

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 11, November 2018

Design of Multi-Electrode and Real-Time Equipment for Spontaneous Polarisation Imaging

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ABSTRACT: The design of an automated equipment for spontaneous polarisation imaging is presented for mineral exploration application. The device is named SPMeter-Box and, with low-cost in mind, it was manufactured using locally available and open-source parts such as raspberry pi and arduino. The SPMeter-Box is designed for fast and real-time SP imaging using a maximum number of 64 non-polarisable electrodes. Each electrode is made of a porous polyvinyl chloride container accommodating a copper rod and a saturated solution of copper sulfate. We validated the equipment using the data obtained from a calibrated Fluke-77 voltmeter and its performance was tested through a graphite exploration within the southern part of Madagascar. Promising results were obtained from the measurement campaign. Good correlations were seen between the SPMeter-Box SP-image, the electrical resistivity tomography profile and the chargeability data given by a syscal-R2 resistivimeter.

KEYWORDS: SPMeter-Box, Spontaneous polarisation, Mineral exploration, imaging, resistivity, chargeability

I. INTRODUCTION

The mining sector is a big opportunity for under-developed countries, such as Madagascar, for having a prosperous economy. So far, international mining firms dominate the market and gain most of the profit. Various reasons explain the situation and politics play an important role on the issue. Nevertheless, local mining industries are unfit to competition due to the use of traditional mining techniques and the lack of appropriate geophysical equipment on local markets. Newer and cutting-edge instruments can be imported but they are often expensive and out of the reach of local companies. We believe that the design and the local production of geophysics instruments, which are competitive to commercial devices, are the key and a step towards having a flourished mining industry. With these in mind, we focused our attention on the design of a multi-electrode equipment for fast spontaneous polarisation (SP) characterization. The device reduces measurement-time and human-effort and is named SPMeter-Box. An automated instrument that can do both acquisition and subsurface imaging in real-time using an array of 64 non-polarisable electrodes. The real-time visualization aspect is particularly useful for long-term monitoring applications such as the

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survey of under-ground water-flow, the primary reason for landslide phenomenon. The instrument was tested on a graphite deposit located in the southern part of Madagascar and obtained results showed a good correlation with electrical resistivity tomography and induced polarization maps.

II. BACKGROUND

Subsoil layers are formed from the mixture and the compaction of organic and inorganic materials over a long geological-period. The electrical properties of the soil, due to chemical compositions, allow geophysicists to characterise and identify ore bodies using three well-known approaches referred to as the geo-electrical methods. Those methods have a common measurement aspect and are all based on a potential-difference measurement between two distant electrodes planted in the ground. The difference lies within the presence or the absence of an external current source within the setup. For active systems, a user-controlled current is injected within the soil via two electrodes, represented by A and B in Figure 1a, for inducing a voltage proportional to the subsoil-layer resistivity across the middle electrodes (M and N). This measurement principle is the base of an electrical resistivity tomography (ERT) investigation and can be used for mapping the subsoil internal layers according to the soil vertical axis. Schlumberger also found that the injected current can provoke the polarisation of the soil deep-layers which result into a gradual cancellation of the measured voltage to zero at the time the source-current is switched-off [1]. The phenomenon is correlated to the layers chargeability and is particularly high for terrain potentially rich in minerals [1, 2]. A terrain chargeability investigation is also known as the induced polarisation (IP) measurement and is extensively used in mineral exploration [2].

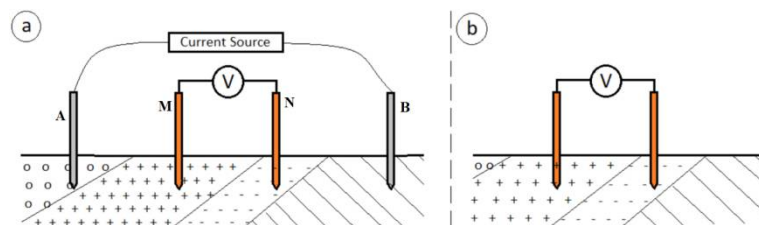


Figure 1. Description on the geo-electrical methodology measurement setup. The picture on the left-hand side shows the basic setup of an electrical-resistivity tomography (ERT) and an induced polarisation method. The one on the right-hand side represents the spontaneous polarisation measurement setup.

In contrast to the two previous measurement principles, passive systems use the natural voltage created across the two electrodes in Figure 1b for detection of ore bodies. The voltage is known as spontaneous polarisation (SP) or self-potential and is the product of various activities occurring within the deep-layer of the soil like an oxidation-reduction reaction and an electrokinetic phenomenon. The technique is among the earliest geophysical method used for subsurface ore deposit detection [3, 4] and has also been utilised in hydrogeology for underground water-flow studies and landslide surveillance [5]. The SP can be subdivided into two major parts. On one hand, we have the potential-difference caused by a mineral body, referred to as the mineral-potential. On the other hand, we have a time-varying component due to natural sources like rainfalls, thunderstorms, or even the earth magnetic fields. An SP-image does not give any information concerning the mineral depth nor its vertical extension within the ground. The map only confirms the presence of ore bodies underneath an area-of-interest and its lateral extension. Following this perspective, an SP investigation is often combined with ERT and IP results for a more accurate estimation of the size and the volume of an ore body.

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III. DESIGNING THE MULTI-ELECTRODE EQUIPMENT

III.1 Equipment Overview

Figure 2 shows our SP imaging instrument, named SPMeter-Box, that was manufactured using locally available components. It is a passive and a battery driven equipment that can be connected to two or a maximum of 64 non-polarisable electrodes. The instrument draws a peak-current of 515 mA and able to continuously work for 9 hours using a single 7 Ah | 12 V battery supply. The power consumption is lower in remote-mode where the on-board screen is unused and the connection with the instrument is established through an ethernet or a wireless link. The battery driven feature offers two main advantages. At first, it reduces the coupling with the environment, especially the low-frequency noise from the mains or an AC generator. Secondly, it is more practical and suitable for measurements at remote locations.

The electrodes are attached to the instrument using eight connectors. Each connector can accommodate eight connections and is similar to the picture shown on the right-hand side of Figure 2. The electrodes are dispersed over the surface under-investigation according to the user requirements and is defined in terms of numbers and spacing. Custom settings can be entered on the equipment graphical interface but predefined values are also available for flexible use of the product. During a measurement, the instrument starts by selecting a single electrode from the array. Afterwards, it measures the SP-voltage with respect to a reference electrode, named ERef in Figure 3, which is placed at an arbitrary and fixed position outside the array. The arduino transfers the digitized value to the raspberry pi and the same procedure is repeated until the last electrode is scanned.

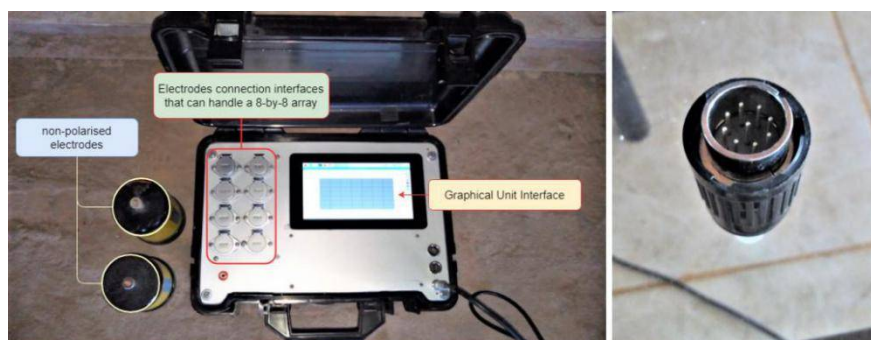


Figure 2. Picture of the SPMeter-Box showing the finished product in its plastic casing. Two non-polarizable electrodes are also presented which can be connected to the device using the connector shown on the right-hand side.

III-2. Acquisition Board Description

The acquisition board is the hardware performing the SP measurements. An Arduino-Mega coordinates the whole process and at the same time transfers the SP data to the instrument main software for processing, visualisation and recording. Figure 3 shows the board working-diagram where three main-blocks are highlighted: the multiplexing, the amplification and the digitization module. The amplification and the digitization form the signal-conditioning part of the instrument where the SP voltage is first amplified, filtered and then converted to a digital voltage value. The multiplexing unit performs the electrode selection and it is based on a single i2c bidirectional switch from Texas Instrument which is the TCA9548A. It is important to note that we used a couple of electromechanical relays for the first prototype of the design. The multiplexing circuit worked fine but the relays' switching events interfered with the voltage measurement and the board was discontinued.

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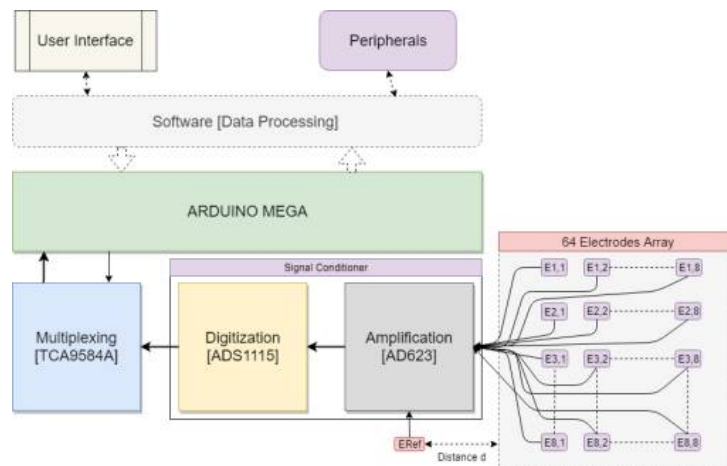


Figure 3. Overview on the SPMeter-Box acquisition hardware and the electrodes interfacing

The electrode-soil contact resistance can change from a few to a hundred of kilo-ohm depending on the condition of the soil where the electrode is located [6]. A dry ground shows the highest contact resistance value and the amplification stage must be able to handle such condition by preserving a relatively good signal-to-noise ratio for the SP measurement. The impact of high electrode impedance on an amplification circuit is a well-know fast in electronic [7] and has been carefully thought to produce an equipment that can be used in different type of soil conditions. We used a $2\text{ G}\Omega$ input impedance instrumentation amplifier, the AD623, to achieve this objective and to provide the amplification module a common-mode rejection of more than 80 dB [8] for any type of terrain under-test. Each individual electrode is connected to a unit-gain amplifier, an AD62, and the output of each chip is filtered with a 16 Hz low-pass filter to avoid an aliasing effect within the digitization unit. Here, the filter also acts as a decoupling capacitor for blocking any high-frequency leakage from the unit gain amplifier to reach the ADC, especially the 50 Hz, the 60 Hz and their individual harmonics. The conversion from analog to digital of an SP-signal is performed with an AD1115 chip and we used the on-board programmable gain amplifier for increasing the SPMeter-Box measurement dynamic-range.

III-3. Designing the non-polarisable electrodes.

The SP voltage between the reference and the selected electrode comes from four major contributions:

- The anomaly contribution, which is the main target of an SP investigation in geophysics.
- An environmental time-varying signal described in section II.
- An artificial voltage source related to measurement setup or induced by nearby sources
- Polarisation potentials occurring on the two electrodes due to electrochemical reaction differences between both electrodes.

The latter can be reduced with non-polarizable electrodes [9] and we designed 64 electrodes using the principle described in [10]. The picture on the left-hand side of Figure 4 depicts the electrode's principle where a rod of copper is placed in a saturated solution of copper-sulfate. The product is accommodated in porous-base PVC container and the outcome is similar to the picture shown on the right-hand side of Figure 4.

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Figure 4. Description of the in-house built non-polarisable electrodes.

The quality of the design can be tested using salt-water. A pair of electrodes is placed within a saline solution and the voltage forming across the electrodes is measured with an ordinary voltmeter. Good electrodes are expected to give a voltage less than 10 mV [11] and on the left-side of Figure 4, a polarisation of 2 mV was achieved. This procedure is also performed before an SP-imaging measurements for identification of damaged electrodes. However, instead of using the 10 mV threshold we use a 5 mV limit for obtaining the most accurate data as possible during a measurement campaign.

III-4. Software Overview

The SPMeter-Box is a computer-controlled device using a linux distribution running on a raspberry pi 3 model B version. The raspberry Pi is dedicated for SP data processing and user interfacing but besides this, it is also connected to the Arduino Mega for controlling the acquisition hardware. The instrument is equipped with a visual interface, displayed on a 7 inch touchscreen, to facilitate the configuration and the manipulation of the equipment. The interface was designed in C++ using the QT package and the QT-designer environment. From the main menu, the user selects the tasks that he wants to perform and this choice is between:

- a real-time monitoring of SP values over a specific range of electrodes or
- a two dimensional imaging of SP voltages over a finite array of electrodes

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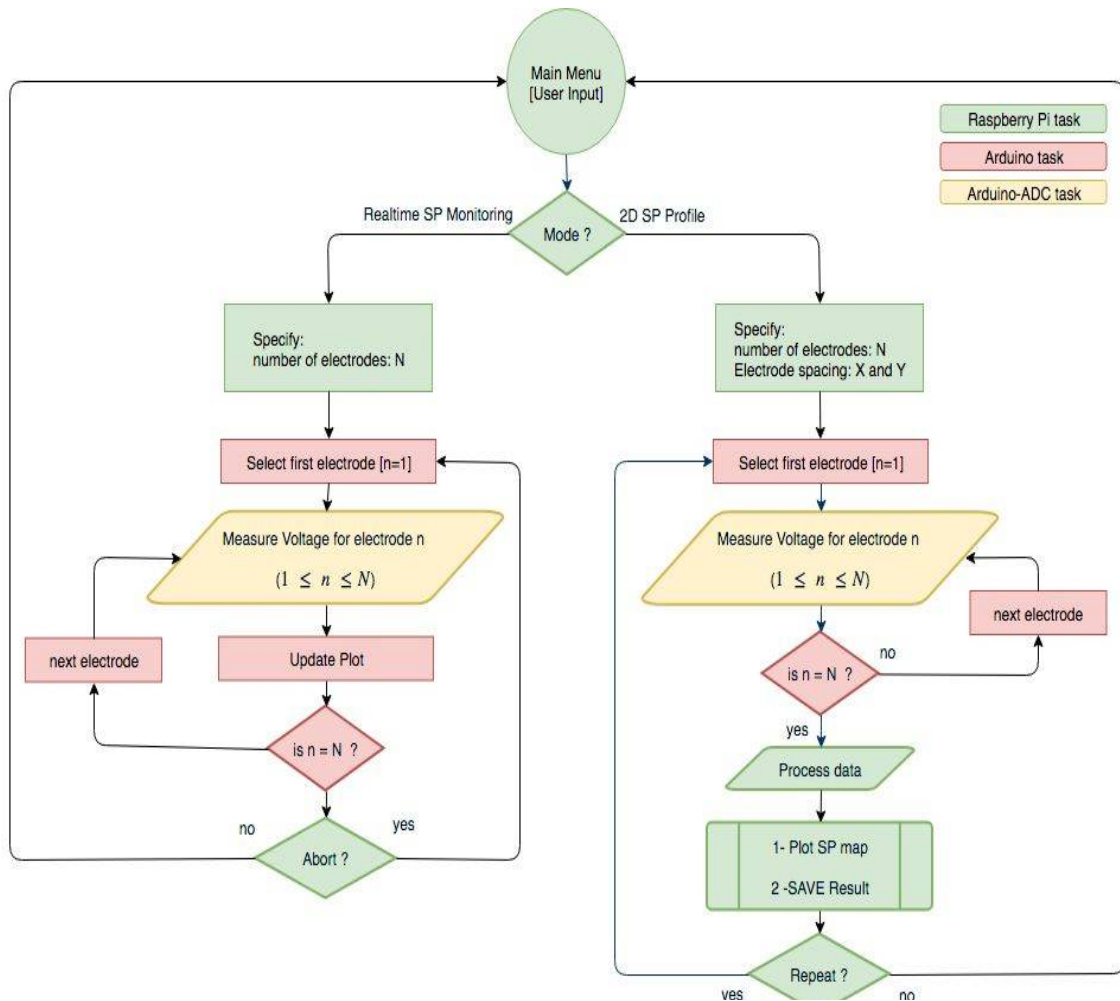


Figure 5. Overview on the SPMeter-Box operational diagram

IV. SP-IMAGING AND DATA PROCESSING.

In general, two corrections must be accounted for during an SP-profile data-processing. The first correction takes into account the reference-electrode displacement while the second concerns about voltage-drifts caused by environmental perturbations, such as telluric noise, on the measurement's setup. The reference electrode is always located at a fixed position during data acquisition and for this reason, no reference-correction is used within the SPMeter-Box internal data-processing. As far as the voltage drift is concerned, it is important to note that the instrument takes 10 ms to capture each electrode voltage and about 640 ms to perform an SP imaging with 64 electrodes. The SP-data acquisitions are relatively fast compared to most environmental perturbations and because of this the voltage-drift is tiny and negligible. It is, however, noted that for a vast area under-investigation, multiple measurements are often performed. Different reference locations are used and the campaign might take from hours to a couple of days. For this particular case, the user must apply the above corrections in post-processing to achieve an accurate results interpretation.

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A bi-cubic interpolation is applied on the SP-voltages every time the equipment finished scanning the entire array. This permits a smoother image rendering and the algorithm permits the calculation of SP values located in-between the electrodes.

V. RESULTS AND DISCUSSIONS

V-1. SPMeter-Box Validation.

We used a Fluke-77 voltmeter for validation of the SPMeter-Box measurements. An array of 64 electrodes of 10 m by 10 m mesh-cell was used for the investigation and the SP voltage at each electrode was measured with both equipment. The figure on the left-hand side of Figure 6 depicts the array geometry while the picture on the right-hand side shows the SP-image generated by the SPMeter-box. The difference between the Fluke and the SPMeter-box voltage data was calculated using equation (E.1) and results are given in Table 1 for each individual electrode.

$$\Delta V \text{ [mV]} = V_{\text{Fluke}} - V_{\text{SPMeter-Box}} \quad (\text{E.1})$$

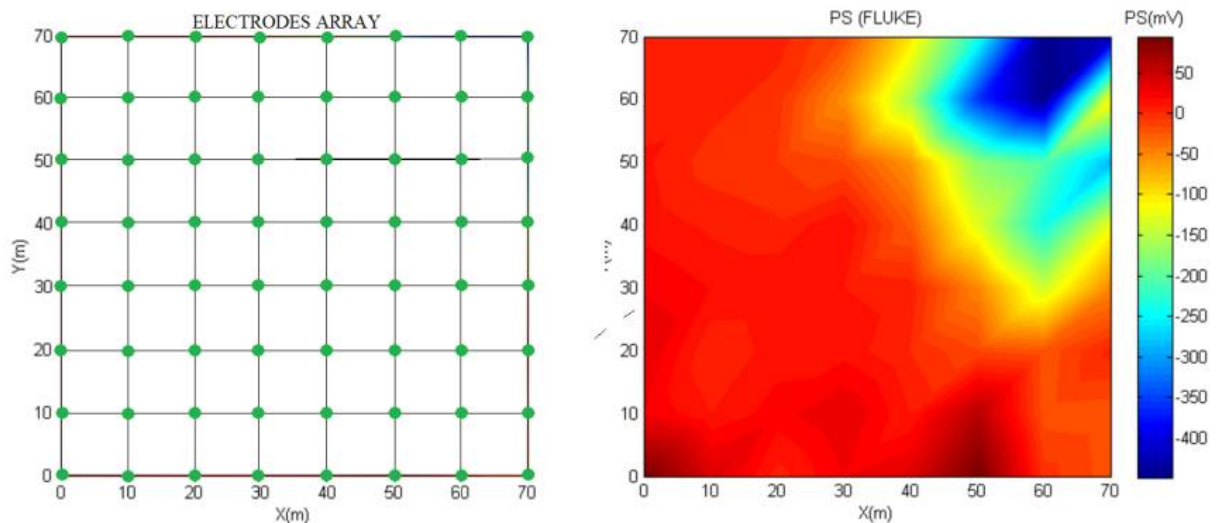


Figure 6. Validation of the SPMeter-Box measurement data. One the left-side is depicted the electrodes geometry while the picture on the right-side displays the SPMeter-box SP-image.

Table 1. Voltage difference in mV between the Fluke-77 and the SPMeter-Box data for each individual electrode.

X\Y [m]	0	1	20	30	40	50	60	70
0	-1	0	0	1	1	-2	3	-1
10	0	2	-1	-4	2	1	5	3
20	-1	0	1	1	2	3	2	4
30	-1	-1	1	1	-1	1	-1	1
40	0	-1	0	1	-1	1	1	1
50	-1	0	-1	1	0	1	-1	-1
60	1	0	-1	1	1	-1	0	-1
70	0	-1	1	-1	0	-1	-1	1

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The Fluke and the SPMeter-Box show similar SP results. A difference less than 5 mV was measured throughout the array. The source of the variation was not quantified but due to the fact that the Fluke measurements were performed manually, the measurements were likely influenced by telluric noise.

V-2. Graphite Deposit Characterisation

The SPMeter-Box was also used during a measurement campaign within the southern part of Madagascar for investigation of graphite deposits within the region. Figure 7a and Figure 8a show two SP-images measured with the SPMeter-Box for two different parts of the same terrain under-investigation. If we focus on negative SP-values coloured in blue on both maps, which are basically due to concentration of minerals within the ground, we can conclude that both maps point to the presence of anomalies within the two areas. In addition to this, the results also illustrate the anomalies extension and trend within the ground. It is, however, noted that the SP manifestation on the ground is correlated with the depth of the mineral-deposit, the electrical characteristics and the thickness of the rock layer sitting above it. In consequence, the effect of the graphite deposit can be masked by superficial layers and its size can be larger than the SP results shown in Figure 7a and Figure 8a.

We checked these SP-findings using ERT and IP data along the profiles depicted by the two lines in Figure 7a and figure 8a. ERT and IP results for each profile are shown on the right-hand side of the corresponding figure. The ERT map on Figure 7b highlights the presence of highly conductive layer from 5 m deep within the ground. From Figure 7c, the IP map shows that a high chargeability material is found at about 10 m from the ground. Then, by coupling the ERT and IP findings, we can say that the hatched area, named D1 and D2, are potentially the location of the graphite deposits along the profile P1. Using the same approach, the results in Figure 8 also depicts the presence of two graphite deposits at about 8 m within the ground. The location of D2 is similar to the SP anomaly seen in Figure 7a. D1 is not visible on the SP-image due probably to the fact that it is too deep within the ground as explained earlier within the previous paragraph. As far as D3 and D4 is concerned, we clearly see the effect of both deposits on the SP-images. D4 is slightly bigger according to the results in Figure 8b and Figure 8c and is the cause for the two hatched anomalies in Figure 8a. The SPMeter-Box are consistent with ERT and IP data, indicating a promising performance of the equipment.

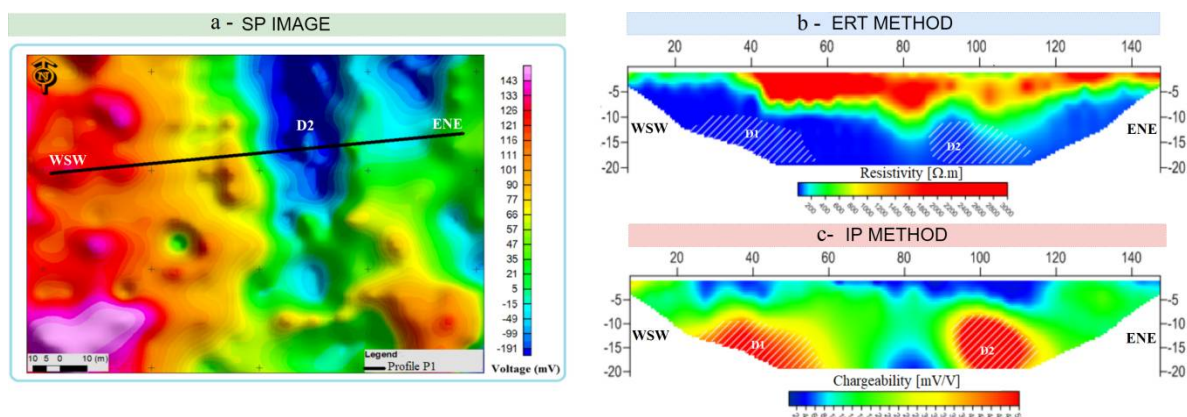


Figure 7. Investigation of a graphite deposit within the Southern part of Madagascar. The picture of the left-hand side shows the SP Image as measured with the SPMeter-Box. The pictures of the right-hand side represent the ERT and the IP result that we performed along the profile P1.

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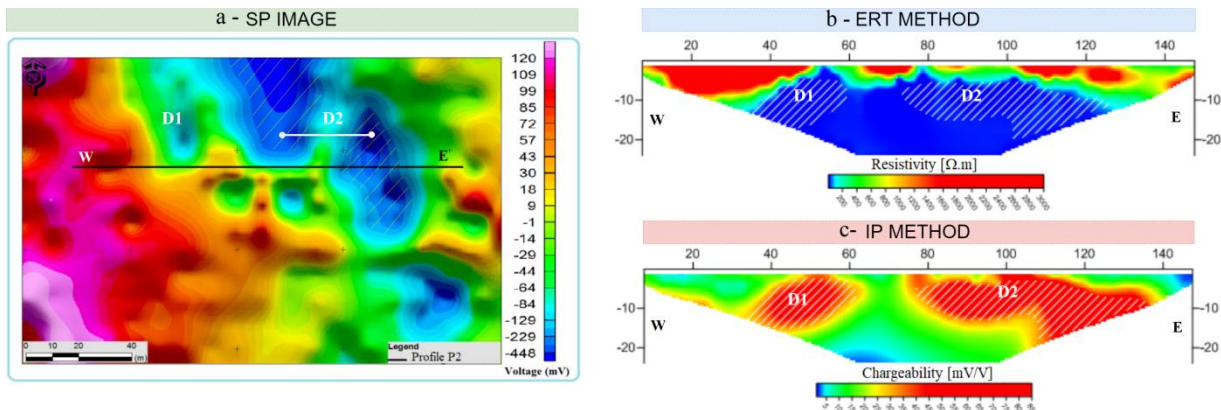


Figure 8. Investigation of a graphite deposit within the Southern part of Madagascar. The picture of the left-hand side shows the SP Image as measured with the SPMeter-Box. The pictures of the right-hand side represent the ERT and the IP result that we performed along the profile P2.

VI. CONCLUSION

We believe that the local production of affordable and competitive geophysics equipment is key for the prosperity of the mining sector within underdeveloped countries like Madagascar. Thus, the design of an automated instrument, named SPMeter-Box, was presented for fast and real-time SP-imaging application. The device is battery driven and made using the latest raspberry-pi 3 single-board computer. It can be connected to an array of 64 non-polarisable electrodes, also manufactured in-house, and achieve an SP-image refreshing rate of about 640 ms. A Fluke-77 voltmeter was utilised for validation of the SPMeter-Box and both equipment showed a good correlation where a voltage difference less than 5 mV was observed. The SPMeter-Box has been used in various geophysics measurement campaigns and the performance of the instrument was discussed using the results from a graphite deposit exploration located within the southern-part of Madagascar. ERT and IP profiles were performed during the characterisation and both results were consistent with the findings from the SPMeter-Box.

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