Y 793605 – 16 grams
Intermediate ultra-mafic Shergottite

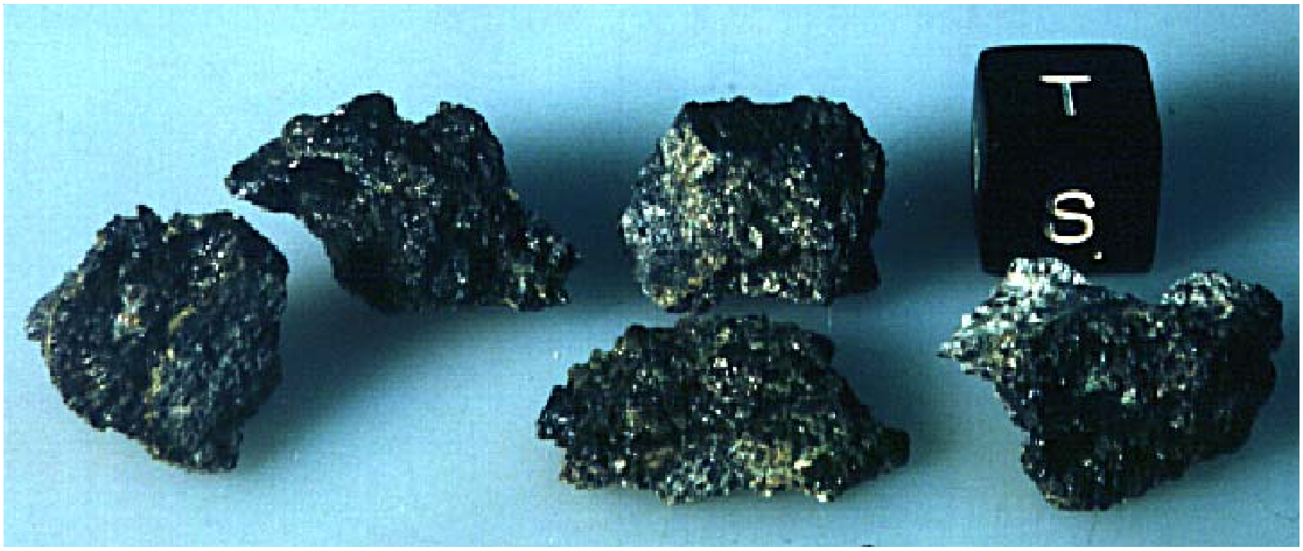

Figure 1. *Photograph of Martian meteorite Yamato 793605 kindly provided by Dr. H. Kojima, NIPR.*

Introduction

In a survey of diogenites in the Japanese Antarctic Meteorite Collection, Yanai (1995) reported a sample of "type D orthopyroxenite" with intermediate plagioclase composition (shocked maskelynite) and speculated that it might be from Mars. This sample (originally designated Y79-25) was collected from the Yamato Mountain site in 1979 (figure 1). A complete collection of papers on Y-793605 can be found together in ***Antarctic Meteorites*** vol 10.

Mikouchi and Miyamoto (1996b, 1997) found that Y793605 "*shows strong affinities to both ALHA77005 and LEW88516 in petrography and mineral chemistry" (although it was found on the other side of the continent !).* Ebihara *et al.* (1997) have shown convincingly that these samples are essentially identical.

Y793605 is 185 m.y. old, with exposure to cosmic ray for about 3.9 m.y. The sample was originally apparently covered >>50% with fusion crust (Kojima *et al.* 1997).

Petrography

Yanai (1995) reported a poikilitic texture, consisting mostly of coarse-grain pyroxene, granular olivine and interstitial plagioclase (maskelynite). Mikouchi and Miyamoto (1996, 1997) and Ikeda (1997) reported two lithologies, poikilitic and non-poikilitic. In the poikilitic area (figure 2), large pyroxene oikocrysts enclose rounded olivines (~1 mm) and euhedral chromites (~0.5 mm), and maskelynite is rarely observed. The non-poikilitic area is composed of subequal amounts of olivine, maskelynite and pyroxene.

A large fraction (perhaps 30%) of the sample consists of "*globby enclaves and veins of a dark grey aphanitic or glassy material - presumably formed by shock melting*" (Kojima *et al*. 1997). These "glassy" regions are actually microcrystalline (Kojima *et al.* 1997). In hand specimen, Y793605 is also fairly extensively weathered, with a few tiny, elongate white minerals (evaporites?). Many mineral grains show secondary alteration around their rims (Ikeda 1997). However, the thin sections of this rock do not show much of the weathering or "glass" lithology.

Ikeda (1997) reported a "*shock-induced crushed zone in one thin section studied (51-1). It consists mainly of fine-grained aggregates of crushed minerals*." Overall, Y793605 is reportedly somewhat less shocked than ALHA77005 (Ikeda 1977; Nagao 1997).

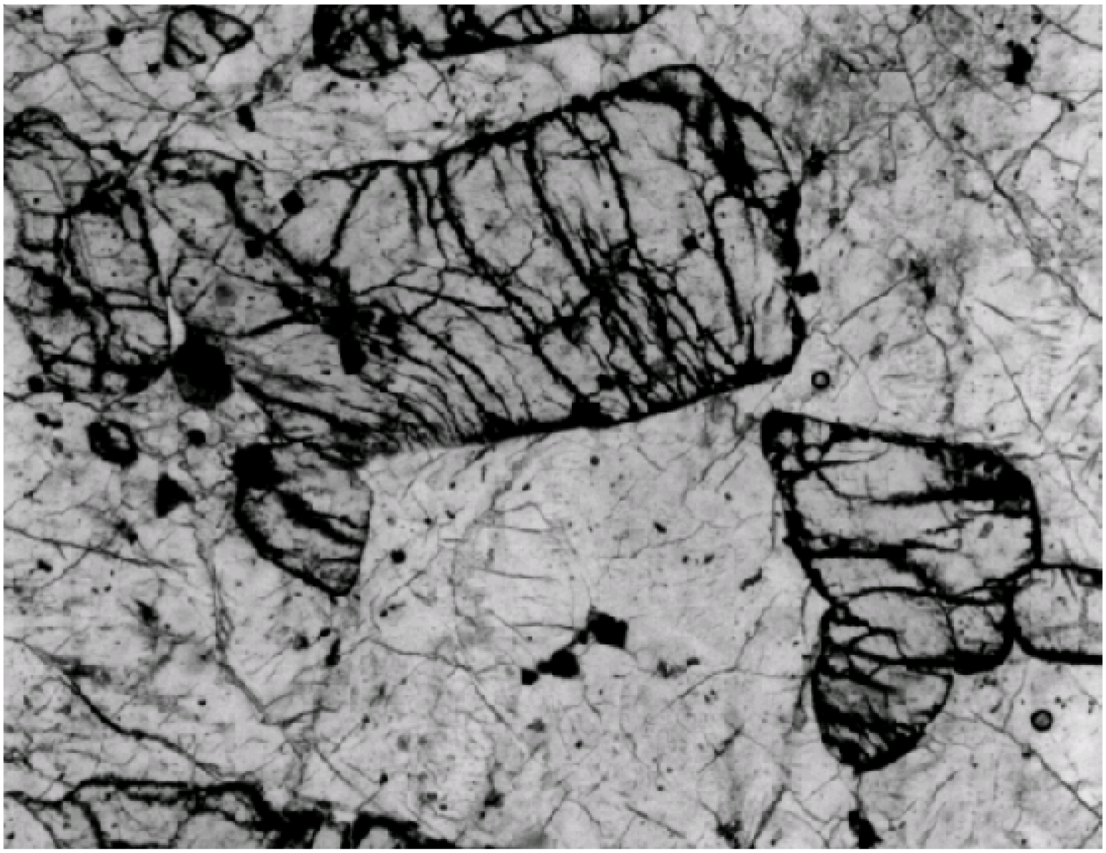

Figure 2. *Photomicrograph of thin section Y793605. With permission of Dr. Kojima. Field of view 2.2 mm.*

Mineral Chemistry

Yanai (1995) first reported mineral compositions for "type D diogenite" - including intermediate plagioclase compositions. Mikouchi and Miyamoto (1997), Ikeda (1997) and Nagao *et al*. (1997) reported detailed mineral compositions and described, in detail, the zoning in mineral composition.

Olivine: The composition of olivine reported (Kojima *et al*. 1997) is Fo_{66-69}, similar to that of LEW88516, but less Mg-rich than that of olivine in ALHA77005 (Fo_{72}). The olivines in Y793605 are brownish-green in color (Mikouchi and Miyamoto 1997) or yellow (Ikeda 1997). Some exhibit undulatory and/or mosaic extinction in crossed Nicols (shock effect). Altered olivine is reported to be dark brown along cracks and outer boundaries.

Maskelynite: The composition of maskelynite is $An_{55}Ab_{44}Or_{1}$ in the core and $An_{45}Ab_{52}Or_{3}$ at the rim (Mikouchi and Miyamoto 1997).

Pyroxene: The host pyroxene in Y793605 is pigeonite (Ikeda 1997; Mikouchi and Miyamoto 1997). Kojima *et al.* (1997) report that one grain is 8 mm across. It is chemically zoned from $En_{76}Fs_{21}Wo_{3}$ in the center to $En_{66}Fs_{23}Wo_{11}$ at the rim. Pigeonite is often rimmed by augite $En_{52}Fs_{16}Wo_{32}$ (figure 3). The trace element contents of pyroxenes are reported by Mikouchi and Miyamoto (1997) and Wadhwa *et al.* (1997). There is little or no orthopyroxene in Y793605.

Chromite: Chromite is found included in olivine and pigeonite and also in contact with maskelynite (Ikeda 1997). Chromite included in olivine is richest in Al_2O_3.

Mineralogical Mode

	Kojima *et al*. 1997	**Ikeda 1997**	**Mikouchi and Miyamoto 1997**
Olivine	35 vol. %	40.4 %	40 %
Pyroxene	60	50.8	50
Maskelynite	5	7.4	8
Opaque	1	1.4	1.5

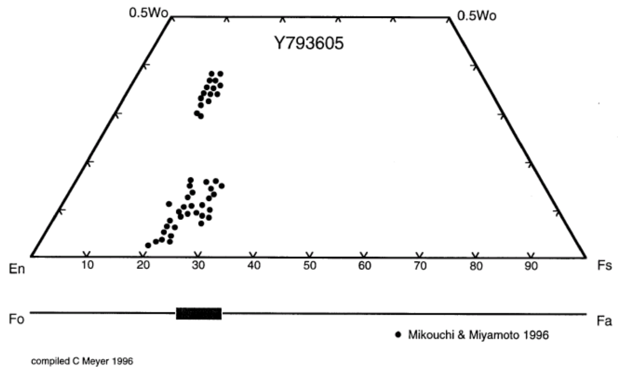

Figure 3. Composition diagram for pyroxene and olivne in Y793605. Data replotted from Mikouchi and Miyamoto (1996).

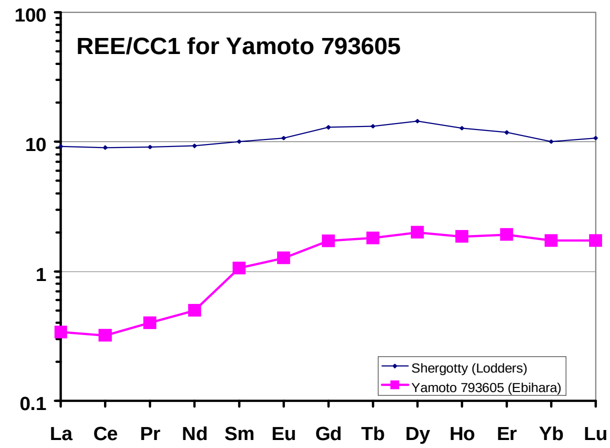

***Figure 4.** Rare earth element diagram comparing the composition of Y793605 with that of Shergotty. Data from Ebihara et al. (1997).*

Chromite found in contact with maskelynite is zoned to ulvöspinel.

Ilmenite: Minor ilmenite (MgO = 5%) has been reported (Mikouchi and Miyamoto 1996b; Ikeda 1997).

Phosphates: An analysis of whitlockite in Y793605 is given in Nagao *et al.* (1997) and an analysis of "P-rich phase" is given in Mikouchi and Miyamoto (1997). Mittlefehldt *et al.* (1997) noted that "igneous Ca-phosphate" was highly pitted (suggestive of decomposition), which is cause for concern in the REE analysis and age dating of the rock, because the phosphate is the main host of the REE (as well as U).

Sulfides: Pyrrhotite analyses are reported by Ikeda (1997) and Nagao *et al.* (1997).

Magmatic inclusions: Small magmatic inclusions (~100 microns) were found in olivine and pigeonite including rhyolitic and "silica-predominate" glass (Ikeda 1997; Mikouchi and Miyamoto 1997).

Shock-melted glass: This microcrystalline material was allocated to various investigators for noble gas studies (Kojima *et al.* 1997).

Alteration products: Ikeda (1997) and Mittlefehldt *et al.* (1997) discuss secondary alteration of various minerals in Y793605. Silica, K-Fe-sulfate and Fe-phosphate have been recognized. Ikeda concludes that Y793605 suffered weathering alteration "*probably at Antarctica. Olivine and opaque minerals, as well as phosphates, have partially or wholly altered, whereas pyroxene and maskelynite remain unaltered*".

Whole Rock Composition

Mittlefehldt *et al.* (1997), Ebihara *et al.* (1997), Warren and Kallemeyn (1997), Warren *et al.* (1999) and Kong *et al.* (1999) reported the chemical composition of Y793605 (Table 1). It has very low, Al2O3 content, so is ultramafic. The trace element pattern is similar to that of LEW88516 and ALHA77005 (figure 4).

Radiogenic Isotopes

Misawa *et al.* (1997) reported U, Th and Pb systematics for Y793605 (figure 5). Leached pyroxene separates gave an apparent isochron with intercepts at 4433 ± 9 and 212 ± 62 m.y. The Pb isotopic composition of Y793605 seems to confirm a low-mu (high initial Pb) source of shergottites (and shergottic peridotites) compared to volcanic rocks on the Earth ***(however, beware of potential alteration, on Mars and in Antarctica).*** Morikawa *et al*. (2001) have obtained a precise Rb-Sr internal isochron with an age of 173 ±14 m.y. and $^{87}Sr/^{86}Sr$ initial ratio of 0.71042 ± 7 (figure 6). Misawa et al. (2006) determined the Sm-Nd internal isochron with an age of 156 ± 14 m.y. and epsilon ^{143}Nd = + 7.5 ± 0.2 (figure 8).

Cosmogenic Isotopes and Exposure ages

Eugster and Polnau (1997) have determined an "average" cosmic ray exposure age of 4.4 ± 1.0 m.y. (generally similar to that of ALHA77005 and LEW88516). However, Nagao *et al.* (1997, 1998) determined 5.4 ± 0.3 m.y. for the non-glassy areas and 3.9 m.y. for the glassy portion, indicating that Y793605 may have had two exposures (on the surface of Mars and in transit from Mars). Nishiizumi and Caffee (1997)

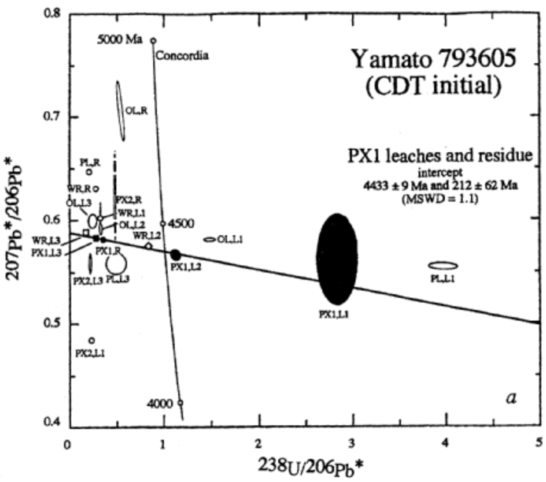

Figure 5. U-Pb concordia diagram from Misawa et al. (1997).

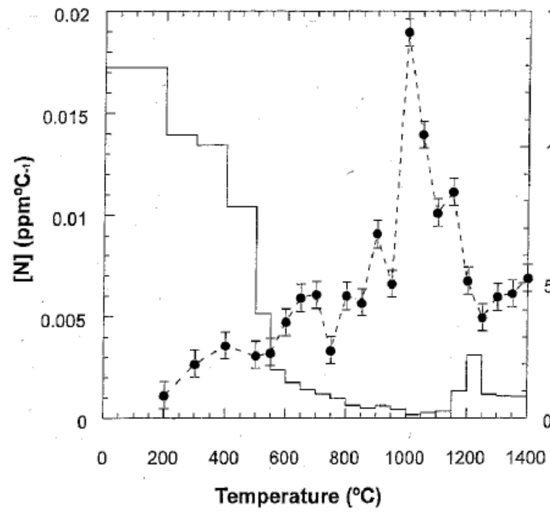

Figure 7. Nitrogen release pattern for Y793605 from Grady et al. (1997)

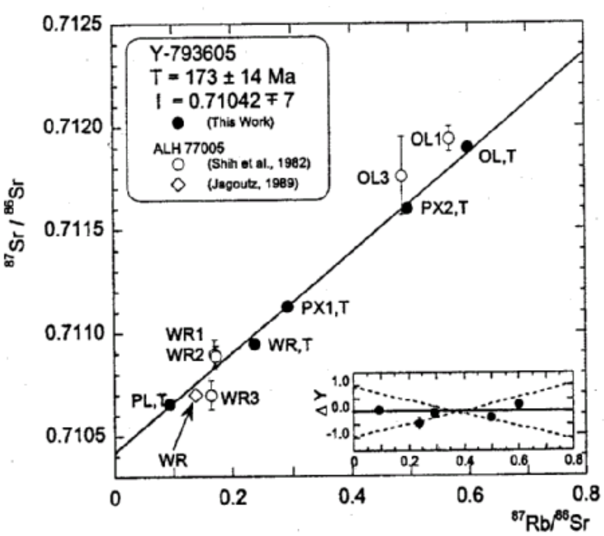

Figure 6. Rb-Sr isochron diagram for Y793605 from Morikawa et al. (2001).

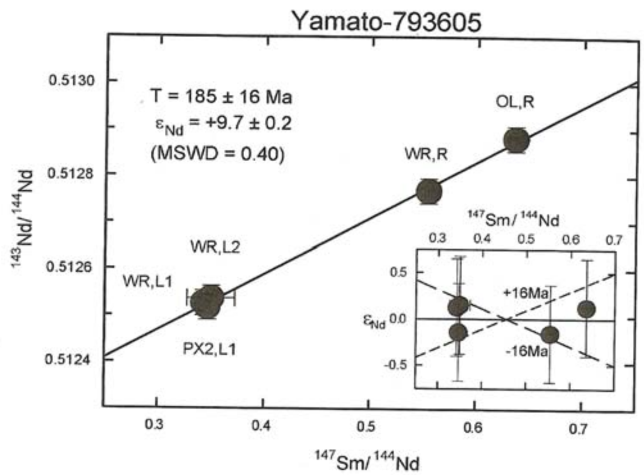

Figure 8. Sm-Nd isochron diagram of Yamato 793605 as determined by Misawa et al. (2006).

also reported cosmogenic ^{10}Be, ^{26}Al and ^{36}Cl. They calculated a terrestrial age of 35 ± 35 thousand years based on the ^{36}Cl data. This is significantly less than the terrestrial residence age of ALHA77005 (210 ± 80 thousand years).

Terribilini *et al*. (1998) calculate an "average" exposure age of 3.9 ± 0.5 m.y. and conclude the "lherzolitic shergottites" were ejected from Mars about 1 m.y. before the "basaltic shergottites".

Other Isotopes

Mayeda *et al*. (1995) and Clayton and Mayeda (1996) reported oxygen isotopes for Y793605 (see figure I-3).

Grady *et al*. (1997) reported the isotopic ratios of C and N as a function of release temperature, up to 1300˚C. They found that the C and N components were from a mixture of Martian atmospheric *(isotopically heavy)*, magmatic *(isotopically light)* and cosmogenic sources. They reported δ^{15}N as high as ~ +150 ‰ for high temperature release (figure 7, table 2).

Nagao *et al*. (1997, 1998) and Eugster and Polnau (1997) reported the isotopic composition of noble gases released by step-wise heating of Y793605. Nagao's splits were carefully prepared to include; 1) only igneous rock material, 2) mostly glass.

Table 1. Composition of Yamato- 793605.

reference	Lodders	Ebihara97		Ebihara 97			Mittlefehldt97		Warren97		Warren99		Kong 99		Wang 98		Misawa06	
weight	*average*	*123 mg*							*310 mg*		*208 mg*		*123 mg*				*408 mg*	
SiO2	*45.4*										45.35							
TiO2	*0.35*	0.193	(a)						0.35	(a)	0.35	(a)	0.19	(a)				
Al2O3	*2.32*	1.43	(a)						2.32	(a)	2.32	(a)	1.28	(a)				
FeO	*19.7*	18.13	(a)				19.3	(a)	19.7	(a)	19.68	(a)	18.14	(a)				
MnO	*0.48*	0.53	(a)								0.48	(a)	0.53	(a)				
CaO	*4.06*	4.35	(a)				2.7	(a)	4.06	(a)	4.05	(a)	4.35	(a)				
MgO	*26.2*	27.36	(a)						26.2	(a)	26.2	(a)	27.36	(a)				
Na2O	*0.36*	0.198	(a)				0.274	(a)			0.35	(a)	0.2	(a)				
K2O	*0.025*	0.014	(a)								0.025	(a)	0.013	(a)			0.026	(c)
P2O5																		
sum																		
Li ppm																		
Sc	*25*	25	(a)				20.7	(a)			25	(a)	25	(a)				
V	*202*	281	(a)						202	(a)	202	(a)	281	(a)				
Cr	*6900*	7290	(a)						6900	(a)	6900	(a)	7290	(a)				
Co	*72*	72	(a)				68.8	(a)			72	(a)	72	(a)	34	(b)		
Ni	*28*	315	(a)				326	(a)			280	(b)	315	(a)				
Cu																		
Zn	*49*	67.3	(a)				83	(a)			51	(b)	67.3	(a)	47.4	(b)		
Ga	*6.8*	6.7	(a)								6.8	(a)	6.7	(a)	5.64	(b)		
Ge											0.71	(b)						
As																		
Se		<0.3	(a)								<0.42	(a)			0.15	(b)		
Br							**Morikawa 01**				0.5	(a)						
Rb							0.0985	(c)							0.48	(b)	0.926	(c)
Sr							1.03	(c)			<44	(a)					8.86	(c)
Y				2.28	2.79	(d)												
Zr											<63	(a)						
Nb																		
Mo													0.027	(b)				
Pd ppb																		
Ag ppb		1.7	(b)										1.7	(b)	2.46	(b)		
Cd ppb											6.2	(b)			8.4	(b)		
In ppb															12.1	(b)		
Sb ppb															0.82	(b)		
Te ppb															2.2	(b)		
I ppm																		
Cs ppm											<0.123	(a)			29.3	(b)		
Ba																	3.42	(c)
La	*0.29*	0.108	(a)	0.08	0.111	(d)	0.201	(a)	0.29	(a)	0.29	(a)	0.11	(a)			0.316	(c)
Ce		0.35	(a)	0.192	0.244	(d)					0.84	(a)	0.35	(a)			0.795	(c)
Pr				0.036	0.047	(d)												
Nd				0.226	0.267	(d)											0.735	(c)
Sm	*0.45*	0.205	(a)	0.156	0.175	(d)	0.298	(a)	0.45	(a)	0.45	(a)	0.205	(a)			0.425	(c)
Eu	*0.21*	0.103	(a)	0.072			0.13	(a)	0.21	(a)	0.206	(a)	0.103	(a)			0.197	(c)
Gd				0.338	0.397	(d)							0.21	(a)			0.857	(c)
Tb	*0.17*	0.047	(a)	0.066	0.072	(d)	0.12	(a)	0.17	(a)	0.168	(a)	0.047	(a)				
Dy				0.489	0.528	(d)					<1.6	(a)					1.14	(c)
Ho				0.103	0.109	(d)					0.234	(a)						
Er				0.305	0.318	(d)											0.72	(c)
Tm				0.042	0.043	(d)												
Yb		0.392	(a)	0.281	0.29	(d)	0.4	(a)			0.56	(a)	0.39	(a)			0.648	(c)
Lu	*0.08*	0.059	(a)	0.042	0.042	(d)	0.065	(a)	0.08	(a)	0.08	(a)	0.05	(a)			0.09	(c)
Hf	*0.51*	0.456	(a)				0.39	(a)	0.51	(a)	0.51	(a)	0.456	(a)				
Ta	*<0.04*										<0.04	(a)						
W ppb		10	(b)				**Brandon 2000**								10	(b)		
Re ppb							0.277	(c)			0.084	(b)						
Os ppb		3.09	(b)				1.017	(c)			2.7	(b)	3.09	(b)				
Ru ppb													3	(b)				
Ir ppb	*3*	3.14	(b)				6	(a)			2.2	(b)	3.14	(b)				
Au ppb	*<0.8*	0.175	(b)								0.22	(b)	0.175	(b)	0.2	(b)		
Pt ppb		2.79	(b)										2.79	(b)				
Tl ppb															3.83	(b)		
Bi ppb															0.48	(b)		
Th ppm	*<0.06*			0.012	0.015	(d)					<0.053	(a)						

Table 2. Carbon and nitrogen contents and isotopic ratios for Martian meteorites.
(This is table 2 in Grady *et al.* 1997, **Antarctic Meteorites** vol. **10**, 156).

Sample	[C] (ppm)	$\delta^{13}C$ (‰)	Ref.	[N] (ppm)	$\delta^{15}N$ (‰)
Lherzolites:					
Y-793605	3.4	−10	This study	0.34	+46
ALHA77005	8−35	−28 to −18	1		
LEW88516				0.27	+7.3
Basalts:					
EETA79001; Lith A	10−24	−18 to −16	1	0.1−0.5	+7
EETA79001; Lith B	7−18	−21 to −7	1		
QUE94201	20−38	−27	4	2.0	+28
Shergotty	23−82	−27 to −20	1	0.1−0.8	+16 to +46
Zagami	30−80	−26 to −23	6	0.6−3.5	−6 to −5

Processing

Yamoto 793605 (collected in 1979) was processed and allocated (in 1996) by the National Institute of Polar Research to a consortium led by Drs. Kojima, Miyamoto and Warren. The sample has been widely distributed internationally (see Kojima *et al.* 1997). The black glass was avoided in preparing the split ,10 for the consortium, but chips of glass were allocated for gas studies. At least 7 thin sections are available, from two different pieces (Kojima *et al.* 1997). *This well-organized consortium study illustrates how much can be learned about another planet from just a small sample (~ 2.1 grams allocated)!*

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