VIII. ALHA77005

Lherzolite, 482 grams

Weathering A, Fracturing A

Figure VIII-1. *Photograph (or Mug Shot) of exterior surface of ALHA77005 showing minor fusion crust and "polished" appearance. The cube is 1 cm. (NASA #S78-31750)*

Introduction

This Martian meteorite was found partially imbedded in the ice at the Allan Hills site during one of the first collecting seasons (Yanai *et al*. 1978). It has a rounded (slightly oblate) shape and its surface was partially-ablated and roughly-polished by wind-blown ice (figure VIII-1). Only ~5% of the surface still had a thin black fusion crust at the time of collection (Mason 1978, 1981). Interior voids (2-4 mm), exposed by the saw cuts, appear to be surrounded by shock melt. At least one small hole (1 mm) extends to the surface (T1).

Preliminary examination of ALHA77005 reported that it is ~55% olivine, ~35% pyroxene, ~8% maskelynite and ~2% opaques (Mason 1981). The olivine (Fa_{28}) occurs as anhedral to subhedral grains up to 2 mm long. The pyroxene occurs as prismatic crystals up to 6 mm long poikilitically enclosing olivine. Maskelynite (An_{53}) is interstitial to olivine and pyroxene. Some pyroxene has undulose extinction and some shock melting has occurred.

ALHA77005, LEW88516 and Y793605 have very similar mineralogy, texture and shock features (Treiman *et al.* 1994; Mikouchi and Miyamoto 1997, 2000). ALHA77005 and LEW88516 have apparently been more heavily shocked than other SNC meteorites (see below).

ALHA77005 has been extensively studied by Ishii *et al.* (1979), McSween *et al.* (1979 a, b), Berkley and Keil (1981), Ma *et al.* (1981), Shih *et al.* (1982), Reitmeijer (1983), Smith and Steele (1984), Collinson (1986), Jagoutz (1989b), Lundberg *et al.* (1990), Mikouchi and Miyamoto (2000) and Ikeda (1994, 1998).

Figure VIII-2. Photograph of first sawn surface of ALHA77005 illustrating "light" and "dark" regions (NASA #S78-37989).

Petrography

ALHA77005 is a cumulate gabbroic rock consisting of brown olivine, low- and high-Ca pyroxene, plagioclase glass, Ti-poor and -rich chromite, ilmenite, whitlockite and sulfides (McSween *et al.* 1979; Lundberg *et al.* 1990; Ikeda 1994). The large sawn surface shows three lithologies: 1) lighter, 2) darker and 3) glass (figure VIII-2).

The saw cut shows that ALHA77005 has distinct, interpenetrating, cm-sized, light and dark regions. The textures of these regions are different. The light-colored regions are composed of large pyroxenes poikilitically enclosing euhedral to subhedral olivine and chromite grains (figure VIII-3). The low-Ca pyroxene megacrysts occur up to 5 mm across. In the dark-colored, interstitial lithology, poikilitic pyroxenes, olivine, maskelynite, small pyroxenes (both pigeonite and augite), titaniferous chromite, ilmenite, sulfides and phosphates are found. In both regions the olivine appears to be cumulus. In thin section, the olivine has a distinct brown color, apparently due to the presence of Fe^{+3}.

This rock has an igneous texture *(see the beautiful color picture of a thin section in Yanai and Kojima (1987, page 52)*. A study of the olivine orientation by Berkley and Keil (1981) showed that ALHA77005 is a cumulate rock that solidified in the act of flow and accumulation. However, this rock has been heavily shocked (see below). In some areas of the meteorite, small patches of melt glass containing skeletal and hollow crystallites

Mineralogical Mode

	Mason 1981	**Treiman *et al.* 1994**	**Ma 1981** *(norm)*	**Wadhwa *et al.* 1994**
Olivine	55	60	52	44-52
Pyroxene	35	13	37	43
Maskelynite	8	9.5	10	10-12
Phosphate		0.4		tr.
Chromite	2	2	1	1
Ilmenite		0.5		
Pyrrhotite		0.3		
Melt		14		

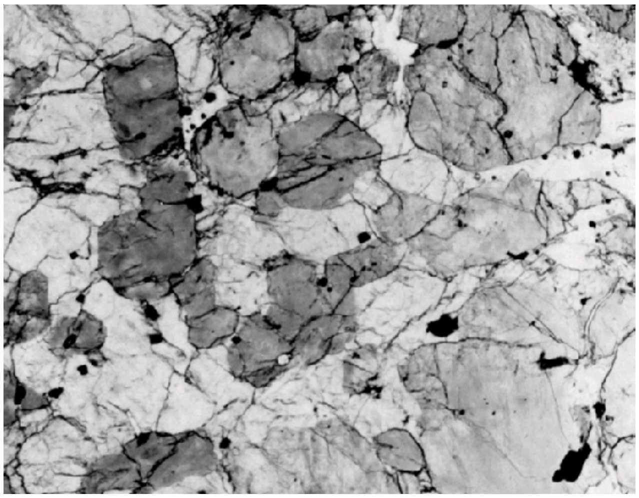

Figure VIII-3. Photomicrograph of thin section of ALHA77005,52. Large poikilitic orthopyroxene encloses euhedral olivine and chromite. Olivine is oddly colored tan to reddish-brown by minor Fe+3. Field of view is 2.2 mm.

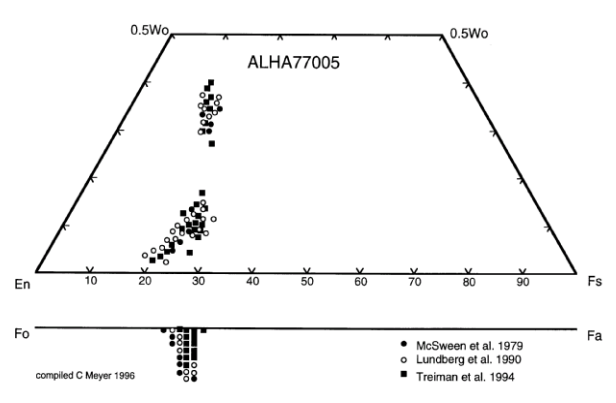

***Figure VIII-4.** Composition diagram for pyroxene and olivine in ALHA77005. Data from McSween et al. 1979, Lundberg et al. 1990, and Treiman et al. 1994.*

of olivine and dendritic chromite grains have been reported (McSween *et al.* 1979).

Lundberg *et al.* (1990) report that the Fe/Mg of the apparently cumulus olivine is out of equilibrium with the coexisting clinopyroxene and the original calculated magmatic liquid. Longhi and Pan (1989), Lundberg *et al.* (1990) and Harvey and McSween (1992) have inferred that original Mg-rich olivine has become more Fe-rich by post-magmatic subsolidus diffusion.

Magmatic melt inclusions in olivine and pyroxene in ALHA77005 have been studied by Ikeda (1998), Stockstill *et al.* (2001) and Zipfel and Goodrich (2001).

Mineral Chemistry

***Olivine*:** Olivine in ALH77005 has an unusual, distinctive pale brown color. Approximately 4.5% of the iron in the olivine in ALHA77005 is trivalent and the distinctive brown color of the olivine may be due to shock-induced oxidation (Ostertag *et al.* 1984).

The average grain size of olivine is 1 mm, with some grains up to 2 mm (Berkley and Keil 1981). A weak preferred orientation of olivine grains indicates that this cumulate rock solidified during magmatic flow. Many grains have a round habit, possibly caused by reaction with intercumulus liquid. The chemical composition of olivine is homogeneous within each grain, but varies from grain to grain, ranging from Fo_{75} to Fo_{70} (Ikeda 1994). Lundberg *et al.* (1990) have shown that this homogeneity was caused by re-equilibration with the intercumulus liquid on cooling.

Quench olivine in shock-melt pockets and veins has chemical zoning from Fa_{16}-Fa_{42}.

***Pyroxene*:** The large pyroxenes in the poikilitic portion of ALHA77005 show chemical zoning from high-Mg, low-Ca orthopyroxene cores to Mg-rich pigeonite with rims of ferroan pigeonite (figure VIII-4) (Mikouchi and Miyamoto 1997). There appears to be a compositional gap from orthopyroxene to Mg-pigeonite. Lundberg *et al.* (1990) have determined the REE composition of large poikilitic pyroxene grains.

High-Ca pyroxene occurs in both the poikilitic and non-poikilitic portions and shows chemical zoning from sub-calcic to Ca-rich augite. Augite often occurs in contact with pigeonite, suggesting that they crystallized in close association with each other. There is no evidence of exsolution in pyroxenes.

Plagioclase: Maskelynite is present in areas of ALH77005 as pseudomorphs of the original plagioclase grains and is found to have refractive indices lower than those of maskelynite in other shergottites (McSween and Stöffler 1980; Stöffler *et al.* 1986). In areas near the melt pockets (lithology 3), Ikeda (1994) noted that the borders of some of the original plagioclase grains were made of rims of recrystallized Ca-rich plagioclase. Ikeda (1994) analyzed the maskelynite in ALHA77005 with broad-beam microprobe technique and found there was a compositional “gap” between the plagioclase rims and the plagioclase glass. The interpretation is that plagioclase melt produced by the shock, partially

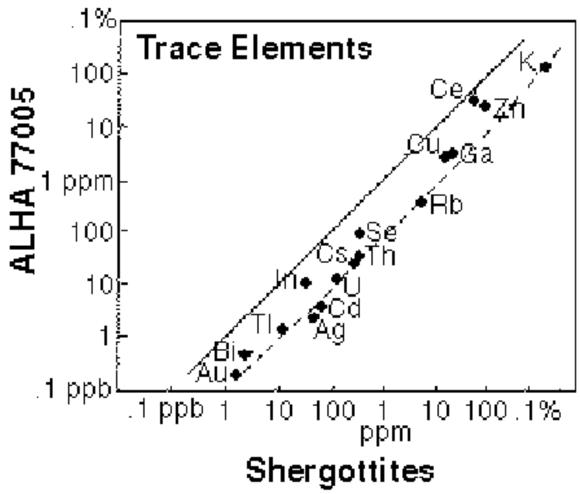

Figure VIII-5. Rough comparison of composition of ALHA77005 with that of Shergotty by McSween et al. 1979, EPSL ***45****, 280.*

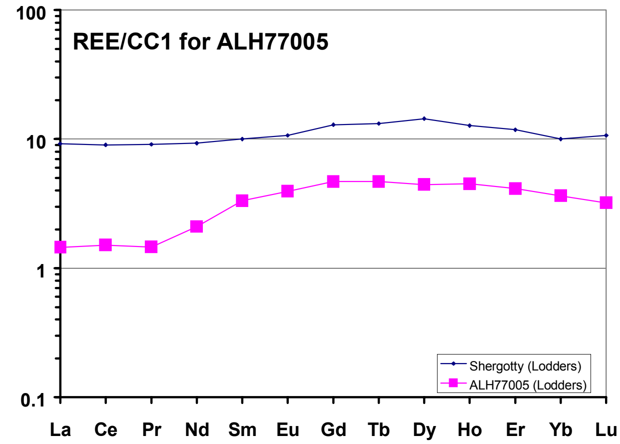

Figure VIII-6. *Normalized rare-earth-element composition diagram comparing ALHA77005 with Shergotty (data from Lodders 1998).*

recrystallized at the rims and the remainder was quenched as glass. In other areas the maskelynite is normally zoned from An_{50} to An_{45}. Tiny vesicles (bubbles?) are present in the plagioclase glass. According to Treiman *et al.* (1994), maskelynite in ALHA77005 has an average composition of An_{52} and a range from An_{24-56}.

Chromite: The chromite in ALHA77005 has four types of occurrence, based on differences in chemical zoning (Ikeda 1994). McSween *et al.* (1979a) reported that as much at 10% of the iron in the chromite was Fe^{+3}.

Ilmenite**:** Treiman *et al*. (1994) and McSween *et al.* (1979a) reported ilmenite with 5% MgO.

Phosphate**:** Lundberg *et al.* (1990) determined the REE composition of whitlockite.

Sulfides**:** Ikeda (1994) gives the compositions of the sulfides (pyrrhotite with exsolved pentlandite, Ni=10%). McSween *et al.* (1979a) and Smith *et al.* (1983) reported troilite in ALHA77005, but this is probably incorrect.

Kaersutite: Ikeda (1998) analyzed kaersutite found in magmatic inclusions in oikocrystic pigeonite.

Salts: McSween *et al.* (1979a) reported a FeO(OH) phase in isolated areas associated with sulfides.

Whole-rock Composition

Jarosewich analyzed prepared powders of both the bulk sample and of the light and dark lithologies (Jarosewich 1990) as part of the McSween consortium. The analyses of the bulk sample and two distinct lithologies were not found to be very different, considering the difference in texture and mineralogy (table VIII-1). McSween *et al.* (1979b) found the trace element content in ALHA77005 compared closely with that in the shergottites (figure VIII-5). The high K/U, Rb/U, Cs/U and Th/U are distinctive (almost Earth-like) when compared to basaltic achondrites.

The REE have been determined by Shih *et al.* (1982), Burghele *et al*. (1983), Smith *et al*. (1984), Treiman *et al.* (1994), and Haramura (1995) (figure VIII-6)**.** REE in the light and dark lithologies vary by a factor of about two (Treiman *et al.*). However, the light rare earth elements (LREE) are found to be depleted (figure VIII-6) as are certain other trace elements (Rb, Nb, Cs, Ba, Ta, Th and U, figure VIII-7). Shimizu and Masuda (1981) reported a Ce anomaly and Lundberg *et al.* (1992) found that the Ce anomaly was related to weathering of the pyroxene.

Dreibus *et al.* (1992) and Treiman *et al.* (1994) found that the composition of ALHA77005 was almost identical to that of LEW88516. Ir was found to be low — *in the range of the terrestrial upper mantle.*

Burgess *et al.* (1989) determined about 400 ppm S and Burghele *et al.* reported 600 ppm S in ALHA77005. Gooding *et al*. (1990) determined the thermal release

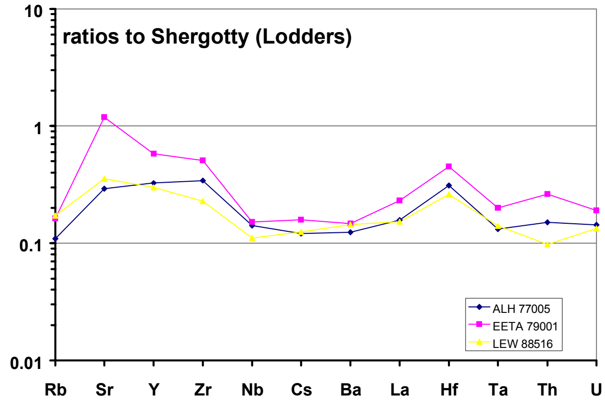

Figure VIII-7. Ratio of trace element contents of ALHA77005, EETA79001 and LEW88516 to those of Shergotty (for reference) showing that Rb, Nb, Cs, Ba, La (and LREE), Ta, Th and U are "depleted" in this special class of Martian meteorites.

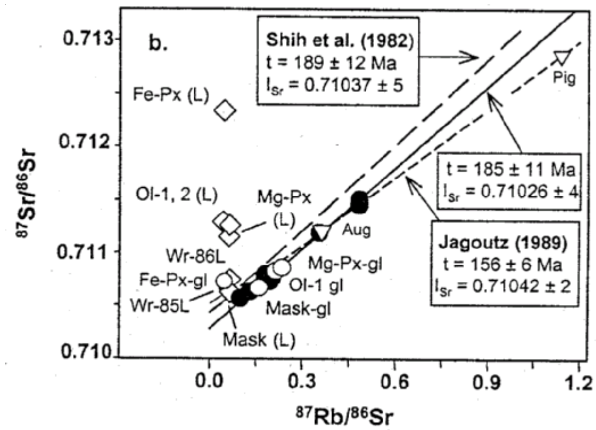

*Figure VIII-8. Rb-Sr isochron for ALH77005 from Borg et al. 2001, GCA **66**, 2037.*

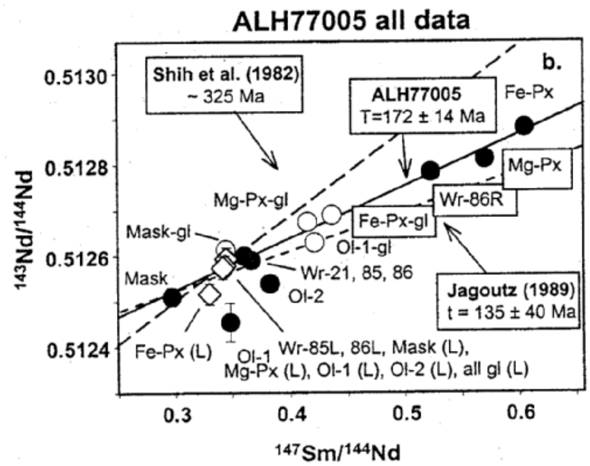

*Figure VIII-9. Sm-Nd isochron for ALHA77005 from Borg et al. 2001, GCA **66**, 2037.*

pattern for several volatile species.

Shock Features

ALHA77005 has been more heavily shocked than the other SNC meteorites. Maskelynite is found to have refractive indices lower than that in other shergottites (McSween and Stöffler 1980; Stöffler *et al.* 1986). Ikeda (1994) reported that all of the olivine and pyroxene showed mosaic extinction under the microscope. McSween and Stöffler found that irregular shock-melt pockets and pseudotachylite veins comprise up to 20% by volume of the rock. Stöffler *et al.* (1986) concluded that ALHA77005 reached equilibrium shock pressure of 43 ± 2 GPa and post-shock temperature of 400 - 800^{o}C. Bishoff and Stöffler (1992) and Boctor *et al.* (1999) have also studied the shock features in ALHA77005 and Rietmeijer (1983) discussed "shock-induced chemical reactions."

Boctor *et al.* noted that the similar shock features and peak shock pressures of ALHA77005, LEW88516 and EETA79001 might indicate that they were all "metamorphosed" by the same impact event! *(however, EETA79001 has a distinct exposure age)*

Magnetic Studies

The anhysteretic remanent magnetization (ARM) technique for the determination of the paleomagnetic field on Mars has been attempted on ALHA77005 (Nagata 1980; Collinson 1986), but the results are inconclusive (Sugiura and Strangway 1988). The presence of Fe^{+3} in the magnetic phases (titanomagnetite) may help this experiment, but the high shock pressures and complicated histories of SNC meteorites may have disturbed any natural remanent magnetism (NRM), making this important experiment very challenging. If the shock event induced enough reheating, the original NRM may have been erased and re-acquired at the time of shock (Sugiura and Strangway 1988). Nagata (1980) reported a small amount of metallic iron in his magnetic studies, but this can not be in equilibrium with the original mineral assemblage.

Radiogenic Isotopes

Shih *et al.* (1982) reported a Rb-Sr age of 187 ± 12 Ma with $^{87}Sr/^{86}Sr = 0.71037 \pm 5$ ($\lambda_{Rb} = 1.39 \times 10^{-11}$ year^{-1}) and a Sm-Nd age of ~ 325 Ma. Schaeffer and Warsila (1981) obtained a vague $^{40}Ar/^{39}Ar$ plateau age of about 1.1 Ga. However, Jessberger *et al.* (1981) used laser probe extraction to show that excess ^{40}Ar is located inhomogenously within the minerals of ALHA77005. Jagoutz (1989b) determined an age of 154 ± 6 Ma (

Table VIII-1a. Chemical composition of ALHA77005.

	Wanke 86	Smith 84	Dreibus92	Dreibus92	Jarosewich90	Jarosewich90	Jarosewich90	Burghele 83	Haramura 95
						*dark **	*light **		
weight									
SiO2 %			43.08 (b)		42.4 (a)	41.41 (a)	45.8 (a)	43.08 (b)	43.02 (a)
TiO2		0.3 (b)	0.44 (b)		0.46 (a)	0.52 (a)	0.31 (a)	0.44 (b)	0.36 (a)
Al2O3		3 (b)	2.59 (b)		3.14 (a)	3.41 (a)	1.99 (a)	2.59 (b)	2.54 (a)
FeO	20.71 (b)	20.2 (b)	19.95 (b)		19.85 (a)	20.84 (a)	18.51 (a)	19.95 (b)	18.97 (a)
MnO	0.461 (b)	0.44 (b)	0.44 (b)		0.46 (a)	0.45 (a)	0.45 (a)	0.457 (b)	0.45 (a)
CaO	3.01 (b)	3.8 (b)	3.35 (b)		3.39 (a)	3.36 (a)	3.37 (a)	3.35 (b)	2.84 (a)
MgO		26.5 (b)	27.69 (b)		28.16 (a)	27.84 (a)	28.16 (a)	27.69 (b)	29.69 (a)
Na2O	0.597 (b)	0.48 (b)	0.44 (b)		0.48 (a)	0.6 (a)	0.27 (a)	0.438 (b)	0.37 (a)
K2O	0.033 (b)	0.028 (b)	0.027 (b)		0.04 (a)	0.04 (a)	0.02 (a)	0.027 (b)	0.03 (a)
P2O3			0.36 (b)	0.44 (d)	0.41 (a)	0.45 (a)	0.19 (a)	0.36 (b)	0.39 (a)
sum					**98.79**	**98.92**	**99.07**	**98.382**	**98.66**
Li ppm			1.31 (b)					1.31 (b)	
C			82 (b)		200	100	200	82 (b)	
F			22 (b)					21.9 (b)	
S			600 (b)					600 (b)	
Cl			14 (b)					14 (b)	
Sc	20.1 (b)	22 (b)	21.1 (b)					21.1 (b)	
V		158 (b)	158 (b)						
Cr	6700 (b)	5679 (b)	6568 (b)		7184 (a)	6090 (a)	7390 (a)	6589 (b)	6842 (a)
Co	75.2 (b)	69 (b)	69.5 (b)					69.5 (b)	
Ni	340 (b)	320 (b)	370 (b)		100	300	300	335 (b)	240 (a)
Cu		5.5 (b)	4.4 (b)						
Zn	62 (b)	49 (e)	71 (b)					71 (b)	
Ga	8.9 (b)	6.1 (e)	7.5 (b)					7.5 (b)	
Ge									
As		0.0014 (e)	0.022 (b)					0.022 (b)	
Se		0.15 (e)	<0.4 (b)					<0.4 (b)	
Br			0.085 (b)					0.069 (b)	**Shimizu 81**
Rb		0.63 (b)	0.63 (b)	0.75 (d)					0.633 (c)
Sr		15		14.1 (d)				100 (b)	8.06 (c)
Y				6.18 (d)					
Zr				19.5 (d)					
Nb				0.57 (d)					
Mo	0.2 (b)								
Pd ppb									
Ag ppb		4.4 (e)							
Cd ppb		6 (e)							
In ppb		11 (e)							
Sb ppb	<50 (b)	0.68 (e)						<60 (b)	
Te ppb		0.5 (e)							
I ppm			1.72 (b)					1.72 (b)	
Cs ppm		0.038 (b)	0.04 (b)	0.037 (d)					
Ba		5.3 (b)		4.64 (d)					3.45 (c)
La	0.49 (b)	0.32 (b)	0.32 (b)	0.37 (d)				0.32 (b)	0.1812(c)
Ce	1.6 (b)	0.84 (b)	1.09 (b)	1 (d)				1.09 (b)	0.758 (c)
Pr		0.13 (b)							
Nd	1.9 (b)	0.82 (b)	1.15 (b)	0.8 (d)				1.15 (b)	0.399 (c)
Sm	0.67 (b)	0.46 (b)	0.42 (b)	0.47 (d)				0.42 (b)	0.226 (c)
Eu	0.288 (b)	0.22 (b)	0.2 (b)	0.22 (d)				0.2 (b)	0.1187(c)
Gd	1.1 (b)	0.92 (b)							0.44 (c)
Tb	0.19 (b)	0.18 (b)	0.17 (b)	0.16 (d)				0.17 (b)	
Dy	1.3 (b)	1.16 (b)	0.96 (b)	1.1 (d)				0.96 (b)	0.569 (c)
Ho	0.28 (b)	0.27 (b)	0.22 (b)	0.25 (d)				0.22 (b)	
Er		0.66 (b)							0.336 (c)
Tm	0.12 (b)	0.09 (b)	0.08 (b)	0.094 (d)				0.08 (b)	
Yb	0.73 (b)	0.55 (b)	0.52 (b)	0.52 (d)				0.52 (b)	0.315 (c)
Lu	0.1 (b)	0.077 (b)	0.073 (b)	0.076 (d)				0.073 (b)	0.0461(c)
Hf	0.78 (b)	0.58 (b)	0.55 (b)	0.57 (d)				0.55 (b)	
Ta	0.033 (b)		0.026 (b)					0.026 (b)	
W ppb			84 (b)					84 (b)	
Re ppb									
Os ppb									
Ir ppb	4 (b)		3.5 (b)					3.5 (b)	
Au ppb	1.3 (b)	0.29 (e)	0.3 (b)					0.3 (b)	
Tl ppb		1.7 (e)							
Bi ppb		(0.7 (e)				**Chen and Wasserburg 86**			
Th ppm	<0.1 (b)		<0.1 (b)	0.53 (d)		0.058 (c)		<0.1 (b)	
U ppm	<0.04 (b)	0.029 (e)	<0.05 (b)	0.012 (d)		0.015 (c)		<0.05 (b)	

technique *(a) wet chem., (b) INAA & RNAA, (c) isotope dilution mass spec., (d) spark source mass spec., (e) RNAA, (f) INAA, (g) ICP-OES”*

** from powder prepared by Jarosewich*

Table VIII-1b. Chemical composition of ALHA77005 (continued).

	Treiman94	Trieman 94	Trieman 94	McSween79	Ma 81	Ma 81	Shih 81	Warren96	Onuma81	Onuma81	Jagoutz89
		*light **	*dark **								
weight	*calculated*	*70 mg*	*74 mg*		*311 mg*	*42.7 mg*					87 mg
SiO2 %	40.8										
TiO2	0.61										
Al2O3	3.8										
FeO	21.7	18.4 (f)	21 (f)								
MnO	0.48										
CaO	2.9	3.4 (f)	3.5 (f)								
MgO	28										
Na2O	0.63	0.296 (f)	0.586 (f)								
K2O	0.04	0.02 (f)									
P2O3	0.34										
sum	**99.3**										
Li ppm							1.58 (c)				
C											
F											
S											
Cl											
Sc		22.2 (f)	22 (f)		22 (f)						
V					158 (f)						
Cr		8142 (f)	6979 (f)								
Co		67.4 (f)	77 (f)	67.2 (e)	70 (f)						
Ni		320 (f)	340 (f)		320 (f)			298 (e)			
Cu				5.47 (e)							
Zn				49.4 (e)				58 (e)			
Ga				6.07 (e)							
Ge								0.58 (e)			
As				0.0014	(e)						
Se			0.5 (f)	0.149 (e)							
Br											
Rb				0.626 (e)			0.783 (c)				0.783(c)
Sr						16 (e)	14.1 (c)		6.2 (f)	6.3 (f)	16.4 (c)
Y											
Zr											
Nb											
Mo											
Pd ppb											
Ag ppb				4.37 (e)							
Cd ppb				5.92 (e)							
In ppb				11.1 (e)							
Sb ppb				0.69 (e)							
Te ppb				0.45 (e)							
I ppm											
Cs ppm		0.03 (f)	0.05 (f)	0.038 (e)							0.083(c)
Ba						6 (e)	4.53 (c)		2.4 (f)	2.3 (f)	
La		0.21 (f)	0.51 (f)		0.33 (f)	0.33 (e)	0.314 (c)				
Ce			2.6 (f)			0.94 (e)	0.74 (c)				
Pr						0.13 (e)					
Nd						0.88 (e)	0.76 (c)				1.119(c)
Sm		0.29 (f)	0.63 (f)		0.46 (f)	0.46 (e)	0.45 (c)				0.631(c)
Eu		0.134 (f)	0.89 (f)		0.21 (f)	0.23 (e)	0.224 (c)				
Gd						0.92 (e)					
Tb		0.13 (f)	0.2 (f)			0.18 (e)					
Dy					1.1 (f)		1.16 (c)				
Ho						0.27 (e)					
Er							0.66 (c)				
Tm						0.09 (e)					
Yb		0.4 (f)	0.71 (f)		0.53 (f)	0.58 (e)	0.54 (c)				
Lu		0.055 (f)	0.099 (f)		0.078 (f)	0.08 (e)	0.074 (c)				
Hf		0.42 (f)	0.81 (f)		0.58 (f)						
Ta		0.02 (f)	0.04 (f)								
W ppb											
Re ppb								0.102 (e)			
Os ppb								4.4 (e)			
Ir ppb		6 (f)	3.3 (f)					4.1 (e)			
Au ppb		3.6 (f)	1.5 (f)	0.288 (e)				0.26 (e)			
Tl ppb				1.7 (e)							
Bi ppb				<0.72 (e)							
Th ppm				0.059 (e)							
U ppm				0.018 (e)		0.04 (e)					

Table VIII-1c. Chemical composition of ALHA77005 (continued).

	Warren 97	Mittlefehldt 97	Mittlefehldt 97	Mittlefehldt 97	Shih 82	Shih 82	Ebihara97	Ebihara97
	615 mg	*light **	*dark **	*bulk*			*119 mg*	
SiO2 %	41.36							
TiO2	<0.83					0.3		
Al2O3	3.02						2.19	
FeO	20.45	17.5 (f)	20.3 (f)	19.9 (f)			18.13	
MnO	0.44						0.5	
CaO	2.94	2.7 (f)	3.6 (f)	3.2 (f)			3.95	
MgO	29.0						25.17	
Na2O	0.443	0.207 (f)	0.541 (f)	0.425 (f)			0.59	
K2O	0.03						0.06	
P2O3								
sum	**98.51**							
Li ppm								
C								
F								
S								
Cl								
Sc	19	20.1 (f)	22.7 (f)	20.4 (f)			21.6 (f)	
V	166						132	
Cr	7000						6520	
Co	78	65 (f)	74.9 (f)	72.2 (f)			77.7	
Ni	310	320 (f)	353 (f)	320 (f)			338	
Cu								
Zn	59	74 (f)	90 (f)	71 (f)			60.7	
Ga	6.9						9.3	
Ge	0.58							
As								
Se	0.04						0.37	
Br								
Rb	<4.2							
Sr	<20							
Y								
Zr	<30							
Nb								
Mo								47.3 (e)
Pd ppb								
Ag ppb								4
Cd ppb	2.1							
In ppb								
Sb ppb								
Te ppb								
I ppm								
Cs ppm	<0.09							
Ba	<18							
La	0.40	0.156 (f)	0.427 (f)	0.325 (f)			0.614	
Ce	<2.5						1.28	
Pr								
Nd	<0.9				0.795 (c)	0.868 (c)		
Sm	0.48	0.216 (f)	0.565 (f)	0.451 (f)	0.361 (c)	0.356 (c)	0.77	
Eu	0.25	0.094 (f)	0.465 (f)	0.241 (f)			0.373	
Gd								
Tb	0.17	0.09 (f)	0.19 (f)	0.16 (f)			0.296	
Dy	1.04							
Ho	0.23							
Er								
Tm								
Yb	0.57	0.33 (f)	0.68 (f)	0.53 (f)			0.919	
Lu	0.085	0.047 (f)	0.097 (f)	0.076 (f)	**Lee 98**		0.127	
Hf	0.57	0.25 (f)	0.67 (f)	0.51 (f)	0.5586 (c)		0.951	
Ta	0.04		0.04 (f)	0.03 (f)				
W ppb					55.43 (c)			38 (e)
Re ppb	0.102							0.197 (e)
Os ppb	4.4							8.98 (e)
Ir ppb	4.1	7 (f)	5 (f)	6 (f)			8.7	9.11 (e)
Au ppb	0.26							0.342 (e)
Tl ppb								
Bi ppb								
Th ppm	<0.1							
U ppm	<0.06							
technique	*(a) wet chem., (b) INAA & RNAA, (c) isotope dilution mass spec., (d) spark source mass spec., (e) RNAA, (f) INAA, (g) ICP-OES*							

** from powder prepared by Jarosewich*

Table VIII-1d. Chemical composition of ALHA77005 (continued).

reference	*Lodders 98*	Warren 99		Wang 98		Kong 99		Brandon 2000		Neal 2001		
weight	*average*	*300 mg*				*118.9 mg*		*202.9 mg*				
SiO2	42.4	41.29										
TiO2	0.39	<0.83	(a)			0.4	(a)					
Al2O3	2.87	3.13	(a)			2.13	(a)					
FeO	20.1	20.45	(a)			20.33	(a)					
MnO	0.45	0.44	(a)			0.5	(a)					
CaO	3.16	2.94	(a)			3.95	(a)					
MgO	28.2	28.19	(a)			25.04	(a)					
Na2O	0.47	0.44	(a)			0.59	(a)			**Bogard 99**		
K2O	0.03	0.026	(a)			0.06	(a)			0.058		
P2O5	0.4											
sum	99.5											
Li ppm	1.5											
Sc	21	19	(a)			21.6	(a)					
V	162	166	(a)			132	(a)					
Cr	6670	7000	(a)			6520	(a)					
Co	72	78	(a)	67.2	(b)	77.7	(a)					
Ni	290	310	(b)			338	(a)					
Cu	5.1											
Zn	60	59	(b)	49.4	(b)	60.7	(a)					
Ga	7.3	6.9	(a)	6.07	(b)	9.3	(a)					
Ge	0.58	0.58	(b)									
As	0.022											
Se	0.15			0.149	(b)							
Br	0.077	<0.05	(a)							**Borg 2001**		
Rb	0.7			0.626	(b)					0.711		
Sr	14	<20	(a)							11.11		
Y	6.2											
Zr	19.5	<30	(a)									
Nb	0.65											
Mo	0.2					0.043	(b)					
Pd ppb										4.67		
Ag ppb	4.4			4.37	(b)	4	(b)					
Cd ppb	2.1	2.1	(b)	5.97	(b)							
In ppb	11			11.1	(b)							
Sb ppb	69			0.68	(b)							
Te ppb	0.5			0.45	(b)							
Cs ppm	0.053	<0.09	(a)	0.0383	(b)							
Ba	4.2											
La	0.34	0.4	(a)			0.614	(a)					
Ce	0.91	<2.5	(a)			1.28	(a)					
Pr	0.13									**Borg 2001**		
Nd	0.95	<0.09	(a)							0.814		
Sm	0.49	0.48	(a)			0.77	(a)			0.486		
Eu	0.22	0.25	(a)			0.373	(a)					
Gd	0.92					0.2	(a)					
Tb	0.17	0.17	(a)									
Dy	1.08	1.04	(a)									
Ho	0.25	0.23	(a)									
Er	0.66											
Tm	0.088					0.296	(a)					
Yb	0.59	0.57	(a)			0.919	(a)			**Blichert-Troft 99**		
Lu	0.078	0.085	(a)			0.127	(a)			0.0988	0.0982	(c)
Hf	0.62	0.57	(a)			0.951	(a)			0.723	0.727	(c)
Ta	0.033	0.04	(a)									
W ppb	84					38	(b)					
Re ppb	0.102	0.102	(b)					0.256	(c)			
Os ppb	4.4	4.4	(b)			8.98	(b)	3.405	(c)			
Ru ppb						3.6	(b)			4.37		
Pt ppb						3.84	(b)			5.4		
Rh ppb										1.3		
Ir ppb	3.9	4.3	(b)			9.11	(b)			3.65		
Au ppb	0.21	0.26	(b)	0.288	(b)	0.342	(b)					
Tl ppb	1.7			1.7	(b)							
Bi ppb	<0.7			<0.72	(b)							
Th ppm	0.057	<0.1	(a)									
U ppm	0.015	<0.06	(a)									

technique (a) INAA, (b) RNAA, (c) IDMS

$^{87}Sr/^{86}Sr$ = 0.71042 ± 2) using Rb/Sr isochron between two pyroxenes. Borg *et al*. (2001) re-determined the age of ALH77005; 185 ± 11 Ma and 173 ± 6 Ma, by Rb-Sr and Sm-Nd respectively (figures VIII-8 and 9).

Cosmogenic Isotopes and Exposure Ages*

The terrestrial residence age as reported by Schultz and Freundel (1984) is 190 ± 70 thousand years. Evans *et al.* (1992) provide the activity of ^{10}Be, ^{26}Al, ^{53}Mn, ^{35}Cl and ^{14}C and also give a terrestrial age of 190 ± 70 thousand years.

Nishiizumi *et al.* (1986) reported a ^{10}Be exposure age of 2.5 ± 0.3 Ma. Pal *et al.* (1986) determined an exposure age of 2.8 ± 0.6 Ma using ^{10}Be. Miura *et al.* (1995) determined 2.9 ± 0.7 Ma and Bogard *et al.* (1984b) determined ~2.6 Ma. From cosmic-ray produced ^{3}He, ^{21}Ne and ^{38}Ar, Eugster *et al.* (1996) derived an exposure age for ALHA77005 of 3.4 Ma and concluded that ALHA77005 was *"ejected from Mars simultaneously with .... LEW88516 (3.6 Ma)."* However, Nyquist *et al*. (2001) calculate an average exposure age of 2.87 ± 0.2 Ma *(which is distinct from that of LEW88516).*

Other Isotopes

Bogard *et al*. (1984b) reported that the ^{129}Xe was not enriched in ALHA77005.

Chen and Wasserburg (1986b) studied the U-Th-Pb isotopic system, Harper *et al.* (1995) reported the isotopic composition of Nd, Blichert-Toft *et al.* (1999) determined Hf and Brandon *et al.* (2000) reported on the Re-Os system.

Garrison *et al.* (1995) studied the Ne isotopic system and determined that ALHA77005 was exposed to solar-flare protons.

Clayton and Mayeda (1996) give the isotopic data for oxygen (figure I-3), and Wiechert *et al.* (2001) have apparently improved the precision of this measurement.

Gao and Thiemens (1990) determined the isotopic composition of two different S components in ALHA77005.

Schnabel *et al*. (2001) reported the activity of ^{10}Be, ^{26}Al and ^{53}Mn.

Other Studies:

Salisbury *et al*. (1991) and Hamilton *et al*. (1997) determined the vibrational emission spectra of ALHA77005 and other Martian meteorites (figure VIII-10) for comparison with spectra that may be obtained someday from Martian orbit.

Processing

Initially a chip (~25 grams) was taken from the S1 face. In 1978, the first saw cut divided the sample into roughly two halves (,8 and ,9). One half (,8; 212 grams) immediately went to Japan, because the 1977 Antarctic field trip was a joint U. S. - Japan mission (Yanai and Iguchi 1981). A second bandsaw cut was made a right angles to the first (figure VIII-11) revealing several drusy interior cavities (figure VIII-12). In 1986, sub-sample ,9 was further sub-divided.

Figures VIII-13 and VIII-14 show the relationship of the various sub-samples of ALHA77005 and the experiments made on them. More than thirty-six thin sections have been made (table VIII-2). Thin sections

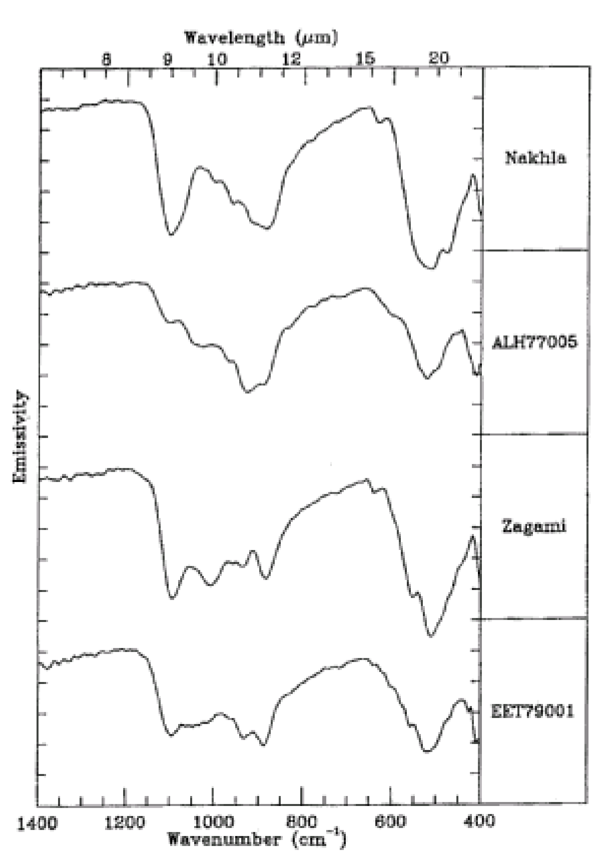

Figure VIII-10. *Mid-IR emission spectra of Martian meteorites as determined by Hamilton et al. 1997, JGR **102**, 597.*

Figure VIII-11. Initial cutting of ALHA77005 in 1978. NASA # S78-37990.

***Figure VIII-12.** Second saw cut of ALHA77005 exposing melted portions in the interior containg large vesicles. NASA S78-37987.*

of this Martian rock are included in the Japanese Educational Thin Section Set (see Kubovics *et al.* 1995).

McSween organized the original consortium to study ALHA77005. Subsample ,38 was a bulk sample (10.1g) made from chips which fell off in initial sawing in 1978. It was homogenized and distributed to consortium members. The meteorite was restudied by the McSween consortium in 1986 when splits of a dark (,89; 5.2g) and light (,90; 5.0g) lithologies were taken and homogenized by Jarosewich (AMN 13(1) p134). The remainders of these samples are available to investigators by request to MWG. These two lithologies are intergrown and there proved to be only a minor REE difference between them (*see section on Whole-rock Composition*).

Table VIII-2. Thin sections of ALHA77005.

butt	section	2001	parent	picture in
,2			,0	
	,54	Rutherford		
	,73	Huguenin		
	,121	Treiman		
	,122	Treiman		
	,137	Treiman		
,4			,0	
	,5	Mason		
	,6	NIPR		
	,7	Neal		
	,50	Wadhwa		
,10			,0	
	,117	Walker		
	,118	Keil		
,13			,0	
	,44	Humayun		
	,45	McKay, G.		Treiman 1994
	,46	Schultz		
	,51	Beachamp		
,16			,0	
	,33	Yang		
	,34	Papike		McSween 1979
	,35	Lipschutz		
,22			,0	
	,29	Wanke		
	,30	Papike		
	,31	Terada		McSween 1979
	,32	Greshake		
,48			,13	
	,52	McSween		
,87			,9	
	,98	McKenzie		
,88			,9	
	,99	McSween		
	,120	Delaney		
	,166	Papike		
	,167	Kurat		
,103			,9	
	,108	Greenwood		
,105			,9	
	,109	Gleason		
,140			,9	
	,148	Lindstrom		
,141			,9	
	,149	Lindstrom		
,145			,129	
	,150	Goodrich		
,147			,129	
	,151	Lindstrom		
,173			,92	
	,180	Kirschvink		
,93-1?				Mikouchi 2000
,93-2?		Ikeda 1998		

three thin sections, cut at right angles to each other from a 1 cm cube, were studied by Berkley and Keil 1981

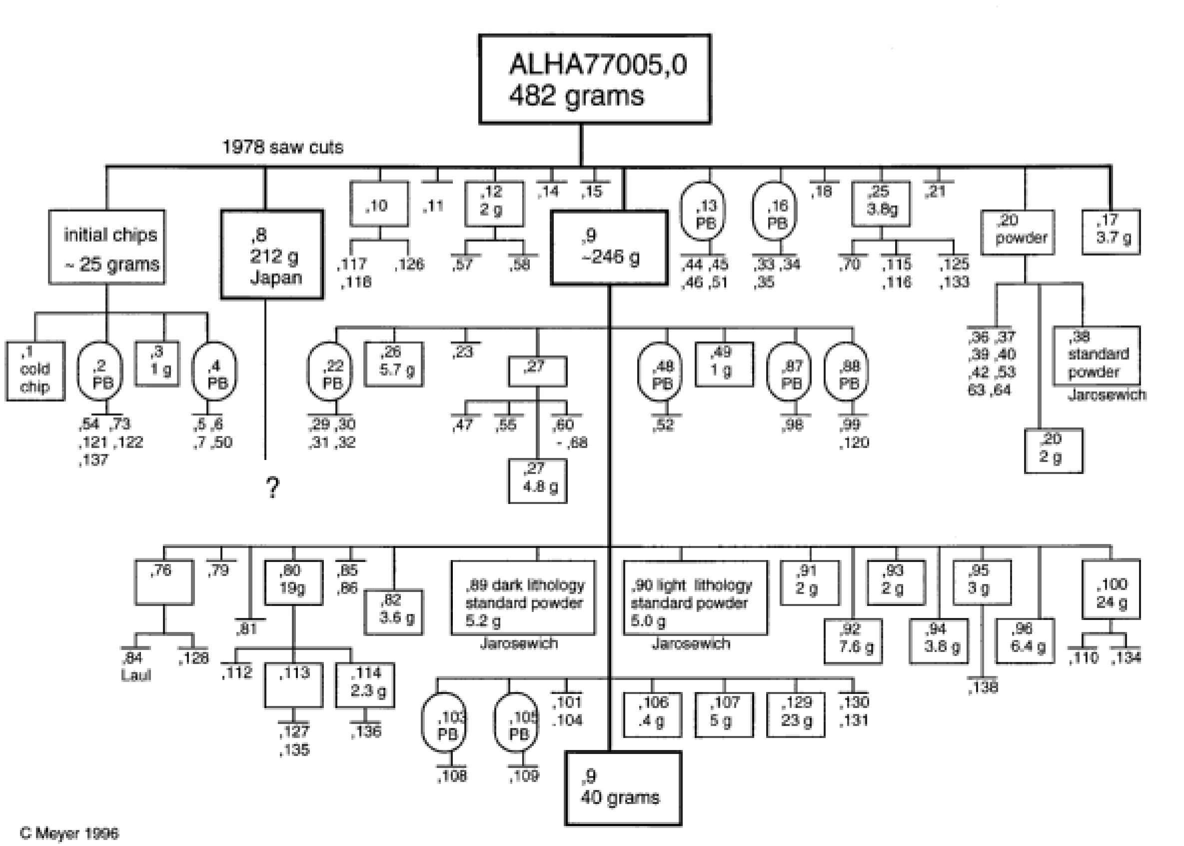

Figure VIII-13. *Geneology diagram of cutting and allocation of ALHA77005, prior to 1996.*

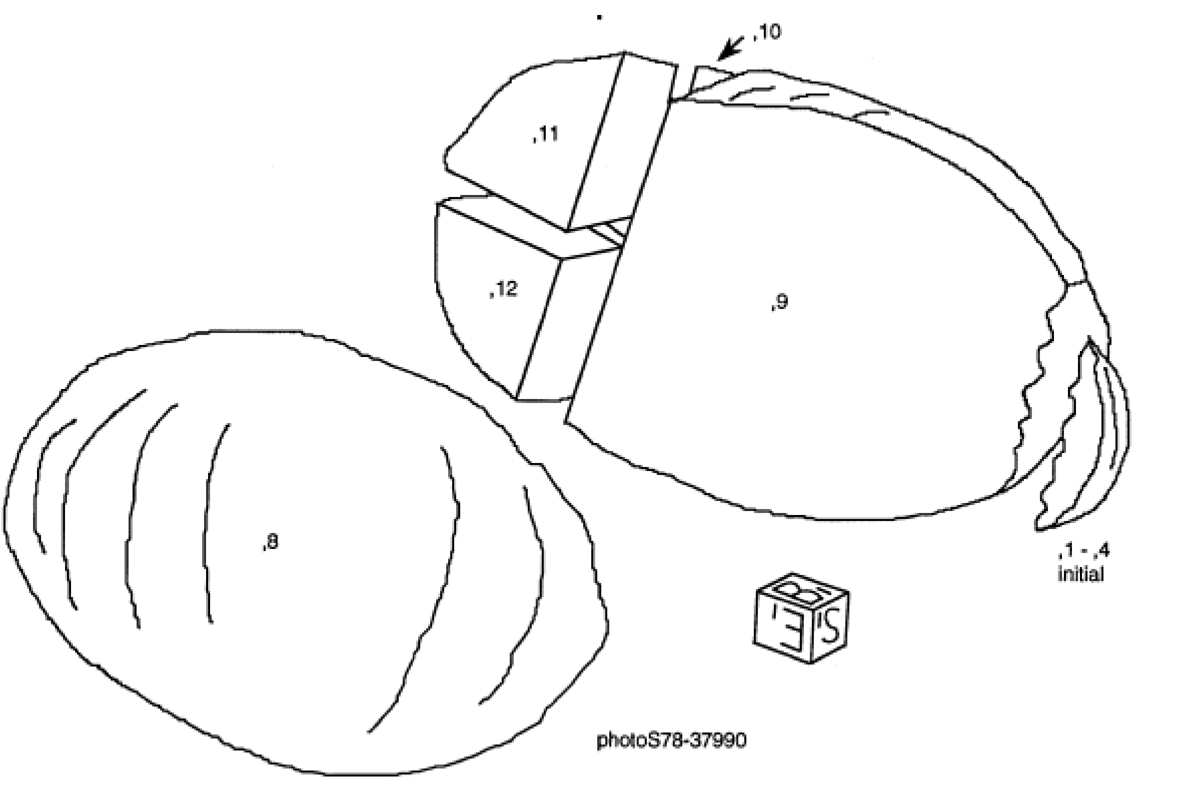

Figure VIII-14. *Exploded parts diagram of ALHA77005 (see also figure VIII-11).*