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3D Geophysical Subsurface Modelling in Quarry Site Research

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INFORMATION

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ABSTRACT

This study aims to investigate the presence, thickness, and vertical and lateral extension of limestone and basalt in quarry sites by geophysical methods and to perform 3D geophysical subsurface modeling. Within the scope of the study, firstly, regional gravity and airborne magnetic data were obtained, and maps were prepared and interpreted to estimate the presence, thickness, and vertical and lateral extent of limestone and basalt in the areas selected as quarries by geophysical methods. In the second stage, in-situ geological observations were made to examine the geological characteristics and to guide the geophysical measurements to be made in these areas. In the third stage, geophysical measurements were carried out at suitable locations determined by geological observations. In the last stage, computer-aided 3D subsurface modeling of the study areas was carried out in light of the geophysical data obtained. As a result of the studies, areas that are suitable and unsuitable for quarrying were identified. This study demonstrates that geophysical methods (especially resistivity method) can be fast, reliable and cost-effective methods for quarry site research.

1. Introduction

Railway consists of two main parts superstructure and infrastructure. On the natural land through which the railway route passes; all of the facilities manufactured for the construction and protection of the road are called infrastructure. The infrastructure consists of cuttings, embankments, tunnels, bridges, platforms, crossings, reinforcement and prevention structures (fortifications). Superstructure is the part of the road built based on certain criteria to ensure that the railway vehicles can move safely, comfortably, and at the desired speeds and where the railway vehicles come into contact with the road.

The superstructure consists of rails, sleepers, connection materials, and ballast. From this point of view, it is of great importance that the ballast, which is one of the elements of the railway superstructure, has the desired geometric and physical properties. The hard and solid rocks with broken, sharp corners and sharp edges that are laid on the platform, filling the spaces between the sleepers and forming an elastic bed for the sleeper, transmitting all the effects transmitted by the sleepers to the platform, are called ballast (Fig. 1) (Kozak, 2021).

The sharp-edged stones seen around the rails are called ballast. During the construction of a railway, ballast is first poured the level of the track is raised and the sleepers are fixed. Sleepers are not fixed to the rails because the expansion of the rails and sleepers causes movement. If they are fixed, breakage may occur in the rails that cannot move. This is where ballast stones come into play. The stones keep the sleepers stable and straight. Thus, the train can easily move along the tracks.

Stones with straight edges, such as you might find in a riverbed or the ocean, roll and slide over each other during the passage of the train. This causes the sleepers to slip. The sharp edges of the stones make it very difficult for them to move - as the sharp edges cut into each other, they essentially compress each other, creating a solid foundation. It also prevents various plants from taking root, which can sprout under the railroad tracks and cause serious disruption.

Limestone-derived rocks were used as ballast in the past years. Limestone-derived rocks were replaced by igneous rocks such as basalt, granite, granodiorite, gabbro and diabase in the following years and these igneous rocks are still used as ballast in railways. The most ideal rocks of igneous origin used as ballast are basalt and granite. With the amendment to the ballast technical specifications, the requirement regarding the origin and name of the rock to be used as ballast has been removed. Therefore, metamorphic, sedimentary and other igneous rocks with suitable technological properties (physical properties, grain density, abrasion resistance, etc.) can be used as ballast (Kozak, 2021).

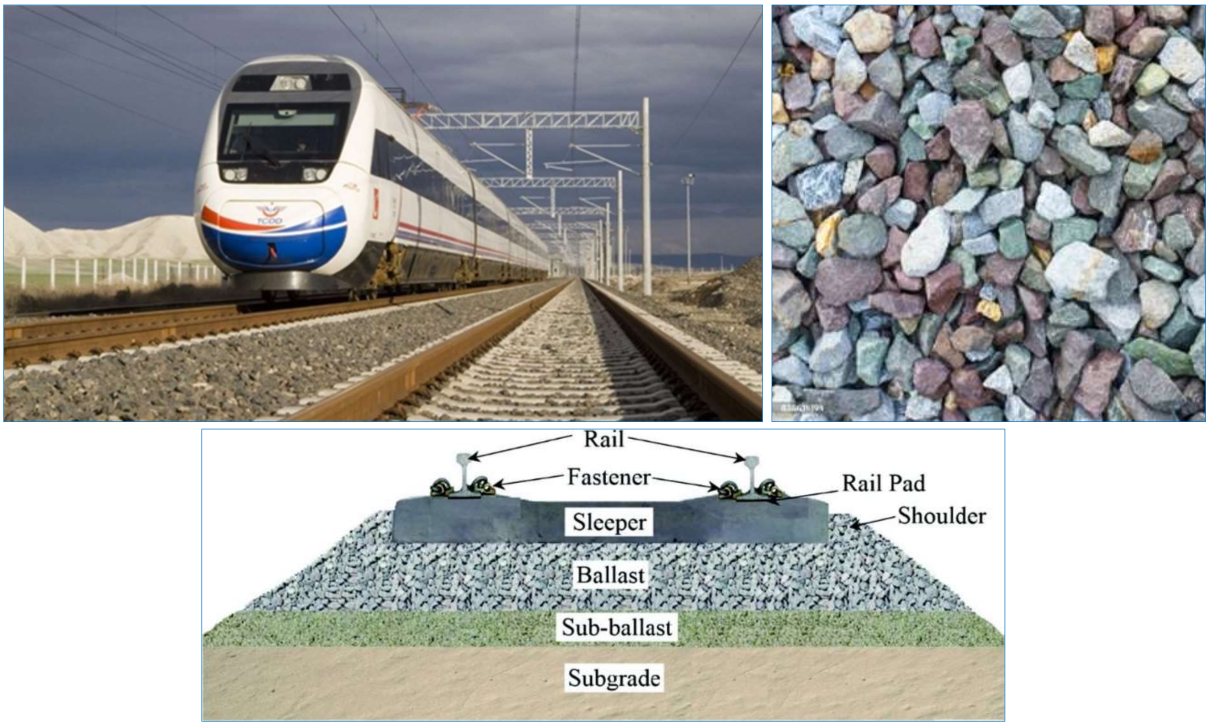

Fig. 1. Ballast use in railways

Ballast and other construction materials in the projects are produced from suitable areas as a result of quarrying activities. In this context, after superficially determining the suitability of both the technological and physical properties of the rocks in the regions to be selected as quarry areas for the properties of the building materials sought, the thickness and extent of the rock in the potential areas gain importance.

Geophysical methods come to the forefront as the fastest and cheapest method to be used to determine the thickness and extent. The most important reason for choosing geophysical methods is that potential quarry areas are areas with a lack of infrastructure (roads, etc.) and there is no need for permission from the institutions for drilling. Geophysical methods are also applied for site development in quarries that are already in operation (Yi et al., 2006; Chambers et al., 2006; Agunleti and Jaiyeola, 2015; Uhlemann et al., 2018; Kayode et al., 2019; Larsson, 2022; Friberg, 2023; Martial et al., 2023).

In this study, geophysical measurements were carried out and 3D geophysical subsurface models were prepared to estimate the presence, thickness, and vertical and lateral extent of limestone and basalt in two quarry areas whose technological properties were evaluated as appropriate according to the surface rock samples taken by the project constructing engineers for the supply of ballast material for the construction of a High-Speed Railways Project.

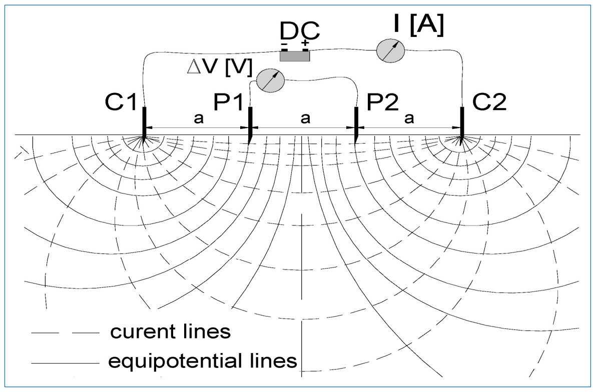

Fig. 2. Field application of resistivity method

2. Material and Method

The physical properties of geological units vary according to their environment. By utilizing this phenomenon, data supporting information about the depth, size and shape of geological units can be obtained by geophysical methods.

The first condition for defining the subsurface structure of any land is the geological survey of the study area. The lateral and vertical extent of a geological unit cannot be fully defined by superficial geological studies. Therefore, after the initial geological studies, the area should be investigated with the help of geophysical methods (Özdemir and Savaş, 2009).

Geophysical investigations are the examination of the invisible and unknown units of the earth by utilizing the physical principles in nature and defining them precisely based on their physical properties. Thus, with the help of geophysical measurements, an explored mine will be examined depending on different physical parameters and a model suitable for the environment can be established. Today, the rapid development of technology and especially the advances in computer technology enable more realistic and visual results to be obtained in such studies. Despite all these, the most important fact is still engineering interpretation (Özdemir and Palabıyık, 2019a).

As it is known, the physical properties of the rocks that make up the earth's crust vary according to their environment and geological formation. In this sense, the electrical resistivity properties of rocks also vary over a wide range. The naming of a rock based on its resistivity value differs for each mine site. Resistivity curve models should be evaluated considering this basic criterion.

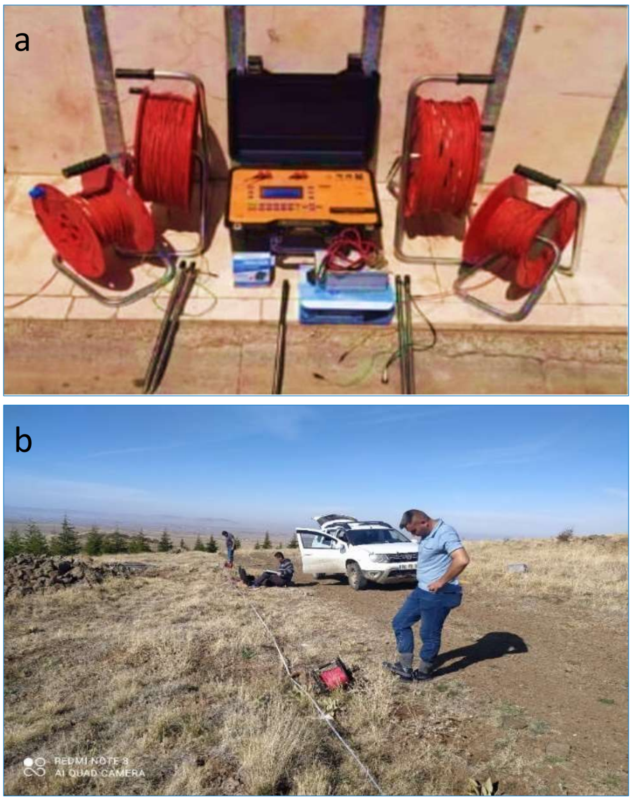

Fig. 3. A view of the device used in geophysical resistivity study (a) and the field measurements (b)

The physical properties of the rock are not the only negative factors affecting resistivity values and the curve models obtained as a result of these values in mining sites. The general tectonic structure of the site also affects the resistivity values due to the direction of the measurement. In general, the rugged structure of the mine sites does not allow measurements to be taken in the desired direction. In this case, it is necessary to know how to make evaluations and how to utilize resistivity methods (Özdemir and Palabıyık, 2019b).

The resistivity method is based on utilizing the difference in electrical resistance in the environment. The method is based on the measurement of the potential field difference on the earth with the electric current applied to the earth from any two points and analyzed according to Ohm's law (Fig. 2)

In the evaluation of Vertical Electrical Sounding (VES) measurements, geological units in the region are taken into account and the geo-electrical structure is compared with these units. In this way, the geological structure is indirectly determined. The geological structure may not always match the ground-electrical structure exactly. However, this method is based on the principle of identifying the subsurface by comparing the detected high resistivity (resistive) and low resistivity (conductive) environments with the geological structure. The evaluation of geophysical data together with geological information is an inevitable practice for the decisions to be made in the future drilling and project design stages in the light of geophysical measurements (Özdemir and Savaş, 2009).

Within the scope of this study, firstly, regional gravity and airborne magnetic data were obtained from the General Directorate of Mineral Research and Exploration of Turkey (MTA) to estimate the presence, thickness, and vertical and lateral distribution of limestone and basalt in the areas selected as quarries by geophysical methods, and maps were prepared and interpreted using Surfer program. In the second stage, geological observations were made and geological maps were prepared in the NetCAD program in order to examine the geological characteristics and to guide the geophysical measurements to be made in these areas. In the third stage, geoelectrical measurements (VES) were carried out to estimate the presence, thickness, and distribution of limestone and basalt in the selected quarry areas by geophysical methods. Geoelectric field measurements were taken using 3-amp resistivity equipment (GeoScannerr 1-2 AH brand). The power source is a gasoline generator producing an alternating current of 220 Volts and 5.5 Kwa. The sensitivity of the receiver is 0.01 mV/scala (Fig. 3)

In the system, the alternating current (AC) obtained from the power source formed by the generator set is first adjusted with a variac and then converted to direct current (DC) by passing through a rectifier. The resulting DC is supplied underground. The DC output voltage is max. 1000 volts and the underground current is max. 2 amps. The current electrodes (C1, C2) used are long rods made of stainless steel. Potential electrodes (P1, P2) are non-polarized copper sulfate electrodes. The cables are all copper and well-insulated. Since the purpose of geoelectrical measurements in the study area is to investigate the deeper changes of geological units, the Schlumberger electrode array was used in VES measurements.

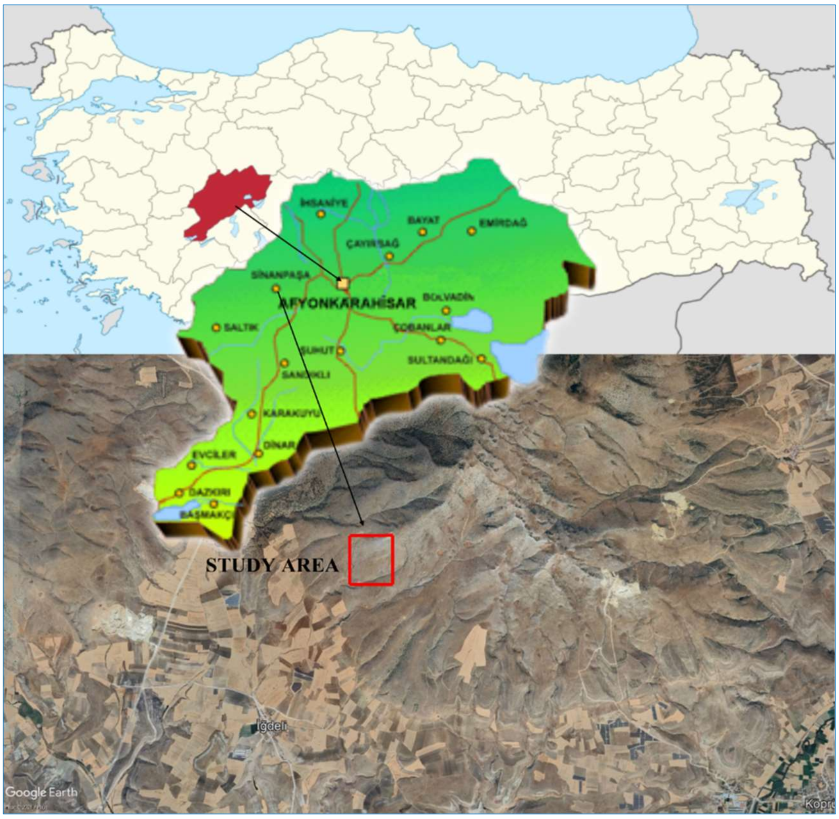

Fig. 4. Location map of İğdeli potential quarry area

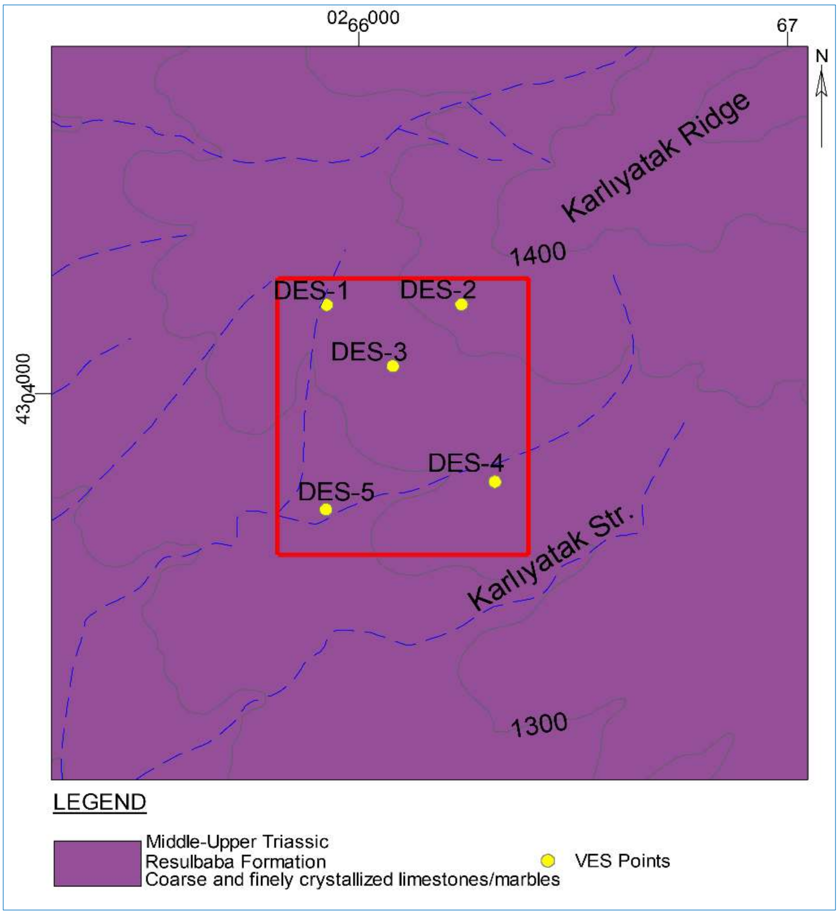

Fig. 5. Geological map of İğdeli potential quarry area

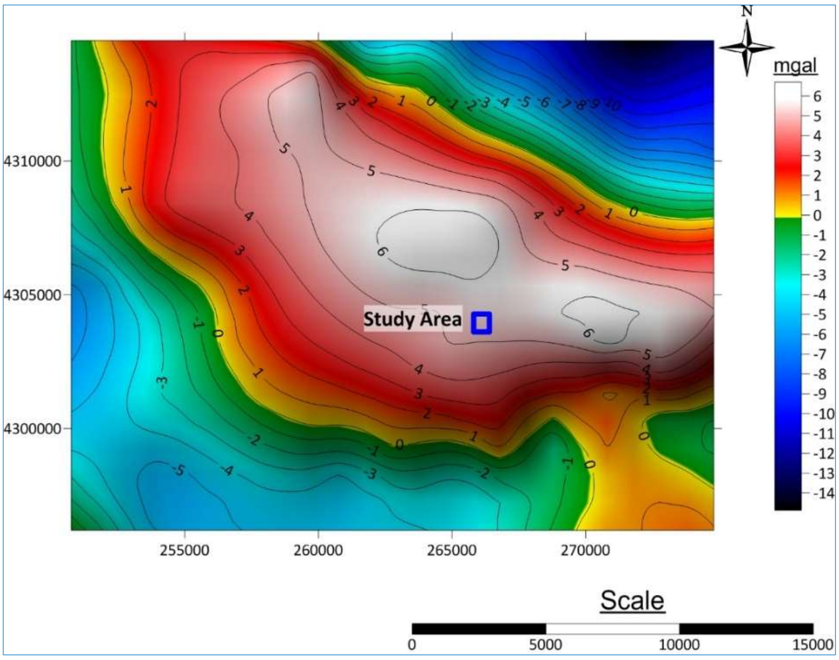

Fig. 6. Color contour map of residual gravity anomalies in and around the study area

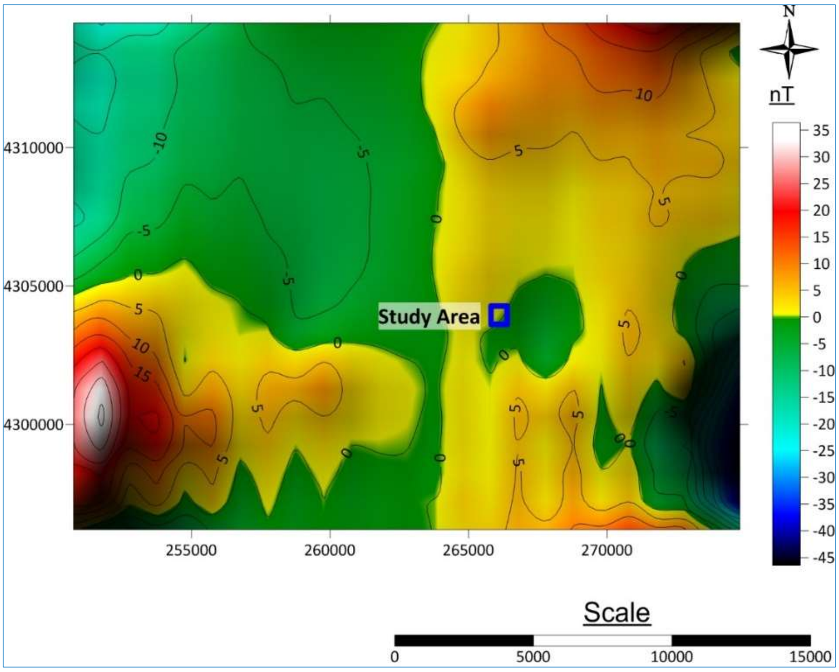

Fig. 7. Color contour map of residual aeromagnetic anomalies in and around the study area

Nowadays, it is possible to computerize and 3D model the raw resistivity values measured in the field. In this process, the raw resistivity values and coordinates measured from the field are entered into the program as data and a three-dimensional model of the data, which is turned into a solid model by using the "Grid Model" (network modeling) and geostatistical methods, is obtained. To better interpret the curves and evaluation results obtained as a result of DES measurements, geoelectrical sections, and 3D models were prepared in the RockWorks program following the geological structure to better interpret the geoelectrical structure. Finally, it assessed whether the site was suitable for a quarry.

3. Findings of the Case Studies and Discussion

Within the scope of the study, the suitability of two potential areas, one limestone, and the other basalt, for quarry was evaluated by geological interpretations of the data obtained as a result of geophysical measurements in the areas.

3.1. Igdeli Potential Quarry (Limestone) Area

The study area is located within the borders of the Sinanpaşa district of Afyon province (Fig. 4). The study area consists of coarse and finely crystallized limestones/marbles belonging to the Middle-Upper Triassic aged Resulbaba Formation (Fig. 5).

3.1.1. Aeromagnetic and Gravity Data

Regional gravity and airborne magnetic maps of the study area were first prepared (Figs. 6 and 7). Massive limestones show low magnetic and high gravity values. In the gravity map prepared for the study area, the area selected as a quarry is located in an area of high density (low-density rocks are represented by dark blue, light blue, and green color tones, and high-density rocks are represented by yellow and red color tones) (Fig. 6).

In the prepared magnetic map (Fig. 7), areas with rocks that do not show magnetization properties (rocks of completely sedimentary origin, such as limestone) and rocks with low magnetization are represented by dark blue, light blue, and green color tones. In other areas, rocks containing magnetizing minerals such as magnetite, ilmenite, pyrrhotine, etc. were found.

Table 1. Coordinates of VES measurements measured in the study area

Measurement No	Coordinates	
	Y	X
DES1	265926	4304221
DES2	266240	4304222
DES3	266080	4304073
DES4	266317	4303793
DES5	265924	4303726

Fig. 8. Locations of the VES measurements in the study area

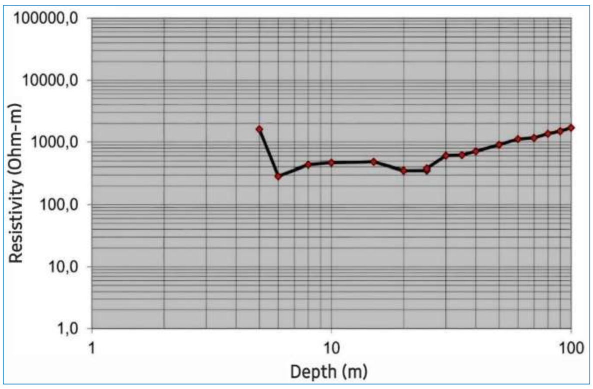

Fig. 9. DES-1 measurement curve

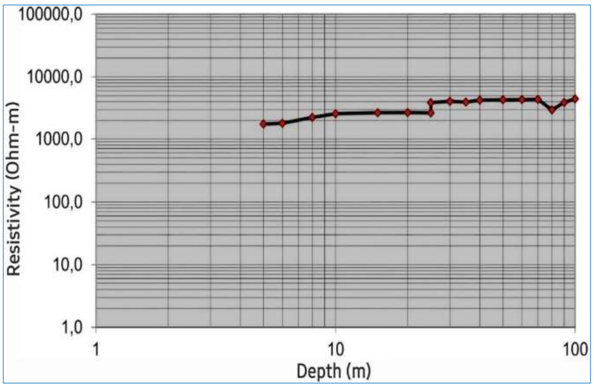

Fig. 10. DES-2 measurement curve

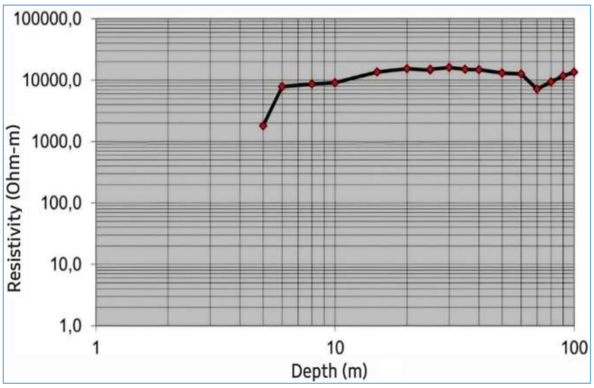

Fig. 11. DES-3 measurement curve

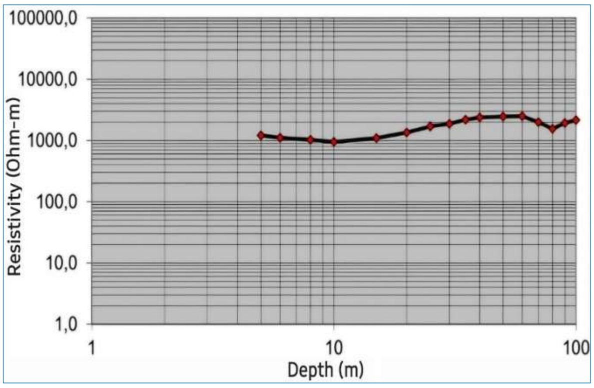

Fig. 12. DES-4 measurement curve

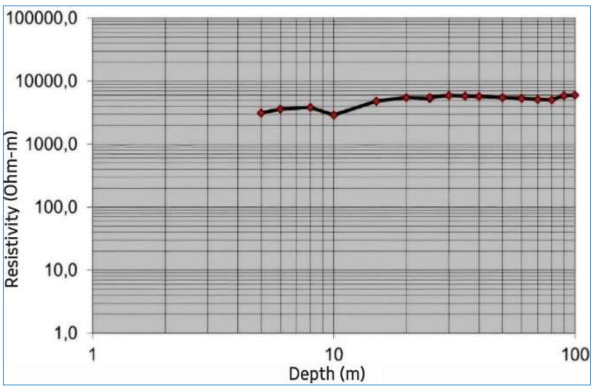

Fig. 13. DES-5 measurement curve

These rocks are represented by yellow, red, and white color tones. The rocks in the study area have low magnetic properties. Since the rocks in the study area show high gravity and low magnetic values, they are considered to be very suitable for quarry, provided that they are suitable for technological analysis.

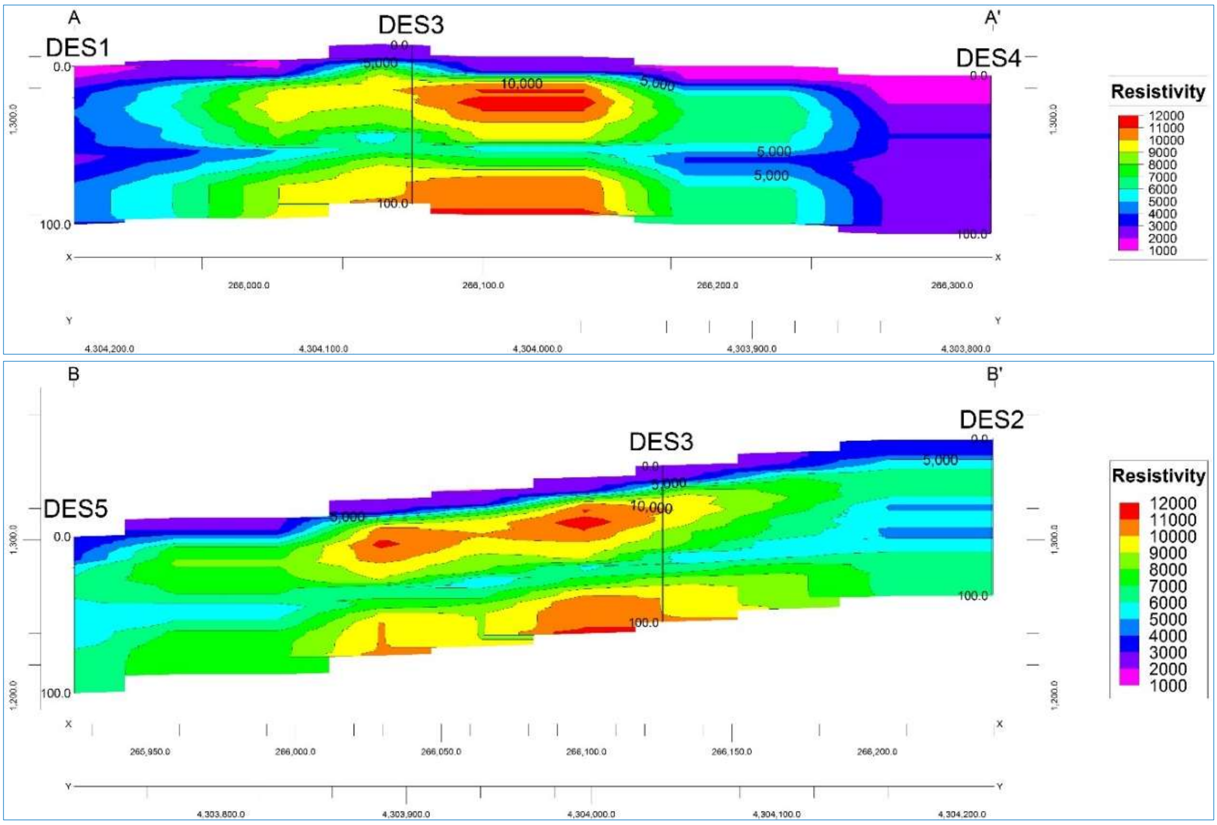

Fig. 14. Geoelectrical cross-sections along profiles A-A' and B-B' (see Fig. 5)

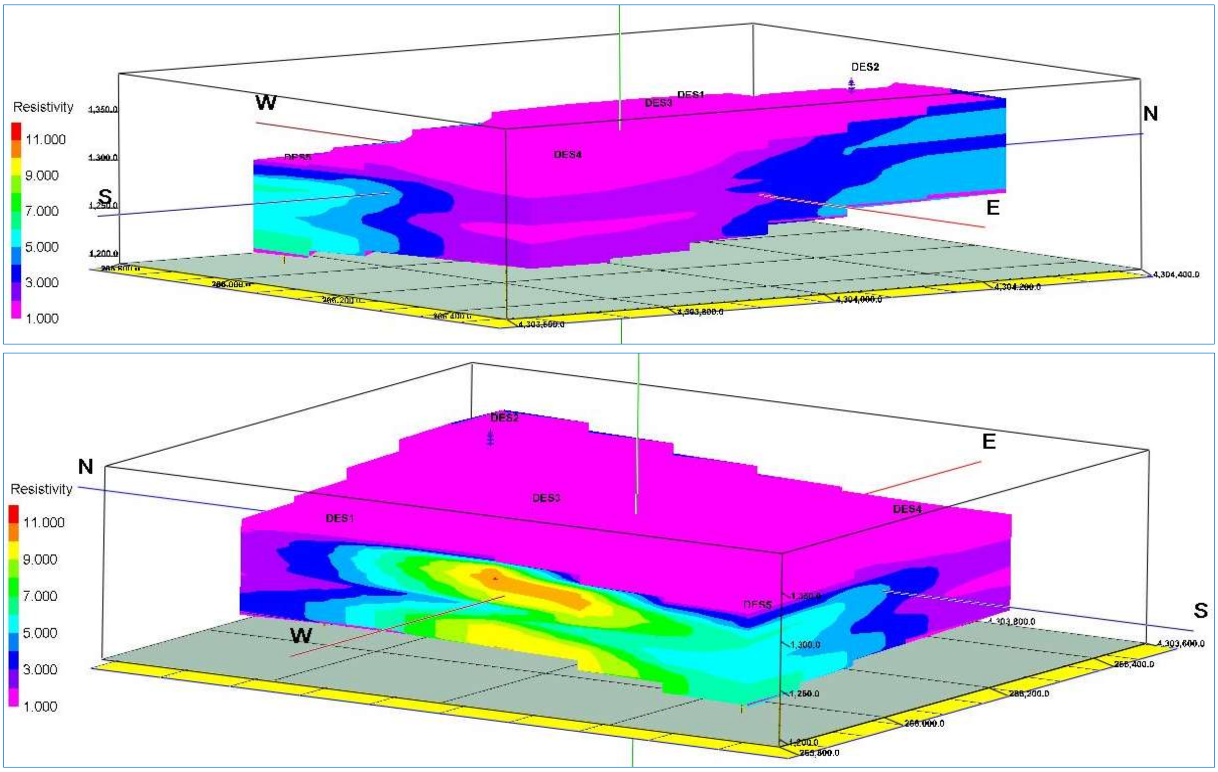

Fig. 15. 3D model of resistivity measurements in the study area

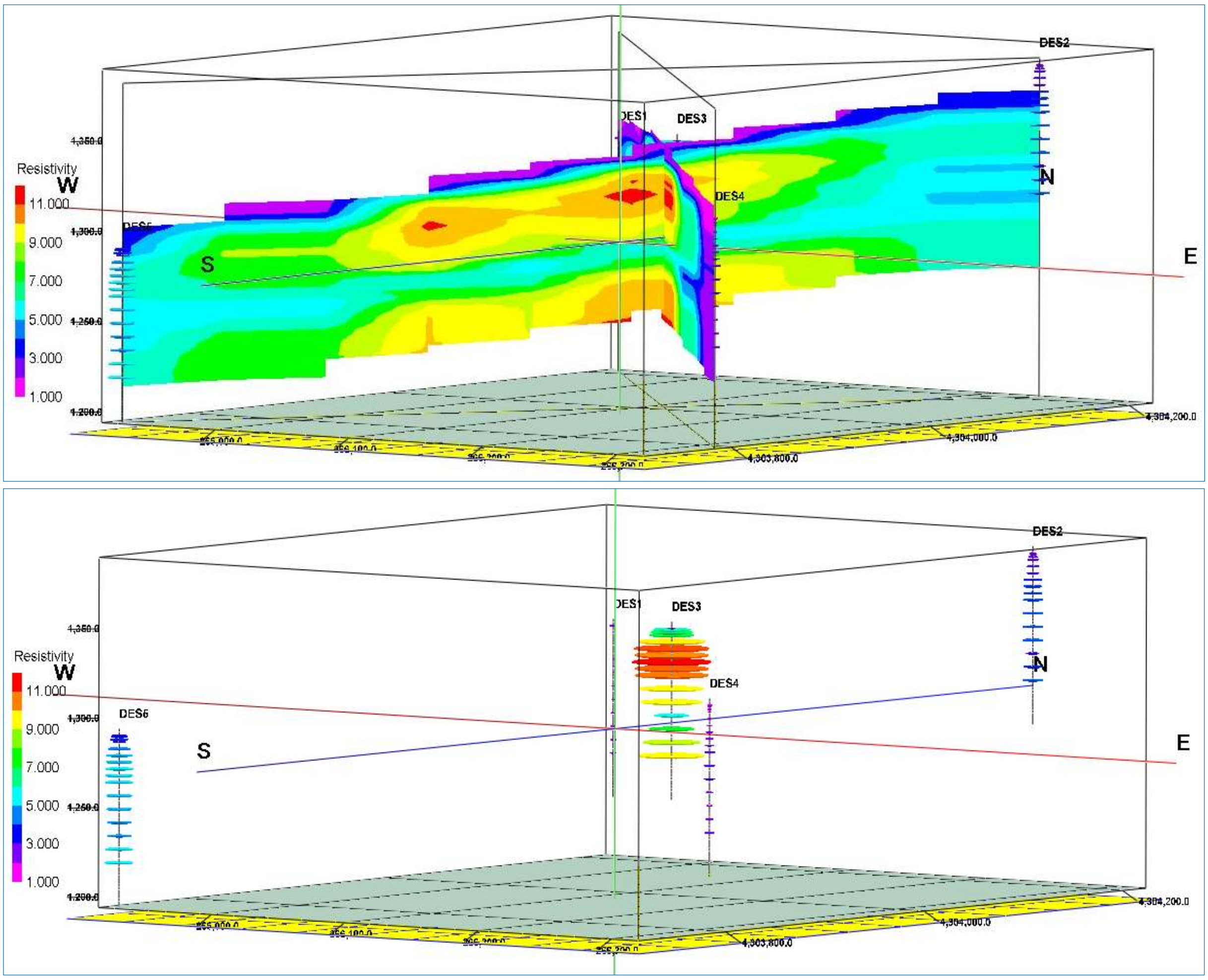

Fig. 16. Fence diagrams of resistivity measurements in the study area

3.1.2. 1D Geoelectrical Model

In the study area, 5 resistivity measurements were made with AB/2 = 100 m. The locations of the measured VES points in the study area are given in Table 1 and Fig. 8. Since the purpose of the geoelectrical survey in the study area is to examine the changes of geological units towards depth, the Schlumberger electrode array was used in VES measurements.

In the DES-2 measurement (Fig. 10), resistivity values of 1760.5-4457.0 ohm.m were measured. These values are quite suitable for massive limestone/marble-type rocks. Therefore, based on geological observations, it is interpreted that massive limestone/marble-type rocks are present at the DES-2 measurement location.

In the DES-3 measurement (Fig. 11), resistivity values of 1802.0-13418.2 ohm.m were measured. These values are quite suitable for massive limestone/marble-type rocks. Therefore, based on geological observations, it is interpreted that massive limestone/marble-type rocks are present at the DES-3 measurement location

In the DES-4 measurement (Fig. 12), resistivity values of 948.6-2489.4 ohm.m were measured. These values are quite suitable for massive limestone/marble-type rocks. Therefore, based on geological observations, it is interpreted that massive limestone/marble-type rocks are present at the DES-4 measurement location. In the DES-5 measurement (Fig. 13), resistivity values of 2892.5-6026.4 ohm.m were measured. These values are quite suitable for massive limestone/marble-type rocks. Therefore, based on geological observations, it was interpreted that massive limestone/marble-type rocks are present at the DES-5 measurement location.

3.1.3. 2D Geoelectrical Model

To better interpret the curves and evaluation results obtained as a result of VES measurements in the study area and the ground-electrical structure, 2 geoelectrical sections were prepared in the RockWorks program in SW-NE and NW-SE directions under the geological structure (Fig. 14). Cross-section A-A' is an NW-SE oriented cross-section. It was prepared by correlating the data of DES-1, DES-3, and DES-4 measurements. Resistivity values are high at all DES points. Resistivity values are quite high at the DES-3 point. The B-B' section is a cross-section in the SW-SE direction. It was prepared by correlating the data of DES-5, DES-3, and DES-2 measurements. Resistivity values are high at all DES points. Resistivity values are quite high at the DES-3 point.

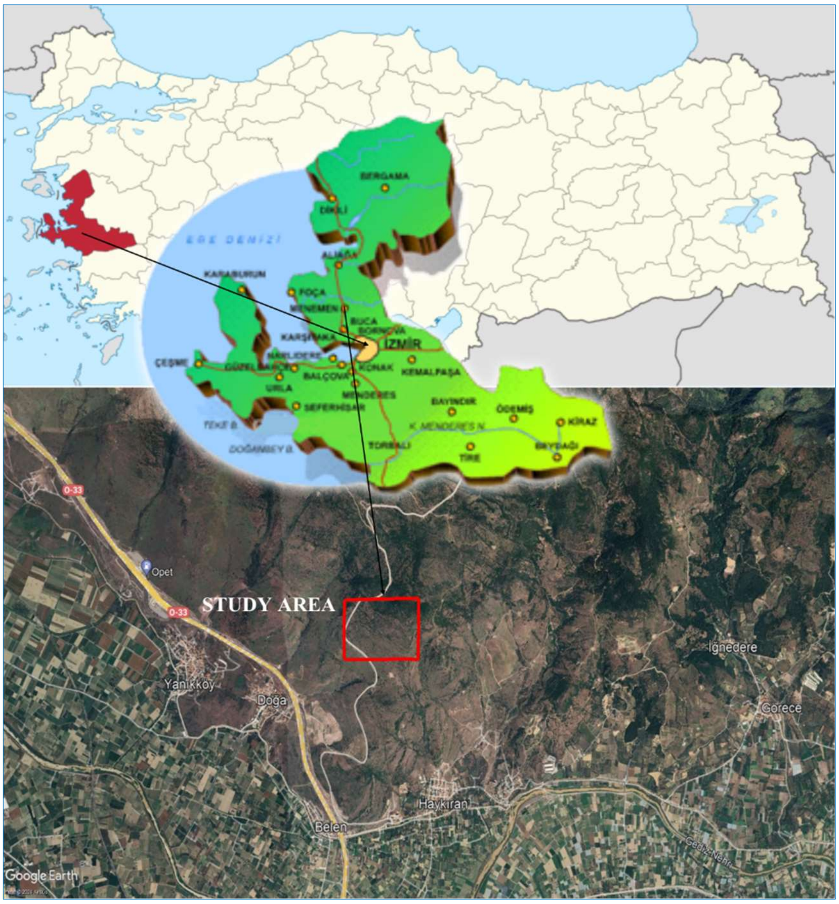

Fig. 17. Location map of Doğa potential quarry area

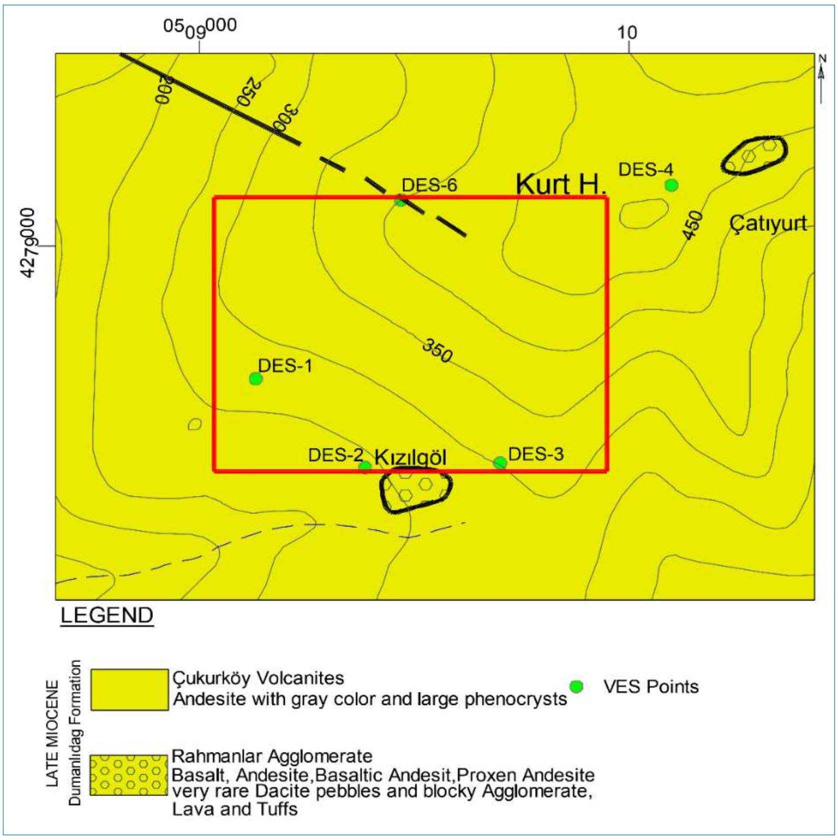

Fig. 18. Geological map of Doğa potential quarry area

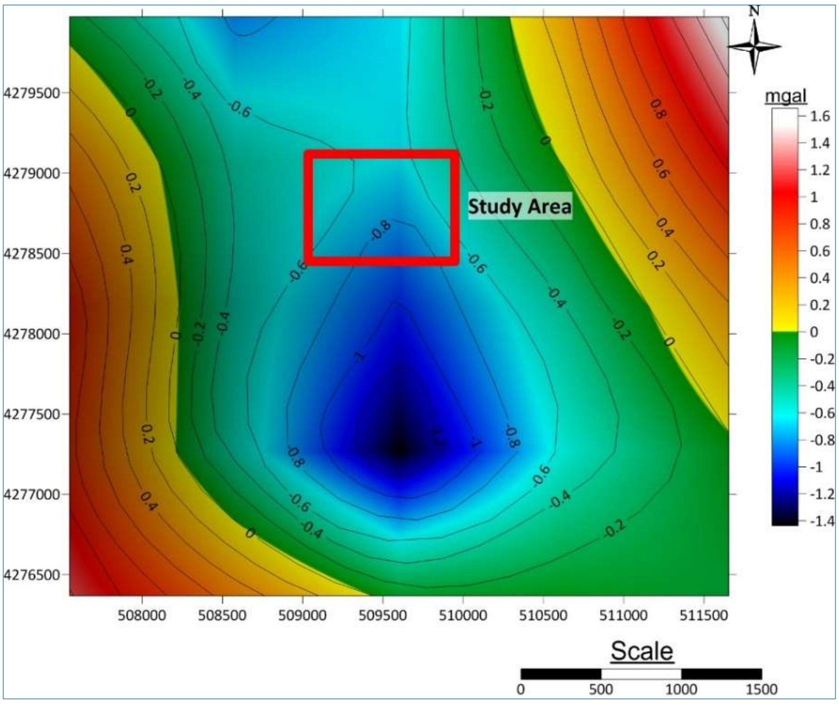

Fig. 19. Color contour map of residual gravity anomalies in and around the study area

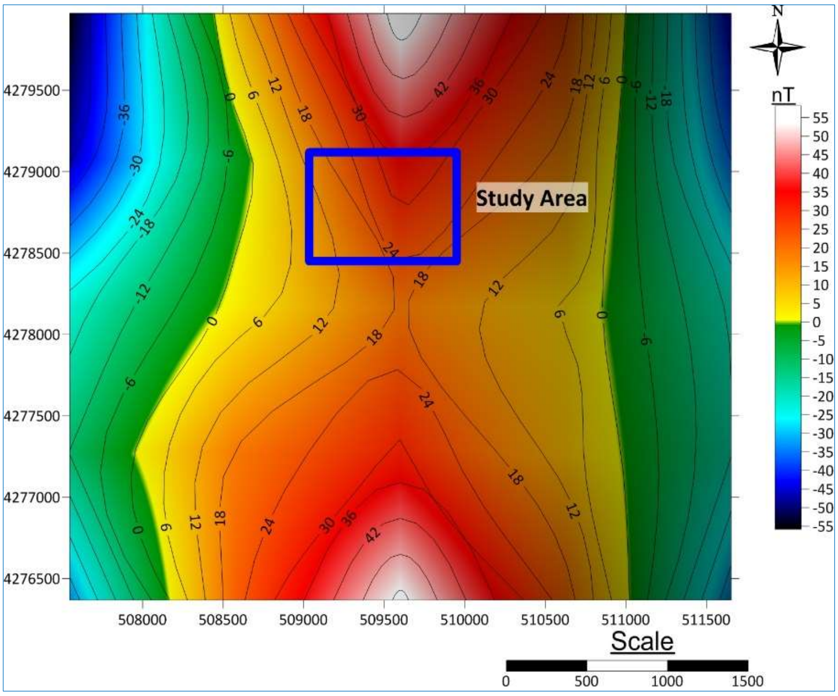

Fig. 20. Color contour map of residual airborne magnetic anomalies in and around the study area

3.1.4. 3D Geoelectrical Model

The 3D resistivity model prepared for the study area is given in Fig. 15 and Fence diagrams are given in Fig. 16. To comment on the subsurface geology of the study area, 3D resistivity models (solid model and panel diagram) are given with different directional views. The resistivity values measured in the study area are quite high and consistent with each other. This indicates that the rocks measured in the study area up to 100 m depth are mostly composed of the same units. Therefore, the study area is generally suitable for material supply provided that the technological analysis results are also positive.

3.2. Doğa Potential Quarry (Basalt) Area

The study area is located within the borders of the Menemen district of İzmir province (Fig. 17). In the study area, basalt, andesite, basaltic andesite, basaltic andesite, proxen andesite, very rare dacite pebbles and blocky agglomerated, lava and tuffs belonging to the Late Miocene Dumanlıdağ Formation are found. In very limited areas, hat-shaped limestone blocks were encountered (Fig. 18).

3.2.1. Aeromagnetic and Gravity Data

Regional gravity and aeromagnetic maps of the study area were first prepared (Figs. 19 and 20). In the gravity map prepared for the study area, low-density rocks (basalt, andesite, tuff, agglomerate, etc.) are represented by dark blue, light blue, and green color tones, and high-density rocks are represented by yellow and red color tones.

The area selected as a quarry is located in an area of low density (Fig. 19). If there were massive basaltic rocks in the study area, it would be expected that the study area would give high-density values in the gravity map.

Table 2. Coordinates of VES measurements measured in the study area

Measurement No	Coordinates	
	Y	X
DES1	509130	4278681
DES2	509385	4278464
DES3	509699	4278475
DES4	510095	4279144
DES6	509468	4279118

Fig. 21. Locations of the VES measurements in the study area

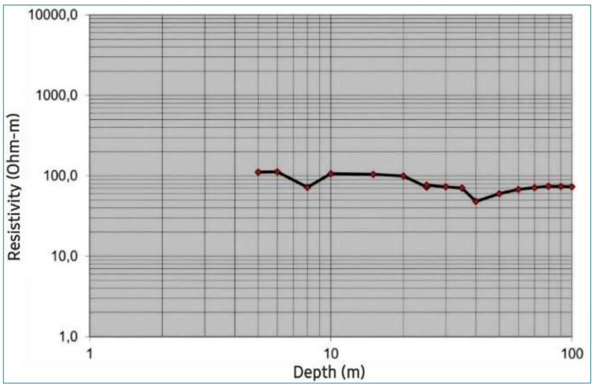

Fig. 22. DES-1 measurement curve

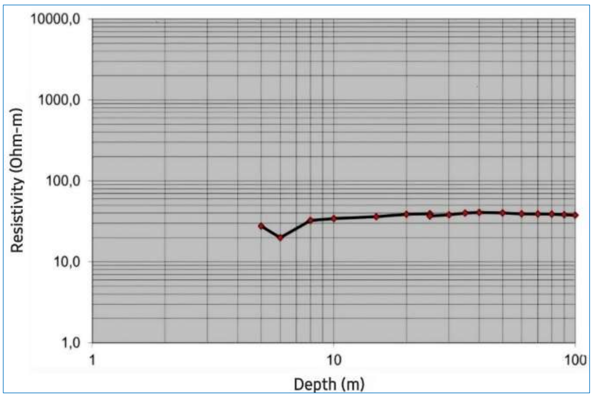

Fig. 23. DES-2 measurement curve

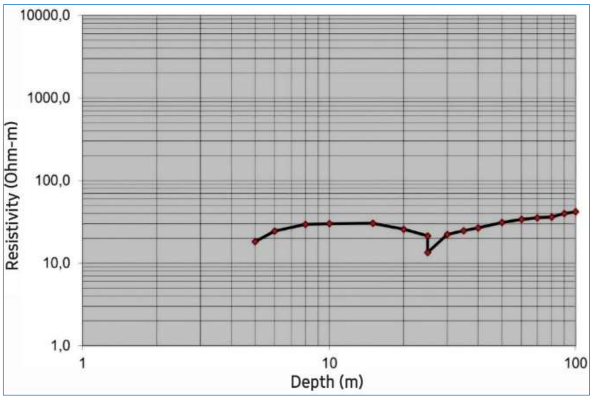

Fig. 24. DES-3 measurement curve

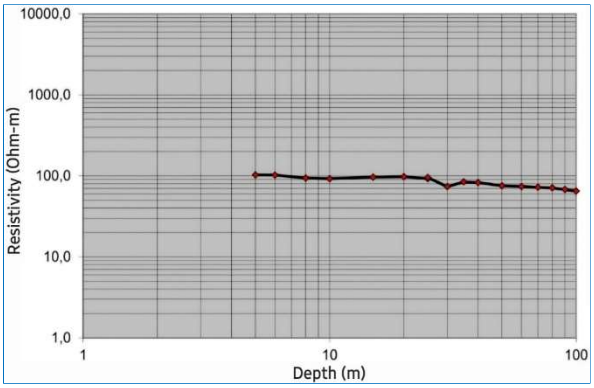

Fig. 25. DES-4 measurement curve

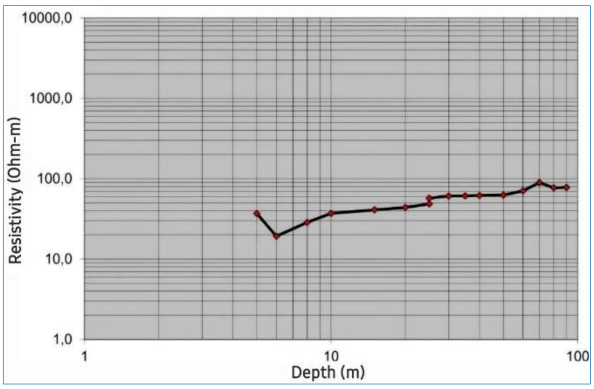

Fig. 26. DES-6 measurement curve

Geological observations revealed that the area is dominated by andesites and blocky agglomerates. In the prepared magnetic map, the areas with rocks that do not show magnetization (rocks of completely sedimentary origin) and rocks with low magnetization are represented by dark blue, light blue, and green color tones (Fig. 20). In other areas, rocks containing magnetizing minerals such as magnetite, ilmenite, pyrrhotine, etc. were found (andesite, etc.). These rocks are represented by yellow, red, and white color tones. Therefore, the selected area is not considered suitable for basalt supply according to its geological, gravity, and magnetic properties.

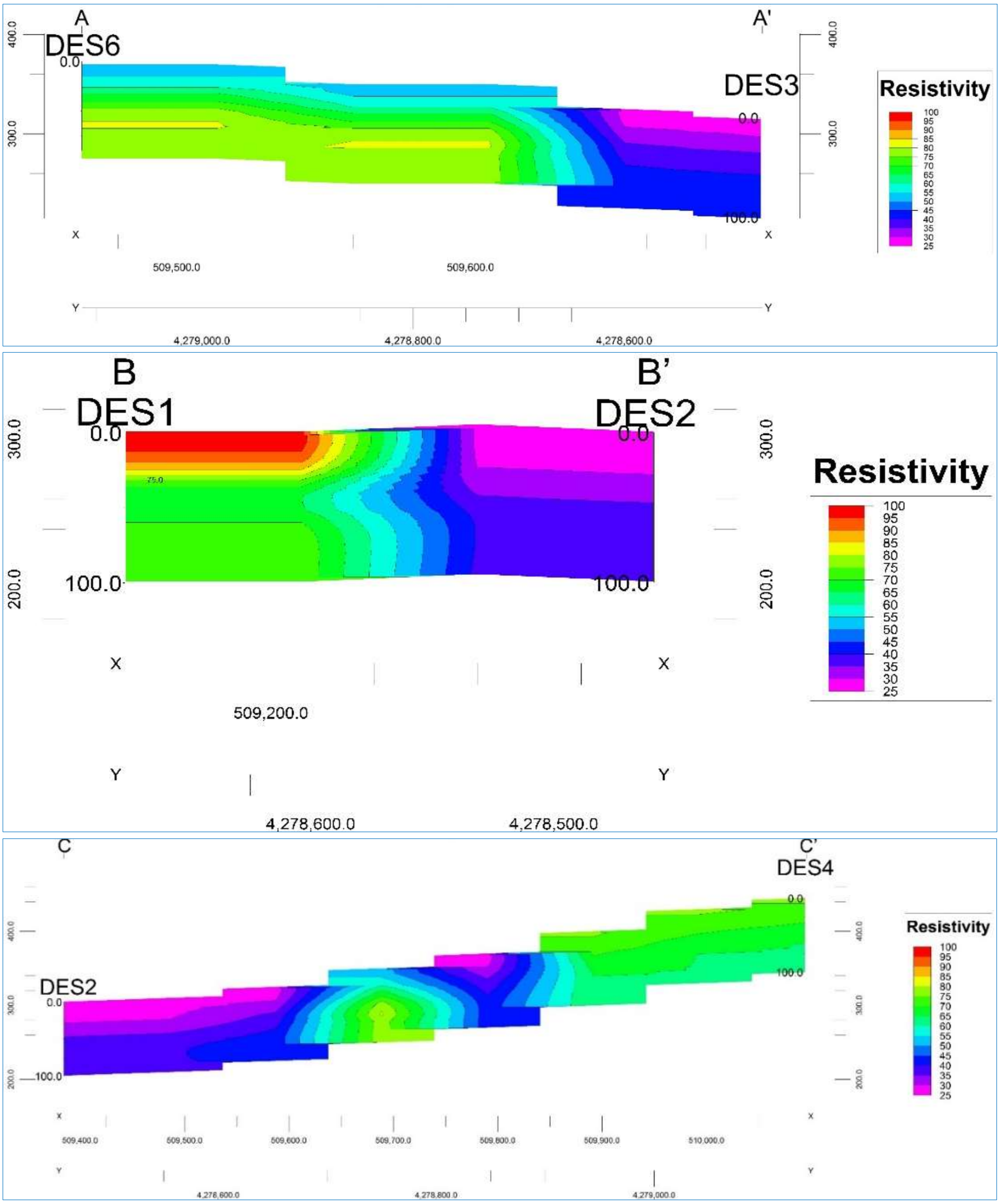

Fig. 27. Geoelectrical cross-sections along profiles A-A', B-B', C-C' (see Fig. 21)

3.2.2. 1D Geoelectrical Model

Five resistivity measurements were made in the study area with AB/2 = 100 m. The locations of the measured VES points in the study area are given in Table 2 and Fig. 21. Since the purpose of the geoelectrical survey in the study area is to examine the changes of geological units towards depth, the

Schlumberger electrode array was used in VES measurements.

In the DES-1 measurement (Fig. 22), resistivity values of 48.0-112.0 ohm.m were measured. These values are quite low for massive rocks. Therefore, based on geological observations, it is interpreted that altered/decomposed andesite and agglomerate, etc. type rocks are present at the DES-1 measurement location

In the DES-2 measurement (Fig. 23), resistivity values of 19.9-40.7 ohm.m were measured. These values are quite low for massive rocks. Therefore, based on geological observations, it is interpreted that altered/decomposed andesite and agglomerate are present at the DES-2 measurement location

In the DES-3 measurement (Fig. 24), resistivity values of 13.4-41.9 ohm.m were measured. These values are quite low for massive rocks. Therefore, based on geological observations, it was interpreted that altered/decomposed andesite and agglomerate are present at the DES-3 measurement location.

In the DES-4 measurement (Fig. 25), resistivity values of 64.9-102.7 ohm.m were measured. These values are quite low for massive rocks. Therefore, based on geological observations, it was interpreted that altered/decomposed andesite and agglomerate are present at the DES-4 measurement location.

In the DES-6 measurement (Fig. 26), resistivity values of 19.3-89.6 ohm.m were measured. These values are quite low for massive rocks. Therefore, based on geologic observations, it is interpreted that altered/decomposed andesite and agglomerate are present at the DES-6 measurement location.

3.2.3. 2D Geoelectrical Model

To better interpret the curves and evaluation results obtained as a result of VES measurements in the study area and the ground-electrical structure, 3 ground-electrical sections were prepared in the RockWorks program in SW-NE and NW-SE directions following the geological structure. Sections A-A' and B-B' are NW-SE-oriented sections.

They were prepared by correlating the data of DES-6 and DES-3 and DES-1 and DES-2 measurements. Resistivity values are quite low at all VES points. The C-C' cross-section is a cross-section in the SW-NE direction (Fig. 27). It was prepared by correlating the data of DES-2 and DES-4 measurements. Resistivity values are very low at all VES points.

3.2.4. 3D Geoelectrical Model

The 3D resistivity model prepared for the study area is given in Fig. 28 and Fence diagrams are given in Fig. 29. To comment on the subsurface geology of the study area, 3D resistivity models (solid model and panel diagram) are given with different directional views.

The resistivity values measured in the study area are quite low. This indicates that the rocks measured in the study area up to 100 m depth are composed of different units. Therefore, the study area is not suitable for the supply of basalt-type material according to geological observations geophysical data, and measurement values

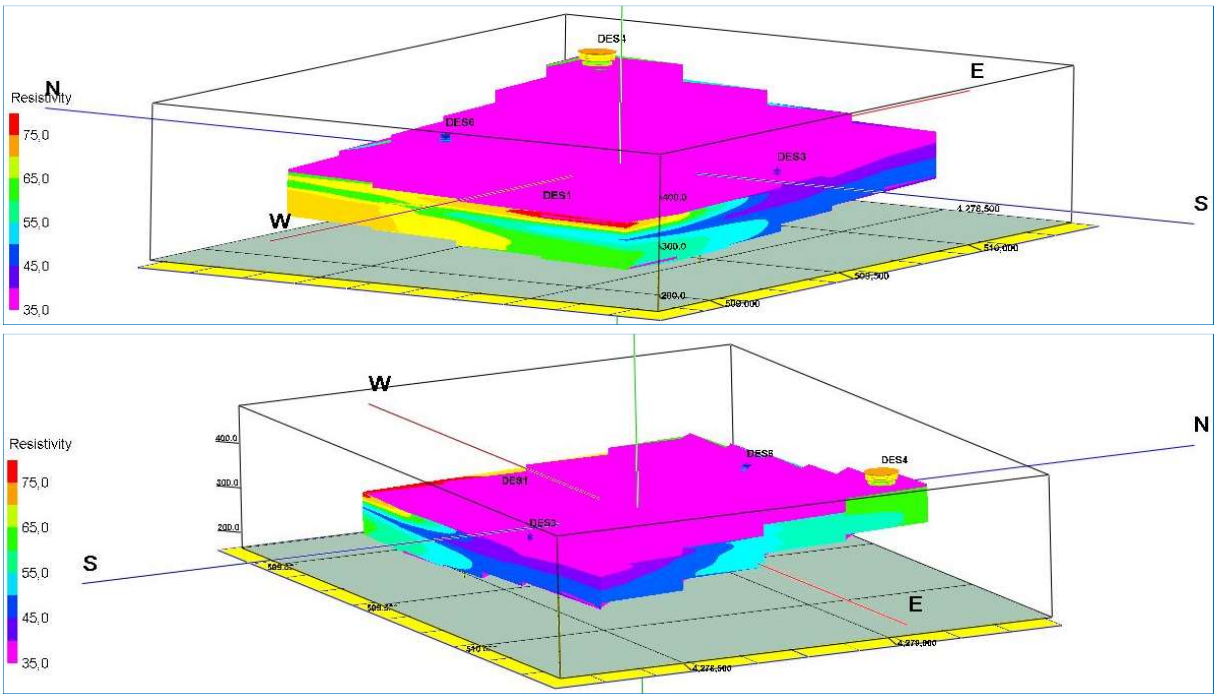

Fig. 28. 3D model of resistivity measurements in the study area

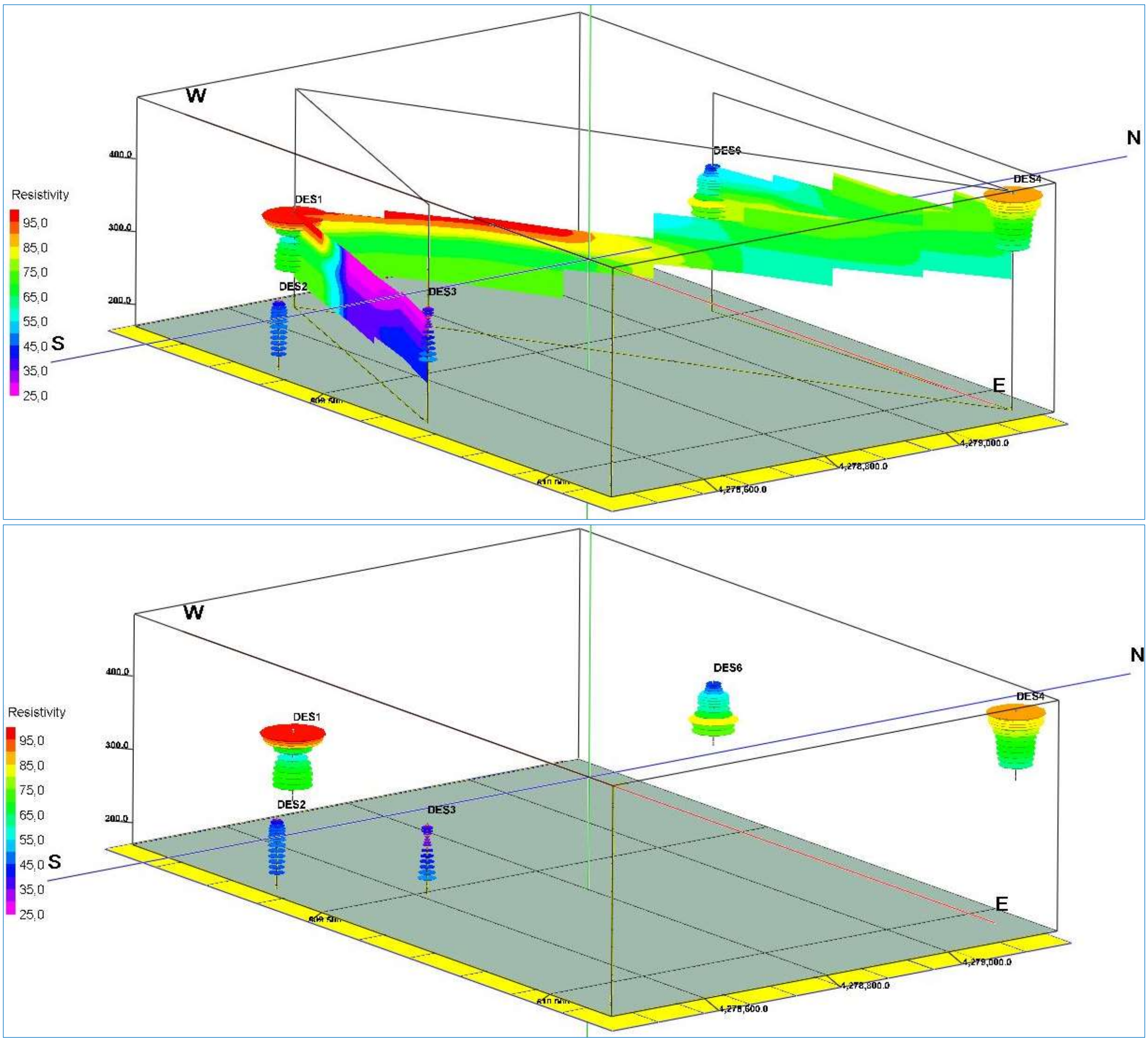

Fig. 29. Fence diagrams of resistivity measurements in the study area

5. Conclusion

Within the scope of the study, firstly, regional gravity and airborne magnetic data were obtained, and maps were prepared and interpreted to estimate the presence, thickness, and vertical and lateral extent of limestone and basalt in the areas selected as quarries by geophysical methods. In the second stage, in-situ geological observations were made to examine the geological characteristics and to guide the geophysical measurements to be made in these areas. In the third stage, geophysical measurements were carried out at suitable locations determined by geological observations. In the last stage, 3D geophysical subsurface modeling of the study areas was carried out in light of the geophysical data obtained.

As a result of the studies, İğdeli potential quarry site was evaluated as suitable for a limestone quarry according to geological observations, geophysical data and measurement values, provided that it is suitable for technological analysis. It was concluded that the Doğa potential quarry site is not suitable for a basalt quarry according to geological observations, geophysical data and measurement values.

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