PREDICTING THE EVOLUTION OF RIA-RIA TRAVERTINE DEPOSIT IN THE SIPOHOLON AREA, NORTH SUMATERA USING GEOLOGICAL AND GEOCHEMISTRY ANALYSIS

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ABSTRACT

The Ria-Ria travertine occurrences developed in eastern side of Tarutung Basin along Great Sumatran Fault. The distribution of the Ria-Ria travertine deposit is strongly related to the neotectonic attributes. Its presence as the upflow zone, the reconstruction of evolution process and the flow direction will help to investigate the location of reservoir in geothermal system and predict the distribution of Ria-Ria travertine naturally. This paper presents the integration among $\delta^{13}C$, $\delta^{34}S$, water geochemistry, petrography, XRD and XRF analysis with respect to the morphology of research area, Great Sumatran Fault and source of travertine to depict the genesis and evolution of Ria-Ria travertine deposit. Based on $\delta^{13}C_{travertine}$ analysis, the CO_2 attained from Alas Formation Basement decarbonization has formed HCO_3-rich liquid. As for the $\delta^{34}S_{SO4}$ analysis, the result show there are two possibilities of the origin of sulfur either from magmatic or sedimentary sulphides. The bicarbonate Ria-Ria hot spring as a part of upflow zone of a geothermal system is controlled by Great Sumatran Fault strike-slip and has deposited a travertine area of 0.1 km^2 with morphology of fissure ridge and terrace-mound. Based on those morphologies, these thermal springs are predicted to evolve along the fissure ridge and move actively following the NNE-SSW direction. Moreover, the fissure ridge travertine characterized by alternating dominant porous fabric of bedded and banded facies with crystalline vein, is controlled by a normal NNE-SSW trending fault that predicted as the extensional fractures of the Sumatran Fault. It is assumed that the Ria-Ria travertine deposit will be grow continuously to the west area or the footwall area of the extension fault. This is also caused by the very fluctuating depth of water table..

1. INTRODUCTION

Travertines are classified geochemically into meteogene and thermal or thermogene travertines. The carrier CO_2 originated from the soil and epigean atmospheres forms limestone deposits called meteogene travertines. As for the thermogene travertines, the carrier CO_2 results primarily from the interaction between CO_2-rich fluids and hot rock (Ohmoto and Rye, 1979). These travertines are distributed in the regions of recent volcanic activity or in the regions of active tectonic setting. It causes most of the travertines deposited from hot springs can depict the contribution of the tectonic process which has happened. In some geothermal fields, travertines are deposited along the fault lines (Hancock, et al 1999). Faults act as fluid path and play an important role in the emergence of hot springs. Hot springs with high carbonate content could deposited travertine as a result of precipitation process from the releasing of carbon dioxide from carbonate rock (Pentecost, 2005). The research area is located in Ria-Ria area, Sipoholon Sub-district, North Sumatera Province (Figure 1). Ria-Ria travertine is one of the travertine deposit that evolves in the northeastern part of the Tarutung basin and lies in the Great Sumatran Fault (GSF) path. In this research, geological and geochemical analyses will be integrated to determine the deposition as well as the evolution process of travertines and its relation to the Sumatran Fault System.

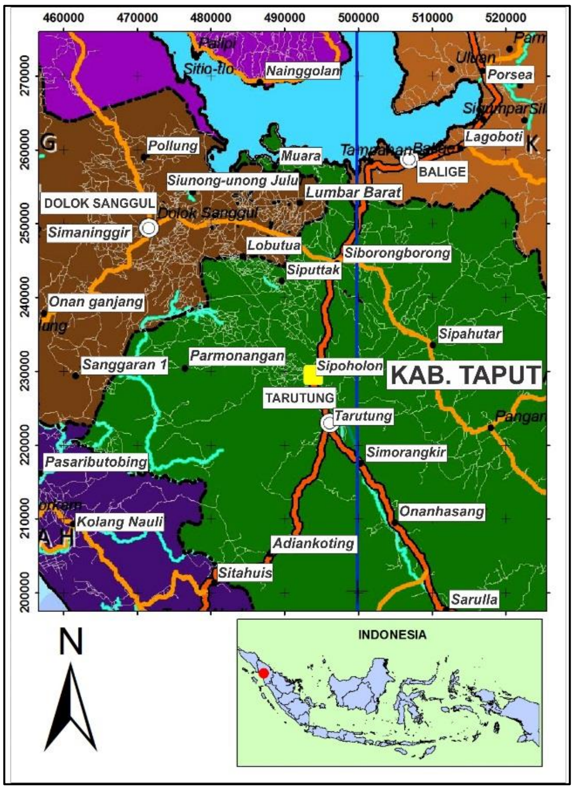


Figure 1: Location map of Ria-ria, Sipoholon, North Sumatera Province, Indonesia.

2. DATA AND METHODS

In this study, geological mapping has been conducted with a focus on Ria-Ria travertine area. Some rock samples have been collected from travertine and tuff deposit. This research is also supported by petrography, XRD, isotope ^{34}S and ^{13}C. In order to confirm the occurrence of travertine deposition, liquid geochemistry analysis was also performed on hot springs emerging from travertine fissure. Number of analyzed samples and the precise observation point is shown in the Figure 2.

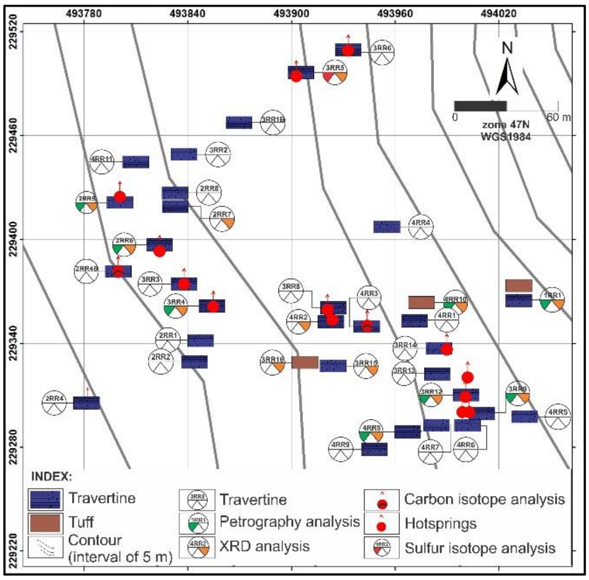


Figure 2: Observation site map of Ria-Ria area

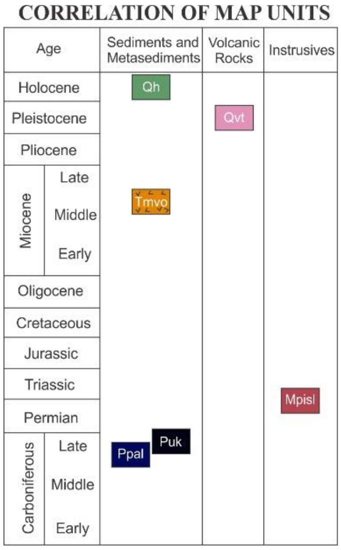
3. GEOLOGICAL SETTING

3.1 Tectonic Setting

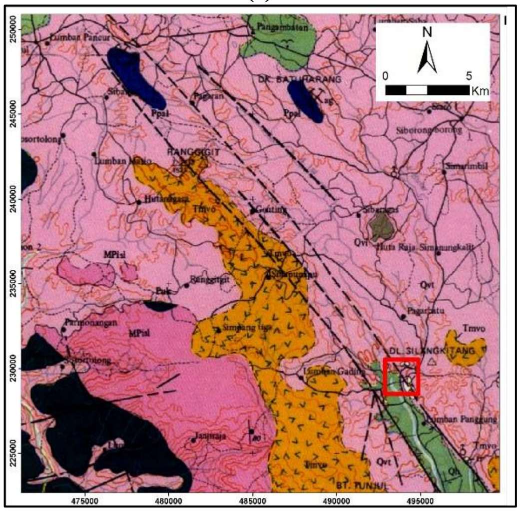
Sipoholon area is located in the northeastern area of Tarutung basin. This basin is about 30 km to the south of the Giant Lake Toba Caldera with 2.5 km long and 15 km wide, prolonged in the direction of NNW-SSE along the prominent NW-SE striking Sumatran Fault System, which represents a dextral strike-slip fault related to oblique subduction along the Sumatra arc where the pull-apart basins was generated (Sieh and Natawidjaja, 2000; Muraoka et al., 2010). In a pull-apart basin, the normal faults often play the most important role in major discharges of geothermal fluids (Muraoka et al., 2010). Ria-Ria travertine is located along the NE boundary normal fault in the Tarutung basin which is interpreted as the controller of the occurrence of Sipoholon manifestation.

3.2 Regional Stratigraphy

Alas Formation (Ppal) is the oldest rocks in the Northern Sumatra (Figure 3). This formation consist of Carboniferous limestone and probably underlies or is equivalent to the lower part of the Kluet Formation (Puk) within the Tapanuli Group (Metcalfe, 1983). These formation was intruded by a granitic intrusion, part of the Sibolga batholith (Mpisl) with its exposure is elongated in NW-SE direction only on the western side of the Tarutung basin. Quarternary deposit overlies the research area is the younger member of the Toba Volcanic Complex (Qvt) consisting of pumice tuff in a welded structure (Chesner, 1998). The youngest units in Tarutung area are travertine and alluvial deposits (Qh). Ria-Ria travertines is one of the travertines exposed in the Tarutung basin and exposed in the northeastern area.



(a)



(b)

Figure 3: (a) Correlation of map units of Sipoholon and surrounding area (b) Regional geological map of Sipoholon and surrounding area (Aldiss et al, 1983)

4. CHARACTERISTIC OF MANIFESTATIONS

The most dominant manifestation occured around Ria-Ria travertine is hot spring. The hot spring is characterized by temperature of 42-63^{0}C and pH of 5-6. Most hot springs emerge along the fissure of travertine with certain direction that fascinates with its intensive bubbles and sulfur deposit around them. Furthermore, hot pools are also found with spectacular bubbles. Also, inactive hot pool seems to be evolved. Their occurrences show certain pattern related with fault-structure, N-E or relatively NNE-SSW (Figure 4). At the same elevation, this movement may be caused by a southward-developed fault zone. The influence of water table can be neglected considering stable elevation.

On the other hand, at the lower elevation, these liquid manifestations discharge along fissure with different elevations that indicates progressive rising of water table. The hot pools deposits aragonite and calcite around the manifestation. The occurrence of aragonite and calcite indicates that the liquid temperature has been evolved due to they occur at the same time.

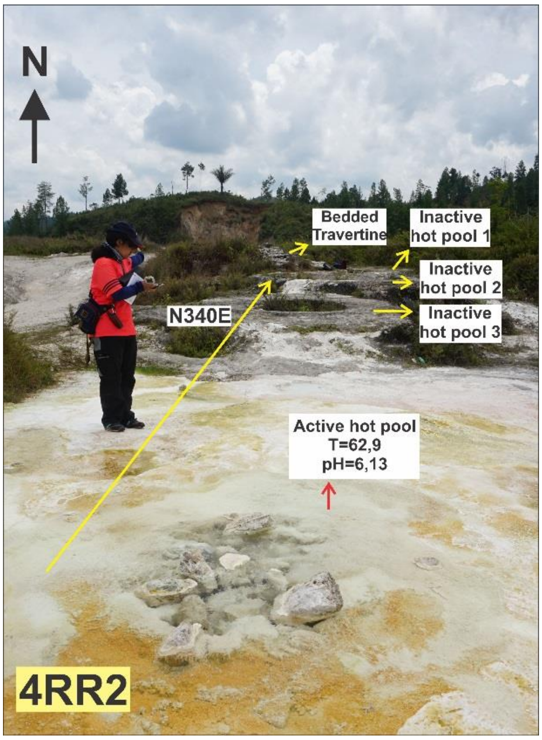


Figure 4: The occurrence of active and inactive hot pools has N340E trend.

Interestingly, fumarole is only found in the most eastern part of Ria-Ria, exactly at the highest elevation of the other manifestations. Sulfur is deposited around fumarole and H_2S odor smell is strong. This manifestation occurs besides travertine fissure ridge.

Geochemical analysis has been conducted to two hot pools. The first hot pool is located at the western part (RR1), while another one is at eastern part (RR2). These two hot pools show similar geochemistry characteristic, which contain bicarbonate water with inconsiderable chloride (Table 1).

Table 2: Water chemistry of hot pools in Ria-Ria.

	RR1	RR2
T	63.3	43.4
pH	5.99	7.13
Li	0.74	0.892
Na	104.576	104.633
HNO_4	0.655	0.909
K	39.982	40.281
Ca	160.909	117.699
Mg	83.565	83.102
SO_4	507.255	498.411
HCO_3	1000	950
Cl	127.752	127.694

High concentration of bicarbonate generates the immense travertine deposits, while the sulfate concentration is also considerable, which predicted to originate from magmatic activity or interaction between water and sulfide-rich rock. This phenomenon is accompanied by the occurrence of sulfur around the manifestation. This interpretation is also supported by the analysis of $\delta^{34}S$ from sulfur sample in 3RR5. It points out the value of 1.806.

5. TRAVERTINE

According to Nicholson (1993), travertine is commonly occurred in the outflow zone of geothermal system. As for geothermal system in Sipoholon, this surface deposit becomes a part of upflow zone (Nukman, 2014). It is accompanied by the geological setting and physical characteristic of manifestation. Based on geological analysis, Ria-Ria hot spring is obviously controlled by permeable fault and shows that the geothermal system of Ria-Ria is associated with tectonic, non-volcanic and flat terrain. Based on geological condition, the interaction between Alas Formation that consist of limestone and hot water in the reservoir causes the deposition of travertine in the upflow zone. The characteristic of upflow zone in Ria-Ria manifestation is showed by the highest temperature and highest flow rate from all of springs in Tarutung. The comparison data is acquired from Nukman (2014).

According to Pentecost (2005), travertine morphologies are frequently constructive in nature. HCO_3-rich fluids that flow with high flow rate will deposit new morphology of travertine. The deposition process of travertine has formed new constructive morphology like mound-terraced, ridges, etc. This condition is in contrast to acid fluids that usually cause the leaching process. Morphologies of travertine that commonly found in Ria-Ria are fissure ridge and terraced-mound travertine.

5.1 Fissure Ridge

Fissure ridge lithofacies is recognized by alternating bedded and banded facies. Banded facies is a set of vertical or sub vertical veins between bedded facies and show the central position of a permeable fissure zone. The most obvious texture in bedded travertine is laminated-crystalline crust with vary thickness from 5 to 10 of cm. Meanwhile, the bedded facies are bedding with dominant porous fabric. Moreover, recrystallized bedded travertine is also found.

The presence of these lithofacies must be controlled by fault. Hot springs with sulfur deposits along fissure are observed especially on some fissure ridges. Fissure ridges in Ria-Ria are mostly found from elevation of 1023 masl on the eastern part until 993 masl on the western part (A, B, C, D and E) (Figure 5). The fissure ridges show the NNE-SSW direction parallel geometry, as opposed to the Great Sumatran Fault.

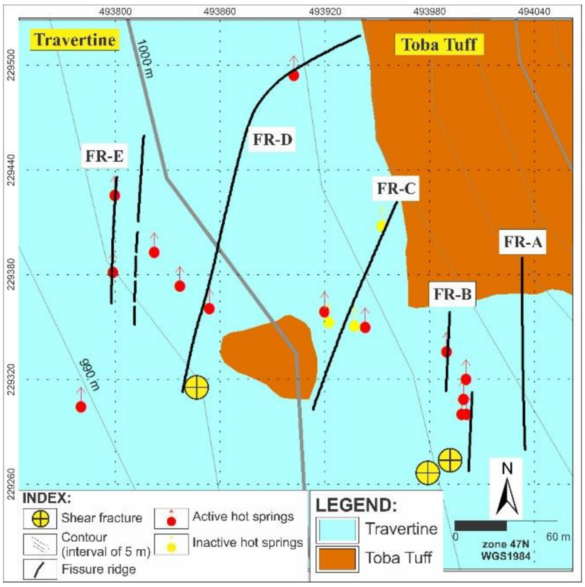


Figure 5: Geological map of research area

At the highest elevation, fissure ridge travertine-A shows well bedded facies with syntaxial direction of banded. This fissure ridge lies along NNE-SSW with 110 m length. In addition, there is also a local N35^{0}E directed fracture in fissure ridge geometry. Other than that, the presence of travertine is predicted has flowed through the altered tuff that has formed earlier. This indicates that there have been occurred an alteration process of cristobalite and halloysite before the deposition of travertine. Fumarole and sulfur deposits also can be found around this fissure ridge (Figure 6 A-B).

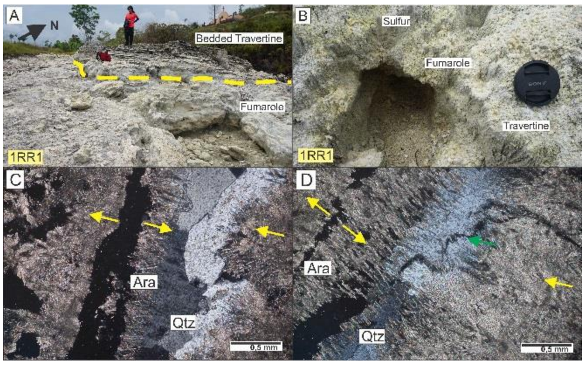


Figure 6: (A-B) Fumarole with sulfur deposits found besides the travertine fissure ridge, (C-D) Banded travertine shows secondary quartz (Qtz) overprinted by calcite (FR-A). The arrows denote the flowing direction.

Based on petrography analysis, banded travertine is composed of secondary quartz that is overprinted by aragonite (Figure 6 C-D). The crystalline and jigsaw-fit textured – quartz shows that it is a result of hydrothermal process. The quartz occurs as vein that has parallel direction with banded travertine. It can be interpreted that the hydrothermal process of the host rock (welded tuff) occurred prior to travertine deposition. After that, both of these veins has been fractured by post-tectonic structure. After the deposition of this fissure ridge, it is believed that the groundwater level was decreased and cause the emergence of gas manifestation like fumarole.

The fissure ridge-B has the same direction with "A". The fault is clearly observed as the hanging wall of fault plane (Figure 7A). The fault evidence indicates oblique kinematic fault. The hot springs appearance depict the high permeability of this zone. In contrast to the fissure ridge "A", bedded facies in fissure ridge-B has different characteristic on top (upper) and base (lower) part. Recrystallization process in the base part is more intensive than in the upper part. Travertine deposit from the upper part show the flat porous fabric that following the direction of HCO_3-rich liquid.

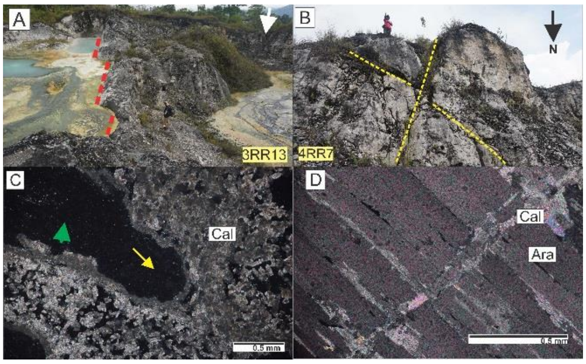


Figure 7: (A) N-S directed fissure ridge travertine as the hanging wall of fault plane (red ash line shows fault plane), (B) Shear fractures were found in FR-B, (C) The arrowheads shows porous texture from bedded travertine, while the arrow shows the fluid's flow direction (FR-B), (D) Bladed calcite cut by micro-dendritic calcite that indicates the appearance of post-deformation's structure (FR-B),

Meanwhile, the occurrence of an intensive recrystallization at the lower part was due to the intensively appearance of fault around this fissure ridge. The evidence that was found in the field is the presence of intersecting calcite-aragonite vein. One of them show that the banded is formed from shear fracture with N10E/71 and N155E/70 direction where fracture striking NW-SE cut NNE-SSW direction (Figure 7B). Petrography analysis does not only show the banded facies texture in the form of alternating between bladed and mosaic texture (but also show that the fault formation has occurred more than once. This is evidenced by the presence of micro-dendritic calcite cuts the bladed banded aragonite (Figure 7D). However, the intensive recrystallization process makes determining part of the banded become difficult sometimes.

Fissure ridge-C has banded travertine with NNE-SSW direction. The captivating part is that this travertine appears around the hot springs by forming the new travertine deposits. Moreover, there is a local outcrop of Toba Tuff that has been altered into clay and oxidized into iron oxide (Figure 8A). The presence of tuff in the form of small and isolated hummock is considered as an autochthon. Until now, there is still no clear the meaning of the presence of this autochthon structure. But, it is believed that hot springs will not form in the top of the hummock because of the structure type and the lower position of groundwater level. Tuff is older than travertine and is predicted to have experienced weakly welded process observed by petrography analysis (Figure 8B).

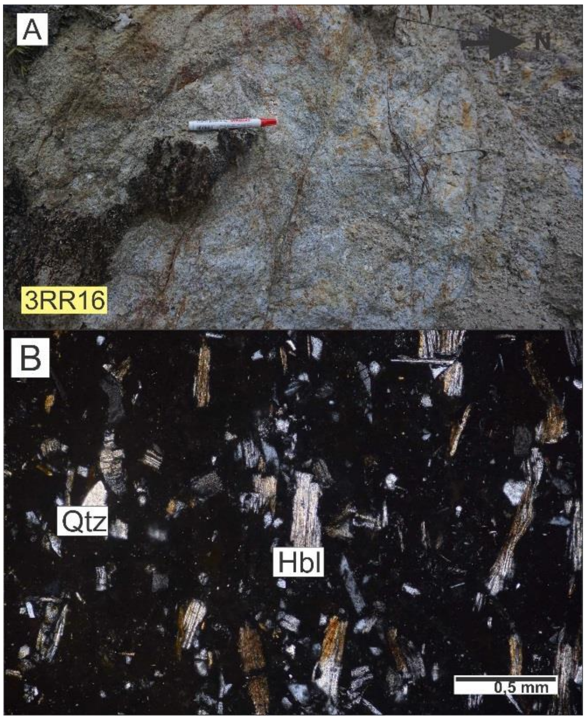


Figure 8: (A) Altered tuff in the western part of fissure ridge-C, (B) Toba Tuff is composed of quartz (qtz), hornblende (hbl), lithic and volcanic glass.

Fissure ridge-D is the longest ridge and has 245 m length. This ridge lies in the lower elevation of fissure ridge-A and B along NNE-SSW direction. This direction clearly shows the NNE-SSW fault which is opposite to Sumatran Fault (Figure 10A). Bubbling hot springs were found with sufficient intensive sulfur deposits and the smell of H_2S gas. The length and model of this fissure ridge can be seen in more detail in Figure 5. This figure clearly shows the relationship of the formation of each banded where the growth of the banded is more dominant to the west area (Figure 9).

Figure 9: Fractures on FR-D that grow to the western part.

In some areas, there is a quarried area to drain water. This condition causes the deposition of terraced-mound travertine in the western area from higher to the lower elevation area. Petrographic analysis shows banded travertine texture namely alternating of bladed aragonite and mosaic calcite (Figure 10B) while texture of bedded travertine is acicular. Those texture is able to show the flow direction of the bicarbonate fluid.

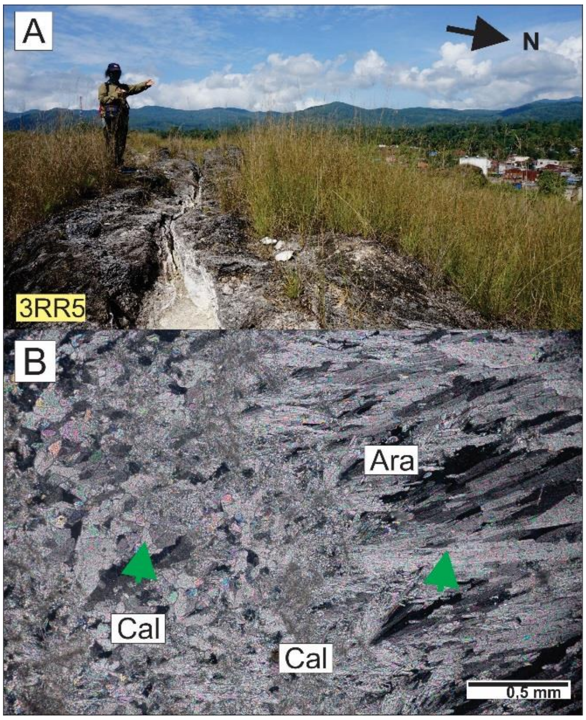


Figure 10: (A) Fissure ridge-D that shows long NNE-SSW directed-banded travertine, (B) Arrowheads indicate the alternating between blocky/ mosaic calcite and bladed aragonite from FR-D.

Fissure ridge-E is located in the lowest elevation and have a length of about 70 m. This fissure ridge is represented by bedded travertine with strike dip N110E/10, N305E/20 and banded travertine with strike dip N200E/76. The recrystallization process occur very intensive with the presence of stalactite and stalagmite structures in the cave (Figure 11A). Both of these structures are predicted to be formed due to small fractures in a wide coverage area causing the water drop passing through them. After this process, groundwater level is estimated to be decreased and form sulfur deposit around the stalactite. The presence of stalagmite prevented the occurrence of new hot springs within the cave. Vise versa, the spectacular manifestation was found in the eastern part of this fissure ridge. Petrography analysis also show the evolution process. Thin section on FR-E show the similar thing with thin section on FR-A, where secondary quartz is cut by aragonite. In addition, the appearance of fractures that cut travertine is also believed to be a post-structure.

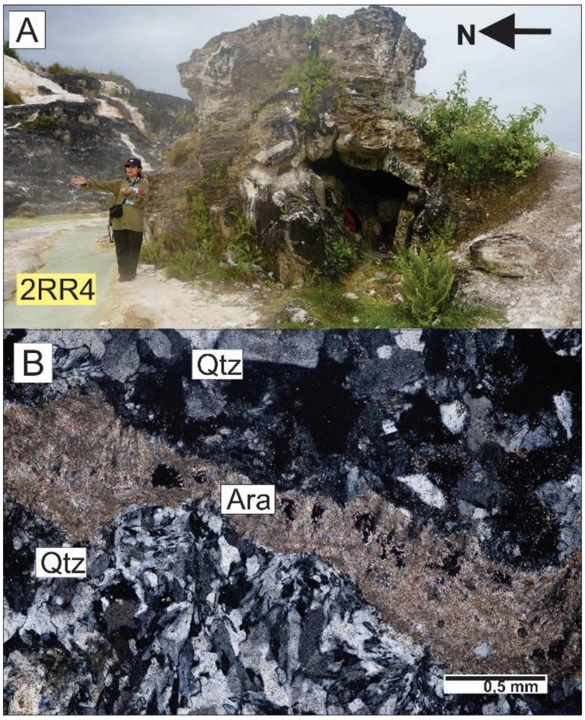


Figure 11: (A) Fissure ridge-E with stalactite and stalagmite structures, (B) Banded travertine also shows secondary quartz overprinted by aragonite.

5.2 Terraced-Mound Travertine

Terraced-mound travertines occur as a result of deposition from bicarbonate-rich hot springs that flow in a steep areas. The highest terraced-mound travertine in Ria-Ria has a maximum height of 15 m and consists of a pool and rim structures both large and micro size which form microterracettes. Other than that, the rootcast structure is often found. This lithofacies is very useful to indicate the flow and discharge direction of a manifestation.

These lithofacies are found abundantly around the fissure ridge “B”, “D” and “E”. On fissure ridge-B, there are many active and inactive terrace travertines found. The distribution of those lithofacies can be seen from the north to the south followed by the presence of active manifestations.

Meanwhile, in the fissure ridge-D, the mound travertine is formed with height of 15 m. Mound travertine with pool, rim and rootcast structures are thought to be formed due to the artificial flow from hotsprings along the fissure ridge. There is a hot spring lineament with N-S direction that deposit the largest terraced-mound travertine around 10 m from the fissure ridge (Figure 12A-B). Diameter of this mound is about 20 meter with height of 15 m. This condition shows that there is a higher flow rates of fluid that moves with a higher velocity causing the hot fluid to flows farther and consequently experience the decreasing of temperature. Based on XRD analysis, this mound travertine has mineral content of aragonite and calcite. Meanwhile, in the northern part, there is mound travertine which has been oxidized forming jarosite. This also shows the development of the mound is increasingly active towards the southern part. Based on petrography analysis, predominant aragonite shows dendritic texture and flow direction (Figure 12C-D).

The role of mound terrace in this research is very important to determine the evolution process of the fissure ridge. Especially for the largest mound travertine, it can be observed that mound travertine is younger than fissure ridge. This can be seen from the color of the travertine deposit and the activity of manifestation. The role of groundwater is clearly observed that there has been an increasing of groundwater from the initial fissure ridge to the mound travertine. Moreover, the height of the mound travertine can also indicate the thickness of the fault scarp of a fault.

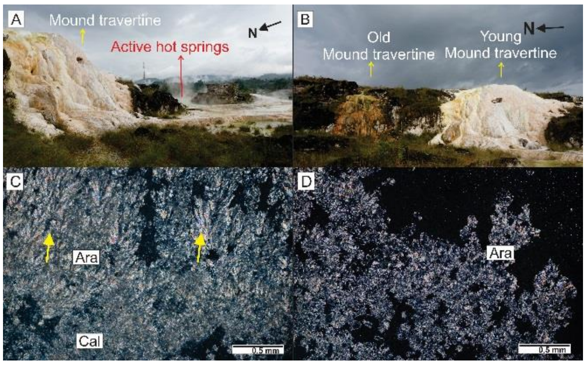


Figure 12: (A-B) The appearance of old and young mound travertine and active hot springs, (C-D) Aragonite and calcite texture on the mound travertine shows the direction of fluid flow.

6. DISCUSSION

6.1 Development Mechanism of Fault-Controlled Fissure Ridge

Based on the presence of fissure ridges and hot springs lineament, the fault zone is predicted to be a NE-SW normal strike slip fault with dipping direction to the west. The fault’s strike defines part of the extension zone or the releasing band of the Sumatran Fault.

The development of fault is keep continuing even after the deposition of travertine. This is confirmed by the evidence like fractures around the travertine. This is clearly observed on fissure ridge “B”, where travertine with NNE-SSW direction was cut by fracture with NW-SE direction. The evidence is shown in the thin section.

Based on evidence that found in the field, it is considered that the deposition of travertine in the Ria-Ria area is associated with the crosscutting of fault with NNE-SSW direction and the western part of Great Sumatran Fault (Figure 11). The crosscutting indicates the presence of geothermal reservoir of Ria-Ria. The direction of fault development is concentrated to the west area which is observed from the development of fissure ridges.

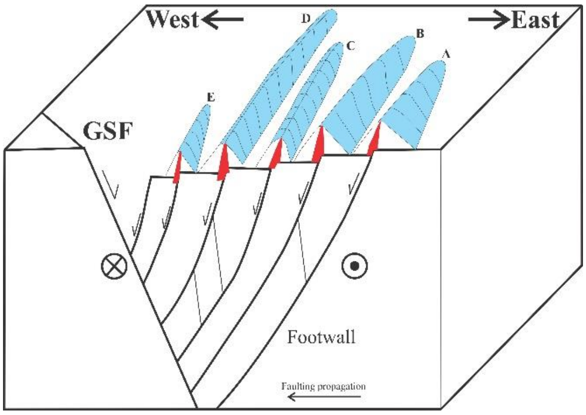


Figure 13: Schematic illustration model of fissure ridges in Ria-Ria, Sipoholon

Figure 14: Google Earth Map of research area (unscaled) showing the strike dip of bedded and banded facies.

6.2 Evolution of Ria-Ria Travertine

The sequence of the formation of travertine shows the deposition and the growth process of itself. The first deposition of travertine was the one in the higher elevation followed by the decreasing of groundwater level and the emergence of fumarole. The next travertine deposition developed westward with a significant decreasing elevation and deposited fissure ridge travertine-B which is fractured intensively. Furthermore, fissure ridge deposition occurs in succession from C, D, and E. These fissure ridges deposition process cannot be ascertained whether they occur at the same time or not. However, by looking at the current position of groundwater level and the presence of the hot springs that are almost throughout the fissure ridge, it is very possible that these three fissure ridges (C, D and E) occur at the same time or simultaneously.

The evolution process is not only observed physically but also geochemically or chemical composition of travertine. The composition of all travertines are relatively similar, namely calcite and aragonite, although they occurred in different time ranges. The formation of calcite and aragonite shows a temperature of 30-43^{0}C simultaneously while aragonite itself will form at temperatures >44^{0}C. Meanwhile, hot springs have temperature of >60^{0}C currently. It is shown that the changes of temperature fluctuate in this area. Besides these two minerals, the content of bedded facies is also similar but there is a little content of gypsum. The presence of gypsum shows the evaporation of sulfate-rich fluids.

Petrographic analysis also depict the significant chemical evolution. Almost all fissure ridges have superimposed laminae texture of banded travertine formed by needle-like crystal. In some banded of fissure ridges like FR-B and "E" alternation of block and acicular crystal laminae are found. Interestingly, quartz are found in some banded travertines which shows the older relation than aragonite and calcite. The presence of quartz here as the low temperature-hydrothermal product shows that this process occurred prior to travertine deposition. The vein of quartz crosscuts the host rock (welded tuff), then is followed by occurrence of banded travertine. The coarse-grained quartz texture and the absence of silica show the precipitation of quartz is not due to the diagenesis process. The relation between travertine and marine carbonate rock in the reservoir is also supported by ^{13}C isotope data with value of 1.79 and 5.10. In addition, the relationship with magmatic process is also indicated by the ^{34}S isotope with value of 1.806. However this value is not enough to show the association of sulfur with travertines come from magmatic. Sulfur deposited on the surface could come from the sedimentary sulfide.

Furthermore, the difference level of groundwater is also predicted to be related to the deposition process of fissure ridge travertine. This is quite clear since the observation of fissure ridge-A. The decreasing of groundwater level causes the emergence of relative intensive gas manifestation like fumarole. It is concluded that hot springs formed earlier than fumarole.

In the future, travertine development is predicted to develop westward especially for mound travertine that flows to the lower elevation while fissure ridge will follow the structural track that leads to the western part of Sumatran Fault.

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