APPLICATION OF NUCLEAR MAGNETIC RESONANCE SOUNDINGS TO GROUNDWATER RESERVES MAPPING IN WEATHERED HARD-ROCK AQUIFERS (BRITTANY, FRANCE)

Francis Mathieu[1], Robert Wyns[2], Jean-Michel Baltassat[1], Anatoly Legchenko[1,3], Patrick Lachassagne[4], Bruno Mougins[5]

[1] BRGM, Development Planning and Natural Risks Division, 3 avenue C. Guillemin, BP 6009, 45060 Orléans Cedex 2, France
[2] BRGM, Geology Division, Modelling and Applications Unit, 3 avenue C. Guillemin, BP 6009, 45060 Orléans Cedex 2, France.
[3]Institut de Recherche pour le Development (IRD), 32, avenue H. Varagnat, 93143 Bondy Cx, France
[4] BRGM, Water Division, 1039, rue de Pinville, 34000 Montpellier, France
[5] BRGM, Agence Bretagne, Rennes Atalante Beaulieu, 2 rue Jouanet, 35700 Rennes, France

INTRODUCTION

The quality of groundwater and river water is increasingly threatened by the growing use of fertilisers and pesticides in agriculture. In the hard-rock context of Brittany, one of the key points in characterising the impact and durability of this diffuse pollution is a better understanding of the structure and functioning of the aquifers. For this, we must aim to quantify and locate the volumes and quality of water stored in the different hydrogeological compartments of the aquifers. An original methodology was thus developed for quantitative mapping of groundwater reserves in hard-rock regions by adopting a dual approach: (i) geometrical aquifer modelling based on both field observations and existing well data (lithology, weathering and piezometry), and (ii) measurements of water contents using Magnetic Resonance Soundings (MRS).

Following this approach, 204 MRS measurements using Numis equipment were performed from 1998 to 2003 on 13 watersheds within the Armorican massif (French Brittany), in various geological environments. These results were obtained in the framework of several projects funded by the Regional Council of Brittany, the County Council of Finistère, the Loire-Brittany Water Authority, the Ministry of Industry (BRGM Public Service grant) and the Ministry of Research (BRGM R&D project).

CONCEPTUAL MODEL OF HARD-ROCK AQUIFERS (WYNS *ET AL.*, 2003)

Most hydrogeological systems within weathered crystalline basement environments can be represented by a sub-horizontal two-layer system cut by vertical fractures of tectonic origin that act as drains:

- an upper layer composed of unconsolidated alterite (20-30 m thick) that, considering its relatively high effective porosity, plays an essential storage role with respect to infiltrated rainwater.
- a lower layer, including the fissured zone (about 50 m thick), that has a drainage role with respect to the overlying storage layer, at least at the scale of intersecting drill holes, as well as a minor storage role. It locally supplies perennial springs that contribute to the minimum flow of rivers.

WATER TABLE MODELLING

As there is generally no piezometric map available for the study area, the elevation of the top of the aquifer is modeled from DEM data and water table elevations measured in sparse boreholes. An empirical relationship is established between the difference in elevation between the topographic surface and the basal thalweg surface ('a' on Fig. 1), and the difference in elevation between the measured water table and the basal thalweg surface ('b' on Fig. 1). This relationship allows us to calculate directly the elevation of the water table from the DEM and the elevation of the envelope-surface of the thalweg base for each grid node.

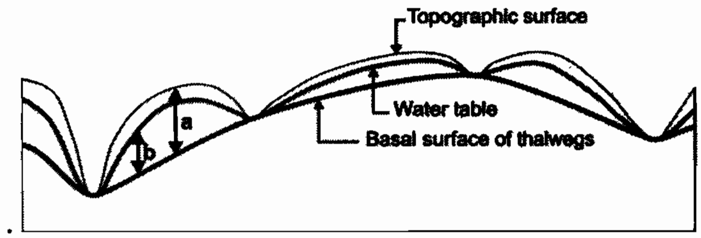

Figure 1: Principle of water-table modelling (from Wyns *et al.* 2003).

GENERAL PROCEDURE FOR MAPPING GROUNDWATER RESERVES

The quantitative mapping of groundwater reserves in weathered basement environments is based on:

- the calculation, for each grid node, of the thickness of each weathering horizon located beneath the water table;
- the evaluation, using MRS, of the mean water content for each of these horizons and for each lithological facies in the study area (Fig. 2).

HORIZON MODELLING WITHIN THE WEATHERING PROFILE

Depending on the available data, elevation values for the base of the alterite are determined through geometrical modeling of drill-hole data and/or MRS results. Because of poor signal-to-noise (S/N) conditions at the soundings end, the MRS inversion results do not generally enable the geometry of the fissured zone to be defined.

The thickness of the alterite in the saturated zone is obtained by calculating the difference between the elevation of the water table and that of the basal alterite surface. The thickness of the fissured zone in the saturated zone is calculated in the same way.

MAPPING GROUNDWATER RESERVES

Assuming that the physical properties resulting from supergene weathering vary vertically for the same lithology according to the difference in elevation with respect to the base of the alterite (Wyns *et al.*, 1999), we can try, for each geological formation, to characterise the average properties of each weathered layer fromMRS. Where possible in terms of S/N level, we attempted several magnetic resonance soundings for each geological formation in the aim of calculating average water contents for the alterite and the fissured zone (Wyns *et al.*, 2003).

Where S/N conditions are unfavourable and horizon geometry cannot be defined, the water reserves are directly obtained by computing water volume per unit surface, V_W, such as $V_W = \sum W_i e_i$ (Legchenko *et al.* 2003). V_W, which is expressed in m^3/m^2, has a dimension of a height and is better determined by MRS than W_i, which cannot be derived without fixing horizon depth and thickness.

The total water reserves computed for the La-Roche-sur-Yon region are presented as a thickness map on Figure 3a. It shows a high degree of correlation with the geology, as expected on the basis of MRS water-content profiles and water volume (Fig. 3b).

Reserves in the in alterite are only 85.10^6 m^3, with most of the reserves being located in the fissured zone (513.10^6 m^3). This is mainly due to the better preservation of the fissured zone, the alterite being more widely eroded, but also to the geometry of the water table with respect to the weathered layers. The elevation of the water table, however, is above the base of the alterite over most of the study area, which indicates that recharge is largely controlled by the properties of the alterite.

CONCLUSION

The present study demonstrates the feasibility of quantitative mapping of groundwater reserves within weathered aquifers of differing geology on the basis of geometrical modelling and MRS water-content evaluation. For the La-Roche-sur-Yon region, it has provided new data concerning aquifer structure. Due to the intense erosion of the alterite, 85% of the groundwater reserves is contained in the fissured zone, compared to only 15% in the alterite. It must be borne in mind that tectonic fractures are not taken into consideration, as their reserves are insignificant compared to those of weathering-related fissures.

According to Shirov *et al.* (1991), MRS water content corresponds to contents of free water as opposed to water bound to the grains. Values measured in the granite environment of Brittany (5 to 10%) are relatively similar to effective porosity. Higher values (15 to 20 %) obtained in certain metasediments (Brioverian schist) indicate that bound water may contribute to MRS water content. Additional field and laboratory study is necessary for calibrating the water content derived from MRS data.

REFERENCES

Wyns R., Gourry J.-C., Baltassat J.-M., and Lebert F. (1999). - Caractérisation multiparamètres des horizons de subsurface (0-100 m) en contexte de socle altéré. *2ème Colloque GEOFCAN*,. BRGM, IRD, UPMC, pp. 105-110. Orléans, France.

Wyns R., Baltassat J.M. , Lachassagne P., Legchenko A., and Vairon J. (2003) - Application of SNMR soundings for groundwater reserves mapping in weathered basement rocks (Brittany, France). *Bull. Soc. Géol. Fr.*, in press.

Shirov M., Legchenko A., and Creer G. (1991). - New direct non-invasive ground water detection technology for Australia: *Expl. Geophys.*, vol. 22, pp. 333-338.

Legchenko A., Baltassat J-M., Bobachev A., Martin C., Robin H., and Vouillamoz J-M. (2003) - The magnetic resonance soundings applied to characterization of aquifers, *Journal of Ground Water, in press.*

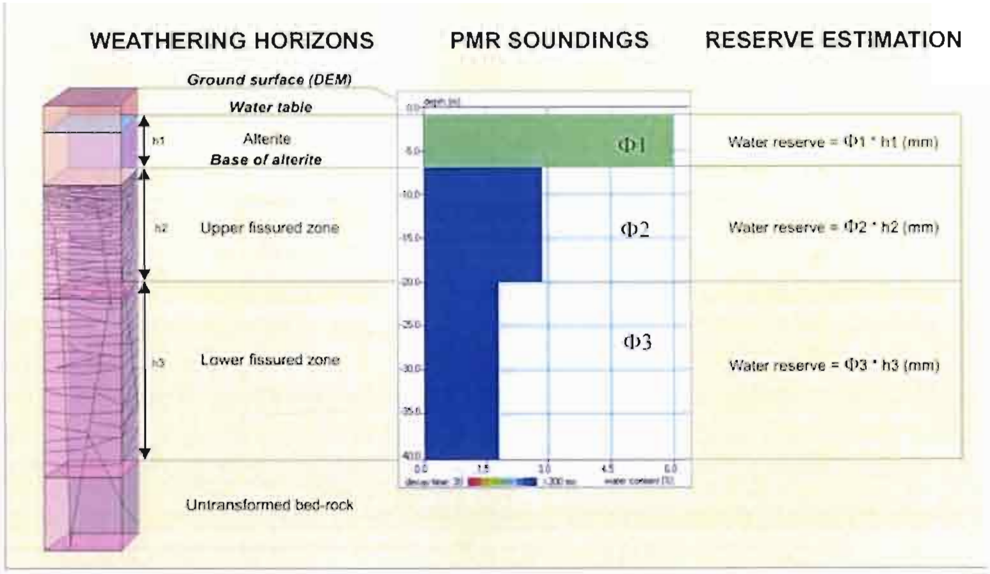

Figure 2: Stages involved in mapping groundwater reserves (from Wyns *et al.* 2003)

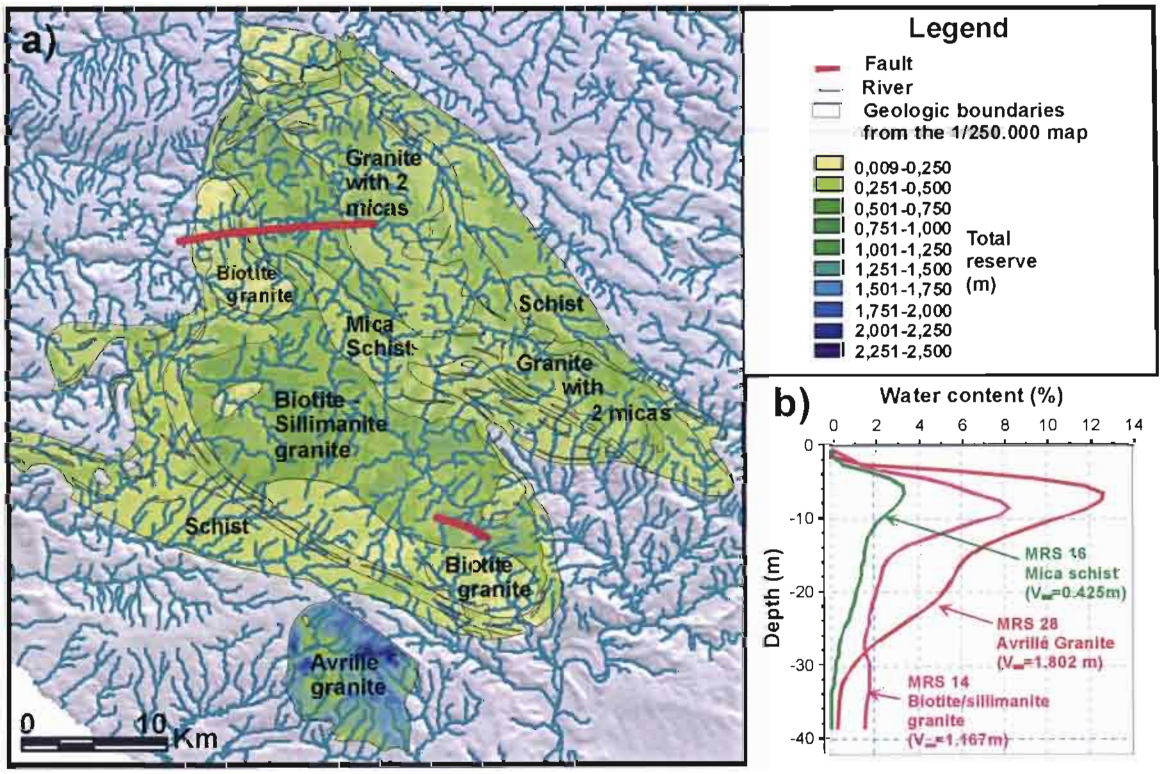

Figure 3: La Roche-sur-Yon region: a) Thickness map of total reserves in the weathered aquifers. b) Example of MRS water content profiles measured in different geological settings.

Geoscience for a sustainable Earth
brgm

MRS

2[ND] INTERNATIONAL WORKSHOP

on the Magnetic Resonance Sounding method applied to non-invasive groundwater investigations

19 - 21 November 2003 - Orléans - France

PROCEEDINGS

Organizer

Geoscience for a sustainable Earth
brgm

Co-organizer

TU berlin

Support

IRIS Instruments

EAGE
EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS