

## IX. EETA79001

Olivine-phyric Shergottite/Basaltic Shergottite, 7942 grams  
*Weathering Ae, Fracturing A*

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*Figure IX-1. Photograph of EETA79001 as it was found on the ice (NASA # S80-28838).*

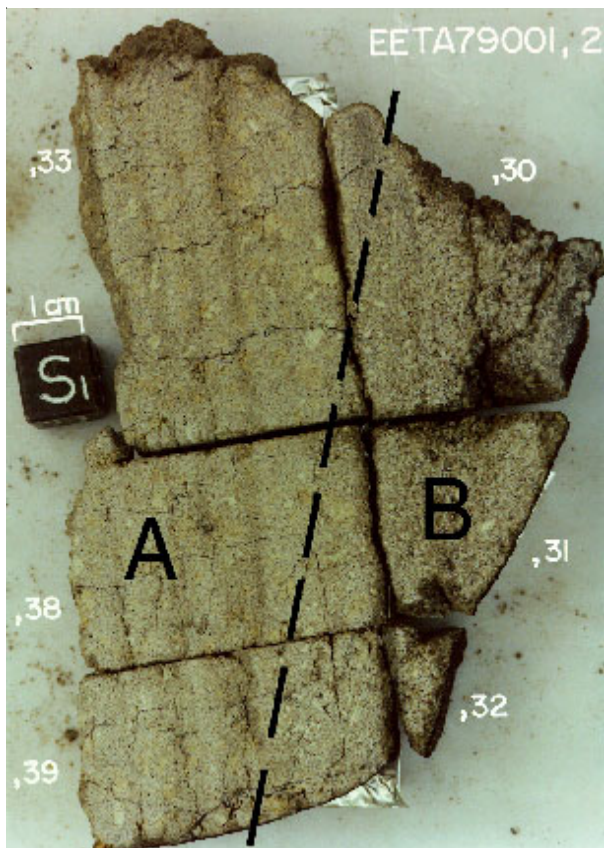
### **Introduction**

EETA79001 is the largest stony meteorite returned by the 1979 ANSMET expedition (Cassidy and Rancitelli 1982). It was found on the ice at the Elephant Moraine location near Reckling Peak, Victoria Land, Antarctica (figure IX-1). This sample is especially important, because glass inclusions in it were found to contain rare-gas and nitrogen isotope compositions matching those of the Martian atmosphere as determined by the Viking spacecraft (Bogard and Johnson 1983a; Becker and Pepin 1984; Ott and Begemann 1985b; Garrison and Bogard 1998), hence demonstrating the Martian origin for this class of meteorites (Hunten *et al.* 1987).

EETA79001 is a unique shergottite (achondrite) containing two different igneous lithologies (labeled A and B) separated by an obvious, linear contact and also containing “pockets” and veinlets of dark glass,

labeled lithology C (Reid and Score 1981). A photograph illustrating the contact between A and B appeared on the cover of EOS, January 1981 (figure IX-2), because this is the first meteorite found to contain a “geological contact” between two lithologies. Based on texture, lithology B is a basalt, whereas lithology A is a basaltic melt containing numerous inclusions of mafic minerals as xenocrysts (McSween and Jarosewich 1983; McSween 1985; Berkley *et al.* 1999, 2000).

The report of the preliminary examination of EETA79001 (Score and Reid 1981) makes interesting reading in light of what has since been discovered (*see below*). “Several large, black fine-grained clasts as large as 2.5 cm are scattered over the cut face. Some of these black clasts contain vugs which have glass in



**Figure IX-2.** Photograph of interior slice of EETA79001 showing contact between lithology A and B. NASA photo # S81-25273. Cube is 1 cm.

their interior. Upon chipping one of these clasts, containing a vug, the entire clast popped out easily and no matrix adhered to the clast. Numerous veins of black material criss-cross each other. These veins run through a black clast. The longest vein is ~14 cm long.” “The dark clasts are apparently loci of melting; in many cases they connect with the thin black glassy (?) veinlets that traverse much of the meteorite.” These glass veins and black clasts have been loosely referred to as lithology C (see below).

It has proven difficult to determine the original igneous crystallization age of this sample (see section on Radiogenic Isotopes), possibly because it contains a mixture of igneous source rocks and has been disturbed by multiple shock events.

Wadhwa *et al.* (1994) presented a model for the origins of the shergottites, including EETA79001 in which “their parent magmas were ultimately derived from partial melts of the partly depleted mantle of their parent planet, and acquired their distinct characteristics through processes such as crystal

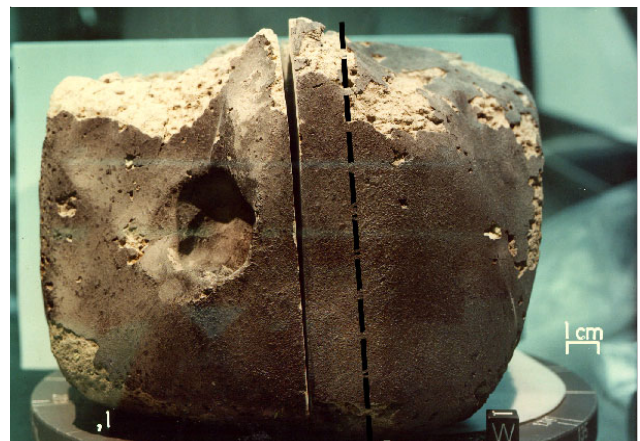
*fractionation, crystal accumulation, magma mixing/assimilation, and crustal contamination.”* On the other hand, Mittlefehldt *et al.* (1997, 1999) have argued that lithology A is an impact melt, which incorporates lithology B as a clast. In their mixing model using both major and trace elements, the composition of lithology A can be reasonably approximated as a simple mixture of 44% lithology B and 56% ALHA77005. Boctor *et al.* (1998) presented preliminary petrologic evidence in favor of an impact-melt origin.

### **Petrography**

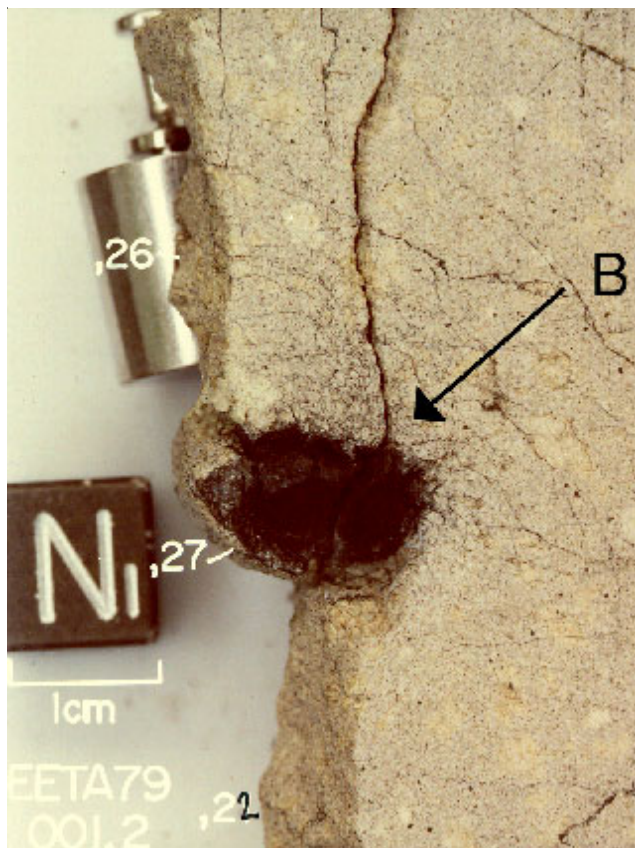
All surfaces of this meteorite are covered by at least some fusion crust, so that the sample represents a nearly complete piece. On the top surface, about half of the



**Figure IX-3.** Photograph of top surface of EETA79001 illustrating partial coating with fusion crust. (NASA # S80-37480)



**Figure IX-4.** Photograph of west end of EETA79001 illustrating unusual “regmaglypt” and first saw cut. The dotted line is approximate location of the second cut. (NASA #S80-37630)

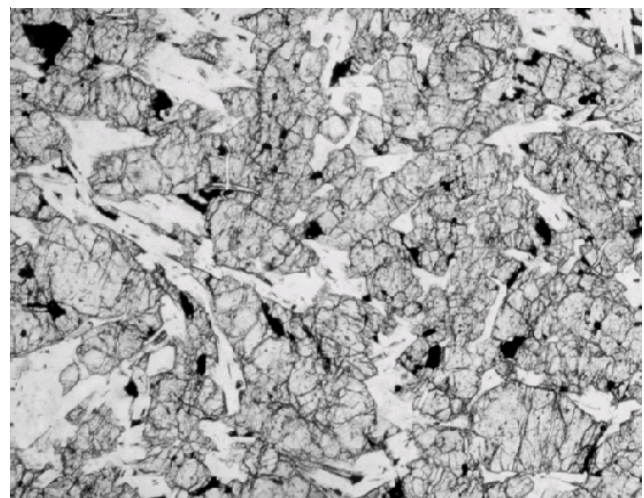


**Figure IX-5.** Close-up photo of a portion of slab EETA79001,22 illustrating mottled appearance of lithology A and “discovery” pod (,27) of glass and fine glass veins. Note the very large vesicle in the glass pod (BRAVO). Cube is 1 cm for scale. (NASA # S81-25242)

fusion crust is partially plucked away (figure IX-3). One end (W) has a deep “regmaglypt” that is covered with fusion crust (Score *et al.* 1982) (figure IX-4). The sample has many penetrating fractures — some lined with thin black glass and connected to interior glass pods. However, the sample was coherent enough to hold together during sawing.

### Mineralogical Mode

	McSween and Jarosewich 1983			Schwandt <i>et al.</i> 2001				
	,75(A),68(A)	,79(A)	,80(A)	,79(B)	,80(B)	,71(B)	,69(B)	,68(A)
thin section								
	<i>volume %</i>							
pigeonite	62.8	60.7	54.5	54.4	32.2	31.8		42
augite	3.2	6.5	8.5	11.6	23.9	24.5		18
maskelynite	18.3	15.9	17.0	28.2	29.4	29.6		22
olivine	10.3	7.2	9.1					3
orthopyroxene	3.4	5.7	7.2					3
opaque	2.2	4.0	3.0	3.4	3.8	3.4		3
whitlockite	tr	tr	0.4	0.7	0.2	0.2		2
mesostasis		tr	0.3	1.1	0.5	0.5		



**Figure IX-6.** Photomicrograph of thin section of EETA79001,79 illustrating the fine-grained matrix of lithology A. Field of view is 2.2 mm.

At least 4 lithological features are found within EETA79001. While most of the rock is a fine-grained mix of pyroxene and maskelynite with small mafic inclusions (termed lithology A), there is a gradational boundary to a sub-ophitic textured basalt (termed lithology B). The numerous examples of shock-melted glass and thin glass veins are termed lithology C (see below) and the small mafic inclusions appear to be another lithology (sometimes called lithology X). Lithology A is somewhat more mafic than lithology B (see table I-1, figure I-2).

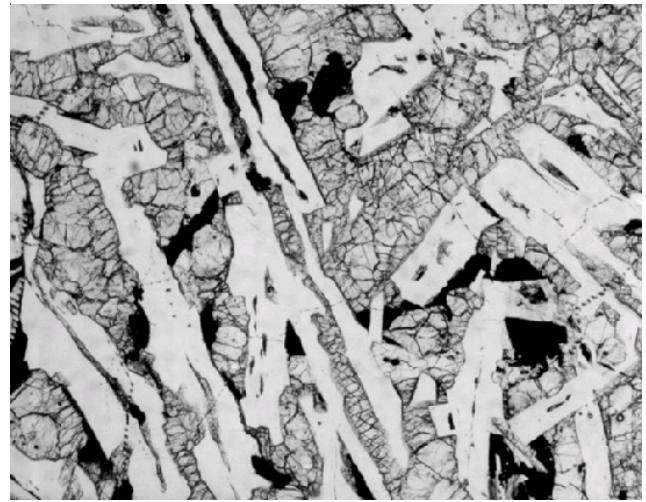
Lithology A is made up of a basaltic host (pyroxene, maskelynite, high-Ti chromite, merrillite, minor Cl-apatite, ilmentite, pyrrhotite and mesostasis) containing apparently exotic crystals and clusters of olivine, Cr-spinel and low-Ca pyroxene) (figures IX-5, 6). Lithology A is now termed an Olivine-phyric Shergottite (Goodrich 2002).



**Figure IX-7.** Close-up photo of sawn surface of EETA79001,30 illustrating the basaltic texture of lithology B. Cube is 1 cm. (NASA # S81-25238)

Lithology B is a homogeneous basalt containing augite laths in a matrix of pigeonite-augite, maskelynite, ulvöspinel-ilmenite intergrowth, whitlockite, Cl-apatite, and mesostasis (figure IX-7). Mineral compositions indicate an oxidation state similar to that of shergottites. The groundmass of lithology B has a slightly larger grain size (0.3 mm) than lithology A (0.15 mm). Overall, the basaltic texture of lithology B (figure IX-8) is similar to that of Shergotty. However, lithology B is depleted in light rare-earth-element contents, when compared with other Shergottites (see figure IX-15).

The mafic xenocrysts found in lithology A consist of light yellow, olivine/orthopyroxene clusters up to 3 mm in size that are evenly spread out throughout the lithology A. These are referred to as “ultramafic clusters” or “megacrysts” (McSween and Jarosewich, 1983) and “lithology X” (Treiman 1995a). The compositions of the minerals in these xenocrysts are Mg-rich and similar to the corresponding phases in the poikilitic areas of ALHA77005 (Wadhwa *et al.* 1994). Wadhwa *et al.* observed that orthopyroxene xenocrysts were often rimmed by coronas of pigeonite having the same composition as that in the groundmass, and that

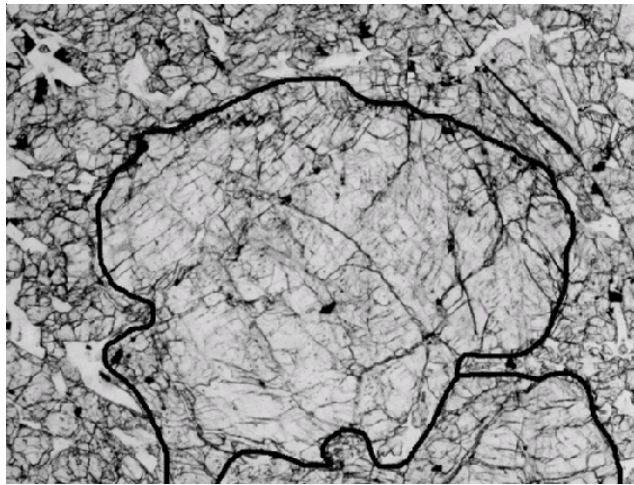


**Figure IX-8.** Photomicrograph of thin section of EETA79001,88 illustrating basaltic texture of lithology B. Field of view is 2.2mm.

xenocrysts of olivine had irregular embayments cutting across internal zoning patterns (figure IX-9). Berkley *et al.* (1999, 2000) carefully studied on particular mafic inclusion (X14, in section ,68) and tentatively concluded that the “Mg-rich orthopyroxene crystallized at some depth, followed by thermal annealing and incorporation into the EETA79001A magma”.

Two working hypotheses need to be considered. An igneous origin is argued by McSween and Jarosewich (1983) who conclude “Both lithologies probably formed from successive volcanic flows or multiple injections of magma into a small, shallow chamber”. However, the difference in initial Sr is proof that the two main lithologies (A and B) are not derived from the same source (see section on Radiometric Isotopes). An alternative interpretation is that lithology A represents an impact melt rock that incorporates Lithology B, and the ultramafic clusters, as clasts (Mittlefehldt *et al.* 1997, 1999). Simonds *et al.* (1976) developed a model for the formation of impact melt rocks which has been successful in explaining the textures of many rocks from the surface of the Moon (although they are more feldspathic), as well as for impact melt sheets found inside large terrestrial craters.

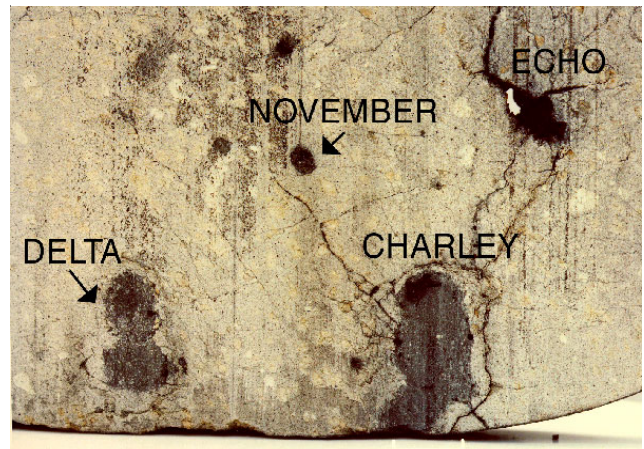
Key to understanding the origin of EETA79001, is the observation of a gradational contact between lithology A and B (Steele and Smith 1982b; McSween and Jarosewich 1983)(see figure IX-2). Is this contact a boundary between different lava flows, or is lithology B, instead, a clast in lithology A? The evidence in the literature is not clear on this point.



**Figure IX-9.** Photograph of thin section of EETA79001,79 illustrating a large olivine clast with irregular boundary in lithology A. Field of view is 2.2 mm.

Lithology C is an assemblage of glass “pods” and thin, interconnecting, glass veins. Although lithology C has commonly been referred to as “glass,” it actually consists of finely intermingled vitreous and cryptocrystalline materials (McSween and Jarosewich 1983; Gooding and Muenow 1986; Rao *et al.* 1998). Martinez and Gooding (1986) describe the true glassy part as dark brown to black, whereas the microcrystalline components include both dark gray-brown phases and colorless to white phases (figure IX-10). Both large vugs and small vesicles are common features. Some dark colored phases (probably pyroxenes) display quench textures that suggest origins by incomplete crystallization of the melt of this unit. In contrast, the light-colored phases might be a mixture of incompletely melted relict grains and post-melting reaction products.

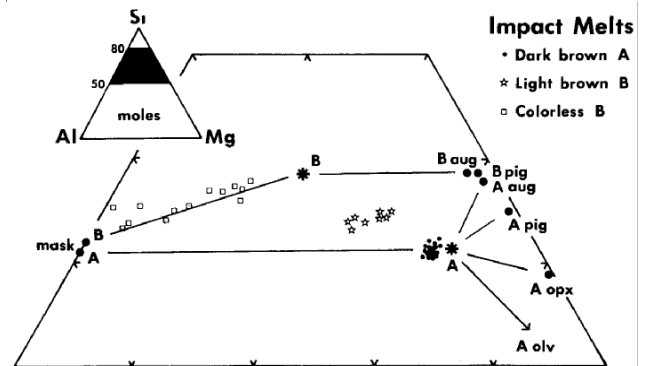
In 1983, Bogard and Johnson discovered high concentrations of rare gases (Ar, Ne, Kr, Xe) in portions of lithology C (see section on *Other Isotopes*). Figure IX-5 illustrates the “discovery pod” (,27) which contains a large (0.8 mm) vug or vesicle. Altogether there are more than 20 glass “pods” exposed on the sawn surfaces of EETA79001, with ~ 5 large ones (~1 cm). Most are found in lithology A, but one (PAPA) was studied from lithology B. Table IX-1 lists these glass pods and gives them each a new name in order to more clearly distinguish them. When the rock was sawn and broken, some of these glass pods broke free from the basaltic matrix (,8 and ,27). Garrison and Bogard (1998) and Bogard and Garrison (1998) have now revised the composition of the Martian



**Figure IX-10.** Close-up photograph of a portion of slab EETA79001,22 illustrating several of the largest glass “pods” and interconnecting glass veins along cracks in lithology A. (NASA # S81-25257)

atmosphere based on their recent measurement of glass pod ,8. Nyquist *et al.* (1986) found that the  $I_{Sr}$  was significantly different for different “pods” (see section on *Radiogenic Isotopes*).

Thin black glass veins (~0.5 mm wide) extend from and connect various “pods” of black glass (Score *et al.* 1982; McSween and Jarosewich 1983; Rao *et al.* 1998). McSween and Jarosewich found the composition of the dark brown vesicular glass veins and pods included in lithology A was generally similar to the bulk composition of lithology A (figure IX-11) whereas, Rao *et al.* find that lithology C represents a mixture of ~85%



**Figure IX-11.** Composition diagram for glass in EETA79001. Stars A and B are bulk compositions of lithology A and B respectively. The dark brown glass has a composition like that of the host rock, while the light brown glass and colorless glasses are along the join with the composition of maskylynite. This is figure 5 in McSween and Jarosewich 1983, GCA 47, 1507.

**Table IX-1. Glass pods (lithology C) and their locations in EETA79001.**  
(*signal corps call letters*)

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ALPHA	- 8 mm, round, with vesicle - exposed by first saw cut on ,1 (figure S80-37631) - piece ,8 broke free from ,2 before slab was cut - portion (~1/2) remains on ,1 sawn surface - studied by Bogard and Garrison 1998 and Garrison and Bogard, 1998
BRAVO	- “discovery pod”, studied by Bogard, Pepin, Swindle - 1 cm, exposed by first sawcut on ,1 - large vug (7 mm) - 1/2 piece ,27 broke free, part remains on ,22 (becomes ,120 -,126) - Sr in ,27 by Nyquist (Sr 15.5 ppm) - piece ,26 (PB) contains thin glass veins associated with ,27 - pieces ,120 - ,126, inc. ,122 Swindle (Hohenberg)
CHARLEY	(1 x 2.5 cm) - exposed by first sawcut - microcrystalline - on ,1 and slab ,22 (did not extend thru slab ,22) - contained in piece ,216 (at edge of both saw cuts 1980 and 1986) - ,249 - ,257 from piece ,216 - closeup photo S81-25257 of Charley, Delta, Echo on slab ,22 - exposed to outer surface of rock and surrounded by penetrating cracks - Sr in ,186 by Nyquist (Sr 15 ppm)
DELTA	- (dumbell-shaped pod) exposed by first sawcut - microcrystalline - on ,1 and ,22 (did not extend thru slab ,22) - exposed again by 1986 cut through ,1 again exposed on ,312 - contained in piece ,216 (at edge of both saw cuts 1980 and 1986) - ,259 - ,263 from ,216 - cracks leading to outside surface S80-37631 - ,194 this half of glass “pod” was carefully lifted out of slab ,22 - “druse” salts studied by Gooding, Clayton, Wright (sample ,239) - S86-37533 shows large patch of “white druse” adjacent to black glass - black glass is surrounded by thick grey (altered) band in ,1 - minor orange “stain” seen in “white-druse” - Sr in ,195 studied by Nyquist (Sr = 15 ppm)
ECHO	- large glass-lined cavity - seen initially on first saw cut on ,1 and ,2 - complex shape along open fracture, portion on ,52 - extends through slab ,22 and on ,312 (derived from ,2) - ,54 ,56 ,57 derived from ,52 S81-25252, S90-34035 - penetrating cracks leading to CHARLEY and outer surface of rock - possibly connecting to “regmaglypt” on exterior surface - Sr in ,54 by Nyquist (17 ppm Sr)
FOXTROT	- 4 mm exposed on first cut S81-25268 S80-37631
GOLF	- 4 mm exposed by 1986 cut S86-26477
HOTEL	- 2 mm glass inclusion, near white inc. on ,38 - S81-25268 S81-25267
ITEM	- exposed by second saw cut from ,2 of backside of slab ,22 - 3 mm with 2 small vesicles exposed on ,312 - on edge of 312 after break during small saw cut - S81-25252
JULIET	- 3 mm with 2 mm vesicle - exposed on ,307 - S90-34035

LIMA	- small shiny black glass pod on ,309 - S90-34036
MIKE	- small pod exposed on ,311 and ,313 (exhibited by Smithsonian) - S90-34042 S90-34041
NOVEMBER	- small exposed by first saw cut ,1 and ,22 - ,197 studied by Nyquist (17 ppm Sr) - salts studied by Gooding
OSCAR	- small exposed first saw cut ,1 and ,22
PAPA	- Glass in lithology B - near outer surface, S81-25259 - , 188 (from ,43) studied by Nyquist (30 ppm Sr) - TS ,71 and ,72 (from ,47) include glass from PAPA - ,104 studied by Bogard and Garrison and Garrison and Bogard, 1998

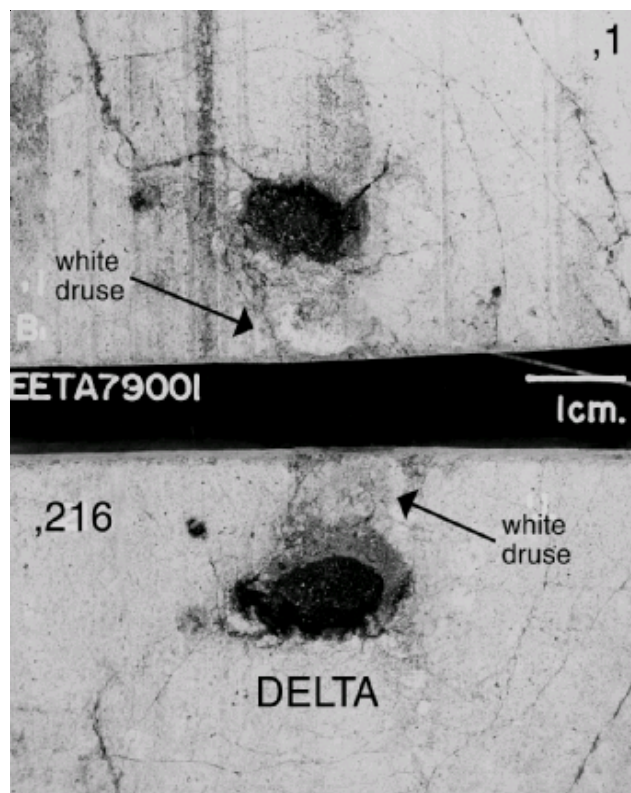
lithology A, plus ~ 7% maskelynite and ~8% Martian soil. However, two different glasses have been found in lithology B. Non-vesicular, clear glass varies in composition from maskelynite to bulk B and light-brown glass found to have a composition intermediate between bulk A and B.

Martinez and Gooding (1986) describe the “white druse” commonly found associated with lithology C in the interior of EETA79001 (figure IX-12). Martinez and Gooding describe this material to consist of “*thin saccharoidal coatings and veins of a colorless to white, translucent phase of dull to resinous luster.*” Gooding and Muenow (1986), Wentworth and Gooding (1986), Gooding *et al.* (1988) and Gooding and Wentworth (1991b) have studied the mineralogical composition of this material. “White druse” material has also been found along rock fractures (*e.g.* piece ,312). Photo S90-34041 of ,313 (display sample) shows a large off-white patch (8 mm) that may be an additional deposit of “druse.” Gooding *et al.* (1988) showed that this material was mostly CaCO<sub>3</sub> (calcite), but also included CaSO<sub>4</sub>. Isotopic data on the “druse” is discussed in the section on “*Other Isotopes*”.

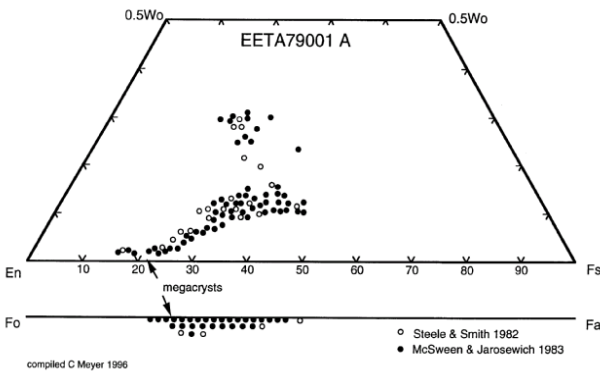
### **Mineral Chemistry**

**Olivine:** Olivine has a range of composition (Fo<sub>81-55</sub>) in EETA79001 and contains a significant amount of NiO (~0.06%) (Steele and Smith 1982b). The Fe/Mg of olivine appears to be in equilibrium with coexisting pyroxene. The olivine in the “megacrysts” in lithology A is the most Mg-rich (McSween and Jarosewich 1983). Boctor *et al.* (1998) have reported evidence of high pressure phase transition and vitrification in olivine megacrysts from lithology A. Herd *et al.* (2001) have determined Ni, Co, Cr and V in olivine from Martian meteorites.

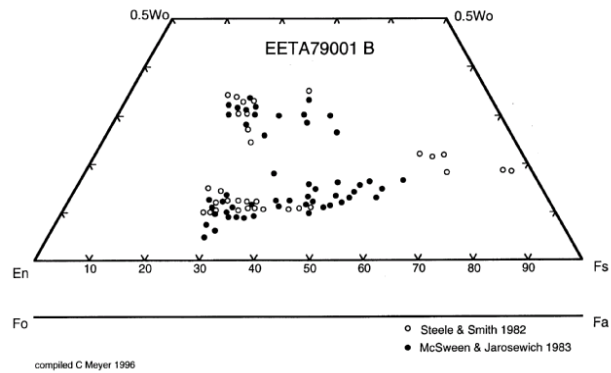
**Pyroxene:** There is a range of pyroxene compositions in EETA79001 (Steele and Smith 1982b; McSween and Jarosewich 1983). Mg-rich orthopyroxene coexists with olivine in the “xenocryst clusters” in lithology A. In the groundmass of lithology A and B, zoned pigeonite and sub-calcic augite vary from Mg-rich to Fe-rich (figure IX-13 and IX-14). Wadhwa *et al.* (1994a) determined Y, Sc, Cr, Zr and Ti in the pyroxenes in EETA79001. McSween and Jarosewich,



**Figure IX-12.** The saw cut that separated ,216 and ,1 exposed another glass pod “DELTA” in EETA79001. Note the concentric color changes in the glass. Adjacent to the glass was a large deposit of white carbonate “druse” (sample ,239). NASA photo # S86-37533



**Figure IX-13.** Composition diagram for pyroxene and olivine in EETA79001 lithology A. Note the data for the megacrysts in lithology A were the most magnesian.



**Figure IX-14.** Composition diagram for pyroxene and olivine in EETA79001 lithology B. Note the pyroxene is zoned to Fe-rich.

and Steele and Smith, reported pyroxferroite in the mesostasis of lithology B, but gave no analysis. Mikouchi *et al.* (1997, 1998) have studied the complex zoning of the pyroxenes in basaltic lithology B, EETA79001 and found the zoning in these pyroxenes to be similar to that of those in QUE94201.

**Plagioclase:** Maskelynite grains generally fill interstices between clinopyroxene crystals in both lithologies, consistent with the interpretation that plagioclase crystallized after pyroxene. Plagioclase is  $An_{65-50}$  in both lithologies. Treiman and Treado (1998) have determined the Raman spectra of maskelynite in EETA79001.

**Chromite:** Chromite occurs as euhedral inclusions in the olivine in the “xenocryst clusters” in lithology A. Chromites are described as “two-phase” by Steele and Smith (1982b). One phase is low Ti, the other high Ti. “About one-fifteenth of the total iron in the Ti-poor chromites, and one-ninth of that in the Ti-rich chromites, was converted to ferric iron to satisfy stoichiometry, again confirming the oxidizing conditions.”

**Amphibole:** Treiman (1997d, 1998b) gives the composition of “kaersutitic” amphibole found in melt inclusions in pigeonite in EETA79001.

**Ulvöspinel and Ilmenite:** These oxides are found in the mesostasis of lithology B. Steele and Smith (1982b), report that “up to one-fifth of the iron was converted to ferric state.”

**Ringwoodite (?) and Majorite (?)** were tentatively

reported in “shock veins” by Steele and Smith (1982b) and Boctor *et al.* (1998). These are high pressure polymorphs of olivine and pyroxene and would give an indication of the shock pressure reached by this meteorite, *if they are confirmed.*

**Phosphate:** Both whitlockite and Cl-apatite have been reported (Steele and Smith 1982b). Wadhwa *et al.* (1994a) determined the REE content of whitlockites in several shergottites and showed that they contained most of the REEs in these rocks.

**Sulfide:** Steele and Smith (1982b) reported pyrrhotite  $Fe_{0.91}S$ . McSween and Jarosewich (1983) reported Ni in the sulfides in lithology A, but not in B. They also reported pentlandite.

**Carbonate:** Calcium carbonate has been reported in the “white druse” (Gooding *et al.* 1988; Clayton and Mayeda 1988; Wright *et al.* 1988) related to glass pod DELTA (sample ,239). X-ray diffraction by Gooding *et al.* established that this material was largely calcite.

**Other salts:** Gooding (1992) summarized the various minor “salts,” including sulfates and phosphates, found in EETA79001 and other Martian meteorites. Gooding and Muenow (1986) reported a grain with Pb:Cr:S ~ 6:2:1, which Treiman (1999) interpreted as phoenicochroite-lanarite solid solution.

**Glass:** The composition of glass in EETA79001 has been reported in McSween and Jarosewich (1983). The glass pods and veins in lithology A generally have the composition of A and often contains secondary skeletal pyroxene crystals. In lithology B, non-vesicular impact



melt occurs between the pyroxene and maskelynite grains and varies in composition between bulk B and maskelynite (figure IX-11). Solberg and Burns (1989) could not find evidence of  $\text{Fe}^{+3}$  in lithology C using Mössbauer spectroscopy. Based on their finding of high S in the glass veins, Rao *et al.* (1999) conclude that glass pods and veins in EETA79001 are a mixture of lithology A, excess plagioclase and Martian soil.

**$\text{SiO}_2$ :** McSween and Jarosewich (1983) reported tridymite (?) associated with pyroxferroite (?) in the mesostasis of lithology B.

### Whole-rock Composition

Ma *et al.* (1982), McSween and Jarosewich (1983), Burghelle *et al.* (1983), Smith *et al.* (1984), Treiman *et al.* (1994a) and Warren and Kallemeyn (1997) give complete analyses of both lithologies A and B in EETA79001 (tables IX-2 and IX-3). The Fe/Mg ratio and Al, K, REE and P contents of lithology B are significantly higher than for lithology A. Siderophiles have been determined by Kong *et al.* (1999), Warren *et al.* (1999) and Neal *et al.* (2001). The Cr, Ni, Re, Os, Ir and Au contents are higher in lithology A than in B (see Warren *et al.*). The REEs are compared with other Martian meteorites in figure IX-15.

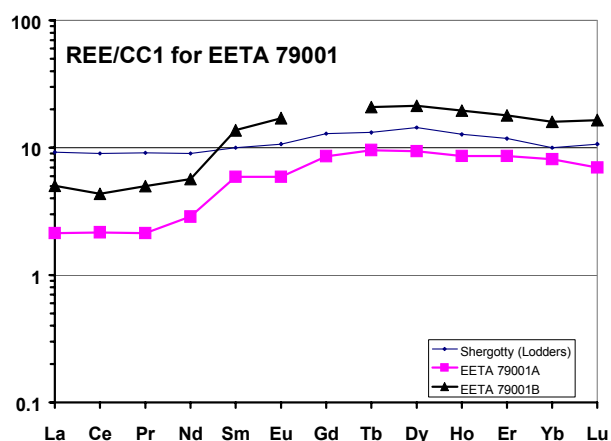
Gibson *et al.* (1985) reported 2540 ppm S in lithology A and 1940 ppm S in lithology B. Jovanovic and Reed (1987) reported 9.4 ppb Hg.

Gooding *et al.* (1990) determined the thermal release pattern for several volatile species. Karlsson *et al.* (1992) determined 640 ppm  $\text{H}_2\text{O}$  in lithology A, but some of this may be adsorbed terrestrial water. Leshin *et al.* (1996) showed that most water in lithology A was released before 350°C.

*Note that the data for major element compositions of A and B in the review paper by McSween (1985) are in the wrong columns in their paper!*

### Radiogenic Isotopes

Wooden *et al.* (1982), reported Rb/Sr isochrons  $173 \pm 10$  Ma with  $I_{\text{Sr}} = 0.71217 \pm 3$  for lithology A and  $185 \pm 25$  Ma with  $I_{\text{Sr}} = 0.71243 \pm 7$  for lithology B ( $\lambda_{\text{Rb}} = 1.39 \times 10^{-11} \text{ year}^{-1}$ ). Nyquist *et al.* (2001) re-determined the Rb-Sr the age of lithology B as  $174 \pm 3$  Ma with  $I_{\text{Sr}} = 0.712564 \pm 11$  (figure IX-16). *These apparent crystallization ages are apparently concordant with the shergottites and ALHA77005, but the range in*



**Figure IX-15.** Normalized rare earth element diagram comparing the compositions of lithology A and B in EETA79001 with that of Shergotty.

*initial Sr ratios indicates separate source rocks. However, please note that they have three or more “cosmic ray exposure ages” (see below).*

Nyquist *et al.* (1984) also reported a Sm-Nd isochron age for pyroxene - whole rock as  $240 \pm 150$  Ma, but made no further reference to this age in Nyquist *et al.* (1986). Wooden *et al.* (1982) determined the Sm-Nd model age of 2.6 Ga. Nyquist *et al.* (2001) determined a precise Sm-Nd internal isochron for lithology B with an age of  $169 \pm 23$  Ma and initial  $\epsilon_{\text{Nd}} = +16.6 \pm 1.4$  (figure IX-17).

Nyquist *et al.* (1984) analyzed hand-picked “mafic xenocrysts” from lithology A and found that they had  $I_{\text{Sr}} = 0.71187 \pm 7$  (calculated for 180 Ma). However, Nyquist later revised this number to be on the isochron (personal communication). Nyquist *et al.* (1986) analyzed the  $I_{\text{Sr}}$  in glass inclusions (lithology C) and found that they were heterogeneous (figure IX-18).

By leaching “whole-rock” samples of EETA79001, Chen and Wasserburg (1986a) obtained a U-Pb “isochron” of  $150 \pm 15$  Ma and a Th-Pb “isochron” of  $170 \pm 36$  Ma. These leach experiments probably attacked the phosphates in the sample.

It has not proven possible to date the crystallization age of EETA79001 by Ar39-40 technique (see Bogard and Garrison 1999).

*Compiler’s Note: This rock has multiple features that require dating. First, there was an event that made*

**Table IX-2a. Chemical composition of EETA79001 lithology A.**

	McSween 83	Burghelle 83	Smith 84	Treiman 94a	Laul 86	Ma 82	Warren 97	Warren 97/Lee 98	
weight			310 mg	67 mg *	310 mg	310 mg	312 mg	321 mg	
SiO <sub>2</sub> %	48.52 (a)	48.58 (b)					51.65	50.57	
TiO <sub>2</sub>	0.7 (a)	0.64 (b)	0.6 (d)		0.6 (d)	0.6 (d)	0.95	0.70	
Al <sub>2</sub> O <sub>3</sub>	5.68 (a)	5.37 (b)	5.6 (d)		5.6 (d)	5.6 (d)	7.18	5.85	
Fe <sub>2</sub> O <sub>3</sub>	0.7 (a)								
FeO	17.94 (a)	18.32 (b)	19.1 (d)	18.4 (d)	19 (d)	19.2 (d)	16.72	18.52	
MnO	0.52 (a)	0.469 (b)	0.47 (d)		0.47 (d)	0.469 (d)	0.47	0.49	
CaO	7.1 (a)	7.05 (b)	6.9 (d)	7 (d)	6.9 (d)	6.9 (d)	8.54	7.42	
MgO	16.59 (a)	16.31 (b)	16.3 (d)		16.3 (d)	16.3 (d)	11.9	14.6	
Na <sub>2</sub> O	0.84 (a)	0.818 (b)	0.87 (d)	0.92 (d)	0.86 (d)	0.87 (d)	0.89	0.80	
K <sub>2</sub> O	0.05 (a)	0.033 (b)	0.042 (d)		0.042 (d)	0.04 (d)	0.04	0.04	
P <sub>2</sub> O <sub>3</sub>	0.65 (a)	0.54 (b)							
<b>sum</b>	<b>99.29</b>	<b>98.13</b>					<b>98.34</b>	<b>98.99</b>	
Li ppm		4.54 (b)							
C	200	36 (b)							
F		39 (b)							
S	1784 (g)	1600 (b)							
Cl		26 (b)							
Sc		36.1 (b)	37 (d)	37 (d)	36 (d)	37 (d)	37.2	38	
V			210 (d)		210 (d)	210 (d)	230	220	
Cr	3968 (a)	4030 (b)	4173 (d)	4392 (d)	4173 (d)	4173 (d)	4290	4760	
Co		47.3 (b)	48 (c)	48.9 (d)	45 (d)	48 (d)	43	55	
Ni	300	158 (b)	140 (d)	160 (d)		150 (d)	128	179	
Cu									
Zn		81 (b)	64 (c)		70 (d)		85	65	
Ga		12.6 (b)	13 (c)				14.2	12.8	
Ge									
As		0.005 (b)	0.044 (c)						
Se		<.8 (b)	0.43 (c)	0.5 (d)				<0.53	
Br		0.189 (e)							
Rb			1.04 (c)				<6.9	<4.3	
Sr		57 (b)	57				<46	<59	
Y									
Zr							67	44	
Nb									
Mo									
Pd ppb									
Ag ppb			19 (d)						
Cd ppb			37 (c)						
In ppb			46 (c)						
Sb ppb		<10 (b)	10 (c)						
Te ppb			5.9 (c)						
I ppm		<0.1 (b)							
Cs ppm			0.075 (c)	0.07 (d)			<0.103	<0.12	
Ba		<10 (b)					<26	<18	
La		0.37 (b)	0.41 (d)	0.32 (d)	0.41 (c)	0.42 (d)	0.48	0.41	
Ce		1.4 (b)	<0.5 (d)	1.4 (d)	1 (c)		1.71	1.13	
Pr									
Nd		1.4 (b)			1.3 (c)		<1.2	<2.6	
Sm		0.75 (b)	0.74 (d)	0.64 (d)	0.78 (c)	0.78 (d)	0.78	0.76	
Eu		0.35 (b)	0.37 (d)	0.331 (d)	0.37 (c)	0.38 (d)	0.40	0.37	
Gd									
Tb		0.3 (b)	0.26 (d)	0.25 (d)	0.34 (c)	0.24 (d)	0.32	0.32	
Dy		2.11 (b)	1.7 (d)			1.7 (d)	2.1	2.2	
Ho		0.5 (b)			0.5 (c)		0.4	0.49	
Er									
Tm		0.21 (b)	0.11 (d)		0.22 (c)				
Yb		1.12 (b)	1.1 (d)	1.03 (d)	1.25 (c)	1.11 (d)	1.16	1.11	
Lu		0.15 (b)	0.18 (d)	0.14 (d)	0.18 (c)	0.19 (d)	0.17	0.16	
Hf		0.93 (b)	0.94 (d)	0.97 (d)	0.94 (c)	0.97 (d)	0.97	0.98	0.8198 (f)
Ta		0.03 (b)	<0.05 (d)	0.03 (d)			<0.08	0.03	
W ppb		83 (b)							0.07709 (f)
Re ppb									
Os ppb									
Ir ppb		<2 (b)					<2.3	<5	
Au ppb		2.8 (b)	3.9 (c)	18 (d)			<2	0.96	
Tl ppb			6.9 (c)						
Bi ppb	<b>Chen 86</b>		0.67 (c)						
Th ppm	0.08 (f)	<.1 (b)					<0.1	<0.07	
U ppm	0.018 (f)	<.06 (b)					<0.16	<0.04	

technique (a) wet chem., (b) INAA & RNAA, (c) RNAA, (d) INAA, (e) Dreibus et al 1985, (f) isotope dilution mass spec. (g) recalculated

\* from powder prepared by Jarosewich

**Table IX-2b. Chemical composition of EETA79001 lithology A (cont.).**

reference weight	Lodders 98 average	Kong 99 100.7 mg.	Mittlefehldt 99 543 mg.	Warren 99 290 mg.	Warren 99 297 mg.	Neal 2001	Neal 2001		
SiO <sub>2</sub>	49.9			51.56	50.49				
TiO <sub>2</sub>	0.7	1.67	(a)	0.95	0.7	(a)		0.69	
Al <sub>2</sub> O <sub>3</sub>	5.91	7.71	(a)	7.18	5.86	(a)		6.12	
FeO	18.4	20.07	(a)	16.72	18.53	(a)		24.3	
MnO	0.48	0.53	(a)	0.47	0.49	(a)		0.54	
CaO	7.26	8.02	(a) 7.7	(a) 8.5	7.4	(a)		7.86	
MgO	16.1	17.58	(a)	11.94	14.59	(a)		16.9	
Na <sub>2</sub> O	0.86	0.77	(a) 0.87	(a) 0.89	0.795	(a)		1.06	
K <sub>2</sub> O	0.04	0.035	(a) 0.05	(a) 0.04	0.04	(a)			
P <sub>2</sub> O <sub>5</sub>	0.6							0.66	
sum									
Li ppm	4.5							1.47	1.69 (d)
Sc	36	36.7	(a) 45.3	(a) 37.2	38	(a)		30.2	32.2 (d)
V	210	234	(a)	230	220	(a)		195.5	189.4 (d)
Cr	4240	4230	(a) 2830	(a) 4290	4760	(a)		3533	3733 (d)
Co	48	59.4	(a) 42.2	(a) 43	55	(a)		44.6	46.4 (d)
Ni	180			123	166	(b)		139.4	147.4 (d)
Cu								11.7	11.7 (d)
Zn	73	87.2	(a)	72	66	(b)		67.7	70.1 (d)
Ga	13.2	13.4	(a)	14.2	12.8	(a)		12.1	12.8 (d)
Ge				0.87	0.8	(b)			
As	0.005		0.22	(a) <0.4		(a)			
Se	0.47				<0.53	(a)			
Br	0.141			0.32	0.28	(a)			
Rb	1.04		2	(a)				1.24	1.27 (d)
Sr	57		20	(a) <46	<59	(a)		20.7	18.3 (d)
Y								10.7	12.4 (d)
Zr	29.4		60	(a) <100	<90	(a)		28.5	29.7 (d)
Nb	0.68							0.8	0.86 (d)
Mo		0.01	(b)					0.19	0.26 (d)
Pd ppb						6.05	(d)		
Ag ppb	19	5.3	(b)						
Cd ppb	37			12.3		(b)			
In ppb	46								
Sb ppb	10		15	(a)				20	10 (d)
Te ppb	5.9								
I ppm	<0.1								
Cs ppm	0.073			<0.103	<0.12	(a)		0.06	0.07 (d)
Ba	<10		12	(a)				4.99	5.56 (d)
La	0.4	0.46	(a) 0.43	(a) 0.48	0.41	(a)		0.5	0.5 (d)
Ce	1.27	0.87	(a) 1.5	(a) 1.71	1.13	(a)		1.26	1.3 (d)
Pr								0.19	0.19 (d)
Nd	1.35			<1.2	<2.6	(a)		1.03	1.3 (d)
Sm	0.74	0.833	(a) 0.78	(a) 0.78	0.76	(a)		0.74	0.87 (d)
Eu	0.37	0.405	(a) 0.36	(a) 0.4	0.37	(a)		0.38	0.33 (d)
Gd		0.59	(a)					1.53	1.69 (d)
Tb	0.28	0.347	(a) 0.32	(a) 0.32	0.32	(a)		0.33	0.35 (d)
Dy	1.9			2.1	2.2	(a)		2.15	2.28 (d)
Ho	0.5			0.4	0.49	(a)		0.45	0.48 (d)
Er								1.32	1.37 (d)
Tm	0.18							0.18	0.19 (d)
Yb	1.12	1.32	(a) 1.28	(a) 1.16	1.11	(a)	<b>Blichert-Toft 99</b>	1.24	1.32 (d)
Lu	0.17	0.172	(a) 0.18	(a) 0.17	0.16	(a)	0.156 (c)	0.17	0.17 (d)
Hf	0.95	1.01	(a) 1.09	(a) 0.97	0.98	(a)	0.936 (c)	0.84	1.03 (d)
Ta	0.03		0.08	(a) <0.08	0.03	(a)		0.05	0.05 (d)
W ppb	83	33	(b) 200	(a)			<b>Brandon 2000</b>	70	90 (d)
Re ppb				0.23	0.085	(b)	0.0989 (c)		
Os ppb		1.5	(b)	2.3	1.55	(b)	0.4811 (c)		
Ir ppb		1.64	(b)	2	1.42	(b)	0.59 (d)		
Au ppb	2.6	0.803	(b) 3.2	(a) 0.92	0.8	(b)			
Pt ppb	0.67	6.38	(b)				8.65 (d)		
Ru ppb		2.2	(b)				1.6 (d)		
Rh ppb							0.88 (d)		
Tl ppb	6.9								
Th ppm	0.08		0.07	(a) <0.1	<0.07	(a)		0.15	0.15 (d)
U ppm	0.019			<0.16	<0.04	(a)		0.02	0.02 (d)

technique (a) INAA, (b) RNAA, (c) IDMS, (d) ICP-MS

Table IX-3a. Chemical composition of EETA79001 lithology B.

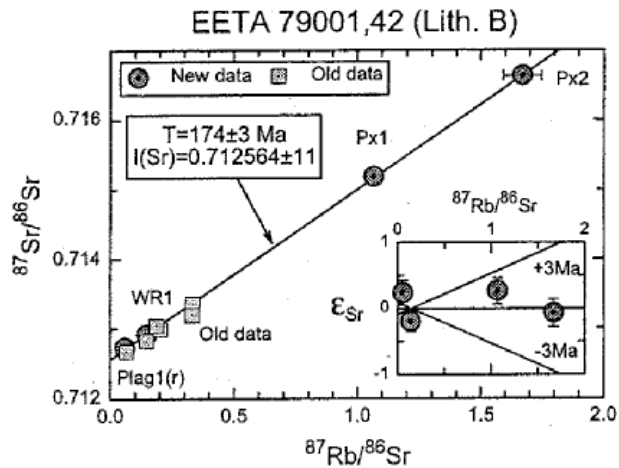
	McSween 83	Burghelle 83	Smith 84	Treiman 94a	Laul 86	Dreibus 96	Ma 82	Warren 97	Warren 97
<i>weight</i>		232.7	301 mg	71 mg *	301 mg		301 mg	319 mg	324 mg
SiO <sub>2</sub> %	49.03 (a)	49.03 (b)						49.72	49.93
TiO <sub>2</sub>	1.23 (a)	1.12 (b)	1.1 (d)		1.1 (d)		1.1 (d)	1.53	1.25
Al <sub>2</sub> O <sub>3</sub>	9.93 (a)	9.93 (b)	10.5 (d)		10.5 (d)		10.5 (d)	11.7	13.4
Fe <sub>2</sub> O <sub>3</sub>	0.22 (a)								
FeO	16.87 (a)	17.74 (b)	17.9 (d)	17.3 (d)	17.9 (d)		17.9 (d)	17.62	16.97
MnO	0.47 (a)	0.452 (b)	0.41 (d)		0.41 (d)		0.413 (d)	0.41	0.41
CaO	11 (a)	10.99 (b)	10.4 (d)	11.3 (d)	10.4 (d)		10.4 (d)	10.92	10.78
MgO	7.32 (a)	7.38 (b)	7.5 (d)		7.5 (d)		7.5 (d)	5.47	5.14
Na <sub>2</sub> O	1.68 (a)	1.66 (b)	1.62 (d)	1.69 (d)	1.62 (d)		1.62 (d)	1.78	2.03
K <sub>2</sub> O	0.09 (a)	0.065 (b)	0.075 (d)		0.075 (d)		0.07 (d)	0.08	0.08
P <sub>2</sub> O <sub>3</sub>	1.25 (a)	1.31 (b)							
<b>sum</b>	<b>99.09</b>	<b>99.677</b>						<b>99.23</b>	<b>99.99</b>
Li ppm		2.21 (b)							
C	100	98 (b)							
F		30.9 (b)							
S	2184 (f)	1920 (b)							
Cl		48 (b)							
Sc		50.5 (b)	50 (d)	50.1 (d)	50 (d)		50 (d)	43.2	42.1
V			206 (d)		206 (d)		206 (d)	159	135
Cr	957 (a)	1252 (b)		1273 (d)	1197			650	420
Co	<100	31.1 (b)	30 (c)	30.8 (d)	30 (d)		30 (d)	27.7	28.4
Ni	<100	46 (b)	30 (d)	50 (d)			20 (d)	23	19
Cu									
Zn		120 (b)	71 (c)		71 (d)			105	92
Ga		24.4 (b)	17 (c)					26.8	29.9
Ge									
As		0.012 (b)	0.021 (c)						
Se			0.42 (c)	0.4 (d)					1.83
Br		0.289 (e)							
Rb			1.78 (c)					<6.9	<4.1
Sr		67 (b)	67	40 (d)				34	28
Y						27.8 (g)			
Zr						64.8 (g)		64	90
Nb						1.66 (g)			
Mo									
Pd ppb									
Ag ppb			6.3 (c)						
Cd ppb			70 (c)						
In ppb			68 (c)						
Sb ppb		<30 (b)	16 (c)						
Te ppb			7.4 (c)						
I ppm		0.96 (b)							
Cs ppm			0.131 (c)	0.13 (d)				0.159	<0.13
Ba		14 (b)				12 (g)		<50	<26
La		0.8 (b)	0.81	0.68 (d)	0.88 (c)	0.781 (g)	0.82 (d)	1.18	1.03
Ce		3.1 (b)	2.2	1.6 (d)	2.2 (c)	2 (g)		2.63	2.34
Pr									
Nd		2.9 (b)	3		2.5 (c)	2.12 (g)	3 (d)	2.55	3.1
Sm		1.56 (b)	1.5	1.28 (d)	1.65 (c)	1.43 (g)	1.5 (d)	2.01	1.95
Eu		0.73 (b)	0.72		0.72 (c)	0.67 (g)	0.72 (d)	0.96	0.95
Gd					3.2 (c)	2 (g)			
Tb		0.64 (b)	0.57	0.64 (d)	0.71 (c)	0.48 (g)	0.55 (d)	0.76	0.79
Dy		4.58 (b)	3.7			3 (g)	3.7 (d)	5.2	5.1
Ho		0.99 (b)			0.98 (c)	0.71 (g)		1.09	1.08
Er									
Tm		0.37 (b)	0.27		0.4 (c)				
Yb		2.14 (b)	2	1.81 (d)	2.3 (c)	1.85 (g)	2.04 (d)	2.61	2.65
Lu		0.3 (b)	0.3	0.25 (d)	0.32 (c)	0.26 (g)	0.3 (d)	0.4	0.38
Hf		1.93 (b)	1.77	1.78 (d)	1.77	1.84 (g)	1.81 (d)	2.26	2.31
Ta		0.09 (b)	0.09	0.06 (d)				0.09	0.068
W ppb		155 (b)							
Re ppb									
Os ppb									
Ir ppb		<3 (b)						<1.3	<2.4
Au ppb		1.1 (b)	0.82 (c)					<1.0	<0.2
Tl ppb			7.9 (c)						
Bi ppb			0.76 (c)						
Th ppm		<0.2 (b)				0.144 (g)		0.14	0.15
U ppm		<0.1 (b)		0.11 (d)		0.0366 (g)		<0.24	<0.07

*technique* (a) wet chem., (b) INAA & RNAA, (c) RNAA, (d) INAA, (e) Dreibus et al 1985, (f) recalculated, (g) spark source mass spec \*from powder prepared by Jarosewich

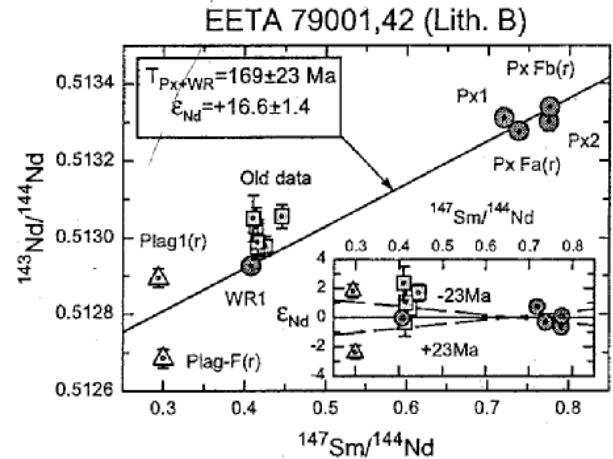
**Table IX-3b. Chemical composition of EETA79001 lithology B (cont.)**

reference weight	Lodders 98 average	Blichert-Toft 99				Warren 99		Brandon 2000	
		275 mg	259 mg	233 mg	92 mg.	297 mg	305 mg.	202 mg.	
SiO <sub>2</sub>	49.4					49.63	49.85		
TiO <sub>2</sub>	1.18					1.53	1.25	(a)	
Al <sub>2</sub> O <sub>3</sub>	11.2					11.71	13.41	(a)	
FeO	17.4					17.62	16.98	(a)	
MnO	0.43					0.41	0.41	(a)	
CaO	10.8					10.91	10.78	(a)	
MgO	6.57					5.47	5.14	(a)	
Na <sub>2</sub> O	1.74					1.78	2.03	(a)	
K <sub>2</sub> O	0.075					0.08	0.08	(a)	
P <sub>2</sub> O <sub>5</sub>	1.28								
sum	100.075								
Li ppm	2.2								
Sc	47					43.2	42.1	(a)	
V	190					159	135	(a)	
Cr	1150					650	420	(a)	
Co	29					27.7	28.4	(a)	
Ni	28					17	14.3	(b)	
Cu									
Zn	91					89	87	(b)	
Ga	21					26.8	29.9	(a)	
Ge						0.69	0.88	(b)	
As	0.017					<0.7			
Se	0.41						<2	(a)	
Br	0.025					0.5	0.4	(a)	
Rb	1.78								
Sr	54					34	28	(a)	
Y	28								
Zr	64.8					64	90	(a)	
Nb	1.66								
Mo									
Pd ppb									
Ag ppb	6.3								
Cd ppb	70								
In ppb	68								
Sb ppb	16								
Te ppb	7.4								
I ppm	0.96								
Cs ppm	0.13					159	<130	(a)	
Ba	13								
La	0.85					1.18	1.03	(a)	
Ce	2.13					2.63	2.34	(a)	
Pr									
Nd	2.63					2.55	3.1	(a)	
Sm	1.66					2.01	1.95	(a)	
Eu	0.78					0.96	0.95	(a)	
Gd	2.7								
Tb	0.62					0.76	0.76	(a)	
Dy	3.76					5.2	5.1	(a)	
Ho	0.89					1.09	1.08	(a)	
Er									
Tm	0.35								
Yb	2.02					2.61	2.65	(a)	
Lu	0.31	0.262	0.302	0.315	0.211	(c) 0.4	0.38	(a)	
Hf	1.87	2.01	2.1	2.29	1.47	(c) 2.26	2.31	(a)	
Ta	0.08					0.087	0.068	(a)	
W ppb	140								
Re ppb						0.0109	0.0166	(b)	0.0658 (c)
Os ppb						0.0029	0.0055	(b)	0.1597 (c)
Ir ppb	<3					0.00189	0.00061	(b)	
Au ppb	0.96					0.25	0.8	(b)	
Pt ppb	0.76								
Ru ppb									
Tl ppb	7.9								
Bi ppb	0.76								
Th ppm	0.145					0.14	0.15	(a)	
U ppm	0.037					<0.24	<0.07	(a)	

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



**Figure IX-16.** Rb-Sr internal mineral isochron for EETA79001B. This is figure 1 in Nyquist *et al.* XXXII.



**Figure IX-17.** Sm-Nd internal mineral isochron for EETA79001B. This is figure 2 in Nyquist *et al.* XXXII.

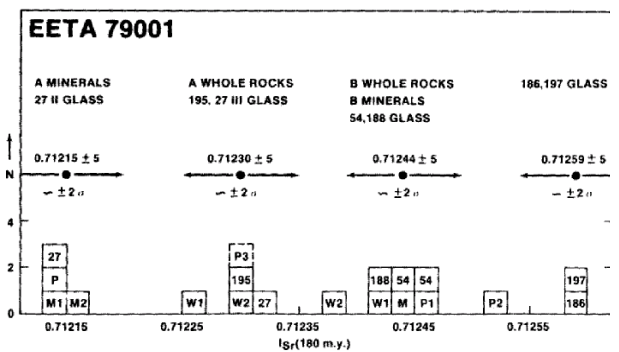
the source region for the materials in this rock. Then, there were two igneous events when lithologies A and B crystallized. Later, there was a shock event that converted the plagioclase into maskelynite and perhaps another shock event that formed the glass pods and veins and also trapping the Martian atmosphere. There may have been a time when the rock was altered by fluids on Mars (forming the salts observed in the void) and there was an event that launched this rock from Mars. Finally, there was a length of time during which the rock was in Antarctica. Which age goes with which event?

sample remains poorly determined.

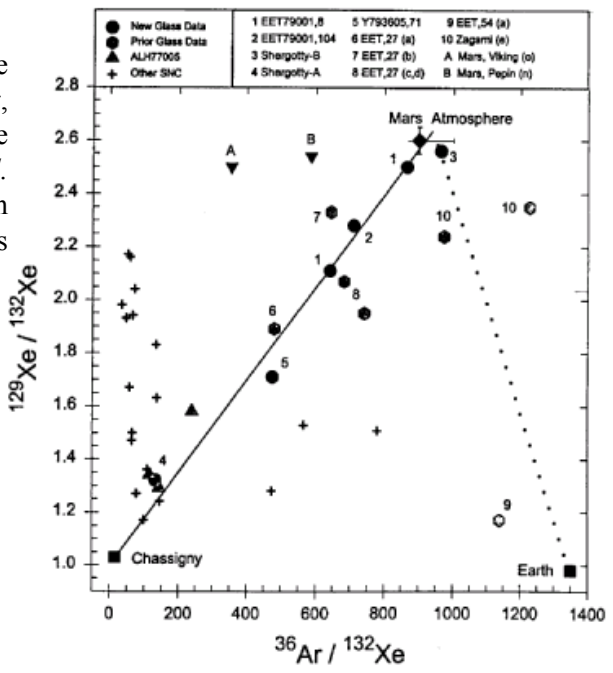
Bogard *et al.* (1984b) determined a cosmic-ray exposure age of  $\sim 0.5$  Ma. Sarafin *et al.* (1985) reported an exposure age of  $0.78 \pm 0.14$  Ma. Nishiizumi *et al.* (1986) reported an exposure age of 0.6 Ma. Pal *et al.* (1986) determined exposure ages of  $0.73 \pm 0.19$  Ma for lithology A and  $0.9 \pm 0.17$  Ma for lithology B using  $^{10}\text{Be}$ . Schnabel *et al.* (2001) determined  $0.70 \pm 0.06$  using  $^{10}\text{Be}$ . Nyquist *et al.* (2001) give a “preferred exposure age” of  $0.6 \pm 0.09$  Ma (*much younger than*

### Cosmogenic Isotopes and Exposure Ages

Jull and Donahue (1988) give a terrestrial exposure age of  $12 \pm 2$  thousand years using  $^{14}\text{C}$ . However, Sarafin *et al.* (1985) reported a “terrestrial residence time” of  $320 \pm 170$  thousand years. Nishiizumi *et al.* (1986) set a limit of  $<60$  thousand years using  $^{36}\text{Cl}$  on a deep sample (2.5 cm) and the terrestrial age for this



**Figure IX-18.** Initial Sr isotopic composition of glass “pods” in EETA79001. This is figure 4 in Nyquist *et al.* 1986, LPS XVI.



**Figure IX-19.** Rare gas composition of Martian meteorites compared with Viking mission. This figure is from Bogard and Garrison 1999.

## Isotopic Results on “White-Druse”

	$\delta^{13}\text{C}$	$\delta^{18}\text{O}$	$^{14}\text{C}$	$\delta^{15}\text{N}$
Clayton and Mayeda (1988)	+9.7 ‰	+21.0 ‰		
Wright <i>et al.</i> (1988)	+6.8 ‰	+21.0 ‰		~0 ‰
Jull <i>et al.</i> (1992)	+3.1 ‰	+20.0 ‰	<i>high activity</i>	
Douglas <i>et al.</i> (1994)	+7.2 and -28.6 ‰			

for the other Martian meteorites).

### Other Isotopes

This is the rock that demonstrated the Martian origin for SNC meteorites (see Pepin 1985; Hunten *et al.* 1987; or review by McSween 1985, 1994). In glass pockets of this meteorite, Bogard and Johnson (1983) and Bogard *et al.* (1984b) found high concentrations of rare gases and determined that the ratios  $^{84}\text{Kr}/^{132}\text{Xe} \sim 15$ ,  $^{40}\text{Ar}/^{36}\text{Ar} > 2000$ ,  $^{129}\text{Xe}/^{132}\text{Xe} > 2$  and  $^4\text{He}/^{40}\text{Ar} < 0.1$  were significantly different than the rare gas component of any other meteorite, but indeed similar to the rare gas analysis made by the Viking spacecraft on Mars (see figure I-1). Becker and Pepin (1984) extended this observation to  $^{15}\text{N}/^{14}\text{N}$  and N/Ar ratios. Ott and Begemann (1985), Wiens (1988) and others have extended and confirmed these measurements (see also Marti *et al.* 1995 for similar data on Zagami). Bogard and Garrison (1999) and Garrison and Bogard (1998) have made further detailed analyses and have developed improved correction procedures for adsorbed terrestrial gases and spallation components. With these improvements, they have now accurately determined the rare gas composition of the Martian atmosphere (*much more accurately than the Viking mass spectrometer could*) (figure IX-19).

Mathew *et al.* (1998) have studied both N and Xe isotopes by stepwise heating and distinguished three different gas components in EETA79001.

Clayton and Mayeda (1983, 1996) reported the oxygen isotopes for EETA79001 A and B (see figure I-3). Romanek *et al.* (1996, 1998) and Franchi *et al.* (1999) reported additional data for oxygen isotopes using laser-fluoridation techniques.

Carr *et al.* (1985) calculated a heavy  $^{13}\text{C}$  component ( $\delta^{13}\text{C} = +36$  ‰) for the gas found in the high temperature release of lithology C in EETA79001 which may be from the atmosphere on Mars. However, this was based on very small amounts of carbon.

Clayton and Mayeda (1988) and Wright *et al.* (1988) determined  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  for “calcite” dissolved by phosphoric acid in “white druse” material supplied by Gooding (see figure IX-12, sample ,239). These authors concluded the “druse” was a product of extra-terrestrial origin (*i.e.* alteration on Mars). Jull *et al.* (1992) studied a different sample of “druse” (,320) and found that it contained significant  $^{14}\text{C}$ , which requires a terrestrial origin.

Wright *et al.* (1988) and Grady *et al.* (1995a) found that the nitrogen released from EETA79001 or its “druse” (carbonates) was not enriched in  $\delta^{15}\text{N}$  and the apparent nitrates in these salts could not have formed by oxidation of the Martian atmosphere. Since the nitrates, carbonates and sulfates are all part of the same mineral assemblage, this also apparently creates a problem for a Martian origin of these salts.

Farquhar *et al.* (2000) have reported S isotope analyses. They are looking for evidence of a contribution of anomalous  $^{33}\text{S}$  from the Mars atmosphere.

Leshin *et al.* (1996) extracted the water out of EETA79001 and measured the isotopic ratio of hydrogen at several temperature steps (see figure V-12).

Chen and Wasserburg (1986) reported the Pb isotopes in EETA79001 and concluded that the parent body (Mars) was enriched in  $^{204}\text{Pb}$  and (probably) other volatiles.

Lee and Halliday (1997) reported excess  $^{182}\text{W}$  and Harper *et al.* (1995) reported a small  $^{142}\text{Nd}$  anomaly indicating early differentiation of Mars (and lack of subsequent mixing). Lu-Hf and Re-Os systematics also support earlier arguments that chemical compositional variability resulting from this early differentiation has been preserved (Blichert-Toft *et al.* 1999; Brandon *et al.* 2000).

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

### **Organics (?)**

Wright *et al.* (1989) and Gooding *et al.* (1990) reported organic compounds released during heating. Gooding *et al.* recognized that the trace organic concentration in their sample was not above background as determined on blanks (Gooding 1992). However, the low temperature release sample studied by Wright *et al.* (EETA79001,239) was reported to have  $\sim 1,000$  ppm C with an isotopically light signature ( $\delta^{13}\text{C} = -30$  ‰). Douglas *et al.* (1994) confirmed this result in a second sample (EETA79001,323) and stated “*if the carbonaceous components in 239 and 323 are truly martian organics, the implications for our understanding of Mars are immense.*”

McDonald and Bada (1995) analyzed samples of “white druse” and lithology A from EETA79001 for amino acids and found approximately 1 ppm and 0.4 ppm respectively. However the amino acids detected were almost exclusively L-enantiomers commonly found in proteins and thus terrestrial contamination. They also found that the amino acids in clean Antarctic ice were of the same kind and concluded that the “white druse” could have been contaminated by organics from melt water in Antarctica. Becker *et al.* (1997) also reported on PAHs in EETA79001, ALH84001 and ice water (figure IX-20).

The possibility of organic contamination by Xylan (used as a lubricant in the processing cabinets) was examined and ruled out by Wright *et al.* (1992g). The possibility of bacterial action was first pointed out by Ivanov *et al.* (1992).

### **Shock Effects**

Stöffler *et al.* (1986, 2000) determined that EETA79001 reached a shock pressure of  $34 \pm 1$  GPa with post-shock temperature about  $250^\circ\text{C}$ . McSween and Jarosewich (1983) pointed out that bulk melting of lithology A, as indicated by the composition of the glass pods and veins, indicates shock pressures in excess of 80 GPa (Schaal and Hörz 1977). Boctor *et al.* (1998a,b) have reported evidence of high pressure phase transition and vitrification in olivine megacrysts from lithology A. Boctor *et al.* also reported the presence of majorite (?) in veins of shock glass in lithology B. However, the shock event that blasted this rock off Mars was

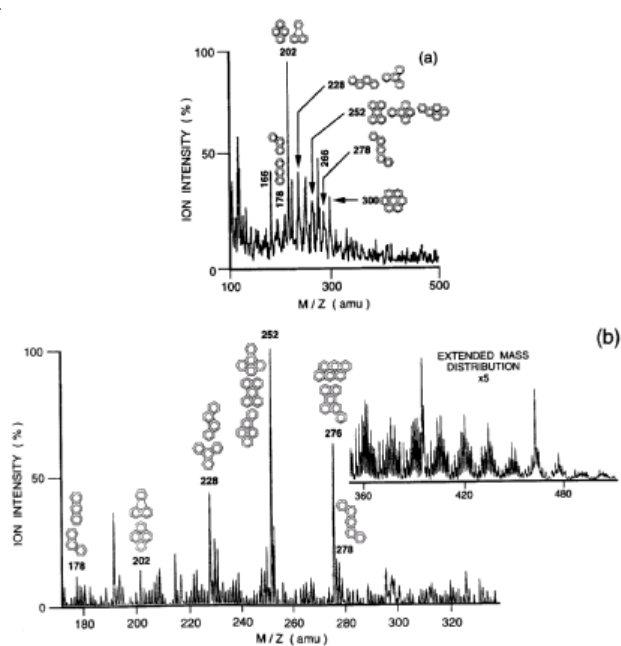
apparently not intense enough to cause decrepidation of the carbonate salts (Gooding *et al.* 1988).

### **Other Studies**

Wasylenski *et al.* (1993) performed melting experiments on the composition of the groundmass of lithology A, EETA79001. Longhi and Pan (1989) have also performed experimental work related to the origin of shergottites.

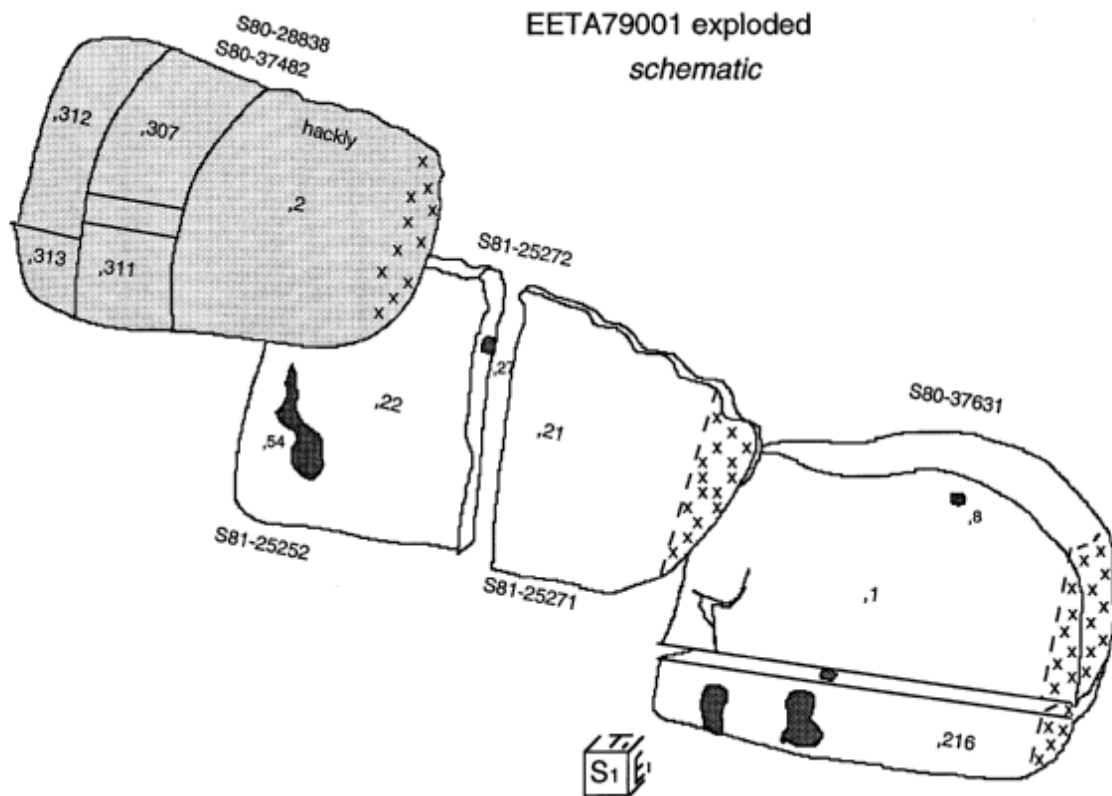
EETA79001 possesses a “weak, very stable primary natural remanent magnetization (NRM)” (see table VI-3). Titanomagnetite, and possibly pyrrhotite, have been identified as the mineral phases that carry the magnetism (Cisowski 1982, 1985, 1986; Collinson 1986, 1997; and Terho *et al.* 1993). Collinson (1997) has estimated that the strength of the magnetizing field on Mars was in the range of 0.5-5 microTesla, which is at least an order of magnitude greater than the present field. Terho *et al.* (1998) has reported additional information on the magnetic properties of a piece of EETA79001.

Salisbury *et al.* (1991), Hamilton *et al.* (1997) and Bishop and Hamilton (2001) have determined the reflectance spectra of EETA79001. Raman spectra of

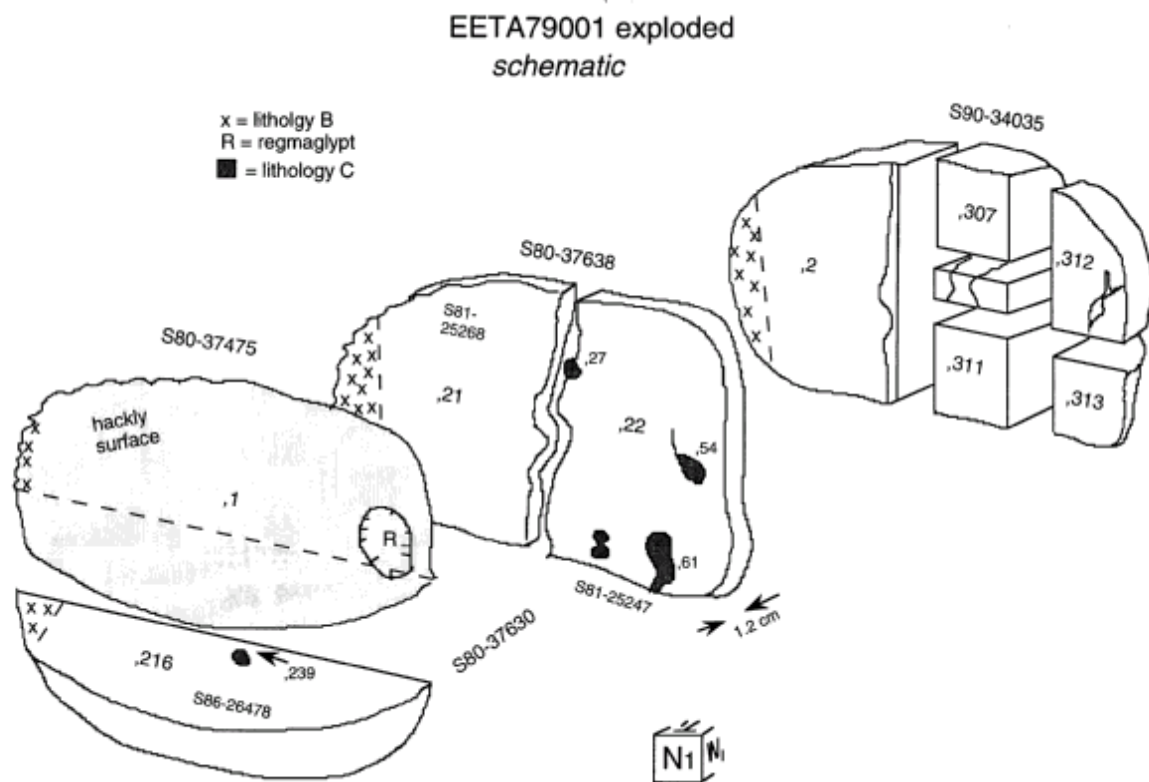


**Figure IX-20.** Mass spectra of organics released from (A) lithology A and (B) carbonate “druse” in EETA79001. This is figure 1 in Becker *et al.* 1997, GCA 61, 477.

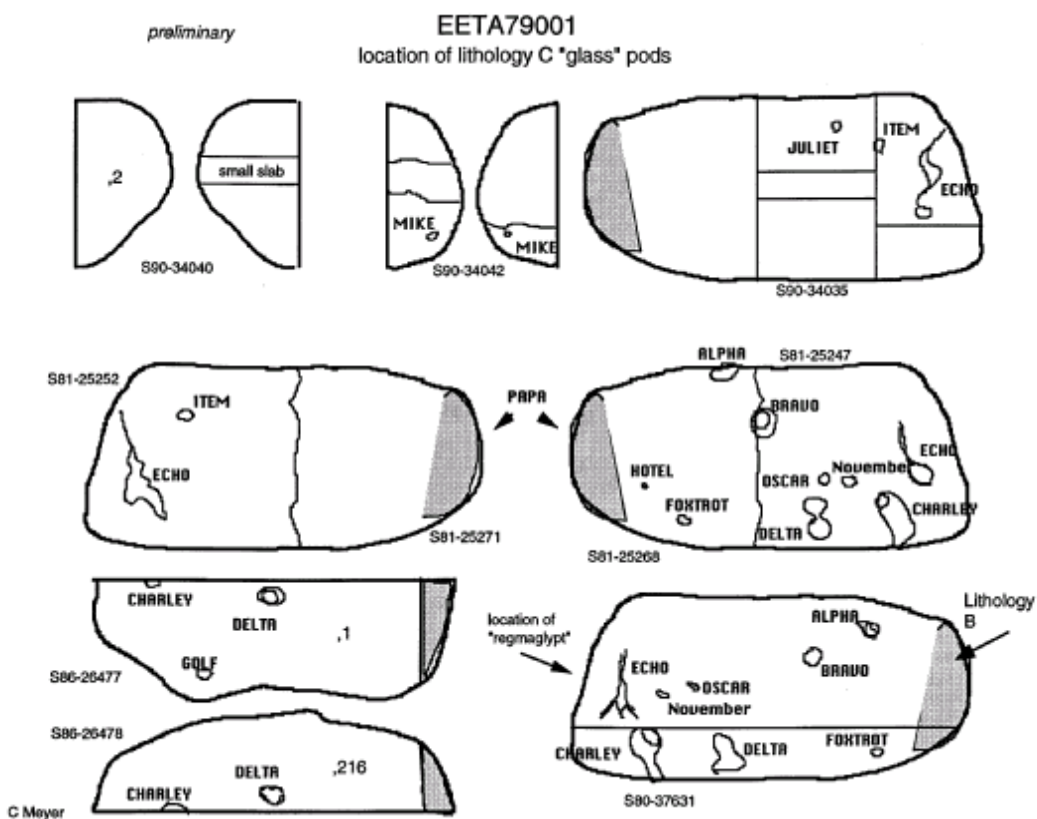




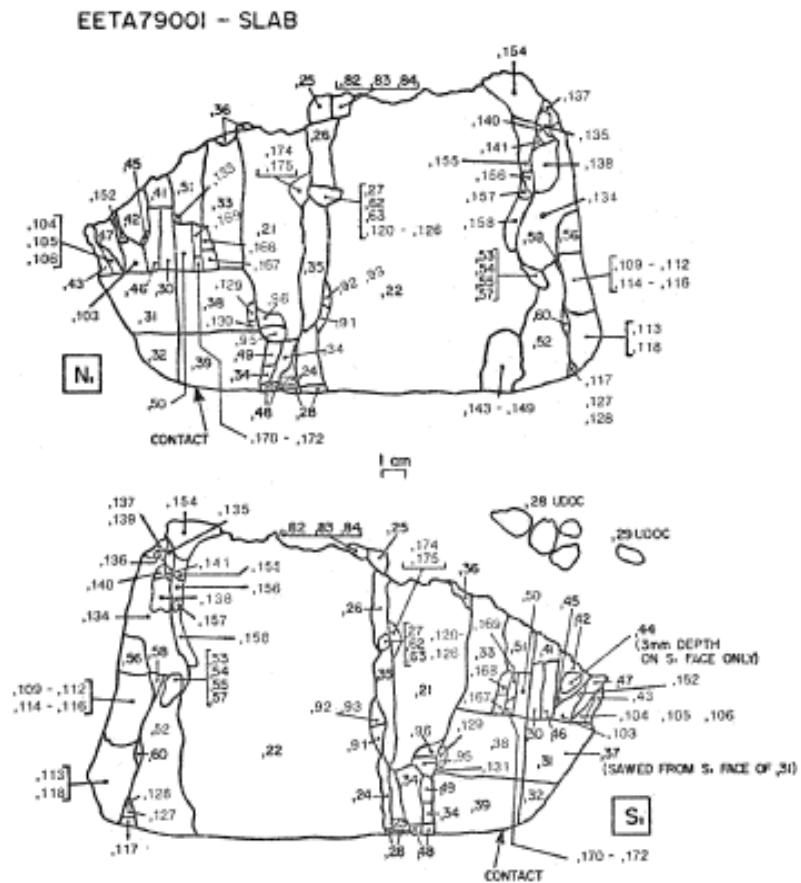
*Figure IX-21. Exploded parts diagram for EETA79001.*



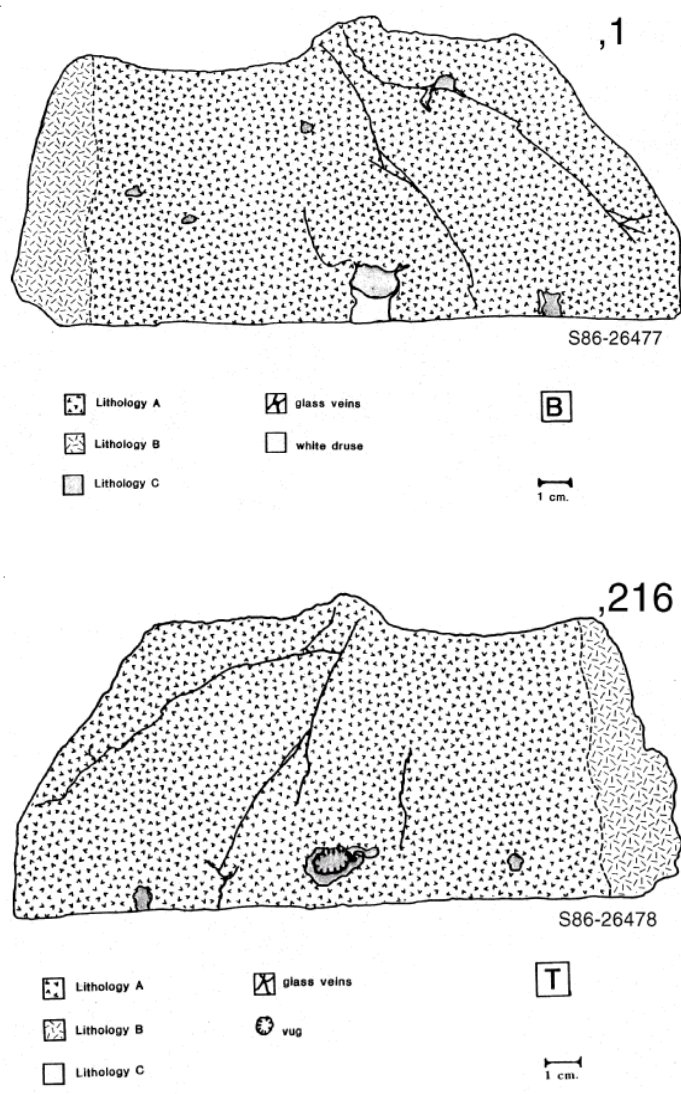
*Figure IX-22. Exploded parts diagram for EETA79001 (reversed).*



**Figure IX-23.** Location of glass "pods" on sawn surfaces of EETA79001 (see table IX-1). This sketch also illustrates the approximate location of lithology B (shaded).



**Figure IX-24.** Allocation plan for slab 22 used by McSween consortium.



**Figure IX-25.** Lithological maps of sawn surfaces of EETA79001,1 and EETA79001,216. Drawings by R. Martinez and J. Gooding 1986.

various minerals in EETA79001 have been determined by Wang *et al.* (2000, 2001).

### **Processing**

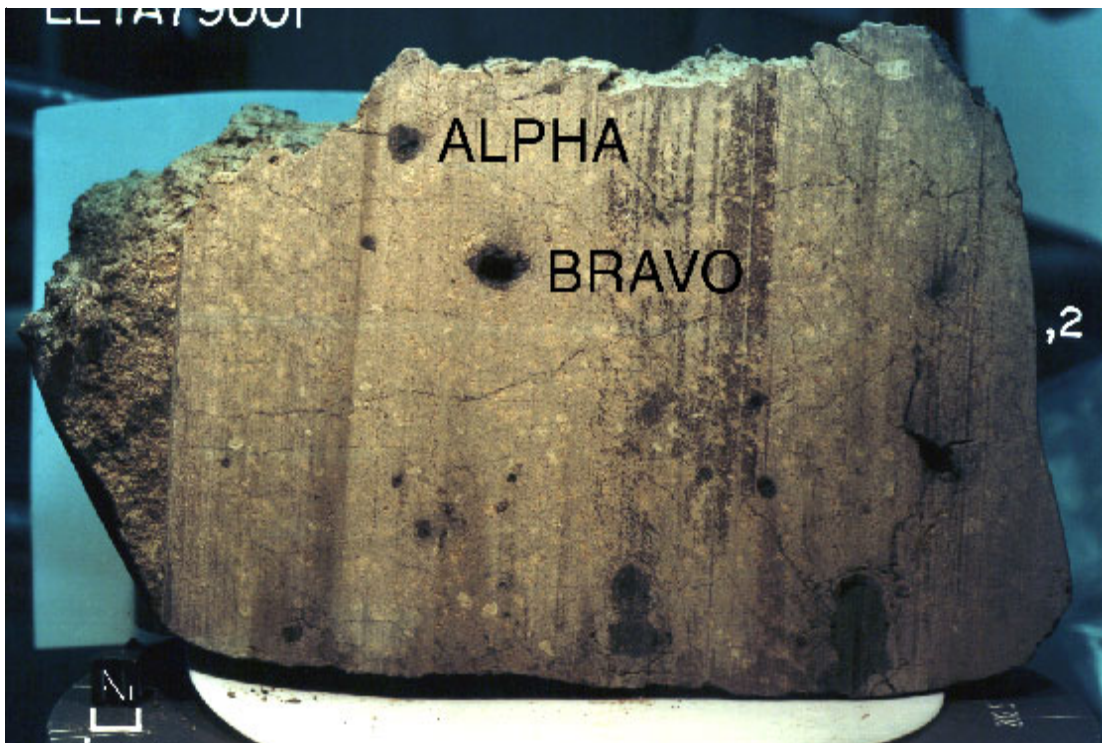
The processing of EETA79001 has proceeded along the lines of a 3D jigsaw puzzle (figures IX-21 and IX-22). In 1980, a slab was cut from the center of the meteorite, along the long dimension of the rock, creating two large pieces (,1 and ,2) and a cm thick slab that broke into two pieces (,21 and ,22). Most initial allocations were made from these slab pieces (figure IX-24). In 1986, a third cut was made perpendicular to the 1980 cuts, dividing ,1 into two pieces (the big piece ,1 and ,216). Lithological maps of these sawn surfaces are figure IX-25 (Martinez and Gooding 1986). In 1990, the remaining large piece

(,2) was further cut to create three pieces (big piece ,2, middle piece ,307, and end piece ,312). A small slab ,310 was created from the center of ,307 leaving end pieces ,307 and ,311. Piece ,313 was also cut from ,312 and adjacent to ,311. Adjacent samples ,311 and ,313 (end pieces with fusion crust) were sent to the Smithsonian (USNM) for public display. The remainder of ,307 was allocated to NASA as a display specimen.

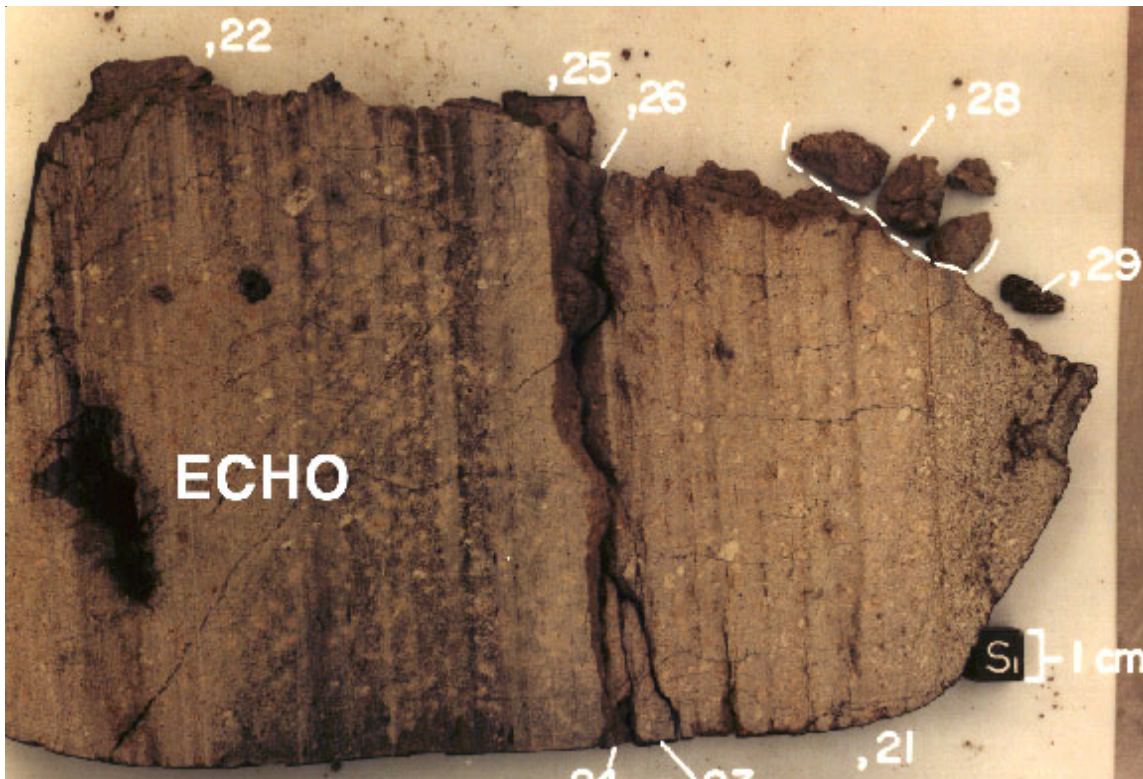
This sample was the subject of a consortium led by Hap McSween (see McSween and Jarosewich 1983; McSween 1985). In 1980, homogenized powders were prepared by Jarosewich of both lithology A (15g) and B (9g) (see Jarosewich 1990b). These powders are available to investigators by request to MWG.



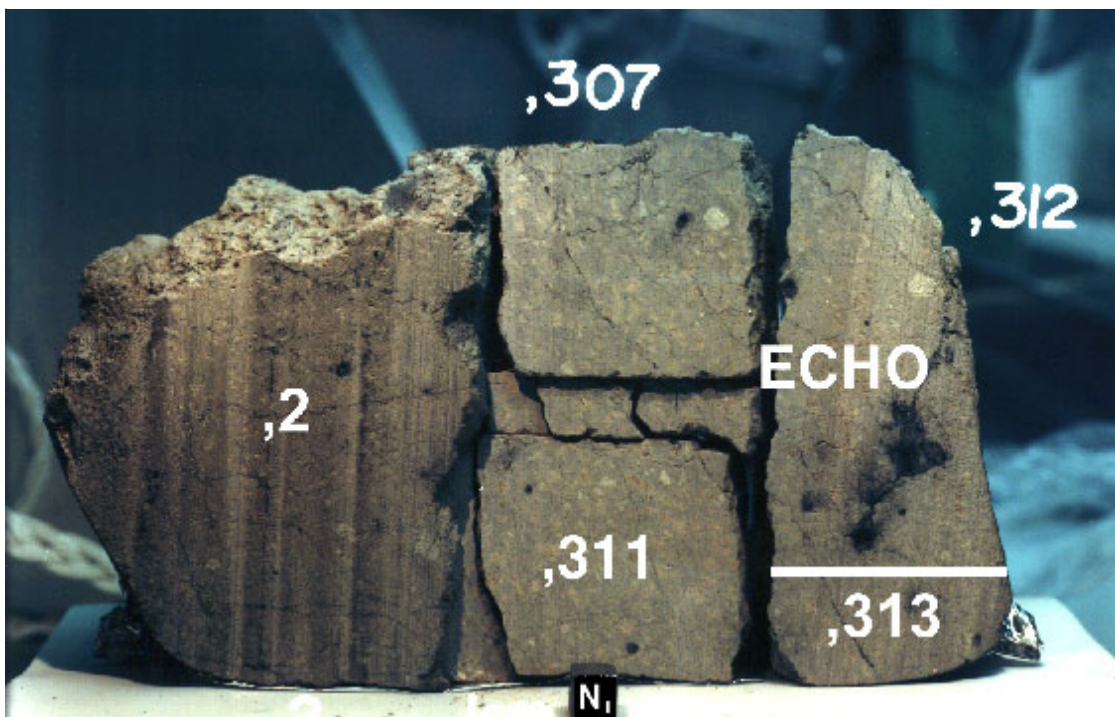
**Figure IX-26.** Sawn face of EETA79001,1 after first saw cut (NASA # S80-37631). See figures IX-21 and IX-23. Sawing was done dry, with a steel band saw.



**Figure IX-27.** Sawn face of EETA79001,2 after first saw cut (NASA # S80-37632). This photo is prior to second saw cut. BRAVO is the glass inclusion (,27) where the discovery of Martian atmospheric gasses was made. Note the large vesicles in the glass pods.



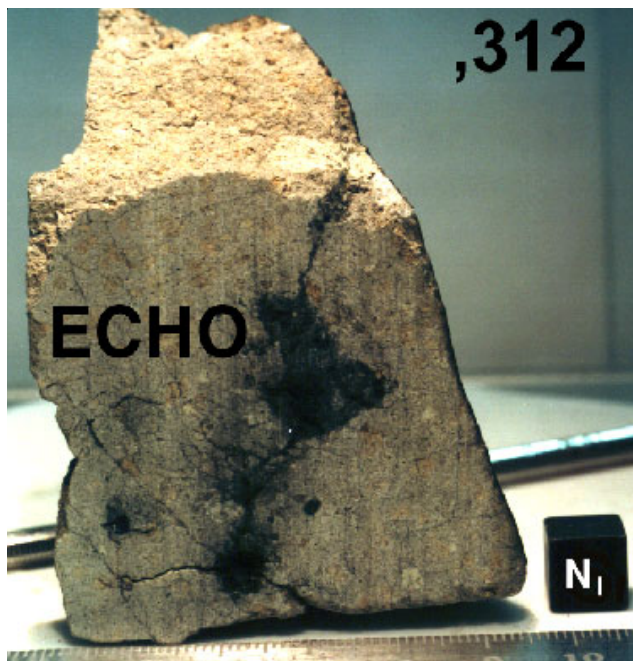
**Figure IX-28.** Photograph of complete slab through center of EETA79001 (see figure IX-21). Slab broke into two pieces ,21 and ,22. Note the basaltic texture of lithology B on the right end of ,21. This is NASA photo # S80-25272.



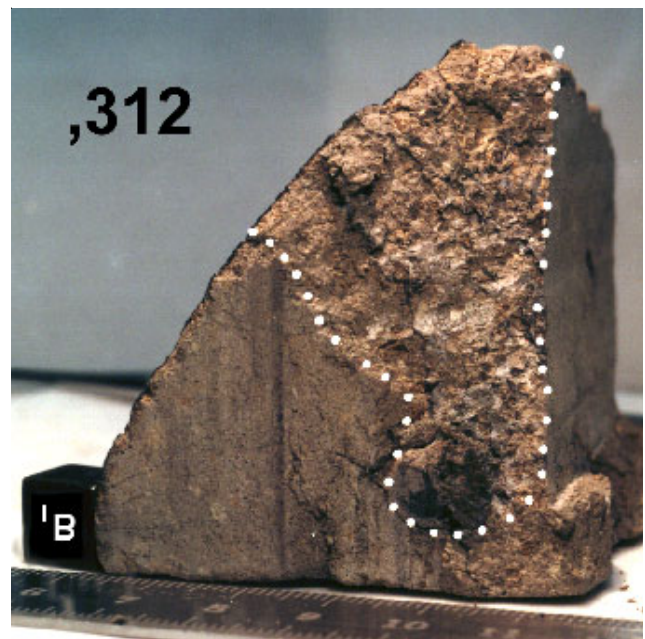
**Figure IX-29.** Group photo of EETA79001,2 after the second saw cut showing additional cuts made in 1990. (NASA # S90-34035). Cube is 1 cm (for scale). See exploded parts diagram, figure IX-22.



**Figure IX-30.** Sawn face of EETA79001 showing opposing pieces. Note the thin glass veins and small glass pods. NASA photo # S90-34042.



**Figure IX-31.** Close-up of glass inclusion (ECHO) and interconnecting glass veins and cracks. (NASA #93-33193).



**Figure IX-32.** Close-up photo of area sampled for "druse" along fracture in EETA79001,312. This sample (,363) was used to search for amino acids. (NASA # S93-33190).

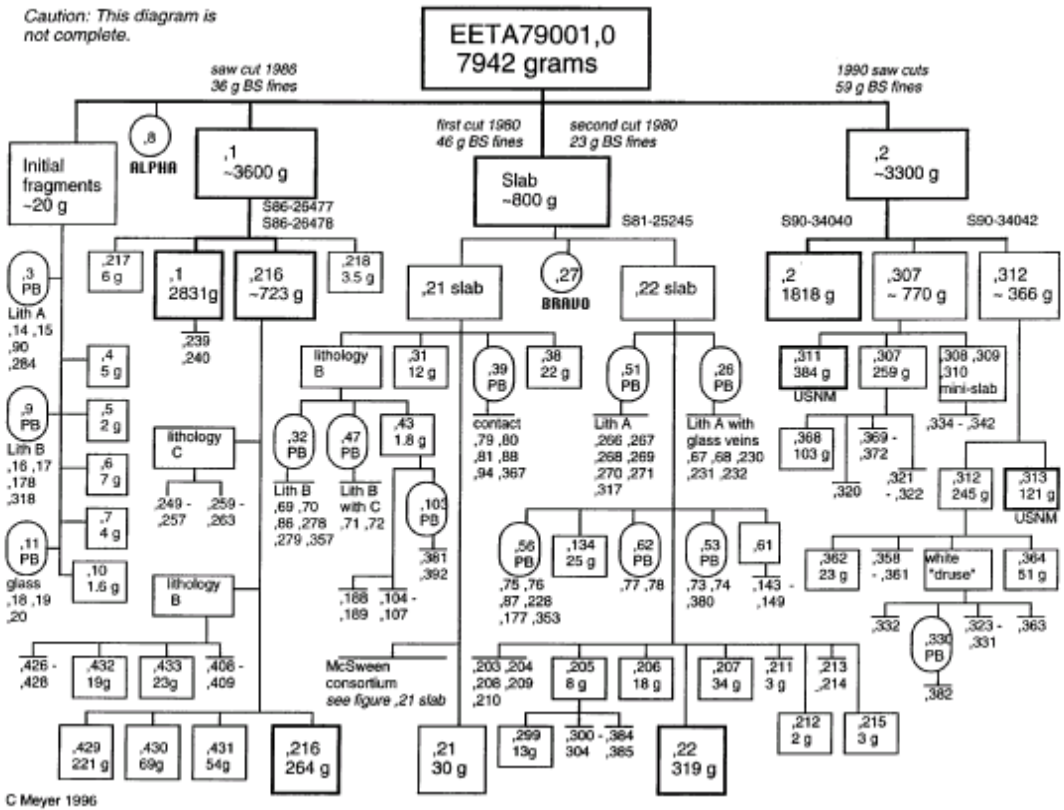


Figure IX-33. Genealogy diagram for initial splits of EETA79001 showing relationship of samples studied and opportunities for future research. See data packs and computer records for details.

### EETA79001 Lithology B

(total weight unknown, but approx. 400 g)

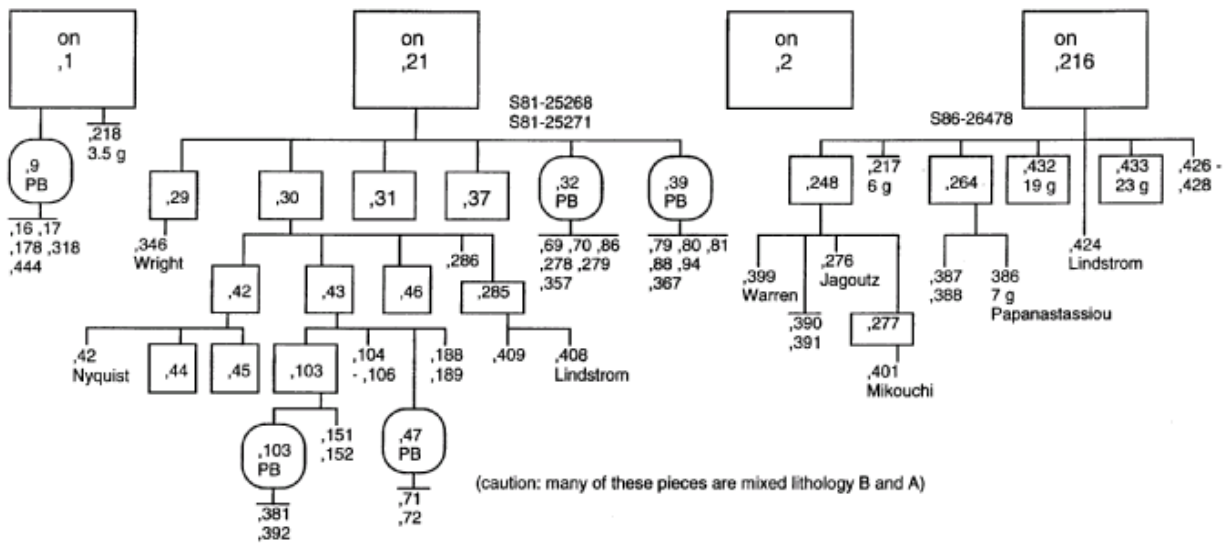


Figure IX-34. Genealogy diagram for lithology B (the basaltic part) of EETA79001.

# EETA79001 Lithology C

(distinct glass pods, most in lithology A)

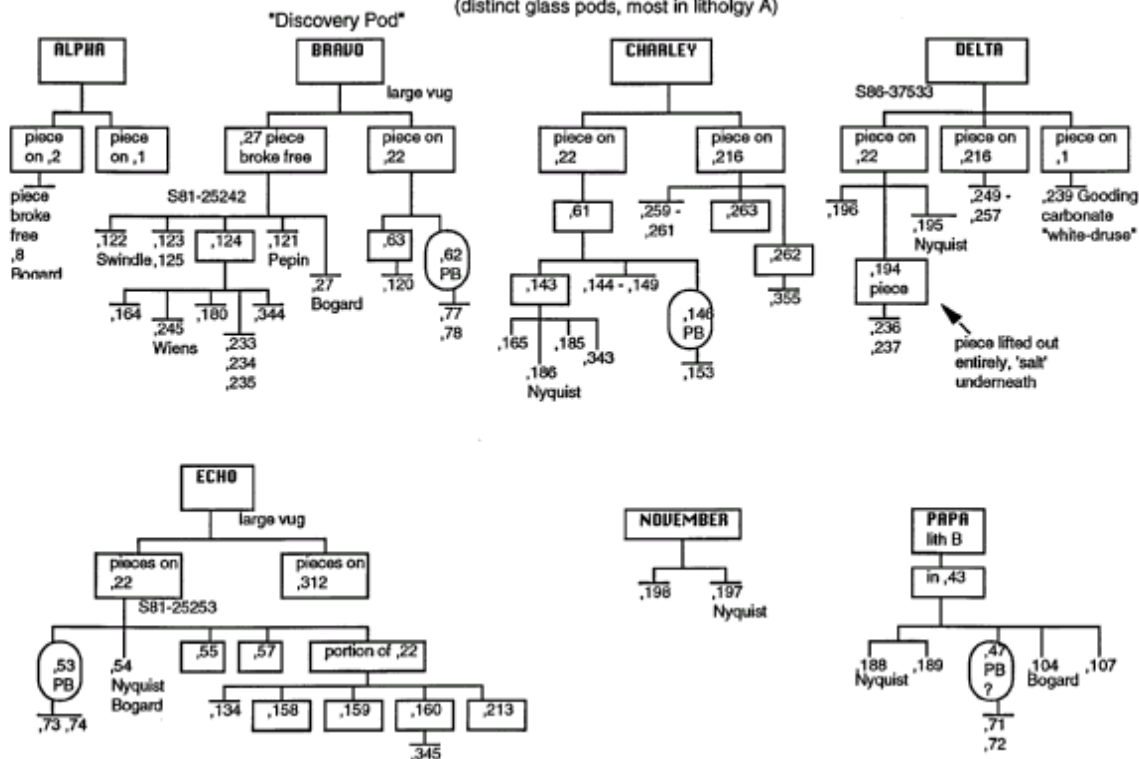
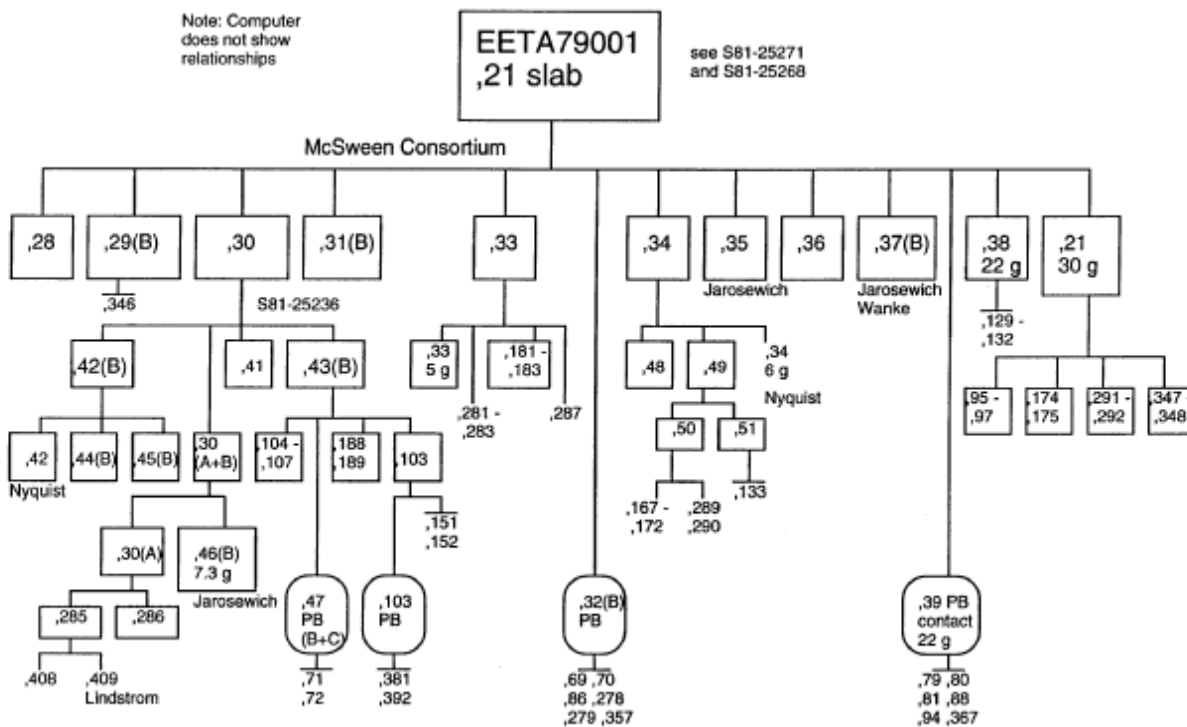


Figure IX-35. Genealogy diagram for lithology C (the glass pods) of EETA79001.



C Meyer 1996

Figure IX-36. Partial genealogy diagram for EETA79001,21 (consortium slab). See also figure IX-24.



**Table IX-4. Thin sections EETA79001.**

butt	section	2002	parent	figure in			
,3	,14	Treiman	,0 lith A		,403	Blake	superglue
	,15	Mason			,494	Blake	superglue
	,90	Papike			,436	Spray	,312 druze
	,284	Shaw			,405		,312 druze
	,442	Haskin			,453	Fisk	,285
	,443	Mikouchi			,454	Lindstrom	,216
	,448	McKenzie			,411	Lindstrom	,216
	,449	Walker			,413	Lindstrom	,216
,9	,16	Jagoutz	,0 lith B		,438	Lindstrom	,216
	,17	Mason			,417	Lindstrom	,216
	,178	Huguenin			,455	Lindstrom	,216
	,318	McSween			,419	Warren	,456
	,444	Terada			,493	Blake	superglue
,11	,18	Rao	,0 lith C		,524	Kurat	,525
	,20	MMC			,421	Papike	,216
,26	,67	Reid	,2 lith A		,439	Lindstrom	,216
	,68	Goodrich			,423	Lindstrom	,216
	,230 ,231 ,232	edu.			,440	Lindstrom	,216
,32	,69	Harvey	,2 lith B	McSween 83	,526	Papike	,216
	,70	Reid			,425	Lindstrom	,216
	,86	Papanastassiou			,441	Lindstrom	,216
	,278	Jagoutz			,427	Lindstrom	,216
	,279	Dyar			,457	Lindstrom	,432
	,357	Haskin			,482	Haskin	,8
	,445	Mikouchi			,491	Goodrich	,104
,39	,79	Delaney	,2 lith A + B	McSween 83	,506	Fisk	,361
	,80	Schultz		McSween 83	,492	Fisk	,361
	,81	Reid			,507	Kirschvink	,134
	,88	Neal			,536	Kirschvink	,432
	,94	Keil			,545	Kirschvink	,432
	,367	Treiman			,547	Kirschvink	,556
,47	,71	Dyar	,2 lith B + C		,556	Kirschvink	
	,72	Gleason					
,51	,266 ,267 ,268 ,269 ,270 ,271	edu.					
	,317	McSween					
,53	,73	Papike	,2 lith C				
	,74	Humayun					
,56	,380	Blake	superglue				
	,75	Boctor	,2				
	,76	Reid					
	,87	Barsukov					
	,177	Huguenin					
	,228	edu.					
	,353	Treiman					
,62	,77	Greenwood	,2 lith C				
	,78	MCC					
,103	,381	Blake	,43 lith B				
	,392	Papanastassiou	superglue				
	,446	McKenzie					
	,447	Walker					
	,577	Treiloff					
,146	,153	MCC	,61				
,330			,312 druze				

Lithology B (~400 grams) was located at one end of the specimen and is now on pieces ,1 ,2 ,216 and slab piece ,21 (figure IX-23).

Lithology C is represented by many different glass “pods” (table IX-1, figures IX-26 to IX-31) and thin glass veins. Sample ,27 (BRAVO) is the large glass inclusions (lithology C) where the evidence of trapped Martian atmosphere was first found (see figure IX-5). The first saw cut went right through this glass inclusion leaving a portion of it attached to ,1. It contained a large glass-lined vug. Much of sample ,27 (BRAVO) later broke free from the boundary of slabs ,21 and ,22. Glass inclusion ,8 (ALPHA), which broke free during initial processing, has now been studied by Garrison and Bogard (1998).

EETA79001 has been frequently broken-up for allocations; there are now well over 500 splits! In order to provide some clarity to the allocation of this large sample, figures IX-33 to IX-36 of the various splits are provided. However, these “genealogy” diagrams are not complete and one must refer to the meteorite data base at JSC (MRP) for complete detail. Table IX-4 gives the current location of the 83 thin section that have been made of this rock. The NASA-Smithsonian Educational Thin Section sets include EETA79001 (French *et al.* 1990).

*Please note that the orientation cube in photos taken in 1990 and 1993 was placed in the wrong orientation (reversed).*

Lithologies B and C have been listed as “*restricted*” samples by the MWG (Score and Lindstrom 1993, page 5), which means that they are allocated and processed with extra-special care.