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MAPPING RAW MATERIAL FOR BRICK INDUSTRIES UTILIZING ELECTRICAL RESISTIVITY, INDUCED POLARIZATION, AND GEOTECHNICAL PROPERTIES IN KURDISTAN REGION, NORTHEAST IRAQ

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ABSTRACT

Electrical Resistivity and Induced Polarization Imaging (ERI and IPI) techniques are selected as non-destructive procedures, which provide continuous imaging of the subsurface. Recently, the demand has increased for obtaining raw materials that represent a more suitable and economical quantity of clay mass for brick industries. This is because of the unexpected expansion of cities and rising demand for brick materials due to their excellent characteristics of resisting earthquakes and isolation. The present study aims to delineate the extensions of the economic layer used for brick's raw material in Sulaymaniyah Province. For this purpose, the ERT and IPI integrated with physical and geochemical analyses were carried out in three separate locations nominated as 1, 2, and 3. The ERI and IPI survey was conducted in these locations by using a Wenner-Schlumberger array with electrode spacing equal to 5 meters. The 2D data were processed, interpreted, and modified to depth view as 3D estimations for each location. The resistivity range of clay for the brick industry was revealed according to the 2D ERI model of the Aso brick quarry and the suitability of this clay was assessed depending on geotechnical parameters, chemical composition, and mineralogical analysis. It is found that the resistivity values of clay range between 7 and 11 Ωm and silty clay from 11 and 13 Ωm, which are suitable for the brick industry. Additionally, the three locations are suitable for clay or silty clay and locations 1 and 2 are economically acceptable since the clay (or silty clay) layer is exposed to the surface. There is an economic quantity in the three surveyed locations estimated as approximately 240000, 330000, and 160000 m^3 for locations 1, 2, and 3, respectively. Further, the IP survey is found to be the most suitable technique used with ERI to indicate the exact boundary of clay mass due to its high capability of electrical storage. The most optimal amount of the chargeability of suitable clay layers is found as equal to more than 5 mV/V and silty clay from 0.9 to 5 mV/V.

INTRODUCTION

Since the ancient Mesopotamian civilization, brick has been the dominating building material in Iraq (Al-Assadi and Al-Dewachi, 2020). Recently, many brick factories in Iraq and the Iraqi Kurdistan Region were built due to a great demand for brick because of their special characteristics in the fields of thermal conductivity and sound isolation (Pacheco-Torgal *et al*., 2014). Brick is one of the most important industrial applications of clay. Clays are detritic materials that form as a result of physical weathering and subsequent chemical reactions. Different types of clay that obtain different properties for brick were formed

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depending on the initial source rock, environmental conditions, topography (basin), and reaction duration (Kornmann, 2007). Only the Aso Brick Factory and the Ashur Brick Factory require one million tons of clay per year. Therefore, detecting suitable claystone with an acceptable thickness for the brick industry is a significant commitment. ERI shows significant imaging of the different resistivity values, especially sand and clay content (Uhlemann *et al*., 2017). Previous studies, such as Baban and Aziz (2015); Aziz (2013); Uhlemann *et al*. (2017); Gardi *et al*. (2013); Gardi (2014); Momhammed *et al*. (2019); Chretien *et al*. (2014); Gunn *et al*. (2015); Rucker *et al*. (2021) and Mashhadi (2022) dealt with utilizing electrical resistivity for subsurface studies, including lithological evaluation and detecting clay layers. In this study, the geophysical method was selected to assess three locations near the high-product brick factories in Sulaymaniyah City, in the Kurdistan region of Iraq. 2D Electrical Resistivity Imaging (ERI) and 2D Induced Polarization Imaging (IPI) were employed in this study. The ERI operates by passing a current through two current electrodes and detecting the difference in voltage between two other potential electrodes that occurs. The ERI combines recorded apparent resistivity values to create pseudo-section profiles (contoured resistivity value diagrams) of the subsurface. Each apparent resistivity measurement's sensitivity, resolution, and incorporation of noise are all influenced by how the four electrodes are arranged or distributed. By using an iterative numerical inversion, the apparent resistivity can be changed to actual resistivity values (Smith and Sjogren, 2006).

Laboratory tests for the raw materials used in the brick factory are required to determine the resistivity value of the clay and silty clay. These tests are usually used to demonstrate the applicability of the clay in the brick industry, such as mineral composition, chemical composition, and geotechnical parameters. The geotechnical parameters of the clay such as plastic properties, particle size distribution, moisture content, salt content, and clay content strongly control the resistivity value (Long *et al*., 2012) (Gunn *et al*., 2015) (Kibria and Hossain, 2012). Other researchers considered essential properties for suitable clay in the brick industry, such as mineral composition, loss on ignition, and calcium carbonate content (Akintola *et al*., 2020) (Awadh and Abdullah, 2011) (Merza and Mohyaldin, 2005). By combining the data and comparing the results, it can present a suitable location with detailed imaging for the quarry.

GEOLOGY OF THE STUDY AREA

The study area is located in the Chamchamal area, about 50 Km southwest of Sulaymaniyah City, and covers an area of about 60 Km^2, as shown in Figure (1). From a tectonic point of view, it is located within the Low Folded Zone. According to Buday and Jassim (1987), the area is covered by the Injana Formation (Late Miocene), which is partially overlain by a thin layer of recent sediments 0.5 to 1 m thick (Figure 2). High compact sandstone, siltstone, and claystone alternation characterize the Injana Formation (Jassim and Buday, 2006). Many researchers have demonstrated that the Injana Formation is suitable as a raw material for the brick industry (Merza and Mohyaldin, 2005) (Mirza and Faraj, 2017) (Surdashy and Aqrawi, 2021) (Al-Jawadi *et al*., 2021). However, the quantity and quality of the claystone cause many difficulties because of the depositional environment of the Injana Formation, which is considered a fluvial, coastal, and near-shore river environment (Al-Juboury, 2009). So, the quantity of raw materials is not easy to evaluate because of variations in the thickness and maintenance of the bed as well as in particle size distribution, which are the main characteristics of the fluvial system (Miall, 2014) and clay brick properties are essentially affected by grain size (Uhlemann *et al*., 2017).

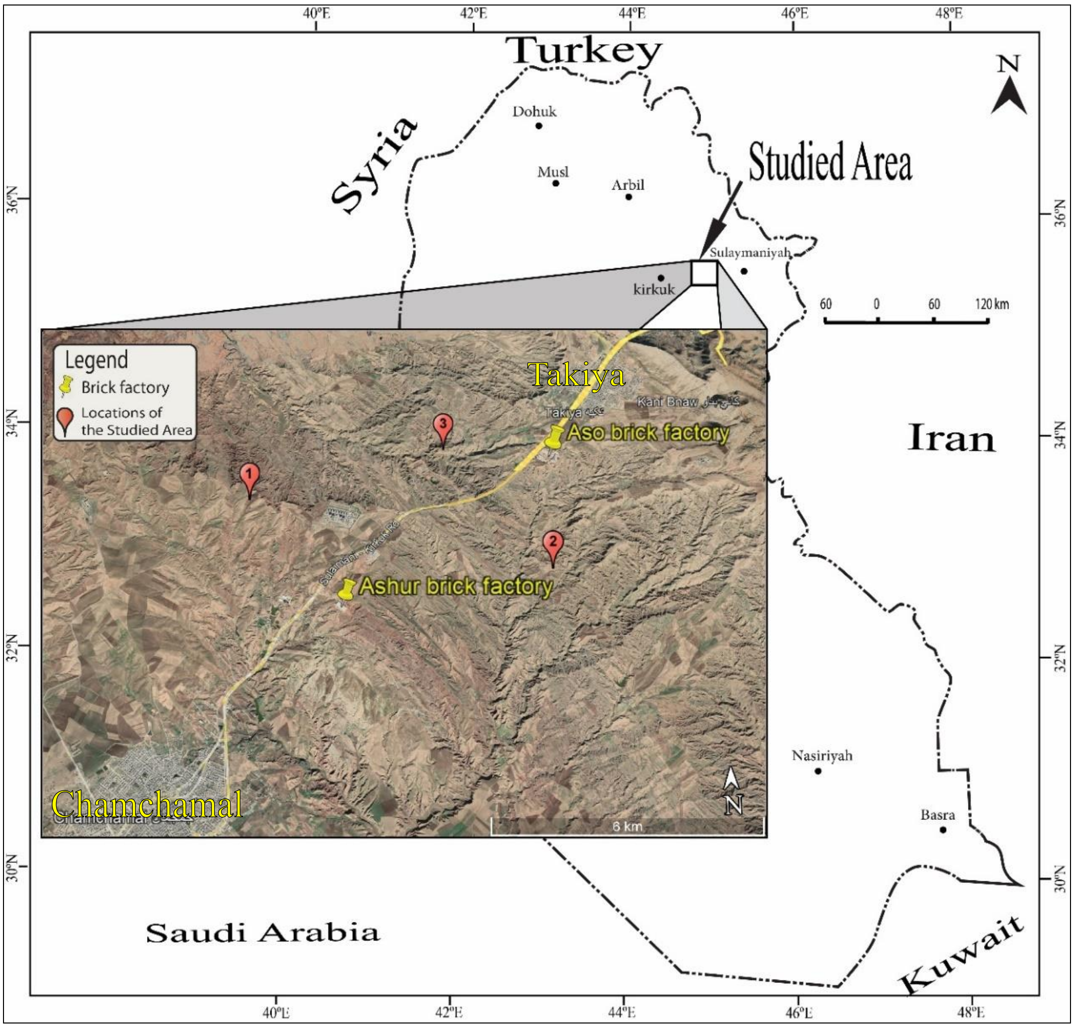

Figure 1: Location map of the study area with an inset (zoomed) of a Google Earth image showing its topography and the studied locations 1, 2, and 3.

METHODOLOGY

The acquired resistivity data were inverted to 2D ERI by utilizing Geotomo Software that commercialized the RES2DINV program (Loke, 2004) and by using Adobe Illustrator to combine the 2D model of three profiles into a 3D view. A Wenner-Schlumberger array was used with an electrode spacing of 5 and 72 electrodes. The 3D view is represented by carrying out three profiles in each location and it represents a subsurface block with a dimension equal to (355 × 100 × 40) m^3. The distance between the profiles is equal to 50 meters and the maximum depth of the investigation is 40 meters. For more certainty, IPI is also performed to verify the electrical resistivity modeling because electrical resistivity is oppositely involved with changeability in the clay (Rucke *et al*., 2021). On the raw materials of the Aso brick quarry, a 2D ERI and 2D IPI profile was performed to determine a reference range of resistivity and changeability that can be more dependable for the other selected locations. Furthermore, plastic properties and particle size distribution based on (ASTM, 2007) were measured in the Aso brick factory lab, and chemical analysis by x-ray fluorescence (XRF) was performed in the research laboratory of the geology department at the University of Soran, and mineral constituents (XRD) were determined in the research laboratory of the geology department at the University of Sulaymaniyah.

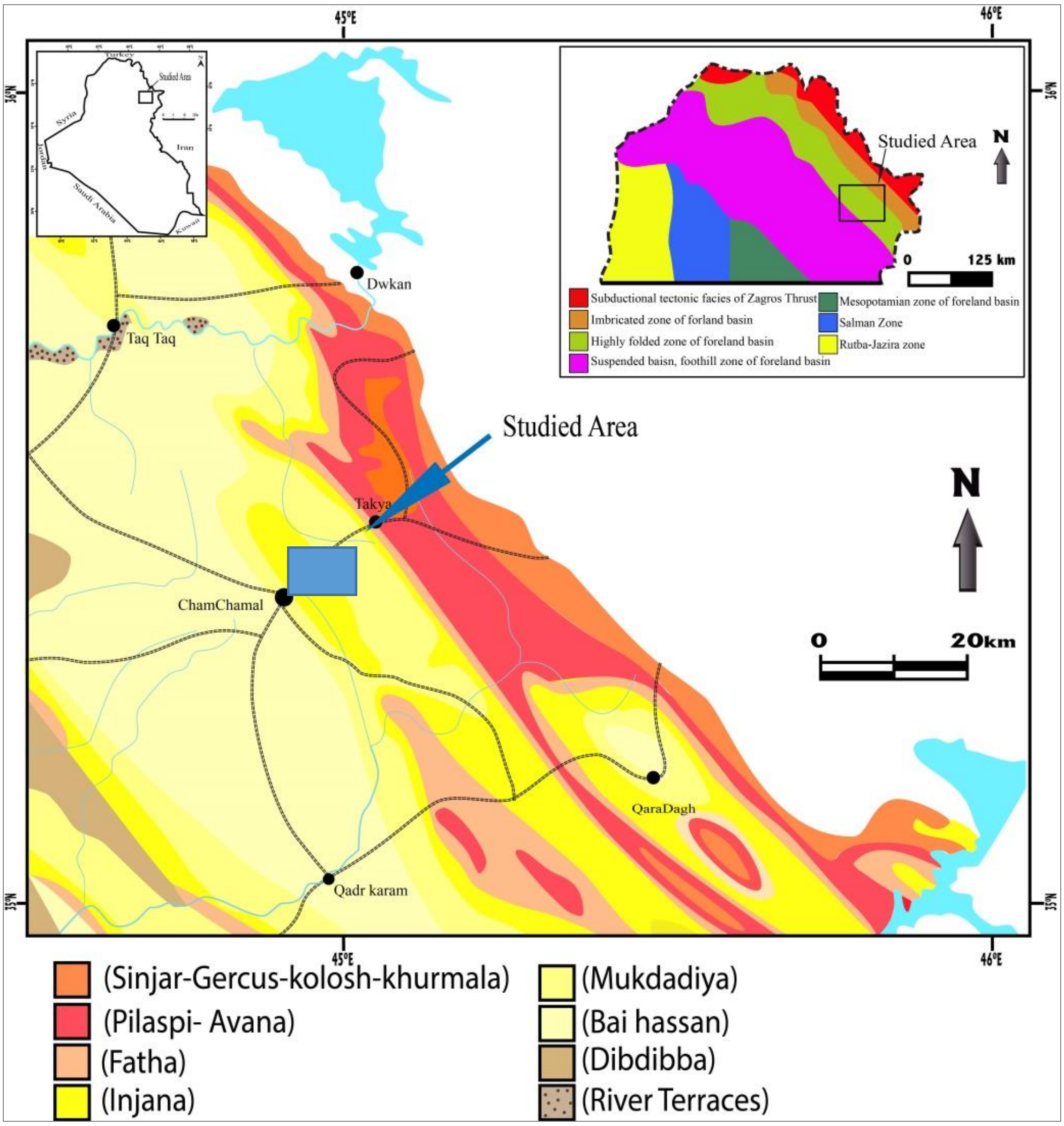

Figure 2: Geological map of studied area after (Sissakian, 2000).

RESULT AND DISCUSSION

- **Determination of clay layer properties**

Four samples were collected in the quarry of the Aso brick factory, where there is an obvious outcrop of a clay layer, which is continuously used as a raw material. The plastic limit, liquid limit, and plastic index are 20%, 39%, and 19%, respectively. According to the Bain and Highley diagram (Bain and Highley, 1979). The result demonstrates that the clay has optimum molding properties, as shown in Figure (3). The result of grain size analysis showed that the major component of the samples is silt made up 57% of the whole sample, clay is about 33%, and sand content is equal to 10%. Therefore, according to the USDA analysis diagram (García-Gaines and Frankenstein, 2015) they are classified as silty clay as shown in Figure (4). It is also verified that according to the Winkler diagram (Winkler, 1954), the samples are located in zone (D), which is used for hollow clay products, as shown in Figure (5). The chemical composition of the clay affects the properties of the brick. For example, silica acts as the backbone and an opening agent, alumina improves plasticity, lime, and magnesia perform as fluxes, and iron oxides provide the red color (Kornmann, 2007). Therefore, according to the triangular diagram that was proposed by (Fabbri and Fiori, 1985), the result of the chemical analysis shows that the clay layer is used as a raw material for red bodies, as shown in Figure (6). The result of the chemical analysis is shown in Table 1. It also specifies the acceptable element range for the brick industry according to Kornmann (2007). According to mineralogical analysis using x-ray diffraction, the main clay minerals are illite and chlorite which give moderate properties for brick (Kornmann, 2007), with traces of kaolinite, as shown in Figures 7B and C, and the non-clay minerals are composed of quartz and calcite, as shown in Figure 7A.

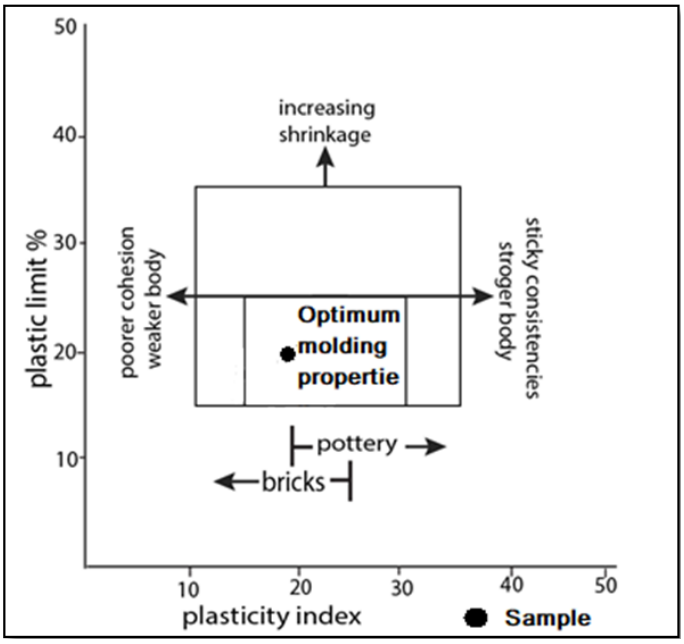

Figure 3: Determination of clay suitability of the studied sample on the Clay Suitability Chart (Bain and Highley, 1979).

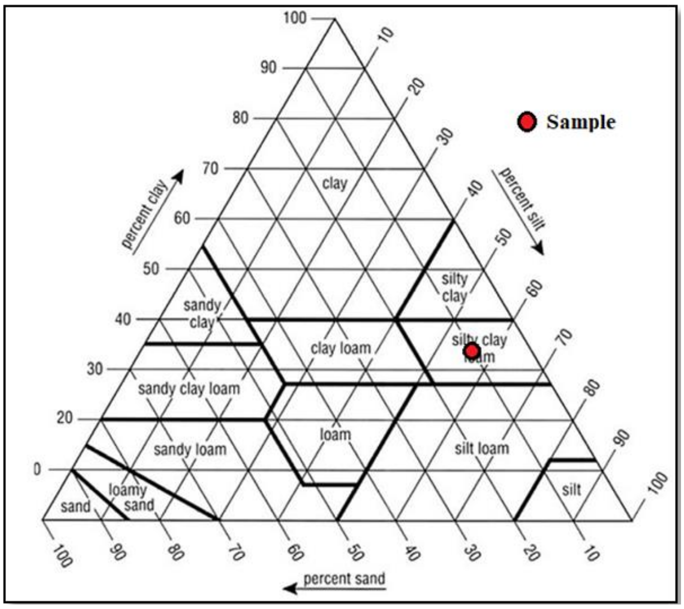

Figure 4: Determination of soil classification of the studied sample on the USDA diagram (García-Gaines and Frankenstein, 2015).

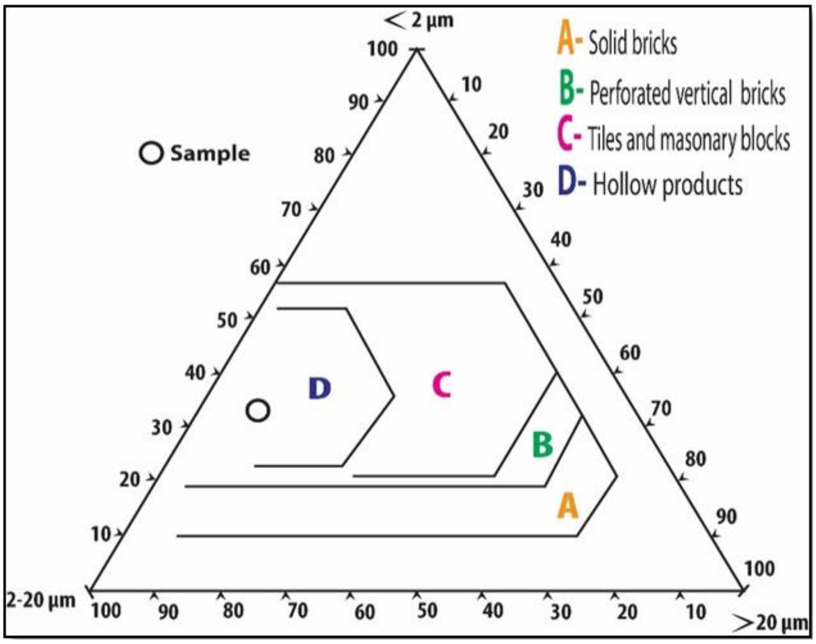

Figure 5: Determination of clay suitability of the studied sample on the Winkler diagram (Winkler, 1954).

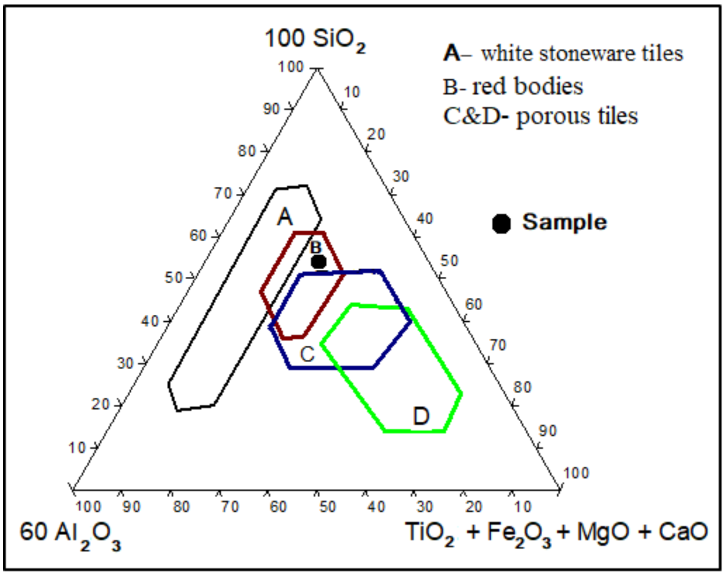

Figure 6: The chemical composition of the studied clay sample posted on the Fabbri and Fiori diagram to show the suitability of the clay layer as a red body (Fabbri and Fiori, 1985).

Table 1: Results of chemical analysis of the studied sample.

Oxides	SiO_2	Al_2O_3	TiO_2	CaO	MgO	MnO	Fe_2O_3	K_2O	P_2O_5	SO_3	Cl	Total
Percent	57.62	14.78	0.0796	9.451	8.799	0.032	6.413	2.389	0.129	0.232	0.01	99.9

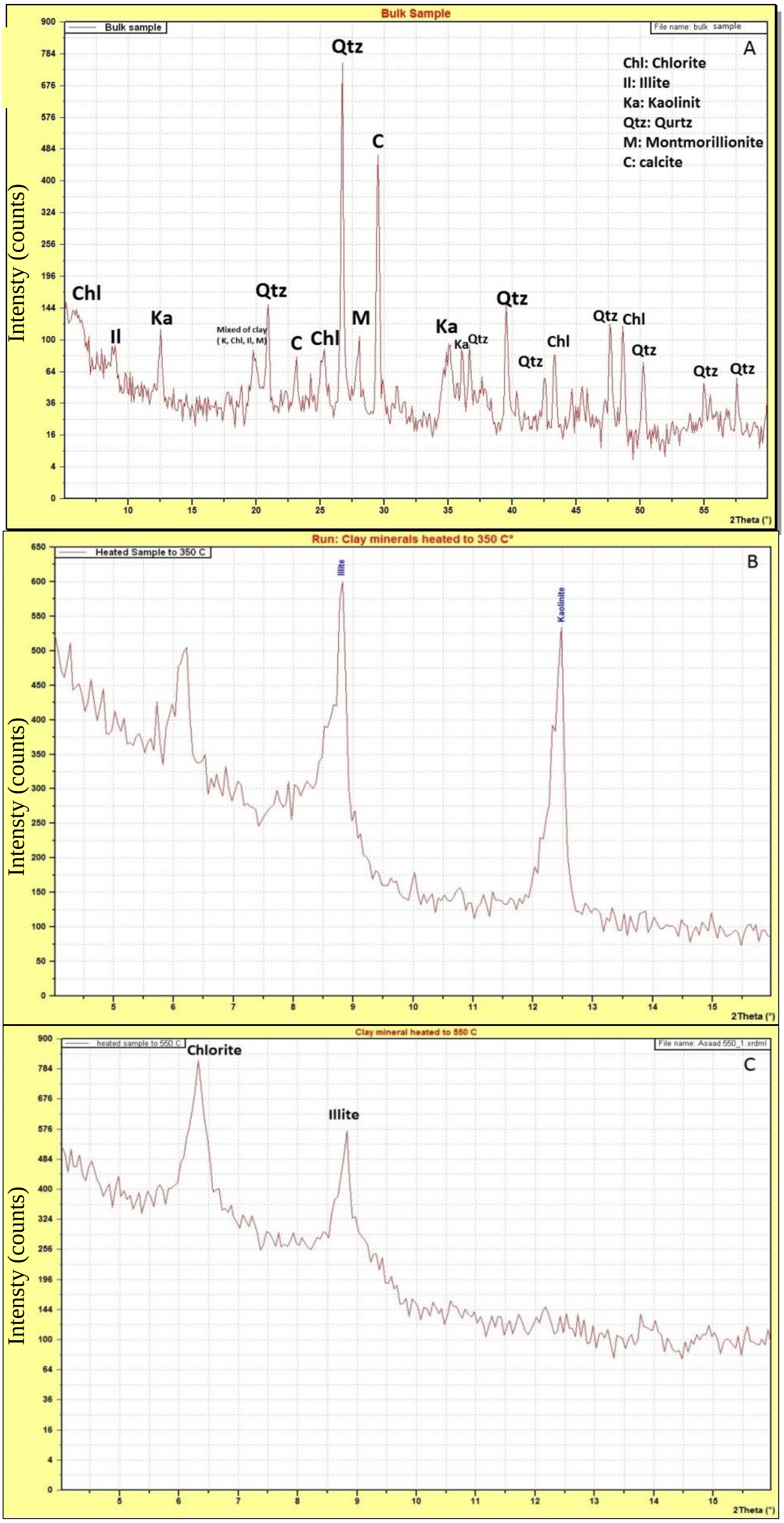

Figure 7: X-ray diffraction pattern for studied four samples. **A:** Bulk sample, **B:** heated up to 350 °C, **C:** heated up to 550 °C.

- **2D ERI and IPI of Aso brick quarry**

The optimal and more realistic ranges of both resistivity and changeability are of great importance for the sake of comparison with those obtained in the selected locations. So, the data is acquired along the Aso brick quarry where the pure clay and silty clay acceptable for the brick industry are clearly identified and used continuously. One 2D profile has a length of 355 m and is carried out with electrode spacing equal to 5 m. This gives the maximum depth of investigation of 40 m, where electrical resistivity and chargeability were measured simultaneously. The inversion was carried out for both datasets with the most suitable parameters. The inverted sections are shown in Figures (8 and 9). The inverted section of the 2D ERI, Figure (8), emphasizes that in some restricted locations below the subsurface, pure clay is detected (dark blue color). The section displays a resistivity ranging from 7 to 11 Ωm, and most of the subsurface is composed of silty clay and clayey silt with resistivity ranging from 11 to 13.1 Ωm and 13.1 to 17 Ωm, respectively. In addition, silt, sandy silt, and silty sand are detected in a small portion that shows a resistivity range from 19 to 26 Ωm, and represents a brown to dark red color. The IP inverted section figure (8) shows the large chargeability of pure clay as it is predicted to be more than 5 mV/V and the chargeability of silty clay ranges from 0.9 to 5 mV/V. The IPI shows a brown to red color for clay and a dark red to purple for silty clay. Also, by comparison, the electrical resistivity to the chargeability demonstrates that chargeability increases with increasing clay content and oppositely decreases electrical resistivity when increasing clay content.

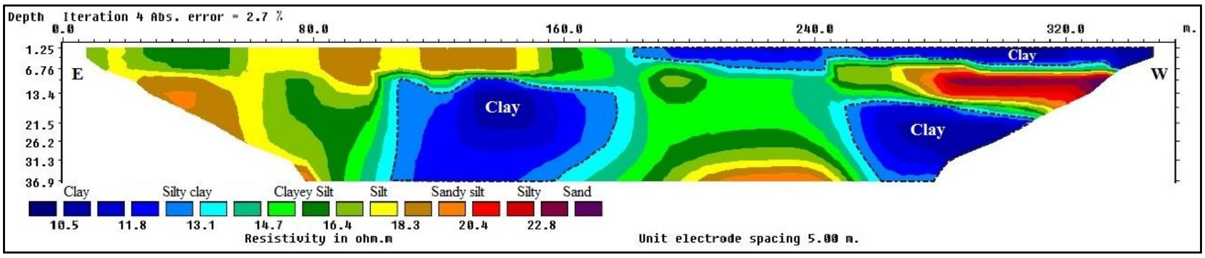

Figure 8: 2D Electrical Resistivity Imaging along a profile in Aso brick quarry.

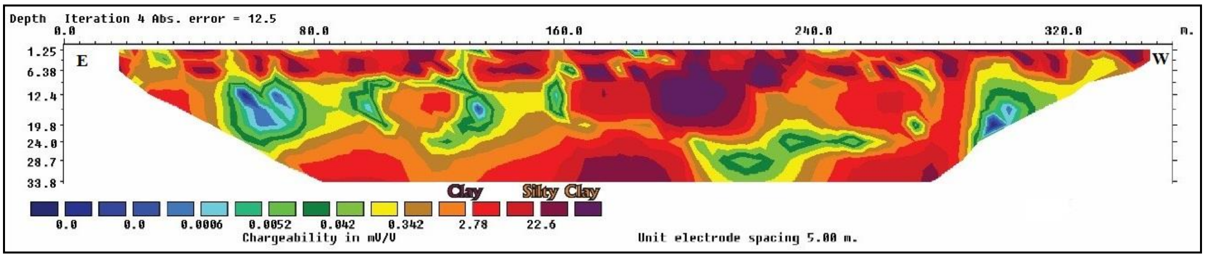

Figure 9: Induced Polarization Imaging along a profile in Aso brick quarry.

- **3D View of three ERI and 2D IPI of the selected locations**

The 3D view was performed by using the latest version of Adobe Illustrator 27.0 (2022), which significantly displays the subsurface clay layer and 2D IPI, verifying the results of the locations. Each 3D view was represented by three 2D inverted sections that were investigated along 355 m of length, 100 m of width, and 33 – 38 m of depth. The data was collected using the latest version of the RES2DINV program (version 4.10.20, 2020) (Prosys III). After processing, the data showed a smooth inversion with good quality, and the bad data were removed manually before the inversion process. Consequently, the resistivity range of the suitable raw material in the Aso brick quarry was specified.

– **ERI of location 1:** Location 1 is located in the north of Chamchamal Town as shown in Figure (1) where thin recent sediments and the Injana Formation are outcropped. The resistivity 2D section shows a resistivity from 11.3 Ωm at the top layer to 19.6 Ωm at the bottom, which indicates that there are coarse materials in the deeper part of the section, as shown in Figure (10). In the inverted section, a dashed black line separates the acceptable silty clay layers such that the resistivity ranges between (11.3 and 13.2) Ωm. The thickness of the silty clay layer is approximately 8 m, so the calculated volume of the whole raw materials through this subsurface block view is approximately equal to 245000 m^3, and it represents 441000 tons if the approximate density of the raw material is considered to be about 1.8 g/cm^3.

– **Results of applying the 2D IPI in location 1:** According to the changeability inverted section, silty clay is certainly separated from the other constituent of the Injana Formation Figure (11). The constituent shows relatively large chargeability related to silty clay that is more than 2 mV/V. Comparing the electrical resistivity with the chargeability demonstrates that chargeability increases with increasing clay content and oppositely electrical resistivity decreases when increasing clay content. Therefore, the utility of IP inversion in location 1 delineates (and also minimizes) the exact boundary between these constituents.

– **3D Resistivity view of location 2:** The area is located south of Takiya Town as shown in Figure (1), where the surface is covered by thin recent sediments and Injana Formation outcrops. The resistivity section shows a range of resistivity from 11.3 Ωm at the top layer to 21.6 Ωm at the bottom, as shown in Figure (12). In the inverted section, a dashed black line separates the acceptable silty clay layers such that the resistivity ranges between (11.3 and 13.6) Ωm. Therefore, if the estimated density of the raw materials is assumed to be about 1.8 g/cm^3, the calculated volume of the total raw materials through this subsurface cube is about equal to 330000 m^3, which is 594000 tons.

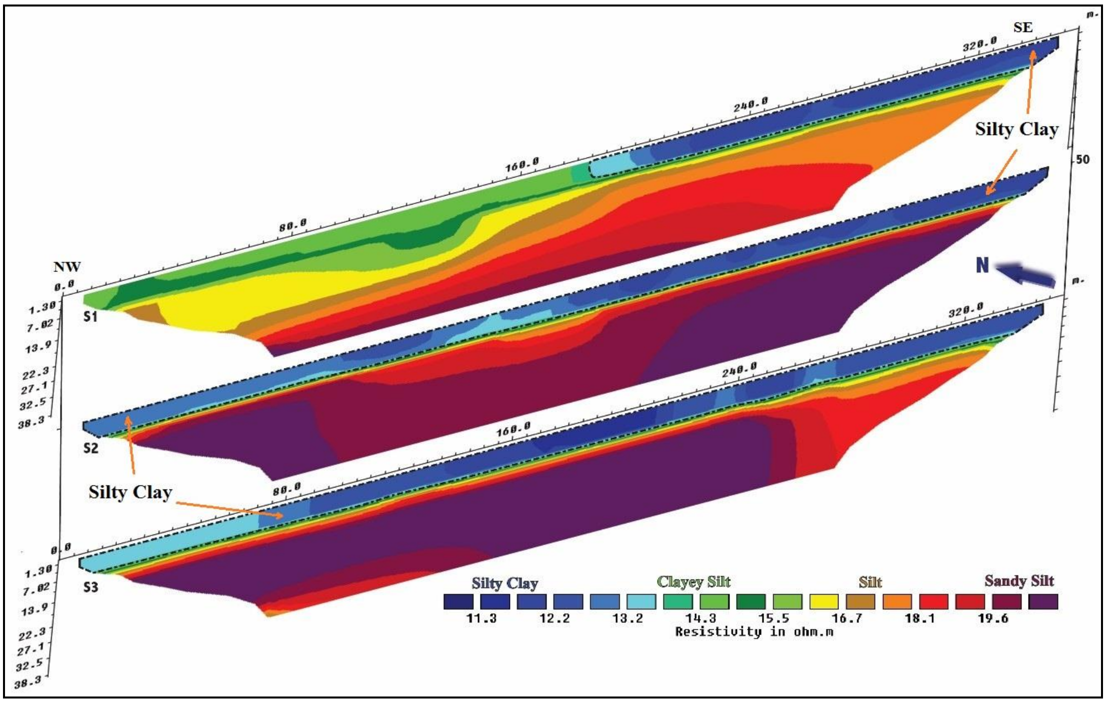

Figure 10: Results of applying the ERI along three profiles; S1, S2, and S3 in location 1. Note that the extensions of the target layer (silty clay) are defined clearly by its resistivity range.

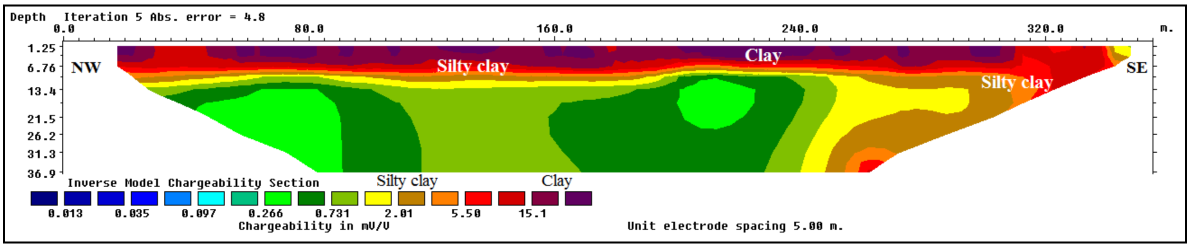

Figure 11: Results of Applying IPI in the location 1. Note the relatively high changeability at the ground surface compared with the low electrical resistivity shown in Figure 10.

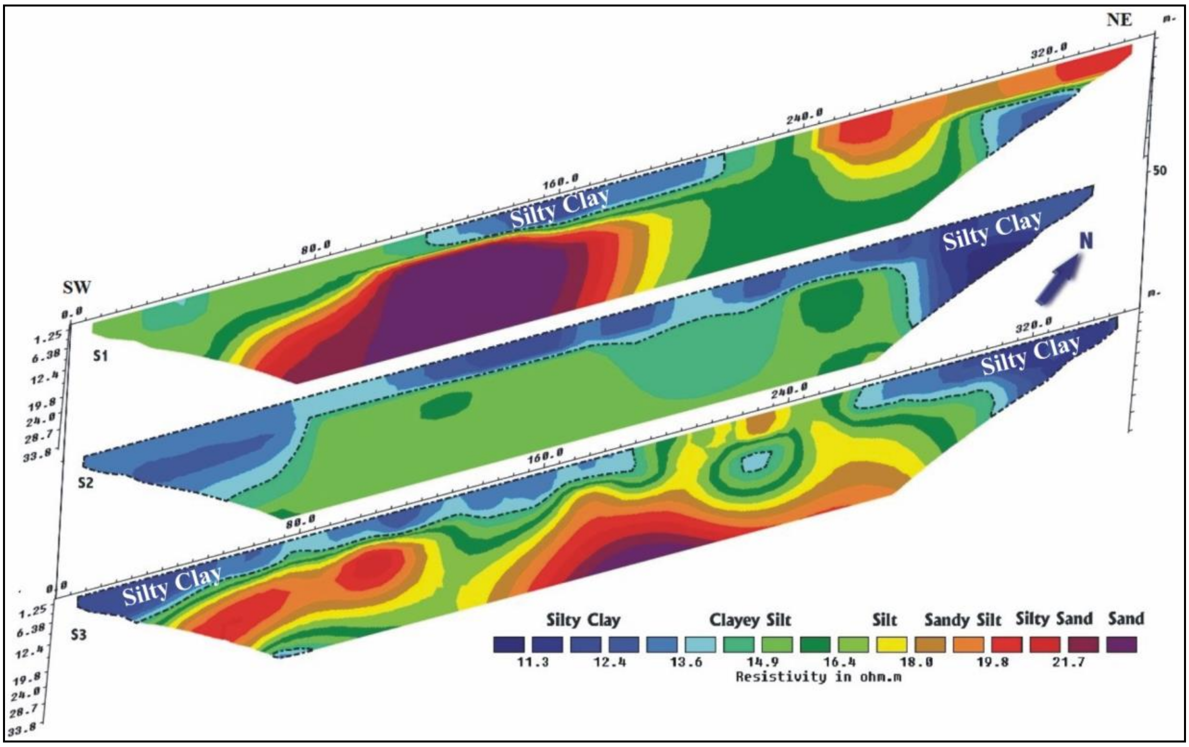

Figure 12: Results of Applying the ERI in the location 2. Note that the extensions of the target layer (silty clay) are defined clearly by its resistivity range.

– **2D IPI of location 2:** As in the case of location 1, the inverted section of changeability in location 2, Figure (13) indicates that silty clay is separated from the other constituents of the Injana Formation. The figure shows a relatively large chargeability of silty clay that is more than 2.57 mV/V. Comparing electrical resistivity to chargeability reveals that chargeability increases as clay content increases. Therefore, the IPI of location 2 delineates (and also minimizes) the boundary between these constituents.

– **3D Resistivity view of location 3:** Location 3 is located south-west of Takiya Town as shown in Figure (1) where the Injana Formation outcrops. The resistivity section shows a range of resistivity from 10.9 Ωm at the bottom layer to 25.5 Ωm at the top layer, which indicates the existence of fine materials (claystone) in the deeper part of the section, as shown in Figure (14). In the inverted section, a dashed black line separates the acceptable quality clay and silty clay layers such that the resistivity ranges between (10.9 and 13.9) Ωm. The thickness of the clay and silty clay layer is variable. Therefore, the calculated volume of the whole raw materials through this subsurface cube is approximately equal to 160000 m^3, and it represents 284800 tons when the approximate density of the raw material is considered to be about 1.78 g/cm^3.

– **2D IPI of location 3:** Pure clay and silty clay are separated from the other constituents of the Injana Formation as a result of the inverted section of changeability, Figure (15). These two constituents reveal a silty clay and pure clay chargeability of greater than 0.9 mV/V. Comparing electrical resistivity with chargeability indicates that chargeability increases as clay content increases and, conversely, electrical resistivity reduces as clay content increases. Therefore, the exact boundary between these electrical layers which have similar resistivity ranges is indicated and minimized by using the IP inversion in location three.

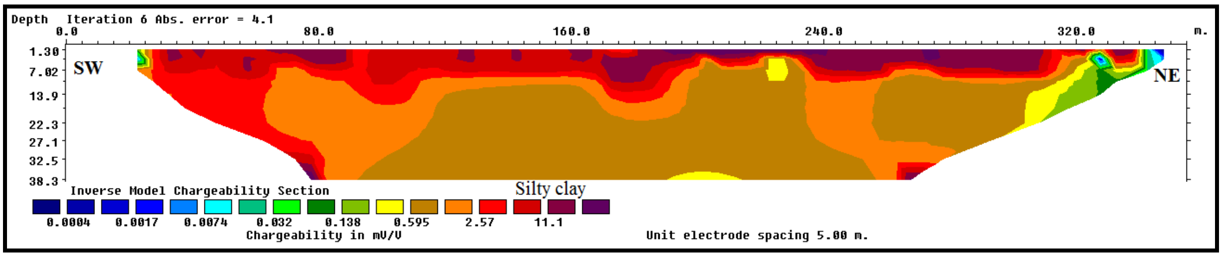

Figure 13: Results of applying IPI on the location 2. Note the relatively high changeability of the target layer (silty clay) compared with the low resistivity range shown in Figure 12.

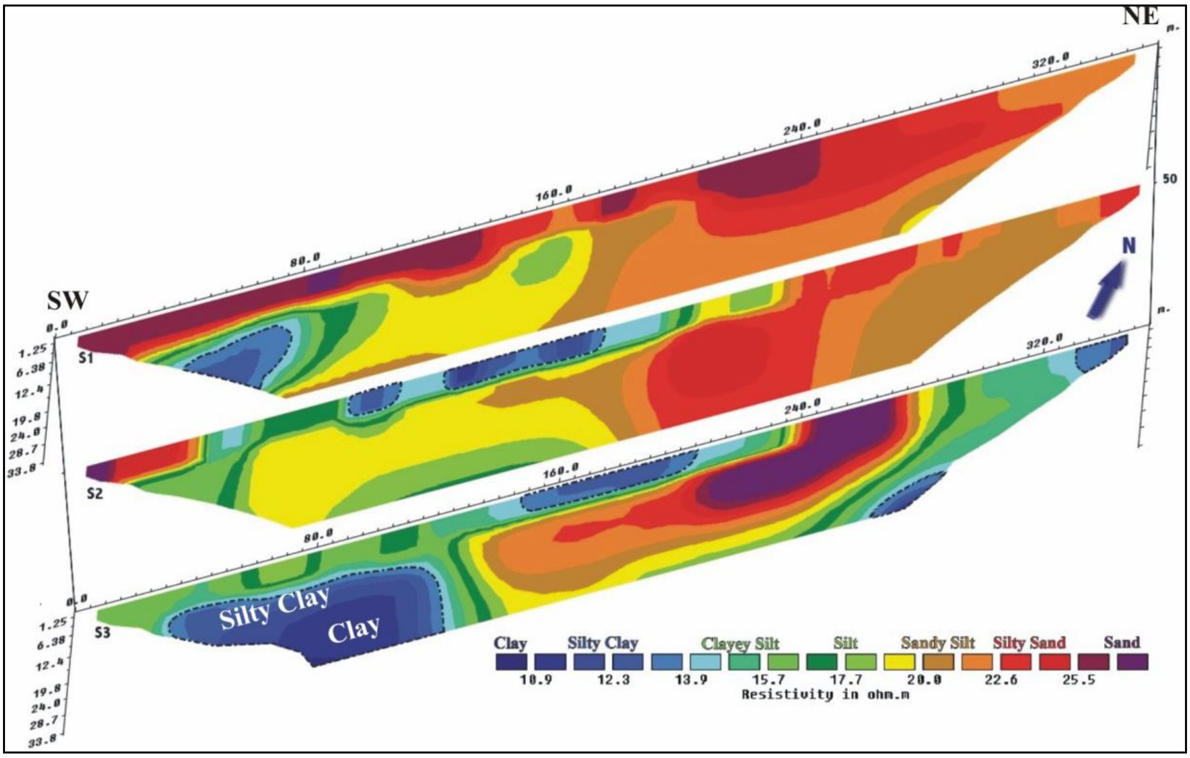

Figure 14: Results of applying the ERI in the location 3. Note that the extensions of the target layers (clay and silty clay) are defined clearly by their resistivity ranges.

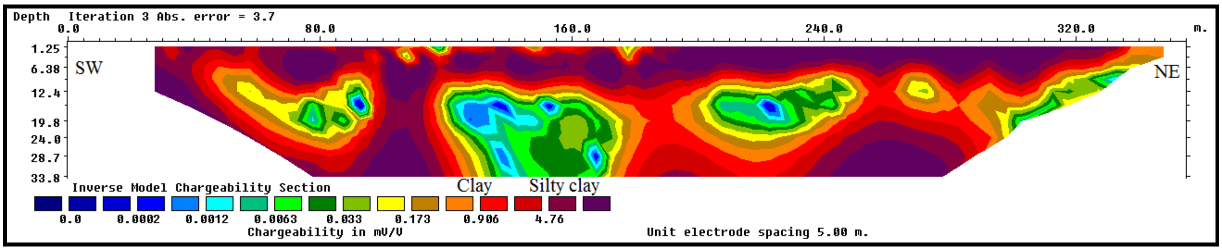

Figure 15: Results of applying IPI on the location 3. Note the relatively high changeability of the target layer (silty clay) compared with the low resistivity range shown in Figure 14.

CONCLUSION

The deficiency of raw materials for brick industries has appeared recently due to unexpected demand for brick as an optimal material for most building construction. Consequently, geophysical, and geotechnical parameter studies were carried out for the sake of determining the best quantity and quality of raw materials. Conclusions that are revealed from the present study are recorded below.

- The optimal resistivity range for clay and silty clay in the study area is approximately 7 to 11 Ωm and 11 – 13 Ωm, respectively.
- Due to its high dielectric constant, the IP is one of the best geophysical methods jointly used with the electrical resistivity method for indicating the exact boundary of clay mass.
- The optimal range of changeability for clay and silty clay is more than 5 mV/V and 0.9 to 5 mV/V, respectively.
- The 3D view gives the total mass of the raw materials in locations 1, 2, and 3, which is approximately estimated as 441000, 594000, and 284800 tons, respectively.
- These quantities in the study area are economical for use in a brick factory for about three years.
- Geotechnical studies show that: the results of plastic limit, liquid limit, and plastic index are 20%, 39%, and 19%, respectively. The result of grain size analysis showed that the major components of the samples are silt, made up of %57, clay is %33, and sand is equal to %10. As a result, it is classified as silty clay.
- Chemical composition indicates that the clay layer is used as a raw material for red bodies.
- Mineralogical analysis shows that the workability of clay is that the main clay minerals are illite and chlorite, which give moderate properties for brick with traces of kaolinite, and the non-clay minerals, quartz, and calcite.

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