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Optimum Drilling Depth of Boreholes in the Crystalline Basement Rocks of Nigeria

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Abstract: *Geology of an area, water quality, local regulations and economic consideration are important in deciding upon well depth in the crystalline Basement rocks. Drilling results in the Basement Complex rocks indicate highly variable amounts of water, decrease in average yield with depth, and decrease in the interception of fractures as the depth increases. This paper gives estimate for probable depths of domestic wells in the crystalline Basement rock areas. These depths are cost-effective, and at the same time will not obscure the primary objective of all water well contractors, which is getting enough yield for efficient development of water supply.*
Keywords*: Crystalline rocks, optimum depth, borehole drilling, fractures, well yield.*

I. Introduction

More than half of Nigeria is underlain by hard crystalline impervious rocks which are either igneous or metamorphic in origin. The rocks cover parts of Kaduna, Kano, Kwara, Kogi, Zamfara, Oyo, Oshun, Niger to mention but few (Figure 1). These rocks are mainly granitic in composition and in different stages of metamorphism. They may occur in the form of gneisses, migmatites, schists, phyllites and quartzites. These rocks are hard, with low permeability and generally not water-bearing. The rocks are aquiferous only when they are weathered or fractured, otherwise they are dry or at best contain just little amount of water (Jones, 1985; Oluyide, 1995).

Over most of the area underlain by the Basement Complex, there is a thin, discontinuous mantle of weathered rock, mostly pronounced where the topography is subdued. The average thickness of the mantle is probably of the order of 15m (Table 1), but in some areas it may extend to depths up to 60m (Hazell et al, 1992, Olaniyan and Olabode, 2012). The actual depth of the weathered zone depends on the length of time in which the rock has been exposed to surface or near-surface conditions and its original mineral composition. The interface between weathered and unweathered rock is usually sharp. Weathering tends to be particularly well developed along fissure systems which allow deep percolation of weathering agents, principally oxygenated water. River system can sometimes be a guide to fault lines and associated fissure systems because they represent lines of weakness for erosion and weathering (Anderson, 1983; Linsley et al 1992; Karanth, 1993). The average yield in this area ranges between 0.75 – 1.8 l/s (see Table 1). Notwithstanding, very high yield of up to about 3 l/s can be obtained in deeply fractured and weathered locations.

Borehole Drilling In Crystalline Basement Rocks

Drilling in this area is always accomplished most effectively by the down-the-hole hammer using air rotary method. A pneumatic drill operated at the end of the drill pipe rapidly strikes the rock while drill pipe is slowly rotated. The hammer is constructed from alloy steel with heavy tungsten-carbide inserts that provide the cutting or chipping surfaces. Tungsten-carbide is extremely resistant to abrasion, but drill bits do become dull with continued use. The inserts are sharpened by grinding when operating conditions indicate that the bit is not cutting properly. Alternatively, the bits may be replaced (NWRI, 1986).

It is important to note that in most cases, the deeper the depth the more difficult the hole becomes to drill, the more the bit wears and the more fuel is used. It is, therefore, uneconomical to drill beyond a reasonable depth which is addressed in this paper. Usually not many options are open to borehole design in this terrain because of its poor permeability; hence the aquifer has to be tapped in its entirety in order to maximize yields. The success rate in this formation is very low. Even when elaborate exploratory methods are employed and well drilled to a greater depth, the yield from well may be disappointingly small. The yield may be so low in some cases that the water standing in a well before pumping represents the total volume that can be pumped at any time. In some cases, sophisticated aquifer stimulation methods like hydraulic fracturing may increase the yield significantly (Campbell and Les, 1973; Diamond and Shanley, 2003).

Data Collection and Analysis

In order to establish the optimum drilling depth in the crystalline Basement rock, a total of 30 borehole drilling data were selected for analysis. The boreholes selected for study were carefully chosen, bearing in mind the need to have a fair representation of all the areas that fall under the Basement complex. The boreholes whose depths range between 40-70m and 150mm (6") in diameter were all drilled by the Hydrogeology Department of the National Water Resources Institute, Kaduna. All the boreholes selected for analysis were properly logged. The geophysical loggings carried out for each of the boreholes include Caliper, Natural Gamma, Point Resistivity and Self Potential logs. The loggings were carried out before installation of casings and screen using a Swedish made S. 1-E Geosource portable borehole logger.

The analysis carried out in this study were based on the caliper log alone as it often directly identify voids, cracks, fractures or shattered weathered zones cut by the bore. Caliper logging involves using a hole caliper to measure well diameters down a hole. The instrument has three extensible arms with an electrical resistor which motivates the arms. The technique is to insert the device with the arms folded into a well until the bottom is reached. Then the arms are released by a detonation of a small charge and the average hole diameter logged as a continuous graph by the recording of resistance changes while the caliper is being raised. Example of caliper log penetrating a fractured zone is shown in Figure 2. For each borehole, the caliper log was carefully examined to get the various depths where there are cracks or fractures. The results of the interpretation are presented as Table 1. A frequency distribution of the depths of fractures for the 30 boreholes was compiled and the result is presented as histogram in Figure 3.

II. Discussion of Results

It can be seen from the results given in Table 2 that about 76% of the total fractures occurred within the depth range of 30m. Between 31-40m, only 11% of the total fractures occurred; only 6.8% was recorded for 51-60m depth and less than 1% fracture occurred after 60m. The above result confirmed the fact that as the depth of a borehole increases, the frequency of interception of fractures decreases. This decrease can be attributed to the effect of the weight of the overlying rock. The increasing weight of the overlying rock tends to close the joints, fractures and faults at greater depth. Another reason could be the tendency of surface disturbances to penetrate only short distances into the bedrock. These reasons can be adduced to be the cause of the general decrease in the frequency of occurrence of fractures with increasing depth noticed during the interpretation of the caliper logs.

Conclusion and Recommendation

The following conclusion and recommendation are made from this study:

- The water-bearing characteristics of the Basement Complex are primarily controlled by weathering and structure. Rock type alone is commonly of secondary importance.
- The average thickness of the weathered mantle over most of the Basement complex in Nigeria is about 15m. However, there may be a few exceptions to this.
- Most of the fractures in the Basement complex can be encountered before the depth of 40m.
- Although extensive studies have not been made in some other parts of the hard rock areas, it is recommended that the depth of domestic well in these areas should not be more than 60m. Exceptions to this approach are, of course, situations in which geologic knowledge or surface geophysical data may predict the existence of productive zones at a particular depth greater than 60m.

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Table 1: Borehole Inventories of Selected Wells in Crystalline Basement Complex

S/No	Borehole Location	Total Depth (m)	Depth to Fresh Basement (m)	Yield m^3/hr	Depth to Fracture (m)	Static Water Level (m)	Date of Completion
1	Arewa Text. Quarters, Kaduna	61.4	11.8	7.9	-	5.6	12:06:86
2	Combined Plain, Keffi	55	6	2.37	17	1.4	14:08:87
3	A.B.U.T.H. Zaria	55	10	2.16	15-18	2.84	10:01:87
4	Budung Kahung, Saminaka	61.35	20.4	2.45	20-25	6.95	22:05:87
5	Paiko, Niger State	50	6.71	1.08	36, 46	3.18	26:02:88
6	Share, Kwara State	61.2	26.5	1.08	25-33	6.25	09:08:86
7	Mopa, Kogi	60.58	3	Very Low	Nil	2.83	05:02:97
8	Suleja	40	9	2.61	14	4	12:08:97
9	Nasarawa	43.5	14.5	3.6	16	3.3	17:07:85
10	Suleja, Dalhatu Road	60	9	2.93	36-44	4.6	09:09:85
11	NWRI, Kaduna	92	34.6	3.24	40-45	6.8	10:11:84
12	A.B.U.T.H. Kaduna	61.3	24	3	25-33	5.27	15:07:86
13	U.N.R.B.D.A. Minna	70	5.4	1.08	5-10, 45-47	6	14:11:85
14	Fed. Poly K/Namoda	36	4	5.4	9-10, 24-25	6.25	13:04:94
15	Police Barrack Kawo, Kaduna	50	27	2.16	25-37	0.86	17:10:97
16	Mopa Quarry, Kogi State	50	9	5.4	9-13, 21	6.62	16:03:88
17	University of Ilorin (Hostel)	61.4	11.4	1.1	36-38	9.85	14:07:87
18	University of Ilorin (Farm)	53	3.5	6	4, 15, 50	0.42	10:07:87
19	Buruku, Kaduna State	67.3	6.1	4	16-23; 55-58	4.5	01:04:86
20	Ogga, Kogi State	40	17	3.6	20-24	2.34	17:12:94
21	N.I.P.S.S. Kuru, Jos	50	25	6	30-34	2.1	1997
22	Jos Township	40	13	0.8	18-21; 25-26	2.65	01:06:94
23	A.B.U. Southern Kaduna	40.35	22	2.8	24, 29, 31, 33	8.5	14:05:90
24	Malle Farms, Lapai Niger State	61.3	24.6	3	-	13	03:12:85
25	Birkiji, Kaura Namoda	36	16	4.32	17,19,28	8.6	16:10:98
26	Kurfi, Katsina State	55.2	25	2.16	31	1.76	18:12:89
27	Zucas, Zungeru, Niger State	62	20	3	25, 36	5.39	29:10:87
28	St. Gerald's Hospital, Kaduna	73.3	24	7.56	30, 53-56	6.7	12:03:86
29	E.C.A. Buruku, Kaduna	102	18	3.56	21-24, 42,51,73	1.9	15:02:85
30	Ihima, Okene	40	26	2.52	28,29, 32-35	2.63	12:02:95

Table 2: Frequency Distribution of Depth of Occurrence of Fractures for Selected Boreholes

FRACTURE HOLE DEPTH (m)	FREQUENCY	%
< 10	11	9.4
10 – 20	40	34
21 – 30	39	33
31 – 40	13	11
41 – 50	5	4
51 – 60	8	6.8
> 60	1	0.8

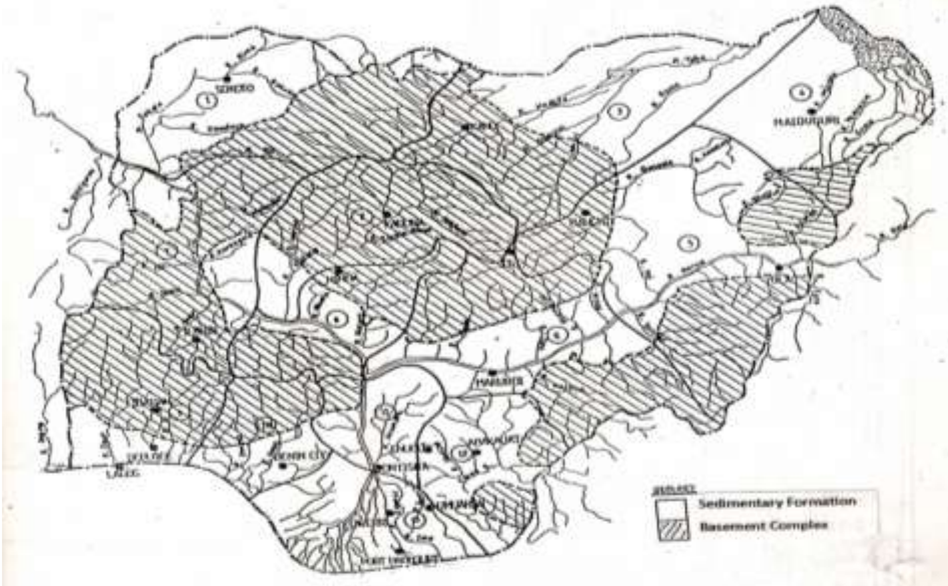

Figure 1: Hydrogeological Map of Nigeria showing Basement Rock Terrain (Offodile, 1992)

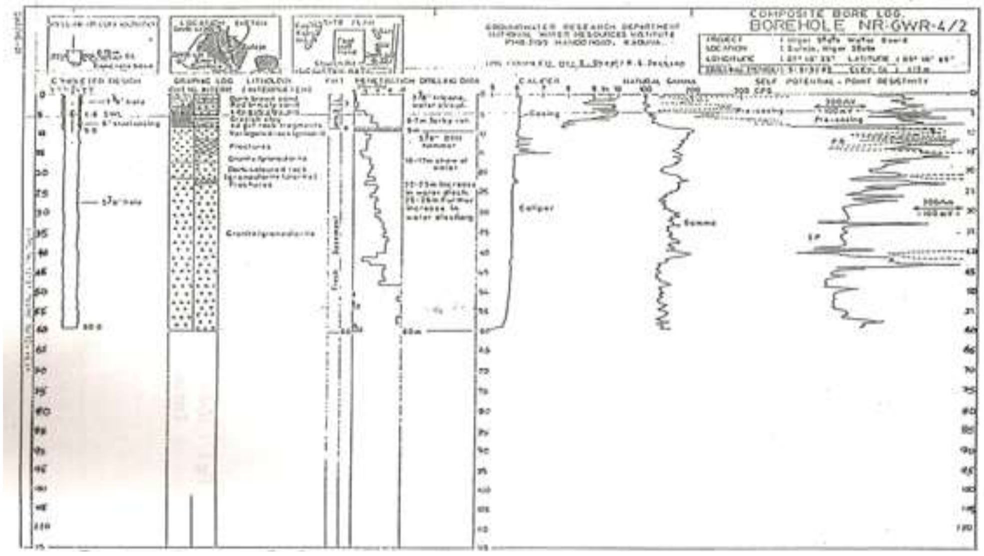

Figure 2: Composite Borehole Log

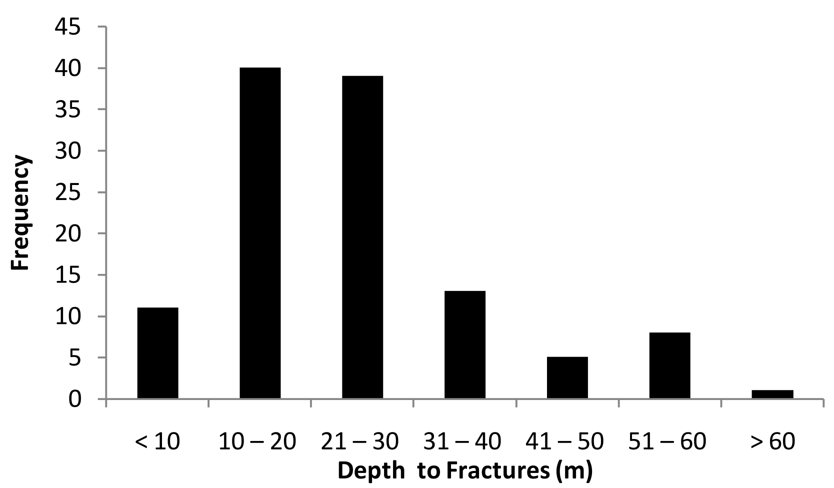

Figure 3: Histogram of Depth to fractures