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U-Th-Pb ISOTOPIC SYSTEMATICS OF LHERZOLITIC SHERGOTTITE YAMATO-793605

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Abstract: We have undertaken U-Th-Pb isotopic studies on lherzolitic shergottite, Yamato-793605. Four mineral separates (olivine, plagioclase, and two phases of pyroxene) and a whole-rock sample were leached with dilute acid in order to remove secondary Pb contamination. However, preferential leaching of U and Th over Pb occurred. The Pb isotopic data points of five residue fractions scattered, and a calculated Pb-Pb age does not clearly indicate either crystallization from a melt or a later disturbance to the U-Pb system, in contrast with other shergottites. The chord through U-Pb data points for pyroxene (PX1) leaches and residue intersects concordia at 4439±9 Ma and 212±62 Ma, suggesting a young disturbance event resulting in Pb loss. The later disturbance event partially reset the U-Pb system. The estimated $^{238}U/^{204}Pb$ ($\equiv\mu$) value from the whole-rock residue for the source of Y-793605 is about 5, suggesting that Y-793605 was derived from a volatile-rich source environment and confirms a low-μ source for shergottites compared to volcanic rocks of the Earth.

1. Introduction

NAKAMURA *et al.* (1982) first proposed from U-Pb and Sm-Nd isotopic studies that Nakhla came from a relatively large, well-differentiated parent body, such as the planet, Mars. It is now widely believed that the SNC (shergottites, nakhlites, Chassigny) meteorites and one orthopyroxenite, Allan Hills (ALH) 84001, came from Mars. After ALH84001 was recognized as belonging to the Martian group, YANAI (1995) re-examined the meteorite collection at the National Institute of Polar Research (NIPR) and found that Yamato- (Y-) 793605 has similar mineralogical and petrological characteristics to those of the shergottite meteorites. Oxygen isotopes of Y-793605 also showed similar compositions with the other shergottites (MAYEDA *et al.*, 1995).

Although the shergottites can be divided into basalts (Shergotty, Zagami, EET79001, and QUE94201) and lherzolites (or peridotites), they are believed to be closely related (MCSWEEN, 1994, and references therein). The Y-793605 meteorite is a lherzolitic shergottite, similar to ALH77005 and Lewis Cliff (LEW) 88516 (YANAI, 1995, 1996; MIKOUCHI and MIYAMOTO, 1996a, b). Chronological studies have already been carried out on both basaltic and lherzolitic shergottites (BOGARD *et al.*, 1979; NYQUIST *et al.*, 1979, 1984, 1987, 1995; SHIH *et al.*, 1982; WOODEN *et al.*, 1982;

JAGOUTZ and WÄNKE, 1986; CHEN and WASSERBURG, 1986 a, b, 1993; JAGOUTZ, 1989; BORG *et al.*, 1996, 1997). Because isotopic systems have been disturbed most likely by intense shock, interpretation of ages obtained using these different isotopic systems is very complex. Nakhlites, Chassigny, and ALH84001 have an exposure age of ~12 Ma. The lherzolitic and basaltic shergottites yield exposure ages of 3.5 Ma (ALH77005 and LEW88516) and 2.6 Ma (Shergotty, Zagami, and QUE94201), respectively, but EET79001 has a lower exposure age of 0.7 Ma (BOGARD, 1995; EUGSTER *et al.*, 1996). Thus, at least three or four impact events are suggested.

Chemical and isotopic studies of a new shergottite are of interest to the planetary sciences and will provide valuable information about mantle evolution and magmatism on a large parent body. As part of a consortium study of this Martian meteorite organized by the NIPR, we have undertaken the U-Th-Pb isotopic analysis of the Y-793605 meteorite.

2. Experimental Procedures

The petrography of Y-793605 has been described by YANAI (1995, 1996), MIKOUCHI and MIYAMOTO (1996a, b), and P. H. WARREN (personal communication). The rock consists mainly of olivine (40%), orthopyroxene and pigeonite (33%), augite (17%), and maskelynite plagioclase (8%) with minor opaque minerals including chromite (MIKOUCHI, personal communication), and shows shock features. Yamato-793605,10 (408 mg) allocated from the NIPR through P. H. WARREN was composed of several fragments containing ~10% fine-grained black material (shock melt). Under the binocular microscope, we recognized black-colored shock melt and numerous euhedral chromite grains. The sample was gently crushed with a stainless steel mortar and divided into three sized fractions (<63 μm, 63–150 μm, 150–300 μm) using nylon cloth sieves. Olivine (OL) was hand-picked from the 150–300 μm fraction. Three separates (two pyroxene-rich phases: PX1 and PX2, and maskelynitized plagioclase: PL) were obtained from the 63–150 μm fraction using a Frantz isodynamic separator equipped with an ethanol-filled chute. The PX1 is more magnetic and dark in color (enriched in black material, shock-melt?) than PX2. It is expected that the non-magnetic fraction (PL) contains trace amounts of Ca-phosphates. The finest fraction (<63 μm) was used as a whole-rock sample (WR).

The four separates and a whole-rock sample were first washed five times with ethanol. Then, they were leached three times in cold 0.01*M* HBr, rinsed twice with distilled water, leached three times in cold 0.1*M* HBr, rinsed twice with distilled water, leached twice in 1*M* HNO_3, and rinsed three times with distilled water. The washing and leaching were done in an ultrasonic bath for 10 min at each step. In previous U-Th-Pb isotopic studies by CHEN and WASSERBURG (1986 a, b, 1993), separated fractions were first etched in a mixture of 2 m*l* 1*M* HBr and 2 m*l* 2*M* HCl at ~75°C for 1 hour, and then the sample was etched again in 2 m*l* 1*M* HNO_3 at ~75°C for 1 hour. Compared to their etching, our leaching procedures were quite gentle.

The leaches and residues were spiked with ^{233}U-^{236}U-^{230}Th-^{205}Pb mixed tracer solutions, dried, and then dissolved in a mixture of HNO_3 and HF. Chemical procedures for separation of U, Th, and Pb were described in MISAWA *et al.* (1993). Analytical

total Pb blanks were 26, 36, 27, 30, 20, 33 pg, for the fractions of 0.01*M* HBr leaches, 0.1*M* HBr leaches, 1*M* HNO_3 leaches, olivine and pyroxene residues, plagioclase residue, and whole-rock residue, respectively. Uranium and Th blanks were lower than 1.5 pg and 0.75 pg, respectively.

3. Results and Discussion

Isotopic compositions of U-Th-Pb isotopes were measured on an NBS-type tandem mass spectrometer equipped with a counting system at the end of the second stage. Lead isotopic compositions in all fractions were corrected for analytical blank ($^{206}Pb/^{204}Pb = 18.4 \pm 0.3$, $^{207}Pb/^{204}Pb = 15.4 \pm 0.3$, $^{208}Pb/^{204}Pb = 37.5 \pm 0.3$), mass fractionation ($0.13 \pm 0.03\%$ per a.m.u.), and spike contribution using LUDWIG's method (1989). Results of U, Th, and Pb analyses are presented in Tables 1 and 2.

3.1. Leaching experiment

For Antarctic meteorites, it is possible that some Pb contamination was incurred both from Antarctic ice and laboratory handling, including analytical blank. Moreover, shergottite meteorites contain trace amounts of secondary minerals of preterrestrial ori-

Table 1. Elemental abundances in leachates and residues of separates.

	weight (g)	Pb[§] (ppb)	U[§] (ppb)	Th[§] (ppb)
1st leaches				
OL	0.11344	7.08 (0.97)[¶]	1.33 (3.3)	1.64 (5.3)
PX1	0.03093	13.6 (2.3)	4.88 (5.6)	8.42 (0.90)
PX2	0.06910	80.2 (0.47)	3.07 (1.3)	4.36 (0.71)
WR	0.10199	75.7 (0.54)	3.50 (0.36)	4.11 (0.71)
PL	0.00609	64.0 (1.8)	30.9 (1.5)	98.4 (1.2)
2nd leaches				
OL	0.11344	9.02 (1.1)	0.294 (4.0)	2.76 (0.73)
PX1	0.03093	14.3 (2.2)	1.99 (1.6)	13.1 (0.70)
PX2	0.06910	failed	0.618 (1.8)	5.34 (0.73)
WR	0.10199	59.2 (0.49)	6.51 (0.38)	26.2 (0.69)
PL	0.00609	6.7 (27)	3.17 (4.0)	28.7 (1.2)
3rd leaches				
OL	0.11344	2.84 (2.4)	0.0568 (15)	0.488 (1.8)
PX1	0.03093	17.0 (1.4)	0.573 (5.3)	3.35 (1.2)
PX2	0.06910	10.3 (1.2)	0.229 (5.1)	1.28 (1.3)
WR	0.10199	37.6 (0.49)	0.800 (1.1)	15.1 (0.76)
PL	0.00609	18.2 (6.6)	1.01 (14)	4.56 (1.6)
Residues				
OL	0.11047	12.3 (2.4)	0.554 (1.2)	0.863 (1.4)
PX1	0.02644	40.0 (0.81)	1.44 (1.9)	3.84 (0.95)
PX2	0.06227	19.9 (0.83)	0.745 (1.5)	1.23 (0.88)
WR	0.09424	75.2 (0.47)	1.95 (0.79)	3.08 (0.73)
PL	0.00473	276 (0.63)	4.62 (7.8)	4.32 (1.6)

[§] U, Th, and Pb concentrations are calculated against the starting weight.
[¶] Errors are 95% confidence limits (in percent).

Table 2. U-Th-Pb isotopic data for leaches and residues of separates.

Sample	$^{204}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{238}U/^{204}Pb$	$^{232}Th/^{204}Pb$	$^{238}U/^{206}Pb^{*\S}$	$^{207}Pb^{*}/^{206}Pb^{*\S}$	$^{207}Pb^{*}/^{235}U^{\S}$	$^{208}Pb^{*}/^{232}Th^{\S}$
1st leaches (0.01M HBr)									
OL	0.05929 (0.13)¶	0.8707 (0.068)	2.169 (0.092)	11.2 (3.5)	14.3 (5.4)	1.48 (3.5)	0.5810 (0.23)	54.1 (3.5)	0.497 (5.4)
PX1	0.05971 (0.56)	0.8642 (1.8)	2.137 (0.97)	21.1 (6.3)	37.6 (2.9)	2.83 (6.4)	0.562 (6.4)	27.3 (9.1)	0.168 (6.8)
PX2	0.04919 (0.065)	0.7687 (0.047)	1.944 (0.085)	2.533 (1.3)	3.710 (0.27)	0.2298 (1.3)	0.4838 (0.16)	290.2 (1.3)	2.708 (0.45)
WR	0.05483 (0.072)	0.8593 (0.77)	2.094 (0.71)	2.916 (0.49)	3.540 (0.37)	0.3265 (0.49)	0.602 (2.3)	254 (2.3)	2.46 (3.1)
PL	0.06065 (0.33)	0.8662 (0.12)	2.224 (0.36)	28.5 (2.9)	93.9 (2.7)	3.97 (3.2)	0.5552 (0.50)	19.3 (3.3)	0.0766 (3.4)
2nd leaches (0.1M HBr)									
OL	0.06768 (0.51)	0.9157 (0.12)	2.363 (0.28)	1.81 (4.2)	17.56 (1.4)	0.331 (4.4)	0.5916 (0.79)	247 (4.6)	0.310 (3.4)
PX1	0.06032 (0.52)	0.8694 (0.18)	2.182 (0.41)	8.18 (3.5)	55.6 (3.1)	1.12 (3.8)	0.5665 (0.78)	69.5 (4.0)	0.120 (4.4)
WR	0.05789 (0.23)	0.8613 (0.18)	2.158 (0.34)	6.690 (0.51)	27.81 (0.35)	0.8397 (0.54)	0.5755 (0.63)	94.50 (0.91)	0.2805 (1.9)
PL	0.0817 (14)	0.985 (6.1)	2.60 (8.4)	23 (49)	220 (49)	8.0 (100)	0.602 (18)	10 (100)	0.011 (120)
3rd leaches (1M HNO_3)									
OL	0.07330 (0.64)	0.9450 (0.33)	2.476 (0.61)	1.06 (16)	9.42 (3.6)	0.245 (16)	0.5993 (0.93)	337 (16)	0.457 (5.7)
PX1	0.06076 (0.19)	0.8787 (0.16)	2.214 (0.15)	1.99 (5.6)	12.0 (2.1)	0.278 (5.7)	0.5827 (0.53)	289 (5.7)	0.5789 (2.3)
PX2	0.06693 (0.37)	0.8996 (0.33)	2.324 (0.42)	1.23 (5.3)	7.069 (1.8)	0.218 (5.4)	0.5586 (1.5)	353 (5.7)	0.742 (3.8)
WR	0.06054 (0.098)	0.8801 (0.094)	2.219 (0.14)	1.263 (1.2)	24.62 (0.43)	0.1752 (1.2)	0.5884 (0.34)	463.1 (1.2)	0.2915 (0.94)
PL	0.06333 (1.1)	0.8812 (0.52)	2.306 (0.90)	3.22 (17)	15.0 (10)	0.496 (18)	0.5584 (1.5)	155 (19)	0.462 (11)
Residues									
OL	0.0731 (2.8)	0.9784 (0.16)	2.434 (0.15)	2.38 (3.9)	3.84 (3.9)	0.546 (6.6)	0.706 (3.4)	178 (9.6)	0.99 (22)
PX1	0.06696 (0.18)	0.9085 (0.076)	2.367 (0.12)	2.02 (2.1)	5.558 (1.1)	0.359 (2.2)	0.5816 (0.31)	223 (2.2)	1.056 (1.5)
PX2	0.07504 (0.27)	0.9604 (1.2)	2.469 (0.49)	1.948 (1.7)	3.326 (1.0)	0.485 (2.0)	0.623 (5.9)	177 (6.2)	1.03 (5.2)
WR	0.06907 (0.18)	0.9363 (0.082)	2.391 (0.10)	1.425 (0.83)	2.333 (0.35)	0.2755 (0.89)	0.6309 (0.42)	315.7 (1.1)	2.204 (1.3)
PL	0.073630 (0.14)	0.9616 (0.12)	2.484 (0.10)	0.887 (7.8)	0.857 (1.6)	0.208 (7.8)	0.6471 (0.49)	430 (7.8)	4.969 (1.8)
Total†									
OL	0.06825 (1.5)	0.9314 (1.5)	2.353 (1.5)	3.93 (2.3)	10.49 (1.9)	0.736 (4.7)	0.627 (3.8)	118 (6.6)	0.477 (11)
PX1	0.06335 (0.92)	0.8883 (0.92)	2.265 (0.92)	6.01 (3.2)	20.07 (0.79)	0.928 (3.9)	0.576 (3.1)	85.5 (4.7)	0.313 (5.2)
WR	0.06053 (0.36)	0.8850 (0.36)	2.214 (0.36)	3.057 (0.37)	12.01 (0.52)	0.4238 (0.91)	0.6000 (0.42)	195.2 (1.3)	0.5910 (2.0)
PL	0.07080 (1.2)	0.9399 (1.2)	2.428 (1.2)	5.884 (1.8)	20.84 (1.2)	1.22 (3.9)	0.6191 (0.49)	69.9 (5.5)	0.212 (8.5)

§ Data are corrected for initial Pb isotopic composition using Cañon Diablo Troilite (CDT) Pb ($^{206}Pb/^{204}Pb$=9.307, $^{207}Pb/^{204}Pb$=10.294, $^{208}Pb/^{204}Pb$=29.476); TATSUMOTO *et al.* (1973).

¶ Errors are 95% confidence limits (in percent).

† Combining U, Th, or Pb in the leaches with those in the residue.

gin (GOODING, 1992). In order to remove any preterrestrial and terrestrial contamination, we carried out acid leaching experiments on all separates. It has been shown that acetone and ethanol washing followed by acid leaching can eliminate large amounts of contamination. However, preferential elemental extraction occurred and U/Pb or Th/Pb were fractionated during leaching (*e.g.*, MISAWA *et al.*, 1993). The leaching procedure seemed to dissolve a phase (or phases) rich in U and/or Th, but poor in Pb. The amounts of sample lost during leaching vary from 3% for the OL fraction to 22% for the PL fraction. As shown in Fig. 1, 75~85% of the U and 85~95% of the Th are leachable in 0.01*M* HBr, 0.1*M* HBr, and 1*M* HNO_3, compared to 25–70% of ^{204}Pb (Fig. 2). The $^{238}U/^{204}Pb$ or $^{232}Th/^{204}Pb$ ratios of the leaches are in general high in the first and second leaches, and then decrease in the third leaches, indicating that U, Th-rich phases were mainly dissolved by the HBr leaching. The leaches have high $^{232}Th/^{238}U$ ($\varkappa$) ratios which are not similar to the residue values, indicating some U-Th fractionation also occurred during leaching. The total $\varkappa$ value of the Y-793605 whole-rock is 3.9 when calculated from the combined data of leaches and residue, and is

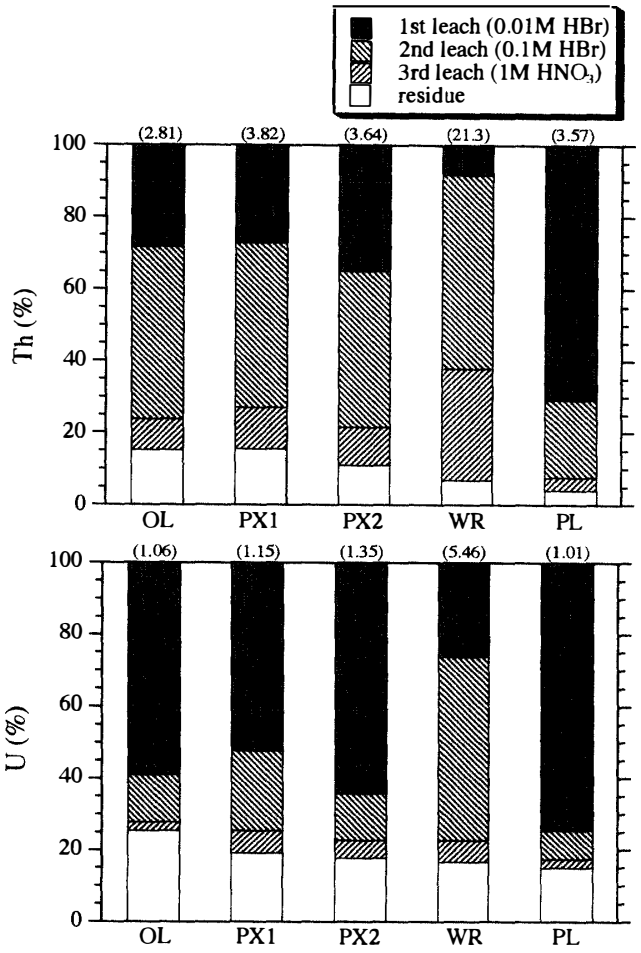

Fig. 1. Abundances of U and Th in the five fractions from Yamato-793605 at different leaching steps. Values in parentheses are total amounts of U or Th (in nanomoles). Up to 85% of the U and 95% of the Th are leachable in 0.01M HBr, 0.1M HBr, and 1M HNO_3.

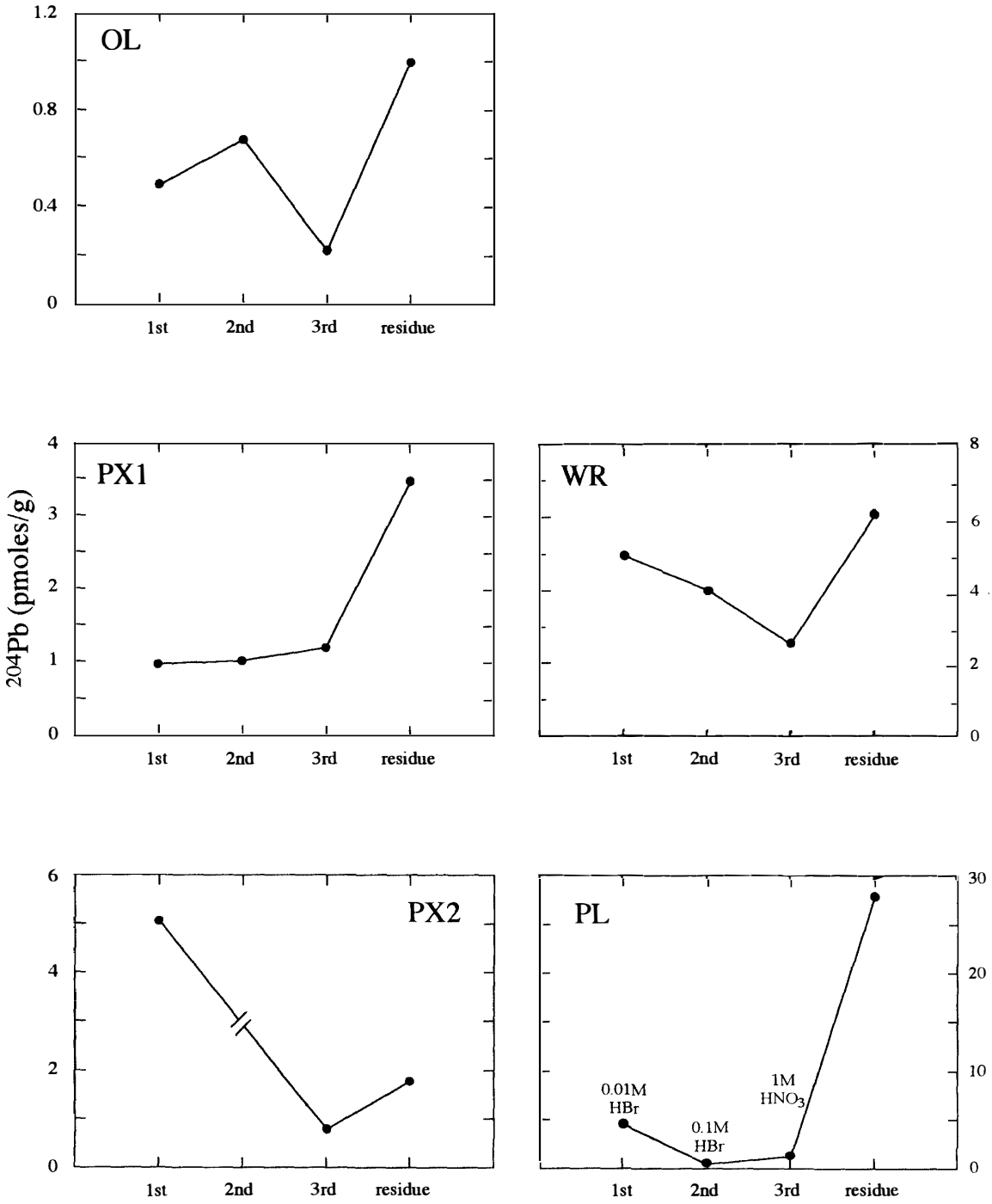

Fig. 2. Abundances of ^{204}Pb (in picomoles/g) in the five fractions from Yamato-793605 at different leaching steps. Isotopic measurement of the second leach of PX2 failed due to unstable ion-beam signals.

similar to those of other shergottites ($\varkappa$=~3.8–4.4; CHEN and WASSERBURG, 1986a, b, 1993). The whole-rock residue of Y-793605 has ^{238}U/^{204}Pb (μ)=1.4, which is similar to other shergottites, EET79001, LEW88516, Shergotty, and Zagami (μ=1.5–3.1; CHEN and WASSERBURG, 1986a, 1993), but is much lower than the residue value of

ALH77005 (μ=10.3; CHEN and WASSERBURG, 1987). The PL residue is high in U, Th, and Pb contents and has the lowest $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ values compared to other fractions. The OL residue has low U, Th, and Pb contents and the highest $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ values. Uranium, Th, and Pb contents of the PX1 residue are about twice those of the PX2 residue.

3.2. *Lead isotopes*

The Pb isotopic compositions of mineral fractions are plotted in a diagram of $^{207}Pb/^{204}Pb$ *vs* $^{206}Pb/^{204}Pb$ (Fig. 3). The data for leaches and residues from each fraction

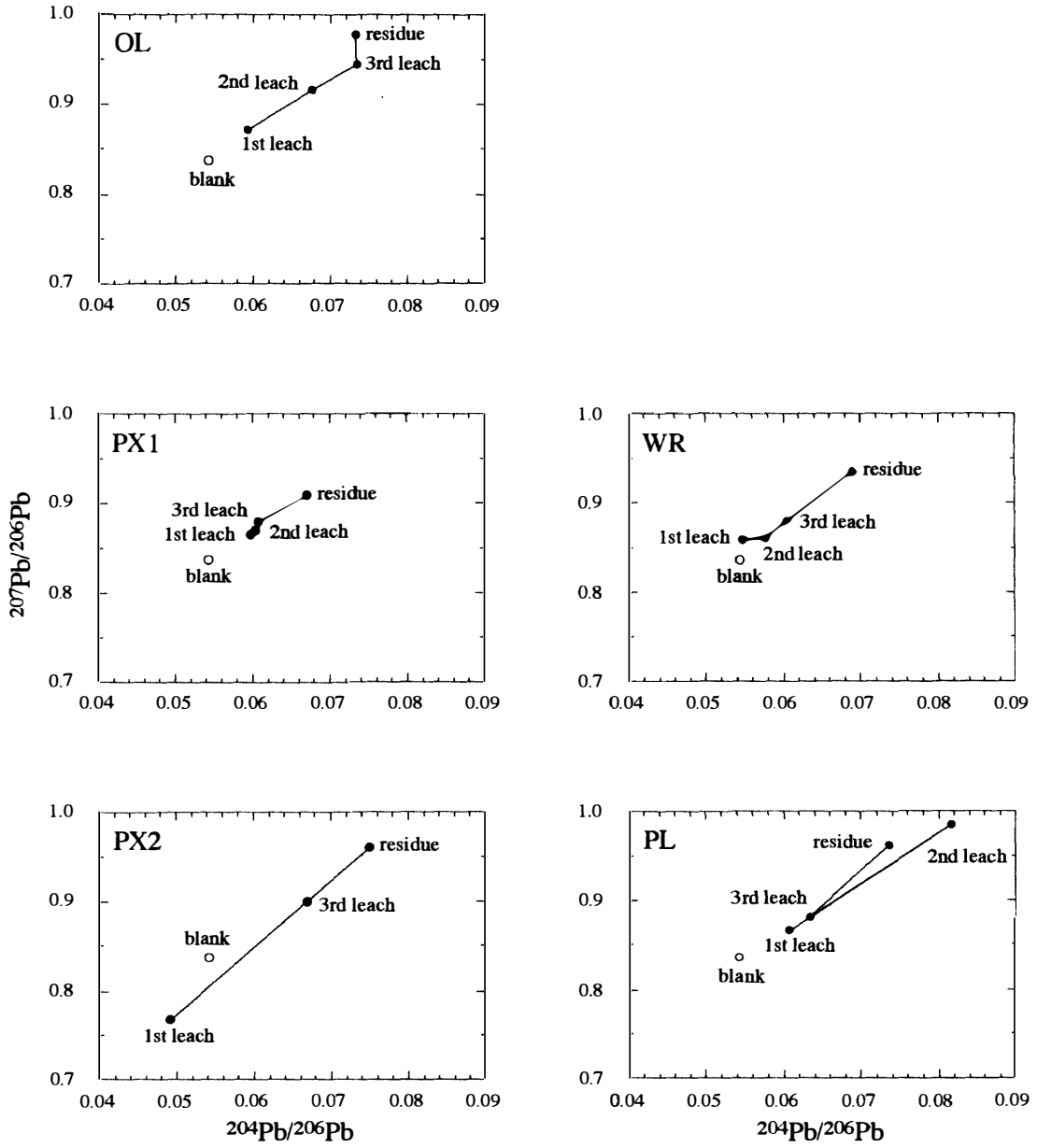

Fig. 3. Lead isotope correlation diagrams for olivine (OL), pyroxene (PX1 and PX2), plagioclase (PL) separates, and a whole-rock (WR) fraction. The data points for leaches and residues are almost collinear between blank Pb and residue Pb.

are almost collinear with blank, except the first leach of PX2 and second leach of PL. The first leaches, except PX2, are less radiogenic than blank Pb, indicating that indigenous Pb is leached out with 0.01*M* HBr. Lead in all residues, except PL, is less radiogenic than Pb in leaches, indicating that more U-rich components (grain surface?) were leached out. The Pb concentration of the first leach of PX2 is higher than those of the third leach and residue, indicating PX2 contained a U-rich component. The third leach (1*M* HNO_3) of PL is more radiogenic than the second (0.1*M* HBr) leach or residue, suggesting that this separate contains another U- and Th-rich component ($^{238}U/^{204}Pb=3$, $^{232}Th/^{204}Pb=15$) that dissolved in dilute HNO_3.

Lead isotopic data of Y-793605 are plotted in Fig. 4, and compared with existing data of Shergotty, Zagami, EET79001, ALH77005, and LEW88516 from CHEN and WASSERBURG (1986a, b, 1993). The Pb isotopic difference among the shergottite whole-rocks suggests that they could not be derived from a single parental source reservoir. The data points of the first leaches of Y-793605 plot close to blank Pb (or modern terrestrial Pb, STACEY and KRAMERS, 1975). Lead isotopic compositions of residues are getting less radiogenic, but plot above the mixing line between CDT (Cañon Diablo troilite) and blank Pb, suggesting that the contribution of terrestrial contamination in these residues is negligible. The data points for the residues scatter due to open system behavior of U-Pb system. A calculated Pb-Pb "age" using five residues is 3800 Ma with a large error (±870 Ma) and does not clearly indicate neither crystallization from a melt nor later disturbance on the U-Pb system, in contrast with other shergottites.

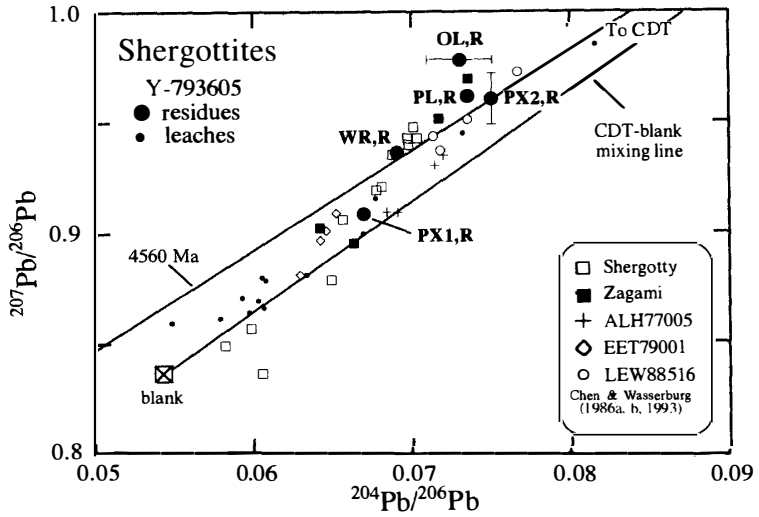

Fig. 4. *$^{207}Pb/^{206}Pb$ vs $^{204}Pb/^{206}Pb$ diagram for Yamato-793605 and other shergottites. Zagami, Shergotty, ALH77005, EET79001, and LEW88516 data are from CHEN and WASSERBURG (1986a, b, 1993). A 4560-Ma reference line through primordial Cañon Diablo troilite (CDT) Pb (TATSUMOTO et al., 1973). Similar to other shergottites, the data point of whole-rock residue of Yamato-793605 plots near the 4560 Ma isochron. All residues of Yamato-793605 yield an age of 3812±870 Ma using regression treatments of LUDWIG (1991).*

3.3. U-Th-Pb system

The relationship of the Pb isotopic compositions with $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ for the leaches, residue, and calculated total (U and Pb in the leaches are combined with those of the residues) of the whole-rock sample is shown in Fig. 5. These whole-rock data indicate that U- and Th-rich components are less abundant in Y-793605 than in ALH77005. Although we could not obtain any linear trends from neither the U-Pb nor the Th-Pb systematics, we can estimate upper limits of initial ratios of the reservoir ($^{206}Pb/^{204}Pb=13.6$, $^{207}Pb/^{204}Pb=13.1$, and $^{208}Pb/^{204}Pb=33.8$) from the PL residue analysis (*i.e.*, the lowest $^{238}U/^{204}Pb$ phase). These values are within the range of those estimated for Shergotty, Zagami, and EET79001 at ~200 Ma ago (CHEN and WASSERBURG, 1986).

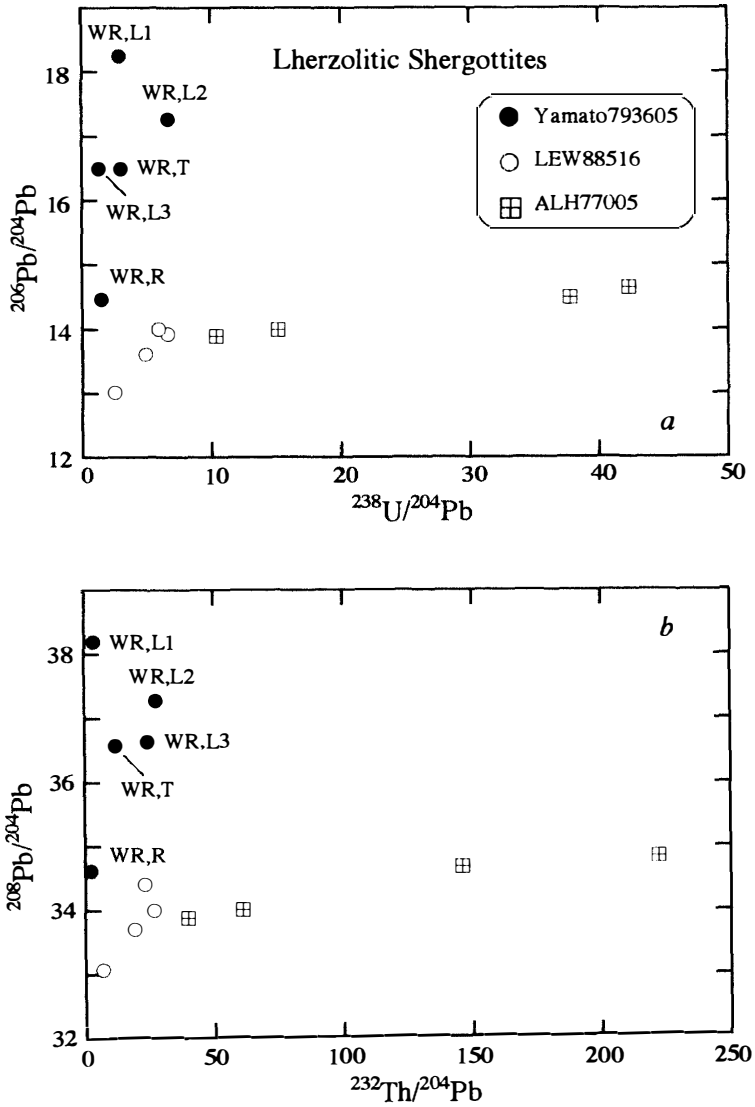

Fig. 5. (a) $^{206}Pb/^{204}Pb$ vs $^{238}U/^{204}Pb$ and (b) $^{208}Pb/^{204}Pb$ vs $^{232}Th/^{204}Pb$ correlation diagrams for lherzolitic shergottites. Data of ALH77005 and LEW88516 are from CHEN and WASSERBURG (1986b, 1993).

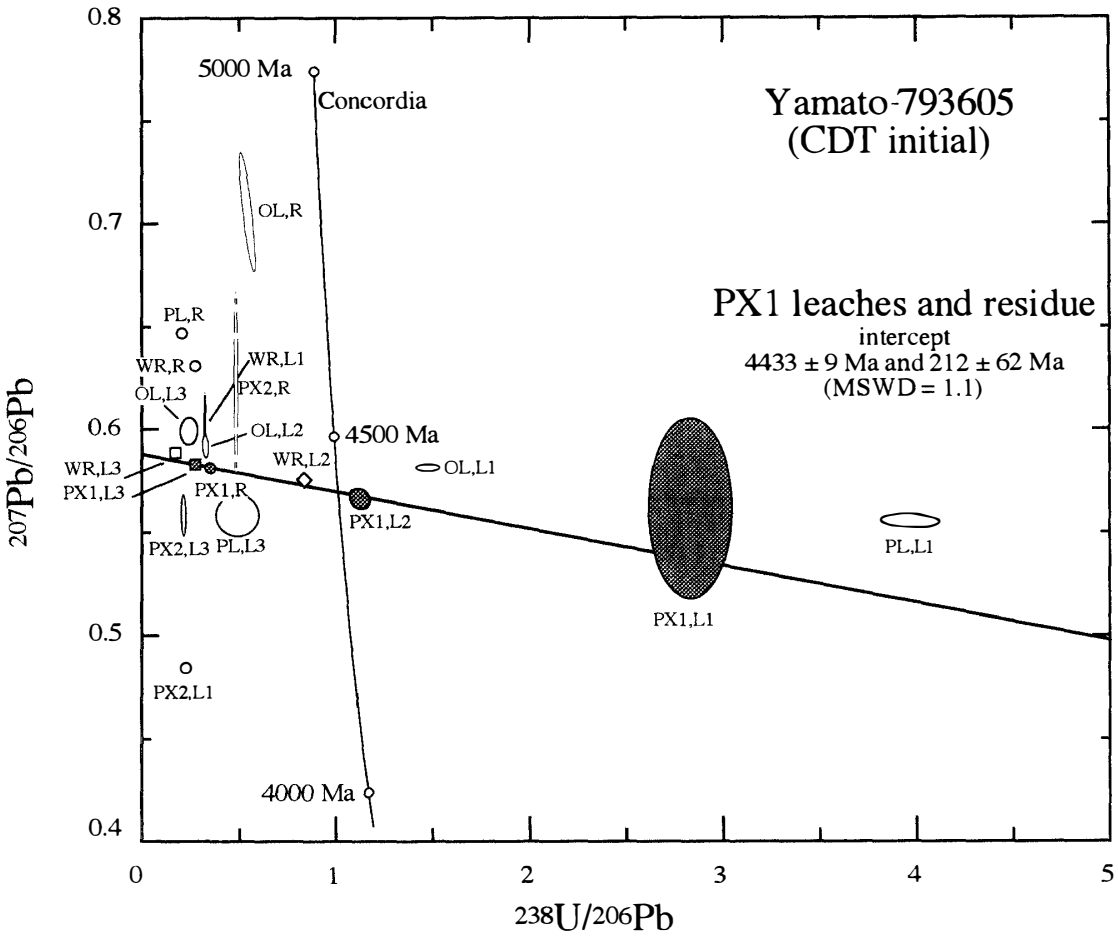

Fig. 6. Modified concordia diagram (TERA and WASSERBURG, 1972) after correction for initial Pb using Cañon Diablo troilite Pb (TATSUMOTO et al., 1973). All analyses but five plot to the left of concordia, suggesting preferential extraction of U from the fractions during leaching. A chord through U-Pb data points for PX1, L1; PX1, L2; PX1, L3; and PX1, R intersects concordia at 4439±9 Ma and 212±62 Ma, suggesting a two-stage evolution of an old parent body which had experienced Pb loss due to a young disturbance event. Because of large analytical errors, the data point of PL, L2 is not shown in this figure.

In Fig. 6, the U-Pb data of the leaches and residues are plotted on a modified concordia diagram (TERA and WASSERBURG, 1972) after correction for initial Pb using the CDT Pb composition (TATSUMOTO *et al.*, 1973). All analyses but five (PL, L1; PX1, L1; OL, L1; PL, L2 and PX1, L2) plot to the left of concordia. We interpret this behavior partly as the result of preferential extraction of U from the fractions during leaching.

A chord through the U-Pb data for both PX1 leaches and residue (PX1, L1; PX1, L2; PX1, L3; PX1, R) intersects concordia at 4439±9 Ma and 212±62 Ma. Because the PX1 separate contains abundant black glassy material, possibly impact melt, we interpret these intercept ages as suggesting a two-stage evolution whereby a 4400-m.y.-old lherzolite parent suffered a 200-m.y.-old disturbance (shock event ?). The data from the OL and WR leaches fall close to the line but that of the OL, PL and WR residues do not, probably due to an old Pb component in olivine which did not equi-

librate with other phases during a young disturbance event, and some radiogenic Pb components which may have incorporated into the maskelynitized plagioclase during shock events.

3.4. Isotopic characteristics of the source reservoir and age of Y-793605

As shown in Fig. 7, the Pb isotopic compositions of Y-793605 indicate that a source reservoir evolved in a low-μ (~5) environment. This μ-value is similar to or higher than those estimated for lherzolitic shergottites, ALH77005 ($\mu \simeq 5$) and LEW88516 ($\mu < 5$).

Although extensive chronological studies have already been carried out on Shergotty, Zagami, ALH77005, EET79001, LEW88516, and QUE94201, the time of crystallization of shergottites has been controversial. Shergottite meteorites have a model isotopic age of ~4500 Ma, which will represent an early initial differentiation of the parent body. Rubidium-Sr data for mineral separates of each analyzed shergottite have plotted along lines corresponding to ages of ~180 Ma. Similar to the U-Th-Pb systems, the initial Sr isotopic ratios of shergottites differ considerably, suggesting that they were not comagmatic at ~180 Ma ago. Earlier work by SHIH *et al.* (1982) and by WOODEN *et al.* (1982) suggested that the young age more likely represented impact-related resetting than a melting event. However, JONES (1986, 1989) concluded that the thermal effects of the shock event were insufficient for isotopic equilibration, and that 180 Ma was the crystallization age and not the time of shock metamorphism. On the basis of a 187±37-Ma Sm-Nd isochron age of Zagami, NYQUIST *et al.* (1995) concluded that basaltic shergottite Zagami crystallized from a melt at ~180 Ma ago.

As mentioned earlier, a chord through the U-Pb data points for both PX1 leaches

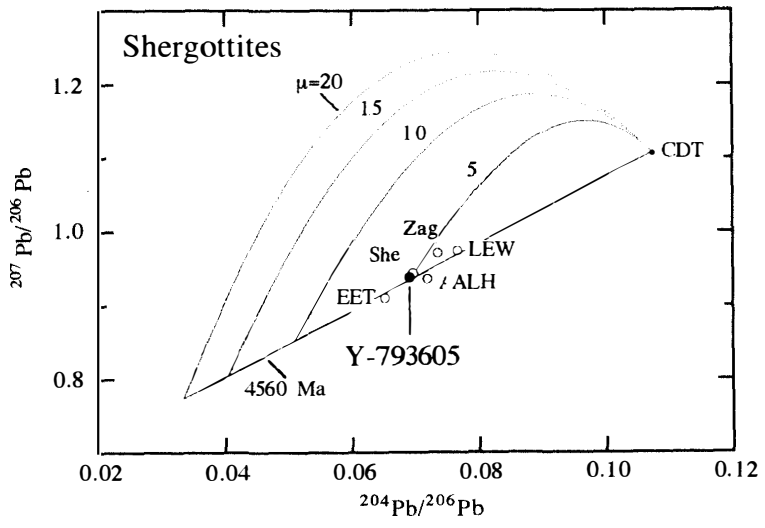

Fig. 7. *$^{207}Pb/^{206}Pb$ vs $^{204}Pb/^{206}Pb$ correlation diagram for whole-rock residues of shergottites. A single-stage evolution curves for samples of different $^{238}U/^{204}Pb$ ($\equiv\mu$) values from Cañon Diablo troilite Pb are shown. Shergotty (She), Zagami (Zag), ALH77005 (ALH), and LEW88516 (LEW) data are from CHEN and WASSERBURG (1986, 1987, 1993).*

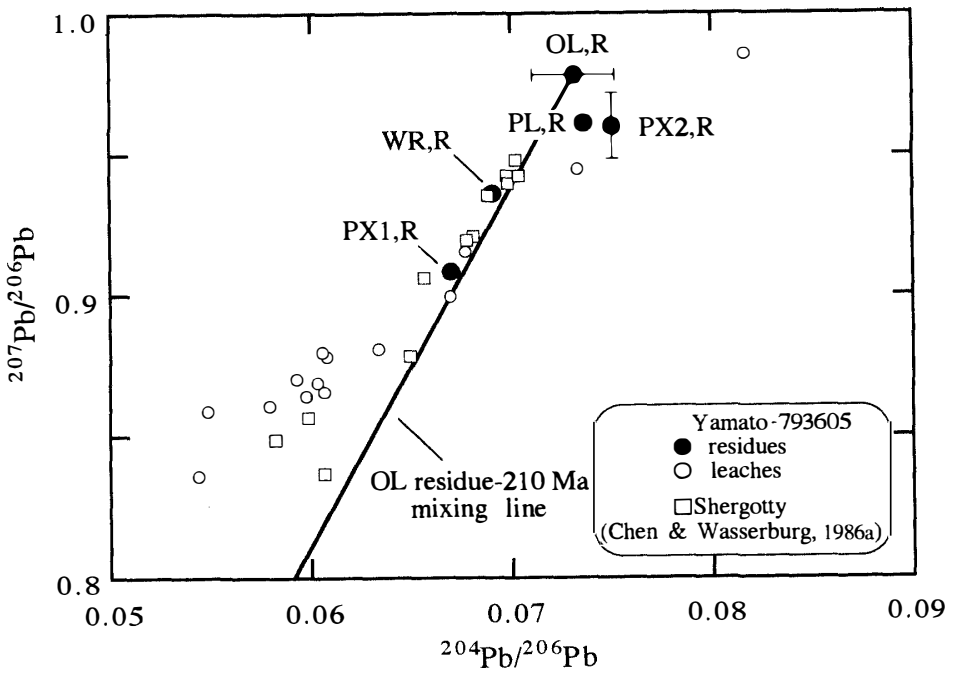

Fig. 8. *$^{207}Pb/^{206}Pb$ vs $^{204}Pb/^{206}Pb$ diagram for Yamato-793605 and Shergotty (CHEN and WASSERBURG, 1986a). A tie line between a 210-m.y.-old radiogenic Pb ($^{207}Pb/^{206}Pb=0.05$) and the olivine residue (OL, R) is drawn. The PX1 and WR residues of Yamato-793605 as well as some data points of Shergotty plot close to the trend of this mixing line, suggesting a young event of U-Pb fractionation.*

and residue intersects concordia at 4439±9 Ma and 212±62 Ma. If a tie line between a 210-m.y.-old radiogenic Pb ($^{207}Pb/^{206}Pb=0.05$) and the olivine residue (OL, R) is drawn on a $^{207}Pb/^{206}Pb$-$^{204}Pb/^{206}Pb$ diagram (Fig. 8), data points of the PX1 and WR residues of Y-793605 as well as the whole-rock leaches (3C, L1; 3C, L2), whole-rock (3A), whole-rock residue (3C, R), and plagioclase residue (PL, R) of Shergotty (CHEN and WASSERBURG, 1986a) plot close to this mixing line, suggesting a young event for U-Pb fractionation. The plagioclase and less-magnetic pyroxene separates (PL, R and PX2, R) did not show such a trend, implying a greater disturbance during shock events or incomplete isotopic equilibrium in the U-Pb system.

4. Conclusions

The Pb isotopic compositions of Y-793605 indicate that a source reservoir evolved in a low-μ (~5) environment. Because of the open-system behavior owing to a disturbance in the U-Th-Pb system, the time of crystallization of Y-793605 was not uniquely determined in this study. Uranium-Pb data points for both leaches and residue of the most magnetic fraction, which contains abundant shock-melt glass, define a chord which intersects concordia at 4439±9 Ma and 212±62 Ma, suggesting a two-stage evolution whereby a 4400-m.y.-old lherzolite parent suffered a 200-m.y.-old disturbance with Pb loss. The later disturbance event partially reset the U-Pb system. The

U-Th-Pb isotopic systematics of Y-793605 and its interpretations are generally follows those of other shergottites (CHEN and WASSERBURG, 1986a, b, 1993).

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