PALEOGROUNDWATERS OF THE VALRÉAS MIOCENE AQUIFER (SOUTHEASTERN FRANCE) AS ARCHIVES OF THE LGM/HOLOCENE TRANSITION IN THE WESTERN MEDITERRANEAN REGION

F. HUNEAU, B. BLAVOUX
Laboratoire d'Hydrogéologie,
Université d'Avignon,
Avignon, France

W. AESCHBACH-HERTIG, R. KIPFER
Swiss Federal Institute of Technology (ETH),
Swiss Federal Institute of Environmental Science and Technology (EAWAG),
Dübendorf, Switzerland

Abstract. An isotopic survey, including ^{18}O, ^{2}H, ^{13}C, ^{14}C, ^{3}H and noble gases, has been carried out since 1998 on groundwaters of the Valréas Miocene aquifer. This aquifer is situated in the South of France, close to the Rhône valley. It consists of calcareous cemented sandstones interbeded with marl and sand lenses. A major paleo-ria, resulting from the drastic Messinian crisis, cuts the Miocene sediments. During the Pliocene, it was infilled with marl and clays. This Pliocene cover keeps the aquifer confined in the South of the study area. A strong isotopic contrast is found between unconfined and confined aquifer. The depletion in the water molecule stable isotopes occurs around 20 000 years BP and points out the transition from the Last-Glacial to Holocene. The constant value of deuterium excess suggests persistence of the atmospheric circulation pattern over the South of Europe since the end of the Pleistocene. The isotopic signature of the Miocene aquifer groundwaters indicates the perfect integration of Southern France palaeoprecipitation into the present-day regional atmospheric frame. A reliable estimate of the warming during the Pleistocene-Holocene transition could only be derived from stable isotopes by calibrating them against noble gas temperatures.

1. INTRODUCTION

Climatic change during the Late Quaternary has been inferred from isotopic composition of groundwater in various places all over the world, in Africa [1, 2, 3], North America [4, 5], Asia [6, 7], Australia [8] and Europe [9, 10, 11]. Only a few of these studies concern Mediterranean regions [12, 13, 14] and none of them the Northern part of the Western Mediterranean basin. Comparison of isotopic composition of dated groundwater in confined and unconfined aquifers can supplement paleoclimatic inferences based on pollen and other currently used paleoclimatic indicators. Stable isotopes analyses of groundwater ($\delta^{18}O$ and $\delta^{2}H$) yield additional information on the Late Pleistocene moisture sources and regional atmospheric circulation.

The understanding of paleoclimatic conditions prevailing during the recharge of groundwaters is obviously an important parameter which contributes to the understanding of complex aquifer systems. Such suitable aquifers are sparse and mainly located in large sedimentary basins (Paris-London basin, Great Artesian basin of Australia, Hungarian plain, etc …), this paper is devoted to a small sedimentary basin from Southeastern France.

The Valreas Miocene Aquifer is an important resource for both domestic and agricultural water supplies in Provence. Declining potentiometric levels are of concern for the long term sustainability of the resource. An isotope study aimed at the estimation of groundwater residence time and paleorecharge conditions has been carried out from 1997 to 2000 in order to contribute to the definition of the system and to set up the basis of a proper managing of the aquifer.

2. HYDROGEOLOGICAL SETTING

The Valreas Miocene Aquifer is located close to the Rhône Valley, within a small sedimentary basin of almost 500 km^2 (Fig. 1). It is formed of multilayered sands, sandstone, clays and marls, with a maximum thickness of 600 m and an average permeability around 10^6 $m.s^{-1}$ [15, 16]. A major paleo-ria resulting from the drastic Messinian crisis cuts the Miocene sediments. During the Pliocene, it was infilled with poorly permeable sediments, mainly marls and clays interbedded with some sand lenses. In the Southern part of the basin, the Pliocene cover keeps the Miocene aquifer confined and most of the boreholes tap the Miocene aquifer through a marlaceous layer of 100 to 300 m thickness. The recharge area is located in the Northern part of the basin where Miocene sediments out crop, at an elevation of about 240 m. The general direction of groundwater flow is oriented from the NE to the SW of the basin and then in direction of the Rhône Valley through the Lez River Valley.

Samples from boreholes tapping the unconfined and the confined Miocene aquifer were collected by means of submersed pumps pre-existing on these irrigation wells. Hydrochemistry, radionuclides (^3H, ^{14}C) and stable isotopes ratios ($\delta^{13}C$, δ^2H and $\delta^{18}O$) were measured.

3. RESULTS

A strong isotopic contrast is found between the unconfined and the confined parts of the aquifer. This suggests the existence of long residence time waters in the confined aquifer. Radiocarbon activities close to the detection limit and the enrichment in $\delta^{13}C$ imply isotope exchange between groundwater and the aquifer matrix. Radiocarbon ages have been corrected by means of the Fontes & Garnier model [17] which accounts for such phenomena. This provides ages up to 30-35 ka within the confined aquifer. Note that the record covers the entire period rather uniformly, there is no indication of an “infiltration gap” at the Last Glacial Maximum as observed in other European aquifers [18, 19].

An isotopic shift is observed (Fig. 2) between recent groundwaters from the recharge area ($\delta^{18}O \approx -7‰$; $\delta^2H \approx -45‰$) and old groundwaters confined under Pliocene sediments ($\delta^{18}O \approx -9‰$; $\delta^2H \approx -60‰$).

The isotopic signature of modern recharge groundwaters is consistent with local precipitation [20] whereas old groundwaters are depleted by up to 2‰ in $\delta^{18}O$ and 15‰ in δ^2H. This indicates that old groundwaters have been recharged under colder climatic conditions than at present time. The depletion in stable isotopes occurs around 18-20 ka and points out the transition from the Late-Glacial to Holocene [21].

All the data match the World Meteoric Water Line and show a good agreement with the regional meteoric water line defined by Celle-Jeanton *et al*. [22] for the Western Mediterranean area ($\delta^2H=8\delta^{18}O+13.7$). The deuterium excess ($d=\delta^2H-8\delta^{18}O$) does not show any strong variations from the Pleistocene to the Holocene and remains close to its present-day value (Fig. 3). 85% of the data set show a deuterium excess between 10‰ and 14‰ that is to say between Atlantic ($d \approx 10‰$) and Western Mediterranean influences ($d \approx 14‰$). This is in good agreement with the observations made by Celle [20] on the atmospheric circulation affecting the study area.

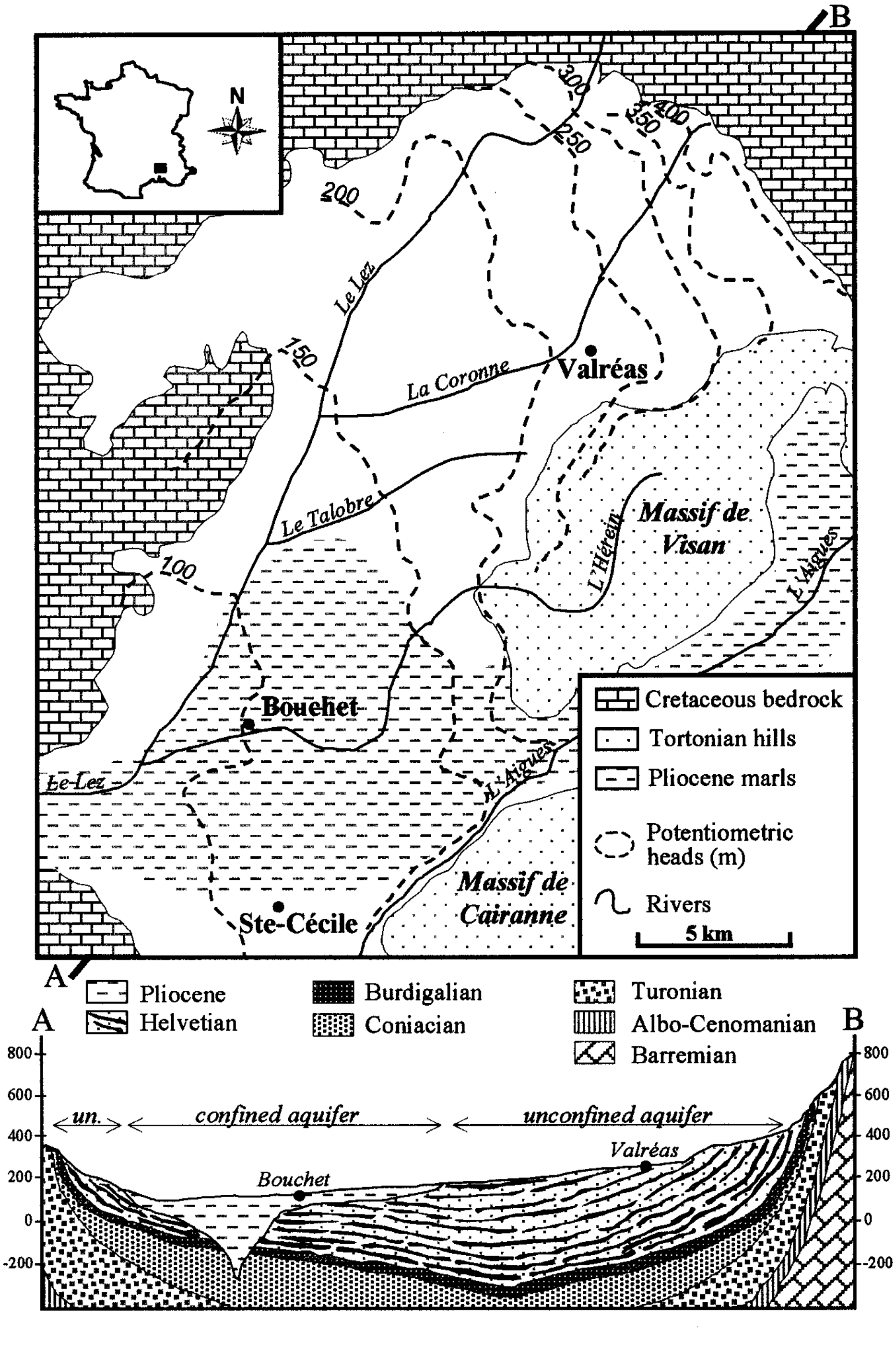

FIG. 1 : Study area, location of the sampled boreholes and geological cross-section of the Valreas Miocene basin.

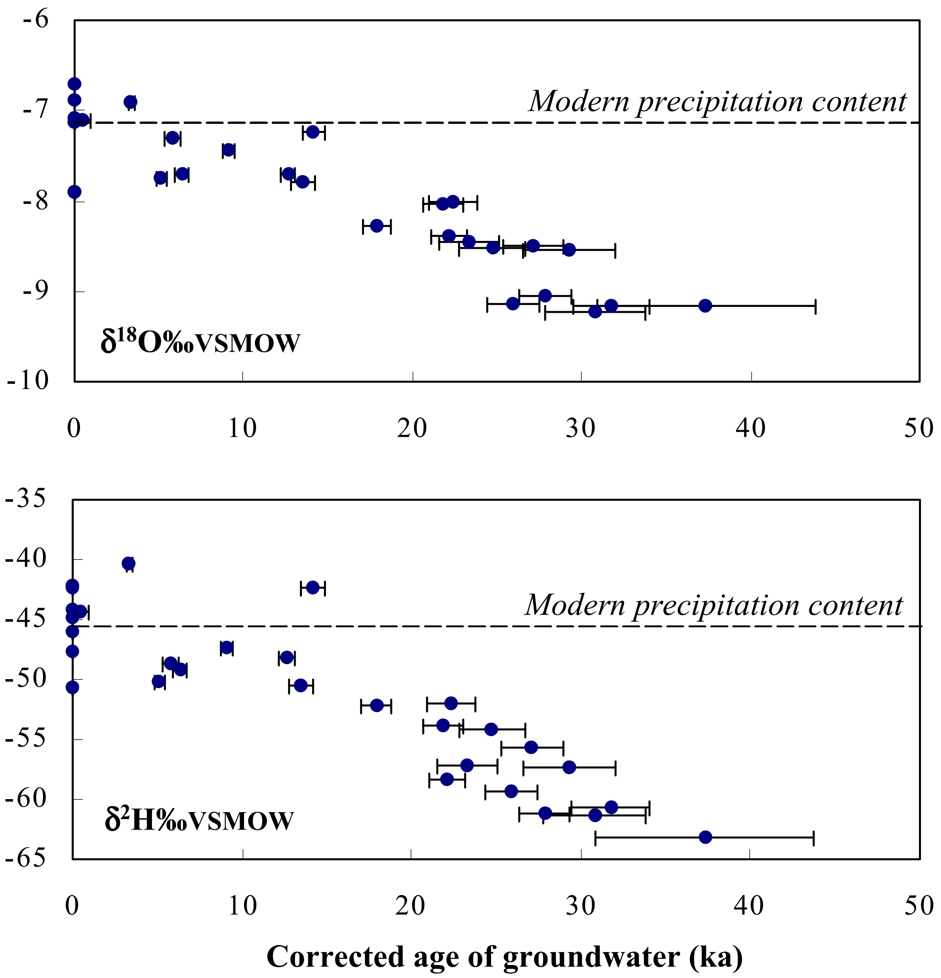

FIG. 2. Evolution of the stable isotopic signature of groundwaters with residence time within the Miocene aquifer.

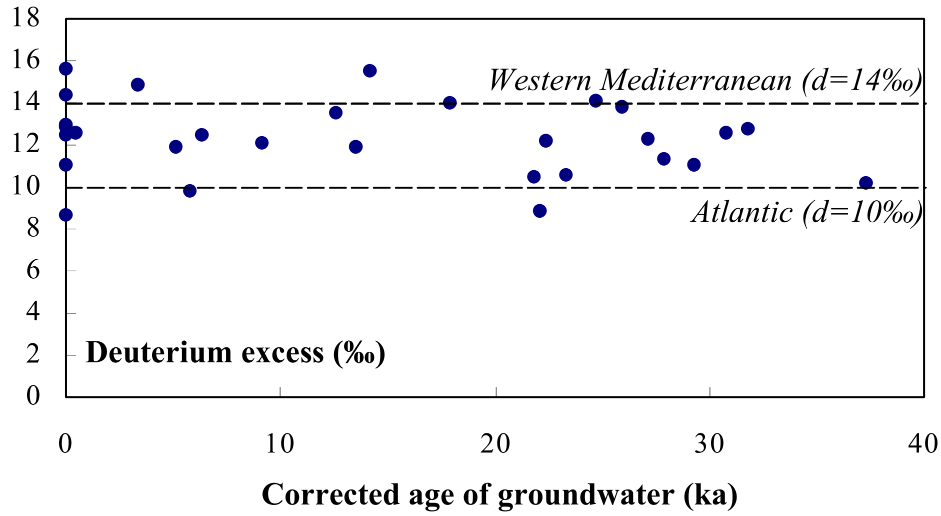

FIG. 3. Deuterium excess (d) against groundwater residence time.

4. DISCUSSION

The deuterium excess in precipitation is usually interpreted as an isotope signal depending on climate conditions during evaporation. So, from a palaeoclimatic point of view, our results suggest that the circulation pattern of the atmosphere over the South of Europe remained unchanged since the Last-Glacial Maximum and confirm the observations made in Western and Central Europe [9].

This study provides strong evidence that deuterium excess in Mediterranean precipitation has remained constant for more than 30 ka. Thus, it suggests a constant relative humidity over the Atlantic Ocean and the Western Mediterranean from the last glacial period up to the present time.

Estimation of the magnitude of the warming that occurred at the Pleistocene-Holocene transition on the basis of the stable isotope data is difficult, because slopes of the $\delta^{18}O$/temperature relationship derived from modern data may not be appropriate for long-term climate changes. Thus, noble gas measurements on 25 boreholes were used to quantify the climate signal recorded in the Valréas Miocene aquifer. Palaeorecharge temperatures indicate an increase of about 7°C during the Pleistocene-Holocene transition. The good correlation between noble gas temperatures and ^{18}O data provides a slope of the $\delta^{18}O$/temperature relationship close to 0.22‰/°C (Fig. 4), clearly lower than present day seasonal or spatial slopes. This highlights the inadequacy of modern analogues [23, 24] to interpret stable isotopes in term of Pleistocene palaeotemperatures, and the need to locally calibrate the long-term $\delta^{18}O$/temperature relationship.

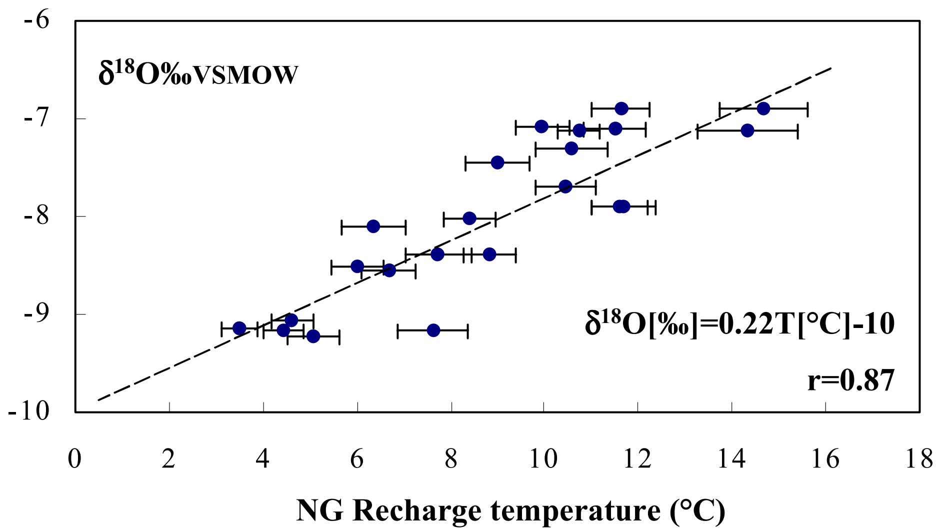

FIG. 4 : $\delta^{18}O$/Noble Gas recharge temperature in Valreas Miocene aquifer groundwaters.

5. CONCLUSIONS

This isotopic study demonstrates the continuous recharge of the Miocene aquifer from the Last Glacial to present time. The depletion in heavy isotopes of the groundwaters with ^{14}C

ages of about 20 ka and higher in comparison to more recently recharged waters clearly marks the climatic transition from the Pleistocene to the Holocene.
In contrast, the deuterium excess remains uniform throughout the record, suggesting that the general cooling during the Late Pleistocene was not accompanied by a major change in source of water vapour recharging the aquifer.

Our data point out that the long term $\delta^{18}O$/temperature relationship has to be locally calibrated in order to reconstruct palaeotemperatures from stable isotope data. This can be done by the noble gas results.

REFERENCES

[1] FONTES, J.C, ANDREWS, J.N., EDMUNDS, W.M., GUERRE, A., TRAVI, Y., Paleorecharge by the Niger river (Mali) deduced from groundwater geochemistry, Water Resources Research **27** (1991) 199-214.

[2] ANDREWS, J.N., FONTES, J.C., ARANYOSSY, J.F., DODO, A., EDMUNDS, W.M., JOSEPH, A., TRAVI, Y., The evolution of alkaline groundwater in the Continental Intercalaire aquifer of the Irhazer Plain, Niger, Water Resources Research **30** (1994) 45-61.

[3] EDMUNDS, W.M., FELLMAN, E., GONI, I.B., Lakes, groundwater and palaeohydrology in the Sahel or NE Nigeria : evidence from hydrogeochemistry, Journal of the Geological Society, London **156** (1999) 345-355.

[4] STUTE, M., SCHLOSSER, P., CLARK, J.F., BROECKER, W.S., Paleotemperatures in the Southwestern United States from noble gases in ground water, Science **256** (1992) 1000-1003.

[5] DUTTON, A.R., Groundwater isotopic evidence for paleorecharge in U.S. High Plains aquifers, Quaternary Research **43** (1995) 221-231.

[6] SHI, D., YIN, X., YIN, Z., A simulation study on the evolution of groundwater circulation systems in Cenozoic basins of Northern China, Acta Geologica Sinica **72** (1998) 100-107.

[7] SUKHIJA, B.S., REDDY, D.V., NAGABHUSHANAM, P., Isotopic fingerprints of paleoclimates during the last 30,000 years in deep confined groundwaters of Southern India, Quaternary Research **50** (1998) 252-260.

[8] LOVE, A.J., HERCZEG, A.L., LEANEY, F.W., STADTER, M.F., DIGHTON, J.C., ARMSTRONG, D., Groundwater residence time and palaeohydrology in the Otway Basin, South Australia : ^{2}H, ^{18}O and ^{14}C data, Journal of Hydrology **153** (1994) 157-187.

[9] ROZANSKI, K., Deuterium and Oxygen-18 in European groundwaters – links to atmospheric circulation in the past, Chemical Geology **52** (1985) 349-363.

[10] DARLING, W.G., EDMUNDS, W.M., SMEDLEY, P.L., Isotopic evidence for palaeowaters in the British Isles, Applied Geochemistry **12** (1997) 813-829.

[11] WALRAEVENS, K., Natural isotopes and noble gases in groundwater of the Tertiary Ledo-Paniselian aquifer in East and West Flanders, Natuurwet. Tijdschr. **78** (1998) 246-260.

[12] SULTAN, M., STURCHIO, N., HASSAN, F.A., HAMDAN, M.A.R., MAHMOOD, A.M., EL ALFY, Z., STEIN, T., Precipitation source inferred from stable isotopic composition of Pleistocene groundwater and carbonate deposits in the Western desert of Egypt, Quaternary Research **48** (1997) 29-37.

[13] MALIKI, M.A., KRIMISSA, M., MICHELOT, J.L., ZOUARI, K., Relationship between shallow and deep aquifers in the Sfax basin (Tunisia), C. R. Acad. Sci. Paris, Earth and Planetary Sciences **331** (2000) 1-6.

[14] BAJJALI, W., ABU-JABER, N., Climatological signals of the paleogroundwater in Jordan, Journal of Hydrology **243** (2001) 133-147.
[15] HUNEAU, F., Fonctionnement hydrogéologique et archives paléoclimatiques d'un aquifère profond méditerranéen, Etude géochimique et isotopique du bassin miocène de Valréas, Sud-Est de la France, PhD Thesis, University of Avignon, France (2000).
[16] HUNEAU, F., BLAVOUX, B., Isotopic hydrogeology within the Miocene basin of Carpentras-Valreas (Southeastern France), In : Dassargues A. (Ed), Tracers and Modelling in Hydrogeology, Proceedings of the TraM'2000 Conference held at Liège, Belgium, May 2000, IAHS Publ. **262** (2000) 433-438.
[17] FONTES, J.C., GARNIER, J.M., Determination of the initial ^{14}C activity of the total dissolved carbon : a review of the existing models and a new approach, Water Resour. Res. **15** (1979) 399-413.
[18] ANDREWS, J.N., LEE D.J., Inert gases in groundwater from the Bunter Sandstones of England as indicators of age and palaeoclimatic trends, Journal of Hydrology **41** (1979) 233-252.
[19] BEYERLE, U., PURTSCHERT, R., AESCHBACH-HERTIG, W., IMBODEN, D.M., LOOSLI, H.H., WIELER, R., KIPFER R., Climate and groundwater recharge during the last glaciation in an ice-covered region, Science **282** (1998) 731-734.
[20] CELLE, H., Caractérisation des précipitations sur le pourtour de la Méditerranée occidentale, approche isotopique et chimique, PhD Thesis, University of Avignon, France (2000).
[21] ROZANSKI, K., JOHNSEN, S.J., SCHOTTERER, U., THOMPSON, L.G., Reconstruction of past climates from stable isotope records of palaeo-precipitation preserved in continental archives, Hydrol. Sciences J. **42** (1997) 725-745.
[22] CELLE-JEANTON, H., TRAVI, Y., BLAVOUX B., Isotopic typology of precipitation in the Western Mediterranean region at three different time scales, Geophysical Research Letters (accepted).
[23] ROZANSKI, K., ARAGUAS-ARAGUAS, L., GONFIANTINI, R., Relation between long-term trends of oxygen-18 isotope composition of precipitation and climate, Science **258** (1992) 981-985.
[24] FRICKE, H.C., O'NEIL J.R., The correlation between $^{18}O/^{16}O$ ratios of meteoric water and surface temperature : its use in investigating terrestrial climate change over geologic time, Earth and Planetary Science Letters **170** (1999) 181-196.