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Rantau Dedap Geology and Alteration Update

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ABSTRACT

A combination of recent well data from development drilling and exploration wells in Rantau Dedap were used to update the subsurface geology and alteration assemblages. Stratigraphy and alteration analyses were done on individual wells utilizing cuttings, core and log data. Faults were interpreted based on offset lithologies supported by fractures interpreted from borehole image logs. The Rantau Dedap stratigraphy mainly consists of sequences of Quaternary silicic welded tuffs and re-sedimented volcano-sedimentary deposits derived in part from older Tertiary formations, probably forming a complex caldera-fill sequence. The reservoir has a stratigraphic (rather than argillic) cap of Subaqueous Debris Flows, overlain by Quaternary andesitic and silicic volcanics. Hypabyssal intrusions were found at the bottom of deep wells and mainly intruded the lower silicic unit or underlying units, probably as stocks and dike/sill swarms. There are two main fault and fracture orientations, NE-SW and NNW-SSE. These faults exist at depth below ~1,000 masl and are buried by sequences of debris flows and younger stratigraphic units, except a NE-SW collapse structure that offset the lithology up to the surface. Hydrothermal alteration is divided into the following classic geothermal system zones (i.e. Argillic-Transition-Propylitic) with the addition of Phyllic, Potassic/Deuteric and Advanced Argillic zones identified in some wells. Transitional alteration strongly overlaps with a thick volcaniclastic sequence dominated by debris flows and containing a variety of marine sedimentary and igneous clasts in a mud to silt matrix. The Transition top corresponds with the 10 to 20 ohm-m isosurface based on resistivity models. Both rock type and fluid composition appear to influence the relative abundance of alteration assemblages. Potassic-deuteric alteration is found in and near granitic intrusions, whereas Phyllic alteration overlies intrusions. Advanced argillic alteration was found in the upper-part of dike swarms. The currently productive reservoir in Rantau Dedap, which is dominated by a phyllic overprint of propylitic alteration is interpreted to be controlled by a combination of structures and stratigraphy. Late prehnite, wairakite, calcite and anhydrite partially fill open space in veins.

1. INTRODUCTION

The Rantau Dedap geothermal field is located in Lahat and Muara Enim district about 200 km SW of Palembang, the capital city of South Sumatra Province (**Figure 1**). The field is situated in the Bukit Barisan mountain about 35 km SW of an active Mt. Dempo and having offset approximately 15 km northeast from the Great Sumatra Fault (GSF). The concession area covers Semendo Caldera complex that having 13-19 km rim diameter and some smaller arcuate and circular structure interpreted as inner-caldera collapse or primordial eruptive impression. Resurgence volcanism results intra-caldera volcanoes i.e. Mt. Bukit Besar – Anak Gunung that have relative west-east trend of fissure eruption centers. The main geothermal system in Rantau Dedap having the upflow at SW part of field correlates with intrusion complex below Mt. Bukit Besar satellite vents and the outflow toward the NE with thermal manifestations including fumaroles, hotsprings, and kaipohan discharges mainly at the arcuate structure further to the north. This field potentially have another system associated with these vents as recognized at Mt. Anak Gunung fumaroles and its northern discharges.

PT Supreme Energy Rantau Dedap was assigned to conduct pre-feasibility studies including geology, geochemistry, geophysics and geotechnical survey in 2008. The tender award and mining licence of the Rantau Dedap concession was issued in late 2010, and power purchase agreement in 2012. Wells in Rantau Dedap have been drilled from pads with elevations ranging from 1700 to 2600 meters above sea level (masl). An exploration drilling campaign was executed in 2014-2015 with six exploration wells drilled from three well pads (B, C, and I). A development drilling campaign was conducted in 2019 with additional well pads (M, N, L, and E).

Several authors have briefly discussed the geology and alteration in the Rantau Dedap field. Mussofan et al. (2019) emphasized the thick silicic sequence identified in wells drilled in Rantau Dedap and other geothermal fields in Sumatara, also the correlation with permeability within the reservoirs. Permana et al. (2018) discussed and compared Rantau Dedap field with Muara Laboh based on the proximity to the Great Sumatran Fault (GSF). White and Dyaksa (2015) identified the occurrence of relic epidote based on surface samples and was compared with epidote identified in exploration drilling cuttings. Santana et al. (2013) showed the dominant NE-SW, NW-SE and N-S structure trends based on surface data taken prior exploration drilling. This paper summarizes results from the exploration and development drilling campaigns. We present an update of the geological work to reconstruct the subsurface geology of Rantau Dedap including stratigraphy, structure, and hydrothermal alteration to better understanding geologic control on geothermal systems in Sumatra.

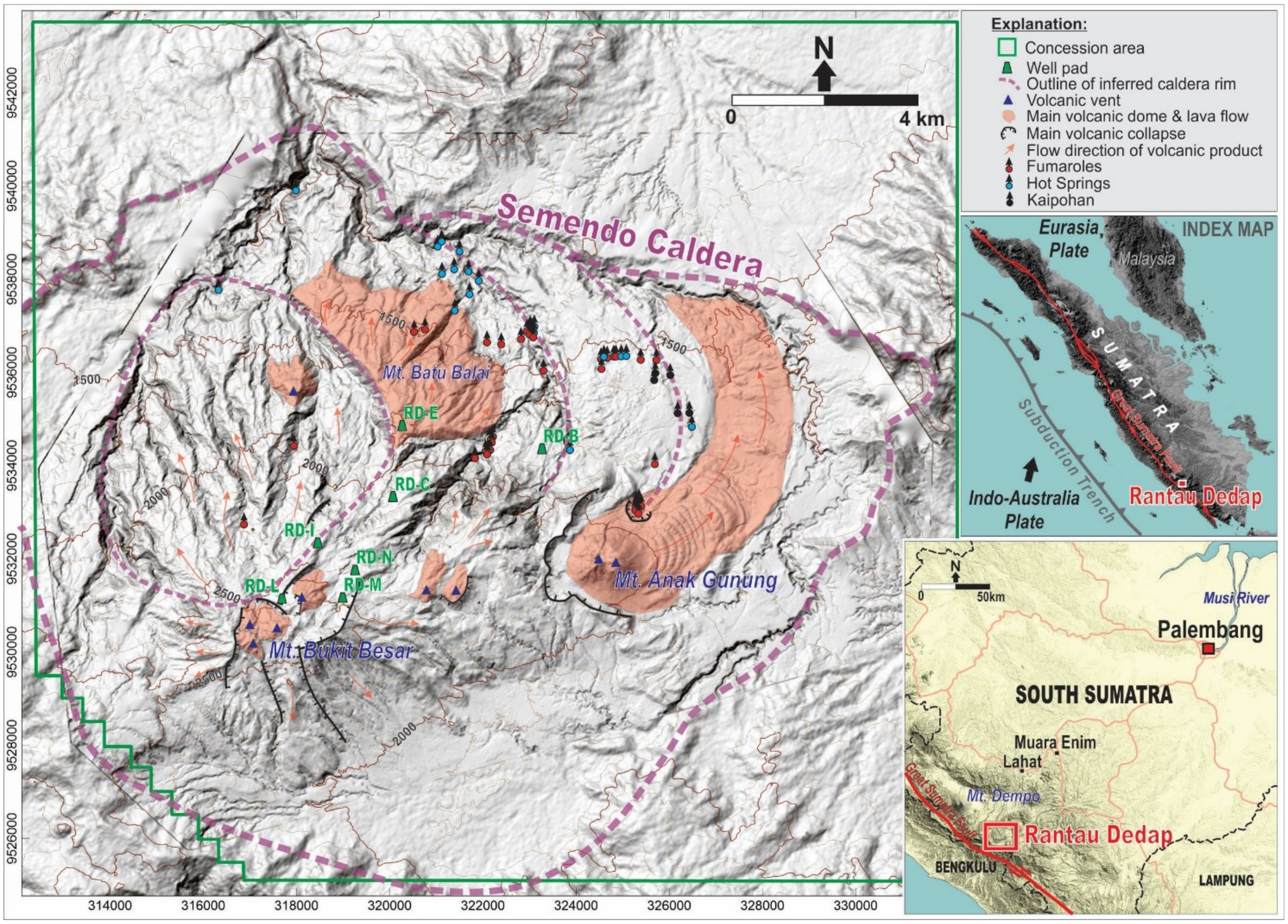

Figure 1:. The compilation of DEM and LiDAR topography of Rantau Dedap field. The concession boundary, well pads, thermal features, and the main topographic features of the area are depicted. Inset shows the location of Rantau Dedap in southern Sumatra.

2. DATA AND METHODOLOGY

The subsurface stratigraphic units in Rantau Dedap were recognized by using geologic data integration in a stratigraphic log. This stratigraphic log incorporated well geology, drilling, and logging data sets including cutting and core description, Methylene Blue (MeB) and petrography analysis, mechanical specific energy (MSE), drilling breaks, XRMI Image and gamma ray (GR) logs, feed zones locations, and well temperature profiles (Mussofan et al., 2019). All of this data integration was used to define the stratigraphic unit characteristics and contacts.

Petrography was used to constrain hydrothermal alteration assemblages and vein filling sequences, and was related to well temperatures, lithology, structure, feed zones, and other permeability indicators from logs. Additionally the distribution of argillic alteration was compared to interpreted clay from geophysical resistivity (MT) and MEB analysis of cuttings at the wellsite. XRD data were available for relatively few samples.

2D geology and alteration cross section was generated by plotting the stratigraphic unit contacts and alteration zonations. The subsurface stratigraphy, structure and alteration zonation were reconstructed by well-to-well correlation in this cross section.

3. RANTAU DEDAP STRATIGRAPHY AND STRUCTURE

3.1 Well Stratigraphic Units

The succession of informal stratigraphic units in Rantau Dedap is summarized in **Figure 2**. The oldest stratigraphic unit is one or more Tertiary silicic intrusion found at the bottom of deep wells at about 2400-2600 mMD. Lithic fragments of intrusive rocks are also abundant in the ash-flow tuff sequence and as clasts in the Debris Flow unit (**Figure 3**). The rocks are recognized as intrusive based on their fine-grained intergrowths of plagioclase, alkali feldspar and quartz in the groundmass, commonly with myrmekitic textures. Plagioclase and possibly alkali feldspar were present as phenocrysts. Biotite is also recognizable in some cases, but most mafic minerals have been completely replaced. The granites intruded older highly altered volcanic below the Lower Rhyolite Tuff unit. A variety of other silicic to intermediate subvolcanic intrusions related to the Quaternary volcanic section are also found in deep wells, as discussed below.

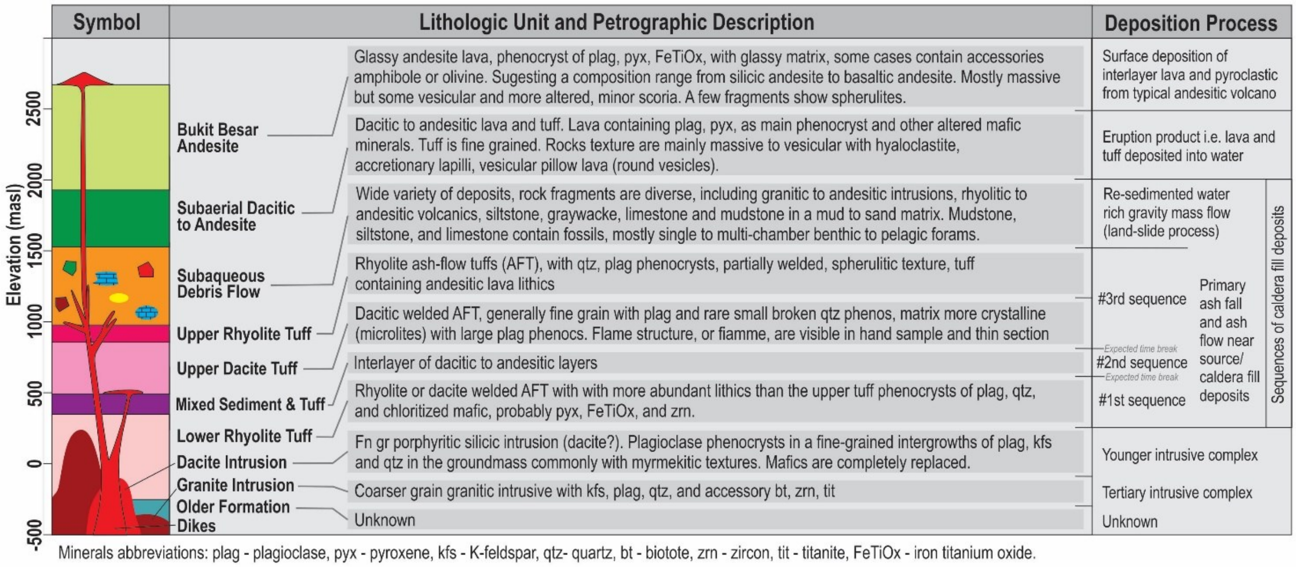

Figure 2: Stratigraphic column that describes the informal units defined from Rantau Dedap wells.

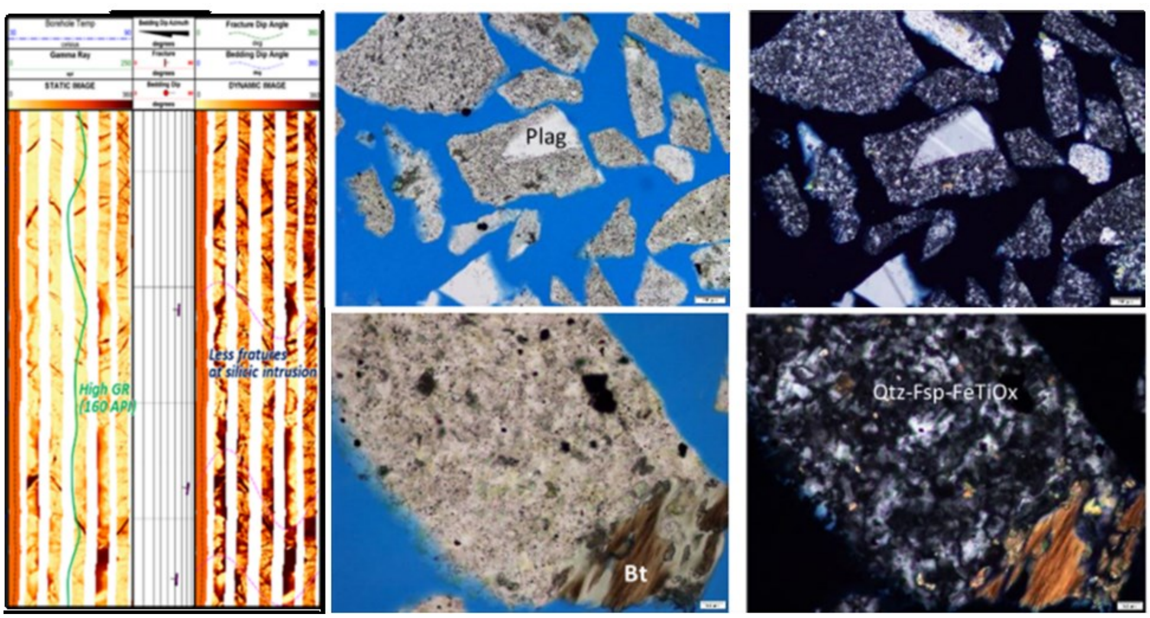

Figure 3: An example of fine grain silicic intrusion identified in RD-I3 (modified from Mussofan et.al, 2019). Parallel nicols at left and cross polarized at right. Mineral abbreviations: Plag, plagioclase, qtz, quartz, Fsp, feldspar, FeTiOx, iron titanium oxides, bt, biotite.

This Tertiary rock package is overlain by sequences of Quaternary, dominantly silicic volcanic products (**Figure 4**) that include the Lower Rhyolite Tuff, Mixed Sediment and Tuff (mainly dacitic in composition), and Upper Dacite and Upper Rhyolite Tuffs. Together these units probably comprise multiple eruptive cycles representing caldera fill. The main characteristic of Lower Rhyolite Tuff unit is its high degree of welding (**Figure 4**). The thickest of the silicic formations, this unit probably represents a major caldera eruption. Wells drilled below the top contact of this units at elevations of ~300-400 masl have very limited permeability and conductive temperature profiles. The mixed sediment and tuff unit is composed of interlayering between volcaniclastic sediment and dacitic tuff and is characterized by a fluctuating gamma ray (GR) profile. The Upper Dacite and Rhyolite Tuff units are highly welded and XRMI data shows high fracture intensity (Mussofan et al., 2019).

The Subaqueous Debris Flow unit overlies the sequences of the silicic tuff units. Image logs and petrography show the unit has a fragmental texture (breccia/conglomerate) with a muddy matrix altered to a transitional mineral assemblage (**Figure 5**). Rock fragments are diverse, including granitic to andesitic intrusions, rhyolitic to andesitic volcanics, siltstone, graywacke, limestone and mudstone. Mudstone, siltstone, and limestone contain fossils, mostly single to multi-chamber benthic to pelagic forams. Most or the igneous rocks show signs of hydrothermal alteration that predates their sedimentation (White and Dyaksa, 2015). This unit correlates with conductive temperatures and likely forms a stratigraphically controlled non-smectite reservoir cap at the current time.

The next eruptive episodes resulted in Subaerial Dacite to Andesite units overlying the Debris Flow unit. The top of this unit correlates well with the top of transition alteration zone (discuss in detail below). The top of stratigraphic section is dominated by Bukit Besar Andesite in the main productive area in the southwestern concession. This unit correlates with high MT conductive layer and hosts smectite-rich argillic alteration zone. Further to the north and east this unit interfingers with and is overlain by more silicic eruptions of Batu Balai and Anak Gunung (Stimac and Mussofan, 2019) (**Figure 6**).

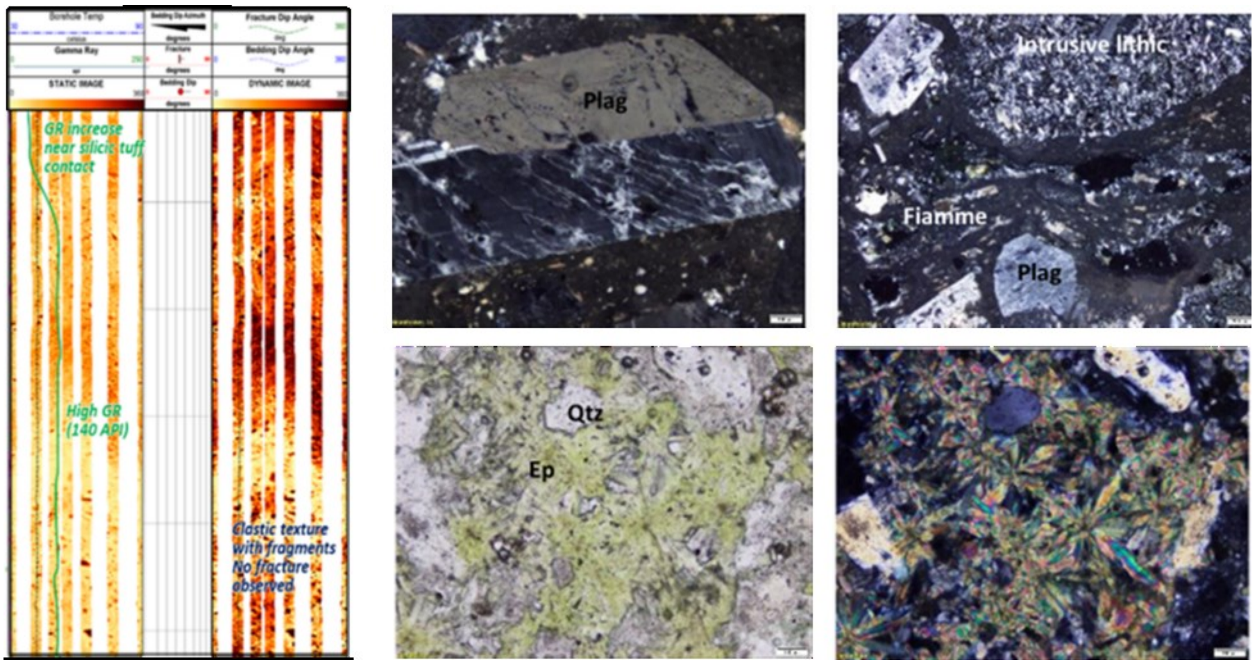

Figure 4: An example image log (left) and thin section of Lower Silicic (Rhyolite-Dacitic) Tuff unit (right) from RD-I1 (Modified from Mussofan et al., 2019). Petrographic analysis showed high degree of welding (right top), while figures below indicated propylitic alteration (right bottom). Parallel nicols at left and cross polarized at right. Mineral abbreviations: ep, epidote, qtz, quartz, plag, plagioclase.

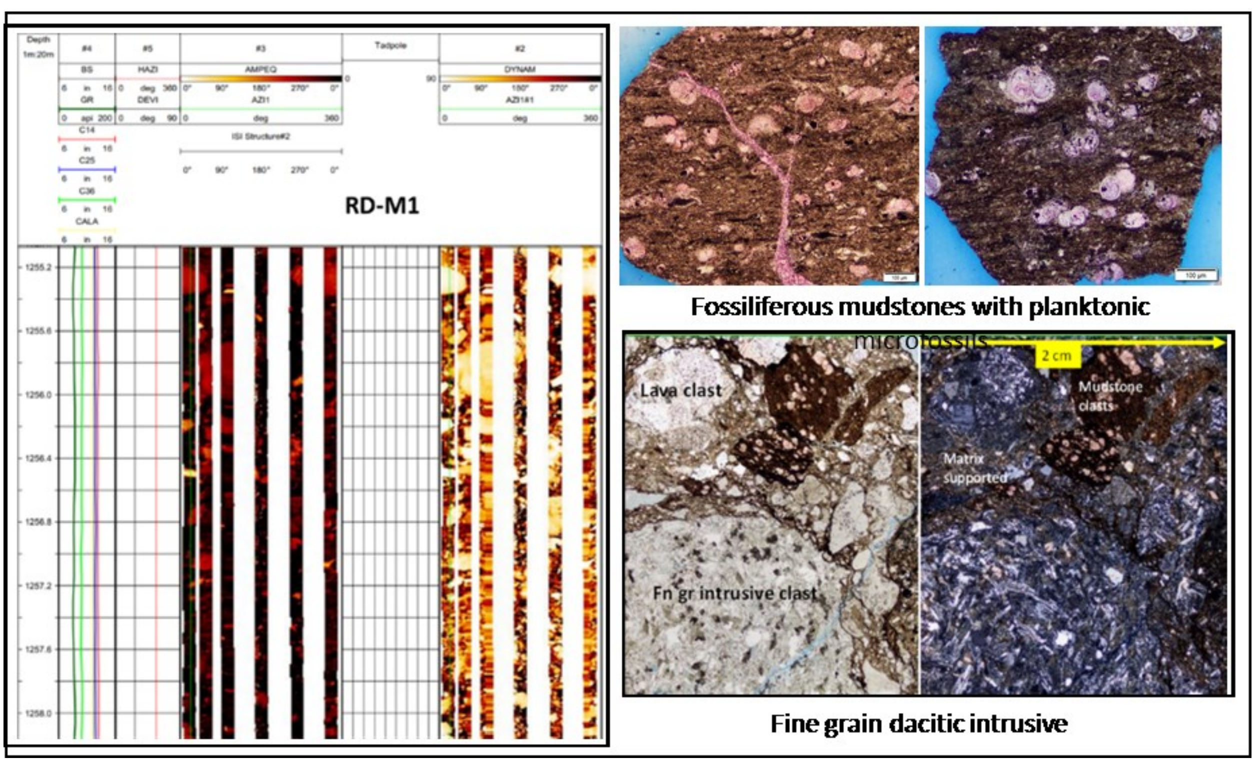

Figure 5: An example of Subaqueous Debris Flow unit from borehole image log (left) and petrography analysis (right). Parallel nicols at left and cross polarized at right.

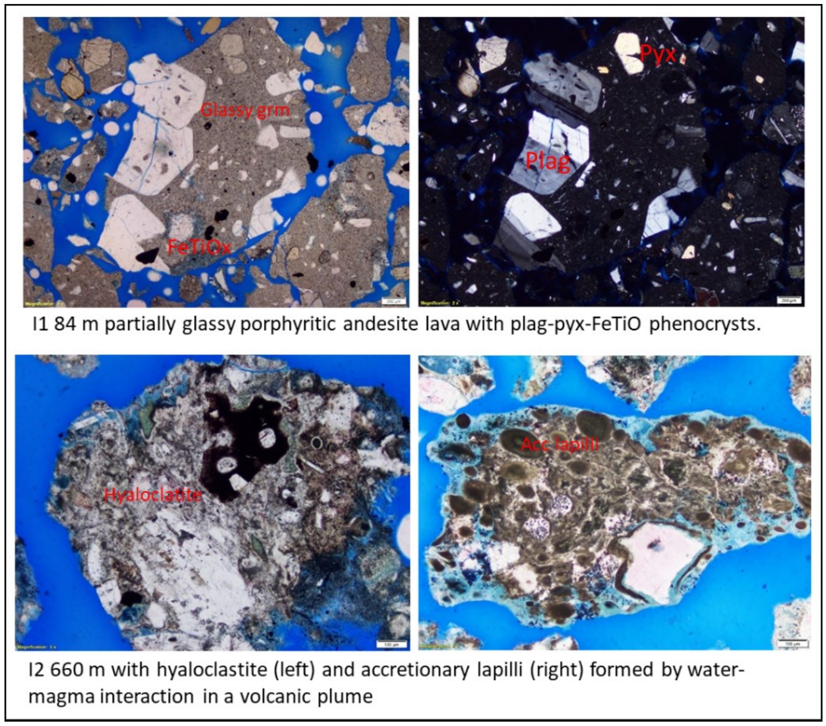

Figure 6: An example of Bukit Besar Andesite (top) and Subaqueous Dacite to Andesite (bottom) petrography analysis. Parallel nicols at left and cross polarized at right. Mineral abbreviations: plag, plagioclase, pyx, pyroxene.

3.2 2D Geologic Cross Sections and Subsurface Structure

Series of NW-SE geologic cross sections were generated across the SW, central, and NE of Rantau Dedap field respectively labeled with A-A’, B-B’, and C-C’(**Figure 7 and 8a, b, c**). These sections were generated perpendicular to the major NE-SW structure direction. An additional NE-SW section (D-D’) was generated to illustrate the general flow direction of the system along this structural grain (**Figure 8d**). All the sections show the granitic rocks intruded the older rocks of likely Tertiary age. These granites and older host rocks are overlain by a series of Quaternary silicic volcanic sequences, i.e., the Lower Rhyolitic Tuff, Mixed Sediment and Tuff, Upper Dacite and Rhyolite Tuff units.

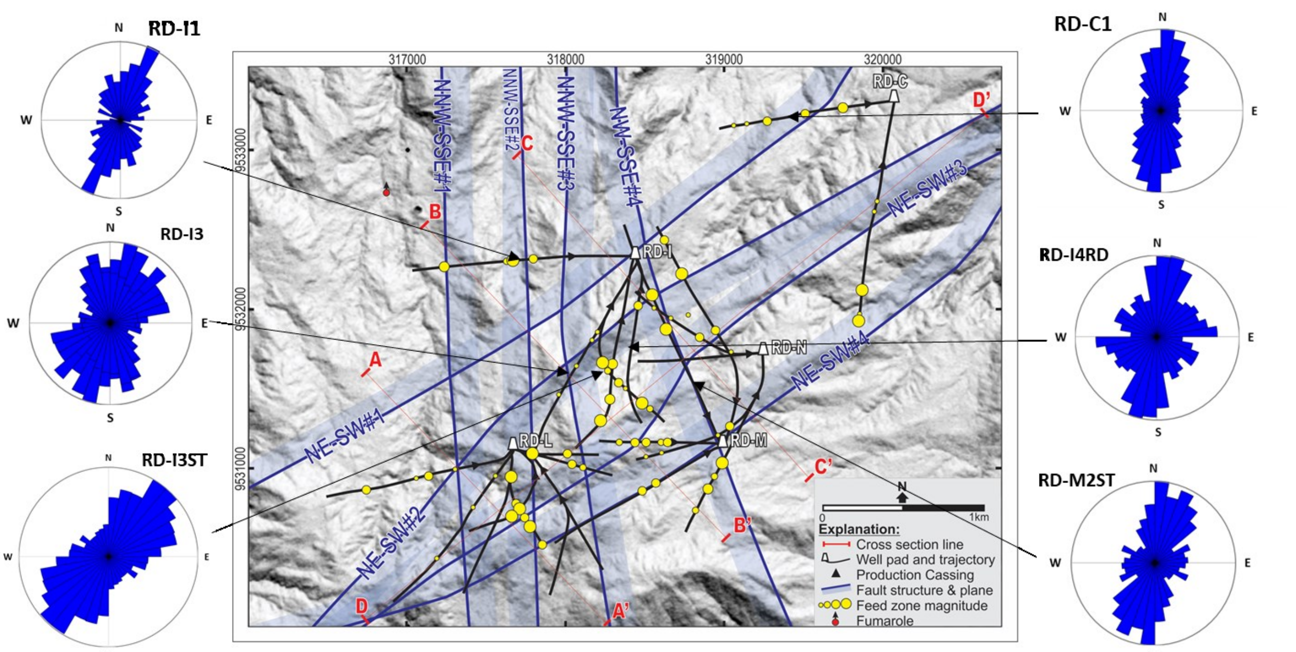

Figure 7: Surface map view showing deep fault structures, well pads and trajectories, and cross section lines. Rose diagram are showing the fracture orientations from image logs. Feed zones and their magnitudes are shown by the size of yellow circles.

Significant stratigraphic offset on a series of mostly normal faults was found within these silicic volcanic sequences (**Figure 8a,b,c**). NE-SW#2 and NE-SW#3 has the opposite dip direction and generated a graben structure. This graben provides a narrow corridor at the SW and NE Rantau Dedap sector (section A-A’ and C-C’) but widens in the central sector (section B-B’). Another fault offset was found further to the southeastern part of the section identified as NE-SW#4. This fault generated stepping to higher block at the southeastern of the field. No significant offset of the shallower stratigraphic units implies that these deep fault structures exist below ~1000 masl, and mostly predate near surface units. Toward the northwest of the sections, NE-SW#1 was interpreted based on surface expression on LiDAR and surface structure data indicating a significant collapse structure extending to the surface. Another NW-SE fault set was found within section D-D’. These faults are interpreted dipping between 85 to 90 degrees as shown in **Figure 7**.

Lithologic offsets indicate a horst and graben structure between NNW-SSE#1, 2, 3 and 4 NNW-SSE trending structures. These structures accommodated dike intrusion rising into shallower level and intruded into Subaqueous Debris Flow and up to the surface, generating volcanic domes. Image log fractures support the interpretation of these subsurface structures. Pad-I wells mainly oriented to the NE-SW as the major direction, and NNW-SSE as a secondary direction. The same fracture orientations are found at RD-M2 (**Figure 7**). This fracture orientation supports the NE-SW and NNW-SSE deep structure orientation.

Isothermal temperature from well data shows that temperatures reach 300˚C within the intrusive body below Pads L and I. More convective isothermal temperature and major entry points indicating the main reservoir in Rantau Dedap are hosted at the silicic volcanic sequences including the Mixed Sediment and Tuff, Upper Dacite and Rhyolite Tuff units and intersection of series of NE-SW and NNW-SSE faults. Specifically, NE-SW cross sections A-A’, B-B’, and C-C’ show convective isothermal temperature and major feed zones also found associated with fault NE-SW#3. Section D-D’ showing two potential upwellings within graben structures below Pad-L and Pad-M, while the outflow tongue moves laterally toward the Pad-C area may be controlled by permeability within the Upper Rhyolite Tuff unit.

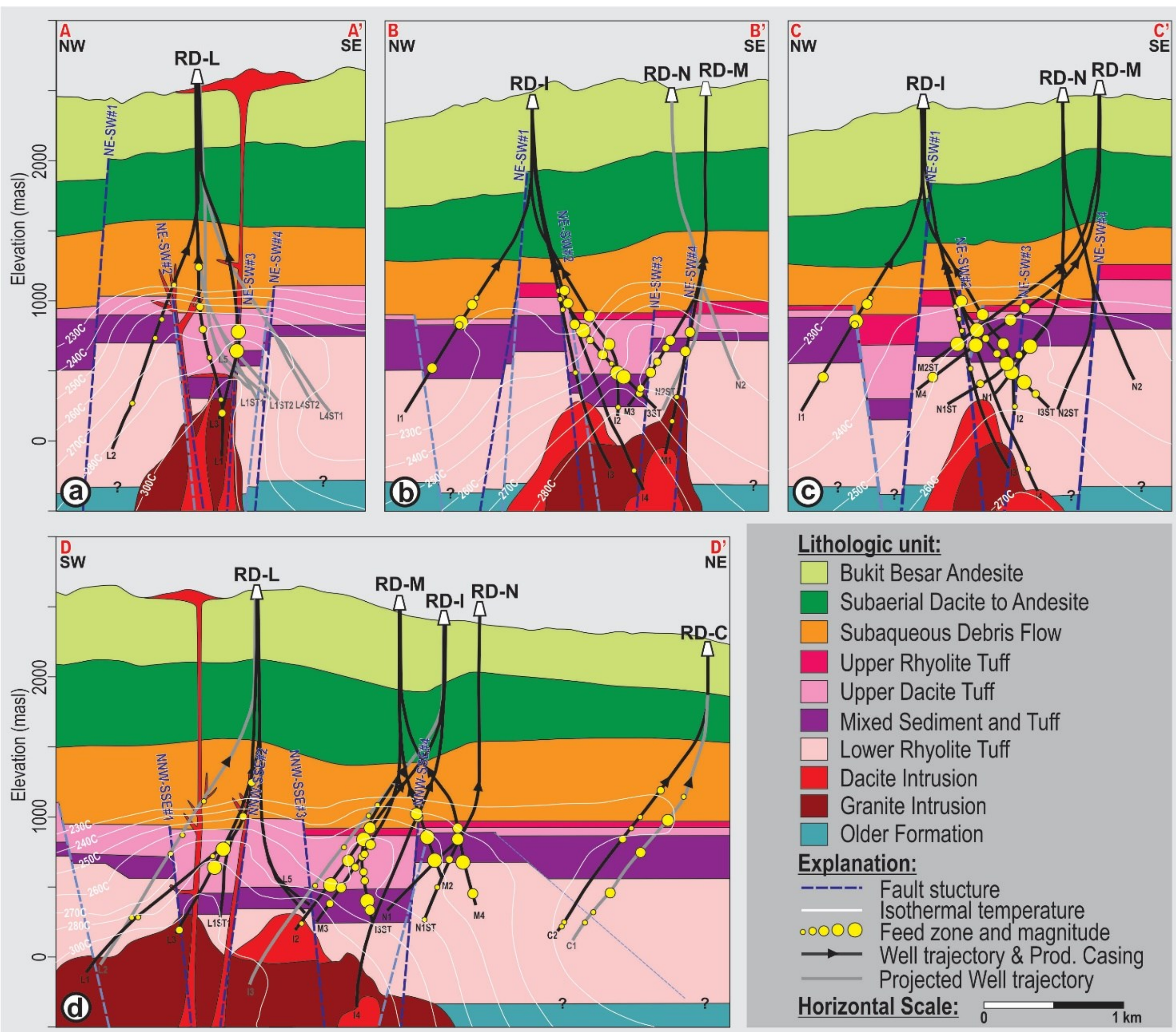

Figure 8: Geologic cross sections A-A’, B-B’, C-C’, and D-D’. Isothermal temperature contours and feed zone location are shows by white dash lines and yellow circles. Section line refer to Figure 7.

4. RANTAU DEDAP ALTERATION

4.1 Well Coverage

A total of 287 thin sections of cuttings and core were examined from 21 well penetrations spanning the main development area. A total of 39 thin sections of surface samples representing major volcanic units were also examined. Of the wells, five from the B, C, and E pads penetrated shallow outflow not considered part of the production area due to temperature considerations (T<220°C). The remaining wells drilled on the L, M, N, and I pads define the production area. Within this area all wells encountered total losses in the reservoir interval except RD-I3OH. Thus coverage of the alteration zonation is skewed toward capping formations and the upper part of the reservoir. However core and log data available from seven wells helps constrain the distribution of alteration in the deeper reservoir.

4.2 Definition of Alteration Assemblages

For the purposes of this study, hydrothermal alteration is divided into the following zones:

1) Argillic (smectite-zeolite-calcite-chalcedony) formed mostly at T<180°C;
2) Transition (mixed layer clays [Ill-Sm- Chl-Sm]-chlorite-zeolite-calcite-quartz) formed at T of 180-220°C;
3) Propylitic (epidote>>illite-chlorite-pyrite-quartz) formed at T>220°C;
4) Phyllic (illite/sericite-quartz-pyrite ± anhydrite) formed at T>220°C; and
5) Potassic/Deuteric (biotite ± k-feldspar ± amphibole ± pyrite ± magnetite ± anhydrite) formed at T>370°C
6) Advance Argillic (combinations of alunite-kaolinite-anhydrite-pyrite-quartz-diaspore-pyrophyllite) formed at a range in temperature.

4.2.1 Argillic Zone

The argillic zone is dominated by conversion of glassy material and susceptible minerals to smectite clay at low temperature by tropical weathering and hydrothermal alteration at T<180°C primarily by bicarbonate and sulfate-rich steam heated groundwaters. The base of the argillic zone corresponds well with the 10 to 20 ohm-m isosurface based on resistivity models (**Figure 9**). MEB analysis of cuttings at the wellsite has values >10 in the argillic zone, and commonly 20-35.

4.2.2 Transition Zone

The transition zone is dominated by mixed-layer clays and chlorite, along with a variety of accessory minerals most likely formed at T of 180-220°C. Zeolites including laumontite are also common. Other minerals occurring in this zone include calcite, quartz, anhydrite, titanite and rutile. Transitional alteration strongly overlaps with a thick volcaniclastic sequence dominated by debris flows and containing a variety of marine sedimentary and igneous clasts in a mud to silt matrix. Some of the propylitic alteration in this unit is found only in igneous clasts that comprise a significant component of some sedimentary layers and is clearly relict (White and Dyaksa, 2015). Because of this, it is difficult to precisely define the transition zone-propylitic zone boundary as related to the current geothermal system. The top of the transition zone corresponds with the 10 to 20 ohm-m isosurface based on resistivity models (**Figure 9**), and its base aligns less closely with a specific isosurface, commonly ranging from 30 to >100 ohm-m. MEB values ranging from about 6-10 are typical of the transition zone, but occasional higher values suggest some intervals of higher smectite content.

4.2.3 Propylitic Zone

The propylitic zone is defined by the occurrence of epidote in veins and vug fillings that appears to have formed from recent or current hydrothermal activity. Commonly associated minerals include adularia, quartz, calcite, chlorite, wairakite, prehnite, and pyrite. This alteration typical forms at T>220°C. Higher temperature propylitic alteration includes amphibole and rare garnet, indicating formation temperatures of 280°C or more. MEB values range are <6, and mostly commonly <3.

4.2.4 Phyllic Zone

Since illite forms at about the same temperature as epidote and overlap of illite and epidote-dominated alteration is common in geothermal systems, distinguishing phyllic and propylitic alteration is not always attempted. Since illite-dominated alteration is very common in the higher temperature parts of the reservoir at Rantau Dedap, we define the propylitic zone as dominated by epidote, and the phyllic zone as dominated by illite (or more commonly coarser grained sericite), with minor (usually overprinted) epidote, or no epidote. Both rock type and fluid composition appear to influence the relative abundance of these and commonly associated minerals.

In general, illite/sericite is more abundant in silicic rocks, whereas epidote is more abundant in intermediate to mafic rocks. But occurrence of illite/sericite accompanied by abundant quartz, pyrite and abundant anhydrite is widespread in all rock types and appears to be a function primarily of fluid composition. The abundance of sulfur-bearing minerals, and the sporadic association of advanced argillic alteration, indicates that a relatively low pH fluid is responsible for this phyllic alteration. Essentially, higher activity of K^+ and H^+ in the fluid both favor formation of illite/sericite over calc-silicate minerals. The prevalence of phyllic alteration in areas of proven shallow intrusion is consistent with this alteration forming in response to their cooling and related proximal fluid circulation. However, in some cases late anhydrite veins may be related to later circulation and descent of cooler fluids through these intervals. This type of alteration may be favored in heat pipe or vapor core systems where drainback of steam condensate is an important contributor to fluid composition.

4.2.5 Advanced Argillic Zone

Advanced argillic alteration forms at a wide range of temperature from low pH fluid. At lower temperature alunite and kaolinite tend to dominate, whereas at higher temperatures pyrophyllite and diaspore are more important. Both types of alteration are present in relatively isolated intervals at Rantau Dedap. Narrow intervals of shallow advanced argillic alteration are present in L and I pad wells, whereas deeper advanced argillic alteration is most pronounced in the well L2 (**Figure 9**).

4.2.6 Potassic Zone

Potassic/Deuteric consists of biotite ± k-feldspar ± amphibole ± pyrite ± magnetite ± anhydrite formed at T>370°C. The term "deuteric" is restricted to reactions involving changes in primary mineral phases during the process of magmatic crystallization. The agent of deuterism is the volatile material dissolved in the magma. Deuteric alteration implies limited circulation of meteoric water exsolved magmatic fluid in the solidus and subsolidus temperature range of the magma. This alteration is only observed in core and cuttings from two deep wells (I3OH and L1).

4.3 Distribution of Assemblages

The dominant alteration assemblage, qualitative mineral abundances and vein filling sequences were documented for each thin section. This data was compiled and plotted in a series of 2D sections (**Figure 9**).

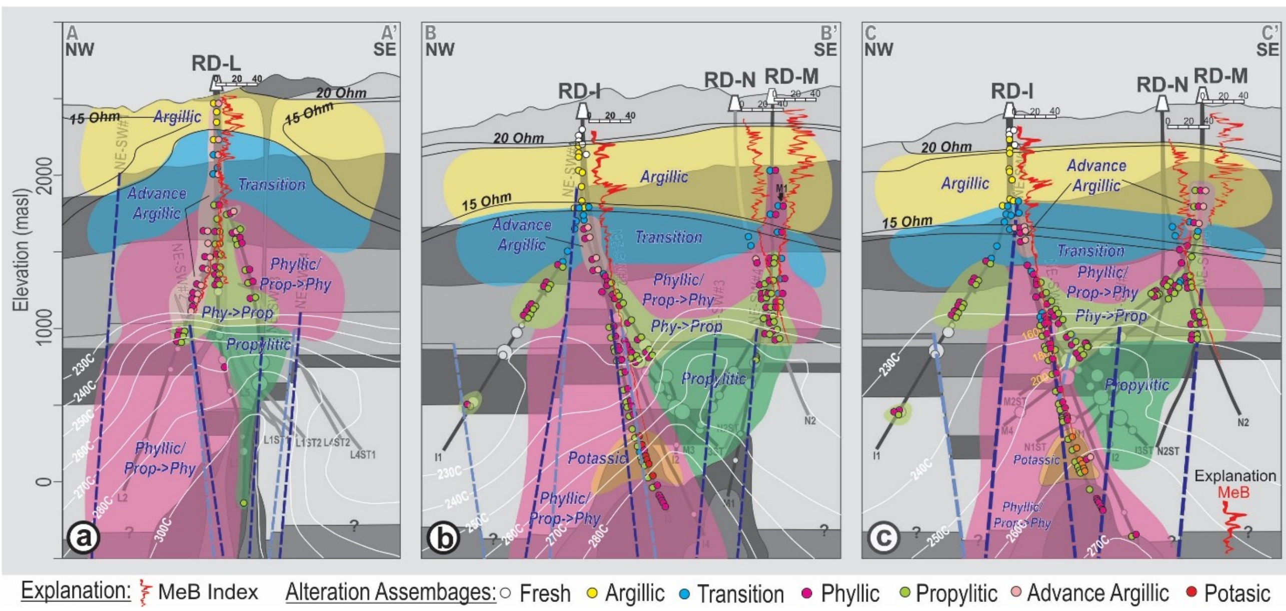

Figure 9: Alteration cross sections A-A', B-B', C-C'. Section line and background geology respectively refer to Figure 7 and 8.

4.3.1 Section A (Western Reservoir/Pad L)

It can be seen in Section A-A' that well defined argillic and transition zone alteration is present at Rantau Dedap at Pad L, but that the reservoir top, as defined by the current 240°C isotherm, lies well below the depth of overlapping propylitic and phyllic alteration. Moreover phyllic alteration (Ill/Ser>>Ep) dominates over propylitic alteration (Ep>>Ill/Ser). Advanced argillic alteration is also present sporadically within the transition zone and propylitic zone, especially in wells L1 and L2. This area has relatively limited permeability and may represent a declining heat pipe or vapor core system above young intrusion, that in part overprinted an older and more established convective system as indicated by phyllic overprinting propylitic alteration.

4.3.2 B (Central Reservoir/Pad I-M-N) and Section C (Central Reservoir/Pad I-M-N)

It can be seen in Section B-B' and C-C' that there is a larger area of propylitic alteration compared to A-A', although phyllic alteration or phyllic alteration overprinting propylitic alteration is more widely distributed. In these sections, there is a relatively sharp vertical contact between phyllic alteration to the northwest and propylitic alteration to the southeast in the I pad area that may be fault controlled. The propylitic zones lies largely within the silicic volcanic sequence, composed mostly of welded ash-flow tuffs. The rocks are relatively altered and infilled by hydrothermal minerals and may be prone to brittle fracture. Some tuffs show evidence of dissolution of primary plagioclase with replacement by albite and adularia. This secondary porosity may enhance the overall permeability of these rocks.

4.4 Paragenetic Relationships

Core samples provide the clearest examples of vein paragenesis at Rantau Dedap. Examples of mineralogical relationships from core petrography that indicate the current state and recent evolution of the system include:

- I3 2333 m MD: Vuggy veins and hydrothermal breccia cutting welded ash-flow tuff have a complex history of Ep-Ad=> Qtz-Ep (breccia cement)=>Wai=>Cc. Sealed veins indicates current low permeability, possible downflow of steam condensate (Wai), followed by steam-heated bicarbonate waters (Cc).

- I4RD 1625 m MD: No obvious veins but significant open space in partially dissolved plagioclase phenocrysts, with epidote ±quartz as infillings.

- I4RD 3008-3012 m MD: Fined-grained dacite porphyry intrusion with propylitic alteration and some minor open space due to plag dissolution. Little open space indicates low permeability in relatively young intrusive rocks.

- L1 1900 m MD: Strongly replaced tuff or sediment with both propylitic and advanced argillic/silicic alteration and replacement by minerals such as pyrophyllite and diaspore. Overall indicates a more magmatic-HT system and possible hot and tight conditions.

- M2ST 1904-1909 m MD (illustrated in **Figure-10**): Complicated vuggy veins and HT breccias cutting ash-flow tuff with multiple generations of Ad-Ep=>Wai-Qtz=>Preh-Anhy. Most open space indicates near-fault/upflow environment with changing conditions to the present. Current conditions (Preh-Anhy, Anhy) suggest some cooling from peak temperatures where epidote was first precipitated.

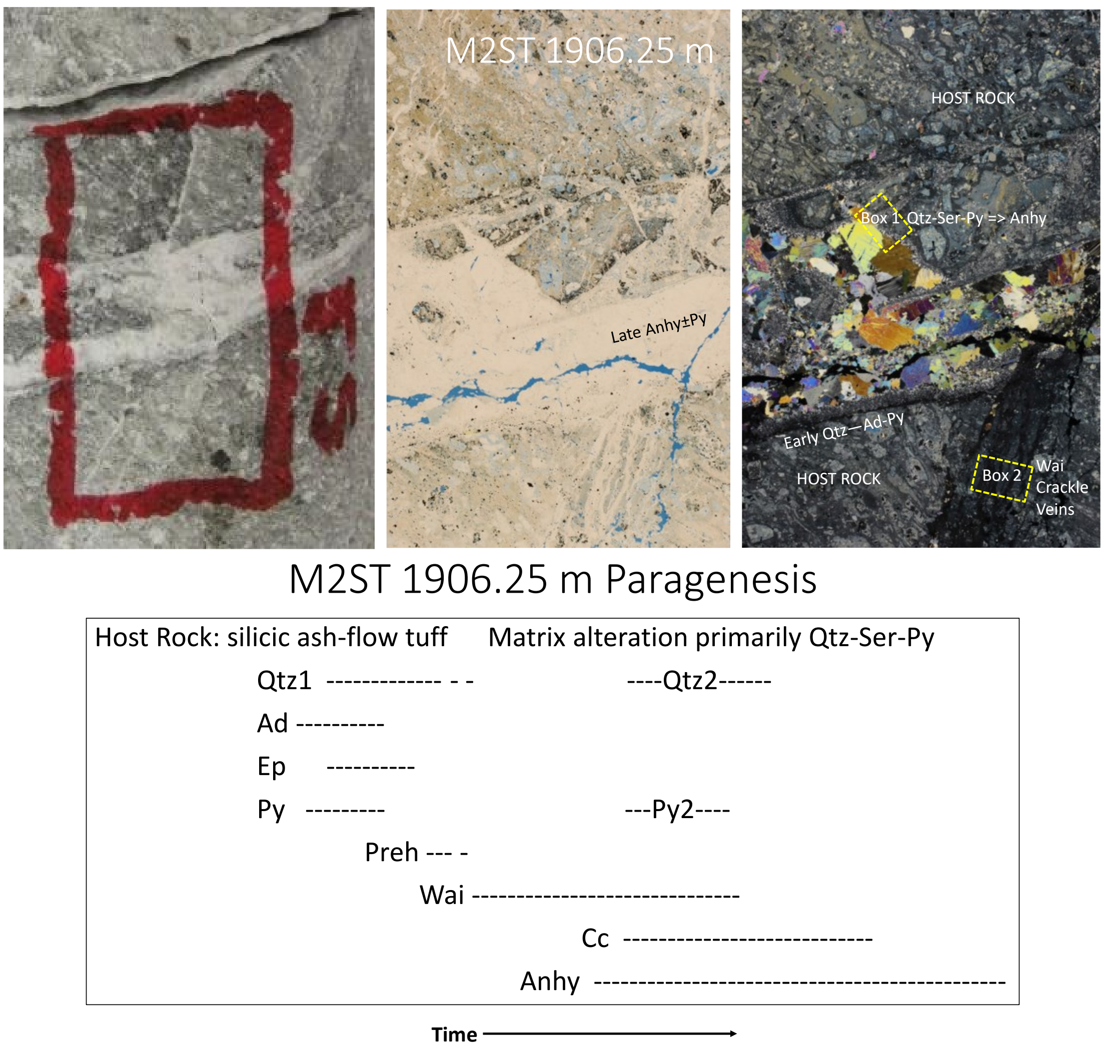

Figure 10: RD-M2ST 1906.25 m core sample (top left) and thin section (top middle, plane polarized light, and right, cross polarized light) showing a complex paragenesis illustrated diagrammatically (bottom). Relatively late hydrothermal breccias have a matrix of wairakite and prehnite. The rock is cut by later anhydrite-rich veins. Mineral abbreviations include ser, sericite, qtz, quartz, ad, adularia, ep, epidote, py, pyrite, preh, prehnite, wai, wairakite, cc, calcite, and anhy, anhydrite.

5. CONCLUSION

Stratigraphic features show that Rantau Dedap is hosted by a thick volcanic rock sequence. At the bottom part of drilled wells some intrusives were found including granitic and fine-grain dacitic types. This Intrusive complex is interpreted as providing the geothermal heat source in Rantau Dedap. The main reservoir in Rantau Dedap is hosted by a sequence of silicic volcanics including the Lower Rhyolite Tuff, Mixed Sediment and Tuff , Upper Dacite Tuff, and Upper Rhyolite Tuff units. These units are recognized as near source caldera fill deposits, products of primary fallout and ash-flow tuff (AFT) and interbedded volcaniclastics. These tuffs are welded and massive with less connected fractures therefore reservoir permeability is largely restricted within fault zones and lithologic contacts rather than well distributed inside the formation. MT conductive layers 15-20 Ohm shows the existence of a shallow clay cap at 1700 to 2200 masl elevation. This clay cap is hosted at Bukit Besar Andesite. Petrographic analysis shows extensive argillic alteration and high MeB index value mainly 20-35. However the current reservoir cap is control by a low permeability stratigraphic unit, the Subaqueous Debris Flow unit. Thick transition alteration was found coincident with the top and bottom of Subaerial Dacite to Andesite units.

Stratigraphic offset and fracture orientation data show that subsurface structure exist mainly below 1000 masl elevation, the exception being a collapse structure that extending to the surface. The structures have the NE-SW and NNW-SSE directions and generate horsts and grabens. This fault structure accommodated dike intrusion below Pad L rising into the shallower level and up to the surface. Major feed zones are distributed within the fault zones and lithologic contacts specifically, faults NE-SW#3, NE-SW#2, and the top-bottom Mixed Sediment and Tuff unit. The NE-SW#3 fault also coincides with convective isothermal temperature contours implying that this fault controls fluid flow from the SW upflow reservoir sector and extensive outflow to the NE. These fault structures also control the distribution of alteration zonation.

The argillic alteration zone coincides with MT conductive layer and high MeB value representing the clay cap layer at the shallow depth. The transition zone is present below the argillic alteration with 200-400 meter thickness. The alteration zonation below the transition zone were previously dominated by a propylitic zone. However phyllic alteration with abundant anhydrite has a very extensive distribution and partially overprints propylitic alteration. This may be related to a recent phase of intrusion observed at depth. This may indicate interaction mature meteoric fluids with relatively aggressive sulphate rich fluids derived from magma volatile and resulting late stage anhydrite-pyrite veins or vuggy filling. The new injection magma process also forms the potassic/deuteric alteration near the intrusive contact at depth, while the advance-argillic alteration is formed near the shallower swarm dikes intrusion below Pad L and some part of I and M pads. This new intrusion phase is likely one of the plausible event that changes the reservoir in Rantau Dedap to become more phyllic alterations. Propylitic alteration present within the debris flow unit is probably limited to reworked altered rock fragments and tend to be relic (well temperature shows <240^0C). Propylitic alteration at deeper reservoir section coincidence with the current system.

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