

ISOTOPE GEOCHRONOLOGY: MODELS VERSUS REALITY

*INVITED LECTURE PRESENTED AT THE 12TH
GEOCHRONOLOGICAL CONFERENCE “DATING OF MINERALS
AND ROCKS XII”, UMCS, LUBLIN, 16.10.2014*

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ABSTRACT

Majority of the papers on isotopic dating of minerals and rocks have been devoted to some new geochronological data important for geology or to developments of apparatus and improvements of laboratory techniques and procedures. However, there are some basic problems concerning credibility of the data published (including the “error brackets”), and their geological meaning, which rarely are touched on.

The issues to be raised may be grouped into two categories: (1) distortion in the course of preparatory operations and final measurements, and (2) some doubts concerning geological interpretation of the data and the models used. First of all it should be realized that what we really analyse in a spectrometer is not an existing rock or mineral but a powder produced by many steps of consecutive procedures, each of them capable of irreversibly distorting the original composition.

Keywords: isotope geochronology, models, dating, mass spectrometry, uncertainty

The routine sequence of operations begins with crushing and grinding, when a selective pulverisation attacks feldspars much more than micas – not to mention quartz. The resulting modification of the original composition may be very

substantial for whole-rock samples. Special care and microscopic control are necessary when age homogeneity may be suspected. This is the case of migmatites and other non-homogeneous rocks (e.g. paleovolcanites consisting of relic pyroxenes surrounded by secondary chlorites, or rocks with well-developed reaction zones). The problem of homogeneity applies also to separated minerals, which often contain tiny inclusion of minerals differing in isotopic composition and/or age. Simple sieving may result in complete loss of tiny zircon grains in favour of large ones, the process strongly distorting the composition of the entire zircon population which often is a mixture, not only of sizes but also ages.

While the aforesaid effects seem to be important only in some special cases, the jaw-crusher “memory” constitutes ubiquitous danger of serious, though undervalued, contamination of the whole-rock samples. Even the most careful cleaning of any jaw-crusher cannot guarantee that the machine becomes absolutely devoid of any traces of a previously treated rock. There are too many recesses, nooks, scratches and some surface imperfections. A significance of such an effect was tested by a simple experiment [1]: the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio was measured in a Precambrian gneiss and a Jurassic limestone in two sequences (gneiss – limestone – gneiss, and limestone – gneiss – limestone). Contamination of the limestone granulated after the gneiss was insignificant, while the effect was very serious for the gneiss granulated after the limestone, the difference between the two rocks in the Sr abundances being the likely explanation. It appears that the magnitude of the contamination depends on three parameters: the ratio of the mass of contaminating matter (dirt or some remnants of the previous rock) to the mass of the sample; the ratio of the element concentrations; and the ratio of the isotope ratios to be measured. It turned out that when the consecutive rocks are very different in the isotope ratios the effect may affect the 3rd decimal place even at very careful cleaning. Therefore, not only thorough cleaning but also a rational sequence of rocks is strongly recommended. An isotopic analysis of a Tertiary basalt crushed after a Precambrian gneiss may be completely worthless even at the most sterile chemical operations and a very high precision of the spectrometric measurements. It should be stressed that contamination introduced in the course of preliminary operations is irreversible and it decisively influences the final spectrometric values. Besides, it is difficult to detect, assess quantitatively, and make proper corrections. Contamination may occur also in the course of consecutive chemical operations and it can affect cleanness of water, reagents, vessels, air, reliability of the spike solutions and their stability, efficiency of chromatographic separation – but that is relatively easy to detect, assess and reduce.

Publications concerning the magnitude of errors (preferably “uncertainties”) are abundant, but almost completely restricted to spectrometric analyses. Actually the apparently precisely determined error brackets expressed by “±” related to an age comprise the spectrometric errors only. It is true that only such uncertain-

ties can be precisely determined. However, we are deluded by apparently high precision of an analysis, while the spectrometric error should be grossly enlarged by the errors of different parentage, if they are to be understood as uncertainty of age.

Various models so far introduced usually are expressed in a form of isochrone diagrams. The initial ratio is either taken from minerals devoid of the radioactive nuclide, or obtained by the least squares method. However, as pointed by Zheng [2] to accept such a calculated value, and to take it for granted for a series of whole rock samples sometimes may be an oversimplification in view of the processes of fractionated crystallisation, partial melting, mixing, or metamorphism. An assumption of a perfect homogeneity of the isotopic ratios in rocks at the initial moment is clearly related to the scale of the object. It may be acceptable for a range of meters, but seems improbable for a large body of anatectic origin. Consequently it is related to the sampling pattern and its conscious choice.

The analytical data representing isotopic ratios are converted to an “age” value expressed in years by means of a tacitly assumed model. Therefore, in order to obtain a reliable age value it is not enough to carry out the analytical operations with the greatest possible care but also to be confident of the proper model applied, a model which expresses the geochemical evolution of the rock examined.

It touches upon the problem of what we date. For a geologist an age of a rock relates to the rock’s position in the architecture of the complex. It is an age of the form, not substance. Sequence of rock layers, intrusive contacts, cross-cutting of veins or microtectonic elements – all the classical tools of geology – refers to the forms. On the other hand, the isotope geochemistry studies the matter only, disregarding the forms of occurrence. Thus there is a substantial difference as regards the object of an analysis, and consequently it may be the source of misunderstanding. Analogous misunderstanding appears when a cooling age is tacitly regarded as an age of crystallisation.

Another remark is related to the models used to describe the evolution of Nd-Sm system. The basis of the model are the *CHUR* or *DM* values taken as the initial ratios. Consequently the very idea of the age of a rock becomes blurred. The “age” value obtained is related to the isotopic evolution of the matter which later became solidified as the rocks. By no means it may be treated as the age of a rock. Sometimes it is labelled as a *crust-formation age* though some authors raised doubts which resulted in the two-stage models.

A process of geological interpretation of the isotopic data is based on comparison of the data with the model expectation which is only a simplification of the processes which actually occurred in nature. Such an approach stems from the principle of uniformity. However, the problem becomes disputable when we proceed to very distant times and depth zones. Certainly our knowledge of the

processes which operated during Precambrian times is definitely insufficient. It especially applies to the processes acting within the mantle, and the exchange reactions between the mantle and the crust. Have such processes been constant for the last 4.6 billion years? How far back in time are we entitled to apply the geology-based models to “pre-geological” times? These are somewhat perplexing questions to which it is difficult to give a well-grounded answer. Without it, any petrogenetic interpretations of the Sm-Nd or Lu-Hf systems remain nothing more than working hypotheses, purely theoretical models.

Certainly the models we use as a basis for dating are gross simplification as compared to the complex and poorly recognised processes which underwent in nature. This lecture was based on some excerpts from a monograph by J. Burchart and J. Kral *Isotope record of the Earth's past* (in Polish *Izotopowy zapis przeszłości Ziemi*) prepared for publication.

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