Sindh Univ. Res. Jour. (Sci.Ser.), Vol: 34 (2) 11 -22 (2002)

THE COMBINED VES/EM SOUNDINGS GEOPHYSICAL METHOD FOR SITING BOREHOLES

Saeed Ahmed Soomro, Sarfraz Hussain Solangi and Saeed Ahmed Bablani

Department of Geology, University of Sindh, Jamshoro.

Abstract

A new simple and quick geophysical method for the siting of boreholes for groundwater supply has been developed from sediments of Aber College Farm, Gwynedd, North Wales, U.K.
Vertical Electric Soundings (VES) are made to locate a potential sub-surface feature which is then assessed by making Electromagnetic (EM) soundings at the selected center of the site where previously VES is made. Groundwater quality has a significant influence on the data. The method and criteria for selecting a site are described in detail. Careful site selection is important in reducing the time and money spent on unproductive drilling.
In the sediments, 5 boreholes had good rates of groundwater production out of 7 sites selected using this method.

Key Words: VES/EM Soundings Method, Siting of boreholes.

Introduction

Increasing demands are being made on the water resources of many countries particularly Third World countries because of their expanding population, especially less rain receiving on coastal areas.

Combined vertical electric and electromagnetic soundings were carried out at Aber College Farm. Gwynedd, North Wales (Soomro, 1993). Based on their results, boreholes were drilled to carry out field pumping tests.

The combined VES/EM sounding method was developed to locate subsurface feature yielding a minimum of 347 l/min from sediments. The siting method found to be rapid and efficient and if various geophysical teams are assigned any big job, they could traverse large areas for investigation and site boreholes within short time. In order to be rapid and efficient it is recommended that the average search distance should be 1000 m and at least 2 km should normally be traversed before any area be rejected.

Regional Setting

Geology:

The site of investigation, the College Farm at Aber, is situated on the coast at the outfall point of the Aber river near Llanfairfechan in Gwynedd (Figure 1). It is a generally flat area although there are a few places of gentle undulations. The Aber river passes through the center of the study area. The lithological units in the area (Pointon and Hart, 1982) can be divided into two major groups: (a) the Holocene (less than 10,000 years old); and (b) the Pleistocene (more than 10,000 years old).

(a) The Holocene:

1. Surface fill.

2. Sand and gravel. The gravel is generally clast-supported with interstitial fine to coarse sand. Pebbles and cobbles are rare. The depositional environment is fluvial.

3. Clays and Silts. Bluish to grey coloured silts, clayey silts, and silty clays.

4. Peat. Brown to black in colour. Depositional environment is terrestrial.

(b) The Pleistocene:

1. Sand and Gravels. In this unit there is an abundance of pebbles and cobbles. Depositional environment is fluvial

2. Irish Sea Till. Red brown diamicton (poorly sorted gravel-sand-mud admixture) with frequent and occasional thick gravel inter beds.

3. Welsh Till. Grey diamicton (till) with frequent and occasional thick gravel inter beds.

Climate and Vegetation:

The Climate of Aber College Farm, Gwynedd, is cold and humid. The annual rainfall during the year 1991 was 878mm and during the year 1992 was 1220mm. Due to the predominance of granular material at the surface, the aquifer is partially recharged from percolation of rainwater falling on the surface of the ground and partially from the Aber River which flows in the vicinity. Fodder is grown on the whole area of this study (Figure 1).

Groundwater Occurrence:

Groundwater occurs within the alluvial sand. All the boreholes completed in the area obtain water from alluvial sand.

The combimed VES/EM soundings method

General Description:

All geophysical methods of water well location depend upon the correlation of subsurface electrical properties with the occurrence of groundwater. The combined VES/EM sounding method locates suitable subsurface electrical conditions by making use of the resistivity contrast which exists between unproductive zones and water bearing zones. The resistivity of water bearing zones is lower being dependent upon the degree of weathering and groundwater quality.

The method exploits the different operating characteristics of instruments. First ABEM SAS 300 Terrameter is used to carry out a sounding until a feature of interest has been located. An electromagnetic sounding is next carried out on the exact center of the feature using MaxMin I-8 (commonly known as Apex MaxMin) portable instrument. The EM sounding is used to assess the suitability of the feature because a variety of subsurface conditions can give rise to similar VES data and to predict the depth to bed - rock, which is an important factor in cost control.

The Wenner in the present study is carried out in simple Wenner array, although the Wenner at some sites has made use of the offset system (Barker, 1981). The Wenner array is one of the most commonly used electrode array for determining resistivity. Four electrodes are equally spaced in it along a straight line. The offset Wenner system has several advantages over both the Schlumberger and the conventional Wenner system. By this system, it is possible to overcome the lateral resistivity variations, which are not detectable by other methods. Also the resistivity surveying is less time consuming a multicore cable and fixed five elctrod arrays can be used for various sorts configuration.

Analysis of the resulting graph of appa resistivity versus current electrode h separation yields a layered earth m

composed of individual layers of specified thickness and resistivity. The data curve must be analysed by computer program; curve matching techniques are too inaccurate for any but the simplest case. In the present study the VES are interpreted by the use of the computer software Bossix or Offix programmes produced by Interpex Ltd. These are in fact forward and inverse modeling programmes for interpreting soundings, from a variety of electrical depth techniques including Offset Wenner soundings data. The forward modeling allows the creation of synthetic resistivity sounding curve for a number of plane layers on the assumption that each layer is laterally homogeneous. Inverse modeling is an interactive iterative process to obtain the best least square fit to the field data.

One of the most popular electromagnetic methods for groundwater exploration is the frequency domain low induction number conductivity mapping; this uses EM terrain conductivity meters (Fraser, 1984; and McNeill, 1980) calibrated directly in ground conductivity, such as the GEONICS em34. The main drawback of the method is its limited exploration depth (<50m) and its restriction to mapping low conductivities. MaxMin is the more traditional horizontal loop EM measuring system which measures in-phase and out-of-phase EM field responses. It is an effective system in obtaining the resistivity and thickness of the subsurface layers. In this study EM soundimgs are measured by the MaxMin. The MaxMin permits the choice of eight octavely spaced operating frequencies i.e. 110, 220, 440, 880, 1760, 3520, 7040 and 14080 Hz. To arrive at the much needed parameters, the most commonly used transmitter powered operating mode, MAX1 (also known as the horizontal loop mode) is used.

Instrumentation and Procedure

The following is the instrumentation and procedure:

(a) The Receiver (b) The Transmitter (c) The Reference cable

(a) **The Receiver.** It is a one piece unit in which there are two coils which are solenoidal in shape and are mounted in the upper end of the tubes on each side of the console. The read out meters, control switches and connectors are all mounted on the console. It is powered by batteries.

(b) **The Transmitter.** It is composed of transmitting coil, a cable connector and a battery pack connected together by retractile cables.

(c) **The reference cable.** This links the transmitter and the receiver. The cable also serves as the intercom link between transmitter and receiver.

(d) **The Procedure.** Before starting to take a EM sounding with MaxMin, it is checked for zero offset on the tilt meter as well as on the in-phase and out-of-phase meters to offset any later on discrepancy. The coils are held horizontal using the bubble levels. To carry out a sounding, 50m and 100m reference cables are used alternatively to change the depth of penetration. In either of the 50m or 100m cables the end of the cable was held over the same point at which a VES was previously made. In mode MAX1 the transmitter operator stands opposite and facing the receiver operator who records the in-phase and out-of-phase readings. The readings are recorded until all the frequencies have been used. To take a second sounding, the transmitter operator moves to take the receiver operator's positions and the receiver operator moves 50m or 100m farther away (depending upon the length of the reference cable used), and then the whole procedure is repeated. In this way at least 4 soundings were

recorded in the case of the 50m cable and 2 soundings if the 100m cable was used. EMIXMM is a forward and inverse modeling software computer programme prepared by the Interpex Ltd., for interpreting EM soundings data taken with the MaxMin. Graphic displays are presented as in-phase and quadrature response versus induction number or as Argand diagram (Eadie, 1979). On the Argand diagram the in-phase component is plotted along the abscissa and out-of-phase component of the same ratio plotted along the ordinate.

Field Operations:

Normally, a √ES/EM survey will proceed as follows:

1. If hand-dug wells exist in the vicinity of the area in which the survey is to take place, measure the water levels and specific electrical conductance (EC in µSiemen/cm at 25°C) of the water in these wells. Ask the well users how much the water level vary annually and examine the lithologic log or the material excavated from the base (look at mineralogy, grain size and variability).

2. The direction of the survey is determined, based upon community preference, local geology, groundwater quality and static water level (SWL). The direction is governed by the settlement pattern, but it is preferable to walk away from high ground where depths to water are greatest.

3. The distance between soundings must be decided. In areas of good potential, an interval of 10m can be used.

4. The VES, if the area is markedly anisotropic should be parallel to the structural strike.

Case Histories

Thirty four VES were made at selected sites (Figure 1). Simple Wenner and offset Wenner arrays were used for this study. Soundings were made up to maximum electrode spacing from 40m to 80m for the simple Wenner array and 32m to 64m for the Offset Wenner array (Table 1). Physical obstructions (metal fences), made it impossible to utilize large electrode spacings. Sixteen electromagnetic soundings were also made at the selected centers of the sites where previously VES were made.

Lithologic information from adjacent boreholes was used to constrain the layer thickness in the VES/EM soundings data interpretation. The higher resistive layer either side of conductive layer means that ambiguity of interpretation due to equivalence would be a problem unless there was some external control. The inversion process then kept the known layer thickness constant whilst the other parameters were varied to produce a best fitting curve. To solve the S-equivalence problem the equivalence option of the program was utilized. This gave the best possible model along with the other close fitting models which are shown alongside the field curve. By this process the fit of the model curves to the VES/EM soundings data is improved considerably compared to direct inversion of the sounding data.

Drilling Technique

The site of investigation, the Aber College Farm, Gwynedd, is situated on the coast at the outfall point of the Aber river near

Llanfairfechan in Gwynedd. Here drilling was carried out and data obtained based on borehole logs collected for their construction, and borehole data obtained in this study after sinking boreholes by the manual percussion method.

The following case histories illustrate the combined VES/EM soundings method. The locations are shown on Figure 1.

CASE 1.

A preliminary geophysical survey had shown that there was an exceptionally good feature approximately 200m wide centered on station VES/EM 4C (Figure - 1). The interpreted curve behaviour suggest that this aquifer is composed of sand and gravel having resistivity of 172 ohm.m and thickness of about 26m (Figure 2). Followed by a layer saturated with some contaminated water, having resistivity of 17 ohm.m. The VES/EM soundings interpreted results along with drill log (Table. 2) show not much difference between them. Subsequent drilling confirmed the presence of sand and gravel layer saturated with water and a borehole was constructed with screen between 4.0m and 30.0m. The airlift yield was 366 l/min. A subsequent three hour pumping test gave a specific capacity of 527 m^3 d^{-1} and groundwater EC of 320 MS /cm.

CASE 2.

The combined VES/EM soundings had again shown that there was still another feature about 300m wide centered on station VES/EM 5B. The interpreted curve behaviour suggests that this formation is mainly composed of sand and gravel having resistivity of 130 ohm.m and thickness of about 37m (Figure 3). Followed by a layer saturated with contaminated water having resistivity of 19 ohm. m. The VES/EM sounding results along with drill log show not much difference between them (Table - 3). Subsequent drilling confirmed the presence of sand and gravel layer saturated with water and a borehole was constructed with screen between 5m to 43m. The airlift yield was 302 l/min. A subsequent three hour pumping test gave a specific capacity of 435 m^3 d^{-1} and groundwater EC of 180 μS /cm.

CASE 3.

The combined VES/EM soundings at site 10B suggested that there were two water saturated formations separated by a high resistivity 614 ohm.m formation, which turned out to be boulders, gravel, sand and mud admixture (Irish sea till) at the depth of 7 meters. Furthermore in the upper aquifer, as appeared on the interpreted model, the bottom of it showed low resisitivity pattern i.e. 15 ohm.m (2m thick), suggests that either it was clay or presence of brackish water and which subsequently after drilling was found to be sandy silt with water having EC of 1700 μS/cm. The lower aquifer however exists at the depth of 15 m having resistively of 111 ohm. m and thickness of 17 m. The borehole was abandoned as its upper aquifer was unlikely to produce 100 l/min or more of low EC water for three hours, and moreover the high resistivity admixture zone was time and money consuming to be drilled through to reach the lower aquifer for tapping.

Results

The decision to abandon a borehole was based on the airlift yield and the quality of water observed at the end of the drilling; if the borehole was unlikely to produce 100 l/min or more for three hours, it was abandoned. Both, depth of water entry and submergence of the drill string must be taken into account when assessing airlift yield.

The drilling and pumping test results achieved using the combined VES/EM soundings are satisfactory.

The average specific capacity shows that for a 10m draw down, the borehole will yield 500 m^3 / d (300 l/min) or more.

Conclusions

The VES/EM soundings method has achieved:

1. A success rate of 71 percent.

2. Boreholes in or very near the settlements to be served.

3. Screen tops averaging 5.4m below static water level, thus providing a reserve for draw down and seasonal long term water level variations.

4. Because the bottom of the screen averages 25m below static water level, drilling and casing costs have been minimized.

The success of the combined VES/EM soundings method in Aber College Farm, Gwynedd, U.K suggests that the method may be useful in any water supply project involving well site selection specially within areas of sediments. The same field technique can be used although the acceptance criteria might have to be reappraised to suit different yield requirements or geological conditions.

Acknowledgements

The authors are thankful to Professor Denzil Taylor Smith, Professor and Head of School of Ocean Sciences, University of Wales, Menai Bridge, U.K., for his guidance.

Stn.	*L1*		*L2*		*L3*		*L4*		*L5*		*L6*		*L7*
	Ωm	m	Ωm	m	Ωm	m	Ωm	m	Ωm	m	Ωm	m	Ωm
10A'	2.6	0.4	15	0.4	267	128	89	8.9	1	-	-	-	-
10A	400	1	56	0.4	14	1	209	18	102	20.5	11	-	-
10B	100	0.5	2090	1.5	45	2.8	15	2.4	614	8	111	17	15
BH10/1	100	0.5	1248	1.5	54	2.8	31	2.4	364	9	112	16	25
10BC	14	0.8	160	4.3	286	11.3	141	11	31	-	-	-	-
10C	24	0.5	157	2.3	98	4.2	247	10	148	26	31	-	-
3A	1851	1.7	109	1.6	34	0.5	317	7	99	7.7	21	-	-
3B	509	1.1	119	1	41	0.7	462	6.9	94	9.7	33	-	-
3C	207	0.7	111	1.3	419	3.6	145	24.3	46	-	-	-	-
7A	550	0.5	1614	1.7	139	1.7	301	8	118	17.9	61	-	-
1A	218	0.9	270	12.5	156	19	35	-	-	-	-	-	-
1B	117	0.1	795	2.4	236	15	169	12	69	-	-	-	-
8B	100	2	164	1.3	280	7.8	86	19.7	35	-	-	-	-
8C	120	0.2	1219	0.4	124	1.6	277	7.3	88	22.5	35	-	-
8D	260	0.3	349	1	57	3	282	9.3	117	21	60	-	-
11A'	2457	0.2	5056	0.8	164	23	30	-	-	-	-	-	-
11A	2011	0.7	335	3.4	161	36.6	33	-	-	-	-	-	-
11B	208	0.9	89	1.5	475	4.4	140	39.3	33	-	-	-	-
11C	588	1.5	142	1.5	524	4.3	140	38.8	76	-	-	-	-
2A	1276	0.4	594	0.4	1530	8	117	-	-	-	-	-	-
2B	1109	0.3	546	0.8	2010	3.7	548	12	60	-	-	-	-
4A'	2.8	0.9	24	0.9	309	11.5	107	10.2	1	-	-	-	-
4A	175	0.4	904	1.4	160	1	35	0.3	407	5	126	16.5	18
4B	448	0.3	8220	0.8	151	2.1	62	0.5	524	4.9	155	14.6	37
4F	151	0.5	219	0.3	140	0.6	837	5.1	120	23.4	44	-	-
4C	1024	0.6	203	0.7	2106	1.9	172	26.1	47	-	-	-	-
4D	160	0.7	50	3.7	2726	1.4	90	21.6	44	-	-	-	-
4E	160	1	788	4.6	141	8.2	217	5	135	13	44	-	-
5A'	3	0.2	31	2.4	443	11.4	83	13	1	-	-	-	-
5A	100	0.5	270	0.4	38	3	121	36	19	-	-	-	-
5B	67	0.3	31	4.4	130	37.9	19	-	-	-	-	-	-
5C	34	0.7	54	10	125	35	41	-	-	-	-	-	-
6A	47	0.7	32	6.8	117	22	52	-	-	-	-	-	-
6B	67	0.4	33	9	149	15.7	52	-	-	-	-	-	-

Table 1: Multilayer Sounding Results.

Stn = Station , L1 = Layer Number , Ω = Resistivity , m = Thickness in meter.

Layer No.	*VES Resistivity (ohm.m)*	*VES Thickness (meters)*	*EM Soundings Resistivity (ohm.m)*	*EM Soundings Thickness (meters)*	*Geological Drill Log*
1	1024	0.6	771	0.8	Sandy silt soil & gravel
2	203	0.7	986	0.4	Sand with some gravel
3	2106	1.9	3581	2.2	Coarse sand gravel
4	172	26.1	93	24.8	Sand & geavel. WT at 4m
5	47	-	65	-	Sand & gravel with contaminated water.

Table 2: VES and EM soundings interpreted data 4C with Geologic log near borehole 4C, Aber College Farm.

Layer No.	*VES Resistivity (ohm.m)*	*VES Thickness (meters)*	*EM Soundings Resistivity (ohm.m)*	*EM Soundings Thickness (meters)*	*Geological Drill Log*
1	67	0.3	67	0.3	Silty sandy clay with pebbles
2	31	4.4	31	4.4	Silty clay. WT at 1m
3	130	37.9	116	36.3	Sand & gravel with water
4	19	-	29	-	Sand & gravel with contaminated water

Table 3: VES and EM soundings interpreted data 5B with geologic log near borehole 5B, Aber College Farm

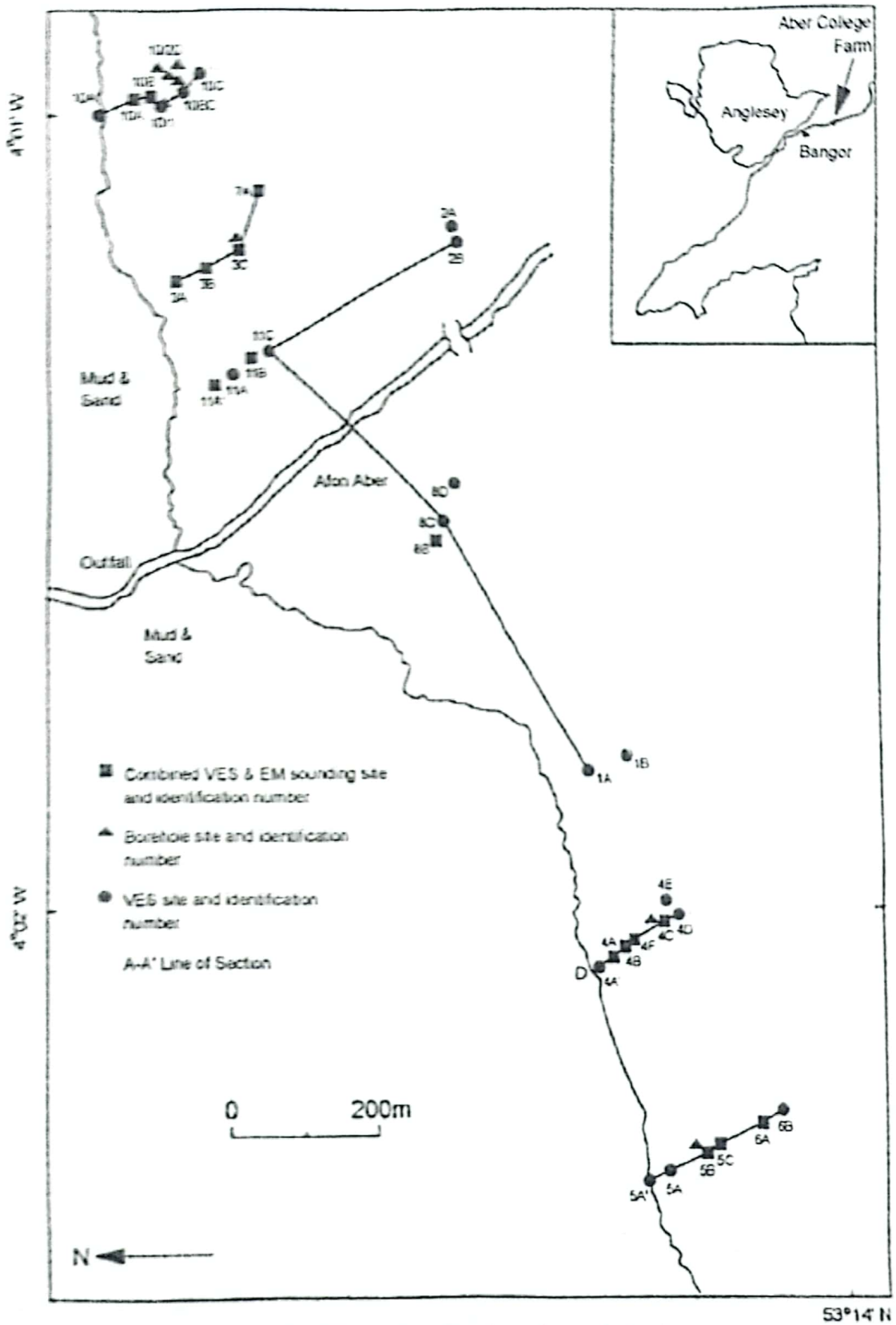
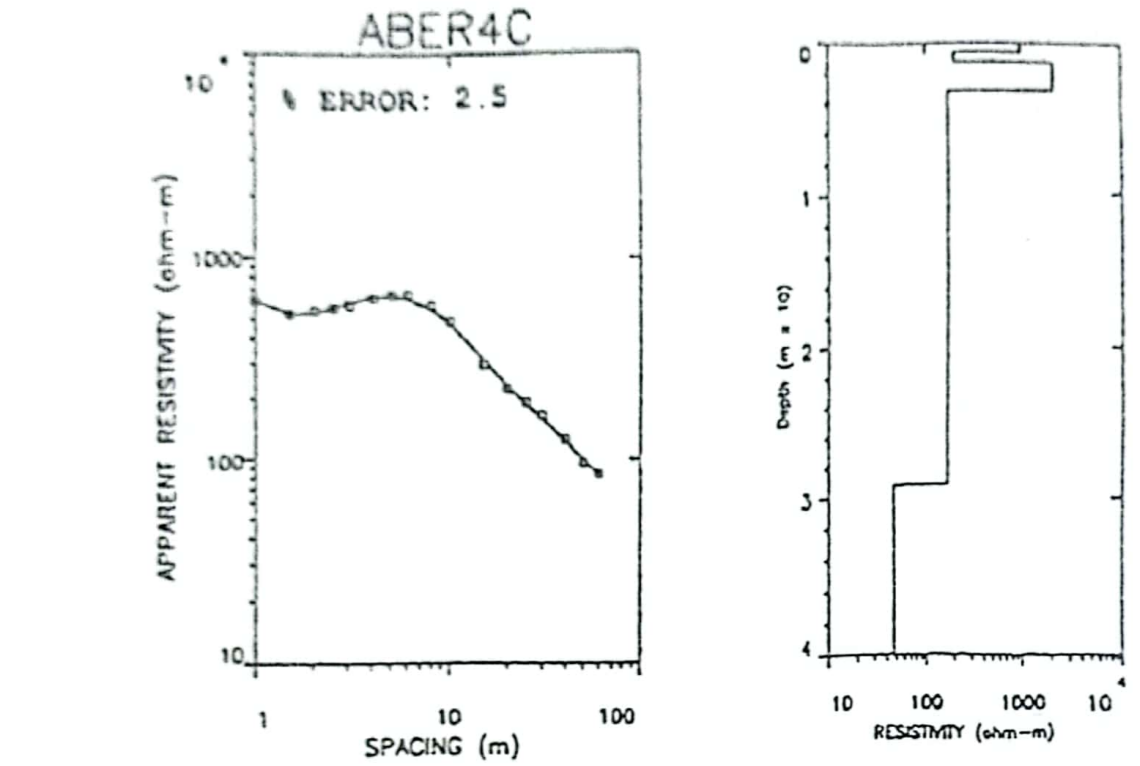
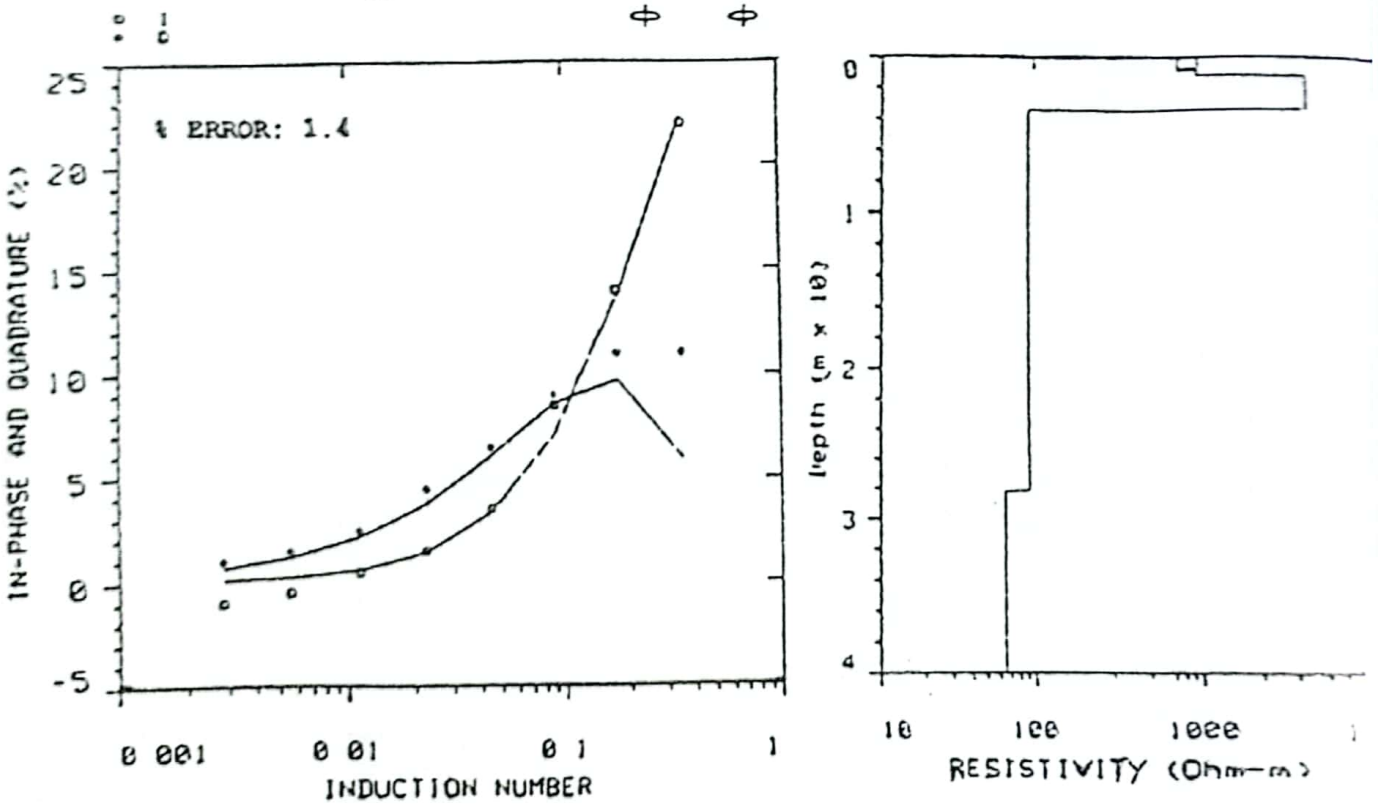


Fig. 1. Map showing location of study area, Aber College Farm, Gwynedd

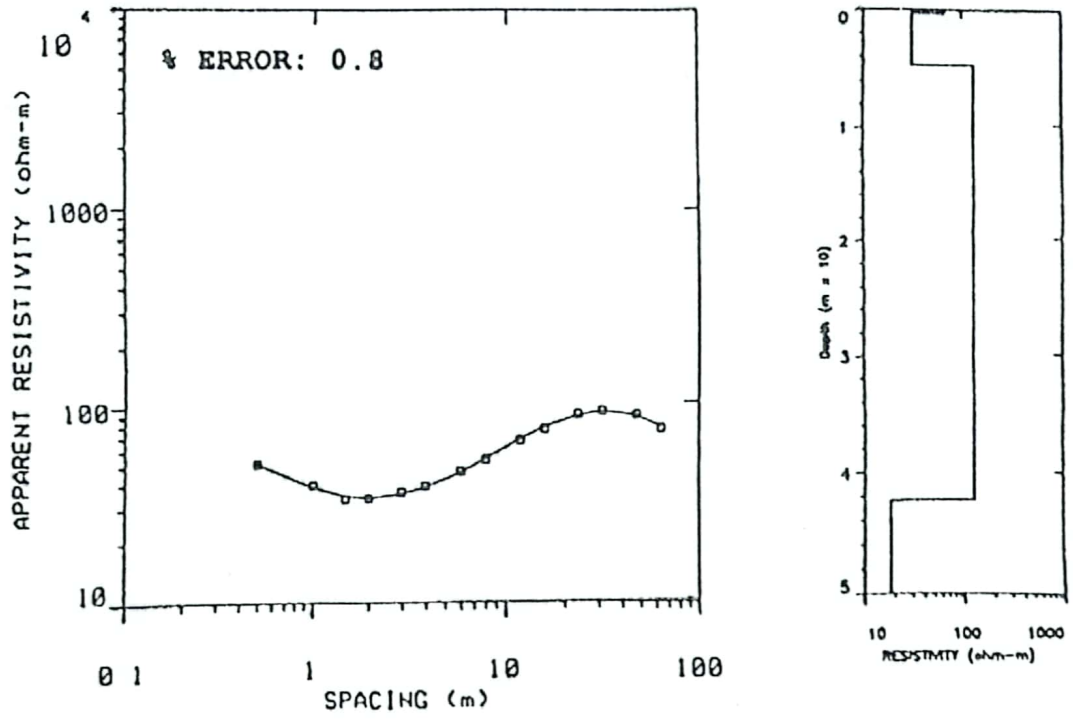


.a.

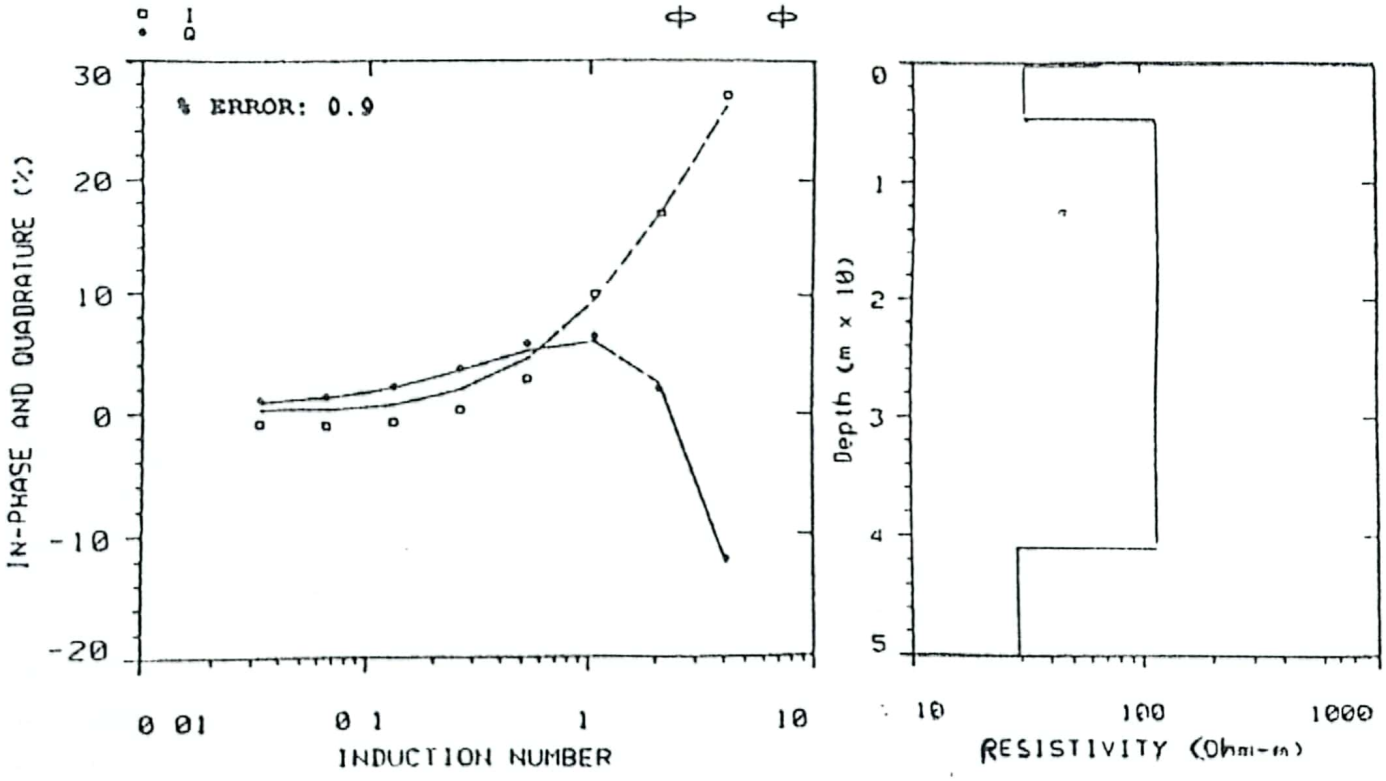


.b.

Figure 2. Vertical electric sounding curve (a) and electromagnetic sounding curve (b) at site 4C based on field data points.



.a.



.b.

Figure 3. Vertical electric sounding curve (a) and electromagnetic sounding curve (b) at site 5B based on field data points.

References

Barker, R. D. (1981). The offset system of electrical resistivity sounding and its use with a multicore cable. Geophysical Prospecting., V.29, 128-143.

Eadie, T. (1979). Stratified earth interpretation using standard horizontal loop EM data. Research in applied Geophysics, No.9, University of Toronto, Toronto, Ontario,Canada.

Fraser, D. C. (1984). Airborne mapping of water resources with DIEGHEM systems. Dieghem surv. and processing, Inc., Mississauga, Ontario.

McNeill, J. D. (1980). Application of Transient electromagnetic techniques. Geonics Ltd., Tech Note TN-7.

Pointon, W. K. and Hart, (1982). Glaciogenic deposits along the eastern Menai straits. Unpubli. M.Sc. thesis, City of London, Polytechnic.

Soomro, S. A. (1993). Detection of saline intrusions in coastal and estuarine sediments. Unpubl. Ph.D thesis, University of North Wales, Bangor,U.K.