

A profile of helium-4 concentration in pore-water for assessing the transport phenomena through an argillaceous formation (Tournemire, France)

F. Bensenouci^{a,b}, J.L. Michelot^{b,*}, J.M. Matray^a, S. Savoye^{a,1}, B. Lavielle^c, B. Thomas^c, P. Dick^a

^a IRSN, Av. du Gen. Leclerc, BP 17, 92262 Fontenay-aux-Roses, France

^b IDES, UMR CNRS – Université Paris-Sud, Bât. 504, 91405 Orsay, France

^c CNAB, UMR CNRS – Université de Bordeaux, BP 120, 33175 Gradignan, France

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ABSTRACT

A vertical distribution of helium-4 was obtained in pore-water from the Toarcian/Domerian argillaceous formation at Tournemire (South Aveyron, France). Most of the studied core samples were collected from two vertical air-drilled boreholes across the impervious argillaceous formation and penetrating the bounding aquifers. Accessible porosities for helium were assumed similar to those of water and calculated by weighting before and after heating the core samples. Helium-4 concentrations were obtained after out-gassing the rock samples in tight containers. The comparison of the total amount of ⁴He produced since the deposition of the formation with that presently measured in the rock reveals that more than 97% of ⁴He has been lost from the solid phase to pore-water and afterwards to the surrounding aquifers. Helium distribution in pore water shows a complex profile because of the presence of unexpectedly ⁴He-rich samples in the lower part of the Upper Toarcian level. In order to understand this distribution and to assess the transport of helium at the formation scale, a series of preliminary model calculations were performed using helium diffusion coefficients three times higher than those of water isotopes. The comparison between simulated and experimental data indicates that: (1) the helium profile could be similar to those of deuterium and chloride in pore-water if some unexpectedly ⁴He-rich samples are not considered; (2) the estimated transport parameters (at small scale) may be transposable at the formation scale with some uncertainties; (3) a steady state has most probably been reached between the in situ helium production and its loss towards the aquifers; (4) only 17–30 Ma of diffusion time would be necessary to obtain steady state; this is short compared to the formation age (180 Ma) and thus the helium profile cannot give very precise information about diffusion time in the massif, but is in agreement with the hypothesis that transport processes are dominated by diffusion.

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1. Introduction

Consolidated argillaceous formations are considered as potential host rocks for the disposal of intermediate long-lived and high-level radioactive wastes, because of their very low permeability and sorption properties. Diffusion is assumed to be the dominant transport phenomenon in compacted clays like those studied in Underground Research Laboratories (URL) at Bure and Tournemire (France), and Mont Terri (Switzerland). In such media, the study of natural tracers in pore-water appears as a relevant method for understanding the water and solute transport properties. Used as a complementary method to other techniques carried

out in surface or underground laboratories, it may give access to larger time and space scales (e.g. Desaulniers et al., 1981; Remenda et al., 1996; Hendry and Wassenaar, 1999; Rübel et al., 2002; Patriarche et al., 2004a,b; Gimmi et al., 2007; Mazurek et al., 2009). However, measuring the tracer concentrations in pore-water along the formation may be difficult and subject to experimental artefacts (Sacchi et al., 2001; Savoye et al., 2006; Altinier et al., 2007). These difficulties are related to the very low porosities and very low mean pore sizes (few nm), in addition to the clay charge surfaces. At Tournemire, Patriarche et al. (2004b), Savoye et al. (2008) and Mazurek et al. (2009) proposed distinct estimates of the diffusion time in the massif from the interpretation of the distribution of stable isotopes or chloride in pore-water. This divergence is mainly linked to the imposed boundary and initial conditions, which are difficult to constrain due to the complex geologic evolution of the site. Helium by its specific characteristics, i.e. inert behaviour and continuous production in the formation, constitutes a different and complementary tracer to those previously used. This study aimed (i) at measuring the helium-4

* Corresponding author.

E-mail addresses: fethi.bensenouci@irsn.fr (F. Bensenouci), jean-luc.michelot@u-psud.fr (J.L. Michelot), jean-michel.matray@irsn.fr (J.M. Matray), sebastien.savoye@cea.fr (S. Savoye), lavielle@cenbg.in2p3.fr (B. Lavielle), thomasb@cenbg.in2p3.fr (B. Thomas).

¹ Present address: L3MR, CEA/Saclay, 91191 Gif sur Yvette, France.

concentrations in pore-water along the Toarcian/Domerian argillaceous formations at Tournemire, (ii) at performing preliminary simulations of He transport through these formations, and (iii) at examining whether the helium-4 concentrations in pore-water can give information about diffusion time in the argillaceous formation.

2. Geological background

The Tournemire Underground Research Laboratory is located in a former railway tunnel near the village of Tournemire in the South of Aveyron (France). The tunnel crosses a 250-m-thick argillaceous and highly compacted formation of Toarcian and Domerian ages (Jurassic). The general bedding of the site is sub-horizontal with a general dipping ranging between 5° and 10° to the North (Fig. 1). The Domerian formation is composed of about 40 m of marls and compacted clays, whereas the Lower Toarcian, the Middle Toarcian, and the Upper Toarcian formations consist of 25 m of organic-rich marls, 20 m of marls, and 160 m of clays, respectively (Boisson et al., 2001; Matray et al., 2007). These upper Liassic series belong to the Mesozoic marine sedimentary basin located at the southern limit of the French Massif Central. The argillaceous formation is overlain by approximately 200 m of limestone and dolomite (Aalenian to Bathonian), characterised by a well-developed karstic system, and underlain by a lower Liassic series (Carixian to

Hettangian) mainly composed of karstified carbonates. An inverse fault (Cernon fault) located at 1550 m from the southern tunnel entrance, puts the whole series in contact with the Hettangian formation (Fig. 1).

Several fault types affect the massif of Tournemire. They result from two main tectonic events characterised by an extension during Jurassic and a compression during Eocene as a consequence of the Pyrenean orogeny. This latter compression phase created most of the faults, reactivating the main accidents at the regional scale including the Cernon fault, and is assumed to have developed the karstification of the carbonated aquifers (Boisson et al., 2001; Constantin et al., 2004).

2.1. Hydrogeology

At the present time, the Toarcian/Domerian aquitard at the Tournemire site is sandwiched by two calcareous aquifers. The lower aquifer (Hettangian and Carixian) outcrops about 2 km southwestward of the studied area and discharges part of its water through the Laurus spring. The recharge zone of the lower aquifer includes the plateau of Saint-Jean d'Alcapiès and Laurus, to the south of Tournemire. The upper aquifer is composed of Aalenian, Bajocian and Bathonian limestone and is recharged from local precipitation falling onto the Larzac plateau. At the Tournemire site, this upper aquifer is known to discharge mainly through the drain

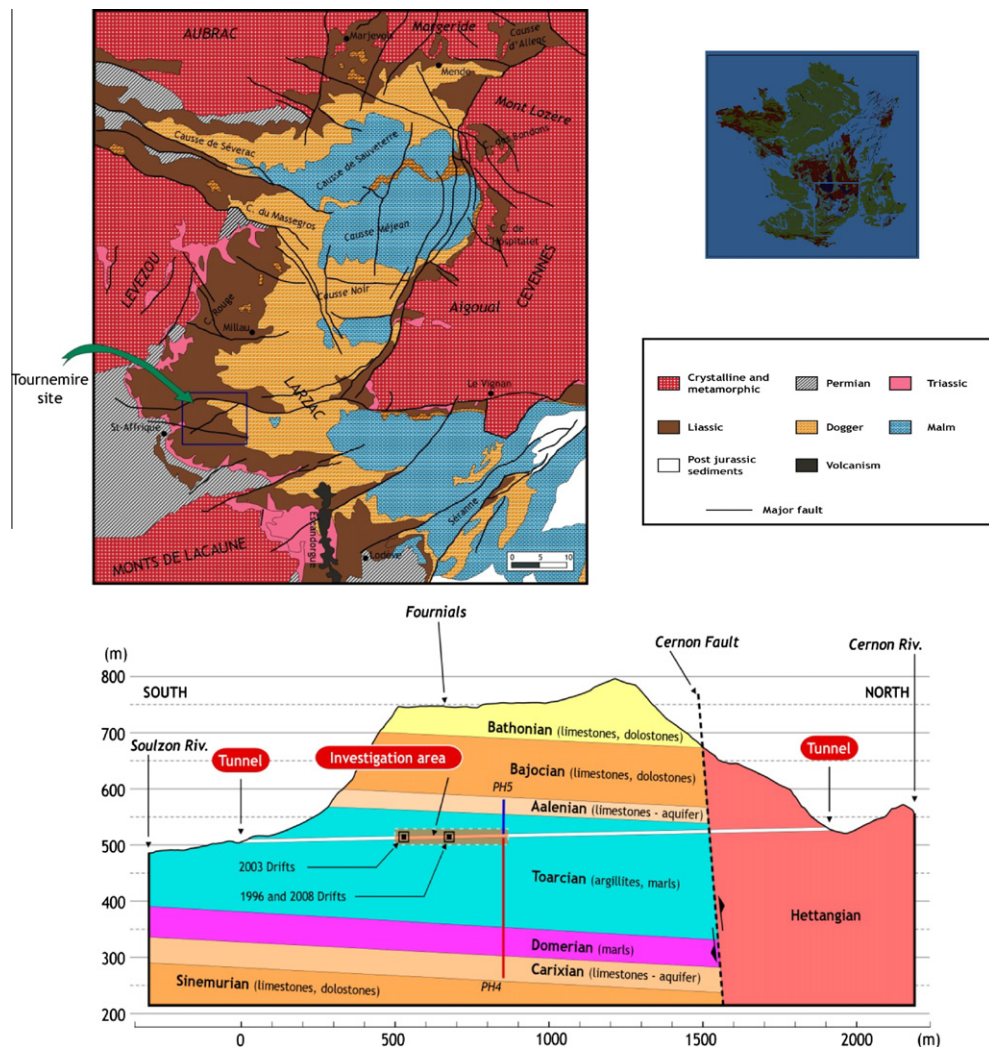


Fig. 1. Geological map of the Causses Basin and cross section of the Tournemire massif.

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