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ArAR — A software tool to promote the robust comparison of K–Ar and $^{40}Ar/^{39}Ar$ dates published using different decay, isotopic, and monitor-age parameters

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ABSTRACT

The comparison of K–Ar and $^{40}Ar/^{39}Ar$ geochronologic data published by different laboratories is markedly hindered by the inconsistent use of the parameters necessary to convert isotopic analyses to dates. This problem is particularly acute when we try to evaluate the significance of datasets obtained prior to the development of community consensus values for basic decay constants, isotopic abundances, and the ages of common monitor minerals. Unfortunately, the effect of using different parameters for the same dataset can sometimes exceed the quoted analytical precision of derived dates. We created the *Argon Age Recalculator*, or *ArAR*, to help researchers account for such discrepancies in a simple, efficient manner, allowing for more robust comparisons among datasets and more effective compilation of existing datasets using self-consistent parameter sets. *ArAR* is freely available as a platform independent executable application at: http://group18software.asu.edu.

1. Introduction

Isotope geochronology provides invaluable timing constraints on the evolution of planetary bodies from which we have samples. The $^{40}Ar/^{39}Ar$ method, for example, has been used extensively since its development in the mid-1960s (Merrihue and Turner, 1966). Since that time, however, there have been significant changes in our understanding of the pertinent decay constants and isotopic abundances, and new research continues to refine our understanding of the ages of the minerals that are commonly used to monitor the irradiation parameters necessary to calculate $^{40}Ar/^{39}Ar$ dates. All of this means that, while archival data from older studies remain scientifically valuable, the dates originally calculated from them may not be directly comparable to more recent datasets. Recognizing a pressing need for some way to easily correct older K–Ar dates for secular changes in the accepted values of physical parameters, Dalrymple (1979) published tables of conversion factors that would allow K–Ar dates based on one of two old parameter sets to be translated into the system of constants recommended by the International Union of Geological Sciences (IUGS) in 1976 (Steiger and Jäger, 1977). Since Dalrymple's seminal paper, however, accepted values for a variety of parameters have continued to evolve. In this contribution, we have generalized Dalrymple's approach and created a software tool to enable the rapid conversion of both K–Ar and $^{40}Ar/^{39}Ar$ dates from any parameter set to another.

2. Background

The K–Ar and $^{40}Ar/^{39}Ar$ dating techniques are based on the ^{40}K–^{40}Ar isotopic system, where ^{40}K naturally decays to produce ^{40}Ca and ^{40}Ar by beta-minus (β^-) decay and electron capture (ε),[1] respectively. With knowledge of the relative abundances of the stable isotopes of K (^{39}K, ^{40}K, ^{41}K), and the β^- and ε decay constants of ^{40}K (λ_β and λ_ε, respectively), a K–Ar age can be determined by measuring the concentrations of K and radiogenic ^{40}Ar (denoted $^{40}Ar^*$) in a sample (Aldrich and Nier, 1948; Dalrymple and Lanphere, 1969). In the $^{40}Ar/^{39}Ar$ method, some of the stable ^{39}K in a sample is converted via the $^{39}K(n,p)^{39}Ar$ reaction to ^{39}Ar ($^{39}Ar_K$ hereafter) by irradiation with high-energy ('fast') neutrons. In order to monitor how much of the ^{39}K is transformed to $^{39}Ar_K$ during

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[1] Beckinsale and Gale (1969) inferred an additional decay mode for ^{40}K where ^{40}Ar is generated by positron (β^+) emission, but this decay mode is considered negligible and is generally ignored (e.g., Renne et al., 2010).

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irradiation, a K-bearing mineral with an independently determined age is co-irradiated and subsequently analyzed alongside the unknown sample. This allows ages to be determined relative to the monitor mineral by measuring the $^{40}Ar^{*}/^{39}Ar_K$ ratio of an irradiated sample (Merrihue and Turner, 1966; McDougall and Harrison, 1999).

Since the K–Ar and $^{40}Ar/^{39}Ar$ techniques were first introduced, the accepted values have periodically changed (or new ones have been proposed) for the isotopic abundances of K (e.g., Nier, 1950; Garner et al., 1975; Steiger and Jäger, 1977; Endt, 1990; Böhlke et al., 2005), ^{40}K decay constants (e.g., Aldrich and Wetherill, 1958; Beckinsale and Gale, 1969; Steiger and Jäger, 1977; Min et al., 2000; Renne et al., 2010, 2011), and ages of common monitor minerals (e.g., Fish Canyon sanidine (FCs): Dazé et al., 2003; Jourdan and Renne, 2007; Kuiper et al., 2008; Renne et al., 2010, 2011; Rivera et al., 2011). As a consequence, K–Ar and $^{40}Ar/^{39}Ar$ ages that have been published at different times or by different laboratories do not all use the same values for these quantities. This can be a source of significant systematic uncertainty when comparing published K–Ar and $^{40}Ar/^{39}Ar$ dates, particularly to other geochronometers (e.g., U/Pb in zircon; Min et al., 2000). In some cases the discrepancies can be greater than the analytical uncertainties of the published dates. For example, a 1.000 ± 0.010 Ma (1% uncertainty at 2σ) K–Ar date published with pre-1976 constants (e.g., with the K isotopic abundances of Nier, 1950 and the ^{40}K decay constants of Aldrich and Wetherill, 1958) would become 1.027 ± 0.010 Ma when recalculated with the values recommended by the IUGS in 1976 (Steiger and Jäger, 1977; Dalrymple, 1979). Furthermore, the offsets are not uniform in magnitude or direction when recalculating published dates due to the non-linear nature of the K–Ar and $^{40}Ar/^{39}Ar$ age equations. While a pre-1976 date of ~1 Ma is 2.7% 'older' when recalculated to the IUGS 1976 recommended values, a ~4200 Ma date becomes ~1.6% '*younger*' (Dalrymple, 1979).

3. Motivation

Development of the software introduced here — the *Argon Age Recalculator*, or *ArAR* — was motivated by a desire to make the process of recalculating K–Ar and $^{40}Ar/^{39}Ar$ dates as rapid and straightforward as possible, allowing both geochronologists and non-specialists to account for the inconsistent usage of K isotopic abundance values, ^{40}K decay constants, and the ages of common monitor minerals that can hinder the robust comparison and interpretation of data published in disparate sources. The program uses customizable libraries of K isotopic abundances, ^{40}K decay constants, and monitor mineral ages, which allow the end user to quickly select the appropriate values to recalculate K–Ar and/or $^{40}Ar/^{39}Ar$ dates, and to easily adjust as new research continues to refine the values of these parameters. The end user may graphically preview the effects of recalculating K–Ar and $^{40}Ar/^{39}Ar$ dates, making it easy to assess the magnitude of the discrepancies based on their current selection of constants. In addition, *ArAR* includes a tool that enables more advanced users to intercalibrate a sample relative to a 'primary' standard with a known K–Ar age and multiple 'secondary' standards using the methods of Renne et al. (1998). This is useful when determining the age of a monitor mineral that was calibrated relative to multiple standards, provided that isotopic and/or age data are available for all samples that were involved in the calibration. Finally, the program tracks all of the values that are used during age recalculations and sample intercalibration, allowing the end user to export a change log for easy reference. *ArAR* is written in Java™, and is freely available as a platform-independent executable application at: http://group18software.asu.edu.

4. Calculations: accounting for discrepancies in K isotopic abundance values, ^{40}K decay constants, and monitor mineral ages

To recalculate a previously published K–Ar or $^{40}Ar/^{39}Ar$ date, t_o, one must know the values of the partial decay constants of ^{40}K, λ_{β_o} and λ_{ε_o}, and the total decay constant, $\lambda_o \equiv \lambda_{\beta_o} + \lambda_{\varepsilon_o}$, that were used to calculate t_o. (Note, only the value of λ_o is needed to recalculate $^{40}Ar/^{39}Ar$ dates.) For a K–Ar date, it is also necessary to know what values were originally used for the relative isotopic abundances of K. In particular, the value that was used for the abundance of ^{40}K relative to total K, $^{40}K_{ao}$, is required. Because $^{40}Ar/^{39}Ar$ dates are determined relative to a monitor mineral that is co-irradiated with the unknown samples, the original value that was used for the age of the monitor mineral, t_{m_o}, must be available to recalculate a $^{40}Ar/^{39}Ar$ date. If all of these 'old' values are known, then a K–Ar or $^{40}Ar/^{39}Ar$ date can be recalculated to use the alternate, or 'new,' values: λ_β, λ_ε, λ, and either $^{40}K_a$ or t_m.

The 'new' values should be chosen carefully to ensure that they are internally consistent. For example, determination of the ^{40}K decay constants

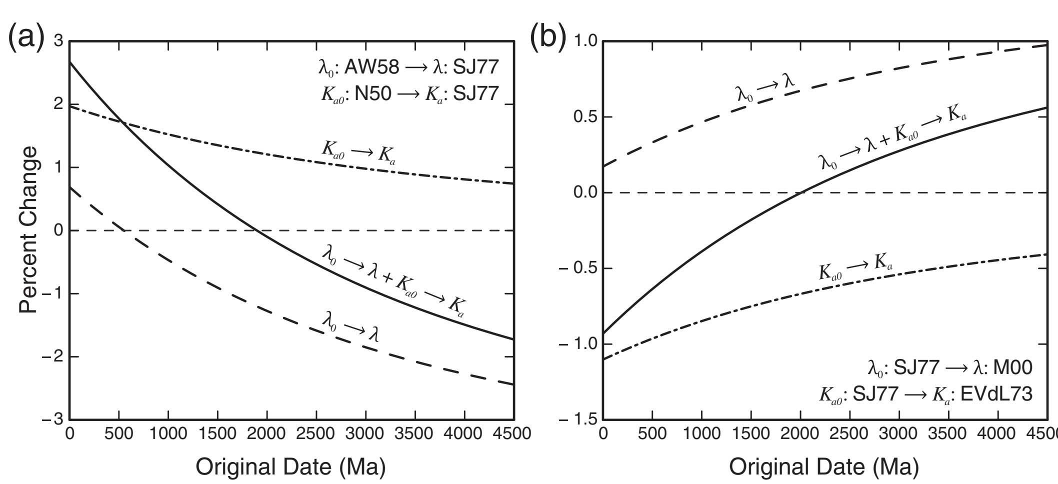

Fig. 1. Examples of the effects of employing Eq. (1) to recalculate K–Ar dates to account for changes in the values of the ^{40}K decay constants and relative isotopic abundances. Black dashed lines represent changes due to differences in the decay constants ($\lambda_o \rightarrow \lambda$), dot-dashed lines represent changes due to differences in the isotopic abundance values ($K_{ao} \rightarrow K_a$), and solid lines represent changes due to differences in both quantities ($\lambda_o \rightarrow \lambda + K_{ao} \rightarrow K_a$). The thin, dashed grey lines represent no change. (a) The effects of recalculating K–Ar dates from the 'old' values of Aldrich and Wetherill (1958) (λ_o, AW58) and Nier (1950) (K_{ao}, N50) to the 'new' values of Steiger and Jäger (1977) (λ and K_a, SJ77). (b) The effects of recalculating K–Ar dates from the 'old' values of Steiger and Jäger (1977) (λ_o and K_{ao}, SJ77) to the 'new' values of Min et al. (2000) (λ, M00) and Endt and Van der Leun (1973) (K_a, EVdL73).