Rb-Sr AGES AND LUNAR ANALOGS IN A BASALTIC ACHONDRITE; IMPLICATIONS FOR EARLY SOLAR SYSTEM CHRONOLOGIES

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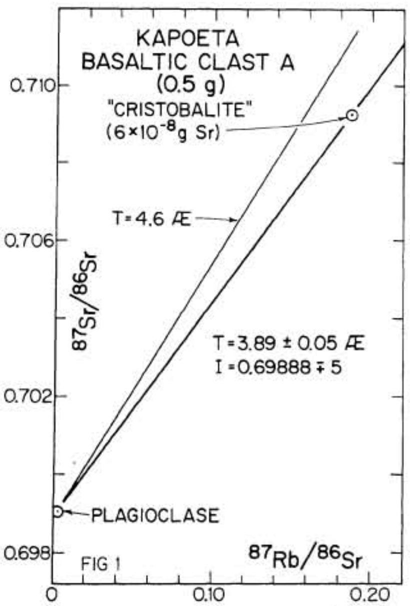
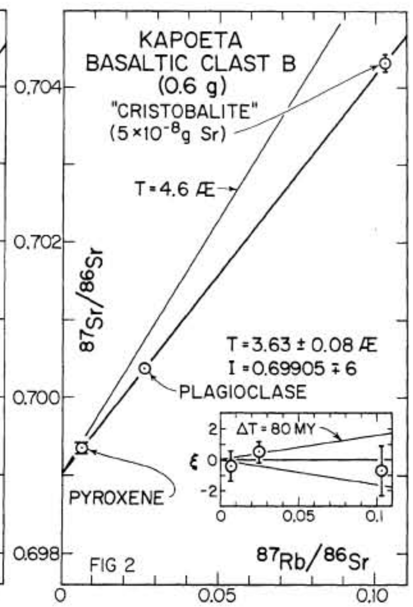
In this report, we present age determinations on two clasts from the basaltic achondrite (howardite) Kapoeta. The basaltic achondrites have long been considered the products of magmatic differentiation of planets of sub-lunar size and bear close chemical and mineralogic affinities to lunar mare basalts. The similarity to lunar rocks extends to the existence of high amounts of surface correlated trapped gases in some of these meteorites (3) and of grains irradiated prior to incorporation of these meteorites (4) which are interpreted in terms of gardening and irradiation as seen in the lunar regolith. More recently, hypervelocity micro-meteorite craters have been observed on glass spheres and in chondrule like objects in Kapoeta (5). The irradiation dosages of the track-rich grains, and the rarity of glass and agglutinates suggest that the regolith on the parent body of Kapoeta was quite immature compared to the average lunar soil. The crystallization ages of the basaltic achondrites are important in elucidating the nature of the primitive Sr composition BABI obtained from a whole meteorite isochron (6). These ages are also critical in the interpretation of the excess fission Xe isotopes attributed to ^{244}Pu and in the determination of $^{244}Pu/^{238}U$ at the end of nucleosynthesis.

We have extracted two basaltic clasts (A and B) from Kapoeta, weighing 0.5 and 0.6 g. This meteorite is a polymict breccia and it is evident that small fragments of different rock types could yield a confused picture, although it may be possible to obtain a total rock isochron with a variety of clasts. Mineral separations were made following our scheme for lunar basalts. We obtained plagioclase and pyroxene separates as well as small amounts of interstitial material enriched in SiO_2 which acts as a carrier of Rb and Sr with relatively high Rb/Sr. The data are shown in the table and fig. 1 and 2. For clast A, a two point line on the Rb-Sr evolution diagram corresponds to a time of 3.89 ± 0.05 AE and an initial $^{87}Sr/^{86}Sr$, I = 0.69888 ∓ 5. Since this meteorite shows some evidence of moderate shock (7), it is evident that a two point line need not represent an isochron. For clast B, we have measured three separates; as shown in fig. 2 and in the insert, the three points lie on a straight line well within the error uncertainties and it appears that an internal isochron is well defined. As in the case of lunar samples, proving that we are not measuring simply a mixing line is not a simple task. For the remaining discussion and subject to further investigation, we shall assume that the data for clast B define a real isochron and that the two data for clast A also determine a true age. We note that both ages are relatively young and both clasts have inherited very primitive initial Sr. In fig. 3, we show an age, initial $^{87}Sr/^{86}Sr$ [T, I] anticorrelation and have outlined the region known from internal isochrons to correspond to lunar magmatism. We also show the primitive isotopic compositions BABI, ADOR and ALL (1). The ages of the Kapoeta basalts are distinct from each other but quite similar to ages of mare basalts. In the past, the strongest argument against the basaltic achondrites originating on the moon has been the distinct $^{18}O/^{16}O$ values for the basaltic achondrites and lunar samples (8,9). However, the oxygen data have been obtained on eucrites and on one mesosiderite, but not on howardites. The low initial Sr of clast A, which is almost equal to ADOR and distinctly lower than all measured I values for lunar samples, appears to exclude the possibility that this meteorite has a lunar origin. If the basaltic achondrites do not come from the moon, there must exist other bodies which have had a lunar type history. It is possible that the basaltic achondrites have a large age spectrum similar to lunar samples.

Some efforts have been made to obtain ages on basaltic achondrites using different methods. ^{40}Ar-^{40}K and ^{40}Ar-^{39}Ar studies by several workers show a large spread in ages and do not appear to yield easily interpretable results. No general rules appear to exist in the Ar-K age patterns for basaltic achondrites. The time scale over which these meteorites have undergone thermal disturbances ranges from 3.5 to 4.4 AE by ^{40}Ar-^{39}Ar studies (10). Total K-Ar ages on various mineral separates were done by Megrue (11) and were interpreted as giving ages, some of which are in the range reported here. However, his approach does not seem to yield results which would establish reliable ages, particularly





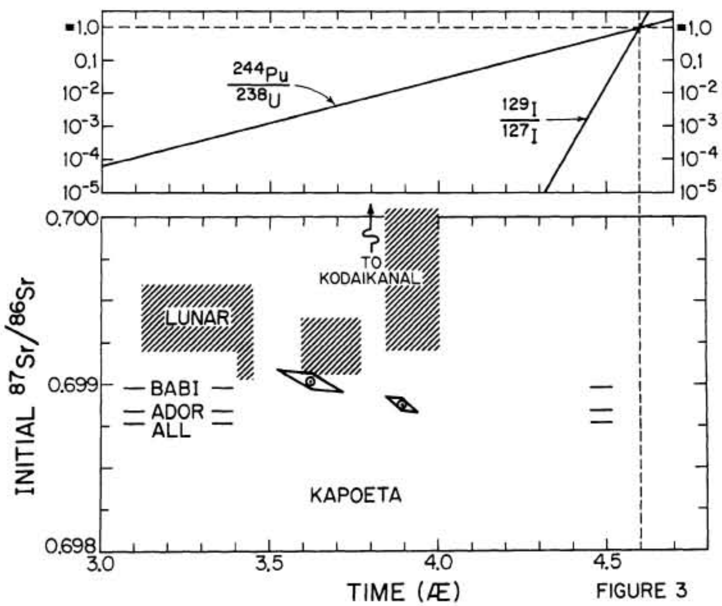


Fig. 1 and 2 Rb-Sr evolution diagrams showing internal isochrons for two distinct clasts from Kapoeta. Note the different scales, I values and ages. The three data for clast B lie on a straight line well within experimental uncertainties, as seen in the insert which shows the deviations ξ (in parts in 10^4) of the data from the best fit line.

Fig. 3 T-I diagram showing the ages and initial strontium for the two Kapoeta clasts. The error envelopes for both samples are shown and indicate that the ages and I values are distinct. I values for the clasts are very primitive despite their young age, indicating a parent body that is highly depleted in alkalis. The I values BABI, ADOR and ALL (1) are shown for comparison. The data on lunar samples are indicated (cf. Tera, *et al.*, this vol.) as well as the age of Kodaikanal (2). These data, together with trapped gases, tracks, and micro-meteorite craters, show that Kapoeta was derived from a parent body which had a long time differentiation history and regolith similar to the earth's moon. This conclusion is in contrast to the observation of ^{244}Pu fission Xe or ^{129}Xe from ^{129}I in dark matrix from Kapoeta which shows these objects to be *very* complex aggregates. In the upper diagram, we note the expected abundances of ^{244}Pu and ^{129}I as compared to arbitrary amounts present at 4.6 AE. It appears that some meteorites are produced over a long time interval which must be taken into account in any estimates of $^{244}Pu/^{238}U$ in the early solar system, or in interpreting the trapped gases and irradiation as representing very early solar processes.

Kapoeta: Rb-Sr Results

Sample[1]		Wt mg	Rb (10^{-8} mole/g)	^{88}Sr (10^{-8} mole/g)	$^{87}Rb/^{86}Sr$ x10^2	$^{87}Sr/^{86}Sr$
Clast A	*Pl*	4	0.245	176.2	0.325	0.69906±5
	Cr	6	1.244	15.52	18.69	0.70927±9
Clast B	Px	40	0.0265	9.58	0.645	0.69935±7
	Pl	5	2.474	225.4	2.558	0.70041±5
	Cr	4	0.883	20.02	10.29	0.70433±11

[1] *Pl*: plagioclase; Cr: "cristobalite"; Px: pyroxene.

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when the possibility of gas loss is considered. Allegre *et al.* (12) have reported in an abstract a Rb-Sr age of 4.59 ± 0.04 AE for Juvinas. This would indicate that Juvinas is an ancient object in contrast to Kapoeta.

Ages of lunar highland rocks have strongly indicated an intense bombardment of the moon at ~3.9 AE which appears to dominate the earlier history. In the case of Kapoeta, we observe that the events which resulted in the breakup of its parent body occurred at least as late as 3.6 AE and were less intense than in the case of the lunar cataclysm. This would indicate that some major collisions occurred in places distinct from the Earth-Moon system as late as 3.6 AE. Whether or not the 3.89 AE age of clast A can be associated with the events which led to the lunar cataclysm remains a tantalizing, but uncertain, possibility. We note, however, that at least one other object, the iron meteorite Kodaikanal, which is highly shocked, has an age of 3.8 AE (2), so that evidence for "late" bombardment throughout the solar system may be found in the meteorites. The question as to whether the cratering time scale determined for the moon can be applied to other planets (e.g. Mars) depends on the extent to which it can be demonstrated (from the study of meteorites) to be a solar system wide phenomenon.

The young age for at least some basaltic achondrites and possibly for many meteorites, requires that properties of the early solar system (e.g., early solar wind) deduced from meteoritic evidence be re-examined and held in abeyance until the ages of the materials have been determined. In the case of Kapoeta, we conclude that the implanted solar wind gases and tracks must represent events extending over 1 AE after the formation of the solar system and not early solar processes. The problem of ^{244}Pu in particular needs to be re-examined. Rowe (13) has identified significant amounts of ^{244}Pu fission Xe and ^{129}Xe from ^{129}I decay in a very dark clast from Kapoeta and some fission Xe, but no excess ^{129}Xe, in a dark matrix sample. This does not comport with the ages of clasts A and B; no significant Xe derived from *in situ* Pu or I decay should be identifiable in young ($<$ 4.0 AE) objects (fig. 3). A similar dichotomy exists in Stannern (10). If the ^{244}Pu fission Xe is produced *in situ*, this would indicate a range of clast ages in Kapoeta (and probably other achondrites) extending over 1 AE. If the Xe excesses are trapped and not associated with U and I, as demonstrated in lunar breccia 14318 (14), then no chronological association can be made. In either instance, the use of achondritic information to determine nucleosynthetic and early solar system chronologies is subject to serious doubt.

One of the important facts proven by lunar exploration is that terrestrial type planets may be highly enriched in the refractory radioactive elements. This enrichment can be much greater than for the earth as was first clearly recognized by Gast (15). If we consider enrichments in U and Th of ten times solar abundances (as compared to a factor of five for the moon), then it is possible to generate magmas in the interior of moonlets 200-400 km in radius at a time 0.5 to 1 AE after planetary accretion (i.e., magmas formed at 4.0 to 3.5 AE). This would avoid the requirement for special initial heat from accretion or extinct nuclides (magic ^{26}Al) or the requirement of an overly massive and unbreakable moon as a parent body. Differentiation at 4.0-3.5 AE would produce basaltic lavas which would be injected into, and flood and incorporate an exterior rubble layer of truly ancient material. This ancient material could either remain undifferentiated during accretion or have been differentiated during or shortly after accretion. Because of the more limited amount of melting, the preservation of ancient materials with Pu and I on mini-moons is much more likely than on lunar sized objects. This would provide a model which explains the observations on basaltic achondrites in the case where *some* of the basaltic material has a young age. The generation of basaltic achondrites at 4.6 AE would still require special heat sources. Even in a model where all materials are subject to planetary differentiation soon after accretion, the ^{244}Pu/^{238}U ratio would not be directly related to nucleosynthetic processes.

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