MINERALOGY AND MICROSTRUCTURE OF RANTAU DEDAP'S GEOTHERMAL RESERVOIR: HYDROTHERMAL ALTERATION INSIGHTS

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Abstract. *The Great Sumatra Fault controls the Rantau Dedap geothermal system in South Sumatra. It is a high-temperature volcano-tectonic system. This study presents a comprehensive mineralogical and microstructural examination of core samples from three deep wells (UJ-A1, UJ-B1, and UJ-C1) at depths ranging from 1,840 to 2,313 m, aiming to elucidate hydrothermal alteration and its impact on reservoir quality. X-ray Diffraction (XRD) and Scanning Electron Microscopy-Energy Dispersive X-ray Spectroscopy (SEM-EDS) analyses demonstrate a distinct propylitic alteration zonation correlated with increasing depth and temperature. UJ-A1 (1840 m) is mainly made up of oligoclase, microcline, and quartz. UJ-B1 (2142 m) is mainly made up of oligoclase-quartz. UJ-C1 (2313 m) is mainly made up of anorthite-quartz with more iron. Anorthite, a calcium-rich plagioclase that stays stable above 280 °C, is found at greater depths. This means that the area is close to a major upflow zone. SEM microstructural analysis reveals hydrothermal breccia textures, characterized by angular fragments within a matrix of secondary minerals, and indicates secondary porosity resulting from mineral alteration. These characteristics suggest that hydraulic brecciation resulting from tectonic activity is essential for the creation and preservation of reservoir permeability. The reservoir's potential is enhanced because it lacks smectite-type clays, which typically block pores. In general, these results indicate that Rantau Dedap is a structurally controlled upflow zone characterized by deep mafic lithologies. The anorthite-quartz assemblage stands out as a key sign for future high-temperature geothermal exploration.*
Keywords: *geothermal; hydrothermal alteration; propylitic; rantau dedap; reservoir characterization*

INTRODUCTION

As the world shifts toward utilizing more renewable resources, the use of geothermal energy is becoming increasingly important. Indonesia is situated on the Pacific Ring of Fire and has significant geothermal energy potential. It has an estimated 23.36 GW spread over 356 sites (Pambudi and Ulfa, 2024). Indonesia has a significant amount of geothermal reserves due to the volcanic and tectonic activity that occure there. But only about 9.81% of the total potential has been used so far (Pambudi and Ulfa, 2024). This gap highlights the importance of utilizing advanced methods for exploration and reservoir characterization immediately to mitigate drilling risks and accelerate the development of new geothermal fields.

It is crucial to study hydrothermal alteration when exploring for geothermal energy. Hydrothermal alteration is the main way that hot fluids (like water, steam, and gas) interact with the rocks around them. This changes the mineralogical, chemical, and textural composition of the host rock in a big way (Guilbert and Park, 1986; Pirajno, 2009). The secondary mineral assemblages produced by this process are not random; they reflect the physicochemical conditions below the surface, such as temperature, pressure, fluid composition (e.g., pH and salinity), and rock permeability (Reyes, 1990; Simmons and Browne, 2000). As a result, figuring out what alteration minerals are like is a very useful way to figure out reservoir conditions, map out fluid flow paths, and finally find the most productive permeable zones (Legat, 2009; Dana *et al.*, 2019).

The Rantau Dedap geothermal field in South Sumatra Province (INPEX, 2025). It is one of Indonesia's high-temperature geothermal systems that has been used for business. The field is located in the Bukit Barisan Mountains, which are part of an active volcanic arc formed due to tectonic activity in the area. This is because it is located near the Great Sumatra Fault (GSF), a system of dextral strike-slip faults that spans a large area.

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This means that faults and fractures in the ground have a significant effect on how easily water can flow through the reservoir at Rantau Dedap (Artyanto *et al.*, 2017; Mussofan *et al.*, 2021). The main reservoir in this field is in volcanic rocks that have changed a lot and broken apart, so to improve production, it is important to understand how tectonics, alteration, and permeability work together (Artyanto *et al.*, 2017).

It has been reported that Rantau Dedap has a general geological framework; however, there is still a lack of detailed information about the mineralogy and microstructure of the reservoir rocks at different depths. This information is necessary to verify and refine the conceptual model of the field, particularly in terms of how temperature and permeability are distributed throughout the reservoir. This study aims to: (1) conduct a thorough elemental and mineralogical characterization of core samples from three deep wells (UJ-A1, UJ-B1, and UJ-C1) using XRD and SEM-EDS analysis; (2) interpret the identified mineral assemblages and microstructures within the context of the established hydrothermal system of the field; and (3) clarify the relationship between alteration processes, rock texture, and the development of reservoir porosity and permeability.

Tectonic Setting and Structural Controls in the Region

The Indo-Australian Plate moved northeastward under the Eurasian (Sunda) Plate, which created the island arc that includes Sumatra (Hall, 2012). This oblique convergence divides strain, which is evident in two primary tectonic features: the subduction zone off the west coast and the Great Sumatra Fault (GSF) system extending along the island (Fitch, 1972; Artyanto *et al.*, 2017). The GSF is a very active dextral strike-slip fault system that has a big impact on volcanism and the formation of geothermal systems along the Bukit Barisan Mountains (Bellier and Sébrier, 1994; Sieh and Natawidjaja, 2000).

The Rantau Dedap geothermal field is located approximately 15 km northeast of the main part of the GSF (Figure 1). This puts it right in the path of the strike-slip tectonic regime (Artyanto *et al.*, 2017; Mussofan *et al.*, 2021). This structural control is necessary for the geothermal system's existence, as fault movement causes deformation that creates a network of fractures and breccia zones that are the main pathways for hydrothermal fluids to flow (Cox, 2005). Borehole imaging and surface structural data at Rantau Dedap have identified two primary orientations of significant faults and fractures: Northeast-Southwest (NE-SW) and North-Northwest-South-Southeast (NNW-SSE) (Artyanto *et al.*, 2017; Mussofan *et al.*, 2021). It has been demonstrated that these faults, particularly those oriented NE-SW, dictate the locations of permeable zones and the primary production wells. The interaction of these fault sets results in elevated secondary permeability, essential for the commercial productivity of a geothermal reservoir. So, it's clear that the permeability at Rantau Dedap is very anisotropic, which means that it mostly happens in these structural corridors instead of being spread out evenly throughout the rock formations.

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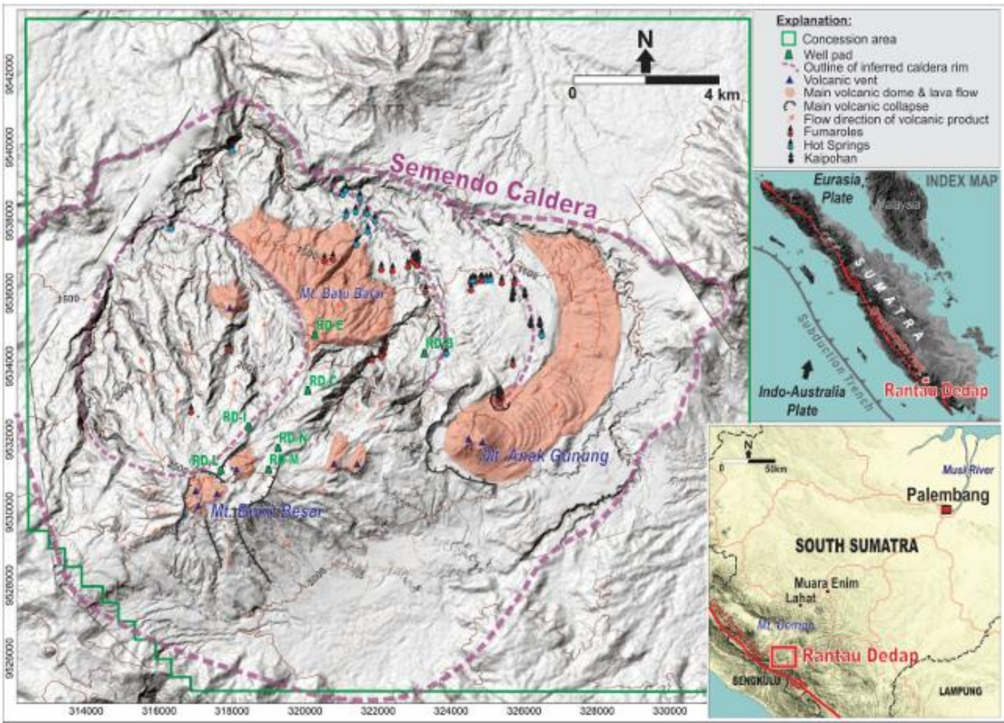

Figure 1. Compilation of DEM and LiDAR Topography of the Rantau Dedap Geothermal *Field* (Mussofan *et al.*, 2021)

Field Stratigraphy and Reservoir Lithology

Mussofan et al. (2021) have conducted extensive drilling to ascertain the stratigraphy of the Rantau Dedap field. This stratigraphic sequence shows that there was a complicated history of volcanoes that led to the ideal structure for a geothermal system's reservoir and cap rock. The following is the order from oldest to youngest:

- Basement: The oldest unit, which has the deepest wells (>2400 m), is a Tertiary silicic intrusive rock. This rock is what the new geothermal system is built on.
- Reservoir Unit: A group of volcanic rocks from the Quaternary period that are mostly made of silica sit on top of the basement. The Lower Rhyolite Tuff, the Mixed Sediment and Tuff, and the Upper Dacite/Rhyolite Tuffs are all smaller parts of this unit. These rocks, especially the well-welded tuffs, are strong and brittle, which means they are very likely to break when subjected to tectonic stress. This is why they are the main reservoir rocks at Rantau Dedap.
- Cap Rock: The Subaqueous Debris Flow unit is on top of the silicic reservoir unit. This unit is made up of breccias and conglomerates with a mud matrix that has been heavily changed into transitional (non-smectite) clay minerals. It works well as a stratigraphic cap rock because it doesn't let fluids through easily. This keeps the hot fluids and heat in the reservoir below.
- Overburden: The newest layer that covers the system is Quaternary andesitic volcanic rock, like the Bukit Besar Andesite. This unit has mostly changed into low-temperature argillic minerals that are high in smectite. This has made a second "clay cap" that helps seal the geothermal system.

This stratigraphic architecture creates a "self-sealing geothermal system." The brittle and permeable reservoir is trapped below a cap rock that naturally has low permeability. The samples analyzed in this study (UJ-A1, UJ-B1, UJ-C1) were obtained from depths ranging from 1840 m to 2313 m, clearly placing them within the silicic tuff reservoir unit, well below the Subaqueous Debris Flow unit and the smectite clay cap. This makes sure that the mineral compositions that were looked at really show what the conditions are like in the productive zone of the reservoir, not the cap zone.

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Hydrothermal Alteration Zoning

Hot fluids have altered the sequence of volcanic rocks at Rantau Dedap, which is evident both on the surface and within the reservoir (Mussofan *et al.*, 2021). This zoning shows how the temperature and fluid chemistry change in the system, which is a useful tool for exploration. The main places that have been found are:

- The Argillic Zone is the shallowest part of the system. Smectite clay minerals, zeolites, and chalcedony are the most common minerals found there. Resistivity geophysical surveys have identified a conductive layer in this region, referred to as the "clay cap" (Mussofan *et al.*, 2021; Ramadhan *et al.*, 2021).
- Propylitic Zone (>220 °C): This is a medium- to high-temperature alteration zone that is common in geothermal reservoirs. It is composed of minerals such as epidote, wairakite, chlorite, adularia, secondary quartz, and calcite. Epidote is a sign that the temperature is usually higher than 220–240°C (Reyes, 1990).
- Phyllic Zone (>220 °C): This zone is mostly made up of illite, sericite, quartz, and pyrite minerals. It forms in more acidic fluids (low pH) than the propylitic zone, and it is often found above or next to magmatic intrusions, which are the source of heat and magmatic fluids (Parry, Jasumback and Wilson, 2002; Sillitoe, 2010).
- Potassic Zone (>370 °C): This is the deepest part of the system and is directly connected to magmatic intrusions. This zone has secondary biotite and K-feldspar, which are made from potassium-rich fluids that usually come from magma (Seedorff *et al.*, 2005).

Figure 2 depicts a three-dimensional geological model that integrates geological, stratigraphic, and structural components to provide a comprehensive representation of the Rantau Dedap geothermal system. The model reveals a significant intrusion deep within, which is believed to be the primary source of heat for the system. Above this intrusion is the layered stratigraphy discussed earlier. This includes the Lower Dacite and Rhyolite Tuffs' reservoir units. The model shows that the main places where fluids can flow, or feed zones, are mostly along big fault lines that cut through these formations. This picture supports the idea that structure controls permeability, which lets hot fluids move from the heat source to the brittle rocks above.

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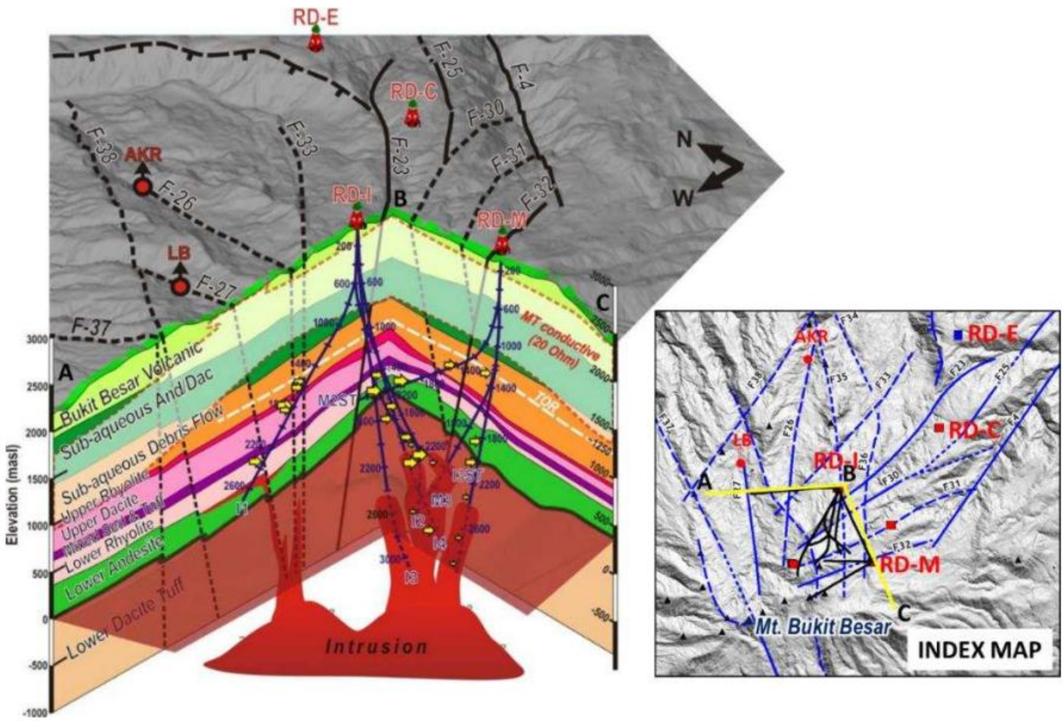

Figure 2. A 3D geological model of the Rantau Dedap field. It shows the subsurface stratigraphy, the central magmatic intrusion, and the location of permeable feed zones (yellow arrows) along structural features (Mussofan *et al.*, 2019)

MATERIALS AND METHODS

Sample Origin

This study utilized three core samples obtained from development wells in the Rantau Dedap geothermal field. The samples were chosen to represent the lithology of the reservoir at various depths, allowing for an examination of the vertical alteration gradient. Here are the details of the sample:

- Sample UJ-A1: Obtained from well UJ-A1 at a depth of 1840 to 1841 meters.
- Sample UJ-B1: Taken from well UJ-B1 at a depth of 2141 to 2142 m.
- Sample UJ-C1: Taken from well UJ-C1 at a depth of 2313 m.

The Quaternary silicic volcanic reservoir unit, which is below the clay cap zone, contains all three samples.

Analytical Procedures

To meet the research goals, each sample underwent a series of petrographic and geochemical tests.

Sample Preparation

There were two parts to every core sample. One part was put in a mortar grinder and ground into a fine, even powder. The particles were 200 mesh in size. This powder was then used for X-ray diffraction (XRD) tests. The other part was cut and polished into a thin section so that it could be looked at with a Scanning Electron Microscope-Energy Dispersive X-ray Spectroscopy (SEM-EDS).

Scanning Electron Microscopy-Energy Dispersive X-ray Spectroscopy (SEM-EDS)

SEM-EDS was used to examine the shape, texture, and spatial relationships of mineral grains on a very small scale, as well as to determine the semi-quantitative elemental composition of the mineral phases. An EDS detector and a JEOL JSM-6510LA electron microscope were used to do this analysis. Secondary Electron (SE) imaging was used to examine the shape of the crystals and the surface topography. Mineral phases were

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differentiated using Back-Scattered Electron (BSE) imaging by analyzing their average atomic number (Z) contrast (Goldstein *et al.*, 2018). EDS spectra from specific points or regions were used on the sample to determine its elemental composition.

X-ray Diffraction (XRD)

The main way to find out what kind of crystals were in each rock sample was to use XRD analysis. The analysis was done with a Rigaku Miniflex diffractometer and a Cu-Kα radiation source. The powdered sample was placed on a holder and scanned at angles ranging from 5° to 70° over a 2θ angle range. The basic idea behind this method is that X-rays diffract through the crystal planes in minerals, creating a unique diffraction pattern (diffractogram) for each mineral (Huff, 1990). We used the International Centre for Diffraction Data (ICDD) database to compare the diffraction patterns obtained to determine which mineral phase they belonged to. The Reference Intensity Ratio (RIR) method was used for a semi-quantitative analysis to determine the relative weights of each mineral in relation to the others. However, it is important to note the inherent limitations of the RIR method compared to whole pattern fitting techniques (e.g., Rietveld refinement), particularly for geological samples rich in feldspars. The accuracy of RIR quantification can be affected by the preferred orientation of crystallites and the significant peak overlap between plagioclase members (Oligoclase vs. Anorthite) and K-feldspar (Tamer, 2013). Therefore, the mineral percentages presented in this study should be interpreted as indicative trends of alteration zonation rather than absolute quantitative values.

RESULTS AND DISCUSSIONS

A comprehensive analysis utilizing SEM-EDS and XRD on three rock samples from the Rantau Dedap reservoir indicates that the mineralogical composition and microtexture exhibit systematic variations with increasing depth. Table 1 presents the principal outcomes of this characterization, followed by a comprehensive description of each sample.

Table 1. Summary of Mineralogical and Elemental Composition of Rantau Dedap Reservoir Rocks

Parameter	Sample UJ-A1	Sample UJ-B1	Sample UJ-C1
Well	UJ-A1	UJ-B1	UJ-C1
Depth (m)	1840–1841	2141–2142	2313
Dominant Elements (EDS)	O, Si, Al, Ca, Na	O, Si, Al, Ca	O, Si, Al, Ca, Fe
Mineral Assemblage (XRD)	Oligoclase (56.1 %) Quartz (26.6 %) Microcline (17.3 %)	Oligoclase (72.3 %) Quartz (27.7 %)	Anorthite (63.6 %) Quartz (36.4 %)
Microstructural Features (SEM)	Breccia texture with angular fragments; secondary mineral growth in vuggy pore space.	Massive crystalline rock, fractured; interlocking crystal texture.	Crystalline texture with microfractures; acicular secondary minerals present.

Sample UJ-A1 (1840–1841 m)

The SEM image of sample UJ-A1 (Figure 3a) shows a clear breccia texture made up of angular and poorly sorted rock fragments that look like an uneven coral reef texture. There is a lot of space between the pieces, and you can see secondary mineral growth there. Some of these minerals have euhedral to subhedral shapes, indicating that they formed crystals in open spaces known as vugs. This is the kind of texture you would expect from a rock that had been broken by machines, had fluids flow through it, and had minerals settle on it. The changing brightness of the picture indicates that the atomic numbers of the elements that make it up are different. The brighter areas have more atoms.

EDS analysis (Figure 4) confirms that this sample is composed of the main silicate-forming elements: Oxygen (38.87%), Silicon (25.59%), Aluminum (16.39%), Calcium (12.17%), and Sodium (6.98%). XRD analysis (Figure 5) shows that the mineral composition of this sample is mostly Oligoclase (56.1%), then Quartz (26.6%), and finally Microcline (17.3%). Oligoclase is a type of plagioclase mineral that is part of the

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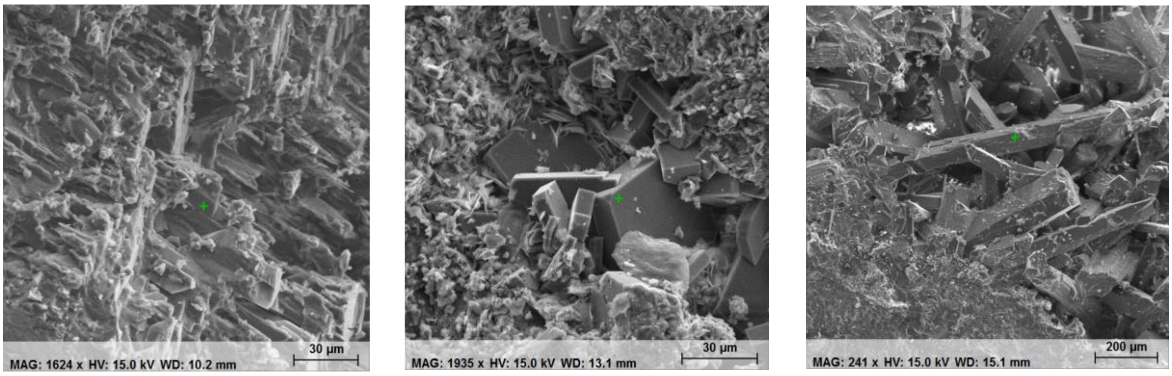
sodium-calcium series. Microcline is a type of feldspar that contains potassium (K-feldspar). The diffractogram pattern in Figure 6 has peaks that are clear and sharp. The strongest peak is at a 2θ angle of approximately 27°, indicating that the material is highly crystalline and lacks significant amorphous phases or clay minerals.



(a) (b) (c)

Figure 3. Morphology of Rock Samples from Well A1(a), Well B1 (b), and Well C1 (c) of the Rantau Dedap Geothermal Field

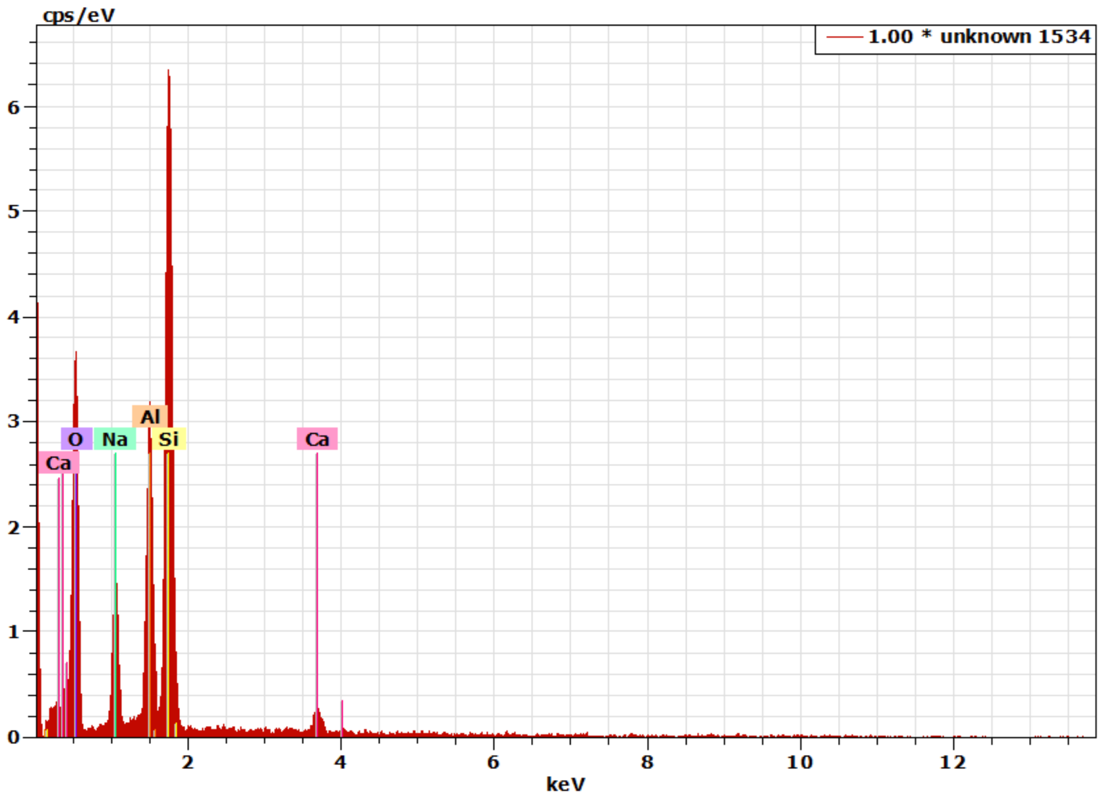


Figure 4. Elemental Content of Sample UJ-A1 from SEM-EDS analysis

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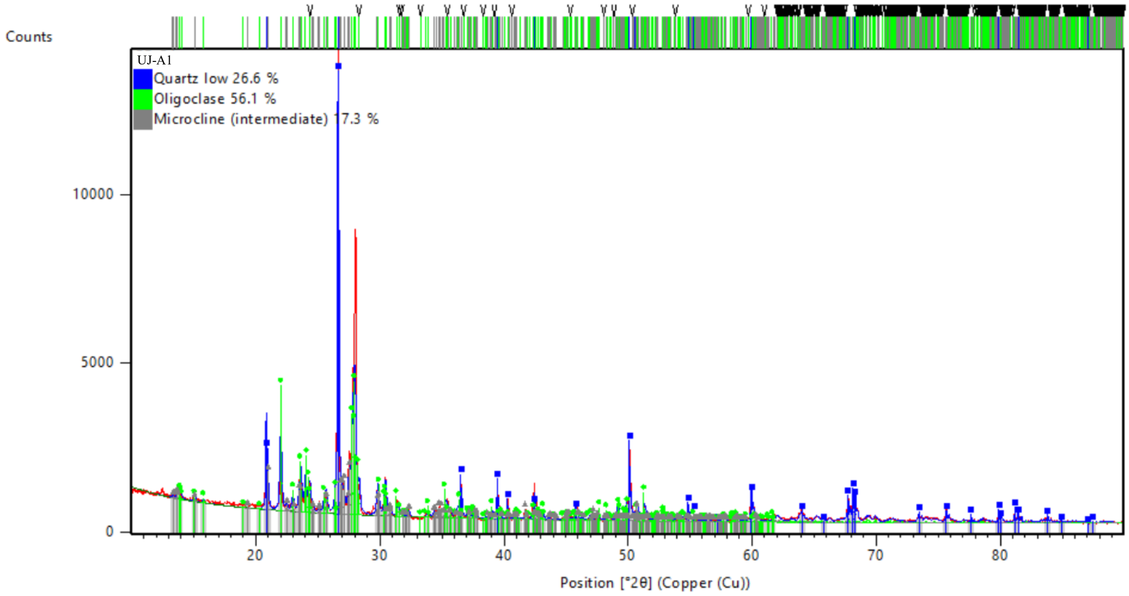

Figure 5. Mineral Content of Sample UJ-A1 from XRD analysis

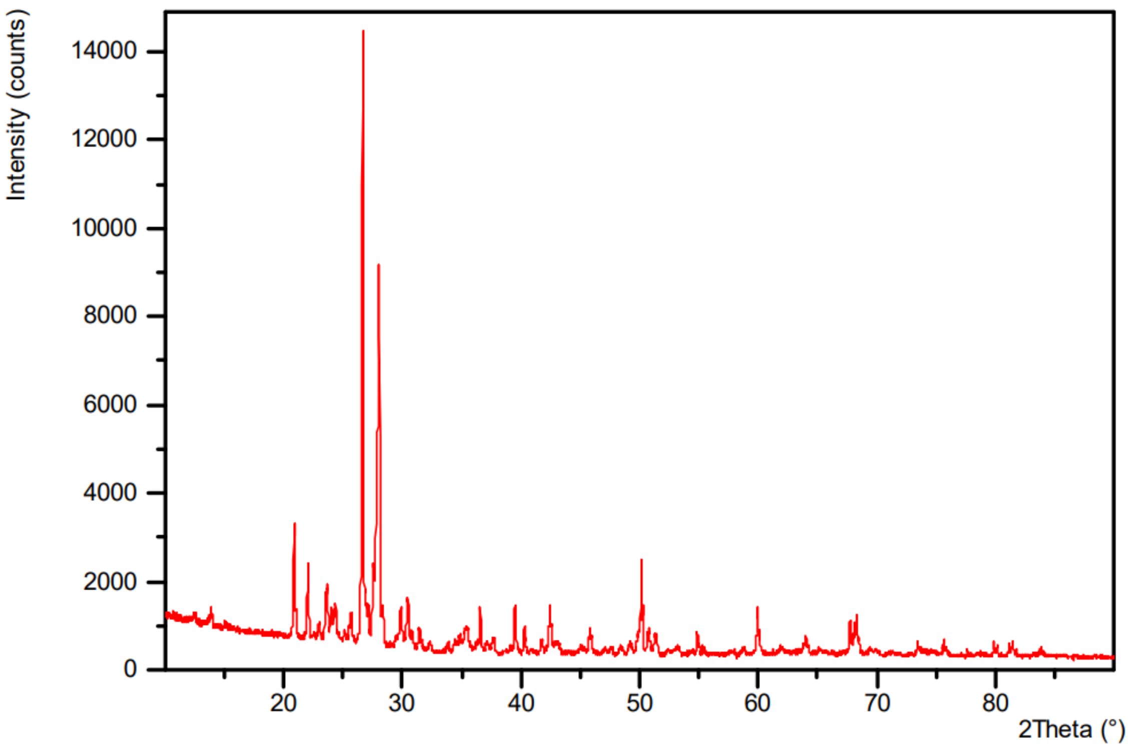

Figure 6. XRD diffractogram pattern of sample UJ-A1

Sample UJ-B1 (2141–2142 m)

Sample UJ-B1 (Figure 3b) has a more solid crystalline texture than UJ-A1, which makes it look like a block that isn't quite even. The rock is composed of crystals that fit together, but it has broken down in a way that renders it brittle, leaving behind a network of tiny cracks. There are no signs of extensive brecciation, like in UJ-A1, which suggests that the protolith is more likely to be a coherent rock, such as a lava flow or shallow intrusion, rather than a fragmental rock.

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EDS analysis (Figure 7) shows that the elemental makeup is similar to UJ-A1, with Oxygen (42.67%), Silicon (18.67%), and Aluminum (12%), but Calcium (26.66%) is much more concentrated and Sodium is not detected at all. XRD analysis (Figure 8) shows that the mineral composition is less complex, with Oligoclase (72.3%) and Quartz (27.7%) making up most of it. The main difference between this and sample UJ-A1 is that detectable microcline (K-feldspar). The diffraction peaks in Figure 9 are also sharp, which means that the crystals are stable and have a high level of crystallinity.

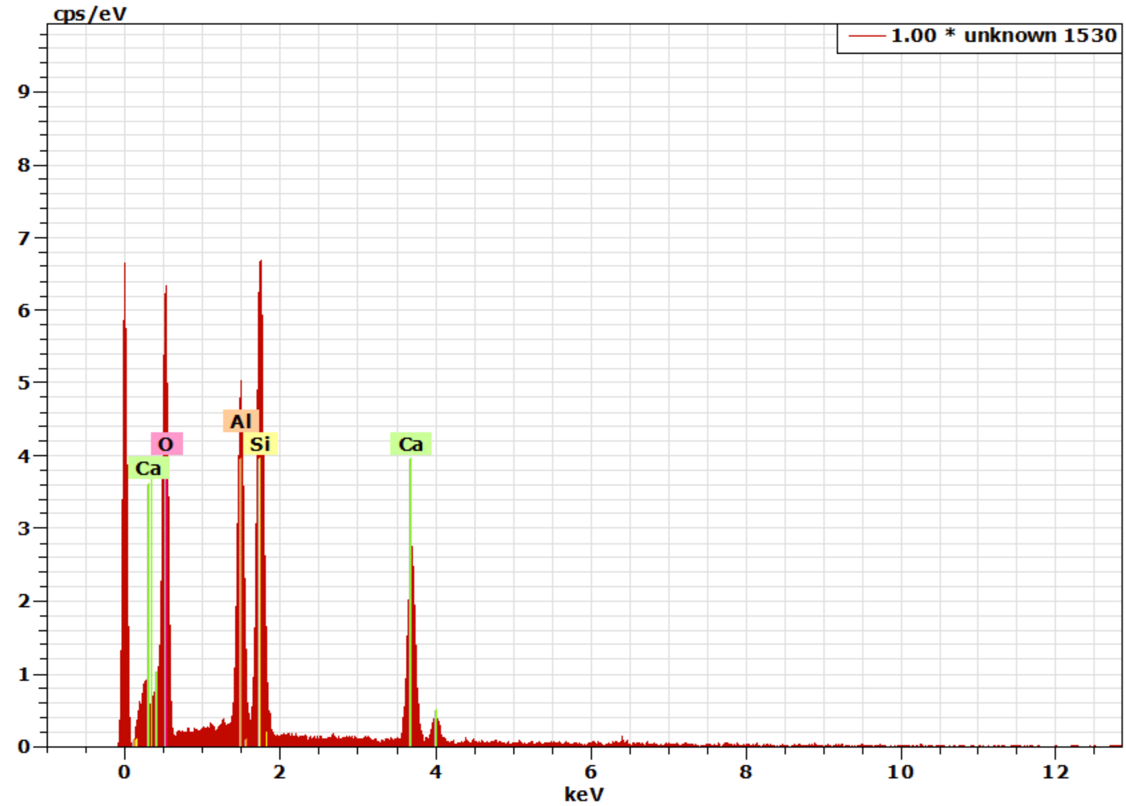

Figure 7. Elemental Content of Sample UJ-B1 from SEM-EDS analysis

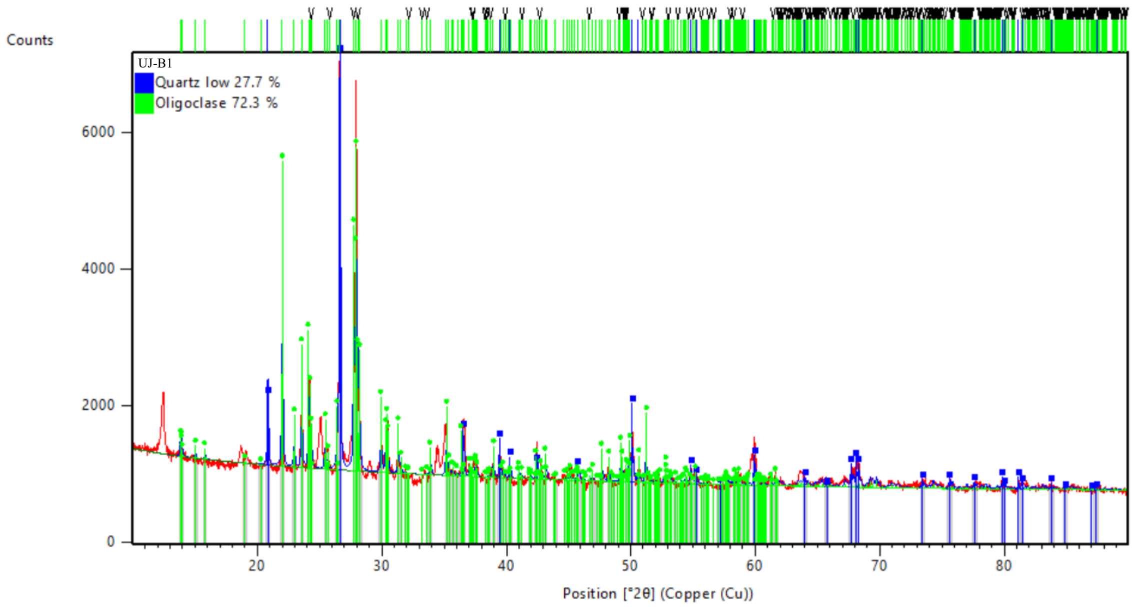

Figure 8. Mineral Content of Sample UJ-B1 from XRD analysis

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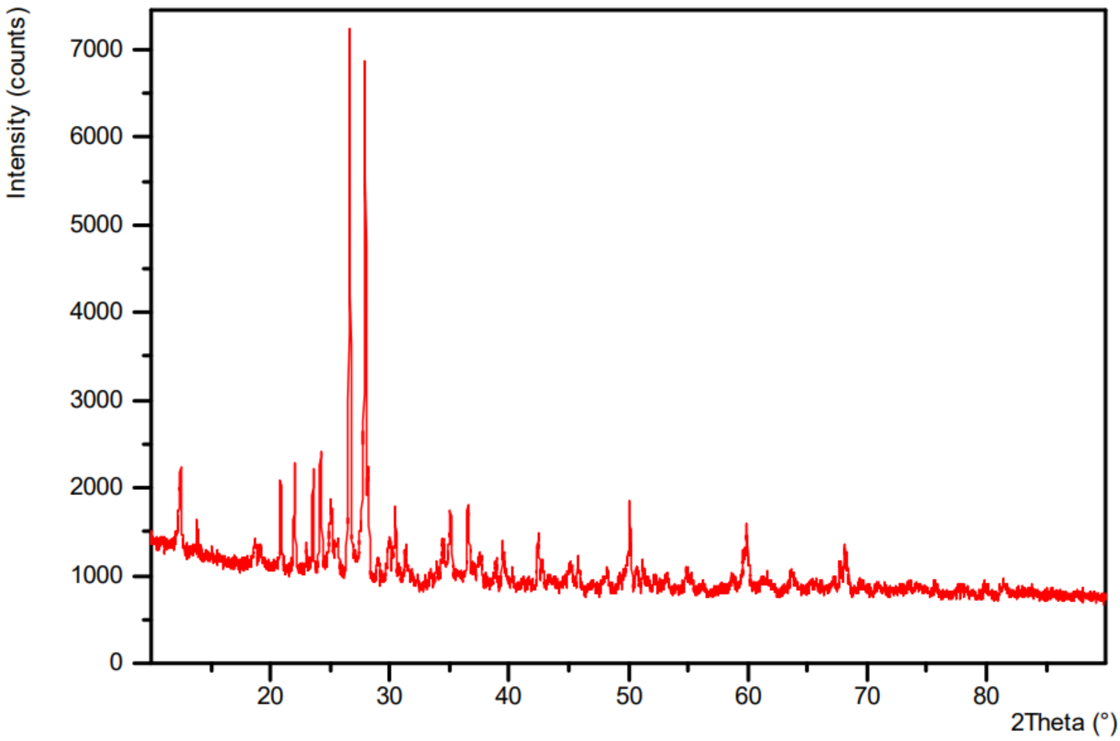

Figure 9. XRD diffractogram pattern of sample UJ-B1

Sample UJ-C1 (2313 m)

Sample UJ-C1 (Figure 3c) shows a crystalline texture that has changed and broken, with an irregular crystal shape. Secondary minerals are observed to develop along microfractures. Some of these secondary minerals have acicular or bladed shapes, which are the shapes crystals assume when they grow from a saturated hydrothermal solution in open spaces.

The elements that make up this sample are very different from each other. This sample has a lot of Iron (Fe) at 22.61% (Figure 10), as well as Oxygen (38.87%), Calcium (16.23%), Silicon (11.37%), and Aluminum (10.92%). This difference is also shown in the XRD results (Figure 11). They indicate that the mineral mix is composed of 63.6% Anorthite and 36.4% Quartz. The calcium-rich end member of the plagioclase series is anorthite (CaAl2Si2O8). It differs from the oligoclase found in the shallower samples. The high levels of Ca and Al are in line with the presence of anorthite. The high Fe content, on the other hand, suggests that there are mafic minerals or iron oxides that XRD can't see (maybe because they aren't very abundant or aren't very crystalline) or that Fe is replacing other minerals in silicate minerals. The diffractogram pattern in Figure 12 shows sharp peaks again, indicating that the crystalline phase remains.

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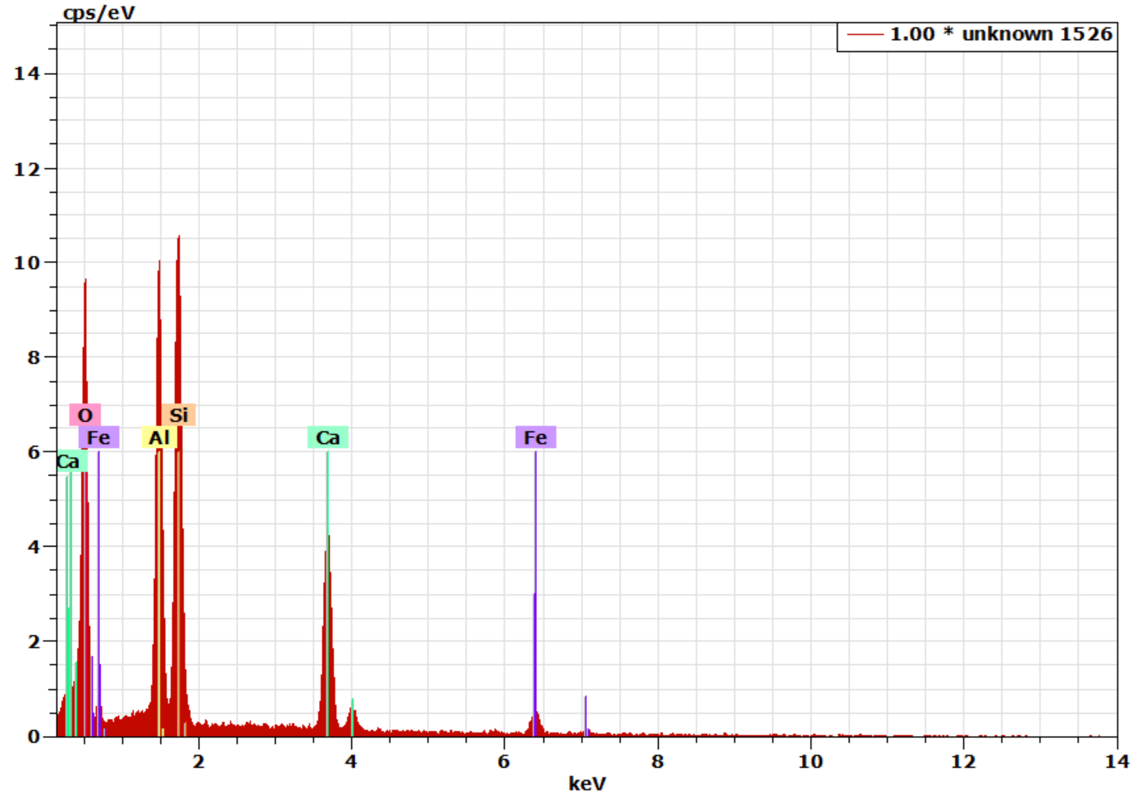

Figure 10. Elemental Content of Sample UJ-C1 from SEM-EDS analysis

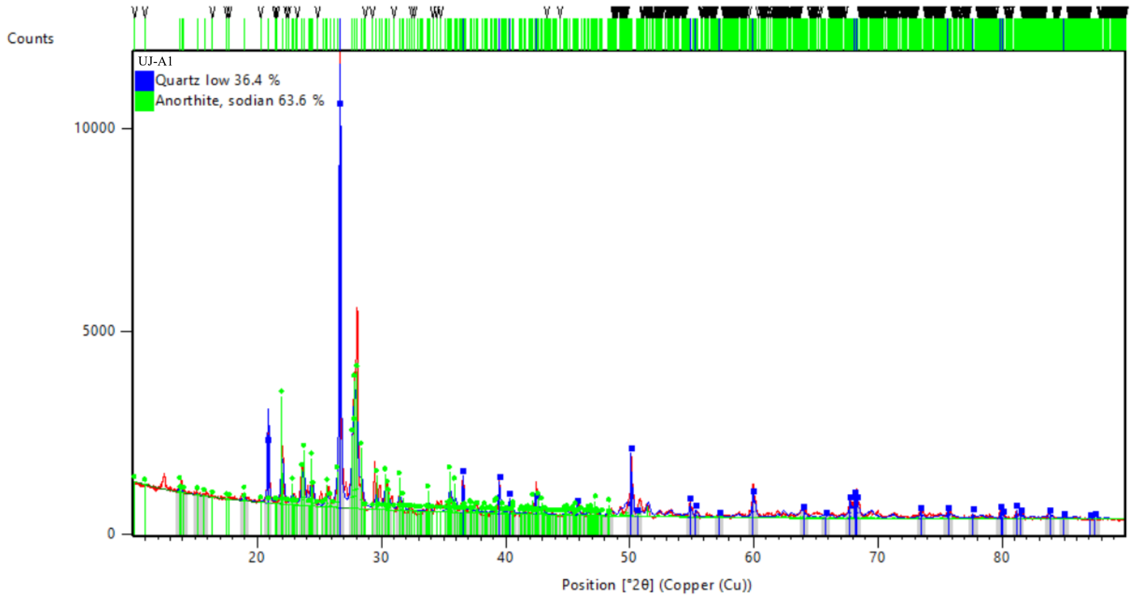

Figure 11.Mineral Content of Sample UJ-C1 from XRD analysis

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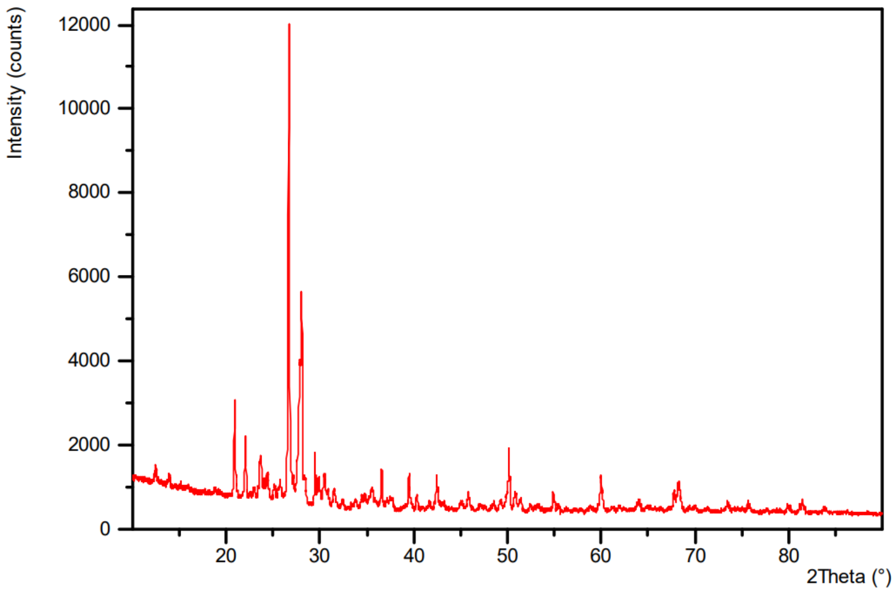

Figure 12. XRD diffractogram pattern of sample UJ-C1

Mineral Assemblages and Alteration Conditions

The mineral assemblages in the three samples, which include secondary feldspars (oligoclase, microcline, and anorthite), quartz, and the absence of primary clay minerals such as smectite or kaolinite, clearly indicate that the rocks in the Rantau Dedap reservoir are located in the propylitic alteration zone. Propylitic alteration is common in the inner parts of geothermal systems with medium to high temperatures. When the temperature is over 220 °C and the pH of the fluid is close to neutral, this happens (Reyes, 1990; Simmons, White and John, 2005). The absence of argillic alteration minerals (clays) indicates that these samples originate from the active reservoir zone rather than the cooler and shallower clay cap zone. The mineralogical succession observed with increasing depth strongly indicates the presence of a temperature gradient within the reservoir.

The Oligoclase-Microcline-Quartz assemblage at a depth of 1840 m (UJ-A1) indicates that the conditions were K-rich propylitic. Microcline (K-feldspar) maintains stability in hydrothermal systems at temperatures ranging from approximately 250 to 400°C, depending on the activity of K+ and H+ ions in the fluid (Giggenbach, 1984; Pandit, 2022). Oligoclase is found with it, which means that Na, Ca, and K are all chemically active in this area.

The fact that microcline is no longer present and Oligoclase is now more common at a depth of 2142 m (UJ-B1) shows that the conditions have changed. This could be because the temperature rises too high for microcline to remain stable in the presence of other reactions, or because the potassium activity in the hydrothermal fluid decreases.

The temperature has increased significantly at a depth of 2313 m (UJ-C1) because the rocks have transitioned from Anorthite to Quartz. Anorthite is the most stable plagioclase member at high temperatures, and it often forms in active geothermal systems where the temperature is above 280–300 °C (Kristmannsdottir, 1979; Bird *et al.*, 1984). Because it is in the deepest sample, well UJ-C1 has likely reached a very hot part of the reservoir, probably near the main upflow zone or a hot fluid conduit.

The iron-rich (Fe) chemical makeup and the fact that anorthite is the main mineral in sample UJ-C1 suggest that its protolith was more mafic (like andesite or dacite) than the likely more felsic protoliths of samples UJ-A1 and UJ-B1 (like rhyolitic tuff). This fits with the stratigraphic model of Rantau Dedap, which shows how silicic tuffs and more intermediate lava flows or intrusions interact with each other (Mussofan *et al.*, 2021). It is not a coincidence that the deepest sample has the highest temperature (as shown by anorthite) and a more mafic protolith (as shown by high Fe). This means that the upflow zone, which is the hottest part of the system, is connected to more mafic igneous intrusions. These intrusions can be dikes and sills. They are

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often the source of heat and the main way for magmatic-hydrothermal fluids to get into the reservoir. So, the anorthite-quartz mineral assemblage with a high Fe geochemical anomaly can be seen as a "fingerprint" of the Rantau Dedap geothermal system's core. This makes it a great way to explore.

Microstructural Implications for Reservoir Permeability

Using SEM to examine the microstructure provides important insights into how reservoir permeability develops. The main breccia texture in sample UJ-A1 and the fractures in the other samples are not just parts of the rock; they are signs of a process called hydrothermal brecciation or hydraulic brecciation. In a tectonically controlled system such as Rantau Dedap, high-pressure hydrothermal fluids ascend from depth through zones of weakness, including faults and fractures (Sibson, 1996)(Sibson, 1996). When the fluid pressure (Pf) is higher than the rock's tensile strength and the minimum lithostatic stress ($\sigma 3$), energy is released in a violent way. This breaks up the rock around it (Sillitoe, 1985; Jébrak, 1997)(Sillitoe, 1985; Jébrak, 1997).

This brecciation process fundamentally generates exceptionally elevated secondary permeability. The rock pieces are angular and not well-sorted, which creates a network of pore spaces that are all interconnected. Geothermal fluids move through these pore spaces (Fanshawe, 1939)(Fanshawe, 1939). The "jigsaw-fit" texture (where pieces can be put back together like a puzzle) and the shattered texture seen in the SEM images are clear signs of this way of making things permeable. The process of changing the material also makes it more porous. The replacement of primary minerals, such as magmatic feldspar, with secondary minerals, such as oligoclase or anorthite, often occurs through a dissolution-reprecipitation mechanism (Putnis, 2009)(Putnis, 2009). Small holes or vugs can form during the dissolution stage. These are a type of secondary porosity. This makes the rock even better at holding and moving liquids. The XRD results are very important because they indicate that there are no clays that swell, such as smectite. Smectite can significantly reduce permeability by occluding pores and fractures (Simmons, White and John, 2005)(Simmons, White and John, 2005). This mineral is not found in the Rantau Dedap reservoir zone, which means that the permeability created by tectonic and hydrothermal processes is preserved.

Context in Indonesian Geothermal Research

The propylitic alteration mineral assemblages identified at Rantau Dedap, consisting of chlorite, epidote, calcite, and secondary quartz, correspond with those recorded from other high-temperature geothermal systems in Indonesia. For example, research at the Tangkuban Perahu geothermal field in West Java (Tubagus et al., 2020) and the Pekasiran geothermal area in Central Java (Robiul et al., 2022)(Robiul et al., 2022) has identified the propylitic zone as a potential reservoir indicator. This suggests that the hydrothermal processes at Rantau Dedap conform to a general framework applicable to geothermal systems associated with volcanic arcs in Indonesia.

Afero, Dear and Husin (2024)Afero, Dear and Husin (2024) examined the Gunung Pancar geothermal field, utilizing the radon method to identify the prevailing fault structure direction as the principal factor influencing permeability. This method emphasizes the same concept found at Rantau Dedap. Similar to the method used at Rantau Dedap, where major structures trending NE-SW and NNW-SSE are known to control the reservoir (Mussofan et al., 2021)(Mussofan et al., 2021), research in other Indonesian geothermal prospects, such as Gunung Pancar, also stresses the need to find the most important fault structures as the main pathways for fluid flow (Afero, Dear and Husin, 2024). This shows a common exploration strategy in the Indonesian archipelago, where permeability affected by tectonics is very important. The Rantau Dedap results are significant in their own right and enhance the overarching narrative regarding regional geology for geothermal exploration.

CONCLUSIONS

A comprehensive mineralogical and microstructural analysis yields several significant conclusions regarding the reservoir characteristics of the Rantau Dedap geothermal system:

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- The reservoir rocks that are between 1840 m and 2313 m deep have mineral groups that have changed at high temperatures. The absence of clay minerals such as smectite or kaolinite in this region indicates that it is situated within the active reservoir rather than the clay cap zone.
- There is a clear mineralogical zonation that goes along with the fact that the temperature rises with depth. The transition from an Oligoclase-Microcline-Quartz assemblage to an Oligoclase-Quartz assemblage, and subsequently to an Anorthite-Quartz assemblage, indicates an intensifying thermal gradient, with temperatures exceeding 280 °C at depths greater than 2300 m.
- The presence of anorthite and a high iron (Fe) content in the deepest sample (UJ-C1) indicates that the principal upflow zone of this geothermal system is associated with the transformation of a more mafic protolith, likely a dike or other intrusion that serves as a conduit for heat and fluids.
- The most common type of rock texture is hydrothermal breccia. It occurs when water pressure fractures rocks along fault lines that are still in motion. This process, along with the formation of secondary porosity through mineral dissolution, is how a geothermal reservoir achieves the high permeability necessary for productivity.

These findings have a significant impact on the conceptual model and exploration strategy at Rantau Dedap. These results provide robust support for a reservoir model characterized by the concentration of hot fluid upflow along significant fault corridors, correlated with deeper mafic lithologies. The mineral assemblage of Anorthite + Quartz ± iron oxide minerals is a reliable indicator of high-temperature production zones in future drilling campaigns. This study demonstrates the effectiveness of an integrated methodology that combines microstructural analysis with conventional mineralogical characterization to achieve a thorough comprehension of complex, structurally controlled geothermal reservoir systems.

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