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A Dual Topographic-Petrographic Control for a 1km^2 VES-IP Study Completed at the Gidan Kwano Campus Phase II Development, Federal University of Technology, Minna, Nigeria

Jonah, S.A., Akpomie, D.P., Ezekwebekwe, L. O., Isah, E.A., Muhammed, A.N., Momoh, A.A., Okoye, C.K., Okpara, K. K., Oni, N.O., *Alade, R. O., *Yahaya, G. A., *Zubair, R.O., Onoja, E.U., and Daramola, O.

Department of Physics, Federal University of Technology, Minna, Nigeria

*Department of Geology, Federal University of Technology, Minna, Nigeria

Abstract

It is usually not the norm, so far as studies carried out in the local basement complex geology of the Minna Area is concerned, to constrain the accuracy of the interpretation of VES data-set with the corresponding topographic and petrographic map of the specific area of study. Such approach would serve as a veritable tool of quality control (QC) of the interpretation of the acquired VES data-set. The aim of this study is to implement a valid quality control scheme for an earlier dual VES-IP study. The topographic survey proceeded along transverse traverses in a west-east, east-west zig-zag format until transverse traverse (TT) 51 was completed. The petrographic survey phase of this study was concerned with the study of the aspects of the different outcrops seen at the area of study in terms of their strike, dip, and other structural orientation. Over the 1km^2 area of study of interest here, it is observed that terrain or ground elevation progressively increases from south to north. An important observation herein, too, is that elevation increases from west to east. It is understood from the petrographic map that the area of study is underlain by a continuous body of granite that is intruded by a small body of schist. Examination of the landform map of the area of study positively correlates the conclusion of aquifer prospects drawn from the earlier survey and it is strongly recommended to drill these locations for groundwater exploitation.

Keywords: Topographic; petrographic; quality-control; groundwater

Introduction

For the 100km^2 areal extent of the Gidan Kwano Campus (GKC), information on spatial topography is as gleaned from Adesoye (1996). Jonah and Jimoh (2013) discussed the production of a topographic map for a 15km^2 extent of the GKC, which at 100m station-spacing of the data collection process, was considered to be a refinement of that of Adesoye (1996) for that corresponding slice of ground. For the 8km^2 areal extent that is being touted as the ideal location for the Gidan Kwano Campus Phase II Development (Jonah *et al.* 2014A; 2014B; 2015A; 2015B; 2015C), Jonah *et al.* (2014B) have produced a site-specific topographic map, with its corresponding site-specific geomorphic map, still at 100m station-spacing of the data collection process, that give more information about landform regimes compared to what could be gleaned from Adesoye (1996). The $1km^2$ areal extent area-of-study of this present study is subsumed in the $8km^2$ areal extent that is being touted as the ideal location for the Gidan Kwano Campus Phase II Development. Over this $1km^2$ areal extent, Jonah *et al.* (2015A) have completed a dual vertical electrical sounding (VES)-induced polarisation (IP) survey to locate aquifer prospects; whilst the rule adopted for the interpretation of the result of their survey followed standardized technical nuances, there was no surface geomorphological control to aid their interpretation. This study is principally concerned with creating a topographic map, at 20m station-spacing of the data collection process to serve as a further aid in the interpretation of the dual VES-IP results of Jonah *et al.* (2015A).

Petrographic mapping, of the type that is being proposed for this study, whence subsurface aquifer information is tied directly to surface systematic description of the texture of rocks in order to constrain interpretation even further, is an entirely novel concept for the $100km^2$ areal extent of the GKC. The work that is most similar in this context is the concurrent study by Jonah and Olasehinde (2015D) for the $8km^2$ Phase II Development areal extent. Suffice to point out, also, that there was no surface petrographic control to aid the interpretation of Jonah *et al.* (2015A). Thus, too, this study is principally concerned with creating a petrographic map to serve as a further aid in the interpretation of the dual VES-IP results of Jonah *et al.* (2015A).

Area of Study:- The $1km^2$ of interest here, subsumed in the Gidan Kwano Campus Phase II Development, is identified by the following georeferenced co-ordinates, viz: $09^0 30'57.8''$N, $006^0 25'39.0''$E (most extreme southwest); $09^0 30'57.8''$N, $006^0 26'11.5''$E (most extreme southeast); $09^0 31'30.3''$N, $006^0 26'11.5''$E (most extreme northeast); $09^0 31'30.3''$N, $006^0 25'39.0''$E (most extreme northwest). It is known that the area of study under consideration herein is part of the Nigerian Basement Complex (NBC).

Statement of the Problem:- It is usually not the norm, so far as studies carried out in the local basement complex geology of the Minna Area is concerned, to constrain the accuracy of the interpretation of VES data-set with the corresponding topographic and petrographic map of the specific area of study. Such approach would serve as a veritable tool of quality control (QC) of the interpretation of the acquired VES data-set. Jonah *et al.* (2014B) used the result of a topographic as a tool of QC for geoelectric data over an 8km^2 areal extent of the proposed Phase II Development of the Gidan Kwano Campus. As at the present, there is no evidence that a dual topographic-petrographic validation of the result of a dual VES-IP survey in the Minna Area has been undertaken.

Aim and Objectives of Study:- The aim of this study is to implement a valid quality control scheme for an earlier dual VES-IP study completed at a 1km^2 tranche of the Gidan Kwano Campus Phase II Development, Federal University of Technology, Minna.

The objectives of this study are the following:

i. The use of a purpose-specific topographic map to validate the result of a dual VES-IP study completed at a 1km^2 tranche of the Gidan Kwano Campus Phase II Development; herein, elevation values (that is, the "z" parameter) at designated principal stations of 20m over the 1km^2 areal extent under consideration would be collected. The full gamut of this "z" values would be contoured in order to create a site-specific topographic map; at 20m station-spacing, it is expected that the topographic map data field should produce a very detailed geomorphological profile of the area of study.

ii. The use of a purpose-specific petrographic map to validate the result of a dual VES-IP study completed at a 1km^2 tranche of the Gidan Kwano Campus Phase II Development; herein, a systematic description of the major outcrops occurring at the area of study would be implemented by means of specifying the nature and structural aspects of the outcrops in terms of their strike, dip, joint character, fracture character, fault character (where applicable), and so on.

Justification of Study:- The result of Jonah *et al.* (2015A), to determine groundwater prospects over a 1km^2 slice of the Gidan Kwano Campus Phase II Development, was based on the conventional "first-stage" VES interpretation schedule. The conclusions drawn regarding groundwater prospects over this 1km^2 slice would be further strengthened when the result of this "first-stage" interpretation is tied to the result of the topographic map (resulting in a "second-stage" interpretation); tying this outcome further to the petrographic map would result in a "third-stage" interpretation scheme in order that the conclusions drawn may be truly relied on.

Scope:- There are 51 transverse traverses of the 1km^2 areal extent of the area of study at 20m station-spacing for the topographic map data-collection phase. Each transverse traverse (TT) is

1km (1000m) long. At 20m station-spacing there are 51 measurement stations on each TT, thus the total number of measurement stations is 51 x 51 = 2601. Elevation information was collected from these 2601 stations in order to create the topographic map of this study. The petrographic phase of this study was determined by the number of major outcrops that occur over the area of study.

The Phase II Development at the Gidan Kwano Campus:- According to Jonah *et al.* (2014A; 2014B; 2015A; 2015B; 2015C), the location most suited for the Phase II Development at the Gidan Kwano Campus is the 8km^2 areal extent shown in Fig.1, defined to be a perfect rectangle on the ground with its ends corresponding to the following georeferenced co-ordinates: 09^{0}30′57.8″N, 006^{0}25′39.0″E (most extreme southwest); 09^{0}30′57.8″N, 006^{0}26′43.8″E (most extreme southeast); 09^{0}33′07.4″N, 006^{0}26′43.8″E (most extreme northeast); 09^{0}33′07.4″N, 006^{0}25′39.0″E (most extreme northwest).

The Nigerian Basement Complex:- According to Obaje (2009), the Nigerian Basement Complex (NBC) is one of the three major litho-petrological components that make up the geology of Nigeria. The NBC forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons and south of the Tuareg Shield (Black, 1980). It is intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and younger sediments. The Nigerian basement was affected by the 600 Ma Pan-African orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006). The basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism, and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African cycles (600 Ma). The first three cycles were characterized by intense deformation and isoclinal folding accompanied by regional metamorphism, which was further followed by extensive migmatization. The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses (Abaa, 1983). Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the end stages of this last deformation. The end of the orogeny was marked by faulting and fracturing (Gandu *et al.*, 1986; Olayinka, 1992). Within the basement complex of Nigeria four major petro-lithological units are distinguishable, namely:

i. The Migmatite-Gneiss Complex (MGC)

ii. The Schist Belt (Metasedimentary and Metavolcanic rocks)

iii. The Older Granites (Pan African granitoids)

iv. Undeformed Acid and Basic Dykes

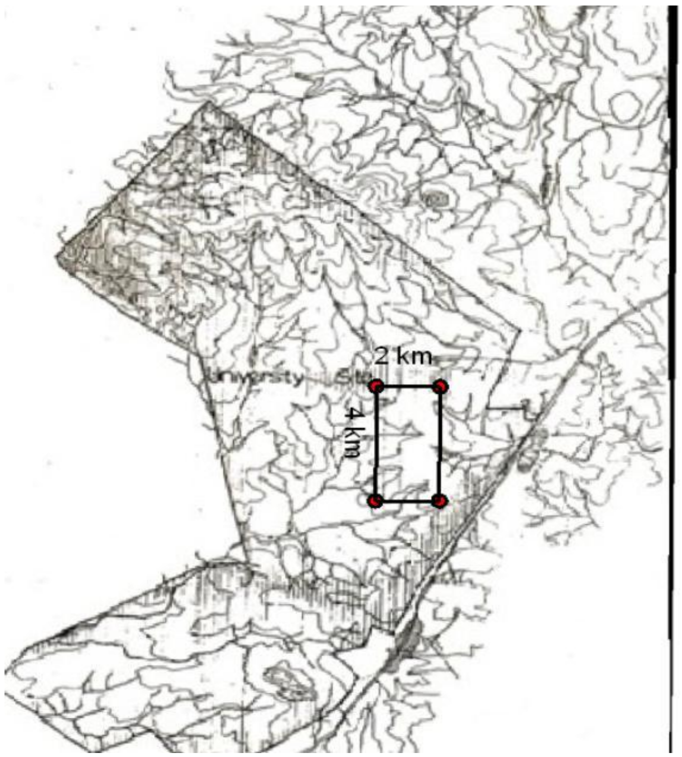

Fig.1. Location most suited for Phase II development at the Gidan Kwano Campus

Survey Methods

The Topographic Survey:- The essential idea herein is the collection of elevation values at 20m station spacing over the 1km^2 areal extent of the study area of interest. The survey proceeded along transverse traverses in a west-east, east-west zig-zag format until TT 51 was completed. It is expected that the 20m station spacing adopted for this study would yield a large data field with a concomitant high resolution of the ground being survey. The layout of this topographic survey is as shown in Fig.2.

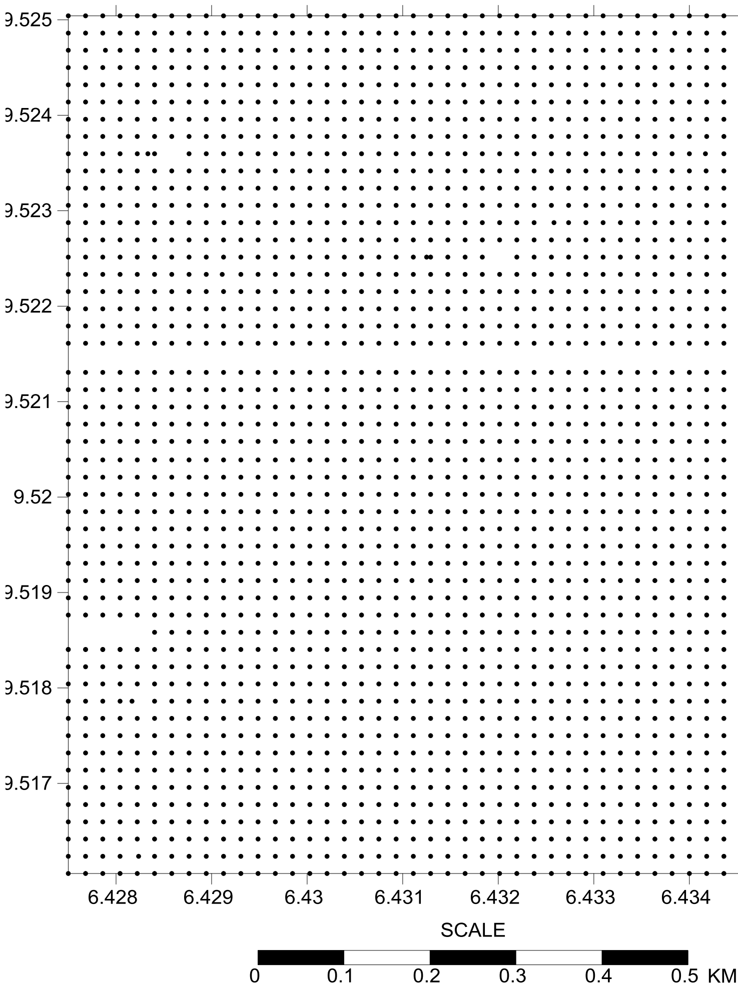

Fig.2. Layout of topographic survey

The Petrographic Survey:- The petrographic survey phase of this study was concerned with the study of the aspects of the different outcrops seen at the area of study in terms of their strike, dip, and other structural orientation. Each of the outcrops encountered was designated by a sample number, a designation of its rock type, its ground location, its georeferenced location, its camera image code, as well as its strike, dip, and other structural aspects.

Results and Discussion

Examination of the Results of the 1km^2 Dual VES-IP Survey:- The field resistivity values of the VES component of the dual survey were initially subjected to the log-log plot routine of the Windows-compatible WinResist® software whence corresponding field curves for all the stations occupied were produced. As a point of emphasis, the field survey trend was in the east-west direction (i.e. transverse traverse or TT designation). At station spacing of 200m for a 1km x 1km areal extent of survey, there were a total of thirty-six (36) TT stations. The transverse traverse designations are in increasing order from south to north (i.e. TT1 to TT6); each profile unit designation is from east to west (as in TT1-1 to TT1-6). Each of the WinResist® log-log plot provides information on the numbers of layers, the average resistivity values of these layers, and their approximate thicknesses. In order to show the variation of resistivity on a constant plane across the area of study, it is instructive to produce resistivity maps at constant depths (i.e. the iso-resistivity maps). For this 1km^2 dual VES-IP study, the Surfer® 10 software was used to generate the iso-resistivity maps at 10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m, 90m, and 100m. The Surfer® 10 package transforms the xyz dataset (longitude, latitude, and resistivity values) to create contour maps and other useful graphic maps.

Function of the Induced Polarisation Data for the 1km^2 Dual VES-IP Survey:- The induced polarization component of the 1km^2 dual VES-IP survey was utilized on a quality control basis for the VES results. In this case, the interpretation was guided by the statement-of-fact enunciated on p. 222 of Kearey and Brooks (1984) to wit: the sources of significant IP anomalies are water-filled shear zones; it is understood from ABEM (1999) that IP results can distinguish between groundwater and clay. This property is significant because it constrains the IP method to be an effective discriminator when making deduction as to the presence of groundwater. According to Parasnis (1986), p. 180, "the advantage of IP soundings (as a complement to VES) is that they are able to distinguish between clay layers (high IP) and some other low-resistivity strata like salt-water beds (no IP)." Thus, where it is suspected that groundwater may be present, recourse to the corresponding IP value recorded in *pari passu* at that depth would help dispel whatever doubt there may be.

Discussion of Result of the 1km^2 Dual VES-IP Survey:-

The "Geoexplore Empirical Standardization for Minna Area" and the "Olasehinde Protocol." Presently, there exist dual empirical rules to determine the likely presence of groundwater in the basement complex geological province. These rules are the "Geoexplore Empirical Standardization for Minna Area" and the "Olasehinde Protocol." For the 1km^2 dual VES-IP study, the interpretation for aquifer prospects at the thirty-six VES locations was based on these rules. The "Geoexplore Empirical Standardization for Minna Area" states that ohmic resistance values of less than or equal to 0.3Ω at the 20m depth or greater (or, in resistivity terms, between 200Ωm and 300Ωm at the 20m depth and less than 200Ωm at depths greater than 20m) is indicative of possible groundwater prospect. The "Olasehinde Protocol" states that resistivity values between 180Ωm and 250Ωm at the 20m to 25m depth mark are indicative of possible groundwater prospect. It is instructive to point out here that even though the resistivities of rocks do not depend on water content only, these informal laws are enunciated "rules-of-thumb" that serve as effective guides to groundwater prospectors out in the field. On the bases of these dual protocols, therefore, TT1-1 is not considered an aquifer prospect; TT1-2 is a good showing up to the 150-m depth, TT1-3 is a good showing up to the 70-m depth, TT1-4 is a good showing up to the 50-m depth, TT1-5 is not considered an aquifer prospect, TT1-6 is a good showing up to the depth of the barrier encountered, TT2-1 is a good showing up to the 40-m depth, TT2-2 is a good showing up to the 80-m depth, TT2-3 is a good showing up to the 50-m depth, TT2-4 is a good showing up to the 50-m depth, TT2-5 has incomplete information, TT2-6 is not a prospect. TT3-1 is a good showing up to the 60-m depth; TT3-2 is a good showing up to the 50-m depth, TT3-3 is a good showing up to the 40-m depth, TT3-4 is a good showing up to the 110-m depth, TT3-5 is a good showing up to the 60-m depth, TT3-6 is not a good showing, TT4-1 is a good showing to the 80-m depth, TT4-2 is a good showing to the 80-m depth, TT4-3 is a good showing to the 80-m depth, TT4-4 is a good showing to the 60-m depth, TT4-5 is a good showing to the 50-m depth, TT4-6 is not a good showing. TT5-1 is a good showing to the 40-m depth; TT5-2 is a good showing to the 40-m depth, TT5-3 coincided with a wet stream barrier, TT5-4 is a good showing to the 120-m depth, TT5-5 is a good showing to the 50-m depth, TT5-6 is not a good showing, TT6-1 is not a good showing, TT6-2 is not a good showing, TT6-3 is not a good showing, TT6-4 would not be a good showing down to the 30m, TT6-5 is a good showing to the 70-m depth, and TT6-6 is a good showing to the 50-m depth.

The WinResist® Plots. The WinResist® plots were vital guides to determining the numbers of layers at each survey location and, most important of all for this survey, for extracting information on the depth to basement used in the production of the isopach map.

The Iso-Resistivity Maps at Depths. The lowest resistivity value of 20Ωm can easily be made out on the 10m-depth map at TT5-4. On the 20m-depth map, TT5-2 to TT5-5 form a linear spread of progressively decreasing resistivity from 100Ωm to 20Ωm. TT4-2 to TT4-5, TT3-2 to TT3-5, and TT2-2 to TT2-5 also mirror this pattern. On the 30m-depth map, TT5-4 stands out as the lowest-resistivity region at 60Ωm in a "sea" of ohmic spikes. On the 40m-depth map, TT5-4, TT2-5, and TT1-2 stand out as the lowest-resistivity regions. TT5-4 and TT1-2 are made out still as the lowest resistivity regions on the 50m-depth map; the resistivity value at TT2-5 increases over this 10m-window enormously. TT4-1 to TT4-4 and TT3-1 to TT3-4 form a region of "associate low-resistivity" at this depth, too. The trend of Fig.4.5 is continued for the 60m-depth map; the new "entrant" here is TT1-3 and TT2-2. For the 70m-depth map, the resistivity trend of the 60m-depth is exactly imaged here. For the 80m-depth map, for the 90m-depth map, and for the 100m-depth map, the resistivity trend of the 60m-depth map is exactly imaged here, too.

The Isopach Map. The regions of low resistivity values at depths correlate strongly with the regions of contour closures observed on the isopach map.

Extraction of Aquifer Information for the 1km^2 Dual VES-IP Survey:-

For the dual VES-IP survey, it can be inferred that based on the dual empirical protocol scheme, the following VES locations are considered good prospects for groundwater: TT1-2, TT1-3, TT1-4, TT1-6, TT2-1, TT2-2, TT2-3, TT2-4, TT3-1, TT3-2, TT3-3, TT3-4, TT3-5, TT4-1, TT4-2, TT4-3, TT4-4, TT4-5, TT5-1 TT5-2, TT5-4, TT5-5, TT6-5, and TT6-6. However, if prevailing economic circumstances dictates that only a very limited number of VES locations could be drilled for boreholes at the area of the present survey and imposing a constraint involving analysis of the iso-resistivity contour maps, then the highly prospective VES locations would be TT5-4, TT1-2, TT1-3, and TT2-2. Now, for the recognised highly prospective VES locations of TT5-4, TT1-2, TT1-3, and TT2-2, how would it be certain that it was freshwater and not clay that is responsible for the observed low resistivity regime at depth? Recourse is made here to the qualitative discussion of the function of the induced polarisation data. Herein, examination of the individual IP tables of values would be undertaken for TT5-4, TT1-2, TT1-3, and TT2-2. This qualitative examination of each of the separate IP tables of values would be done only to a TD of 40m. This 40m-window restriction is due to the fact that, in the larger basement complex region of which the present area of study is but a small constituent, the thicknesses of the different phases of overburden materials never exceed 35m (Jimoh, 1998).

Qualitative Examination of IP Table for TT5-4 (09°31′23.7″; 006°25′51.9″). It is observed that a negative chargeability value of -55.4ms exist for TT5-4 at the 40m-depth mark: according to ABEM (1999), negative IP values can only mean that the resistivity of the current layer is less than that of the layer just above it; this trend would be contrary to the theoretical expectation that resisitivity should increase as the depth increases for any VES location. Interestingly, above this 40m-depth mark layer for TT5-4, the absolute IP value of 178ms is much greater than the absolute value of 55.4ms at the 40m-depth. Since Parasnis (1986) pointed out that clay layers correspond to “high IPs”, and salt-water beds correspond to “no IPs”, it can be inferred that freshwater beds correspond to “low IPs.” However, according to Mr. Jonah (personal communication), in his work since 2011 at the greater area of the Phase II Development, what is “high” or “low” IP is a subjective matter depending on the prevailing values of the current survey under analysis. This being the case, the absolute IP value of 178ms at the 30m-depth mark is “high” compared to the absolute value of 55.4ms at the 40m-depth mark (i.e. “low IP”). Based on this reckoning, TT5-4 is a very strong candidate for groundwater prospect at the 40m-depth mark, and the iso-resistivity maps have also indicated a continuation of low-resistivity trend at depths beyond this 40m-depth mark.

Qualitative Examination of IP Table for TT1-2 (09°30′ 57.8″; 006°26′4.9″). At the 40m-depth mark, a chargeability of -9.19ms is observed in contrast to an absolute “high” IP value of 106ms at the 5m-depth mark. The deduction that the clay bed lies atop the water-bearing strata in this situation is not misplaced. Based on this reckoning, TT1-2 is a very strong candidate for groundwater prospect at the 40m-depth mark, and the iso-resistivity maps have also indicated a continuation of low-resistivity trend at depths beyond this 40m-depth mark.

Qualitative Examination of IP Table for TT1-3 (09°30′57.8″; 006°25′58.4″). The corresponding observation for the TT1-2 VES table of the TT1-3 location can be made out at the 5m-depth mark and at the 6m-depth mark. The iso-resistivity maps have indicated a continuation of low-resistivity trend at depths beyond the 40m-depth mark for this VES location.

Qualitative Examination of IP Table for TT2-2 (09°31′04.3″; 006°26′4.9″). The corresponding observation for the TT1-2 VES table of the TT2-2 location can be made out at the 6m-depth mark and at the 8m-depth mark. The iso-resistivity maps have indicated a continuation of low-resistivity trend at depths beyond the 40m-depth mark for this VES location.

Summarising, it is recognized that the aquifer prospects identified from the 1km^2 dual VES-IP survey are the following:

TT5-4: 09°31′23.7″; 006°25′51.9″ ≡ 9.523^0; 6.431^0

TT1-2: 09°30′ 57.8″; 006°26′4.9″ ≡ 9.516^0; 6.435^0

TT1-3: 09°30′57.8″; 006°25′58.4″ ≡ 9.516^0; 6.433^0

TT2-2: 09°31′04.3″; 006°26′4.9″ ≡ 9.518^0; 6.435^0

Examination of the Results of the Present Survey

The Topographic Map:- The topographic map for this study was produced by the aid of the Surfer-11® and Rockworks2006® applications. The "raw" elevation data in Microsoft Word® was converted into Microsoft Excel® by the Rockworks2006® application by which route the co-ordinates in degrees, minutes, and seconds were converted into degree-decimals values for ready input into the Surfer-11® application. In the Surfer-11® environment, the degree-decimals values data-field was saved initially, then the saved data was gridded, and subsequently the gridded data was used to create the required two-dimensional and three-dimensional maps. The result of this exercise showing the two-dimensional map is presented as Fig.3.

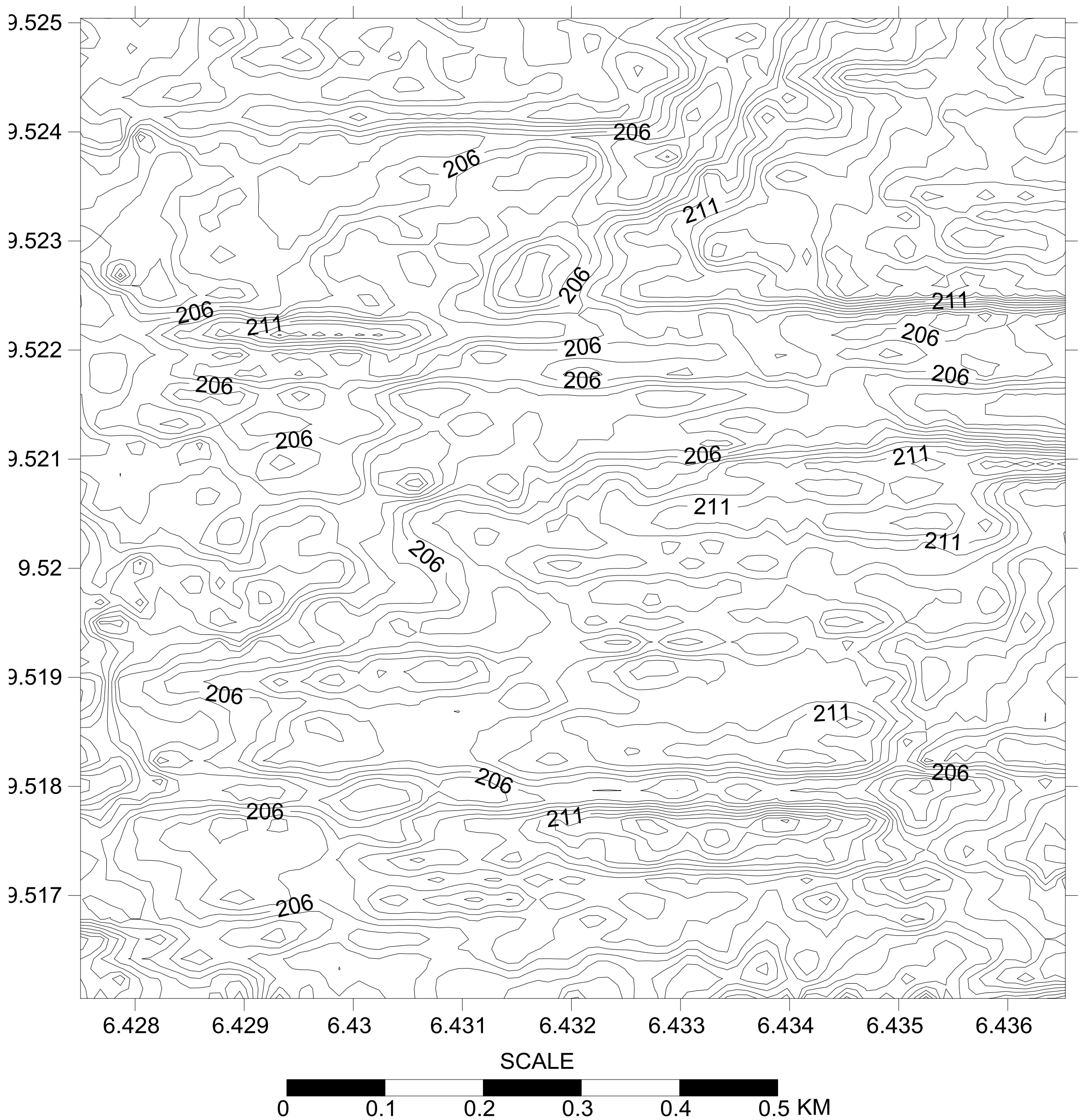

Fig.3. Topographic map of the area of study

The corresponding digital elevation model map is shown as Fig.4.

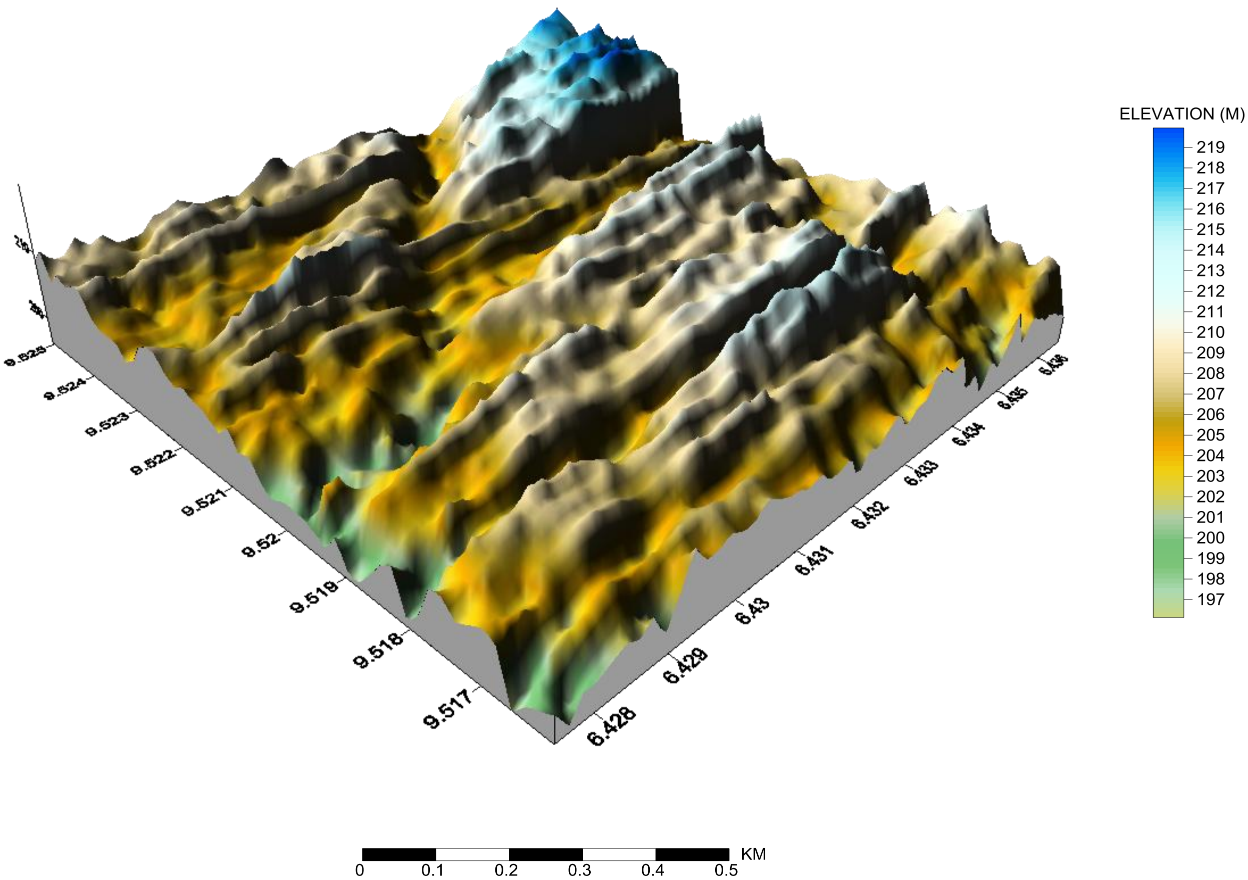

Fig.4. Digital elevation model map of the area of study

The Petrographic Map:- Production of the petrographic map was rather straightforward; information obtained from the recorded sample data set (rock type, plate location, GPS location, strike, description, etc.) was embedded into Microsoft Word® and transferred to the Surfer-11® to produce the petrographic map. On this map, there is a key representing different rock types. The result of this exercise is presented as Fig.5.

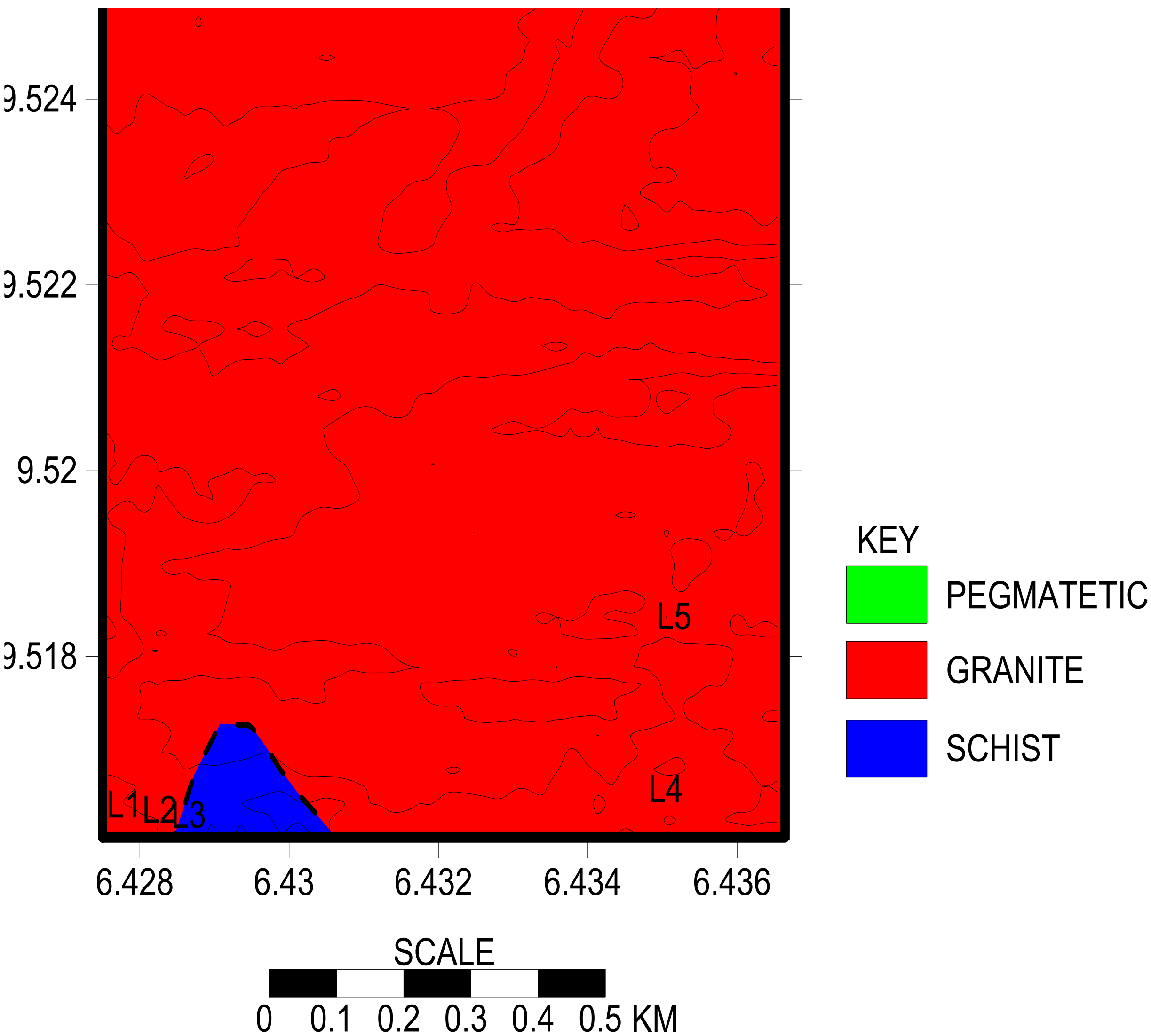

Fig.5. Petrographic map of the area of study

Discussion of Result of the Present Survey

The Topographic Map:- Over the 1km^2 area of study of interest here, it is observed that terrain or ground elevation progressively increases from south to north; this can be made out in Fig.3. An important observation herein, too, is that elevation increases from west to east. On the three-dimensional (3-D) digital elevation model (DEM) map of Fig.4, the elevation information of Fig.3 translates to an understanding that the landform of the 1km^2 area of study gently slopes from north to south and from east to west.

The Petrographic Map:- The petrographic survey proceeded in accordance with the basic requirement of this kind of survey: "*petrographic descriptions start with the field notes at the outcrop and include macroscopic description of hand specimens:*" en.wikipedia.org. It is understood from the petrographic map of Fig.5 that the area of study is underlain by a continuous body of granite that is intruded by a small body of schist.

Conclusion and Recommendation

Conclusions Drawn from Topographic Map:- The gentle slopes of the landform, north-to-south and east-to-west, observed in Figs 3 and 4 can only mean that there is a residual southwest slope of the area of study; the implication of this fact for groundwater prospects, by intuitive deduction, is that if conclusions concerning locations of aquifers that are drawn from a geophysical survey identifies prospects at the southwest corner of the area of study, then these conclusions must not be ignored. Intuitive deduction aside, what is most important out in the field is the conclusion drawn based on the results that are got from a proper field survey. Recall that it was observed that the previous 1km^2 dual VES-IP survey identified aquifer prospects at the following locations:

TT5-4: 09°31′23.7″; 006°25′51.9″ ≡ 9.523^0; 6.431^0

TT1-2: 09°30′ 57.8″; 006°26′4.9″ ≡ 9.516^0; 6.435^0

TT1-3: 09°30′57.8″; 006°25′58.4″ ≡ 9.516^0; 6.433^0

TT2-2: 09°31′04.3″; 006°26′4.9″ ≡ 9.518^0; 6.435^0

Fig.4 is a veritable platform by which validation of the conclusion drawn from the 1km^2 dual VES-IP survey can be made. Consider, first, TT5-4 at 9.523^0; 6.431^0: where is this point located on Fig.4? The point 9.523^0; 6.431^0 is located smack in a depression, not at the exact southwest corner of the area of study, but at a location much closer to the northeast; this location is a valley morphology. Because of this fact, it is concluded that TT5-4: 09°31′23.7″; 006°25′51.9″ ≡ 9.523^0; 6.431^0 remains a strong candidate for drilling for groundwater prospect.

Consider TT1-2 at 9.516^0; 6.435^0: on Fig.4, it is seen that TT1-2 is a depression along the first profile line, quite close to the east than the exact southwest but located on a fertile depression far away from any observable outcrop, more like a sediment-filled ancient valley. Because of this fact, it is concluded that TT1-2: 09°30′ 57.8″; 006°26′4.9″ ≡ 9.516^0; 6.435^0 remains a strong candidate for drilling for groundwater prospect.

Consider TT1-3 at 9.516^0; 6.433^0: on Fig.4, it is seen that TT1-3, which is 200m to the west of TT1-2 on the same profile line is still identified with the fertile depression of TT1.2. Because of this fact, it is concluded that TT1-3: 09°30′57.8″; 006°25′58.4″ ≡ 9.516^0; 6.433^0 remains a strong candidate for drilling for groundwater prospect.

Consider TT2-2 at 9.518^0; 6.435^0: the latitude line of 9.518^0 slices through the landform of the area of study as a continuous local depression and the point of 9.518^0; 6.435^0 is far removed from the exact southwest corner of the area of study, located at the eastern flank. This location being in a valley morphology, it is concluded that TT2-2: 09°31′04.3″; 006°26′4.9″ ≡ 9.518^0; 6.435^0 remains a strong candidate for drilling for groundwater prospect.

This "valley morphology" concept herein well means locations at the area of study where local rock emplacements may have been significantly eroded and sand cover has accumulated over time.

It is interesting to point out that, against intuitive deduction, none of the prospect locations identified from the earlier $1km^2$ dual VES-IP survey fall smack at the exact southwest corner of the area of study.

Conclusions Drawn from Petrographic Map:- The schist body intrusion into the granitic substrate of the area of study does not coincide with any prospect locations identified from the earlier $1km^2$ dual VES-IP survey. What this means is that, barring significant sand thicknesses as the constituent bodies of aquifers at the locations identified herein, it follows that the sources of groundwater at the points identified would be fracturing of the mass of the granitic rock at depths.

Recommendation:- It is strongly recommended that all of the aquifer prospects identified from the previous $1km^2$ dual VES-IP survey be drilled for groundwater exploitation at the planned Gidan Kwano Campus Phase II Development.

References

Abaa, S.I. (1983). The structure and petrography of alkaline rocks of the Mada Younger Granite Complex, Nigeria. *J Afr Earth Sci*, 3, 107–113.

ABEM (1999). *Instruction Manual: Terrameter SAS 4000/SAS 1000*, ABEM Instrument AB, Sundbyberg (Sweden).

Adesoye, S.A. (1986). *Master Plan of the Federal University of Technology's Permanent Site, Minna*. Adesoye and Partners, Kaduna, Nigeria.

Black, R. (1980). Precambrian of West Africa. *Episodes* 4:3–8.

Burke, K.C. and Dewey, J.F. (1972). Orogeny in Africa. In: Dessauvagie, T.F.J., Whiteman, A.J. (eds), *Africa Geology*, University of Ibadan Press, Ibadan, pp 583–608.

Dada, S.S. (2006). Proterozoic evolution of Nigeria. In: Oshi, O. (ed), *The Basement Complex of Nigeria and its Mineral Resources (A Tribute to Prof. M. A. O. Rahaman)*, Akin Jinad & Co., Ibadan, pp 29–44.

Gandu, A.H., Ojo, S.B., Ajakaiye, D.E. (1986). A gravity study of the Precambrian rocks in the Malumfashi area of Kaduna State, Nigeria. *Tectonophysics*, 126, 181–194.

https://en.wikipedia.org/wiki/Petrography. Date and time visited: 10/20/2015; 1:22p.m.

Jimoh, M.O. (1998). *Report on the Six Boreholes Drilled at the Main Campus of the Federal University of Technology, Minna, for the Petroleum (Special) Trust Fund.* Cemaco Ventures Ltd., Minna.

Jonah, S.A. and Jimoh, M.O. (2013). Production of a topographic map and the creation of a six-layer Geographic Information System (GIS) for a fifteen square-kilometre (15 km^2) areal extent of the Gidan Kwano Campus of the Federal University of Technology, Minna, Niger State, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, 9(2), 75 - 89.

Jonah, S.A. and Olasehinde, P.I. (2015B). Interpretation of two-dimensional vertical electrical sounding data of a 4km^2 tranche of new development, Gidan Kwano Campus Phase II, Federal University of Technology, Minna, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST): **Accepted for Publication***.

Jonah, S.A. and Olasehinde, P.I. (2015C). On the consistently low-resistivity regimes of the central to the southwest portions of a 4km^2 tranche of New Development, Gidan Kwano Campus Phase II, Federal University of Technology, Minna, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST): **Accepted for Publication***.

Jonah, S.A. and Olasehinde, P.I. (2015D). Petrographic control for an 8km^2 tranche of the Gidan Kwano Campus, Federal University of Technology, Minna, Nigeria. ***Paper-in-the-Making***.

Jonah, S.A., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kwaghhua, F.I., Kyari, M., Macaulay, V. F., Olarewaju, S.I., Onyeodili, G., Popoola, G.B., Sofeso, O.A., Switzer, F.K., and Umoh, U.E. (2014A). Geoelectrical investigation for aquifer and geotechnical properties at the planned Gidan Kwano Campus Development Phase II, Federal University of Technology Minna, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, **11**(**2**), 81 - 100.

Jonah, S.A., Olasehinde, P.I., and Umar, M. (2014B). Evaluation of geomorphological quality control of geo-electrical data at Gidan Kwano Campus, Federal University of Technology, Minna, Central Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*, **2** (**1**), 122 –134.

Jonah, S.A., Olasehinde, P.I., Jimoh, M.O., Umar, M., and Yunana, T. (2015A). An intercalated dual geoelectrical survey of an earlier study for groundwater at the planned Gidan Kwano Campus Development Phase II, Federal University of Technology, Minna, Nigeria. *Journal of Information, Education, Science, and Technology (JOSTMED)*, **11**(**2**), 32 - 50.

Kearey, P. and Brooks, M. (1984). *An Introduction to Geophysical Exploration*, Blackwell Scientific Publications, Oxford.

Obaje, N.G. (2009). *Geology and Mineral Resources of Nigeria*. In: Lecture Notes in Earth Sciences, Springer-Verlag, Berlin.

Olayinka, A.I. (1992). Geophysical siting of boreholes in crystalline basement areas of Africa. *J Afr Earth Sci*, 14,197–207.

Parasnis, D.S. (1986). *Principles of Applied Geophysics (4 ed.)*, Chapman and Hall, London.