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Application of the NMR-tomography technique for groundwater investigations in Equatorial Africa: a case-history in Guinea

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Abstract

The nuclear magnetic resonance (NMR) geophysical technique has been applied in the Guinea Republic (Africa) for groundwater exploration. The hydrogeological context is quite typical for Equatorial Africa, namely a fissured rocks aquifer. The study led to finding a location with favourable aquifer characteristics. The follow-up drilling resulted in a well producing water with a yield of 30 m^3/h. This case-study illustrates the cost savings that can be obtained by using the surface NMR technique for sitting groundwater supply boreholes.

1. Introduction

Nuclear magnetic resonance (NMR)-tomography, the original Russian name for surface nuclear magnetic resonance (SNMR), is a geophysical technique that is well suited for groundwater exploration because it directly determines the water content as a function of depth in subsurface rock layers. Under a contract with Zarubezhgeologiya of Russia, a survey has been performed by Hydrogeotom JSC (Russia) within the Guinea Republic in Equatorial Africa, about the town of Forecariah, to study the hydrogeological conditions of the area, and identify sites for drilling wells that could provide a reliable domestic water supply to this town.

2. Geography and geology

The area of interest is 0.8×1.2 km wide. It is limited to the north by the flood plain of the Kisikisi river, and to the east by its Darakoro tributary (Fig. 1). In between lies a water divide, the slopes of which are cut by deep ravines. The Kisikisi river flows from the east to the west as it enters the Atlantic ocean. However, it is subject to tidal reversal, so that the aquifers underneath the flood plain are likely to be saline as seawater can easily infiltrate into the underground.

The geology of this area is composed of Quaternary sedimentary rocks overlying Upper Archean rocks. The Quaternary sediments are 15- to 20-m-thick laterites. The Upper Archean Kasilian rocks include amphibolites, crystalline gneisses, and quartzites. They were known by previous drillholes down to a depth of 50 m.

The underground waters in this area are found within the laterites and in the fissured Archean rocks.

3. Geophysical measurements

The NMR-tomography measurements have been performed with the Hydroscope equipment developed by ICKC (Novosibirsk, Russia). After processing of

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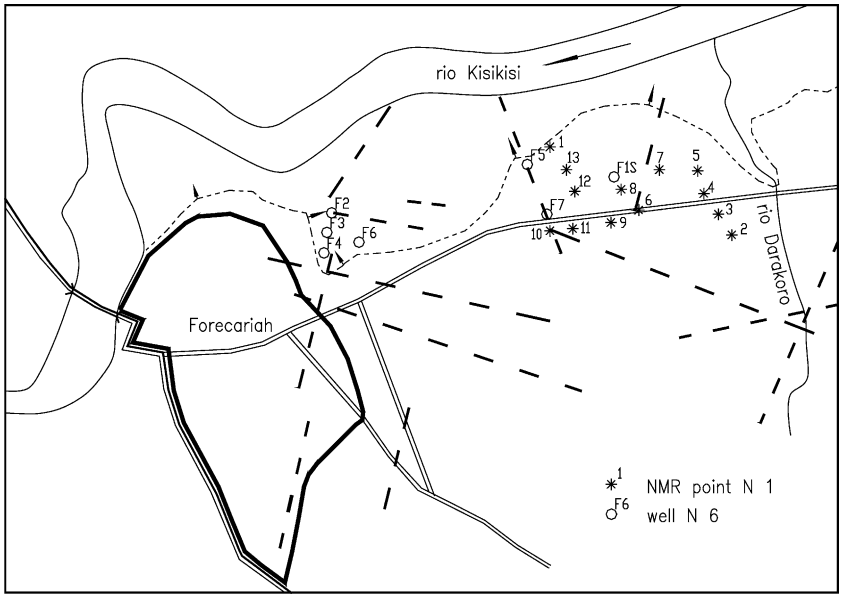

Fig. 1. Base map of the survey area about the town of Forecariah, Guinea Republic.

the first test data, it was established that the signal intensity did not exceed 25 nV; therefore, it was decided to have smaller spacing between observation stations to achieve a more detailed study of the hydrogeological structure of the area. A total of 13 stations were surveyed. Their location was chosen taking into account both the area geomorphology and the possibility to transport a drilling rig latter on.

Table 1
Table of the field NMR data (Forecariah)

No. of station	Loop diameter, m	Loop shape	Frequency, Hz	Number of stacks	Field angle, deg	Mean value (arithmetic)							Noise/*E*, %
						E, nV	ES, nV	EM, nV	EL, nV	|DF|, Hz	Phase, deg	Noise, nV	
1	100	Circle	1369	49	15	13	5	4	4	2,2	231	12	0.9
2	100	Circle	1358	64	15	18	16	1	1	0,2	85	13	0.7
3	100	Circle	1352	80	15	5	2	1	2	0,3	185	3	0.6
4	100	Circle	1361	64	15	28	24	2	2	−2,1	162	22	0.8
5	100	Circle	1359	72	15	26	24	1	1	0,7	103	18	0.7
6	100	Circle	1355	80	15	11	5	4	2	−0,3	193	9	0.8
7	100	Circle	1355	80	15	16	13	2	1	−0,4	202	9	0.6
8	100	Circle	1354	64	15	13	6	4	3	−0,9	175	9	0.7
9	100	Circle	1352	80	15	20	18	1	1	−0,6	221	9	0.5
10	100	Circle	1356	80	15	20	18	1	1	0,4	124	12	0.6
11	100	Circle	1352	80	15	10	8	1	1	−0,5	200	6	0.6
12	100	Circle	1352	36	15	20	11	5	4	−1,6	182	29	1.4
13	100	Circle	1352	64	15	18	11	4	3	−0,3	241	9	0.5
Minimum			1352	36		5	2	1	1	−2.1	85	3	0.5
Average			1356	69		18	13	2	2	1	177	12	0.7
Maximum			1369	80		28	24	5	4	2.2	241	29	1.4

For each station, measurements were made for 28 values of the moment Q of the energising pulse. The other data acquisition parameters are summarised in Table 1. All measurements were conducted with a 100-m-diameter circular loop antenna. The Larmor resonance frequency ranged from 1352 to 1361 Hz. The inclination angle of the Earth magnetic field was about 15°. The maximum and minimum levels of the signal in all observation stations were respectively 66 and 2 nV while the average values ranged from 13 to 16 nV; the maximum noise value was 59 nV while its average values were about 6–9 nV.

Examples of the signal amplitudes and of the change of the signal phase and resonance frequency are given in Fig. 2a–c for stations 2 and 4 that are typical of the survey.

For each station, the data inversion was performed down to a depth of 138 m. Examples of the data inversion results are given in Fig. 3 again for stations 2 and 4.

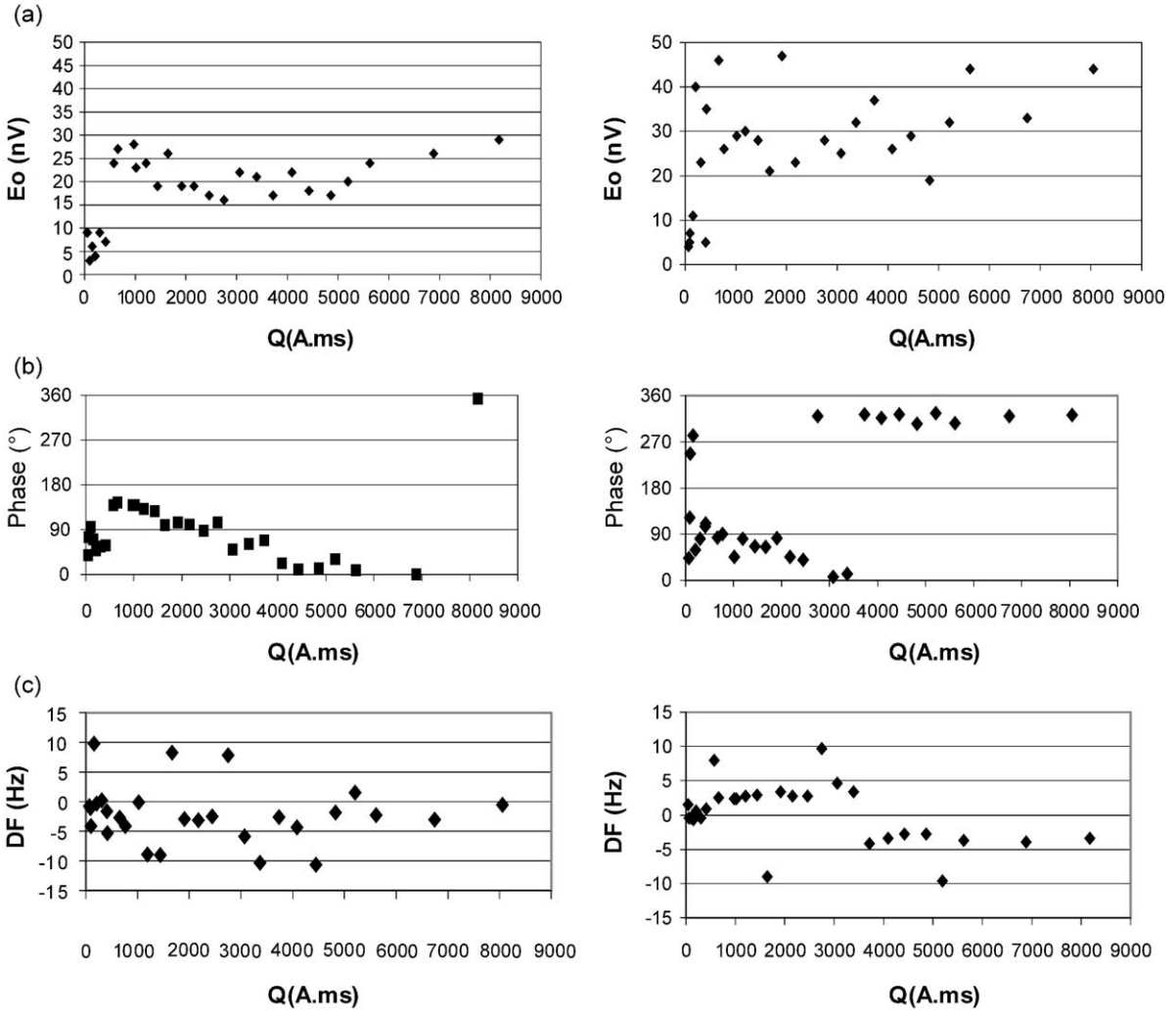

Fig. 2. (a) Diagrams of the signal amplitudes for stations 2 (left) and 4 (right). (b) Diagrams of changes of the signal phase for stations 2 (left) and 4 (right). (c) Diagrams of changes of the resonance frequency for stations 2 (left) and 4 (right).

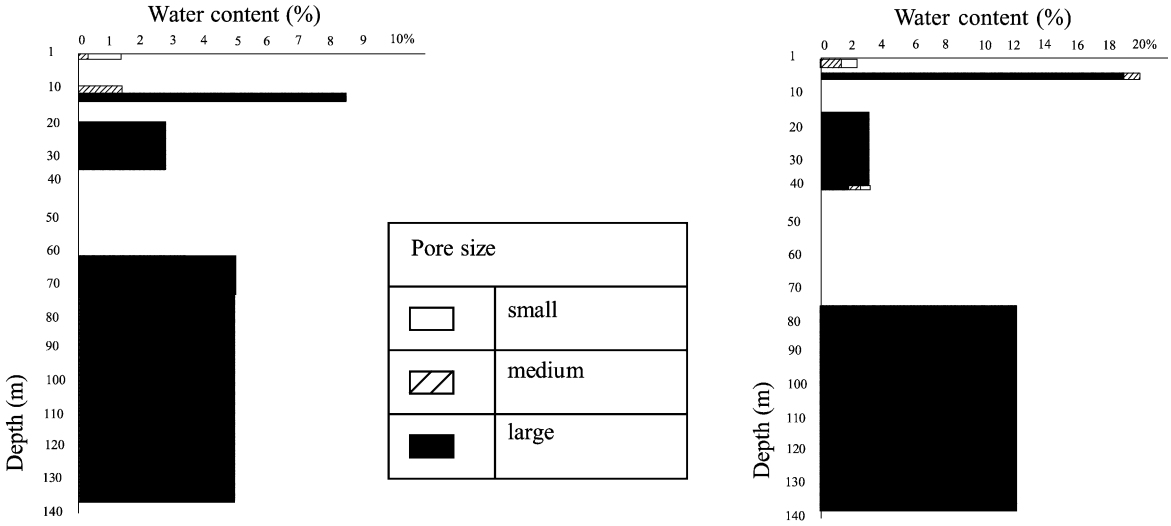

Fig. 3. Interpreted water content profiles for stations 2 (left) and 4 (right).

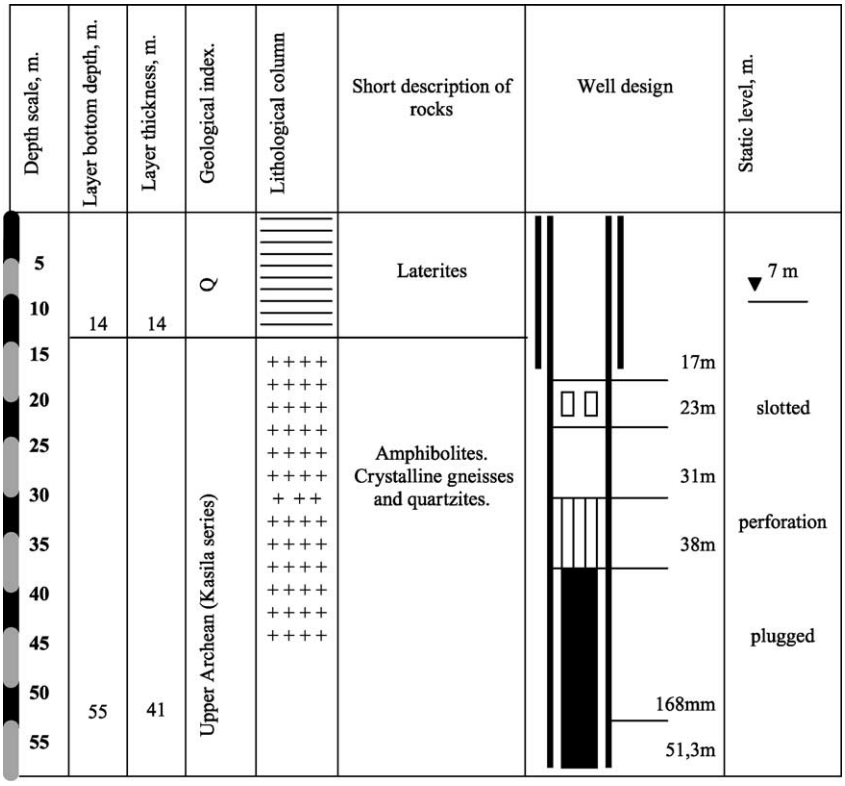

Fig. 4. Geological cross section and design of well F5 at Forecariah.

4. Borehole site selection and drilling result

After analysing and comparing the NMR-tomography results from the various stations, the three sites with the best potential for a water well were fingered out. The well drilled by the SOGUIRUSSE JSC (Konakri) at the first of these sites, F5, was sunk down to a 70 m depth. Its flow rate was found to be 30 m^3/h from a pumping test. This is a much higher value that what was obtained from boreholes drilled before the geophysical survey, closer to the town (Fig. 1). The characteristics of the geology at this successful well, together with its design and further equipment, are shown in Fig. 4.

5. Conclusion

This case-history of application of the NMR-tomography geophysical technique for the exploration of underground water and the siting of water production wells demonstrates the value of this technique under the conditions of Western Africa, where aquifers are mainly fissured rock ones: it allowed to locate a zone of maximum water content without the drilling of expensive exploration wells.