during the previous winter can depress ground temperatures over anomalous areas even though volcanic heat discharge through the site remains constant.

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Chondrites: Initial Strontium-87/Strontium-86 Ratios and the Early History of the Solar System

Abstract. A sodium-poor, calcium-rich inclusion in the carbonaceous chondrite Allende had a $^{87}Sr/^{86}Sr$ ratio at the time of its formation of 0.69880, as low a value as that found in any other meteorite. The higher $^{87}Sr/^{86}Sr$ ratios found in ordinary chondrites indicate that their formation or isotopic equilibration occurred tens of millions of years later.

During the past 20 years, radioactive dating methods have increasingly been applied to the problems of establishing the chronology of the earth, moon, and solar system. Many of these methods involve a fixed percentage error, which makes it impossible to resolve events occurring within ~ 100 × 10^6^ years of one another early in the history of the solar system.

Two methods have been developed for the resolution of the fine structure in the time scale for the formation of the solar system. One of these is based on the xenon daughter products of the extinct radioactive isotopes ^{129}I (half-life $t_{1/2} = 17 \times 10^6$ years) (*1*) and ^{244}Pu ($t_{1/2} = 80 \times 10^6$ years) (*2*), and the other depends on the initial isotopic abundance of radiogenic ^{87}Sr, the daughter of ^{87}Rb ($t_{1/2} = 50 \times 10^9$ years).

This latter method is based on the assumption that at the time of its formation the solar nebula had a uniform $^{87}Sr/^{86}Sr$ ratio (about 0.698). If the solar nebula had a $^{87}Rb/^{86}Sr$ ratio typical of chondrites (0.75), the $^{87}Sr/^{86}Sr$ ratio of the solar nebula will increase at the rate of 0.0001 per 9×10^6 years. If the $^{87}Rb/^{86}Sr$ ratio of the solar nebula were that of the sun (1.9), the $^{87}Sr/^{86}Sr$ ratio of the solar nebula will increase at the rate of 0.0001 per 4×10^6 years (*3*). At the time of formation of the planetary bodies or of the parent bodies of meteorites or at the time of mineral separation of the constituents of these bodies, the preexisting $^{87}Rb/^{86}Sr$ ratio was changed (fractionated). If the resulting $^{87}Rb/^{86}Sr$ ratio was sufficiently low, and if the time since the ratio changed is known, then it is possible to calculate the $^{87}Sr/^{86}Sr$ ratio which prevailed at the time of fractionation. The differences between these initial ratios for various objects can then be interpreted as time intervals in the formation of the solar system.

Using this method, Papanastassiou and Wasserburg (*4*) have shown that, if the parent bodies of the differentiated basaltic achondrites were fractionated from material of chondritic composition, the fractionations took place over a time span of about 4×10^6 years or less, as indicated by their having nearly the same $^{87}Sr/^{86}Sr$ ratio (0.69899 ± 0.00004) at the time of this fractionation. The pyroxene achondrite Angra dos Reis had an even lower initial $^{87}Sr/^{86}Sr$ ratio (0.69884 ± 0.00003), thus suggesting that the corresponding fractionation of this material occurred about 10×10^6 years earlier.

The chondritic meteorites have long been considered to be among the most primitive objects in the solar system, both because of their age (~ 4.6×10^9 years) (*5*) and because of their lack of extensive chemical differentiation (*6*). Therefore it was somewhat surprising to find that the chondrite Guareña [H6 in the Wood–Van Schmus classification

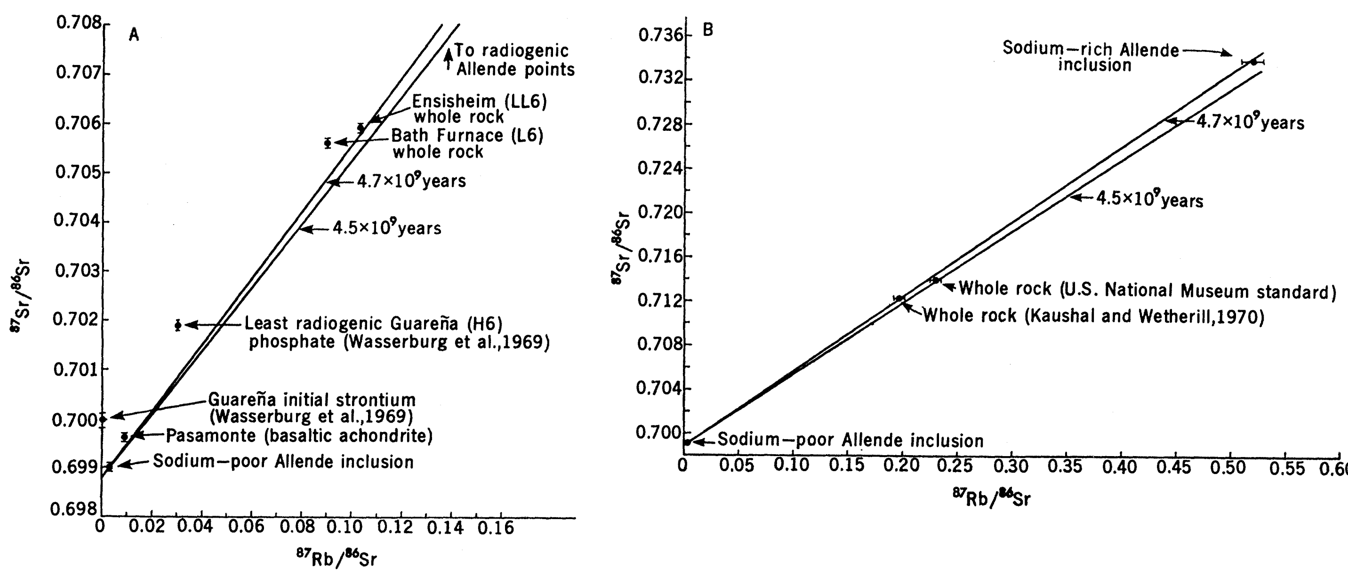

Fig. 1. Strontium evolution diagrams. (A) Less radiogenic samples. The extrapolation of the sodium-poor Allende inclusion point to the $^{87}Sr/^{86}Sr$ axis gives an initial ratio of 0.6988, lower than the initial ratio for the Pasamonte basaltic achondrite. The other chondrites shown have higher initial ratios. (B) Allende samples including more radiogenic data. All of the points lie between the lines corresponding to ages of 4.5×10^9 and 4.7×10^9 years. The initial ratio for the sodium-poor Allende inclusion is insensitive to whichever of these ages is used.

Table 1. Analytical data and $^{87}Sr/^{86}Sr$ ratios.

Sample	Rb (μg/g)	^{86}Sr (μg/g)	$^{87}Rb/^{86}Sr$ (atomic)	$^{87}Sr/^{86}Sr$ (atomic)	K (μg/g)	K/Rb (by weight)
Allende inclusion (Na = 0.085 percent)	0.159	13.51	0.00328	0.69901 ± 5	36.1	227
Allende inclusion (Na = 1.01 percent)	3.137	1.676	0.521	0.73385 ± 20	996	317
Allende, whole rock (U.S. National Museum)	1.182	1.419	0.232	0.71390 ± 7	299	253
Allende, whole rock (*13*)	0.99	1.393	0.1972	0.7123	229	232
Bath Furnace, whole rock	0.339	1.047	0.0902	0.70562 ± 10	539	1590
Ensisheim, whole rock	0.401	1.078	0.1036	0.70591 ± 6	265	660
Pasamonte, whole rock	0.251	7.359	0.00948	0.69962 ± 7	367	1464

system (*7*)] has a higher initial $^{87}Sr/^{86}Sr$ ratio of 0.69995 ± 0.00015 (*8*), corresponding to a final isotopic equilibrium that occurred 74×10^6 years later than that of the basaltic achondrites on the basis of Guareña's $^{87}Rb/^{86}Sr$ ratio, or 34×10^6 years later on the basis of the solar $^{87}Rb/^{86}Sr$ ratio. Because this measurement represented the only published initial $^{87}Sr/^{86}Sr$ ratio of sufficient accuracy for comparison with achondrites, it was unclear whether or not this result is characteristic of chondrites in general or of equilibrated (metamorphosed) chondrites such as Guareña, or whether it is peculiar to Guareña.

Petrographic studies (*9*) of the recently fallen carbonaceous chondrite Allende (C3) have shown that is is composed of inclusions consisting of those calcium, aluminum, silicon, and magnesium minerals characteristic of high-temperature condensation from a solar nebula (*10*). Although these inclusions vary considerably in their rubidium concentrations, some of them have very low $^{87}Rb/^{86}Sr$ ratios, and so it is possible to make accurate measurement of their initial $^{87}Sr/^{86}Sr$ ratios. Recently (*11, 12*) three groups of investigators have presented abstracts showing that the initial $^{87}Sr/^{86}Sr$ ratios of these rubidium-poor inclusions were in the range of the ratios found for the achondritic meteorites, and distinctly lower than that found for Guareña.

Our results for such an inclusion in Allende are shown in row 1 of Table 1. We obtained the data presented in Table 1 by averaging 70 sets of ten $^{87}Sr/^{86}Sr$ ratios, obtained on an automated mass spectrometer, using programmed magnet switching and automatic digital data acquisition and processing. Corrections for mass spectrometric fractionation were made by normalization to $^{86}Sr/^{88}Sr = 0.11940$ and interlaboratory standardization to $^{87}Sr/^{86}Sr = 0.71014$ for National Bureau of Standards standard 987 and 0.70794 for Eimer and Amend standard strontium. The errors given are the standard errors of the mean of these sets of ratios. The rubidium and strontium concentrations were determined by isotope dilution analysis. Of the 700 $^{87}Sr/^{86}Sr$ ratios, we obtained 300 using ^{84}Sr tracer for the concentration determination; the remainder contained no isotopic tracer. The difference between the means of these "spiked" and "unspiked" $^{87}Sr/^{86}Sr$ ratios was 0.00001.

Even before correction for radiogenic strontium generated during the history of the solar system, the $^{87}Sr/^{86}Sr$ ratio of this Allende inclusion is much lower than the initial $^{87}Sr/^{86}Sr$ ratio of Guareña, and, within experimental error, is equal to the initial $^{87}Sr/^{86}Sr$ ratio of the basaltic achondrites (Fig. 1A). The initial $^{87}Sr/^{86}Sr$ ratio of the inclusion is insensitive to the age of the inclusion, since its low $^{87}Rb/^{86}Sr$ ratio causes a change in the $^{87}Sr/^{86}Sr$ ratio of only 0.00004 per 10^9 years. We carried out the extrapolation to the initial ratio using the results of new measurements on a whole-rock sample of Allende, supplied as a standard by the U.S. National Museum and on a sodium-rich inclusion from our Allende sample. These results, together with the results of an earlier published measurement on Allende (*13*), are shown in Table 1 and Fig. 1B. Extrapolation of the line defined by these points give an initial $^{87}Sr/^{86}Sr$ ratio of 0.69880 for Allende, essentially equal to that found for the achondrite Angra dos Reis (*4*).

On the basis of the above findings, it may be concluded that at least some material now found in chondritic meteorites separated from the solar nebula at least as early as the achondritic meteorites and the moon (*14*). The higher value found for Guareña is thereby shown not to be characteristic of all chondritic material.

There are some chondrites with sufficiently low $^{87}Rb/^{86}Sr$ ratios to permit extrapolation of their whole rock $^{87}Sr/^{86}Sr$ ratios back to the time of formation of the solar system. New measurements have been made on two such meteorites, Bath Furnace (L6) and Ensisheim (LL6) (Table 1 and Fig. 1A). Whole rock isochrons of 4.55×10^9 years have been published for both of these classes of meteorites (*15*). Use of this age for extrapolation of their $^{87}Sr/^{86}Sr$ ratios to their initial values gives results of 0.6997 for Bath Furnace and 0.6992 for Ensisheim. Like the value found for the internal initial ratio of the phosphate phase from Guareña (*8*), these ratios are distinctly higher than the value found for the sodium-poor Allende inclusion, the achondrites, and the moon. The time intervals between the isotopic equilibration of Bath Furnace and Ensisheim and that of the Allende inclusion are 81×10^6 and 32×10^6 years if we use the chondritic $^{87}Rb/^{86}Sr$ ratio, and 36×10^6 and 14×10^6 years if we use the solar $^{87}Rb/^{86}Sr$ ratio.

As Gray *et al.* have pointed out (*12*), this result differs from that based on ^{129}I chronology, which gives a time interval of 4×10^6 years between the formation of the Allende inclusions and that of other chondrites (*16*). Understanding of these differences will require further work. It may be that the metamorphism of these chondrites has caused a reequilibration of their strontium isotopic composition without loss of the high-temperature ^{129}Xe fraction on which the xenon-formation interval is based.

These data suggest that there is much more information concerning solar system processes contained in the strontium isotopic composition of meteorites and their constituents than has been revealed as yet. In addition to the time intervals discussed herein, evidence for internal strontium isotopic redistribution in Allende has been reported by Gray *et al.* (*12*). It has also been found that collisional processes can cause reequilibration of meteoritic strontium (*15*). The discordant rubidium-strontium data reported for carbonaceous chondrites may not entirely reflect terrestrial alteration, as was previously suggested (*13*). Although to a remarkably good approximation many meteorites have preserved the record of events extremely early in the history of the solar system, this preservation has not been complete and future work promises to teach us more concerning the subsequent histories of these objects and their parent bodies.

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Copulation in Castrated Male Rats following Combined Treatment with Estradiol and Dihydrotestosterone

Abstract. *Castrated male rats injected daily with 2 micrograms of estradiol benzoate (EB) combined with 200 micrograms of dihydrotestosterone propionate (DHTP) displayed masculine mating behavior which was indistinguishable from that of other castrates treated with 200 micrograms of testosterone propionate (TP). Significantly less copulation was seen in rats treated with either 4 micrograms of TP plus 200 micrograms of DHTP or 2 micrograms of EB. Mating in male rats may depend on the action of both estrogenic and 5α-dihydro metabolites of testosterone.*

Castration of the adult male rat invariably results in the disappearance of intromission and ejaculation behavior (*1*). Either of the testicular androgens, testosterone or androstenedione, is highly effective in maintaining copulation when administered systemically immediately after castration, and both restore mating when given many months after castration (*2*). This behavioral facilitation is thought to result from the action of a hormone on the hypothalamic and spinal neurons that control copulation (*3*); however, it is not known which hormone—testosterone, androstenedione, or one or several of their metabolites—is active in this respect. It has been shown that 5α-androstan-17β-ol-3-one (dihydrotestosterone, DHT), a metabolite which apparently mediates many of the effects of androgen on the accessory sex organs including the penis (*4*), can be formed in the male rat hypothalamus (*5*). Even so, administration of DHT does not prevent the postcastration decline in mating behavior (*6*) and is unable to duplicate the stimulatory effect of TP on penile reflexes in castrated rats with transected spinal cords (*7*). Estrogens constitute another group of androgen metabolites whose production has also been demonstrated in the male rat hypothalamus (*8*), leading to speculation that many of the effects of androgens on the rat brain, including the facilitation of masculine sex behavior, depend on their conversion to estrogens. However, administration of estradiol to castrated adult rats fails to stimulate intromission and ejaculation to the degree possible with testosterone (*9, 10*). We present evidence which suggests that the activational effects of testicular androgens on the mating behavior of male rats may depend on the formation and subsequent action of both estrogenic and 5α-dihydro derivatives of these androgens.

Thirty-four male hooded rats, born in the breeding facility of Erasmus University, Rotterdam, and caged in groups of four, were castrated when they were 49 to 55 days old. The animals were not sexually experienced. The rats lived in a room where the lights were off between noon and 8 p.m., during which period all behavioral tests were conducted. Between 26 and 30 days after castration all males were given three tests for masculine behavior and a single test for receptive behavior. In the tests of masculine behavior an animal was placed in a plastic cage identical to its home cage with two females whose ovaries had been removed and who had been made receptive with injections of EB and progesterone. Simple mounts, mounts with pelvic thrusting with and without intromission, and ejaculation responses were scored separately in each male. The tests lasted 15 minutes but were extended to 30 minutes whenever a mount with pelvic thrusting occurred. If an intromission was observed during this time, the test was extended to 1 hour or until the rat ejaculated, in which case the time elapsed between the initial intromission and the ejaculation (ejaculation latency) was noted. Following an ejaculation all tests were extended until postejaculatory interval of sexual inactivity had passed and the male had resumed intromitting. Tests of receptive behavior involved placing the individual males in a cage and recording all of their lordotic responses to mounts with pelvic thrusting performed by either of two stud males. Tests were stopped after ten mounts, and each animal's lordosis-to-mount ratio (lordosis quotient, L.Q.) was calculated.

Beginning 31 days after castration the animals, which weighed approximately 300 g, received daily subcutaneous injections of different steroids dissolved in 0.1 ml of sesame oil. One group received 200 μg of TP, a treatment which has been shown to stimulate high levels of copulation in sexually inexperienced, castrated rats (*10*). A second group received 2 μg of EB plus 200 μg of DHTP. This dose of EB was administered because in a previous experiment we found that daily injections of less than 2 μg of EB in