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3D Modelling and Feasibility Assessment of Granite Deposit using 2D Electrical Resistivity Tomography, Borehole, and Unmanned Aerial Vehicle Survey

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Abstract

This research work aims to critically analyze the efficacy of inexpensive and rapid 2D electrical resistivity tomography (2D ERT) survey for sub-surface geological delineation of granite deposits. The research work involves six ERT profiles using the Schlumberger protocol with an inner and outer electrode spacing of 5 m and 10 m, respectively. In addition, the unmanned aerial vehicle (UAV) survey is also performed to obtain the terrain information of the studied area. At the same time, a few boreholes are drilled to validate the 2D ERT interpretations. The 2D ERT survey reveals that strong resistivity contrast enables inverted resistivity imaging to characterize the deposit such as topsoil (100-800 Ωm), fracture granite (800-2300 Ωm), and solid granite (> 2300 Ωm). The results obtained from UAV, 2DERT, and borehole survey are further processed to estimate the bedrock to topsoil ratio to assess the feasibility of the deposit. The bedrock to topsoil ratio, estimated by 2D ERT and borehole, is 3.2 and 2.2, respectively. At the same time, the combined UAV, 2D ERT, and borehole survey calculates the bedrock volume 3.2 times to topsoil. Thus the research work allows us to conclude that 2D ERT is an inexpensive, viable, and efficient technique for sub-surface geological documentation, and helps select appropriate mining methods.

1. Introduction

In the last decade, the demand for rock aggregates has increased considerably in response to the construction of new infrastructures such as housing societies, roads, and hospitals due to socio-economic development and increasing population. Consequently, the demand for rock aggregate rises, thus causing the need for exploration of new aggregates resources. The conventional technique for granite resource exploration is a direct method named boreholes drilling [1, 2]. However, the borehole technique has a high cost, while crushed rock aggregate has a low commodity price [3-8]. In addition, the core drills provide point base information, whereas continuous sub-surface geological information is a prerequisite for precise rock reserve estimation. Alternatively, a cost-effective approach is crucial to provide reliable subsurface geological interpretations and significantly reduce the expensive boreholes. To this end, geo-physical exploration techniques, particularly 2D Electrical resistivity (2D ERT), offer a promising approach to rapidly and economically evaluate the subsurface geology using limited core data.

Nowadays, 2D ERT is a well-established technique for various applications such as hydrogeological study, groundwater exploration, geotechnical site investigation, environmental assessment, and archaeological site delineation [9-16]. In the realm of mineral exploration, 2D ERT has also proven its significance [17-20]. The increasing interest in the application of 2D ERT for

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mineral exploration is because it is a simple, rapid, inexpensive, and viable technique for sub-surface geological feature identifications [18, 21, 22]. Despite the aforementioned advantages of 2D ERT, it is not yet efficiently utilized for granite resource exploration.

The fundamental principle of 2D ERT is the injection of galvanic current via a pair of contiguous current electrodes, and subsequently, measuring the potential difference across other twin electrodes [23-25]. The desired targeted depth is manipulated by increasing the electrode spacing; however, the resolution decreases [26, 27]. The increased interest in 2D ERT for mining and geo-technical investigation in the last few decades is favoured a lot by automated computerized data acquisition resistivity instruments and rapid 2D and 3D inversion software. Furthermore, 2D ERT is a simple, rapid, inexpensive, and viable technique for sub-surface geological feature identifications [25, 28-30].

This paper presents the multidisciplinary methodology approach using 2D ERT, UAV, and borehole for a feasibility assessment of granite deposit. Six ERT profiles were performed to obtain the sub-surface resistivity distribution of the targeted area. The UAV survey was conducted to extract the surface topographic information. This research study also involves a few boreholes to authenticate the 2D ERT interpretations. This contribution mainly emphasized demonstrating the success of the 2D ERT technique for sub-surface geological feature recognition of granite resources. The research study also aims to estimate the bedrock and topsoil volume for the feasibility assessment of granite deposits.

2. Geological studied area description

The studied area is located in Senawang district, Malaysia, about 7 km away from the nearest town, Seremban Jaya, towards the east. The ground elevation of the area is in the range of 150-250 m. The site can be accessed by an unpaved road from the Seremban-Tamping trunk road.

According to the department of geoscience and minerals, Malaysia, the major portion of the district is an acidic intrusion. The granitic rock in the studied area belongs to the Main range S type granitoid [31]. Figure 1a represents the map of peninsular Malaysia, and Figure 1b shows the extent and boundary of the studied area.

3. Methodology

A combined 2D ERT, UAV, and borehole survey of the studied area was carried out to accurately estimate the volume of bedrock and topsoil for a feasibility assessment of the deposit. The fieldwork was completed in five days, starting on 27th February 2018 and ending on 3rd March 2018. The weather condition during the fieldwork was rainy and cloudy.

3.1. UAV survey data collection and processing

The aerial images of the studied area were captured using DJI S1000 (Fig. 2(a)) at the height of approximately 150 m from the ground. The UAV DJI S1000 system is equipped with GPS navigation system and Sony NEX 5T digital camera. A forward and lateral overlap with a minimum 70% and 45% were adopted to obtain good three-dimensional models of the site. The ground control (GCP) points were established utilizing a pair of Topcon Hyper II GPS systems shown in Fig 2(b). A total of 11 GCP points were used for the georeferencing of 3D point cloud.

The aerial images were loaded in the Agisoft photoscan software to construct the 3D point cloud of the studied area. The software used the structure from motion (sfm) technique for the reconstruction of the 3D point cloud. The 3D point cloud presents the northing, easting, and elevation of the studied area. This information was extracted from the Agisoft photoscan software, and was processed in Golden surface software to generate the contour-maps of the area.

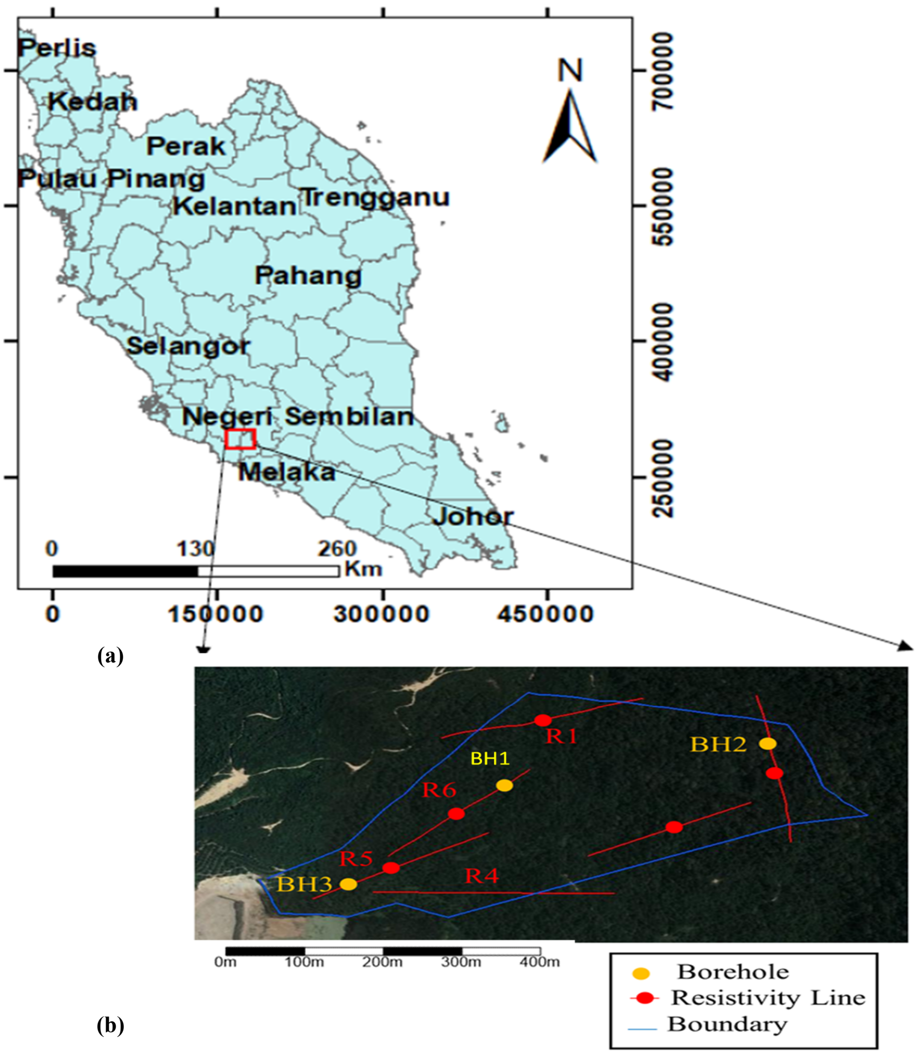


Figure 1. a) Peninsular Malaysia b) Studied area.

(a) (b)

Figure 2. Boundary demarcation and photogrammetry survey using UAV. A) Establishing GCP points. B) UAV DJI S1000.

3.2. Borehole Sampling

Three boreholes (BH1, BH2, BH3) of the studied area were drilled at varying positions on different resistivity profiles (see Figure 1b). Various sub-surface geological layers were inferred by three boreholes, BH1, BH2, and BH3, based on the colour of return water, washed drill cuttings, and rock quality designation (RQD) value. The diameter of the recovered borehole sample, BH1, BH2, and BH3, were 54 mm, and the depth were 23 m,18 m, and 22 m, respectively, as shown in Figure 3.

(a) (b) (c)

Figure 3. Core sample from three boreholes, a) BH1, b) BH2, c) BH3.

3.3. 2D ERT data acquisition and processing

The 2D ERT survey arrangement of the area of the investigation consisted of six resistivity lines, namely R1, R2, R3, R4, R5, and R6. The length of each ERT profile was 400 m length each, schematized in Figure 1b. The sub-surface apparent resistivity data was acquired by exploiting multichannel ABEM LS Terameter, connected to two multi-cable systems with 31 output each, allowing a total number of 61 stainless steel electrodes arrangement linearly [32-34]. Schlumberger protocol with an inner and outer electrode spacing of 5 m and 10 m was utilized. The Schlumberger array configuration was employed for data acquisition because of good compromise for both vertical and horizontal structural resolutions [18, 35].

The collected ERT field data collected was processed further using the ZondRes2DInv software to obtain true sub-surface resistivity values [36]. The ERT survey processing is a multi-stage process including forward modelling, extraction of bad data points, and inversion using least square and root mean square error (RMS) convergence restrain. This study obtained an RMS error of 8.07%, 7.2%, 8.7%, 6.03%, 6.07%, and 1.67% for R1, R2, R3, R4, R5, and R6, respectively.

4. Results

4.1. UAV survey

The contour-map of the studied area reproduced based on the UAV survey is shown in Figure 4. This figure shows that the project area is between a minimum of 294900 N and a maximum of 295500 N, whereas the minimum is 448300 E and 448900 E. The elevation of the site ranges from 135 m to 255 m above the mean sea level (MSL). The higher elevation lies in the north-eastern area, gradually reducing to the south-west. A depression (valley) can be found close to the north-western border of the area.

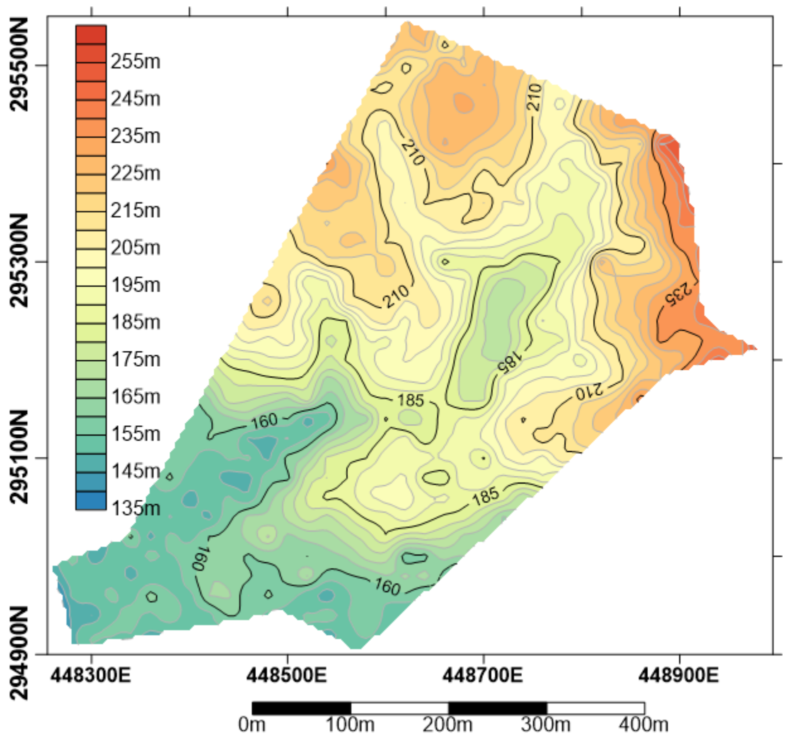


Figure 4. Contour map of studied area.

4.2. Borehole sampling

The sole purpose of the core logging was to identify the exact thickness of the topsoil. No cores were recovered up to a depth of 10-15 m. This region was characterized as topsoil. The cores also discern a varying thickness of fracture and solid granite, as provided in Table 1.

4.3. 2D ERT

The sub-surface resistivity distribution obtained from ERT survey lines (R1, R2, R3, R4, R5, R6) are manifested in Figures 5 and 6. The ERT survey profiles reveal that the granite bedrock exists at a depth of 15-20 m, which is extended up to 80 m. Huge resistivity contrast is shown by 2D ERT images, which reflect the presence of various geological strata in the form of different colours. The resistivity of the rock is a function of porosity, permeability, weathering, and presence of water content, as well as mineral composition, texture, and structure of soil and rock. The topmost layer of around 15-20 m, represented by dotted lines, shows non-uniform resistivity values. This layer was characterized as a topsoil layer possessing resistivity from 100 to 800 Ωm. In the topsoil region, a dark reddish colour with resistivity > 2500 Ωm was also observed. The high resistivity values in topsoil refer to the compacted and crystalized boulder layers [18]. A resistivity layer of 800-2300 Ωm was evaluated by all ERT profiles represented by greenish to yellowish colour, and was characterized as fractured granite. A solid granite rock shown by dark reddish colour with a resistivity value greater than 2300 Ωm was also identified by ERT profiles. Near the surface, an unexpectedly low resistivity layer having a resistivity between 100 to 300 Ωm was exposed by all ERT lines. These low resistivity layers were characterized by dark blue and were revealed as water-saturated zones. It is interesting to notice that these low resistivity layers are surrounded by fractured granite bedrock, thus confirming water infiltration from the surface.

5. Discussion

The precise and accurate estimation of the thickness of the topsoil and bedrock is necessary for the reliable feasibility assessment of the granite deposit. The ERT profiles successfully delineated the lateral and vertical extent of topsoil and bedrock. The 2D ERT efficiently identifies the sub-surface geological layers, and provides continuous sub-surface information more rapidly. The zonation of various sub-surface geological layers was carried out in the Surfer software by utilizing kriging interpolation (see Figure 7). In this figure, the topmost green colour layer having 15-20 m thickness was identified as topsoil. The dark red, yellow, and blue colour represents the solid granite, fracture granite, and water-saturated zone, respectively. The resistivity lines R1, R2, and R3 identified a small portion of fracture granite and a greater portion of thick solid granite layer. On the other hand, a high proportion of fracture granite compared to solid granite was delineated by the resistivity lines R4, R5, and R6 depicted. Although the 2D ERT survey efficiently exposed various sub-surface geological layers, it is believed that the ERT interpretations may have ambiguity due to the resistivity overlap of various geological layers. To remove the ambiguity from the ERT data, the coring was performed to estimate the thickness of topsoil accurately. The depth of Investigation of the boreholes was limited but it improved the confidence of 2D ERT data.

The 2D ERT data was imported in the Mapinfo software to construct 3D geological models represented in Figure 8. The software uses the resistivity data of the known close points, and interpolates the optimum point of the data at other points using the kriging interpolation technique. The 3D models also revealed that the granite bedrock in the studied area is highly fractured. The existence of solid granitic bedrock compared to fracture granite is in less proportion.

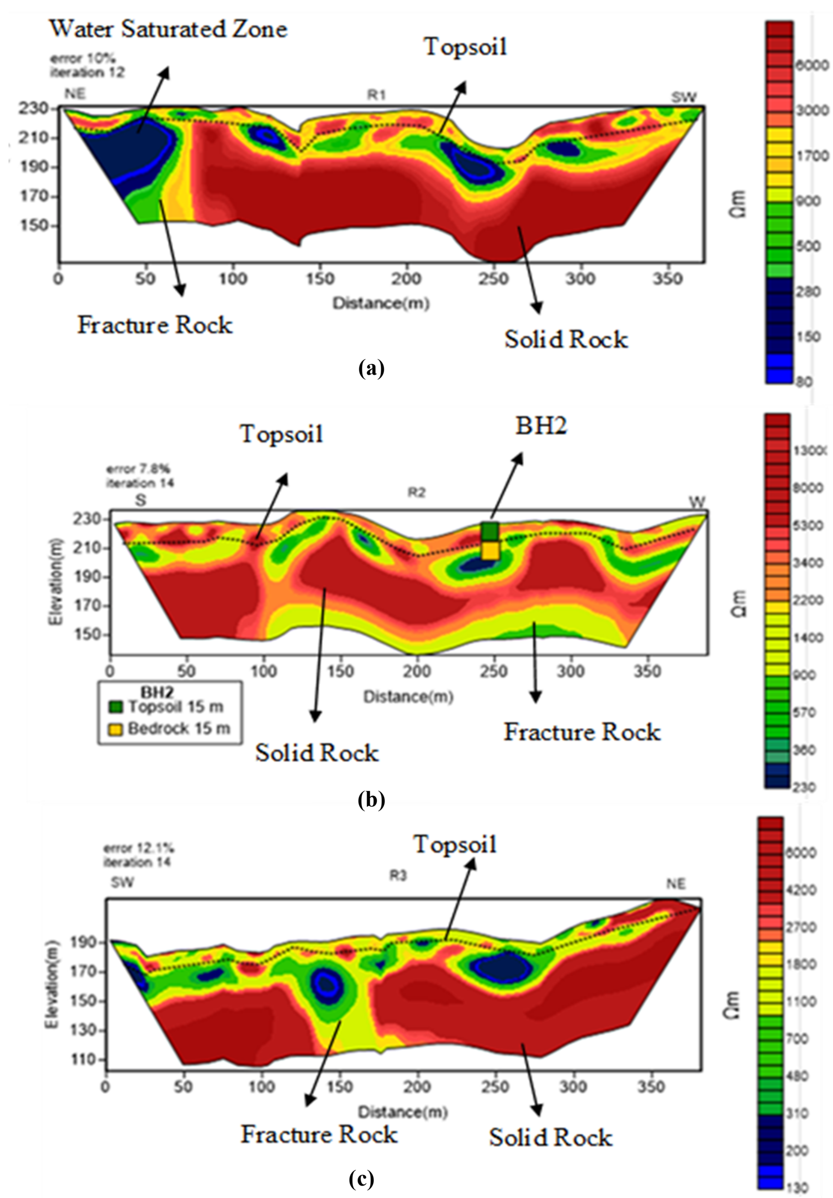


Figure 6. 2D inverted resistivity images. a) Resistivity line R4. b) Resistivity line R5. c) Resistivity line R6.

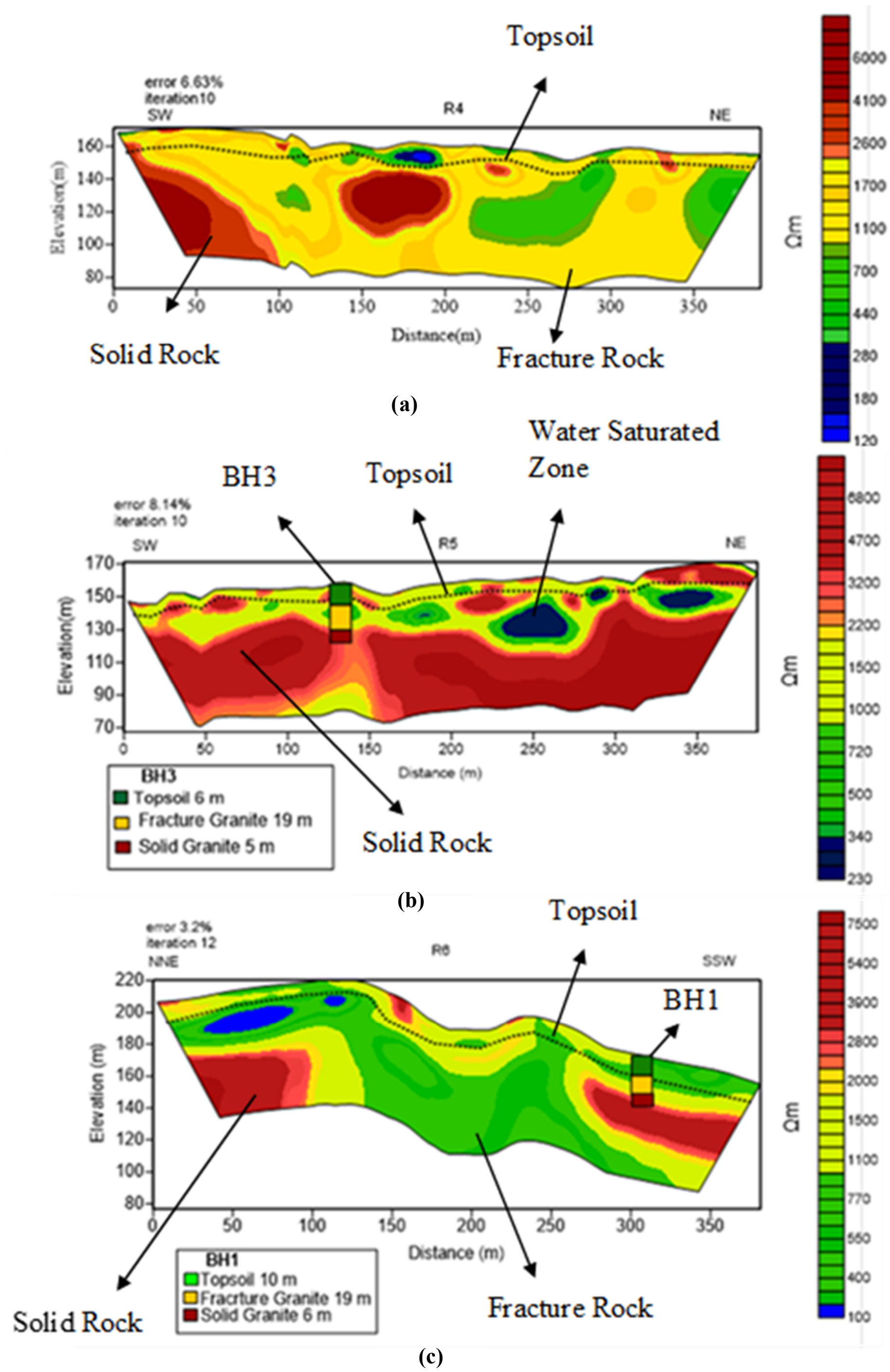


Figure 6. 2D inverted resistivity images. a) Resistivity line R4. b) Resistivity line R5. c) Resistivity line R6.

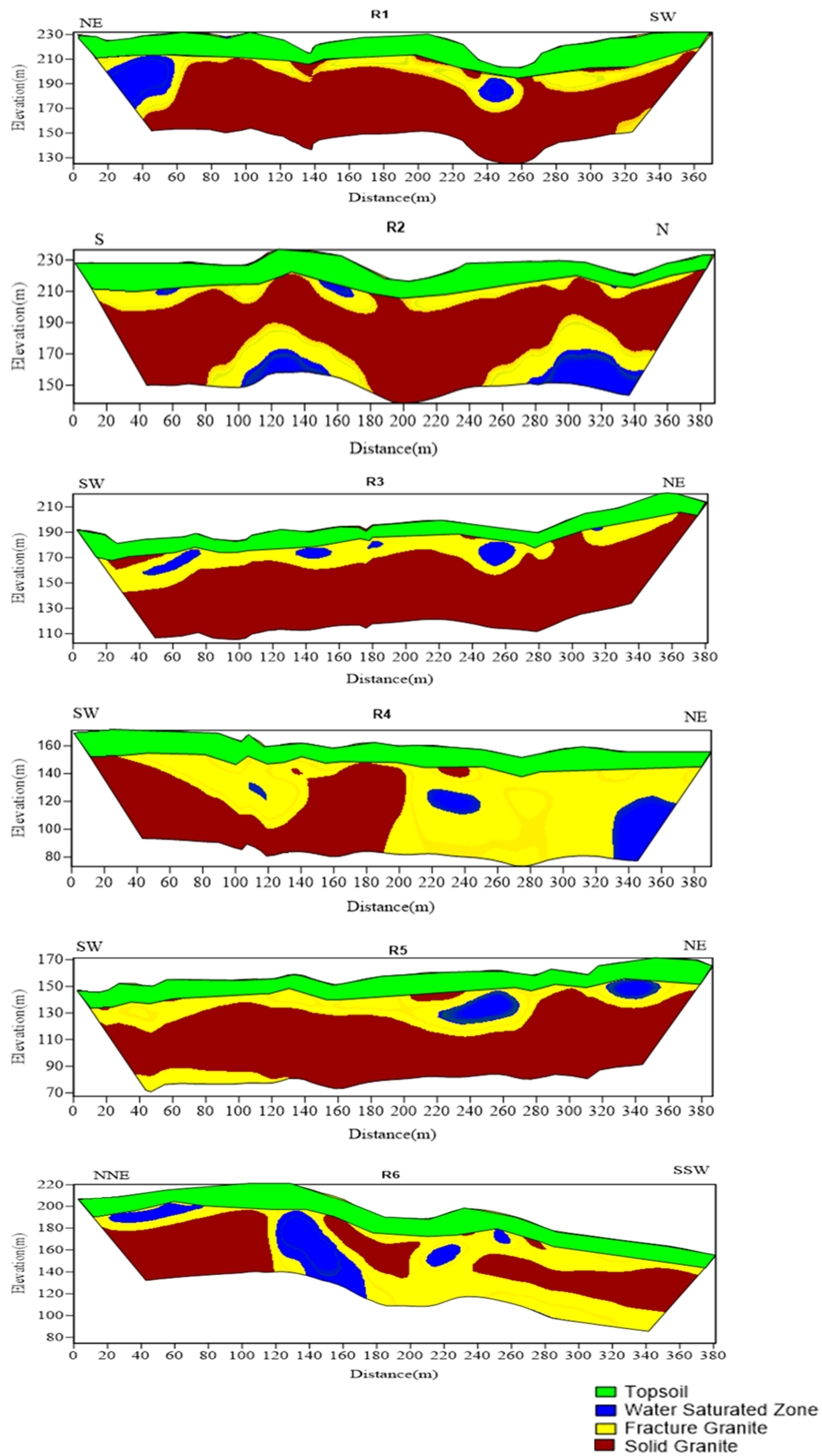


Figure 7. Various geological layers evaluated by ERT profiles.

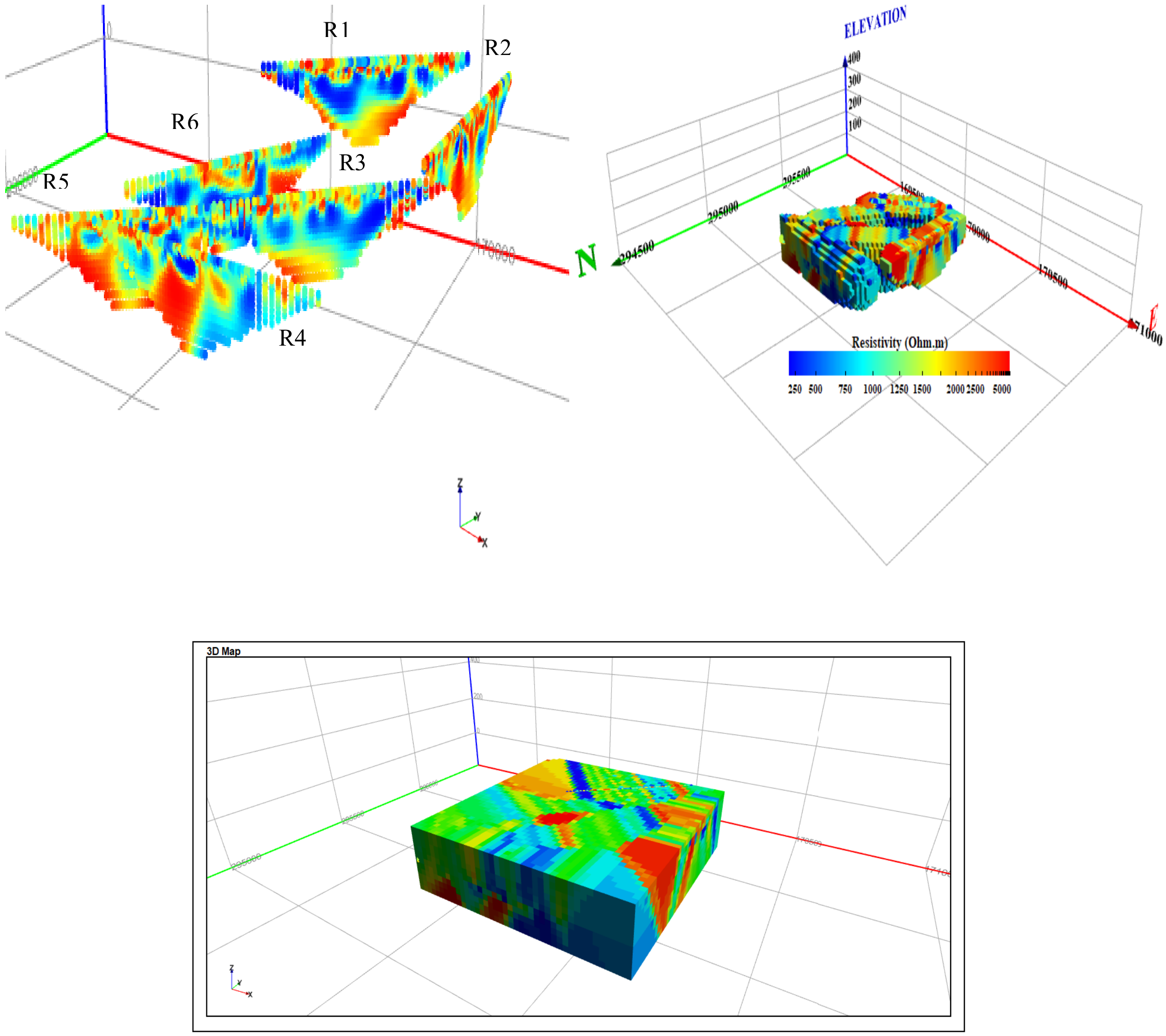


Figure 8. 3D geological models using 2D ERT lines.

To assess the deposit's economic viability, the bedrock and topsoil volume were estimated by generating the contour-maps using the Golden surfer software. The granite deposit is considered viable for mining if the volume of bedrock to topsoil is equal to or greater than 3.2 [37]. In this research work, the volume of topsoil and bedrock was estimated for three techniques. The contour-maps of topsoil obtained based on the combined UAV, borehole, and 2D ERT survey is shown in Figure 9a. Figures 9b and 9c represent the contour-maps of topsoil generated using borehole and UAV, and 2D ERT and UAV, respectively. In the same way, the bedrock contour generated using combined 2D ERT, borehole, and UAV is given in Figure 10a. At the same time, Figure 10b and Figure 10c depict the contour-maps obtained by 2D ERT and UAV, and borehole and UAV, respectively. Figures 9a and 10a reveal that the volume of topsoil and bedrock is 2344505 m^3 and 7449072 m^3, respectively. These statistics show that the bedrock is 3.2 times the topsoil; hence, the deposit is feasible for mining. The combined 2D ERT and UAV survey calculated the volume of topsoil as 2387031 m^3 and bedrock as 7407176 m^3. This reflects that the bedrock volume is 3.1 times the topsoil, confirming the deposit is feasible for mining. However, the estimated volume of topsoil (2978263 m^3) and bedrock (6815944 m^3) by borehole and UAV shows the bedrock volume is 2.2 times of the topsoil; thus the deposit is not viable for mining. These findings clarify that the 2D ERT provides a more precise and robust estimation of bedrock and topsoil volume compared to the borehole. The imprecise bedrock and topsoil volume estimation by borehole is due to the limited depth and number of core data. The results of borehole data can be improved by increasing the number of cores and depth of estimation. However, this will considerably increase the cost of exploration. 2D ERT efficiently overcame this shortcoming by providing detailed lateral and vertical sub-surface information of various geological layers. Thus the integrated 2D ERT, UAV, and borehole approach adopted in this study provides reliable subsurface geological delineation with a limited number of boreholes. This approach was found efficient in reducing the cost and time required for the feasibility assessment of granite deposits.

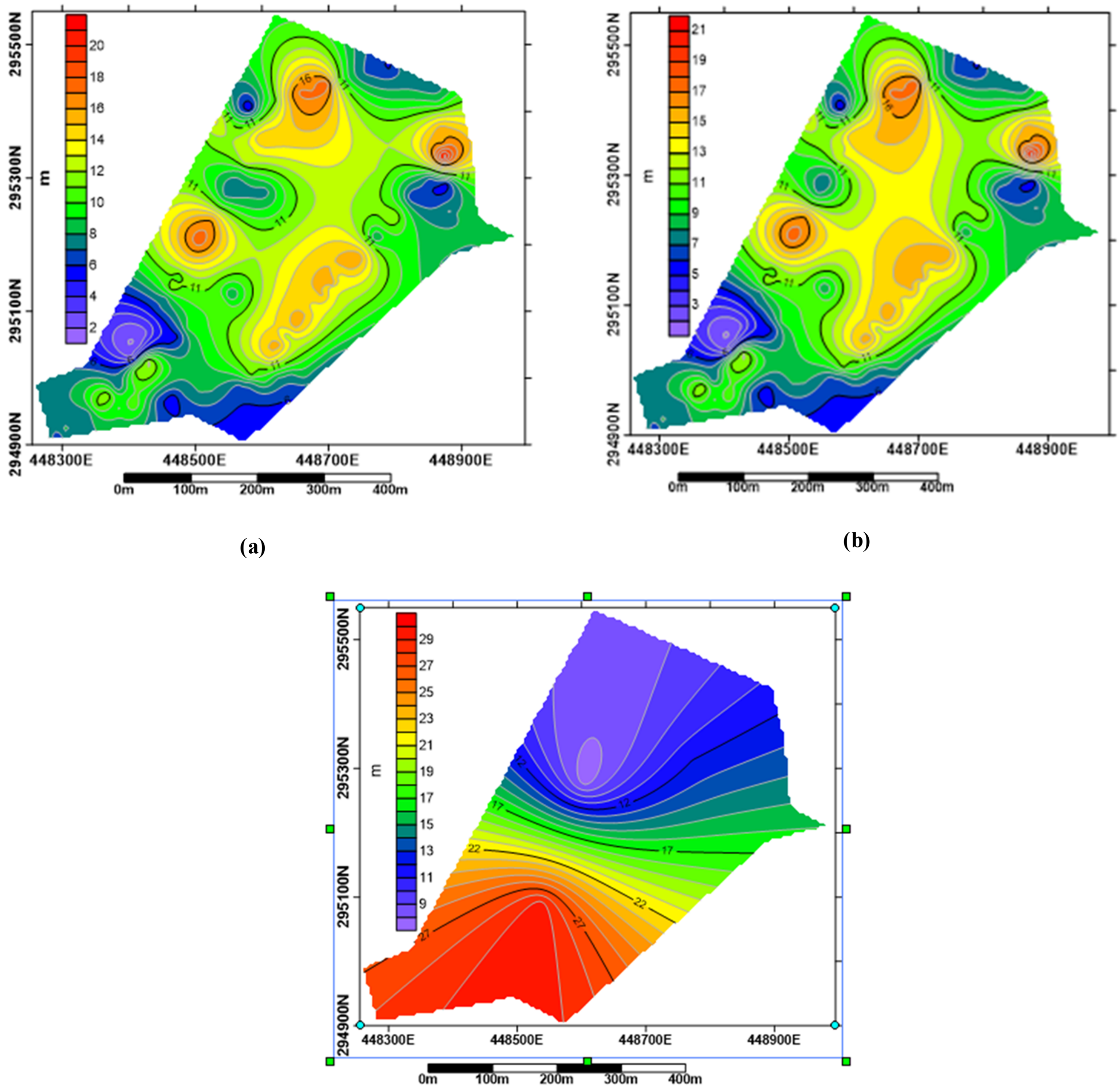
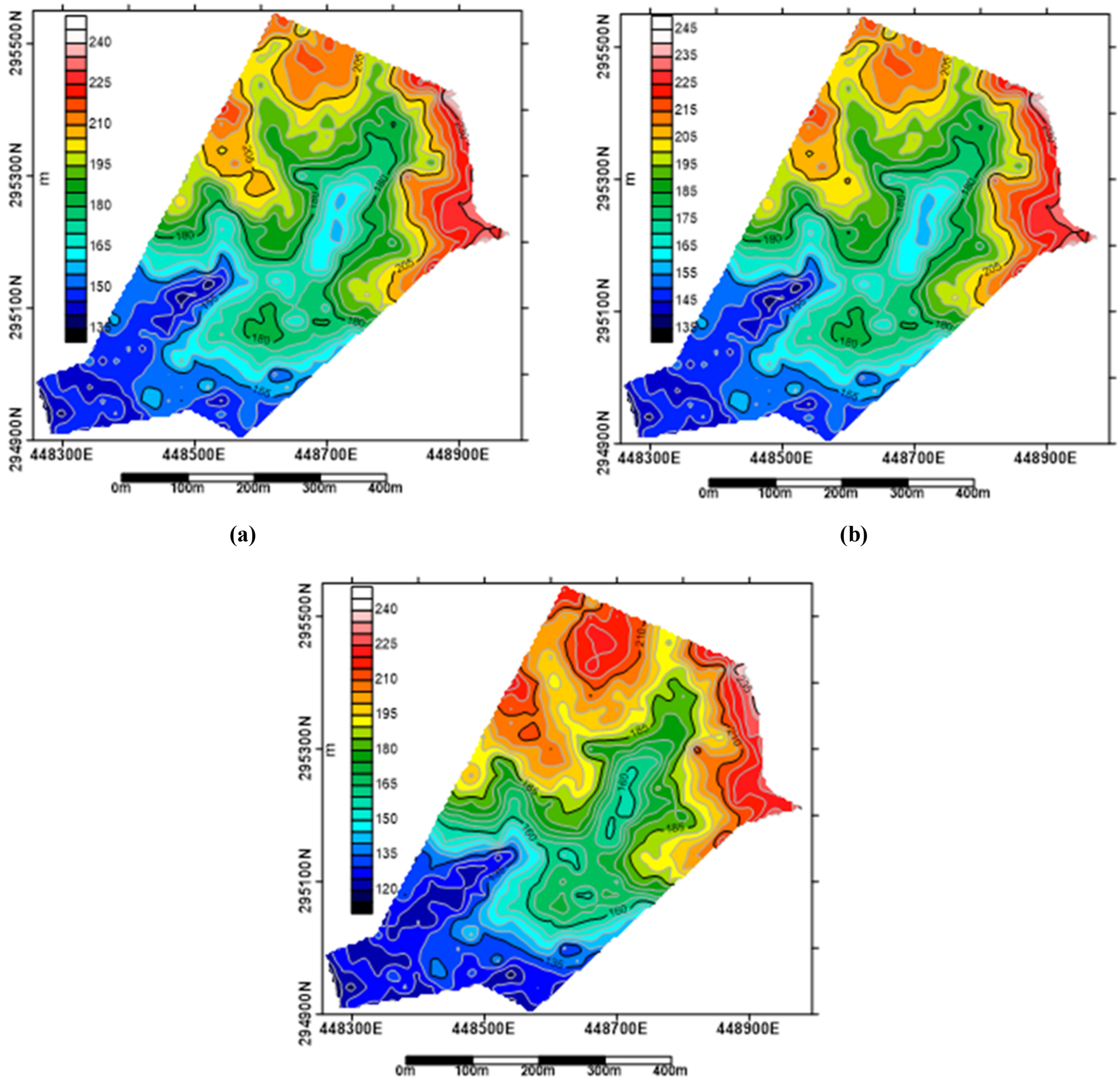


Figure 9. Contour-maps of topssoil a) Combine 2D ERT, UAV and Borehole b) 2D ERT and UAV c) Borehole and UAV.



(a) (b) (c)

Figure 10. Contour-maps of bedrock a) Combine 2D ERT, UAV, and Borehole b) 2D ERT and UAV c) Borehole and UAV.

6. Conclusions

The research work presented in this paper shows that 2D ERT successfully characterizes three major geological layers in the studied area based on resistivity contrast. These geological layers were identified as topsoil or residual soil, moderately to highly fractured granite, and solid granite. The resistivity of topsoil ranges 0-800 Ωm, fractured rock 800 to 2300 Ωm, and fresh rock > 2300 Ωm. Moreover, 2D ERT was also found efficient in accurately estimating bedrock to topsoil ratio. Based on the ERT survey, the selected studied site is feasible for mining as the bedrock rock to topsoil ratio is more than 3. In contrast, based on the borehole survey, the bedrock to topsoil ratio is equal to 2; thus the deposit is not economically viable. The outcome of this research work allows us to mark the following conclusions:

a) The selection of mining method for granite deposits highly relies on the quality of the bedrock. 2D ERT, compared to the borehole, successfully provides information regarding the quality of the entire granite rock in the studied area, and helps in selecting the appropriate mining method.

b) The volume of bedrock and topsoil estimated by 2D ERT was more precise compared to the borehole. Therefore, 2D ERT is considered more effective for feasibility assessment of granite deposits.

c) The 2D ERT result may have ambiguity especially when there is low resistivity contrast. However, it can easily be compensated by the supplementary borehole survey. Note that 2D ERT was successful in lowering the exploration cost and time by reducing the boring and trenching considerably.

d) The effectiveness of 2D ERT depends on the resistivity contrast, and there is a huge resistivity contrast between topsoil and granite bedrock; hence, 2D ERT is adapted for granite deposit characterization.

e) Thus 2D ERT is mooted as an inexpensive, simple, rapid, and viable exploration technique for granite sub-surface geological investigation. In addition, the technique is also environmental non-destructive.

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مدلسازی سه بعدی و ارزیابی امکان سنجی ذخایر گرانیت با استفاده از توموگرافی مقاومت الکتریکی دوبعدی، گمانه و بررسی وسایل هوایی بدون سرنشین

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چکیده:

هدف این کار تحقیقاتی تحلیل انتقادی کارایی توموگرافی مقاومت الکتریکی دوبعدی ارزان و سریع(D ERT۲) برای ترسیم زمین‌شناسی زیرسطحی ذخایر گرانیتی است. کار تحقیقاتی شامل شش پروفایل ERT با استفاده از پروتکل شلمبرگر با فاصله الکترود داخلی و خارجی به ترتیب ۵ متر و ۱۰ متر است. علاوه بر این، بررسی هواپیمای بدون سرنشین (UAV) نیز برای به دست آوردن اطلاعات زمین‌شناسی منطقه مورد مطالعه انجام شده است. در همان زمان، چند گمانه برای اعتبار بخشیدن به تفسیرهای ۲ بعدی ERT حفر می‌شود. بررسی دوبعدی ERT نشان می‌دهد که کنتراست مقاومتی قوی، تصویربرداری با مقاومت معکوس را قادر می سازد تا رسوباتی مانند خاک سطحی (۱۰۰-۸۰۰Ωm)، گرانیت شکستگی(۸۰۰-۲۳۰۰Ωm) و گرانیت جامد (< ۲۳۰۰Ωm) را مشخص کند. نتایج به‌دست‌آمده از پهپاد، DERT۲ و بررسی گمانه بیشتر برای تخمین نسبت سنگ بستر به خاک سطحی برای ارزیابی امکان‌سنجی کانسار پردازش شده است. نسبت سنگ بستر به خاک سطحی که توسط D ERT۲ و گمانه تخمین زده شده است، به ترتیب ۳/۲ و ۲/۲ است. در همان زمان، پهپاد ترکیبی، ۲ بعدی ERT و بررسی گمانه، حجم سنگ بستر را ۳/۲ برابر به خاک سطحی محاسبه کرد. بنابراین کار تحقیقاتی به ما این امکان را می‌دهد که نتیجه بگیریم که ERT دوبعدی یک تکنیک ارزان، قابل دوام و کارآمد برای اطلاعات زمین‌شناسی زیرسطحی است و به انتخاب روش‌های معدنکاری مناسب کمک می‌کند.

کلمات کلیدی: تصویربرداری مقاومت الکتریکی، بررسی گمانه، بررسی توپوگرافی، خصوصیات زمین شناسی گرانیت، ارزیابی امکان سنجی.