

**ALH77005** - 482grams  
Intermediate Lherzolithic Shergottite



*Figure 1. Photograph (or Mug Shot) of exterior surface of ALH77005 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 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 ALH77005 reported that it is ~55% olivine, ~35% pyroxene, ~8% maskelynite and ~2% opaques (Mason 1981). The olivine (Fa<sub>28</sub>) 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<sub>53</sub>) is interstitial to olivine and pyroxene. Some pyroxene has undulose extinction and some shock melting has occurred.

ALH77005, LEW88516 and Y793605 have very similar mineralogy, texture and shock features (Treiman *et al.* 1994; Mikouchi and Miyamoto 1997, 2000). ALH77005 and LEW88516 have apparently been more heavily shocked than other SNC meteorites (see below).

ALH77005 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) Ikeda (1994, 1998) and Walton *et al.*



**Figure 2.** Photograph of first sawn surface of ALH77005 illustrating “light” and “dark” regions (NASA #S78-37989).

(2006, 2008). Papike et al. (2009) directly compared the fabric, texture and composition of silicate minerals in ALH77005 with many of the other Martian shergottites.

The age of ALH77005 is about 175 m.y. with an exposure to cosmic rays of about 3 m.y. (see below).

### **Petrography**

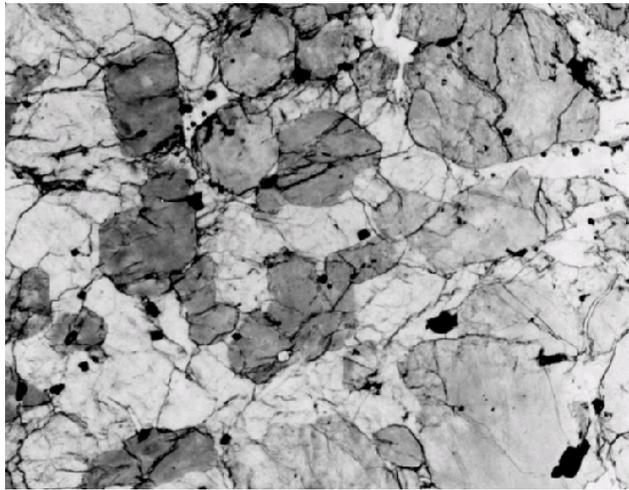
ALH77005 is a cumulate gabbroic rock consisting of brown olivine, low- and high-Ca pyroxene, plagioclase glass, Ti-poor and -rich chromite, ilmenite, whitlockite and sulfides (McSween *et al.* 1979; Lundberg *et al.* 1990; Ikeda 1994). The large sawn surface shows three lithologies: 1) lighter, 2) darker and 3) glass (figure 2).

### **Mineralogical Mode**

	<b>Mason 1981</b>	<b>Treiman <i>et al.</i> 1994</b>	<b>Ma 1981 (norm)</b>	<b>Wadhwa <i>et al.</i> 1994</b>
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		

The saw cut shows that ALH77005 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 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<sup>+3</sup>.

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



**Figure 3.** Photomicrograph of thin section of ALH77005,52. Large poikilitic orthopyroxene encloses euhedral olivine and chromite. Olivine is oddly colored tan to reddish-brown by minor Fe<sup>3+</sup>. Field of view is 2.2 mm.

Berkley and Keil (1981) showed that ALH77005 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 of olivine and dendritic chromite grains have been reported (McSween *et al.* 1979).

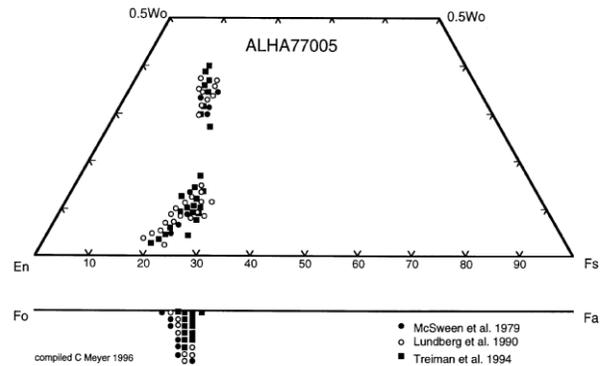
Lundberg *et al.* (1990) report that the Fe/Mg of the apparently cumulus olivine is out of equilibrium with the coexisting clinopyroxene and the original calculated magmatic liquid. Longhi and Pan (1989), Lundberg *et al.* (1990) and Harvey and McSween (1992) have inferred that original Mg-rich olivine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

Magmatic melt inclusions in olivine and pyroxene in ALH77005 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 ALH77005 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



**Figure 4.** Composition diagram for pyroxene and olivine in ALH77005. Data from McSween *et al.* 1979, Lundberg *et al.* 1990, and Treiman *et al.* 1994.

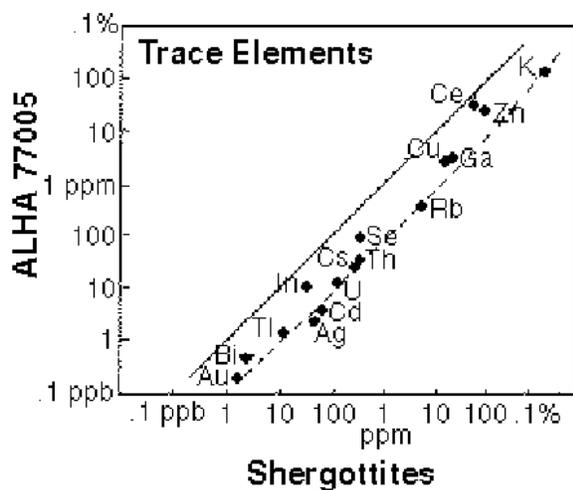
grains have a round habit, possibly caused by reaction with intercumulus liquid. The chemical composition of olivine is homogeneous within each grain, but varies from grain to grain, ranging from Fo<sub>75</sub> to Fo<sub>70</sub> (Ikeda 1994). Lundberg *et al.* (1990) have shown that this homogeneity was caused by re-equilibration with the intercumulus liquid on cooling.

*Quench olivine in shock-melt pockets and veins has chemical zoning from Fa<sub>16</sub>-Fa<sub>42</sub>.*

**Pyroxene:** The large pyroxenes in the poikilitic portion of ALH77005 show chemical zoning from high-Mg, low-Ca orthopyroxene cores to Mg-rich pigeonite with rims of ferroan pigeonite (figure 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



**Figure 5.** Rough comparison of composition of ALH77005 with that of Shergotty by McSween *et al.* 1979.

grains were made of rims of recrystallized Ca-rich plagioclase. Ikeda (1994) analyzed the maskelynite in ALH77005 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 recrystallized at the rims and the remainder was quenched as glass. In other areas the maskelynite is normally zoned from An<sub>50</sub> to An<sub>45</sub>. Tiny vesicles (bubbles?) are present in the plagioclase glass. According to Treiman *et al.* (1994), maskelynite in ALH77005 has an average composition of An<sub>52</sub> and a range from An<sub>24-56</sub>.

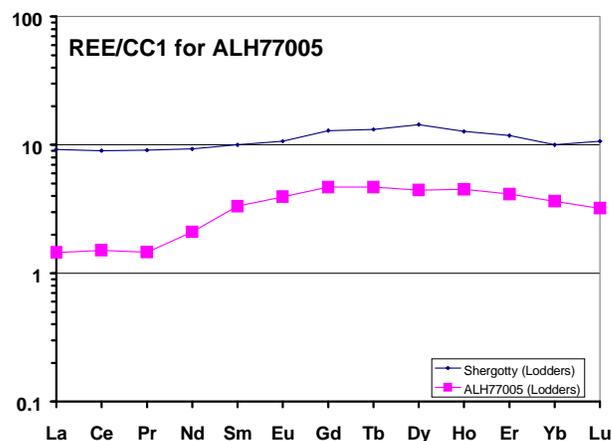
**Chromite:** The chromite in ALH77005 has four types of occurrence, based on differences in chemical zoning (Ikeda 1994). McSween *et al.* (1979a) reported that as much as 10% of the iron in the chromite was Fe<sup>+3</sup>.

**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 ALH77005, but this is probably incorrect.

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



**Figure 6.** Normalized rare-earth-element composition diagram comparing ALH77005 with Shergotty (data from Lodders 1998).

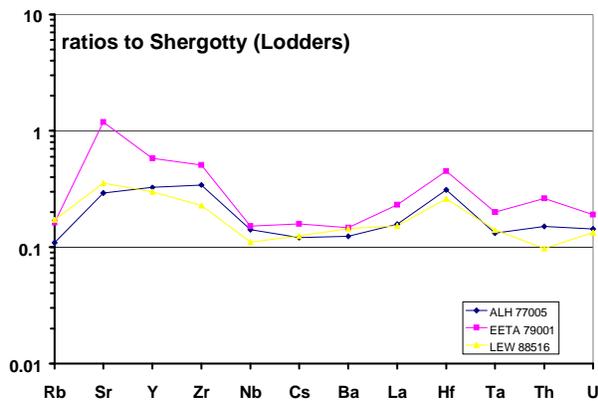
**Salts:** McSween *et al.* (1979a) reported a FeO(OH) phase in isolated areas associated with sulfides.

### 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 ALH77005 compared closely with that in the shergottites (figure 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), Burgehele *et al.* (1983), Smith *et al.* (1984), Treiman *et al.* (1994), and Haramura (1995) (figure 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 6) as are certain other trace elements (Rb, Nb, Cs, Ba, Ta, Th and U, figure 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 ALH77005 was almost identical to that of LEW88516. It was found to be low — *in the range of the terrestrial upper mantle*. Brandon *et al.* (2012) determined PGE and Re in three splits (table 2).



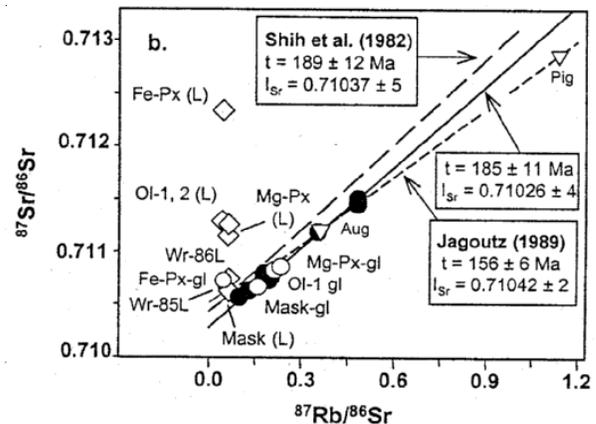
**Figure 7.** Ratio of trace element contents of ALH77005, EETA79001 and LEW88516 to those of Shergotty (for reference) showing that Rb, Nb, Cs, Ba, La (and LREE), Ta, Th and U are “depleted” in this special class of Martian meteorites.

Burgess *et al.* (1989) determined about 400 ppm S and Burghelle *et al.* reported 600 ppm S in ALH77005. Gooding *et al.* (1990) determined the thermal release pattern for several volatile species.

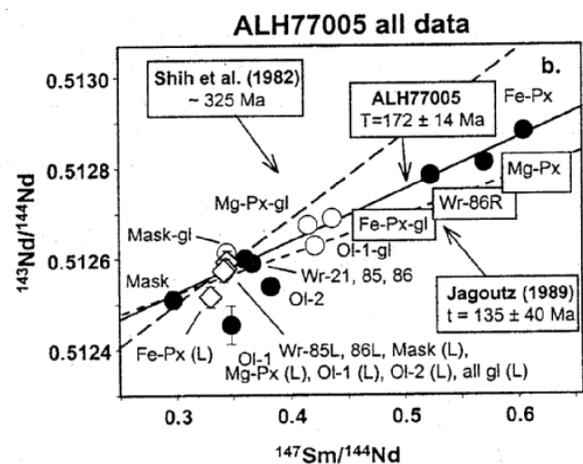
### Shock Features

ALH77005 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 ALH77005 reached equilibrium shock pressure of  $43 \pm 2$  GPa and post-shock temperature of 400 - 800°C. Bishoff and Stöffler (1992) and Boctor *et al.* (1999) have also studied the shock features in ALH77005 and Rietmeijer (1983) discussed “shock-induced chemical reactions.”

Walton and Herd (2007) and Walton *et al.* (2006, 2008) have studied the shock melt pocket found in ALH77005 (figure 12). “The melt pocket has an irregular shape (~3mm) characterized by a microporphyrritic texture of olivine and chromite crystals embedded in silicate glass with minor acicular crystals of clinopyroxene”. Shape changes as function of distance from contact with host rock. Olivine is 75%, chromite 3%, void 4%, glass 10%, with some rock clasts. They have also attempted to date this shock event, by laser probe.



**Figure 8.** Rb-Sr isochron for ALH77005 from Borg *et al.* 2001.



**Figure 9.** Sm-Nd isochron for ALH77005 from Borg *et al.* 2001.

Boctor *et al.* noted that the similar shock features and peak shock pressures of ALH77005, 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 ALH77005 (Nagata 1980; Collinson 1986), but the results are inconclusive (Sugiura and Strangway 1988). The presence of Fe<sup>+3</sup> 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

**Table 1a. Chemical composition of ALH77005.**

	Wanke 86	Smith 84	Dreibus92	Dreibus92	Jarosewich90	Jarosewich90	Jarosewich90	Burghel 83	Haramura 95
					<i>dark</i> *	<i>light</i> *			
<i>weight</i>									
SiO <sub>2</sub> %			43.08 (b)		42.4 (a)	41.41 (a)	45.8 (a)	43.08 (b)	43.02 (a)
TiO <sub>2</sub>		0.3 (b)	0.44 (b)		0.46 (a)	0.52 (a)	0.31 (a)	0.44 (b)	0.36 (a)
Al <sub>2</sub> O <sub>3</sub>		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)
Na <sub>2</sub> O	0.597 (b)	0.48 (b)	0.44 (b)		0.48 (a)	0.6 (a)	0.27 (a)	0.438 (b)	0.37 (a)
K <sub>2</sub> O	0.033 (b)	0.028 (b)	0.027 (b)		0.04 (a)	0.04 (a)	0.02 (a)	0.027 (b)	0.03 (a)
P <sub>2</sub> O <sub>3</sub>			0.36 (b)	0.44 (d)	0.41 (a)	0.45 (a)	0.19 (a)	0.36 (b)	0.39 (a)
<b>sum</b>					<b>98.79</b>	<b>98.92</b>	<b>99.07</b>	<b>98.382</b>	<b>98.66</b>
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)	<b>Shimizu 81</b>
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)							
Th ppm	<0.1 (b)		<0.1 (b)	0.53 (d)				<0.1 (b)	
U ppm	<0.04 (b)	0.029 (e)	<0.05 (b)	0.012 (d)				<0.05 (b)	
						<b>Chen and Wasserburg 86</b>			
						0.058 (c)		0.015 (c)	

*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 1b. Chemical composition of ALH77005 (continued).**

	Treiman94	Treiman 94	Treiman 94	McSween79	Ma 81	Ma 81	Shih 81	Warren96	Onuma81	Onuma81	Jagoutz89
		<i>light</i> *	<i>dark</i> *								
<i>weight</i>	<i>calculated</i>	70 mg	74 mg		311 mg	42.7 mg					87 mg
SiO <sub>2</sub> %	40.8										
TiO <sub>2</sub>	0.61										
Al <sub>2</sub> O <sub>3</sub>	3.8										
FeO	21.7	18.4 (f)	21 (f)								
MnO	0.48										
CaO	2.9	3.4 (f)	3.5 (f)								
MgO	28										
Na <sub>2</sub> O	0.63	0.296 (f)	0.586 (f)								
K <sub>2</sub> O	0.04	0.02 (f)									
P <sub>2</sub> O <sub>3</sub>	0.34										
<b>sum</b>	<b>99.3</b>										
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 1c. Chemical composition of ALH77005 (continued).

	Warren 97 615 mg	Mittlefehldt 97 light *	Mittlefehldt 97 dark *	Mittlefehldt 97 bulk	Shih 82	Shih 82	Ebihara97 119 mg	Ebihara97
SiO <sub>2</sub> %	41.36							
TiO <sub>2</sub>	<0.83					0.3		
Al <sub>2</sub> O <sub>3</sub>	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	
Na <sub>2</sub> O	0.443	0.207 (f)	0.541 (f)	0.425 (f)			0.59	
K <sub>2</sub> O	0.03						0.06	
P <sub>2</sub> O <sub>3</sub>								
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							
Sm	0.48	0.216 (f)	0.565 (f)	0.451 (f)	0.795 (c)	0.868 (c)	0.77	
Eu	0.25	0.094 (f)	0.465 (f)	0.241 (f)	0.361 (c)	0.356 (c)	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 1d. Chemical composition of ALH77005 (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)	<b>Bogard 99</b>	
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)			<b>Borg 2001</b>	
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						<b>Borg 2001</b>
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)	
Lu	0.078	0.085	(a)		0.127	(a)	<b>Blichert-Troft 99</b>
Hf	0.62	0.57	(a)		0.951	(a)	0.0988 0.0982 (c)
Ta	0.033	0.04	(a)				0.723 0.727 (c)
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

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't be in equilibrium with the original mineral assemblage.

### **Radiogenic Isotopes**

Shih *et al.* (1982) reported a Rb-Sr age of  $187 \pm 12$  m.y. with  $^{87}\text{Sr}/^{86}\text{Sr} = 0.71037 \pm 5$  ( $\lambda_{\text{Rb}} = 1.39 \times 10^{-11}$  year $^{-1}$ ) and a Sm-Nd age of  $\sim 325$  m.y. Schaeffer and Warsila (1981) obtained a vague  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau age of about 1.1 b.y. However, Jessberger *et al.* (1981) used laser probe extraction to show that excess  $^{40}\text{Ar}$  is located inhomogeneously within the minerals of ALH77005. Jagoutz (1989b) determined an age of  $154 \pm 6$  m.y. ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.71042 \pm 2$ ) using Rb/Sr isochron between two pyroxenes. Borg *et al.* (2001) re-determined the age of ALH77005;  $185 \pm 11$  m.y. and  $173 \pm 6$  m.y., by Rb-Sr and Sm-Nd respectively (figures 8 and 9).

### **Cosmogenic Isotopes and Exposure Ages\***

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

Nishiizumi *et al.* (1986) reported a  $^{10}\text{Be}$  exposure age of  $2.5 \pm 0.3$  m.y. Pal *et al.* (1986) determined an exposure age of  $2.8 \pm 0.6$  m.y. using  $^{10}\text{Be}$ . Miura *et al.* (1995) determined  $2.9 \pm 0.7$  m.y. and Bogard *et al.* (1984b) determined  $\sim 2.6$  m.y. From cosmic-ray produced  $^3\text{He}$ ,  $^{21}\text{Ne}$  and  $^{38}\text{Ar}$ , Eugster *et al.* (1996) derived an exposure age for ALH77005 of 3.4 m.y. and concluded that ALH77005 was “ejected from Mars simultaneously with . . . LEW88516 (3.6 m.y.)” However, Nyquist *et al.* (2001) calculate an average exposure age of  $2.87 \pm 0.2$  m.y. (which is distinct from that of LEW88516).

### **Other Isotopes**

Bogard *et al.* (1984b) reported that the  $^{129}\text{Xe}$  was not enriched in ALH77005.

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 ALH77005 was exposed to solar-flare protons.

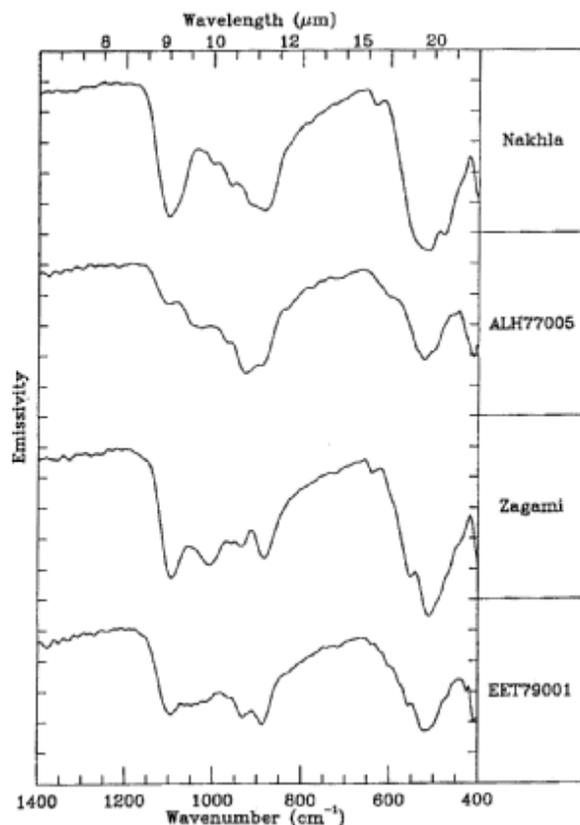
Clayton and Mayeda (1996) give the isotopic data for oxygen (figure I-3), and Wiechert *et al.* (2001) have apparently improved the precision of this measurement.

Gao and Thiemens (1990) determined the isotopic composition of two different S components in ALH77005.

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

### **Other Studies:**

Salisbury *et al.* (1991) and Hamilton *et al.* (1997) determined the vibrational emission spectra of ALH77005 and other Martian meteorites (figure 10) for comparison with spectra that may be obtained someday from Martian orbit.



**Figure 10.** Mid-IR emission spectra of Martian meteorites as determined by Hamilton *et al.* 1997.



**Figure 11.** Initial cutting of ALH77005 in 1978. NASA # S78-37990.



**Figure 12.** Second saw cut of ALH77005 exposing melted portions in the interior containing large vesicles. NASA S78-37987.

### 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 at right angles to the first (figure 11) revealing several drusy interior cavities (figure 12). In 1986, sub-sample .9 was further sub-divided. *The sample known as Yanai#1075 is apparently .8.*

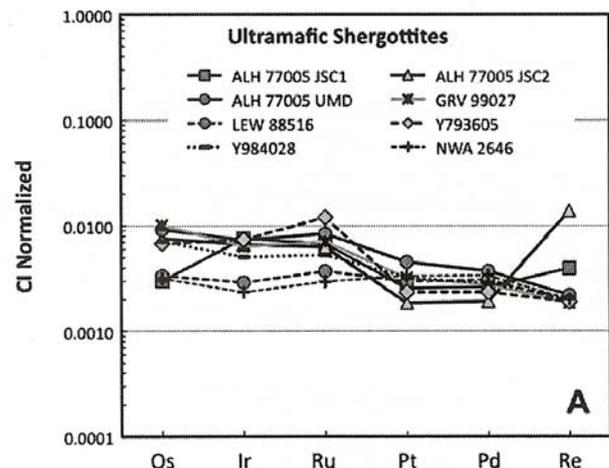
Figures 13 and 14 show the relationship of the various sub-samples of ALH77005 and the experiments made on them. More than thirty-six thin sections have been made. Thin sections of this Martian rock are included in the Japanese Educational Thin Section Set (see Kubovics *et al.* 1995).

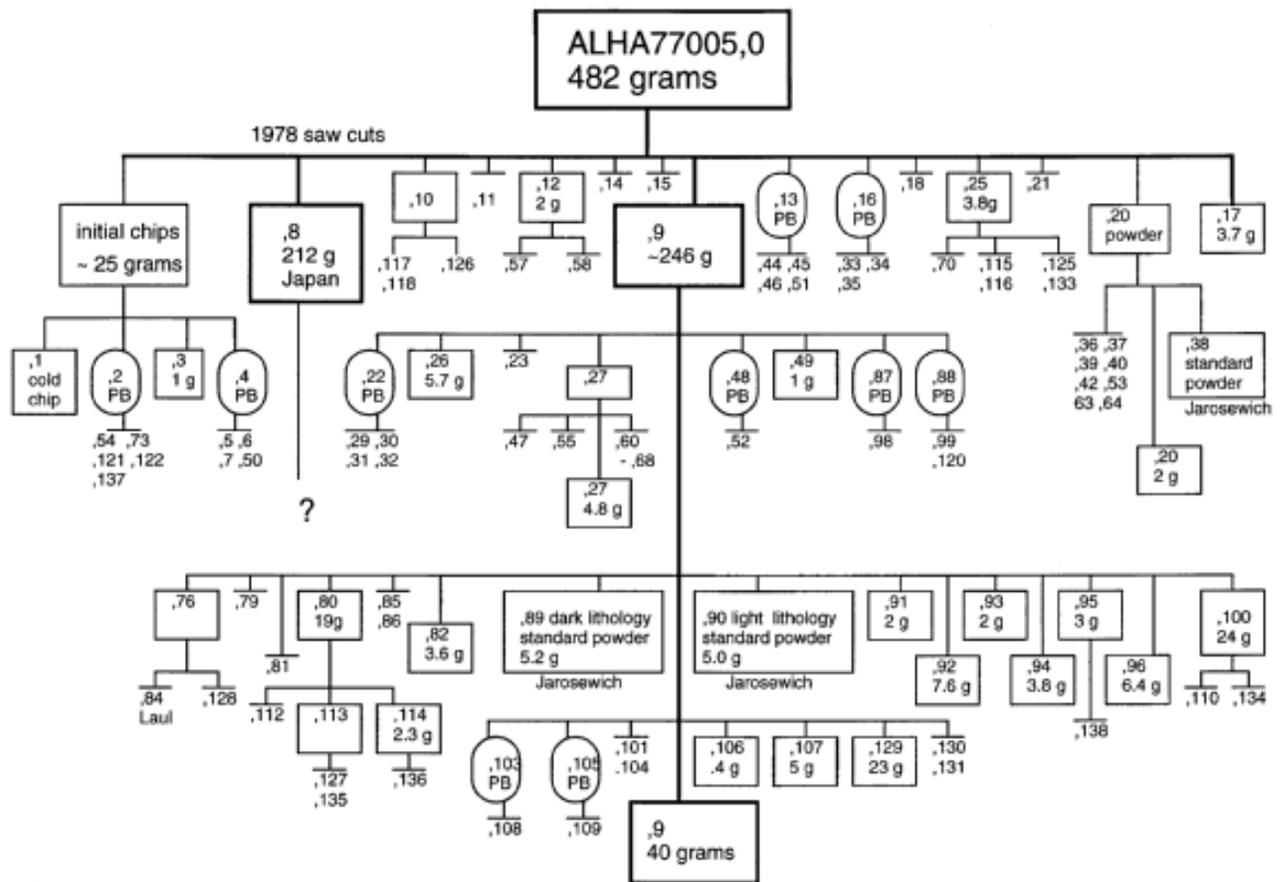
McSween organized the original consortium to study ALH77005. Subsample .38 was a bulk sample (10.1g) made from chips which fell off in initial sawing in 1978. It was homogenized and distributed to consortium members. The meteorite was restudied by the McSween consortium in 1986 when splits of a dark (.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*).

### References for ALH77005

**Table 2: PGE and Rhenium (Brandon *et al.* 2012).**

	ALH77005	ALH77005	ALH77005
Os ppb	1.38	4.22	3.48
Ir ppb	3.37	3.27	2.96
Ru ppb	4.39	5.48	4.1
Pt ppb	2.22	3.93	1.6
Pd ppb	1.5	2.12	1.09
Re ppb	0.156	0.087	0.548





C Meyer 1996

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

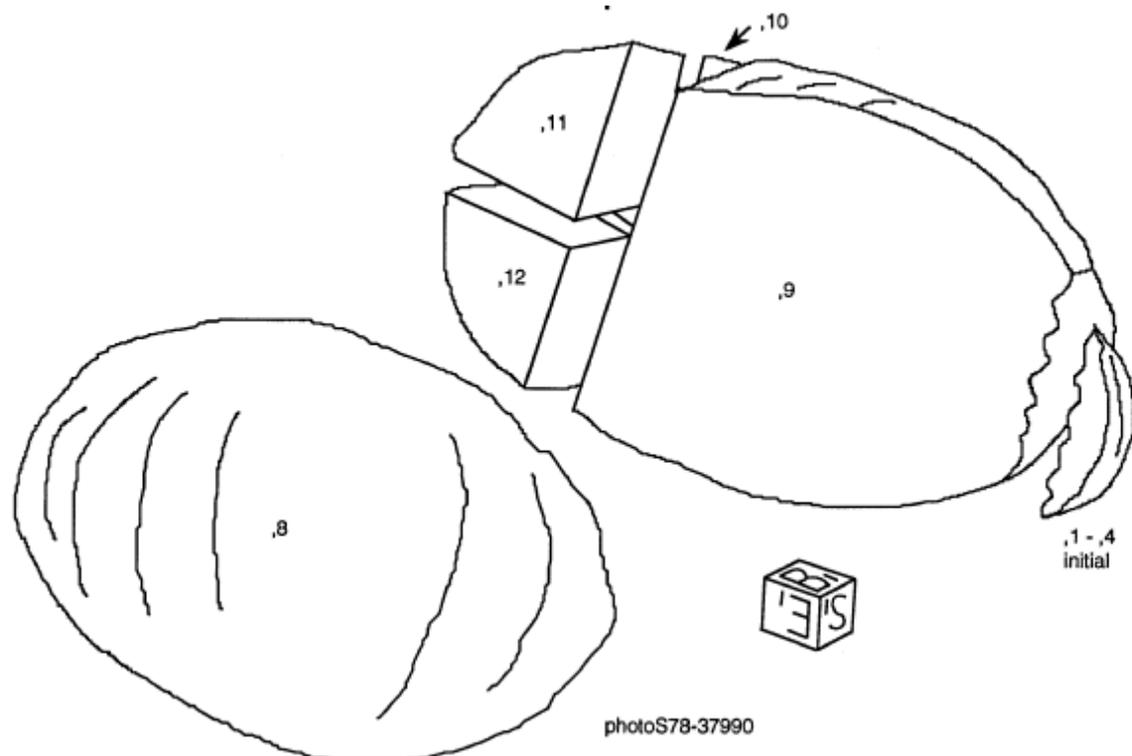


Figure 14. Exploded parts diagram of ALHA77005 (see also figure VIII-11).