UNDERGROUND WATER İNVESTİGATİONS BY MEANS OF GEOPHYSİCAL METHODS (PARTİCULARLY ELECTRİCAL) IN THE CENTRAL ANATOLİA

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SUMMARY

The main purpose of these investigations was to find out about the applicability of the resistivity, electromagnetic and magnetic methods in locating water horizons and sccumulations in the Central Anatolia.

The area under investigation rims between Polatlı and Konya. Its eastern boundary is formed by the weşt coast of Tuzgölü. lt has an average rainfall of 200 mms. per year and is one of the most fertile regions of Turkey.

The geology of this region can be summarised as follows:

The surface is covered by a layer of soil and alluvium of about 10 m. thickness. This is underlain by horizontal Tertiary (Neogene) freshwater lake deposits of clay, limestone and marl. Occasionally small outcrops oflimestone containing nummulites are observed. The base is formed of schists, marbles and gneisses etc. of probably Paleozoic era and of diorite. The visible depth of the Neogene formation could be observed in the Sakarya Basin and, measures to be about 250 m. But it is impossible to solve the problem of depth in the other parts of the region by geological observatıons alone.

The usefulness of the electrical and magnetic methods in helpirıg solve this problem öf depth and in elucidatmg the water horizons and drinking water accumulations are discussed.

INTRODUCTİON

The region under investigation is a plateau, 900-1100 m. high, roughly bound by the polygon Cihanbeyli, (İnevi) - Kadınhanı-Ilgın-Polatlı - Cihanbeyli, its surface area being about 6000 $km.^2$ This is shown on the Geological map of Turkey (Fig. 1).

As regards rain - oatchmet and distribution, this plateau is self - contained with no apparent inlet or outlet. lt is encircled by mountains of 1200-2000 m. of height.

This plateau is traversed by gently dipping dry stream beds, most of which' run ,towards its deepest part which is occoupied by the river Sakarya with a datum of 750 m. height above the sea level. Some of the other streams, such as Insuyu- and its branches run into the lake Tuzgölü.

Geology:

There is no detailed geological map of the region, but generally speaking, the whole are is coverd by an almost horizontal Tertiary (Neogene) formation. At the outskirts' and at some places in the middle part older formations have been observed. The first formation consists of alternate beds of fresh-water limestons, marl and clay, Near the older rocks, conglomerates can also be observed. The average thickness of the Neogene formation is in the neighbourhood of 200 meters with a gradual decrease in thickness from North to South. The older rocks consist of diorites, gneisses, serpantines, marbles, limestones half metamorphosed to marble, schists, grawackes and limestones with Nummulites. (The geological information written here is drawn from the explanations given by Dr. M. Topkaya during an excursion in the Central Anatolia and also from the later Observations of the author).

Rain-fail:

This region between Polatlı and Konya is one of the mosf arid regions of Turkey, though its soil is quite fertile. Its annual rainfall is no more than 250 mm.

There can be seen no continuous water horizons in this region; most of the water occurences seem to be associated with the soil and the limestone beneath it. Most of these occurrences, however, have limited lives, running in rainy seasons, and drying up in dry seasons such as in Summer.

Purpose of the investigations:

This work was conducted with the primary purpose of finding out the applicability of the electrical and magnetic methods to underground water investigations in the region between Polatlı and Konya. This amounted to:

1) makig a study of the true water and rock resistivities in different parts of the region and correlating the resistivity Surveys with known data and facts,

2 — investigating whether each layer or formation had a resistivity characteristic throughout the region,

3 — finding out whether the old formations had a magnetic susceptibility differing from that of the newer formations,

4 — finding out the electrical methods most suitable for the purpose.

It was also desirable to conduct the Surveys in such a manner as to solve the following problems near some of the state farms which were short of drinking and irrigation waters:

1 — to investigate the possible water horizons,

2 — to find the shape of the top of the older formation along some lines,

3 — to investigate the possible water accumulations between the newer and older formations.

İNVESTİGATİONS NEAR THE STATE FARM ALTINOVA

The first investigations were conducted near Altınova, where an outcrop of the old formations consisting of marbles, conglomerates and diorites dipping NE-SW can be observed. Here 2 traverses roughly in the directions of NNW-SSE and E-W, were run. One end of the first traverse was extended to the outcrop of the old formations. See the Geological Map of Turkey in Fig. 1. Using the method of Wenner-Gish-Roony,resistivity measurements were taken at each Station. The distance between 2 consecutive stations was kept at about 1200 m. and at each Station the electrode separation was varied betvveen 20 and 800 m.

Apparatus:

The apparatus used for this survey was of the standard Gish-Ronney type.

The potentiometer with an optical galvanometer, had two ranges, 0-1100 and 0-110 m.v., with the first range, voltages down to 1 m.v., and with the second, voltages down to 1/10 m.v. could be measured with fair accuracy.

A multi-range ammeter was incorporated in the potentiometer box. The potentiometer could be calibrated by an artificial earth system.

Method of Survey :

In order to reduce the self and mutual induction effects due to the cable leads and the ground with large eloctrode separation (larger than 250 m.), a method of correction was used. This correction was based on the fact that, for the case of the induction effect if R ohms is the resistance of the ground included in the measurement and L henries the self inductance of the ground included in the measurement, and M henries the mutual inductarce between the current and potential leads, the effective resistance R' is given by

$$R' = [R^2 + (L \pm M)^2 \omega^2]^{1/2}$$

where wis the angular velocity of the commutator.

To find the true resistance R, two measurements were made at two different and krown commutator speeds for the same electrode separation Since the effective resistance for each of the measurements were known, the true resistance could be calculated.

Some experiments were made as regards the accuracy with which *the* true resistance of the ground could be found by this method. At the same Station, and with the same electrode separation, measurements of R' were taken for the same commutator speeds and the corresponding Rs. were calculated. This procedure was repeated for Several electrode seperations at different stations. lt was concluded from these investigations that the true resistances could be calculated with an error of 1 - 3 % up to the electrode separation of 800 m. This accuracy was good enough for the work envisaged.

This method of resistivity survey is found to be about 3 times more time saving than that in which non-polarising electrodes and a compensator âre used. With the former, an expanding-eloctrode survey' up to the separation of 800 m. could take no more than 2.5 hours.

Method of Analysis of the Reslstivity Curves:

The resistivity curvesobtained from the field measurements were all similar in shape indicating three layers. A typical curve is show ı in Fig. 2. lt will be observed that the first and third layers have resistivities of the same order, the middle, on the other band, has a much higher resistivity.

In analysing the resistivity curves, much attention was paid to the determination of the true resistivities öf the layers and to seeing whether the anomalies were due to layers. This was due to the nature of the work, since true resistivities are of paramount importance in finding and correlating ground water horizons and in detecting water accumulations. To this end, use was made of the logarithmical two-layer curves. Log $\frac{\varrho_a}{\varrho_1}$ was plotted against Log a/h for different valuesof $K = \frac{\varrho_1 - \varrho_2}{\varrho_2 + \varrho_1}$ where d_1 and d_2 are the resistivities of the first and the second layers respectively, da the apparent resistivity due to the 2 layers, h the thickness of the first layer, a the electrode separation.

If the field curve plotted logarithmically coincides with one of these master curves, it can be said that the curve corresponds to a 2-layer case, the thickness of the first layer being the distance between the two Log $\frac{\rho_a}{\rho_1}$ axes and the resistivity of the first layer betwcen the two other axes. The factor K can also be read off, from which the resistivity of the second layer can be calculated.

For the purpose of analysis, the field curves were reduced to 2 parts:

1 — The first part contained the anomaly due to only the first and the second layers. This was achieved by eliminating the effect of the third layer.

2 — The bottom part contained the anomaly due tp only the third layer and another having a thickness equal to the sum of those of the first and second layers with an equivalent resistivity of both.

In reducing the 3 - layer problem to a two layer one, the principle used was that «the average resistivity of infinite layers of resistivity d_1 and d_2 with respective thicknesses of h_J and h_a is given by $\frac{h_1 + h_2}{\rho_{av.}} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2}$, if the electrode separation employed is more than 3 times the thickness of the first layer.» To find the effect of the 3rd layer on the first part of the curve the average resistivity of the first and the second layers were calculated by taking approximate resistivity and depth values relating to them and then for an electrode separation just below the maximum of the field curve, the percentage effect of the third layer on this average resistivity was calculated and then this percentage was applied to the apparent resistivity of the field curve corresponding to the electrode separation chosen. From this point a tangent was drawn to the first part of the field curve. This constituted the desired curve. Since a percentage effect was involved, the errors due to the approximations made as to the values of depths and resistivities were reduced.

The curve so obtained was then applied to the logarithmical master curves and the true resistivity of the first layer was obtained as described above. Using this value, the thickness of the first layer and the resistivity of the second layer were calculated by the Tagg's method. See Fig. 3.

The depth to the third layer was then estimated by applying the approximation $h_1 + h_2 = 2/3$ d where d is the distance to the inflection point. The apparent resistivity ρ' of the 2 upper layers (ρ_1 and ρ_2) in parallel was then calculated from $h_1 + h_2 / \rho' = h_1 / \rho_1 + h_2 / \rho_2$ and the Tagg's method was applied to the bottom part of the curve between the lowest two points of mazimum curvature and a more accurate value was then obtained for the depth $h_1 + h_2$ The resistivity of the bottom layer d_3 was determined from $K_2 = \frac{\rho_3 - \rho_2}{\rho_3 + \rho_2}$. The above procedure was repeated with better values of d'to obtain more accurate figures for $h_1 + h_2$ and d_3 and so on. See Fig. 4.

RESULTS

The results obtained are shown in Figs. 6 and 7 in which two ground sections along the traverses NW-SE. and E-W. can be seen. The positions of them can be seen in Figs. l and 5. The length of the firt and the second sections were 22 and 15 kms. respectively. Considering Fig. 6, it will be observed that the average thickness of the first layer having a mean resistivity of 50 ohm-m, is about 30 m., and that of the second layer with a mean resistivity of 300 ohm-m, is 240 m. Here it should be stated that in calculating the resistivity of the top layer, the effect of the soil was eliminated.

To interpret the first layer, some Preliminary measurements were made on the local outerops of limestone using separations'up to 50 m. Tis showed that the resistivity of the limestone changed from 60 to 100 ohm-m. The lower figüre of 50 ohm-m, may be due to the effect of the wet soil which saturates the first few meters of the rock. The second layer can be interpreted as the Neogene series consisting of thin alternate beds of marl, limestone and clay. Considering its high resistivity, it is highly probable that the limestones in it are thin and badly fractured, jointed and porous.

lt will be seen that the interface of the first and second layers is ondulated and follows that of the second and third, but the intensity of ondulations in the latter is larger.

As regards those ondulations, they can most probably be,

1 — due to folding,
2 — > > erosion,
3 — » » unconformity.

The third probablity is most unlikely, since the resistivity of the third layer is almost constant, varying about a mean value of 45 ohm-m.

The second probability is less likely than the first, because the two interfaces follow each other. lt is most probable that these ondulations are due to folding.

To investigate the nature of the third layer, 2 magnetic profiles showing vertical and horizontal magnetic intensity variations, were made. See Fig. 6. lt will be observed that the horizontal intensity variations follow closely the ondulations, though the vertical intensity variations do not. Along the E-W travers, however, the magnetic intensity variations follow the ondulations.

To have some idea about the nature of the bottom layer, some curve fitting calculations were made for various susceptibility values of the bottom layer, assuming that the variations were due to its top surface.

These showed that the bottom layer could be gneiss, diorrte, granite or Serpentine. From the geological evidences, gneiss and diorite are more likely to be. But these results must be taken with reserve, since the susceptibility of the same rock may- vary between vide limits.

lt should be observed that folding is more intense along the E-W than along the N-S direction, indicating that force was along the S-N direction. See Figs. 6 and 7,

To investigate water accumulations and horizons, the true resistivities of the first and third layers were plotted along the sections as shown in Figs. 6 and 7 and compared with the mean resistivity of the local well - waters in the neighbourhood, which was about 15 ohm-m.

lt was found that, the low resistivities observed at places E.S. 31 and 3 coresponded to water wells. See Fig. 7. lt is very likely that the others also, such as at E.S. 7, 13, 19 indicate patches of water accumulations. But before giving a decisive answer, the conditions for water accumulations should be studied carefully.

The bottom layer resistivity curve exhibits decisive falls corresponding to the troughs of the bottom layer. For instance in Fig. 7 at E. S. 28, quite a large resistivty fall occurs, corresponding to the deep trough at the same point. The resistivity of the 3rd layer at this point which is about 410 m. below the surface, is nearly the same as that ol the local well-water.' It is probable that here between the bottom and the middle layer, there exists an old valley filled with loose materials, carrying water. In Figs. Band 3, more such points can be observed at E. S. 10, 11 and 15. These may also be valleys of the same type carryingwater. The average width and depth of these valleys seem to be of the order of 300 and 30 m. respectively. It would be interesting to follow them by resistivity contouring. Again, as said before, a more accurate interpretation can be given if the favourability of these locations for water accumulation is studied by a hydrogeologist.

Here 2 resistivity Surveys were made along the NW-SE and E-W directions as shown in Figs. 1 and 8, one 13 km. the other 15 km. in length. The purr-bse of the second survey was to study the Strata and the different water horizons here and compare with those at Altınova. The purpose of the first which run along a valley approximate'y 50 m. in height and 100 m. in width, towards the river of Sakarya, was to determine the total thickness of the Neogene formation and the distribution of the water of Sakarya if any.

Method Used:

Here thinner beds than those near Altınova occurred. To elucidate them, in addition to Wenner configuration, single probing was employed. It was found out that if the ground was free from topographical irregularities and fractures, this latter method would give better results. It has a larger resolving power than that of the Wenner for thin and near-surface beds. This is illustrated in Figs. 9 and 9' which are the resistivity curves for both methods at the same Station. It will be ,seen that the Wenner method shows only 2 layers, the other, on the other hand, indicates 4 thin beds. But where the topography was rough, the anomalies due to the beds were obscured. This is illustrated in Figs. 10 and 10which are the resistivity curves for both methods at the same Station It will be seen that the Wenner curve is smooth; the other is much too irregular, though its mean varies in the same manner.

To analys the single probe curves, master curves in which the distance betvveen the potential electrodes is (dl) were constructed and the 3 layer curves were analysed in a similar mantıer as described for the Wenner configuration. But if the curve exhibited more than 3 layers, it wâs found useful to apply the following approximations obtained from the master curves:

1 — If $K = \frac{\varrho_2 - \varrho_1}{\varrho_2 + \varrho_1}$

first and second turning points correspond to r/h = 0.75 and r/h = 3.5 respectively where r is the distânce of the midd'e of the potential electrodes from the current electrode and h is the thickness of the first layer.

The inflection point, however, corresponds to r/h — 1.55

2 — If K is positive, the first turning point remains the same, the second chânges to r/h =4 — 12 and the inflection point to r/h = 1.60-2.30.

Of these, especially the rule for the second turning point was found useful, since this was almost always exhibited clearly on the field curves.

There was encountered one difficulty in calculating apparent resistivities for the survey along the NW-SE direction which passed through a valley (Kürt Taciri). The valley was of a cross section 50 m. (height) X 100 m. (width) and in calculating the apparent resistivities the factor 2 in $da = 2 p a_1$ could not be used. For this purpose a small scale experiment was conducted. An insulated body of the same cross seotional shape as that of the valley was immersed in a barrel full of water so that its top coincided with the surface of the water.

The electrodes were positioned along the bottom of the body and for each separation measurements of V and I were taken. Knowing the resistivity of the water, which was measured with small separation before the body was placed in, the factor K was calculated

$$K = \frac{Sa}{\pi a \frac{V}{I}} \qquad \varrho_a$$

tivity of the water, a the, electrode separation. Care was taken not to include the wall effects in the current and potential measurements.

The result of this experimen is shown in Fig. 11. lt will be observed that the most effect of the valley occurs when the electrode separation is 170 m. i.e. 1.7 times the .width of the valley. These values of K, were used in the calculations.

RESULTS

The results of the survey are shown in Figs. 12 and 13. Considering Fig. 12, five horizons can be seen, with the resistivities and the average thicknesses of the order of 30, 200, 25, 50 and 40 ohm-m, and 20, 100, 20, 80 m. respectively. According to a bore hole data at E.S. 49 the first layer consists of limestone, the surface and fractures of which are covered and filled with soil; the second is again limestone and the others are clay and marl of different sort which appear to be Several nundred meters thick.

The section along the Kürt Taciri valley (see Fig. 13) shows that these beds get thinner towards Sakarya. The first horizon ends near E. S. 45 and the second near E.S. 46. Near E.S. 47 conglomerates can be seen (See Figs. 14 and 15). lt will be observed from the resistivity survey in Fig. 13, that there is a bed 200 m thick dipping up the valley. This may be conglomerates.

Here, along the same traverses, vertical intensity variations were determined as seen in Figs. 12 and 13. The intensities decrease towards East and increase towards North. Again using the method of curve fitting, curves were calculated for different values of susceptibility and depth and dip for a body with a plane surface, lt was found that the anomaly of 300 gammas could be produced by a body with a plane top, dipping S. E. with an angle of 6 degrees and passing 800 m. below E.S. 49. This body could be gneiss, diorite, Serpentine or granite, lt seems that the Neogene formation is much thicker here than at Altınova.

The resistivities of the first and third layers are plotted along the traverse E.-W. as shown in Fig. 12, in order to compare them with the local well-water resistivity which is about 5 ohm-m. lt will be observed that there are no decisive resistivity falls. Here it should be remarked that the big resistivity highs for the first layer are due to the fractures ın the limestone. The resistivities of the first and third layers are plotted also in the traverse along the Kürt Taciri Valley. The low resistivity of the first layer between E S. 36 and 47 is due to the marshy land batween these stations. lt will be observed that a very low resistivity zone starts at B. 3. 47 and runs to about 100 m. below E. S. 36 where it ends abruptly. There appears to be most probably, a fault here and that the conglomerates filled with the water of Sakarya come up against the clay at this end.

lt seems also that 200 m. below the Station E. S. 46 and 47 there is another bed saturated with water. This may be grawackes. See Fig. 13.

GENERAL CONCLUSIONS

These general conclusions can be drawn from the Studies between Polatlı and Konya:

1 — There is a fairly large resistivity difference between that of water and the different kinds of rock and deposits.

2 — The Wenner method of resistivity mapping gives in general 3 layers; the top layer being soil and limestone, the middle layer being the whole Neogene formation and the bottom layer being the older formations. lt is however possible to find the thicknesses and resistivities of the different layers of the Neogene formation by the careful use of Single Probing.

3 — The susceptibility of the older formation is much higher than that of the Neogene formation as a whole; hence for the purpose of determining the gereral qualitative shapes of the top of the older formation, magnetic methods dan be used. This is İmportant, for magnetic surveying is much cheaper than resistivity surveying.

4 — The water horizona between Polatlı and Konya appear to be patchy, not continuous. For instance near Altınova D. Ü. Ç. there seem to be 2 water horizons; one is about 30 m. below the surface öt the base of a limestone layer. This horizon seems to be very discontinuous. The water patches appear to be irregularly disposed throughout it. Careful resistivity mapping and the application of the electromagnetic methods can elucidate these points. lt is well worth mentioning here that the inductive electromagnetic methods are especially suitable for the exploration of irregular water accumulation in fractured limestones.

The other horizon appears to be at the interface of the newer and the older formations. This interface seems to contain large erosion valleys holding water. Further detailed resistivity Surveys are needed to find their dips and directions in order to see whether they can contain water under pressure.

The locations for the likely valleys are indicated in the text.

5 — The thickness of the Neogene formation chânges from place to place. For instance, near Polatlı D. Ü. Ç. it appears to be about 800 m.; in contrast to this, it is only 250 m. near Altınova.

6 — The water of Sakarya seems to saturate the conglomerates and the grawackes around it Use çan be made of this, by following the saturated beds from Sakarya onwards and drawing water from them at the desired locations.