

## GEO-ELECTRICAL RESISTIVITY CHARACTERIZATION OF SEDIMENTARY ROCKS IN DENT PENINSULAR, LAHAD DATU, SABAH

Hardianshah Saleh & Abdul Rahim Samsudin

Geology Programme,  
School of Environmental Science and Natural Resources,  
Faculty of Science and Technology,  
Universiti Kebangsaan Malaysia,  
43600 UKM Bangi, Selangor D. E Malaysia

**ABSTRACT.** *A vertical electrical sounding (VES) survey was conducted in Dent Peninsular, Lahad Datu Sabah. The main objectives of the study are to determine the geo-electrical characteristic curves of the sediments and to relate them to various rock formations and layer of aquifer potential. In this study, the schlumberger electrode configuration was adopted for the acquisition of VES data in the field. A total of 31 VES stations were occupied within Sebahat, Ganduman and Togopi Formation of the study area. Resistivity curve types identified ranges from simple H until HQ, QH, KA, AA and QQ curve types, reflecting facies or lithological variations in the area. Four typical geo-electrical resistivity curves obtained can be associated with different rock formations in the study area. Four pattern of resistivity curves were obtained for Sebahat Formation with no typical characteristic type of curves which include HQ, QQ, QH and H types. Two typical resistivity curves were observed for the Lower Ganduman Formation (HQ and QQ) and three typical curves characterized the Upper Ganduman Formation (H, HQ and KA). Similarly, three typical resistivity curves (HQ, AA and H) were obtained for Togopi Formation. Interpreted 2D geo-electrical resistivity section obtained for all the sedimentary rock formations were used to evaluate the potential aquifer in the study area. The results show that the thick sandstone layers found in the Lower Ganduman and Togopi Formation have potential to become good groundwater aquifers. In addition, there is also a possibility of variable thickness of sandstone layer in the Upper Ganduman Formation to become a possible unconfined aquifer.*

**KEYWORDS.** Vertical Electrical Sounding, groundwater, geo-electrical characterization, Schlumberger.

### INTRODUCTION

The resistivity techniques especially the Vertical Electrical Sounding (VES) method has been used for investigating subsurface layer properties and groundwater potential. By this method, the subsurface characterization is determined based on the change of resistivity values with depth. Range of specific resistivity value indicates the presence of certain rock mass characteristic. Telford *et al* (1975) and some other researchers have the proposed range of resistivity values based on the rock or soil conditions. Resistivity values can provide an overview of the groundwater type that exists in the study area.

Vertical electrical sounding (VES) field method that used in this research involves the measurement of the variation of resistivity value with depth. This method was found suitable for hydro-geological surveys in sedimentary rocks (Kelly and Stanislav (1993) in Hadi (2009)). In this study, a VES survey was conducted in Dent Peninsular, Lahad Datu, Sabah. The main objectives of the study were to determine the geo-electrical characteristic of the

sedimentary rocks and to relate the VES curves with various rock types layer of to the aquifer potential.

The most extensively applied relationship to interpret electrical resistivity in terms of porosity or moisture content is Archie's Law. For fully saturated porous block, relation between porous media with resistivity or Archie's Law can be written as:

$$R_b = R_w \theta^m \quad (1.1)$$

Where  $R_b$  is the electrical resistivity of the block (Ohm.m),  $R_w$  is the resistivity of the aqueous phase (Ohm.m),  $\theta$  is the porosity, and  $m$  is known as the cementation exponent.

## GEOLOGY AND STRATIGRAPHY

The study area is located in Lahad Datu district, the south-eastern part of Sabah and forms the tip of Dent Peninsular (Figure 1). Haile and Wong (1965) found that the Dent peninsula comprises of two groups of rocks; Segama Group and Dent Group. The Segama Group is made of Neogen Volcanic rocks whilst the Dent Group consists of sedimentary rocks of Sebahat, Ganduman and Togopi Formation (Table 1). This study focuses only on the Dent Group rock formation.

**Table 1. The geological stratigraphy of the study area based on previous studies.**

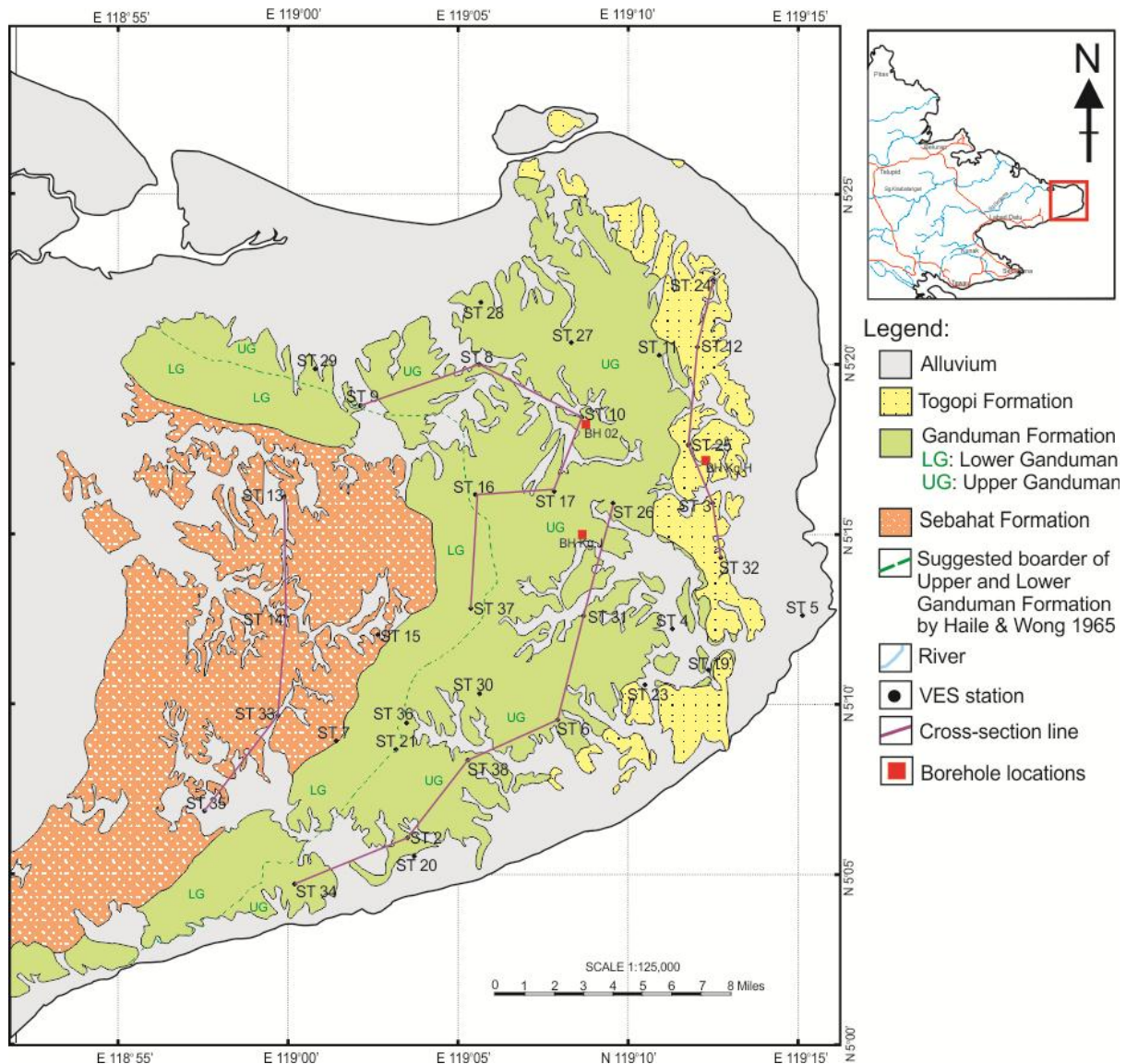
Mil. years	Age	Group	Haile & Wong 1965	Walker 1993	R.F.H Wong 1993	Sanudin & Baba 2007
2.0	Pleistocene	Dent	Togopi	Togopi	Togopi	Togopi
5.1	Pliocene		U.Ganduman	Ganduman	Ganduman	Ganduman
			L.Ganduman			
			Sebahat	Sebahat	Sebahat	Sebahat
	Miocene	Late				
		Middle	Sebahat	Tanjong	Tungku	Tungku
			Libong Tuffite	Tungku (Volc.)	Libong	Libong Tuffite
		Segama	Tabanak			Tabanak

The earliest geological study in Dent peninsula was done by Wenk in 1938. Wenk (1938) named the formation of Togopi (Wenk 1938, in Haile and Wong 1965) and estimated the age of the formation is Plio-Pleistocene based on mollusc and foraminifera fossil. Then, a detailed study was done by Whittaker and Hodgkinson (1979) on foraminifera fossil in Togopi Formation and confirmed that the age of the formations is Pliocene. Togopi Formation is the youngest sedimentary rocks in Dent Group which consists of big boulder of limestone, calcareous sandstone, sandy silt, silt and marl.

Abd.Manaf *et. al* (1990) found that the Ganduman Formation can be divided into Lower and Upper Ganduman. The Lower Ganduman consists of sandstone, lignite and coaly clay with plant remains whilst Upper Ganduman layer consists of clay, coaly clay with plant remains and sandstone (Hutchison 2005). The Upper and Lower Ganduman Formations were combined into a single Ganduman Formation by Sanudin & Baba (2007).

Sebahat Formation is the oldest rock formation in the Dent Group. It is characterized by dark grey mudstone with thick until massive mudstone layer, interbedded with thin silt and clay. Based on fauna analysis, reliable sedimentation environment of the formation was found

to be near the beach (shallow marine), between the intertidal areas to depths of several meters below sea level (Sanudin & Baba 2007).

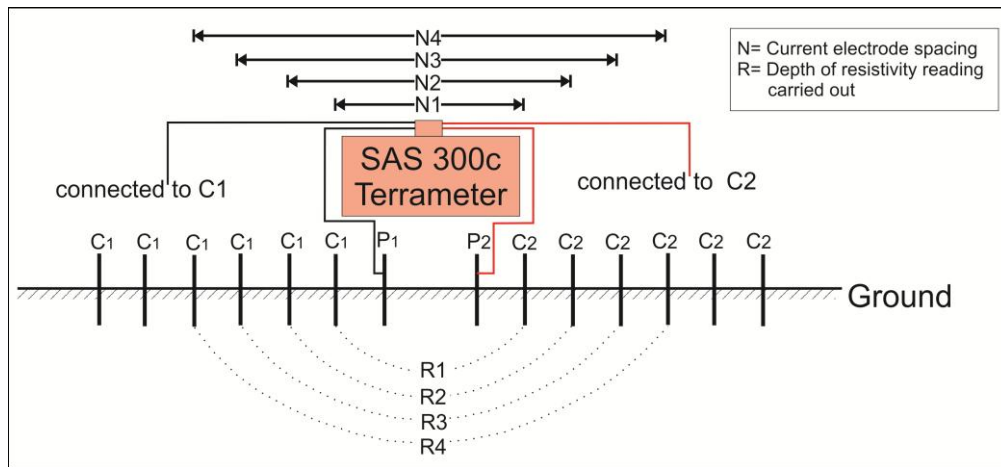


**Figure 1: Geological map and location of VES stations.**

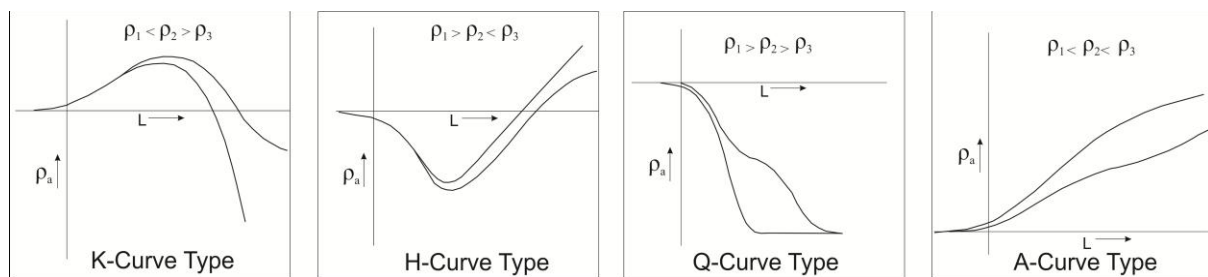
## MATERIALS AND METHOD

Vertical Electrical Sounding (VES) technique was performed by measuring the resistivity change with depth (Koeffoed 1979). The resistivity measurements were conducted using ABEM SAS 300c Terrameter. A total of thirty three (33) VES stations have been established across the study area using Schlumberger electrode configuration (Figure 2) with maximum current electrode separation ( $C_1$  and  $C_2$ ) of 500m and maximum depth of resistivity information about 100m (Umar et. al 1993). Figure 1 shows the location of the VES stations. The field curves were interpreted through partial curve matching (Koeffoed, 1979) with the help of master curves (Orellana and Mooney, 1966) and auxiliary point charts (Zohdy, 1965). From the preliminary interpretation, initial estimates of the resistivity and thickness of the

various geo-electrical layers at each VES location were obtained. Types of the resistivity geo-electrical curves were determined based on Parasnis (1962) curve types (Figure 3).



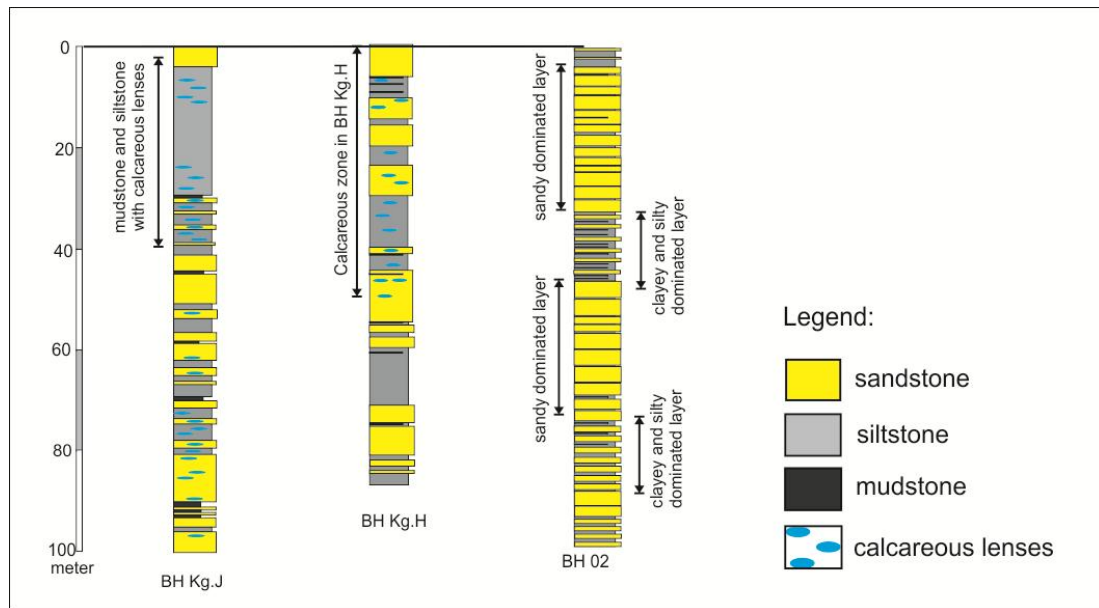
**Figure 2. Schematic diagram showing the electrode configuration of Schlumberger array.**



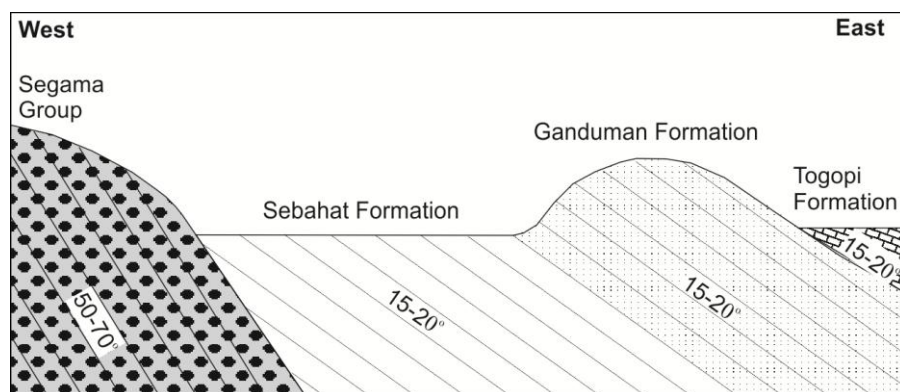
**Figure 3. VES curve types (After Parasnis 1962).**

These geo-electrical resistivity curves were later used as starting model for PROGRESS software which produces thickness and resistivity values of each geo-electrical layer by using forward and inverse modelling methods. A forward modeling is an integral part of any inversion program since it is necessary to calculate the theoretical apparent resistivity values for the model produced by the inversion routine to see whether it agrees with the measured values (Loke 2012). While inverse modelling is to compute a layered earth model whose theoretical apparent resistivity curve agrees as closely as possible (in a least-squares sense) with the field curve (Mooney 1980).

Three existing borehole data (BH02, BH Kg.J and BH Kg. H) (Figure 4) were used to interpret the geo-electrical cross-section (Figure 4). Borehole BH02 and BH Kg.J are correlated with the results of geo-electrical cross-section of the Lower and Upper part Gaduman Formation. BH02 shows interbedded of sand dominated layer and clayey and silty dominated layer. Whilst BH Kg.J comprises of mudstone, siltstone and calcereous lenses. BH Kg.H was correlated with geoelectrical layer of Togopi Formation which shows zone of calcereous lenses. There is no borehole data available for the Sebahat Formation, hence interpretation was mainly based on the surface geology and information from litterature review (Figure 5).



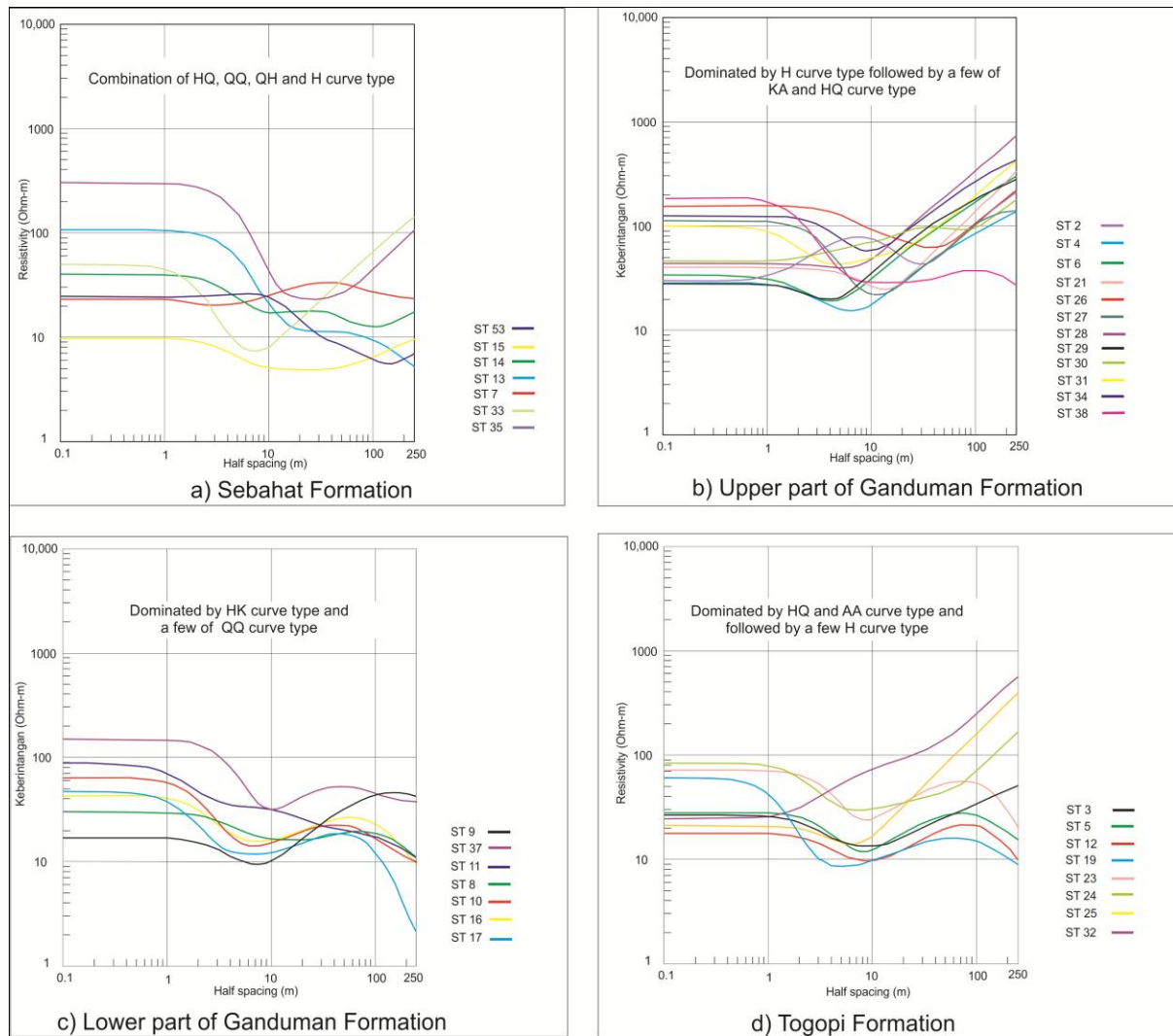
**Figure 4. Borehole data in the study area.**



**Figure 5. Schematic east-west geological cross section of Dent Peninsula. (Horizontal scale 1:250,000, vertically not to scale). Ismail (1994).**

## RESULTS AND DISCUSSION

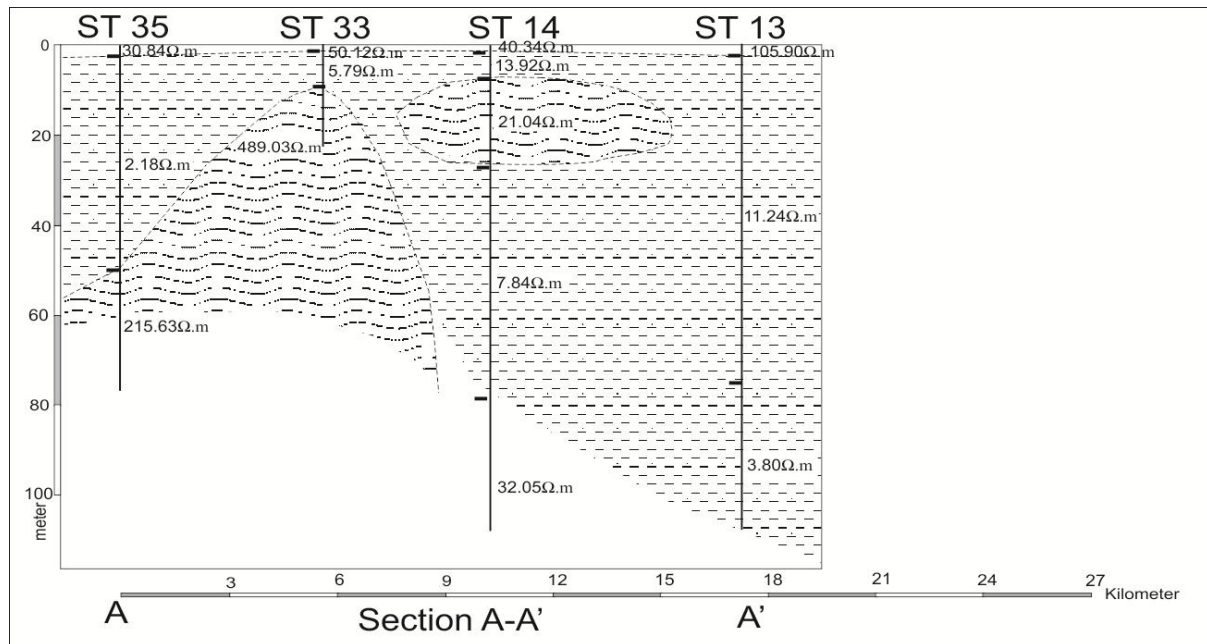
Typical geo-electrical resistivity curves corresponding to VES data for the whole study area are shown in Figure 6. The curve types identified ranges from simple H until QQ, QH, HA, KH and HK curve types, reflecting facies or lithological variations in the area. The geo-electrical curves can be classified into four typical curve groups according to lithology and rock formation in the study area.



**Figure 6. Graph of typical resistivity curve (Ohm-m) versus distance (m) for a) Sebahat Formation, b) Upper part of Ganduman Formation, c) Lower part of Ganduman Formation and d) Togopi Formation.**

### *The Sebahat Formation*

Resistivity curves obtained from VES stations carried out in the Sebahat Formation show a variety of forms that may have caused by irregular geological structures and non-homogenous nature of the earth materials. The curve types identified are HQ, QQ, QH and H. Resistivity curves from Sebahat Formation has two to five interpreted resistivity layers as shown by 4 VES stations (ST35, ST33, ST14 and ST13). Figure 7 shows resistivity section of the Sebahat Formation. Generally two to three geo-electrical layers were obtained except for ST14 which have interpreted five geo-electrical layers. High resistivity layers (215-490 Ohm-m) observed at station ST33 and ST 35 at depth from 10 to 50 meter is interpreted as shale or highly compacted mudstone.

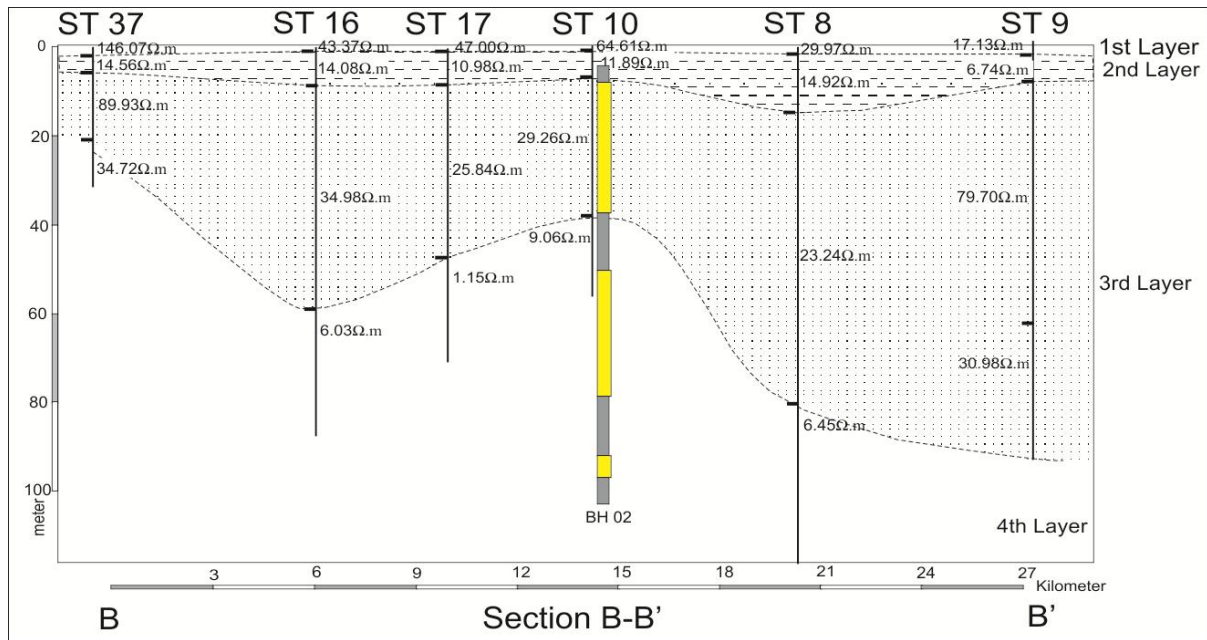


**Figure 7. Interpreted 2-D geo-electrical resistivity layers for the Sebahat Formation.**

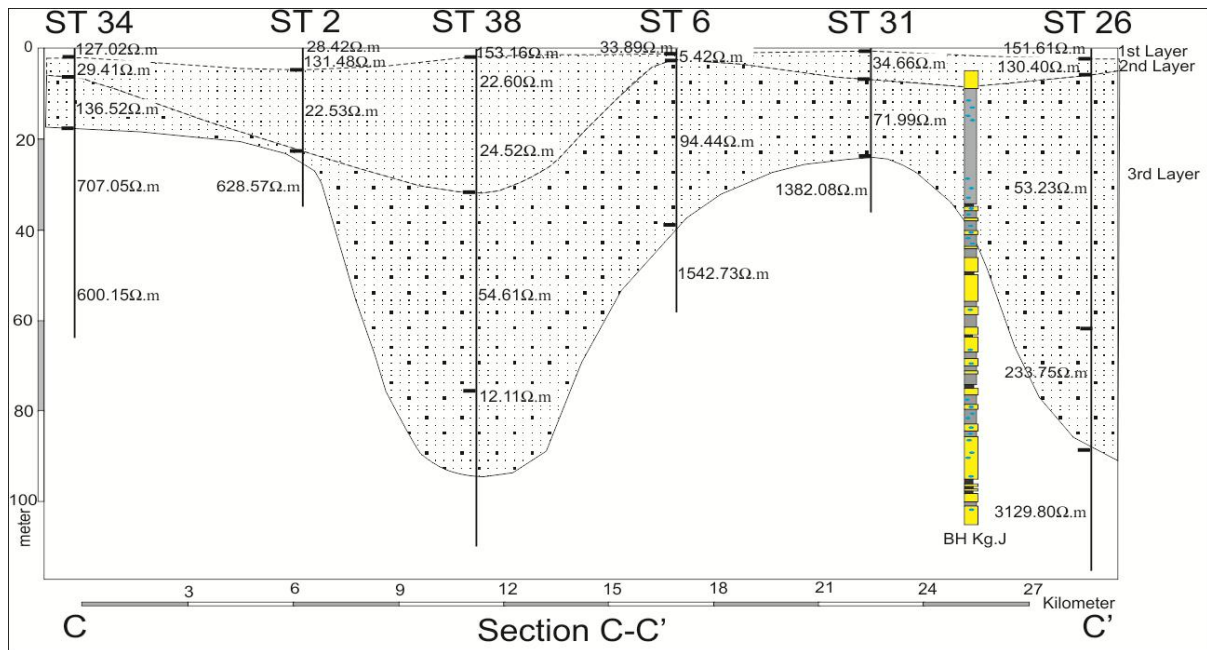
### ***The Ganduman Formation***

The Ganduman Formation shows various types of resistivity curves (Figure 3) that may have caused by variation of the earth materials within the formation. Noad (1998 in Hutchison 2005) had divided the Ganduman Formation into two groups; Lower and Upper Ganduman Formation. However later research by Sanudin and Baba (2007), indicates there is no clear boundaries between the Lower and Upper Ganduman Formation. The Lower Ganduman Formation has an abundance of foraminifera, corals, algae and some molluscs that are not appear in the Upper Ganduman Formation. In the stratigraphy of Sabah, Ganduman Formation has been considered just as one formation which has deposited during Upper Miocene to Pliocene.

The resistivity curves for the Lower Ganduman Formation are dominated by HQ and QQ curves type. Interpreted 2-D resistivity section derived from VES station ST37, ST16, ST17, ST10, ST8 and ST9 produced four geo-electrical layers as shown in Figure 8. The first top layer shows high resistivity value (17-146 Ohm-m) which is interpreted to be associated with unsaturated gravel layer as indicated in the existing data of borehole (BH02) which was drill closed to VES station ST10. The second layer with low resistivity values (6-15 Ohm-m) indicates of clay layer which also correlate well with borehole data (BH02). The third layer with intermediate resistivity values ranging from 23.24 to 89.93 Ohm-m is associated with thick sandstone layer which is underlain by impermeable clay layer. Based on this section, the thick sand layer has a potential to be a good confined aquifer.



**Figure 8. Interpreted 2-D geo-electrical resistivity section of the Lower Ganduman Formation.**



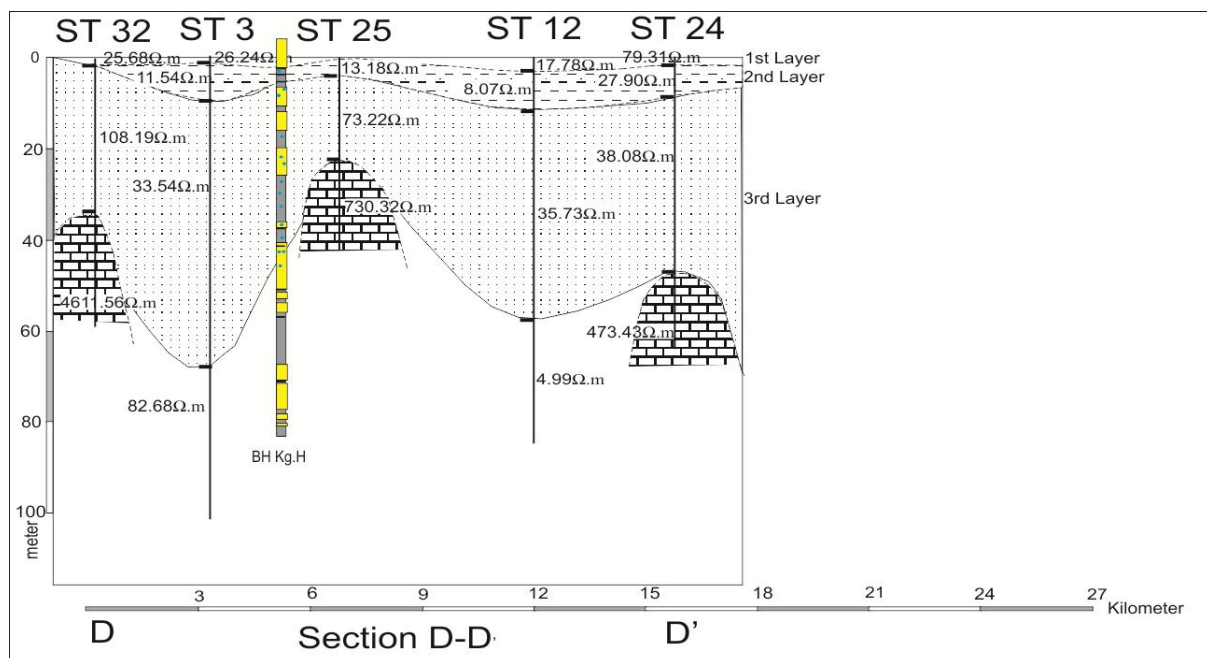
**Figure 9. Interpreted 2-D geo-electrical resistivity section for the Upper Ganduman Formation.**

The Upper Ganduman Formation is dominated by H and followed by KA and HQ curves type. An interpreted 2-D geo-electrical resistivity section obtained from ST34, ST2, ST38, ST6, ST6, ST31 and ST26 produced 4 to 5 geo-electrical resistivity layers (Figure 9). The first layer is interpreted as unsaturated gravel layer followed by variable thicknesses (5 to 30m) of sandstone layer which is potential to become an unconfined aquifer. The third layer as shown by borehole data (BH Kg.J) comprises of mudstone, siltstone and lenses of calcareous layer with thickness ranging from 5 to 40m. The most bottom layer shows

relatively high resistivity value (230-3130 Ohm-m) which is interpreted to be associated with massive calcareous rock materials.

### ***The Togopi Formation***

The Togopi Formation appears to be dominated by HQ and AA followed by a few of H curve types. Based on surface geology and previous geological studies, the Togopi Formation is interpreted to comprise of big blocks of limestone, loose sandstone and clay material. Some resistivity curves in the Togopi Formation show similarity in characteristic of curve types with the Upper Ganduman Formation. This curve characteristic could possibly suggest a presence of rock layers of the Upper Ganduman Formation underneath the Togopi Formation. Interpreted 2-D geo-electrical resistivity section derived from VES station ST32, ST3, ST25, ST 12 and ST24 produced 3 to 4 geo-electrical layers (Figure 10). Correlation with borehole data (BH Kg.H) indicates the first layer is unsaturated thin sandstone layer. The second layer is associated with unsaturated clay layer (8-27 Ohm-m) which is underlain by thick sand layer with intermediate value of resistivity ranging from 35-110 Ohm-m. The bottom layer with high resistivity value is interpreted to be associated with several blocks of limestone.



**Figure 10. Geo-electrical cross section in Togopi Formation.**

## **CONCLUSION**

The results of the VES survey show that the sedimentary rock formations in the study area can be classified into four resistivity curve types. Resistivity curve types identified ranges from simple H until HQ, QH, KA, AA and QQ which reflect different lithological materials of the formation. Based on 2-D geo-electrical resistivity section in conjunction with existing borehole data indicate that the thick sandstone layers found in both the Lower Ganduman and Togopi Formations have potential to become good confined and semi-confined aquifer layers respectively. There is also a possibility of variable thickness of sandstone layer in the Upper Ganduman Formation to become a possible unconfined aquifer. Surface geological studies

and resistivity results indicate the Sebahat Formation is made up of thick and massive mudstone, hence no prospect of aquifer layer in this formation.

## ACKNOWLEDGEMENT

The authors wish to thank FELDA Sahabat management for giving permission and providing necessary data during the field survey. Not forgetting the Faculty of Science and Technology, UKM for giving permission to use scientific equipment and research facilities during this study. In addition, thanks to the technical staff of the Geology Program, UKM for their technical support during the research.

## REFERENCES

- Abd. Manaf Ishak, Gamble, D. H. F., & Krishna Kumar. 1990. *Dent Peninsular Water Supply: Supply to Village D and The Industrial Complex*. Groundwater & the Environment: Proceedings of The 2<sup>nd</sup> International Groundwater Conference, Kota Bharu. Hlm. B26-B36.
- Hadi Tahmasbi Nejad. 2009. Geoelectrict Investigation of the Aquifer Characteristic and Groundwater Potential in Behbahan Azad University Farm, Khuzestan Province, Iran. *Journal of Applied Science*, **9** (20): 3691-3698.
- Haile, N. S., & Wong, N. R. Y. 1965. *The Geology and Mineral Resources of Dent Peninsula, Sabah*. Geological Survey, Borneo Region, Malaysia. Memoir 16. Kuching, Sarawak: Vincent Kiew Fah San, Goverment Printer.
- Hutchison, C. S. 2005. *Geology of North-West Borneo: Sarawak, Brunei and Sabah*. Kuala Lumpur: Universiti Malaya.
- Ismail Che Mat Zin. 1994. Dent Group and its Equivalent in the Offshore Kinabatangan Area, East Sabah. *Bulletin Geology Society of Malaysia*, **36**: 127-143.
- Koeffoed, O. 1979. *Geosounding Principle: 1, Resistivity Sounding Measurements*. Amsterdam: Elsevier.
- Loke, M. H. 2012. *Tutorial 2D and 3D Electrical Imaging Surveys*. Revision date 2012. Geotomo Software, Malaysia. Retrieved from [www.geotomosoft.com](http://www.geotomosoft.com).
- Mooney, H. M. 1980. *Handbook of Engineering Geophysics, Volume 2: Electrical Resistivity*. United State of America: Bison Instrument INC.
- Oseji, J. O., Atakpo, E. A., & Okolie, E. C. 2005. Geoelectric Investigation of the Aquifer Characteristics and Groundwater Potential in Kwale, Delta State, Nigeria. *Journal of Applied Science Environmental*, **9** (1): 157 – 160.
- Oseji, J.O., & Ujuanbi, O. 2009. Hydrogeophysical Investigation of Groundwater Potential in Emu kingdom, Ndokwa Land of Delta State, Nigeria. *International Journal of Physical Sciences*, **4** (5): 275-284.
- Parasnis, D. S. 1962. *Principles of Applied Geophysics*. London: Chapman & Hall.
- Sanudin Tahir, & Baba Musta. 2007. *Pengenalan Kepada Stratigrafi*. Kota Kinabalu, Sabah: Penerbit UMS.
- Sanudin Tahir., Shariff A. K. Omang, & Majeed M. F. 1995. Middle Miocene Volcanic Sequence in Eastern Sabah. *Borneo Science*, **1** (1): 9-27.
- Telford, W. M., Geldart, L. P., Sheriff, R. E., & Keys, D. A. 1990. *Applied Geophysics*. 2nd ed. Cambridge: Cambridge University Press.

- Umar Hamzah, Abd. Rahim Samsudin, & Edna Pilis Malim. 2006. Groundwater Investigation in Kuala Selangor Using Vertical Electrical Sounding (VES) Survey. *Environmental Geology*, **51**: 1349-1359.
- Umar Hamzah, Abd. Rahim Samsudin & Ismail Mohd. Noor. 1993. Hasil Awal Survei Geoelektrik dan Analisis Air di Beberapa Lokaliti Air Panas di Malaysia. *Sains Malaysiana*, **22 (1)**: 21-34.
- Whittaker, J. E., & Hodgkinson, R. L. 1979. *Foraminifera of the Togopi Formation, Eastern Sabah, Malaysia*. London: Publisher British Museum (Natural History).
- Zohdy, A. 1965. The Auxiliary Point Method of Electrical Sounding Interpretation and its Relationship to the Dar Zarrouk Parameters. *Geophysics*, **30**: 644-660.