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Geological Assessment for The Construction of an Underground Railway in Bali

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KEY W O R D S
subsurface railway line, tourism.

A B S T R A C T
The Surface Geological Study for the Feasibility of Subsurface LRT Development in Bali was carried out as a preliminary study to determine rock types, stratigraphy, rock strength and depth of subsurface railway tunnels in Bali. The method used is collecting primary data through selected trajectories to determine the rocks found by making profiles and collecting detailed data at each point, including geological structure data. This detailed surface geology data will be used to determine drilling points to determine a detailed geological profile at each point. The expected results from this surface geological assessment and drilling will be used to create geological correlations and determine the depth of tunnels for prospective subsurface railway construction in Bali. This study will help determine whether to construct a prospective subsurface railway line in Bali properly and safely. Hopefully the construction of the subsurface railway line in Bali, which will start in early 2024, will be completed quickly and will reduce busy traffic on the surface. This will make tourists and Balinese residents in general comfortable.

I. INTRODUCTION

Engineering geology or Engineering Geology is the application of geology in engineering practice for the purpose of ensuring that geological factors that affect the location, design, construction, operation and maintenance of engineering work have been carefully recognized and calculated. Engineering geological research can be carried out at the time of planning, environmental impact analysis, civil engineering design, optimization engineering and construction stages of public and private projects, as well as at the stage after construction and project investigation. Engineering geological research is carried out by a geologist or educated engineering geologist, professionals who are trained and have the ability to recognize and analyze geological hazards and adverse geological conditions. The whole purpose is to protect life and property from damage and solutions to geological problems.

Geology can be classified as a complex science, has a diverse discussion of material but is also an interesting field of science to study. This science studies from objects as small as atoms to the size of continents, oceans, basins and mountain chains.

Observation of geological structures in the form of stout, faults and folds is a very important parameter carried out in the planning stage of a development because it is very influential in the short, medium, and long-term stability of a civil building. Detailed measurements and mapping of the intensity level of geological structures will be able to assist engineering geologists in formulating recommendations for a civil building project.

Engineering geological studies at the location of Ngurah Rai Airport and its surroundings are intended to test the strength and stability of the slopes that develop at the site. This can

be used in engineering the construction of an Integrated Cross Rail (LRT) will be erected on top of the research site.

Regional Physiology

Bali Province is a mountainous and hilly area that covers most of the area. The relief of Bali Island is a mountain chain that extends from west to east (Figure 3.1). Among the mountains are active volcanoes, namely Mount Agung (3,142 m) and Mount Batur (1,717 m). Some other dormant mountains reach heights between 1,000 – 2,000 m. The mountain chain that stretches across the central part of Bali Island causes this region to be geographically divided into two distinct parts, namely North Bali with narrow lowlands of foothills and mountains and South Bali with wide and gently sloping lowlands. Judging from the slope, the island of Bali mostly consists of land with a slope between 0 – 2% to 15 – 40%. The rest is land with a slope above 40% (Purnomo, 2010).

As one of the criteria for determining the level of land suitability, land with a slope below 40% can generally be cultivated as long as other requirements for land determination are met. Meanwhile, land with a slope above 40% needs attention if it will be used as a cultivation business. Land with a slope of 0-2 % dominates the southern coastal area and a small part of the northern coast of Bali Island, with an area of 96,129 ha. While land with a slope of *2-15* % is mostly found in the areas of Badung, Tabanan, Gianyar, Buleleng, and the rest is evenly distributed in the area around the coast with an area of 132,056 ha.

Areas with a slope of 15-40 % covering an area of 164,749 ha are predominantly found in the central part of the island of Bali, following a row of hills that stretch from west to east of this region. Areas with slopes exceeding 40% are mountainous and hilly areas located on part of Nusa Penida Island.

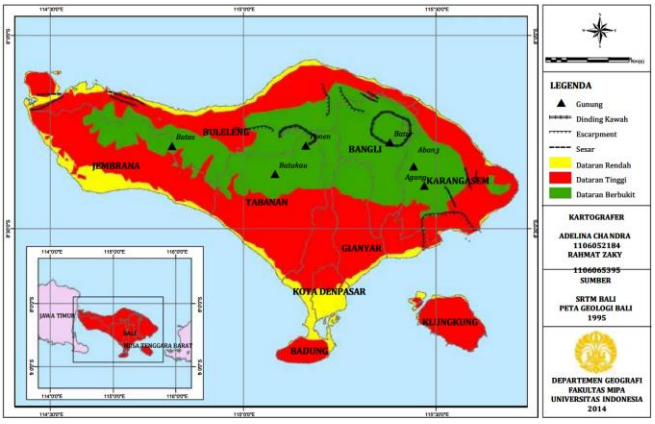

Figure.1 Physiographic Map of Bali (Chandra, 1995)

Regional Stratigraphy

Regional stratigraphy based on the Bali Geologic Map, Bali's geology is relatively young (Figure 3.2). The oldest rocks are probably Middle Miocene in age. According to Purbohadiwidjoyo, (1974) and Sandberg, (1909) in Dena (2012), geologically the island of Bali is still young, the oldest rocks are Miocene age. Broadly speaking, rocks in Bali can be divided into several units, namely:

1. Ulakan Formation (Tomu)

It is the oldest formation of Upper Miocene age, consisting of a pile of rock that ranges from pillow lava and basalt breccia with limestone inserts. The name of the Ulakan formation is taken from the name of the village of Ulakan which is located in the middle of the distribution.

2. Sorga Formation (Tms)

The upper part of the ulakan form is a Sorgaly formation composed of tuff, nafal and sandstone. Outcrops are quite wide in the middle of the watershed of Sorga.Here the rocks generally slope to the south or slightly to the southeast (170-190^{o}) with slopes to quite steep slopes (20-50^{o}). Another outcrop in the form of a window is located southwest of Pupuan, with a similar lithology.

3. Southern Formation (Tmps)

This formation occupies the Southern peninsula. The rocks are mostly hard limestone. according to Kadar, (1972) in K.M Ejasta, (1995) the thickness ranges from 600 meters, and the slope towards the south is between 7-10^{o}. The fossil content consisting of Emfine Lepidocyclina, Cycloclypeus Sp,

Operculina Sp, shows Miocene age. In addition to the southern peninsula, this formation also occupies NusaPenida Island.

4. Pulaki Volcano Rock Formation (TPVP)
This group of rocks is of Pliocene age, is a group of igneous rocks that are generally basalt, consisting of lava and breccia. It is actually limited near Pulaki. Although it is certain to have come from a volcano, the center of the eruption can no longer be recognized. In this area there are a number of straightnesses in a west-east direction, at least partially connected with the alignment. The hot springs at the foot of the mountains, on the border with the flat strip in the north, can be considered one of the indications of residual volcanism, with heat reaching 47oC and a rather harsh smell of sulfur.

5. Prapatagung Formation (TPSP)
This group of rocks is Pliosin age, occupying the Prapatagung area at the western tip of Bali Island. Limestone jam in this formation there are also limestone and napal.

6. Asah Formation (Tpva)
This group of rocks in the Pliocene spread from southwest Seririt to the east to the southwest of Tejakula. The lower layer generally consists of breccia which consists of pieces of rock are basalt, lava, obsidian. These rocks are generally hard because the adhesive is usually limestone. At the top there is lava that often shows cavities, sometimes showing plates and generally fine-grained. Kerpakali Pillow structure appears that shows the atmosphere of sea deposition.

7. Quaternary Volcano Formation (Q)
Volcanic activity in the quarter resulted in the formation of a number of cones that are generally no longer active. The volcano produces tuff rocks and lava deposits of Buyan-Beratan and Batur, Mount Batur volcanic rocks, Mount Agung volcanic rocks, Batukaru volcano rocks, lava from Mount Pawon and volcanic rocks from the subcentric cones of Mount Pohen, Mount Sangiang and Mount Lesung. Of the volcanoes, only two are still active, namely Mount Agung and Mount Batur in the Batur Caldera.

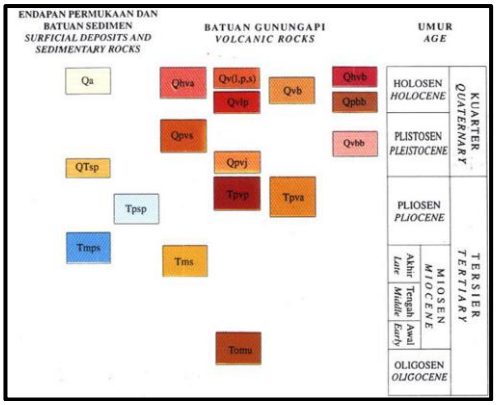

Figure.2 Stratigraphy of Bali Island (Hadiwidjojo, 1998)

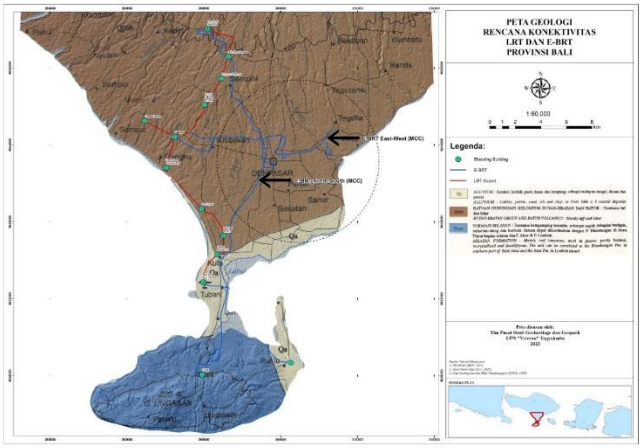

Figure.3 Regional geological map of the study area

3. Geology of Regional Structures

Bali's regional geological structure began with activities in the ocean during the Lower Miocene that produced pillow lava rocks and breccia inserted by limestone (Figure 3.3). In the southern part there was deposition by limestone which later formed the Southern Formation. In the path adjacent to its northern edge there is a finer deposition of sediments. At the end of the Pliocene, the entire depositional area appeared above sea level. Along with the lifting, there is a shift that causes various parts to be faulted with one another. Generally these faults are submerged by organic rock material or younger deposits. During the Pliocene, in the northern ocean there were deposits in the form of materials derived from deposits which later produced the Asah Formation. In the northwest, part of the rock rises above sea level. While this is increasingly west, the deposition of carbonate rocks is more dominant. The entire path was at the end of the Pliocene uplifted and faulted.

Volcanic activity is more prevalent on land, which results in volcanoes from west to east. Along with the occurrence of two calderas, namely first the Buyan-Bratan caldera and then the Batur caldera, the island of Bali is still experiencing movements that cause uplift in the north. As a result, the Palasari Formation is raised to sea level and the island of Bali in general has an asymmetrical North-South cross-section. The southern part is more gentle than the northern part.

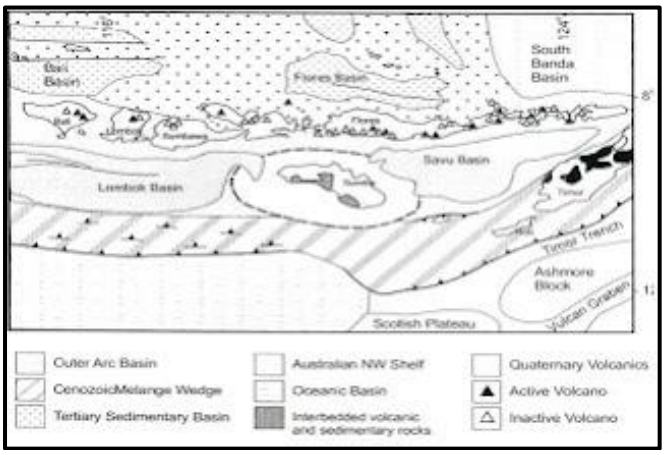

Figure. 4 Map of Regional Geologic Structures modified from Hamilton, 1979

2. METHOD

Research Methods

This study adopts an exploratory research method by combining surface geological mapping and geotechnical investigation. The following stages are conducted:

Primary Data Collection

Primary data is collected through field surveys involving surface geological mapping along the selected trajectory. The steps include:

1. Trajectory Determination: Selecting the research route based on the preliminary LRT development plan.
2. Geological Profiling: Creating geological profiles based on direct field observations.
3. Detailed Data Collection, including:
    - Identification of rock types and stratigraphy
    - In-situ rock strength measurements
    - Analysis of geological structures (folds, faults, and fractures)

Geotechnical Investigation (Drilling)

Following the surface geological mapping, drilling points are determined to obtain subsurface rock conditions. The steps include:

1. Drilling Point Selection: Based on surface geological survey results.
2. Geotechnical Drilling: Conducted to acquire subsurface stratigraphic data.
3. Laboratory Testing: Analysis of rock samples to determine geotechnical parameters such as compressive strength, permeability, and mechanical properties.

Data Analysis

The collected data from surface geological mapping and geotechnical drilling is analyzed to:

1. Establish geological correlations between study points.
2. Determine suitable rock conditions for tunnel construction.
3. Estimate the safest and most efficient tunnel depth.

Expected Outcomes

The results of this study will be utilized to:

1. Develop surface geological maps and subsurface models.
2. Provide recommendations on the appropriate depth and route for tunnel construction.
3. Support technical decision-making for the Bali subsurface LRT project.

3.RESULT & DISCUSSION

Results of Regional Geological Studies

1. Geologic Map

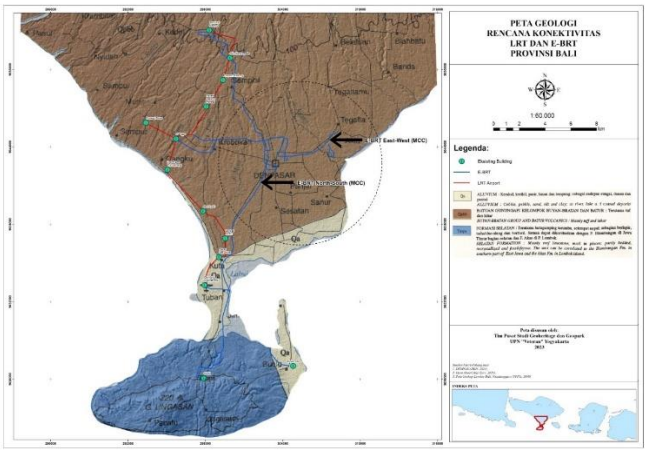

Figure 3. 1. Regional Geologic Map of Research Areas

Based on the results of the study on the regional geological map of the research area, we can know that the research location found three formations from the old one, namely the Southern Formation, the Buyan-Bratan and Batur Group Volcanic Rock Formation, and Alluvial. The Southern Formation occupies 20% of the area of the geological map. In this formation usually found reef limestone, some places are found napal. This formation can be correlated with the Blambangan Formation in southern East Java. The volcanic rock formations of the Buyan-Bratan and Batur groups occupy 60% of the area of the geological map. In this formation usually found tuff and lava. While alluvials occupy 15% of the map area. Usually in this unit found robbery material from older rocks and has not undergone compaction or is still in the form of loose material.

High Resolution Satellite Imagery (CSRT) Maps

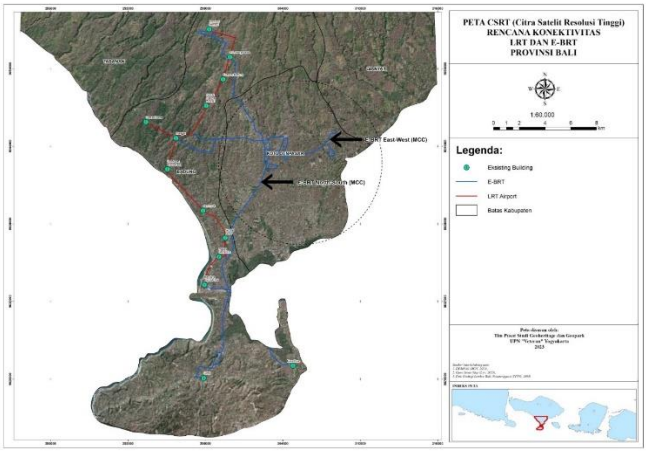

Figure 3.2. High-Resolution Satellite Imagery Map of Research Sites

Image is a picture of the appearance of the earth's surface which is the result of sensing a satellite with high resolution. Based on the map above, there are two tracks, the blue track which is the E-BRT track while the red track is the Airport LRT track. The green dot is an existing building at several important points passed by the Airport LRT track.

Digital Elevation Model (DEM) Map

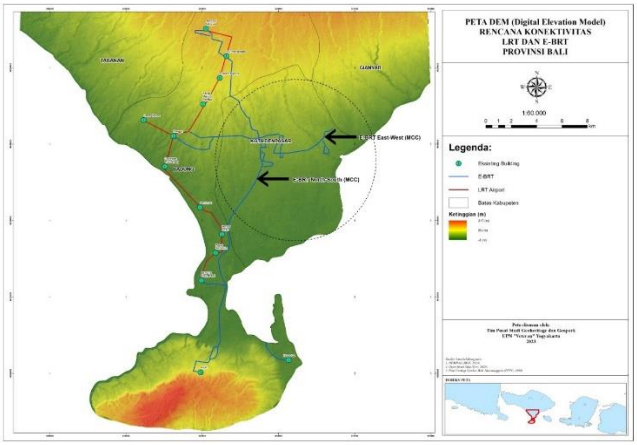

Figure 3.3. DEM Map

DEM (Digital Elevation Model) is a map that depicts the height above sea level for all of Indonesia. The map can be accessed online on the internet. Based on the Demnas map, the study location has varying surface heights. For the green color it means that the low height is 0-50 meters, for the yellow color it means that the medium height is around 50-100 meters, while for the red color it means that the height is very high ranging from 100-217 m.

Seismicity Map

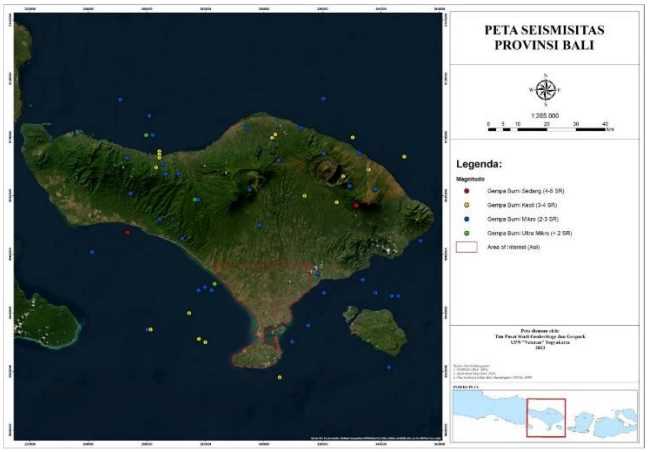

Figure 3. 2. Seismicity Map

A seismicity map is a map that contains the distribution of earthquakes, which only includes the main earthquake. The high seismicity value of an area is characterized by the increasing number of points on the seismicity distribution map. With seismicity, a review of an area's seismicity activity can be carried out. As in the picture above, we can know, the red box is the location of the study. Many seismicity points are scattered around the island of Bali, but at the study location there are no seismicity points. So we can mean that the research location can avoid the danger of seismicity. Therefore, when a building construction will be carried out, the building can avoid the danger of destructive seismic activity even though it can still receive the impact of earthquakes from around the research site.

Results of Field Survey Studies

Field studies are carried out by collecting data directly in the field starting from T1 to T5 location points and E-BRT location points, accompanied by surface lithology data collection, samples and profiles. So the following results were found:

Location Point T1

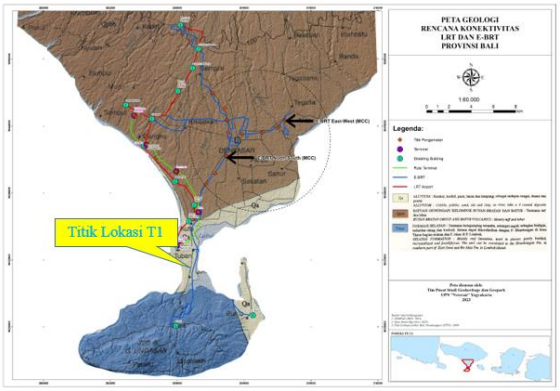

Figure 3. 5. Regional Geologic Map of Research Areas and Railway Lines and Station Points

Location Point T1 at the Multi-storey Car Park on the north side of Ngurah Rai Airport (Figures 3.1, 3.2, 6.3 and 3.4). The coordinates at this location are longitute 115.166 and latitute -8.741 (Table 3.1). Because the T1 point is in the airport area, it is recommended to be moved to the field outside the airport with longitude coordinates 115,169 and latitude -8,740 (Figure 3.3).

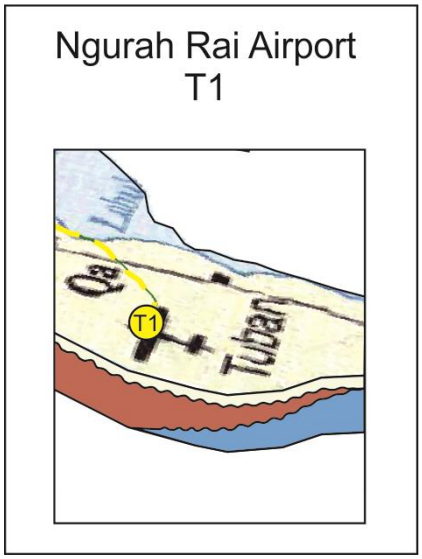

Figure 3. 6. Location of T1 Point and Subsurface Lithology

Figure 3. 7. Location Point T1 at Ngurah Rai Airport

Table 3. 1. Station Point Coordinates

No	Longitude	Latitude	Waktu	Deskripsi
1	115.181	-8.714	2023-12-19 16:31 WITA	T 2
2	115.163	-8.681	2023-12-19 16:57 WITA	T 3A (Rekomendasi)
3	115.166	-8.741	2023-12-20 09:03 WITA	T 1
4	115.169	-8.740	2023-12-20 10:03 WITA	T 1A (Rekomendasi)
5	115.163	-8.681	2023-12-20 10:28 WITA	T 3
6	115.139	-8.659	2023-12-20 12:53 WITA	T 4
7	115.131	-8.637	2023-12-20 13:26 WITA	Kedudukan Batuan Sungai
8	115.129	-8.635	2023-12-20 14:53 WITA	T 5
9	115.139	-8.653	2023-12-20 15:40 WITA	Singkapan Breksi Sungai
10	115.146	-8.671	2023-12-20 16:55 WITA	Litologi Breksi Tufan Sungai
11	115.252	-8.640	2023-12-21 09:32 WITA	E-BRT (E-W)
12	115.247	-8.645	2023-12-21 11:59 WITA	Sungai Jalur E-BRT (E-W)
13	115.203	-8.630	2023-12-21 13:09 WITA	Litologi Breksi
14	115.204	-8.669	2023-12-21 14:36 WITA	Rekomendasi Lapangan Kosong
15	115.205	-8.669	2023-12-21 15:39 WITA	E-BRT (N-S)

The lithological profile found here is only alluvial at the top which is approximately 10 meters thick. Therefore, to find out the bottom we can use the regional study from the Geological Map issued by the Geological Survey Center (PSG). The results of the study found under the alluvial found volcanic breccia that are very hard, gray-black in color, very compact and hard, almost not found burly with a thickness of more than 150 meters.

Figure 3. 8. Location of Point T1 at Ngurah Rai Airport

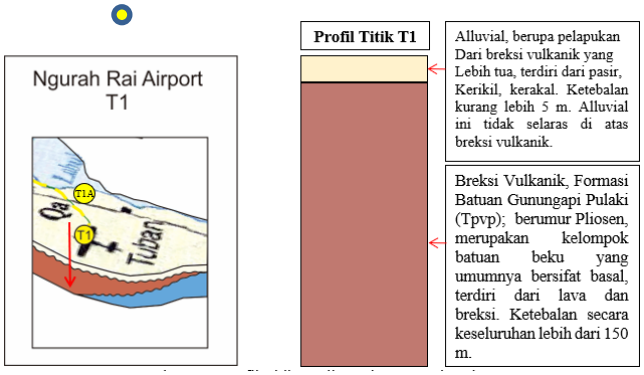

Figure 3. 9. Profile of Point T1 at Ngurah Rai Airport

Location Point T1

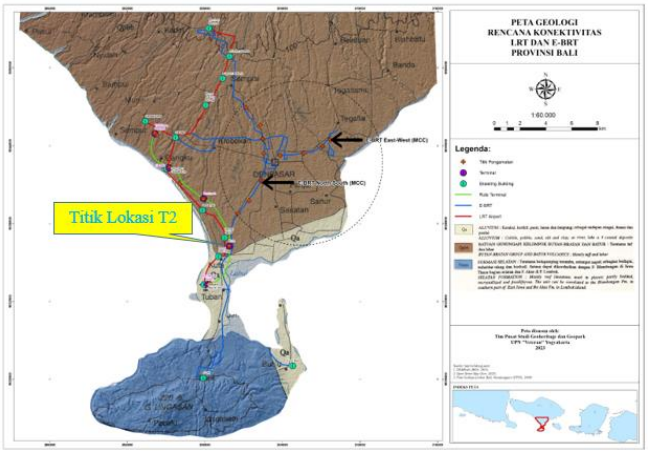

Figure 3. 10. Regional Geologic Map of Research Areas and Railway Lines and Station Points

Location Point T2 in Tanah Field to the west of Street Raya Kuta. The coordinates at this location are longitut 115.181 and Latitut -8.714. The lithological profile found here is only alluvial at the top which is approximately 10 meters thick. Therefore, to find out the bottom we can use regional studies from the

Geological Map issued by the Center for Geological Surve (PSG). The results of the study found under the alluvial found volcanic breccia that are very hard, gray-black in color, very compact and hard, almost not found burly with a thickness of more than 150 meters.

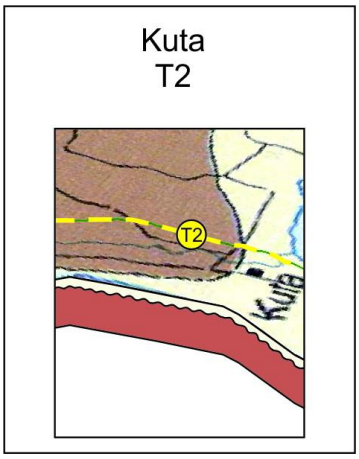

Figure 3.11. T2 Point Location and Subsurface Lithology

Figure 3.12. Location of Point T2 on vacant land west of Jalan Raya Kuta

Table 3. 2. Station Point Coordinates

No	Longitude	Latitude	Waktu	Deskripsi
1	115.181	-8.714	2023-12-19 16:31 WITA	T 2
2	115.163	-8.681	2023-12-19 16:57 WITA	T 3A (Rekomendasi)
3	115.166	-8.741	2023-12-20 09:03 WITA	T 1
4	115.169	-8.740	2023-12-20 10:03 WITA	T 1A (Rekomendasi)
5	115.163	-8.681	2023-12-20 10:28 WITA	T 3
6	115.139	-8.659	2023-12-20 12:53 WITA	T 4
7	115.131	-8.637	2023-12-20 13:26 WITA	Kedudukan Batuan Sungai
8	115.129	-8.635	2023-12-20 14:53 WITA	T 5
9	115.139	-8.653	2023-12-20 15:40 WITA	Singkapan Breksi Sungai
10	115.146	-8.671	2023-12-20 16:55 WITA	Litologi Breksi Tufan Sungai
11	115.252	-8.640	2023-12-21 09:32 WITA	E-BRT (E-W)
12	115.247	-8.645	2023-12-21 11:59 WITA	Sungai Jalur E-BRT (E-W)
13	115.203	-8.630	2023-12-21 13:09 WITA	Litologi Breksi
14	115.204	-8.669	2023-12-21 14:36 WITA	Rekomendasi Lapangan Kosong
15	115.205	-8.669	2023-12-21 15:39 WITA	E-BRT (N-S)

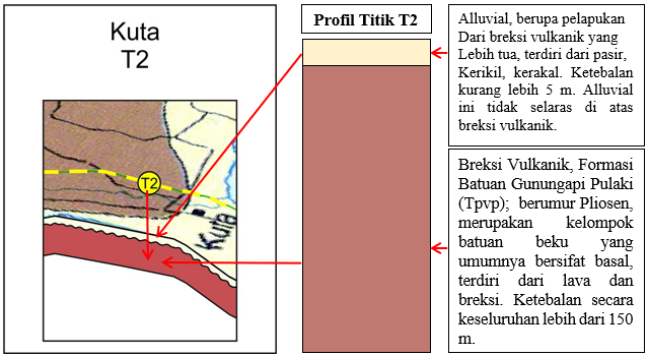

Figure 3. 13. Profile of Point T2 on the West Side of Jalan Raya Kuta

Location Point T3

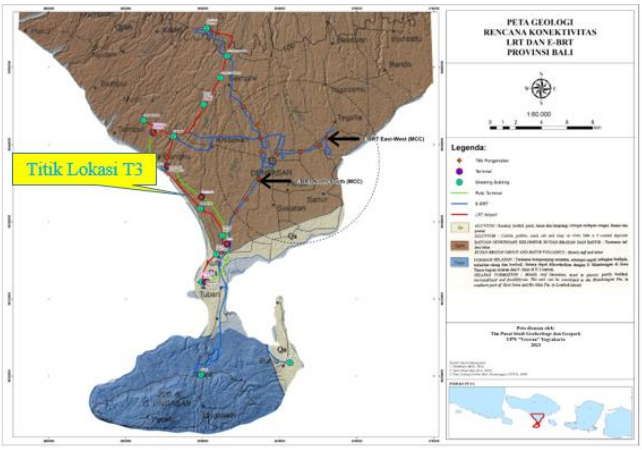

Figure 3. 14. Regional Geologic Map of Research Areas and Railway Lines and Station Points

Location Point T3 in front of mangkrak hotel in Seminyak Area. The coordinates at this location are longitut 115.163 and Latitut -8.681. Because the T3 point is in front of the Mangkrak Hotel and at the bend of the road, it is recommended to be moved to the field to the north with longitude coordinates 115,163 and latitude -8,681. The lithological profile found here is only alluvial at the top which is approximately 5-10 meters thick. Therefore, to find out the bottom we can use regional

studies from the Geological Map issued by the Center for Geological Surve (PSG). The results of the study found under the alluvial found volcanic breccia that are very hard, gray-black, very compact and hard, almost no burly with a thickness of approximately 150 meters.

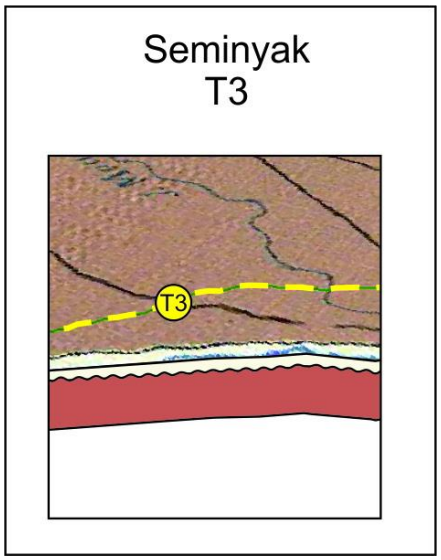

Figure 3. 15. T3 Point Location and Subsurface Lithology

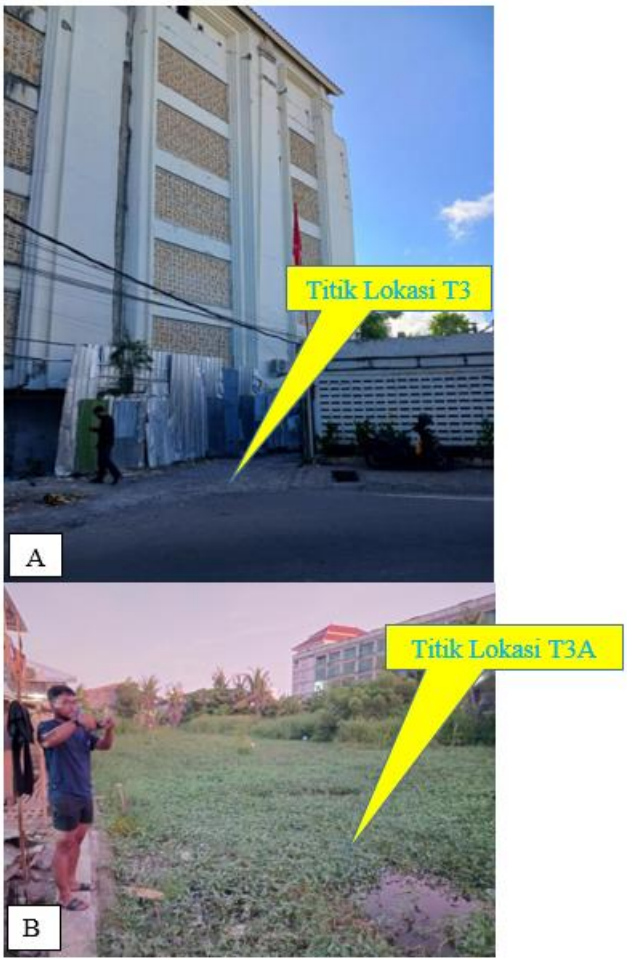

Figure 3. 16. (A). Location Point T3 in front of Hotel Mangkrak Street Seminyak (B). Location Point T3A to shift point T2

Figure 3. 17. Location Points T3 and T3A (recommended)

Table 3. 3. Station Point Coordinates

No	Longitude	Latitude	Waktu	Deskripsi
1	115.181	-8.714	2023-12-19 16:31 WITA	T 2
2	115.163	-8.681	2023-12-19 16:57 WITA	T 3A (Rekomendasi)
3	115.166	-8.741	2023-12-20 09:03 WITA	T 1
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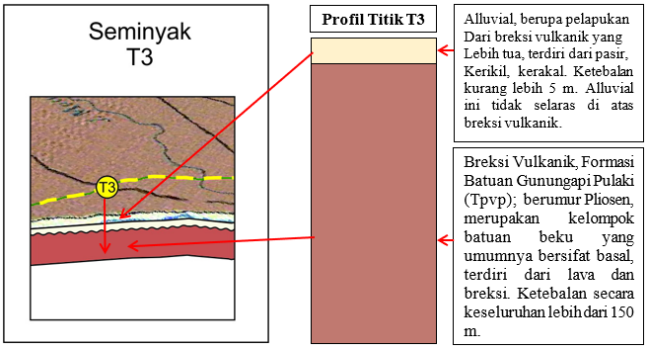

Figure 3.18. Profile of T3 Point in Seminyak

Location Point T4

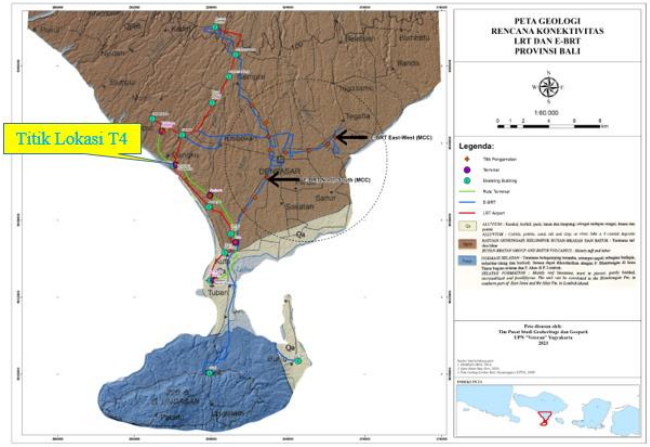

Figure 3. 19. Regional Geologic Map of Research Areas and Railway Lines and Station Points

Location Point T4 in Tibubeneng Village Field. The coordinates at this location are longitute 115.139 and latitut -8.659. The lithological profile found here is only alluvial at the top which is approximately 5-10 meters thick. Lithology in this area is found in the river to the west of it as well as using its regional studies from the Geological Map issued by the Geological Surve Center (PSG). The results of the study found under the alluvial found volcanic breccia that are very hard, gray-black, very compact and hard, almost no burly with a thickness of approximately 100-150 meters.

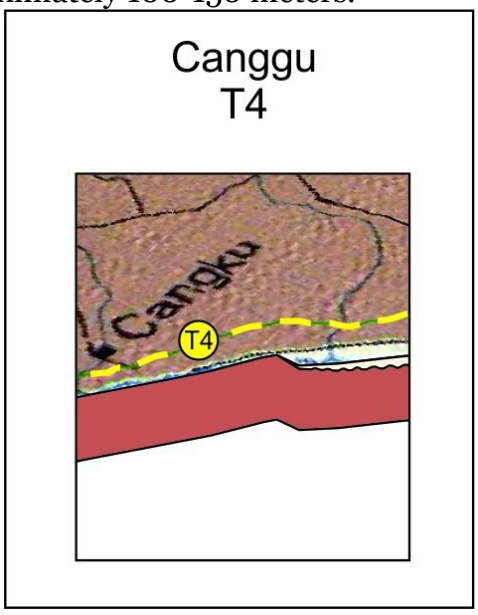

Figure 3. 20. T4 Point Location and Subsurface Lithology

Figure 3. 21. (A). Location of Point T4 in Tibubeneng Village Field, (B). Access to the driveway is quite good

Table 3. 4. Station Point Coordinates

No	Longitude	Latitude	Waktu	Deskripsi
1	115.181	-8.714	2023-12-19 16:31 WITA	T 2
2	115.163	-8.681	2023-12-19 16:57 WITA	T 3A (Rekomendasi)
3	115.166	-8.741	2023-12-20 09:03 WITA	T 1
4	115.169	-8.740	2023-12-20 10:03 WITA	T 1A (Rekomendasi)
5	115.163	-8.681	2023-12-20 10:28 WITA	T 3
6	115.139	-8.659	2023-12-20 12:53 WITA	T 4
7	115.131	-8.637	2023-12-20 13:26 WITA	Kedudukan Batuan Sungai
8	115.129	-8.635	2023-12-20 14:53 WITA	T 5
9	115.139	-8.653	2023-12-20 15:40 WITA	Singkapan Breksi Sungai
10	115.146	-8.671	2023-12-20 16:55 WITA	Litologi Breksi Tufan Sungai
11	115.252	-8.640	2023-12-21 09:32 WITA	E-BRT (E-W)
12	115.247	-8.645	2023-12-21 11:59 WITA	Sungai Jalur E-BRT (E-W)
13	115.203	-8.630	2023-12-21 13:09 WITA	Litologi Breksi
14	115.204	-8.669	2023-12-21 14:36 WITA	Rekomendasi Lapangan Kosong
15	115.205	-8.669	2023-12-21 15:39 WITA	E-BRT (N-S)

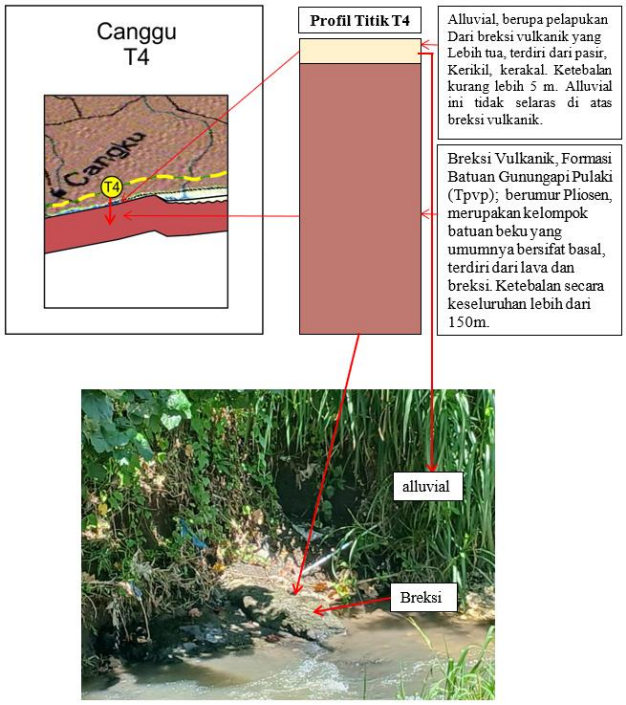

Figure 3. 22 Profile at Location Point T4; Volcanic and incongruous Breksi lithology is found on it Alluvial lithology

Location Point T5

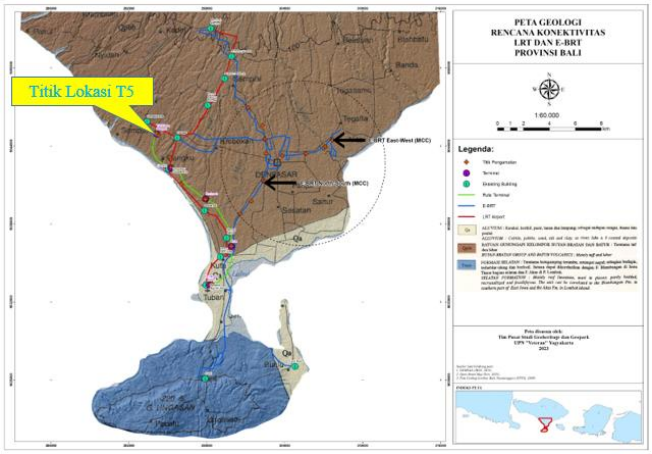

Figure 3. 23. Regional Geologic Map of Research Areas and Railway Lines and Station Points

Location Point T5 in the rice fields of Sampur area. The coordinates at this location are longitut 115.129 and Latitut -8.635. The lithological profile found here is only alluvial at the top which is approximately 5-10 meters thick. Lithology in this area is found in the river to the west of it as well as using its regional studies from the Geological Map issued by the Geological Surve Center (PSG). The results of the study found under the alluvial found volcanic breccia that are very hard, gray-black, very compact and hard, almost no burly with a thickness of approximately 100-150 meters.

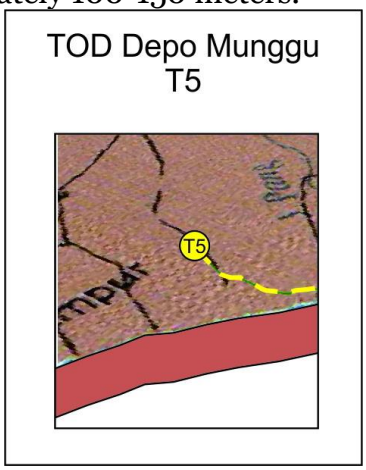

Figure 3. 24. T5 Point Location and Subsurface Lithology

Figure 3. 25. (A). Location Point T5 in the middle of residents' rice fields (B). Access road to T5 road with a width of 8m

Table 3. 5. Station Point Coordinates

No	Longitude	Latitude	Waktu	Deskripsi
1	115.181	-8.714	2023-12-19 16:31 WITA	T 2
2	115.163	-8.681	2023-12-19 16:57 WITA	T 3A (Rekomendasi)
3	115.166	-8.741	2023-12-20 09:03 WITA	T 1
4	115.169	-8.740	2023-12-20 10:03 WITA	T 1A (Rekomendasi)
5	115.163	-8.681	2023-12-20 10:28 WITA	T 3
6	115.139	-8.659	2023-12-20 12:53 WITA	T 4
7	115.131	-8.637	2023-12-20 13:26 WITA	Kedudukan Batuan Sungai
8	115.129	-8.635	2023-12-20 14:53 WITA	T 5
9	115.139	-8.653	2023-12-20 15:40 WITA	Singkapan Breksi Sungai
10	115.146	-8.671	2023-12-20 16:55 WITA	Litologi Breksi Tufan Sungai
11	115.252	-8.640	2023-12-21 09:32 WITA	E-BRT (E-W)
12	115.247	-8.645	2023-12-21 11:59 WITA	Sungai Jalur E-BRT (E-W)
13	115.203	-8.630	2023-12-21 13:09 WITA	Litologi Breksi
14	115.204	-8.669	2023-12-21 14:36 WITA	Rekomendasi Lapangan Kosong
15	115.205	-8.669	2023-12-21 15:39 WITA	E-BRT (N-S)

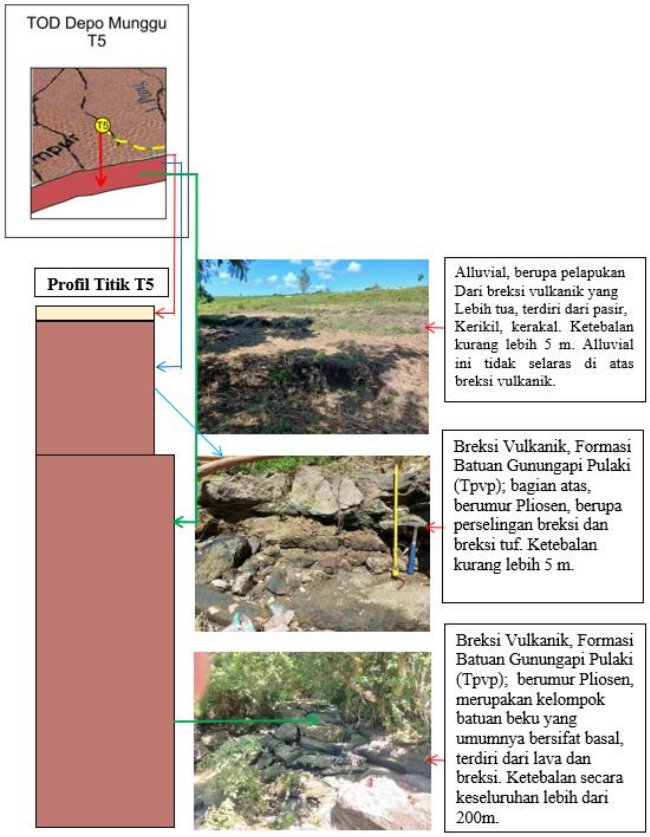

Figure 3. 26. Location Point Profile T5; Volcanic and incongruous Breksi lithology is found on it Alluvial lithology

Location Point T1 E-BRT (Points T1 – T5)

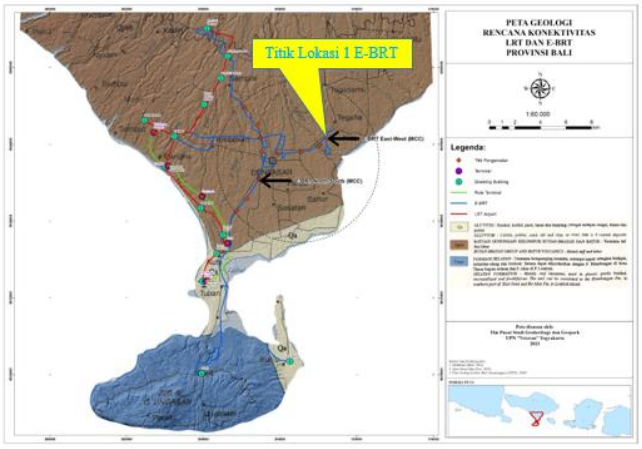

Figure 3. 27. Regional Geologic Map of Research Areas and Railway Lines and Station Points

Location Point T1 E-BRT in front of Mangkrak Office on Jl. Tegalta. The coordinates at this location are longitute 115.252 and Latitut -8.640. The lithological profile found here is only alluvial at the top which is approximately 5 meters thick. Lithology in this area is found in the river to the west with longitute coordinates 115,247 and Latitut -8,640. It also uses its regional studies from the Geological Map issued by the Center for Geological Surve (PSG). The results of the study found under the alluvial found volcanic breccia that are very hard, gray-black, very compact and hard, 913amper not found burly with a thickness of approximately 150 meters.

Table 3. 6. Station Point Coordinates

No	Longitude	Latitude	Waktu	Deskripsi
1	115.181	-8.714	2023-12-19 16:31 WITA	T 2
2	115.163	-8.681	2023-12-19 16:57 WITA	T 3A (Rekomendasi)
3	115.166	-8.741	2023-12-20 09:03 WITA	T 1
4	115.169	-8.740	2023-12-20 10:03 WITA	T 1A (Rekomendasi)
5	115.163	-8.681	2023-12-20 10:28 WITA	T 3
6	115.139	-8.659	2023-12-20 12:53 WITA	T 4
7	115.131	-8.637	2023-12-20 13:26 WITA	Kedudukan Batuan Sungai
8	115.129	-8.635	2023-12-20 14:53 WITA	T 5
9	115.139	-8.653	2023-12-20 15:40 WITA	Singkapan Breksi Sungai
10	115.146	-8.671	2023-12-20 16:55 WITA	Litologi Breksi Tufan Sungai
11	115.252	-8.640	2023-12-21 09:32 WITA	E-BRT (E-W)
12	115.247	-8.645	2023-12-21 11:59 WITA	Sungai Jalur E-BRT (E-W)
13	115.203	-8.630	2023-12-21 13:09 WITA	Litologi Breksi
14	115.204	-8.669	2023-12-21 14:36 WITA	Rekomendasi Lapangan Kosong
15	115.205	-8.669	2023-12-21 15:39 WITA	E-BRT (N-S)

Figure 3. 28. Location Point-1 E-BRT E-W (A). in front of Indomart and (B). In front of the bowl office

Figure 3. 29. Profile of T1 E-BRT Point on the River Bank west side T1

Location Point T2 E-BRT

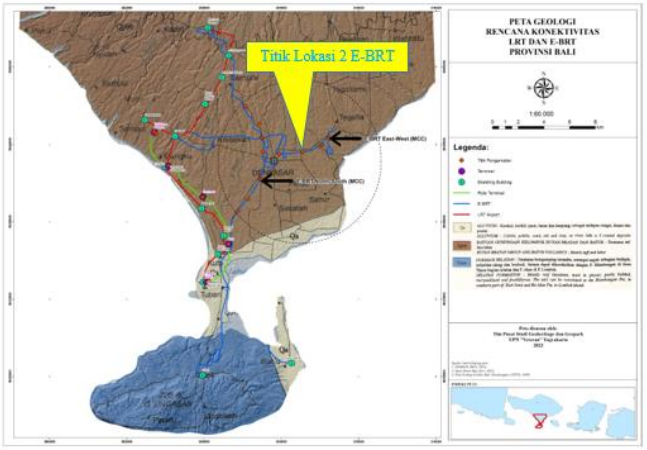

Figure 3. 30. Regional Geologic Map of Research Areas and Railway Lines and Station Points

Location Point T2 E-BRT in front of the Field. The coordinates at this location are longitut 115.204 and Latitut -8.669. The lithological profile found here is only alluvial at the top which is approximately 5-10 meters thick. In this area because it is only visible in the field, it also uses regional studies from the Geological Map issued by the Geological Surve Center (PSG). The results of the study found under the alluvial found volcanic breccia that are very hard, gray-black, very compact and hard, almost not found burly with a thickness of approximately 150 meters.

Table 3. 7. Station Point Coordinates

No	Longitude	Latitude	Waktu	Deskripsi
1	115.181	-8.714	2023-12-19 16:31 WITA	T 2
2	115.163	-8.681	2023-12-19 16:57 WITA	T 3A (Rekomendasi)
3	115.166	-8.741	2023-12-20 09:03 WITA	T 1
4	115.169	-8.740	2023-12-20 10:03 WITA	T 1A (Rekomendasi)
5	115.163	-8.681	2023-12-20 10:28 WITA	T 3
6	115.139	-8.659	2023-12-20 12:53 WITA	T 4
7	115.131	-8.637	2023-12-20 13:26 WITA	Kedudukan Batuan Sungai
8	115.129	-8.635	2023-12-20 14:53 WITA	T 5
9	115.139	-8.653	2023-12-20 15:40 WITA	Singkapan Breksi Sungai
10	115.146	-8.671	2023-12-20 16:55 WITA	Litologi Breksi Tufan Sungai
11	115.252	-8.640	2023-12-21 09:32 WITA	E-BRT (E-W)
12	115.247	-8.645	2023-12-21 11:59 WITA	Sungai Jalur E-BRT (E-W)
13	115.203	-8.630	2023-12-21 13:09 WITA	Litologi Breksi
14	115.204	-8.669	2023-12-21 14:36 WITA	Rekomendasi Lapangan Kosong
15	115.205	-8.669	2023-12-21 15:39 WITA	E-BRT (N-S)

Figure 3. 31. Location Point T2 E-BRT in the open field

Figure 3. 32. Location of T2 E-BRT Point on the river near T2

Location Point T3 E-BRT (NORTH SIDE)

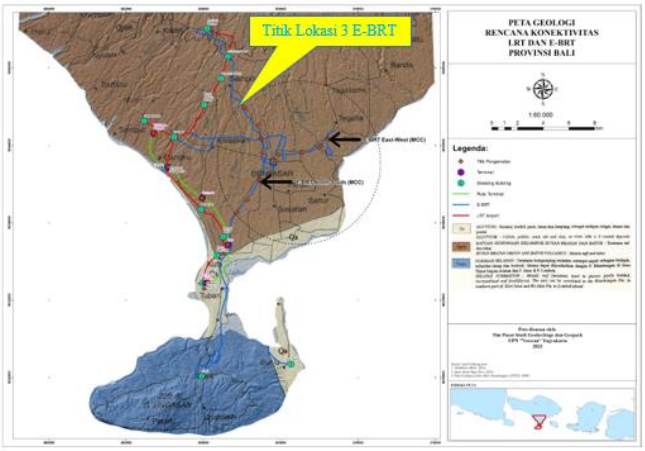

Figure 3. 33. Regional Geologic Map of Research Areas and Railway Lines and Station Points

Location Point T3 E-BRT on the edge of the village road. The coordinates at this location are longitut 115.205 and Latitut -8.669. The lithological profile found here is only alluvial at the top which is approximately 5-10 meters thick. In this area in addition to using its regional studies from the Geological Map issued by the Geological Surve Center (PSG). The results of the study found under the alluvial found volcanic breccia that are very hard, gray-black, very compact and hard, almost not found burly with a thickness of approximately 150 meters.

Table 3. 8. Station Point Coordinates

No	Longitude	Latitude	Waktu	Deskripsi
1	115.181	-8.714	2023-12-19 16:31 WITA	T 2
2	115.163	-8.681	2023-12-19 16:57 WITA	T 3A (Rekomendasi)
3	115.166	-8.741	2023-12-20 09:03 WITA	T 1
4	115.169	-8.740	2023-12-20 10:03 WITA	T 1A (Rekomendasi)
5	115.163	-8.681	2023-12-20 10:28 WITA	T 3
6	115.139	-8.659	2023-12-20 12:53 WITA	T 4
7	115.131	-8.637	2023-12-20 13:26 WITA	Kedudukan Batuan Sungai
8	115.129	-8.635	2023-12-20 14:53 WITA	T 5
9	115.139	-8.653	2023-12-20 15:40 WITA	Singkapan Breksi Sungai
10	115.146	-8.671	2023-12-20 16:55 WITA	Litologi Breksi Tufan Sungai
11	115.252	-8.640	2023-12-21 09:32 WITA	E-BRT (E-W)
12	115.247	-8.645	2023-12-21 11:59 WITA	Sungai Jalur E-BRT (E-W)
13	115.203	-8.630	2023-12-21 13:09 WITA	Litologi Breksi
14	115.204	-8.669	2023-12-21 14:36 WITA	Rekomendasi Lapangan Kosong
15	115.205	-8.669	2023-12-21 15:39 WITA	E-BRT (N-S)

Figure 3. 34. Lithology of volcanic breccia and at the top of the Alluvial misaligned

Figure 3. 35. Location of T3 Point E-BRT NORTH SIDE

Location Point T4 E-BRT (SOUTH SIDE)

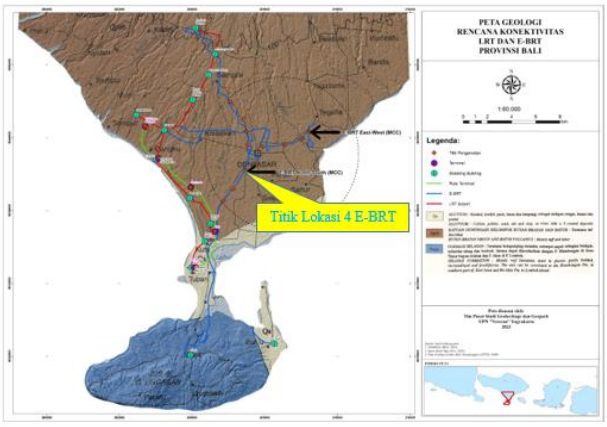

Figure 3. 36. Regional Geologic Map of Research Areas and Railway Lines and Station Points

Location Point T9 E-BRT in the Field. The coordinates at this location are longitut 115.205 and Latitut -8.669. The lithological profile found here is only alluvial at the top which is approximately 5-10 meters thick. In this area because it is only visible in the field, it also uses regional studies from the Geological Map issued by the Geological Surve Center (PSG). The results of the study found under the alluvial found volcanic breccia that are very hard, gray-black, very compact and hard, almost not found burly with a thickness of approximately 100 meters.

Table 3. 9. Station Point Coordinates

No	Longitude	Latitude	Waktu	Deskripsi
1	115.181	-8.714	2023-12-19 16:31 WITA	T 2
2	115.163	-8.681	2023-12-19 16:57 WITA	T 3A (Rekomendasi)
3	115.166	-8.741	2023-12-20 09:03 WITA	T 1
4	115.169	-8.740	2023-12-20 10:03 WITA	T 1A (Rekomendasi)
5	115.163	-8.681	2023-12-20 10:28 WITA	T 3
6	115.139	-8.659	2023-12-20 12:53 WITA	T 4
7	115.131	-8.637	2023-12-20 13:26 WITA	Kedudukan Batuan Sungai
8	115.129	-8.635	2023-12-20 14:53 WITA	T 5
9	115.139	-8.653	2023-12-20 15:40 WITA	Singkapan Breksi Sungai
10	115.146	-8.671	2023-12-20 16:55 WITA	Litologi Breksi Tufan Sungai
11	115.252	-8.640	2023-12-21 09:32 WITA	E-BRT (E-W)
12	115.247	-8.645	2023-12-21 11:59 WITA	Sungai Jalur E-BRT (E-W)
13	115.203	-8.630	2023-12-21 13:09 WITA	Litologi Breksi
14	115.204	-8.669	2023-12-21 14:36 WITA	Rekomendasi Lapangan Kosong
15	115.205	-8.669	2023-12-21 15:39 WITA	E-BRT (N-S)

Figure 3. 37. Location of the South Side T4 E-BRT point inside the Field

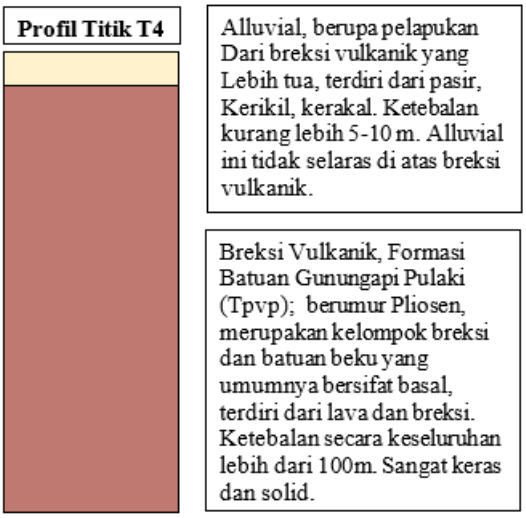

Figure 6. 38. Location of T4 E-BRT POINT SOUTH SIDE

4. CONCLUSION

A. Lithology and Stratigraphy Analysis

The results of Field Surveys starting from Location Points T1 to T5 and Points T1 to T4 E-BRT can be summarized lithological arrangement from top (surface) to bottom as follows:

- **Alluvial**
  Alluvial lithology occupies the upper part of all the surve, varies in thickness from 5 to 10 meters and thickens towards the south. This alluvial is the result of weathering of volcanic breccia rocks consisting of soil, sand, gravel and kerakal with a little mixture of mud. Alluvial lithology compaction is quite good and not muddy. These alluvials are misaligned over the tuff and breccia layers.

- **Quaternary Volcano Formation (Q)**
  Volcanic activity in the quarter resulted in the formation of a number of cones that are generally no longer active. The volcano produces tuff rocks and lava deposits of Buyan-Beratan and Batur, Mount Batur volcanic rocks, Mount Agung volcanic rocks, Batukaru volcano rocks, lava from Mount Pawon and volcanic rocks from the subcentric cones of Mount Pohen, Mount Sangiang and Mount Lesung. Of the volcanoes in total, only two are still active, namely Mount Agung and Mount Batur in the Batur Caldera.The thickness of this tuff layer is estimated to be between 5-10 meters. But it was not evenly distributed throughout the study area. This tuff layer is also misaligned above the oldest breccias layer in the Study Area. From the petrographic results in Appendix 2, it was found that the name of the rock, sample 4 - LP-4 has the name tuff according to Fisher's classification (1966).

- **Volcanic Breccia of Pulaki Volcano Rock Formation (Tpvp).**
  Solid volcanic breccia, black to brownish in color, fragments of pebble-sized to kerakal-sized andesite, iron oxide cement, very hard and solid. This rock is included in the Pulaki Volcano Rock Formation (Tpvp). The thickness of this formation is more than 100-150 meters. From the results of petrographic analysis in Examples B1-Lp 1 and B2-Lp 2 produced the name andesite. This volcanic breccia rock is very solid and hard because it consists of andesite fragments, dacite, with sandstone matrix and iron oxide smen. The geological structure in the form of stout is very minimal almost nothing, so if later the railway tunnel will be made at a depth of 20-25 meters below the surface and all about this volcanic breccia rock must be very safe.

B. Faults and Active Structures

Inside the island of Bali is not found active faults, only found outside the island of Bali. The south of Bali Island is approximately 100km in the form of *a mega thrust*, (the collision between Indo-Australia hit the island of Bali), in the east in the form of a left horizontal fault, in the west of Bali Island in the form of a left horizontal collision and in the north in the form of *a backthrust fault*. So that on the island of Bali itself is quite safe in terms of internal rocks and seismicity. The earthquake will only occur if there is a megathrust impact activity in the south of Bali Island.

C. Compressive Strength Test Analysis (Uniaxial)

In theory in calculations in rock mechanics rock samples are considered homogeneous, isotrope, and continuous, in fact rock samples taken from the same geological formation can have different strengths because of their heterogeneous nature. The results of compressive strength tests of rock samples show that the strength of rocks varies, ranging from very strong to those that are easily cracked or broken. This is also influenced by the presence of fractures contained in the sample rock. Uniaxial compressive strength test is one of the important tests in rock mechanics, this compressive strength test is performed to measure the uniaxial compressive strength of a block rock sample in one direction (uniaxial). The main purpose of this test is to classify the strength of rocks and the characteristics of compact rocks. This test produces some information, such as the stress-strain curve, poisson ratio, uniaxial

compressive strength, fracture energy, and specific fracture energy.
In theory, the spread of voltage in the example is in the direction of the force imposed in the example. But in fact the direction of the voltage is not in the same direction as the force given in the example. This happens because there is an influence from the pressure plate that is on the press machine in the form of a broken plane that is in the direction of the force, cone-shaped. The ratio between the height and diameter of the rock sample sample (L/D) will affect the compressive strength of the rock. In accordance with the International Society of Rock Mechanics (ISRM 1981) for compressive strength testing using a ratio (L/D) between 2-2.5 and vice versa diameter (D) sample rock sample ±45 mm. The greater the ratio between the height and diameter of the rock sample sample used, the smaller the compressive strength. The placement of rock samples, both from axial and lateral directions during the test can be measured using an electric strain gauge. The uniaxial compressive strength test will show the strain stress curve.

This test was carried out on 6 (six) rock samples taken from the research site, which were then formed into rock *cores* with a diameter of 4-5 cm and a height of 8-10 cm.

Figure 4. 1. Andesite igneous rock cores (LP 1 and LP 2 samples) and sandstone tuff pyroclastic (LP 4 samples)

After testing the Uniaxial Compressive Strength Test, the uniaxial compressive strength value, Young's Modulus, Poisson *'s ratio* can be seen in Table 4.1:

Table 4. 1. Uniaxial compressive strength test results

Nomor Sampel	Jenis batuan	Kuat tekan uniaksial (MPa)	Nisbah Poisson	Modulus Young (MPa)
LP 1	Andesit	31,06	0,21	22.055,94
LP 2	Andesit	46,82	0,212	47.167,99
LP 3	Andesit	9,17	0,22	21.998,95
LP 4	Tuff pasiran	15,71	0,17	21.998,95
LP 5	Andesit	21,04	0,22	36.558,72
LP 6	Andesit	23,38	0,22	39.281,95

D. Direct Shear Test Analysis

Rock shear strength is the rock's internal resistance to stresses acting along the shear plane in the rock, which is influenced by intrinsic characteristics and external factors. The sample is subjected to a certain normal force (Fn) applied perpendicular to the discontinuous plane surface and a shear or horizontal force (Fs) is applied to shift the rock sample until it breaks. Rock shear strength is very useful as a slope stability design parameter and the most widely used shear collapse criterion is the Mohr-Coulomb criterion.

The results of the direct shear strength test are then plotted into the Mohr-Coulomb curve so that the following rock strength parameters can be determined: the relationship curve between normal stress and shear strength, normal stress, shear strength, cohesion, and deep shear angle. The following are the results of direct shear strength testing on ten rock samples from the study area:
LP 5
Residual cohesion (Cr) : 0.5756 kg/cm2
Shear angle in residue (fr) : 43.180

Table 4.2. Direct *shear test results* on LP 1 samples

Sample No.	Tegangan Normal (kg/cm^2)	Beban geser, (kg)		Kuat geser, (kg/cm^2)	
		Puncak	Residu	Puncak	Residu
1	1,74	0.00	27,65	0.00	2,43
2	3,58	0.00	38,51	0.00	3,49
3	5,48	0.00	64,19	0.00	5,94

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