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THE YAMATO-793605 MARTIAN METEORITE CONSORTIUM

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Abstract: We describe the consortium that has been organized to coordinate study of the Yamato-793605 shergottitic peridotite, a 16-g meteorite of presumed martian origin. Y-793605 is similar to two other Antarctic martian meteorites, ALH-77005 and LEW88516. One of the most important goals of the consortium is to determine how the cosmic-ray exposure history of Y-793605 compares with those of ALH-77005 and LEW88516. An aphanitic-glassy shock melted lithology that constitutes, as scattered veins and globby enclaves, roughly 30 vol% of the rock, has also been targeted for particularly intense scrutiny. Consortium results reported in the papers that follow confirm strong similarities between Y-793605 and ALH-77005 and LEW88516, in terms of mineralogy and petrology, trace elements, and cosmic-ray exposure. The mineralogical, petrological, and trace-element similarities are so strong, they suggest that Y-793605, ALH-77005 and LEW88516 formed as cumulates (*i.e.*, mainly large poikilitic pyroxenes enclosing cumulus olivines and chromites) from a single parent magma. The igneous crystallization age of Y-793605 has not yet been precisely determined. However, some important consortium investigations are still underway.

1. Introduction

Yamato-793605 is a small, 16-g meteorite that was tentatively classified as a common Antarctic diogenite (see YANAI, 1995), until MITTLEFEHLDT (1994) observed that another, much larger Antarctic "diogenite" was misclassified. That meteorite, Allan Hills 84001, is not a diogenite, because, among other differences, it is comparatively rich in ferric iron, contains preterrestrial carbonates, and has Na-rich maskelynite. MITTLEFEHLDT (1994) deduced that ALH84001 is instead related to the "SNC" meteorites of presumed martian origin. YANAI (1995) and MAYEDA *et al.* (1995) soon found evidence from mineralogy and oxygen isotopes, respectively, indicating that Y-793605 is another member of the SNC/martian group (at that time Y-793605 was still known by an informal preliminary designation: "Y79-25").

Currently, only a total of 12 meteorites from Mars have been identified, of which half are from Antarctica (MCSWEEN, 1994; MEYER, 1996). Y-793605 is the first martian meteorite belonging exclusively to the Japanese Antarctic meteorite collection. The NIPR also possesses about half (212 g) of the similar ALH-77005 martian meteorite (ISHII *et al.*, 1979; YANAI *et al.*, 1987; IKEDA, 1994), but the other half belongs to the USA (where it is usually known by the alternative abbreviation, "ALHA77005"). The relatively small mass of Y-793605 (Fig. 1) poses a severe constraint for efforts to utilize it as a geologic sample of the parent planet. Under such circumstances, care must be taken to balance and coordinate sample investigation efforts, to ensure that a wide variety of meteorite properties are measured, and yet conserve sample mass for the most essential measurements (and for future studies utilizing technology not currently available). The NIPR always strives to achieve balance in deciding on whether to allocate requested samples from Antarctic meteorites, but the best way to achieve such a coordinated study is by organizing investigators under the proactive management of a consortium.

The NIPR recognized the need for a consortium to study Y-793605 as soon as the martian affinity of the meteorite was established (YANAI, 1995; MAYEDA *et al.*, 1995). The authors volunteered to lead the consortium, and NIPR's Committee on Antarctic Meteorite Research approved our proposal in mid-1995. Considering the precious, irreplaceable nature of this small sample, we proceeded with the consortium operations, *i.e.*, deciding on an allocation plan and then making the actual allocations, with considerable deliberation. We received approximately 20 sample requests, nearly all from researchers who had extensive previous experience in the study of meteorites from the Japanese and/or American Antarctic collections. Sample requests for investigation of the cosmic-ray exposure history of Y-793605 were particularly encouraged, because the similarity between Y-793605 and ALH-77005 and LEW88516 was already apparent (YANAI, 1995; plus our reconnaissance observations, described below). One of the most important goals of the consortium is to determine how the cosmic-ray exposure of Y-793605 compares with that of these two similar meteorites. The recent suggestion of possible fossil microbes associated with the carbonates in the ALH84001 martian meteorite (MCKAY *et al.*, 1996) has greatly stimulated research on martian meteorites. However, the consortium received few sample requests with direct

Fig. 1. Macroscopic view of the Yamato-793605 meteorite after initial splitting. The cube is 1 cm^3.

relevance to the question of martian biology, perhaps because the similar ALH-77005 and LEW88516 meteorites are uncommonly carbon-poor compared to other martian meteorites (WRIGHT *et al.*, 1986, 1993; JAROSEWICH, 1990; DREIBUS *et al.*, 1992). Indeed, the consortium study of GRADY *et al.* (1997) indicates that Y-793605 has the lowest bulk-rock C concentration yet observed in a martian meteorite.

Most of the sample requests were tentatively accepted, under terms of participation in the consortium (*e.g.*, coordinated publication of results). After final approval of the resulting allocation plan by the Committee on Antarctic Meteorite Research, most samples were sent to investigators in May, 1996. Preliminary results from thin-section studies began appearing soon thereafter (MIKOUCHI and MIYAMOTO, 1996a, b). Many of the consortium investigations are reported in papers that follow in this volume. Other studies are still underway. In this paper, we give an overview of the consortium, and describe some general features of this extraordinarily interesting Antarctic meteorite.

2. Macroscopic Observations on Yamato-793605

On fresh igneous surfaces, the rock appears to consist of roughly 60 vol% pyroxene, 35% olivine, 5% maskelynite (or glass formed by shock melting/quenching of plagioclase), and 1% black opaque phases. The pyroxene is pale olive green, and occurs mainly as coarse oikocrysts that enclose smaller (0.5–1.0 mm) and relatively euhedral medium-brown olivines. The opaque phases are scattered and very small ($\ll$ 0.5 mm). This mode features a slightly higher pyroxene/olivine ratio, and lower maskelynite, compared to modes reported for the ALH-77005 and LEW88516 shergottitic peridotites (TREIMAN *et al.*, 1994; WADWHA *et al.*, 1994). The significance of this disparity is unclear, however, because only a small fraction of the surface was "fresh igneous", and the thin sections later produced for the consortium (see below) reveal considerable cm-scale heterogeneity—as has also been noted for ALH-77005 (MEYER, 1996).

Much (probably $\gg$50%) of the original surface of the meteorite was covered by fusion crust. On one surface, we noted fairly extensive orange discoloration (rusting). A few tiny, elongate grains of bright white material, possibly evaporite weathering products, were noted, clustered in several small regions of the surface. However, rust and other weathering products seem quite rare in the thin sections that were later produced for the consortium. Apparently, Y-793605 is, by Antarctic meteorite standards, moderately weathered.

A large fraction (roughly 30%) of the rock consists of globby enclaves and veins of a dark grey aphanitic or glassy material that presumably, by analogy with similar lithologies in ALH-77005 and LEW88516 (HARVEY *et al.*, 1993), formed by shock melting. Analogous materials in ALH-77005 and LEW88516 are commonly termed simply "glass" (MEYER, 1996, and references cited therein). Actually, these globs and veins seem in general largely crystalline (albeit extremely fine-grained), and far from pure glass. See, for example, the two large aphanitic, but not truly glassy, shock-melt globs shown in ALH-77005,83-1 on page 52 of YANAI *et al.* (1987). The shapes of the glassy-aphanitic shock-melt enclaves in Y-793605 are rounded (not angular), but they are typically elongated, and in places they connect with narrow veins of the same material. These veins are in some places remarkably thin ($\ll$0.3 mm). In a few small areas, the glassy impact melt material appears to be diffusely scattered amidst surviving crystals of the original igneous-cumulate lithology. During processing for the consortium, the large combined surface area of the 2 g, multi-fragment sample Y-793605,10 was examined carefully for content of the glassy impact melt lithology. The observed average abundance of the glassy material for Y-793605,10 is roughly 11 vol% (Table 1), considerably below the meteorite average (roughly 30%). However, the consortium (MITTLEFEHLDT and NAGAO) also received two small samples of relatively pure glassy impact melt lithology.

Table 1. Distribution of chip samples for the Y-793605 consortium.

parent sample	investigator	institution	type of investigation	type of sample	mass (mg)	est. vol% impact melt lithology
Y-793605,10	Ebihara, M.	Tokyo Metropolitan U.	bulk composition	individual lump	209	5-10
	Eugster, O.	U. Bern, Switzerland	noble gases, CRE	individual lump	39	10-20
				individual lump	14	nd*
	Grady, M.	Open U., U. K.	noble gases, carbon	individual lump	102	10
	Mittlefehldt, D., et al.	NASA-JSC, USA**	chronology + (see text)	individual lump	572	15
	Nagao, K.	Okayama U.	noble gases, CRE	individual lump	132	10
				individual lump	10	nd*
				individual lump	10	nd*
	Nakamura, N.	Kobe U.	igneous chronology	individual lump	218	10
				individual lump	188	5-10
	Nishiizumi, K.	U. California, USA	CRE	individual lump	63	5-10
				individual lump	19	nd*
	Warren/Fukuoka	UCLA/Gakushuin U.	bulk composition	individual lump	285	10
				many lumps	27	nd*
	residual		many lumps	many lumps	85	nd*
	Total mass allocated from Y793605,10				1888	
Y-793605,71	Mittlefehldt, D., et al.	NASA-JSC, USA	noble gases, CRE +	three lumps	152	70
Y-793605,75	Mittlefehldt, D.	NASA-JSC, USA	weathering products	individual lump	16	nd*
Y-793605,73	Nagao, K.	Okayama U.	noble gases, CRE	many lumps	60	80
Y-793605,77	Nishiizumi, K.	U. California, USA	near-surface CRE	individual lump	24	80
Y-793605,90	Mikouchi, T.	U. Tokyo	crystallography	pyroxene grains	9	0
Y-793605,91	Mikouchi, T.	U. Tokyo	crystallography	olivine grains	5	0
Total mass of chip samples allocated for consortium					2154	

* nd = not determined (but probably <<10 vol%) ** also (M. Lipschutz) Purdue U., USA

3. Curatorial Processing of Yamato-793605

Initial processing of the meteorite took place in the normal sample-processing area of the NIPR, using the usual array of stainless steel tools. Early inspection of this small (16-g) meteorite led K. YANAI to tentatively classify it as a diogenite (see YANAI, 1995). However, before the consortium commenced, a mass of 30 mg was allocated to R. N. CLAYTON for an oxygen-isotopic measurement (MAYEDA *et al.*, 1995) that confirmed YANAI's (1995) suspicion that Y-793605 is related to the 11 other meteorites of presumed martian origin.

Apart from polished thin sections, the main allocation for the consortium was in the form of Y-793605,10. The original mass of Y-793605,10 was 1.992 g. It consisted of many lumps, as large as 958 mg, derived from Y-793605,1 and Y-793605,6, exclusively (or nearly so) from the interior of the meteorite. Division of Y-793605,10 into subsamples suitable for consortium allocations was accomplished in a clean room at UCLA, where the 958 mg chip was broken into smaller pieces using an agate mortar and pestle. These allocations are summarized in Table 1.

In addition to allocations of approximately representative materials from Y-793605,10, several allocations were made targeting specific components of the meteorite. As described above, Y-793605 contains scattered globs and veins of a dark gray glassy-aphanitic material. Roughly similar glassy enclaves in the EETA79001 and Zagami shergottites have been found to contain C, N and noble gases in proportions (including isotopic ratios) remarkably similar to the atmosphere of Mars as measured by the Viking probe (BOGARD and JOHNSON, 1983; MARTI *et al.*, 1995). Thus, the glassy globs in Y-793605 were targeted for detailed characterization, especially for noble gases. The NASA-JSC group led by D. MITTLEFEHLDT received, in addition to their main allocation, a 152 mg sample of glass-rich material (Y-793605,71), and K. NAGAO received, in addition to his main allocation, a 60 mg sample of glass-rich material (Y-793605,73). MITTLEFEHLDT was also allocated a 16 mg piece from the surface of the meteorite (Y-793605,75) for a study of weathering products. K. NISHIIZUMI was allocated a 24 mg chip of near-surface material (Y-793605,77) in order to study cosmic-ray effects as a function of depth. Finally, T. MIKOUCHI was allocated a few grains of pyroxene and olivine for crystallographic study.

D. MITTLEFEHLDT's group at NASA-JSC received the largest allocation, because they are a large group, with plans for a wide range of investigations. Other senior NASA-JSC personnel involved include: D. BOGARD, who will study noble gases and cosmic-ray exposure, L. NYQUIST, who will study isotope geochemistry (and thus, igneous chronology), and M. LINDSTROM, who will assist MITTLEFEHLDT in studying the meteorite's bulk composition. MITTLEFEHLDT has also passed the samples used for bulk composition analysis to M. LIPSCHUTZ (Purdue University), for determination of a number of additional trace elements. Similar arrangements for sharing of samples involve N. NAKAMURA and K. MISAWA (Kobe University) in combination with M. TATSUMOTO and W. PREMO (USGS, Denver), K. NAGAO (Okayama University) in combination with N. TAKAOKA (Kyushu University), and P. WARREN (UCLA) in combination with T. FUKUOKA (Gakushuin University).

Not counting the earlier allocation of a polished thin section (PTS) to K. YANAI,

Table 2. Allocation of PTS samples for the Y-793605 consortium.

Sample	Investigator	Institution
Y-793605 ("Y79-25")	K. YANAI*[1]	Iwate U.
Y-793605,50-1	Y. IKEDA	Ibaraki U.
Y-793605,50-2	P. WARREN*[2]	UCLA, USA
Y-793605,51-1	H. KOJIMA	NIPR
Y-793605,51-2	M. MIYAMOTO	U. Tokyo
Y-793605,51-3	H. KOJIMA	NIPR
Y-793605,51-4	D. MITTLEFEHLDT*[3]	NASA-JSC, USA

*[1]YANAI's sample was allocated before the inception of the consortium, but he is continuing to study it as a member of the consortium.
*[2]WARREN is collaborating with A. DAVIS (U. Chicago, USA).
*[3]MITTLEFEHLDT is collaborating with G. MCKAY (NASA-JSC), G. CROZAZ (Washington U., USA) and M. WADHWA (Field Museum, Chicago, USA).

six PTS were produced for the Y-793605 consortium, from two separate parent chips (Y-793605,50 and Y-793605,51), which had original masses of 464 and 375 mg, respectively. Both Y-793605,50 and Y-793605,51 were originally derived from the same 4.2 g subsample (many fragments) of the meteorite, Y-793605,6; Y-793605,10 was also derived partly from Y-793605,6. Except for Y-793605,51-3 (23 mm^2), the thin sections have similar areas of 30 (Y-793605,50-1) to 41 (Y-793605,51-2) mm^2. The initial round of consortium PTS allocations is listed in Table 2. Thin sections may also be loaned in the future to petrologists who have not yet requested to participate in this consortium.

4. Reconnaissance Results from Consortium Thin Sections

As in the ALH-77005 and LEW88516 shergottitic peridotites (HARVEY *et al.*, 1993; IKEDA, 1994; TREIMAN *et al.*, 1994), Y-793605 features considerable cm-scale heterogeneity. Consequently, despite their comparatively large sizes, the consortium thin sections are diverse in mode and texture (Fig. 2). Maskelynite is far more abundant in Y-793605,51-1 than in the other sections. As in ALH-77005 and LEW88516 (HARVEY *et al.*, 1993), abundance of maskelynite is correlated with a hypidiomorphic-granular texture. Typical, maskelynite-poor portions of the rock are poikilitic, with pigeonite oikocrysts up to 8 mm across (*i.e.*, the complete span of Y-793605,51-4) enclosing pleochroic cumulus olivines. In Y-793605,51-3, cumulus olivines are as large as 2.2×0.7 mm, but in Y-793605,50-1 none is larger than 0.9×0.9 mm. Aphanitic-glassy quenched impact melt (the gray-black material in macroscopic view) is not as abundant in any of the thin sections as it appears from macroscopic observations of the complete meteorite. The highest proportion of the glassy impact melt lithology among the thin sections is 3 vol%, in Y-793605,51-3. The Y-793605,50 thin sections are virtually devoid of the glassy impact melt lithology. Fusion crust is absent or virtually absent in all of the consortium thin sections.

For purposes of consortium planning, we studied olivine compositions in Y-793605,50-2 and Y-793605,51-1, employing an automated JEOL JCXA733 electron

(a)

(b)

(c)

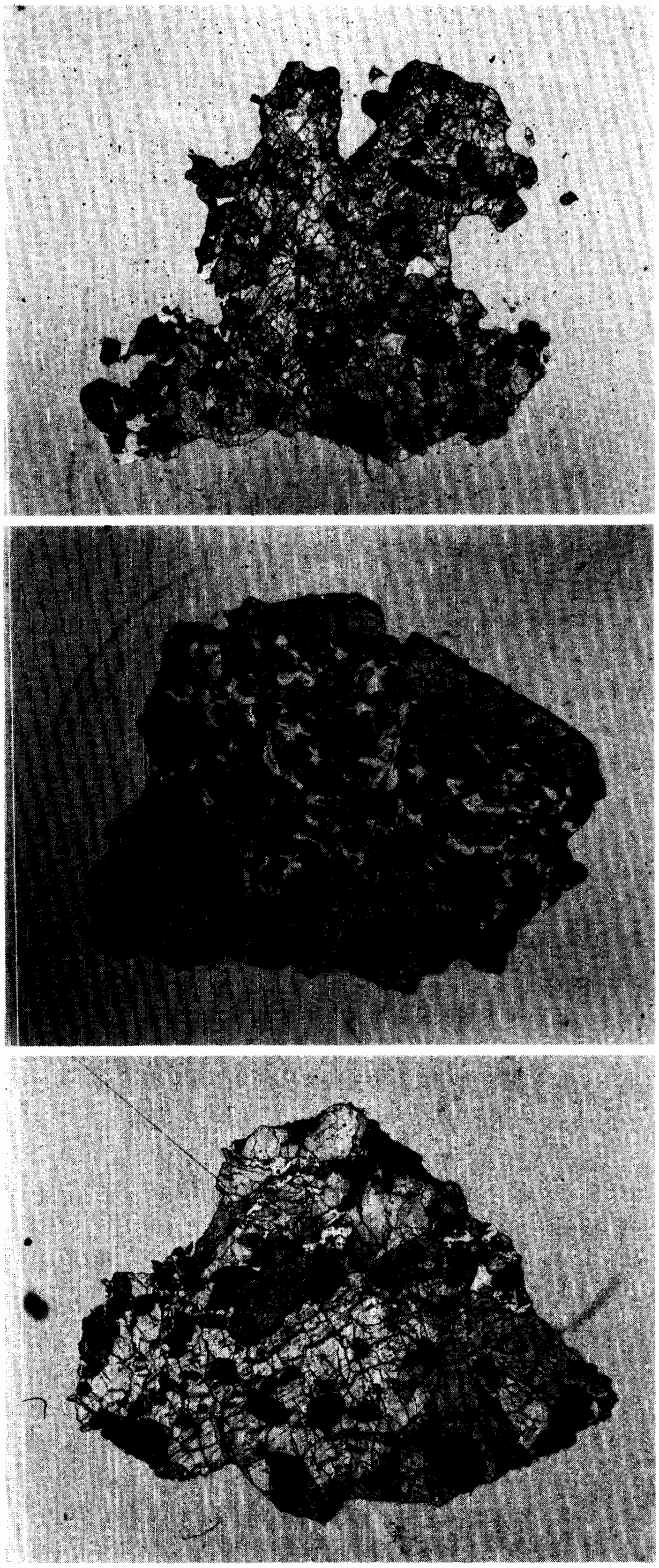

Fig. 2. Thin sections (a) Y-793605,50-1 and (b) Y-793605,51-1, showing typical poikilitic texture in most of Y-793605,50-1, and contrasting nonpoikilitic, hypidiomorphic-granular texture in most of Y-793605,51-1. Note that Y-793605,51-1 is also comparatively rich in maskelynite (white). Both samples are 8 mm in width. Shown for comparison in (c) is a mostly poikilitic region of ALH-77005,105-2; sample is 6 mm in width.

probe microanalyzer (EPMA) at the NIPR. In nonpoikilitic areas (most of Y-793605,51-1 and several large areas within Y-793605,50-2), the average olivine core Mg/(Mg+Fe) is 66.2±0.9 mol% (43 analyses), but in the poikilitic area of Y-793605,50-2, the average is 69.1±0.7 mol% (4 analyses). These results are in excellent agreement with data reported for the poikilitic and nonpoikilitic textural domains in Y-793605,51-2 by Mikouchi and Miyamoto (1997). They are also remarkably similar to results reported for the two textural domains in LEW88516 (Harvey *et al.*, 1993). Olivine compositions in ALH-77005 are slightly (but significantly) more magnesian, with average Mg/(Mg+Fe) ≈72 mol% (Ishii *et al.*, 1979; Harvey *et al.*, 1993; and other sources cited by Meyer, 1996).

5. Conclusions

The Y-793605 consortium has arranged for this important meteorite to be studied for a wide range of properties, at leading laboratories in Japan, the USA and Europe. The present volume contains only some of the consortium's early results, from studies that could be accomplished relatively quickly. Several of these studies have elucidated the meteorite's mineralogy and petrology (Mikouchi and Miyamoto, 1997; Ikeda, 1997; Nagao *et al.*, 1997; Mittlefehldt *et al.*, 1997), indicating remarkable similarity to ALH-77005 and LEW88516. All three of these rocks formed as poikilitic cumulates, dominated by large pyroxene oikocrysts surrounding cumulus crystals of olivine and chromite, although in all three cases there are also areas of nonpoikilitic texture. Bulk compositional data (Ebihara *et al.*, 1997; Mittlefehldt *et al.*, 1997; Warren and Kallemeyn, 1997) show that the resemblance extends to various types of trace elements. Compared to basaltic shergottites, Y-793605, in common with ALH-77005 and LEW88516, features relatively low contents of incompatible elements, especially light rare-earth elements, and relatively high contents of siderophile elements, such as Ir.

Yamato-793605 also closely resembles ALH-77005 and LEW88516 in terms of noble gas concentrations and cosmic-ray exposure history (Eugster and Polnau, 1997; Grady *et al.*, 1997; Nagao *et al.*, 1997), with a 4π (small body in space) exposure of about 4 Ma. However, some of these data hint at a slightly longer 4π exposure for Y-793605 than for LEW88516 and especially ALH-77005. The new 4π exposure data for Y-793605 make it seem highly doubtful that the three peridotites were launched off Mars in the same event as the basaltic shergottites (*e.g.*, Eugster and Polnau, 1997). Grady *et al.* (1997) find that the bulk concentration of carbon in a small chip of Y-793605 is the lowest yet observed for a martian meteorite, and their isotopic data indicate this scarce C is mostly of terrestrial origin.

Isotopic measurements to constrain the igneous chronology of Y-793605 are as yet relatively incomplete. However, U-Th-Pb isotopic systematics (Misawa *et al.*, 1997) show similarities with other shergottitic meteorites, implying two-stage evolution of an old parent body, followed by lead loss during a recent disturbance.

The observations summarized here will soon be augmented by results from ongoing Y-793605 consortium investigations. Already, however, we can see a remarkable degree of similarity between Y-793605 and two other martian meteorites, ALH-77005 and LEW88516.

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