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Solar System, Meteorites, Moon: A 87Rb-U decay connection

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This contribution is aimed at summarising elements of knowledge with regard to the use of chondritic meteorites for comparison of decays of unstable isotopes. The object of the comparison is to connect the poorly known 87Rb decay rate (error about ±1.6 % 1s; see Odin, Audi & Bé, this volume, ref. 330) with the comparatively precisely known U decays (error about ±0.2 %). The commented information mostly comes from a few published papers and additional recent developments undertaken at IPGP Paris.

1. Rb-Sr systematics

In 1982, Minster et al. published a paper suggesting the revision of the decay constant of 87 Rb using the assumed age of meteorites at 4,555 ± 10 Ma itself derived from the U-Pb age of the same objects. The principle can be summarised as follows.

Among meteorites, the H, LL and E-type chondrites have been considered. Independently plotted on a isochron diagram, the Rb-Sr data used by the authors (whole-rock chondrites) allow to calculate the analytical ages of 4,518 ± 39 Ma, 4,486 ±20 Ma and 4,508 ±37 Ma for H, LL, and E chondrites respectively. The analytical precision of these ages is first dependent of a good reproducibility of the analytical facility. The accuracy of the measurements is not known with confidence.

The value of 1.42 10-11/a was used for the 87Rb decay (corresponding to the half-life = 48.8 ±0.8 -1s- Ga mostly derived from Neumann & Heuster 1974; 1976, and recommended by the Subcommission on Geochronology). Only a few meteorites of the three quoted types fall out of (and above) the isochrons and were removed from the data set. For the removed material, it is suggested that shocks have disturbed the Rb-Sr system. The three ages of the three groups of meteorites being undistinguishable, Minster et al. justifiably combine all data for derivation of a best age of 4,498 ±15 Ma. This age is understood as the age of accretion of the chondritic parent bodies. The precision of this latter age is significantly increased compared to the previous ones and a sharp isochronism of the accretion of these distinct parent bodies can be concluded.

If contemporaneity of the closure time of the Rb-Sr (whole-rock) system and of the U-Pb systems is assumed as can be reasonably inferred from the nature of the dated material, the geochronological ages obtained using the two systems should be similar. But Minster et al. observe that when concordant U-Pb ages are obtained from diversified meteoritic material (whole-rock chondrites, chondrite minerals, or achondrites) they fall around 4,555 ±10 Ma (using Jaffey et al.'s decay constants recommended by the Subcommission on Geochronology). The age difference between the U-Pb systems and the Rb-Sr system is considered too large for being explained by supposedly small different closure times of these isotopic systems. Therefore, the authors suggest to recalculate the decay constant of 87Rb for unifying the ages of the meteorites taking into account the fact that the decay constants of 235U and 238U are better known (more precisely) that the one of 87Rb. This led the authors to suggest a decay of 1.402 ±0.008 10-11/a for 87Rb (or a half-life of 49.4 ±0.3 Ga).

The suggested value is fully consistent (at a 1s level) with the best direct measurement of the 87Rb decay (48.9 ±0.4 Ga: see Odin, Audi & Bé, this volume, ref. 330).

2. U-Pb systematics of refractory inclusions and phosphate in chondrites

In 1994, Göpel et al. measured the U-Pb isotopic composition of 14 secondary phosphates separated from unshocked ordinary chondrites and 20 whole-rock fragments of the same meteorites. They calculated ages between 4,419 ±2 Ga and 4,614 ±4 Ga for rock fragments and between 4,563 ±1 Ma and 4,506 ±1 Ma for the phosphate fractions. The rock fragments show more or less pronounced excess radiogenic Pb. This excess is related to a recent disturbance and is observed in all bulk samples of chondrites which, thus and unfortunately, cannot be used to measure the original age of this kind of material using the U-Pb systems. But the phosphate separates apparently allow to derive realistic ages for their formation which is accompanied by a significant enrichment of U (20 to 150 times) compared to the bulk-rock. In addition, the analytical precision of these ages is very good. The authors conclude that the oldest age of these secondary minerals (4,563 Ma) provides a younger limit for the accretion time of the meteoritic parent bodies.

In comparison with the previously accepted age of 4,555 (±10) Ma, the new U-Pb ages document a slightly older mean age for the time of accretion, though this new value remains analytically consistent. This slightly older age is supported by the quotation of a Pb/Pb age of 4,566 ±2 Ma for the refractory inclusions of the Allende meteorite. The age of the accretion process would thus be strictly constrained between the age of the Allende inclusion and the age of the oldest phosphate. If the Allende age is used as the correct Rb-Sr age for the whole-rocks dated by Minster et al. (1982), then, the half life of 87Rb should be proportionally increased from 49.4 to 49.5 Ga (49.4 x 4,566 : 4,555).

According to Göpel et al., the meaning of the calculated ages of the phosphates must be discussed however.

1- The concordant nature of the U-Pb systems is not established for sure due to the comparatively short half life of 235U which results in a sub-linear portion of the Concordia curve for ages older than 4 Ga (very small change in the 235U/207Pb ratio for large 238U/206Pb changes).

2- The authors also comment that the sand-box model (schematically, a well defined closure time followed by lack of isotopic exchanges with the exterior) used for interpreting isotopic data in terms of ages may not be valid. This is due to the fact that one ignores the precise thermal history of the parent bodies of chondrites and its timing. In short, phosphates may have been submitted to original isotopic disequilibrium because they could have differentially incorporated U and Pb (the latter easily substitutes for Ca) depending on the relative mobility of these two cations during metamorphism.

3- Accretion and thermal history of the parent bodies are presently described following several models. According to Göpel et al (1994), no one of these models fully agrees with isotopic and petrographic observations, and relevant thermodynamic constraints as known to date. So that, the interpretation of the difference of 60 Ma between the U-Pb “youngest” and “oldest” phosphate apparent ages as a record of the duration of a monotonous cooling inside a layered body is not proved for sure.

In conclusion, the apparent U-Pb ages of phosphates do not definitely constrain a specific model for the structure and thermal evolution of the chondritic parent bodies. As far as the decay constants are concerned, the oldest U-Pb apparent age of secondary phosphate can be used to document a minimum age for the accretion procedure.

3. About the “age” of the meteorites and the “Solar System”

Elements of knowledge about the age constraints and significance of the age of meteorites have been summarised in the paper by Allègre et al. (1995). Thanks to its precision, the Pb-Pb “dating method” (i. e. the combined 235U / 238U decays) allows to suggest that what is called the “age of the

Solar System" (i.e. the individualisation of the material of our nebula with regard to the rest of the cosmic material) is precisely constrained at 4,566 +2/-1 Ma (Manhès et al., 1988, in Allègre et al., 1995). This is the mean age calculated for the refractory mineral inclusions within the Allende meteorite. The Pb-Pb age of the meteorites can be assumed to be the same or nearby, in the sense that their accretion occurred during the 8 Ma which followed the initiation of the Solar System as concluded by Allègre et al., (1995). This interval of time (8 Ma) originates from the comparison between 1- the Pb-Pb ages of secondary phosphates from chondrites calculated between 4,563 and 4,506 Ma (Göpel et al, 1994); 2- the age of the refractory inclusions of Allende, and 3- the age of basaltic achondrites which gave Pb/Pb ages between 4,558 and 4,530 Ma. The oldest age at 4,558 ±1 Ma indicates that some meteorites were already submitted to magmatism 8 Ma after their accretion and thus, this is considered as proving that they were already fully accreted (see Figure).

The relationship between the U-Pb systematics and other (K-Ar, Rb-Sr, Re-Os) systematics is model-dependent. This means that the closure times of the U-Pb, Rb-Sr, Re-Os systems are not known for sure to be contemporaneous due to the imprecisely known thermal history of the chondrite parent bodies. Due to different behaviours of the Rb-Sr and Re-Os isotopes compared to the Pb-Pb one versus the thermodynamic constraints, it is suspected that the apparent ages of the different isotopic systems MAY differ by as much as 0.1 Ga. In fact, K-Ar data would suggest this **if one considers that the decay constant and abundance ratio for 40K are correct**.

The synthetic scenario proposed by Allègre et al. (Figure 1) suggests that condensation of refractory minerals occurred at 4,566 Ma (Allende); accretion of H chondrites started shortly after at a minimum age of 4,563 Ma (maximum U-Pb age of phosphate); volcanism, and thus melting of the interior of large parent bodies, began 4,558 Ma ago (maximum U-Pb age of basaltic achondrites); metamorphism would have occurred up to about 4,500 Ma ago; and possible resetting of the K-Ar dating system by collision between parent bodies (brecciation connected to additional accretion on very large bodies such as the Earth) would have occurred up to 4,450 Ma ago (age of the core segregation and atmosphere out gassing on Earth according to Allègre et al.).

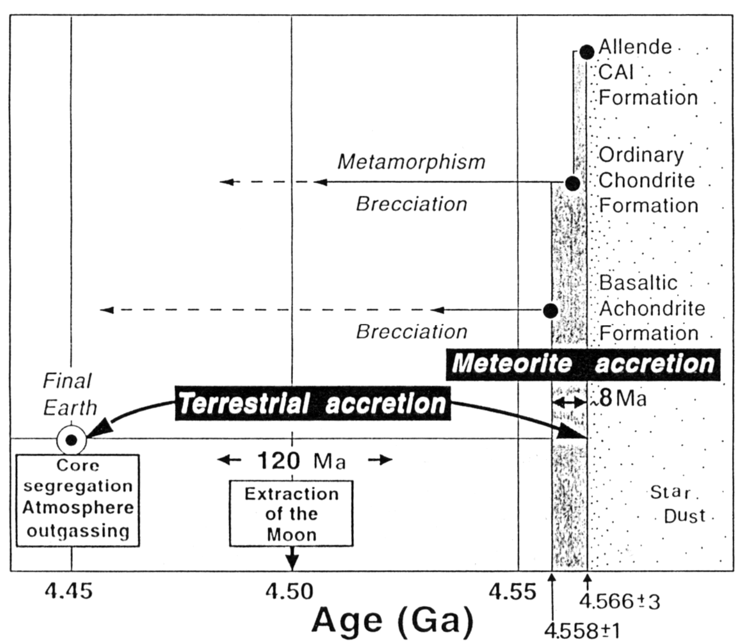

Figure 1. The isotopic ages of chondrites within the Earth and meteorite historical scenario of Allègre, Manhès & Göpel (1995). (Borrowed from Allègre et al. 1995, Figure 10 of the authors).

4. Conclusions and perspective

The thermal history of the parent bodies of the chondritic meteorites is not know precisely enough as far as a precision of better than 1% would be necessary for definitely constraining the dimensional relationship between the half-lives of the different isotopic systems. With regard to the interpretation of the unstable isotopic data, a first problem is the fact that the closure time of the diverse isotopic systems may have occurred during a significantly long interval of time (up to about 100 Ma) compared to the time elapsed since then. A second problem is that the interpretation of the analytical measurements in terms of historical ages is **model dependent**.

In this situation, the use of the isotopic ratios of the different dating systems for intercomparison of decay constants is not unequivocal in general. The decay constant of 87Rb can however be approached using the "sub contemporaneous" historical age of the closure time of the U-Pb systems. The Rb-Sr whole-rock isochrone age of chondritic meteorites is most certainly older than 4,506 Ma (the younger U-Pb age of secondary phosphates). As a first approximation, it can also be postulated as equal to 4,566 Ma (U-Pb age of refractory minerals of the Allende chondrite) or slightly younger (4,563 Ma which is the U-Pb age of the oldest chondritic phosphate). If one uses the approach of Minster et al. (1982) and taking into account both the new U-Pb data available and a 0.2 % uncertainty for the decay constants of U, **a half-life of 49.5 ±0.4 Ga** can be calculated for 87Rb. This is a maximum value if one considers that metamorphism may have disturbed the Rb-Sr whole-rock isotopic system after the time of accretion. However, this value can also be considered a solid basis on several grounds: i- the samples used as whole-rocks were large enough to actually represent the Rb/Sr chondritic system; ii- the analysed pieces of thermally affected chondrites always showed higher 87/86Sr initial isotopic ratios in the internal isochrones compared to the whole-rocks. Considering these two facts, the Rb-Sr combined isochrone age most probably correspond to the age of accretion of the chondritic parent bodies and thus to the age of refractory minerals of the Allende chondrite.

In order to further improve the precision of the comparison, it could be possible to consider again the chondritic meteorites and apply the more precise Rb/Sr analytical techniques available to day. In addition to chondritic meteorites, there would be another promising material able to be used as a source for age comparisons. Volcanic rocks 3.3 to 3.8 Ga old are known from the moon. These rocks are very old and have accumulated enough radiogenic isotopes to be measured on small samples. Such rocks can be assumed to have been closed at the same time for 235U, 238U, 87Rb, and 40K systems. Compared to terrestrial material, these rocks have not suffered significant alteration of their isotopic systems.

References

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