	0.106	0.300
		Max	0.331	0.305	0.10	2 0.0.	39	54.872	0.233	5.	045	42.127	0.150	0.919
		StDev	0.040	0.053	0.02	8 0.0	12	0.615	0.049	0	.416	0.377	0.014	0.172
Data Collection	Point	Comment	MgO	Al2O3	MnO	Ce2O3	Nd2	2O3 T	otal	D=F,Cl	-0=F2	2 -0=0	Cl2 To	tal recalc
Rice Uni.	86	ALH84001 Ap1 bright 1	0.043	0.020	0.068	0.047	0.1	00 10	2.022	1.364	0.282	1.08	2 1	00.658
Rice Uni.	87	ALH84001 Ap1 bright 2	0.047	0.008	0.049	0.000	0.2	24 10	1.011	1.173	0.233	0.94	0	99.838
Rice Uni.	88	ALH84001_Ap1_bright_3	0.008	0.000	0.060	0.038	0.0	000 10	1.617	1.019	0.143	0.87	6 1	00.598
Rice Uni.	89	ALH84001_Ap1_bright_4	0.031	0.008	0.035	0.022	0.0	000 10	1.246	1.184	0.205	0.97	19 1	00.062
Rice Uni.	90	ALH84001_Ap1_bright_5	0.011	0.000	0.012	0.000	0.1	83 10	1.119	1.380	0.241	1.13	8	99.739
Rice Uni.	91	ALH84001_Ap1_bright_6	0.050	0.175	0.020	0.000	0.0	99 00	.823	1.244	0.126	1.11	8	98.579
Rice Uni.	130	ALH84001_Ap4_bright_1	0.033	0.000	0.004	0.016	0.3	73 10	1.972	1.112	0.231	0.88	31 1	00.860
Rice Uni.	131	ALH84001_Ap4_bright_2	0.023	0.100	0.021	0.040	0.1	21 10	2.097	1.157	0.288	0.86	68 1	00.940
Rice Uni.	132	ALH84001_Ap4_bright_3	0.026	0.052	0.022	0.035	0.3	03 10	1.049	1.281	0.321	0.95	9	99.768
Rice Uni.	133	ALH84001_Ap4_bright_4	0.028	0.003	0.019	0.052	0.0	000 10	1.051	1.346	0.280	1.06	6	99.705
Rice Uni.	134	ALH84001_Ap4_bright_5	0.039	0.052	0.058	0.025	0.0	000 10	0.577	1.235	0.331	0.90)4	99.342
Rice Uni.	135	ALH84001_Ap4_bright_6	0.035	0.161	0.000	0.016	0.1	50 10	1.222	1.342	0.387	0.95	5	99.880
Rice Uni.	136	ALH84001_Ap4_bright_7	0.033	0.004	0.040	0.030	0.0	000 10	1.545	1.286	0.255	1.03	1 1	00.259
		Average	0.031	0.045	0.031	0.025	0.1	12 10	1.258	1.240	0.256	0.98	34 1	00.018
		Min	0.008	0.000	0.000	0.000	0.0	00 99	.823	1.019	0.126	0.86	8	98.579
		Max	0.050	0.175	0.068	0.052	0.3	73 10.	2.097	1.380	0.387	1.13	8 1	00.940
		0.10	0.010	0.0/0	0.000	0.010		A A 4 A	141	0 4 0 0		0.00		

Supplementary Table 7. Summarized quantitative point analyses for apatite (contained within CPX) in NWA 998. Data used to calculate average wt% and formula amounts were collected at Rice University (JEOL JXA-8530F Hyperprobe). Comments denote mineral names given at time of data collection.

Data Collection	Point	Comment	Na2O	SiO2	La20	03 K2	0	CaO	Fe	0	Cl	P2O5	SO3	F
Rice Uni.	34	NWA998_Ap3_in_CPX_1	0.042	0.553	0.73	3 0.0	12	53.378	0.6	70 3	.626	41.272	0.029	1.234
Rice Uni.	35	NWA998 Ap3 in CPX 2	0.007	0.564	0.20	8 0.0	00	53.378	0.8	64 3	.376	40.886	0.056	1.262
Rice Uni.	36	NWA998 Ap3 in CPX 3	0.063	0.589	0.59	2 0.0	00	53.893	0.8	07 3	.511	40.807	0.040	1.406
Rice Uni.	37	NWA998_Ap3_in_CPX_4	0.023	0.563	0.50	1 0.0	00	54.236	0.8	14 3	.060	40.816	0.029	1.230
		Average	0.034	0.567	0.50	9 0.0	03	53.721	0.7	89 3	.393	40.945	0.039	1.283
		Min	0.007	0.553	0.20	8 0.0	00	53.378	0.6	70 3	.060	40.807	0.029	1.230
		Max	0.063	0.589	0.73	3 0.0.	12	54.236	0.8	64 3	.626	41.272	0.056	1.406
		StDev	0.024	0.015	0.22	2 0.0	06	0.420	0.0	83 0	.245	0.221	0.013	0.083
Data Collection	Point	Comment	MgO	Al2O3	MnO	Ce2O3	Nd2	203	Total	O=F,Cl	-0=	F2 -O=	Cl2 To	tal recalc
Rice Uni.	34	NWA998_Ap3_in_CPX_1	0.048	0.000	0.103	0.233	0.1	54 10	02.087	1.338	0.52	20 0.8	18 1	00.749
Rice Uni.	35	NWA998_Ap3_in_CPX_2	0.054	0.000	0.087	0.300	0.0	00 10	01.042	1.293	0.53	0.76	52	99.749
Rice Uni.	36	NWA998_Ap3_in_CPX_3	0.049	0.000	0.091	0.276	0.0	92 10	02.216	1.384	0.59	0.79	92 1	00.832
Rice Uni.	37	NWA998_Ap3_in_CPX_4	0.043	0.009	0.088	0.298	0.0	00 10	01.710	1.208	0.51	8 0.69	90 1	00.502
		Average	0.049	0.002	0.092	0.277	0.0	62 10	01.764	1.306	0.54	0 0.70	56 1	00.458
		Min	0.043	0.000	0.087	0.233	0.00	00 10	01.042	1.208	0.51	8 0.69	00	99.749
		Max	0.054	0.009	0.103	0.300	0.1	54 10	02.216	1.384	0.59	0.81	8 1	00.832

Supplementary Table 8. Summarized quantitative point analyses for apatite in NWA 998. Data used to calculate average wt% and formula amounts were collected at Rice University (JEOL JXA-8530F Hyperprobe). Comments denote mineral names given at time of data collection.

Data Collection	Point	Comment	Na2O	SiO2	La2O3	K2O	CaO	FeO	Cl	P2O5	SO3	F
Rice Uni.	4	NWA998_Ap1_1	0.050	0.250	0.298	0.055	54.674	0.638	2.942	41.704	0.024	1.188
Rice Uni.	5	NWA998_Ap1_2	0.076	0.349	0.268	0.044	54.717	0.645	2.979	41.307	0.009	1.098
Rice Uni.	6	NWA998_Ap1_3	0.062	0.374	0.363	0.035	55.093	0.595	2.700	41.421	0.000	1.070
Rice Uni.	7	NWA998 Ap1_4	0.097	0.251	1.122	0.044	54.833	0.468	2.844	41.266	0.013	1.117
Rice Uni.	9	NWA998_Ap1_6	0.074	0.234	0.252	0.085	54.464	0.467	2.961	41.421	0.015	1.155
Rice Uni.	10	NWA998_Ap1_7	0.046	0.174	0.192	0.034	54.212	0.675	2.812	41.543	0.060	1.313
Rice Uni.	11	NWA998_Ap1_8	0.040	0.222	0.173	0.046	54.445	0.665	2.920	41.568	0.011	1.160
Rice Uni.	12	NWA998_Ap1_9	0.070	0.208	0.601	0.054	55.143	0.655	2.624	41.256	0.003	1.129
Rice Uni.	13	NWA998_Ap1_10	0.106	0.160	0.000	0.011	54.599	0.605	2.722	41.838	0.067	1.161
Rice Uni.	14	NWA998_Ap1_11	0.072	0.301	0.382	0.038	54.576	0.581	2.810	41.672	0.000	1.191
Rice Uni.	15	NWA998_Ap1_12	0.095	0.164	0.920	0.038	54.370	0.741	2.773	41.352	0.078	0.980
Rice Uni.	16	NWA998_Ap1_13	0.088	0.170	0.383	0.079	54.483	0.594	3.245	41.270	0.019	1.369
Rice Uni.	17	NWA998_Ap1_14	0.094	0.293	0.376	0.083	54.009	0.684	3.043	40.950	0.031	1.192
Rice Uni.	18	NWA998_Ap1_15	0.074	0.126	0.350	0.038	55.340	0.738	2.423	41.150	0.123	0.954
Rice Uni.	19	NWA998_Ap1_16	0.067	0.189	0.387	0.073	53.275	0.701	3.517	40.922	0.060	1.391
Rice Uni.	20	NWA998_Ap1_17	0.029	0.311	0.000	0.125	53.928	0.691	3.335	41.219	0.017	1.525
Rice Uni.	21	NWA998_Ap1_18	0.130	0.400	0.226	0.153	53.469	0.778	3.045	40.453	0.257	1.490
Rice Uni.	22	NWA998_Ap2_1	0.019	0.082	0.279	0.000	54.457	0.517	3.167	41.726	0.012	1.792
Rice Uni.	23	NWA998_Ap2_2	0.058	0.125	0.357	0.017	54.099	0.647	3.226	41.264	0.011	1.508
Rice Uni.	24	NWA998_Ap2_3	0.082	0.074	0.000	0.000	53.810	0.614	3.069	41.010	0.058	1.715
Rice Uni.	25	NWA998_Ap2_4	0.052	0.254	0.404	0.004	53.801	0.711	3.285	41.360	0.046	1.598
Rice Uni.	26	NWA998_Ap2_5	0.104	0.080	0.317	0.003	54.329	0.531	3.241	41.504	0.003	1.704
Rice Uni.	27	NWA998_Ap2_6	0.000	0.154	0.223	0.002	54.084	0.577	3.171	41.788	0.000	1.750
Rice Uni.	28	NWA998_Ap2_7	0.100	0.100	0.038	0.000	54.354	0.627	3.277	41.706	0.000	1.733
Rice Uni.	29	NWA998_Ap2_8	0.016	0.174	0.163	0.000	51.240	0.587	3.246	40.499	0.013	2.061
Rice Uni.	30	NWA998_Ap2_9	0.080	0.175	0.000	0.004	53.765	0.497	3.442	41.765	0.004	1.759
Rice Uni.	31	NWA998_Ap2_10	0.042	0.181	0.191	0.008	54.019	0.547	3.312	41.425	0.000	1.842
Rice Uni.	32	NWA998_Ap2_11	0.060	0.184	0.000	0.015	54.444	0.481	2.942	41.493	0.008	1.528
Rice Uni.	33	NWA998_Ap2_12	0.102	0.122	0.182	0.008	54.298	0.474	3.273	41.922	0.013	1.702
Rice Uni.	39	NWA998_Ap4_2	0.031	0.304	0.196	0.045	53.624	0.544	3.287	40.962	0.047	1.308
Rice Uni.	40	NWA998_Ap4_3	0.071	0.228	0.464	0.021	53.121	0.567	3.228	41.192	0.048	1.320
Rice Uni.	41	NWA998_Ap4_4	0.076	0.272	0.177	0.014	51.980	0.734	3.311	40.581	0.065	1.351
Rice Uni.	42	NWA998_Ap4_5	0.029	0.207	0.293	0.017	52.824	0.721	3.024	40.160	0.085	1.245
Rice Uni.	43	NWA998_Ap4_6	0.043	0.408	0.406	0.004	53.145	0.933	3.470	40.738	0.042	1.210
Rice Uni.	44	NWA998_Ap4_7	0.052	0.400	0.067	0.004	53.101	1.187	3.485	41.126	0.007	1.179
Rice Uni.	45	NWA998 Ap4 8	0.065	0.278	0.738	0.000	53.103	1.283	3.297	41.379	0.029	1.253

| Data Collection | Point | Comment

 | Na2O | SiO2 | La2O3
 | K2O | Ca | 0 | FeO
 | Cl | P2O5 | SO3
 | F |
|---|--
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Rice Uni.	46	NWA998_Ap4_9

 | 0.070 | 0.385 | 0.364
 | 0.025 | 53.0 | 50 | 1.020
 | 3.344 | 41.115 | 0.032
 | 1.209 |
| Rice Uni. | 47 | NWA998_Ap4_10

 | 0.051 | 0.362 | 0.149
 | 0.000 | 53.4 | 58 | 1.100
 | 3.466 | 40.824 | 0.026
 | 1.394 |
| Rice Uni. | 48 | NWA998_Ap5_1

 | 0.071 | 0.173 | 0.331
 | 0.051 | 53.6 | 84 | 0.647
 | 3.231 | 42.017 | 0.015
 | 1.264 |
| Rice Uni. | 49 | NWA998_Ap5_2

 | 0.078 | 0.138 | 0.396
 | 0.027 | 53.4 | 04 | 0.624
 | 3.458 | 41.377 | 0.005
 | 1.274 |
| Rice Uni. | 50 | NWA998_Ap5_3

 | 0.033 | 0.154 | 0.121
 | 0.002 | 53.5 | 10 | 0.730
 | 3.621 | 41.276 | 0.024
 | 1.180 |
| Rice Uni. | 51 | NWA998_Ap5_4

 | 0.080 | 0.173 | 0.244
 | 0.020 | 53.4 | 18 | 0.769
 | 2 1 90 | 40.099 | 0.111
 | 1.455 |
| Rice Uni | 52 | NWA998 Ap5 6

 | 0.080 | 0.370 | 0.000
 | 0.044 | 53.5 | 10 | 0.708
 | 3.169 | 40.369 | 0.074
 | 1.401 |
| Rice Uni | 54 | NWA998 Ap5 7

 | 0.036 | 0.631 | 0.007
 | 0.055 | 52.2 | 48 | 0.910
 | 3 347 | 40.342 | 0.065
 | 1.330 |
| Rice Uni | 57 | NWA998 Ap5 10

 | 0.064 | 0.626 | 0.000
 | 0.172 | 53.7 | 41 | 0.661
 | 3 4 56 | 41 253 | 0.010
 | 1 234 |
| Rice Uni. | 59 | NWA998 Ap5 12

 | 0.112 | 0.586 | 0.000
 | 0.116 | 52.5 | 25 | 0.997
 | 3.122 | 40.392 | 0.187
 | 1.373 |
| Rice Uni. | 60 | NWA998 Ap6 1

 | 0.069 | 0.170 | 0.000
 | 0.015 | 53.1 | 80 | 0.630
 | 3.656 | 41.261 | 0.012
 | 1.163 |
| Rice Uni. | 61 | NWA998 Ap6 2

 | 0.024 | 0.784 | 0.615
 | 0.117 | 52.9 | 86 | 0.553
 | 3.453 | 41.124 | 0.016
 | 1.187 |
| Rice Uni. | 62 | NWA998_Ap6_3

 | 0.139 | 0.165 | 0.227
 | 0.022 | 53.4 | 74 | 0.554
 | 3.222 | 41.331 | 0.140
 | 1.261 |
| Rice Uni. | 63 | NWA998_Ap6_4

 | 0.044 | 0.158 | 0.097
 | 0.055 | 54.0 | 14 | 0.364
 | 3.476 | 41.490 | 0.013
 | 1.340 |
| Rice Uni. | 64 | NWA998_Ap6_5

 | 0.063 | 0.901 | 0.000
 | 0.133 | 53.4 | 97 | 0.507
 | 3.404 | 41.082 | 0.010
 | 1.250 |
| Rice Uni. | 65 | NWA998_Ap6_6

 | 0.078 | 0.281 | 0.753
 | 0.047 | 53.3 | 79 | 0.443
 | 3.337 | 41.773 | 0.006
 | 1.382 |
| Rice Uni. | 66 | NWA998_Ap6_7

 | 0.043 | 0.474 | 0.273
 | 0.104 | 52.5 | 80 | 0.524
 | 3.410 | 40.436 | 0.039
 | 1.168 |
| Rice Uni. | 67 | NWA998_Ap6_8

 | 0.059 | 0.272 | 0.415
 | 0.088 | 53.8 | 23 | 0.527
 | 3.410 | 41.646 | 0.031
 | 1.388 |
| Rice Uni. | 68 | NWA998_Ap6_9

 | 0.114 | 0.200 | 0.211
 | 0.062 | 53.8 | 56 | 0.697
 | 3.214 | 41.306 | 0.084
 | 1.358 |
| Rice Uni. | /1 | NWA998_Ap6_12

 | 0.090 | 0.324 | 0.266
 | 0.095 | 53.2 | 61 | 0.8//
 | 3.431 | 41.336 | 0.000
 | 1.465 |
| Rice Uni. | 72 | NWA998 Ap6 13

 | 0.070 | 0.259 | 0.459
 | 0.104 | 53.7 | 36 | 0.90/
 | 3.26/ | 41.013 | 0.009
 | 1.301 |
| Rice Uni | 7/ | NWA996_Ap0_14
NWA998_Ap6_15

 | 0.000 | 0.200 | 0.004
 | 0.083 | 53.9 | 23 | 0.787
 | 3.271 | 41.228 | 0.007
 | 1.393 |
| Rice Uni | 77 | NWA998 Ap7 3

 | 0.007 | 0.280 | 0.094
 | 0.099 | 54.0 | 06 | 0.634
 | 3 471 | 41.038 | 0.035
 | 1.362 |
| Rice Uni. | 78 | NWA998 Ap8 1

 | 0.032 | 0.572 | 0.000
 | 0.006 | 53.6 | 16 | 0.896
 | 3.667 | 40.968 | 0.000
 | 1.238 |
| Rice Uni. | 79 | NWA998 Ap8 2

 | 0.071 | 0.593 | 0.175
 | 0.000 | 53.6 | 13 | 0.773
 | 3.843 | 41.135 | 0.008
 | 1.261 |
| Rice Uni. | 80 | NWA998 Ap8 3

 | 0.023 | 0.648 | 0.432
 | 0.006 | 53.3 | 39 | 0.720
 | 3.693 | 40.776 | 0.009
 | 1.246 |
| Rice Uni. | 81 | NWA998 Ap8 4

 | 0.080 | 0.563 | 0.521
 | 0.011 | 53.1 | 74 | 0.926
 | 3.756 | 40.685 | 0.020
 | 1.256 |
| Rice Uni. | 82 | NWA998_Ap8_5

 | 0.039 | 0.560 | 0.596
 | 0.023 | 53.8 | 25 | 0.843
 | 3.867 | 40.794 | 0.004
 | 1.373 |
| Rice Uni. | 83 | NWA998_Ap8_6

 | 0.126 | 1.437 | 0.009
 | 0.198 | 52.9 | 95 | 0.647
 | 3.614 | 40.771 | 0.018
 | 1.334 |
| Rice Uni. | 84 | NWA998_Ap8_7

 | 0.079 | 0.444 | 0.000
 | 0.164 | 53.0 | 96 | 0.787
 | 3.306 | 40.417 | 0.040
 | 1.574 |
| | | Average

 | 0.067 | 0.319 | 0.272
 | 0.048 | 53.7 | 06 | 0.691
 | 3.251 | 41.161 | 0.036
 | 1.354 |
| | | Min

 | 0.000 | 0.074 | 0.000
 | 0.000 | 51.24 | 40 | 0.364
 | 2.423 | 40.099 | 0.000
 | 0.954 |
| | _ | Max

 | 0.139 | 1.437 | 1.122
 | 0.198 | 55.34 | 40 | 1.283
 | 3.867 | 42.017 | 0.257
 | 2.061 |
| | | StDev

 | 0.028 | 0.225 | 0.233
 | 0.048 | 0.74 | 1 | 0.176
 | 0.288 | 0.440 | 0.046
 | 0.216 |
| Data Collection | Point | Comment

 | MgO | AI2O3 | Mn()
 | (203 1 | Nd2O3 | Tote |
 | | <u></u> |
 | |
| Rice Uni. | 4 | NIW A 0.09 A - 1 1

 | 0.042 | 0.000 | 0.066
 | 0.126 | 0.000 | 102.0 | ai 0-i
 | 64 0 | 5 00 0.6 | 4
 | tal recalc |
| Rice Uni | 4 | NWA998_Ap1_1
NWA998_Ap1_2

 | 0.042 | 0.000 | 0.066
 | 0.126 | 0.000 | 102.0 |)57 1.1
879 1.1
 | 64 0 | 500 0.6
462 0.6 | 64 1
72 1
 | 00.893 |
| Rice Uni.
Rice Uni. | 4
5
6 | NWA998_Ap1_1
NWA998_Ap1_2
NWA998_Ap1_3

 | 0.042
0.054
0.051 | 0.000 0.000 0.000 | 0.066 0.077 0.085
 | 0.126
0.245
0.219 | 0.000 0.011 0.000 | 102.0
101.8
102.0 | 057 1.1
057 1.1
058 1.0
 | 64 0
35 0
60 0 | 500 0.6 462 0.6 451 0.6 | 64 1
72 1
09 1
 | 100.893
100.744 |
| Rice Uni.
Rice Uni.
Rice Uni. | 4
5
6
7 | NWA998 Ap1 1 NWA998 Ap1 2 NWA998 Ap1 3 NWA998 Ap1 4

 | 0.042
0.054
0.051
0.052 | 0.000
0.000
0.000
0.000 | 0.066
0.077
0.085
0.111
 | 0.126
0.245
0.219
0.239 | 0.000
0.011
0.000
0.021 | 102.0
101.8
102.0
102.4 | 057 1.1
057 1.1
068 1.0
068 1.0
 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | -F2 -O 500 0.6 462 0.6 451 0.6 470 0.6 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$
 | 100.893
100.744
101.008
01.366 |
| Rice Uni.
Rice Uni.
Rice Uni.
Rice Uni. | 4
5
6
7
9 | NWA998_Ap1_1
NWA998_Ap1_2
NWA998_Ap1_3
NWA998_Ap1_4
NWA998_Ap1_6

 | 0.042
0.054
0.051
0.052
0.061 | 0.000
0.000
0.000
0.000
0.000
0.000 | 0.066
0.077
0.085
0.111
0.117
 | 0.126
0.245
0.219
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Data Collection	Point	Comment	MgO	Al2O3	MnO	Ce2O3	Nd2O3	Total	O=F,Cl	-O=F2	-O=Cl2	Total recalc
Rice Uni.	46	NWA998_Ap4_9	0.057	0.000	0.086	0.276	0.095	101.128	1.264	0.509	0.755	99.864
Rice Uni.	47	NWA998_Ap4_10	0.073	0.000	0.097	0.208	0.017	101.225	1.369	0.587	0.782	99.856
Rice Uni.	48	NWA998_Ap5_1	0.058	0.007	0.090	0.128	0.000	101.767	1.261	0.532	0.729	100.506
Rice Uni.	49	NWA998_Ap5_2	0.050	0.005	0.111	0.129	0.008	101.084	1.317	0.536	0.780	99.767
Rice Uni.	50	NWA998_Ap5_3	0.034	0.000	0.091	0.119	0.024	100.912	1.314	0.497	0.817	99.598
Rice Uni.	51	NWA998_Ap5_4	0.065	0.017	0.100	0.176	0.000	99.789	1.321	0.613	0.708	98.468
Rice Uni.	52	NWA998_Ap5_5	0.097	0.000	0.099	0.147	0.000	100.044	1.335	0.615	0.720	98.709
Rice Uni.	53	NWA998_Ap5_6	0.089	0.000	0.139	0.171	0.005	100.617	1.304	0.568	0.736	99.313
Rice Uni.	54	NWA998_Ap5_7	0.106	0.077	0.123	0.152	0.000	99.614	1.250	0.495	0.755	98.364
Rice Uni.	57	NWA998_Ap5_10	0.074	0.059	0.084	0.169	0.000	101.603	1.299	0.520	0.780	100.304
Rice Uni.	59	NWA998_Ap5_12	0.162	0.061	0.195	0.104	0.037	99.969	1.283	0.578	0.704	98.686
Rice Uni.	60	NWA998_Ap6_1	0.036	0.000	0.109	0.175	0.000	100.476	1.315	0.490	0.825	99.161
Rice Uni.	61	NWA998_Ap6_2	0.036	0.115	0.138	0.183	0.032	101.363	1.279	0.500	0.779	100.084
Rice Uni.	62	NWA998_Ap6_3	0.047	0.000	0.155	0.182	0.086	101.005	1.258	0.531	0.727	99.747
Rice Uni.	63	NWA998_Ap6_4	0.040	0.000	0.047	0.096	0.000	101.234	1.349	0.564	0.784	99.885
Rice Uni.	64	NWA998_Ap6_5	0.049	0.104	0.070	0.154	0.134	101.358	1.294	0.526	0.768	100.064
Rice Uni.	65	NWA998_Ap6_6	0.038	0.018	0.115	0.244	0.000	101.894	1.335	0.582	0.753	100.559
Rice Uni.	66	NWA998_Ap6_7	0.033	0.033	0.070	0.262	0.000	99.449	1.261	0.492	0.769	98.188
Rice Uni.	67	NWA998_Ap6_8	0.048	0.000	0.091	0.160	0.000	101.958	1.354	0.584	0.769	100.604
Rice Uni.	68	NWA998_Ap6_9	0.033	0.005	0.098	0.183	0.060	101.481	1.297	0.572	0.725	100.184
Rice Uni.	71	NWA998_Ap6_12	0.041	0.036	0.043	0.166	0.000	101.431	1.391	0.617	0.774	100.040
Rice Uni.	72	NWA998_Ap6_13	0.046	0.045	0.084	0.175	0.000	101.535	1.310	0.573	0.737	100.225
Rice Uni.	73	NWA998_Ap6_14	0.052	0.000	0.049	0.205	0.000	101.841	1.325	0.587	0.738	100.516
Rice Uni.	74	NWA998_Ap6_15	0.043	0.039	0.085	0.176	0.102	101.509	1.309	0.582	0.727	100.200
Rice Uni.	77	NWA998_Ap7_3	0.059	0.033	0.105	0.030	0.158	101.532	1.327	0.544	0.783	100.205
Rice Uni.	78	NWA998_Ap8_1	0.043	0.000	0.095	0.285	0.000	101.418	1.349	0.521	0.827	100.069
Rice Uni.	79	NWA998_Ap8_2	0.054	0.013	0.123	0.304	0.040	102.006	1.398	0.531	0.867	100.608
Rice Uni.	80	NWA998_Ap8_3	0.042	0.000	0.087	0.240	0.000	101.261	1.358	0.525	0.833	99.903
Rice Uni.	81	NWA998_Ap8_4	0.045	0.039	0.093	0.259	0.186	101.614	1.376	0.529	0.847	100.238
Rice Uni.	82	NWA998_Ap8_5	0.040	0.027	0.106	0.253	0.000	102.350	1.451	0.578	0.873	100.899
Rice Uni.	83	NWA998_Ap8_6	0.064	0.336	0.105	0.211	0.000	101.865	1.377	0.562	0.815	100.488
Rice Uni.	84	NWA998_Ap8_7	0.045	0.108	0.043	0.142	0.000	100.245	1.409	0.663	0.746	98.836
		Average	0.054	0.041	0.098	0.186	0.041	101.326	1.304	0.570	0.734	100.022
		Min	0.020	0.000	0.043	0.030	0.000	98.971	0.948	0.402	0.547	97.676
		Max	0.162	1.399	0.258	0.306	0.371	102.579	1.600	0.868	0.873	101.366
		StDev	0.021	0.174	0.033	0.053	0.076	0.822	0.121	0.091	0.065	0.833

Supplementary Table 9. Normalized formula amount calculation for datapoint 22 ("Kep9a"). Calculated formula amounts noted in table were derived from the quantitate point analysis datapoint which exhibited the lowest content of sodium.

		Data C	ollection: JS	C-ARES - Point 2	2 - Kep9a - Normal	ized to 28 O (apfu)			
Oxide	wt%	molecular weight of oxide	molecular proportion of oxide	number of oxygen atoms in oxide concerned	atomic proportion of oxygen from each molecule	no. of anions on the basis of X# (O,OH)	no. atoms per oxygen	no. of ions in formula	
Na ₂ O	0.291	61.979	0.005	1	0.005	0.052	2	0.10	Na
CaO	46.381	56.077	0.827	1	0.827	9.091	1	9.09	Ca
MgO	2.583	40.304	0.064	1	0.064	0.704	1	0.70	Mg
FeO	3.583	71.844	0.050	1	0.050	0.548	1	0.55	Fe
P_2O_5	45.353	141.940	0.320	5	1.598	17.561	0.4	7.02	Р
SiO2	0.119	60.080	0.002	2	0.004	0.044	0.5	0.02	Si
Total	98.310				2.547	28		17.49	
					28.000	*Normalized to 28 O for merrillite, keplerite			
					10.992				
						_			-
				Mg#	56.00	Mg ratio = 100 x M	g / (Mg + Fe	e)	
				Na#	1.09	Na ratio = 100 x Na	/ (Na + Ca)		

Supplementary Table 10. Normalized formula amount calculation for Datapoint 210 ("Tissint_merrl_4"). Calculated formula amounts noted in table were derived from the quantitate point analysis datapoint which exhibited the highest content of sodium.

]	Data Collect	tion: Rice U	ni Point 210 - Ti	issint_merr1_4 - Nor	rmalized to 28 O (apf	u)		
Oxide	wt%	molecular weight of oxide	molecular proportion of oxide	number of oxygen atoms in oxide concerned	atomic proportion of oxygen from each molecule	no. of anions on the basis of X# (O,OH)	no. atoms per oxygen	no. of ions in formula	
Na ₂ O	0.981	61.979	0.016	1	0.016	0.170	2	0.34	N
CaO	46.423	56.077	0.828	1	0.828	8.910	1	8.91	Ca
MgO	3.196	40.304	0.079	1	0.079	0.853	1	0.85	M
FeO	2.387	71.844	0.033	1	0.033	0.358	1	0.36	Fe
P_2O_5	46.127	141.940	0.325	5	1.625	17.488	0.4	7.00	Р
SiO2	0.618	60.080	0.010	2	0.021	0.221	0.5	0.11	Si
Total	99.732				2.602	28		17.57	
					28.000 2.602	*Normalized to 28 O for merrillite, keplerite			
					10.762				
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				Mg#	70.23	Mg ratio = 100 x M	g / (Mg + Fe	e)	
				Na#	3.68	Na ratio = 100 x Na	/ (Na + Ca)		

Supplementary Table 11. Normalized formula amount calculation for datapoint 15 ("Kep5f"). Calculated formula amounts noted in table were derived from the quantitate point analysis datapoint which exhibited the lowest content of magnesium.

		Data C	ollection: JS	C-ARES - Point 1	15 - Kep5f - Normali	ized to 28 O (apfu)			
Oxide	wt%	molecular weight of oxide	molecular proportion of oxide	number of oxygen atoms in oxide concerned	atomic proportion of oxygen from each molecule	no. of anions on the basis of X# (O,OH)	no. atoms per oxygen	no. of ions in formula	
Na ₂ O	0.453	61.979	0.007	1	0.007	0.080	2	0.16	Na
CaO	46.960	56.077	0.837	1	0.837	9.209	1	9.21	Ca
MgO	2.567	40.304	0.064	1	0.064	0.700	1	0.70	Μş
FeO	2.931	71.844	0.041	1	0.041	0.449	1	0.45	Fe
P_2O_5	45.001	141.940	0.317	5	1.585	17.433	0.4	6.97	Р
SiO2	0.352	60.080	0.006	2	0.012	0.129	0.5	0.06	Si
Total	98.264				2.546	28		17.56	
					28.000 2.546	*Normalized to 28 O for merrillite, keplerite			
					10.997				
						-			-
				Mg#	60.87	Mg ratio = 100 x M	g / (Mg + Fe	e)	
				Na#	7.71	Na ratio = 100 x Na	/ (Na + Ca)		

Supplementary Table 12. Normalized formula amount calculation for datapoint 211 ("Tissint_merr1_5"). Calculated formula amounts noted in table were derived from the quantitate point analysis datapoint which exhibited the highest content of magnesium.

	I	Data Collect	ion: Rice U	ni Point 211 - Ti	ssint_merr1_5 - Nor	rmalized to 28 O (apf	u)		
Oxide	wt%	molecular weight of oxide	molecular proportion of oxide	number of oxygen atoms in oxide concerned	atomic proportion of oxygen from each molecule	no. of anions on the basis of X# (O,OH)	no. atoms per oxygen	no. of ions in formula	
Na ₂ O	0.638	61.979	0.010	1	0.010	0.113	2	0.23	Na
CaO	47.111	56.077	0.840	1	0.840	9.201	1	9.20	Ca
MgO	3.323	40.304	0.082	1	0.082	0.903	1	0.90	Μş
FeO	1.763	71.844	0.025	1	0.025	0.269	1	0.27	Fe
P_2O_5	45.387	141.940	0.320	5	1.599	17.510	0.4	7.00	Р
SiO2	0.011	60.080	0.000	2	0.000	0.004	0.5	0.00	Si
Total	98.233				2.557	28		17.60	
					28 2.557	*Normalized to 28 O for merrillite, keplerite			
					10.952				

Mg#	76.92	Mg ratio = $100 \times Mg / (Mg + Fe)$
Na#	2.44	Na ratio = 100 x Na / (Na + Ca)

APPENDIX C:

WAVELENGTH DISPERSIVE SPECTROMETRY (WDS)



Supplementary Figure 1. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of calcium (Ca) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 2. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chlorine (Cl) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 3. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of fluorine (F) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 4. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of iron (Fe) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 5. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of potassium (K) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 6. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of magnesium (Mg) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 7. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sodium (Na) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 8. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of phosphorous (P) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 9. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sulfur (S) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 10. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of silicon (Si) in keplerite grain #1 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 11. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of calcium (Ca) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 12. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chlorine (Cl) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 13. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of fluorine (F) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 14. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of iron (Fe) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 15. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of potassium (K) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 16. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of magnesium (Mg) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.


Supplementary Figure 17. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sodium (Na) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 18. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of phosphorous (P) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 19. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sulfur (S) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 20. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of silicon (Si) in keplerite grain #2 in Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 31. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 21. Quantitative WDS (Wavelength Dispersive Spectrometry) element map distribution and BSE (BackScattered Electron) image of symplectite in Tissint. WDS element maps illustrate elemental distributions in symplectite and surrounding phases; maps are given in weight percent (wt%). WDS element maps correspond to BSE image in the top right-hand corner.





Supplementary Figure 22. BSE (BackScattered Electron) image of symplectite in Tissint.

Supplementary Figure 23. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of aluminum (Al) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 24. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of calcium (Ca) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 25. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chlorine (Cl) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 26. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chromium (Cr) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 27. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of fluorine (F) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 28. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of iron (Fe) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 29. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of potassium (K) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 30. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of magnesium (Mg) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 31. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of manganese (Mn) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 32. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sodium (Na) in the symplectite of Tissint. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Supplementary Figure 22. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 33. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of calcium (Ca) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 34. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sulfur (S) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 35. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of silicon (Si) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 36. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of potassium (K) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 37. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of iron (Fe) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 38. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of phosphorus (P) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 39. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of magnesium (Mg) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 40. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of calcium (Ca) in apatite-merrillite intergrown grains #4-6 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 41. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sulfur (S) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 49. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 42. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of silicon (Si) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 53. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 43. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of potassium (K) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 53. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 44. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of iron (Fe) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 53. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 45. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of phosphorus (P) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 53. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.

Mg Conc.%



Supplementary Figure 46. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of magnesium (Mg) in apatite-merrillite intergrown grains #1-3 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 53. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 µm in length.



Supplementary Figure 47. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of calcium (Ca) in apatite-merrillite intergrown grain #8 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 57. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 48. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sulfur (S) in apatite-merrillite intergrown grain #8 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 57. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 49. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of silicon (Si) in apatite-merrillite intergrown grain #8 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 57. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



^K <u>Source</u> Source So



Supplementary Figure 51. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of iron (Fe) in apatite-merrillite intergrown grain #8 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 57. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.



Supplementary Figure 52. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of phosphorous (P) in apatite-merrillite intergrown grain #8 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 57. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.


Supplementary Figure 53. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of magnesium (Mg) in apatite-merrillite intergrown grain #8 in ALH 84001. WDS element maps are given in weight percent (wt%). WDS element maps correspond to BSE image from Figure 57. Plag = plagioclase; Mer = merrillite; Ap = apatite; OPX = orthopyroxene. Scale bar is 50 μ m in length.

NWA 998





Supplementary Figure 55. False color composite map of Ca-K-Mg in apatite-assemblage #1 in NWA 998.



Supplementary Figure 56. False color composite map of P-Fe-Na in apatite-assemblage #1 in NWA 998.



Supplementary Figure 57. Quantitative WDS (Wavelength Dispersive Spectrometry) element map distribution of apatite-assemblage #1 in NWA 998.



Supplementary Figure 58. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of calcium (Ca) in apatite-assemblage #1 in NWA 998.



Supplementary Figure 59. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chlorine (Cl) in apatite-assemblage #1 in NWA 998.



Supplementary Figure 60. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of fluorine (F) in apatite-assemblage #1 in NWA 998.



Supplementary Figure 61. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of iron (Fe) in apatite-assemblage #1 in NWA 998.



Supplementary Figure 62. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of potassium (K) in apatite-assemblage #1 in NWA 998.



Supplementary Figure 63. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of magnesium (Mg) in apatite-assemblage #1 in NWA 998.



Supplementary Figure 64. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sodium (Na) in apatite-assemblage #1 in NWA 998.



Supplementary Figure 65. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of phosphorous (P) in apatite-assemblage #1 in NWA 998.



Supplementary Figure 66. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of silicon (Si) in apatite-assemblage #1 in NWA 998.



Supplementary Figure 67. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sulfur (S) in apatite-assemblage #1 in NWA 998.





Supplementary Figure 69. Quantitative WDS (Wavelength Dispersive Spectrometry) element map distribution of apatite-assemblage #2 in NWA 998.



Supplementary Figure 70. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of calcium (Ca) in apatite-assemblage #2 in NWA 998.



Supplementary Figure 71. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chlorine (Cl) in apatite-assemblage #2 in NWA 998.



Supplementary Figure 72. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of fluorine (F) in apatite-assemblage #2 in NWA 998.



Supplementary Figure 73. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of iron (Fe) in apatite-assemblage #2 in NWA 998.



Supplementary Figure 74. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of potassium (K) in apatite-assemblage #2 in NWA 998.



Supplementary Figure 75. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of magnesium (Mg) in apatite-assemblage #2 in NWA 998.



Supplementary Figure 76. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sodium (Na) in apatite-assemblage #2 in NWA 998.



Supplementary Figure 77. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of phosphorous (P) in apatite-assemblage #2 in NWA 998.



Supplementary Figure 78. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of silicon (Si) in apatite-assemblage #2 in NWA 998.



Supplementary Figure 79. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sulfur (S) in apatite-assemblage #2 in NWA 998.





Supplementary Figure 81. Quantitative WDS (Wavelength Dispersive Spectrometry) element map distribution of apatite-assemblage #3 in NWA 998.



Supplementary Figure 82. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of calcium (Ca) in apatite-assemblage #3 in NWA 998.



Supplementary Figure 83. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of chlorine (Cl) in apatite-assemblage #3 in NWA 998.



Supplementary Figure 84. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of fluorine (F) in apatite-assemblage #3 in NWA 998.



Supplementary Figure 85. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of iron (Fe) in apatite-assemblage #3 in NWA 998.



Supplementary Figure 86. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of potassium (K) in apatite-assemblage #3 in NWA 998.



Mg ______ 50 um Ave 5.04 Supplementary Figure 87. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of magnesium (Mg) in apatite-assemblage #3 in NWA 998.



Supplementary Figure 88. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sodium (Na) in apatite-assemblage #3 in NWA 998.


Supplementary Figure 89. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of phosphorus (P) in apatite-assemblage #3 in NWA 998.



Supplementary Figure 90. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of silicon (Si) in apatite-assemblage #3 in NWA 998.



Supplementary Figure 91. Quantitative WDS (Wavelength Dispersive Spectrometry) elemental map distribution of sulfur (S) in apatite-assemblage #3 in NWA 998.

APPENDIX D:

RAMAN SPECTROSCOPY



Supplementary Figure 92. Backscattered electron (BSE) image of keplerite grains targeted for Raman analysis. BSE image (a) is of keplerite grain #1. BSE image (b) is of keplerite grain #2. Highly birefringent "phases" noted in BSE images are carbon coating.



Supplementary Figure 93. Representative analysis of measured Raman spectra for keplerite (grain #1) in Tissint over the 700 to 1700 cm⁻¹ range. Spectrum 212.



Supplementary Figure 94. Representative analysis of measured Raman spectra for keplerite (grain #1) in Tissint over the 880 to 1080 cm⁻¹ range. Spectrum 212.



Supplementary Figure 95. Representative analysis of measured Raman spectra for keplerite (grain #1) in Tissint over the 850 to 1100 cm⁻¹ range. Spectrum 213.



Supplementary Figure 96. Representative analysis of measured Raman spectra for keplerite (grain #1) in Tissint over the 850 to 1100 cm⁻¹ range. Spectrum 213.



Supplementary Figure 97. Representative analysis of measured Raman spectra for keplerite (grain #2) in Tissint over the 700 to 1700 cm⁻¹ range. Spectrum 215.



Supplementary Figure 98. Representative analysis of measured Raman spectra for keplerite (grain #2) in Tissint over the 870 to 1050 cm⁻¹ range. Spectrum 215.

Spectrum212: Keplerite Grain #1			
General:			
System ID:	100-1200-1546		
Start Time:	10:51:37 AM		
Start Date:	Tuesday, October 4, 2022		
Duration:	0h 5m 7s		
User Name:	Witec		
Sample Name:			
Configuration:	Raman 532		
UHTS600S_VIS:			
Excitation Wavelength [nm]:	487.954		
Laser Power [mW]:	3.175		
Grating:	G2: 1200 g/mm BLZ=500nm		
Center Wavelength [nm]:	518.303		
Spectral Center [rel. 1/cm]:	1200		
DU970P_BVF:			
Serial Number:	21926		
Readout Mode:	Single Track (1-20)		
Output Amplifier:	Conventional		
Vertical Shift Speed [µs]:	l [μs]: 9.68		
Horizontal Shift Speed [MHz]:	0.05		
Preamplifier Gain:	4		
Cycle Time [sec]: 30.13534			
Sensor Temperature [°C]:	-59		
Number Of Accumulations:	10		
Integration Time [s]:	30		
Objective:			
Objective Name:	Zeiss EC Epiplan 50x / 0.75		
Objective Magnification:	50		
Sample Location (global position):			
Position X [µm]:	-2917.5		
Position Y [µm]:	-319.5		
Position Z [µm]:	2001.12		

Supplementary Table 13. Analytical conditions for Raman spectrum 212 (keplerite grain #1).

Spectrum213: Keplerite Grain #1				
General:				
Fit Function Name:	Lorentz			
Fit Function Description:	y = y0 + 2 * 5	Sum(i=0->N-1) (A(i) / PI * w(i) / $(4*(x-x))$	$0(i))^2 + w(i)^2$
GOOD KEP1 Big grain				
Spectrum213Spec.Data				
1 (CRR) (Repaired) (Sub				
BG)				
Fit Description:				
Number of Sampling	170			
Points:	170			
Degree of Freedom (DoF):	161			
ChiSqr / DoF:	19.2832			
Coefficient of				
Determination				
CoD (R^2):	0.968732			
Correlation (R):	0.984242			
Average Error:	4.27345			
Parameters:				
Name	Value	Error	Vary	Unit
y0	0	0	no	CCD cts
x0(0)	971.889	0.498979	yes	rel. 1/cm
w(0)	8.16653	0.92389	yes	rel. 1/cm
A(0)	731 481	182 359	Vec	(rel. 1/cm)*(CCD
A(0)	/51.401	162.339	yes	cts)
x0(1)	966.559	0.854878	yes	rel. 1/cm
w(1)	7.25837	3.55889	yes	rel. 1/cm
A(1)	301 287	240 876	Vec	(rel. 1/cm)*(CCD
A(1)	501.287	240.870	yes	cts)
x0(2)	957.14	0.405754	yes	rel. 1/cm
w(2)	13.0625	0.872712	yes	rel. 1/cm
A(2)	1240.1	116.076	Vec	(rel. 1/cm)*(CCD
rn(2)	1270.1	110.770	yes	cts)

Supplementary Table 14. Lorentz conditions for Raman spectrum 213 (keplerite grain #1).

Spectrum213: Keplerite Grain #1		
General:		
System ID:	100-1200-1546	
Start Time:	10:57:29 AM	
Start Date:	Tuesday, October 4, 2022	
Duration:	0h 10m 9s	
User Name:	Witec	
Sample Name:		
Configuration:	Raman 532	
UHTS600S_VIS:		
Excitation Wavelength [nm]:	487.954	
Laser Power [mW]:	4.997	
Grating:	G2: 1200 g/mm BLZ=500nm	
Center Wavelength [nm]:	518.303	
Spectral Center [rel. 1/cm]:	1200	
DU970P_BVF:		
Serial Number:	21926	
Readout Mode:	Single Track (1-20)	
Output Amplifier:	Conventional	
Vertical Shift Speed [µs]:	9.68	
Horizontal Shift Speed [MHz]:	0.05	
Preamplifier Gain:	4	
Cycle Time [sec]:	30.13534	
Sensor Temperature [°C]:	-59	
Number Of Accumulations:	20	
Integration Time [s]:	30	
Objective:		
Objective Name:	Zeiss EC Epiplan 50x / 0.75	
Objective Magnification:	50	
Sample Location (global position):		
Position X [µm]:	-2917.5	
Position Y [µm]:	-319.5	
Position Z [µm]:	2001.12	

Supplementary Table 15. Analytical conditions for Raman spectrum 213 (keplerite grain #1).

Spectrum214: Keplerite Grain #2				
General:				
Fit Function Name:	Lorentz			
Fit Function Description:	y = y0 + 2 * S	Sum(i=0->N-1) (A(i)	/ PI * w(i) / (4*(x-x0	$(i))^{2} + w(i)^{2}$
GOOD Kep2 Left Grain				
Spectrum214Spec.Data				
1 (CRR) (Sub BG)				
Fit Description:				
Number of Sampling	173			
Points:	175			
Degree of Freedom (DoF):	164			
ChiSqr / DoF:	91.1895			
Coefficient of				
Determination				
CoD (R^2):	0.979214			
Correlation (R):	0.989552			
Average Error:	9.29761			
Parameters:				
Name	Value	Error	Vary	Unit
y0	0	0	no	CCD cts
x0(0)	958.037	0.235535	yes	rel. 1/cm
w(0)	10.9012	0.661396	yes	rel. 1/cm
A(0)	2852-16	239 381	Ves	(rel. 1/cm)*(CCD
A(0)	2052.10	257.501		cts)
x0(1)	968.764	0.715944	yes	rel. 1/cm
w(1)	8.76938	2.1779	yes	rel. 1/cm
A(1)	1576.22	676.434	ves	(rel. 1/cm)*(CCD
	10,0122		<i>,</i>	cts)
x0(2)	973.699	0.320652	yes	rel. 1/cm
w(2)	5.96298	1.05165	yes	rel. 1/cm
A(2)	1271.45	468.628	ves	(rel. 1/cm)*(CCD
(-)	12,110		,	cts)

Supplementary Table 16. Lorentz conditions for Raman spectrum 214 (keplerite grain #2).

Spectrum214: Keplerite Grain #2		
General:		
System ID:	100-1200-1546	
Start Time:	11:08:33 AM	
Start Date:	Tuesday, October 4, 2022	
Duration:	0h 10m 11s	
User Name:	Witec	
Sample Name:		
Configuration:	Raman 532	
UHTS600S_VIS:		
Excitation Wavelength [nm]:	487.954	
Laser Power [mW]:	5.01	
Grating:	G2: 1200 g/mm BLZ=500nm	
Center Wavelength [nm]:	518.303	
Spectral Center [rel. 1/cm]:	1200	
DU970P_BVF:		
Serial Number:	21926	
Readout Mode:	Single Track (1-20)	
Output Amplifier:	Conventional	
Vertical Shift Speed [µs]:	9.68	
Horizontal Shift Speed [MHz]:	0.05	
Preamplifier Gain:	4	
Cycle Time [sec]:	30.13534	
Sensor Temperature [°C]:	-59	
Number Of Accumulations:	20	
Integration Time [s]:	30	
Objective:		
Objective Name:	Zeiss EC Epiplan 50x / 0.75	
Objective Magnification: 50		
Sample Location (global position):		
Position X [µm]:	-2754.7	
Position Y [µm]:	56.3	
Position Z [µm]:	2001.12	

Supplementary Table 17. Analytical conditions for Raman spectrum 214 (keplerite grain #2).

Spectrum215: Keplerite Grain #2				
General:				
Fit Function Name:	Lorentz			
Fit Function Description:	y = y0 + 2 * 3	Sum(i=0-N-1) (A(i)) / PI * w(i) / (4*(x-x))	$0(i))^2 + w(i)^2$
GOOD Kep Right bottom				
grain Spectrum215				
Spec.Data 1 (CRR) (Sub				
BG)				
Fit Description:				
Number of Sampling				
Points:	207			
Degree of Freedom (DoF):	198			
ChiSar / DoF:	176.213			
Coefficient of				
Determination				
CoD (R^2):	0.962298			
Correlation (R):	0.980968			
Average Error:	12.9827			
Parameters:				
Name	Value	Error	Vary	Unit
y0	0	0	no	CCD cts
x0(0)	973.807	0.390616	yes	rel. 1/cm
w(0)	5.79932	1.24623	yes	rel. 1/cm
A(0)	1388.38	622.436	ves	(rel. 1/cm)*(CCD
		0.004/000	J	cts)
x0(1)	969.054	0.984628	yes	rel. l/cm
w(1)	8.46137	2.76667	yes	rel. l/cm
A(1)	1509.46	862.201	yes	(rel. 1/cm)*(CCD cts)
x0(2)	957.891	0.24783	yes	rel. 1/cm
w(2)	10.6055	0.727197	yes	rel. 1/cm
A(2)	3270.86	285.248	yes	(rel. 1/cm)*(CCD
. ,			,	cts)

Supplementary Table 18. Lorentz conditions for Raman spectrum 215 (keplerite grain #2).

Spectrum215: Keplerite Grain #2		
General:		
System ID:	100-1200-1546	
Start Time:	11:20:57 AM	
Start Date:	Tuesday, October 4, 2022	
Duration:	0h 10m 10s	
User Name:	Witec	
Sample Name:		
Configuration:	Raman 532	
UHTS600S_VIS:		
Excitation Wavelength [nm]:	487.954	
Laser Power [mW]:	5.017	
Grating:	G2: 1200 g/mm BLZ=500nm	
Center Wavelength [nm]:	518.303	
Spectral Center [rel. 1/cm]:	1200	
DU970P_BVF:		
Serial Number:	21926	
Readout Mode:	Single Track (1-20)	
Output Amplifier:	Conventional	
Vertical Shift Speed [µs]:	9.68	
Horizontal Shift Speed [MHz]:	0.05	
Preamplifier Gain:	4	
Cycle Time [sec]:	30.13534	
Sensor Temperature [°C]:	-59	
Number Of Accumulations:	20	
Integration Time [s]:	30	
Objective:		
Objective Name:	Zeiss EC Epiplan 50x / 0.75	
Objective Magnification:	50	
Sample Location (global position):		
Position X [µm]:	-2722.1	
Position Y [µm]:	28.3	
Position Z [µm]:	2001.12	

Supplementary Table 19. Analytical conditions for Raman spectrum 215 (keplerite grain #2).

APPENDIX E:

ELECTRON BACKSCATTERED DIFFRACTION (EBSD)



Supplementary Figure 99. Backscattered electron (BSE) image and phase map (Ph) of keplerite grain #1 (and associated) phases in Tissint. Keplerite grains outlined in red.



Supplementary Figure 100. Backscattered electron (BSE) image and phase map (Ph) of keplerite grain #2 (and associated) phases in Tissint. Keplerite grains outlined in red.