U-Pb AND Lu-Hf SYSTEMATICS OF ANTARCTIC METEORITES

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Abstract: U-Th-Pb analyses for the chondrites—ALHA77278 (LL3), Bishunpur (LL3) and McKinney (L4) have been performed in order to evaluate the effects of weathering under Antarctic conditions on the U-Th-Pb system. The ALHA77278 data indicate that, although this sample is apparently less contaminated than McKinney, a normal "find", it may still contain as much as 50 ppb terrestrial Pb. In addition, both meteorites seem to have experienced some leaching of U, Th, and/or Pb, and perhaps some preferential leaching of Pb isotopes. Lu-Hf analyses of 3 Antarctic eucrites—ALH-77302, Yamato-74159 and Yamato-74450 have been performed to evaluate the effects of Antarctic weathering on this system. In addition, the Bouvante eucrite was analyzed in an attempt to improve the precision of the solar system initial $^{176}Hf/^{177}Hf$ ratio as determined from a whole-rock isochron for eucrite meteorites. The most weathered sample, ALH-77302 appears to have suffered terrestrial Lu loss, whereas data from the two Yamato eucrites plot precisely on the eucrite whole-isochron. When the data from the two Yamato meteorites and Bouvante are included with those previously obtained from other eucrites, a revised $^{176}Hf/^{177}Hf$ initial of 0.27978 ± 9 (2σ) is obtained, 25% more precise than that previously reported. A revised half-life of 3.57 ± 0.14 $(2\sigma) \times 10^{10}$ a for ^{176}Lu is also obtained by inclusion of the new data.

1. Introduction

The U-Th-Pb systematics of chondrites ALHA77278 (LL3) and McKinney (L4) and the Lu-Hf systematics of the Bouvante eucrite and three Antarctic eucrites ALH-77302, Yamato-74450 and Yamato-74159 will be discussed in this paper.

There are two major problems regarding interpretation of U-Th-Pb data from chondrites: (1) apparent ^{207}Pb-^{206}Pb age differences of up to 50 Ma have been observed, even among chondrites of a single class and petrologic type, and (2) most chondrites contain more ^{206}Pb, ^{207}Pb and ^{208}Pb than could have been produced U and Th decay over the last 4550 Ma (*e.g.* GALE *et al.*, 1972; TATSUMOTO *et al.*, 1973). This paper represents a part of our attempt to determine the source of this excess radiogenic Pb.

A recent study of equilibrated L chondrites (UNRUH, 1981) has shown that a majority of this excess radiogenic Pb is the result of terrestrial Pb contamination in these meteorites prior to analysis, thus to some extent confirming the assumption of MANHES and ALLÈGRE (1978) that all excess radiogenic Pb is terrestrial. However, studies of L3 (UNRUH *et al.*, 1981) and L4 chondrites (UNRUH, 1981) suggest that some of the excess Pb in these meteorites is not easily attributable to terrestrial Pb contamination, and may instead be due to recent U loss or recent partial re-equilibration of U-Pb.

These recent studies have also shown that troilite in chondrites contains very little U ($\lesssim$1 ppb) and may also be depleted in indigenous Pb relative to the bulk meteorite. Consequently, chondrite troilite is very sensitive to terrestrial Pb contamination, and it has been shown (UNRUH, 1981) that the isotopic composition of contaminant Pb in the bulk meteorite can be obtained from the Pb isotopic composition in the troilite.

ALHA77278 was analyzed in order to evaluate the effects of weathering and Pb contamination on meteorites under Antarctic conditions. The ALHA77278 data are compared to those from a normal "find", McKinney (L4), and to data from two observed falls, Bishunpur (LL3) and Barwell (L5, UNRUH *et al.*, 1979).

Lu-Hf analyses of Bouvante, Yamato-74159 and Yamato-74450 were performed in part, to see if improvements in precision of the solar system initial $^{176}Hf/^{177}Hf$ as inferred from a eucrite whole-rock isochron, and the ^{176}Lu decay constant could be made (PATCHETT and TATSUMOTO, 1980a). The two Yamato meteorites were also analyzed in order to determine whether the apparent Lu-loss due to weathering observed in ALH-77302 (PATCHETT and TATSUMOTO, 1980a) was a common feature of Antarctic meteorites.

2. Analytical Procedures

2.1. *Sample Preparation*

Whole-rock analyses were performed on interior portions of allocations either sawn (McKinney and ALH-77302) or broken (ALHA77278 and the two Yamato eucrites) from larger masses. ALHA77278 was also sawn, but our allocation came from several cm away from the sawn surface. The two Yamato eucrites and McKinney were partially coated with fusion crust, and the ALHA77278 specimen contained one uncrusted, exterior face.

Troilite separates were obtained by hand-picking under a binocular microscope on a clean-air bench. Troilite in Bishunpur was too fine-grained to be easily hand-picked, so a magnetic separate from Bishunpur was analyzed in an attempt to find the least-radiogenic component in this meteorite. All samples for U-Th-Pb analyses were washed with ethanol for 10 minutes in an ultra-sonic bath prior to dissolution.

2.2. *Chemical Procedures*

Chemical procedures used in this study were similar to those of UNRUH *et al.* (1979) and PATCHETT and TATSUMOTO (1980b). Pb blanks are listed in Table 1. One high blank for ALHA77278 was traced to a contaminated HNO_3 storage bottle. Blank uncertainties are 2σ and were obtained from duplicate or triplicate blank analyses performed concurrently with 1 to 4 sample analyses. U and Th blanks were approximately 1–5 pg (10^{-12} g) and 2–10 pg, respectively. Lu-Hf blanks were identical to those reported earlier; less than 25 pg Lu and less than 200 pg Hf (PATCHETT and TATSUMOTO, 1980b).

3. Results and Discussion

3.1. U-Th-Pb study of chondrites

U, Th, and Pb concentrations in ALHA77278 (LL3; reclassified by MCSWEEN and WILKENING, 1980) are shown in Table 1. For comparison, U, Th, and Pb concentrations in Bishunpur (LL3; reclassified by DODD and JAROSEWICH, 1979), another "find", McKinney (L4), and a "typical" equilibrated L chondrite, Barwell (UNRUH *et al.*, 1979) are also shown.

The high Pb content in ALHA77278 (1 ppm) relative to that in Bishunpur (0.37 ppm) is consistent with enrichments of other volatile elements found in this meteorite (BISWAS *et al.*, 1979). However, the 1 ppm Pb in ALHA77278 is well within the range of Pb contents found in type 3 ordinary chondrites in general ($\sim$0.2–5 ppm, UNRUH *et al.*, 1981; and unpublished data). Thus, the Pb data are consistent with MCSWEEN and WILKENING's (1980) observation that ALHA77278 is not one of the most unequilibrated chondrites yet found.

U and Th abundances in three L3, three L4 chondrites and Bishunpur (Table 1; UNRUH *et al.*, 1981; UNRUH, 1981) fall within rather narrow ranges of 11.2–12.3 ppb, and 37.7–43.9 ppb, respectively. $^{232}Th/^{238}U$ ratios in these meteorites ranged from 3.34 to 3.89. ALHA77278 shows more variation than was found among all of these other meteorites, although the mean of the two analyses is within the normal range. The variation found in ALHA77278 may be the result of weathering, but could also simply suggest that U and Th are not as homogeneously distributed in LL3 chondrites as they are in L3 chondrites. Note that the other find, McKinney, has a Th/U ratio that is well within the normal range. It should also be mentioned that variations in the Th/U ratios and U and Th abundances of more than a factor of 2 have been observed among equilibrated L chondrites (UNRUH, 1981).

The Pb isotopic compositions of the meteorites are shown in Table 2. The Pb isotopic compositions of Bishunpur and ALHA77278 are considerably less radiogenic than those of L4–L6 chondrites, and are similar to those in the L3 chondrites Khohar, and Mezö-Madaras (UNRUH *et al.*, 1981). Also shown in Table 2 are $^{207}Pb/^{206}Pb$ model ages relative to Cañon Diablo troilite Pb (TATSUMOTO *et al.*, 1973). Bishunpur and Barwell have model ages near 4550 Ma, those for McKinney are slightly younger, and those for ALHA77278 are significantly younger. The larger uncertainties in the model ages of Bishunpur and ALHA77278 result from propagation of errors due to the large initial Pb correction for these meteorites ($\sim$85% and 91–95%,

Table 1. U, Th and Pb abundances in selected chondrites.

Meteorite	Class		Sample Wt (mg)	Pb blank (ng)	ppb			Atomic ratio		
					U	Th	Pb	$^{238}U/^{204}Pb$	$^{238}U/^{235}U$	$^{232}Th/^{238}U$
Bishumpur	LL(L)3	WR	82.75	0.35±0.7	11.70±0.8	37.7±1.2	366±2	1.49±.01	137.7±4	3.34±.12
		Magnetic	20.69	0.28±.02	7.03±.08	17.4±.08	525±2	0.605±.007	—	2.55±.04
ALHA77278	LL(L)3	WR1	64.94	0.53±.12	12.16±.19	46.5±.4	1014±11	0.542±.10	—	3.95±.07
		WR2	52.64	0.24±.05	9.24±.08	25.5±.2	1091±7	0.377±.004	137.1±.7	2.85±.03
		Troilite	11.70	0.121±.008	0.14±.07	0.18±.07	28.4±.8	0.25±.12	—	1.3 ±.8
McKinney	L4	WR1	62.61	0.16±.02	11.50±.06	38.6±.2	234.5±.5	3.14±.02	137.5±.4	3.46±.02
		WR2	68.44	0.16±.03	12.27±.07	41.4±.2	284.0±.6	2.77±.02	137.8±.9	3.48±.03
		Troilite	23.36	0.15±.02	0.93±.03	2.44±.05	39.1±.6	1.35±.05	—	2.71±.09
Barwell*	L5–L6	WR1	100.19	0.27±.08	9.35±.07	38.9±.5	33.8±.4	53.2±2.6	137.2±.6	4.30±.07
		WR2	93.40	0.27±.08	9.84±.05	—	39.0±.4	36.9±1.2	—	—
		Troilite	17.93	0.21±.06	0.85±.07	0.65±.05	199±3	0.27±.02	—	0.80±.09

* Data are from UNRUH *et al.* (1979), except redetermined $^{238}U/^{235}U$ ratio.

respectively). The troilite separates from McKinney and ALHA77278, and the magnetic separate from Bishunpur have model ages which are, within error, the same as those of the whole-rocks, whereas the troilite separate from Barwell has a significantly younger model age. Notice also, among the three troilite separates analyzed, that from Barwell is the only one which shows an enrichment in Pb relative to the whole-rock (Table 1).

U-Pb data corrected for Cañon Diablo troilite Pb as the initial Pb are shown on a modified U-Pb evolution diagram (TERA and WASSERBURG, 1972) in Fig. 1. All of the whole-rock data plot to the left of the curve indicating net enrichment of Pb relative to U. Bishunpur and Barwell show ~5% and 22% excess ^{206}Pb, respectively, whereas the two finds, ALHA77278 and McKinney show ~60% and 320% excess ^{206}Pb, respectively. Troilite separates show even larger enrichments (up to 3300% for Barwell).

The excess radiogenic Pb, which is found in virtually all chondrites has been interpreted in several ways: (1) improper initial Pb correction (*e.g.* GALE *et al.*, 1972); (2) recent large scale redistribution of U-Pb (*e.g.* UNRUH *et al.*, 1979; GALE *et al.*, 1980), and terrestrial Pb contamination prior to analysis (*e.g.* MANHES and ALLÈGRE, 1978; UNRUH, 1981). A two-stage model involving formation at ~4550 Ma ago and a recent disturbance which produced Pb enrichment relative to U would predict an increase in the ^{207}Pb-^{206}Pb model age within increasing discordancy above the concordia curve (or no change in the model age for a precisely 0-age disturbance). The young model ages ($\lesssim$4550 Ma) observed in the two highly discordant meteorites, McKinney and ALHA77278 suggest that either U-Th-Pb systems of these meteorites have experienced three or more stages of evolution, or that Pb (terrestrial?) with a model age of $\lesssim$4480 Ma has been added to these meteorites.

Recent studies of L chondrites (UNRUH and TATSUMOTO, 1980; UNRUH, 1981) have shown that the majority of the excess radiogenic Pb and young model ages ($\lesssim$4540 Ma) observed in L5–L6 chondrites is due to terrestrial Pb contamination, thus, in part, confirming the assumption of MANHES and ALLÈGRE that all excess Pb is of terrestrial origin. However, it has also been shown (UNRUH *et al.*, 1981; UNRUH, 1981) that terrestrial contamination alone will not easily account for the excess radiogenic Pb found in some L3 and L4 chondrites. That is the old model ages ($\geq$4550 Ma) and agreement between the U-Pb and Th-Pb ages observed in these meteorites suggest that some of the excess radiogenic Pb resulted from a recent geologic event.

Given that the majority of the excess radiogenic Pb in the samples in Fig. 1 is probably terrestrial, then it would appear that ALHA77278 is somewhat less contaminated than McKinney, but is still much more contaminated than either Bishunpur or Barwell. If all of the discordancy is attributable to terrestrial Pb, this would imply that ALHA77278 contains ~40–50 ppb terrestrial Pb and McKinney ~150 ppb, whereas Barwell and Bishunpur contain ~15 and 6 ppb, respectively. Sawing is known to produce large amounts (several ppm) of terrestrial Pb contamination in

Table 2. Pb isotopic compositions in

Meteorite	Class		Raw data $^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
Bishunpur	LL(L)3	WR	10.999±.013	1.0284±.0008	2.800±.0038
		Magnetic	10.320±.009	1.0562±.0009	2.927±.002
ALHA77278	LL(L)3	WR1	10.224±.030	1.0574±.0010	2.945±.005
		WR2	9.947±.010	1.0707±.0007	2.996±.006
		Troilite	13.772±.006	0.9305±.0009	2.438±.002
McKinney	L4	WR1	18.730±.020	0.8545±.0010	2.032±.001
		WR2	18.695±.010	0.8552±.0002	2.037±.001
		Troilite	15.896±.041	0.8999±.0010	2.205±.002
Barwell***	L5–L6	WR1	63.4 ±.2	0.6862±.0013	1.337±.004
		WR2	50.8 ±.2	0.7028±.0010	1.309±.002
		Troilite	18.40 ±.04	0.8477±.0008	2.046±.003

* Blank uncertainties from Table 1; Isotopic composition of blank: $\alpha=19.0\pm.1$, $\beta=15.65\pm.05$,
** Model ages relative to Cañon Diablo troilite Pb (TATSUMOTO *et al.*, 1973).
*** From UNRUH *et al.* (1979).

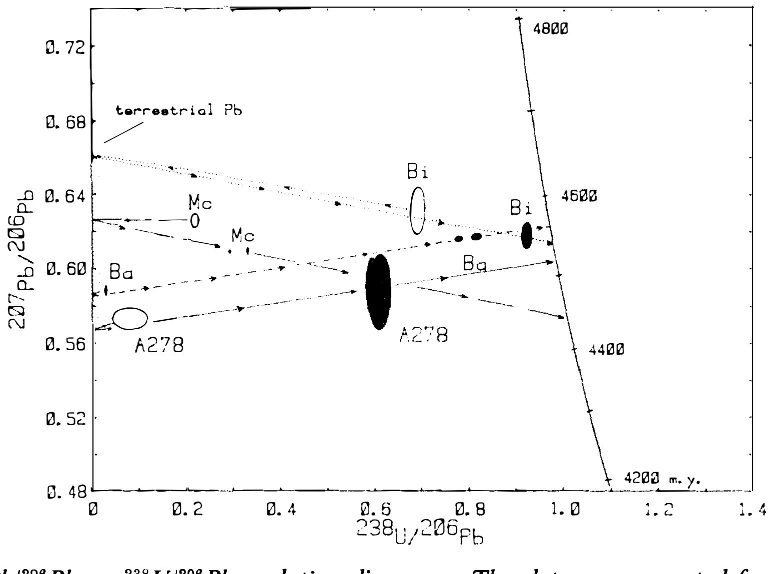

Fig. 1. *$^{207}Pb/^{206}Pb$ vs. $^{238}U/^{206}Pb$ evolution diagram. The data are corrected for Cañon Diablo troilite Pb as the initial Pb. All of the samples plot to the left of the curve and show ~5%–3300% excess ^{206}Pb. The excess Pb is assumed to represent terrestrial contamination. The tie lines from the troilite point to the ordinate and from the ordinate through the whole-rock point to the concordia curve schematically illustrate how the data were corrected for terrestrial Pb. Abbreviations used are A278=ALHA77278, Bi=Bishunpur, Mc=McKinney and Ba=Barwell. Open symbols represent troilite analyses and closed represent whole-rocks.*

selected chondrites.

Corrected for blank and fractionation*			$^{207}Pb/^{206}Pb$** model age (Ma)
$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	
10.928±.015	1.0336±.0009	2.821±.004	4550±14
10.181±.017	1.0653±.0012	2.965±.004	4581±28
10.196±.032	1.0609±.0012	2.960±.006	4470±50
9.940±.012	1.0732±.0008	3.007±.006	4486±36
12.41 ±.10	0.9728±.0048	2.616±.015	4442±14
18.765±.024	0.8557±.0010	2.036±.002	4530±5
18.730±.015	0.8564±.0003	2.041±.002	4531±3
15.48 ±.07	0.9146±.0023	2.243±.005	4569±40
74.8 ±3.3	0.6779±.0027	1.297±.012	4549±4
56.7 ±1.6	0.6961±.0022	1.270±.010	4545±3
18.44 ±.05	0.8497±.0010	2.053±.003	4452±6

γ=38.5±.3; Mass fractionation: 0.1±.03%/mass unit.

areas of the sample immediately adjacent to sawn surfaces (TATSUMOTO *et al.*, 1971; NUNES *et al.*, 1977), but the extent of this contamination to areas several cm from the cut has never, to our knowledge, been examined. In any case, it seems likely that at least some of the contamination of ALHA77278 was induced by sample handling.

A method to correct the whole-rock data for preanalytical terrestrial Pb contamination has been devised (UNRUH and TATSUMOTO, 1980). In this model, the Pb isotopic composition of the troilite is used to calculate that of the contaminant. The correction procedure is outlined as follows: We assume that the apparent troilite Pb (after a small correction for Pb produced *in situ* from U and Th decay) is a mixture of indigenous troilite Pb and terrestrial Pb. The field of terrestrial Pb's is defined by reported Pb blank isotopic compositions from several laboratories in the U.S. and Europe, and is approximated by the equations:

$$^{207}Pb/^{204}Pb=0.0898\times{}^{206}Pb/^{204}Pb+13.92$$

$$^{208}Pb/^{204}Pb=0.697\times{}^{207}Pb/^{204}Pb+25.3\,.$$

The isotopic composition of the contaminant in a given meteorite is calculated from the intersection with the terrestrial trend of a line through Cañon Diablo troilite and the chondrite troilite. A second blank correction using this calculated Pb isotopic composition is then applied to the whole-rock Pb data such that the U-Pb data become precisely concordant when Cañon Diablo troilite Pb is used as the initial Pb. The correction procedures are shown schematically in Fig. 1. The intersection of the line through a given troilite point with the ordinate defines the $^{207}Pb/^{206}Pb$ ratio of the contaminant relative to Cañon Diablo troilite Pb. The intersection with the concordia curve of a line through this point and the whole-rock data yields the contamination-corrected concordant $^{207}Pb/^{206}Pb$ model age.

The concordant $^{207}Pb/^{206}Pb$ model ages obtained by this procedure are shown in Table 3. Also shown are $^{208}Pb/^{232}Th$ model ages obtained after the aforementioned corrections were made. In order for this correction procedure to be considered valid, the $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{232}Th$ model ages must be in agreement.

Table 3. Contamination-corrected concordant $^{207}Pb/^{206}Pb$ model ages and resulting $^{208}Pb/^{232}Th$ model ages.

Meteorite	Class	Model ages in Ma	
		$^{207}Pb/^{206}Pb$	$^{208}Pb/^{232}Th$
Bishunpur	LL(L)3	4543±17	4556±160
ALHA77278	LL(L)3	4503±49	3306±480
		4519±38	3104±490
McKinney	L4	4438±8	4243±49
		4422±8	4192±58
Barwell	L5–L6	4560±5	4590±72
		4560±5	—

Barwell and Bishunpur yield $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{232}Th$ ages which are in reasonably good agreement. However, the $^{208}Pb/^{232}Th$ ages of ALHA77278 and McKinney are distinctly younger than their respective $^{207}Pb/^{206}Pb$ model ages. This implies that the data may have been over-corrected for terrestrial Pb. Furthermore, the $^{207}Pb/^{206}Pb$ age of Bishunpur is in agreement with the 4550±5 Ma mean age obtained for L5–L6 chondrites (including Barwell) using the same correction procedure (UNRUH, 1981), whereas those of ALHA77278 are slightly lower and those of McKinney are distinctly lower.

The young $^{207}Pb/^{206}Pb$ model ages of ALHA77278 and McKinney and the disagreement between the $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{232}Th$ ages can be reconciled in two general ways: (1) the U-Th-Pb systems of these two meteorites could have suffered a 3-stage history involving fractionation of U-Th-Pb at ~4400–4500 Ma ago, and a recent disturbance which produced Pb enrichment relative to U in the stones analyzed; (2) the effects could be due almost entirely to terrestrial processes, and may represent some combination of U, Th, and/or Pb leaching and terrestrial Pb contamination. Given that Th and U may be enriched to different degrees among different minerals within the meteorite (*e.g.* CROZAZ, 1979), it is also possible that the radiogenic Pb isotopes were not leached out in the same proportions as they occur in the bulk sample. The young $^{207}Pb/^{206}Pb$ model ages of ALHA77278 and McKinney could reflect under correction for terrestrial Pb—the samples should plot below the concordia curve showing recent Pb loss, and the still younger $^{208}Pb/^{232}Th$ model age could reflect preferential loss of ^{208}Pb.

In view of the fact that no evidence has been found for ~4400–4500 Ma disturbances to the U-Th-Pb system in unequilibrated "falls" (UNRUH *et al.*, 1981; UNRUH, 1981), and in view of the apparent inhomogeneous distribution of U and Th in ALHA 77278, we prefer the latter interpretation. Consequently, ages for these samples cannot be determined with any degree of confidence.

3.2. *Lu-Hf study of Antarctic eucrites*

The isotope ^{176}Lu (2.6% of natural lutetium) decays by β^- to ^{176}Hf, with a long half-life. Recently, we have presented the first Lu-Hf isochron, based on 10 whole-rock eucrite meteorite analyses, and this allowed a determination of the hitherto poorly-known ^{176}Lu decay constant (PATCHETT and TATSUMOTO, 1980a). In that study, it was found that duplicate analyses of the Antarctic eucrite ALH-77302 fell above the isochron (see Fig. 2). This discordance could be explained by either of the following situations:

(1) Contamination of ALH-77302 by more radiogenic Hf of terrestrial origin. However, this is unlikely because any Hf available in quantity on the Earth ($^{176}Hf/^{177}Hf<0.284$) is quite similar to that in ALH-77302 (0.282), so that a large proportion of contaminant Hf would be required.

(2) Loss of Lu from ALH-77302 in the recent past. PATCHETT and TATSUMOTO (1980a) suggested that this might have occurred while the meteorite was embedded for a long time period in the Antarctic ice.

Because ALH-77302 is a somewhat weathered sample, having pits in the fusion crust and internal limonite-stained cracks, it was not clear whether leaching effects would be common in Antarctic meteorites, or were due simply to the weathered condition of ALH-77302. Accordingly, we have analyzed two further Antarctic eucrites, Yamato-74159 and -74450, to determine whether they are concordant with the Lu-Hf isochron. Because we desired to improve precision on the solar system initial $^{176}Hf/^{177}Hf$, assumed to be given by the eucrites, we also analyzed the Bouvante eucrite. This fell in France in 1978, and the mineralogy is briefly described by CHRISTOPHE MICHEL-LÉVY *et al.* (1980). The two Yamato eucrites are much fresher than ALH-77302, and lack any conspicuous weathering features. Additionally, we obtained interior chips of the two Yamato eucrites, in contrast to the sawn slice of ALH-77302. The Yamato eucrites are described and chemical analyses are given by TAKEDA *et al.* (1978).

During the course of these analyses, 6 runs of the JMC 475 Hf standard yielded a mean $^{176}Hf/^{177}Hf$ of 0.282208 ± 28 (2σ). This is indistinguishable from the 0.282195

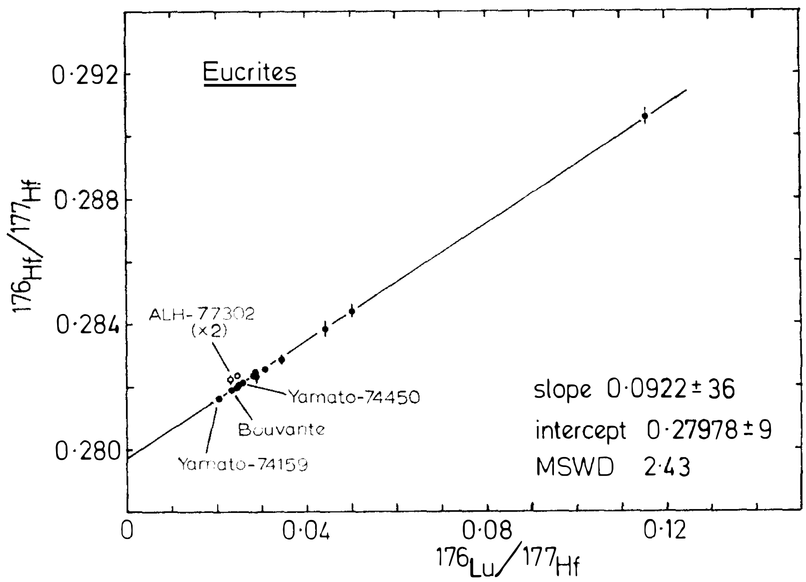

Fig. 2. Lu-Hf data for three eucrites and revised isochron parameters for all 13 analyses. As earlier, ALH-77302 is omitted from the regression. Other analyses reported previously (PATCHETT and TATSUMOTO, 1980a) are not identified by name.

Table 4. Lu-Hf isotopic data for eucrite meteorites.

Sample	Lu-ppm	Hf-ppm	$^{176}Lu/^{177}Hf$*	$^{176}Hf/^{177}Hf$*
Standard				
JMC 475 (6 runs)				0.282208±28
Eucrites				
Bouvante	0.445	2.670	0.02362±5	0.281968±24
Yamato-74159	0.382	2.716	0.01994±4	0.281631±45
Yamato-74450	0.343	1.946	0.02450±5	0.282114±38
ALH-77302**	0.273	1.544	0.02508±6	0.282418±58
ALH-77302**	0.260	1.539	0.02394±6	0.282316±144

* Errors correspond to last significant figures and are 2σ mean.
** ALH-77302 data are from PATCHETT and TATSUMOTO (1980a).

±15 (2σ) (which was reported with the earlier results), and thus our new eucrite data are closely comparable analytically to those already published. The reader will note, however, that 2σ precision on $^{176}Hf/^{177}Hf$ is improved in the new analyses, with 0.01–0.02% uncertainty being usually obtained from 1–2 μg of Hf.

The results all fall near the low-Lu/Hf end of the isochron (Fig. 2). Bouvante is slightly more enriched in Lu and Hf than Stannern (Table 4), as it is for light REE (CHRISTOPHE MICHEL-LÉVY *et al.*, 1980). Yamato-74159 has less Lu than Stannern, but higher Hf, and thus defines a point closer to the intercept of the isochron.

Regression results for all 13 eucrite analyses (excluding as before, ALH-77302) are a little altered from those for only 10 data points. There is a marginal improvement in isochron statistics, with MSWD=2.43 instead of 2.50. The revised slope of 0.0922±36 has a precision 10% improved over that reported earlier. Using the well-known 4.55 Ga igneous differentiation age of the eucrites (see PATCHETT and TATSUMOTO, 1980a, for discussion), we now redefine:

$$\lambda^{176}\mathrm{Lu}(\beta^-)=1.94\pm0.07\times10^{-11}\mathrm{a}^{-1}$$

$$t_{1/2}{}^{176}\mathrm{Lu}(\beta^-)=3.57\pm0.14\times10^{10}\mathrm{a}\ .$$

This is ~1% lower than that previously calculated.

The initial $^{176}Hf/^{177}Hf$ of 0.27978±9 is slightly higher within error than the earlier value of 0.27973±12, and shows a 25% improvement in precision. Closer definition of this intercept will require analysis of a Hf-rich phase such as zircon from a eucrite or other meteorite.

The fact that the two Antarctic eucrites are concordant with the isochron shows that the recent disturbance which has affected ALH-77302 (see Fig. 2) is probably a result of the weathering features in that sample, as mentioned above. The Yamato eucrites are undisturbed in their Lu-Hf systematics.

4. Conclusions

(1) The U-Th-Pb systems of ALHA77278 and McKinney have apparently experienced a rather complex terrestrial history involving Pb contamination and U, Th, or Pb leaching during weathering. The results may also indicate preferential leaching of radiogenic Pb isotopes. The complex nature of the data preclude any rigorous age interpretations for these samples. The data taken at face value suggest that ALHA 77278 is less contaminated than McKinney, a normal "find", but is still more contaminated than two observed falls, Barwell and Bishunpur. We suspect that sawing of the sample for allocation and general sample handling may be responsible for a significant amount of the Pb contamination in ALHA77278. Although we are unable to determine precisely how much contamination is present in this sample, the U-Pb data would be consistent with ~50 ppb terrestrial Pb. Th-Pb data suggest that this is an upper limit to the amount of terrestrial Pb in the sample, provided that ^{208}Pb has not been preferentially leached out of this sample.

(2) The Yamato-74159 and -74450 eucrites give Lu-Hf whole-rock analyses which are consistent with the reported isochron for other eucrites. Together with the Bouvante eucrite, they lead to a revised 13-point eucrite isochron result with initial $^{176}Hf/^{177}Hf$=0.27978±9. A slightly revised ^{176}Lu half-life of 3.57±0.14×10^{10}a can be calculated. The fact that the two Yamato eucrites are consistent with the isochron shows conclusively that the recent Lu-Hf disturbance documented in ALH-77302 is

a result of the weathered nature of that meteorite, and is not a general feature of Antarctic eucrites.

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