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Diagnostic resistivity sounding curves of karstic aquifers in the Chuping Limestone

MOHAMMED SAYYADUL ARAFIN AND C.Y. LEE

Universiti Sains Malaysia
Minden, Penang

Abstract: Interpretation of ten VES (Vertical Electrical Sounding) curves from the Chuping Limestone is presented here. Quantitative interpretation of these data in terms of the lithologic logs show some interesting features. These features when properly identified can be very useful in site selection for drilling.

INTRODUCTION

Karstic limestone beds in many parts of Peninsular Malaysia especially in Perlis, are a potential source of groundwater. However, the main difficulty in harnessing this precious resource is the proper identification of the karstic zones, which in most cases are not thick enough to be detected by surface geophysical methods such as resistivity. The problem of detection is further complicated by the presence of overburden material, which in some areas has a thickness of about 30 m. Numerous faults in Perlis distort the resistivity sounding curves making them unsuitable for interpretation in terms of horizontal layers. These adverse conditions are prevalent more in the Setul Limestone than in the Chuping Limestone. We discuss here the results of some resistivity sounding curves from the Chuping Limestone, which appears to be a potential groundwater source.

The geophysical literature does not contain abundant examples of the application of surface geophysical methods to the prospecting for groundwater in karstic limestone beds. Sumi (1965) and Vincenz (1968) have used induced polarization and resistivity methods respectively to detect cavities in limestone beds. Recently Arafin and Lee (1987) have discussed the successful application of the combined resistivity and induced polarization methods to the identification and delineation of karstic aquifers in the limestone beds in Perlis.

GEOLOGY AND HYDROGEOLOGY

The geology of Perlis (Fig. 1) is complex and the hydrogeology is expected to be the same. The three main rock formations are the Setul Limestone, the Kubang Pasu formation and the Chuping Limestone. The Setul Limestone, a continental shelf deposit, consists of hard brittle dark grey crystalline limestone. The formation forms typically steepsided topography and lies in the western part of the state. Large scale karst development with small solution

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cavities can be observed at the outcrops. The eastward dipping Kubang Pasu formation (mudstone, and shales interbedded with minor sandstone beds) overlies the Setul Limestone unconformably. Above the Kubang Pasu formation lie the eroded residues of the Chuping Limestone, which occurs in an anticline striking northsouth. The Chuping Limestone passes upwards from calcareous sandstones and shaly into pale grey to white finely crystalline limestones with some dolomitic limestones and limestone breccias.

Although karst zones at shallow and greater depths have been encountered both in the Setul and Chuping Limestones, it is generally believed that the Chuping Limestone is more fractured than the Setul Limestone. The Setul Limestone is rather fresh compared to the Chuping. The Chuping Limestone is a better source of groundwater. The karst zone at shallow depth is usually a highly fractured zone with limestone gravel and rubble beds. More isolated karst features of more random occurrence are found at greater depths. The yield in these types of aquifers is more than 50 litre/sec (PWD Report, 1982). From the hydrogeological point of view, the Kubang Pasu formation, whether fractured or not, is incompetent as a source of groundwater although yields of 0.4 to 17.8 litre/sec have been obtained from the relatively thin and fractured sandstone bands. The average depth to the water table from the ground surface varies between 2 and 4 m and it rarely exceeds 10 m. Groundwater flow occurs downslope through the lower weathered and fractured zones to produce confined artesian groundwater conditions. Drilling in the Setul and Chuping Limestone show intervals of increased transmissivity associated with the cavities, mainly along bedding planes.

DATA ACQUISITION

Out of the ten VES (Vertical Electrical sounding) curves discussed here, three (GS 771, GS 762 and GS 764) were taken from the PWD Report, 1982. These soundings were obtained using the Schlumberger configuration by the Geological Survey of Malaysia. The remaining VES curves were obtained using the Offset Wenner Array (Barker, 1981) by the authors. The lithologic logs done by the Geological Survey of Malaysia were also taken from the PWD Report, 1982.

INTERPRETATION OF THE VES DATA

We present here quantitative interpretation, using the resistivity inverse programme (Mooney, 1980), of some vertical electrical sounding (VES) curves obtained from the Chuping Limestone area. Almost all the soundings were carried out at or near the existing boreholes in the area. These data are confined to the northern and southern ends of the Chuping Limestone. The reason for this is the inaccessibility to the area in between. It is interesting to note that most of these curves show presence of water in the karstic bed of the Chuping Limestone.

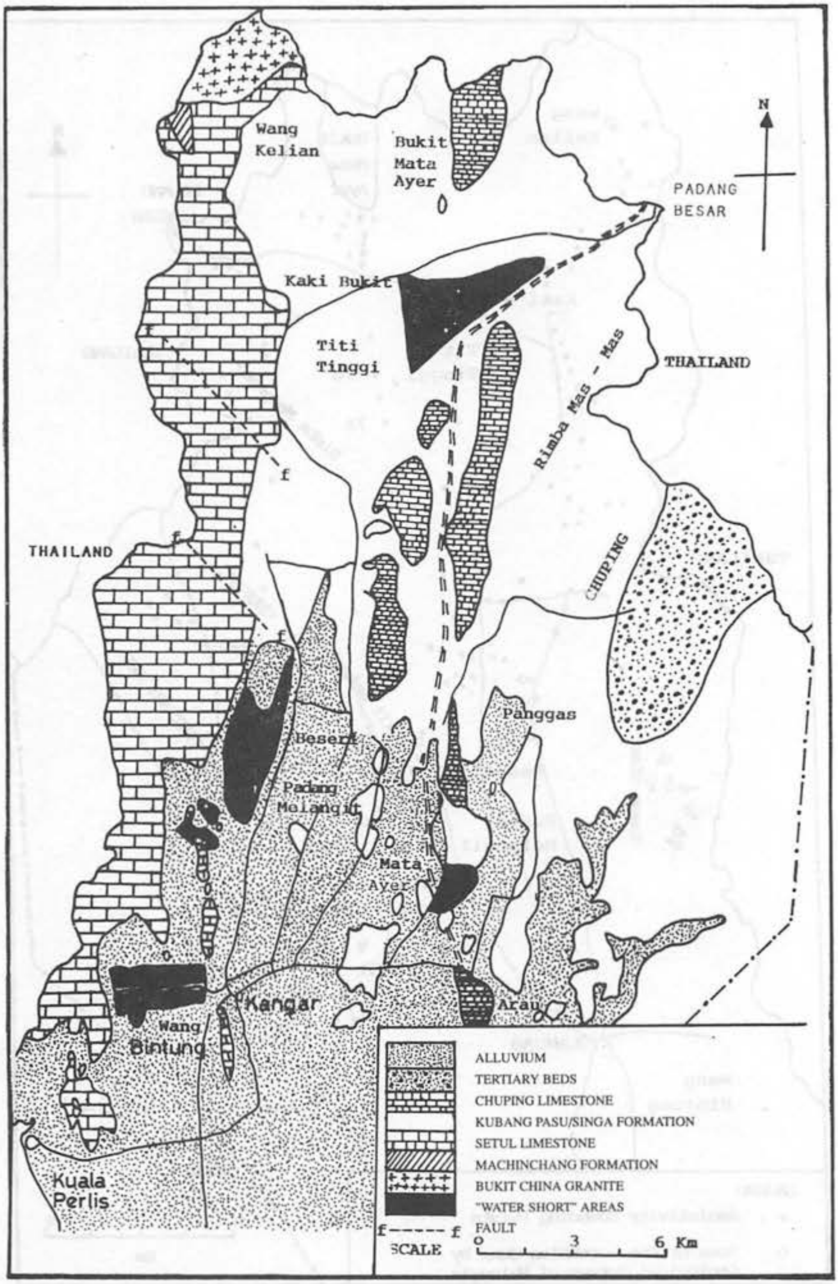

Figure 1 : Geology and "water short" areas of Perlis

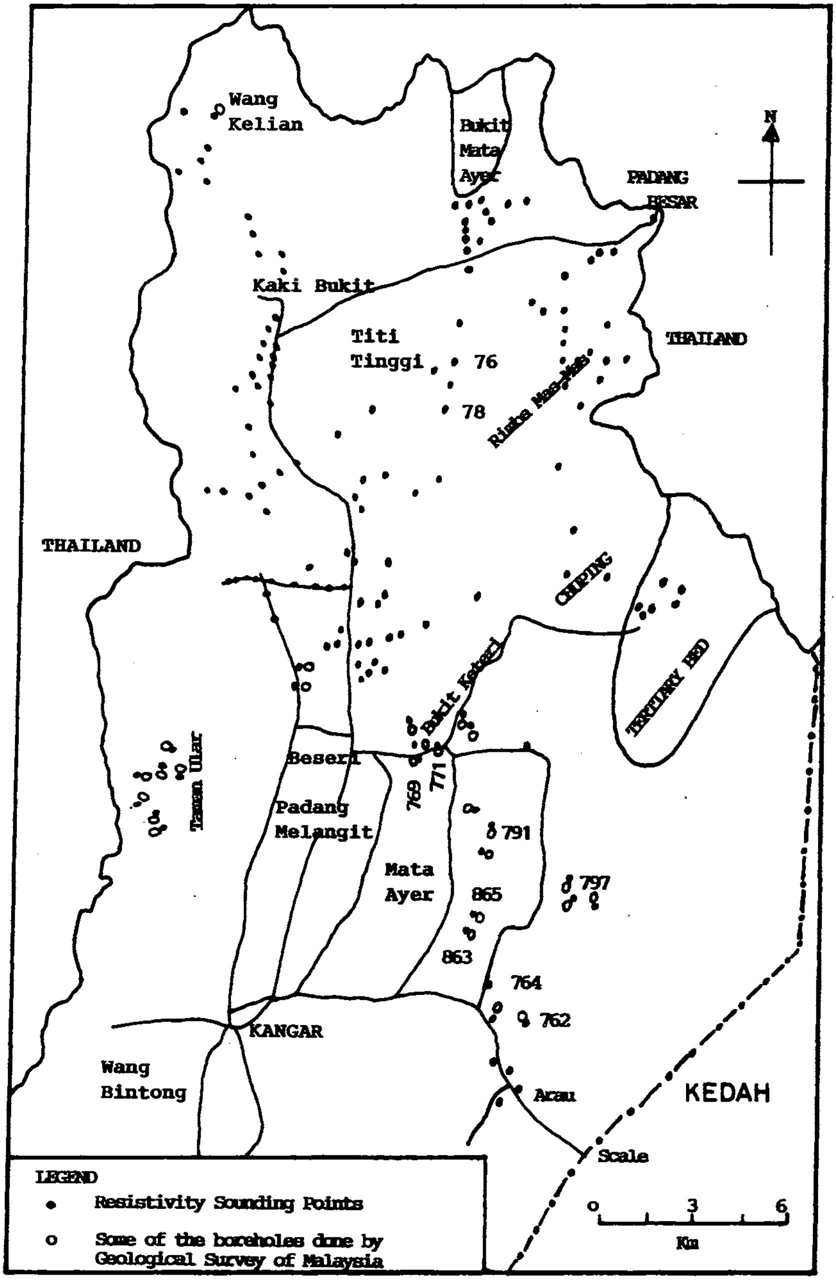

Figure 2 : Vertical electrical sounding (VES) borehole locations

GS 863 AND GS 865

The shape and size (magnitude of the apparent resistivity) of these two VES curves are similar although they are about 300 m apart. The minimum of GS 863 is however located at larger electrode spacing than that of GS 865 indicating a deeper causative layer. The broad minimum of GS 865 is indicative of a thicker water-bearing layer. The resistivity modeling of these two VES curves reflect that the subsurface conditions are consistent with the lithologic logs (Fig. 3 & 4). The resistivities of the water-bearing layers at GS 863 and GS 865 are 160 ohm-m and 110 ohm-m respectively in the models. This difference in the resistivity of the karstic aquifer is reasonable if we look at the lithologic logs, which show the water-bearing layers to be composed of a combination of different materials such as clay, sand, gravel and fractured limestone.

GS 769 AND GS 771

These two sounding curves are located near the railway crossing at Bukit Keteri (Fig. 2). These two sounding curves also are quite similar. The sounding curves together with the respective models and the lithologic logs are shown in Fig. 5. The sounding curve of GS 769 has been modeled with both a 4-layer and a 5-layer earth. The modeling results show that the minimum of the sounding curve is due to the clay layer and that the fourth layer, which has a resistivity of 227 ohm-m is the karstic limestone layer. The 5-layer model in which the solution is obtained by keeping the thickness of the fourth layer fixed at 50 m, shows that the resistivities of the fourth layer (193 ohm-m) and the fifth layer (245 ohm-m) do not vary appreciably from each other. This means that both the fourth and the fifth layers are actually the same and represent the karstic layer, which could be thicker than 50 m.

The solution for the sounding curve at GS 771 is obtained by keeping the thickness of the water-bearing layer (i.e. the third layer) fixed at 20 m. This thickness represents the layers below the watertable and above the limestone as shown in the lithologic log of GS 771.

GS 762 AND GS 764

These two boreholes and the corresponding resistivity sounding curvcs are shown in Fig. 6. Both the boreholes are located in Arau. The two resistivity curves are fairly similar in the sense that the minimum apparent resistivity in both cases is 40 ohm-m and that it occurs at an electrode spacing of about 20 m. However they are quite different from the rest of the sounding curves such as GS 863, GS 865, GS 797 and others. The resistivity modeling of these two sounding curves gives about 14 ohm-m and 6 ohm-m as the resistivities of the third layers for GS 762 and GS 764 respectively. Comparing the modeling results with the lithologic logs we find that such a low resistivity can possibly be attributed to saturated laterite layers and not to fractured limestone. Quantitative interpretation of the sounding curve, GS 762 shows that the fourth layer has a resistivity of about 100 ohm-m. We have interpreted this layer as the saturated karstic limestone. Its low resistivity is consistent with the fairly high electrolytic conductivity (870 mhos/cm) of the water at 25° measured in the laboratory (PWD Report, 1982). The low resistivity of the karstic limestone layer is an indication that the water could be brackish. However a quantitative analysis of the sounding curve at GS 764 shows that the karstic limestone layer has a resistivity of about 231 ohm-m indicating a better quality of water than that at CS 762. This could not be confirmed because of the lack of electrolytic conductivity data for the water in this borehole.

ESP 76 AND ESP 78

These two resistivity soundings were done on the northern tip and the western flank of the Chuping limestone (Figures 1 & 2) bordering the Kubang Pasu formation. There are no boreholes nearby to provide lithologic information. The resistivity models and the VES curves are shown in Figure 7. It is very likely that the third layer of ESP 76 which has a resistivity of 29 ohm-m consists of clay and/or laterite. The fourth layer is probably weathered Kubang Pasu rocks or fractured Chuping Limestone. This conclusion is based on the following:

(1) the resistivity of the fourth layer is too low to be attributed to fractured limestone although the interpretation of the VES curve at GS 862 in Arau shows that the fractured Chuping limestone there has a comparable resistivity of 100 ohm-m.

(2) the sounding point is very close to the boundary between the Chuping Limestone and Kubang Pasu formation so that it could possibly be in any of the formations.

(3) KH-type VES curves having very low apparent resistivity at the minimum are generally not indicative of competent groundwater bearing layers. Very low resistivity is, in most of the cases, associated with clays, silts or laterite. But the VES curves, especially the one at GS 762, rise very gently indicating probable fractured zones. ESP 76 is very much similar to VES curves at GS 762 & 764.

From the above discussion it is therefore clear that the possibility of striking a saturated fractured zone or a dry fractured zone is almost equal. It is worth drilling at this point.

ESP 78 is about 1.5 km south of ESP 76 and its resistivity curve is of the KH type. The striking difference between these two curves lies in their minima. ESP 78 very much resembles the curves GS 863, GS 865, GS 797, GS 769 and GS 771. The apparent resistivity for the minimum of the curve is about 160 ohm-m, which indicates that the third layer is possibly a waterbearing layer. Resistivity modeling (Fig. 7) shows that the bedrock is limestone and the depth to it is about 21 m. The water-bearing layer is about 17 m thick and has a resistivity of 81 ohm-m. This sounding curve indicates the presence of water.

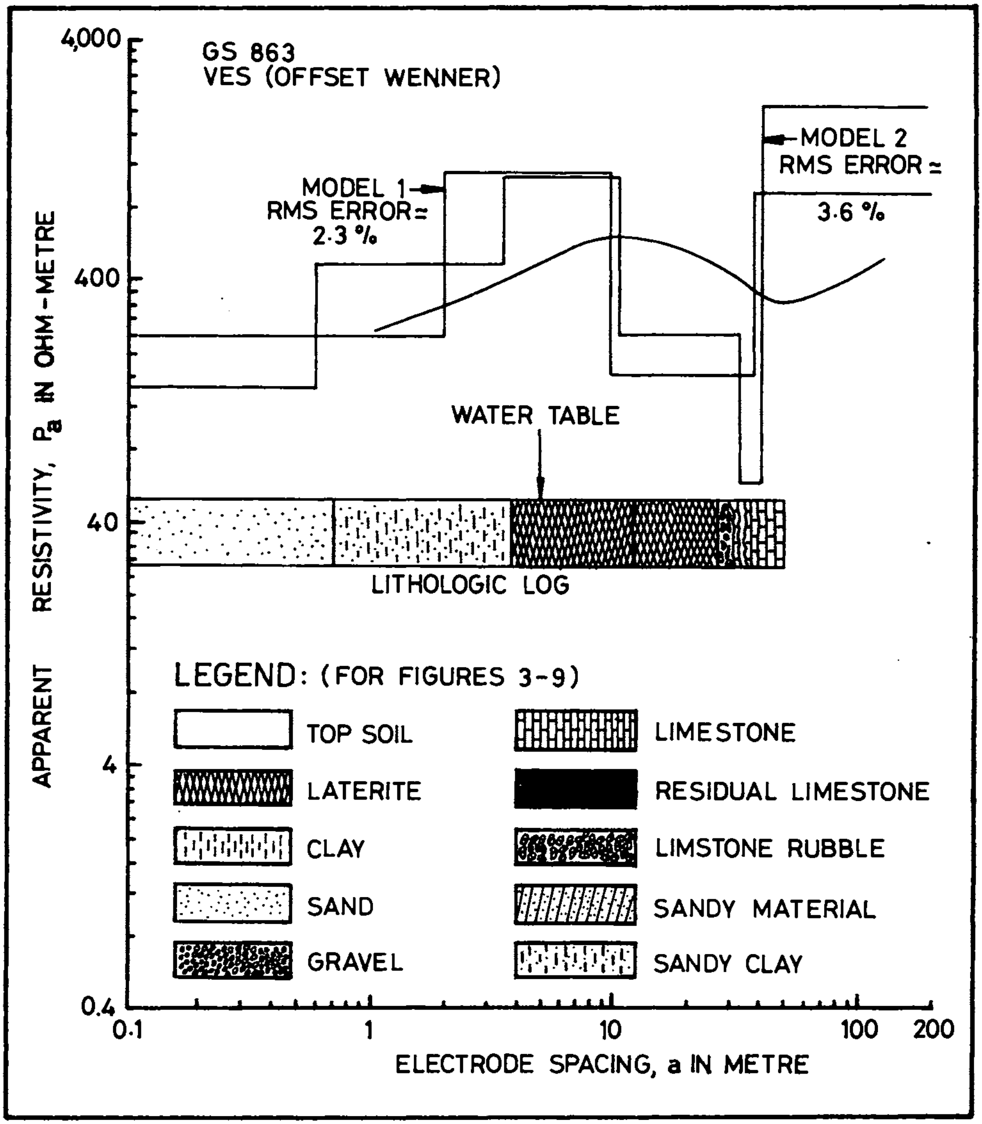

Figure 3 : Interpretation of Vertical Electrical Sounding (VES) at GS 863

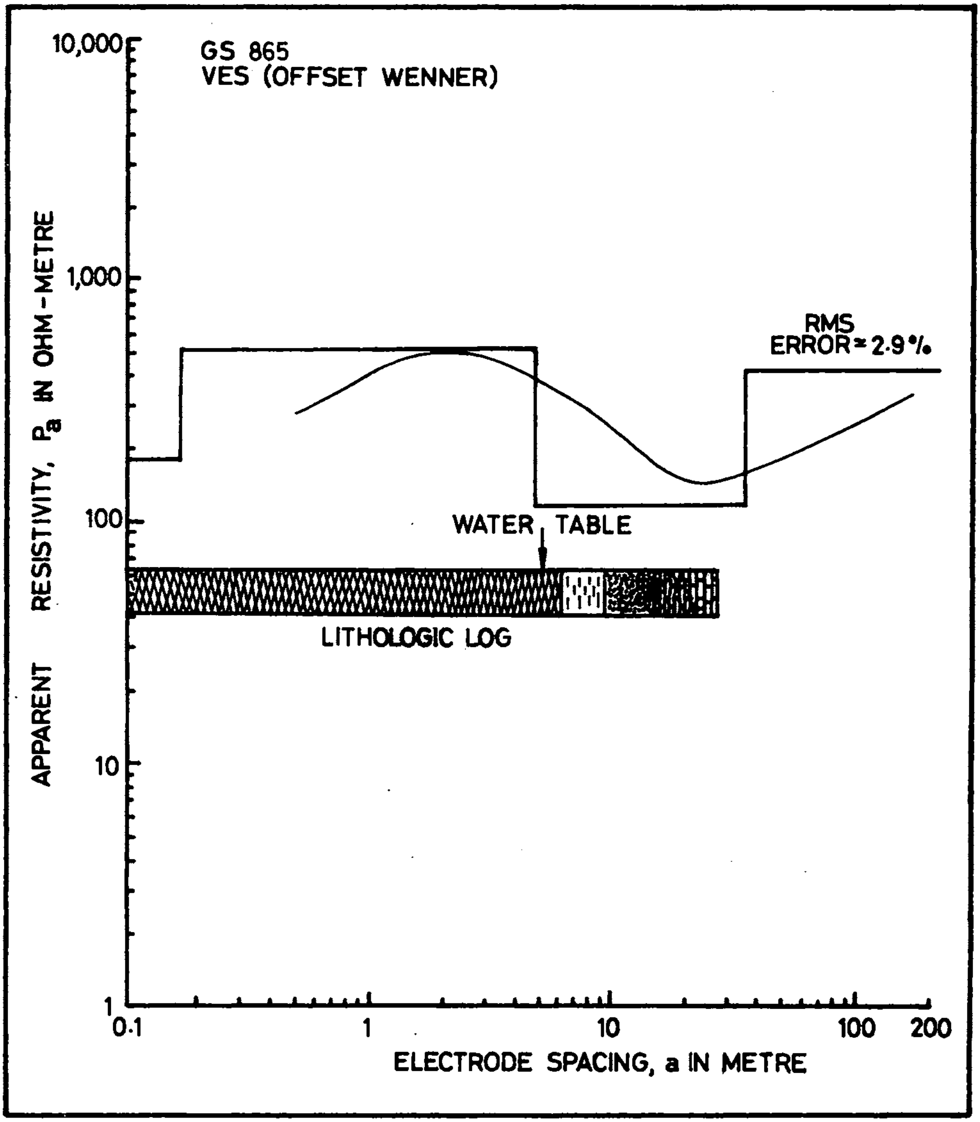

Figure 4 : Interpretation of Vertical Electrical Sounding (VES) at GS 865

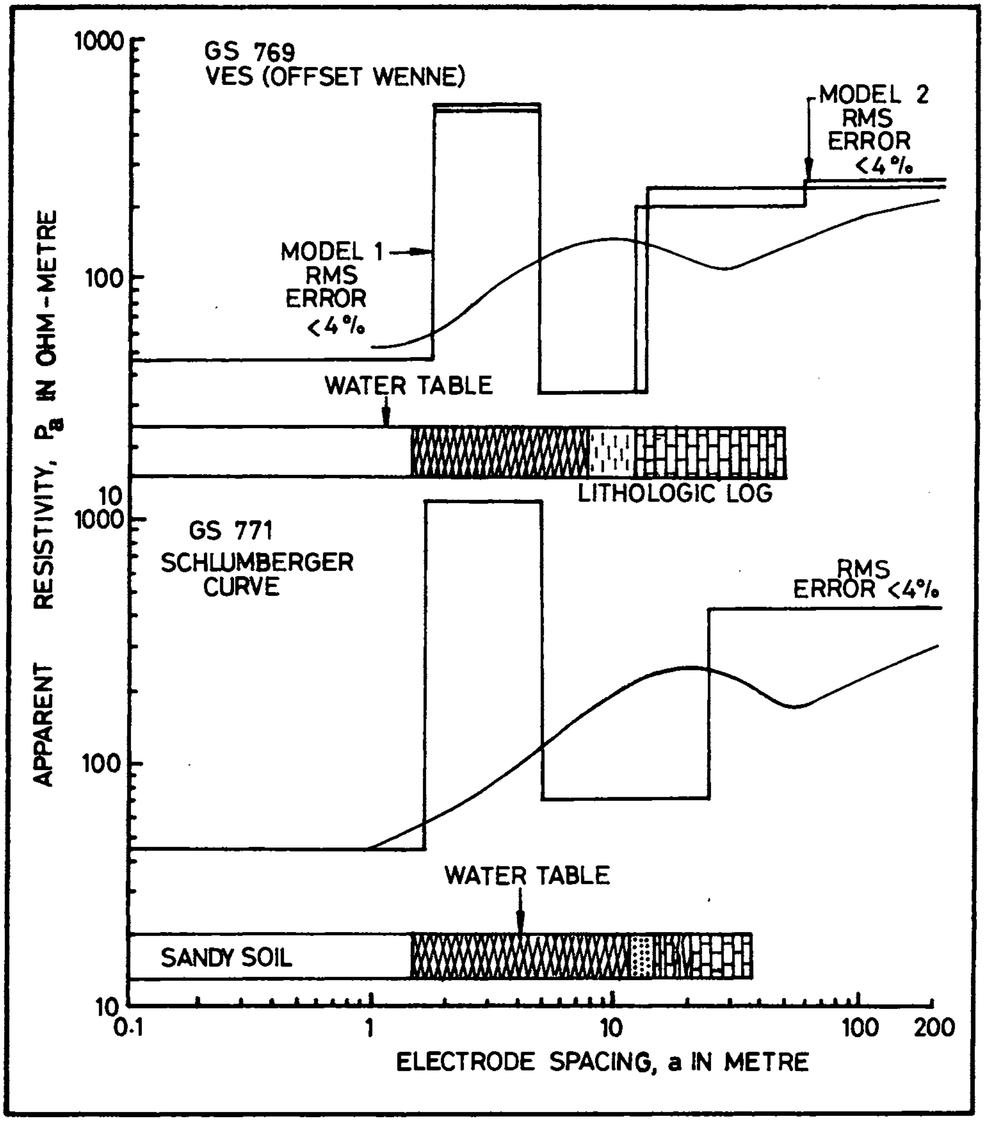

Figure 5 : Interpretation of Vertical Electrical Sounding (VES) at GS 769 & 771

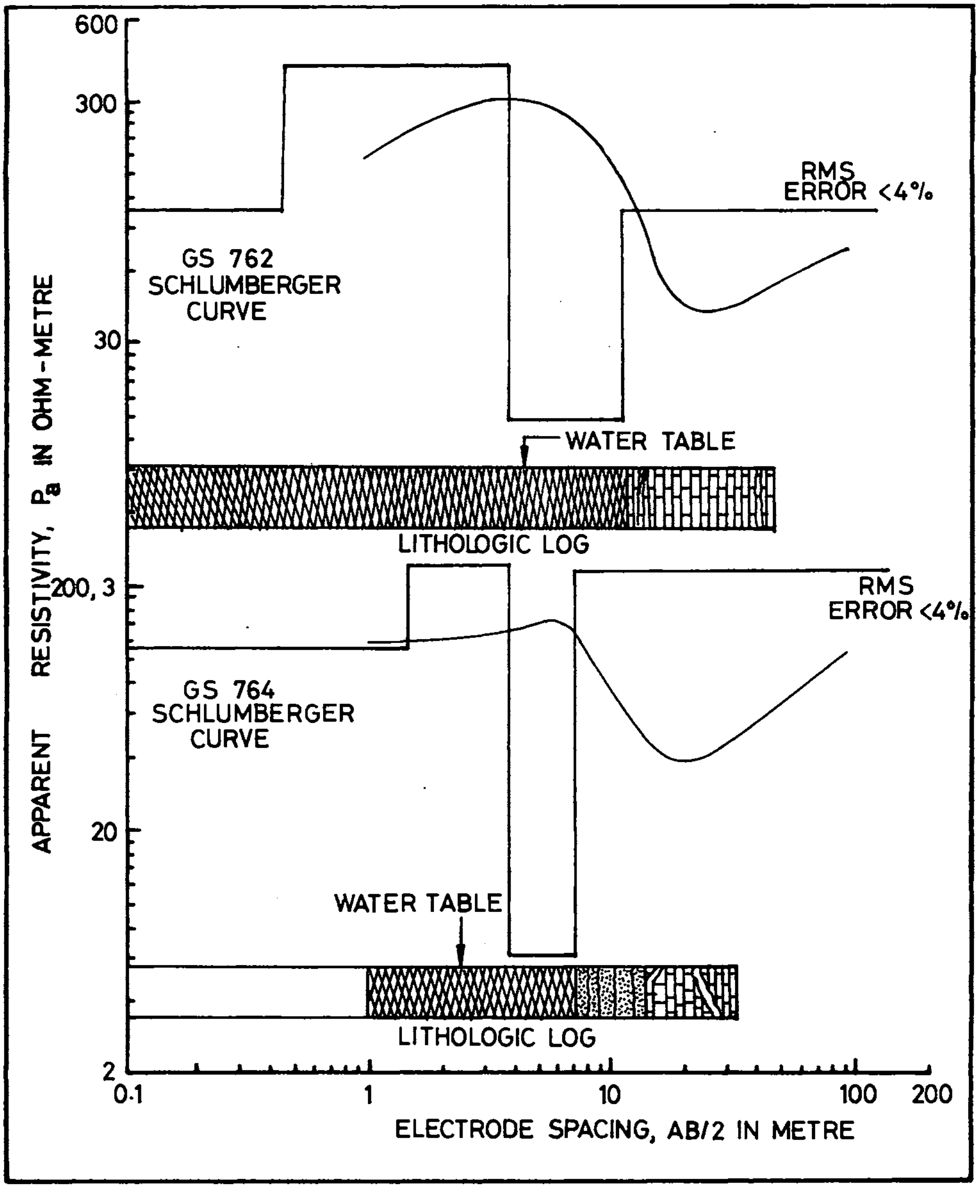

Figure 6 : Interpretation of Vertical Electrical Sounding at 762 & 764

GS 797

A four-layer and a five-layer models are presented for this VES curve (Figure 8). Both the models show almost the same resistivity (208 ohm-m) for the water-bearing layer and the thickness obtained from these models differs slightly from each other. The thickness of the water-bearing layer is consistent with that of the saturated zone as shown in the lithologic log.

GS 791

So far we have shown examples of VES curves, which show presence of water-bearing layer in the fractured zone of the Chuping Limestone.

However this particular VES curve demonstrates that all the KH-type curves from the Chuping Limestone do not necessarily show the presence of waterbearing layer (Fig. 9). The diagnostic characteristics of this curve are that the apparent resistivity of the minimum of the curve is quite low (40 ohm-m) and that the minimum occurs at small electrode spacing (about 17 m). Modeling gives a resistivity of about 20 ohm-m for the third layer and extremely high resistivity for the limestone (fourth layer). This kind of subsurface condition is an indication that most probably there is no water-bearing zone.

CONCLUSION

Most of the resistivity sounding curves of the Chuping Limestone are of the KH type indicating a four-layer earth. Whether these curves indicate the presence of water-bearing zones depends on the following features of the curves:

(a) the apparent resistivity at the minimum (corresponding to the third layer) of the VES curve should be high (greater than 100 ohm-m).

(b) the position of the minimum of the VES curve should be at large electrode spacings (greater than 20 m) indicating that the third layer (corresponding to the minimum of the VES curve) is deep.

(c) the true resistivity of the fourth layer (bedrock) should be less than 350 ohm-m which is indicative of karstic limestone.

However, the first two conditions are not satisfied in case of GS 762 and GS 764 located in Arau. The low resistivity (less than 250 ohm-m) of the limestone at these two sounding points is indicative of the presence of groundwater in Arau. The shape of ESP 76 is very similar to the VES curve at GS 762.

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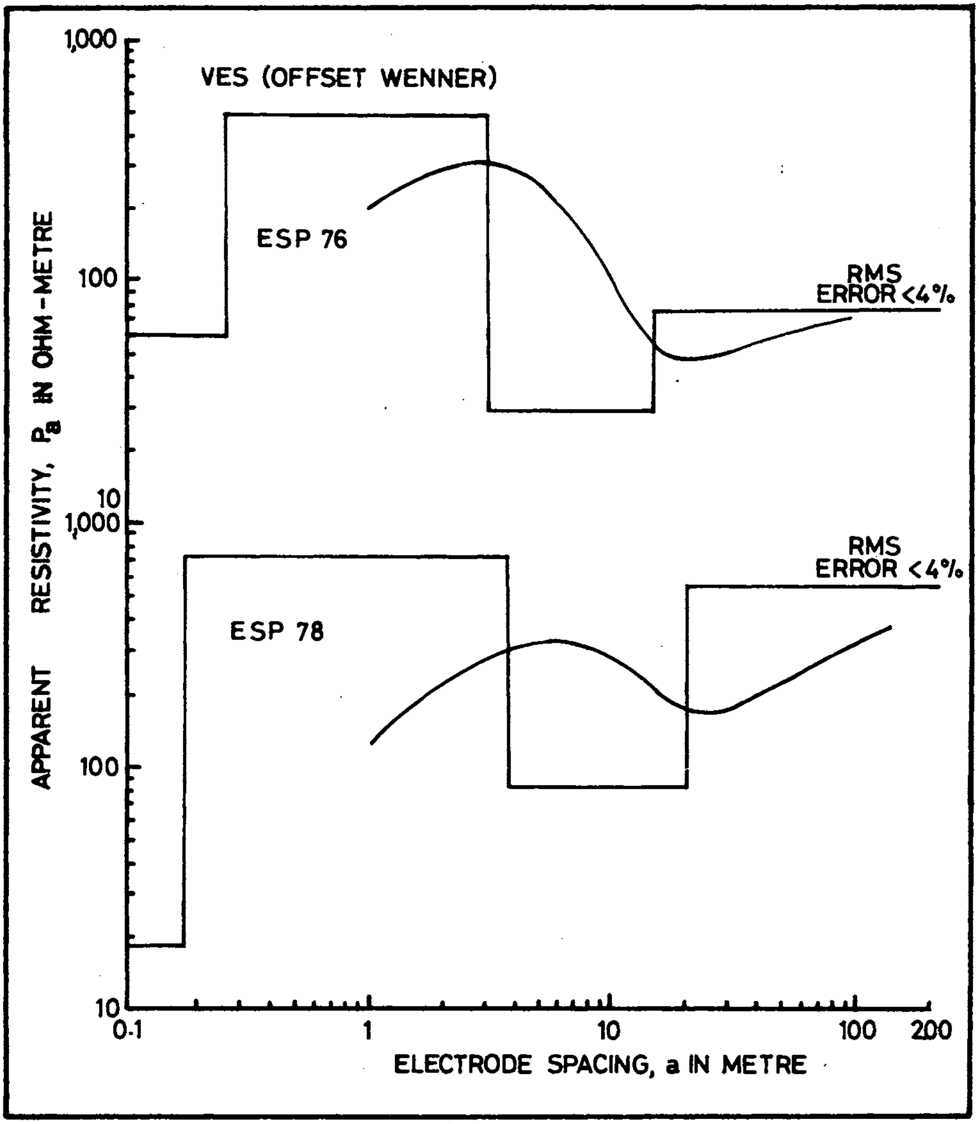

Figure 7 : Interpretation of Vertical Electrical Sounding at ESP 76 & 78

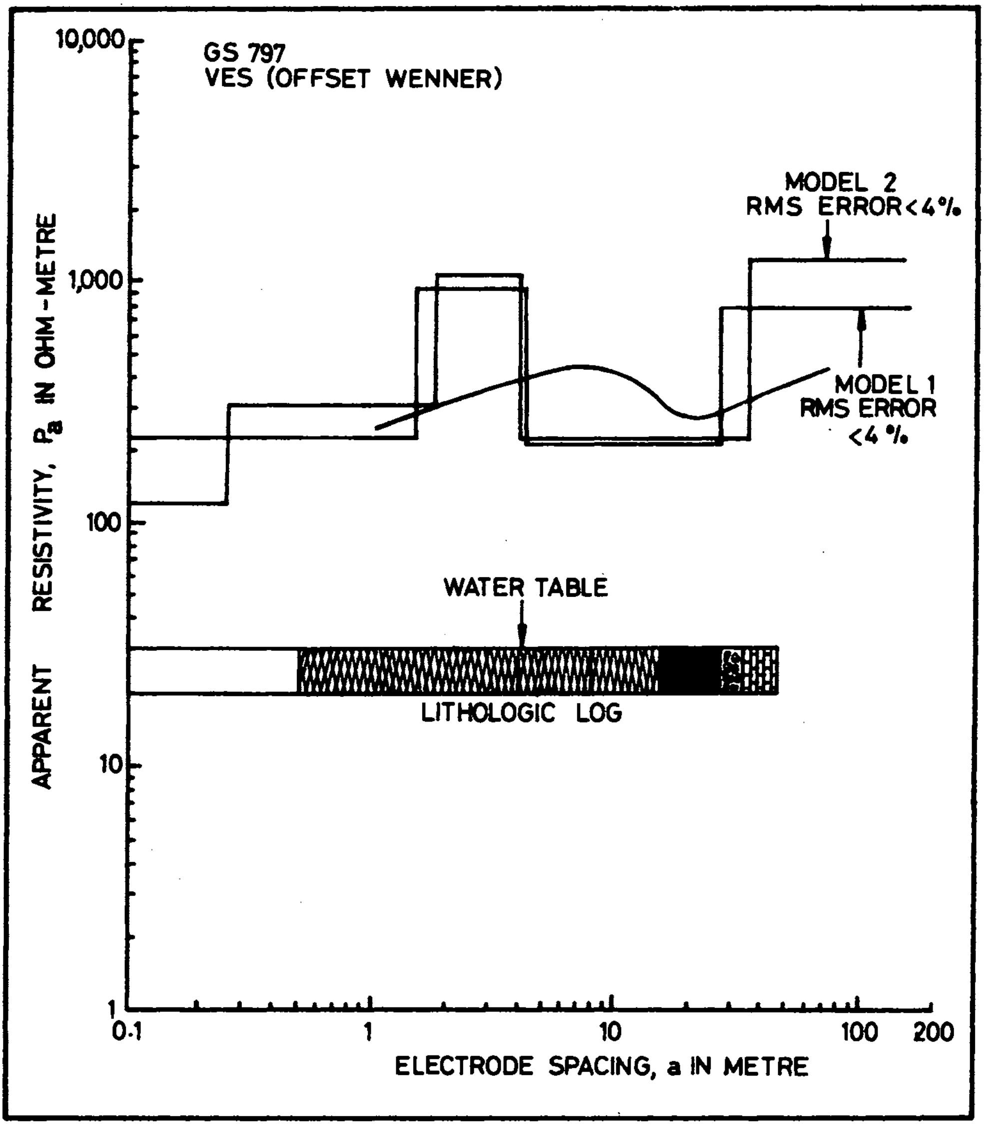

Figure 8 : Interpretation of Vertical Electrical Sounding at GS 797

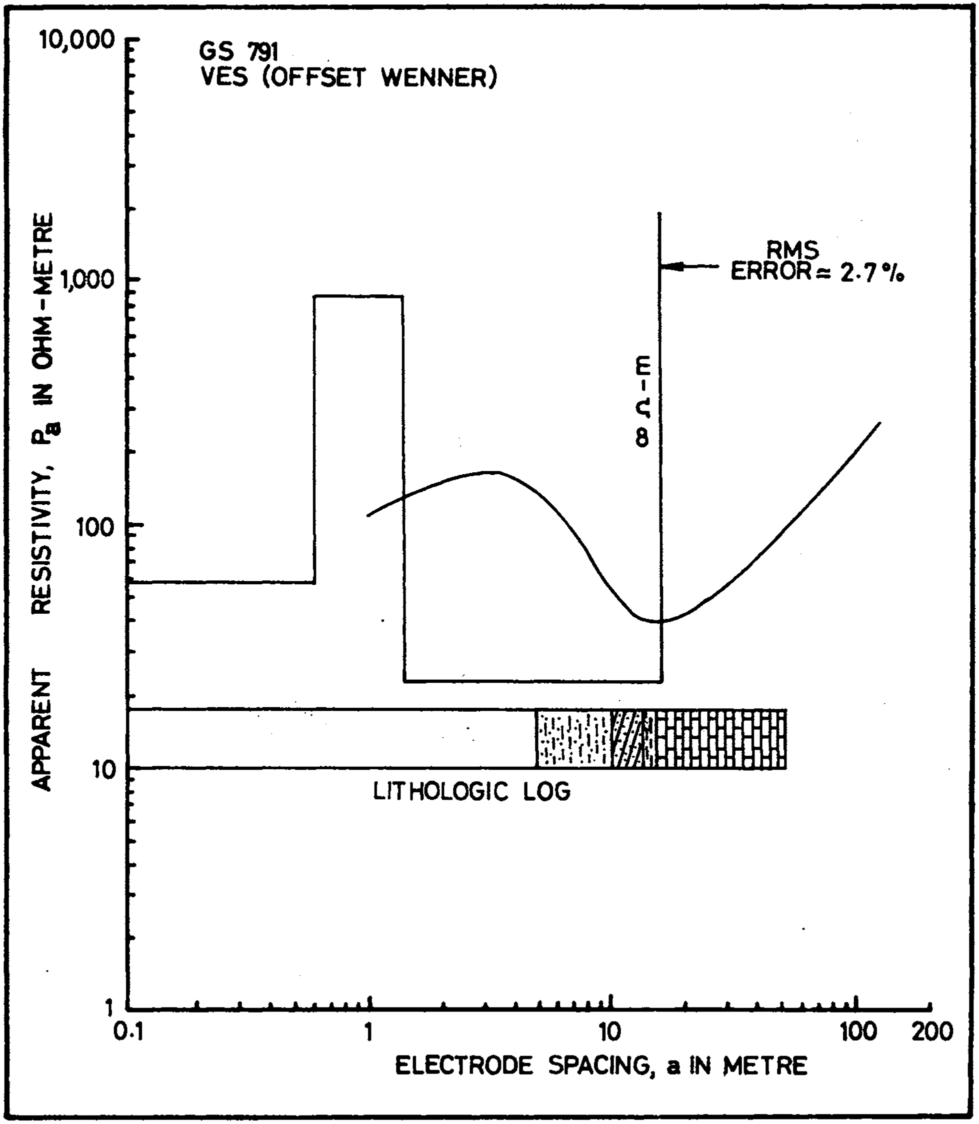

Figure 9 : Interpretation of Vertical Electrical Sounding at GS 791

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REFERENCES

ARAFIN, M.S. and LEE, C.Y. 1987. Application of resistivity and induced polarization methods in locating karstic aquifers in Perlis. Paper presented at the *International Conference on Groundwater and Environment,* Kuala Lumpur, June 22-26, 1987.

BARKER, R.D. 1981. The offset system of electrical resistivity sounding and its use with a multicore cable. *Geophys. Prosp.* 29(1): 128-143.

MOONEY, H.M. 1980. *Handbook of Engineering Geophysics 2.* Minneapolis: Bison Instrument Inc.

Public Works Department's Amended Report, 1982. *National Water Resources Study, Malaysia 3.*

SUMI, F. 1965. Prospecting for non-metallic minerals by induced polarization. *Geophys. Prosp.* 13: 603-616.

VINCENZ, S.A. 1968. Resistivity investigation of limestone aquifers in Jamaica (Caribbean groundwater karst). *Geophys. 33(6)*: 980-994.

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