

PROGRESS BY THE CONSORTS OF ANGRA DOS REIS*

The Angra dos Reis, Rio de Janeiro, Brazil, achondrite fell in January, 1869, as one stone weighing 1.5kg (1). It is a unique meteorite, an ultramafic pyroxenite, having very primitive ⁸⁷Sr/⁸⁶Sr [ADOR (2)], an old ²⁰⁷Pb-²⁰⁶Pb age of 4.555 AE (3), and evidence for extinct ²⁴⁴Pu (4). Because of the importance of this meteorite for understanding the early differentiation of meteorite parent bodies, a comprehensive consortium study was initiated. The entire remaining 122.6 gm specimen of Angra dos Reis was made available for inspection and sampling under controlled conditions through the cooperation of the Museu Nacional, Rio de Janeiro, Brazil.

Polished thin sections of the rock and of separates were studied microscopically and by electron microprobe. Mineral analyses are in general similar to those reported by Hutchison (5) and Albee and Chodos (6), except that we report for the first time kirschsteinite from a meteorite. There are no grain to grain compositional variations exceeding the precision of the analyses. The meteorite consists of over 90% of *clinopyroxene* of *fassaite* composition (Table 1; Fig. 1), characterized by high Al and Ca contents. In the structural formula, Al in tetrahedral position does not balance the sum of other trivalent cations and an amount of divalent iron was converted into the trivalent state to make up the difference. Olivine ($\leq 5\%$ of the meteorite) in grains up to 1 mm in size contains small islands ($\leq 100 \mu\text{m}$) of *kirschsteinite* ($\leq 0.1\%$ of the meteorite), a member of the isomorphous series of monticellite (Mo) and kirschsteinite (Ks) (Table 1, Fig. 1). The mineral in Angra dos Reis is $\sim \text{Ks}_{62.3} \text{Mo}_{37.7}$. *Magnesian-aluminian hercynite* makes up about 0.5%-2% of the rock, with Fe³⁺ content calculated to balance the structural formula. Noteworthy are the large (mm-sized) grains of *whitlockite* ($\leq 1\%$ of the rock) (Table 1) which can be recognized by their greenish color. Metallic nickel-iron (Fe 95.5, Ni 3.5, Co 1.15, total 100.15) and *troilite* (Fe 62.9, Co 0.07, S 36.5, total 99.47) are rare. *Baddeleyite*, plagioclase (*bytownite*) and SiO₂ were found for the first time in this meteorite.

The major mass of ADOR was brought to Caltech for preparation of samples for a prototype experiment for chemical and isotopic studies. The fragment surfaces contained fusion crust and saw cuts and a 5.8 g fragment was broken off to provide interior material. A mass of 0.8 g was crushed to $-75\mu\text{m}$ and separated using heavy liquids. The 3.3 sinks were distributed to the consorts. The weight of all material with $\rho < 2.8$ was ~ 1 mg. The main *low* density fraction ($\rho = 2.8-3.3$) weighed 10 mg and was 40% whitlockite and 60% pyroxene. Abundant vacuoles and inclusions were observed in the phosphate. During sample preparation several larger (~ 1 mm) yellow-green grains were observed which proved to be whitlockite (Table 1). A 240 μm grain was analyzed for Pb to determine the concentration level and isotopic composition; ten clean, clear whitlockite grains ($\sim 250\mu\text{m}$ each) were picked with a total weight of $\sim 200 \mu\text{g}$ (estimated from diameters) and analyzed for Pb, U and Th using a ²⁰⁵Pb tracer and microprocedures (7, 8). INAA analyses of putative ultrapure whitlockite were aborted because it was discovered that not all yellow-green grains were phosphate but were En₅₂Wo₂Fs₄₆ to the embarrassment of the distributing agent. Each density fraction was analyzed for selected elements including Xe (Table 2).

To establish the REE pattern of "pure" pyroxene a sample of 3.3 sinks was split and subjected to INAA (Table 3). One split was leached with acid to dissolve phosphates and the other not treated. The results show no difference in the concentrations for the REE measured and are somewhat lower than those reported for the total rock (9). We conclude that the REE are in pyroxene and not in trapped liquid or phosphate. The pyroxene concentrations may thus be used to calculate the composition of the magma from which ADOR crystallized. Using D values from (10) and for Eu at f(O₂) $\sim 10^{-11}$ bars from (11) we obtain values for the magma (Table 3). The parent magma appears to be highly enriched relative to chondrites, has a positive Eu anomaly and is the most highly fractionated extraterrestrial magma source so far observed. This requires that the parent magma itself be derived from a previous partial melting process.

Rb-Sr analyses were carried out on a 75 mg rock fragment (Table 4). The observed ⁸⁷Sr/⁸⁶Sr and ⁸⁴Sr/⁸⁶Sr are given along with the calculated initial values. The ⁸⁴Sr abundance is not distinguishable from ALL or seawater. The ⁸⁷Sr/⁸⁶Sr clearly confirm the original data (2) which showed this meteorite to have an I value far below BABI. The value for ADOR is confirmed but may possibly be the same as ALL to within limits of error. We conclude that an ancient, highly differentiated parent planet has preserved initial Sr that is distinctive.

Xe was measured in 199 mg of 3.3 sinks and 4.7 mg of 2.8 sinks to establish ²⁴⁴Pu fission (F), trapped (T) and spallation (S) Xe distributions (data in Fig. 2). Xe was extracted in three steps; only 1450°C data are presented. 700°C fractions contained only Xe with air composition. Blank Xe of air composition contributed 3% of ¹³²Xe of the 3.3 sinks and 11% of ¹³²Xe of the 2.8 sinks in the 1450°C fractions.

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Table 1. (Univ. of New Mexico data)

Element	1.	2.	3.	4.	5.
SiO ₂	45.9	36.3	34.6	0.51	0.67
TiO ₂	2.16	0.05	0.02	0.65	n.d.
Al ₂ O ₃	10.0	0.02	0.33	54.5	n.d.
Cr ₂ O ₃	0.21	0.03	0.02	3.3	n.d.
Fe ₂ O ₃	n.d.	n.d.	0.07	1.5	1.71
FeO	2.89	—	3.4	4.5	4.2
MnO	4.1	38.3	26.2	28.4	1.29
MgO	0.06	0.60	0.42	0.18	n.d.
CaO	10.6	24.3	8.9	8.0	2.82
ZnO	24.1	1.29	28.9	0.76	49.4
NiO	n.d.	n.d.	n.d.	0.17	n.d.
Na ₂ O	n.d.	0.04	0.06	n.d.	n.d.
P ₂ O ₅	<0.02	n.d.	0.05	n.d.	0.68
Ce ₂ O ₃	n.d.	n.d.	n.d.	45.1	n.d.
Y ₂ O ₃	n.d.	n.d.	n.d.	n.d.	0.25
Total	100.02	100.91	99.50	99.94	100.22

1. Pyroxene (fassaite); En 33.5, Wo 54.7, Fs 11.9. 2. Olivine; Fo 53.1, Fa 46.9. 3. Kirschsteinite; Ks 62.3, Mo 37.7. 4. Spinel (magnesian-aluminian hercynite); Cr 3.8, Hc 56.4, Sp 33.4, Mt 3.6, Uv 2.79. 5. Whitlockite (Caltech data). *Fe²⁺ and Fe³⁺ ratio calculated from measured total iron content.

Table 2. (Caltech data)

Sample	K	Rb	Sr	Ba	Nd	Th
Total	32	0.063	135	26.5	—	—
Total ²	13	0.031	133	21.5	—	—
p < 2.5 ¹	470	0.70	436	—	—	—
2.5 < p < 2.7 ¹	630	0.98	928	—	—	—
2.8 < p < 3.3 ³	237	0.28	1055	780	180	15.5
3.3 < p ⁴	20	0.041	132	17.4	17.2	0.71

1) Concentrations by isotope dilution in ppm; Xe, in units of 10⁻¹¹ cc STP/g. 2) Tera et al., Proc. Ap. 11 (1970) 1637. 3) 40% whitlockite, 60% pyroxene by grain count. 4) 99% pyroxene, 1% phosphate observed in 100 grains. 5) Munk, EPSL 3 (1967) 457. 6) Hohenberg, G. & C. Acta 34 (1970) 185. 7) Sample weight not well known; relative abundances are precise.

Table 3. (Oregon State Univ. data)

Element	Pyroxene ¹	T	Rock	Magma ⁴ x chondrite
Al ₂ O ₃ (%)	9.2	10.4	—	—
Na ₂ O (%)	0.033	0.032	0.026 ²	—
La ppm	5.7	5.3	—	162
Sm ppm	5.8	5.9	6.5 ³	60
Eu ppm	1.5	1.5	1.8 ³	171
Yb ppm	4.5	4.2	4.7 ³	36
Lu ppm	0.68	0.65	—	33

1) Estimated errors are 1-5% for Al, Na, La, Sm, Eu, Yb and 7% for Lu. Pyroxene is a split of p > 3.3g/cm³ listed in other table. U: weight 82mg, untreated; T: weight 53mg, treated with of Total-3. 7) Ca-Al rich chondrule (D7) from Allende (Gray et al. Icarus 20, 1973). 8) Normal 3N HNO₃ to remove whitlockite prior to analysis. 2) Tera, et al., Proc. Ap. 11 (1970) 1637. 3) Schnezler and Philpotts (in, Proc. Research, 1969, p. 206). 4) Assumed D(s/l) for augite under f(O₂) ~ 10⁻¹³ atm: La 0.1; Sm 0.5; Eu 0.12; Yb 0.6; Lu 0.6.

Table 4. (Caltech data)

	Rb ¹	Sr ¹	⁸⁷ Rb/ ⁸⁶ Sr ²	(⁸⁷ Sr/ ⁸⁶ Sr) _M ³	(⁸⁷ Sr/ ⁸⁶ Sr) _I ⁴	⁸⁷ Sr/ ⁸⁶ Sr
T-1 ⁵	0.097	156.8	0.145	0.69892 ± 7	0.69883 ± 7	—
T-2 ⁵	0.044	125.4	0.082	0.69889 ± 4	0.69884 ± 4	—
T-3	0.074	127.5	0.136	0.69888 ± 5	0.69879 ± 5	—
ALL ⁷	0.010	217.6	0.014	0.69889 ± 5	0.69880 ± 5	0.006736 ± 8 ⁸
				0.69877 ± 2	0.69876 ± 2	0.006748 ± 2 ⁸

1) Concentration in 10⁻⁶ mole/g. 2) x100. 3) Measured composition; errors are 2σ and correspond to last figures given; average of eight recent seawater runs yields ⁸⁷Sr/⁸⁶Sr = 0.70907 ± 4. 4) Initial composition assuming an age of 4.6 AE. 5) From D. A. Papanastasiou, Ph.D. thesis (1970). 6) Measured compositions on unspiked solution aliquot of Total-3. 7) Ca-Al rich chondrule (D7) from Allende (Gray et al. Icarus 20, 1973). 8) Normal ⁸⁷Sr/⁸⁶Sr = 0.006748 ± 2 (seawater).

Table 5. (Caltech data)

Sample	²⁰⁷ Pb/ ²⁰⁶ Pb	²⁰⁸ Pb/ ²⁰⁶ Pb	²⁰⁸ Pb/ ²³⁸ U	²⁰⁸ Pb/ ²³² Th
TR	4.548	4.62	4.53	4.53
Phosphate	±0.001	±0.07	±0.10	±0.10
	±0.001	±0.60	4.61	4.61
	±0.001	±0.07	±0.11	±0.11

Table 6. Ages in AE (Caltech data)

Sample	K	Rb	Sr	Ba	Nd	Pu	U	Th
Total	28	16	18	111	25	18	[12] ¹	[49] ¹

1) Uncertain because of whitlockite sample weight. Th/U = 18.6 for whit.

1) Estimated errors are 1-5% for Al, Na, La, Sm, Eu, Yb and 7% for Lu. Pyroxene is a split of p > 3.3g/cm³ listed in other table. U: weight 82mg, untreated; T: weight 53mg, treated with of Total-3. 7) Ca-Al rich chondrule (D7) from Allende (Gray et al. Icarus 20, 1973). 8) Normal ⁸⁷Sr/⁸⁶Sr = 0.006748 ± 2 (seawater).

Table 7. Enrichment Factors (Whit/Pyx)

	K	Rb	Sr	Ba	Nd	Pu	U	Th
Total	32	0.063	135	26.5	—	—	—	—
Total ²	13	0.031	133	21.5	—	—	—	—
p < 2.5 ¹	470	0.70	436	—	—	—	—	—
2.5 < p < 2.7 ¹	630	0.98	928	—	—	—	—	—
2.8 < p < 3.3 ³	237	0.28	1055	780	180	15.5	5.3	28
3.3 < p ⁴	20	0.041	132	17.4	17.2	0.71	5.6	3.5

1) Concentrations by isotope dilution in ppm; Xe, in units of 10⁻¹¹ cc STP/g. 2) Tera et al., Proc. Ap. 11 (1970) 1637. 3) 40% whitlockite, 60% pyroxene by grain count. 4) 99% pyroxene, 1% phosphate observed in 100 grains. 5) Munk, EPSL 3 (1967) 457. 6) Hohenberg, G. & C. Acta 34 (1970) 185. 7) Sample weight not well known; relative abundances are precise.

Table 8. (Caltech data)

Sample	Weight	²⁰⁷ Pb	²⁰⁸ Pb	²⁰⁸ Pb	Comp	Conc	²³⁸ U	Th ¹
TR	25	4.68	11.41	18.29	0.02964	424.2	424.9	17.15
Phosphate	~0.2	9.833	1.345	2.165	0.002876	299.1 [*]	2.050	38.1

1) In picomoles. 2) Corrected for blank with α = 18.30, β = 15.46 and γ = 38.01. 3) Uncorrected for blank; α value for conc. run is corrected for cross contamination from spikes. 4) Sample was spiked with ²⁰⁵Pb; Pb comp. and conc. as well as U and Th were determined in the same aliquot. ²⁰⁵Pb Blank 0.0140 and 0.00465 respectively.

Table 9. (Caltech data)

Sample	¹³⁶ Xe/ ¹³² Xe	¹³⁴ Xe/ ¹³² Xe	¹³⁸ Xe/ ¹³² Xe
spallation Xe	0.2	0.4	0.6
Murray	0.4	0.6	0.8
Terrestrial	0.5	0.7	1.0
Angro dos Reis release (Hohenberg, 1970)	0.5	0.7	1.0
2.8 sinks	0.5	0.7	1.0
3.3 sinks	0.5	0.7	1.0
244Pu fission Xe	0.5	0.7	1.0
238U fission Xe	0.5	0.7	1.0
meteorite	0.5	0.7	1.0
244Pu fission Xe	0.5	0.7	1.0
Angro dos Reis (Hohenberg, 1970)	0.5	0.7	1.0
Angro dos Reis	0.5	0.7	1.0
Angro dos Reis (this work)	0.5	0.7	1.0

Fig. 2: Three isotope correlation diagrams for Xe in pyroxene and whitlockite-enriched separates. Thermal release data on total rock shown. Relative amounts are ¹³⁶XeF: ¹³⁴XeF: ¹³⁸XeF = 56:32:12¹; (3.3 > p > 2.8) fraction and 35:17:48²; (p > 3.3).

Table 10. (Oregon State Univ. data)

Element	Pyroxene ¹	T	Rock	Magma ⁴ x chondrite
Al ₂ O ₃ (%)	9.2	10.4	—	—
Na ₂ O (%)	0.033	0.032	0.026 ²	—
La ppm	5.7	5.3	—	162
Sm ppm	5.8	5.9	6.5 ³	60
Eu ppm	1.5	1.5	1.8 ³	171
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Table 11. (Oregon State Univ. data)

Sample	²⁰⁷ Pb/ ²⁰⁶ Pb	²⁰⁸ Pb/ ²⁰⁶ Pb	²⁰⁸ Pb/ ²³⁸ U	²⁰⁸ Pb/ ²³² Th
TR	4.548	4.62	4.53	4.53
Phosphate	±0.001	±0.07	±0.10	±0.10
	±0.001	±0.60	4.61	4.61
	±0.001	±0.07	±0.11	±0.11

Table 12. (Oregon State Univ. data)

Sample	²⁰⁷ Pb/ ²⁰⁶ Pb	²⁰⁸ Pb/ ²⁰⁶ Pb	²⁰⁸ Pb/ ²³⁸ U	²⁰⁸ Pb/ ²³² Th
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Phosphate	±0.001	±0.07	±0.10	±0.10
	±0.001	±0.60	4.61	4.61
	±0.001	±0.07	±0.11	±0.11

1) Concentrations by isotope dilution in ppm; Xe, in units of 10⁻¹¹ cc STP/g. 2) Tera et al., Proc. Ap. 11 (1970) 1637. 3) 40% whitlockite, 60% pyroxene by grain count. 4) 99% pyroxene, 1% phosphate observed in 100 grains. 5) Munk, EPSL 3 (1967) 457. 6) Hohenberg, G. & C. Acta 34 (1970) 185. 7) Sample weight not well known; relative abundances are precise.

Table 13. (Oregon State Univ. data)

Sample	Weight	²⁰⁷ Pb	²⁰⁸ Pb	²⁰⁸ Pb	Comp	Conc	²³⁸ U	Th ¹
TR	25	4.68	11.41	18.29	0.02964	424.2	424.9	17.15
Phosphate	~0.2	9.833	1.345	2.165	0.002876	299.1 [*]	2.050	38.1

1) In picomoles. 2) Corrected for blank with α = 18.30, β = 15.46 and γ = 38.01. 3) Uncorrected for blank; α value for conc. run is corrected for cross contamination from spikes. 4) Sample was spiked with ²⁰⁵Pb; Pb comp. and conc. as well as U and Th were determined in the same aliquot. ²⁰⁵Pb Blank 0.0140 and 0.00465 respectively.

Table 14. (Oregon State Univ. data)

Sample	¹³⁶ Xe/ ¹³² Xe	¹³⁴ Xe/ ¹³² Xe	¹³⁸ Xe/ ¹³² Xe
spallation Xe	0.2	0.4	0.6
Murray	0.4	0.6	0.8
Terrestrial	0.5	0.7	1.0
Angro dos Reis release (Hohenberg, 1970)	0.5	0.7	1.0
2.8 sinks	0.5	0.7	1.0
3.3 sinks	0.5	0.7	1.0
244Pu fission Xe	0.5	0.7	1.0
238U fission Xe	0.5	0.7	1.0
meteorite	0.5	0.7	1.0
244Pu fission Xe	0.5	0.7	1.0
Angro dos Reis (Hohenberg, 1970)	0.5	0.7	1.0
Angro dos Reis	0.5	0.7	1.0
Angro dos Reis (this work)	0.5	0.7	1.0

Fig. 2: Three isotope correlation diagrams for Xe in pyroxene and whitlockite-enriched separates. Thermal release data on total rock shown. Relative amounts are ¹³⁶XeF: ¹³⁴XeF: ¹³⁸XeF = 56:32:12¹; (3.3 > p > 2.8) fraction and 35:17:48²; (p > 3.3).

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The 1650°C reextracts contained 3.5% and 2% additional ^{126}Xe from 3.3 sinks and 2.8 sinks respectively. Xe in both samples is a complex mixture of S, T and F. The position of the data on Fig. 2b along the line joining XeT and ^{244}Pu fission Xe indicates large amounts of ^{244}Pu fission Xe in both pyroxene and phosphate. The displacement of 2.8 sinks below the line is caused by substantial addition of XeS. The positions of the two data points in Fig. 2a show that ^{132}Xe in pyroxene is primarily ^{132}XeT and ^{132}XeF with minor spallation contributions. Spallation contributions to ^{132}Xe in whitlockite can be quite large and seriously affect partitioning of the heavy isotopes between T and F.

Ba/Nd in the 2.8 and 3.3 sinks are similar to Ba/Nd in Apollo 11 high- and low-K rocks respectively (12), and we take XeS compositions in these rocks to determine spallation contributions ($^{132}\text{XeS}/^{126}\text{XeS}=0.9$, $\rho > 3.3$; $^{132}\text{XeS}/^{126}\text{XeS}=0.15$, $3.3 > \rho > 2.8$). Remaining ^{132}Xe is partitioned into T and F using known trapped and ^{244}Pu fission Xe compositions. 66% of the total ^{136}Xe in 3.3 sinks and 94% in 2.8 sinks is ^{244}Pu fission ^{136}Xe . Blank Xe and pyroxene trapped Xe is sufficient to account for all XeT in the 2.8 sinks; all ^{136}Xe in whitlockite is fission Xe. S, T and F contents are in Table 2.

The large Ba enrichment in the whitlockite separate indicates whitlockite comprises only $\sim 0.4\%$ of the total rock. From the chemical and isotopic data, it follows that the dominant part of the ^{244}Pu , U and Th in ADOR are in the $\rho > 3.3$ separate and almost certainly in the pyroxene. This result on a magmatic rock cannot be directly compared to the more complex chondrites. From the Xe data on whitlockite and the stepwise heating measurements of Hohenberg (4) on a total rock (Fig. 2), which yield points much closer to pure ^{244}Pu fission Xe, we conclude that there must exist a different phase (not pyroxene) rich in ^{244}Pu and poor in REE and Ba. $^{244}\text{Pu}/^{238}\text{U} \sim 0.006$ in the total rock (4) as compared to 0.015 in the St. Séverin chondrite (13). The highly fractionated nature of the parent magma and the cumulate nature of ADOR suggest the low $^{244}\text{Pu}/^{238}\text{U}$ most reasonably results from strong elemental fractionation. Since ADOR is a magmatic differentiate it could also be explained by a formation time of ADOR ~ 0.1 AE later than chondrites.

The large Xe S contents in both separates and the x4 enrichment in Ba relative to Nd in whitlockite (Table 7) allow a unique determination of XeS from Ba and from REE in a meteorite. Using Nd as a measure for total REE, the relative production is $P126(\text{Nd})/P126(\text{Ba})=2.0$. The production rate of ^{126}XeS over the 63×10^6 yr cosmic ray exposure age of Angra dos Reis is $P126=0.21 \times 10^{-12} [\text{Ba} + 2.0 \text{Nd}] \text{ cc STP/g}/10^8 \text{ yr}$, with Ba and Nd in ppm. This result agrees well with the only similar result, on lunar rock 12013 (14).

Pb-U-Th data are given in Table 5. The radiogenic ^{207}Pb - ^{206}Pb ratios for the total meteorite confirm the value reported by Tatsumoto *et al.* (3). Our $\alpha=617$ is three times larger than they report. These workers washed their samples with acid and also obtain discordant Pb-U-Th ages. The phosphate experiment was very successful and yielded highly radiogenic Pb in this phase which is enriched in Th/U. Ages by all Pb-U-Th methods were determined on ADOR. This is the first time that self-consistent Pb-U or Pb-Th ages have been determined on a meteorite. As is manifest from the existing data in the literature, Pb-Pb model ages are not sufficient to define a reliable age [cf. (15)]. All three independent ages on the whitlockite and the total rock ages are in agreement within experimental errors and demonstrate the existence of planetary differentiates at 4.55 AE within an error of ± 0.05 AE. The gap in time between this age and the Pb model ages for the earth and the moon (~ 4.45 AE) urgently demands a solution.

Sm-Nd measurements were carried out at UCSD to establish the feasibility of determining an internal isochron. Two samples were analyzed—the $\rho > 3.3$ fraction and a single grain of whitlockite (~ 1.2 mg). Fractions of both separates were dissolved and aliquots of each sample spiked. Only the spiked aliquots have so far been analyzed. The Sm/Nd ratio in whitlockite is extremely low (0.215) while the Nd concentration is ~ 600 x chondritic. The pyroxene exhibits Sm/Nd only 6% higher than found in total rock samples of eucrites. The spread in Sm/Nd between samples is 59%. The slope of the line determined by the data yields an apparent age of 4.42 AE. However, the calculated $^{143}\text{Nd}/^{144}\text{Nd}$ is critically dependent on the assumed $^{142}\text{Nd}/^{144}\text{Nd}$ ratio, and a reliable age can only be assessed after measurement of the unspiked aliquots.

Ref. (1) G. Tschermak and E. Ludwig, *Tschermak's Min. Pet. Mitt.* 8 (1887) 341; 9 (1888) 423. (2) D. A. Papanastassiou, PhD Thesis (1970). (3) M. Tatsumoto *et al.* *Science* 180 (1973) 1279. (4) C. M. Hohenberg, *G & C. Acta* 34 (1970) 185. (5) R. Hutchison, *Nature* 240 (1972) 58. (6) A. L. Albee and A. A. Chodos, *Proc. Ap-11* (1970) 135. (7) F. Tera and G. J. Wasserburg, this vol. (8) F. Tera and G. J. Wasserburg, *Anal. Chem* 47 (1975) 2214. (9) C. C. Schnetzler and J. A. Philpotts, in *Met. Research* (1969) 207. (10) J. G. Arth and G. N. Hanson, *G & C Acta* 39 (1975) 325. (11) Grutzeck, *et al.* *Geophys. Res. Lett.* 1 (1974) 273. (12) J. C. Huneke *et al.*, *G & C Acta* 36 (1972) 269. (13) F. A. Podosek, *G & C Acta* 36 (1972) 755. (14) Lunatic Asylum, *EPSL* 9 (1970) 137. (15) J. H. Chen and G. R. Tilton, *G & C Acta* 1976 (in press). *Acknowledgment.* This work was supported by NASA and NSF.