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U-Pb ISOTOPIC CHARACTERISTICS OF LUNAR METEORITES YAMATO-793274 AND YAMATO-86032

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Abstract: U-Pb data from lunar meteorites Yamato (Y)-86032 and Y-793274 confirm that they are of lunar origin, but also indicate that they are not from the same source region on the Moon and experienced different events while residing as lunar regolith. The Pb of both clast and matrix from Y-86032 is the least radiogenic among lunar meteorites thus far analyzed, similar to that of lunar anorthosite 60025, and indicates derivation from a low-^{238}U/^{204}Pb (μ) source, assuming initial lunar Pb compositions were essentially primitive in nature. Whereas the data from Y-86032 plot slightly above the geochron on a ^{206}Pb/^{204}Pb *vs.* ^{207}Pb/^{204}Pb diagram, data from 60025 and Y-82192 (considered a pare of Y-86032) plot precisely on the geochron. Very small amounts of U, Th, and Pb were leached from Y-86032 using 0.1N HBr; the Pb isotopic compositions of the leaches are essentially modern terrestrial values, indicating that this rock probably did not reside long at the lunar surface and was not exposed to volatile-rich gases expelled during impact event (s).

In contrast, large amounts of the three elements (up to five times those of Y-86032) were removed from Y-793274 during leaching, and the Pb isotopic compositions of these leaches are very radiogenic and similar to those of mare basalt and some lunar soils, indicating that this rock was subjected to lunar impact-related, volatile-rich gases containing radiogenic ^{206}Pb-rich Pb, very similar to typical lunar soils and some breccias containing significant amounts of mare-derived material. This is the first occurrence of leaches that are more ^{206}Pb-rich than their corresponding residues and indicate that the meteorite may have originated from near a mare region. To compare, the Pb from leaches of Y-791197 clasts (N. NAKAMURA *et al.*; Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 106, 1986a) was ^{206}Pb-poor, indicating the meteorite may have originated from the lunar highlands. The Pb in residues of Y-793274 is more radiogenic than that of Y-86032 and Y-82192, similar to that in ALHA81005 and lunar anorthositic gabbros 78155 and 15418, and indicate a lunar source region with high-μ ($>$100 and possibly as high as 300). Corrected U-Pb data indicate a formation age of ~4.4 Ga and a disturbance to the system at ~4.0 Ga.

1. Introduction

The Moon is thought to have been depleted in volatile elements at its formation and, therefore, the lunar U/Pb value was probably high, relative to chondrites and the Earth. Because Pb is more abundant than U or Th, lunar anorthosites tend to retain their initial Pb isotopic composition that is often strikingly radiogenic (*e.g.* TATSUMOTO, 1972). This characteristic of some lunar anorthosites is unique in comparison to usual meteorites and terrestrial rocks. Therefore, the U-Th-Pb isotopic data from anorthositic meteorites can be powerful indicators of a lunar origin. Furthermore, as has been shown in previous studies (PREMO *et al.*, 1989; PREMO and TATSUMOTO, 1990), a step-wise leaching procedure can help to decipher different lunar environments, characterized by specific Pb isotopic signatures, that the meteorites experienced as they resided on or near the lunar surface.

Since the discovery that a meteorite collected from the Antarctic ice was of lunar origin (MASON, 1982), ten other Antarctic meteorites (so far) are thought to have lunar affinities. There is little doubt that Antarctic meteorites Allan Hills (ALH) A81005, Yamato (Y)-791197, Y-82192, Y-82193, and Y-86032 are of lunar origin as shown by the collective detailed geochemistry compiled by EUGSTER (1989). In this paper, we report U-Th-Pb isotopic data from samples of Y-86032 and Y-793274 as part of a consortium study (TAKEDA *et al.*, 1989, 1990), not only to confirm their lunar origin (exhibited by initial radiogenic $^{207}Pb/^{206}Pb$ values of ~1.45 to 1.5, similar to lunar anorthosite values), but also to determine crystallization and/or metamorphic ages, and compare their isotopic systematics with various U-Th-Pb signatures from lunar anorthositic samples. Such a comparison should help us identify possible source areas on the Moon for these meteorites. In addition, the Pb from leaches, that is mostly secondary in nature, should tell us whether these rocks experienced residency as lunar regolith and what type of lunar material was near the meteorite source region.

2. Samples and Chemical Procedures

Y-86032 is a large lunar meteorite, weighing 648.43 g, and was described as an anorthositic regolith breccia (YANAI and KOJIMA, 1987a). A matrix sample (,77) of Y-86032, weighing 160 mg, was allocated from the National Institute of Polar Research (NIPR) via NASA-JSC in 1988, and a 57 mg clast sample (,118) of Y-86032 was allocated from NIPR in late 1989. The clast was observed to be a feldspathic fragmental breccia and one side was layered with gray matrix material (TAKEDA *et al.*, 1989, p. 11). Attempts to separate the dark portion from the light-colored clast resulted in breaking the clast into small pieces. Clast samples are: (1) two light-colored pieces (29.6 and 9.7 mg each: designated A and C, respectively), (2) predominantly gray-colored material or matrix (8.4 mg: B), and (3) left-over powders (4.8 mg: D). The matrix was divided into two portions (76.4 and 80 mg: E and F). In retrospect, the clast was divided into too many portions and data from fractions B, C, and D are marginally usable, due to the extremely low Pb, U, and Th abundances.

Y-793274 has been classified as an anorthositic regolith breccia by YANAI and KOJIMA (1987b), but LINDSTROM and MARTINEZ (1990) argued that it must be a basaltic breccia. Three clasts of Y-793274 (,84 ,86, and ,92: weighing 32, 42, and 16 mg, respectively) were supplied from NIPR in early 1990. These gray materials (although listed as anorthositic clasts) had a compacted-regolith appearance with white specks; whereas, Y-86032 appeared to be compacted anorthositic norite fragments. No attempt was made to further separate the three clasts into purer fractions (*e.g.* monomineralic separates).

Separates of clasts (four fractions, A, B, C, and D) and matrix (two fractions, E and F) from Y-86032 were first washed in a 1 m*l* polyethylene centrifuge tube with ethanol (one-time, sub-boiling distilled); the ethanol was decanted following centrifuging. Samples were further leached with cold 0.1N HBr in order to remove terrestrial contamination. The washing and leaching were repeated four times in an ultrasonic bath for 5 minutes each.

For Y-793274, 0.5N HBr leaching was performed in addition to the ethanol washing and 0.1N HBr leaching, because considerable amounts of U, Th, and Pb were removed during the 0.1N HBr leaching step. Washes, leaches, and residues were analyzed for U, Th, and Pb isotopes. Separation chemistry for U, Th, and Pb is described in PREMO *et al.* (1989) and PREMO and TATSUMOTO (1990). Pb blanks were 25, 30, and 45 pg for the ethanol wash, 0.1N HBr and 0.5N HBr leaches, and residue fractions, respectively. However, because correction of the Pb data due to blank resulted in no radiogenic Pb in some fractions, the actual Pb blanks are lower than the measured values in some cases. Blanks for U and Th were lower than 2 and 1 pg, respectively, for all fractions.

3. Results

Results of U, Th, and Pb analyses are presented in Tables 1 and 2. U, Th, and Pb abundances for Y-86032 and Y-793274 at each step of the leaching procedure are depicted in Fig. 1a and 1b. The concentrations of these three elements in Y-86032 fractions are extremely low and only very small amounts were removed during washing and leaching. ^{206}Pb/^{204}Pb values for the washes and leaches are essentially terrestrial ($\sim$19), indicating two interesting points: (1) Very little Pb was incorporated or adsorbed to this rock during impact events as it resided on the Moon, perhaps because it was not exposed at the lunar surface or not exposed for very long prior to ejection into space, consistent with the short lunar regolith residence times reported in EUGSTER (1989), and (2) There is very little terrestrial contamination of this meteorite following its arrival at the Earth's surface, consistent with the short terrestrial age reported by EUGSTER (1989). In any case, fractions B, C, and D were too small, and their data are marginally significant. Therefore, the discussion of Y-86032 is limited to data from fractions A, E, and F—weighing more than 10 mg each.

In contrast, concentrations in Y-793274 are higher (Fig. 1b), more than five times those in Y-86032, and significant amounts of these elements, especially Th, were removed from Y-793274 during the 0.1N HBr leaching step, indicating significant amounts of Pb were incorporated into or adsorbed to this rock during impact events as it resided at the Moon's surface. The ^{206}Pb/^{204}Pb values for separates of Y-763274 at each step of sample processing are shown in Fig. 2, and the Pb in 0.1N and 0.5N HBr leaches is much more radiogenic than that in the residues, indicating that the incorporated or secondary Pb is from a different source than the original sample Pb.

Pb isotopic compositions of all fractions from these meteorites are shown in a ^{206}Pb/^{204}Pb *vs.* ^{207}Pb/^{204}Pb diagram (Figs. 3 and 4), together with the data from other lunar meteorites and selected lunar samples taken from the literature. Because ^{235}U has a shorter half-life than ^{238}U, ^{207}Pb-growth is faster than ^{206}Pb early in lunar history, but later ^{206}Pb-growth is more significant as most of the ^{235}U has decayed out. Most meteorites, including unequilibrated chondrites, equilibrated ordinary

Table 1. U-Th-Pb data of Y-86032.

Clast No.	Fraction	Designated	Weight (mg)	U (ppb)	Th (ppb)	Pb (ppb)	^{206}Pb/^{204}Pb†	^{207}Pb/^{204}Pb†	^{208}Pb/^{204}Pb†	^{238}U/^{204}Pb†	^{232}Th/^{204}Pb†	^{206}Pb/^{238}U$^{\dagger *}$	^{207}Pb/^{235}U$^{\dagger *}$	^{207}Pb/^{206}Pb$^{\dagger *}$	^{208}Pb/^{232}Th$^{\dagger *}$
,118	Alcohol wash	AA	29.56	0.07	1.59	1.67	18.50	15.45	37.26	2.54	61.47	3.613	279.8	0.5613	0.127
							(0.64)‡	(0.71)	(1.06)	(35.0)	(45.3)	(34.7)	(34.90)	(1.29)	(37.80)
	.1N HBr leach	AB		0.26	0.65	1.40	21.88	17.66	41.91	13.37	34.16	0.940	75.95	0.5858	0.364
							(6.30)	(5.08)	(3.35)	(55.6)	(65.6)	(55.4)	(54.40)	(2.10)	(55.60)
	Residue	AR		23.72	88.50	104.05	33.07	23.95	52.92	21.85	84.23	1.088	86.20	0.5747	0.2783
							(1.92)	(1.54)	(1.20)	(5.47)	(5.59)	(3.49)	(3.49)	(0.20)	(3.70)
,118	Alcohol wash	BA	8.38	0.38	0.34	3.42	20.69	17.59	39.71	7.49	7.09	1.519	134.3	0.6412	1.444
							(4.51)	(5.52)	(1.29)	(75.00)	ϕ	(64.6)	(60.50)	(0.11)	(73.1)
	.1N HBr leach	BB		1.60	0.18	0.00	18.86	15.63	39.47	0.00	0.00	0.00	0.00	0.5590	0.0000
							(0.94)	(0.98)	(1.52)	--	—	--	--	(2.22)	--
	Residue	BR		57.72	155.60	149.99	56.92	46.73	75.30	59.80	166.59	0.796	84.01	0.7653	0.2751
							(1.95)	(1.93)	(1.41)	(4.00)	(3.66)	(2.74)	(2.71)	(0.19)	(2.21)
,118	Alcohol wash	CA	9.70	0.08	0.14	1.28	27.03	16.08	44.08	3.65	0.00	2.211	181.5	0.5954	0.0000
							(13.40)	(6.41)	(24.0)	ϕ		ϕ	ϕ	(9.99)	ϕ
	.1N HBr leach	CB		0.80	2.16	1.83	25.65	20.98	46.05	35.56	98.93	0.459	41.4	0.6541	0.1675
							(53.00)	(50.10)	(30.9)	(65.6)	(65.6)	ϕ	ϕ	(15.3)	ϕ
	Residue	CR		18.85	73.26	78.62	40.98	28.7	60.23	27.12	108.92	1.168	93.8	0.5823	0.2824
							(9.54)	(7.97)	(6.24)	(26.4)	(26.4)	(13.2)	(13.10)	(0.35)	(13.3)
,118	Alcohol wash	DA	4.87	0.64	1.28	0.47	20.92	16.33	41.32	12.46	13.40	0.179	7.80	0.3167	0.2007
							(10.5)	(4.16)	(6.45)	(5.80)	(56.3)	ϕ	--	--	ϕ
	.1N HBr leach	DB		0.31	3.77	1.55	18.00	16.31	35.36	12.08	153.11	0.720	68.7	0.6921	0.0384
							(33.0)	(5.86)	(10.3)	(6.78)	ϕ	ϕ	ϕ	ϕ	ϕ
	Residue	DR		24.16	86.95	170.67	30.01	24.02	49.01	12.72	47.31	1.627	148.7	0.6629	0.4127
							(8.43)	(7.83)	(4.67)	(30.3)	(30.1)	(19.8)	(18.70)	(1.56)	(20.0)
,77	Alcohol wash	EA	50.38	0.10	5.49	4.76	18.60	15.93	38.39	1.36	74.30	6.520	566.2	0.6299	0.1133
							(0.37)	(0.39)	(0.39)	(6.52)	(5.97)	(6.52)	(6.31)	(0.78)	(6.42)
	.1N HBr leach	EB		0.98	1.83	5.24	21.95	18.68	41.12	13.34	25.73	0.947	86.69	0.6637	0.4526
							(0.50)	(1.06)	(0.96)	(42.3)	(42.3)	(4.80)	(4.61)	(0.53)	(6.96)
	Residue	ER		51.19	188.09	208.32	52.65	45 5	69.25	35.73	135.62	1.213	135.7	0.8111	0.2933
							(0.56)	(0.57)	(0.40)	(1.72)	(1.79)	(1.48)	(1.47)	(0.12)	(1.56)
,77	Alcohol wash	FA	49.64	0.13	1.36	4.25	19.78	16.73	40.12	1.96	20.91	5.068	447.2	0.6400	0.4796
							(0.23)	(0.38)	(0.22)	(7.85)	(8.59)	(49.5)	(7.52)	(7.30)	(8.44)
	.1N HBr leach	FB		0.34	1.55	0.85	37.96	30.30	57.64	43.13	205.63	0.664	63.9	0.6981	0.1370
							(16.9)	(16.2)	(10.9)	(34.2)	(33.9)	(22.3)	(20.70)	(2.11)	(22.4)
	Residue	FR		49.07	180.74	177.73	63.93	51.90	79.63	46.84	178.27	1.166	122.4	0.7617	0.2814
							(0.79)	(0.79)	(0.58)	(1.89)	(1.94)	(1.50)	(1.49)	(0.10)	(1.56)

†: Data corrected for mass fractionation and laboratory blank (LUDWIG, 1989).

*: Data corrected for the primordial Pb (^{206}Pb/^{204}Pb=9.307, ^{207}Pb/^{204}Pb=10.294, ^{208}Pb/^{204}Pb=29.476: TATSUMOTO *et al.*, 1973).

‡: Error at 95% confidence limits (in percent). 2σ errors for measured ratios are less than 0.3% in most cases.

ϕ: Estimated errors are larger than 100% due to non-radiogenic Pb nature.

Table 2. U-Th-Pb data of Y-793274.

Clast No.	Fraction	Desig- nated	Weight (mg)	U (ppb)	Th (ppb)	Pb (ppb)	^{206}Pb/ ^{204}Pb†	^{207}Pb/ ^{204}Pb†	^{208}Pb/ ^{204}Pb†	^{238}U/ ^{204}Pb†	^{232}Th/ ^{204}Pb†	^{206}Pb/ ^{238}U†*	^{207}Pb/ ^{235}U†*	^{207}Pb/ ^{206}Pb†*	^{208}Pb/ ^{232}Th†*
,84	Alcohol wash	A84	32.02	0.69	1.78	6.90	25.28 (1.20)#	20.06 (0.95)	44.76 (0.64)	7.78 (7.06)	20.77 (5.46)	2.0538 (6.52)	173.16 (6.90)	0.6115 (1.71)	0.7358 (4.87)
	.1N leach	B84		39.38	136.38	73.15	200.63 (3.16)	124.63 (3.06)	210.34 (2.85)	249.41 (4.33)	892.42 (3.86)	0.7671 (2.49)	63.21 (2.50)	0.5976 (0.18)	0.2027 (1.56)
	.5N leach	C84		32.78	144.86	130.02	193.59 (1.44)	158.90 (1.44)	204.97 (1.31)	121.56 (2.20)	555.02 (2.23)	1.5160 (1.47)	168.55 (1.47)	0.8064 (0.10)	0.3162 (1.52)
	Residue	R84		226.35	799.10	989.94	136.13 (0.31)	114.77 (0.34)	139.5 (0.32)	77.25 (1.50)	281.82 (1.53)	1.6416 (1.48)	186.46 (1.49)	0.8238 (0.18)	0.3904 (1.52)
,86	Alcohol wash	A86	41.35	12.80	9.20	6.50	24.32 (0.97)	19.03 (0.74)	45.43 (0.59)	154.16 (7.35)	114.72 (4.51)	0.1006 (7.12)	7.81 (7.70)	0.5631 (2.04)	0.1391 (4.11)
	.1N leach	B86		51.38	282.51	91.04	179.31 (1.96)	104.81 (1.86)	250.26 (1.86)	261.00 (2.98)	1482.87 (2.73)	0.6514 (1.99)	49.93 (2.00)	0.5560 (0.19)	0.1489 (1.59)
	.5N leach	C86		22.36	92.84	57.82	334.04 (4.06)	214.36 (3.99)	341.69 (3.81)	297.46 (4.62)	1276.33 (4.62)	1.0917 (1.52)	94.59 (1.53)	0.6284 (0.09)	0.2446 (1.53)
	Residue	R86		214.05	710.03	754.28	103.74 (0.55)	74.01 (0.55)	103.34 (0.55)	69.10 (1.55)	236.84 (1.60)	1.3666 (1.48)	127.13 (1.52)	0.6747 (0.24)	0.3119 (1.57)
,92	Alcohol wash	A92	19.16	45.40	17.30	92.60	19.42 (0.44)	16.08 (0.49)	39.27 (0.48)	32.10 (4.85)	12.64 (2.30)	0.3150 (5.68)	24.87 (7.15)	0.5725 (2.91)	0.7748 (4.10)
	.1N leach	B92		97.53	504.77	208.46	332.29 (3.31)	177.48 (3.20)	410.25 (3.18)	372.12 (4.08)	1990.06 (3.88)	0.8679 (1.98)	61.94 (1.98)	0.5176 (0.13)	0.1913 (1.52)
	.5N leach	C92		58.49	173.06	162.54	178.02 (1.57)	120.76 (1.53)	165.72 (1.36)	144.58 (2.68)	442.03 (2.36)	1.1669 (2.00)	105.35 (2.01)	0.6548 (0.18)	0.3082 (1.55)
	Residue	R92		168.90	610.67	651.87	120.70 (0.36)	93.35 (0.36)	132.04 (0.34)	77.64 (1.52)	290.06 (1.56)	1.4325 (1.48)	147.50 (1.50)	0.7456 (0.17)	0.3536 (1.52)

†: Data corrected for mass fractionation and laboratory blank.

*: Data corrected for the primordial Pb (^{206}Pb/^{204}Pb=9.307, ^{207}Pb/^{204}Pb=10.294, ^{208}Pb/^{204}Pb=29.476: TATSUMOTO *et al.*, 1973).

‡: Error at 95% confidence limits (in percent).

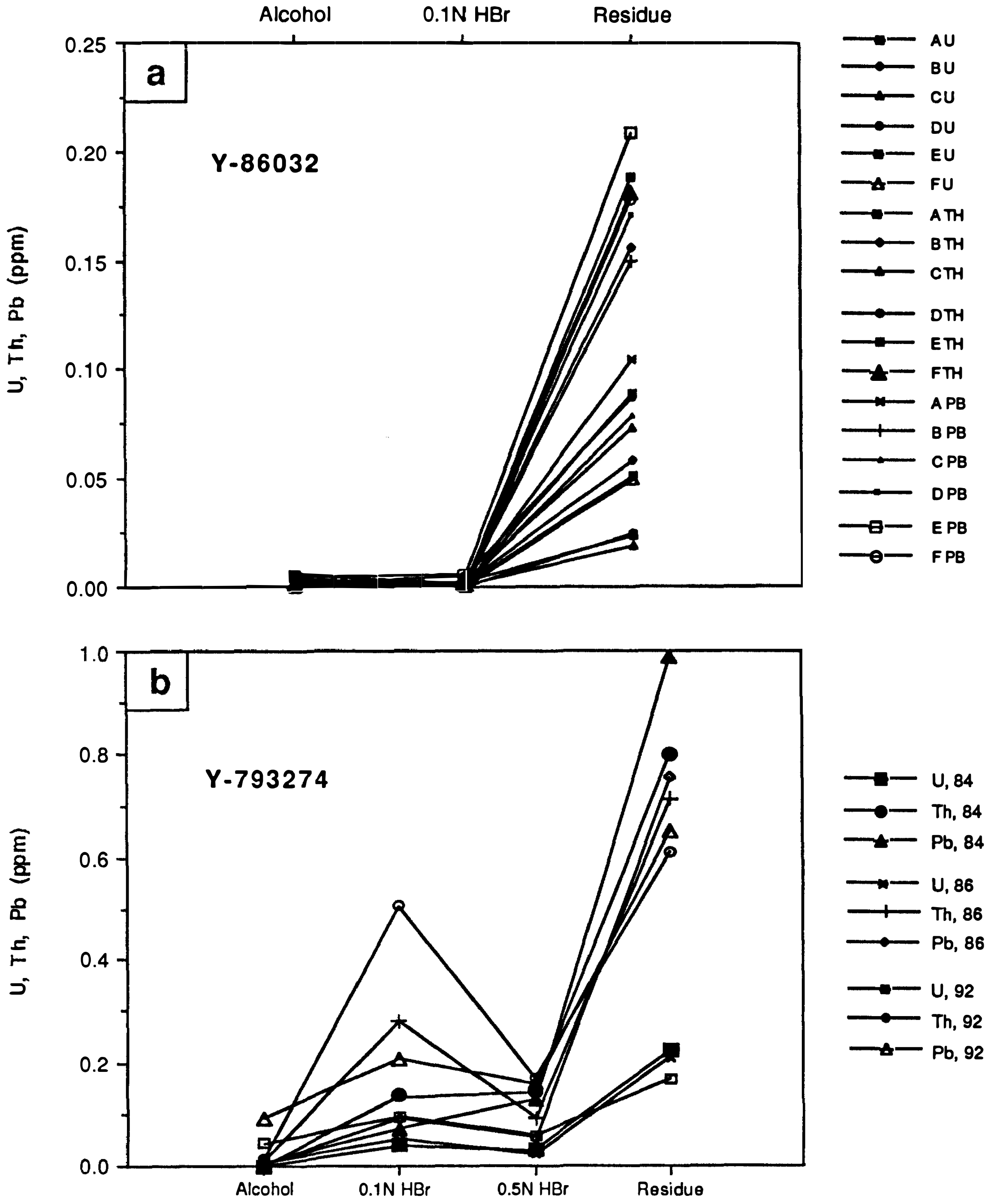

Fig. 1. a) U, Th, and Pb abundances in fractions from Y-86032 at different leaching steps. For Y-86032, there is very little U, Th, or Pb removed during washing and leaching.
b) For Y-793274, significant amounts of U, Th, and Pb were removed from each fraction, particularly during the 0.1N HBr leaching step and especially from fraction ,92.

chondrites, and some achondrites, have evolved in closed systems and their Pb data plot on or near the geochron. In contrast, most lunar anorthositic rock data plot on the ^{207}Pb-rich side of the geochron which indicates a minimum of two stages of

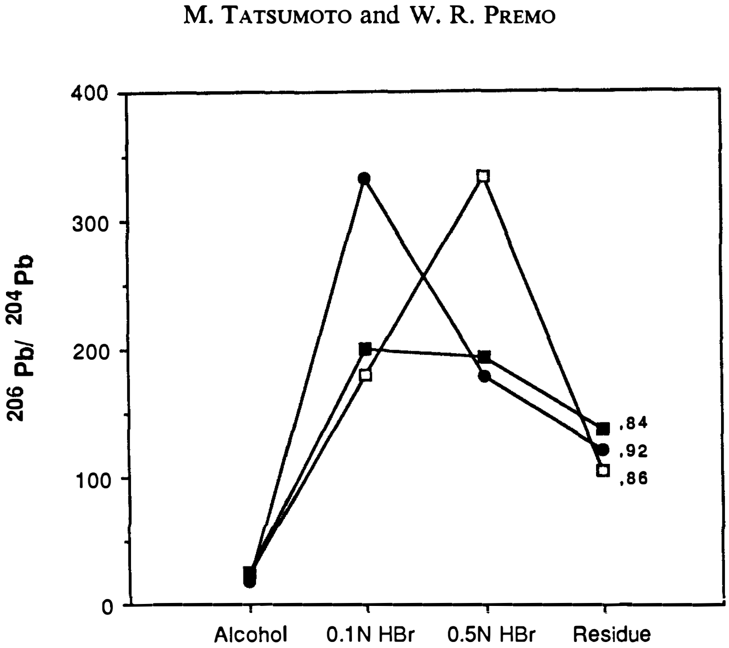

Fig. 2. Variations of $^{206}Pb/^{204}Pb$ values in the three fractions of Y-793274 at different leaching steps. Pb isotopic compositions in acid leaches are more radiogenic than those in residues, indicating a radiogenic adsorbed Pb component.

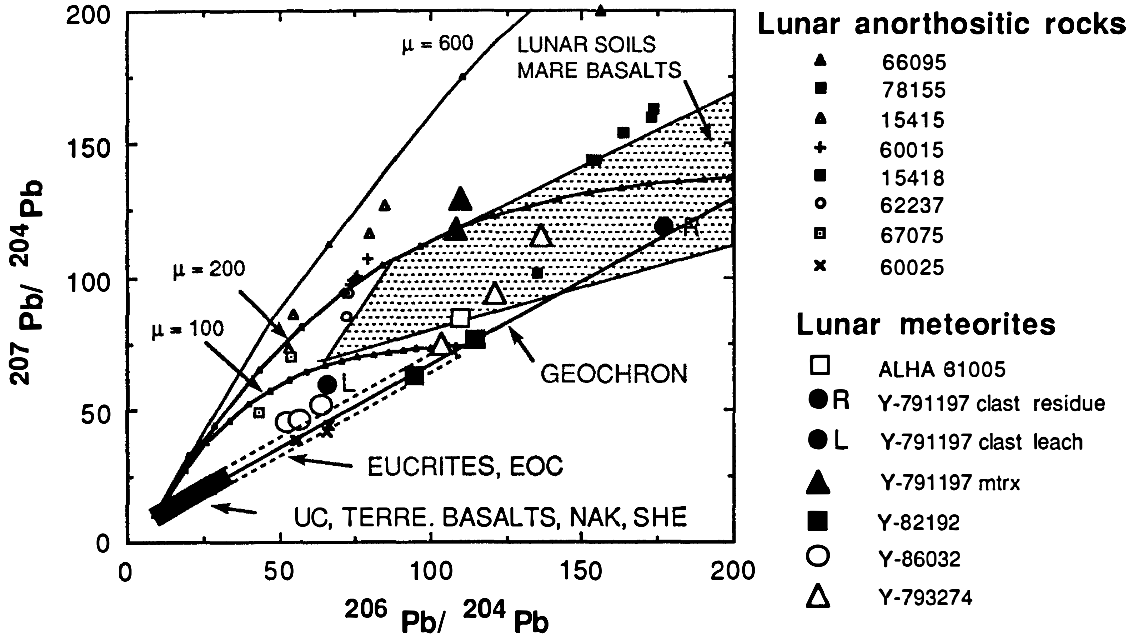

Fig. 3. $^{206}Pb/^{204}Pb$ vs. $^{207}Pb/^{204}Pb$ diagram for Y-86032. Large symbols are for lunar meteorites, thus far analyzed; small symbols are selected data for lunar anorthositic rocks from the literature. Also shown are the data field for usual chondrites, terrestrial basalts, Nakhla, and Shergotty (solid rectangle), the data field for eucrites and equibrated ordinary chondrites (dashed oval), and the data field for mare basalts and lunar soils (dotted polygon). Growth curves for $\mu = 100$, 200, and 600 ($\mu = {}^{238}U/{}^{204}Pb$), and the geochron (4.56 Ga), indicating present Pb values for closed systems, are also shown. For comparison, lunar meteorites ALHA81005 (Chen and Wasserburg, 1985), Y-791197 (Nakamura et al., 1986a), Y-82192 (Nakamura et al., 1986b), and selected anorthositic Apollo samples (refer to Nakamura et al., 1986b) are also plotted. Anorthosite 67075 is from Oberli et al. (1979). All Apollo anorthositic rocks plot above the geochron. Data for Y-86032 plot above the geochron, while Y-82192 data plot precisely on the geochron.

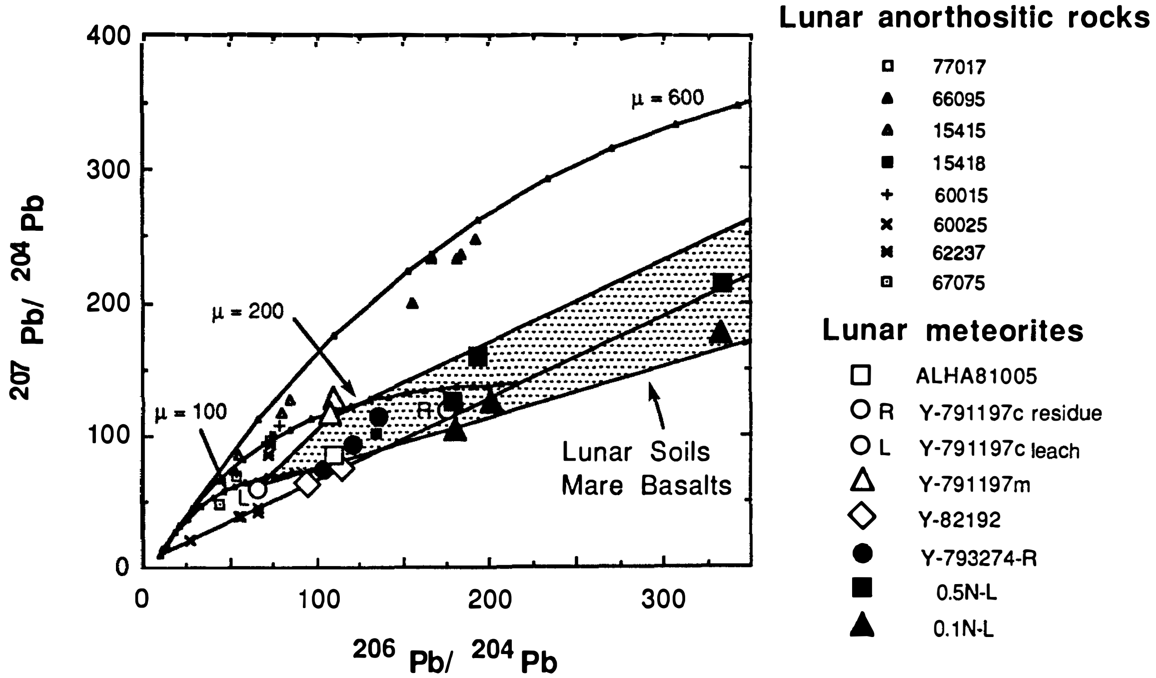

Fig. 4. $^{206}Pb/^{204}Pb$ *vs.* $^{207}Pb/^{204}Pb$ *diagram for Y-793274. Symbol sizes correspond to the same groupings as in Fig. 3. Pb in the 0.1N HBr leaches plot below the geochron in the lunar soil field, indicating that it is absorbed Pb from lunar regolith containing a significant mare component. In contrast, leached Pb from Y-791197 is lunar anorthositic Pb.*

Pb evolution—first in a high-μ environment, but followed by a stage characterized by a low-μ environment. In contrast, μ values for lunar basalt sources increased three or more times those of older highland rocks during differentiation events at later times, for example 3.5 Ga. So Pb derived from later-stage mare regions is ^{206}Pb-rich and the lunar basalt data plot on the ^{206}Pb-rich side of the geochron.

Washes and leaches for Y-86032 are not radiogenic and plot near the terrestrial basalt field (Fig. 3). However, Pb in acid leaches of Y-793274 are very radiogenic and plot well inside the mare basalt and lunar soil field (Fig. 4), indicating that Pb of this type was added or adsorbed later by meteorite impact and/or volcanic activity before or at the time the rock was ejected into space. From our previous experiments (NAKAMURA *et al.*, 1986a, b), Y-791197 and Y-86192 leaches and residues all plot in the ^{207}Pb-rich field, indicating that these meteorites experienced different events than Y-793274 while residing at the lunar surface.

Residues of Y-86032 (Fig. 3) and Y-793274 (Fig. 4) all plot in the lunar anorthosite field, above the geochron which indicates a minimum two-stage history, involving Pb evolution in a high-μ environment, followed by a drastic decrease in μ. This is strong independent evidence that both meteorites are of lunar origin. Y-86032 residues are the least radiogenic among Antarctic lunar meteorites so far analyzed; however, they plot close to the most primitive lunar anorthosite, 60025 (HANAN and TILTON, 1987). These results are consistent with petrographic data suggesting that Y-86032 is composed of mainly highlands material and chemical data indicating its similarity to Apollo 16 samples (WARREN, 1990). Several workers previously suggested that

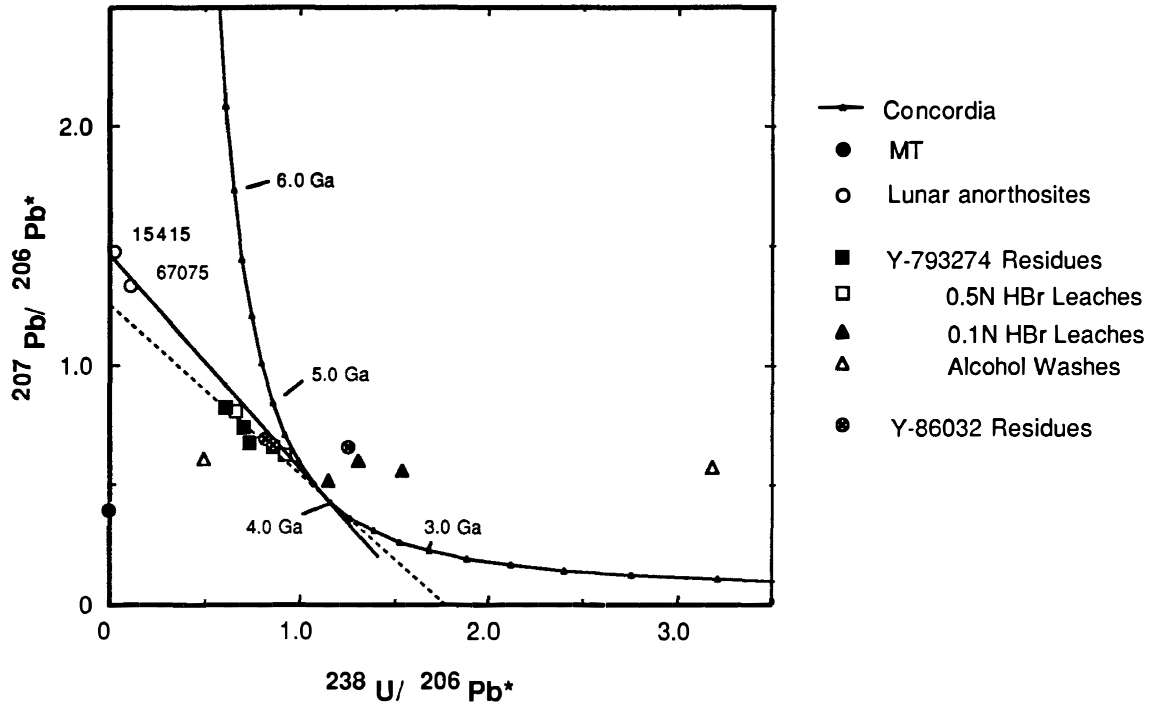

Fig. 5. Modified concordia diagram ($^{238}U/^{206}Pb$ vs. $^{207}Pb/^{206}Pb$) for Y-86032 and Y-793274. All data are corrected for CDT initial Pb values of TATSUMOTO *et al. (1973). The concordia curve represents all the possible solutions for a closed U-Pb system as a function of time (given in Ga-billions of years). The solid line marks the cataclysm array of* TERA *et al. (1974) and the dashed line indicates the trend defined by the meteorite fractions (see legend).*

Y-82192, Y-82193, and Y-86032 are the same lunar meteorite that has broken apart before or upon impact with the Earth (*e.g.* EUGSTER, 1989). The Pb isotopic features of Y-86032 are similar to Y-82192 (NAKAMURA *et al.*, 1986a); however, Y-86032 is less radiogenic and more ^{207}Pb-rich than Y-82192. Residues of clasts from Y-793274 also plot above the geochron but are more ^{206}Pb-rich than most lunar anorthosites. The Pb in Y-793274 residues is similar to anorthositic gabbros 78155 and 15418, suggesting some mare component. These results are consistent with petrographic data indicating that Y-793274 is approximately 30% mare material (YANAI and KOJIMA, 1987b).

^{238}U/^{206}Pb and radiogenic ^{207}Pb/^{206}Pb data for Y-86032 (only three residue fractions) and Y-793274 are shown on a modified concordia diagram (TERA and WASSERBURG, 1974) in Fig. 5. The Pb are corrected for Cañon Diablo troilite Pb (CDT). The 0.5N HBr leaches and residues of Y-793274 plot to the left of the concordia, indicating either the presence of excess radiogenic Pb or preferential leaching of U to Pb during the 0.1N HBr leaching. Fraction B92 plots to the left of concordia, indicating excess Pb as discussed above (terrestrial contamination?). Fractions B84 and B86, however, plot to the right of concordia, indicating preferential U leaching (and perhaps Th also) in these fractions. The two fractions of Y-86032 matrix plot with the Y-793274 data, but one clast fraction plots to the right of concordia. The residues and 0.5N HBr leaches from Y-793274 and two residues of Y-86032 plot just to the left of the Lunar Cataclysm array (solid line) of TERA *et al.* (1974), defining a linear array (dashed line) with an initial $^{207}Pb/^{206}Pb$ value (*Y*-axis intercept) that is significantly lower (~1.25) than that defined by TERA *et al.*'s Cataclysm array (~1.45–1.5).

4. Discussion

4.1. Lunar regolith residency

For Y-793274, Pb in the 0.1N HBr leach (B fractions) is quite abundant and radiogenic with $^{206}Pb/^{204}Pb = 180$–330, corresponding to high μ's of 150 to 300. If the Pb in this leach has some contribution of adsorbed secondary Pb, deposited onto grain surfaces following the production of volatile-rich gases during lunar impact event (s), then the leached Pb signature characterizes a mixture of sample Pb (residue Pb), Pb from the lunar target area, Pb from the impactor, and terrestrial Pb contamination. Although we cannot know the proportions of each type of Pb, the fact that three of the four components plot to the nonradiogenic side of the leaches (Fig. 4), assuming the impactor had low Pb abundances of typical meteoritic Pb compositions with $^{206}Pb/^{204}Pb$ values ~100 or less (Fig. 3), implies that Pb from the lunar target area is a major component. The only known lunar source capable of supplying the unique ^{206}Pb-rich component into the adsorbed secondary Pb is mare basalt, or soil containing an appreciable amount of mare material. This observation suggests that Y-793274 resided near or at a mare basalt region before being ejected into space. The impact event that produced the secondary Pb coating probably was not the same as the one responsible for the meteorite, as the rock would have reached escape velocity before any volatile gas adsorption could have taken place. At any rate, the fact that a secondary Pb component exists tells us that this rock exists at or very near the lunar surface prior to ejection into space.

In contrast, for Y-86032, the near-absence of Pb in the leaches indicates that this rock probably did not reside at or near the lunar surface before ejection. Moreover, the lack of any significant amount of Pb indicates that terrestrial contamination of this meteorite was not extensive as suggested by other studies of Antarctic meteorites (*e.g.* NAKAMURA *et al.*, 1986a).

Several papers have suggested that because small chemical differences exist between Antarctic meteorites and Apollo and Luna samples, the lunar meteorites must come from an area far from KREEP reservoirs, located on the nearside of the Moon—perhaps being derived from the lunar farside (*e.g.* WARREN *et al.*, 1989). However, as far as the Pb data is concerned, this suggestion cannot be applied to Y-86032. The Pb for this sample is less radiogenic than that in lunar anorthositic breccias, but more radiogenic than lunar anorthosite 60025. WARREN (1990) suggested that highland meteorites ALHA81005, Y-791197, Y-86032, and Y-793274 (?) all contain considerable amounts of a VLT-basalt component, and if these meteorites do not represent different samples of debris from a single lunar source crater, then VLT basalts must be common on the Moon. Because leaches from Y-793274 clasts contain a very radiogenic, mare-type Pb and Pb in leaches from Y-791197 is anorthositic in character (^{207}Pb-rich), it is suggested that Y-793274 is from a mare region and Y-791197 is from the lunar highlands. If this is the case, then VLT basalts are indeed common in both the mare and highland regions.

4.2. Characterisitics of the source for the original lunar rock

If we assume that Pb in the source evolved from near primitive values, then the residue data from Y-793274 fractions indicate a high-μ source with values between 100 and 200. However, the different fractions can be thought of as mixtures of terrestrial Pb contamination, lunar surface Pb adsorbed to the sample following impact events, and some small amount of indigenous Pb. If we eliminate all terrestrial contamination (not only analytical blank), the adsorbed secondary Pb is probably more radiogenic than indicated here. So it is possible that the μ is as high as 300 for this sample, similar to that of lunar anorthositic regolith (*e.g.* TATSUMOTO, 1972). Since the Pb abundance is more than two times and is also more radiogenic in fraction B92 than in fractions B84 and B86, fraction B92 has a much larger proportion of adsorbed lunar Pb ($\mu \geq 400$) than the other fractions. It is important that the Pb in the residues is less radiogenic than the Pb in the leaches. This means that the original sample material is perhaps dominantly anorthositic in origin.

The relatively non-radiogenic plot of Y-86032 residues indicates derivation from a low-μ source (μ ~50–60) compared to Y-793274, but similar to anorthosite 60025. The contrast between Y-86032 and Y-793274 indicates that they were not derived from the same source on the Moon.

4.3. Ages for meteorite Y-793274

As previously discussed (*e.g.* NUNES *et al.*, 1975; PREMO and TATSUMOTO 1990), concordia intercept ages can vary depending on one's choice of initial Pb composition. Figure 6a and 6b, show how the initial Pb compositition can affect the intercept ages. The intent of the leaching procedure is to remove secondary adsorbed Pb from the sample surface, a problem that has been documented by many previous studies (see TATSUMOTO *et al.* (1987) for a review). Since U and Th are not volatile elements and therefore not easily vaporized during impact events, they are not expected nor are they found to adhere to lunar sample surfaces. Unfortunately, during the leaching procedure, some U and Th as well as Pb is removed from the sample. Assuming sample U is unintentionally removed during sample processing, then it is reasonable to add the leached U to the residue U. When this is done, the data is altered such that the points gradually move toward concordia. In Fig. 6a, the CDT-corrected data do not produce a reasonable concordia intercept age (~4.8 Ga). However, if we use initial Pb values calculated using $\mu = 500$ at 4.4 Ga and assuming 4.56 Ga for the age of the Moon, two of the data plot very close to concordia (Fig. 6b). The upper and lower intercept ages for the two fractions, B84 and B86 (solid diamonds—leach U added to residue U), are 4.4 and 4.0 Ga, respectively. This exercise suggests that the anorthositic clasts of Y-793274 were brecciated around 4.0 Ga to form lunar regolith, but formed around 4.4 Ga, an age agreeable with general consensus for the formation of the lunar highlands.

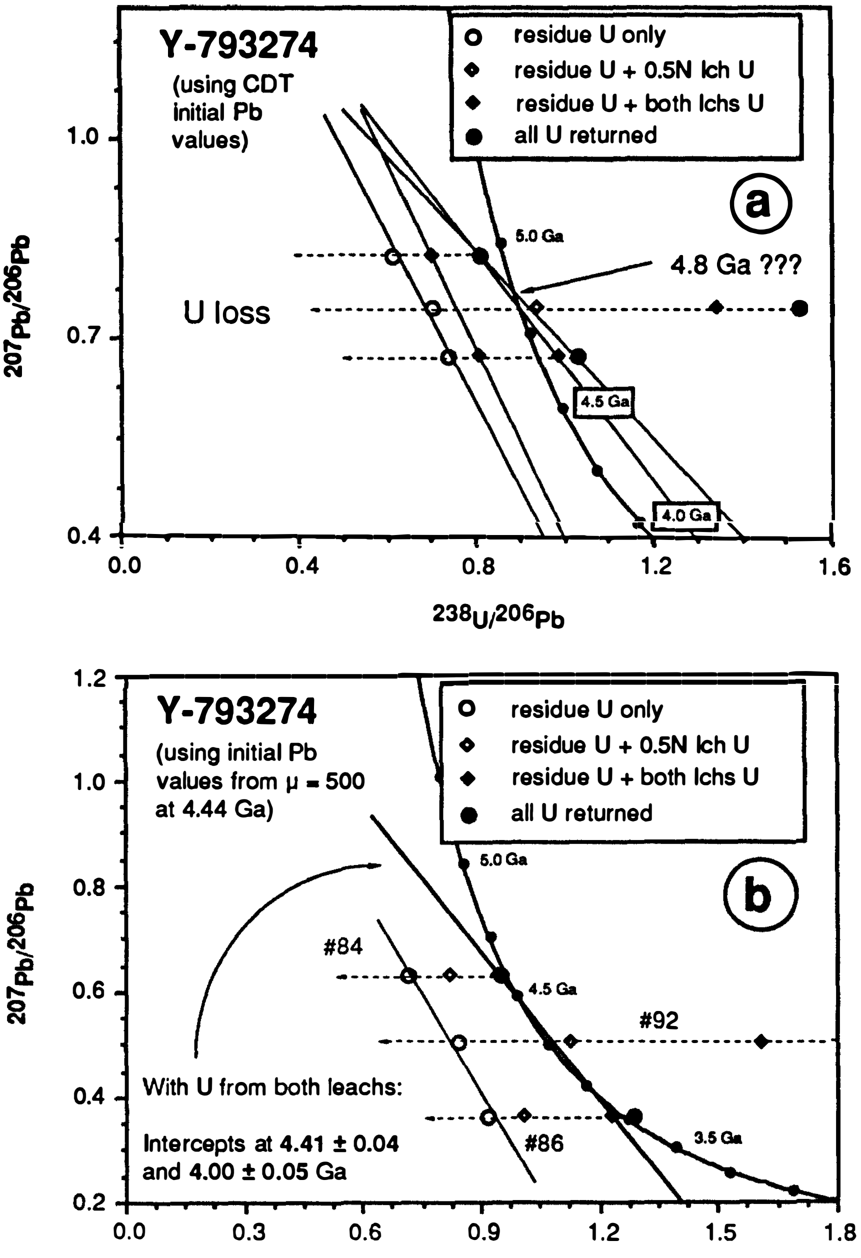

Fig. 6. a) Modified concordia diagram ($^{238}U/^{206}Pb$ vs. $^{207}Pb/^{206}Pb$) showing variations of data from Y-793274 residues as a function of U concentration and the CDT initial Pb composition. Open circles are for residue U only, open diamonds for residue U plus 0.5N HBr leach U, solid diamonds for residue U plus 0.5N and 0.1N HBr leach U, and solid circles for addition of all U. Adding back U removed during leaching procedures produces an unreasonable upper-intercept age of ~4.8 Ga.

b) Same as in Fig. 6a, except the data is corrected using initial Pb values calculated from $\mu = 500$ at 4.4 Ga, assuming 4.56 Ga as the age of the Moon. A chord between two of the three residues (corrected for removed U from both leaches) intersects concordia at 4.4 and 4.0 Ga, similar to ages defined by the lunar cataclysm array (TERA et al. 1974).

5. Conclusions

(1) Pb isotopic compositions of Y-86032 are similar to those in anorthositic rocks from the lunar highlands (especially primitive anorthosite 60025), and Pb isotopic compositions of clasts from Y-793274 are similar to those from anorthositic gabbros 78155 and 15418, supporting the idea that these meteorites are of lunar origin.

(2) Elemental abundances of U, Th and Pb are very low in Y-86032 and the Pb is similar to that of Y-82192, suggesting that Y-86032 pared with Y-86192 and -3 (EUGSTER, 1989). The Pb in Y-86032, however, is the least radiogenic among lunar meteorite thus far analyzed, and it plots above the geochron (^{207}Pb-rich), whereas Pb of Y-82192 plots on the geochron (NAKAMURA *et al.*, 1986b).

(3) The ^{206}Pb-rich, adsorbed secondary Pb component is mare in nature and suggests that Y-793274 resided near or at a mare basalt region before being ejected into space. In contrast, for Y-86032, the near-absence of Pb in the leaches indicates that this rock probably did not reside at or near the lunar surface before ejection.

(4) Corrected U-Pb data indicate that Y-793274 clasts fromed ~4.4 Ga and that a disturbance to the U-Pb system occurred ~4.0 Ga, consistent with ages defined by the cataclysm array of TERA *et al.* (1974) for lunar highland samples.

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