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Problems in radiometric data interpretation

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ABSTRACT. — The Rb/Sr fictitious isochrons are a simple linear correlation of the $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios of cogenetic but no-comagmatic rocks. This is the case of radiometric data of some Tertiary intrusive bodies of Eastern Alps that can be interpreted as the result of an interaction process between a common parental magma with low $^{87}Sr/^{86}Sr$ ratio and a crustal component.

Key words: Tertiary granitoids, Rb-Sr systematics, fictitious isochron, mixing process, Eastern Alps.

RIASSUNTO. — Le « isocrone di mixing » sono state scelte come un esempio fra le varie problematiche che vengono incontrate nel corso degli studi radiometrici. Esse costituiscono il risultato di un processo di interazione fra due componenti, di natura diversa, in molti eventi magmatici e potrebbero essere confuse con le familiari e più significative « rette isocrone ».

La relazione lineare fra la composizione isotopica e l'inverso della concentrazione dello Sr, che risulta dal mixing, è un dato diagnostico di questo processo; in questo la determinazione dell'età può essere effettuata (molto spesso con approssimazione per difetto) solamente attraverso i concentrati minerali.

Sulla base della suddetta relazione, la genesi magmatica dei corpi plutonici oligocenici di Vedrette di Ries, Cima di Vila e la porzione terziaria del massiccio di Bressanone può essere ricondotta ad un processo di interazione fra un fuso proveniente da una sorgente con basso rapporto $^{87}Sr/^{86}Sr$ ed un componente crostale.

Parole chiave: plutonismo oligocenico, sistematica Rb-Sr, « isocrone di mixing », contaminazione, Alpi Orientali.

Introduction

The fundamental role of radiometric geochronology in Earth Sciences is now universally accepted; its help as a tool to settle controversies is more and more needed. However, it can cause many a perplexity if its results are used inappropriately or hurriedly. Undoubtedly, geochronology's role in Earth Sciences is to introduce quantitative criteria, but this role cannot be restricted to providing numerical data, and should instead take into account the scientific value of geochronological investigations per se.

Only the art of grasping the most appropriate interpretation for the radiometric data allows their complete exploitation; the difficulty of this art also dispels the aura of «dryness» and automaticity which still partly surrounds quantitative methods. It is therefore true that radiometric geochronology must answer questions with increasing precision, but it is also true that these answers will depend on the quality of the user's interpretations.

The applicability of radiometric geochronology

The capability to resolve small time intervals obviously depends on the development of analytical and instrumental techniques. This development not only entails a greater analytical precision but also allows to extend the applicability of the various dating methods to an increasing number of rocks of an increasingly wide age range.

But it would be a dangerous illusion to think that this development entails some kind of infallibility of radiometric geochronology: although its foundations are valid, samples not always fulfill the applicability requirements. All dating methods are plagued by «difficult» situations: ideal cases are pratically rare in geochronology and are usually found only as theoretical examples in textbooks.

Disturbing factors such as excess argon, detritic zircon crystals and radiogenic daughter diffusion have been found to be all frequent, making the interpretation of experimental data difficult.

Listing all the problems encountered in radiometric geochronology, in addition to those mentioned above, would require a massive effort and would only be tedious for the reader; every investigation is a case in its own right, where the complexity of the data is determined by a multitude of causes: I will therefore chose one «real-life» example to show some of the problem-solving approaches which can be used.

I will now set out to describe the procedure of Rb-Sr total rock isochron, its uncertainties and its failures (this procedure is very extensively used, and the writer has a long direct experience of it). We recall that, in *any* isotopic system, the construction of an isochron from a suite of comagmatic rocks dates the time when all had the same isotopic composition.

This requirement, i.e., that the initial isotopic composition was uniform is supplemented by the requirement that the analyzed rocks behaved as closed systems with respect to gain and/or loss of the elements relevant to the chosen dating method.

Obviously, if these two requirements are fulfilled, the obtained age will be reliable. Unfortunately, there is no direct check of this fact.

An indirect one is provided by comparing the analytical uncertainty of the measurement with the scatter of the data points about the best fit line.

If the scatter was the only reliability test, interpreting Rb/Sr data would be trivial: the ages of magmatism, metamorphism and diagenesis could always be determined from a suite of suitable rocks provided they were not disturbed during their geological history. But unfortunately a Rb/Sr isochron on cogenetic samples can be vanified by other causes: (*a*) a very small variation in the Rb/Sr ratio among the samples; (*b*) a heterogeneous initial isotopic composition.

Phenomenon (*a*) is determined by a lack of chemical fractionation in the magmatic body or metamorphic or sedimentary formation; this causes the Sr isotopic composition of the different samples to remain almost uniform throughout time, so that the resulting isochron has little, if any at all, precision.

Possibility (*b*), as we shall see in some detail, can deceitfully simulate an isochron array which is totally devoid of geological significance.

Let us consider a composite pluton made up of various intrusive units. In principle, this would be the ideal situation for a geochronological investigation: a series of lithotypes offering a wide choise of rock-types from which to derive a well-defined isochron. But, alas, magmatic cogeneticity does not guarantee the uniformity of the Sr initial isotopic composition: during magmatic evolution there can be additional processes which alter the original isotopic signature and which often cannot be traced by other means. Moreover, this isotopic modification is frequently associated with a variation in the Rb/Sr ratio: it is then understandable that the distribution of the modified points simulates an isochron. As for the reason why a suite of cogenetic magmatic rocks can have different Sr initial isotopic compositions, the most favoured explanation in literature is the interaction of the primary magma with a second component, such as: (*a*) «unmixing» as defined by COMPSTON & CHAPPEL (1979); (*b*) mixing between two magmas of different nature; (*c*) assimilation; (*d*) different episodes of partial melting of a heterogeneous source region, be it in the mantle or in the crust. MCCARTHY & CAWTHORN (1980) attribute the variations in Sr initial isotopic composition in a set of genetically correlated magmatites, to a very extreme differentiation process which progressively increased the Rb/Sr ratio, and consequently the $^{87}Sr/^{86}Sr$ ratio, in the residual magma.

A case study: Cainozoic granitoids in the Eastern Alps

a) General remarks

Let us now study the implications and

possible interpretations of some literature data on Cainozoic magmatites in the Eastern Alps.

A systematic Rb/Sr investigation on the magmatic activity which affected the Italian sectors of the Alps during the Cainozoic, mainly the Oligocene, is now almost complete (Borsi et al., 1978a, 1979; Del Moro et al., 1981, 1985a; Bigioggero et al., 1983; Venturelli et al., 1984). Radiometric data (Del Moro et al., 1984) show that the occurrence of an early phase (Upper Eocene) is restricted to a small part of the Adamello batholith; also a late phase of the post-collisional calc-alkaline magmatism is found in the easternmost Alps (Deutsch, 1984). The majority of radiometric ages was obtained by K/Ar and Rb/Sr on mineral separates; Rb/Sr whole-rock isochrons are hampered both by the variability of the Sr initial isotopic composition and of the small range of variation in Rb/Sr ratios. Only in two cases it has been possible to obtain a whole-rock isochron: for the granitic portion of the Rensen massif (Borsi et al., 1978 a) and for a small portion of the Vedrette di Ries massif, north of Lake Anterselva (Borsi et al., 1979).

These two isochrons were not based on the fundamental lithotypes but rather on the aplitic differentiates: this further underlines the general difficulty of applying the whole-rock isochron to granitoids of such a young age.

However, great caution in the use of data from dykes is always necessary, since their peculiar way of formation and emplacement does not guarantee an identification of their provenance so that there always is the risk of grouping together no-comagmatic rocks.

b) Rb/Sr ages of the Vedrette di Ries massif

As an example of the difficulties encountered in whole rock investigations let us now examine the radiometric data reported by Borsi et al. (1979) on the granitoids of the Vedrette di Ries granodioritic-tonalitic massif.

This large plutonic body of the Eastern Alps consists of several acidic intrusive units, locally cut by aplitic veins and dykes (Bellieni, 1978).

In their Rb/Sr investigation, Borsi et al. (1979) found an intrusion age of 31 Ma (recalculated with $\lambda^{87}Rb = 1.42 \times 10^{-11}\ a^{-1}$); the samples define a bundle of parallel isochrons, each one of which pertains to a distinct intrusive unit which is thus characterized by a different Sr initial isotopic composition.

This investigation had not been adequately prepared by a sufficiently detailed geological field-work beforehand, so that a very massive and tiresome laboratory work has been necessary to get rid of uncertainties and apparent absurdities. After the first phase of the work, a paradoxical age situation was apparent: two subsets of samples of the massif yielded significantly different ages, one Alpine, one Hercynian (fig. 1). The Alpine age group comprised compositionally different lithotypes, while the « Hercynian » age group consisted of a suite of predominantly acid differentiates from the NW sector.

Only an extension of the investigation to the widest possible area and a very large number of samples were necessary to elucidate the situation by allowing the construction of several different parallel isochrons, each corresponding to an almost contemporaneously emplaced unit having a different Sr initial isotopic composition (.7089 - .7207).

c) Sr isotope geochemistry of the Vedrette di Ries massif

Let us now examine the behaviour of the Sr isotopic composition during the magmatic history of the Vedrette di Ries massif in the context of the other nearby Periadriatic plutons of Alpine age, i.e. Rensen, Cima di Vila, M. Alto and the Oligocene tonalite belt of the Bressanone massif (tab. 1). Despite the fact that they belong to the same magmatic province, these plutonic bodies have significantly different Sr isotopic characteristics and peculiar Sr concentration ranges (for Vedrette di Ries and Cima di Vila, see Bellieni, 1978 and 1980).

These two parameters define a correlation in a $(^{87}Sr/^{86}Sr)_i$ vs 1/Sr plot for the various units of Vedrette di Ries, for Cima di Vila and for the tonalitic belt of the Bressanone. It corresponds to a series of discontinuous magmatic sequence (M. Alto and the two

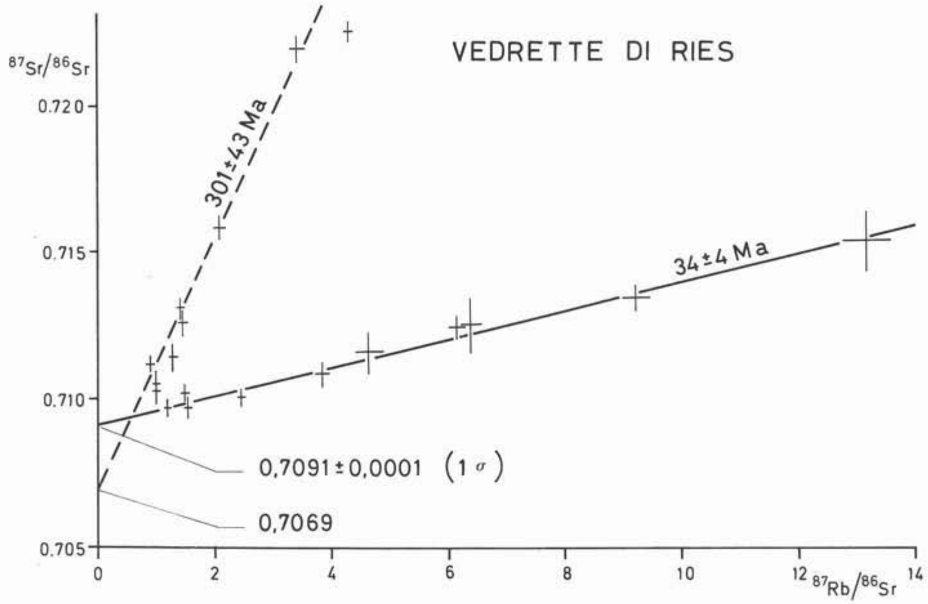

Fig. 1. — $^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$ plot for some Vedrette di Ries samples (from Borsi et al., 1979) which have non-uniform $(^{87}Sr/^{86}Sr)_i$ ratios. A subset defines a «mixing line» which simulates a Hercynian isochron.

parts of Rensen are separate episodes) resulting from repeated interactions between two components having different Sr concentrations and isotopic compositions: one term, with a relatively low Sr isotopic ratio, derives from a deep source, which has a low Rb/Sr ratio; the other term can be assumed as crustal in origin. Using Borsi et al.'s (1978b) chemical and isotopic characterization of the country rocks (the mean values of 12 samples are: Sr concentration = 125 ppm, Sr isotopic composition extrapolated back 31 Ma = 0.732) and assuming a parent magma having corresponding values of 750 ppm and 0.707, it is possible, following De Paolo (1981), to model the evolutionary path of a polyphasic magmatic process which combines assimilation and fractional crystallization. The open squares in fig. 2 represent the different steps of a magmatic evolution consisting in a mixing between two components; this mixing is characterized by a ratio contamination rate/crystallization rate equal to 1:5 and by fractional crystallization of plagioclase, hornblende and biotite in such proportions as to determine a global Sr partition coefficient equal to 1.25.

Table 1
Average concentration values

	N° Samples	$(^{87}Sr/^{86}Sr)_i$	Conc. range Sr ppm	Mean conc. Sr ppm
Vedrette di Ries (1)				
C	4	0.7089	317-388	357
A + D	11	0.7096	224-377	315
B	7	0.7109	243-331	285
E	2	0.7122	201-222	211
Cima di Vila (1)				
CV	2	0.7078	589-612	600
M.te Alto (1)				
MA	2	0.7110	475-579	527
Bressanone (2)				
Br	[illegible]	0.7099	264-345	305
Rensen (3)				
g	4	0.7097	207-260	244
gd + t	7	0.7075	307-367	339

g = granites; *gd* = granodiorites; *t* = tonalites. (1) Borsi et al., 1979. (2) Unpubl. (3) Borsi et al., 1978 a.

The average concentration values for each unit have been calculated from the main petrographic types so as to most faithfully reflect the Sr content of the parent magma. The highest values have not been considered because it is not possible to consider plagioclase- (and therefore Sr-) rich cumulitic rocks as good representatives of the parent magma. This choice is justified by the fact that the resulting Sr contents are comparatively uniform within each plutonic unit.

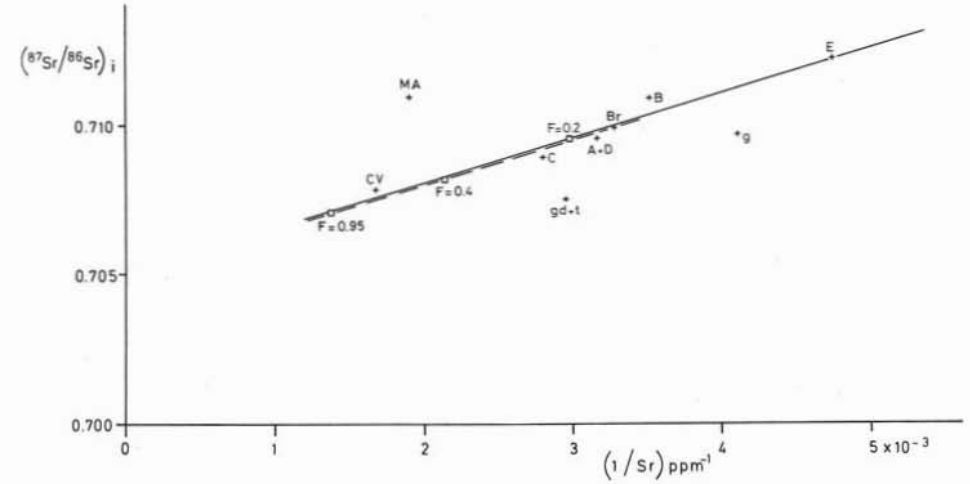

Fig. 2. — ($^{87}Sr/^{86}Sr$)$_i$ vs 1/Sr plot for the Cainozoic granitoids of the Eastern Alps. The dashed line indicates a magmatic sequence deriving from a process consisting of assimilation of wall rocks (Sr = 125 ppm, $^{87}Sr/^{86}Sr = 0.732$) by a hypothetical parent magma (Sr = 750 ppm, $^{87}Sr/^{86}Sr = 0.707$) together with fractional crystallization of 60 % plag + 30 % hbl + 10 % biot, according to De Paolo's model, 1981). The solid line is the least squares fit through the representative points of the various units of Vedrette di Ries, Cima di Vila, Bressanone. - Abbr.s as in Table 1.

Concluding remarks

The above model could represent an explanation of the Sr isotopic evolution in the Cainozoic granitoids of eastern Alto Adige. It requires the presence of two types of material deriving from sources with complementary chemical and Sr-isotopic characteristics: mantle-derived melts (sometimes evolved) and highly radiogenic material from the crust. This magma-generating mechanism can probably be generalized to all of the Cainozoic calc-alkaline magmas of the Alps; it was satisfactorily applied to the Adamello massif (Del Moro et al., 1985b) and to the granitoids of the Biella region (Bigioggero et al., 1983).

The purpose of this note was to discuss an example in order to show the practical complexities of data interpretation in radiometric geochronology. It is always necessary to bear in mind what I mentioned in the introduction: the indications provided by geochronology must always be supplemented by other information for the sake both of completeness and of a greater reliability.

Last but not least, a fundamental prerequisite for radiometric geochronology is operating on suitable material; otherwise even the most advanced and sophisticated technology will give only meaningless results.

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