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Geology Structure Identification based on Polarimetric SAR (PolSAR) Data and Field Based Observation at Ciwidey Geothermal Field

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Abstract. Geological structure observation is difficult to be conducted at Quaternary volcanic field due to the classical problem at tropical region such as intensive erosion, dense vegetation covers, and rough terrain. The problem hampers the field observation especially for geological structures mapping. In order to overcome the problems, an active remote sensing technology based on Polarimetric Synthetic Aperture Radar (PolSAR) data was used in this study. The longer wavelength of microwave than optical region caused the SAR layer penetration higher than optics. The Ciwidey Geothermal Field, Indonesia was selected as study area because of the existence of surface manifestations with lack information about the control of geological structures to the geothermal system. Visual interpretation based on composite polarization modes was applied to identify geological structures at study area. The color composite Red-Green-Blue for HV-HH-VV polarizations provided highest texture and structural features among the other composite combination. The Linear Features Density (LFD) map was also used to interpret the fractures zones. The calculated LFD showed high anomaly about 3.6 km/km^2 with two strike directions NW-SE and NE-SW. Interestingly, the surface geothermal manifestation agreed with the low anomaly of LFD. The geological structures consisted of ten faults were successfully detected and mapped. The faults type mainly are oblique-slip with strike directions NE-SW and NW-SE.

1. Introduction

Study area is a geothermal field located around crater lake and tourism spot Kawah Putih, Ciwidey, Bandung with the average elevation about 2.000 meter above sea level (m.a.s.l). The land use in Ciwidey area consists of farm land, estate crops (i.e, tea, strawberry, coffee, and other vegetable crops), tourism area, and conservation forest. Mt. Patuha and Mt. Kendeng are two volcanoes which contribute to produce Quaternary volcanic rocks in study area (Figure 1).

There are two geothermal working areas, which are operated by PT. Geo Dipa Energi and PT. Yala Teknosa Geothermal. Patuha Geothermal Field operated by PT. Geo Dipa Energi has completed exploration activities and Unit-1 of Patuha Geothermal Power Plant with a capacity of 55 MWe has operated since July, 2014 [1].

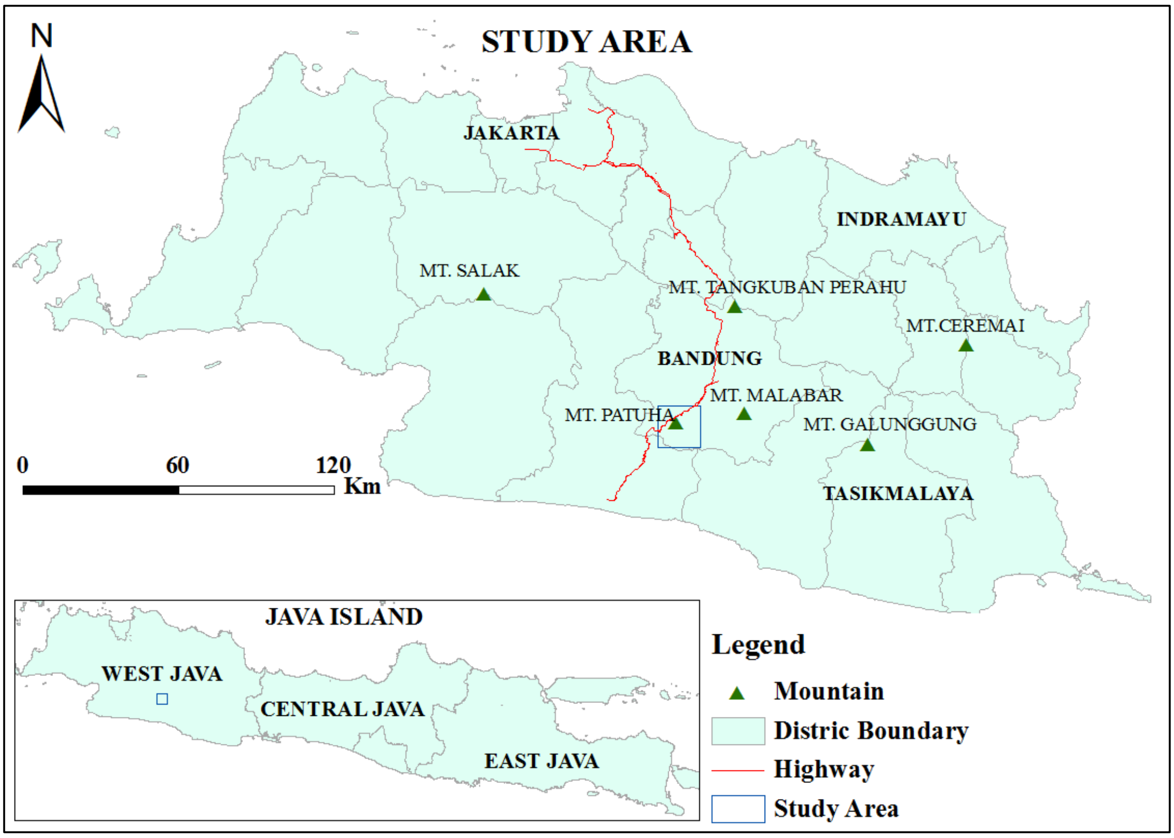

Figure 1. Study area located at Ciwidey Geothermal field about 46 km Southwest from Bandung is presented by light blue box.

Geological, Geochemical, and Geophysical surveys were able to delineate the study area widely [2]. Gravity and resistivity (MT and TDEM) survey had been conducted in the Patuha field. Based on their report, gravity lineament and electrical discontinuity were estimated for consideration of geological structure in this field [3]. In addition, geologic structures were also identified by cliff, rim features, waterfall, river stream lineament/morphology, continuity of eruption centre, and hotspring which may exist along the fault line [4]. Both methods only derived structure lineament without its kynematics and dynamics analysis, while those analyses have big role in permeability zone identification in this study area.

However, there was still minor information about surface geology structure in study area. Therefore, geology structure mapping need to be conducted in detail. Detailed distribution of geology structure could be used to predict the permeability of the surface/subsurface layers. The correct information about geological structures were required to interpret thermal fluid and conceptual model of geothermal system as well as prospecting geothermal well target.

This paper discussed about surface geologic structure identification using active remote sensing technology and geological mapping. We applied visual analyses of linear features based on Synthetic Aperture Radar (SAR) data. The Polarimetric SAR, termed as PolSAR is superior to detect Geomorphologic and Structural Features (GSF) under canopy vegetation and rough terrain in volcanic field [5]. In addition, the superiority of the microwave sensors is their capability to penetrate canopy vegetation and cloud cover [6].

2. Geology

Study area is located at Quarternary volcanic field in Java, Western part of Indonesia [7]. Historical geology of Java Island has been formed since early Tertiary through a convergent tectonic margin between the Indian-Australian Plate and the southeastern margin of Eurasian Continental Plate called the Sundaland [8]. The regional geology of study area is dominated by Quaternary volcanic products, which cover most of the Patuha field [9]. The volcanic products are determined by andesitic lavas and pyroclastics from Mt. Patuha and Mt. Kendeng. Majority of geology structures identified at Patuha is normal fault with strike direction at NW-SE and minority at E-W and N-S [4].

Rocks penetrated by geothermal wells at Patuha were dominated by lavas, tuffs, and breccias. The existence of eruption center formed volcanic cone and crater structure, apparently has been controlled by normal faults [3]. Fractures within the volcanic axis probably control intrusion at depth of the magmatic heat source for the Patuha geothermal system, as well as the eruption of magma to the surface. Structures in this zone also control fracturing system in the geothermal reservoir and serve as the path of the discharge of fumaroles to the surface [10].

Surface manifestations in study area are composed by fumaroles, thermal springs, cold gas discharges, mud pool, cold acid water, and steaming ground. Fumaroles are located at Cibuni Crater, Putih Crater, and Ciwidey Crater (Figure 2).

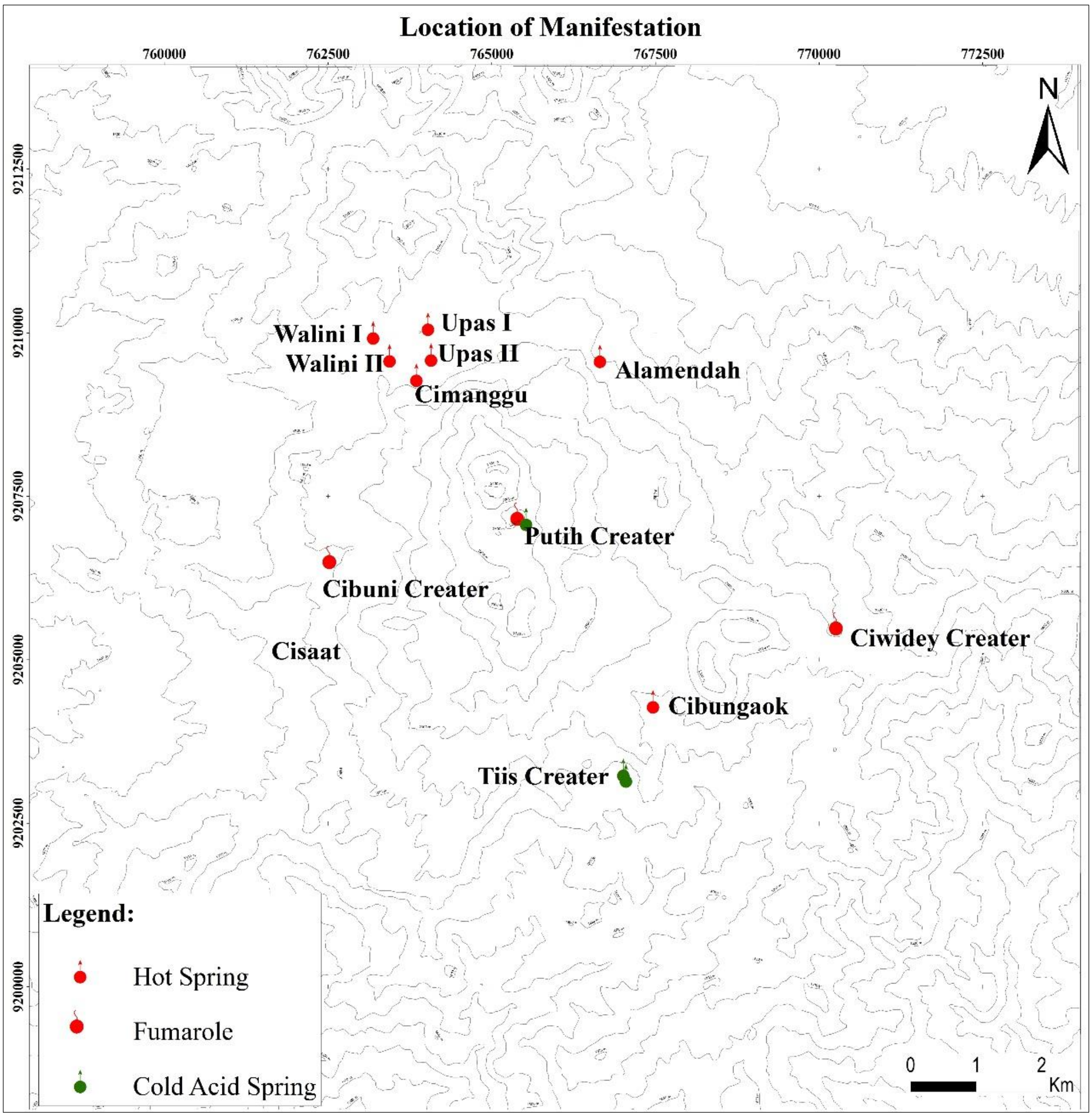

Figure 2. Location of manifestations in study area. Hot/ thermal springs and fumarol showed by red color and cold water showed by green color.

3. Remote Sensing

The Phased Array L-band type Synthetic Aperture Radar (PALSAR) full polarimetric (HH, HV, VV, and VH) with acquisition date on 19th April 2010 data onboard the Advanced Land Observing Satelite (ALOS) data was used in this study. The objective are to obtain Geomorphologic and Structural Features (GSF) and to interpret preliminary targets of permeability zone at study area. Visual analysis of GSF and Linear Features Density (LFD) based on color composite of SAR polarimetric data were applied to detect targets at ground surface. In order to predict the surface permeability zones targetted in this study, we correlated the fault at the field to the GSF and LFD.

3.1. Visual Analysis of PolSAR

Visual interpretation based on composite polarization modes was applied to identify geological structures at study area. The color composite of R-G-B for polarization HV-HH-VV provided highest texture and structural features among the others composite combinations. Comparing the histogram of each polarization data, there are two classifications: (1) high peak – high steepness and (2) low peak – low steepness. The second class, consists of HV and VH, one of them is choosen as red composite because its relatively more variety value compared to the first class. The green and blue composite are filled with the others straight polarization mode (HH and VV). The reason for this is because, based on the scatter plot, the combination between cross and straight polarization mode shows more variety value compared to the combination between cross and cross polarization mode.

This analysis was used as guidance for field observation and also used as detection basis for geologic structures such as fault lines in accordance to the evidence at the field. There were two geological features detected: linear and circular features. The linear features were interpreted as fault structures. A rose diagram showed four structural patterns, which were NW-SE, NE-SW, E-W, and N-S (Figure 3). Most structures were identified with NE-SW direction. These structures encompassed along hot spring, crater, and lake. Some manifestations also exhibited at NE-SW structures, such as the Walini area and Ciwidey Crater. It’s inferred that manifestations in the study area were controlled by fault structures.

There were 25 circular features detected based on visual analysis in this study. These features were interpreted as volcanic morphology such as crater, caldera, or the eruption center. One of the circular features was found as a lake in the field. Based on large number of circular features found in the area, it could be interpreted that the study area had high intensity of volcanism.

3.2. Linear Features Density (LFD)

The Linear Features Density (LFD) map and geologic structures identification were derived from detected linear features by visual analysis on each polarization mode data (HH, HV, VH, and VV) of PolSAR image. Total total lenght of linear features was calculated within grid size 1×1 km^2. The total length each grid was used to generate density contour map. The density value was in range 0–3.6 km/km^2 and the blue – red scale bar was adopted to simplify the interpretation process (Figure 4).

A rose diagram of the detected linear features shows two dominant patterns, which are NW-SE and NE-SW. High LFD associated with surface linear features and located at NE part of the study area, SE-SW of Putih Crater, and around Tiis Crater. In general, high LFD value corresponded with high topographic of mountainous range.

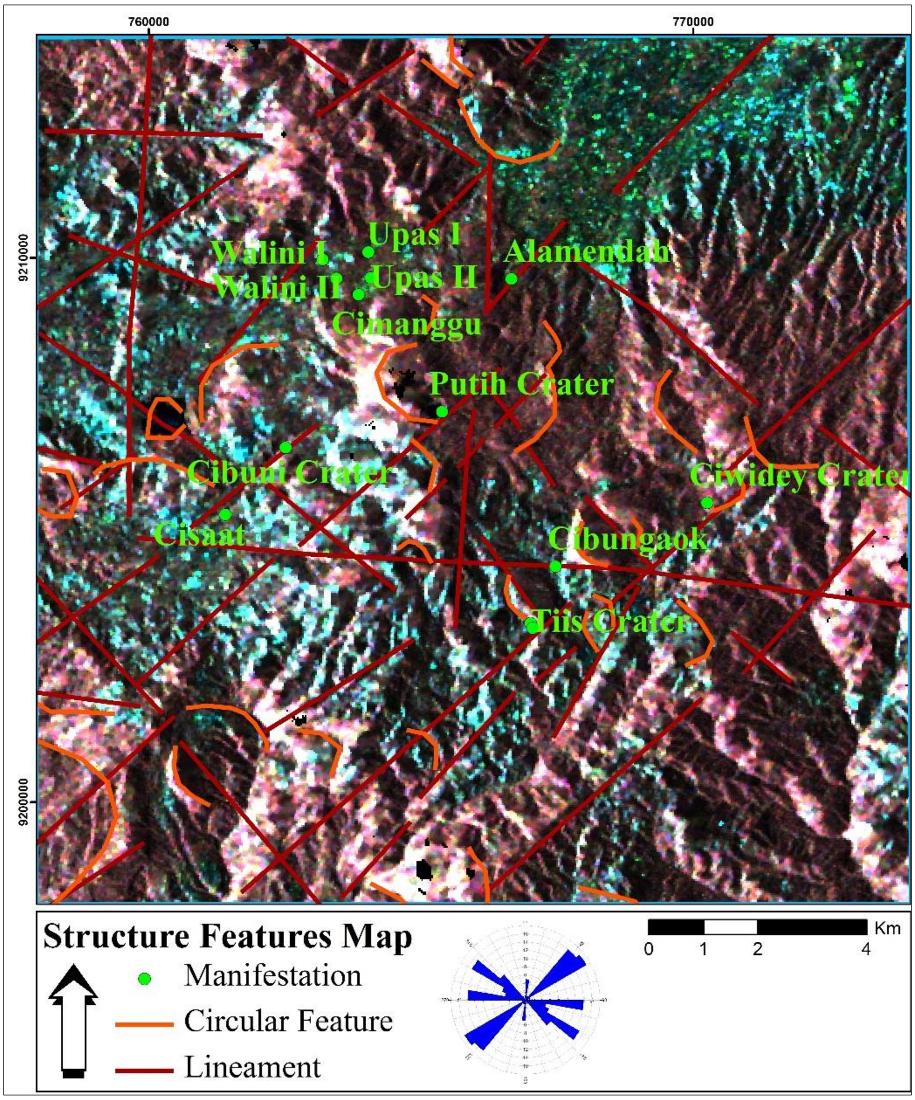

Figure 3. Visual analyses of study area in light blue box based on Polarimetric ALOS PALSAR with color composite for R=HV, G=HH, B=VV. Red lines and orange circulars are interpreted linear and circular features.

Low LFD value occurs at low topographic or valley area such as Walini and Upas area. Those low value forms an elongated shape from NE to SW in general and agrees with visual analysis in NE to SW trend. Based on manifestation occurences, those NE to SW lineament was interpreted as geologic structure.

This study shows that in general, surface manifestations associate with low LFD area such as Walini I-II, Upas I-II, Cimanggu hotsprings and medium LFD such as Cibuni Crater, Cisaat and Tiis Crater acid-springs, Cibungaok hotspring, and Ciwidey Crater. These phenomena are interpreted as structure trace dissipation due to high erosion, weathering, and alteration.

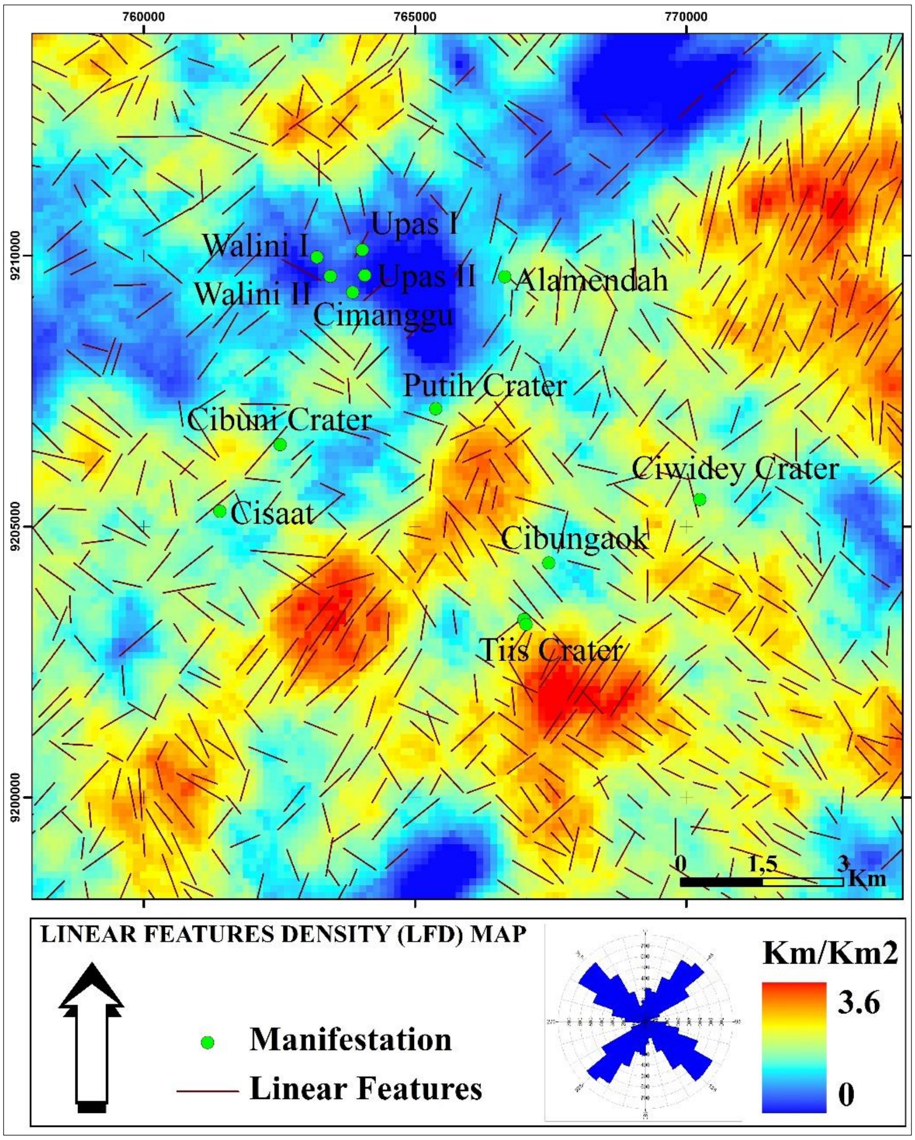

Figure 4. Linear Features Density (LFD) map shows surface manifestations from low to intermediate value with structural pattern NE-SW and NW-SW.

4. Geology Mapping

Geological mapping was performed and focused to geologic structure observation including measurements of shear, tension fracture, slicken slide, and brecciated zone. The measurements were conducted along detected faults based on SAR remote sensing as explained in the previous section. It is a clasical problem in tropical region that the geological structures at field is difficult to be found due to thick vegetation, intensive weathering, thick soil layer, and steep terrain.

The ten faults were identified in the study area based on SAR image analysis, field observation, and kinematics analysis (Figure 5). The faults type mainly are oblique-slip with strike directions are NE-SW and NW-SE, with N-S as the main stress formed the faults.

Manifestations are commonly located among the fault lines, as showed in Walini I, Walini II, Upas I, Upas II, and Cimanggu hotsprings (Figure 5). Those manifestations were located among Cimanggu Faults system with low LFD value. The Putih crater, Ciwidey crater, and Alamendah hotspring were also located among the fault lines with medium LFD value. The similar phenomena were also existed at Cibuni Crater, Tiis Crater, Cisaat acid-spring, and Cibungaok hotspring.

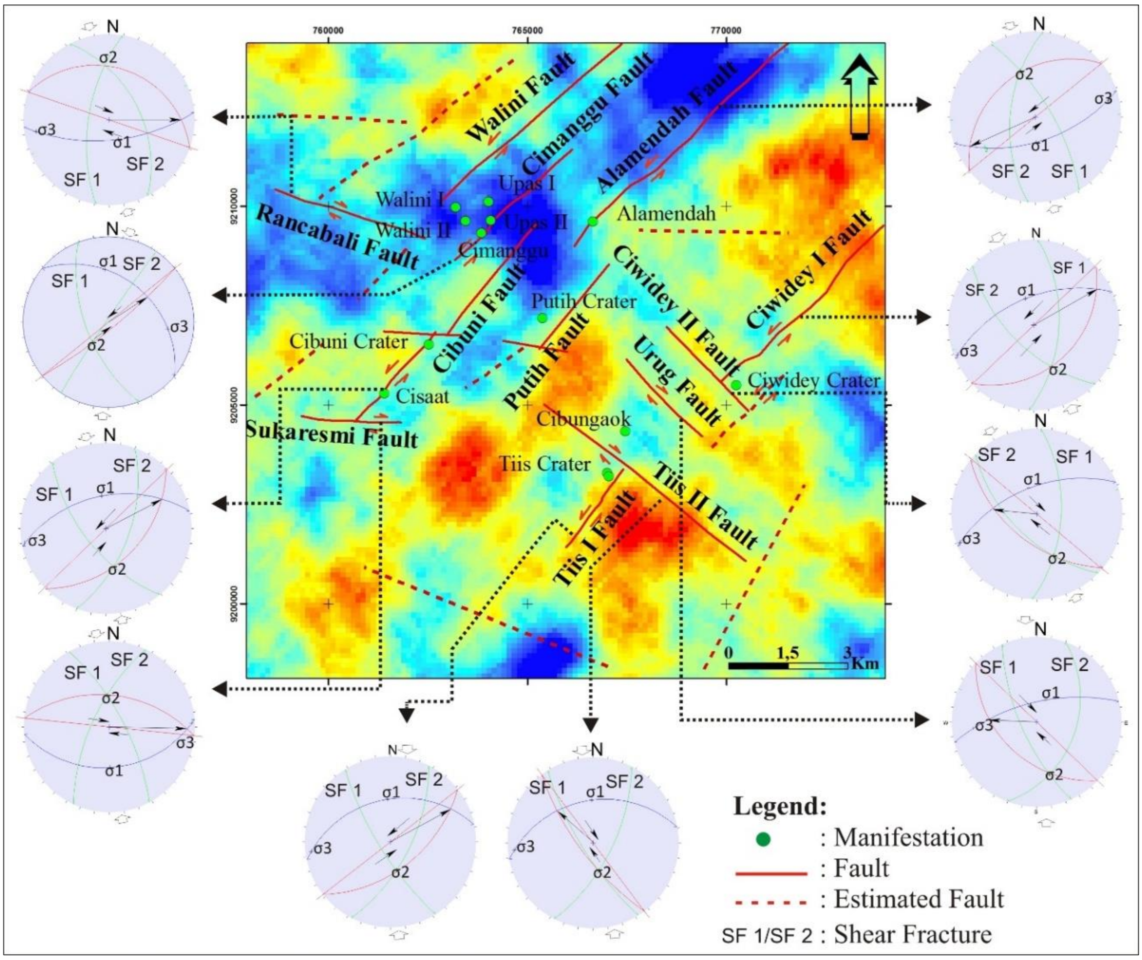

Figure 5. Geologic structures map and stereonet diagram analyses at study area overlaid on LFD Map. Geological structures (presented by red lines) were derived from PolSAR analyses confirmed by field observation as showed by black dots.

We interpreted that the surface manifestations located among the fault lines due to the faults system controlling the hydrothermal fluid paths. The segmentation and separation of the faults system caused offsets zones or extensional step-overs which increase the permeability of the rocks [11], [12] (Figure 6).

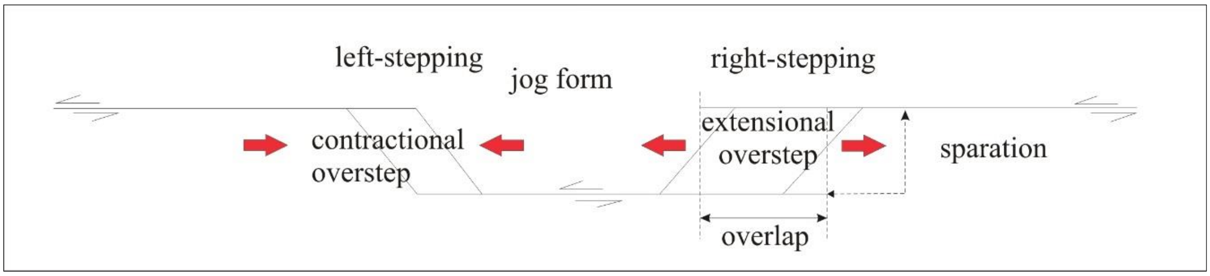

Figure 6. Conceptual model of restraining (contractional) and releasing (extentional) stepovers along a sinistral-slip fault for study area [11].

5. Conclusions

Visual analysis showed that there were four structural patterns, which were NW-SE, NE-SW, E-W, and N-S with dominant NE-SW trend. There were 25 circular features detected successfully and confirmed that the study area was located at volcanic terrain which plausible for the heat source occurrence in a geothermal system in Indonesia. Based on Polarimetric SAR image, the detected linear features are composed by two dominant patterns: NW-SE and NE-SW. Those patterns are justified as the existing faults direction and as discharge path of hydrothermal fluid.

Geothermal manifestations in the study area commonly associate with low-medium Linear Features Density (LFD). This phenomena caused structure trace dissipation due to high erosion and/or rock interaction with hydrothermal fluid.

According to PolSAR image analyses and geological mapping, the ten geological structures could be clarified. The faults type are mainly oblique-slip with strike directions NE-SW and NW-SE. The N-S is the main stress which formed the faults. Surface manifestations are commonly exhibit among the segmented fault lines. The segmented faults were separated by offsets or extensional stepover area and generated pulled apart system. The system provided subvertical conduits of high fracture density that enhance permeability and facilitate the rise of deep-seated thermal plumes.

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