Physics and Chemistry of the Earth 36 (2011) 1679–1687

Contents lists available at SciVerse ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Pumping tests in a low permeability rock: Results and interpretation of a four-year long monitoring of water production flow rates in the Callovo-Oxfordian argillaceous rock

A. Vinsot *, J. Delay, R. de La Vaissière, M. Cruchaudet

Andra, Centre de Meuse/Haute-Marne, RD 960, F-55290 Bure, France

ARTICLE INFO

Article history:
Available online 17 August 2011

Keywords:
Permeability
Darcy's law
In situ experiment
Pore pressure
Underground Research Laboratory

ABSTRACT

Hydraulic conductivity of the Callovo-Oxfordian argillaceous rock ranges between 10^{-14} and 10^{-12} m/s. In spite of these low values, long term 'pumping tests' covering a range of head differentials have been performed in several boreholes in the Andra Meuse/Haute-Marne Underground Research Laboratory (URL). Specifically designed experimental setups made it possible to monitor water production flow rates ranging from 0.5 to 50 mL/day, during more than 4 years. Long term pumping tests provided an alternative to the pressure test method for evaluating hydraulic conductivities at the −430 m and −505 m depth levels in the URL. The obtained values were close to 0.8×10^{-13} m/s and 1.3×10^{-13} m/s, respectively. The lowest flow rate measured under well-established hydraulic head boundary conditions was close to 2.5 mL/day. It corresponds to a calculated hydraulic gradient value less than 120 m/m. This result indicates that water can flow in the Callovo-Oxfordian with such a hydraulic gradient value.

1. Introduction

The Callovo-Oxfordian formation of the eastern Paris Basin is a 130 m thick clay rich sedimentary sequence. It contains in average more than 40% clay minerals, associated with about 30% carbonates, 25% silicates (quartz and feldspars) and a small percentage of subordinate minerals. Its water content is between 6 wt% and 8 wt%. Since 1994, Andra (the French Radioactive Waste Management National Agency) has been studying the feasibility of a high-level and intermediate-level long-lived radioactive waste disposal facility in this formation (Andra, 2005a). The Callovo-Oxfordian's hydrogeological characteristics are an important parameter influencing the confining properties of this argillaceous rock. A great number of permeability coefficients were obtained *in situ* by using short term and long term hydraulic tests performed in boreholes drilled from drifts in the Meuse/Haute-Marne Underground Research Laboratory (URL) or in deep boreholes from the surface (Delay et al., 2006; Distinguin and Lavanchy, 2007; Delay, 2007). The obtained permeability coefficients all range between 10^{-14} and 10^{-12} m/s (equivalent to 10^{-21}–10^{-19} m^2). They are coherent with values measured on rock samples (Andra, 2005b).

Generally, pumping tests are not carried out for hydraulic characterization purposes in such low-permeability rocks (Neuzil, 1986; Renard, 2005; Mejías et al., 2009). Nevertheless, since 2005, long term pumping tests have been performed in several Meuse/Haute-Marne URL boreholes equipped with specifically designed setups (Delay et al., 2007). Two types of tests were performed: one in a gas-filled borehole interval and another in a saturated borehole interval. Originally, these tests were dedicated to the characterization of the pore water composition (Vinsot et al., 2008), but they also made it possible to monitor the water production flow rate of the formation. This paper presents the characteristics of these *in situ* tests and the measured water production flow rates. These results were compared with the water flow rates calculated with a 1D radial water flow numerical model to evaluate: (i) the rock permeability coefficients and the hydraulic gradients around the borehole intervals; (ii) the distance of influence of the test.

2. Material and methods

2.1. Experimental principles and setups

The first type of hydrogeological pumping test was performed in an ascending borehole interval filled with gas at a depth of −430 m[1] (borehole PAC2002, Fig. 1). It consisted in filling the 5-meter-long borehole interval with argon at a pressure close to 1 bar and maintaining the gas pressure at this value over a period of months to years. This pressure was much lower than the pore pressure in the

* Corresponding author. Fax: +33 329 75 53 89.
E-mail address: agnes.vinsot@andra.fr (A. Vinsot).

[1] Depth of the middle of the interval.

1474-7065/$ - see front matter
doi:10.1016/j.pce.2011.07.091

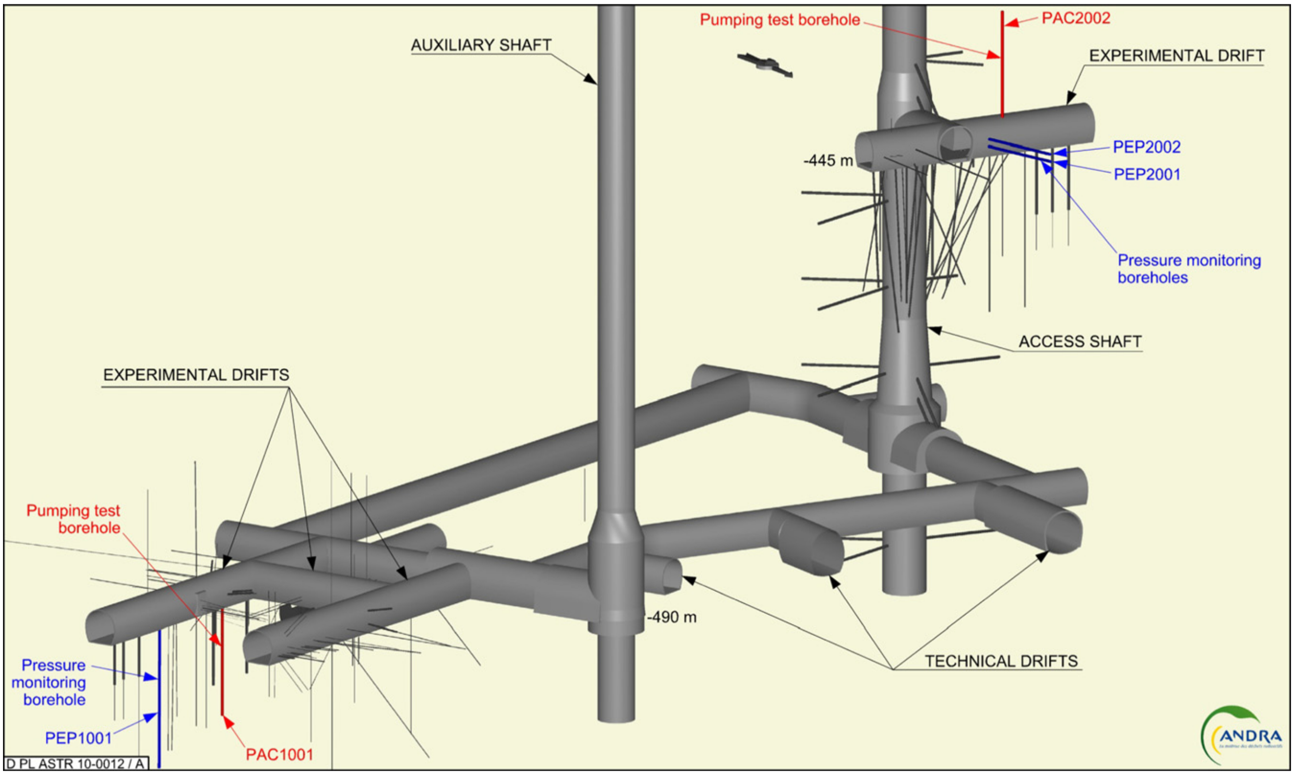

Fig. 1. Location of the boreholes used for the long term pumping tests and for pore pressure monitoring at −445 and −490 m in the Meuse/Haute-Marne URL.

surrounding rock, which was higher than 3 MPa (300 m of water). Under the effect of the hydraulic pressure difference of several MPa between the borehole and the surrounding rock, water flowed into the borehole interval, where it accumulated and from which it was pumped out.

The experimental setup for this test consisted of an equipment installed in the ascending borehole (Fig. 2), a control unit, a gas control module and a water-sampling module (Solexperts, 2005; Vinsot et al., 2008). The borehole equipment included a packer isolating the test interval. Two gas flow lines, one water pumping line and three pressure control lines linked the test interval to the control unit in the drift. The water sampling module, designed by Metromesures (Vinsot et al., 2008), allowed water to be pumped out of the test interval with a 9-mL-volume syringe at a controlled flow rate.

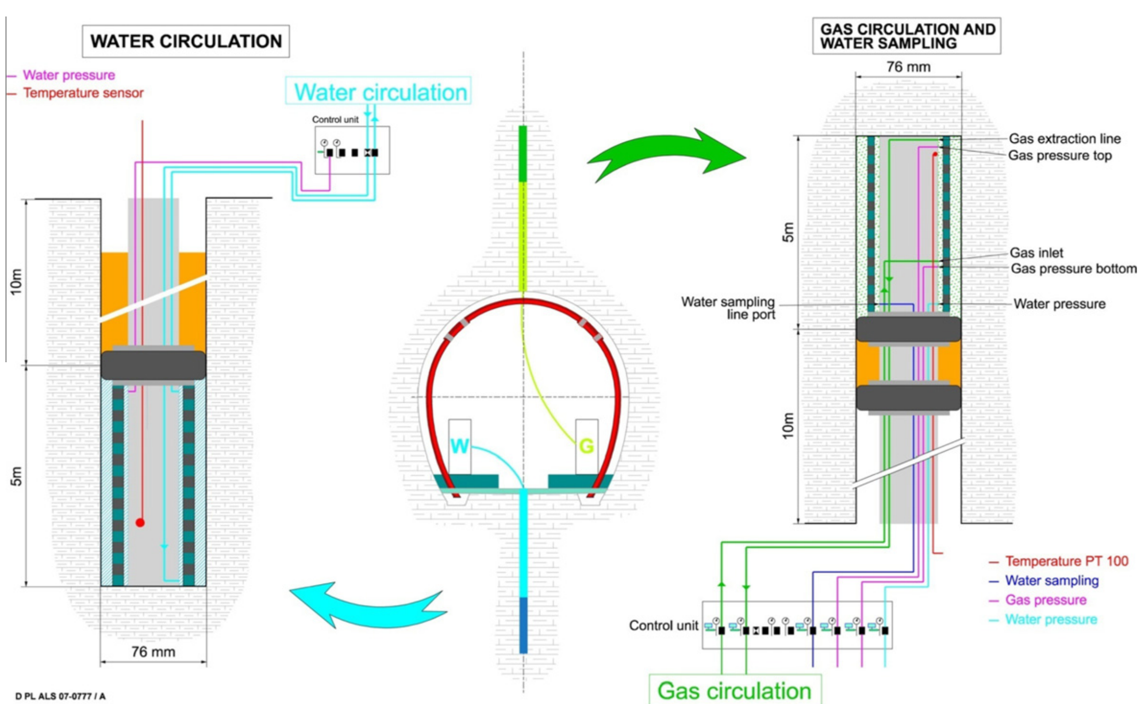

Fig. 2. Schematic representation of the borehole instrumentation for both the test in a gas-filled interval (on the right) and the test in a saturated interval (on the left).