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Impact of the landscape evolution on the hydraulic boundary conditions of the Callovo–Oxfordian formation

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Abstract

The Callovo–Oxfordian formation in the Eastern part of France was recognized as a potential nuclear waste repository layer. The Andra (National Agency for Nuclear Waste Management) has launched a few years ago a research program that aims to define the mechanisms of importance in the impact of the surface environment evolution on the site hydrogeology.

Based on mapping and dating results, Andra has quantified the geomorphological evolution of the Meuse/Haute-Marne site in the past and has estimated the future evolution over 1 million years. The Callovo–Oxfordian boundary conditions depend on the hydraulic heads in the two surrounding aquifers, the Oxfordian limestone above, and the Dogger one, below. Both aquifer outcrops are modified over the next million years.

For the present study, the geomorphologic evolution is considered independently of other processes and translated in the hydrogeological model in terms of changes in the hydraulic boundary conditions at the surface. The hydrodynamic simulations have been performed with the code Cast3M (implemented by CEA (Atomic Energy Commissariat)) using a mixed hybrid finite-element formulation. For these groundwater flow simulations, three modelled stages are presented: the Present, 500,000 years (500 Ky) and 10^6 years (1 Ma) in the future. The landscape evolution is merely considered through the use of three different topographies on which the boundary conditions are applied. According to Andra predictions, at the Meuse/Haute-Marne site, the valley incisions on the Bure plateau will locally reach the Oxfordian limestone. Thus, the Oxfordian aquifer exhibits more changes due to topographic evolution than the Dogger aquifer.

Hydrodynamic simulations show a significant impact of the valley incisions on the groundwater flow by the creation of local outlets to the Oxfordian limestone aquifer in the North of the area for the 1 My topography. It induces local perturbations of the saturation level. The global erosion of the topography also pulls down the hydraulic heads on a regional basis. Changes induced by the geomorphologic evolution in the Dogger aquifer are located around 30 km East from the Underground Laboratory site, at the outcropping areas. Thus, at the Laboratory location, the piezometric surface does not show, for the future, significant modifications compared to the present state. The 20-m general lowering of the hydraulic heads in the Dogger is also globally less important than for the Oxfordian aquifer.

The consequence on the Callovo–Oxfordian boundary conditions for the future is an increase of the internal upward vertical hydraulic gradient which, at present state, is well developed only immediately to the North of the Laboratory.

Keywords: Geomorphology; Hydrogeology; Valley incision; Nuclear waste repository

1. Introduction

The Callovo–Oxfordian formation in the Eastern part of France (Fig. 1) was recognized as a potential deep nuclear waste repository layer. Potential geological host formations

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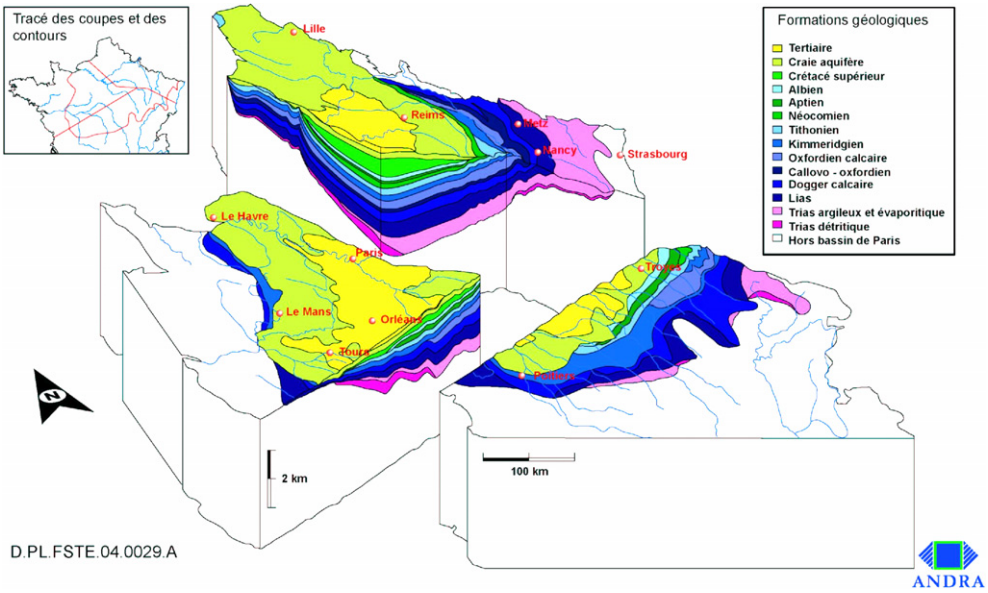

Fig. 1. Geological map and cross section of the sedimentary Parisian Basin.

(and their surroundings) are chosen in particular for their long-term stability, their ability to accommodate the waste disposal facility, and to attenuate potential release of radioactivity. To estimate potential transfers from the host formation to the biosphere, it is important to understand the evolution through time of the hydraulic boundary conditions of the clay layer as well as the evolution of the whole hydrological system. The Andra (National Agency for Nuclear Waste Management) has launched in 1994 a research program on the geoprospective of the Meuse/Haute-Marne site, where the underground research laboratory is being constructed. This program aims to define what could be, for the next million years, the possible evolution of the climate, the surface environment (geomorphology, hydrology and permafrost dynamics), and to assess their potential effects on the surface and subsurface hydrodynamics in the Bure area. In order to assess evolution through time of this system and to support a coupled phenomenological approach, Andra develops a generic modelling. It aims to define the main mechanisms in the surface environment evolution that impact the site groundwater dynamics. Here, generic means simpler and easier to handle. This generic model will serve as a basis for the future integrated models.

Over 1 million year, natural system evolution mainly depends on internal geodynamical (tectonics) and external climate conditions. One may reasonably assume that, in the North-East of France, tectonics play a minor role in terms of site stability at a time scale of a few hundred thousands of years since it exhibits slow uplift and deformation kinetics (Brulhet, 2004). However, the regional uplift drives the long-term landscape evolution mainly through valley incision dynamics. Plateaus should not be much eroded over 1 million years (Brulhet, 2004; Cojan et al., 2006). On the contrary, climate cyclic variations may have important regional and local consequences at a shorter scale. The period of these cycles varies from 1000 up to a 100,000 years (Jousseaume, 1999). The two main climatic variables, temperature and precipitation, influence the surface and subsurface environmental conditions mainly through two types of processes: erosion (landscape evolution) and ground freezing (permafrost formation). Besides these natural forcings, one should bear in mind the anthropic forcings which importance is now recognized [greenhouse gas emission (Duplessy, 2001), deforestation, urbanization,...]. These anthropic impacts on long-term climate evolution has been investigated (BIOCLIM program, Texier et al., 2003).

The purpose of this work is to assess through numerical modelling the impact of the topography evolution through time on the hydrological system of the Bure site and on particular, on the boundary conditions of the Callovo–Oxfordian formation. The Callovo–Oxfordian boundary conditions depend on the hydraulic heads in the two surrounding aquifers, the Oxfordian limestone, on top, and the Dogger one, below. Both aquifer outcrops are modified over the next million years. Here, a natural evolution of the landscape is considered, it embeds both geodynamical and natural climate forcings. The modelled area and the data used for the numerical simulations are first described. Secondly, simulation results are presented for both aquifers surrounding the Callovo–Oxfordian formation. Lastly, the implications on the head gradient in the host formation is studied.

2. Geological and geomorphological context

The deep underground laboratory is located in the Callovo–Oxfordian formation in the Eastern part of the sedi-