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Research Article

Modeling of Copper Mine in Istanbul (Turkey) by using Self Potential (SP) Method

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Abstract Sulfite mineralization, which was determined by the presence of pyrite and chalcopyrite minerals in the surrounding rocks at the Sarıyer Nalbant Fountain in Istanbul, was determined by self-potential (SP) study. The natural polarization (SP) study was carried out by shift measurement technique and the distance between each profile and cups was planned as five meters. At the end of this study, equal voltage curves whose value falls below -120mV levels were determined. These interlocking equilibrium curves clearly indicate to us the existence of a sphere or a cylindrical sphere beneath the surface. The evaluations in the cross-sectional studies were made by nomogram technique. Because of the evaluation, it has been determined that the mineralization is located at 36 meters depth and 27 ° polarization angle. Subsequent drilling studies confirmed these findings of the existing sulfurous structure.

Keywords Self Potential (SP); nomogram method; İstanbul (Turkey); copper ore

1. Introduction

The Natural / Self-Spontaneous Potential (SP) method is a natural method. The method is the oldest geophysical method used in the exploration of sulfur ore since the 1920s. Natural potential method, determination of hydrogeological conditions, determination of leakage points in dam structures, finding drainage structures, water movement in non-stationary soil masses such as landslides, prevention of water pollution and so on. It is used frequently in exploration of shallow mines, ground and hot water studies, and fault and fracture zones [1].The method is sensitive to electrical charges in the ground. This natural tension is caused by electrochemical and electrokinetic phenomena at the boundaries of minerals and solutions. This tension is constant in some places and variable in some places. Constant and unchanging stresses are caused by electrochemical events occurring in the surface rocks or structures embedded in them. In the SP method, the voltage difference can be measured between 1,2-10,20 millivolts. In mineral fields where sulfuric graphite, magnetite, galenite and other minerals with high electrical conductivity are present, the tension value can be measured up to several hundred millivolts (-1000 millivolts) as negative values [2- 3]. Due to the oxidation in the upper part of the ore mass, a tension difference occurs between the top and bottom of the ore. The voltage differences due to mineralization are negative. The sulphurous mass causes an underground current to be formed and the largest voltage differences over the ore mass are measured. SP data can be presented by displaying the voltage differences measured along a line depending on the distance. The locations of the ore bodies can be found assuming that the higher SP values are associated with the ore. Natural stress maps are also a good guide for locating ores [4].
Copper sulphide (chalcoprite) mineral, which is thought to exist in the Sarıyer Nalbant Fountain in Istanbul, was determined by SP study. Based on the report produced at the end of the studies, drilling at various points on the ore was carried out and core samples of the ore were taken. In the study supported by drillings, it has been

proved that the mineralization has a polarization angle of 27 ° in the light cylindrical sphere structure, 36 meters deep from the surface.

Methods

Negative (-) centers observed in the equivalent contour maps obtained from the mine sites where SP studies are conducted determine the location of the mineral deposits. These centers also provide information about the shape and extension of the ore. If the mineral structure is spherical, circular, intertwined contours and horizontal elliptical contours are observed. Furthermore, in the profiles to be taken in a certain direction on the map, the variation of the volatility by distance allows to obtain useful information. The structure of the SP data is assumed simple geometric shapes and modeling studies are performed on it. First, the geometric shape (spot welding, sphere, cylinder, plate, etc.) of the structure which is thought to be buried in the ground is decided. Theoretical symptoms are obtained by developing mathematical theory depending on the chosen form. Then, an analogy is sought between these theoretical curves and the symptoms obtained from the field. Thus, the parameters of the obtained theoretical model help us to give the parameters of the underground mass being searched for. Since the data obtained in the surveyed area makes us think that there is a spherical structure underground, only the sphere model will be examined.

Sphere problem

The appearance of a polarized sphere in an infinite environment has a dipole behavior due to the opposite marked poles. The inclusions of the force lines between these two extremes spreading into the medium are spherical. Let us place a sphere underground at depth h. The polarization axis of this sphere is β and the polarization angle is α. The radius of the sphere is R, and the electrical charges that we assume are collected at both ends are the total voltage values that this sphere will form at a P point on earth,

$$V_T = \frac{Q(r_2 - r_1)}{r_1 r_2} \qquad (1)$$

r_1, r_2 ; the distance of the $+Q$ and $-Q$ charge points of the current sphere to the point P on a direction on the surface of the earth [3].

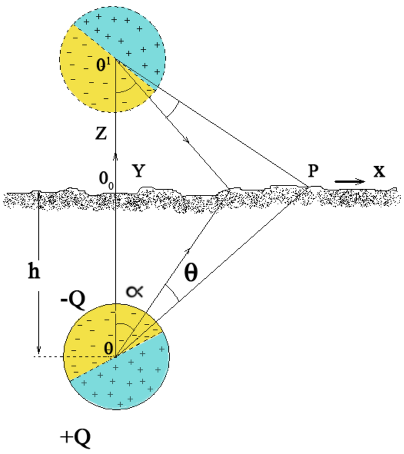


Figure 1: A polarized sphere and its image embedded in a semi-infinite ground environment [3]

A polarized sphere in the Earth and its image is shown in Figure 1. If $2R \langle\langle$ r is considered in relation $(r_2 - r_1) / 2R \approx \cos\theta$. Whereθ is the angle between O_O OP. r is OP distance. Since $2R \langle\langle$ r is $r_1 \approx r_2 \approx r$ taken:

$$V_T = \frac{2QR\cos\theta}{r^2} \qquad (2)$$

writable. Electrical dipole moment $M = 2QR; O_0OP = \theta$internal tension in the sphere for the angle of angle;

$$\frac{E}{2}\cos\theta \qquad (3)$$

This electric field should be equal to the Coulomb force. In that case;

$$\frac{E}{2}cos\theta = \frac{Mcos\theta}{R^2} \quad (4)$$

So the dipole moment of the sphere;

$$M = \frac{ER^2}{2} \quad (5)$$

Here, E is the voltage difference between the two ends of the sphere. The total voltage V_T formed by a sphere with α polarization angle at the point P $(x, 0, 0)$ can therefore be given by the following relation.

$$V_T = M\frac{xSin\alpha + hCos\alpha}{\left[x^2 + h^2\right]^{3/2}} \quad (6)$$

This correlation is the total voltage Vt (x) since it is progressed along the x direction in SP measurements. This is the desire to examine the variable by changing the sum of the highest and least points for the abscissa of the points if the derivative by x:

$$\frac{dV_T}{dx} = M\left\{\frac{-3hxCos\alpha + \left(h^2 + 2x^2\right)Sin\alpha}{\left(x^2 + h^2\right)^{5/2}}\right\} \quad (7)$$

This correlation is the total voltage Vt (x) since it is progressed along the x direction in SP measurements.

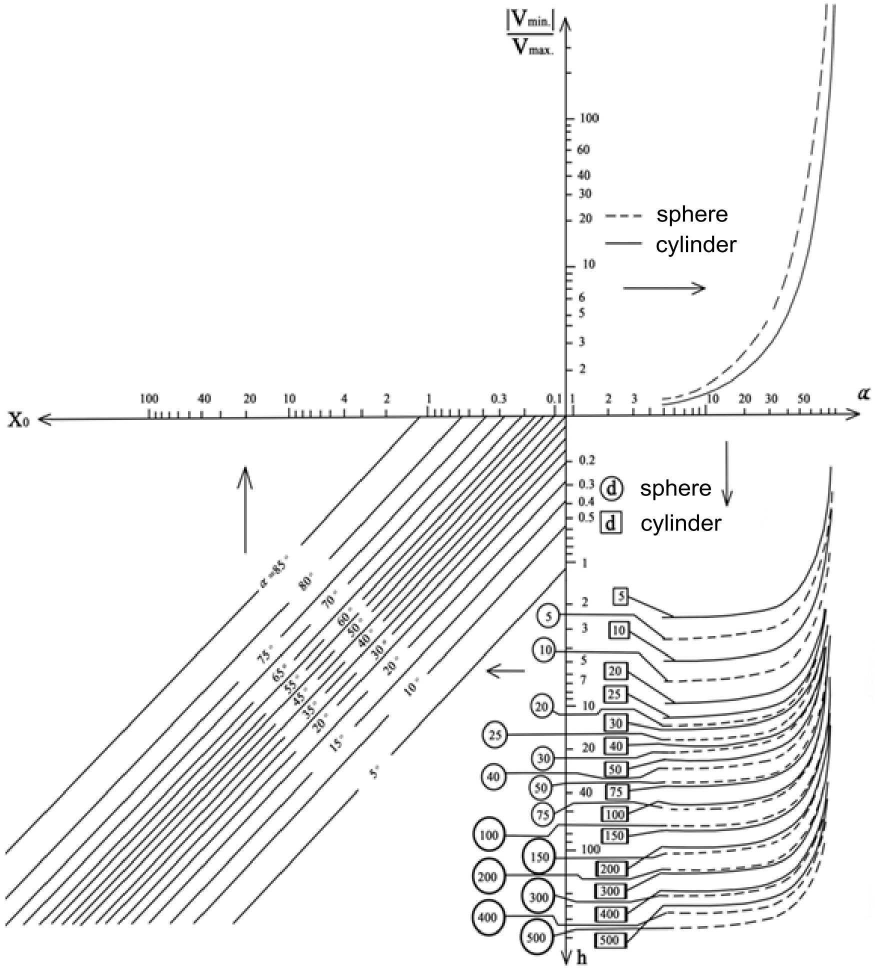


Figure 2: SP anomaly evaluation nomogram prepared according to sphere and cylinder model [3 Taken by modification].

Nomogram evaluation for sphere and cylinder models

SP stresses to be created at the point P (x, 0, 0) on the surface of the sphere and cylindrical geological structure located in the orthogonal coordinate system in a uniform ground environment are as follows [5].

V(x,0,0) = M $\frac{xCos\alpha - hSin\alpha}{(x^2+h^2)^{3/2}}$ (sphere) (8)

V(x,0,0) = M $\frac{xCos\alpha - hSin\alpha}{x^2+h^2}$ (cylinder) (9)

Taking advantage of these relations for both models;

$\frac{|V_{min}|}{V_{max}} = F(\alpha) \rightarrow$ (sphere models) $\frac{|V_{min}|}{V_{max}} = F_1(\alpha) \rightarrow$ (cylinder models)

open software of relations [6]. On the other hand, if the minimum and maximum voltage of the SP anomaly is given as the x and x values of the abscissa values of the observed points and the distance between them is defined by d:

h = $\frac{2d}{3} \cdot \frac{1}{(\tan^2\alpha - 8/9)^{1/2}} = f(\alpha, d)$ sphere (10)

h = $\frac{d}{2}.Cos\alpha = f_1(\alpha, d)$ cylinder (11)

V(x,0,0) when x is equal to zero and x is substituted for x_0:

h = $x_O \cot\alpha = \phi(x_O, \alpha)$ (12)

The relationship between sphere and cylinder is obtained.

The axes of the nomogram are selected logarithmically based on the evaluation of the relations developed so far as a function of the polarization angle α. SP anomaly evaluation nomogram prepared according to sphere and cylinder model is given in Figure 5. Based on the SP anomaly map, underground shapes that are likened to spherical or cylindrical structures are modeled based on this nomogram. In the equivalent contour map obtained from the SP study conducted at the Sarıyer Nalbant Fountain Location in Istanbul, intertwined negative values were observed. Based on this, it was thought that the underground mass could be spherical with a slightly cylindrical structure and the evaluations were made according to the sphere model. The results were supported by soundings after the study. The soundings revealed that the underground mass was indeed spherical. Here, only the sphere model will be processed as the modeling system. There is no need to explain other modeling options.

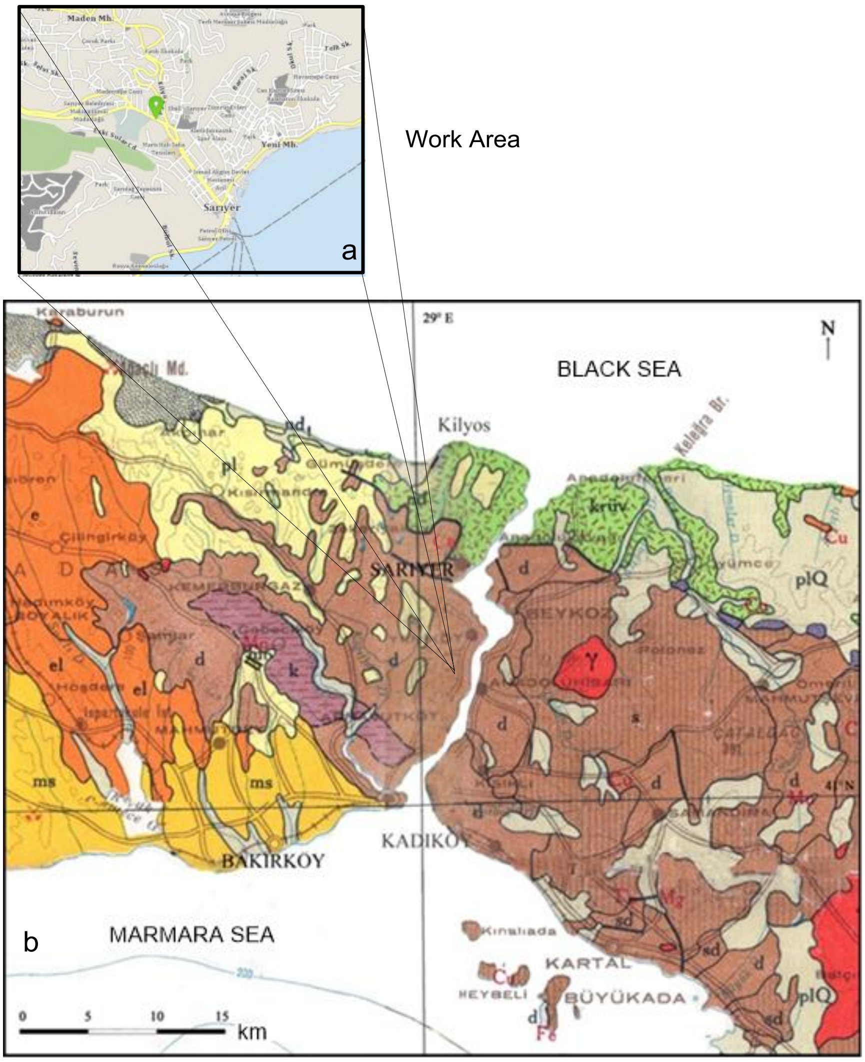
The nomogram based on the evaluation of the relations developed as far as a function of polarization angle α is given in Figure 2. The axes used for this nomogram are selected logarithmically. The arrows indicate the direction of use of the nomogram during evaluation.

Geology of the work area

Geological structure in Istanbul is quite complex (Figure 3). The main reason for this is the repetition of very similar units in the stratigraphic sequence, the fact that the guide levels are sparse and not easily recognizable, the orogenic movements undertaken, the interference folds, the introduction of numerous faults and andesite or diabase dykes. In addition, coverings or fillings in residential areas make it difficult to monitor structural elements. The geometry formed in the horizontal and vertical cross-sections with the folds in different directions or interference folds is quite complex. The Paleozoic sediments of Istanbul, which form a concave sequence, were folded together with the Hercynian orogeny. Hercynian folds are mainly compact, closed, asymmetric and concentric. Locally there are diapiric ones as well. In the Paleozoic sequences of Istanbul, where the relatively more resistant units are found, the folds are larger and concentric. Conversely, at less durable levels, congested folds are observed. In the Alpine orogeny affecting the region, all aged units were pushed over the Upper Cretaceous-Paleocene and Lower Eocene aged units. With these movements, Paleozoic units have been folded again and Mesozoic-Lower Tertiary units have been folded for the first time [7].

The underlying units in the Istanbul region are Paleozoic in age. These units form a compatible sequence from Silurian to Lower Carboniferous. These clastic and carbonate-rich units are generally mixed with tectonism. At the bottom, the Silurian Dolayoba formation consists of tightly bonded limestones, quartz clastic sandstones and tuber-banded limestones. Limestones are generally reefal. The Dolayoba formation is overlain by Devonian aged Kartal and Tuzla formations. The Kartal formation consists of coarse-grained limestone lenses, occasionally carbonated shales, groves and abundant fossiliferous clayey limestones. Tuzla formation is composed of nodular limestone, calcareous shale and layered cherts. Lower Carboniferous Baltalimanı formation overlies the Tuzla formation. This unit consists of black colored laminated cherts. Thrace formation; mainly composed of brown sandstone (greywacke), shale and limestone lenses [8]. Sarıyer Formation is composed of marl conglomerate and grease with volcanic tuff, andesite and agglomerate additives. The lower parts of the unit have a volcanic flysch character. Lower Carboniferous units overlie the Eocene sequence with angular unconformity. The Soğucak formation, which consists of clayey limestone and limestone, is rich in white, yellowish white, or grayish, thin medium bedded, hard, clayey limestones. Soft marl layers are also found as intermediate layers. Hard, thick bedded, massive limestone levels are also present in the formation[8]. These levels show reef features. The Ceylan formation passes gradually and gradually over the Soğucak limestones. On the other hand, an Oligocene heater is deposited on the Ceylan formation, which was deposited as a marl and clay sequence [9-10].During the Upper Miocene, there were clay deposits in the temporary lakes. The unit, which consists mainly of green colored, thin laminated, plastic clays, is defined as Güngören formation. This formation is also intercalated with limestone and gradually passes into the Bakırköy formation. Limestone-marl alternation has been deposited in this marine environment, which is generally dominat.

The Sarıyer formation is dominated by clastics at the lower level and volcanics at the upper level. These two levels, which are lateral and vertical transitive with each other and can cover interrelated rock formations, are called members of a single formation.



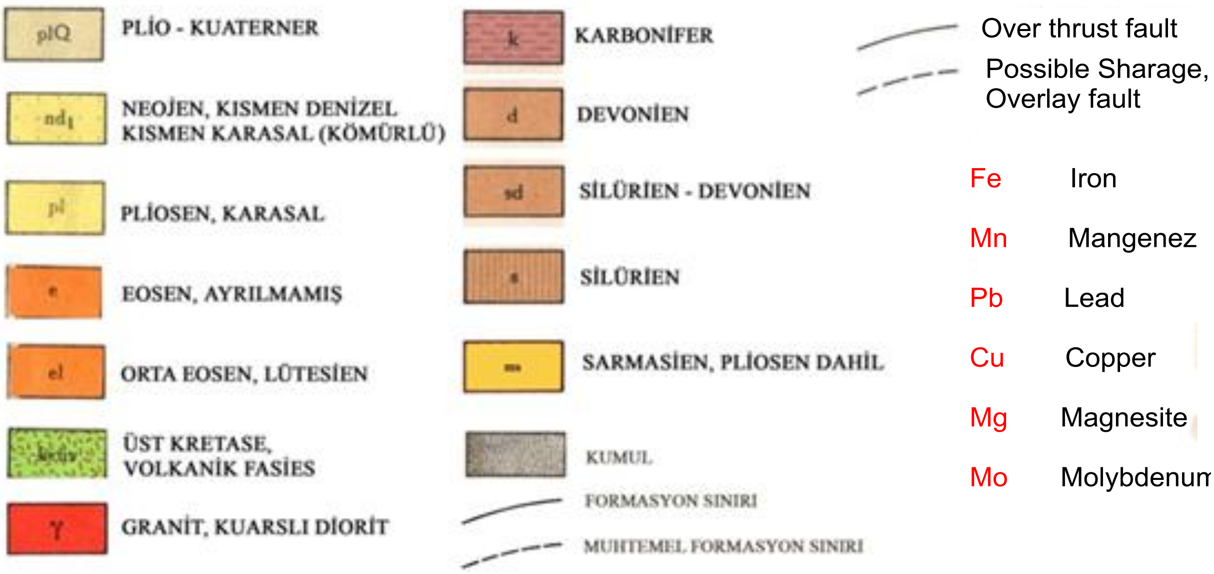


Figure 3: Sp method belongs to the area a) Working area b) General geological map of Turkey in Istanbul [11 Taken by modification].

Application on land sample

Figure 4 shows the cross-section of the contour map SP. The evaluation of SP according to this section is done according to the following process steps. From the negative inclusions in the related map, it is estimated that the mineralization is spherical.

- **a.** The map is crossed along the A - A direction and the SP anomaly is drawn accordingly.
- **b.** V_{min}, V_{max}, d values are read from this anomaly. $|V_{min}|/V_{max}$ is obtained.
- **c.** The angle determined by the perpendicular to the α axis from the point where the direction drawn in parallel with the α horizontal axis from the value determined on the $|V_{min}|/V_{max}$ axis intersects the sphere curve is the polarization angle.
- **d.** The direction that intersects the α axis is extended to the lower right part of the nomogram and the curve of the sphere is estimated and the new value perpendicular to the h axis is drawn and the h value is obtained.
- **e.** By extending this last direction, the α curve is estimated and a new direction perpendicular to the x_0 axis is drawn and x_0 is found.

In order to locate the ore, the SP anomaly obtained by the section taken along the YX direction was plotted. This SP is the projection of the ore on the ground surface by going from the x point to the zero tension point determined by the suture reduced from the maximum value in the voltage curve. The angle α is taken in the direction in which the largest absolute tension value is measured in the SP anomaly and the position of the underground ore is obtained.

An SP study is foreseen for the ore mass estimated from chalcopyrite and pyrite formations on the surface of the Nalbant Fountain located on the ridge of the Bosphorus in Sarıyer district of Istanbul. During the applied natural polarization study, the distance between the measurement points and the profile were taken as five meters. Devonian aged schist belonging to Sarıyer Formation was observed as surface rock in the region where the slope reached to 0.5% in places during the study. Andesite formations were found under the schist.

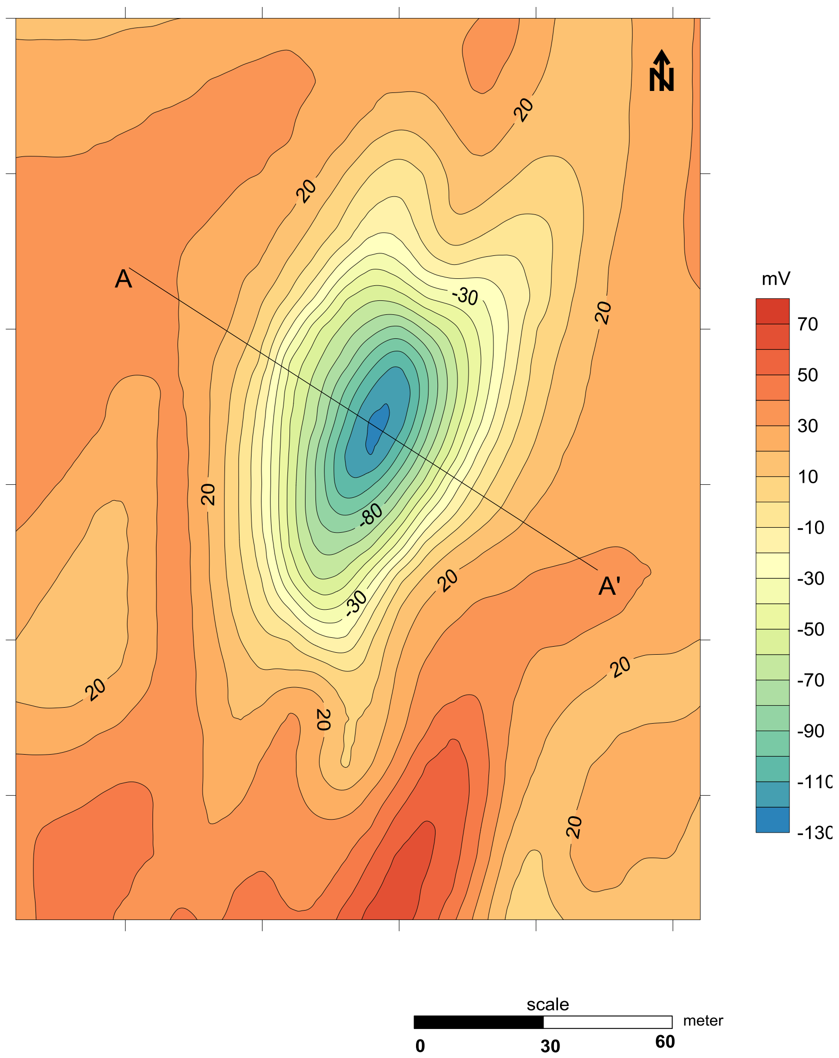


Figure 4: SP anomaly map in Istanbul-Sarıyer Nalbant Çeşmesi

The measured values on the surface are generally positive, 20 to 30 mV values were found. When the anomaly map given in Figure 4 is examined, the nested negative value inclusions show the presence of a polarized spherical sulfur structure in the region very close to the surface. Since mineralization is thought to be spherical, the priority in evaluations is given to spherical modeling. As a matter of fact, a cross - sectional study was conducted in the NW - SE direction A – A' direction in the obtained tension map. The section taken from the Sp anomaly map is given in Figure 5. The values obtained from the section were evaluated by nomogram technique. As a result, the presence of spheroidal structure was clearly demonstrated. After the SP study, various drilling works supporting the studies were carried out on the ore body and the accuracy of the study was proved physically. The chalcopyrite mineralization, whose existence is proved by drilling, is modeled in vertical direction in Figure 5.The overlapping negative inclusions in the co-tension map suggest the presence of a sulphide mineralization in the region, but this mineralization has a spherical structure. Consequently, the studies are focused on the sphere model. On the negative inclusions from the co - tension map KB - SE direction A - B | a cross - sectional study was conducted. Evaluations were made by nomogram technique. Because of the evaluation, it has been determined that the mineralization is located at 36 meters depth and 27 ° polarization angle.

Evaluation: In the same voltage map, V_{min} value -121.65mV was read from cross section A –A' direction taken in NW - SE direction. In the same section, the V_{max} value was found to be 32.45mV. The distance d from the same section was determined as 51 meters.

The values found are put in place in the formula; $\left|{V_{min}}/{V_{max}}\right| = 3.75$

In the nomogram, α polarization angle is obtained by estimating the sphere curve with the suture drawn from the 3.75 value determined on the $\left|{V_{min}}/{V_{max}}\right|$ axis to the α horizontal axis;

$\alpha = 27^0$

The stitch drawn towards the A axis is further extended downwards to the dashed curve of d = 51 meters read from the cross-section of the co-tension map. From there, a post is drawn towards the h axis; h = 36 meters.
By extending this last direction, the curve $\alpha = 27^0$ is estimated and a new stitch is drawn again on the x_o axis and the xo value; X_o = 18 meters.

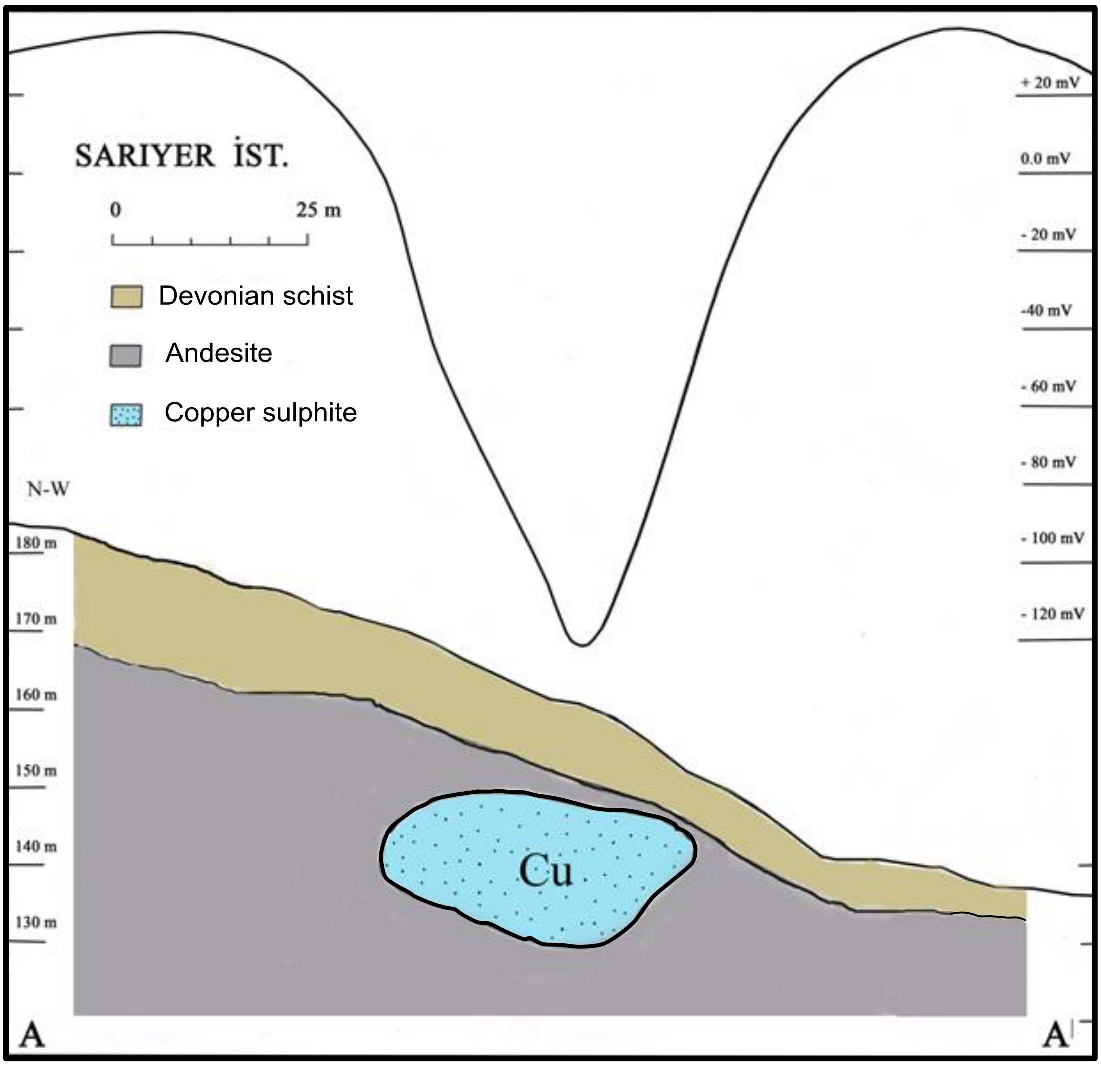


Figure 5: SP anomaly curve obtained from the section along the A – A' direction in NW-SE direction from SP study conducted in Sarıyer Nalbant çeşmesi and representation of the calculated model structure.

Result

An SP study is foreseen for the ore mass expected to be found in the Nalbant Fountain location of Sarıyer district of Istanbul. During the applied natural polarization study, the distance between the measurement points and the profile were taken as five meters. Devonian aged schist belonging to Sarıyer Formation was observed as surface rock in the region during the study. Andesite formations were found under the schist. The measured values on the surface are generally positive, 20 to 30 mV. values were found. However, a very very rapid negative value increase was achieved between profile 9 and profile 21. This increase in negative value reached the maximum value in profile 13 and -120 mV value. The available values were processed in the Surfer 9.0

drawing program after the necessary corrections were applied. As a result of this process, very intense intertwined, negative values inclusions were observed in the map of the stress curves. These nested negative value inclusions indicate the presence of a polarized spherical sulfur structure in the region very close to the surface. Since mineralization is thought to be spherical, the priority in evaluations is given to spherical modeling. As a matter of fact, a cross - sectional study was carried out in NW - SE direction A - B direction in the obtained tension map. The values obtained from the section were evaluated by nomogram technique. As a result, the presence of spheroidal structure was clearly demonstrated. After the SP study, various drilling studies supporting the studies were carried out on the ore body and the accuracy of the study was proved physically. The mineralization is located at a depth of 36 meters from the surface and with a polarization angle of 27 °.

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