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Determination of the Dolines Phenomenon Using by Geological and Geoelectrical Resistivity Survey Approach in Bedoyo Village, Ponjong Subdistrict, Gunung Kidul

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Abstrak
Kabupaten Gunung Kidul merupakan dataran tinggi yang didominasi oleh batuan karbonat. Desa Bedoyo di Kecamatan Ponjong memiliki banyak telaga, tetapi pada musim panas doline menjadi kering dan tidak dapat menampung air. Pemetaan geologi meliputi pemetaan geomorfologi, pengamatan batuan, dan pemetaan struktur serta analisis petrografi di laboratorium. Survei geofisika yang dilakukan untuk mengetahui sebaran batuan bawah permukaan secara lateral dan vertikal dengan konfigurasi dipole-dipole. Metode resistivitas digunakan dalam menentukan nilai resistivitas untuk kedalaman kurang dari 40 meter dengan panjang elektroda sekitar 250 meter. Hasil analisis geologi dan geofisika adalah mengkaji fenomena doline yang bukan merupakan akuifer dangkal. Hal ini disebabkan oleh kondisi bawah permukaan di bawah telaga terdiri dari batuan berkarbonasi dengan porositas yang buruk, lensa dari batulempung tufaan yang kedap air, dan batuan beku. Batuan dasar tersebut memiliki porositas sedang sampai buruk pada akuifer. Semakin kecil peluang untuk menjadi akuifer yang baik jika batuan yang lebih dalam merupakan batuan beku yang impermeabel. Survei geofisika alternatif diperlukan untuk mengamati batuan yang lebih dalam secara vertikal.

Kata kunci: telaga; akuifer; Bedoyo: geolistrik; resistivitas

Abstract
Gunung Kidul Regency is a highland consisting of carbonate rocks dominantly. Bedoyo village in Ponjong sub district has a lot of dolines, but in the summer season, the dolines become dry and could not be water storage. Geological mapping is included in geomorphological, rock observation, structural mapping also petrographical analysis in the laboratory. A Geophysics survey is to observe the subsurface rock distribution laterally and vertically with dipole-dipole configuration. The resistivity method is to determine the resistivity value for the depth of fewer than 40 meters with the length of electrodes of about 250 meters. The result of the geological and geophysical analysis is to review the dolines phenomenon that could not be a shallow aquifer. It is caused by the subsurface condition beneath the dolines consisting of carbonated rocks with poor porosity, lenses of impermeable tuffaceous claystone, and igneous rock. Those rock basements have a moderate to poor porosity in the aquifer. The less opportunity to be a good aquifer if the deeper rock is an impermeable igneous rock. An alternative geophysical survey is needed to observe the deeper rock vertically.

Keywords: doline; aquifer; Bedoya; geoelectrical; resistivity

INTRODUCTION

Karst landform is a geological phenomenon that typically emerges from the dissolving impact of groundwater on soluble carbonate rocks (Parise et al., 2015). Such a mechanism is very difficult to foresee (Angel et al., 2004) but it can create underground cavities that cause overload discomfort, leading (sometimes) to an opening in the ground surface in the form of sinkholes (Beck, 2004). Gunung Kidul is located in Sewu Karst, especially in Bedoyo, Ponjong sub-district. In tropical areas such as Gunungkidul Subdistrict, specific karst morphologies such as doline, uvala,

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and polje can grow without active river processes (Faivre and Reiffsteck, 2002).

Dolines are enclosed depressions in karst landscapes. They are typically subcircular and can range in diameter from a few meters to several hundred meters. Several doline classifications have recently been published (Waltham and Fookes, 2003; Beck, 2004; Waltham et al., 2005; Ford and Williams, 2007). There are eight dolines in the research area. The research area is located in Bedoyo, Ponjong sub-district, Gunung Kidul Regency. The karst doline landform is one of karst unit in Gunung Sewu Karst. In the form of steep terrain in the lowlands, there is no doline with a random pattern. This shows that the majority of doline in Ponjong District is a random distribution pattern that is present on wavy plains, and it can be seen if the majority of doline are found in areas flanked by undulating plateaus, or it can be concluded that doline in Ponjong District is scattered on the slopes of the highlands (Damayanti, 2018).

Changes in rock due to the dissolving process can be at the surface or below the soil surface. One example of changes in land surface, namely changes in a doline. Angel et al. (2004) stated that a doline is an object of karst morphology that is widely studied because of its location on the earth's surface and can be used as an indication of the existence of underground river flows. Water that falls to the surface of the doline will be brought below the surface through the widening vessels of the doline to the underground channel network (White, 1988). Doline which is located in the Gunung Sewu Karst in Gunungkidul Regency is different from other karst areas, namely, there is a doline that contains water known as a lake.

According to Bahagiarti (2004), the doline layer in the lake is covered by impermeable sediments known as lokva. Several dolines have sinkholes to be water input to the ground. Several geologic, geomorphologic, hydrogeological, and anthropogenic factors had major effects on sinkhole development (Caramanna et al., 2008; Yilmaz, 2010; Doğan and Yılmaz 2011; Guarino and Nisio 2011; Galve et al. 2015) This research would focus on geologic and geomorphologic factors. In addition to determining subsurface conditions, geoelectrical resistivity was conducted in the research area. The research is located in Bedoyo, Ponjong District, Gunungkidul Regency. As a distinctive landform and morphology, the potential of doline ponds to support water resources in Gunungkidul, particularly during dry seasons, needs to be addressed. The existing doline ponds have been experiencing problems related to decreasing water quantity and degrading water quality. Therefore, this research aims to determine the characteristics, structural geology control, and rock distribution in the research area.

METHOD

Secondary data was conducted in the literature review. The primary data obtained in this research is not only focused on lithological (geological data) but also on subsurface data (Figure 1). The presence of lines that are usually called 'telaga' is covered by geological mapping. Several geological aspects were conducted by detailed observation. Geomorphological landform aspects are included in the

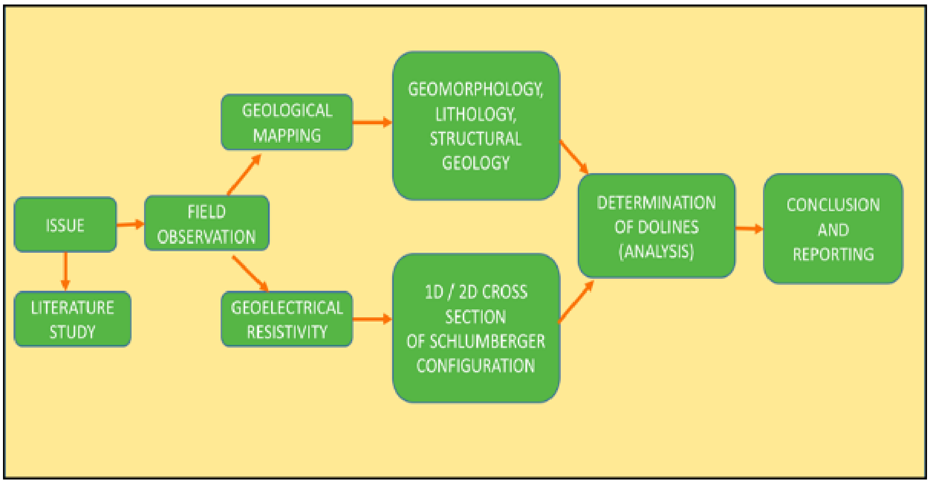

Figure 1. The methodology flow chart

morphometric and morphogenetic unit (van Zuidam, 1979; van Zuidam 1983). To determine the distribution of dolines in Bedoyo Village, 1/25000 scale topographic maps provided by The General Mapping were used in this analysis. Rock observation is conducted to the rock description by megascopic or microscopic analysis. The microscopic analysis used thin section analysis (petrography analysis). Carbonate rock description and classification used by Dunham (1962), Mount (1985) also Embry and Klovan (1971). The SRTM image delineated the lineaments, fault, and presence of dolines.

Subsurface data was conducted to geoelectrical resistivity surveys that were usually performed to assess the resistance of the subsurface with a resistivity meter. from vertical data, namely 1D, then correlated between points into a 2D model, followed by a 3d model. Resistance data may be used to assess the position of different geological and soil strata, bedrock cracks, faults, and voids. The Schlumberger configuration acquisition in the research area was conducted in 4 locations such as Asem Lulang, Ngalas Ombo, Bedoyo Lor, and Telaga Mendak. By using the Schlumberger configuration, the subsurface data vertically could be represented in the rock/lithology column. The rock distribution beneath the dolines and their surroundings was interpreted by Telford (1990). The compilation of surface and subsurface data would explain the occurrence and tectonic genetics of dolines in the research area.

RESULT

Geological Condition

The research area is located in the physiography of Sewu Karst Hill which consisted of conical hills and dolines. The geomorphological units are represented in Geomorphological Map (Figure 2). A geomorphological map was made by using van Zuidam's classification (1979 and 1983). The morphometrical unit classification was taken by van Zuidam (1979) compiles the slope and elevation data. The geomorphological unit for land use is divided into 8 units (van Zuidam, 1983). The research area is included in the denudational unit due to the erosional process intensively occurring. The evidence of erosional process such as thick soil. The soil is red to blackish colored at the surface called terra rosa. The karst unit is controlled by water desolvation. Rock pores are called lapies and the presence of a cave is evidence of intensively dissolving water. Based on the van Zuidam classification (1979 and 1983), the research area consists of three geomorphological units denudational weakly undulated unit, karst strongly hills unit, and karst weakly undulated unit. The presence of dolines was distributed in several areas that were dominantly there in the karst weakly undulated unit and karst strongly hill unit. Dolines could be occurred due to the impermeable rocks deposited beneath the dolines.

The rocks distributed in the research area are composed of four rocks unit tuff, clastic (chalky) limestone, crystalline or coralline limestone, and alluvial deposit. The tuff was locally deposited at N4 to N5 (Early Miocene) in Gesing doline, Pucang anom (Rizqi, 2020). Crystalline or Coralline limestone was deposited unconformity on the top of the tuff layer. It was distributed in the southern part of the research area. This rock is characterized as tight and impermeable, lapies are common, mainly composed of calcite minerals and partly algae or coral (Figure 3a). Based on the composition of the rock (fossil, calcite, micrite, and cavity) shown that crystalline limestone has the name Packstone (Dunham, 1962) in the BDY 02, BDY 03, and BDY 05. Grainstone (Dunham, 1962) or named Rudstone (Embry and Klovan, 1971) is found in the BDY 06 incision. Fossils recorded on the incision can be small foraminifera and large foraminifera (*Nummulites sp.*). Calcite has an anhedral - subhedral shape, the cavity is shown in black color.

Clastic (chalky) limestone is widely spread in the north to the eastern part of the research area with the dip direction of the rock layer in the south and southeast direction. Its main characteristics are porous and occasionally composed of pelecypods and large foraminifera.
Petrographic analysis was performed on the BDY-01 incision which showed the following composition: fossil (36.5%), micrite (42.5%), and the presence of cavities (21%). Based on this composition, the rock is called Packstone (Dunham, 1962) (Figure 3b).

The youngest formation, alluvial deposited covered the northwest part of the research area. The loose materials are commonly deposited along the Bindo river and its surrounding area.

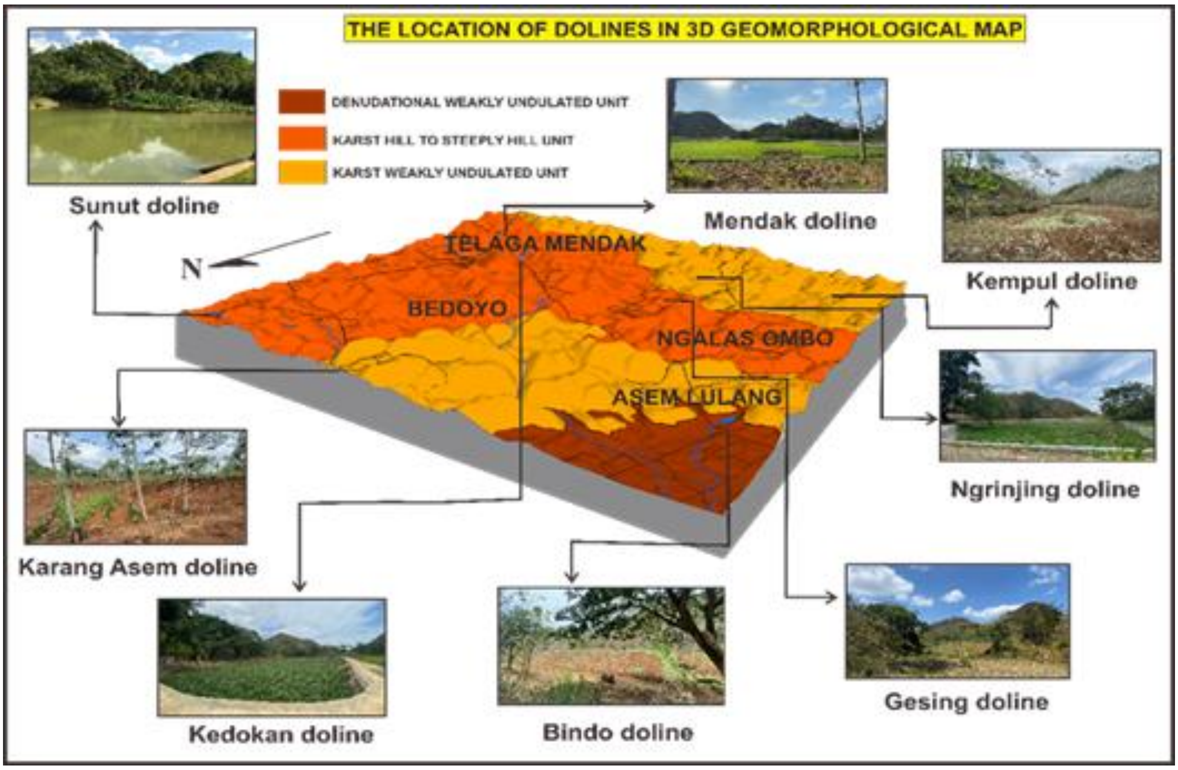

Figure 2. Several dolines in the research area were plotted by a 3D geomorphological map.

Figure 3 a. Crystalline / Coralline limestone with a lot of lapies and, b. the chalky / clastic limestone with fine to coarse grain size.

Table 1 List of Doline names in Bedoyo Village, Ponjong sub district, Gunung Kidul Regen

No. Name of dolines	Geomorphology unit	Lithology unit (Geological data)
1. Bindo	Denudational Weakly undulated	Alluvial deposit
2. Karang Asem	Karst strongly hill unit	Chalky / clastic limestone
3. Sunut	Karst strongly hill unit	Chalky / clastic limestone
4. Mendak	Karst weakly undulated unit	Crystalline / coralline limestone
5. Kedokan	Karst weakly undulated unit	Crystalline / coralline limestone

However, several dolines were dominantly located in the crystalline / coralline limestone, partly in chalky / clastic limestone. One doline (Bindo doline) was formed by alluvial deposit (Table 1).

Subsurface Condition

Geoelectrical data were collected at four locations, namely Asem Lulang Section, Ngalas

Ombo Section, Bedoyo Lor Section, and Medak Doline Section (Figure 4). The electrodes used are 200 meters long and have a relative north-south direction.

The Asem Lulang Section measured the resistivity value around Bindo Doline. Meanwhile, Ngalas Ombo Section was conducted to measure the resistivity value at Gesing, Ngrinjing, and Kempul Doline. Bedoyo Lor Section measured the resistivity value around the Karang Asem doline. The Mendak Doline Section was conducted to measure the resistivity value in Bedoyo Village around the Kedokan, Sunut, and Mendak doline (Table 1).

Asem Lulang

Data collection was carried out on denudational weakly undulated morphology with gravel-clay sediment lithology on the surface, northwest of the study area. Based on the results of data processing and lithological interpretation using the classification of rock resistivity determination Suyono, (1999), the constituent lithology is in the form of crystalline limestone, calcarenite (coarse grain), and calcilutite (fine grain). The range of resistivity values for deposits is in the range of 0.12 - 4.63 ohmmeter with a thickness of 15 meters. Under the deposition, there is a relatively small resistivity value of 0.18 ohmmeter. This value is interpreted as an aquifer.

The presence of layered limestone/calcarenite (chalky) (Grabau, 1905) is interpreted from the resistivity values of 124.90 and 129.96 at a depth of about 74 meters and 90 meters. Calcarenite has a grain size of sand (1/16 - 2 mm). Calcirudite limestone which has a grain size larger than calcarenite (more than 2 - 4 mm) is interpreted to insert between layered limestone/calcarenite with a resistivity value of 698.78 ohmmeters. Crystalline limestones are interpreted at a resistivity value of 988.12 ohmmeters. The rock bottom layer in Asem Lulang Village is interpreted as an aquifer with a resistivity value of 0.25 ohmmeter. Telaga Bindo is one of the dolines in Asem Lulang which has long dried up without water. This is caused by there is a crack in the dam foundation at the edge of the lake.

Ngalas Ombo

Geoelectric data taken in Ngalas Ombo Village is found in strong undulating morphology - karst hills with lithology of layered limestone units (chalky). The results of data processing interpreted that the lithology in Ngalas Ombo Village was composed of loose deposits, calcarenite limestone, and crystalline limestone.

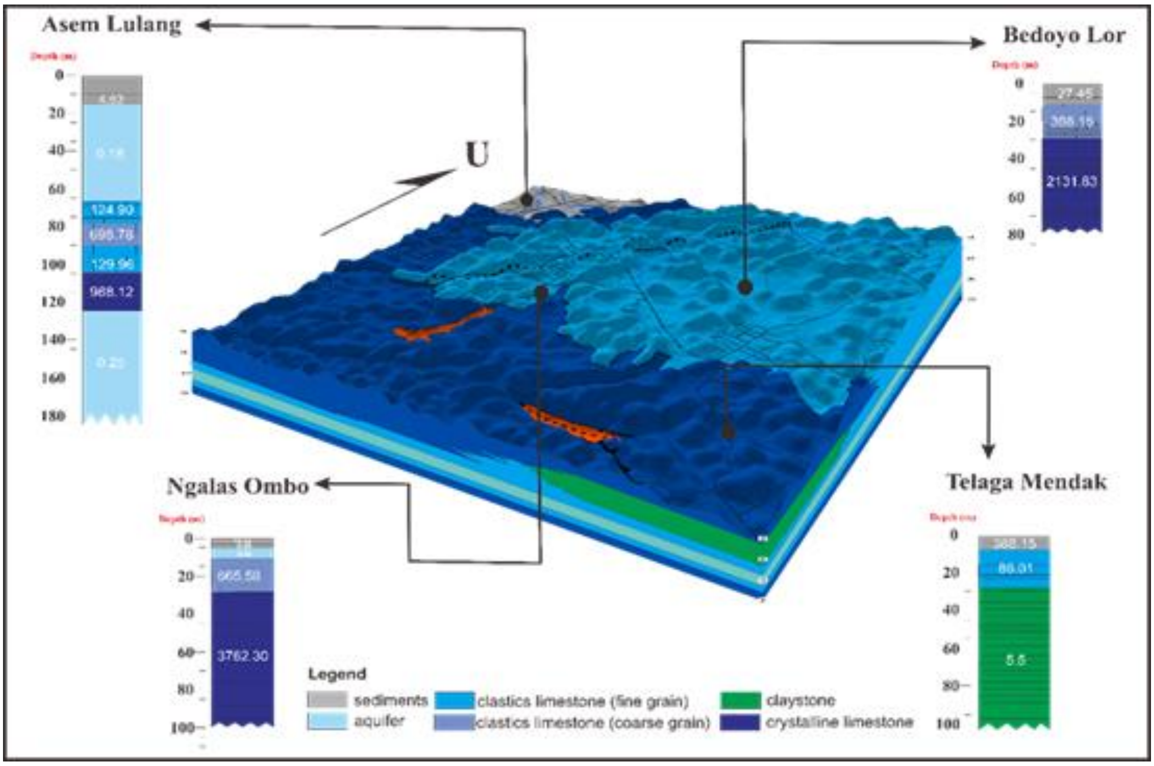

Figure 4. Acquisition of subsurface data using geoelectrical resistivity in 3D Geological Map

In the case of Gesing doline (Ngalas Ombo area). The results of the 2 D section show that the bedrock layer (seal rock) is a tuff layer interpreted with a resistivity value ranging from 8.08 - 41.0 Ohmmeter shown by light blue to light green which can be found up to a depth of 30 meters (Rizqi, 2020). Ngrinjing doline is located in the eastern part of Gesing doline. Meanwhile, Kempul doline is located in the southern part of Gesing doline. All dolines often have no surface water. Some sinkholes were founded in Gesing and Ngrinjing doline (Figure 5). Sinkholes are the pathway to water input to the ground that have variation sizes at the surface.

Figure 5. up, the sinkhole on the edge of Ngrinjing doline, and (down) the sinkhole that elongates at 2-3 meters

Bedoyo Lor

Geoelectric data acquisition in Bedoyo Lor Village is located in a strong undulating geomorphological unit - karst hills with layered limestone lithology (Chalky). The rock composition in Bedoyo Lor consists of sediment, calcarenite limestone, and crystalline limestone. At the Bedoyo Lor location, the resistivity value of 27.49 ohmmeters at a depth of 10 meters is interpreted as sediment. The resistivity value of 388.15 ohmmeters was interpreted as calcarenite limestone (Grabau, 1904). Crystalline limestone has a resistivity value of 2131.83 ohmmeters. Limestone, and claystone. The deposits occupy the distribution on the surface to a depth of 8 - 10 meters and have a resistivity value of 388.15 ohmmeters. The calcarenite /chalky limestone has a resistivity value of 86.01 ohmmeters. Lithology with a thickness of 70 meters is claystone with a resistivity of 5.5 ohmmeters.

Mendak, Kedokan and Sunut are dolines in Telaga Mendak area. Occasionally, Sunut doline and Mendak have surface water, especially in the rainy season, and become dry doline in the summer season. The human construction at the edge of doline would be affected by water storage.

Meanwhile, Kedokan has had no water for the last decade. The presence of water at those dolines is controlled dominantly by lithology. For example: Mendak doline has a thick of claystone which is an impermeable rock or zone to be sealed rock in preserving surface water.

Table 2 List of sections, lithology interpretation, and dolines

No. Name of Section	Lithology	Scope of doline
1. Asem Lulang	Alluvial deposit, clastic limestone (sand to gravel grain size), Crystalline limestone	Bindo
2. Ngalas Ombo	Alluvial deposit, clastic limestone (gravel grain size), Crystalline limestone	Gesing, Ngrinjing, Kempul
3. Bedoyo Lor	Alluvial deposit, clastic limestone (gravel grain size), Crystalline limestone	Karang Asem
4. Mendak doline	Karst weakly undulated unit	Mendak, Kedokan, Sunut

DISCUSSION

The Doline Occurance

Based on the topography map of the research area, the dolines formed the lineaments. The doline lineaments relatively have the same direction at Northeast – Southwest and are divided into three main for doline group of lineaments. The first group is located in the northern part of Bedoyo Village and consisted of Karang seam and Bindo doline. In the middle area is the second group such as Sunut, Kedokan, and Gesing doline. The Ngrinjing and Kempul as the last group are located at the southern part of Bedoyo and also have the same lineament direction.

Dolines are used as a sensitive indicator of tectonic activity in the karst zone, as there is a specific relationship between structural elements such as faults and joint structures also the orientation and density of karstic landforms (Orndorff et al., 2000). Based on the Geological map of the research area included I. Yogyakarta Geological Map (Surono and Sudarno, 1992), the research area is controlled by three main faults with the direction at northeast-southwest (NE-SW) and all of these are relative to the direction at east-west (E-W). It caused the presence of dolines to elongate in the same direction as the faults (Figure 6). The genetic east-west (E-W) direction according to Prasetyadi et al (2011), the main fault with the direction of East–West is the youngest tectonic period. This tectonic event occurred during Pliocene to Pleistocene when the Wonosari or Kepek Formation has been deposited. Several dolines in the research area have sinkholes either at the edge or at the base dolines. Sinkhole formation is the most threatening geological hazard in the study area because sinkholes can damage engineering structures, settlements, and agricultural areas around dolines. Therefore, to prevent damage caused by sinkholes, it is necessary to identify susceptible areas (Ozdemir, 2016).

The sinkhole is connected to the underground by a ponor. Ponor is a vertical hole as water input to the underground stream. These underground streams could be deep aquifers with a depth of 120 meters at Asem Lulang (Figure 7). The underground stream at Gunung Sewu Karst has the direction of east-west (E-W) (Adji, 2003). The presence of a sinkhole or ponor could make reduce water storage for dolines. Two basic pore mechanisms are considered to be important define the porosity in carbonate rocks. The ability to connect microporous grains and to macropores makes micropores crucial (Cantrell and Hagerty, 1999).

In addition, based on the above composition in petrographic analysis, the research area is dominated by crystalline limestones (packstone) which almost have porosity (cavity). In several places also found Floatstoneand Rudstone (Embry and Klovan, 1971). However, to become a seal rock, it must have low permeability and low porosity (low micropores value) (BDY 02, BDY03, and BDY 05) (Table 3).

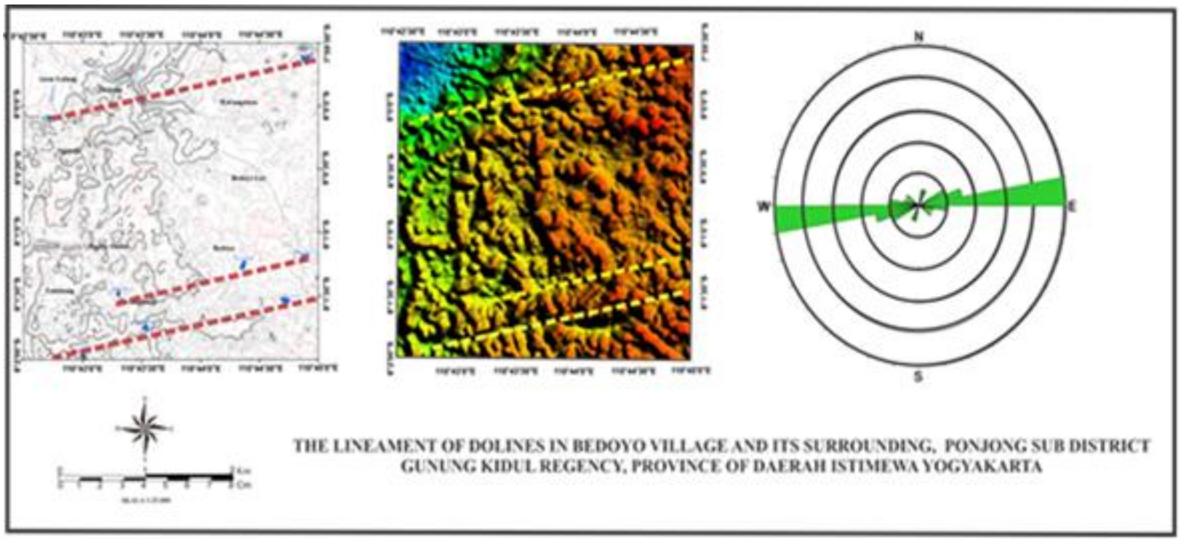

Figure 6. Structural geology factor is controlling the presence of dolines in the research area with the direction of lineament at N 265 E (East-West).

Table 3. The rock composition in petrographic analysis

No	Code	Kind of limestone	Rock Composition (%)				Petrographic Name
			Fossils	Calsite	Micrite	Micropores	
1	BDY01	*Chalky* (clastic)	36.5	-	42.5	21	*Packestone*
2	BDY02	Crystalline (nonclastic)	51.75	8.75	34.25	5.25	*Packestone / Floatstone*
3	BDY03	Crystalline (nonclastic)	34	6.25	50.55	9.25	*Packestone*
4	BDY05	Crystalline (nonclastic)	41.25	20.5	37.75	0.5	*Packestone*
5	BDY06	Crystalline (nonclastic)	72.25	5.75	6.5	15.5	*Grainstone / Rudstone*

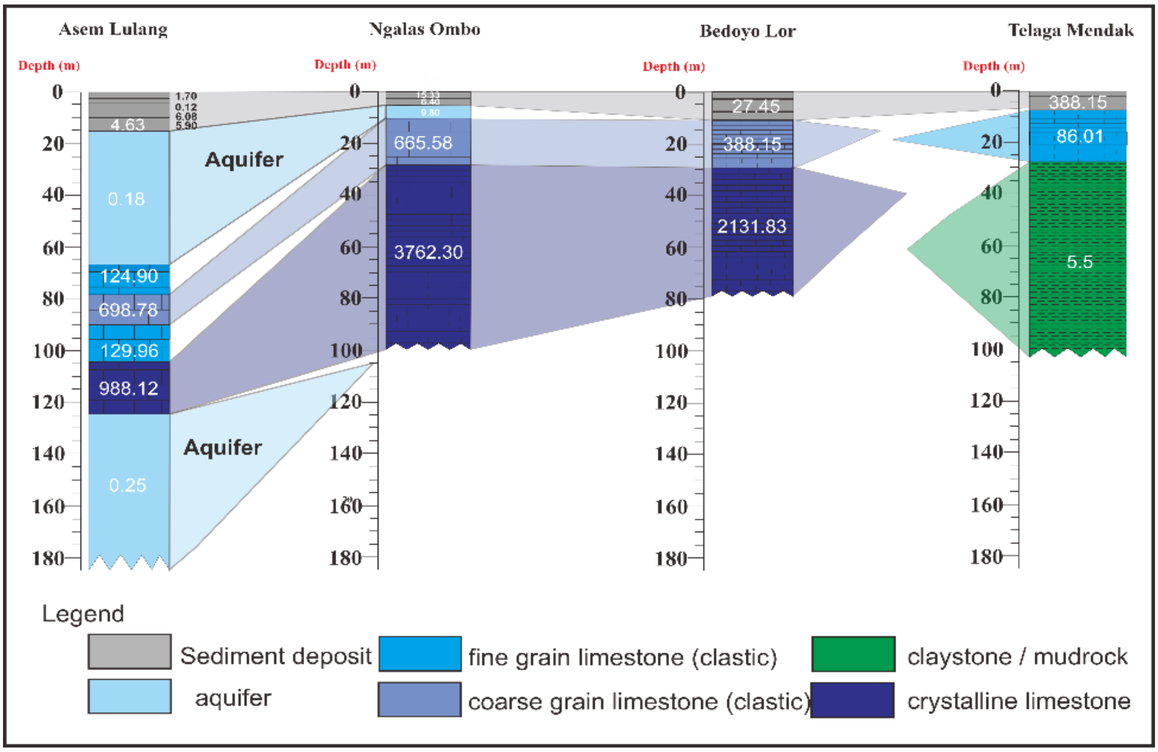

Figure 7. The cross section and correlation of Schlumberger geoelectrical acquisition data in research area.

The lithology spread over the surface to a depth of 10 meters is sediment. The resistivity value for the precipitate ranges from 0.12 - 4.63 ohmmeter. A thin insert 5 meters thick is interpreted as an aquifer. Calcirudite limestone (Grabau, 1905) is in the resistivity value range of 665.58 ohmmeters. Crystalline limestone with a resistivity of 3762.30 ohmmeters could be the rock basement at the measurement at this location.

BDY 01 and BDY 06 have a larger value in microporosity than BDY 02, BDY 03, and BDY 05. BDY 01 and BDY 06 has a value of 21 and 15.5 for microporosity. Meanwhile, BDY 02, and BDY 03 have a value of 5.25 and 9.25 microporosity. The smallest value of microporosity is BDY 05 which has a value of 0.5 The tuff layer in the field has low porosity (impermeable) and is petrographically rich in glass (clay) so that it is interpreted as the bedrock (seal rock) of Telaga Gesing (Rizqi, 2020). The physical characteristics of clay are sticky and malleable when moist, but hard and cohesive when dry (Nagendrapapa, 2002).

CONCLUSION

The presence of dolines phenomenon is mainly located at karst weakly undulated geomorphological unit. It affected rock distribution and rock composition. The structural geology factor controlled the lineament of dolines with direction at east-west (E-W). Several sinkholes and ponors were interpreted as pathway surface water input to the underground.

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