Tectonic and compositional variation in Flores Island, Indonesia: implication for volcanic structure and geothermal occurrences

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ABSTRACT

Flores Island is located in Indonesia, at the southernmost of Sundaland that stretches from Sumatra to Flores, and which is the most complex part of the Sundaland. Flores Island is part of a volcanic arc in an active continental margin, straddling between Sunda Arc and Banda Arc. This specific location is overlying the boundary of accretion, that has undergone various process including; rifting, drifting and subduction, in the Late Cretaceous and Early Miocene. An additional interest of Flores Islands lies in the transition from a subduction of the Indo-Australian oceanic crust to the west to the Australian continental plateau to the east. The subducted Australian continental crust has an effect on the geometry of the tectonic in the volcanic arc and for the purpose of this work on Flores Island.

The formation of Flores Island is the result of this evolution and variability of both the composition and tectonic that has brought the shape we can observe and measure today. The high volcanism activity on the Flores Island also coincides with the most important structure of the island. In this work we present the results the first step of the analysis, which focuses on obtaining a better understanding of the tectonic setting of Flores Island magmatic occurrences, and lithospheric structures, and their effect and control on magmatism for geothermal energy exploration. Available geological, geophysical, and geochemical data suggest that Flores can be divided into several regions that have a different geothermal signature and potential. The geothermal potential on western-half of Flores Island are located on the Tertiary – Quaternary volcanism, while the eastern-half of Flores are located on the Quaternary volcanism, which are associated with faults, post-volcanic features, and caldera structures.

1. INTRODUCTION

Flores island has been stated as Geothermal Island by The Ministry of Energy and Mineral Resources (MEMR) in 2018, in order to accelerate the geothermal energy exploration. The elongated island with 350 km in length and 60 km in width has estimated geothermal energy potential about 402,5 MWe. From this potential, only two site of fourteen geothermal potential location have been developed. Those are the Ulumbu (12,5 MWe) and Mataloko (2,5 MWe) (ESDM, 2017). Despite its abundance potential of geothermal energy, there only some research that have been carried out on Flores island with either with detail scale view on specific location along the Flores island, i.e. Ulumbu, and Mataloko; or very large scale view on spatial and temporal evolution on several area in eastern Indonesia that mainly not focusing on Flores island. This leaves an important gap in our understanding at regional scale where the tectonic and volcanism of Flores island are important in order to help accelerating exploration program. This paper gives refined interpretation of the tectonic settings from examination of the compiled published literature from various journals. This contribution enlighten the characteristics of known geothermal prospects in Flores Island in relation to their geologic environments.

2. LARGE SCALE BACKGROUND TO THE FLORES ISLAND

2.1 Tectonic framework of the Lesser Sunda Island

The Lesser Sunda Island (LSI) is located in the eastern part of Indonesia which is consist of many islands. The main island are, from west to east: Bali, Lombok, Sumbawa, Flores, Sumba, Timor, Alor, Wetar, Romang, Damar, and Tanimbar Island (Figure 1). Geologically, The LSI could be divided into two major tectonic element. The northern island (Bali to Damar island) are volcanic island arc, which mainly been built by the volcanic activity resulted by the partial melting of the subducted plate, while the southern island (Roti and Timor Island) are islands of accretionary wedge product which uplifted as the consequence of the collision of Australian continental crust with LSI (Katili, 1975; Hamilton, 1979). An exception condition for Sumba island, despite its location at the forearc region, it is known as an isolated microcontinent which was drifted away from Sundaland southward (Abdullah, 1994; Wensink, 1997; Fleury, et al, 2009).

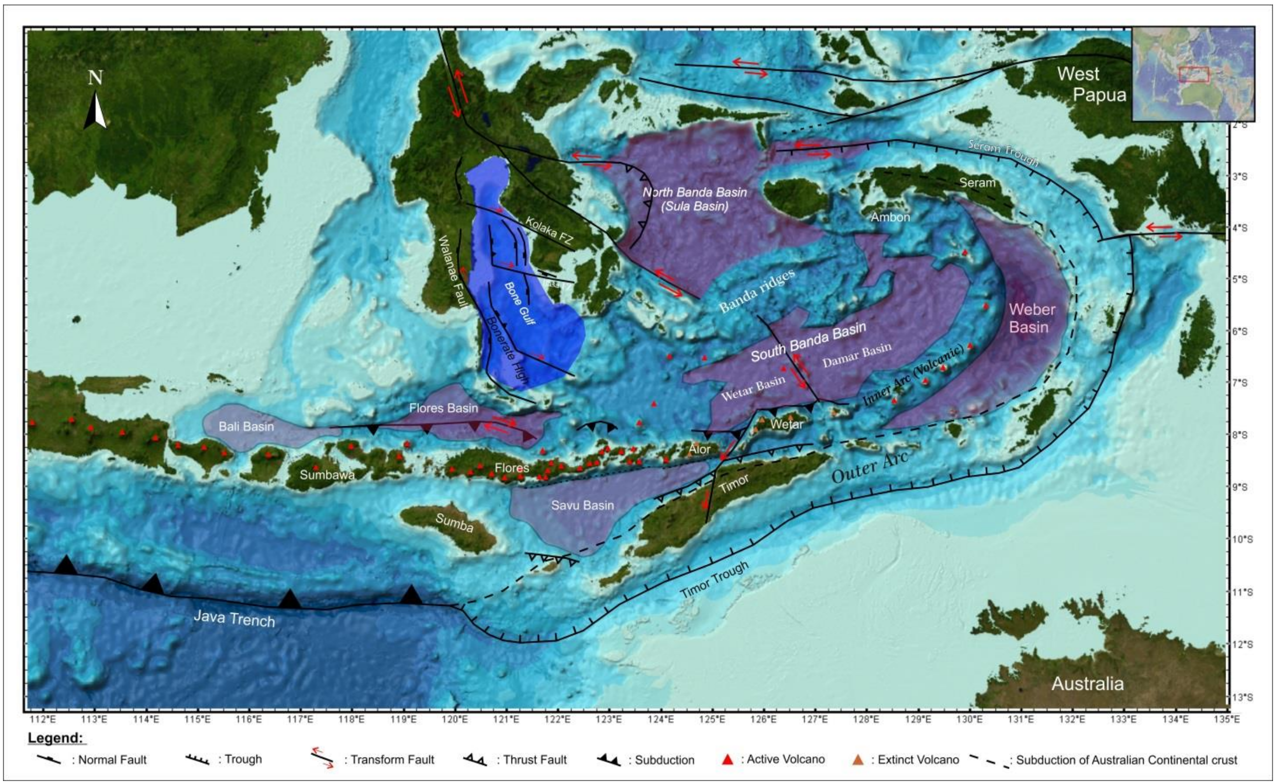

Figure 1: Simplified tectonic settings of Lesser Sunda Island (LSI), and its volcanism occurrences. (compiled from Hinschberger, et al, 2005; Hall, 2012; Camplin and Hall, 2014).

The genesis and evolution of the Flores island only represent the latest stage of a complex and long history of LSI due to the interaction between the Eurasian plate (Sundaland) and Australian plate which includes various process, i.e. rifting, drifting, subduction, and collision (Wensink, 1994; Hall, 2012, Tate, et al, 2015). The history of tectonic evolution of Lesser Sunda Island in general, and specifically in Flores island is important from the geothermal perspective, as it could give an implication for the origin of major features in the upper crustal structure, which may act as pathways for, or barrier to deep fluid flow (Rowland and Simmons, 2012).

The LSI mainly have two phase of tectonic settings. An extensional phase of LSI was started from ~20 – 4 Ma, which resulted in the south-migrating of Sumba Microcontinent and also the opening of basins i.e. Bone gulf, Banda, Flores, Savu and Weber Basin (Wensink, 1994; Hinschberger, et al, 2005; Rigg and Hall, 2011; Hall, 2012; Camplin and Hall, 2014). Subsequent to the extensional phase, the oncoming Australian continental crust induced collisional phase since ~8 Ma onwards which is started at the south of Wetar island and spreading to its surrounding at the east and west side (Hall, 2012; Tate, et al, 2015). This present day configuration coupled with the kinematic framework (Koulali, et al, 2016) shows the eastern of Indonesia has undergone an anticlockwise rotation with progressively increase motion from 9 mm/yr in Bali to 82 mm/yr toward the eastern end of Timor Trough, with Flores island as the transition zone from subduction to collision setting.

2.2 Composition of crust and subducted slabs

The crust underneath the volcanic arc thins eastward, from approximately 35 km beneath the Java island to 20 km beneath the Alor island (Pasyanos, et al, 2014; Syuhada, et al, 2016). The compositions of the subducted crusts along the Java trench are cold Indian-Australian oceanic crust with ages increasing eastwards from 80-150 Ma (Hall, 2012). In contrast, the subducted crusts along the Timor trough are a buoyant Australian continental crust which has thickness around ~40 km (Syuhada, et al, 2016).

2.3 Flores Island: the segmented volcanic arc

As a consequence of the tectonic setting of Flores island, which located at the transition zone from subduction to collision, a rollback on the subducted slab established beneath the Flores island. This rollback contribute the southward migrating volcanic arc on Komodo and Flores island, in contrast with the surrounding island which has northward migrating volcanic arc.

The southward-migrating volcanic arc is clearly visible on the West Flores, and progressively become less visible on the Central Flores, and become absent in the East Flores. The occurrences of volcanic edifice along the Flores island showed a progressive en echelon volcanic lineament, mainly E-W on the west and become NE-SW eastward (Figure 3).

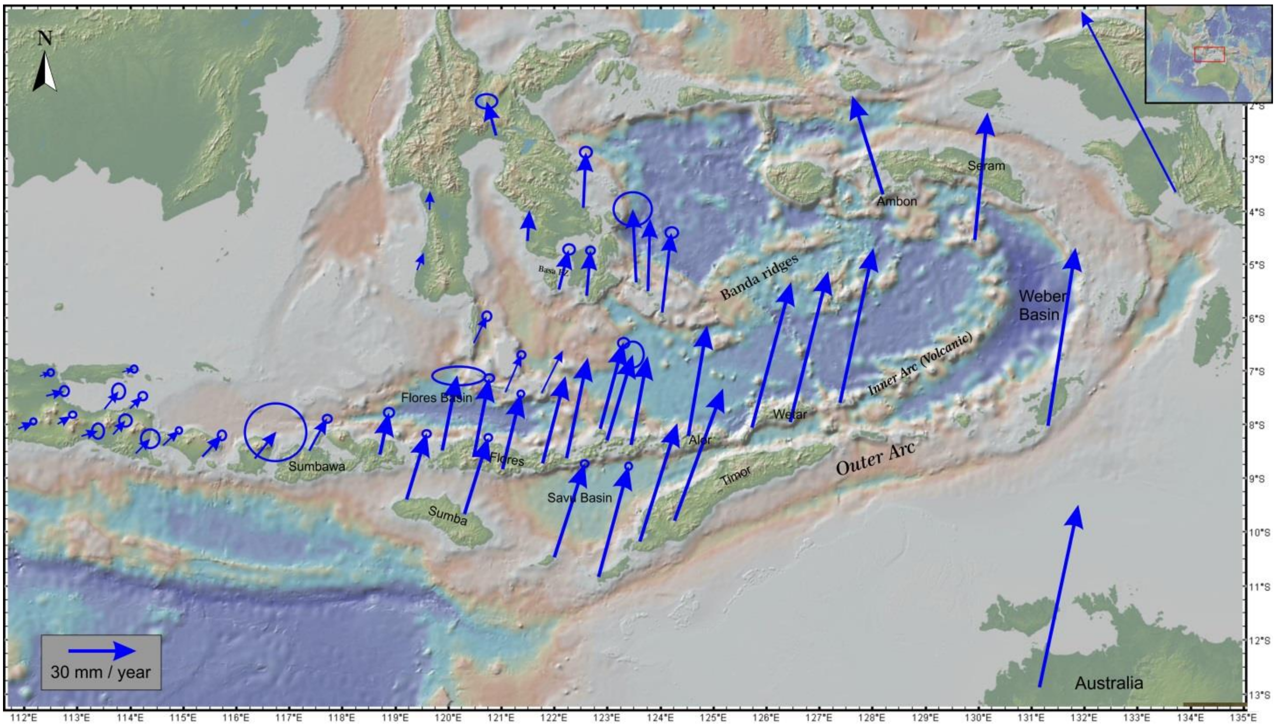

Figure 2: Kinematic framework of Lesser Sunda Island and eastern Indonesia with respect to Sunda Block (modified from Koulali, et al, 2016).

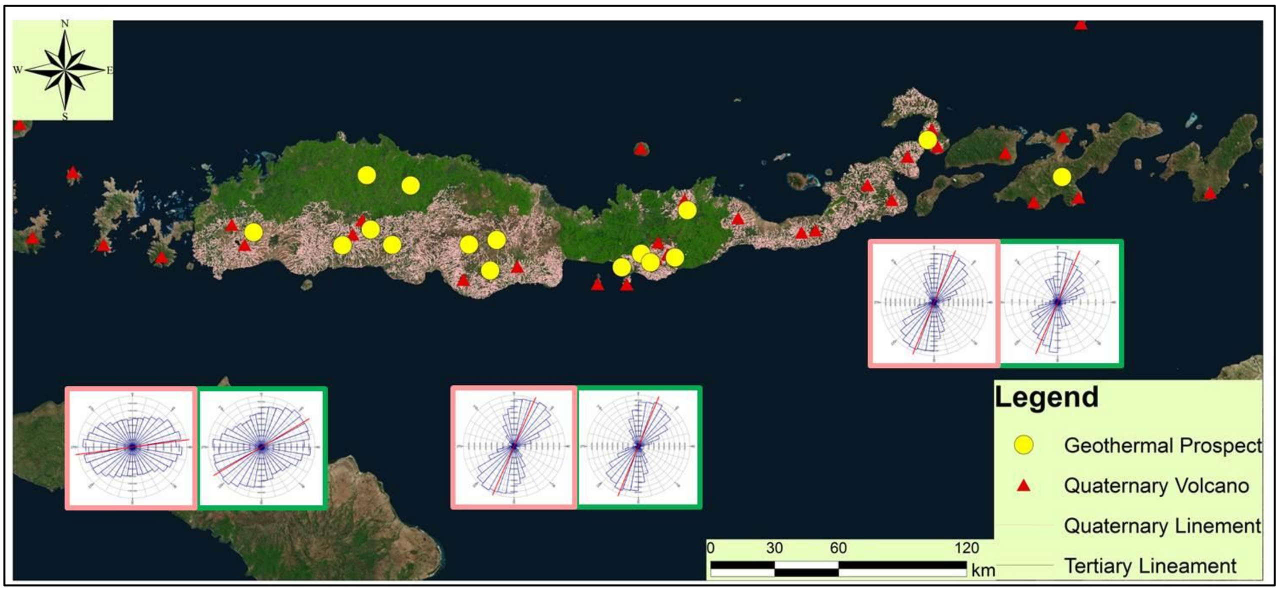

Figure 3: Lineament extraction of Flores Island and its rose diagram

3. VOLCANISM AND GEOTHERMAL FIELDS

3.1 Volcanism on Flores Island

Based on its age, the volcanism on Flores island could be divided into two main categories; Oligocene-Pliocene and Quaternary. The oldest volcanic rocks dated is about 27 Ma (Hendaryono, 1998), which mark the beginning of Flores volcanism. The Oligocene-Pliocene volcanism is mainly distributed over the West and Central Flores. This volcanism phase were developed while the Flores Island undergone in extensional tectonic settings. Afterwards, the Quaternary volcanism appear only in the southern part of the older volcanism specifically in

West and Central Flores, while in East Flores, the Quaternary volcanism dominate and covering all the older volcanism. This Quaternary volcanism is related to the rollback of subducted slab which only locally happen on West and Central Flores Island (Figure 3). The volcanic edifice on Flores Island are present either as cluster volcanoes or single chain volcanoes. The slab rollback beneath West and Central Flores cause the occurrence of cluster volcanoes while in the East Flores dominated by single chain volcanoes. (Figure 3).

3.2 Geothermal Fields

Related with the spatial distribution of the volcanoes, the geothermal prospect area were distributed as clustered especially in the West Flores and become less to the East Flores. Most geothermal prospect are spatially related with the Quaternary volcanic complex. Figure 3 shows that majority of geothermal prospect were found in the high elevation associated with the volcanic edifice, while two of them were found on the Tertiary volcanic complex with low elevation.

The clustered geothermal prospect occurrence are highly associated with the volcanic occurrences, which in directly controlled by the tectonic setting in the past.

5. CONCLUSIONS

The regional segmentation of West, Central and East Flores volcanic arc has affected different geothermal prospectivity of each segment. In this case, prospectivity decreases from the west to the east. West Flores which is the most prospective at a regional scale is spatially associated with the highest crustal heatflow due to the rollback of the subducted slab underneath.

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