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DETECTION OF CAVITIES AND SOIL SETTLEMENTS IN AN INDUSTRIAL SITE USING ELECTRICAL RESISTIVITY METHOD SOUTHERN IRAQ

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ABSTRACT

Six horizontal electrical profiles (Wenner array) and two vertical sounding measuring points (Schlumberger array) were chosen to completely cover the study area in an industrial site located in the southern Iraq. Geotechnical and hydrogeological investigations were also used in the detection of cavities and loose zones as well as the resulting channels underlying the considered site.

Contour maps, histograms and curves of apparent resistivity values were used to delineate the location, volume and shape of the detected cavities. Several pronounced anomalies of high resistivity zones, which indicate existence and extension of cavities were also presented and analyzed.

INTRODUCTION

The studied area located southern Iraq covers about (13.2) Km^2 Lithologically is mainly consisting of sequence of clay, silt and sand sediments. It represents an industrial site that subjected to soil settlements problem in it's southern sector, (Fig.1).

The routine work within the site understudy yield sewage sulfuric water which penetrates through the porous substrate soil, causing the dissolution of gypsiferous cementing materials, hence, subsurface cavities and loose zones (disintegrated zones) were developed. This case present a problem, the problem is due to existence of cavities and loose zones underlying the investigated site. Subsurface cavities most commonly occur as solution cavities in saline rocks, while, the loose zones hardly presented in the consolidated sand and clay layers. These cavities either empty or filled with collapse soil, water or any fluid. High resistivity contrast with the surrounding soil may be noted if the cavities are filled by non-conductive hydrocarbons or other fluids, (Griffin, 1995).

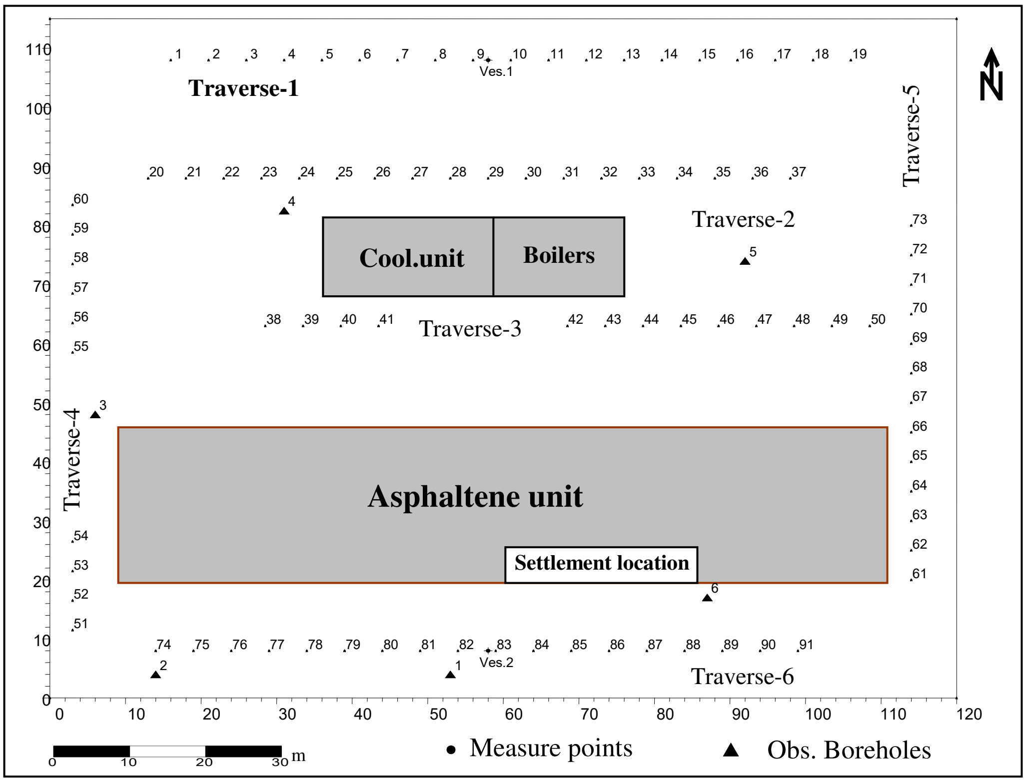
The caving problems in an industrial sites were studied by various investigators, Palmer, 1954 used geoelectrical method to locates subterranean cavities, whereas (Al-Ani, 1993) investigate the subsurface cavities in Hammam Al-Aleel area using apparent resistivity method. Al-Jiboury, 1994 used vertical electrical sounding and wenner profiling arrangements to trace the possible locations of the loose zones and cavities in an industrial site at Makhul area.

The main task of the present study is to find the exact locations of the soil cavities and loose zones; and thereafter suggesting the most successful treatment for this problem.

BACKGROUND THEORY

Electrical survey method is characterized by it's diversity and capability in solving many problems, therefore it is necessary to select the most adequate technique in the field operation to obtain an accurate results about the concerned phenomena. Several considerations should be taking into account when using this method: (1) purpose of the survey (2) maximum investigation depth (3) required wire length (4) efficiency of the used method (5) simplicity of data interpretation (6) execution time; and (7) economic cost, (Dobrin and Savit, 1988).

The most commonly electrode arrays in electrical survey are: (Keller and Frischknecht, 1966)



(Fig.1) Study area showing the location of observation boreholes, electrical traverses, Settlement site and the main units of the studied industrial establishment

1.Schlumberger array:

In usual field operations, the inner (potential) electrodes remain fixed, while the outer (current) electrodes are adjusted to vary the distance (AB). It is typical practice to use a finite electrode spacing and equation (1) to compute the geometric factor (K):

$$k = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right) \qquad (1)$$

Therefore, the apparent resistivity (ρ_a) is:

$$\rho_a = \pi\frac{V}{I}\left(\frac{a^2}{b} - \frac{b}{4}\right) = \pi R\left(\frac{a^2}{b} - \frac{b}{4}\right) \qquad (2)$$

Where:

R: Resistance (ohm)

V: Volt contrast (millivolt)

I: Applied current (milliamp.)

The spacing (a) is adjusted when it is needed because of decreasing sensitivity of measurement. (a) must never be larger than (0.4 AB/2) or the potential gradient assumption is no longer valid. Also, the (a) spacing may sometimes be adjusted with (AB/2) held constant in order to detect the presence of local inhomogeneties or lateral changes in the neighborhood of the potential electrodes, (Fig.2A).

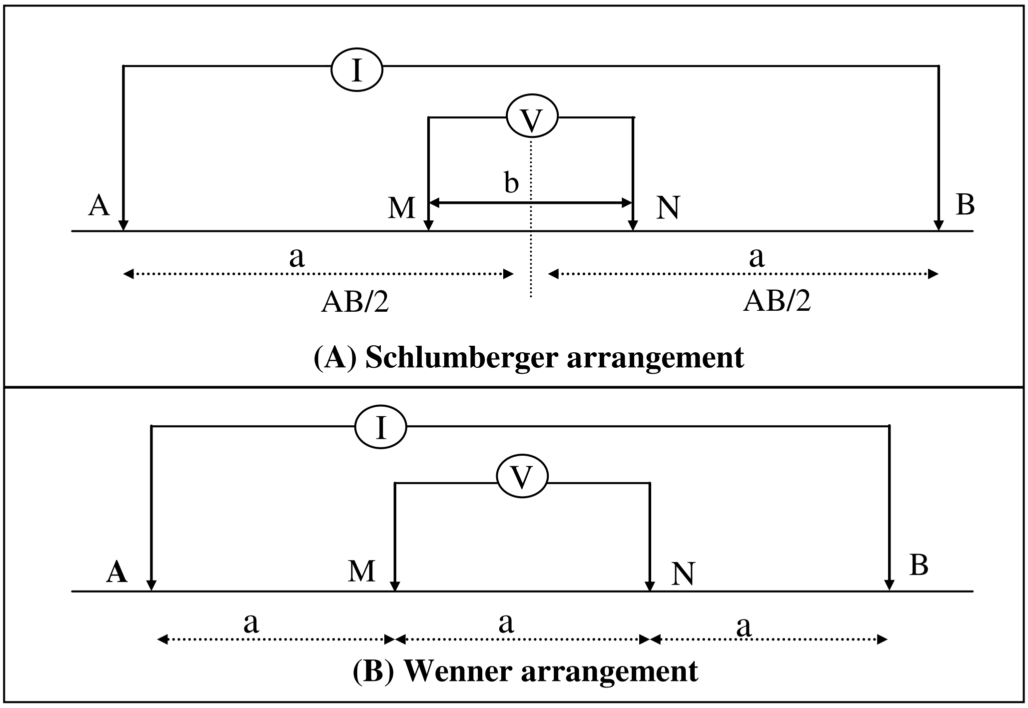
2.Wenner array:

This array consists of four electrodes in line separated by equal intervals, denoted (a), (Fig.2B). Applying equation (1) above, the user will find that the geometric factor (K) is:

$$K = 2\pi a \qquad (3)$$

So, the apparent resistivity (ρ_a) is given by:

$$\therefore \rho_a = 2\pi a \frac{V}{I} = 2\pi a R \qquad (4)$$



(Fig.2) Types of the used electrical arrays

Interpretation problems are: (1) the variation of rersistivity with depth, reflecting more or less horizontal stratification of earth materials; and (2) lateral variations in resistivity can be useful for the investigation of any geological features that can be expected to offer resistivity contrasts with there surroundings. Cavities or joint openings (channels) may be detected as a high resistivity anomaly. For the first kind of problem, measurements of apparent resistivity are made at a single location (or around a single center point) with systematically varying electrode spacing. This procedure is sometimes called (Vertical Electrical Sounding-VES). The apparent resistivity values, and layer depths interpreted from them, are referred to the center point. Surveys of lateral variations may be made at spot or grid locations or along definite lines or traverses, a procedure sometimes called (Horizontal Profiling). After each reading, each potential electrode is moved out by half the increment in electrode spacing, and each current electrode is moved out by (1.5) times the increment.

The increment to be used depends on the interpretation methods that be applied, (Telford et. al., 1976).

METHODS AND DATA USED

Five observation boreholes were drilled to investigate the ground water flow direction as well as achieving Standard Penetration Test (SPT) to determine the bearing capacity and other geotechnical properties of the investigated soil. Two vertical electrical sounding points (Ves1,Ves2) using Schlumberger arrangement were carried out to find the vertical variations in the apparent resistivity values. Beds depths and thicknesses were also calculated depending upon the resistivity survey results.

(91) measuring points and different electrode spacing of Wenner arrangement (2,4,6,8) m were also conducted within six traverses (1,2,3,4,5,6) to recognize the anomalous zones which is regarded as a good indicator for locating such cavities and loose zones, (Fig.1).

(Table-1) shows the results of ground water table (above sea level) monitoring for six weeks taken at two and three weeks intervals. (Table-2) presents the lithology, chemical and engineering properties of the soil at location of borehole-6

(Table-1) Ground water levels of the observation boreholes

Well no.	Water Table (m.) (a.s.l)		
	1st week	3rd week	6th week
1	12.91	12.8	12.81
2	13.09	13.05	12.86
3	13.09	13.07	12.91
4	13.21	13.18	12.92
5	12.55	12.34	11.83
6	13.02	12.93	12.52

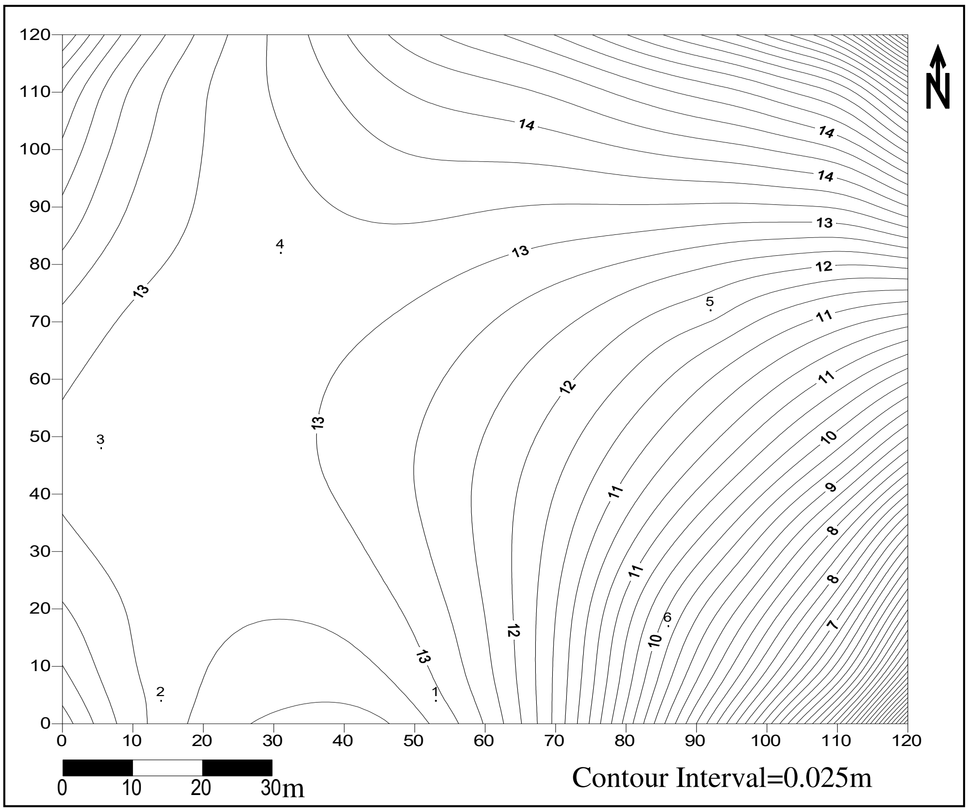
RESULTS AND DISCUSSION

1. Ground water:

As shown by the plotted ground water flow map related to (6th week), the flow direction is from the west and south western parts to the south eastern, in which the above parts can be regarded as a recharging and discharging zones respectively. Recharging zone represents water leaking area from the used processing units which finally infiltrates to ground water, (Fig.3).

(Table-2) Engineering, chemical properties and soil composition at borehole-6 nearby Asphaltene unit

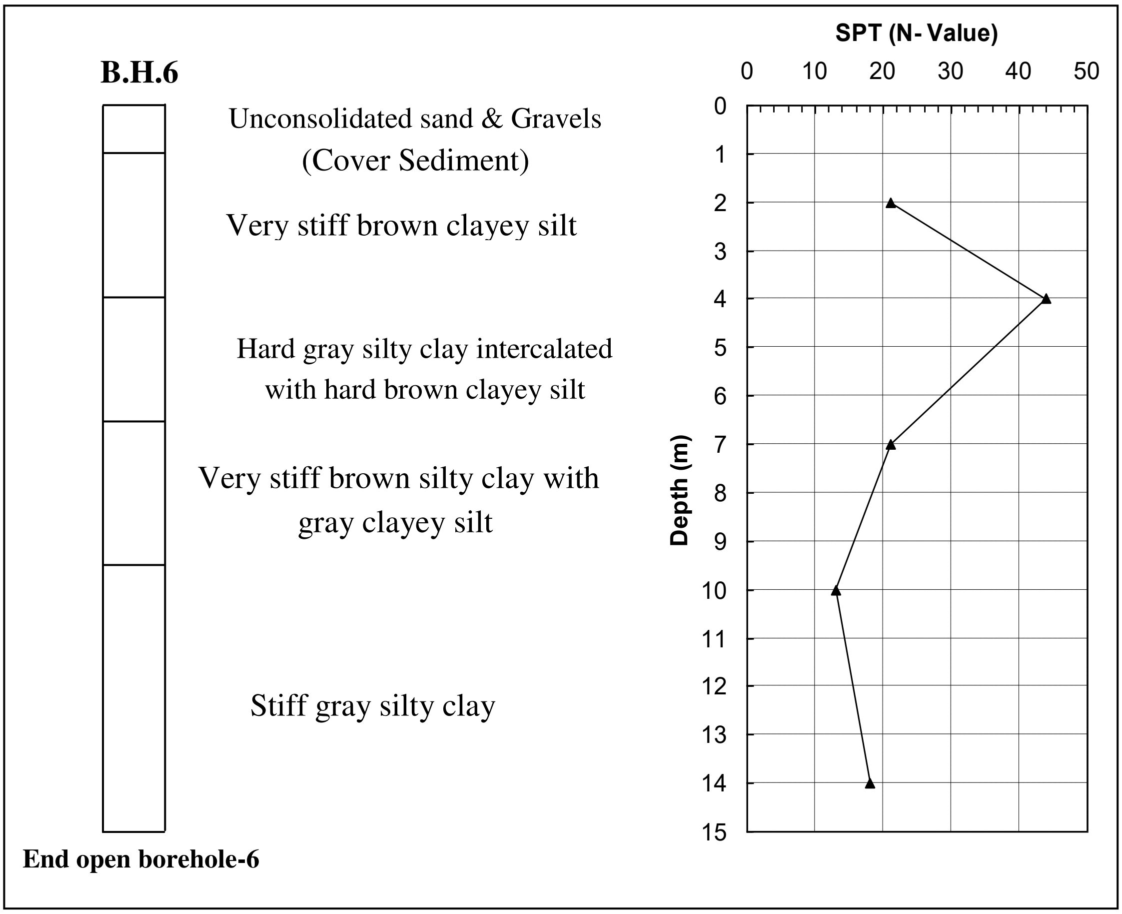
Depth (m)	Texture			SPT	SO_4 (%)	T.D.S (%)	Org.mat (%)	Gyp. (%)	$CaCo_3$ (%)	pH
	Clay (%)	Silt (%)	Sand (%)							
1.0-1.5	23	77	0	-	0.10	-	-	0.22	-	8.0
1.5-2.0	40	59	1	21	-	1.53	0.14	0.43	-	-
3.5-4.0	-	-	-	-	-	-	-	-	30	-
4.0-4.5	39	54	7	44	0.14	-	0.19	0.30	-	-
6.0-6.5	52	47	1	-	-	2.53	-	-	-	-
6.5-7.0	-	-	-	21	-	-	-	0.43	-	8.1
8.5-9.0	-	-	-	-	-	-	1.76	-	35	-
9.5-10.0	70	29	1	13	-	0.30	-	-	-	-
11.5-12.0	-	-	-	-	0.13	-	0.22	0.31	-	-
12.0-12.5	65	33	2	-	-	1.66	-	-	-	8.1
14.0-14.5	57	41	2	18	-	-	-	0.38	-	-
14.5-15.0	50	47	3	-	0.10	-	0.19	-	36	-



(Fig.3) Ground water flow direction map

2. Geotechnical tests:

Distinct variations in the soil composition with depth were recognized, (Table-2). As can seen by this table, cementing materials carbonate ($CaCo_3$) and gypsum are ranged (30-36)% and (0.22-0.43)% respectively. These high percent may cause significant damage in the soil when they dissolve. Concerning bearing capacity test conducted at the borehole-6, the present value is (18) Ton/m^2, whereas the designed bearing capacity was (30) Ton/m^2. So, there is a clear deterioration in the soil characteristics due to the continuous leaking resulting from the processing problems, (Fig.4)



(Fig.4) Subsoil profile for borehole-6 position

2. Electrical survey data interpretations:

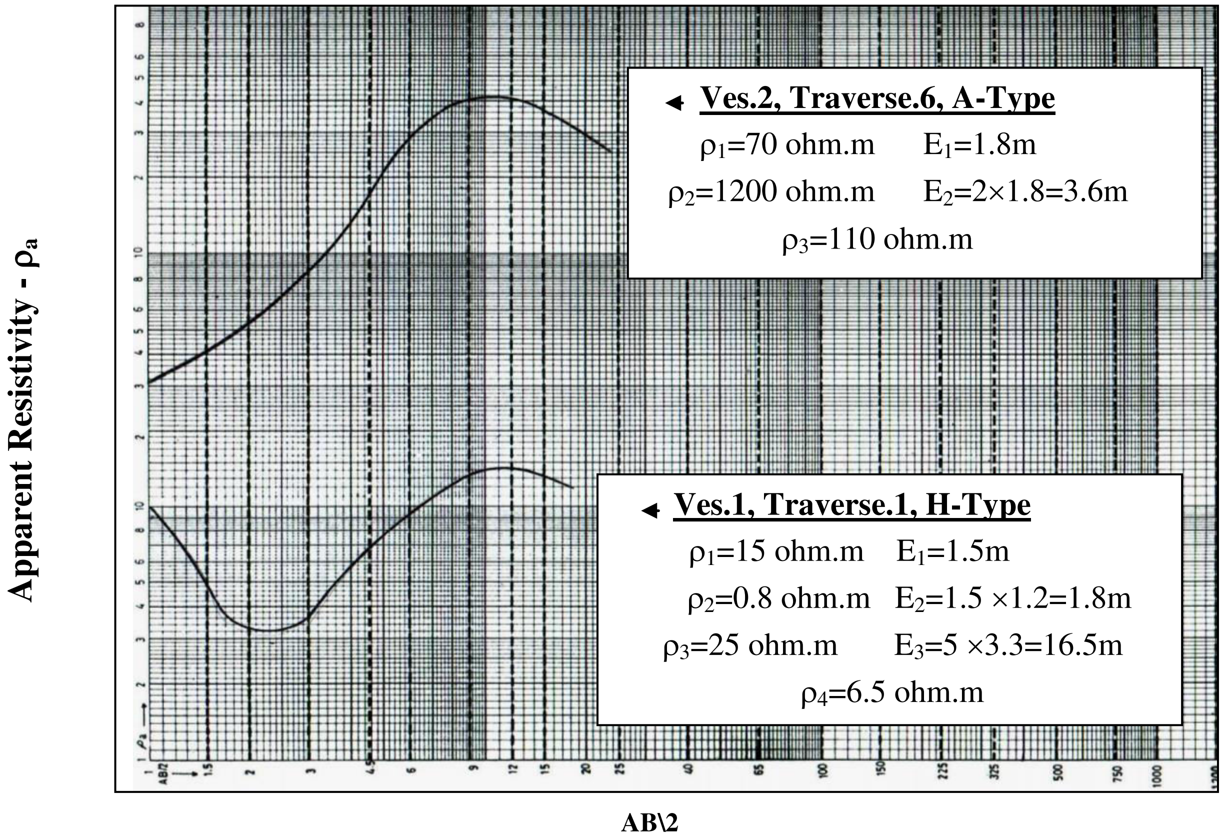
a. Quantitative interpretation of the apparent resistivity values:

Partial curve matching technique was used to interpret the electrical data, (Zohdy,1965). Two vertical electrical sounding points (Ves1,Ves2) were made using Schlumberger arrangement at the mid of the parallel traverses (1,6) respectively, in order to understand the variation occurred in the apparent resistivity verses depth and to determine beds depths, thicknesses and apparent resistivity values.

Ves1, at the undamaged northern part of the studied area was regarded as a control point for comparison purposes, whereas Ves2 is sited nearby the Asphaltene unit which is subjected to settlement problem, (Fig.1).

According to the obtained results, (Fig.5), H-type curve of four layers was observed at Ves.1. The first one extends from the surface to (1.5) m depth with high resistivity values, (15) ohm.m. Unsaturated and compact soil are the main responsible reasons of the above highly resistivity occurrence, whereas the second layer of low resistivity, (0.8) ohm.m which locates at (1.5) m depth is resulting from soil interval saturation. Thick third layer with highly apparent resistivity values, (25) ohm.m represents the moderate-hard zone, while the last layer at (16.5) m depth has similar behavior of the second one.

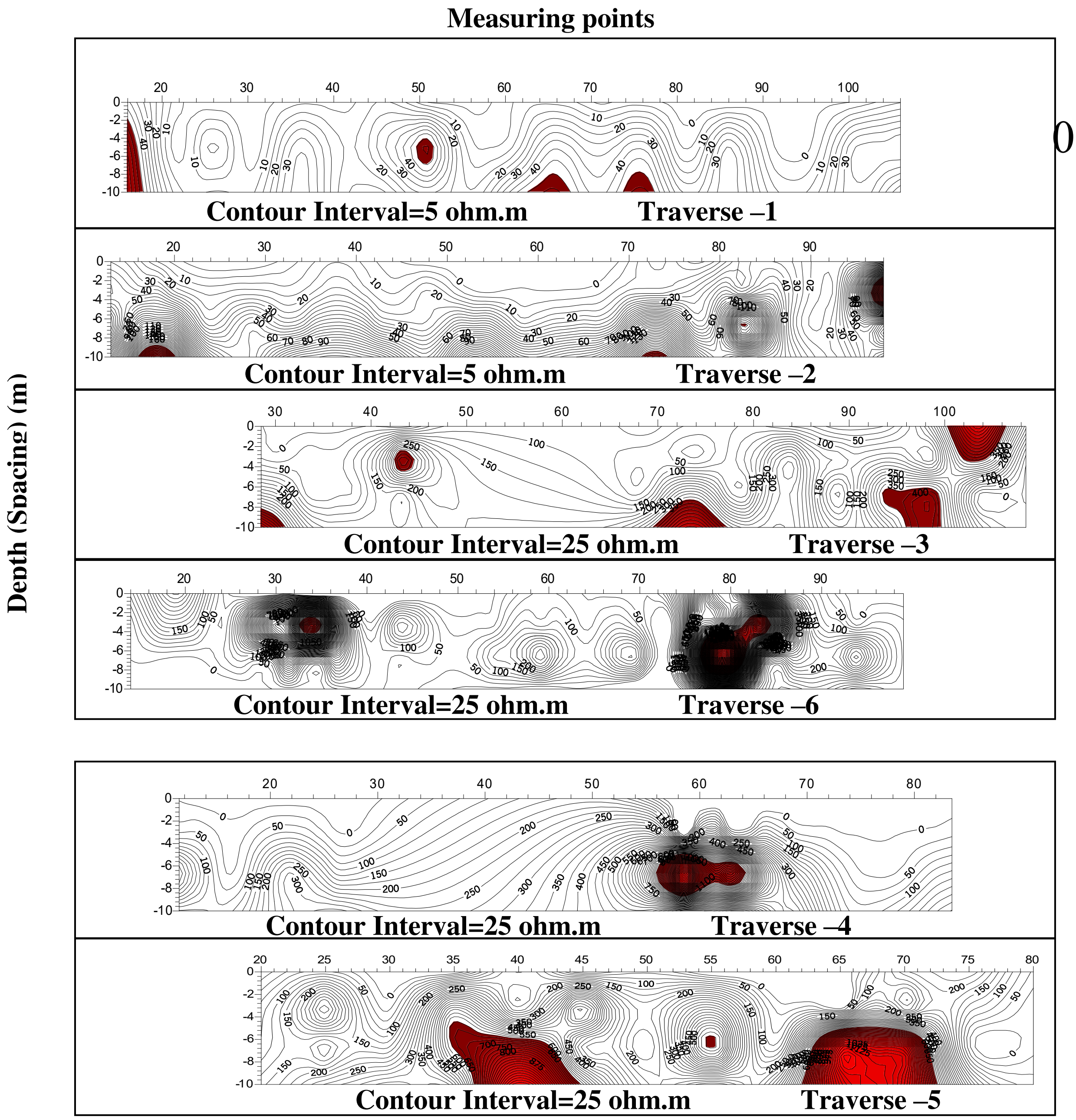
By the comparison between (Ves.1) and (Ves.2) curves, it appears that the last one of A-type consisting three layers. All these layers have highly apparent resistivity values, especially the second one, (1200) ohm.m that restricted between (1.8-3.6) m depth. It represents the cavities and loose zones.



(Fig.5) Vertical variations of apparent resistivity (Schlumberger array) at traverses (1,6)

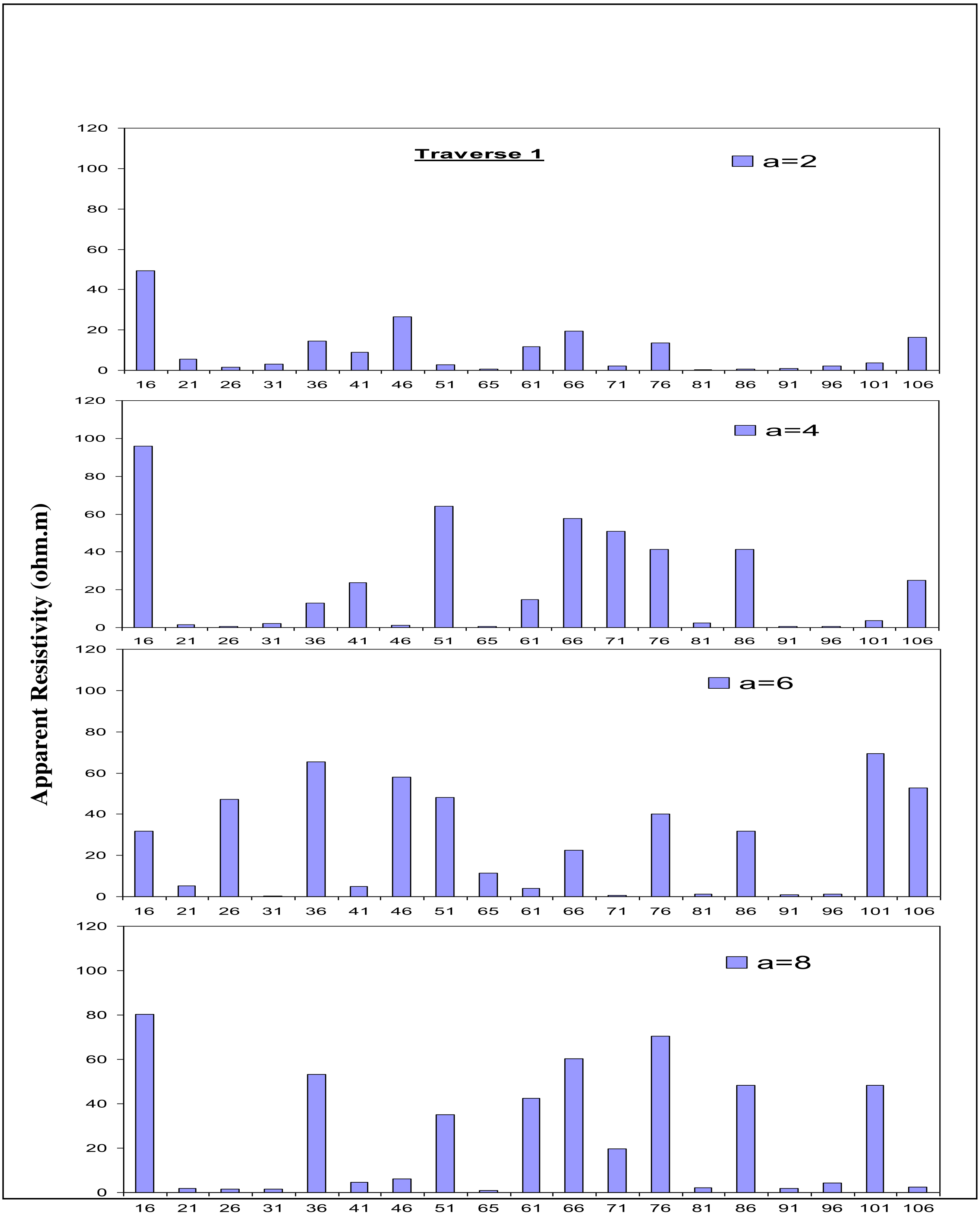
b. Qualitative interpretation of the apparent resistivity values:

(91) measuring points were carried out by Wenner arrangement with different spacing (a=2,4,6,8) m at six traverses (1,2,3,4,5,6), in order to detect the lateral variations in apparent resistivity values. By comparing the resistivity sections of the different spacing, (Fig.6), a characterize anomalies were observed, especially at traverse-6, spacing (a=2,4,6)m and traverse-5, (4,6,8)m spacing. Traverses 1 and 2 show unclear anomalies due to absence of any processing units, and they are away from leaking problems area (Asphaltene unit). Three and single anomalous resistivity zones were also noticed at traverses 3 and 4 respectively.

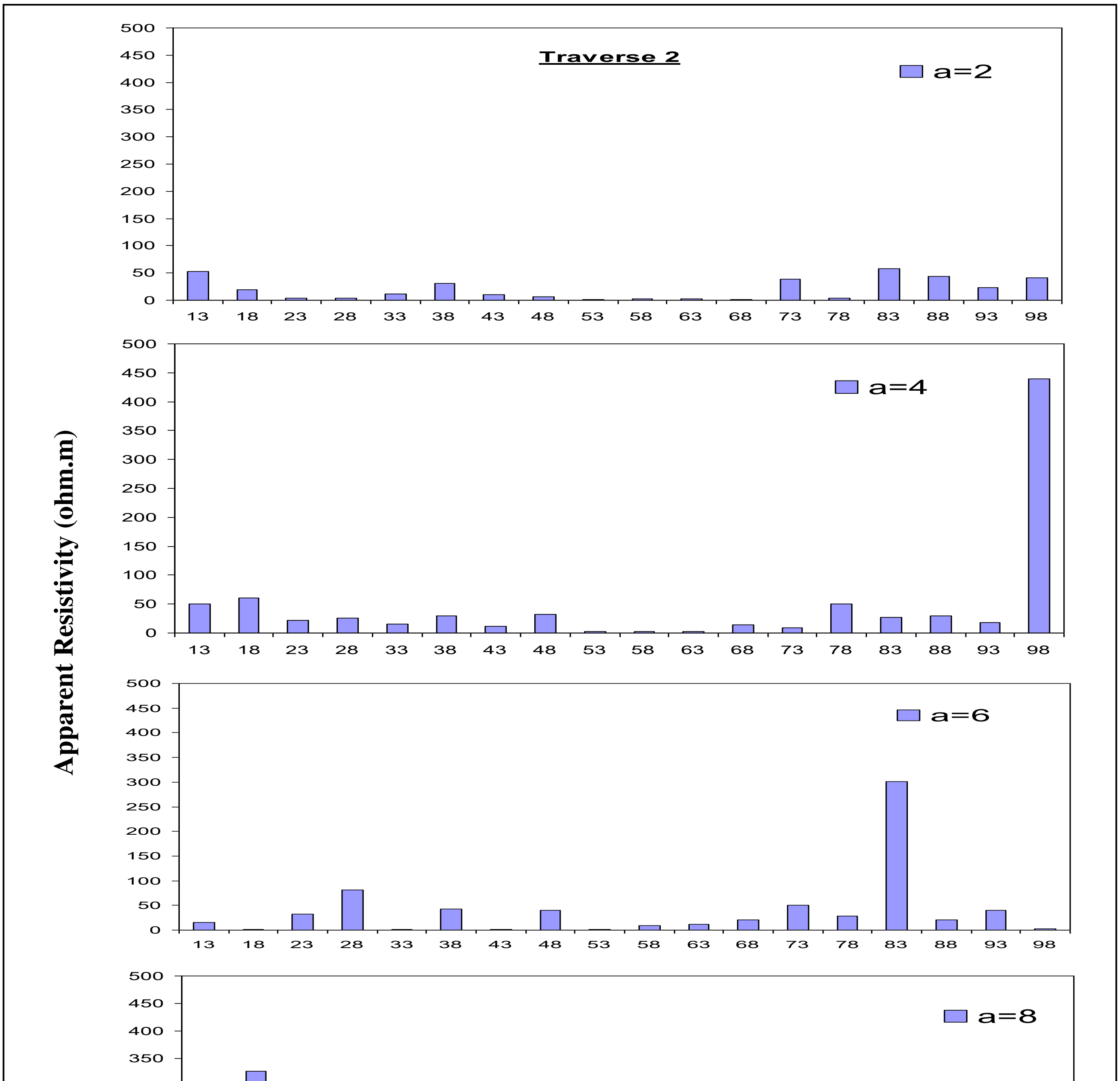


(Fig.6) Isoresistivity sections (Wenner arrang) for the parallel traverses (1,2,3,6) and (4,5) with spacing (a=2,4,6,8) m

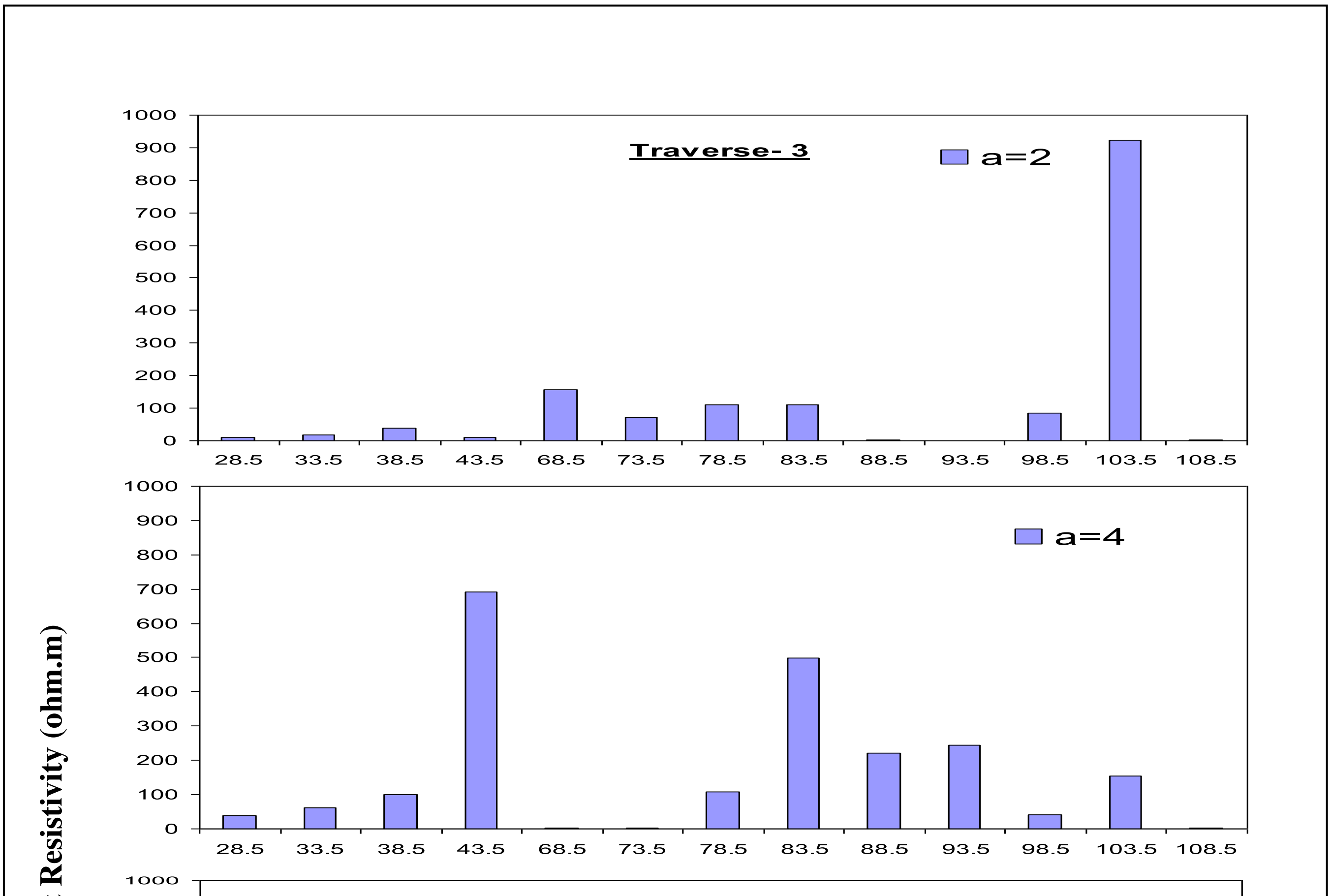
The above anomalies are more clear in the drawn resistivity histograms, (Fig.7, 8,9,10,11,12) and maps (Fig.13,14,15,16). Histograms and maps also show the extensions and depths of the mentioned anomalies which is thought to be highly related to the caving and the surrounding loose zones, which are exactly located under the damaged processing units, therefore, it is possible to treat these zones according to their anomalous values.



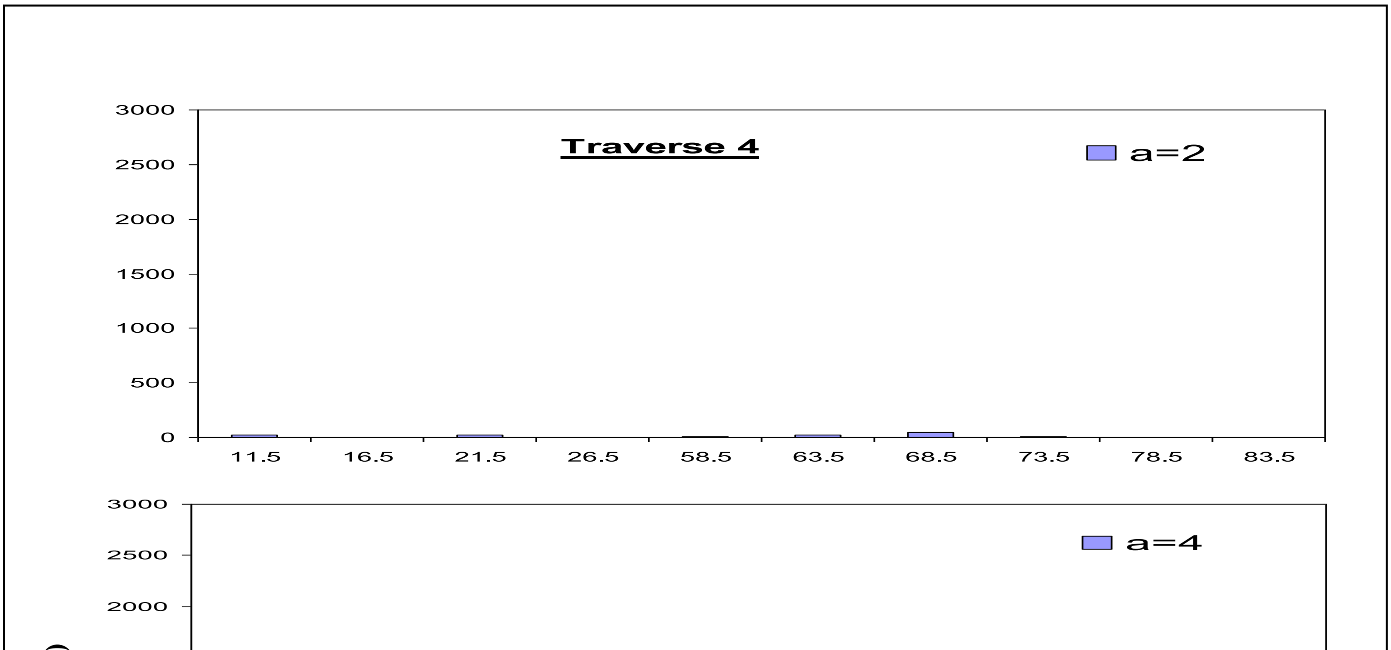
(Fig.7) Lateral variations of apparent resistivity (Wenner array) with spacing (a=2,4,6,8)m at traverse-1 detected from (Fig.6)



(Fig.8) Lateral variations of apparent resistivity (Wenner array) with spacing (a=2,4,6,8)m at traverse-2 detected from (Fig.6)

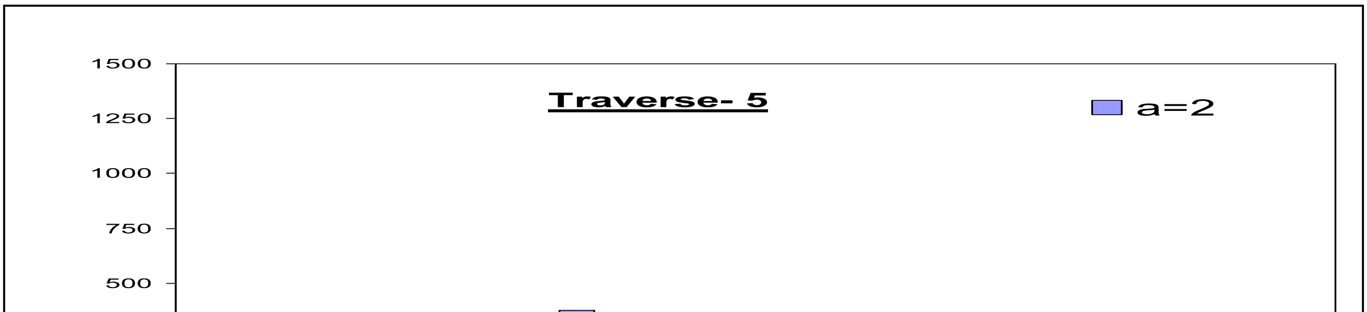


(Fig.9) Lateral variations of apparent resistivity (Wenner array) with spacing (a=2,4,6,8)m at traverse-3 detected from (Fig.6)

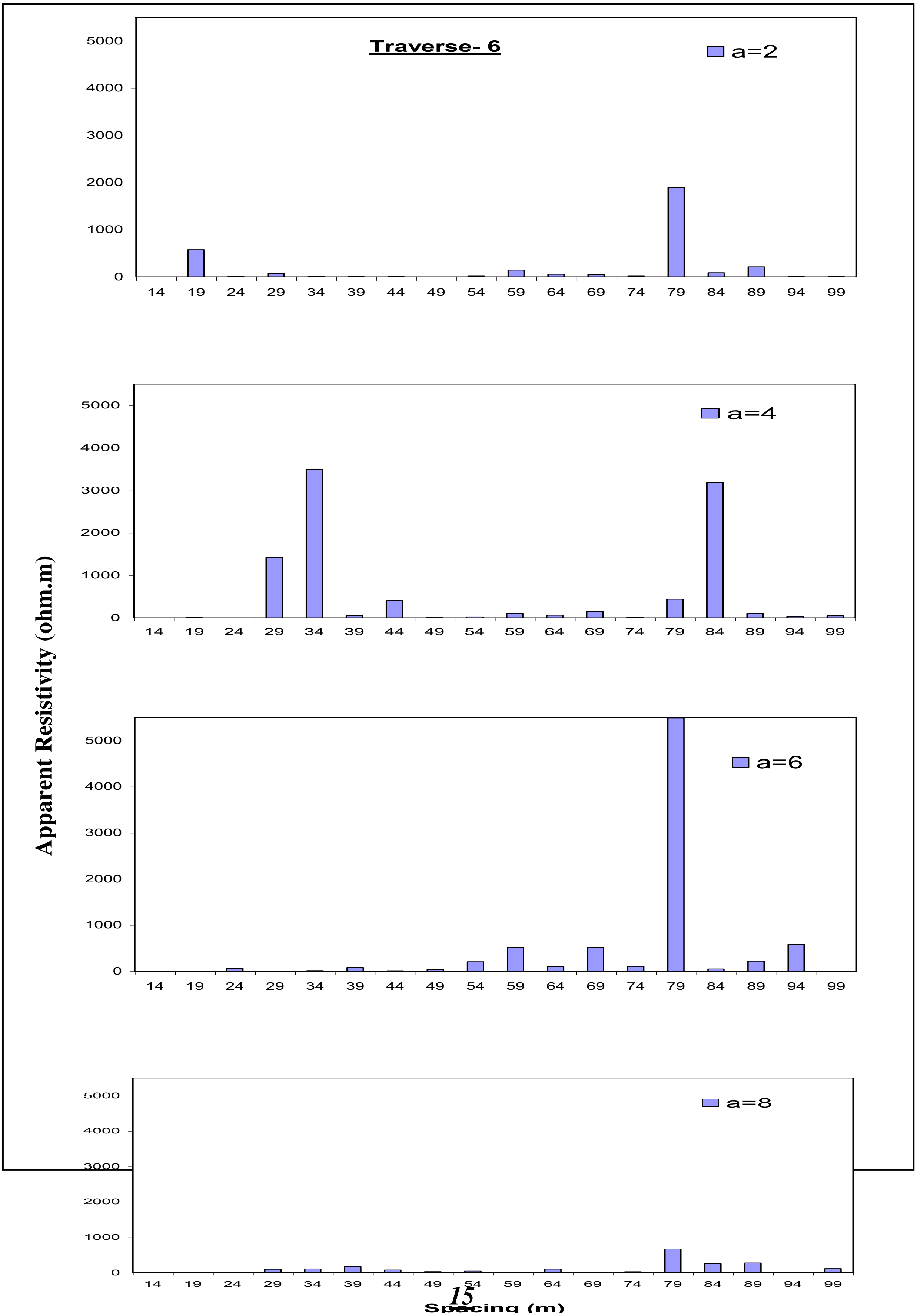


(Fig.10) Lateral variations

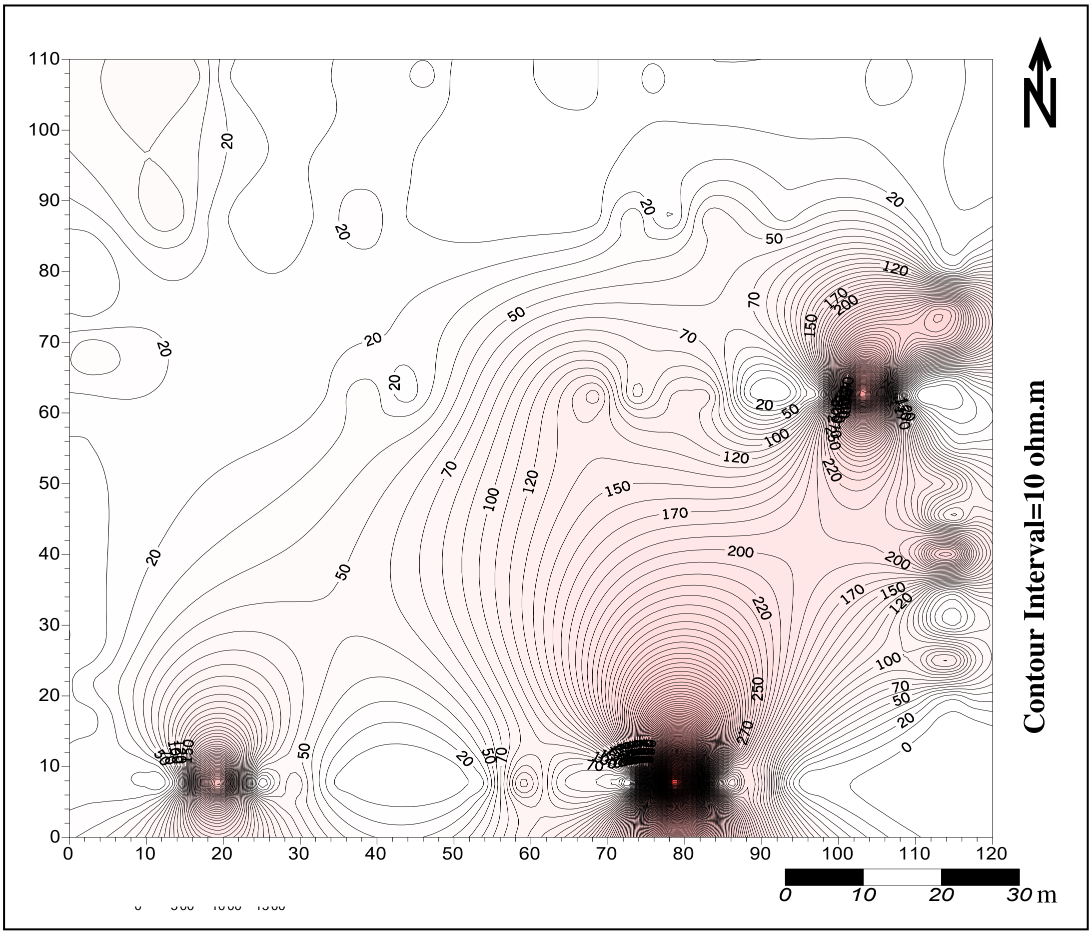
(Fig.10) Lateral variations of apparent resistivity (Wenner array) with spacing (a=2,4,6,8)m at traverse-4 detected from (Fig.6)



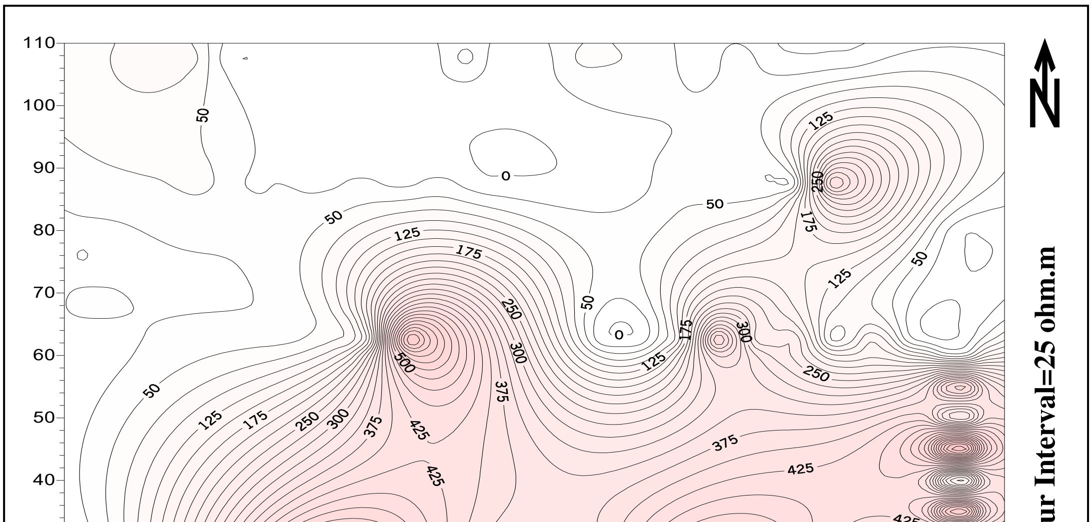
(Fig.11) Lateral variations of apparent resistivity (Wenner array) with spacing (a=2,4,6,8)m at traverse-5 detected from (Fig.6)


Traverse- 6
a=2
a=4
a=6
a=8
Apparent Resistivity (ohm.m)
Spacing (m)
0
1000
2000
3000
4000
5000
14 19 24 29 34 39 44 49 54 59 64 69 74 79 84 89 94 99

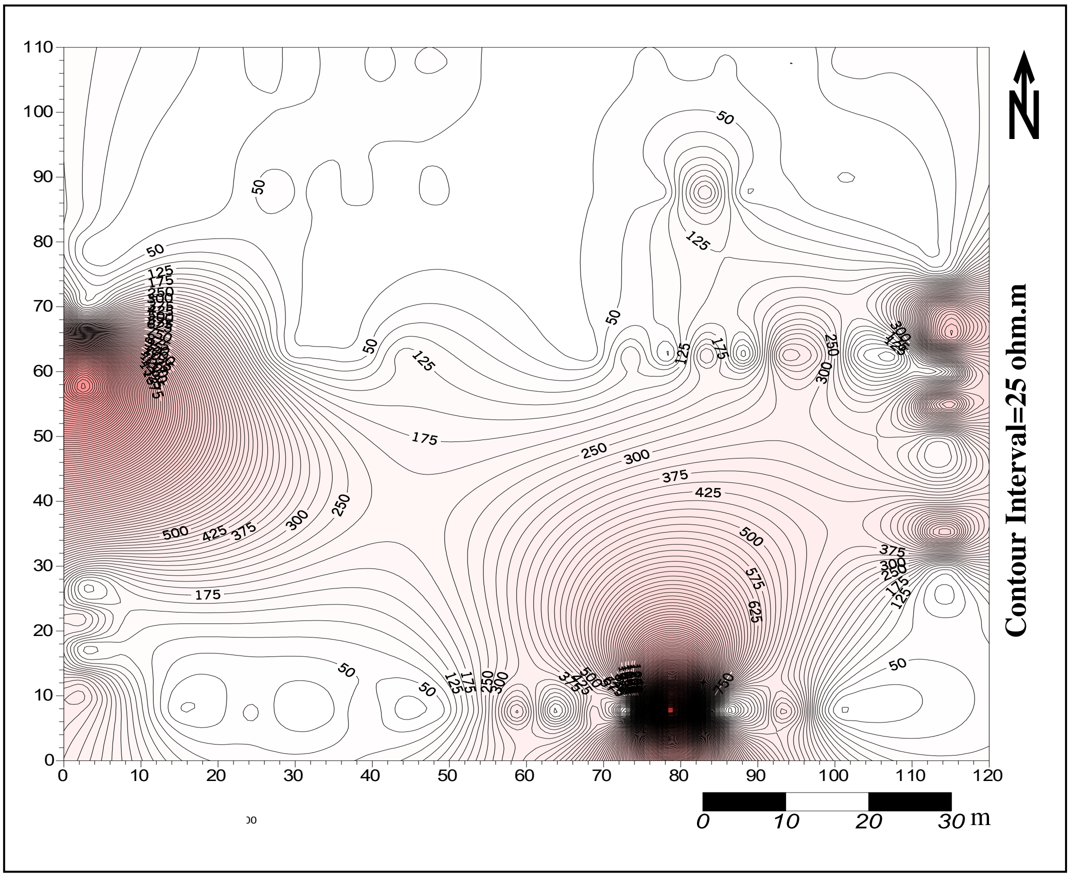
(Fig.12) Lateral variations of apparent resistivity (Wenner array) with spacing (a=2,4,6,8)m at traverse-6 detected from (Fig.6)



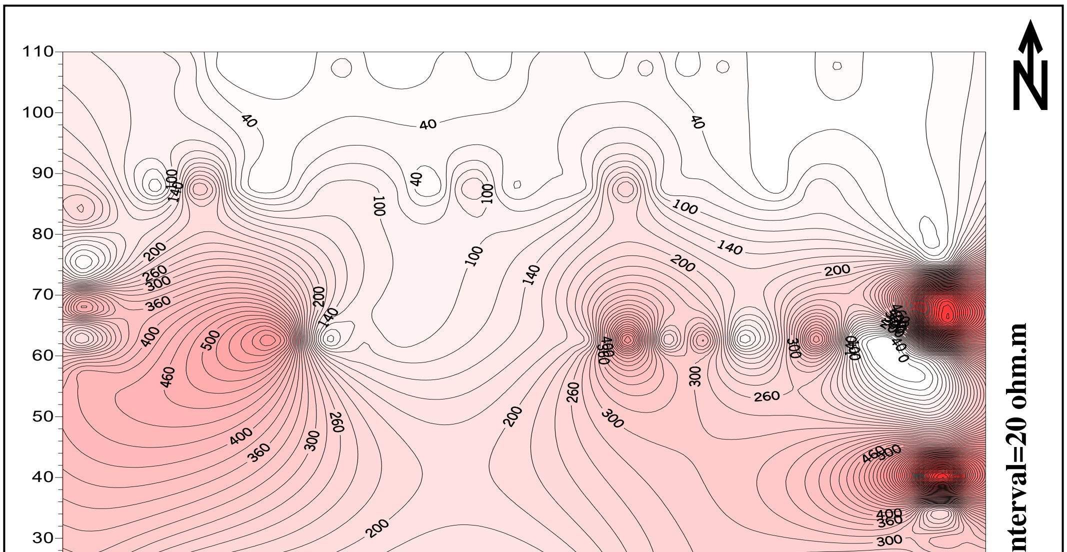
(Fig.13) Distribution of apparent resistivity of Wenner arrangement spacing (a=2m)



(Fig.14) Distribution of apparent resistivity of Wenner arrangement spacing (a=4m)



(Fig.15) Distribution of apparent resistivity of Wenner arrangement spacing (a=6m)



(Fig.16) Distribution of apparent resistivity of Wenner arrangement spacing (a=8m)

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be drawn from the present study, there are:

1. Continuous leaking of the water from the cooling units leads to dissolution of the soil cementing and hence forming caves and channels through the soil.
2. Washing out of fine grains (clays) from the soil structure leads to degrading of soil characteristics, especially it's bearing capacity.
3. Depending upon the electrical survey results, the caves and loose zones exit between (2-8) m depth at the southern and eastern parts of the studied area nearby the Asphaltene unit, while these zones were presented and distributed heterogeneously at the remaining parts according to the distance away from the leaking areas.
4. According to soil characteristics and caving volumes, cement grouting can be used to treat the caves and loose zones and to cease the settlement problem in it's present situation.

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