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EXPLORATION OF BITUMINOUS MATERIALS USING 2D ELECTRICAL RESISTIVITY IMAGING, KURDISTAN REGION, NE IRAQ

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ABSTRACT

Solid bituminous materials are widely spread in the Iraqi Kurdistan Region, they are filled so many locations, such as fracture zones, fault planes, and bedding planes. These materials can be used in several industries like pavement road, roofing, bituminous paint and waterproof, etc. The study aims to find an economical quantity of these materials by using 2D resistivity imaging in three locations that are different in geology and tectonic settings. These locations are Alla Syaw, Mera De, and Nasalih villages. The data are collected using Syscal R1 plus resistivity meter, for the sake of following up horizontal and vertical extension of these materials Wenner-Schlumberger array is used with 72 electrodes and a spacing interval of 5 m. Three profiles were conducted for each location, which have lengths equal to 360 m. The data processing was carried out by using the RES2DINV, and the smoothness was performed using finite difference forward modeling. The results show that all the bituminous materials are detected in shallow depths and only in the sandstone layers of the Tanjero, Gercus, and Injana formations filling the fracture zones and fault planes. This is also attributed to the more brittle behavior of the sandstone layer than other layers of these formations which deforms easily by applying external stresses. In the Tanjero Formation bituminous body is detected at a depth of about 10 m, which has an extension of more than 50 m from profile-1 to profile-2 (this is a lateral extension). The average width and height of the body are about 8m and 20 m, so it forms an approximate total volume equal to 8000 m^3. The study concludes that the preliminary estimation of the total volume of the detected bituminous bodies is about 20000 m^3, which has great importance as raw material for different industries. The bituminous material has a high resistivity value in most of the profiles reaching more than 200 ohm.m.

1. INTRODUCTION

The term "bituminous" refers to a substance that is obtained either from natural sources or as a byproduct of the distillation of crude petroleum oils or low-grade coal. This substance is predominately made up of hydrocarbons and is soluble in carbon disulfide (Goetz, W.H. and Wood, 1960). For civil engineering applications, bituminous materials include primarily asphalts and tars. Asphalts may occur in nature or may be obtained from petroleum processing. Tars do not occur in nature and are obtained as condensates in the processing of coal, petroleum, oil shale, wood, or other organic materials. Pitch is formed when tar is partially distilled so that

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the volatile constituents have evaporated off from it. Bituminous mixtures are generally used to denote the combinations of bituminous materials (as binders), aggregates, and additives; it is known that bitumen is a dielectric material (Read, 1990). Natural solid bituminous material in the study area comes from destroying most of the oil fields in the High Folded Zone due to tectonic activity during the past geological time; they lost their volatile components leaving a denser residue.

The purpose of 2D Electrical Resistivity Imaging (ERI) measurements is to determine the subsurface resistivity distribution. From these measurements, the true resistivity of the subsurface can be estimated. At present, 2-D surveys are the most practical economic compromise between obtaining accurate results and keeping the survey costs down (Dahlin, 1996). However, one of the frequent problems of ERT technique is choosing the most suitable electrode configuration to address a particular problem. Numerical modelling using 2D ERT method is useful for planning of electrical resistivity surveys before carrying out costly field surveys. In the literature, several authors have discussed the suitability of the electrode configurations for resolving the subsurface structures (Al-Kubbaysi, 1989; Zhou et al, 2002; Ali, 2009; Metwaly and AlFouzan, 2013; Thabit and Al-Zubedi, 2015). Recently, Electrical Resistivity Tomography ERT technique has increasingly been adopted for geotechnical site investigations (Sudha, 2009; Ayolabi, 2013; Karim, 2013).

The free program, RES2DINV.EXE, is a 2-D forward modeling program, which calculates the apparent resistivity pseudo-section for a user-defined 2-D subsurface model. With this program, the user can choose the finite-difference (Dey & Morrison, 1979) or finite-element (Silvester & Ferrari, 1990) method to calculate the apparent resistivity values. This approach gives satisfactory results for the Wenner and Wenner-Schlumberger arrays where the pseudo-section point falls in an area with high sensitivity values, which means points of nearly equal resistivity. Wenner-Schlumberger array is a hybrid between the Wenner and Schlumberger arrays (Pazdirek & Blaha, 1996) arising out of relatively recent work with electrical imaging surveys. In particular, the application of ERI in the characterization of hydrocarbons has increased recently (Batayneh, 2005; Godio & Naldi, 2003; Newmark et al., 1999; Shevnin et al., 2003).

Bitumen has been used in Iraq for building boats and mortar since the Sumerian times around 4000 BC. The bitumen was probably obtained from bitumen seepages along the upper Euphrates in central west Iraq and the upper reaches of the Tigris River in north Iraq (Jassim & Goff, 2006).

There are small accumulations of bituminous materials in some formations in the Kurdistan region within sandstone and limestone beds that are filled with bituminous materials as they are visible on the surface. One of the most important research for bituminous material in the area is in the Qaradagh region (Aziz et al., 1999). The current study was performed at three sites located in Alla Syaw, Mera De, and Nasalih villages (Figure 1). The bituminous bodies are found in three formations. In the Alla Syaw Village, the Tanjero Formation is exposed to the surface and the bitumen materials may have originated from the Aqra Formation of massive Rudists dolomitized and impregnated with bitumen. In the Mera De site, the bituminous materials were found in the Gercus Formation, and the underlying Sinjar Formation is considered a source of rocks for these materials. The Nasalih site is covered by the Injana Formation and the bitumen materials may have originated from the Fat’ha Formation. This formation has a limestone-dominated unit at its base that contains heavy oil and bitumen (Jassim & Goff, 2006).

A bituminous body in the Alla Syaw site is located in the Sulaimani Governorate, about 10 Km northeast of the city center, and about 2 Km from Alla Syaw Village. The area is bounded by latitudes (35°35'23"N – 35°35'37"N) and longitudes (45°32'03"E – 45°32'15"E) and is elevated about 1050 m a.s.l. While the Mera De Village is located southeast of Sulaimani City by about 42 Km. Geographically, the area is bounded by latitudes (35°13'25"N – 35°13'50"N) and longitudes (45°40'14"E – 45°41'03"E). The site elevation is from 715 m to 850 m a.s.l (Figure 1a).

The Nasalih Village is located east of Kifre town by about 4 Km, and southwest of Sulaimani City by about 103 Km. Geographically, the area is bounded by latitudes (34°41'04"N – 34°41'21"N) and longitudes (45°00'12"E – 45°00'36"E), and its elevation ranges from 238 m to 257 m a.s.l.

2. GEOLOGIC AND TECTONIC SETTINGS

Several outcrops of solid bituminous materials were found about 750 m south of Alla Syaw Village (Figure 1b); it is almost recognized from Cretaceous sequences within the Tanjero Formation in Kurdistan imbricated zone. The Tanjero Formation comprised mostly of alternation of clastic rocks of sandstone, marl, and calcareous shale with the occurrence of very thick conglomerate and biogenic limestones (Bellen et al., 1959). The Tanjero Formation is underlined by the Shiranish Formation and the Aqra Formation overlies it conformably. From a structural point of view, the Kora Kazhaw multi-imbricated slice plunges in the northwest direction along a valley just about 500 m north of the Alla Syaw Village; The Kora Kazhaw structure represents five imbricated segments of anticlines. Accordingly, bituminous bodies in the Alla Syaw site are recorded in the fault zone that results from intersections of the NE – SW transversal fault and NW – SE strike-slip fault. Those faults are active and they are still indications of a recent seepage in this area.

The Mera De area is covered by several geological formations that are from older to younger: Sinjar, Gercus, and Pila Spi formations, as well as recent sediments that cover a vast part of the area. The bituminous bodies are found in the Gercus Formation which is mostly composed of clastic rocks, such as claystone, sandstone, siltstone, and a thin bed of conglomerate and characterized by a red to reddish brown color appearance. Its lower contact with the Sinjar Formation is gradational and represented by the existence of a sequence of thin beds of limestone rocks having a thickness between 10 – 30 cm. Depending on the tectonic map of Iraq, the area is located within the High Folded Zone and is exactly situated within the Balambo-Tanjero subzone, which is the northeastern part of the Foothill Zone and it is structurally the highest part of the zone.

The area is characterized by rigid and low to moderate amplitude topography at Nasalih Village due to the exposure of a compact sandstone layer of the Injana Formation that resists weathering. The dense erosion during the past geological time led to the occurrence of several valleys either running parallel to the strike or the dip of the outcrops. They are trending NW – SE as the general strike of the structural features in the region. In addition, several geomorphologic features are constructed such as dense dendritic derange patterns, hogback, and Questa escarpments. The area is covered by recent sediments that are composed of clay, silt, and sandstone rock fragments of different sizes. According to the tectonic map of Iraq (Jassim & Goff, 2006), the area is located within the Foot-hill Zone and exactly situated within the Makhul – Hamren Subzone, which is the northeastern part of the Foothill Zone and is the structurally the highest part of the zone (Figure 1a).

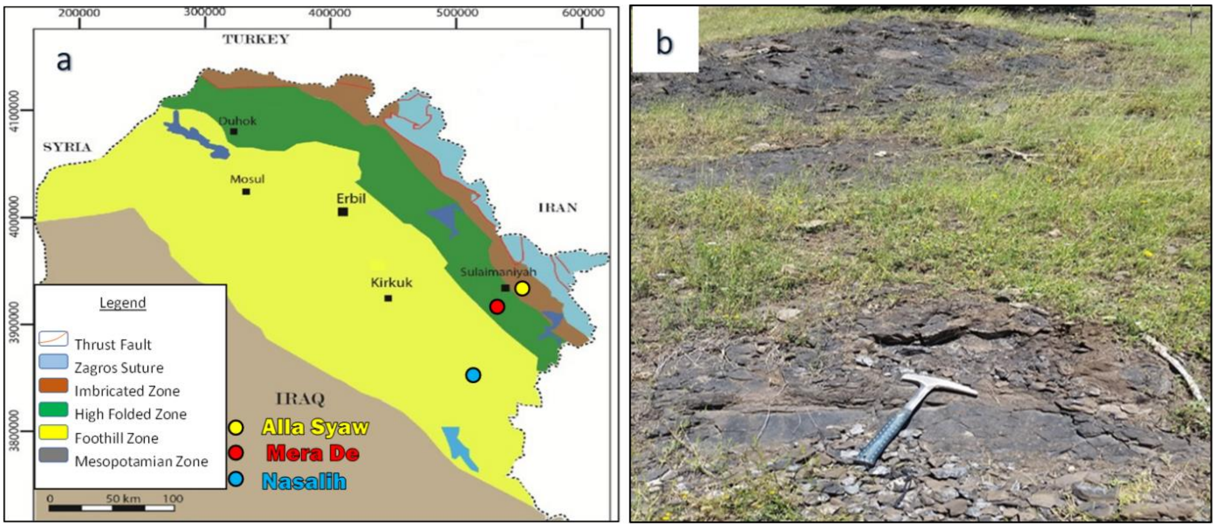

Figure 1: **a)** Locations of the studied sites posted on the tectonic map of Iraq after (Jassim & Goff, 2006); **b)** Exposed rock filled with bituminous materials (body) of Tanjero Formation in the Alla Syaw Village.

3. FIELD INSTRUMENTS, TESTING FIELD PARAMETERS AND METHODOLOGY

In the study under consideration, a new modern computerized static-type resistivity meter was used called SYSCAL Jr switch-72 (Figure 2). Tests before plotting the 2D electrical profiles were carried out to obtain the appropriate magnitudes of several field parameters that have significant relationships to the geological condition and the structural situation of the studied sites. There are many field parameters such as the number of stacks required for each measurement (maximum and minimum stacks), pulse duration, and the usage voltage. Each parameter must be tested and investigated to select the optimal value. The optimizing quality, total field time for each sounding, and battery autonomy must be taken into consideration during the investigation. A successful choice of the magnitude of these parameters has a great influence on obtaining smooth and high-quality data as well as on damping the noise to its lower limit. A 2-D resistivity imaging survey was carried out in some stations distributed throughout these sites. Two types of electrical arrays were used, Wenner and Wenner-Schlumberger. In each sounding station, the measurement was conducted several times using different voltages, 50 v, 150 v, and 300 v, and the maximum output was 400 v. In addition, for each voltage usage three variable pulse durations were tested, they are 500 ms, 1000 ms, and a maximum value equal to 2000 ms. The investigations show that when the voltage is 150 to 300 v and pulse duration is between 500 to 1000 ms few bad data have been recorded and the most accurate quality of data points are obtained. The test investigation results revealed that the following field parameters are optimum for the field survey of all three locations (Table 1).

Three profiles were laid out in each area to be surveyed continuously by 2D resistivity imaging (Figure 3). Wenner-Schlumberger array was utilized with a profile length of 360 m and a spacing interval is 5 m. The profiles run approximately parallel to the bed but sometimes are perpendicular to the strike due to complex topography.

Table 1: Optimum field parameters used in the present survey

Minimum Stack	Maximum Stack	Pulse Duration, (ms)	Voltage Used, v
2	6	500 – 1000	150 – 300

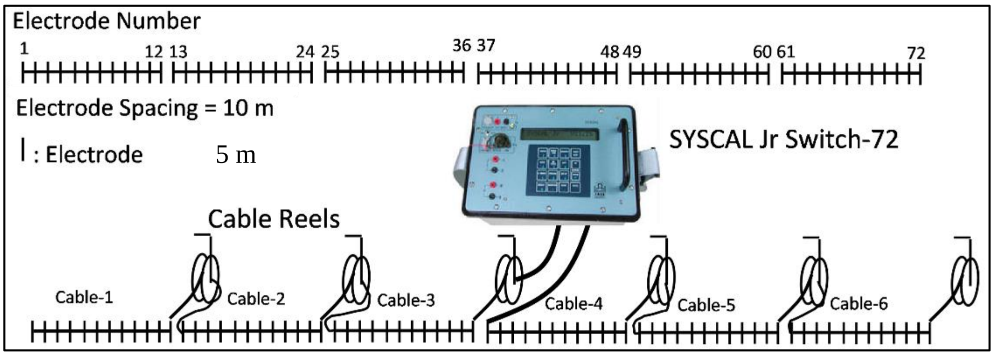

Figure 2: SYSCAL Jr switch-72 resistivity meter and electrode array

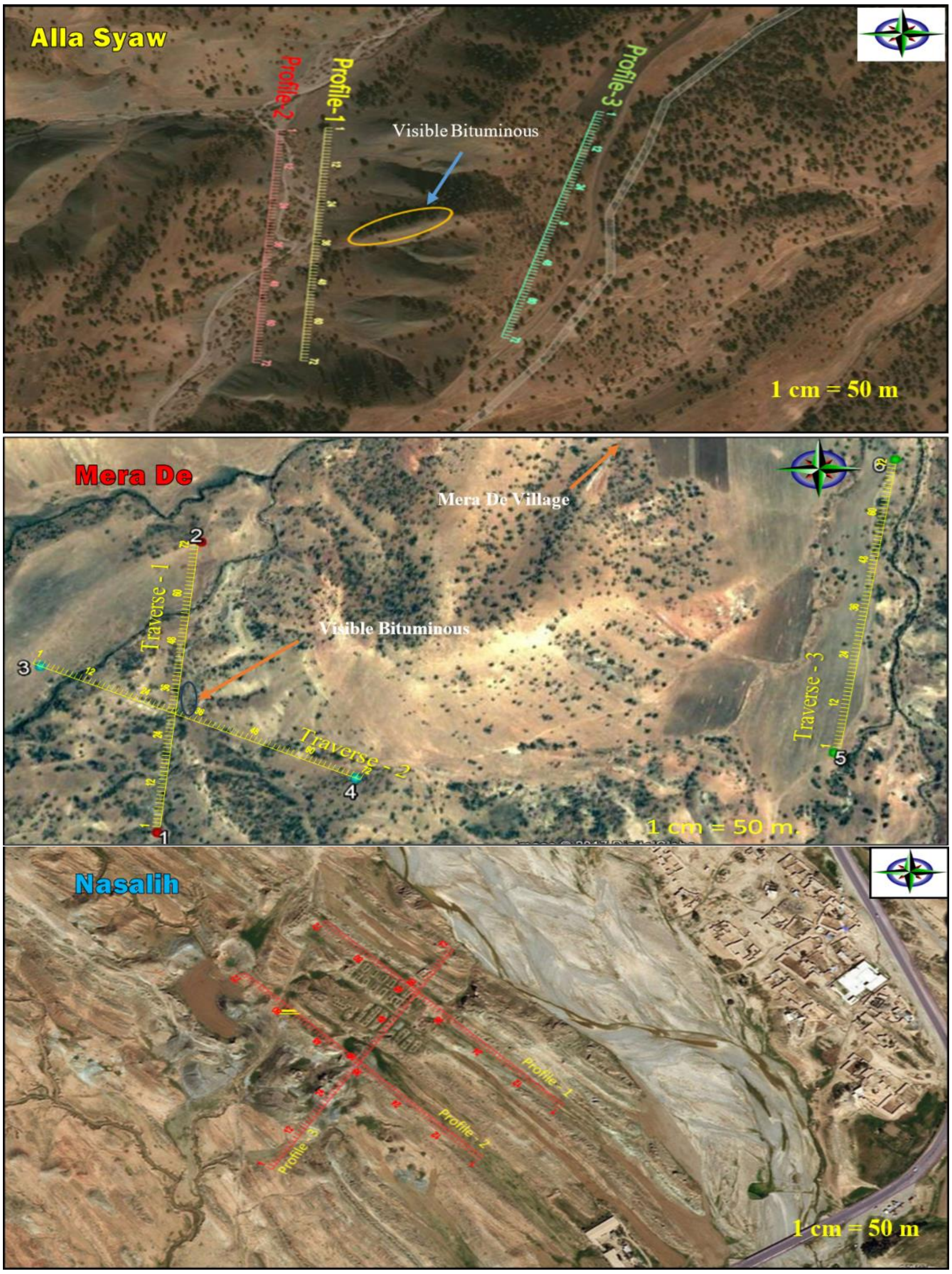

Figure 3: Locations of the 2D Resistivity Imaging profiles in the studied sites.

4. INTERPRETATION AND DISCUSSION

The interpretation of the 2D ERI models was performed using the latest version of the software package "RES2DINV" version 3.54.53. It performs smoothness-constrained inversion using finite difference forward modeling and Quasi-Newton techniques (Loke and Dahlin, 2002). An important factor in the inversion process of 2D imaging data is the quality of the field data. Good quality data usually show smooth variation in apparent resistivity values in the pseudo section. All the soundings show very good quality, therefore the little appearance of irregularity and spots that show higher or lower resistivity than surrounding has been observed in the pseudo sections. The interpretation of the ERI survey in the studied sites is explained below.

4.1. Alla Syaw Site

4.1.1. Profile-1

The length of this profile is 360 m and extends N10E (Figure 3, upper image), the first electrode is plotted at the NE end of the profile, and electrode no. 72 at the SW end. Three distinguished zones have been identified (Figure 4):

– **Zone 1:** is represented by the green color of intermediate resistivity; 8 – 200 Ohm.m. The resistivity of this zone is related to the existence of a large amount of clay, marl, and siltstone of the Tanjero Formation.

– **Zone 2:** has a reddish color with relatively high resistivity ranging from 200 – 600 Ohm.m. This zone represents the sandstone and siltstone cycle sedimentation of the Tanjero Formation.

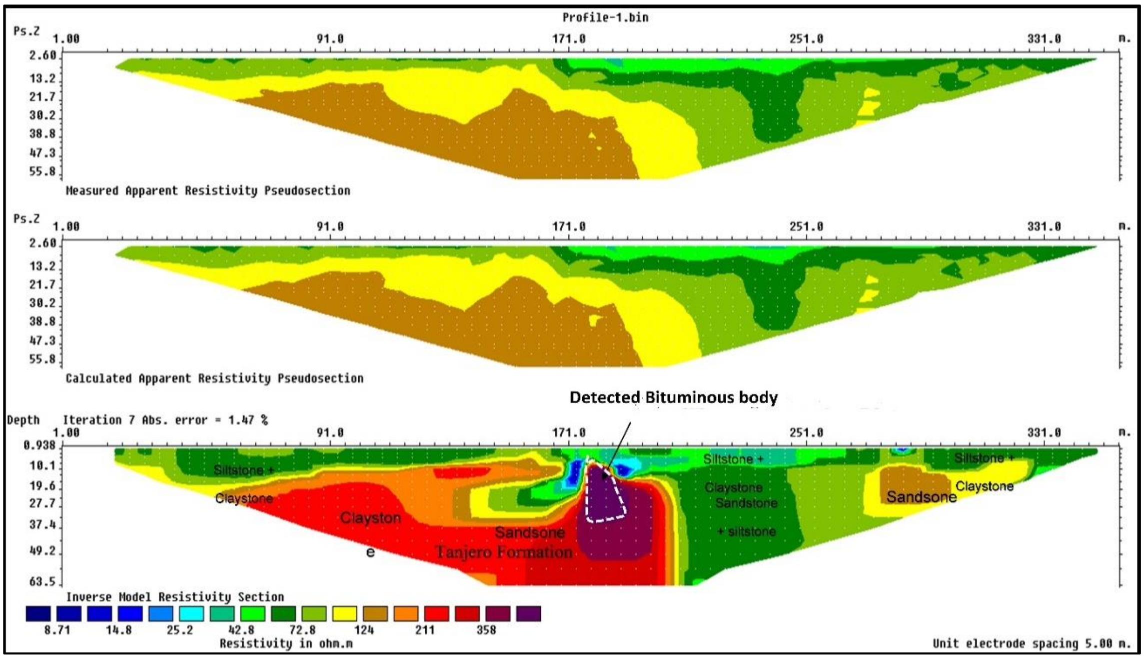

Figure 4: Interpretation of the 2D ERI model for Profile-1 in the Alla Syaw Site.

– **Zone 3:** has a dark reddish color with a resistivity of more than 200 ohm.m and is detected between electrodes 36 and 38 and below at a depth range from 8 to 10 m and extends to a depth of 27 m. It represents a bituminous body that has a thickness range from 5 to 10 m and a height of about 20 m. It most probably represents a fault running normal to the general strike of the bedding plane and filled with bituminous materials. The maximum depth of investigation is equal to 65 m, no trace of hydrocarbon is detected in the deeper part of the inverse section according to resistivity ranges, and it mostly represents sandstone layers of the Tanjero Formation.

4.1.2. Profile-2

It also has an N10E orientation and is parallel to the first profile (Figure 3, upper image). The distance between them is about 45 meters. The first electrode is plotted at the NE end of the profile and electrode no. 72 at the SW end (Figure 5). Similar to the first profile three distinguished zones have been identified:

– **Zone 1:** is represented by the green color of low resistivity; 8 – 100 Ohm.m. concerning the other zones. The intermediate resistivity of this zone is related to the existence of a large amount of clay, marl, and siltstone of the Tanjero Formation.

– **Zone 2:** has a reddish color, and is of intermediate resistivity ranging from 100 to 200 Ohm.m. It represents the sandstone and siltstone cycle sedimentation of the Tanjero Formation.

– **Zone 3:** has a dark reddish color with a resistivity of more than 200 ohm.m, is detected between electrodes no. 40 to 41 and below a depth ranging from 8 to 10 m. It is extended to a depth of 17 m. It represents a bituminous body and has a thickness ranging from 3 to 5 m and a height of about 7 m (vertical thickness). It is most probably representing the same fault running normally to the general strike of the bedding plane and filled with bituminous materials. The maximum depth of investigation is 65 m, no trace of hydrocarbon is detected in the deeper part of the inverse section, and it mostly consists of sandstone layers of the Tanjero Formation.

4.1.3. Profile-3

It is about 360 m in length extending N35E and running approximately parallel to the general strike of the outcrops (Figure 3, upper image). The first electrode is plotted at the NE end of the profile and electrode no. 72 at the SW end. The quality of recorded data is good due to the presence of a fine clay bed that covers the surface of the area. It appears clearly from the measured apparent resistivity pseudo-section, several spots of high and low resistivity appear throughout the whole section (Figure 6). Two distinguished zones have been identified:

– **Zone 1** is represented by the blue color of low resistivity; 7 – 30 Ohm.m concerning the second zone covers a small part of the inverse section. The low resistivity of this zone is returned to disseminating a large amount of clay with fine siltstone. This layer is composed of clay, marl, and siltstone cycles of sedimentations of the Tanjero Formation, its thickness ranges from 30 – 75 m.

– **Zone 2** (green to light green color) is of moderate resistivity ranging from 30 – 110 Ohm.m. It represents the sandstone and siltstone layers of the Tanjero Formation. No intrusion of the bituminous materials in the fracture and joint of the sandstone layers has been detected. The maximum depth of investigation is equal to 65 m, no trace of hydrocarbon is detected in the deeper part of the inverse section, and it mostly represents sandstone layers of the Tanjero Formation.

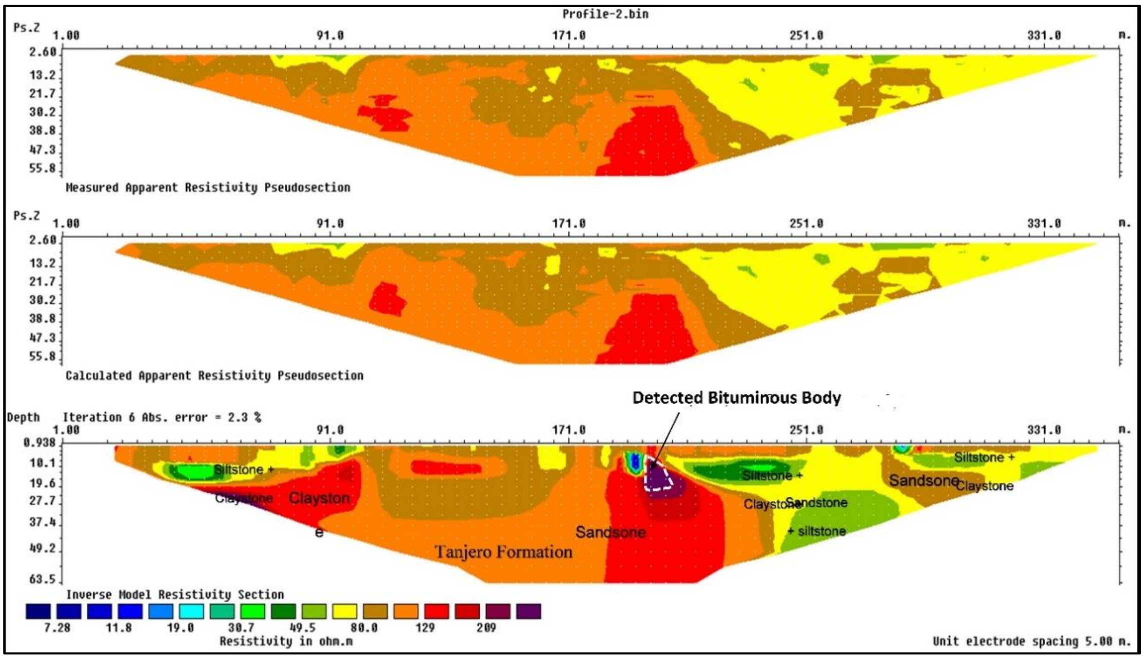

Figure 5: Interpretation of the 2D ERI model for Profile-2 in the Alla Syaw Site.

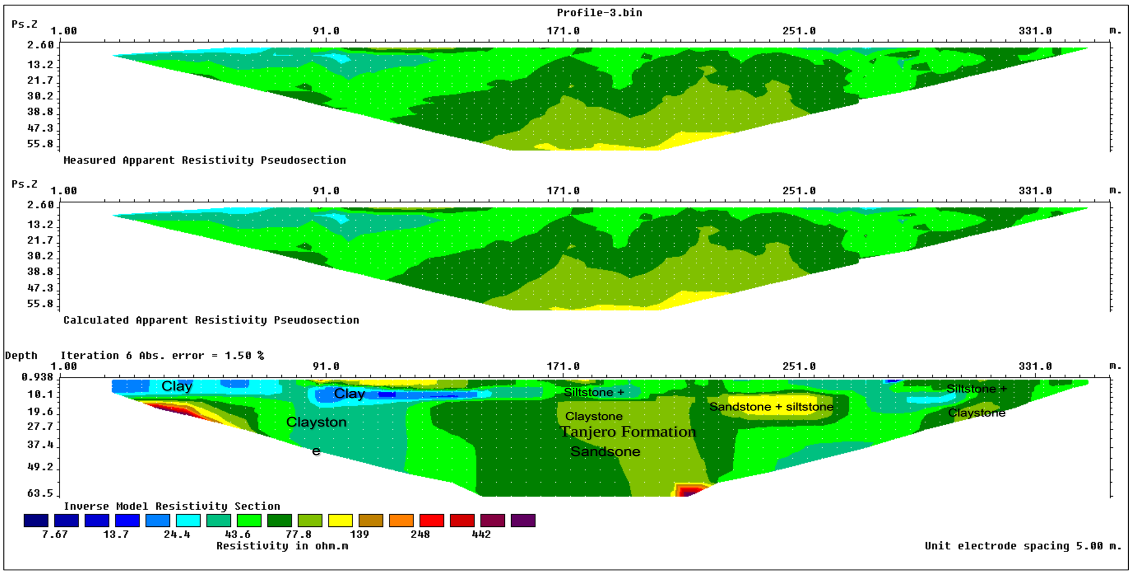

Figure 6: Interpretation of the 2D ERI model for Profile-3 in the Alla Syaw Site.

4.2. Mera De Site

4.2.1. Profile-1

It is about 360 m in length extending N10E (Figure 3, middle image), the first electrode is plotted at the SW end of the profile, and electrode no. 72 at the NE end (Figure 7). Two distinguished zones have been identified:

– **Zone 1** is represented by the blue and green colors of low resistivity; 6 to 14 Ohm.m concerning the second zone, the low resistivity is due to the dissemination of a large amount of clay with the fine silt. This zone is composed of clay and silt cycle sedimentation of the Gercus Formation. The thickness of this zone ranges from 4 m to 10 m.

– **Zone 2** has high resistivity ranging from 35 to 60 Ohm.m. It represents the intrusion of the bituminous materials in the fracture and joint of sandstone. Different sizes of high anomalous features are detected at three locations showing resistivity ranging from 25 to 50 Ohm.m:

1. Anomaly (I) beneath electrodes no. 21 to 27 and at a depth equal to 20 m. It has a thickness of 7 m and a horizontal distance equal to 30 m.
2. Anomaly (II) beneath electrode no. 34 to 38 and at a depth of 14 m. It has a thickness of 14 m and a horizontal distance of 20 m.
3. Anomaly (III) beneath electrode no. 52 to 54 and at a depth of 10 m. It has a thickness of 10 m and a horizontal distance of 10 m.

The maximum depth of investigation is 65 m, and no trace of hydrocarbon is detected in the deeper part of the inverse section. It mostly represents claystone and sandstone.

4.2.2. Profile-2

It runs NW – SE and is approximately parallel to the strike of the outcrops (Figure 3, middle image). The area is covered by thick soil. As in the profile-1 two distinguished zones have been identified, (Figure 8);

– **Zone 1** is characterized by blue color and a low resistivity; 6 to 17 Ohm.m. concerning the second zone. The low resistivity is due to the existence of a thick claystone bed with a little siltstone. This zone is composed of claystone and siltstone of the Gercus Formation. The thickness of this zone ranges from 2 m to 32 m and extends to the maximum depth of investigation equal to 65 m.

– **Zone 2** shows high resistivity ranges from 18 to 50 Ohm.m and is detected at depths ranging from 5 m to 23 m. This zone is composed of coarse materials such as gravel, sandstone, and little clay. It extends to the lower part of the resistivity section and the maximum depth of investigation is equal to 65 m and represents the coarse grain sediments cycle of the Gercus Formation.

The location beneath electrodes no.7 to 10 and at a depth of 10 m may represent the saturation of joints and fractures by hydrocarbons. It has a width equal to 17 m and a height of 9 m.

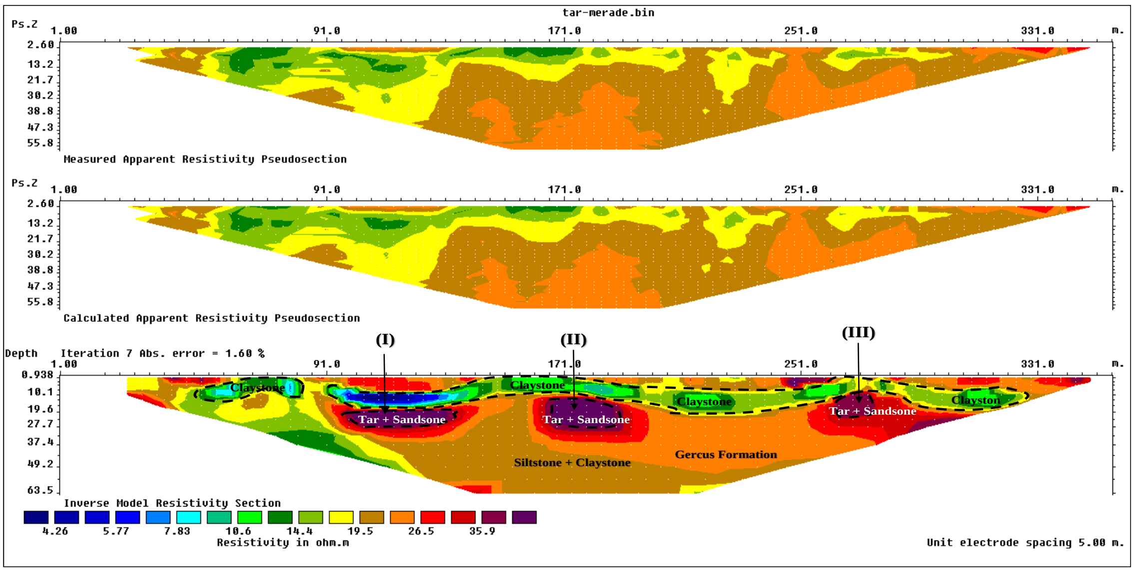

Figure 7: Interpretation of the 2D ERI model for Profile-1 in the Mera De Site.

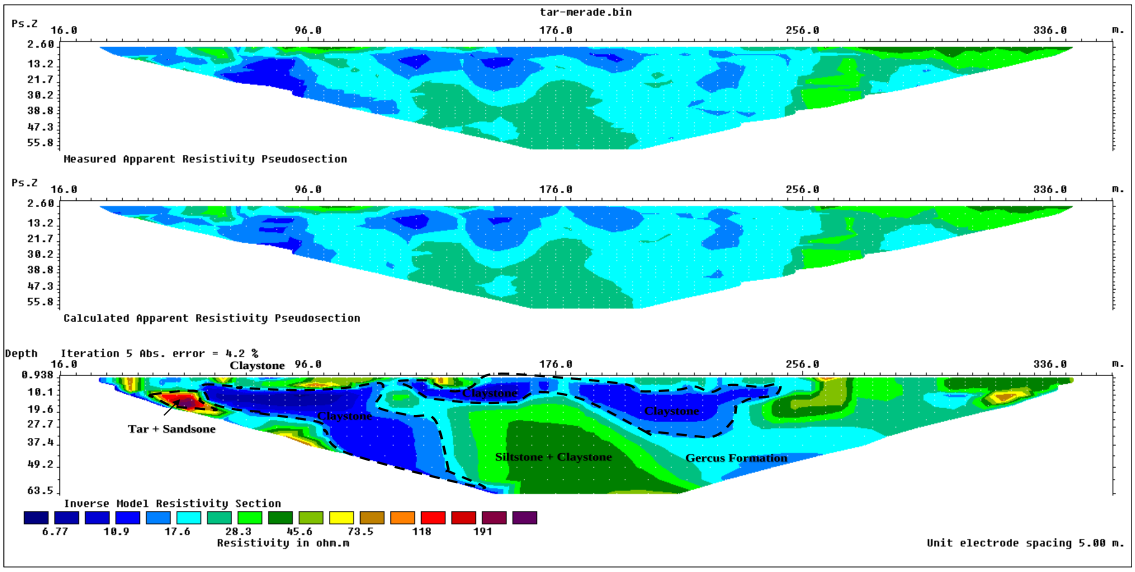

Figure 8: Interpretation of the 2D ERI model for Profile -2 in the Mera De Site.

4.2.3. Profile-3

It runs parallel to profile-1 (Figure 3, middle image), the first electrode plotted at the SW end of the profile, and electrode 72 at the NE ends (Figure 9). The quality of the measured data is good due to the presence of a fine clay bed that covers the surface of the area. It appears clearly from the apparent resistivity pseudo-section, where several spots of high and low resistivity appear throughout the whole section. Two distinguished zones have been identified;

– **Zone 1** is characterized by the blue color and low resistivity; 9 to 18 Ohm.m concerning the second zone. The low resistivity of this zone is returned to the disseminating of a large amount of clay with the fine siltstone. This layer is composed of claystone and siltstone cycle sedimentations of the Gercus Formation. The thickness of this layer ranges from 10 m to 25 m.

– **Zone 2** has a high resistivity range of 50 to 120 Ohm.m, it represents the intrusion of the bituminous materials in the fracture and joint of sandstone. They are detected at three locations shown as follows:

1. Anomaly (I) beneath electrodes no. 21 to 24 and at a depth of 4 m. It has a thickness of 5 m and a horizontal distance of 15 m.
2. Anomaly (II) beneath electrode no. 34 to 36 and at a depth of 4 m. It has a thickness of 4 m and a horizontal distance of 10 m.
3. Anomaly (III) beneath electrode no. 40 to 43 and at a depth of 4 m. It has a thickness of 5 m and a horizontal distance of 15 m.

The maximum depth of investigation of 65 m, no trace of hydrocarbon is detected in the deeper part of the inverse section, which mostly represents claystone and sandstone of the Gercus Formation.

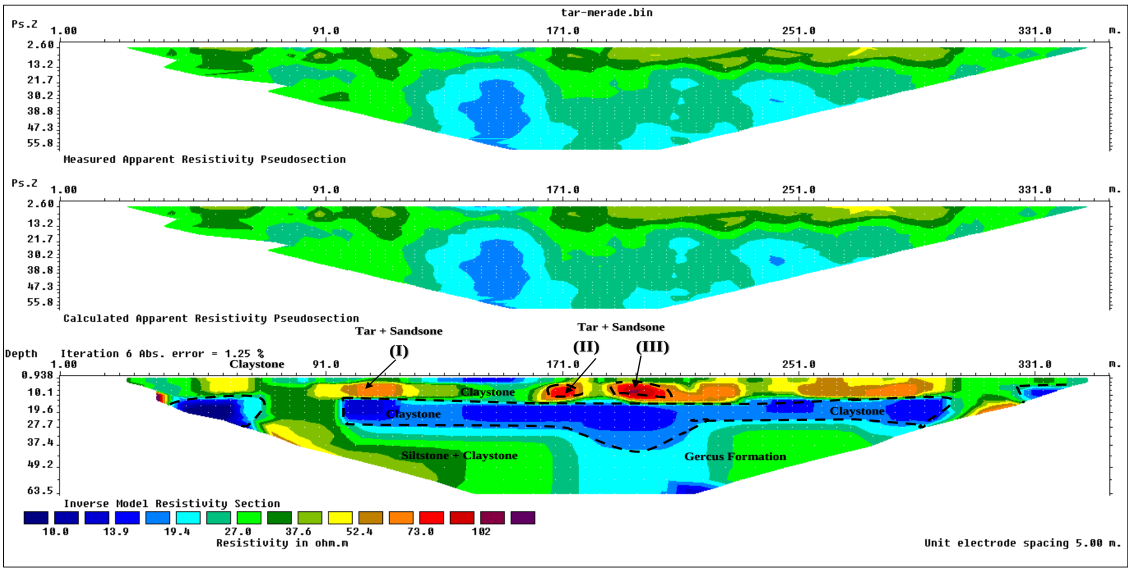

Figure 9: Interpretation of the 2D ERI model for Profile-3 in the Mera De Site.

4.3. Nasalih Site

4.3.1. Profile-1

It extends N45W parallel to the strike of the outcrops (Figure 3, lower image), the first electrode is plotted at the SE end of the profile, and electrode no. 72 at the NW end. Two distinguished zones have been identified;

- **Zone 1** is represented by the blue color and low resistivity concerning the second zone. The low resistivity of this zone is due to the dissemination of a large amount of clay with fine silt. This zone is composed of clay and silt cycle sedimentation of the Injana Formation showing resistivity ranging from 6 – 14 Ohm.m.
- **Zone 2** has a green to reddish color and high resistivity ranges of 17–120 Ohm.m. It represents the sandstone and siltstone cycle sedimentation of the Injana Formation. The fractures and joints of sandstone layers are filled with bituminous materials. High anomalous features are detected at five locations as follows (Figure 10):

Anomaly (I) beneath electrodes no. 12 to 15, and at a depth of 13 m has a thickness of 4 m. Anomaly (II) beneath electrodes no. 27 to 29, and at a depth of 14 m, has a thickness of 3 m. Anomaly (III) beneath electrode no. 32 to 34, and at a depth of 14 m, it has a thickness of 3 m. Anomaly (IV) beneath electrode no. 34 to 35, and at a depth of 8 m, it has a thickness of 2 m, it represents a cavity filled with water. Anomaly (V) beneath electrode no. 51 to 53, and at a depth of 11 m, it has a thickness of 3 m. The maximum depth of investigation is 65 m, no trace of hydrocarbon is detected in the deeper part of the inverse section, and it mostly represents clay stone.

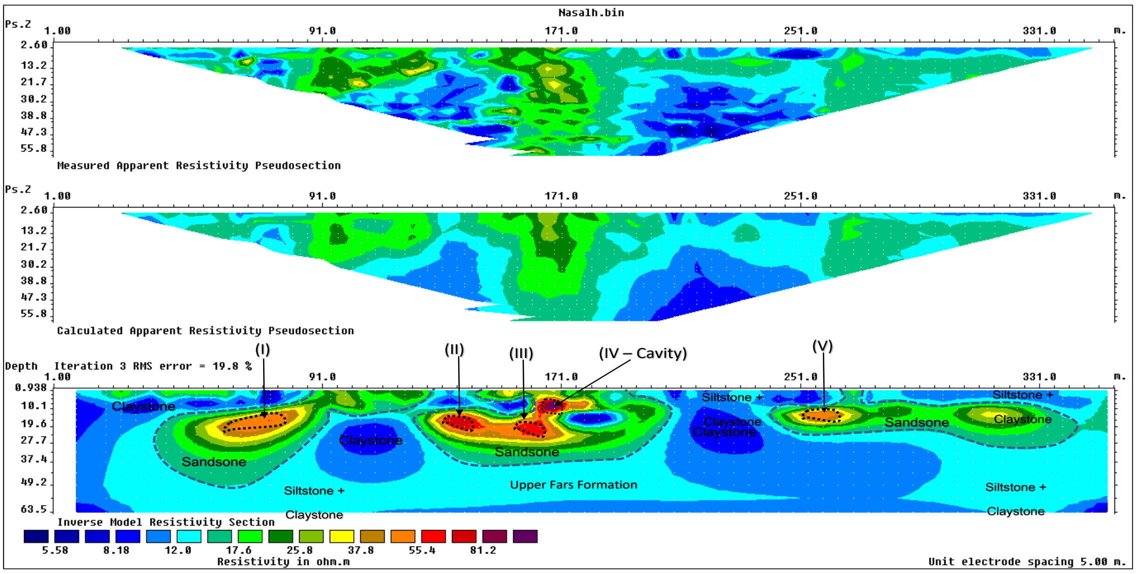

Figure 10: Interpretation of the 2D ERI model for Profile -1 in the Nasalih Site.

4.3.2. Profile-2

The length of this profile is equal to 360 m, it is running NW – SE, approximately parallel to the main strike of the outcrops (Figure 3, lower image), and the area is covered by thin soil. The quality of recorded data is slightly better than the previous traverse; and it appears clearly from the measured apparent resistivity pseudo-section, that no or little spots of high and low resistivity appear throughout the whole section (Figure 11). As the first profile, two distinguished zones have been identified;

– **Zone 1** is represented by a blue color and low resistivity (concerning the second zone), also the low resistivity is due to the existence of a thick claystone bed with a thin siltstone layer. This zone is composed of claystone and siltstone of the Injana Formation and it shows resistivity ranging from 5 – 12 Ohm.m. The thickness of this zone ranges from 30-70 m and extends to the maximum depth of investigation which is equal to 65 m.

– **Zone 2** shows high resistivity ranging from 15 – 110 Ohm.m, and it is detected at depths ranging from 1 – 65 m. This zone is composed of coarse-grain sandstone and little clay. It extends to the lower part of the resistivity section and the maximum depth of investigation is equal to 65 m, it represents the coarse material cycle of the Injana Formation. No locations of saturation of joints and fractures by hydrocarbon materials were found.

4.3.3. Profile-3

It is running in the direction of the dip and normal to the strike of the outcrops (Figure 3, lower image). The first electrode is plotted at the SW end of the profile and electrode no. 72 at the NE end. The quality of recorded data is good due to the fine clay cover surface of the area which appears clearly from the measured apparent resistivity Pseudo-section; where several spots of high and low resistivity appear throughout the whole section (Figure 12). Two distinguished zones have been identified;

– **Zone 1** is represented by the blue color and low resistivity concerning the second zone, the low resistivity of this zone is due to the dissemination of a large amount of clay with the fine siltstone. This zone is composed of claystone and siltstone cycles representing fine sedimentation of the Injana Formation. It shows resistivity ranges from 5 – 10 Ohm.m. The thickness of this zone ranges from 30 – 75 m.

– **Zone 2** has a green to reddish color and is of high resistivity ranges from 18 – 110 Ohm.m. It represents sandstone layers of the Injana Formation with the intrusion of the bituminous materials in fractures and joints of the sandstone layers, they are detected at four locations:

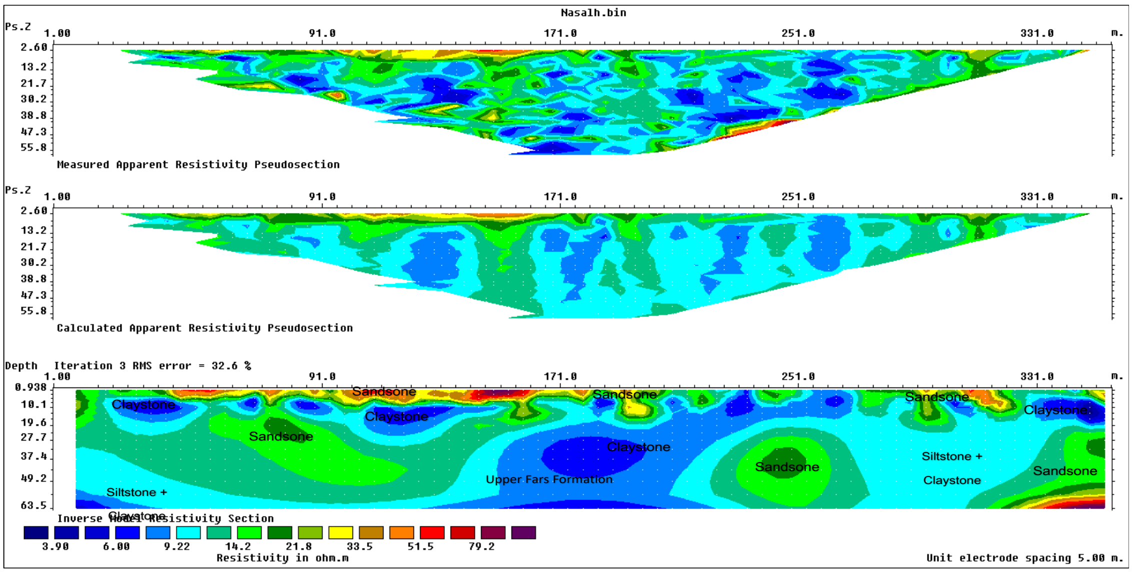

Figure 11: Interpretation of the 2D ERI model for Profile-2 in the Nasalih Site.

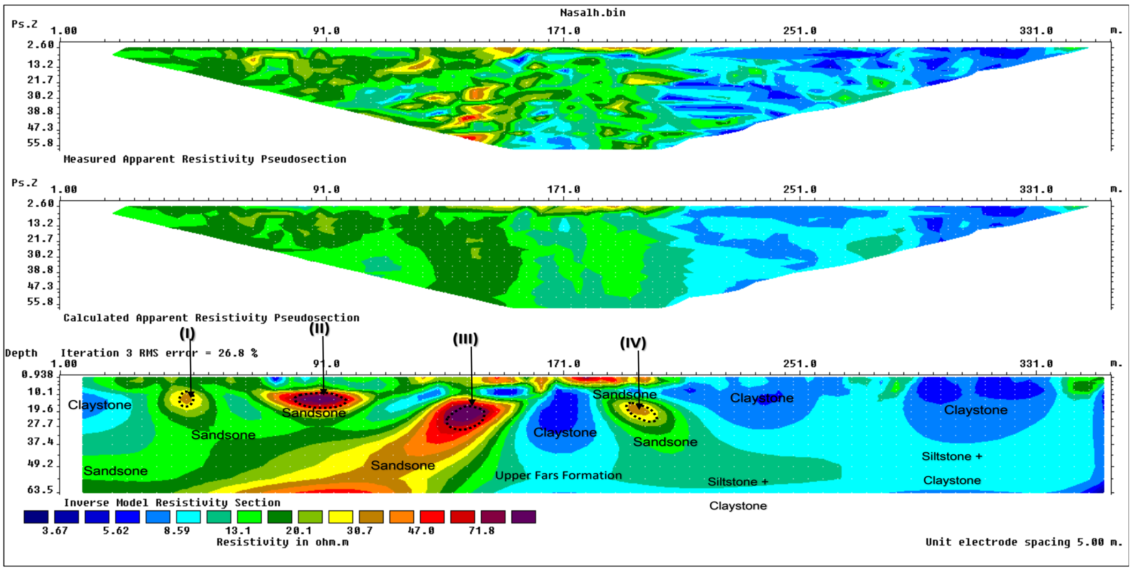

Figure 12: Interpretation of the 2D ERI model for Profile-3 in the Nasalih Site.

Anomaly (I) beneath electrode no. 10, and at a depth of 10 m, has a thickness of 2 m. Anomaly (II) beneath electrodes no. 17 to 20, and at a depth of 10 m, has a thickness of 5 m. Anomaly (III) beneath electrodes no. 28 to 30, and at a depth of 18 m, has a thickness of 10 m. Anomaly (IV) beneath electrode no. 40 to 42, and at a depth of 14 m.

3. CONCLUSIONS

The current study, in three different locations and three different geological and tectonic settings, reveals a set of conclusions, that are listed below:

- All the bituminous materials are detected in the sandstone layers of the Tanjero, Gercus, and Injana Formations. They are filling fracture zones and fault planes, and in many locations during the fieldwork, these features have been observed in sandstone layers. This is also related to the more brittle behavior of the sandstone layer than other layers of these formations which deforms easily when applying external stresses.
- In the Tanjero Formation, just one bituminous body is detected at a depth of about 10 m, which has an extension of more than 50 m from profile-1 to profile-2. Its average width and height are 8m and 20 m, resulting in an approximate total volume of 8000 m^3.
- The little chance of the existence of bituminous bodies in the Tanjero Formation is related to the thin thickness of the very dense and compacted sandstone layers as well as to the old geological age of this formation compared to the other two studied formations which gave sufficient time for escaping these materials.
- Several small to large bituminous bodies are detected in the sandstone layer of the Gercus and Injana Formations that have an extension beneath the profiles. The existence of a large number of these bodies has a great relation to the existence of thick brittle layers of fractured and faulted sandstone within these two formations.
- All detected bituminous bodies appear in shallow depths not exceeding 30 m. Below the depth ranges of 30 m to 65 m, no bituminous body is detected. This may be related to the lower density of these materials than the host rocks which may have led to escape them gradually due to large overburden load during the past geological time.
- The study concludes that the preliminary estimation of the total volume of the detected bituminous bodies is more than 20000 m^3, which is important as raw materials used for different industries.
- From a tectonic point of view, the studied sites are located in the Imbricated Zone, High Folded Zone, and Foothill Zone. The numbers of detected bituminous bodies are one, three, and five, respectively. This is obvious evidence indicating that the majority of these materials in the Alla Syaw area have been rushed outside due to high tectonic activity in this region.

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