Physical-Mechanical Characteristics of Limestone and Underground Rivers Mapping to Support the Development of Micro-Hydro Installation in Karst Landforms, Case Study: Cave Seropan, Gunung Kidul, Indonesia

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Key words: Karst, Seropan, geoelectrical, cave, microhydro

SUMMARY

Water is a basic requirement for human life, such as eating, drinking and other needs. At the area composed of limestone, especially in karst areas, water availability measly that is insufficient for the needs of everyday life. In karst areas, the conditions on the surface are generally very barren and dry, especially during the dry season. But nevertheless, under the surface actually stored plenty of water. Availability of subsurface water can even be a river flowing along the underground cave. Gunung Kidul region is a karst area. This region has the potential of water resources a lot so it is possible to be used by the surrounding community. Currently, developed a way to raise underground river water that effectively and efficiently so that community can get water easily and cheaply. One way to do is making of subsurface dam in the cave. Underground river need to be dammed to take advantage of the kinetic energy of water to drive a turbine of micro hydro power plant in the cave. The electricity generated is then used to pump water from underground rivers rise to the top in order to be used for the needs of everyday life and to agriculture. For the construction of the installation, it is necessary to know the physical-mechanical characteristics of the rock which is planned to be footstool for micro-hydro installations. Various research methods used to determine the characteristics of the rock, whether in the studio or in the field. One of them uses resistivity geoelectrical method. Measurement of resistivity at surface of the Cave Seropan conducted on four extensions. Qualitative and quantitative approach applied to obtain near-perfect results. The results showed that the resistivity of rock under the surface that is above the Seropan Cave vary greatly. Generally, subsurface conditions at the top of the cave not solid and massive, but there are cavities. The phenomena are caused by the the dissolution process that occurs in limestone. These conditions resulted in physical and mechanical properties of limestone is very heterogeneous. Resistivity value for each cavity also varies. If the cavity is filled with water, then a small resistivity values. So that happened in the Cave Seropan. If there is an underground river, the small resistivity value, otherwise if conditions dry cave so large resistivity values. Cavities are at varying depths, with a distribution of about 10% to 15%. Schlumberger configuration geo-electrical method can be relied on to determine the existence of an underground cavity and mapping of underground river.

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1. INTRODUCTION

Cave Seropan is one of the caves in the karst area of Gunung Kidul District, located about 45 km Southeast of Yogyakarta. Based on the results of the British government consultant in 1980 showed that in Gunung Kidul found a large amount of water collecting in the basement, in the form of an underground river (Anonymous. 2009). There are four sources of underground rivers with sufficient discharge, the water source Baron 1,080 liters per second, the water source Bribin 1,000 liters per second, the water source Seropan 800 liters per second and water source at Ngobaran 135 liters per second (Anonymous. 2009).
Follow-up of these findings, the Ministry of Research and Education of the Government of the Federation of German via Institute for Water Resources Management, Hydraulic and Rural Engineering Karlsruhe University carried out an intensive survey of the utilization and management of underground water (KIT, 2010). The survey results conclude that the underground river water should be used for the purposes on the surface, such as a water supply for the purposes of daily life. For those reasons, the underground river water should be raised to the surface. Ways to raise the water if pumped using a conventional pump would be very expensive so it is planned to make the weir below the ground. The water flow of underground river dammed then used to drive the micro-hydro installations, so as to generate the electricity used to pump water to the surface. For the construction of the micro-hydro installations, need some engineering geological studies, which are to determine subsurface conditions around the cave Seropan with geoelectric method.

2. METHODOLOGY

2.1 Kasrtification

Karst is a term in German, originating from the Slovenian language, namely Kras, which means barren rocky land. Karst is an area with typical hydrologic conditions as a result of rock-soluble and has a well-developed secondary porosity (Ford and Williams, 1989), characterized by several things:

- There is a closed basin or dry valleys in various sizes and shapes.
- Drainage on the surface is rarely found.
- The presence of cave from the underground drainage system.

Karstification is a karst land formation process, which is dominated by the dissolution process at rocks containing carbonate, generally is limestone. Limestone dissolution process begins with dissolution of CO_2 in water, forming H_2CO_3. H_2CO_3 solution is not stable and will decompose into

H- and HCO_3^{2-}. H-ions were then deciphering $CaCO_3$ into Ca^{2+} and HCO_3. In short, the dissolution process was formulated by a chemical reaction in formula 1.

$CaCO_3 + H_2O + CO_2 \rightarrow Ca_2+ + 2HCO_3$ .... (1)

This solution can occur on the surface or in the body of limestone, so as to form holes. Karstification influenced by two factors, namely controlling and driving factors (Ford and Williams, 1989). Controlling factor is the factors that determine whether or not a process of karstification took place, among others are (Koesoemadinata, 1987):

- Rocks containing carbonate and soluble, compact, thick, and have a lot of fractures.
- High rainfall.
- The rocks exposed at a height that allows the development of circulating water or drainage vertically.

The driving factor is a factor that can determine the speed and perfection process of karstification. Included in this factor is temperature and vegetation cover. Process by rain water on the surface of the limestone will produce a landscape that is typical, i.e. lapies, conical hills, doline, karst lakes, sinkholes, and blind valley. Furthermore, the processes of dissolution develop into sub surface that produces endokarst. The processes produce a series of cave passage network with varying types and sizes. The cave passage network formed cave system, and generally there is also an underground river system flowing in the hallway cave. All the landscape when found in a limestone region is proof that the process is in progress actively karstification.

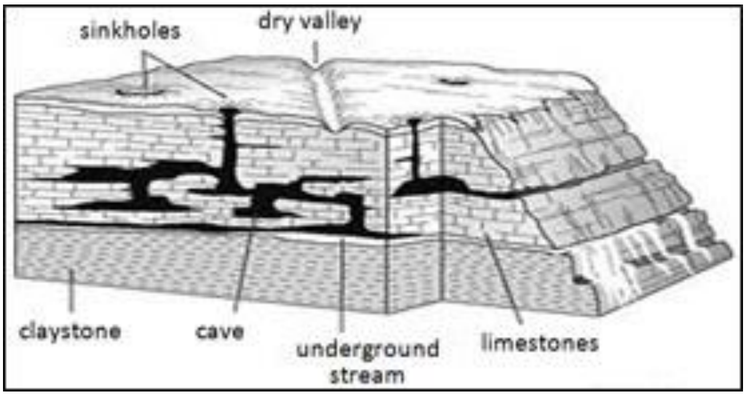


Figure 1. Variation of eksokarst and endokarst (Ford and Williams, 1989)

2.2. Geo-electricity Method

Geo-electricity is a geophysical method to determine changes in resistivity layer of rock below the surface by flowing high voltage DC electric current into the ground (Telford et. al, 1976). This injection of electrical current flow using two electrodes A and B are inserted into the ground at a certain distance. The longer the distance of the electrodes A and B will cause a flow of electrical current can penetrate the deeper layers of rock.

The flow of electric current will cause the voltage in the soil or rock. Voltage that occurs on the surface was measured using a multi meter connected through two pieces of voltage electrodes M

and N are the distance is shorter than the distance of the electrodes A and B. When the electrode spacing A and B is converted into larger, then the voltage that occurs at the electrodes M and N also change in accordance with the information on the type of rock that participate injected electric current at a greater depth (Figure 2). Assuming that the depth of rock layers which can be penetrated by the electric current is equal to half of the distance AB or AB/2 and use the electric current pure DC, the estimated effect of the injection flow of electric current is hemispherical with radius AB/2. From the combination of the distance AB/2, MN/2 distance, the amount of electric current flowed, and the voltage that occurs will be obtained a value of Apparent Resistivity. Apparent resistivity occurs because the starting resistivity is a combination of many layers of rock below the surface through which the electrical current.
The flow of electric current in the rock can be classified into three kinds, namely electronic conduction, electrolytic conduction and conduction in the dielectric. Electronic Conduction occurs when rocks have many free electrons so that electric current flows in the rock by the free electrons. Electrolytic conduction occurs when rocks are porous and the pores are filled by electrolytic fluids. At this conduction, the electrical current is carried by ions electrolyte. While the dielectric conduction occurs if the rock is the dielectric to the flow of electric current, which is occurs when the polarization of the material is electrified. Based on the value of the electrical resistivity, rocks are classified into three, namely:

- Good conductor: 10-8 < ρ < 1 Ωm
- Intermediate conductor: 1< ρ < 107 Ωm
- Isolator: ρ > 107 Ωm

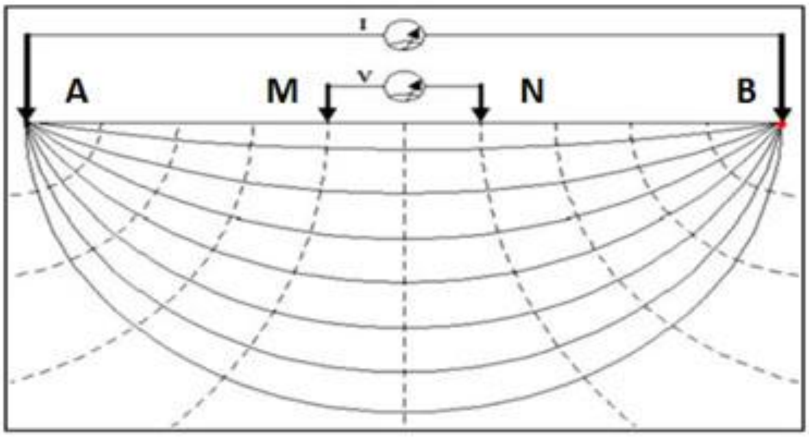


Figure 2. The position of the current electrodes A and B and the voltage electrodes M and N (Anonymous, 2010b)

2.3. Wenner and Schlumberger Configuration

Based on the configuration of the potential electrodes and electrodes currents, known some type resistivity methods, such as configuration Wenner, Schlumberger, dipole-dipole and so on. Configuration is a rule in conducting research using geo-electric method. There are several configurations, such as those into 4 pieces electrode located in a straight line with the position of the electrode AB and MN are symmetrical to the center point on both sides. This condition is made to

the configuration Wenner and Schlumberger (Figure 3). Each configuration has its own calculation method to determine the value of the thickness and resistivity of rock below the surface.
Schlumberger configuration geo-electric method is a method that is widely used to determine the characteristics of the rock layers below the surface, because it is practical and relatively cheap cost of the survey. Generally the rock layers have heterogeneous nature, are not required under geo-electric measurements namely perfectly homogeneous. To the position of rock layers that lie close to the surface, greatly affect the voltage measurement results and this will make the data geo-electric be deviated from the true value. Conditions heterogeneous rock that are natural will be combined with local conditions, for example, the existence of other rock fragments that penetrate between the layers, a factor unevenness of weathering of host rock, the material contained in the road, a pool of local water, piped from metallic materials that can deliver electric current, fencing wire which is connected to the ground, and so on.
The superiority of Wenner configuration is on the electrode MN voltage reading accuracy better with relatively large numbers. This is caused by the MN electrodes are relatively close to the electrode AB. Here can be used multimeter with an impedance measuring instrument that is relatively smaller. The weakness is not able to detect the homogeneity of rocks near the surface which could affect the results of the calculation. Data obtained from Wenner configuration, it is very difficult to eliminate the heterogeneity factor of rock, so that the calculation results to be somewhat less accurate.
Schlumberger configuration ideally at a distance of MN is made as small as possible, so that the distance MN theoretically unchanged. However, due to the limited sensitivity of the measuring instrument, then when the distance AB is relatively large, the distance MN should be changed. MN distance changes should be no larger than 1/5 the distance AB.

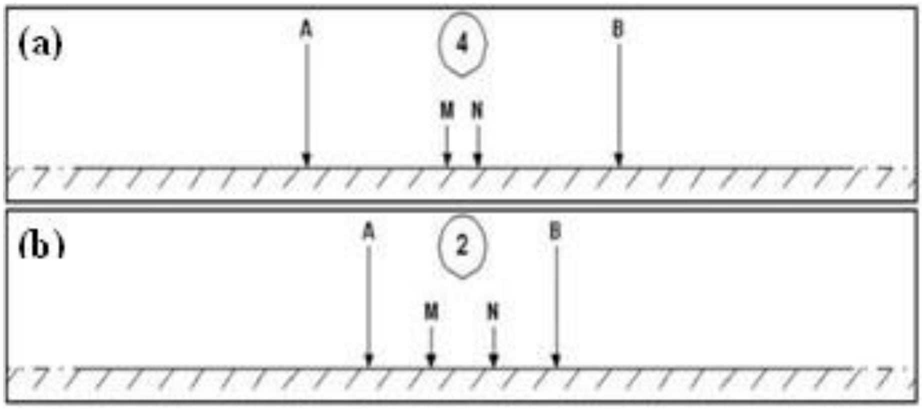


Figure 3. (a) Schlumberger configuration and (b) Wenner Configuration (Anonymous, 2010b)

The downside of this Schlumberger configuration is measurable voltage on the electrode MN is generally smaller, especially when relatively far distance AB.Therefore we need a measuring tool multimeter that has the characteristics of high impedance with high accuracy, which can display a minimum voltage four digits or two digits after the decimal point. By other means necessary tool current senders that have a DC power supply voltage is very high. While the advantage is the ability

to detect the presence of heterogeneity layers of rock on the surface the better, which is done by comparing the apparent resistivity values when there is a change within the electrode MN/2. In order to measure the voltage on the electrode MN to be believed, it should when the distance AB is relatively large, the electrode MN spacing also enlarged. Consideration of changes in the electrode MN spacing towards the electrode AB spacing when electrical voltage reading on the multimeter is so small, for example 1.0 milliVolt.
The equipment used in this study was resistivity meter OYO Model McOhm El 2119C (Figure 4). The equipment is equipped with several additional tools such as cable, the power source in the form of 12-volt battery and Res2DInv software for data processing (Anonymous, 2004).

Figure 4. Geoelectricity tools OYO Model McOhm El 2119C and several additional tools

3. RESULT AND DISCUSS

3.1. Condition of Cave Seropan

Figure 5. The entrance to the Cave Seropan

Goa Seropan length is approximately 888 meters with a depth 62 meters from the ground. The entrance of the cave is located at the bottom of a closed basin (Figure 5). Low-roofed hallway early to arrive at a larger space and part of the next hall is accessible by foot. The hall of the mouth of the cave to the body of the underground river has a length approximately 211 meters. Underground river in the Cave Seropan have a debit of 600 to 800 liters per second during the dry season (Anonymous, 2009). Subsurface illustration of the Cave Seropan shown by Figure 6.

Upstream hallway, fully submerged in water with a depth between 1 meter to 1.5 meters. The hallway ended in a sump, the cave passage which is entirely submerged in water, from the bottom up to the roof. Downstream, relatively shallow water depth, approximately 0.6 meters to 1.5 meters. The hallway ends at a place where there is the first waterfall with a height of 8 meters. After this first waterfall, the hall continues about 200 meters before ending at the second waterfall with a height of approximately 9 meters. Furthermore, underground river ended in a sump again (Anonymous, 2010a).

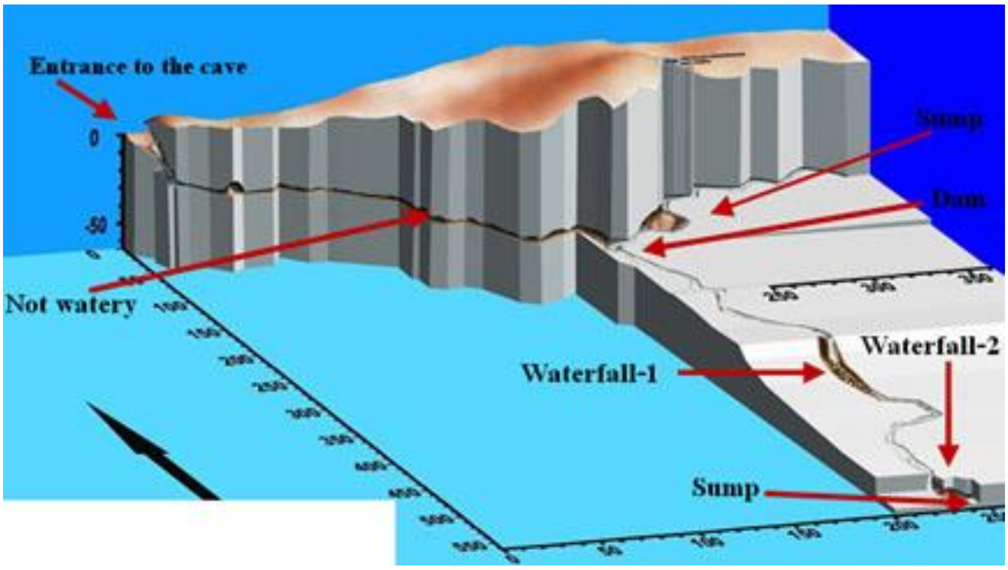


Figure 6. Subsurface ilustration of Cave Seropan (Anonymous, 1988)

3.2. Physical and mechanical characteristic of limestone

Geoelectric measurements above the cave Seropan with surface topography as in Figure 7, conducted with four expanse to the position as Figure 8. In doing geoelectric measurements to obtain resistivity value of the object of investigation, the known location of the cave Seropan existing underground through mapping speleology. Resistivity value of the location of the cave was then used as a reference in determining the position of an underground cave on the other expanse. Likewise, the estimation of other underground conditions. For example the presence of cavities and so on (Darsono, 2012).

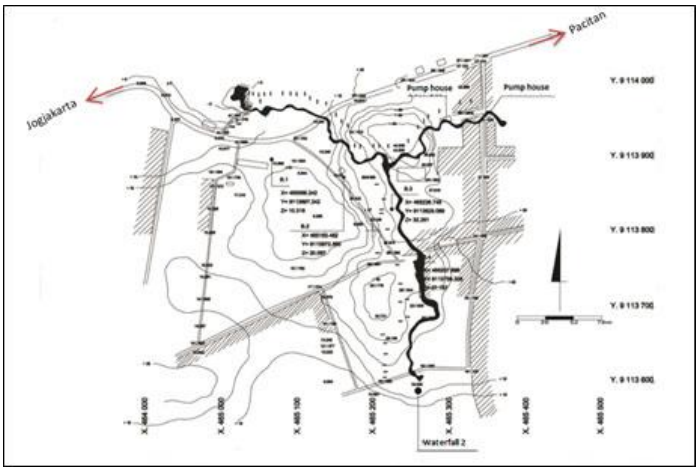
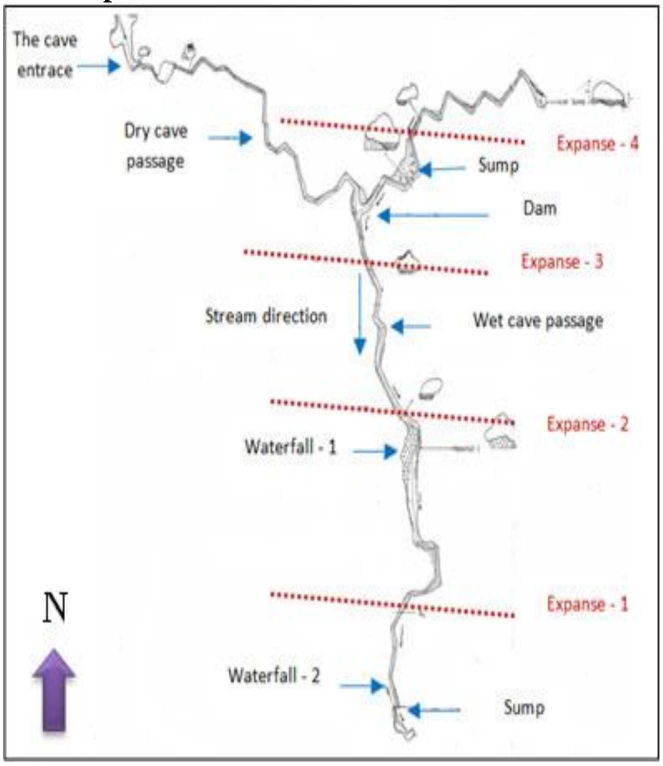


Figure 7. Topographic map on the top of Cave Seropan (KIT, 2010)

The expanse-1



Measurements of expanse-1, with total length are 432 meters and spaced 9 meters. Tracks are along the village road are relatively flat. Based on the results of these measurements, it is known that there is an underground river at a depth of 35 to 50 meters with the possibility of also contained an underground river to a depth of 70 meters. Resistivity values were obtained for underground cave is more than 450 ohm and underground rivers range from 10 to 45 ohms. Resistivity values on the underground river less than the resistivity of cavities or caves are relatively less water content (Figure 9a).

Clastic limestone reflected in blue and green, reefs limestone in yellow to brownish, while the purple color with high resistivity reflecting the caves or voids (Rahardjo et.al., 1995). Based on the calculation in the expanse-1, the distribution of voids in the area below this expanse is estimated at 15%.

Figure 8. The expanse location of geoelectricity measurement on the top of Cave Seropan

The expanse-2

Each electrode with a spacing 18 meters. Length of expanse reaching 288 meters. Measurements in this expanse was performed using Schlumberger configuration, the depth can reach about 57.4 meters. Measurement starts at UTM coordinates 9113838 L0465280, extending from west to east through the residential area. The results obtained, as shown in Figure 9b.

Expanse-2 at the surface lies in the region composed of clastic limestone. In the cross section of expanse-2, it appears that the value of resistivity of rocks vary greatly (Figure 9b). It can be interpreted that the rock conditions are not homogeneous because there are many cavities as a result of the dissolution process. If correlated with the condition of the rock on the surface, the area expanse-2 is located in clastic limestone. At that location, relatively low resistivity, so interpreted that the blue to green region relatively solid condition, not a lot of cavities. The yellow color is a rock with a resistivity greater, with resistivity values ranging from 100 to 950 ohm meter. This color is interpreted as reefs limestone, dense and massive condition. Red and purple, with resistivity values between 1,016 to 3,000 ohm meters, with a depth range of 30 to 40 meters, are interpreted as a cavity large enough. This is the cave itself. Based on these results concluded that subsurface conditions in expanse-2 contained cavities with varying shapes and sizes. Overall, the distribution of these cavities reaches 10%.

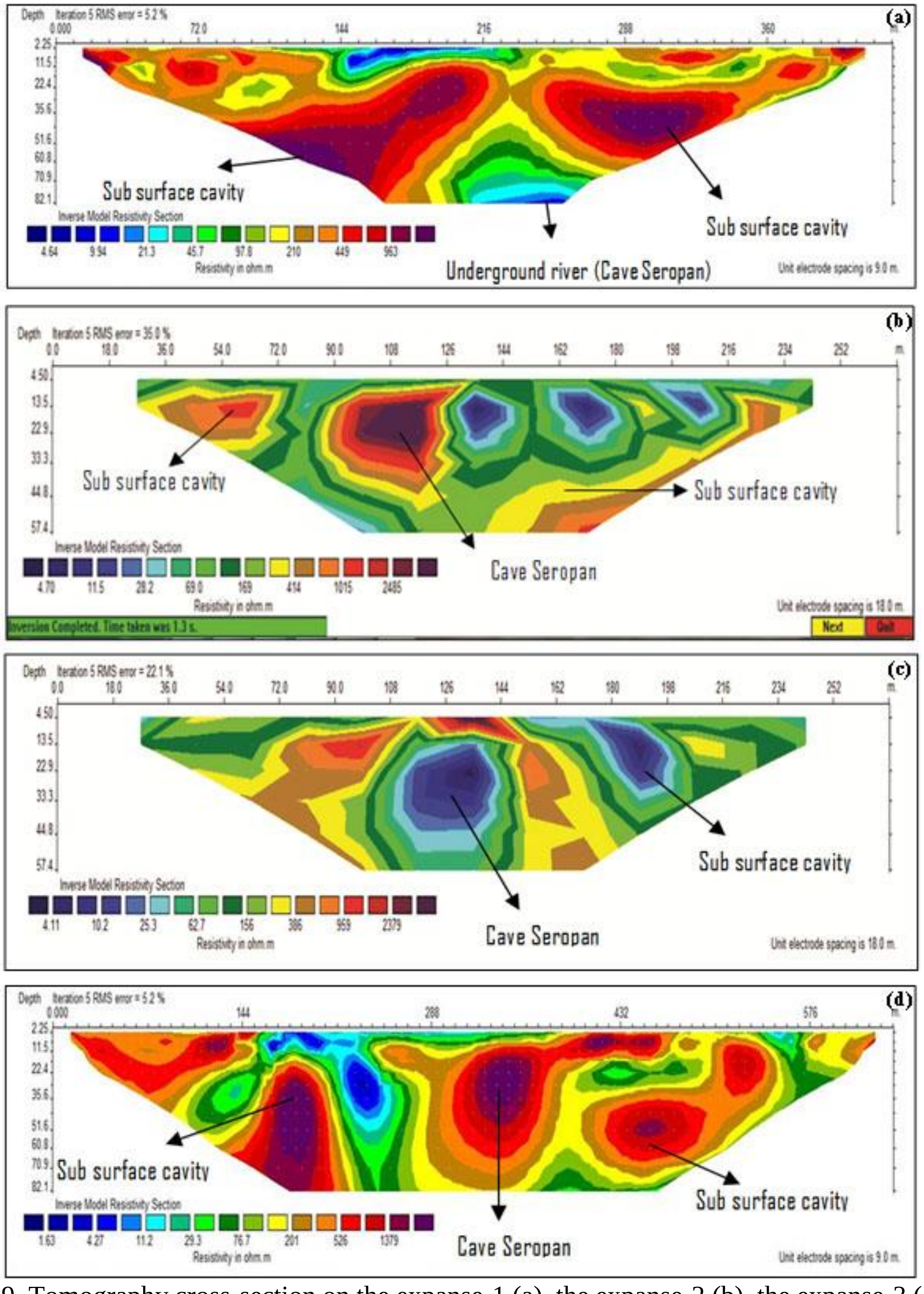


Figure 9. Tomography cross-section on the expanse-1 (a), the expanse-2 (b), the expanse-3 (c), and the expanse-4 (d)

The expanse-3

Expanse-3 also conducted above the cave Seropan, with electrode spacing 18 meters along the 288 meters. Measurements in this expanse conducted using Schlumberger configuration, the depth can reach about 57.4 meters. Position measurement expanse-3, extending from west to east through a residential area, located in clastic limestone.

In the tomography cross-section of expanse-3 (Figure 9c), it appears that the value of resistivity of rocks is also very varied. It can be interpreted that the rock conditions are not homogeneous because there are many cavities as a result of the dissolution process. Blue-green color indicate the presence of carbonate rocks with depth range between 5 to 54 meters and has a resistivity values between 4.11 up to 62.7 ohm meter. Clastic limestone porous and there are many cavities as a result of the dissolution process. The rounded shape of the blue color is a form of the condition is very watery caves, both as an underground river and water dripping from the roof of the cave. The yellow color is a carbonate rock with depth range between 6 to 50 meters and has a resistivity value varies between 62.7 up to 919 ohm meter. This is a limestone reefs is massive and dense, so the water is difficult to flow. Red and purple is the cavity surface has a depth range of 2 meters to 7 meters and has a value of resistivity of 1,000 to 3,000 ohm meter. Based on these results, concluded that under the surface in the expanse-3 contained cavities with varying shapes and sizes, with distribution reaching 15%.

The expanse-4

Measurement along 432 meters with a space 9 meters. Tracks are along the village road is relatively flat. The measurement results show there is an underground river at a depth of 35 to 50 meters. Even, allegedly found also an underground river to a depth of 70 meters.

Based on the results of this geoelectric investigation, there may be some other underground caves in the eastern part of the Cave Seropan. The investigation on a expanse-4 shows that the resistivity value of underground river cave more than 500 ohms. Resistivity values were obtained for underground cave are more than 450 ohms and underground rivers range from 10 to 45 ohms. Resistivity values on the underground river less than the resistivity of cavities or caves are relatively less water content (Figure 9d). There may be some other underground caves in the eastern part of the cave Seropan. As in expanses of the others, subsurface conditions on this expanse also has a lot of cavities. Based on the calculation, distribution cavity under expanse-4 reaching 10%.

CONCLUSION

The resistivity value of rock below the surface that is above the cave Seropan known to so varied. This shows that the condition of limestone that make up this region is very heterogeneous. Subsurface conditions at the top of the cave Seropan, generally not solid and massive but found the cavities beneath the surface. Resistivity value of the cavity turns out varying. If the cavity is filled with water, then the resistivity value is low. Likewise, Seropan cave with an underground river. Conversely, if the conditions are dry then the value of resistivity is high. Cavities are located at varying depths, with a distribution of about 10% to 15% of the total volume of rock.

Geo-electric method with Schlumberger configuration besides being able be relied on to determine the existence of an underground cavity, it can also be used for mapping underground river.

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