# INDUCED POLARIZATION METHOD ON LIGNITE PROSPECTION OF MUĞLA-TINAS

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ABSTRACT. — This paper presents the results of experimental time-domain induced polarization (I.P.) soundings carried out on drilling sights in the Muğla-Tınas lignite field. The applicability of I.P. method was investigated by using Schlumberger vertical electrical sounding technique on Neogen sediments in a narrow graben region to obtain thickness and depths of the formations which have different electrical properties. In order to interpret the I.P. soundings quantitatively the chargeability values were obtained using fictitious resistivity curves and the resistivity field curves together. The quantitative interpretation of the soundings generally corresponded very well with data from holes which were drilled prior or after I.P. soundings in the area under investigation and it has been concluded that seperation of the lignite series from surrounding formations was possible by their small chargeability values and that the use of this method for lignite investigation could be useful.

## INTRODUCTION

The following information can be obtained using resistivity method in lignite exploration:

1. The basement topography of the area;
2. The depths and thicknesses of the formations in the area with different electrical characteristics;
3. The required depths of bore holes for the field exploration with drilling.

But generally these results can not be sufficient for the explorationist since they can not show directly the depths and thicknesses of lignite deposits. For this reason and to improve the quality of the results obtained from the geoelectrical investigations, the Induced Polarisation Method was planned to investigate its applicability for lignite exploration.

The previous, exploration survey carried out using a new parameter suggested by Patella (1973) in Muğla Eskihisar lignite field (Turgay, 1976) proved that the applicability of I.P. Method was very encouraging for these kind of explorations.

On the basis of the reasons mentioned above the application of I.P. Method in Muğla-Tınas lignite field and the quantitative interpretation of results will be discussed particularly by means of Patella's works (Patella and Mongelli, 1971; Patella, 1*972a,b,* 1973) in detail in the following section.

## GEOLOGY

The exploration area is located on the outskirts of Tinas and Bağyaka villages in a coridor shaped valley with steep margins which forms a graben. Tinas and Bağyaka villages are 16 and 21 kms. far from the city of Muğla respectively.

The geology of the area taken from Gökmen (Gökmen, 1978) is shown in Fig. 1.

Tınas-Bağyaka Neogene sediments had been precipitated in a Tertiary aged Lake which formed in a Pre-Neogene basin.

Paleozoic and Mesozoic aged marbles, calcereous limestones, mica schist and phyllites overlain by Neogene formations form the basement rocks and they extend in the steep margins of graben and outcrop in some parts of Neogene cover. Neogene formations from bottom to top layers in Tınas-Bağyaka lignite field are:

1. The clastic sediments seen at the bottom change gradually into coarse grained and fine grained sand, silt and marl series. The contact between these layers and overlying marl-limestone has coal layers;

2. The marl-limestone series overlying coal layers show gradual change into limestone layers with increasing carbonate ratio;

3. Tuffite, marl and conglomerate formations;

4. Taluses;

5. Alluvium.

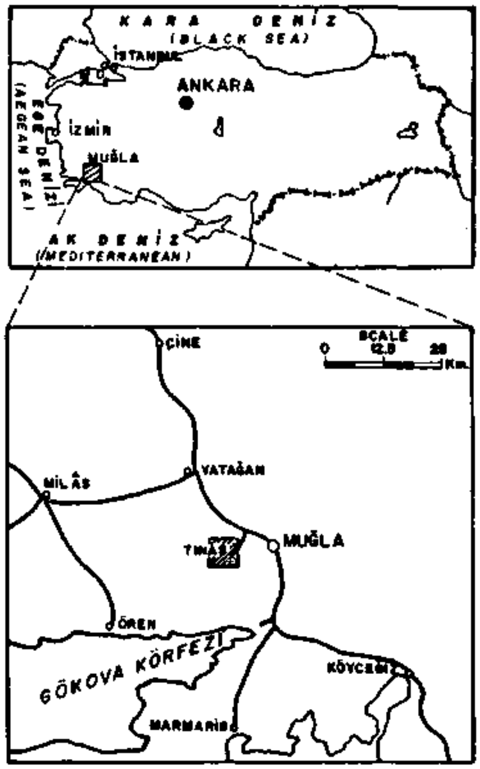


Fig. 1 - Location map.

The central part of Tinas are deeper than its edges. The outcropped coal seams on the east and west dip to the north and northeast part of the area with rather high angle.

The besement rocks reach to the surface in some parts of the graben field extending to NW. The thickness of Neogene cover are not uniform in the area.

## FIELD PROCEDURES

The Seintrex IPC-7, 2.5 KW Induced Polarization unit was used in the field in order to measure the Induced Polarization effects in the time-domain by using Schlumberger vertical electrical sounding technique. The electric current from the unit is sent to the ground by means of two current electrodes (A, B) and the I.P. secondary voltage produced between the two potential electrodes (M,N) was measured.

The measurement of I.P. with Scintrex IPC-7 unit is given by the time integral of the transient I.P. voltage A Up(t) which begins in 0.5 sec. time procedure from the discontinuation time of the primary current which flows 1.5 sec. in the ground.

The desired parameters given below can be obtained from the DU measurements of the current sent to the ground and the primary voltage applied:

a) The dimensionless «apparent chargeability, m(a)» (Patella, 1972 *a,b*):

$$m_{(a)} = \frac{\frac{1}{t_2-t_1}\int_{t_1}^{t_2} \Delta U_p(t)\,dt}{\Delta U} \tag{1}$$

Generally $m_{(a)}$ is demonstrated as mV/V or directly in parts per thousand.

b) The «Apparent resistivity $\rho_{(a)}$»:

$$\rho_{(a)} = K\left(\frac{\Delta U}{I}\right) \tag{2}$$

where, I is total current given by the source K is the geometrical factor used in the measurement with respect to the electrode arrangement. The geometrical factor K for the vertical Schlumberger electrical sounding technique is given as

$$K = \pi r^2 \tag{3}$$

and apparent resistivity is obtained as

$$\rho_{(a)} = \pi r^2 \frac{E_{ss}}{I} \tag{4}$$

where $E_{ss}$ is steady state electric field.

c) The apparent fictitious resistivity ρ′ (a) «(Apparent fictitious resistivity-Patella, 1973)»:

$$\rho'_{(a)} = K \frac{\frac{1}{t_2-t_1}\int_{t_1}^{t_2} \Delta U_p(t)\,dt}{I} \tag{5}$$

or for the Schlumberger electrode arrangement used in our measurement is given as:

$$\rho'_{(a)} = \pi r^2 \frac{\frac{1}{t_2-t_1}\int_{t_1}^{t_2} \Delta U_p(t)\,dt}{I} \tag{6}$$

where the unit of $\rho'_{(a)}$ is $\Omega\text{-m}.10^{-3}$

## INTERPRETATION

Induced Polarization (I.P.) is a very complex event on account of the occurrence of the different electro-chemical procedures at the same time. For this reason with D.Patella's utterance, «I.P. has to be thought very wide in I.P. studies, that is, all of the electro-chemical procedures which cause I.P. have to be accepted only one mechanism, that causes the secondary effects.»

In order to make the quantitative interpretation of I.P. field work, some limitations and assumptions whose accuracies proved by some experiments are needed, (Patella, 1972 *a, b,* 1973). I.P. surveys carried out in the sedimentary rocks showed that I.P. voltage has been increasing linearly with the increment of the current density which causes the polarization (Wait, 1959).

As it is known, the mathematical expression of the apparent chargeability M (a) in a horizontally layered earth was given by Patella (1972 *a,b)* as:

$$m_{(a)} = m_1 \frac{1+2(AB/2)^2\int_0^{\infty} K'(\lambda)J_1(\lambda AB/2)\lambda d\lambda}{1+2(AB/2)^2\int_0^{\infty} K(\lambda)J_1(\lambda AB/2)\lambda d\lambda} \tag{7}$$

where AB/2 is the half distance between the current electrodes for Schlumberger electrode array, K(l) is Kernel function in the resistivity D-C sounding theory, and K'(l) is a new Kernel function depending upon also the chargeability of each layer.

Such an expression of the apparent chargeability is justified the use of the standard graphics which do not exist in published form, although a method of easy construction of m (a) master curves have been developed by Patella (1972 *b).* Therefore the comparison of the curve obtained from the measurements with the theoretical curves which will be created by choosing suitable variable groups is very tiresome job (Patella, 1973).

Patella (1973) proposed a new expression in order to overcome such a disadvantage. The theoretical foundations of this expression are the same basic hypotheses as the first expression. But the second expression has considerable advantage since the resistivity master curves can be adopted to fit apparent fictitious resistivity curves entirely.

The apparent fictitious resistivity curve p' (a) mentioned above was determined as the production of the apparent chargeability and apparent resistivity by Patella (1973):

$$\rho'_{(a)}=m_{(a)}\rho_{(a)} \tag{8}$$

since the general expression of $\rho_{(a)}$ is given as:

$$\rho_{(a)}=\rho_1\left\{1+2(AB/2)^2\int_0^{\infty}K(\lambda)J_1(\lambda AB/2)\lambda d\lambda\right. \tag{9}$$

and from expressions (7) and (9):

$$\rho'_{(a)}=\rho'_1\left\{1+2(AB/2)^2\int_0^{\infty}K'(\lambda)J_1(\lambda AB/2)\lambda d\lambda\right. \tag{10}$$

is obtained. In this expression $r' = m_1 r_1$ is the fictitious resistivity of the first layer.

As it is seen, the mathematical expression of both $r_{(a)}$ and $r'_{(a)}$ is identical, for this reason it is justifiable to use the usual resistivity standard graphs curve matching method in the interpretation.

The interpreted fictitious resistivity value of each layer found from this curve matching metdod plays the role of true resistivity.

If an I.P. sounding is interpreted with respect to r', only fictitious resistivity of each layer and the depths of the discontinuities are obtained. But the chargeability is more useful physical variable for the investigation of the underground structures.

Therefore, the fictitious resistivity curves and the associated resistivity field curves have to be interpreted together to obtain the chargeability values of each layer. Because the chargeabilities are computed as the ratio of the interpreted true resistivity and fictitious resistivity values (i.e. $m = r'/r$) (Patella, 1973).

We will now discuss the combination of both method of soundings (I.P. and resistivity) carried out in Muğla-Tınas lignite exploration field. The location of electrical soundings were chosen on the drilling sites which were drilled prior or after soundings in the area under exploration.

The figure's given in the following pages are resistivity and fictitious resistivity field curves obtained from I.P. soundings carried out on the drilling sites, such as T-17, T-18, T-20, T-24, T-31 and each of them can characterise a curve group (Fig. 2,3,4,5,6). The interpreted results of both curves obtained assuming horizantally layered earth were given under the figures with the results of associated boreholes.

In each figure the resistivity data are represented by small circles and the fictitious resistivity data are represented by small squares. The theoretical fits are represented by dashed lines.

The quantitative interpretations of the field curves were done by curve matching method, using the master curve album of Orellana and Mooney (1966) and auxiliary point charts. If the increments of the end parts of the field curves as seen in T-20 and T-24 vertical electrical soundings were greater than 45°, then the curves obtained using Gosh (1970) transform coefficients were interpreted using Koefed (1970) two layers and auxiliary point curve groups.

Then the theoretical model curves were obtained as a fonction of the interpreted datas by using Canıtez's program (1974).

After the information given about the interpretation, let us examine our field graphs.

## a. T-17 Electrical I.P. sounding

The following datas were obtained by interpreting the resistivity field curve in Fig. 2 for 7 layer case;

$\rho_1$=140 Ω m; $\rho_2$=115 Ω m; $\rho_3$=200 Ω m; $\rho_4$=75 Ω m; $\rho_5$=250 Ω m;

$\rho_6$=45 Ω m; $\rho_7$=250 Ω m;

$h_1$=14 m; $h_2$=23 m; $h_3$=29 m; $h_4$=55 m; $h_5$=75 m; $h_6$=170 m.

The following datas were also obtained from the interpretation of the fictitious resistivity field curve for 7 layer case;

$\rho'_1$=700mΩm; $\rho'_2$=450 mΩm; $\rho'_3$=850 mΩ m; $\rho'_4$=290 mΩ m; $\rho'_5$=70 mΩ m;

$\rho'_6$=270 mΩ m; $\rho'_7$=700 mΩ m;

$h'_1$=8 m; $h'_2$=14 m; $h'_3$=29 m; $h'_4$=65 m; $h'_5$=80 m; $h'_6$=150 m.

The stratigraphic series obtained from the drilling at this point are;

0-12 m, limestone with tuffite bands,

12-55 m, marl with limestone bands,

55-74 m, lignite series interbedded with marl and silt bands,

74-80 m, silt with clay.

As it is seen from the interpretation of the resistivity curves, the depths of marl, lignite series and calcereous silt layers were found with a good approximation. Besides this, marl layers with or without limestone bands can be differentiated.

The depths of marl and silty clay beds were also found with a good approximation by the interpretation of the fictitious curve. In addition to this, another layer which is not seen in borehole results was also obtained within tuffite banded limestone and marl layers. Finally the calcereous, silty lignited level at the bottom of lignite series were obtained.

The chargeability values of the existing layers obtained by the interpretation of these two curves are;

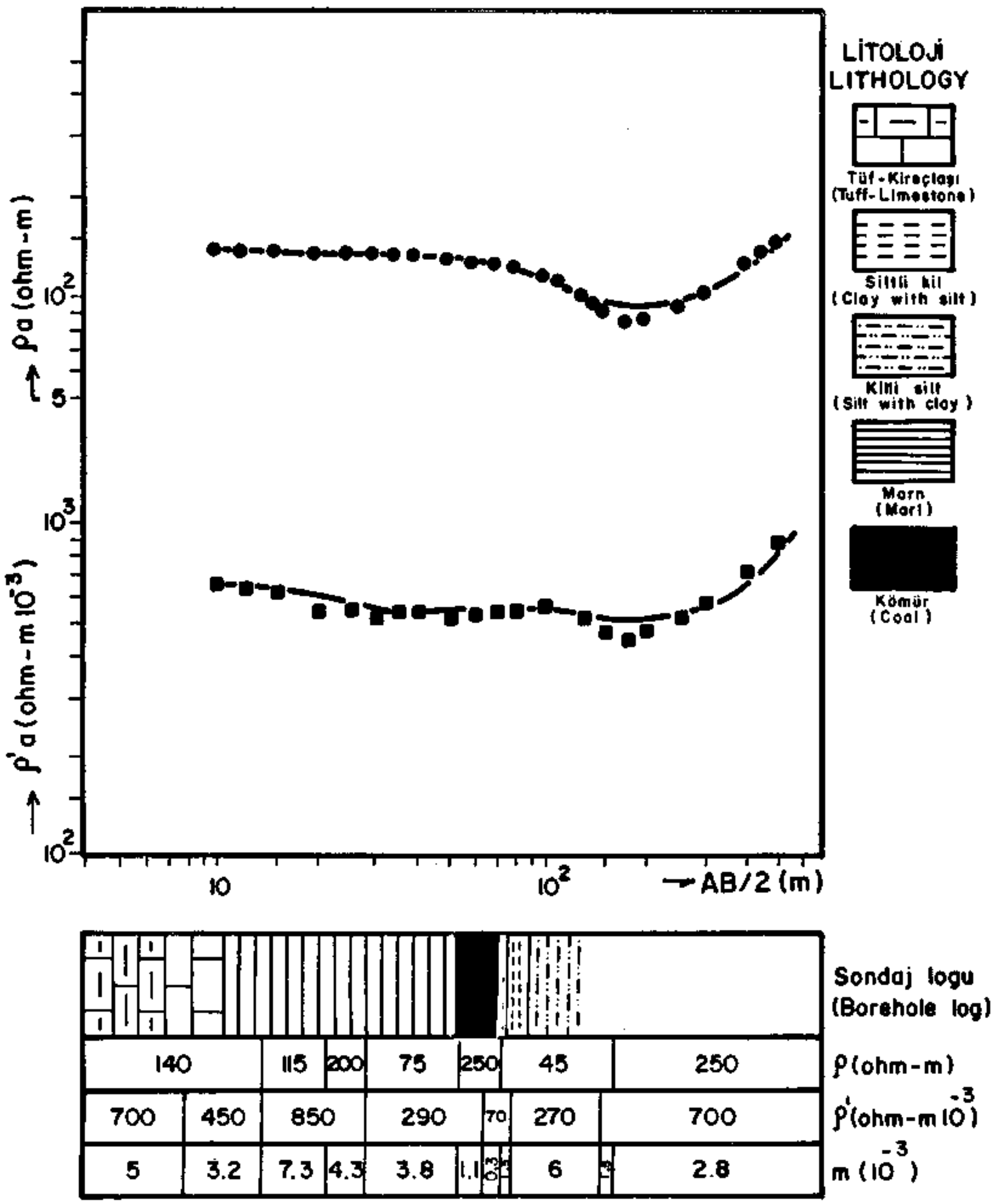


Fig. 2 - Interpretation of T-17 sounding.

$m_1 = 5.10^{-3}$ for $0 < Z < 8$ m (tuffite banded limestone)

$m_2 = 3.2.10^{-3}$ for $8 < Z < 14$ m (tuffite banded limestone)

$m_3 = 7.3.10^{-3}$ for $14 < Z < 23$ m (limestone banded marl)

$m_4 = 4.3.10^{-3}$ for $23 < Z < 29$ m (marl)

$m_5 = 3.8.10^{-3}$ for $29 < Z < 55$ m (limestone banded marl)

$m_6 = 1.1.10^{-3}$ for $55 < Z < 65$ m (lignited series with interbedded marl and silt)

$m_7 = 0.3.10^{-3}$ for $65 < Z < 75$ m (clay, lignited silt, lignite)

$m_8 = 1.5.10^{-3}$ for $75 < Z < 80$ m (silt with clay)

$m_9 = 6.10^{-3}$ for $80 < Z < 155$ m (clay with silt)

$m_{10} = 15.10^{-3}$ for $155 < Z < 170$ m (clay with silt)

$m_{11} = 2.8.10^{-3}$ for $170 \text{ m} < Z$ (limestone)

With the chargeability values obtained from these interpretations, the depths found for marl, lignite series, silt with clay, clay with silt were in good agreement with the results of borehole. Besides, the levels with or without limestone beds in marls are clearly identified. Moreover, lignited beds with clay and silt overlain by lignited series which could not be identified with the interpretation of single curve are now differentiated from the surrounding formations.

**-b. T-18 Electrical I.P. Sounding**

The depths and resistivity values obtained from the interpretation of the field curves (Fig. 3) for three layer case are;

$\rho_1 = 18\ \Omega$ m; $\rho_2 = 45\ \Omega$ m; $\rho_3 = 2000\ \Omega$ m;

$h_1 = 10$ m; $h_2 = 160$ m.

the fictitious resistivity values and the layer thicknesses are;

$\rho'_1 = 60$ m $\Omega$ m; $\rho'_2 = 1000$ m $\Omega$ m;

$h'_1 = 91$ m.

The stratigraphic sequences obtained from the borehole drilled at the same point are;
0-16 m taluses, 16-94.5 marl banded limestone, 94.5-121 m marl, 121-135 m lignited series, 135-159 m alternating clay and silt layers, 159-163 m sandy, clayey level with diasporite conglomerates.

As seen from the interpretation of resistivity curve, the thickness of taluses and the depth of sandy, clayey bottom level with diasporite conglomerates are obtained with a good approximation.

Though it could not be obtained any information for lignited series. The interpretation of the fictitious resistivity curve had only given the depth of the marl level.

The chargeability values of interpreted layers from resistivity and fictitious resistivity curves are;

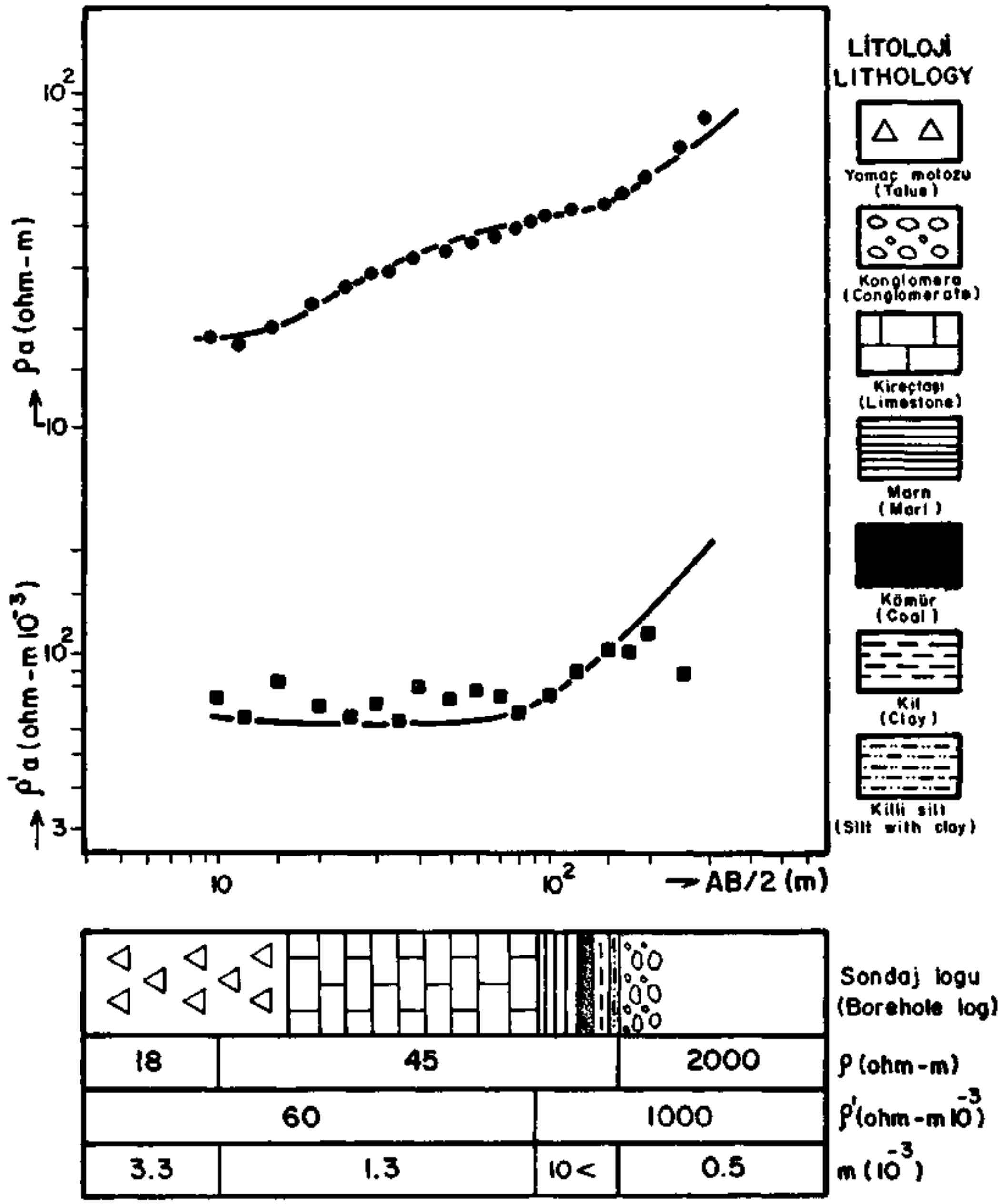


Fig. 3 - Interpretation of T-18 sounding.

$m_1 = 3.3.10^{-3}$ for $0 < Z < 10$ m (taluses)

$m_2 = 1.3.10^{-3}$ for $10 < Z < 91$ m (limestone)

$m_3 =$ large $10^{-3}$ for $91 < Z < 160$ m (marl, lignited series and alternation of clayey silt)

$m_4 = 0.5.10^{-3}$ for $160$ m $< Z$ (sandy, clayey level with diasporite conglomerates)

Thus, the thicknesses of taluses and limestone beds and the depth and thickness of lignited series as single layer with overlying marl level which could not be observed from the interpretation of a single field curve were obtained with a good approximation using the chargeability values computed from the interpretation of both field curves. Besides, interpreted values agrees with drilling results.

### c. T-20 Electrical I.P. Sounding

The depths and resistivity values obtained from the interpretation of the field curves (Fig. 4) for four layer case are;

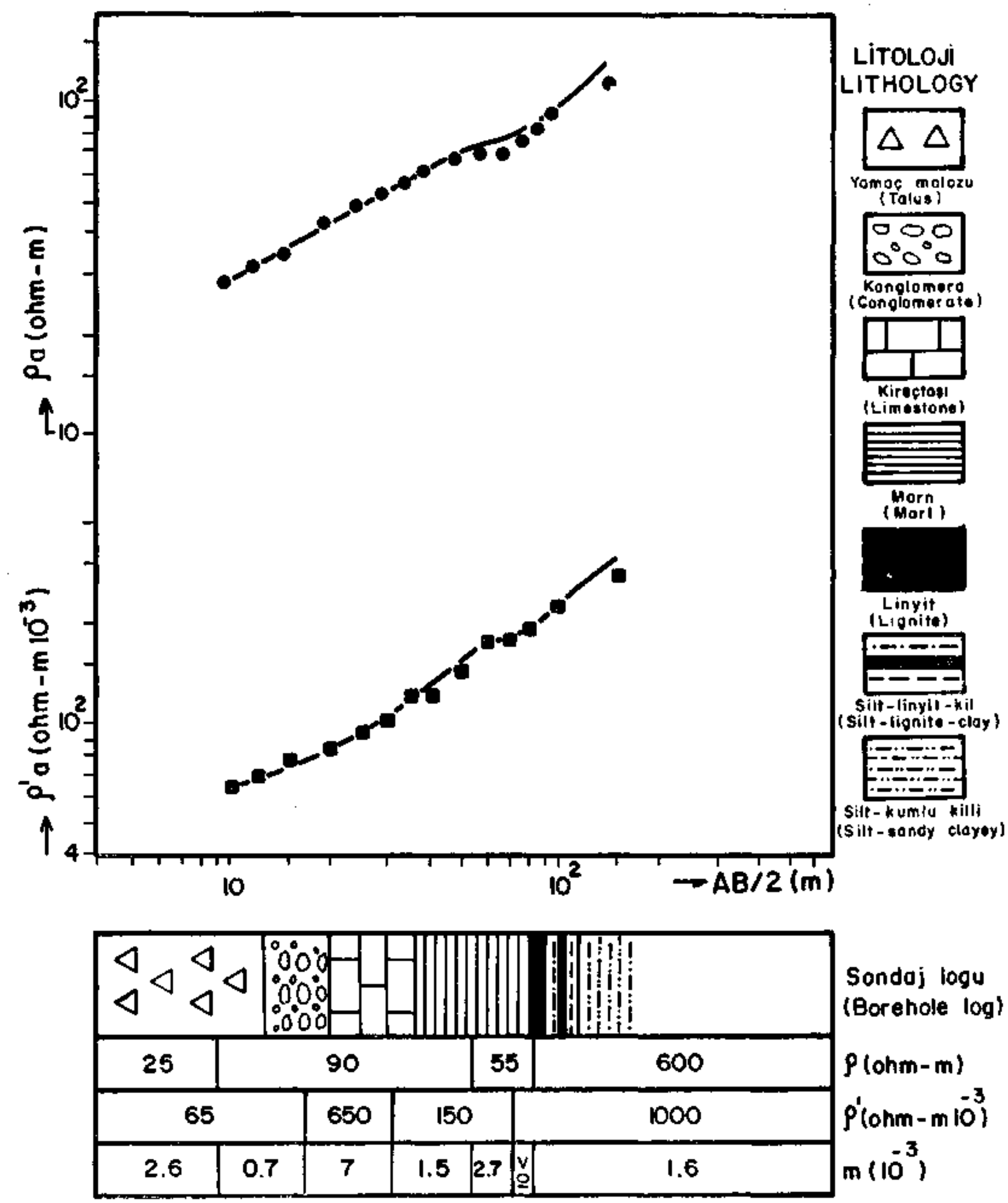


Fig. 4 - Interpretation of T-20 sounding.

$\rho_1=25\ \Omega\ m$; $\rho_2=90\ \Omega\ m$; $\rho_3=55\ \Omega\ m$; $\rho_4=600\ \Omega\ m$;

$h_1=9\ m$ ; $h_2=55\ m$ ; $h_3=85\ m$.

The fictitious resistivity values and the layer thicknesses are;

$\rho'_1=65\ m\ \Omega\ m$; $\rho'_2=650\ m\ \Omega\ m$; $\rho'_3=150\ m\ \Omega\ m$, $\rho'_4=1000\ m\ \Omega\ m$;

$h'_1=17\ m$ ; $h'_2=32\ m$ ; $h'_3=72\ m$.

The stratigraphic sequences obtained from the borehole drilled later at this point are;

0-13 m, taluses, 13-20 m conglomerate,

20-37 m well bedded limestone, 37-84 m marl,

84-97 m lignited series, 97-128 m silty, sandy clay with lignite bands.

As seen from these results, the depths of taluses and lignited series obtained from the in terpretation of resistivity field curve are in good agreement with the borehole results.

The depths of well bedded limestone, marl and lignited series are evaluated with a finite approximation.

The chargeability values of interpreted layers obtained from the interpretation of both fielde curves are;

$m_1=2.6.10^{-3}$ for $0 < Z < 9$ m (taluses)

$m_2=0.7.10^{-3}$ for $9 < Z < 17$ m (conglomerate)

$m_3=7.10^{-3}$ for $17 < Z < 32$ m (well bedded limestone)

$m_4=1.5.10^{-3}$ for $32 < Z < 55$ m (marl)

$m_5=2.7.10^{-3}$ for $55 < Z < 85$ m (marl)

$m_6=1.6.10^{-3}$ for $85m < Z$ (lignited series with sandy, clayey silt).

As seen from these results, conglomerate bed and some levels in marl formation which are not met in borehole indications and in our early interpretation were pointed out.

Thus the depths of lignited series and the thicknesses of overlying formations were found within a good approximation.

### d. T-24 Electrical IP. Sounding

The results obtained from the interpretation of resistivity field curve in Fig. 5 for 7 layer case are;

$\rho_1=27\ \Omega\ m$; $\rho_2=130\ \Omega\ m$; $\rho_3=30\ \Omega\ m$; $\rho_4=75\ \Omega\ m$; $\rho_5=260\ \Omega\ m$; $\rho_6=36\ \Omega\ m$; $\rho_7=1000\ \Omega\ m$;

$h_1=9\ m$; $h_2=14\ m$; $h_3=34\ m$; $h_4=108\ m$; $h_5=125\ m$; $h_6=280\ m$.

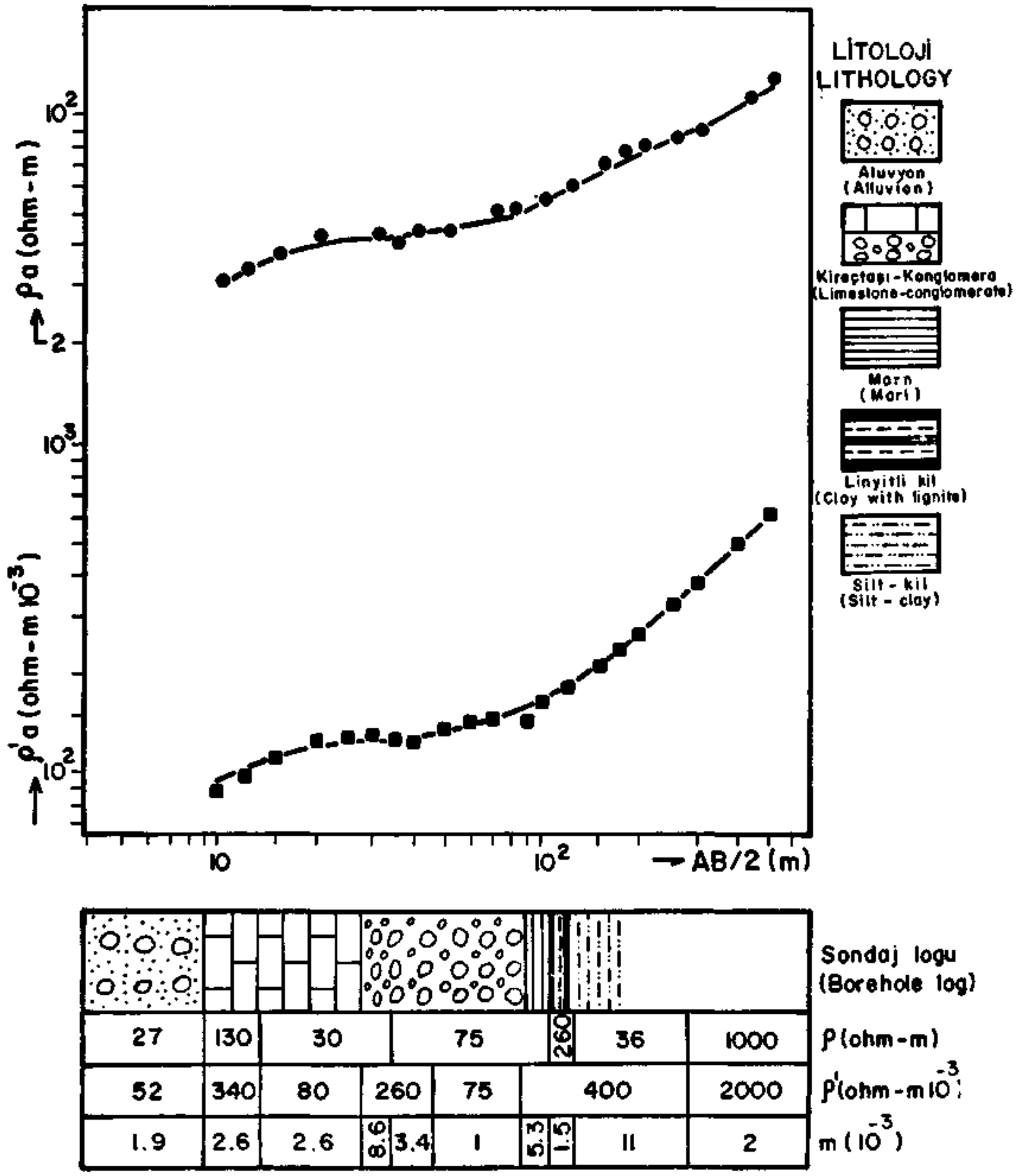


Fig. 5 - Interpretation of T-24 sounding.

The data obtained from the interpretation of fictitious resistivity field curve for seven layer case are;

$\rho'_1=52$ m Ω m; $\rho'_2=340$ m Ω m; $\rho'_3=80$ m Ω m; $\rho'_4=260$ m Ω m; $\rho'_5=75$ m Ω m; $\rho'_6=400$ m Ω m; $\rho'_7=2000$ m Ω m;

$h'_1=9$ m; $h'_2=14$ m; $h'_3=28$ m; $h'_4=46$ m; $h'_5=89$ m; $h'_6=280$ m.

The stratigraphic sequences from the drilling results at this point are;

0-9 m alluvium, 9-91 m limestone and conglomerate, 91-108 m marl, 108-122 m lignited series, 122-161 m clayey, sandy silt (drilling stopped at this depth).

As it is seen from the interpretation of the resistivity curve the thicknesses of alluvium layer and lignited series were found with a good approximation. Limestone conglomerate between 9-91 m in drilling results were differentiated into two levels, with our interpretation. Marl level overlying the lignited series could not also be separated from the conglomerate and basement rock was pointed out under the level where the drilling stopped.

The thickness of alluvium layer and the depth of marl layer and basement rock could also be interpreted with a good approximation from the fictitious resistivity field curve. But lignited series could not be differentiated from sterile zones.

The chargeability values of the interpreted layers computed from the evaluation of both field curves are;

$m_1 = 1.9.10^{-3}$ for $0 < Z < 9$ m (alluvium)

$m_2 = 2.6.10^{-3}$ for $9 < Z < 14$ m (conglomerate)

$m_3 = 2.6.10^{-3}$ for $14 < Z < 28$ m (conglomerate)

$m_4 = 8.6.10^{-3}$ for $28 < Z < 34$ m (conglomerate)

$m_5 = 3.4.10^{-3}$ for $34 < Z < 46$ m (conglomerate)

$m_6 = 1.10^{-3}$ for $46 < Z < 89$ m (conglomerate)

$m_7 = 5.3.10^{-3}$ for $89 < Z < 108$ m (marl)

$m_8 = 1.5.10^{-3}$ for $108 < Z < 122$ m (lignited series)

$m_9 = 11.10^{-3}$ for $122 < Z < 280$ m (clayey, sandy silt)

$m_{10} = 2.10^{-3}$ for $280 \text{ m} < Z$ (limestone)

Alluvium, marl and lignited layers were differentiated from other layers and their depths were computed with a very good approximation using chargeability datas obtained above. Moreover the depth of basement limestone was obtained and four different layers not seen in the borehole results taken in the conglomerate were depicted.

### e. T-31 Electrical I.P. Sounding

Each of the resistivity and the fictitious resistivity curves obtained from the field measurements were interpreted for 6 layer case and the following resistivity values and depths were computed;

$\rho_1=120\ \Omega$ m; $\rho_2=235\ \Omega$ m; $\rho_3=70\ \Omega$ m; $\rho_4=190\ \Omega$ m; $\rho_5=36\ \Omega$ m; $\rho_6=460\ \Omega$ m; $h_1=9$ m; $h_2=20$ m; $h_3=61$ m; $h_4=105$ m $h_5=180$ m and

$\rho'_1=165$ m $\Omega$ m; $\rho'_2=1650$ m $\Omega$ m; $\rho'_3=100$ m $\Omega$ m; $\rho'_4=580$ m $\Omega$ m; $\rho'_5=50$ m$\Omega$m; $\rho'_6=800$ m$\Omega$m; $h'_1=9$ m; $h'_2=20$ m; $h'_3=48$ m; $h'_4=90$ m; $h'_5=200$ m.

The following stratigraphical sequences were found by drilling done later at this point: 0-20 m taluses, 20-108 m conglomerate, 108-137 m well bedded limestone, 137-147 m marl, 147-156 m, conglomerate 156-164 m lignited series and calcereous sandy silt below 187 m.

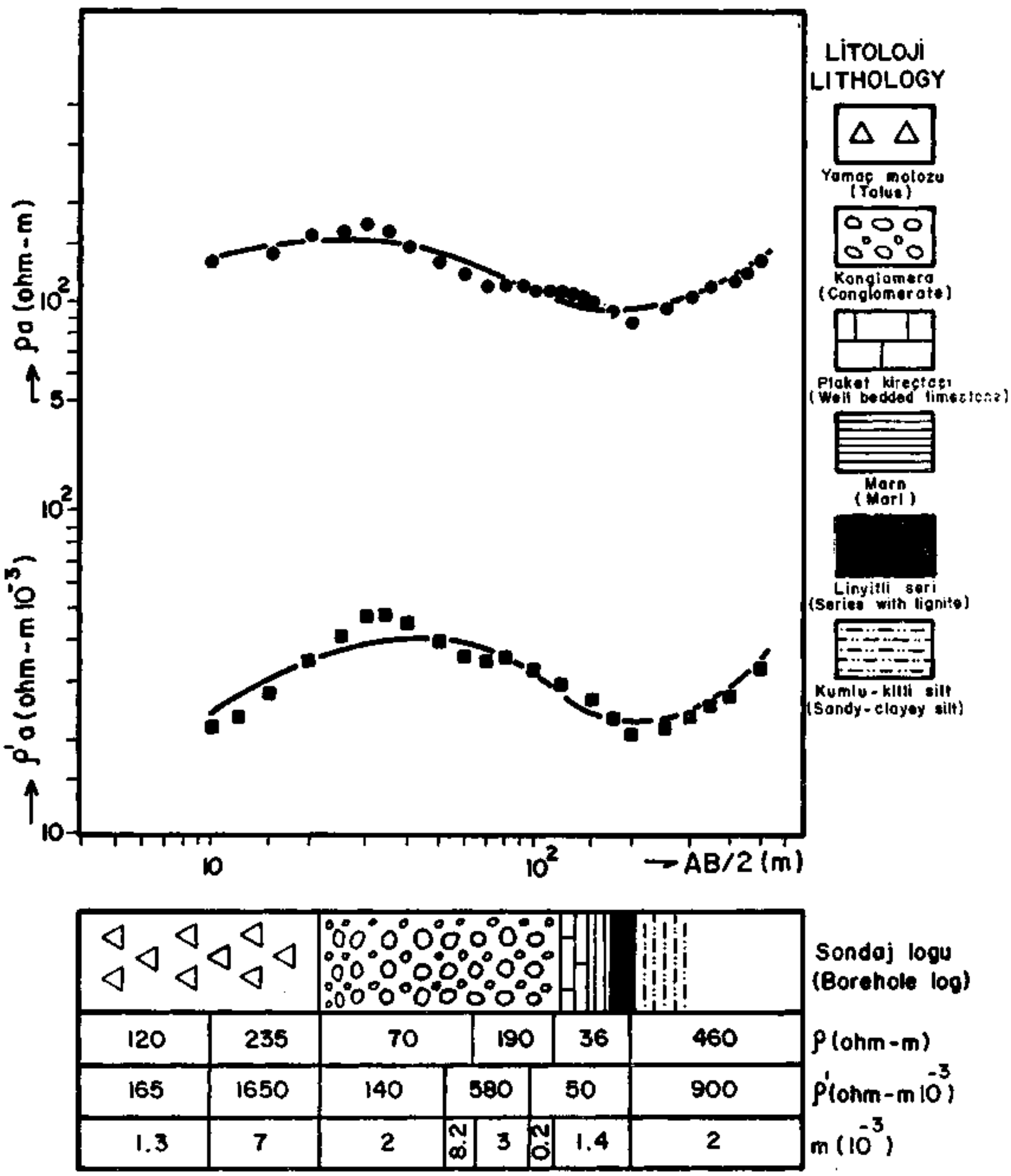


Fig. 6 - Interpretation of T-31 Sounding.

The datas obtained from the interpretation of resistivity curve and from the borehole results were in good agreement for the depths of conglomerate, well bedded limestone and calcereous sandy silt layers. But it could not be obtained any information for the lignited series.

The values above, were also computed with slight differences from the evaluation of fictitious resistivity curve but it could not be obtained any information for the lignited series.

The following datas were computed from the interpreted results of both curves mentioned above;

$m_1 = 1.3.10^{-3}$ for $0 < Z < 9$ m (taluses)

$m_2 = 7.10^{-3}$ for $9 < Z < 20$ m (taluses)

$m_3 = 2.10^{-3}$ for $20 < Z < 48$ m (conglomerate)

$m_4 = 8.2.10^{-3}$ for $48 < Z < 60$ m (conglomerate)

$m_5 = 3.10^{-3}$ for $60 < Z < 90$ m (conglomerate)

$m_6 = 0.2.10^{-3}$ for $90 < Z < 105$ m (conglomerate)

$m_7 = 1.4.10^{-3}$ for $105 < Z < 180$ m (well bedded limestone marl and lignited series)

$m_8 = 2.10^{-3}$ for $180$ m $< Z$ (sandy, clayey silt)

As seen above, four more discontinuities within conglomerates could be differentiated. But it could not be found any information to indicate the existence of the lignited series. Therefore it was thought that the lignited series were outside the range of electrical effective probing depth.

## CONCLUSIONS

The lignite series in Muğla-Tınas lignite field could not be differentiated from the surrounding formations by using resistivity method, because the resistivity ranges of these formations were found to be very large.

However, the quantitative interpretation of I.P. soundings from our field work corresponded very well with the data of the depth and the extension of lignited series obtained from the boreholes in the area under investigation. Based upon the datas in the previous chapter, it was concluded that I.P. survey is powerful method for lignite explorations.

With the quantitative interpretation of I.P. sounding in the survey field, lignited series could be differentiated from surrounding formations by their relatively small chargeability values. The results obtained from I.P. soundings and drilling indications were approximately the same when lignited series were located in a vicinity of around 100 m depth from the surface.

In addition, if the details of the borehole results were considered, it was seen that the different range of chargeability values observed within lignite series, matched with marl, clay, and silt levels which get thicker in some localities.

**ACKNOWLEDGEMENTS**

I am grateful to Mr. Savcı Sülün for his assistance in every step of this study. I also would like to express my appreciation to Mr. Asım Özmen, Mr. Altan İçerler, Mr. Muammer Atiker and Mr. Resul Özgür for their contribution in the field work.

In addition, 1 wish to thank Miss Sultan Tunç for technical drawings and to Miss Sultan Sevinç for typing.

*Manuscript received September 17, 1982*

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