The geometry of pull-apart basins in the southern part of Sumatran strike-slip fault zone

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Abstract. Models of pull-apart basin geometry have been described by many previous studies in a variety tectonic setting. 2D geometry of Ranau Lake represents a pull-apart basin in the Sumatran Fault Zone. However, there are unclear geomorphic traces of two sub-parallel overlapping strike-slip faults in the boundary of the lake. Nonetheless, clear geomorphic traces that parallel to Kumering Segment of the Sumatran Fault are considered as inactive faults in the southern side of the lake. I demonstrate the angular characteristics of the Ranau Lake and Suoh complex pull-apart basins and compare with pull-apart basin examples from published studies. I use digital elevation model (DEM) image to sketch the shape of the depression of Ranau Lake and Suoh Valley and measure 2D geometry of pull-apart basins. This study shows that Ranau Lake is not a pull-apart basin, and the pull-apart basin is actually located in the eastern side of the lake. Since there is a clear connection between pull-apart basin and volcanic activity in Sumatra, I also predict that the unclear trace of the pull-apart basin near Ranau Lake may be covered by Ranau Caldera and Seminung volcanic products.

1. Introduction

The pull-apart basin is the topographic depression formed within the bends or step-overs in the strike-slip fault systems [1,2]. Bends and step-overs are typically different in the origin of the pull-apart basin (Figure 1). The bends are commonly formed from one segment and the step-overs are formed by two parallel strike-slip faults [3]. However, fault step-overs may evolve into continuous fault bends and connect with the splays from the fault [4]. Therefore, the terms of structural connection of pull-apart basins could be used either as step-overs or bends [5]. The rectangular form of pull-apart basins in dextral strike-slip structure results from the lengthening of Z-shaped basin (Figure 1A) [1].

The length, width and acute of strike slip basins (Figure 1B) have clear characteristics and its geometry has been well classified from field studies [6,7], experimental analogue modelling [8–11], and numerical modelling [12,13]. The pull apart-basins have an aspect ratio of 3:1 of length and width in two dimensional (2D) view. Although the value may vary depending on the structure, physiographic, and basin dimension, the most common range is between 3 and 4 [6,14].

The Sumatran active fault consists of several pull-apart basins i.e.: Aceh to Kutacane graben, Toba Caldera, Tarutung-Sarulla Basins, Barumun-Angkola Segments, Lake Singkarak, Muaralabuh-Sungaipenuh Basin, Musi-Manna Segments, Ranau Lake, Suoh Valley and extensional system in Sunda Strait [15]. In the southern part of Sumatra, there is Ranau Lake which is considered to be

formed as a caldera [16]. Nonetheless, the finite element model shows that Ranau Lake was formed by an overstep of Sumatran Fault [16]. Otherwise, in the middle of 1990, the relationship between Sumatran Fault and volcanism along the fault was revealed by remote sensing analysis [3]. The ~500 Ma of Ranau Tuff deposit also in support to the connection and describe the collapse and paroxysmal activity in the southern part of Sumatra [17]. The hypothetical sketches of Ranau and Sumatran Fault show the evolution within the tectonism and volcanism process in the southern part of Sumatran Fault. However, the southern part of the step-over structures appears not to have connected with the northern part. The structures in the southern part of Ranau Lake were in inactive during Holocene (Figure 2). This paper evaluates scale characteristics of the southern Sumatra pull-apart basins between Ranau Lake to Suoh valley. Furthermore, I propose that the Ranau pull-apart basin has no correlation with the inactive fault in the southern part of the Lake; the Limaukunci Fault.
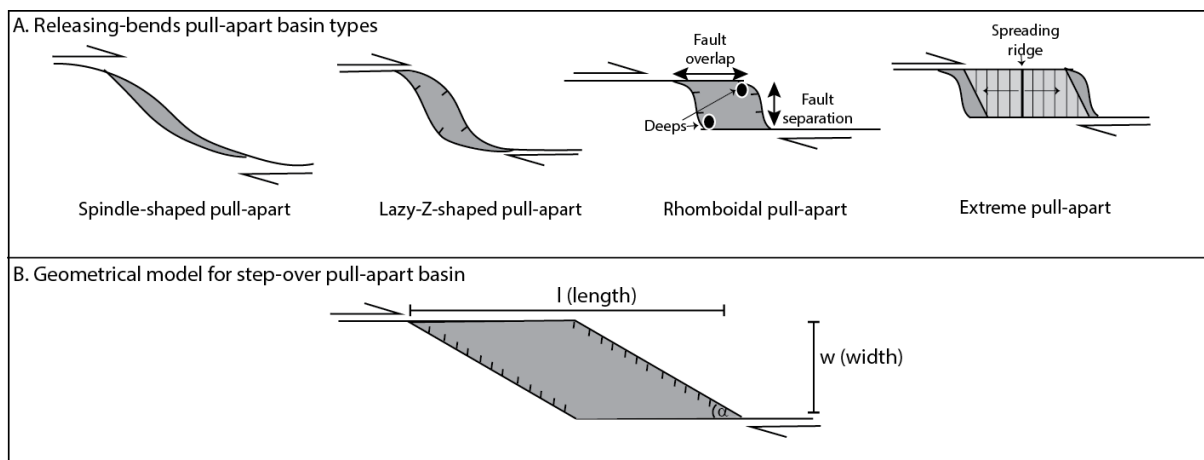

Figure 1. A Releasing-bends pull-apart basin types in dextral system modified after [1]. B. Geometrical model for step-over pull-apart basin, l = length, w = width, α = acute angle).
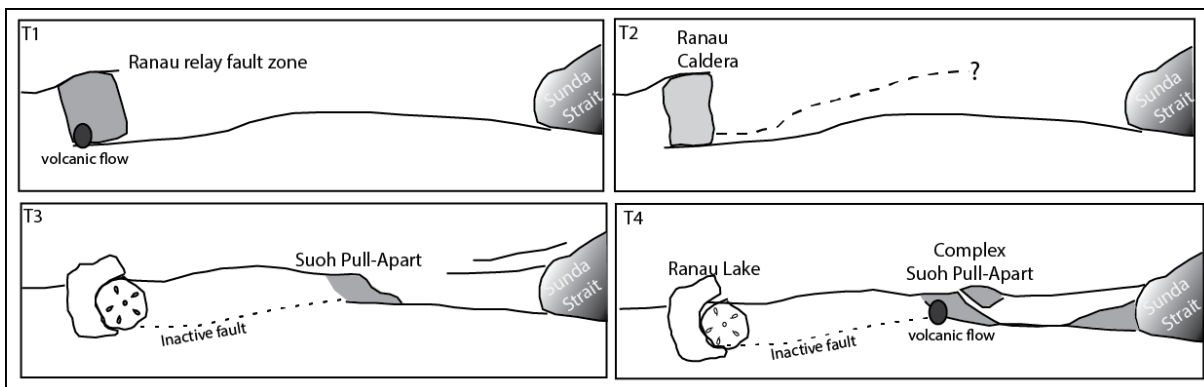

Figure 2. Tectonic evolution of the Sumatran Fault in the Ranau Lake and Suoh valley modified after [3].

2. Methods
To address the geometric characteristics of pull-apart basins I use the equation of pull-apart basins in the North Anatolian pull-apart basin [14], the equation to predict the depth of the basin is defined as:

$$d = 0.1104l - (8.7550 \times 10^{-2})w$$

This method tried to predict the depth of the pull-apart basin and it is also the modification of the equation which also measured the depth of the pull-apart basin [7]. The metric measurements of pull-apart basin in the South Sumatra are taken from a manual measurement of the tectonic geomorphology mapping of the Kumering Segment in the Sumatran Fault based on a high-resolution topography [18, 19].

3. Result and discussion

I measured the dimension of 4 active pull-apart basins along the South Kumering Segment of Sumatran Fault (Figure 3). I defined 4 pull-apart basins and compared them with the dimension of Ranau pull-apart [3]. The Pagardewa pull-apart basin is located at the east side of present Ranau Lake, the length of the basin is 6.02 km and the width is 2.67 km with an acute angle of 250. To the southernmost of Kumering segment, I described 3 pull-apart basins which are the Malbui pull-apart basin, Suoh pull-apart basin and Natarang pull-apart basin. The name Natarang pull-apart basin is adapted from the article that discussd a new slip-rate of southern part of Sumatran Fault and the new age for Ranau Tuff [20]. The Malbui pull-apart is 4.75km in length, 1.5km in width and an acute angle of 250. The Natarang pull-apart has 7.7 km in length, 2.4 km in width and an acute angle of 450. The Suoh pull-apart is the biggest pull-apart in the Suoh region with 17.8 km in length, 7.85 km in width and an acute angle of 460.
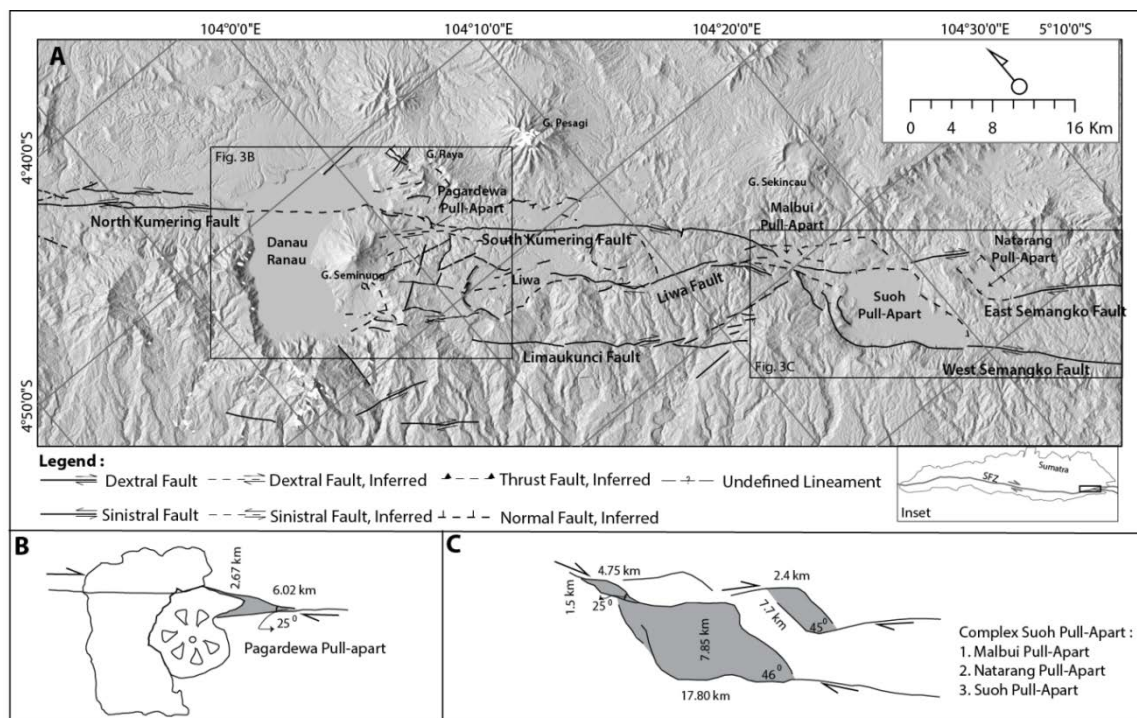

Figure 3. A. Structural map of Ranau, Liwa and Suoh Area. B. Cartoon illustration of Ranau Lake area. C. Cartoon illustration of Complex Suoh pull-apart.

Based on the measurement of the depth prediction of the pull-apart basin, Suoh pull-apart seems to be the deepest pull-apart along the Kumering Segment. Comparing with the depth measurement of the Ranau pull-apart, it seems that the depth of Ranau pull-apart does not reflect its true depth.

According to my calculations (Table 1), the linear correlation between length and width have a value of about 2.5:1 and 3:1 respectively. The calculations are in agreement with the linear correlation between length and width of the North Anatolian pull-apart basins [14] which varies between 3 and 4 divided by 1. Ranau pull-apart geometry, which is considered as pull-apart basin [16], seems to not be

in good agreement with the linear correlation. The considered Ranau pull apart in T1 shows that the linear correlation of the length and width is about 4:3. Although the value of 3:1 may vary depending on whether the structural, physiographic or active dimensions of the measured basin, the 4:3 ratio is too far with the most common ratio.

Table 1. Geometric characteristic of pull-apart basins along the southern part of Sumatra Island. Note(*) [3]

Basin	Acute angle (degree)	l (meter)	w (meter)	d (meter)
Ranau	-	16,500*	12,500*	727.225
Pagardewa	25	6,020	2,670	430.8495
Malbui	25	4,750	1,500	393.075
Natarang	45	7,700	2,400	639.96
Suoh	46	17,800	7,850	1965.12

It is still debatable that the Limaukunci Fault at present time was previously the overstep of Kumering Segment Fault. The geometry of Ranau Caldera and the two step-over strike-slip structures are not showing similarity with other tectonic pull-apart basin lakes in Sumatra i.e Toba and Singkarak. The ancient Ranau caldera seems to be bounded by Sumatran Fault at the northern part with the chamber located in the south of the fault.

From the hypothetical sketch of Ranau evolution (Figure 2), it can be assumed that the South Kumering Segment is younger than the trace of Limaukunci Fault and the Ranau pull-apart basin is developed earlier than the Suoh pull-apart. This assumption really needs to be evaluated since the fact of geometry of pull-apart basin shows the contrary hypothesis. A good model to be compared with the evolution of Ranau Lake is the simulation of strike-slip tectonics with a passive magma chamber and low opening angles [20]. The models show the same age of strike-slip fault linked with the chamber at the southwest of the fault similar with the relationship of present Kumering Segment, Seminung volcano and Ranau Lake.

4. Conclusions

The angular data from southern part of Sumatra pull-apart basin is in agreement with the previously published angular data with the acute angle of $\sim 25^0$ and $\sim 45^0$. The scale characteristic of the measured pull-apart basins has good comparison with other examples in the published works. The Ranau pull-apart basin is hypothesized not to be developed earlier than Suoh pull-apart basin. The conclusion is based on the interpretation that the two fault segments, the North Kumering Segment and the South Kumering Segment, were initiated contemporaneously. Furthermore, the southern part of Ranau Lake is considered to have formed as a caldera with a passive magma chamber.

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