Lawrence Berkeley National Laboratory

Recent Work

Title

AGE DATING OF GROUNDWATER IN FISSURED ROCK: THE INFLUENCE OF WATER VOLUME IN MICROPORES

Permalink

<https://escholarship.org/uc/item/8ww2v6mn>

Author

Neretnieks, I.

Publication Date

1979-07-01

AGE DATING OF GROUNDWATER IN FISSURED ROCK:
THE INFLUENCE OF WATER VOLUME IN MICROPORES

Ivars Neretnieks

July 1979

Prepared for the U. S. Department of Energy
under Contract W-7405-ENG-48

TWO-WEEK LOAN COPY

This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782

RECEIVED
LAWRENCE
BERKELEY LABORATORY

SEP 28 1979

LIBRARY AND
DOCUMENTS SECTION

LBL-9473.c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Age Dating of Groundwater in Fissured Rock:
The Influence of Water Volume in Micropores

Ivars Neretnieks

(until January 1980)

Lawrence Berkeley Laboratory
Earth Sciences Division
Berkeley, California 94720

Department of Chemical Engineering
Royal Institute of Technology
Stockholm, Sweden

Paper submitted to Science, American Association
for the Advancement of Science, Washington, D. C.
August 1979.

Age dating of groundwaters by measuring their content of some radio nuclide is based on the assumption that the nuclide, e.g. C-14 or H-3 follows the water. In fissured media such as granitic rocks, the water flows in the fissures of the rock. It is assumed that a water age as determined by C-14 dating in some way reflects the time the water has been underway from the surface of the ground where it obtained the radioactive species.

The aim of this short communication is to demonstrate that there may be a large difference between the residence time of water in the fissures and the "water age".

The residence time of the water is the ratio of the volume of the water-bearing fissures to the volumetric flow rate of the water. The small molecules in the water - be it carbonate ions or water molecules with a tritium atom - have access to the micropores of the rock matrix by diffusion but not by flow. The residence time of individual molecules will thus be larger than the residence time of the flowing water.

If all micropores where no flow occurs were accessible to the radioactive species, the residence time of this species would be determined by the fissure volume plus the micropore volume of the rock. The residence time of the water in the conventional sense would be determined by the volume of those fissures where water flows.

This ratio can be expressed by

$$\frac{t_a}{t_w} = \frac{\epsilon_p + \epsilon_f}{\epsilon_t} \quad (1)$$

t_a = the "water age" or residence time of diffusing species

t_w = the residence time of flowing water

ϵ_f = the porosity of fissures where water flows

ϵ_p = the porosity of the rock matrix, i.e. micropores accessible by diffusion only

The accessibility of the micropores will depend on the diffusivity of the species as well as on the distance the species has to diffuse.

Porosities have been measured for granites by Brace (1), Brace et al. (2) and Brace and Orange (3). Porosities range from about 0.4% at confining pressures of 100 bar to over 1% at 1 bar confining pressure. Brace et al. (2) and Brace and Orange (3) measured the electrical resistivities of rock samples where the pores had been filled with salt water. From these data and the analogy between electrical conductivity and diffusivity (4), the diffusivity of species in the water in the pores in the rock was found to be 6.4-27% of the diffusivity in unconfined water for confining pressures of the rock of 50-100 bar. Pore diffusivities for other porous particles such as catalyst particles usually are 17-50% of the diffusivity in the unconfined fluid (5).

For small ions like CO_3^{2-} and HCO_3^- the pore diffusivity will be approximately $D_p = 2 \cdot 10^{-10} \text{ m}^2/\text{s}$.

The fissure width $2b$ is not well known in fissured rock. Snow (6) developed a model based on the assumption that fissures have parallel walls and that the resistance to flow can be determined from laminar flow theory. Snow's model will give a lower bound on actual fissure widths.

Fissure widths determined by Snow range from 0.3 mm near the surface to less than 0.1 mm at depths of 130 m. Recent measurements (7) at depths down to 500 m give permeabilities of 10^{-9} m/s. The equivalent fissure widths $2b$ are about 0.01 mm. Fissure spacings may range from fractions of meters to many meters (6, 7). In a rock with fissure spacings $S = 1$ m, fissure width 0.1 mm and a porosity $\epsilon_p = 0.005$ the residence time ratio $t_a/t_w = 51$ if all micropores are accessible by diffusion.

The accessibility can be determined by use of the diffusion equation. For the purposes of this paper it will suffice to describe the fissures in the rock as parallel, equidistant fissures of equal width.

The diffusion in the micropores of the rock matrix from the fissure surface is described by equation 2 if steady state is assumed

$$D_p \frac{\partial^2 C_p}{\partial z^2} = \lambda C_p \quad (2)$$

D_p is the diffusivity in the pore water, C_p the concentration in the pore fluid, z the distance from the fissure surface and λ the decay constant.

A mass balance along the fissure gives

$$u_f \frac{\partial C_f}{\partial x} = \frac{D_p \epsilon_p}{b} \cdot \left. \frac{\partial C_p}{\partial z} \right|_{z=0} - \lambda C_f \quad (3)$$

u_f is the water velocity in the fissure, C_f the concentration in the water in the fissure and x the distance along the fissure.

At the inlet end of the fissure $C_f = C_p = C_0$ and at the fissure surface $C_f = C_p$. The third boundary condition is $\left. \frac{\partial C_p}{\partial z} \right|_{z=S/2} = 0$ which implies that in the rock at a point midway between two fissures no net transport of the diffusing species occurs. The solution to equations 2 and 3 for the fluid in the fissures is

$$\frac{C_f}{C_0} = e^{-t_w} \left\{ \frac{\epsilon_p(2A - 1)}{b} \sqrt{\lambda D_p} + \lambda \right\} \quad (4)$$

where

$$A = \frac{e^{\frac{S}{2} \sqrt{\frac{\lambda}{D_p}}}}{e^{\frac{S}{2} \sqrt{\frac{\lambda}{D_p}}} + e^{-\frac{S}{2} \sqrt{\frac{\lambda}{D_p}}}} \quad (5)$$

and $t_w = x/u_f$.

For large spacings $A \rightarrow 1$. The water age or residence time of the decaying species is determined from

$$\frac{C_f}{C_0} = e^{-t_a \lambda} \quad (6)$$

Combining equations 4 and 6 gives

$$\frac{t_a}{t_w} = 1 + \frac{\epsilon_p(2A - 1)}{b} \sqrt{\frac{D_p}{\lambda}} \quad (7)$$

Table 1 below gives some ratios of t_a/t_w for $\epsilon_p = 0.005$.

$D_p = 2 \cdot 10^{-10} \text{ m}^2/\text{s}$ for C-14 with a half life of 5730 years.

Table 1. Shows t_a/t_w for various fissure spacings and fissure widths.

Fissure width mm	Fissure spacing		
	> 50 m (eq. 7)	2 m (eq. 7)	2 m (eq. 1)
0.01	7200	995	1001
0.1	720	100	101
1	72	11	11

For carbon-14 age dating the results in Table 1 indicate that if the distances between water-bearing fissures are large, > 50 m, the micropores in the rock between the fissures will not be fully utilized. For smaller fissure spacings, 2 m, the entire micropore volume is accessible to the diffusing species, as can be seen from a comparison of the second and third columns in Table 1.

Available data indicate that the diffusivity of small molecules and ions in the water-filled micro fissures of granite matrices is of the order of some percent to some tens of percent of the diffusivity in unconfined water. Such a diffusivity will allow a considerable amount of the water in the micropore volume of the rock matrix to be reached by the diffusing species.

The retention time of flowing water in the fissures in the rock will under such circumstances be very much smaller than that of carbon-14 atoms which have access to the micropore volume of the rock as well.

Acknowledgements. This work was supported by KBS Stockholm and the U. S. Department of Energy under Contract W-7405-ENG-48.

- (1) Brace, W. F., J. Geophys. Res. 70, 391 (1965)
- (2) Brace, W. F., Orange, A. S., Madden, T. R., J. Geophys. Res. 70, 5669 (1965)
- (3) Brace, W. F., Orange, A. S., J. Geophys. Res. 73, 1433 (1968)
- (4) Klinkenberg, L. J., Geol. Soc. Am. Bull., 62, 559 (1951)
- (5) Perry, H., Chilton, C. H., Chemical Engineers Handbook, 5th Edition, McGraw-Hill, 16-19 (1973)
- (6) Snow, D. T., J. Soil Mech. Found. Div., Amer. Soc. Civil Eng., 94, (SM1), 73 (1968)
- (7) KBS-report. Handling of Spent Nuclear Fuel and Final Storage of Vitrified High-Level Reprocessing Waste. Volume II, Geology, KBS, Stockholm, Nov. 1977.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720