

Long term behaviour of continental hydrothermal systems: U-series dating of hydrothermal carbonates from the French Massif Central (Allier Valley)

S. Rihs
M. Condomines
J.-L. Poidevin

Université Blaise Pascal et CNRS (UMR 6524), 5 rue Kessler,
63038 Clermont Ferrand cedex, France

U-series age of hydrothermal carbonates deposited by CO₂-rich thermo-mineral waters of the French Massif Central, provide new insights on the long term behaviour of a continental hydrothermal system. Dating of aragonite veins and travertines impregnating an old terrace level of the Allier river allowed to identify the main episodes of deposition of the hydrothermal system, and thus factors likely to influence these circulations. Fifteen layers from three veins and one travertine from a high terrace level of the Allier river, in the Coudes area, were analysed. Since the lowest terrace levels were missing in this sector, travertines impregnating these levels were sampled a few kms to North, around the Saladis spring. Isochron plots were used to date impure travertines, according to the 'total sample dissolution' (TSD) method (Bischoff and Fitzpatrick, 1991; Luo and Ku, 1991).

Mass spectrometry has been used to measure of ²³⁸U and ²³²Th contents, whereas (²³⁴U/²³⁸U) activity ratios and (²³⁰Th) activities were analysed by α spectrometry. Furthermore, isotopic composition of Sr, O and C were measured on vein samples to compare the composition of fluids during the various periods of deposition.

The results show that this region was subjected to at least 2 main episodes of hydrothermal circulations before the current one. An oldest event occurred from 253 to 208 ky. No deposits were found between 208 and 135 ky. At 135 ky, a major stage of circulation began and lasted until 81 ky, attested by deposition of abundant and wide (more than 10 cm) veins within a few ky. Again, deposition seems to have stopped after 81 ky, until the recent and still active period (probably a few ky old). Comparison of these ages with global climatic curves indicate that preferential deposition of carbonates occur during interglacial periods, suggesting a strong influence of climatic conditions on the hydrothermal system. If climatic influence has been widely demonstrated in supergene

carbonate deposits, (e.g. speleothems), this study offers one of the few evidences of climate forcing in hydrothermal circulation and/or deposition.

In addition, the composition of fluids recorded by the ⁸⁷Sr/⁸⁶Sr, $\delta^{18}\text{O}$, $\delta^{13}\text{C}$ and (²³⁴U/²³⁸U) ratios in the aragonite veins remained remarkably constant over 250 ky. The ⁸⁷Sr/⁸⁶Sr ratio determined on the 15 vein layers range from 0.71360 to 0.71372, comparable to the current nearby mineral spring water (0.71361, Négrel *et al*, 1997). The $\delta^{13}\text{C}$ (PDB) in these samples range from +5.1 to +5.9‰. $\delta^{18}\text{O}$ range from +18.6 to +19.7‰, and are consistent with deposition from a fluid with a $\delta^{18}\text{O}$ similar to that of present-day spring water. But the most remarkable feature is that initial (²³⁴U/²³⁸U) ratios remain constant through the whole period, from 253 ky to the present day. They range from 3.2 to 3.38 independently of the age of the Coudes deposits. The 2 samples coming from Saladis (6 kms to the North) show a slightly higher ratio around 3.9.

All these results show that very little modification in the fluid composition has occurred over the past 250 ky. This suggest that the thermal waters have undergone little mixing with superficial waters, unless the mixing proportions have remained constant, which seems unlikely over such a long period. The fluids certainly are close to the deep thermal fluids, in relative reducing conditions permitting significant (²³⁴U/²³⁸U) disequilibrium (Andrews and Kay, 1982; Osmond *et al*, 1983). The present reducing conditions are supported by the low U content (0.18 ppb) in Saladis spring, and indirectly by its high Ra content (= 1.7 Bq/l), indicating that Ra was not coprecipitated with Ca or Ba sulphates or adsorbed onto MnO₂, both characteristics of oxidizing conditions (Herczeg *et al*, 1988). Furthermore, the constancy of the isotopic ratios over such a long period suggests a strong buffering capacity of the host rocks on fluids, and a system in a near steady state with respect to water-

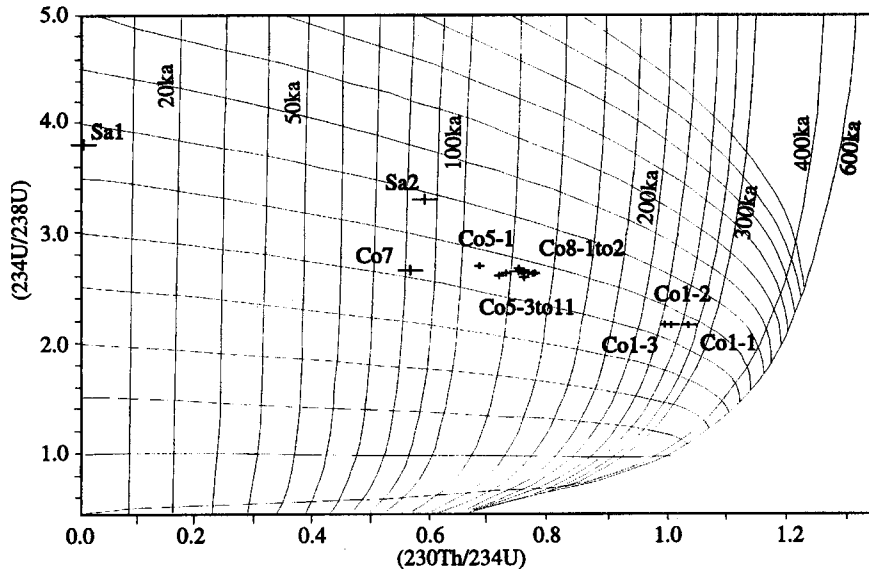


FIG. 1. Variations of $(^{230}\text{Th}/^{234}\text{U})$ and $(^{234}\text{U}/^{238}\text{U})$ activity ratios with time, in a closed system. The near horizontal curves correspond with various initial $(^{234}\text{U}/^{238}\text{U})_i$ ratios after Schwarcz, 1979). Co refers to samples from the Coudeus system and Sa to the Saladis system. Note the constant isotopic $(^{234}\text{U}/^{238}\text{U})_i$ ratio around 3.3 in all samples from Coudeus. The Saladis system seems slightly different with an initial $(^{234}\text{U}/^{238}\text{U})_i$ ratio around 3.9.

rock interaction. Such an homogeneous reservoir would imply a relatively long residence time of water at depth. Although small, the difference between $(^{234}\text{U}/^{238}\text{U})$ isotopic ratios measured in the Coudeus and Saladis deposits suggests two different origins for these waters, in agreement with the measurements by Negrel *et al* (1997) on the present springs from these two areas. This would imply that the Limagne hydrothermal systems consists in a series of several small and independant cells.

There is an apparent contradiction between the constancy of $(^{234}\text{U}/^{238}\text{U})$ ratios over 250 ky, suggesting a steady state reservoir, and the episodic deposition, linked to climatic variations. We will discuss possible models able to reconcile these two constraints. An essential factor might be the variation in pressure transmission. Glacial periods would induce a strong decrease in the recharge rate, producing a decrease in the hydraulic head on the entering part of the system in the infiltration area, which can be tranferred quickly to the overall system,

despite the slow water flow. Thermo-mineral waters could thus display much lower discharge rates, so that either they were unable to reach the surface or the deposited most of calcium carbonate at depth.

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