EET A79002

Olivine-bearing Diogenite, 2.843 kg

Antarctic Find

***Figure 1**: EETA79002 as discovered in the blue ice at Elephant Moraine icefield in the TransAntarctic Mtns. The division sat the bottom of the counter are 1 cm.*

Introduction: The EETA79002 diogenite (**Figure 1 and 2**) is the largest diogenite collected in Antarctica (Mittlefehldt, 2000). It was found in the main icefield of the Elephant Moraine in Antarctica (**Figure 2**), centered on 76°11'S and 157°10'E, during the 1979 ANSMET field expedition (Grossman, 1994). It was first reported as a diogenite by the Antarctic Meteorite Newsletter, Volume 3, Issue 3, which noted its weight (2843 g) and dimensions (15 cm x 13.5 cm x 10cm); a later edition of the newsletter characterized its weathering character (B = moderate rustiness) and fracturing (B = moderate cracks), with the comment made that many fractures penetrated the whole meteorite (Antarctic Meteorite Newsletter 3/3, 4/1). EET79002 has a dull black fusion crust that covers all surfaces but one defined by a fracture plane, and in many places has been "plucked away" revealing an unusual blue-gray matrix with small clasts (<2 mm diameter) and some larger light to cream-colored clasts (~0.5 cm diameter) (Antarctic Meteorite Newsletter 3/3, 4/1; Reid and Score, 1981). A large, orange-brown weathering rind up to 1 cm in width was exposed during chipping of the sample, and some parts of EETA79002 are red-brown, indicative of heavy oxidation (Antarctic Meteorite Newsletter, 3/3, 4/1; Reid and Score, 1981).

While EETA79002 is clearly a diogenite, there are some distinct textural and mineralogical elements that make this sample unique. EETA79002 is one of the few HED meteorites that contains relatively pervasive

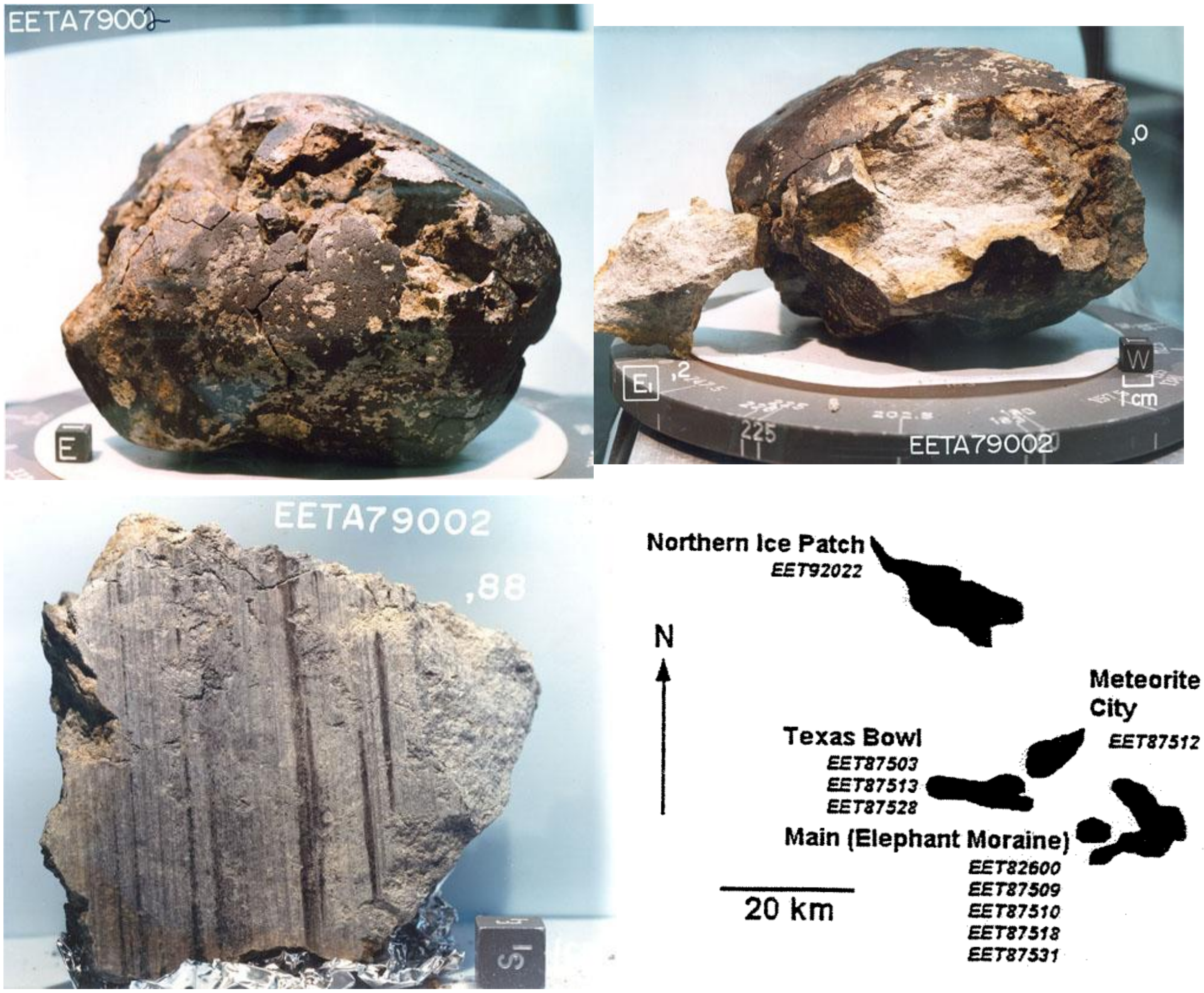


Figure 2*: Three different views of EETA79002, from the NASA-JSC Antarctic Meteorite Curation website. The top left shows the original meteorite as it was collected; the top right photo shows the weathering rind that was exposed by chipping away a small portion of the sample. The bottom left image is a cut face, with some marks added during sawing. The bottom right image shows the location of the Main icefield portion of the EET region.*

olivine, with a few samples having up to ~69 modal % (Bowman et al, 1997), leading some workers to term it an "olivine diogenite" (Sack et al, 1991). However, other researchers have noted that the modal percentage of olivine in EETA79002 varies between samples and thin sections, but is generally present in minor amounts (Reid and Score, 1981; Mittlefehldt, 1994a), with some showing no olivine at all (Bowman et al, 1997). In addition, pyroxene compositions in EETA79002 display a wider range than are found in most diogenites, with some more magnesian pyroxenes having an Mg# up to 88 (Sack et al, 1991). At least one unique, polymineralic but extremely fine-grained angular lithic clast has been isolated (Antarctic Meteorite Newsletter 3/3, 4/1; Reid and Score, 1981; Sack et al, 1991). Some small areas within the brecciated matrix are rich in very fine opaques (Antarctic Meteorite Newsletter 3/3, 4/1; Reid and Score, 1981), and the meteorite exhibits a subtle but pronounced "light-dark structure" in both clasts and matrix material (Mittlefehldt and Myers, 1991; Mittlefehldt, 2000). Finally, whereas most diogenites show abundant recrystallization textures (Reid and Score, 1981), only one report of such a texture has been made in EETA79002 (Berkley and Boynton, 1992).

A historical note: In 1986, a potted butt of EETA79002 was mislabeled as ALH84001, and one of ALH84001 was labeled as EETA79002 (Antarctic Meteorite Newsletter 16/3). Thus, much of the early work on ALH84001, which is a Martian orthopyroxenite, is actually describing EETA79002. From my survey of the literature, I believe that this is limited to the work of Sack et al (1991) (which was corrected by Sack et al, 1994), Shearer and Papike (1992), Papike et al (1993), and Shearer et al (1993); however, researchers should use extra caution when referencing early studies of both meteorites, and any descriptions of ALH84001 that include olivine are most likely referring to EETA79002.

General Petrography: EETA79002 is a diogenitic breccia, with small, highly angular clasts up to 2 mm in diameter set in a very fine-grained, cohesive, medium-gray, light green, or blue-gray granulated matrix (Antarctic Meteorite Newsletter 3/3, 4/1; Reid and Score, 1981; Mittlefehldt, 2000; **Figure 3**), though one worker reported a coarse-grained, recrystallized matrix texture in sample ,48 (Berkley and Boynton, 1992). Early workers also noted a number of larger, light to cream-colored clasts (up to 0.5 cm in size) (Antarctic Meteorite Newsletter, 3/3, 4/1; Reid and Score, 1981), and at least two authors have reported an unusual, very fine-grained, polymineralic clast (Reid and Score, 1981; Sack et al, 1991). (A glassy, aphanitic clast was also reported by Reid and Score, 1981; see Figure 13 of that source for a photo.) Clasts are nearly entirely composed of medium green to black, low-Ca pyroxene (Mittlefehldt, 2000); though *all* clasts were initially classified as monomineralic (Antarctic Meteorite Newsletter, 3/3, 4/1; Reid and Score, 1981), most authors have reported minor but pervasive, anhedral to subhedral olivine and trace amounts of accessory minerals in a number of clasts (Antarctic Meteorite Newsletter, 3/3, 4/1; Reid and Score, 1981; Mittlefehldt and Meyers, 1991; Sack et al, 1991; Berkley and Boynton, 1992; Bowman et al, 1997; Mittlefehldt, 2000; **Figure 4**). However, it is important to note that the olivines are in non-igneous breccia contact with the pyroxene, and thus were probably comminuted by mixing after initial igneous formation (Mittlefehldt, 2000).

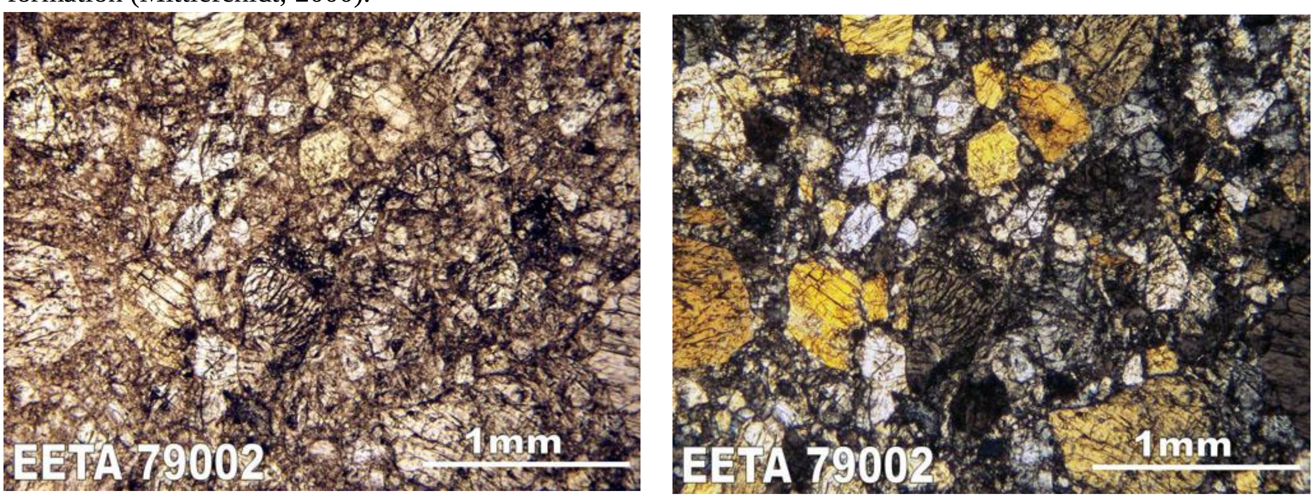


Figure 3*: Plane-polarized (top) and cross-polarized (bottom) thin section photomicrographs of EETA79002, showing up to 2 mm angular fragments in a comminuted matrix. From the NASA-JSC Antarctic Meteorite Curation website.*

Early petrographic analyses revealed that some parts of the matrix are very rich in fine opaque minerals (Antarctic Meteorite Newsletter 3/3, 4/1; Reid and Score, 1981); later research reported that both clasts and matrix show a subtle yet pronounced light-dark texture, with dark areas having higher abundances of metal and troilite as isolated grains, minute inclusions in larger grains, and symplectic intergrowths with pyroxene (Mittlefehldt and Meyers, 1991; Mittlefehldt, 2000). This distinct color contrast is distributed in lens-shaped patches and elongate stringers throughout the matrix (Mittlefehldt, 2000).

Chromite is present in slight amounts in EETA79002, but it does not contribute to the aforementioned light-dark texture; trace amounts of silica (tridymite) and diopside are also found in the meteorite (Berkley, 1987; Mittlefehldt and Meyers, 1991; Sack et al, 1991; Berkley and Boynton, 1992; Bowman et al, 1997), with one report of plagioclase feldspar in sample ,155 (Bowman et al, 1997).

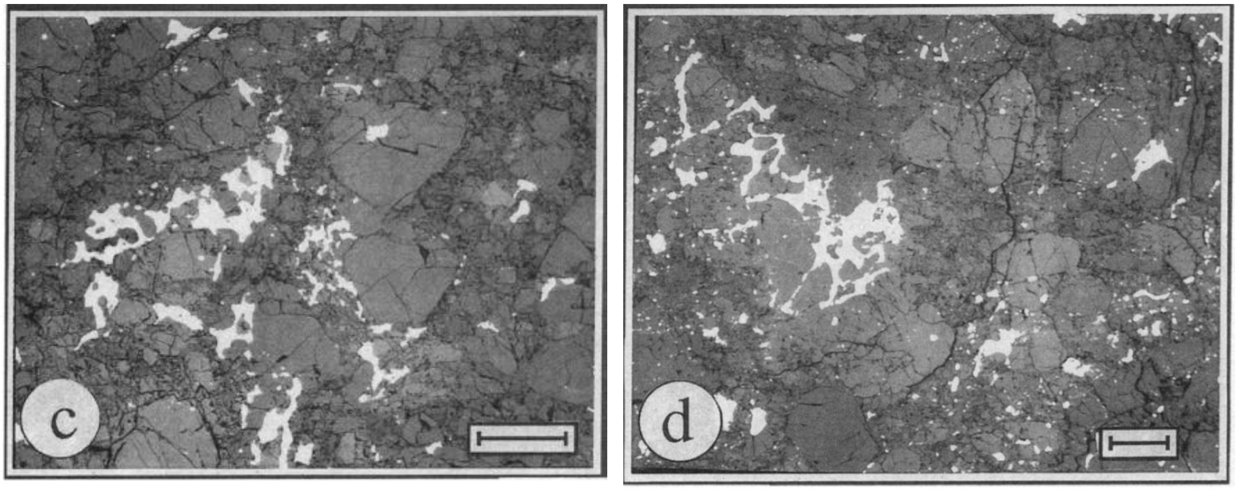


Figure 4*: Assemblages of olivine (lighter gray), orthopyroxene (darker gray), and spinel, troilite, and metal (all white) in EETA79002. Scale bars are 100 µm.Reflected light images from Sack et al (1991).*

Modal abundances in EETA79002 were first reported from a single thin section by Sack et al (1991) , who found 71% pyroxene, 27% olivine, and accessory metal, troilite, chromite, and tridymite. A more recent automated modal abundance study (Bowman et al, 1997) found extremely variable olivine abundances between three thin sections, from none (sample ,145) to nearly 69% (sample ,155). The heterogeneity of different samples reveals the need for extra care when drawing broad conclusions from a limited number of EETA79002 samples; whereas Sack et al (1991) interpreted the meteorite as a partial-melting residue based on one thin section (terming it an "olivine diogenite"), Mittlefehldt (2000) used at least 16 different samples to interpret EETA79002 as a mixture of three or more related plutons (a "genomict breccia"), at least one of which was similar to terrestrial harzburgites.

Mineral Petrography and Chemistry:

Pyroxene: The first pyroxenes identified in EETA79002 were low-calcium orthopyroxene ($Wo_2En_{76}Fs_{22}$: Antarctic Meteorite Newsletter 3/3, 4/1; Reid and Score, 1981), though one early report noted the presence of both high-Cr, high-Al (i.e., high temperature) and low-Cr, low-Al varieties (i.e., low temperature), possibly indicative of post-cumulus brecciation (Berkley, 1987). Later work revealed compositions with a bimodal distribution, ranging from a more calcic $Wo_{2.1\text{-}2.9}En_{71.7\text{-}75.6}$ (with a strong peak at $Wo_{2.2\text{-}2.4}En_{74.0\text{-}75.6}$) to a more magnesian $Wo_{1.7\text{-}2.3}En_{78.0\text{-}80.2}$ (Mittlefehldt and Meyers, 1991), with a single pyroxene from the fine-grained polymineralic clast having an especially high Mg# of 88 (Sack et al, 1991). Mittlefehldt (2000) classified EETA79002 orthopyroxenes into four different categories based on major and minor element chemistry, with total abundances and major element chemistry for each type shown in **Figures 5a** and **b**:

(1) *Typical*: The vast majority of orthopyroxenes in EETA79002 fall into this category (including the initial chemical analyses in the Antarctic Meteorite Newsletters 3/3 & 4/1, and Reid and Score, 1981). They have a limited range of Mg# from 75.6-77.3 and narrow Wo contents (~2-2.5), with Al_2O_3 and TiO_2 contents that cluster tightly and are well within the range for typical diogenites (Mittlefehldt, 2000). Cr_2O_3 is somewhat more variable (0.35-0.75 wt%: Mittlefehldt,

2000). These orthopyroxenes are found in both light and dark samples of EETA79002 (Mittlefehldt, 2000).

(2) *Ferroan I*: Orthopyroxenes of this variety have a slightly lower Mg# range (74.9-75.3), with more variable Wo contents (2-3) and lower Al_2O_3 and TiO_2 than the "typical" category, though Cr_2O_3 contents overlap completely (Mittlefehldt, 2000). They are also found in both dark and light samples, and may represent a continuum from the typical pyroxenes, but this is unclear (Mittlefehldt, 2000).

(3) *Ferroan II*: These orthopyroxenes are even more Fe-rich (Mg# = 73.8-74.2), with similar Wo contents to the ferroan I pyroxenes (2-3), and even lower Al_2O_3 and TiO_2 contents (Mittlefehldt, 2000). Interestingly, Cr_2O_3 still abundances overlap the two previous categories (Mittlefehldt, 2000). Ferroan II pyroxenes are found in both light and dark samples (Mittlefehldt, 2000).

(4) *Magnesian*: A small subset of orthopyroxene grains are especially magnesian in relation to the other categories, with Mg# = 79.3-81.5 and Wo = 1.7-2.5 (Mittlefehldt, 2000). Al_2O_3 and Cr_2O_3 are lower in these grains but TiO_2 is similar to the other categories (Mittlefehldt, 2000). These orthopyroxenes have, as of yet, only been identified in the dark samples (Mittlefehldt, 2000).

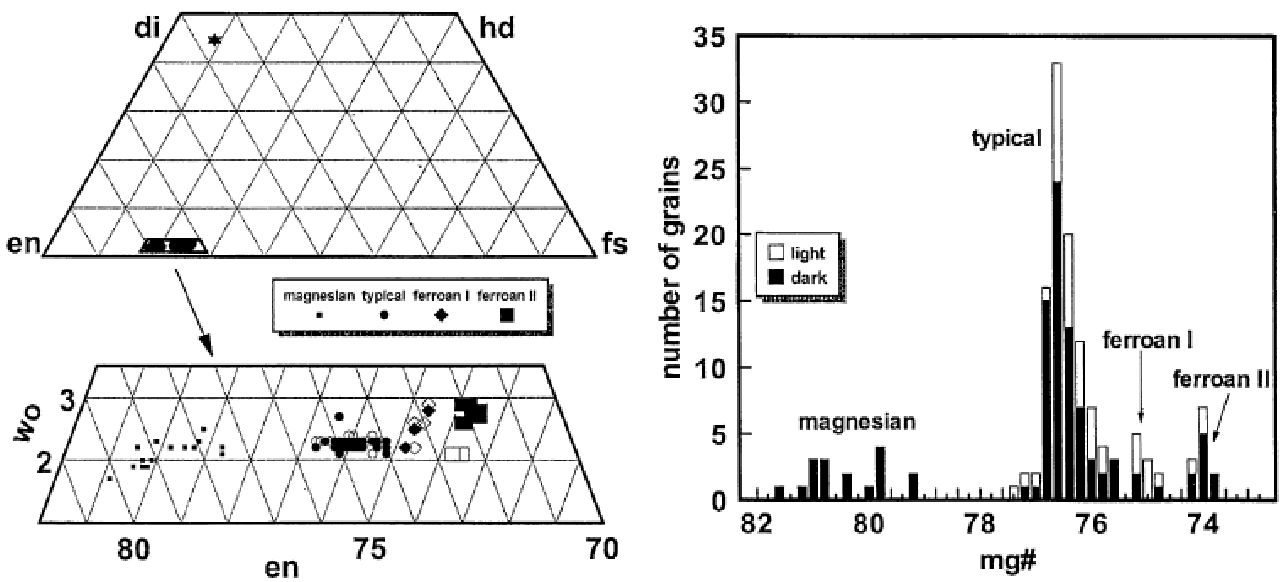
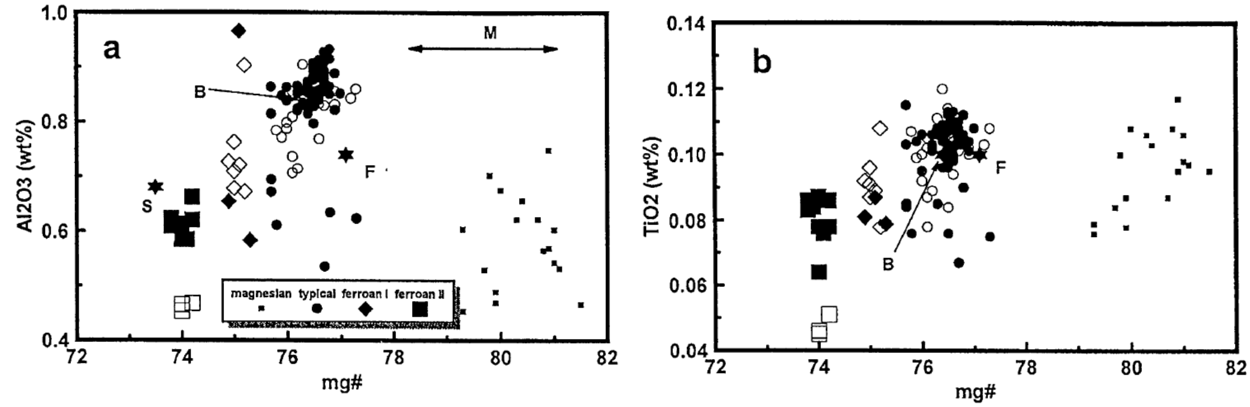


Figure 5a*: Distribution of orthopyroxene compositions in EETA79002, both in light and dark samples. The four categories are clearly demarcated based on major element chemistry. From Mittlefehldt (2000).*

This is a much greater range of pyroxene compositions than those seen in most other diogenites (Mittlefehldt and Meyers, 1991; Mittlefehldt, 2000). Some pyroxenes with variable Mg# are in breccia contact with each other; because these pyroxenes have equilibrated compositions within individual grains, this implies that major element equilibration occurred within the parent plutons rather than by later thermal metamorphism (Mittlefehldt, 1994a). Exsolution lamellae of high-Ca are rare (Sack et al, 1991), though trace amounts of high-Ca diopside (Mg# = 84.1) have been found (Mittlefehldt and Meyers, 1991; Mittlefehldt, 1994a; see **Figure 5b**). Pyroxenes in the darker portions of the meteorite can be essentially black due to fine metal and troilite inclusions; the parent rock was darkened either during igneous crystallization or thermal metamorphism (e.g. Harlow and Klimentidis, 1980), but not by later brecciation (Mittlefehldt, 2000).

EETA79002 orthopyroxenes are depleted in LREE relative to HREE (Shearer and Papike, 1992; Shearer et al, 1993), with a pronounced negative Eu anomaly (Shearer et al, 1993). Overall, REE in EETA79002 orthopyroxenes are generally close to the mean values, and this phenomenon is especially true for LREE (e.g., 5-12 ppb La: Mittlefehldt and Meyers, 1991). This contrasts with diogenites like Johnstown, which show highly variable LREE contents (e.g., 7-2680 ppb La), indicating that EETA79002 does not contain a significant amount of a trapped, REE-rich component inferred in other diogenitic orthopyroxenite clasts (Mittlefehldt and Meyers, 1991).



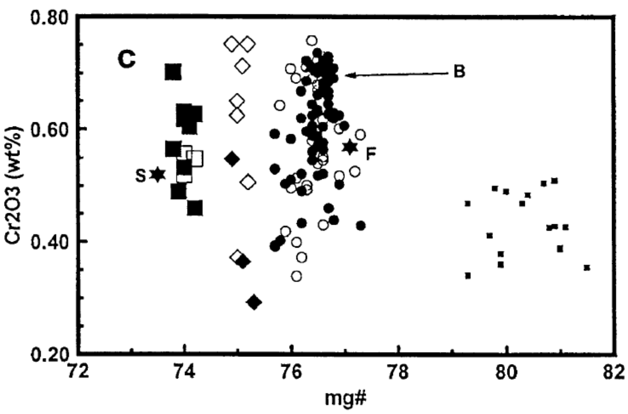


***Figure 5b**: Plots of major and minor elements in EETA79002 orthopyroxenes. Light/dark samples are indicated by the coloring of the symbol; magnesian orthopyroxenes were only found in dark samples. Data from Berkley and Boynton (1992) is shown with the arrow marked "B", from Fowler et al (1994) by the star marked "F", and from Sack et al (1991) by the star marked "S". The star on the top diagram shows a single grain of diopside. From Mittlefehldt (2000).*

Olivine: Mg-rich olivine ($Fo_{75\text{-}76}$) was identified in the initial description of EETA79002 as the only other obvious silicate phase (Antarctic Meteorite Newsletter 3/3, 4/1; Reid and Score, 1981). Ensuing chemical analyses have revealed some deviation from the original report, with the bulk of olivines having an Mg# ≈ 76 (Mittlefehldt and Meyers, 1991; Sack et al, 1991; Mittlefehldt, 2000); one reported olivine poikiloblast is significantly more magnesian (Mg# = 80.5-82.4), while a smaller ameboid olivine from the fine-grained

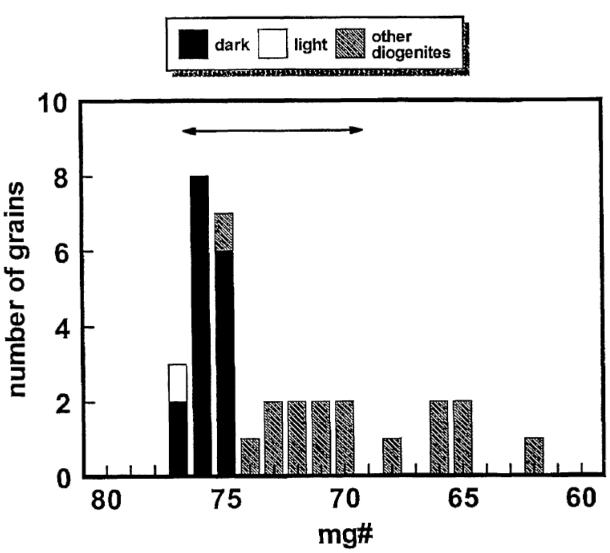


***Figure 6**: Comparison of olivine in light and dark samples of EETA79002 with other diogenites (sources: Floran et al, 1981; Fredriksson et al, 1976; Gooley, 1972; Heyse, 1975; Mittlefehldt, 1994; and Sack et al, 1991). EETA79002 contains much more forsteritic olivine than the other previously analyzed diogenites. From Mittlefehldt (2000).*

polymineralic clast was found be more ferroan (Mg# ≈ 68) (Sack et al, 1991). The forsteritic olivines in

EETA79002 are more Mg-rich than other diogenites (Mittlefehldt, 2000; **Figure 6**).

Though there has been some question about the true modal amount of olivine in EETA79002, Mittlefehldt (2000) noted that the olivine is more common in areas with the magnesian orthopyroxene described above. The bulk olivine composition (Mg# ≈ 76) could have been in equilibrium with those orthopyroxenes, but not with the more widespread Fe-rich pyroxenes that compose the bulk of EETA79002 (Mittlefehldt and Meyers, 1991); however, no direct igneous relationships can be inferred because all the olivine appears to be in breccia contact with pyroxene (Mittlefehldt, 2000).

Troilite and Metal: Unique, opaque-rich areas in the matrix of EETA79002 were identified by early workers (Antarctic Meteorite Newsletter 3/3, 4/1; Reid and Score, 1981) but only more recently found to contain preponderances of ~5-400 µm-sized troilite and metal grains (Mittlefehldt and Meyers, 1991). Compositionally, metal grains form at least four distinct populations (represented by Ni and Co contents), with most grains having 1.2-2.9 wt% Ni and 0.57-0.94 wt% Co (Mittlefehdlt and Meyers, 1991; Mittlefehldt, 2000). Some grains in the light samples have especially high Co (>1.3 wt%), a subset of which have high Ni (4.7-5.5 wt%); one small group of grains has both lower Co (0.43-0.48 wt%) and Ni (2.0-2.3 wt%) (Mittlefehldt, 2000). These compositions are all representative of primary, igneous metal, and all compositions plot away from metal analyzed in chondrites (Mittlefehldt, 2000; **Figure 7**). Troilite is Co-free with a trace amount of Ni (≤0.03%) and Se (~0.07%) (Mittlefehldt and Meyers, 1991).

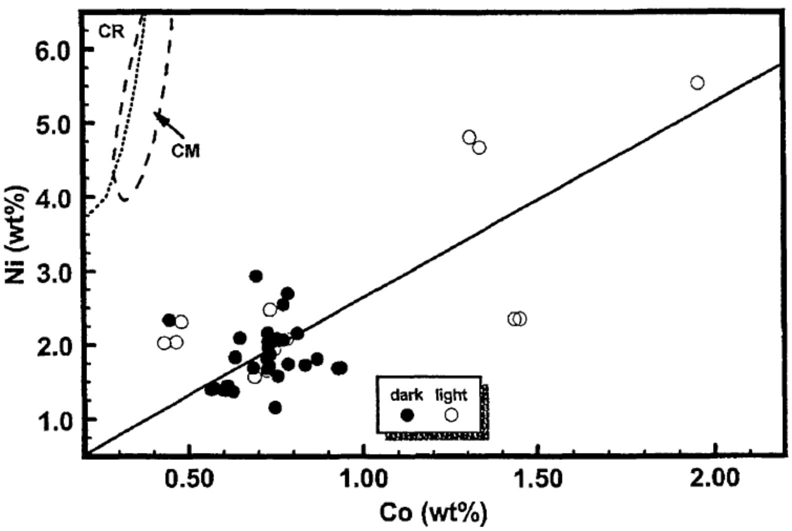


Figure 7*: Ni vs. Co for EETA79002 metal grains; the solid line is the average of both dark and light samples. Note that these compositions plot significantly away from chondritic samples, indicating that they are a primary igneous feature. From Mittlefehldt (2000).*

Besides being concentrated in opaque-rich areas of the matrix, both troilite and metal are found as "minute, spherical inclusions" along healed fractures in pyroxene and olivine, as well as in 300-500 µm-sized symplectic intergrowths with pyroxene (Mittlefehldt and Meyers, 1991). These troilite- and metal-rich areas are responsible for the "light-dark" texture seen in the meteorite, with dark areas having higher troilite and metal abundances than corresponding light areas; as such, dark areas contain more Ni (40-180 ppm Ni vs 10-60 ppm Ni), Co (20-60 ppm Co vs. 10-30 ppm Co), and Se (0.5-3 ppm Se vs ≤0.7 ppm Se), with Ni and Co abundances indicating an admixture of ≤1% metal, and Se abundances implying ≤0.5% troilite (Mittlefehldt and Meyers, 1991).

Troilite-rich clasts in EETA79002 were posited by Delaney (1982b) to represent evidence of a late sulfide-rich stage of the parent melt that either separated as an immiscible liquid or formed a cumulate, sulfide-rich layer. While this type of S-enrichment is mostly seen in howardite clasts, its presence in a diogenite can provide further constraints on fractionation models of basaltic achondrite formation (Delaney, 1982b).

Chromite: Minor chromite was first noted in EETA79002 by Berkley (1987), who also found a slight negative correlation between Fe and Cr in chromite grains (that is, decreasing Cr with increasing Fe content) (Berkley, 1987). Chromite was later reported as an included phase in olivine and orthopyroxene, as well as in association with troilite and metal; measured chromite compositions are highly variable in Mg# (~11-32) but slightly more consistent in Cr# (72-79) (Sack et al, 1991; Berkley and Boynton, 1992; Mittlefehldt, 2000), with inclusions showing more ferroan compositions than interstitial grains (Sack et al, 1991). Zoning was investigated but not found in EETA79002 chromites (Sack et al, 1991). Though chromite does appear to occur widely in EETA79002, Cr contents are not elevated in the dark areas of the light-dark structure noted by Mittlefehldt and others, indicating that chromite does not contribute to this unique texture (Mittlefehldt and Meyers, 1991).

Silica: Minor silica has been reported in EETA79002 by a small subset of authors who have worked on the meteorite (Berkley, 1987; Mittlefehldt and Meyers, 1991; Sack et al, 1991; Berkley and Boynton, 1992), and it appears to be tridymite rather than quartz (Sack et al, 1991). It occurs as <1 mm-sized grains with orthopyroxene, chromite, and troilite in the matrix, and a small (<0.5 mm) piece, rimmed by troilite, occurs in the unique fine-grained polymineralic clast (Sack et al, 1991).

Plagioclase: Plagioclase was found in EETA79002 by Bowman et al (1997), but only in a single thin section (sample ,155) and in very trace amounts (0.3 vol% - perhaps a single grain). No detailed chemical analyses have been published in the literature.

Whole-Rock Chemistry: Whole-rock major, minor, and trace element analyses are shown below in **Table 1**. REEs are plotted relative to chondrites (and the Johnstown diogenite) in **Figure 8**.

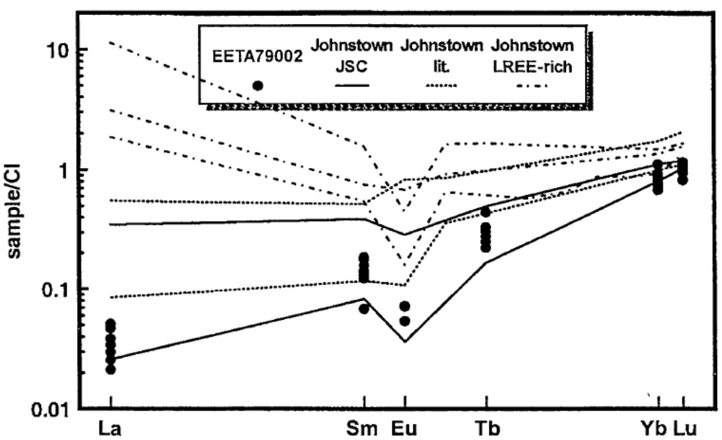


***Figure 8**: CI-normalized REE patterns for EETA79002 (solid circles) plotted against Johnstown samples for comparison. Unlike Johnstown, EETA79002 does not contain a significant LREE-enriched trapped melt component. From Mittlefehldt (2000).*

Radiogenic Isotopes: Crystallization ages for EETA79002 are unavailable; the only radiogenic age available in the literature is a ^{14}C terrestrial age from Fireman (1983), which indicated that the meteorite fall occurred >40 ka. (This is concordant with a more recently-measured terrestrial age of 30 ± 20 ka based on cosmogenic ^{41}Ca, from Welten et al, 2007.)

Cosmogenic Isotopes: Sarafin et al (1984) first reported data for cosmogenic isotopes in EETA79002, including ^{26}Al (74.2 ± 2.9 dpm/kg: sample ,16) and ^{53}Mn (357± 73 dpm/kg-Fe: sample ,42), with reported cosmic-ray exposure (CRE) ages of ~18 Ma (^{21}Ne) and ~11 Ma (^{38}Ar). These data were republished in Herpers and Sarafin (1987); some of the data were also republished in Vogt et al (1986), with the addition of ^{10}Be (23.0 ± 0.8 dpm/kg: sample ,42), additional ^{26}Al data tied to Si abundances (287 ± 11 dpm/kg-Si_{eq}: sample ,16), and a slightly different ^{21}Ne CRE age (~17 Ma). An additional ^{21}Ne CRE age (24.1 Ma) was put forth by Eugster and Michel (1995); using previously published values in combination with their own data, they reported an "adopted" CRE age of 21.2 Ma.

Table 1: Major, minor, and trace element analyses of the EETA79002 diogenite.

reference	**Sack et al 91**	**Welten et al 97a**	**Mittlefehldt 2000**	
comments	--	--	average of 4 dark samples	average of 2 light samples
weight	--	--	379.82 mg	133.17 mg
SiO_2	50.19	48.14	--	--
TiO_2	0.08	0.08	--	--
Al_2O_3	0.67	0.60	--	--
FeO	16.78	16.72	15.8	14.4
MnO	0.49	0.50	--	--
MgO	29.15	26.20	--	--
CaO	0.93	0.92	5.2	1.25
Na_2O	0.02	--	0.01	0.01
K_2O	0.01	--	--	--
Cr_2O_3	0.84	0.76	0.67	0.75
S%	--	0.51	--	--
sum (reported)	**99.15**	**--**	**--**	**--**
Sc ppm	--	--	13.2	14.1
Co ppm	--	--	34.6	12
Ni ppm	--	--	73	18
Se ppm	--	--	1.5	≤0.16
La ppb	--	--	7	8
Sm ppb	--	--	81	25
Eu ppb	--	--	3	4
Tb ppb	--	--	9	14
Yb ppb	--	--	130	140
Lu ppb	--	--	26	25
Hf ppb	--	--	35	30
technique:	EPMA	ICP/XRF	INAA	

The work of Welten et al (1997a, 2007) has updated many of the early published values for EETA79002. Welten et al (1997a) reported a new terrestrial age (70 ± 30 ka), updated ^{3}He, ^{21}Ne, and ^{38}Ar CRE ages (26.0-26.2 Ma, 23.8-24.2 Ma, and 22.2-23.6 Ma, respectively: samples ,53 and ,61) , and smaller ^{10}Be and ^{26}Al contents than previously published literature values would suggest (21.6 ± 0.4 – 22.3 ± 0.7 dpm/kg ^{10}Be, 56.3 ± 1.2 – 56.9 ± 1.6 dpm/kg ^{26}Al: samples ,53 and ,61). Cosmogenic ^{41}Ca abundances (3.1 ± 0.2 dpm/kg, 20 ± 2 dpm/kg-[Fe*+Ca]: sample ,53) were reported by Welten et al (2007), which resulted in a revised ^{41}Ca terrestrial age of 30 ± 20 ka, which is concordant with the radiogenic ^{14}C terrestrial age from Fireman (1983).

Other Isotopes: Preliminary carbon abundances and isotopes were analyzed by Grady and Pillinger (1985); they only considered carbon released at >600°C to mitigate the effects of terrestrial carbon contamination. Total >600°C carbon abundances for EETA79002 were on the order of 10-11 ppm, with liberated carbon showing a bimodal release pattern; peaks were seen at 800°C ($\delta^{13}C$ = -24‰) and 1100°C ($\delta^{13}C$ = -17‰). The lower temperature peak was interpreted to be elemental, graphitic carbon, while the higher temperature peak was taken to be carbon released from the breakdown of pyroxene (Grady and Pillinger, 1985). Similar experiments were undertaken by Grady et al (1997), who found similar >600°C carbon abundances between 11-12 ppm ($\delta^{13}C$ = -19 to -21); this value is significantly lower than the total (0-1200°C) carbon abundance (88-605 ppm), which was also isotopically lighter ($\delta^{13}C$ = -23 to -27). The diogenites, as a group, were found to have isotopically heavier indigenous carbon than the eucrites, with EETA79002 showing the heaviest isotopic signature of the four diogenites measured in the study (the others being Johnstown, Shalka, and Tatahouine).

Experiments: Sears et al (1991) and Batchelor and Sears (1991) investigated thermoluminescence in EETA79002 (samples ,83 and ,84), finding low TL intensities (4 ± 2 krad at 250°C, 14 ± 5 krad at 450°C: Sears et al, 1991) that were ascribed to possible solar heating at <0.8 AU (Sears et al, 1991).

Natural remnant magnetic properties in EETA79002 were studied by Collinson and Morden (1994), who reported a "soft, probably viscous NRM component representing about 90% of the initial NRM." This component was removed in a 2.5 mT demagnetizing field, but further demagnetization revealed no discernable primary NRM (Collinson and Morden, 1994). Values for AMS (anisotropy of magnetic susceptibility) degree (P = 1.457) and the AMS shape parameter (T = 0.63) were published by Gattacceca et al (2005).

Finally, Shestopalov et al (2008) has recently published data on the reflectance spectrum of sample ,146 from EETA79002, with a weak, low-intensity band centered at 608 nm within a band range of 575.0-640.0 nm.

Weathering Products: Gooding (1986) examined an exterior sample (,34) of EETA79002; he found evidence of clay weathering in the fusion crust of the meteorite (**Figure 9**). A chemical analysis indicated that this weathering phase was mostly composed of Si, Al, and Fe, with minor amounts of K and Mg, and trace amounts of P, S, Ti, and Cl; these compositions fall within the smectite stability field, though they have much more iron than typical terrestrial smectite (Gooding, 1986).

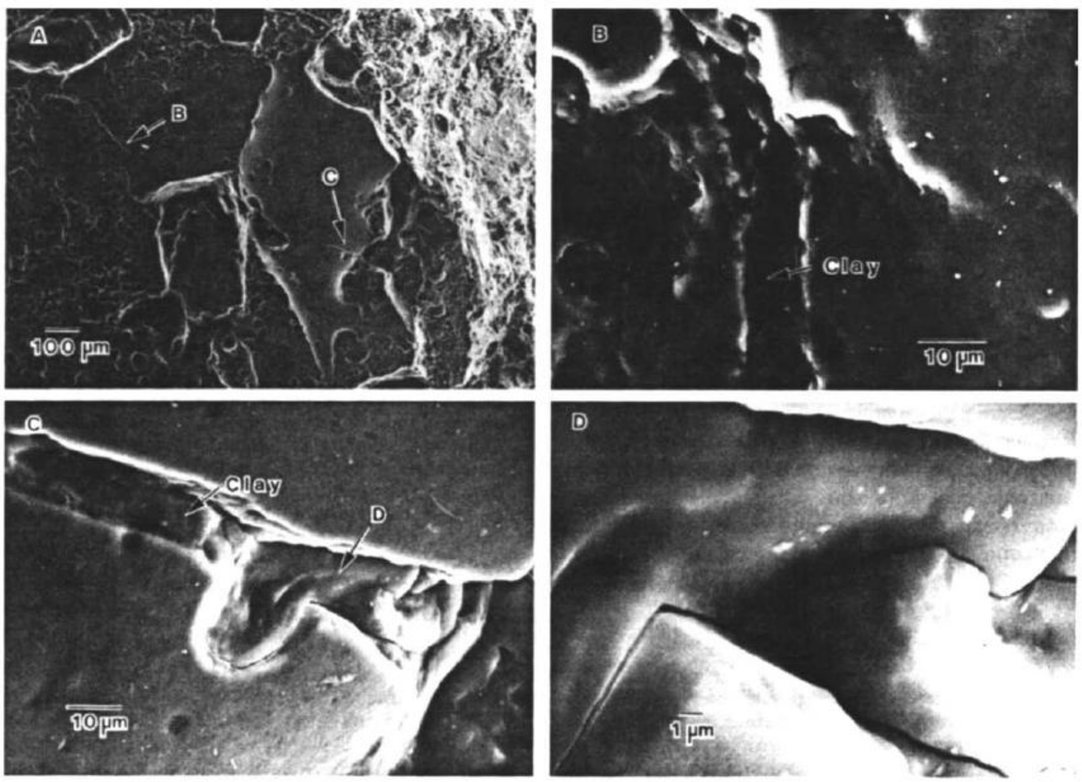


***Figure 9**: SEI images of "smectite-like" or "clay" weathering products in the fusion crust of EETA79002. (A) Wide-angle view of B and C. (B) Clay as a typical fracture-filling phase within the fusion crust. (C) Clay as a fracture-filling phase in a "glassy spatter" droplet coating the fusion crust. (D) High-resolution image of C, showing texturally homogenous clay at a 1 µm scale (suggestive of a single phase or an extremely fine intergrowth). Figure and modified caption from Gooding (1986).*

Metamorphism: In terms of quantifying temperatures of possible metamorphism, Mittlefehldt (1994a) calculated an equilibration temperature of 750°C for EETA79002 using the orthopyroxene-spinel thermometer of Mukherjee et al (1990), much lower than reported equilibration temperatures of 850°C-

1000^{o}C from Sack et al (1991). Because EETA79002 pyroxenes show clouding phases (metal and troilite), it is possible that they have experienced some thermal annealing (e.g., Harlow and Klimentidis, 1980), but it is unclear whether these phases are a primary igneous feature or a secondary metamorphic feature (Mittlefehldt, 2000).

Shock Effects: Other than the very fine brecciation noted by many authors (e.g., Reid and Score, 1981), and a comment that there appears to be no shock darkening of the matrix (Berkley and Boynton, 1992), there have been no detailed reports on the nature of shock effects in EETA79002.

Petrogenesis: Sack et al (1991) termed EETA79002 an "olivine diogenite"; as their sample contained nearly 30 wt% olivine, they argued that such an olivine/pyroxene ratio could not be produced in a fractional crystallization model for the eucrite parent body (Sack et al, 1991). Based on the bulk composition of the meteorite, Sack et al (1991) inferred that EETA79002 represented the residual source region for the partial melting trend that produced the main-group eucrites. Trace element analyses of orthopyroxene initially supported this conclusion: Shearer and Papike (1992) found that the chemistry of orthopyroxenes in EETA79002 could be produced by 25% fractional melting of a "plagioclase-bearing EPB mantle". However, the same authors later amended this view, most notably finding that (1) the orthopyroxene in EETA79002 was not significantly different than other diogenites, and (2) the olivine diogenites could be produced in the same fractional crystallization sequence that produced the main-group eucrites; thus, EETA79002 is most likely a cumulate rather than a restite (Papike et al, 1993; Shearer et al, 1993; Fowler et al, 1995). Mittlefehldt (1994a) added that the modal percentage of olivine reported by Sack et al (1991) is likely unrepresentative of the whole sample, and thus the amount of olivine in EETA79002 may not be unusually high. An more recent analysis of sixteen different EETA79002 samples revealed at least three separate source regions, most likely from three genetically related plutons; one of those plutons would have been a harzburgite, contributing both the olivines and the magnesian orthopyroxenes to the breccia (Mittlefehldt, 2000).

Processing: Nearly 200 separate samples have been divided from the original mass of EETA79002; the processing and allocation history of the meteorite is shown in **Table 2**, below. Note that sample ,66 and all derived samples and thin sections are actually ALH84001.

Table 2: Processing and allocation history of EETA79002, current as of August 20th, 2009 (courtesy of MPL staff at JSC). Samples marked "renumbered" were from a mislabeled potted butt of ALH84001, and were recalled and renumbered once the error was discovered.

Sample #	Parent	Location/Investigator	Mass (g)	Description
EETA79002, 0	0	Entirely Subdivided	--	--
EETA79002, 1	0	MPL (Houston)	52.580	Documented Piece
EETA79002, 2	0	MPL (Houston)	31.121	Documented Piece
EETA79002, 3	0	MPL (Houston)	18.741	3 LOC Chips
EETA79002, 4	0	MCC (Houston)	1.662	Potted Butt
EETA79002, 5	0	MPL (Houston)	5.243	Chips + FI
EETA79002, 7	4	MCC (Houston)	0.010	PM 39mm
EETA79002, 8	4	Mason, B. (NSF)	0.010	PM 21mm
EETA79002, 10	2	MCC (Houston)	2.945	Potted Butt
EETA79002, 11	2	Arnold, J.R.	1.341	LOC Interior Chip
EETA79002, 12	2	MCC (Houston)	3.069	Potted Butt
EETA79002, 13	2	MRS (Houston)	2.350	3 LOC Interior Chips
EETA79002, 14	2	MPL (Houston)	1.732	Chips + FI
EETA79002, 15	0	MPL (Houston)	12.388	Documented Exterior Chip
EETA79002, 16	0	MPL (Houston)	11.760	Documented Exterior Chip
EETA79002, 17	0	MRS (Houston)	2.300	3 Interior Chips
EETA79002, 18	0	MCC (Houston)	1.614	Potted Butt
EETA79002, 19	0	MPL (Houston)	2.188	Interior Chips
EETA79002, 20	0	MPL (Houston)	8.801	Chips + FI
EETA79002, 21	10	MCC (Houston)	0.010	PM 28mm
EETA79002, 22	10	MCC (Houston)	0.010	PM 33mm
EETA79002, 23	18	MCC (Houston)	0.010	PM 24mm
EETA79002, 24	18	MCC (Houston)	0.010	PM 24mm
EETA79002, 25	18	MCC (Houston)	0.010	PM 29mm
EETA79002, 26	0	MPL (Houston)	26.630	Pieces + FI
EETA79002, 27	0	Fireman, E.L.	8.108	Consumed
EETA79002, 28	0	MPL (Houston)	4.211	Chips + FI
EETA79002, 29	12	MPL (Houston)	2.268	Chips WX RIND
EETA79002, 30	12	MCC (Houston)	0.010	PM 33mm
EETA79002, 31	2	MPL (Houston)	21.612	Documented Chip
EETA79002, 32	2	MRS (Houston)	1.254	Documented Exterior Chip
EETA79002, 33	2	MPL (Houston)	0.453	2 LOC Interior Chips
EETA79002, 34	2	MRS (Houston)	4.263	Documented Exterior Chip
EETA79002, 35	2	MPL (Houston)	1.834	Documented Exterior Chip
EETA79002, 36	2	MPL (Houston)	7.774	Documented Exterior Chip
EETA79002, 37	2	Pillinger, C.T.	1.237	Interior Chip
EETA79002, 38	2	Hewins, R.H.	0.878	Interior Chip
EETA79002, 39	2	MPL (Houston)	0.995	Interior Chips
EETA79002, 40	2	MPL (Houston)	1.639	Chips + FI
EETA79002, 42	16	MRS (Houston)	0.200	Interior Chip
EETA79002, 43	16	MPL (Houston)	1.533	Interior Chips
EETA79002, 44	16	MPL (Houston)	4.979	2 Chips
EETA79002, 46	42	Herpers, U.	0.934	Consumed
EETA79002, 47	12	Treiman, A.H.	0.010	PM
EETA79002, 48	12	MCC (Houston)	0.010	PM
EETA79002, 49	12	MCC (Houston)	0.010	PM

EETA79002, 50	0	MPL (Houston)	162.537	Documented Piece
EETA79002, 51	0	MPL (Houston)	12.528	Interior Chips
EETA79002, 52	0	MPL (Houston)	272.100	Documented Piece
EETA79002, 53	0	Lindner, L.	3.210	Documented Chip with Fusion Crust
EETA79002, 54	0	MPL (Houston)	8.390	Documented Chip
EETA79002, 55	0	MPL (Houston)	25.350	Documented Chip
EETA79002, 56	0	NMNH/Smithsonian	206.180	Documented Piece
EETA79002, 57	0	MPL (Houston)	2.230	Documented Exterior Chip
EETA79002, 58	0	MPL (Houston)	180.830	Documented Chip
EETA79002, 59	0	MPL (Houston)	38.850	Documented Chip
EETA79002, 60	0	MPL (Houston)	4.140	Interior Chip
EETA79002, 61	0	Lindner, L.	3.180	Interior Chips
EETA79002, 62	0	MPL (Houston)	9.440	Interior Chips
EETA79002, 63	0	MPL (Houston)	26.870	Interior Chips
EETA79002, 65	12	MCC (Houston)	0.010	PM
EETA79002, 66	60	Renumbered	--	ALH84001, 61
EETA79002, 67	60	Lipschutz, M.E.	0.570	Interior Chips
EETA79002, 68	66	Renumbered	--	ALH84001, 62
EETA79002, 69	60	Dyar, M.D.	0.190	Interior Chips
EETA79002, 70	60	MPL (Houston)	3.570	Interior Chip
EETA79002, 72	58	Mittlefehldt, D.W.	0.970	Pyroxene Chip
EETA79002, 73	58	Mittlefehldt, D.W.	0.310	Matrix Chip
EETA79002, 74	58	MPL (Houston)	99.250	Large Chips
EETA79002, 75	58	MPL (Houston)	6.790	Chips + FI
EETA79002, 76	60	Shaw, D.	1.000	1 Chip
EETA79002, 79	66	Renumbered	--	ALH84001, 63
EETA79002, 81	59	Swindle, T.D.	0.110	Interior Chip
EETA79002, 82	59	Swindle, T.D.	0.180	Interior Chip
EETA79002, 83	59	Sears, D.W.G.	0.260	Interior Chip
EETA79002, 84	59	Sears, D.W.G.	0.330	Interior Chip
EETA79002, 85	59	MPL (Houston)	1.410	Interior Chips + FI
EETA79002, 86	0	MPL (Houston)	365.000	Documented Piece
EETA79002, 87	0	MPL (Houston)	428.500	S Butt End
EETA79002, 88	0	Desanctis, M.C.	298.600	N Butt End
EETA79002, 89	0	MPL (Houston)	22.428	2 LOC Chips
EETA79002, 90	0	MPL (Houston)	5.850	LOC Chip
EETA79002, 91	0	MPL (Houston)	44.690	Documented Chip
EETA79002, 92	0	MPL (Houston)	17.661	Documented Chip
EETA79002, 93	0	MPL (Houston)	2.286	2 Exterior Chips
EETA79002, 94	0	MPL (Houston)	10.839	4 LOC Chips
EETA79002, 95	0	Lipschutz, M.E.	0.619	Interior Chip
EETA79002, 96	0	MPL (Houston)	5.942	SW Chips
EETA79002, 97	0	MPL (Houston)	2.140	Chip
EETA79002, 98	0	Mittlefehldt, D.W.	0.283	CL Interior Chips
EETA79002, 99	0	MPL (Houston)	0.061	CL F Chips
EETA79002, 100	0	MPL (Houston)	10.845	SW Chips
EETA79002, 101	0	MPL (Houston)	5.550	SW Chip

EETA79002, 102	0	Mittlefehldt, D.W.	0.264	Clast A + Matrix
EETA79002, 103	0	MPL (Houston)	3.164	Documented Chip
EETA79002, 104	0	Mittlefehldt, D.W.	0.126	Clast B Chips
EETA79002, 105	0	MPL (Houston)	3.169	SW Chip
EETA79002, 106	0	Mittlefehldt, D.W.	0.016	Clast D + Matrix
EETA79002, 107	0	Mittlefehldt, D.W.	0.282	Matrix Chips
EETA79002, 108	0	MCC (Houston)	0.654	Potted Butt
EETA79002, 109	0	MPL (Houston)	1.016	SW Chip
EETA79002, 110	0	MPL (Houston)	1.488	SW Chip
EETA79002, 111	0	MPL (Houston)	6.282	Interior Chip
EETA79002, 112	0	MPL (Houston)	3.324	SW Chip
EETA79002, 113	0	MPL (Houston)	9.279	Interior Chip
EETA79002, 114	0	MPL (Houston)	1.816	SW Chip
EETA79002, 115	0	MPL (Houston)	1.129	Chip
EETA79002, 116	0	MPL (Houston)	2.293	Chip
EETA79002, 117	0	MPL (Houston)	3.553	SW Chip
EETA79002, 118	0	Beard, B.L.	1.087	Interior Chip
EETA79002, 119	0	MPL (Houston)	1.768	Interior Chip
EETA79002, 120	0	MPL (Houston)	7.121	3 Chips
EETA79002, 121	0	MPL (Houston)	34.004	BS FI
EETA79002, 122	0	Mittlefehldt, D.W.	0.140	Clast J + Matrix
EETA79002, 123	0	MPL (Houston)	1.710	Interior LOC Chip
EETA79002, 124	0	Mittlefehldt, D.W.	0.500	Clast G + Matrix
EETA79002, 125	0	Mittlefehldt, D.W.	0.310	Light Matrix Chips
EETA79002, 126	0	MCC (Houston)	0.260	Potted Butt
EETA79002, 127	0	Mittlefehldt, D.W.	0.130	Clast I + Matrix
EETA79002, 128	0	Mittlefehldt, D.W.	0.299	Light Matrix
EETA79002, 129	0	MCC (Houston)	0.206	Potted Butt
EETA79002, 130	0	Mittlefehldt, D.W.	0.142	Clast M + Matrix
EETA79002, 131	0	Mittlefehldt, D.W.	0.037	Clast K + Matrix
EETA79002, 132	0	Mittlefehldt, D.W.	0.296	Chips
EETA79002, 133	0	MTS (Houston)	1.830	Potted Butt
EETA79002, 134	0	MPL (Houston)	2.427	LOC Chip
EETA79002, 135	0	MPL (Houston)	2.843	Chips + FI
EETA79002, 136	0	Mittlefehldt, D.W.	0.070	Clast L (?) Chips
EETA79002, 137	0	MPL (Houston)	13.200	Chips + FI
EETA79002, 139	108	MCC (Houston)	0.010	PM
EETA79002, 140	126	MCC (Houston)	0.010	PM
EETA79002, 141	129	MCC (Houston)	0.010	PM
EETA79002, 142	133	MCC (Houston)	0.010	PM
EETA79002, 143	59	MPL (Houston)	15.620	Chips
EETA79002, 144	59	Collison, D.W.	9.390	Interior Chip
EETA79002, 145	12	MCC (Houston)	0.010	Thin Section
EETA79002, 146	26	Hiroi, T.	9.950	Interior Chip
EETA79002, 147	26	Sugiura, N.	4.100	Interior Chips
EETA79002, 148	26	MPL (Houston)	1.230	Interior Chips
EETA79002, 150	66	Renumbered	--	ALH84001, 64

EETA79002, 151	60	Entirely Subdivided	--	--
EETA79002, 152	151	Walker, R.J.	0.010	PM
EETA79002, 153	151	MCC (Houston)	0.010	PM
EETA79002, 154	151	Shearer, C.K.	0.010	PM
EETA79002, 155	151	Shearer, C.K.	0.010	PM
EETA79002, 156	151	MCC (Houston)	0.010	PM
EETA79002, 158	4	MCC (Houston)	0.010	Thin Section
EETA79002, 159	4	Lost in the Mail	0.010	Thin Section
EETA79002, 160	51	Molin, G.	0.132	Interior Chip
EETA79002, 161	2	Vogt, S.	2.199	Interior Chips
EETA79002, 162	2	NMNH/Smithsonian	15.779	Chips + FI
EETA79002, 164	58	MPL (Houston)	4.270	Chips + FI
EETA79002, 165	58	Thomas, K.	0.030	LOC Chip
EETA79002, 166	58	Thomas, K.	0.040	LOC Chip
EETA79002, 168	1	Humayun, M.	2.120	Exterior Chip
EETA79002, 169	1	Humayun, M.	3.097	Interior Chip
EETA79002, 170	1	Treiman, A.H.	0.290	Interior Chip
EETA79002, 171	1	MPL (Houston)	5.910	Interior Chips
EETA79002, 172	1	MPL (Houston)	22.330	Interior/Exterior Chips
EETA79002, 174	19	Barrat, J.A.	0.199	Interior Chip
EETA79002, 176	50	Lee, D.	14.643	Interior Chip
EETA79002, 177	50	MPL (Houston)	36.568	Chips with Fusion Crust
EETA79002, 178	50	MPL (Houston)	25.956	Interior Chips + FI
EETA79002, 180	39	Walker, R.J.	2.038	Interior Chips
EETA79002, 182	12	Walker, R.J.	0.010	THK
EETA79002, 183	43	Moynier, F.	0.845	Interior Chip