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The use of noble gases for tracing fluid circulations in sedimentary basins: A case study of the Paris Basin, France

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Introduction

Understanding underground fluid circulations in basins is essential for a variety of economic activities and their environmental impact. Because noble gases are chemically inert, their abundance and isotopic composition can only be changed by phase changes (e.g., solution of atmospheric gases in groundwater, gas-water-rock interactions), nuclear reactions producing noble gas isotopes and giving access to the geochronological dimension, and mixing between specific end-members (mantle, crust, atmosphere). Our group has been involved since 1990 in the study of noble gases in the Paris Basin, France, We present here a summary of these studies, aimed to better understand the origin, path, and residence time of fluids in well-characterized aquifers. The Paris Basin is an intracratonic basin that contains several permeable terranes allowing fluid circulation and/or storage (Fig. 1). From top to bottom in the basin, the aquifers are the Albian sandstone, the Dogger (Jurrasic) limestone, and the Trias sandstone, which overlies the basement that formed during the Hercynian orogeny. The E-SE borders of the basin have been uplifted in the Tertiary during the Alpine orogeny, so that the general circulation path is from E-SE to N-NW, with recharge area being located in the Morvan and in Lorraine (where Nancy stands).

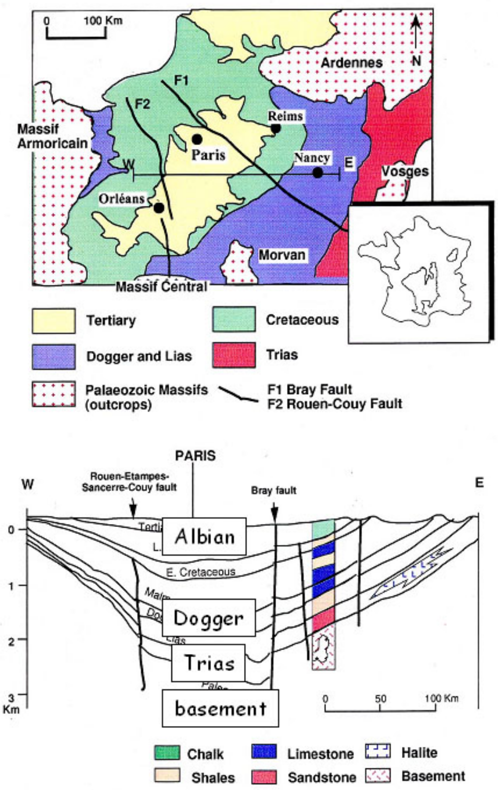

Fig. 1 : Summary of the Paris Basin geometry (adapted from ref. [1])

Fluid circulation in a multi-stored aquifer system

The most shallower aquifer of this study, the Albian sandstone, could be dated by ^{14}C along a SE-NW flow line which allowed us to propose a temperature increase of 8-10 °C in central France since the last glacial maximum using noble gas paleo-

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temperatures determined in ETH Zurich. He amount and isotopes along the flow line, together with water chemistry, indicate first internal radioactive production of ^{4}He in the aquifer, and then mixing with groundwaters from the underlying Neocomian aquifer towards the central area of the basin. Because ^{4}He correlates with water chemistry, we argue that the transfer of noble gases between the two superposed aquifers occurs by advection through the sandwiched aquitard, rather than by diffusion.

The fact that the He content of the different aquifers increases with depth can be regarded as a decrease of water movement with depth, assuming that the basin is now close to equilibrium in term of mass transfer. A model age of a few Ma for water in the Dogger aquifer is derived [2], which is in agreement with a pre-quaternary stable isotope signature of the Dogger waters [3]. Correlations between salinity and geographical distribution of waters, together with ratios between noble gas isotopes produced by nuclear reactions (e.g., $^{4}He/^{40}Ar^{*}$ vs. $^{21}Ne^{*}/^{40}Ar^{*}$) in Dogger and Trias waters [1] are consistent with water mixing, rather than diffusive transfer, for mass transfer between the two deep aquifers. The distribution of these geochemical tracers together with that of salinity in the Dogger aquifer indicate that water mixing tends to occur in areas where major faults originating in the basement crosscut the sedimentary units.

Evidence for long term isolation between the Dogger and Trias aquifers in the East of the basin.

We have undertaken a study of the Trias aquifer from the eastern recharge area in the Vosges county towards the center of the basin through Lorraine. The evolution of ^{14}C ages versus distance from the recharge together with ^{3}He and ^{4}He concentrations indicates that the Trias aquifer is collecting mantle ^{3}He, in probable association with rifting in Alsace that marks the limit of the basin to the East and allowed subvertical fracture and water circulation deep in the basement. The ^{4}He flux required to account for the increase of [^{4}He] along the flow path is ~20 times that estimated for the quiescent basin center, and a factor of 2 that of the whole crustal production at the fractured border, consistent with episodic purging of the crust. The analysis of Dogger groundwater in the East above the Lias aquitard and the Trias aquifer shows that the mantle ^{3}He signal observed in the underlying Trias water has not yet reached the Dogger, which, together with other geochemical tracers, allow us to settle a confinement duration of 7 Ma for the Lias aquitard [4].

Conclusion

We propose that, in the case of the Paris basin, fluid mixing between the basement and the overlying aquifers occurs by advection through area affected by major tectonic accidents. The ^{4}He flux varies by one order of magnitude over the basin and is clearly tectonic-dependent. In one case, we have shown that an aquitard can isolate efficiently fluids for time lags of several Ma, provided that no major fracture system is present.

Acknowledgments

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References

1 D.L. Pinti and B. Marty, Geochim. Cosmochim Acta 59, 3389-3404, 1995.
2 B. Marty, T. Torgersen, V. Meynier, R.K. Onions and G. Demarsily, Water Res. Res. 29, 1025-1035, 1993.
3 J.M. Matray, M. Lambert and J.C. Fontes, Appl. Geochem. 9, 297-309, 1994.
4 B. Marty, S. Dewonck and C. France-Lanord, Nature 425, 55-58, 2003.

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