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Rb-Sr Isotope Evolution in Solar System/Planet Earth and the Preferred Decay Constant of ^{87}Rb

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Abstract

Any model trying to define the Rb-Sr isotopic evolution in Solar System/planet Earth has to specify the beginning $^{87}Sr/^{86}Sr$ isotope ratio of the planet Earth at the time of its formation, and its present-day Sr isotope and $^{87}Rb/^{86}Sr$ ratios. Furthermore, such a model attempting to describe this evolution has to take into account several other factors such as age of Earth, decay constant of ^{87}Rb, present-day Rb/Sr ratio, and isotopic characteristics of the mantle as seen through the initial Sr isotope ratio of certain ancient mantle-derived rocks, as these factors impose significant constraints on this evolution. The present study shows that one model for the isotopic evolution in the/Solar System/Earth which stipulates beginning (initial) and present-day Sr isotope ratios of 0.69877 and 0.7047, respectively, and the present-day $^{87}Rb/^{86}Sr$ ratio of 0.09 satisfies all the above mentioned constraints. However, for this model to be feasible, age of the Earth must be assumed to be similar to the mean age of the meteorites, that is, 4.555 Gyr, and the decay constant of ^{87}Rb must be revised to a lower value of 1.4087(10^{-11} yr^{-1}).

***Keywords:** Model for the Rb-Sr isotope evolution; Rb-Sr isotope parameters for the Solar system/Earth; Age of the Earth; Initial Sr isotope ratio of the Earth, Present-day $^{87}Rb/^{86}Sr$ ratio of the Earth, Decay Constant/Half-life of ^{87}Rb.*

Introduction

The beginning $^{87}Sr/^{86}Sr$ isotope ratio (equivalent to the initial Sr isotope ratio) of the Solar System/planet Earth has been assumed to be 0.69899±0.00005 (BABI - Basaltic Achondrites Best Initial Sr isotope ratio) which is based on the very well-defined Rb-Sr isochron of basaltic achondrites [1-4]. However, there are some meteorites that yield initial ratios much lower than BABI [5,6]. For instance, the initial ratios of the white refractory inclusions of carbonaceous chondrite Allende (ALL) and achondrite Angra Dos Reis (ADOR) have been found to be 0.69877±0.00005 and 0.69883±0.00002, respectively [6-8]. In view of this Minster et al. expressed their doubts about BABI being assumed as the beginning Sr isotope ratio of the Earth. In their view, the higher initial ratio of the basaltic achondrites compared with the refractory inclusions of Allende is due to later differentiation of their parent meteorite body.

On the other hand, chondritic meteorites are regarded as the most primitive undifferentiated planetary objects, but they are very difficult to date because they either do not yield a well-defined isochron or they show initial ratios much higher than BABI - the only exceptions being the white refractory inclusions of Allende and the low Rb phases of the CI chondrite Orgueil [6, 7, 9-15]. Hence, the chondrites were considered to be of uncertain origin and probably genetically unrelated to each other. However, according to Minster et al. 1982 all the chondritic meteorites are genetically related because they were able to obtain a well-defined whole-rock joint isochron of the various groups of chondrites with the exception of those that were affected by severe shocks and brecciation or for which there is evidence of crustal contamination [6]. Their joint isochron for the chondrites yields an age of 4498±15 Myr and an

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initial Strontium isotope ratio of 0.69885±0.00010 which is lower than that of BABI but close to that of ADOR. Minster further noticed that the age given by the joint isochron of the chondrites is approximately 1% younger than the mean age of the meteorites which is approximately 4555±10 Myr [6, 8, 16, 17]. According to them the age given by the joint isochron is slightly younger because the decay constant λ for ^{87}Rb of 1.42(10^{-11} yr^{-1}) currently being used is incorrectly estimated which in their view should be revised to a lower value of 1.402(10^{-11} yr^{-1}) so that the age of meteorites given by the Rb-Sr, U-Th-Pb and Pb-Pb geochronometers is in agreement with each other [6, 18-20]. They further expressed the view that the slightly higher initial ratio of chondrites (0.69885±0.0001) in comparison to that of the refractory inclusions of carbonaceous chondrite Allende (0.69877±0.0001) is due to some time-delay in the fractionation of Rubidium in the chondrites relative to the formation of the Allende refractory inclusions. Therefore, according to Minster et al. 1982, the ALL value of 0.69877±5 should be regarded as the beginning Sr isotope ratio of the Earth as well as of the Solar System [6, 7]. They also asserted that the chondrites and the white refractory inclusions of Allende should be considered 'synchronous' only on a time scale of 10±17 Myr.

The beginning Sr isotope ratio of the planet Earth so far has been assessed only on the basis of meteorites as it is not possible to determine this ratio directly from terrestrial rocks. Hence, the main objective of this paper is to gather evidence for this ratio by using a theoretical model that utilizes the Sr isotope data of some ancient mantle-derived rocks in conjunction with the present-day planet Earth Rb-Sr isotope parameters. The other objective is to see if the observations made by Minster et al. with regard to the age and the beginning Sr isotope ratio of the planet Earth and the decay constant λ of ^{87}Rb can be substantiated by this model [6].

Estimating the beginning Strontium isotope ratio of the Earth from the present-day Rb-Sr isotope parameters of the Earth

The present-day $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios for the Earth were estimated by DePaolo & Wasserburg, 1976a, and DePaolo & Wasserburg, 1976b [$^{87}Rb/^{86}Sr$=0.084, $^{87}Sr/^{86}Sr$=0.7045]. O'Nions et al., 1977 also determined these ratios [$^{87}sr/^{86}sr$ = 0.7050 and Rb/Sr = 0.032] by independent evidence from the anti-correlation of $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ isotope ratios of some recent (0 age) oceanic basaltic rocks [21-23]. Since then, a few additional sets of present-day Rb-Sr isotope parameters for the planet Earth have been proposed, such as [24-26]. The planet Earth parameters signify that if the mantle reservoir/planet Earth had remained a completely closed and homogeneous system throughout its geologic history, then its present-day $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios would be indicated by the respective planet Earth parameters. Hence, if the planet Earth parameters, the decay constant for ^{87}Rb and age of the Earth are all correctly estimated, it would then be possible to obtain a model beginning $^{87}Sr/^{86}Sr$ ratio for the Earth using equation (2) given by McCulloch and Wasserburg, 1978 as follows [27]:

$$I_{PE}\,(T) = (^{87}Sr/^{86}Sr)_{PE} - [(^{S7}Rb/^{86}Sr)_{PE}\,(e^{\lambda T}- 1)] \qquad (1)$$

where λ is the decay constant of ^{87}Rb, the subscript PE stands for planet Earth and T is the age of Earth. I_{PE} denotes the Sr isotope ratio of the planet Earth, which at time T in the past indicates its beginning Sr isotope ratio. The I_{PE}(T) given by the above equation thus indicates the model beginning Sr isotope ratio of the Earth with respect to a particular set of Earth parameters, age of the Earth and decay constant of $_{87}Rb$. Thus by using different sets of parameters, age of the Earth and decay constant in this way, a number of model beginning Sr isotope ratios for the Earth could be obtained.

Using a computer-generated model, Zindler et al., 1982 suggested a revised set of Earth parameters ($^{87}Sr/^{86}Sr$ = 0.7052, Rb/Sr = 0.032) [26]. However, they did not suggest any corresponding $^{87}Rb/^{86}Sr$ ratio, which, however, as per their other parameters should be approximately 0.093. However, their Earth parameters correspond to the age of the Earth as being equal to 4.57 Gyr [26]. Therefore, for the sake of comparison, the model beginning Sr isotope ratio for the Earth has been computed for each set of planet Earth parameters corresponding to both 4.555 Gyr and 4.57 Gyr age of the Earth [6, 8, 16, 17, 26, 27]. The results thus obtained are displayed in Table 1 and Table 2. It is observed that when the decay constant for ^{87}Rb of 1.42(10^{-11} yr^{-1}) is used, a model beginning Sr isotope ratio approximating BABI is obtained only with respect to the planet Earth parameters of Zindler et al., 1982 for both 4.555 Gyr and 4.57 Gyr age of the Earth, whereas with respect to the other Earth parameters, using the decay constant of 1.42(10^{-11} yr^{-1}), the model beginning Sr isotope ratio approaches neither BABI nor ALL for both 4.555 and 4.57 Gyr age of the Earth (Table 1) [26]. On the other hand if the decay constant for ^{87}Rb proposed by Minster et al., 1982 of 1.402(10^{-11} yr^{-1}) is used, then the above equation indicates a beginning Sr isotope ratio within the limits of error of BABI or ALL, depending upon whether the Earth parameters of De Paolo and Wasserburg 1976b ($^{87}Rb/^{86}Sr$ = 0.084, $^{87}Sr/^{86}Sr$ = 0.7045) or those of All`egre, 1982 ($^{87}Rb/^{86}Sr$ = 0.09, $^{87}Sr/^{86}Sr$ = 0.7047) are used [6, 22, 25]. These observations hold for both 4.555 and 4.57 Gyr age of the Earth. However, with respect to the planet Earth parameters of Zindler et al., 1982 and decay constant of 1.402(10^{-11} yr^{-1}), the beginning Sr isotope ratio close to the limits of error of BABI is obtained only if the age of the Earth is assumed to be 4.57 Gyr (Table 2) [26].

Table 1. Table shows different values of the model beginning Sr isotope ratio of the Earth with respect to the various present-day Earth parameters, age of the Earth, and ^{87}Rb decay constant of 1.42(10^{-11} yr^{1}) obtained by using Equation (1).

Age of the Earth (in Gyr)	Planet Earth's $^{87}Rb/^{86}Sr$ ratio at the present time	Planet Earth's $^{87}Sr/^{86}Sr$ ratio at the present time	Model Beginning $^{87}Sr/^{86}Sr$ ratio of the Earth
4.555	0.09	0.7047	0.698686
4.555	0.084	0.7045	0.698887
4.555	0.093	0.7052	0.698986*
4.57	0.09	0.7047	0.698666
4.57	0.084	0.7045	0.698868
4.57	0.093	0.7052	0.698965*

Model beginning Sr isotope ratios marked with * are approaching ***BABI***

Model beginning Sr isotope ratio approaching BABI is obtained only with respect to the planet Earth parameters of Zindler et al., 1982 for both 4.555 Gyr and 4.57 Gyr age of the Earth [26].

Table 2. Different values of the Model Beginning Sr isotope ratio of the Earth with respect to the various present-day Earth parameters, age of the Earth and the ^{87}Rb decay constant of 1.402(10^{-11} yr^{1}) obtained by using Equation (1).

Age of the Earth (in Gyr)	Planet Earth's $^{87}Rb/^{86}Sr$ ratio at the present time	Planet Earth's $^{87}Sr/^{86}Sr$ ratio at the present time	Model Beginning $^{87}Sr/^{86}Sr$ ratio of the Earth
4.555	0.09	0.7047	0.698765$
4.555	0.084	0.7045	0.698961*
4.555	0.093	0.7052	0.699067
4.57	0.09	0.7047	0.698745$
4.57	0.084	0.7045	0.698942*
4.57	0.093	0.7052	0.699046*

Values of the model beginning Sr isotope ratio marked with * approach ***BABI.***

Values of the model beginning Sr isotope ratio marked with $ approach ***ALL.***

The table shows that the beginning Sr isotope ratio, BABI is compatible only with the planet Earth parameters of De Paolo and Wasserburg, 1976b, whereas the ALL ratio is compatible only with the parameters of All`egre, 1982 [22, 25]. This holds for both 4.555 Gyr and 4.57 Gyr age of the Earth. However, the beginning Sr isotope ratio BABI, just close to its limits of error, is also compatible with the planet Earth parameters of Zindler et al., 1982 for the 4.57 Gyr age only [26]. For further information see the text.

The above observations lead one to think that the decay constant for ^{87}Rb of 1.42(10^{-11} yr^{-1}) currently in wide use is in all likelihood a little too high because it is only by the use of the lower decay constant of 1.402 (10^{-11} yr^{-1}) that the beginning Sr isotope ratio close to either BABI or ALL could be obtained for both 4.555 and 4.57 Gyr age of the Earth [6, 18-20]. It also shows that whether BABI or ALL should be regarded as the beginning Sr isotope ratio of the Earth depends mainly on which set of planet Earth parameters is finally considered to be valid. If the planet Earth parameters suggested by All`egre, 1982 are considered to be valid then the beginning Sr isotope ratio should be equal to the ALL value of 0.69877±5 as suggested by Minster et al., 1982, otherwise, it should be equal to BABI (0.69899±5) [6, 25].

As the increase in the $^{87}Sr/^{86}Sr$ ratio in the Earth/mantle is time-correlated, the beginning Sr isotope ratio of the Earth on the one hand and the present-day Sr isotope ratio of the Earth on the other form the two end members of the Sr isotope evolution line in the planet Earth. Thus, several such Sr isotope evolution lines are possible because of more than one set of planet Earth parameters and beginning Sr isotope ratios prevalent in the literature. The various Sr isotope evolution lines formed by the different combinations of the beginning Sr isotope ratio and the present-day Rb-Sr Earth parameters can be used to resolve the problem of whether ALL or BABI should be regarded as the beginning Sr isotope ratio of the Earth by comparing them with the isotopic characteristics of the mantle, as reflected by the initial Sr isotope ratio of some ancient mantle-derived rocks. For example, the parent magma of the 3.78-old Amitsoq gneisses, the oldest known crustal rock, Moorbath et al., 1975, is believed to have been derived from an undepleted mantle because not much magma had been removed from the mantle towards the formation of the continental crust till that time, Wetherill, 1975 [14, 29]. Additionally, extraction of felsic magma from the mantle is normally accompanied by positive fractionation of Rb relative to Sr which after a certain time delay results in an elevated initial Sr isotope ratio of the rock relative to that of the mantle at that time [23, 24, 27]. Therefore, it follows from this that the initial ratio of the Amitsoq gneisses should either be slightly higher or very close to the Sr isotope ratio of the Earth at the time of interest in the past. Hence, only that model for the Sr isotope evolution in the Earth would be considered valid which would indicate the Sr isotope ratio of the Earth at that time (3.78 Gyr ago) either very close to or lower than the initial ratio (0.6998) of the Amitsoq gneisses [29]. Therefore, any model that shows the Sr isotope ratio of Earth 3.78 Gyr ago more than 0.6998 would be rejected because it would imply that the Amitsoq gneisses originated from a depleted mantle.

Thus, there are six potential models for the isotopic evolution of ^{87}Sr in the Earth because of the two possible beginning Sr isotope ratios (BABI and ALL) and three different present-day Sr isotope ratios corresponding to the 4.555 Gyr age of the Earth. However, if the age of the Earth is assumed to be 4.57 Gyr then six more such models would be possible [26, 28]. Thus, in all, there are 12 possible models that can possibly describe the isotopic evolution of ^{87}Sr in the Earth (Table 3). However, it is noticed that out of the six possible models corresponding to the 4.555 Gyr age of the Earth, only two models appear to be plausible: (i) with ALL as the beginning ratio and 0.7045 as the present-day Sr isotope ratio and (ii) with ALL as the beginning ratio and 0.7047 as the present-day Sr isotope ratio of the Earth because these two models show Strontium isotope ratios for the Earth of 3.78 Gyr ago less than the initial ratio (0.6998) of the Amitsoq gneisses [29]. Therefore, in view of the foregoing discussion, all the remaining models with BABI as the beginning Sr isotope ratio and/or 0.7052 as the present-day Sr isotope ratio that show Sr isotope ratio for the Earth greater than 0.6998 at 3.78 Gyr in the past are rejected and are not discussed any further. If the age of the Earth is assumed to be 4.57 Gyr, even in that case, the two similar models satisfy the stipulated conditions for the Sr isotopic evolution in the Earth because the ALL value of 0.69877 as the beginning Strontium isotope ratio is common in both the models. It follows from this then that the ALL value of 0.69877 should be regarded as the beginning Sr isotope ratio for the planet Earth. The problem now is which of the two Sr isotope ratios 0.7045 or 0.7047 should be regarded as the present-day Sr isotope ratio of the planet Earth. It was shown earlier (Table 2) that the beginning Sr isotope ratio equal to the ALL value of 0.69877 is compatible only with the planet Earth Sr isotope ratio of 0.7047, which implies that the model with 0.69877 (ALL) as the beginning Sr isotope ratio and 0.7047 as the present-day planet Earth ^{87}Sr/^{86}Sr ratio is the only viable model that explains the isotope evolution of ^{87}Sr in the Earth. However, this is a sort of indirect evidence, and for further support of this model some additional evidence from the Rb-Sr isotope data of some mantle-derived igneous rocks in conjunction with the planet Earth parameters has been obtained.

Table 3. Shows ^{87}Sr/^{86}Sr ratio of Earth at 3.78 Gyr in the past calculated for the various possible combinations of the age of Earth, beginning Sr isotope ratio, and the present-day Sr isotope ratio. The latter two ratios form the end members of the Sr isotope evolution line in the planet Earth.

Age of the Earth (in Gyr)	**Beginning ^{87}Sr/^{86}Sr ratio of the Earth**	**Planet Earth's ^{87}Sr/^{86}Sr ratio at the present time**	**^{87}Sr/^{86}Sr ratio of the Earth 3.78 Gyr ago**
4.555	0.69899	0.7045	0.6999275
4.555	0.69899	0.7047	0.6999615
4.555	0.69899	0.7052	0.7000466
4.555	0.69877	0.7045	0.6997449*
4.555	0.69877	0.7047	0.6997789*
4.555	0.69877	0.7052	0.699864
4.57	0.69899	0.7045	0.6999425
4.57	0.69899	0.7047	0.6999771
4.57	0.69899	0.7052	0.7000635
4.57	0.69877	0.7045	0.6997605*
4.57	0.69877	0.7047	0.6997951*
4.57	0.69877	0.7052	0.6998815

The values of the Sr isotopic ratios marked with * are less than the initial Sr isotopic ratio, 0.6998, of the Amitsoq gneisses for both 4.555 Gyr and 4.57 Gyr age of the Earth [29]. In each case, the beginning Sr isotope ratio of the Earth is the ALL value of 0.69877.

Therefore, the end members of any of these two sets of isotope evolution arrays could be viable end members of the Sr isotope evolution for the planet Earth, the other sets of the end members of the Sr isotope evolution are therefore rejected. For further information see the text.

Estimating the beginning Strontium isotope ratio of the Earth from mantle-derived crustal rocks

The nature of the Rb-Sr systematics is such that it is not possible to obtain direct evidence about the beginning or the present-day Sr isotope ratios of the Earth by linear extrapolation of the line formed by plotting the initial Sr isotope ratios of crustal rocks against their respective age, as has been done in the case of the Sm-Nd systematics [21, 22, 30]. This is because Rb and Sr in comparison to Sm and Nd as discussed earlier are differentially fractionated during the extraction of magma from the mantle. As a consequence, the initial ratio of mantle-derived rocks may not reflect the Sr isotope ratio of the mantle at the time of their emplacement in the crust. Moreover, the problem is further complicated because the differential fractionation of Rb in the magma causes the mantle to be continually depleted in Rb since the time of its formation. This is probably the reason why it is difficult to find young magmatic rocks that are unfractionated and derived from an undepleted mantle. However, these problems can be overcome by calculating the T_{UR} ages of mantle-derived rocks, as suggested by McCulloch and Wasserburg, 1978 [27]. The T_{UR} age of a mantle-derived rock dates the Rb fractionation event, which is generally coincident with the extraction of magma from the mantle. The T_{UR} age thus in most of the magmatic rocks denotes the time of the primary magma extraction from the mantle and is given by:

$$T_{UR} = 1/\lambda \ \ln\{[(^{87}Sr/^{86}Sr)_M - (^{87}Sr/^{86}Sr)_{PE}] \div [(^{87}Rb/^{86}Sr)_M - (^{87}Rb/^{86}Sr)_{PE}] + 1\} \quad (2)$$

where the subscript M denotes the present-day ratio measured in the rock, PE the planet Earth and λ the decay constant of ^{87}Rb. Thus, if the TUR age reflects the age of the primary magma extraction from the mantle, then it follows that the initial ratio of these rocks computed with respect to their T_{UR} age should in fact reflect the Sr isotope ratio of the planet Earth at the time of interest in the past. The initial ratio $I_{PE}(t)$ of a rock with respect to its T_{UR} age is in fact the model $^{87}Sr/^{86}Sr$ ratio of the planet Earth at the time of interest in the past and is given by:

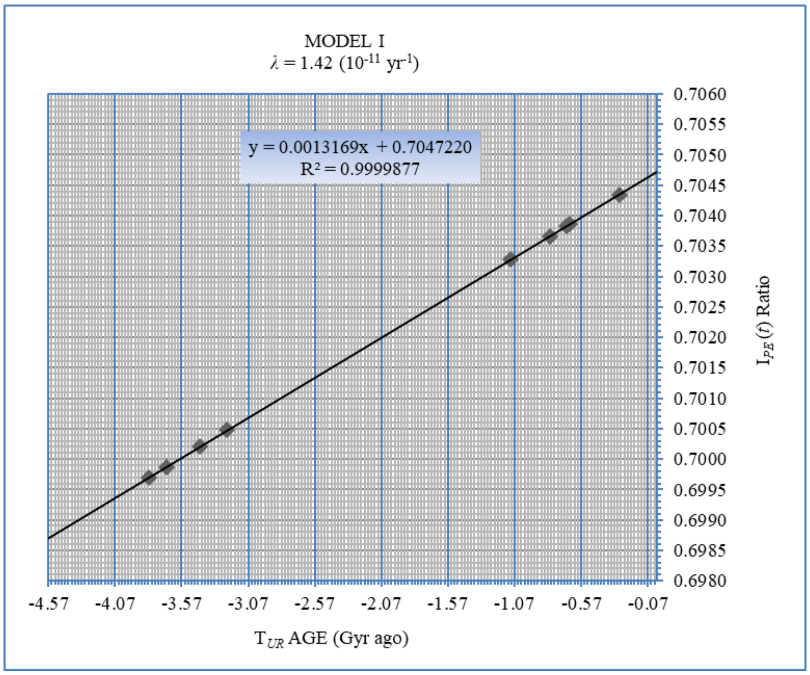
$$I_{PE}(t) = (^{87}Sr/^{86}Sr)_M - (^{87}Rb/^{86}Sr)_M \times (e^{\lambda t} - 1) \quad (3)$$

where t is the T_{UR} age of the rock. The above equation indeed yields the Sr isotope ratio of the planet Earth because the $I_{PE}(t)$ ratios of rocks of varying ages form a linear relationship with their respective T_{UR} ages. The array thus formed is of great significance because it defines the Sr isotope evolution line of the planet Earth and therefore can be used to gather the evidence for the beginning Sr isotope ratio and other planet Earth parameters as well.

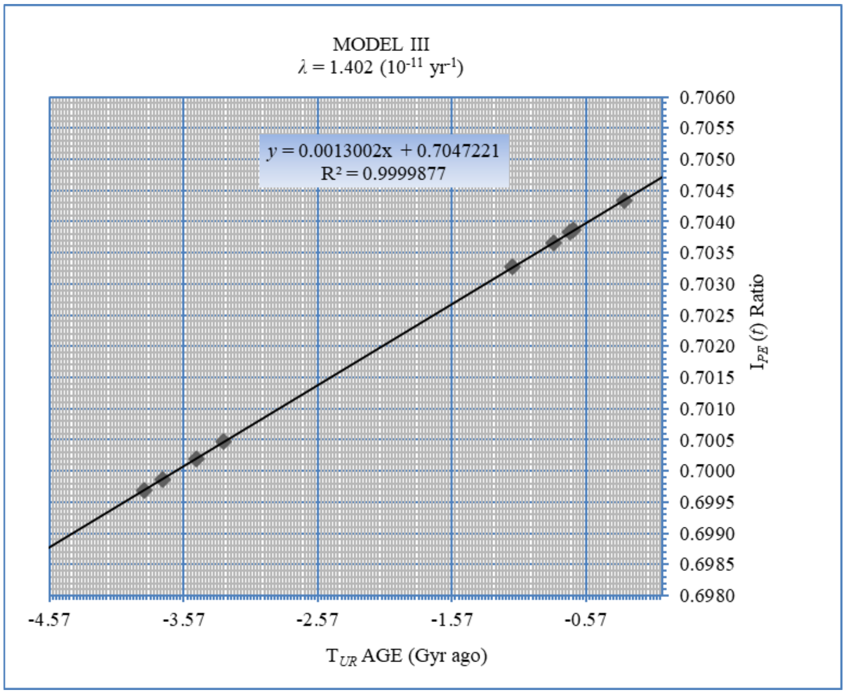
Keeping in mind the constraint imposed by the initial ratio of the Amitsoq gneisses (Table 3), it was noticed earlier that there are only two models that appear to be feasible for defining the Sr isotope evolution on the planet Earth. Interestingly, according to both these models the ALL value of 0.69877 must be the beginning Strontium isotope ratio of the Earth. Hence, only that particular set of planet Earth parameters and ^{87}Rb decay constant λ would be regarded as valid which would define a Strontium isotope evolution array that would indicate a model beginning Sr isotope ratio for the Earth of 4.555 Gyr ago equal to the ALL value of 0.69877. To see this, Rb-Sr isotope data of some mantle-derived rocks of varying geologic ages were taken from the literature and their $I_{PE}(t)$ ratios and T_{UR} ages were determined (Tables 4 and 5). Then the Sr isotope evolution array for the planet Earth was obtained by plotting the $I_{PE}(t)$ ratios against their respective T_{UR} ages (Figures 1 and 2, Tables 4 and 5). It was observed that when the present-day Earth parameters suggested by All`egre, 1982, that is, 0.7047 for the $^{87}Sr/^{86}Sr$ ratio and 0.09 for the $^{87}Rb/^{86}Sr$ ratio, and the decay constant λ for ^{87}Rb equal to $1.42(10^{-11}\ yr^{-1})$ were used, the Strontium isotope evolution array thus obtained when extrapolated back to the time 4.555 Gyr ago intersects the Y-axis at 0.698722 (Figure 1- Model I, Table 4) [25]. This shows that the beginning Sr isotope ratio for the planet Earth as per these parameters should be less than the ALL value of 0.69877. However, if the age of the Earth is assumed to be 4.57 Gyr, the beginning Sr isotope ratio in that case would be even much lower than 0.698722. As in both these cases the beginning Sr isotope ratio does not approximate the ALL value of 0.69877, it follows from this then that either the present-day Earth parameters or the decay constant for ^{87}Rb or both used in the equation (2) are not viable, and need to be modified. Therefore, the $I_{PE}(t)$ ratios and the T_{UR} ages for the same set of rocks were recomputed using the same decay constant but with the present-day Earth parameters of DePaolo and Wasserburg, 1976 b [22]. Using these planet Earth parameters, the Sr isotope evolution array thus obtained indicated the model beginning Sr isotope ratios of 0.69892 and 0.69890 corresponding to 4.555 Gyr and 4.57 Gyr age of the Earth, respectively (Figure 2- Model II, Table 5). However, both these values for the beginning ratio indicated by this linear array are again far removed from the ALL value of 0.69877. Thus, it is quite evident that neither of the two sets of planet Earth parameters together with the value of $1.42\ (10^{-11}\ yr^{-1})$ for the decay constant yield a beginning isotope ratio close to the ALL value. This further enhances the view that this value of the decay constant is rather a little too high. As a result, similar isotope evolution arrays for the planet Earth were obtained from the same set of rocks using the present-day Earth parameters of All`egre, 1982 and De Paolo and Wasserburg, 1976 b and a lower value of 1.402(10^{-11} yr^{-1}) for the ^{87}Rb decay constant suggested by Minster et al., 1982 (Figure 1 - Model III, Figure 2 - Model IV and Tables 4 & 5) [6, 22, 25].

Figure 1. Shows three different models, MODEL I, MODEL III and MODEL V of ^{87}Sr isotope evolution in Earth. In these models, the $I_{PE}(t)$ ratio is plotted against the respective T_{UR} age of some mantle-derived rocks. These ratios were computed by applying the present-day $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios of 0.7047 and 0.09, respectively. The value of the decay constant λ for ^{87}Rb used for computing these ratios is 1.42((10^{-11} yr^{-1}) in Model I, 1.402(10^{-11} yr^{-1}) in Model III, and 1.4087(10^{-11} yr^{-1}) in Model V. For further information see the text.

MODEL I: X-Y plot of ^{87}Sr isotope evolution in Earth. In this plot, the $I_{PE}(t)$ ratio is plotted against the respective T_{UR} age of some mantle-derived rocks. These ratios were computed by applying the present-day $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios of 0.7047 and 0.09, respectively. The value of the decay constant λ for ^{87}Rb used for computing these ratios in this model is 1.42((10^{-11} yr^{-1}). For further information see the text.



MODEL III: X-Y plot of ^{87}Sr isotope evolution in Earth. In this plot the $I_{PE}(t)$ ratio is plotted against the respective T_{UR} age of some mantle-derived rocks. These ratios were computed by applying the present-day $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios of 0.7047 and 0.09, respectively. The value of the decay constant λ for ^{87}Rb used for computing these ratios in this model is 1.402((10^{-11} yr^{-1}). For further information see the text.



MODEL V: X-Y plot of ^{87}Sr isotope evolution in Earth. In this plot, the $I_{PE}(t)$ ratio is plotted against the respective T_{UR} age of some mantle-derived rocks. These ratios were computed by applying the present-day $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios of 0.7047 and 0.09, respectively. The value of the decay constant λ for ^{87}Rb used for computing these ratios in this model is 1.4087((10^{-11} yr^{-1}). For further information see the text.

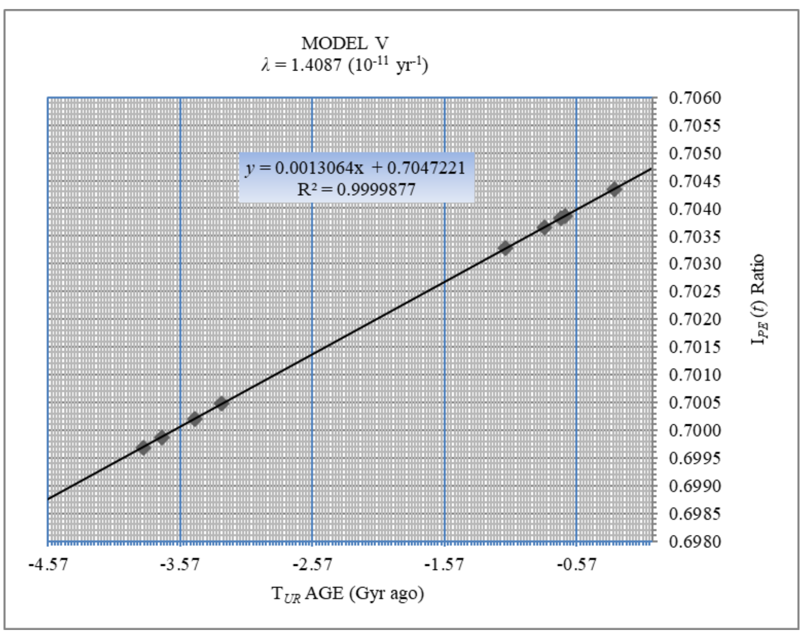
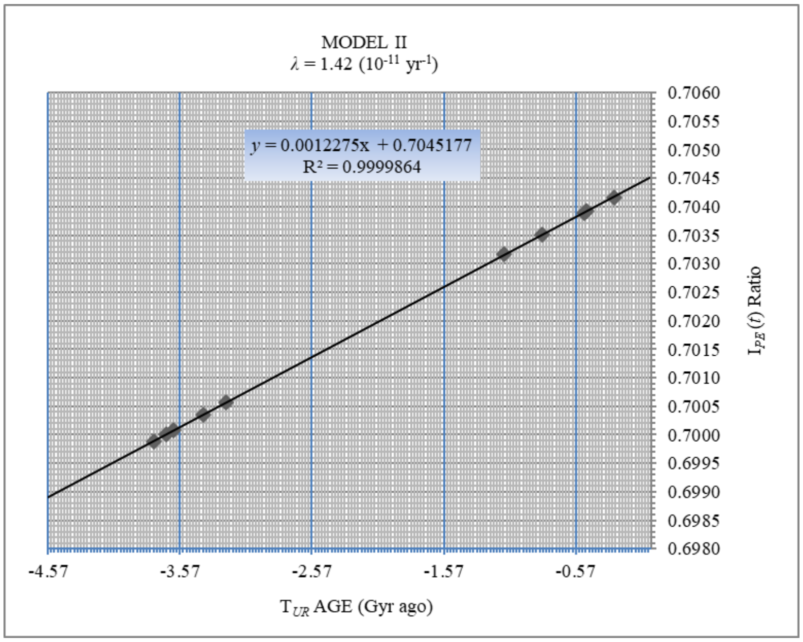
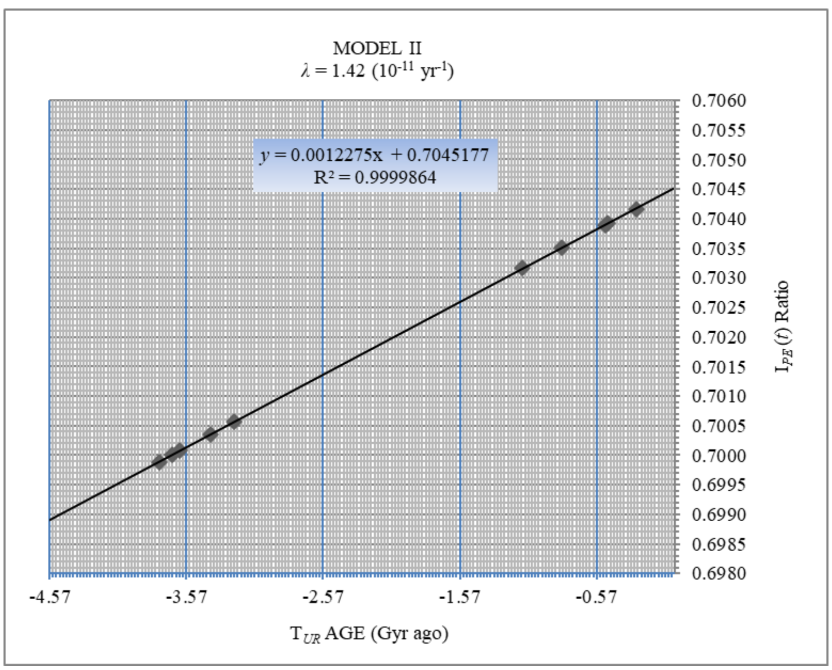


Figure 2. X-Y plots of two different models, Model II and Model IV, of ^{87}Sr isotope evolution in Earth. In these plots the $I_{PE}(t)$ ratio is plotted against the respective T_{UR} age of some mantle-derived rocks. These ratios were computed by applying the present-day $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios of 0.7045 and 0.084, respectively. The value of λ for ^{87}Rb, used for computing these ratios, is 1.42(10^{-11} yr^{-1}) in Model II, and 1.402(10^{-11} yr^{-1}) in Model IV. For further information see the text.

MODEL II: The X-Y plot of ^{87}Sr isotope evolution in Earth. In this plot the $I_{PE}(t)$ ratio is plotted against the respective T_{UR} age of some mantle-derived rocks. These ratios were computed by applying the present-day $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios of 0.7045 and 0.084, respectively. The value of the decay constant λ for ^{87}Rb used for computing these ratios in this model is 1.42 (10^{-11} yr^{-1}). For further information see the text.



MODEL IV: X-Y plot of a model of ^{87}Sr isotope evolution in Earth. In this plot the I_{PE} (t) ratio is plotted against the respective T_{UR} age of some mantle-derived rocks. These ratios were computed by applying the present-day ^{87}Sr/^{86}Sr and ^{87}Rb/^{86}Sr ratios of 0.7045 and 0.084, respectively. The value of λ for ^{87}Rb used for computing these ratios in this model is 1.402(10^{-11} yr^{-1}). For further information see the text.



MODEL IV: X-Y plot of a model of ^{87}Sr isotope evolution in Earth. In this plot the I_{PE} (t) ratio is plotted against the respective T_{UR} age of some mantle-derived rocks. These ratios were computed by applying the present-day ^{87}Sr/^{86}Sr and ^{87}Rb/^{86}Sr ratios of 0.7045 and 0.084, respectively. The value of λ for ^{87}Rb used for computing these ratios in this model is 1.402(10^{-11} yr^{-1}). For further information see the text.

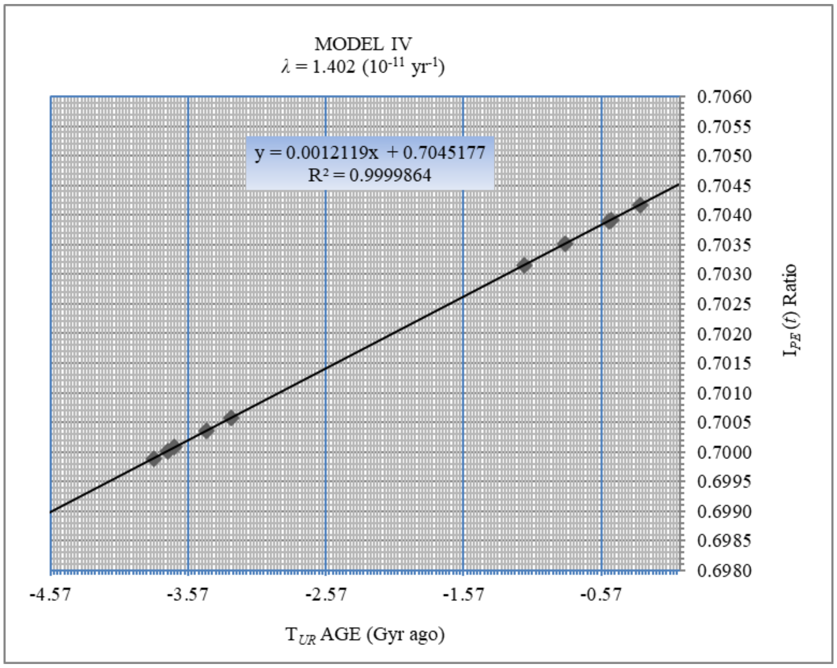


Table 4. Shows data for the Sr isotope evolution in Earth computed assuming present-day ratios of 0.7047 for the $^{87}Sr/^{86}Sr$ ratio and 0.09 for the $^{87}Rb/^{86}Sr$ ratio and using different values for the decay constant of ^{87}Rb. The table also shows information about the Sr isotope evolution array formed by plotting the T_{UR} ages against their respective $I_{PE}(t)$ ratios.

				Model I	**Model III**	**Model V**		
				λ = 1.42 (10^{-11} yr^{-1})	λ = 1.402 (10^{-11} yr^{-1})	λ = 1.4087 (10^{-11} yr^{-1})		
Sr #	**Sample #**	**$^{87}Rb/^{86}Sr$**	**$^{87}Sr/^{86}Sr$**	**T_{UR} age (in Gyr)**	**T_{UR} age (in Gyr)**	**T_{UR} age (in Gyr)**	**$I_{PE}(t)$**	**References**
1	171747	0.592	0.73131	-3.6373803	-3.6840799	-3.6665578	0.6999293	[29]
2	17151	0.988	0.7529	-3.6819644	-3.7292364	-3.7114996	0.6998693	[29]
3	86509	0.627	0.7299	-3.2295468	-3.2710103	-3.2554528	0.7004765	[51]
4	86518	0.284	0.7155	-3.8151925	-3.864175	-3.8457964	0.6996897	[51]
5	86256	0.234	0.7119	-3.4359271	-3.4800402	-3.4634886	0.7002	[51]
6	SL2	0.0552	0.7043	-0.8048377	-0.8151709	-0.8112938	0.7036655	[52]
7	SL5	0.1435	0.7052	-0.655098	-0.6635088	-0.660353	0.7038589	[52]
8	SL6	0.0283	0.7041	-0.6815137	-0.6902635	-0.6869805	0.7038248	[52]
9	WAK-2L	0.682	0.71404	-1.1023848	-1.1165381	-1.1112276	0.7032801	[53]
10	WAK-17L	3.37	0.71773	-0.2792036	-0.2827882	-0.2814433	0.7043425	[53]

Corr. Coefficient (r) ……....... = -0.9999942 -0.9999941 -0.9999941
Y-Intercept at 0 age ……….... = 0.7047221 0.7047221 0.7047221
Y-Intercept at 4.555 Gyr ago = 0.6987227 0.6987988 0.6987705
Y-Intercept at 4.57 Gyr ago ... = 0.6987030 0.6987793 0.6987509

Table 5. Shows data for the Sr isotope evolution in the planet Earth computed assuming present-day ratios of 0.7045 for the $^{87}Sr/^{86}Sr$ ratio and 0.084 for the $^{87}Rb/^{86}Sr$ ratio and using different values for decay constant of ^{87}Rb. The table also shows information about the Sr isotope evolution array formed by plotting the T_{UR} ages against their respective $I_{PE}(t)$ ratios.

				MODEL II	MODEL IV		
				λ = 1.42 (10^{-11} yr^{-1})	λ = 1.402 (10^{-11} yr^{-1})		
Sr #	**Sample #**	**$^{87}Rb/^{86}Sr$**	**$^{87}Sr/^{86}Sr$**	**T_{UR} age (in Gyr)**	**T_{UR} age (in Gyr)**	**$I_{PE}(t)$ Ratio**	**References**
1	171747	0.592	0.73131	-3.6218378	-3.6683378	0.70008	[29]
2	171751	0.988	0.7529	-3.6729404	-3.7200966	0.7000027	[29]
3	86509	0.627	0.7299	-3.219442	-3.2607758	0.7005707	[51]
4	86518	0.284	0.7155	-3.7704765	-3.8188849	0.69988	[51]
5	86256	0.234	0.7119	-3.3912001	-3.4347391	0.700356	[51]
6	SL 2	0.0552	0.7043	-0.4873551	-0.4936122	0.7039167	[52]
7	SL 5	0.1435	0.7052	-0.8236648	-0.8342396	0.7035118	[52]
8	SL 6	0.0283	0.7041	-0.5039201	-0.5103898	0.7038968	[52]
9	WAK-2L	0.682	0.71404	-1.114596	-1.128906	0.7031599	[53]
10	WAK-17L	3.37	0.71773	-0.282964	-0.2865969	0.7041618	[53]

Corr. Coefficient. (r) ..……...... = -0.9999955 -0.9999954
Y-Intercept at 0 age…………. = 0.7045177 0.7045177
Y-Intercept at 4.555 Gyr ago …. = 0.6989236 0.6989945
Y-Intercept at 4.57 Gyr ago …. = 0.6989073 0.6989791

When the present-day Earth parameters of All`egre, 1982 were used, the isotope evolution array indicated values of 0.698798 and 0.698779 for the beginning Sr isotope ratio of the Earth corresponding to 4.555 Gyr and 4.57 Gyr of age, respectively (Figure 1 - Model III, Table 4) [25]. The important point to note here is that both these values for the beginning Sr isotope ratio are within the limits of error of the ALL value of 0.69877±5. This suggests that this model for the Strontium isotope evolution in Earth and the decay constant of 1.402(10^{-11} yr^{-1}) for ^{87}Rb could be viable. However, this would be considered conclusive only if the beginning Sr isotope ratio close to the ALL value is not indicated by any other set of planet Earth parameters using the same decay constant. Thus, the initial Sr isotope ratios of 0.698993 and 0.698975 respectively corresponding to 4.555 and 4.57 Gyr age of the Earth were obtained by using the present-day Earth parameters of De Paolo and Wasserburg, 1976 b (Figure 2 - Model IV, Table. 5), which are significantly higher than the ALL value of 0.69877±5 [22]. If the Sr isotope evolution array of Model IV were to indicate a beginning Sr isotope ratio exactly equal to the ALL value of 0.69877 corresponding to 4.555 Gyr age of the Earth, then the decay constant for ^{87}Rb must be 1.4587(10^{-11} yr^{-1}), which is way high and thus renders this model implausible. This shows that Model III consisting of ALL as the beginning Sr isotope ratio and 0.7047 as the present-day Sr isotope ratio of the Earth is the most viable model for the Sr isotope evolution in the planet Earth. This further adds weight to the earlier suggestion that if ALL is to be the beginning Sr isotope ratio then the planet Earth's Sr isotope ratio can in no case be equal to 0.7045 (Table 2). These observations strongly suggest that if the present-day Earth parameters have to have any significance, then the decay constant for ^{S7}Rb has to be lower than the present value of 1.42(10^{-11} yr^{-1}). So now the moot question is how low it should be! Although by using the lower value of 1.402(10^{-11} yr^{-1}) for the decay constant in Model III, a beginning Sr isotope ratio of 0.698798 was obtained which is within the limits of error of the desired ALL value of 0.69877±5 [6]. However, to obtain an initial Sr isotope ratio exactly equal to the ALL value of 0.69877 for the 4.555 Gyr old Earth, the decay constant for ^{87}Rb must be 1.4087(10^{-11} yr^{-1}) instead of 1.42(10^{-11} yr^{-1}) currently being used or 1.402(10^{-11} yr^{-1}) proposed by Minster et al., 1982 (Figure 1- Model V, Table 4) [6]. The value of the decay constant as suggested here has been computed by assuming that the age of the Earth is 4555 Myr [6, 8,16, 17]. Therefore, the value of 1.4087(10^{-11} yr^{-1}) for the decay constant of ^{87}Rb suggested here is correct insofar as the age of the Earth and the present-day Earth parameters are correct. If the age of the Earth is assumed to lie anywhere between 4.54 Gyr and 4.57 Gyr, then the decay constant for ^{87}Rb computed for these extreme limits would vary from 1.4134(10^{-11} yr^{-1}) to 1.4040(10^{-11} yr^{-1}). Thus, even if the extreme limits of the decay constant λ of 1.4087±0.0047 are used for defining the ^{87}Sr isotope evolution in Earth, the model beginning Sr isotope ratio of the Earth corresponding to any age within this range would fall within the limits of error of the ALL value of 0.69877±5.

Furthermore, there is another line of evidence in favor of the above value for the decay constant of ^{87}Rb. Minster et al., as mentioned earlier, proposed a lower decay constant of 1.402 (10^{-11} yr^{-1}) so that the joint chondrite isochron yields an age exactly equal to the mean age of the meteorites or the refractory inclusions of Allende, i.e., 4.555 Gyr, as deduced from the U-Th-Pb geochronometers [6, 8, 16, 17]. However, they maintained that the slightly higher initial ratio of the chondrites (0.69885±0.0001) as indicated by the joint chondrite isochron in comparison with the ALL value of 0.69877±.00005 is because of some time-delay in the fractionation of Rb in the chondrites relative to the refractory inclusions of Allende. According to them, the maximum time-delay could be 3.9±7.3 Myr if the chondrites evolved directly from the Solar Nebula (Rb/Sr = 0.6 to 0.5) or 9.4±17.6 Myr if they evolved from a reservoir of chondritic composition (Rb/Sr = 0.3 to 0.2). However, their suggestion of the value of 1.402(10^{-11} yr^{-1}) for the decay constant of ^{87}Rb to bring the age of the chondrites exactly on par with that of the inclusions of Allende (4.555 Gyr) would imply that there was either a very little or absolutely no time delay in the fractionation of Rb between them, which would suggest their origin directly from the Solar Nebula. Their suggestion, however, seems to be contrary to their own observations that the chondrites and the refractory inclusions are synchronous only on the scale of 10±17 Myr. Moreover, no evidence can be furnished on the basis of the Rb-Sr systematics that the chondrites and the Allende inclusions evolved directly from the Solar Nebula. Therefore, the decay constant of 1.402 (10^{-11} yr^{-1}) as suggested by Minster et al., 1982 is considered here to be a little low [6]. On the other hand, by applying the decay constant of 1.4087(10^{-11} yr^{-1}), the same joint chondrite isochron yields an age of 4534 Myr which is approximately 21 Myr younger than the mean age of the meteorites and/or the refractory inclusions of Allende. This difference in the Rb-Sr age between the chondrites and the white inclusions of Allende is within the maximum limit of the difference that could occur between their Rb-Sr ages as a result of the delayed fractionation of Rb in the chondrites. Furthermore, this difference in the Rb-Sr age between the chondrites and the refractory inclusions of Allende also implies that both of them evolved from a chondritic reservoir (Rb/Sr = 0.3 to 0.2). Therefore, it is also very important to mention here that at least in the case of CI chondrites there is direct evidence of such an origin. According to Ebihara et al., 1982, CI chondrites represent the least fractionated material in the Solar System [31]. However, a few elements in these chondrites particularly Rb and Cs are soluble and were fractionated during aqueous alterations in the parent meteorite body. They also contended that there is no evidence of nebular fractionation of Rb in these meteorites. Furthermore, according to Macdougall et al.,1984, the action of liquid water on the parent meteorite body also resulted in the formation of some secondary mineral phases [15]. This event, according to them occurred during the formation of the parent meteorite body or immediately after within 100 Myr of its formation. This suggests that Rb in the CI chondrites was fractionated due to hydrothermal alteration of the parent meteorite body, which lends credence to the views of Minster et al., 1982 that there was some measurable time delay in the fractionation of Rb between the chondrites and the refractory inclusions of Allende. Therefore, the age given by the joint chondrite whole-rock isochron cannot be brought exactly on par with that of the white inclusions of Allende by lowering the decay constant λ to 1.402 (10^{-11} yr^{-1}) [6]. The joint chondrite isochron age of 4534 Myr obtained by using the suggested decay constant λ of 1.4087(10^{-11} yr^{-1}) most likely dates such a Rb fractionation event in the meteorite parent body. Furthermore, if the decay constant for ^{87}Rb is to be defined at all on the basis of the sharp isochronism of dates given by the Rb-Sr and U-Th-Pb dating techniques then it should be done by comparing the dates of ancient volcanic rocks with co-genetic Rubidium and Uranium minerals. The chondrites do not seem to be a good choice for this purpose because their early differentiation history is not exactly known.

Thus, Aldrich et al., 1956 by comparing the Rb-Sr and ^{235}U-^{207}Pb ages of igneous rocks and using the decay constant for Uranium given by Fleming, Jr et al., 1952, derived a half-life of ^{87}Rb equal to 5.0±0.2(10^{10}) yr, [λ=1.386(10^{-11} yr^{-1})] [32, 33]. However, the Uranium decay constants defined by Fleming, Jr et al., 1952 were later revised by Jaffey et al., 1971 and are now considered to be final [20, 33, 34]. Interestingly, if the half-life of ^{87}Rb is recomputed in light of the revised decay constant for Uranium then the outcome of Aldrich et al., 1956 [1] is reduced to 4.90(10^{10}) yr, [λ=1.4142 (10^{-11} yr^{-1})] when compared with the ^{235}U-^{207}Pb method and 4.93(10^{10}) yr, [λ=1.4056(10^{-11} yr^{-1})] compared with the ^{238}U-^{206}Pb method. Though both the outcomes are in good agreement with the half-life of 4.9194(10^{10}) yr, [λ= 1.4087(10^{-11} yr^{-1})] proposed here for ^{87}Rb, but the one based on comparison with the ^{238}U-^{206}Pb method is in much better agreement with the one proposed here. This is quite significant because the half-life of ^{238}U-^{206}Pb is considered to be the gold standard for computing the half-life of ^{87}Rb. Furthermore, Davis et al., 1977 obtained a value of 1.414±0.015 (10^{-11} yr^{-1}) for the decay constant of ^{87}Rb by measuring ^{87}Sr accumulated in a Strontium-free Rubidium salt [35]. This decay constant for 87Rb again compares favorably with the one suggested here.

In the following paragraphs, I will review very briefly some of the important papers which were published on this topic after 1984. However, Gargi, 2019 also reviewed all the previous literature published so far pertaining to the half-life/decay constant of ^{87}Rb in quite detail [36].

Shih et al., 1985 based on the Rb-Sr and Sm-Nd methods of dating of a granite clast from Apollo 14 breccia suggested a revised decay constant for ^{87}Rb of 1.402 (10^{-11} yr^{-1}) which is similar to the one proposed by Minster et al., 1982 [6, 37].

Begemann et al., 2001 with a view to get an improved value for the decay constant of ^{87}Rb carried out a meta-analysis on the analytical data gathered from the experiments conducted by Neumann and Huster, 1974 and Neumann and Huster, 1976 [18, 19, 38]. Their meta-analysis led them to believe that the value of the decay constant should be reduced to (1.403 ± 0.009) ($10^{−11}$ $yr^{−1}$) which is quite similar to the value suggested by Minster et al. [6]. However, they did not explicitly recommend any value to be considered for the decay constant of ^{87}Rb. Instead, they gave a call for getting an improved set of decay constants for geochronological use. Subsequently, perhaps in response to the call given by Begemann et al., 2001 a few more attempts were made to ascertain the half-life/decay constant of ^{87}Rb [38]. For instance, Kossert, 2003 used the scintillation method for counting β particles, Amelin and Zaitsev, 2002 and Nebel et al., 2011 used inter-comparison of Rb-Sr and U-Pb dates obtained independently for the same rock, and Rotenberg et al., 2012 used artificial accumulation of radiogenic ^{87}Sr over a time period of 34 years; An interesting outcome of all these experiments where the three possible techniques for measuring the half-life were used was that the values of half-life of ^{87}Rb overlapped in the narrow range of 49.53 to 49.69 Gyr [39-42].

Villa et al., 2015 were struck by the narrow range of the values of half-life of ^{87}Rb given by the various independent experiments using three totally different techniques for measuring the half-life [43]. They believed that this was not a coincidence but rather an indication of the true value of the decay constant falling somewhere within this range. Their view about the need for getting an improved value for the decay constant of ^{87}Rb also got an impetus from the fact that at present the widely used value of ^{87}Rb decay constant (λ = 1.42 (10^{-11} yr^{-1})) recommended by the Sub-Commission of Geochronology, Steiger and Jager, 1977 is actually an interim value that has not been universally accepted by geochronologists [20]. Hence, Villa et al., 2015 wanted to get an improved and more agreeable value of the half-life/decay constant of ^{87}Rb [43]. They wanted to do this by carrying out a meta-analysis on the experimental data gathered from the experiments done by other workers. As per their assertion, for their so-called meta-analysis, they took into account the independently reassessed measurement uncertainties of the analytical data, and based on that analysis they recommended a value of 49.61 ± 0.16 Gyr for the half-life of ^{87}Rb which translates to a decay constant of (1.3972 ± 0.0045) (10^{-11} yr^{-1}). It should be noted that in fact, this value is virtually identical to the one suggested by Wetherill, 1966 which was widely used till 1977 when it was discarded in favor of the value (λ = 1.42 (10^{-11} yr^{-1})) recommended by the Sub-commission on Geochronology, Steiger and Jager, 1977 [20, 44]. The Sub-commission proposed that the latter value should be adopted as an interim value for the decay constant until some more high-quality experimental data becomes available. Villa et al., 2015 maintained that for this study they considered all the publications pertaining to this subject matter through early 2015, and their emphasis was mainly only on the independent reassessment of measurement uncertainties of the analytical data reported by other workers [43]. Actually, for their meta-analysis they did not consider any paper published before 2015 except for the aforementioned four papers on measuring the half-life. They didn't review even the latest paper on this topic by Gargi, 2012 [45]. Furthermore, it is noticed here that their so-called meta-analysis is essentially based only on the analytical data derived from the above referred four experiments, and their meta-analysis is nothing but just an average of the two extreme values of the decay constants from the four experiments they used for their meta-analysis. It is important to mention here that actually meta-analysis is done on the analytical data of a single experiment as was done by Begemann et al., 2001 and not on a group of experiments where different techniques are used for measuring the half-life [38]. Also, the senior author of the paper by Villa et al., 2015 was one of the authors in the Begemann et al.'s, 2001 paper where they carried out meta-analysis on the experimental data from Neumann and Huster, 1974 and Neumann and Huster, 1976 [18, 19, 38, 43].

Villa et al.'s, 2015 recommendation of (1.3972 ± 0.0045) (10-11 yr-1) as the value for the decay constant of ^{87}Rb takes us back to the point in time about forty to fifty years ago when a value [(1.39) (10^{-11} yr^{-1})] very similar to the one recommended by Villa et al., 2015 was discarded [43]. If there were some concerns at that time about the viability of that value, the same concerns still persist today for this value which cannot be ignored. Therefore, Villa et al.'s, 2015 recommendation with regard to the value of the decay constant cannot be considered a credible proposition [43]. Villa et al.'s, 2015 argument in support of this value was that it is very unlikely for the three totally different independent experimental approaches to yield three coincidental incorrect values for the half-life of ^{87}Rb and for this to happen the experimental artifacts would have to be of the same magnitude and in the same direction [43].

Gargi, 2019 reviewed all the previous literature related to this subject matter [36]. Further, he evaluated in quite detail the four papers on which Villa et al.'s, 2015 so-called meta-analysis was based [43]. His response to Villa et al.'s, 2015 argument regarding the closely matching values given by the four totally different experiments was that that it may indeed be highly unlikely, but no matter how unlikely it still cannot be considered scientific evidence for the validity of the recommended value [43]. Gargi, 2019 further showed that going by their criterion one can find in the literature three or more such sets comprising three or four different experiments showing closely matching values for the decay constant of ^{87}Rb. He also showed that even the currently used value (λ = 1.42 (10^{-11} yr^{-1})) was indicated by four to five different independent experiments.

Gargi, 2012 also developed a computer model (herein referred to as SG model) using MS Excel Spreadsheet program for inferring the isotopic characteristics of source reservoirs of igneous rocks with respect to their $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratio [45]. The SG model is purely a theoretical model and is not dependent on any data from meteorites or terrestrial rocks. It is simply based on the inherent characteristics of the Rb-Sr isotopic systematics. In this model the cosmic evolution of ^{87}Rb and ^{87}Sr was calibrated to get information about all those entities that have a bearing on the Rb-Sr isotopic evolution. In addition, SG model also comprises several other relations such as Rubichron and Puci which can respectively be used for determining the age and beginning Sr isotope ratio of a rock. Further, the SG model comprises another important relation, the Ruh relation which is unique in the sense that all the entities that affect the Rb-Sr isotopic evolution are directly involved in this relation which makes it possible to obtain information about all those entities. In this relation, the X-axis entity is dependent on the $^{87}Rb/^{86}Sr$ ratio and the Y-axis entity on the $^{87}Sr/^{86}Sr$ ratio, Gargi, 2012 [45]. Therefore, the linear array formed by these two entities on an X-Y plot should go to the point of origin, that is, the Y-intercept should have NULL value. This is because if there is no ^{87}Rb, there cannot be any ^{87}Sr. This is based on the premise that the chemical elements in the Universe were not synthesized in the interior of stars by the process of stellar nucleosynthesis, but instead manifested in space-time in the order of their atomic mass, Gargi, 2019 [36]. However, according to this idea radiogenic nuclides such as ^{87}Sr, ^{143}Nd and others did not manifest in space-time but were produced by the decay of their parent nuclides. It follows from this that at a certain point of time in the past when ^{87}Rb had just manifested, $^{87}Sr/^{86}Sr$ ratio at that time must have been NULL This means that the cosmic ratios such as Rb/Sr, $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ have been evolving with time due to decay of ^{87}Rb and the resulting accumulation of ^{87}Sr since the time ^{87}Rb nuclides first manifested in space-time about 542 Gyr ago (Gargi, 1987, Gargi, 2005, Gargi, 2019) [36, 46, 47]. This concept has been discussed in detail by Gargi, 2019 [36].

As the SG model is in fact a single MS Excel Spreadsheet program, any change in any entity affects all the other entities and the spreadsheet as a whole, and its effect is immediately noticed [45]. Thus, all the entities in the Ruh relation are mutually constrained. In order to ascertain the true value of the various entities such as Rb-Sr isotopic parameters, age of the Earth, decay constant etc., values of the various entities to begin with were presumed which were within the known range of the values found in the literature. These values were later modified by using the interplay of the constraints imposed by the entities on each other. Thus in order to determine the final values of the entities their values were altered one by one by hit and trial method and its impact was observed on the Y-Intercept of the linear array of the Ruh relation. This was done until the linear array showed a NULL Y-Intercept, or was as close as possible to the NULL value. However, the lowest value that could be obtained this way for the Y-Intercept was 0.000000000021 which is virtually a NULL value. That is how the final values of the various entities were inferred.

The final values of the various entities that were inferred this way are as follows:

Age of the Earth:	4.55 Gyr
Decay constant for ^{87}Rb, λ (^{87}Rb):	1.408(10^{-11} yr^{-1})
Rb/Sr ratio of the Earth:	0.031
$^{87}Rb/^{86}Sr$ ratio of the Earth at the time of its formation 4.55 Gyr ago:	0.09536
$^{87}Rb/^{86}Sr$ ratio of the Earth at the present time:	0.089442
$^{87}Sr/^{86}Sr$ ratio of the Earth 4.55 Gyr ago (the beginning Sr isotope ratio):	0.69878
$^{87}Sr/^{86}Sr$ ratio of the Earth at the present time:	0.704698:

The values of the various entities that were deduced by the model under discussion are summarized below:

Age of the Earth:	4.555 Gyr
Decay constant λ for ^{87}Rb:	1.4087(10^{-11} yr^{-1})
Rb/Sr ratio of the Earth:	0.031
$^{87}Rb/^{86}Sr$ ratio of the Earth at the present time:	0.09
$^{87}Sr/^{86}Sr$ ratio of the Earth 4.555 Gyr ago (the beginning Sr isotope ratio):	0.69877
$^{87}Sr/^{86}Sr$ ratio of the Earth at the present time:	0.7047:

It is noticed that values of the various entities indicated by the Isotopic Evolution model are quite similar to those of the SG model. This is highly significant that the two totally independent theoretical models show very similar values for the various entities that affect the Rb-Sr isotope evolution. This lends strong credence to the SG model. If there are slight differences between the values of the entities of the two models it is because of the fact that the age of the Earth in the Isotopic Evolution model is presumed to be 4.555 Gyr, whereas in the SG model it comes out to be 4.55 Gyr. However, as mentioned earlier that in the Isotopic Evolution model it is the framework of the entities that is constrained and within the framework values of the individual entities are fixed. The SG model being a computer model, values of the individual entities were inferred by the interplay of the constraints imposed by the entities themselves on each other. This also is the reason that values of the entities in the SG model could be finely resolved up to several significant digits. However, if the age of the Earth in the model under discussion were to be presumed 4.55 Gyr then the values of the decay constant and other entities would have matched even much more closely with those of the SG model.

Ducharme et al, 2021 carried out U-Pb zircon geochronology of the Flowers River granite from the Flowers River Igneous suite in the Nain Plutonic Suite batholith of north-central Labrador [48]. They reported an age of c. 1281 Myr which they believe is within error of the original 1271 ± 15 Ma age reported by Hill, 1991 [49]. The Igneous suite also comprises several peralkaline granite ring intrusions. Collerson, 1982 reported a much younger Rb-Sr whole rock age of 1262 ± 7 Myr for the peralkaline granite to the NE of their study area [50]. In view of some recent revisions in the ^{87}Rb decay constant used by Collerson, 1982, they adjusted this age with the revised ^{87}Rb decay constant of $(1.3972 \pm 0.0045) \times 10^{-11}$ yr^{-1} (Villa et al., 2015), and obtained an age of 1281 ± 3 Myr (MSWD = 1.2) which they think is in good agreement with the U-Pb ages that they had reported for these rocks [43, 49, 50]. However, when they recomputed the age with the revised decay constant of 1.408×10^{-11} yr^{-1} (Gargi, 2019) the data showed an age of 1271 ± 3 Myr ((MSWD = 1.2), which overlaps with the U-Pb ages they obtained for a subset of Nuklavik Volcanics [36]. They contended that as no peralkaline granite samples analyzed by them yield an age in this range, therefore, they favour the result using the decay constant by Villa et al., 2015 [43]. However, it is their discretion what decay constant for ^{87}Rb to use, but they are writing a scientific paper, so there has to be some sound scientific reason for favouring a particular decay constant over the other. A decay constant is not rejected just because it does not yield a desired or expected age. If this were to be the case then there would be many decay constants based on the expected age of a rock. They rightly mentioned that the existence of peralkaline intrusive phase coeval with the youngest volcanic lithologies cannot be ruled out. Therefore, either of these ages may be correct, meaning thereby either of the two decay constants may be correct. Values of the decay constants are derived based on their own criteria. The decay constants are not selected to suit the expected age of a rock. Also, there can be only one correct value not two for the decay constant. It was already discussed in the foregoing paragraphs that the value (1.3972 ± 0.0045) × 10-11 yr-1 suggested by Villa et al., 2015 for the decay constant of ^{87}Rb is very similar to the values which were rejected about 50 years ago/ So this value cannot be considered a credible value for the decay constant of ^{87}Rb [43]. Also, another point to note is that they are trying to match the U-Pb age with the Rb-Sr age of an intrusive igneous rock. The U-Pb age of an intrusive rock will never match its Rb-Sr age because the blocking temperatures of the two systems are very much different from each other [29, 51-53]. As the blocking temperature of the Rb-Sr system is much lower than the U-Pb system, the age of an intrusive igneous rock given by the Rb-Sr system would always be less than the one given by the U-Pb system. Therefore, the age of 1271 ± 3 Myr (MSWD = 1.2) for peralkaline granites obtained by using the ^{87}Rb decay constant of 1.408×10^{-11} yr^{-1} (Gargi, 2019) is the correct age [36].

Conclusion

The intent of this paper was to develop the best combination of the beginning and the present-day Sr isotope ratios that best describes the Rb-Sr isotope evolution in the Earth. These two ratios, particularly the initial Sr isotope ratio, cannot be determined directly but must be inferred by indirect evidence. Additionally, these two ratios are not only interrelated but are also constrained by all those factors that influence their isotopic evolution. Therefore, they should not be considered in isolation from each other or from all those other factors that have a bearing on their isotopic evolution. Thus, this study shows that within the framework of the various entities such as age of the Earth, decay constant of ^{87}Rb, present-day ^{87}Rb/^{86}Sr ratio and the isotopic characteristics of the primeval mantle as reflected by the initial Sr isotope ratio of Amitsoq gneisses, the model for the Rb-Sr isotope evolution in the planet Earth that stipulates the ALL value of 0.69877 as the beginning Sr isotope ratio and 0.7047 as the present-day ^{87}Sr/^{86}Sr ratio appears to be the most plausible and apt model. Furthermore, it was also shown that for this model to be feasible, the decay constant λ for ^{87}Rb must be revised to a lower value of $1.4087 \pm 0.0047 (10^{-11}$ yr$^{-1})$. This model also requires that the present-day ^{87}Rb/^{86}Sr ratio for the Earth should be 0.09, and age of the Earth must be assumed to be equal to the mean age of the meteorites, that is, 4.555 Gyr. Other models for the planet Earth specifying ALL as the beginning Sr isotope ratio and 0.7045 or 0.7052 as the present-day ^{87}Sr/^{86}Sr isotope ratio are not considered feasible either because of the constraint imposed by the initial ratio of the Amitsoq gneisses or because of the very high/very low value required for the decay constant of ^{87}Rb for such models. Similarly, models involving BABI as the initial Sr isotope ratio and any of the other present-day Earth parameters are also not feasible for the same reason.

Further, the SG model is a computer model wherein each entity is individually constrained. Because of this the entities in the SG model are better constrained and thus their values are very finely resolved to several significant digits; and therefore, are more likely to be apt and credible. Hence values of all the entities as indicated by the SG model are the recommended values.

Data Availability

All data generated or analyzed during this study are included in this published article.

All the data used in this article are not derived from any kind of laboratory analysis or fieldwork. It is mathematical data derived from manipulating radioactivity equations. So, there is nothing proprietary in the data that I have used in this article. However, in one table the data used comes from some other authors' laboratory data and for that, all the references have been provided.

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