Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Detailed Surface Structural Mapping of the Dieng Geothermal Field in Indonesia

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Keywords: geology, structural geology, structural, mapping, Dieng, geothermal

ABSTRACT

The Dieng field is located in Central Java, Indonesia with a 63 km^2 concession area. This field is also known as the vulcan complex area. About 47 wells were drilled to prove that the potential geothermal resources of this field can generate enough electricity for Unit 1 (60 MW). For Units 2 and 3, created for development purposes, resource assessment was done in the Dieng field. This included reservoir modeling and the evaluation of surface and subsurface structural mapping. Detailed surface structural mapping was conducted to evaluate the surface structural pattern and to reconstruct the volcano-tectonic structural play in the Dieng field. Detailed surface structural mapping consisted of two phases: the presurvey analysis phase and the postsurvey analysis phase. In presurvey analysis phase, structural analysis derived from IFSAR-DEM was conducted. IFSAR-DEM was chosen because of its spatial accuracy which can reach up to 8 m. The three steps of IFSAR-DEM structural analysis was conducted. This included IFSAR-DEM interpretation, including hillshade analysis, manually lineament delineation, and digitally extraction lineament; Statistic analysis; and Kinematics analysis. In the postsurvey phase, an analysis of structural geology data derived from field data was conducted to reconstruct the volcano-tectonic structural play. The result of this study indicated that Dieng field was located in the NE Flank of Serayu Geanticline, which was elongated in the E-W direction. The structural play consisted of three main orientations, which are NW-SE, N-S, and E-W. This structural play was believed to be responsible for controlling the permeability zone in the Dieng field.

1. INTRODUCTION

The Dieng field is located in Central Java, Indonesia with a 63 km^2 concession area. This concession area is owned by PT Geo Dipa Energi (Persero), an Indonesian geothermal state owned company (SOE). Resource estimation conducted by West JEC (2006) using numerical methods indicate that the Dieng Field resource size is 240 MW. Currently, the Dieng field is utilized for Unit 1, which is a 60 MW power plant. For the development of Units 2 and 3, several production wells should be drilled to supply the steam demand for the power plant. Based on this condition, both the resource assessment and evaluation have been done. Resource assessment activities consist of detailed structural mapping, reprocessing of geophysical data, and updating of the reservoir model. This paper will explain the detailed structural mapping, which is a part of the resource assessment activity.

2. REGIONAL GEOLOGY

The Dieng field is located in the North Serayu Mountainous Zone (van Bemmelen, 1949) with aged Oligo-Miocene (Figure 1). Van Bemmelen (1949) divided the volcano-tectonic evolution in Java into seven stages. The first stage is the central java volcanism in Early Miocene, which caused the depression of the North Serayu back-arc basin. The second stage is the highest activity in the South Serayu volcanic-arc in early-Middle Miocene. The third stage is the orogenetic activity in Middle Miocene, which caused sedimentary debris to accumulate at the edge of North Serayu Zone. Next, the fourth stage is the end of the South Serayu volcanic activity and the beginning of the North Serayu volcanic arc activity in late-Middle Miocene. The fifth stage consists of orogenetic activities, which caused the uplifting of the South Serayu Zone in Late Miocene. The sixth stage is composed of orogenetic activities, which cause the uplifting of the North Serayu Zone in Late Pliocene. The seventh stage is indicated by the intensive activity of younger volcanism in the North Serayu Zone, which caused volcanoes to appear in this mountainous zone (Figure 2). The overburden from the appearance of these volcanoes triggered gravitational mass distribution in this zone. Overall, the Dieng field is believed to have formed during the seventh stage activity.

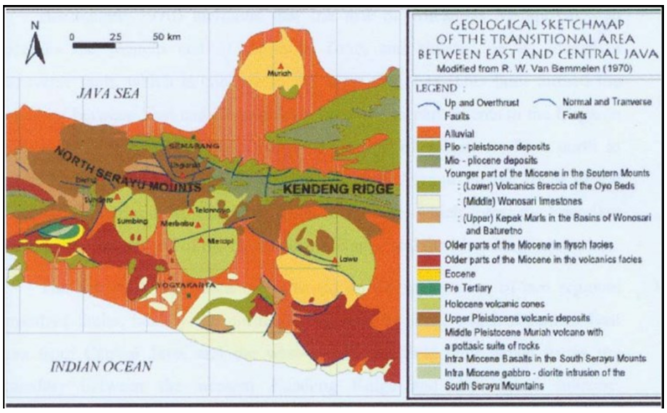

Figure 1: Central Java Physiography (modified from van Bemmelen, 1970)

Van Bemmelen (1949) also divided the regional stratigraphy of North Serayu Zone into several series. The oldest rocks called “Eocene Series”, outcropped at Karangkobar area, are aged Eocene. Above this series, sequentially, overlay the Sigugur Limestone series in Oligo-Miocene, Merawu Series in Early Miocene, Penjatan Series in Middle Miocene, Bodas Series (volcanic facies) in Late Miocene, Bodas Series (neritic facies) in Early Pliocene, Ligung Series in Early-Middle Pleistocene, Jembangan Series in Middle-Late Pleistocene, and Alluvial and Dieng Volcanic deposited in Holocene. Dieng field’s stratigraphy is believed to consist of Dieng Volcanics deposited during the Holocene. However, the oldest Dieng Volcanic deposited sample had been from dating measured by Budihardi (1991) which put the age at 3.6 Ma (Late Pliocene). This is interpreted to be a part of the van Bemmelen’s Ligung Series.

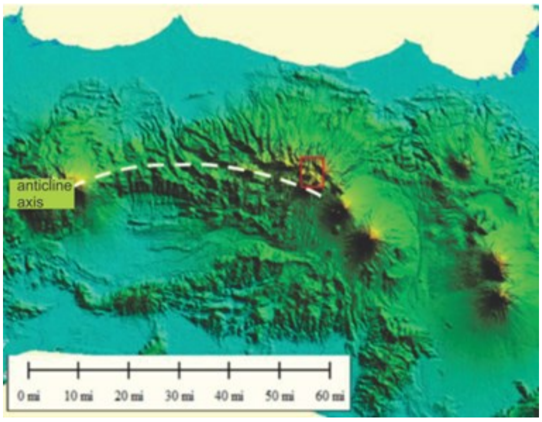

Figure 2: North Serayu Mountainous Zone (Dieng Field in red box)

3. GEOMORPHOLOGY AND STRATIGRAPHY OF DIENG FIELD

3.1 Geomorphology

The geomorphology of the Dieng field has been analyzed using two approaches for determining the geomorphology unit: morphology identification and process interpretation;

3.1.1 Morphology Identification

The morphology identification of the Dieng Field was conducted using the IFSAR-DEM image, which has an 8 m resolution. It helped in precisely distinguishing the morphology features in Dieng field.

3.1.2 Process Interpretation

The process interpretation of the Dieng field is conducted by determining the most dominant geomorphic process which controlled the landscape. This method included the interpretation of endogenic processes such as lithology and structural geology and also the interpretation of exogenic processes such as the degree of deformation, slope, and elevation. According to this approach, the most dominant process that controlled the Dieng field was a volcanic process.

3.1.3 Geomorphology Unit

The geomorphology units (Figure 3) of Dieng Field were determined based on the two approaches stated above. The geomorphology units are:

1) Volcanic cone unit. There are 20 volcanic cones identified in the Dieng field which are: Gn. Sikunang; Gn. Seroja; Gn. Pakuwaja; Gn. Kendil; Gn. Watusumbu; Gn. Sikunir; Gn. Prambanan; Gn. Igirbinem; Gn. Pangonan; Gn. Merdada; Gn. Sipandu; Gn. Pagerkandang; Gn. Sembungan; Gn. Sidede; Gn. Bisma; Gn. Nagasari; Gn. Jimat; Gn. Reban; Gn. Sigemplong 1; Gn. Sigemplong 2,
2) Gn. Prau structural-denudational unit,
3) Gn. Gajahmungkur denudational unit,
4) Alluvial plain unit.

3.2 Stratigraphy

According to a study performed by Miller et al. (1984), geological map by Sukhyar et al (1986), and dating of several rocks by Budihardi (1991), the Dieng field is divided by three parts which are: older Dieng, mature Dieng, and younger Dieng.

Based on these data, the stratigraphy distribution of Dieng Field was determined using two approaches: the interpretation of lithology unit distribution from IFSAR-DEM image analysis and the interpretation of the lithology unit distribution from field checks. Wohletz et al (1992) stated that the identification of volcanic facies and stratigraphy relationships among lithology units are the key factors to determining a precise distribution of the lithology units in a volcanic area. The result derived from these approaches show that the Dieng field consists of several lithology units (Figure 4), which are:

1) Older Dieng. The older Dieng consists of Gajahmungkur tuff breccia, Prau andesite lava, and tuff breccia (3.60 Ma), Reban andesite pyroxene lava, Sigemplong 1 andesite pyroxene lava, Sigemplong 2 andesite pyroxene lava, Nagasari andesite lava & tuff breccia (2.99 Ma), Jimat andesite lava & tuff breccia, Bisma tuff breccia (2.53 Ma), Sidede tuff breccia, Sembungan andesite pyroxene and tuff breccia.

2) Mature Dieng. The mature Dieng consists of the Pagerkandang lava and tuff breccia, Sipandu andesite pyroxene lava, Pangonan andesite lava and tuff breccia (0.37 Ma), and Merdada lava and tuff breccia (0.37 Ma).
3) Younger Dieng. The younger Dieng consists of Igir Binem tuff breccia, Prambanan andesite basaltic lava & tuff breccia, Watusumbul andesite basaltic lava and tuff breccia, Sikunir andesite basaltic lava, Kendil andesite basaltic lava and tuff breccia (0.19 Ma), Pakuwaja andesite basaltic lava and tuff breccia (0.09 Ma), Seroja andesite basaltic lava and tuff breccia (0.07 Ma), Sikunang andesite basaltic lava, and Alluvial.

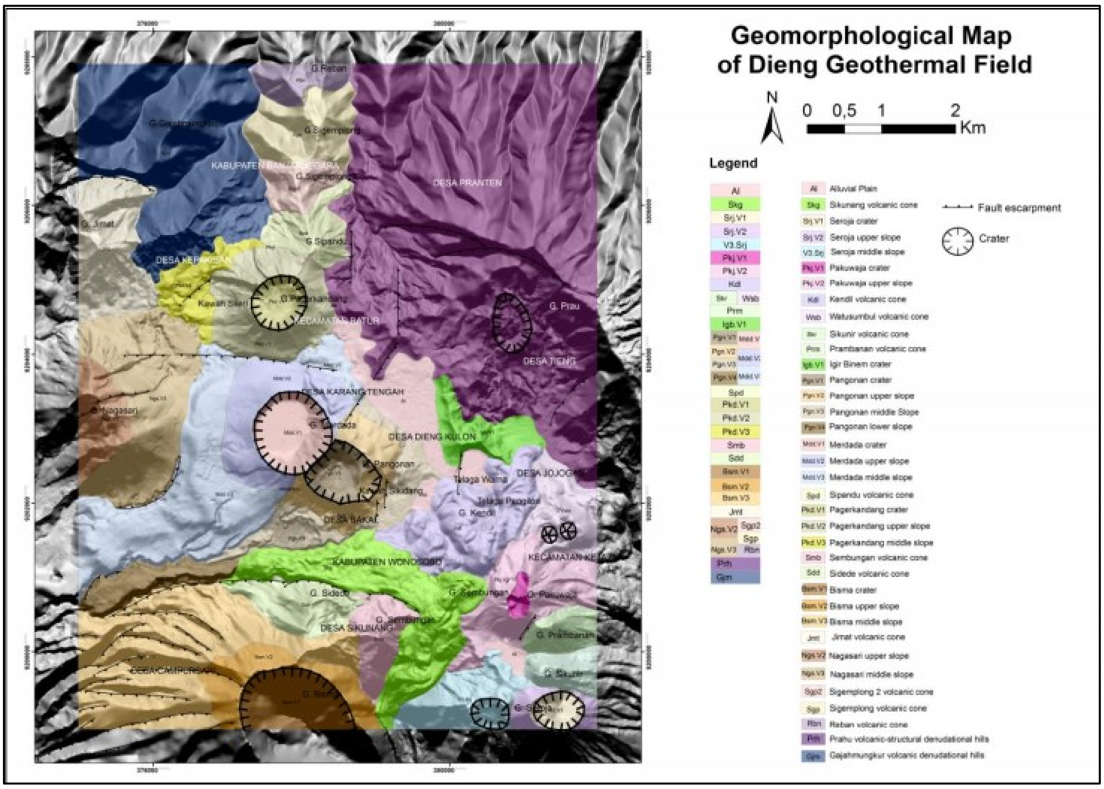

Figure 3: Geomorfology Map of Dieng Field

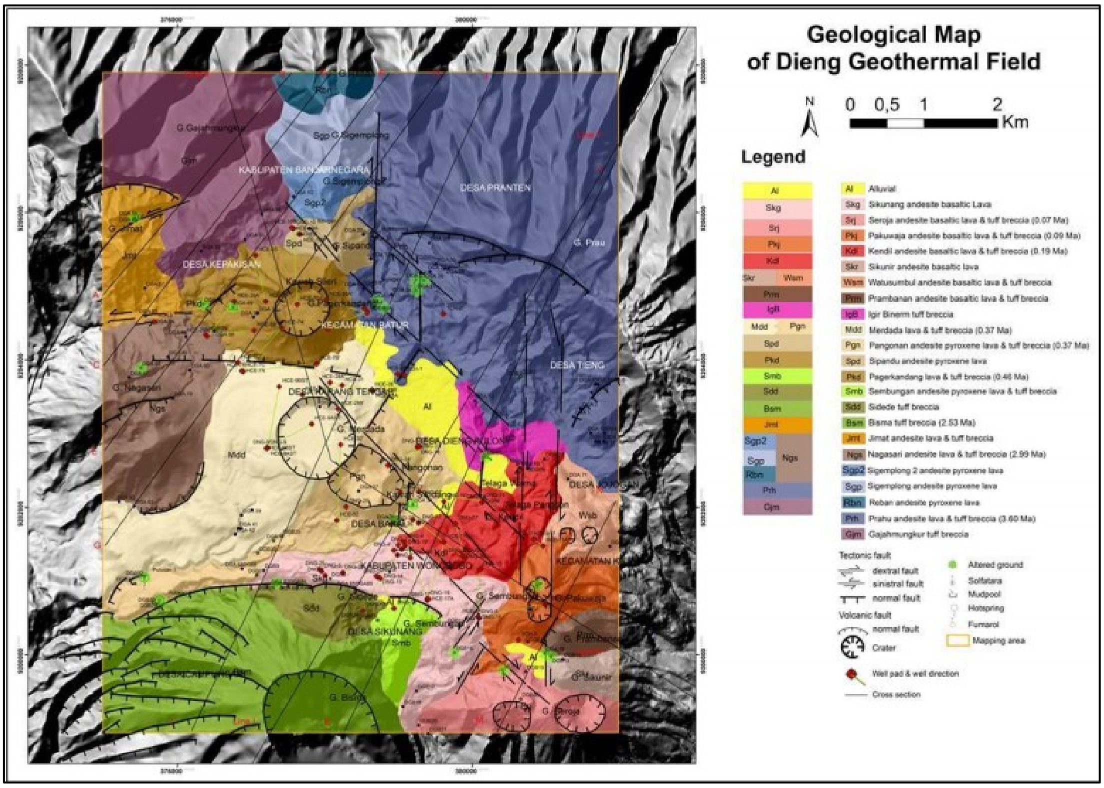

Figure 4: Geological Map of the Dieng Field

4. DETAILED STRUCTURAL GEOLOGY

The detailed structural geology of the Dieng field was determined using two approach phases, which are: 1) pre-survey analysis phase and the post-survey analysis phases. The result of both approaches were combined to obtain a comprehensive analysis of the structural geology play that controlled the Dieng Field.

4.1 Pre-Survey Analysis phase

In the pre-survey analysis phase, IFSAR-DEM image was used as the basic data for analysis and interpretation. QC checks were done to assure the accuracy of the IFSAR-DEM image, which resulted to 8 m accuracy. Several analyses were conducted to obtain a detailed structural geology interpretation derived from the IFSAR-DEM image, which are: hill-shade analysis, manual lineament delineation, digital lineament extraction, and statistical analysis.

4.1.1 Hill-shade analysis

Hill-shade analysis was conducted to obtain a proper figure of relief from IFSAR-DEM, especially for a steep slope which probably indicated a major lineament. Eight azimuth directions were used in the software in order to do the Hill-shade analysis to get a proper relief from the IFSAR-DEM image (Figure 5). The result from this analysis will be used for the next analysis.

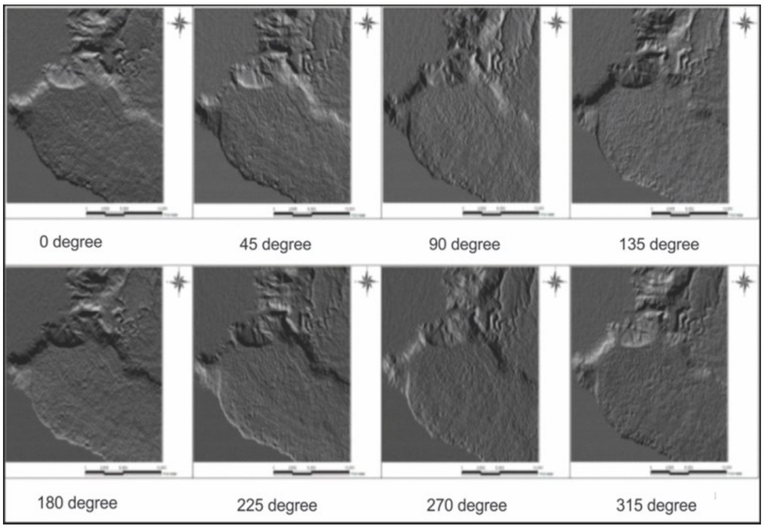

Figure 5: 8 Eight azimuth directions from the Hill-shade analysis

4.1.2 Manual lineament delineation

Manual lineament delineation is conducted by delineating a relatively linear lower slope which has a particular length. By manually delineating, the linear feature resulted from tectonic activity could be differentiated from the linear feature which resulted from non-tectonic activity. The linear feature which resulted from tectonic activity has a specific characteristic such as repetitive with an arranged interval. There are 53 (fifty-three) lineaments recovered from this analysis in the Dieng Field, which were probably related with tectonic activity.

4.1.3 Digital lineament extraction

Digital lineament extraction was conducted using a software programs with several parameters such as pixel filter radius, gradation edge limit, curve length limit, differential degree limit, etc. The purpose of this analysis was to obtain a larger amount of lineament distributions based on those parameters. There were 1651 lineaments recovered from this analysis, which were probably related with both tectonic and nontectonic activity.

4.1.4 Statistical analysis

Statistical analysis was conducted for several data sets such as joint data and lineament data. The purpose of this analysis was to obtain the maxima from several sets of data and recover the spatial distribution of those data. There are two ways to visualize the result from statistical analysis, which are: rose diagrams and stereonets.

The result of the statistics analyses from manual lineament delineation using a rose diagram show two maxima values, one is N-S trending and the other is E-W trending (Figure 6). These maxima are interpreted as an extensional fracture of E-W trending anticline, which resulted from a compression force which is trending N-S. These evidences also show that the Dieng Field lineation is still influenced by the tectonic uplifting of the North Serayu zone. The E-W trending lineation appears to be the tension fracture of an anticline crest (tension joint), and the N-S trending lineation appears to be a tension fracture of the anticline flange (dip joint). Beside these two maxima, there are also NW-SE and NE-SW trending lineations (Figure 6). In the anticline framework, these lineations are interpreted as oblique shear joints which appear in the anticline flange, which complements the tension fracture (dip joint) that is N-S trending (Figure 5).

The result from the statistical analysis from digital lineament extraction shows a different trend compared to the manual lineament delineation, where a single maxima appears with an E-W trending direction (Figure 7). A combination of a lithology distribution and digital lineament extraction is conducted by isolating the digital extraction process in each lithology unit. The result shows that the NW-SE trending and NE-SW trending lineaments distribute mostly in the northern part of the field along with older lithology units such as Gajahmungkur, Jimat, Prau, Reban, Nagasari, Sigemplong 1 and Sigemplong 2 (Figure 8). On the other hand, the E-W trending lineament distributes from the middle of the field up to the southern part of the field along with younger lithology units such as Pagerkandang, Pangonan, Merdada, Kendil, Sikunang, Pakuwaja, Seroja, Prambanan, Watusumbul, Sikunir and Alluvial (Figure 8). The E-W trend is interpreted as a tension joint near the anticline crest. On the other hand, the NE-SW and NW-SE trends are interpreted as oblique shear joints in the anticline flange. This result is coherent with the results from manual lineament delineation, which show four trends: E-W, N-S, NW-SE, and NE-SW. This result also strongly indicated that the tectonic regional play in the Dieng Field is influenced by the North Serayu Geanticline.

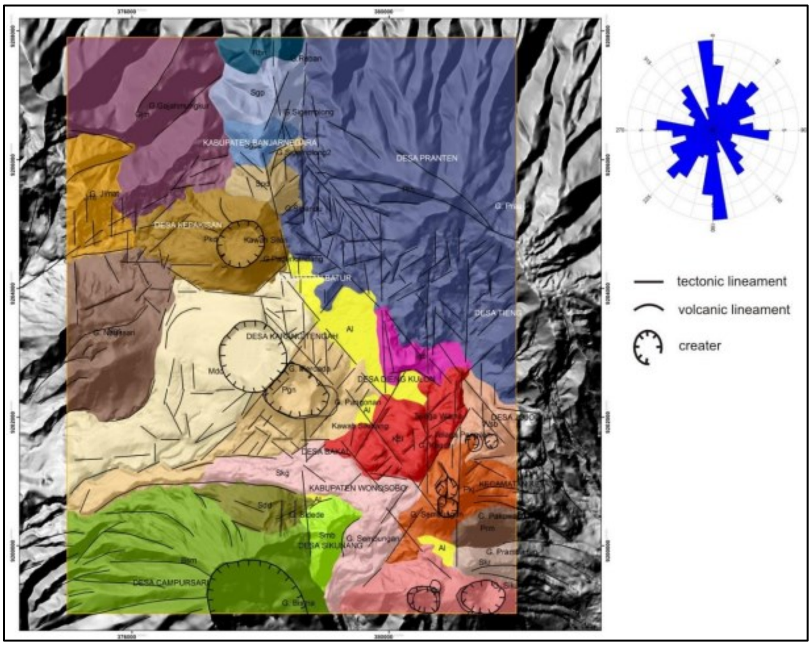

Figure 6: The result from manual lineament delineation

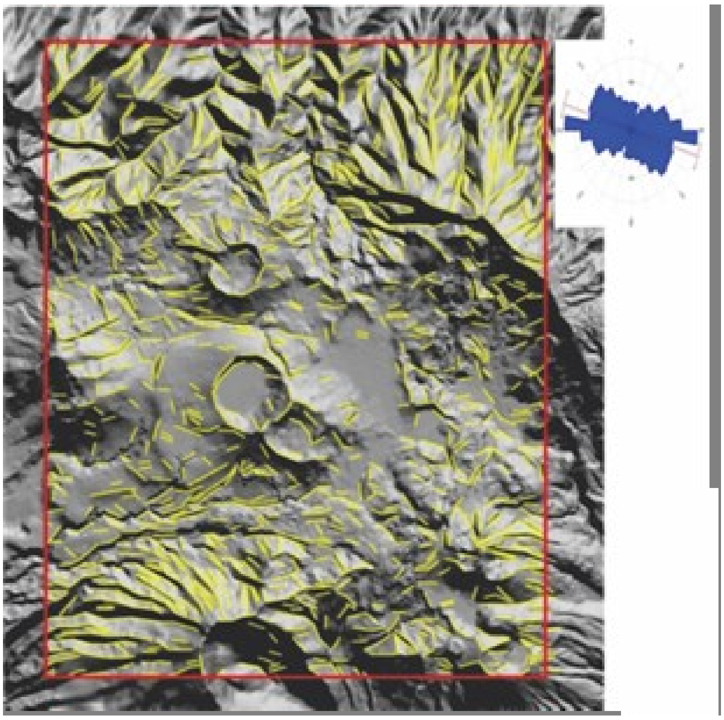

Figure 7: The result from digital lineament extraction

4.2 Post-Survey Analysis phase

The post-survey analysis phase is conducted after the field check. The data derived from field check, including lithology distribution and structural geology, will be analyzed to update the results from the pre-survey analysis phase.

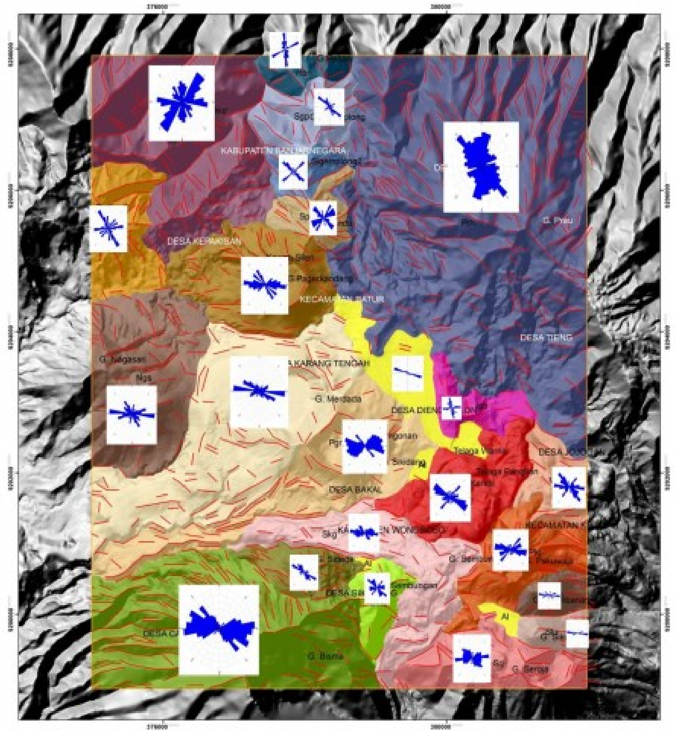

Figure 8: The result from the combination of digital extraction and lithology distribution

4.2.1 Statistics analysis

About 396 data of shear joints and tension joints have been analyzed using a rose diagram to determine its trend (Figure 9). Shear joints show two maximum directions with NE-SW and NW-SE trends. However, tension joints show two maximum directions with N-S and E-W trends. These results are coherent with the tectonic regional concept derived from the pre-survey analysis phase results. Shear joints with NW-SE and NE-SW trends are interpreted as oblique shear joints, which are products of a N-S compression that caused the uplifting of the North Serayu zone. Tension joints with N-S and E-W trends are interpreted as extensional zones in the anticline crest and anticline flange.

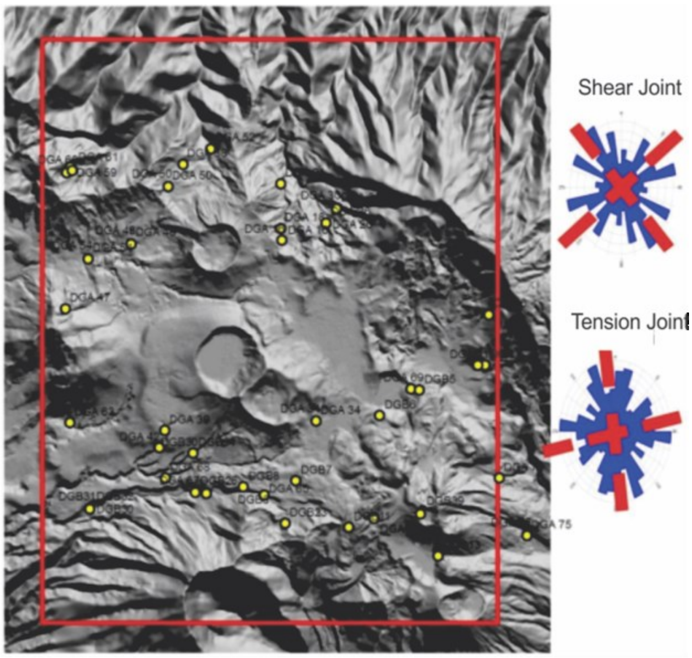

Figure 9: The result of statistical analysis from 396 joints data sets. The yellow dots are the data locations.

4.2.2 Kinematics analysis

Kinematics analysis is conducted on the fault data to determine its relative movement and to predict the tectonic regime working in Dieng field. About nine fault data sets have been analyzed, six faults are located in the younger lithology units and three fault data sets are located in the older lithology unit (Figure 10). The result indicated that the extensional tectonic regime trending N-S is working on a normal fault which strikes E-W in younger lithology units. The normal fault, which strikes N-S, also appears, although not dominant, in the northeastern part of the Dieng field as a result of extensional tectonics regime that trend in the E-W direction. On the other hand, the older lithology units located in northwestern part of Dieng field are influenced by the compressional tectonics regime trending N-S, which resulted in a strike-slip fault.

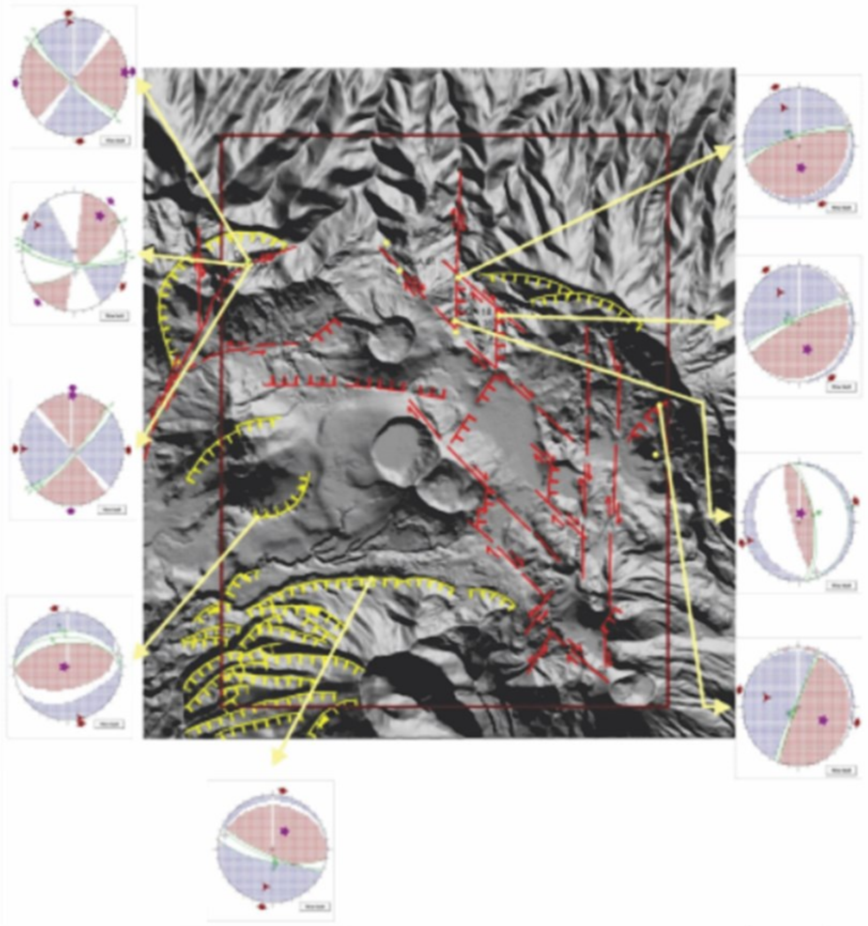

Figure 10: The result from the kinematics analysis based on the data from nine faults.

Volcanic-triggered faults are also found in the Dieng Field. Generally, a volcanic-triggered fault appears to be a gravitational fault that resulted from a lateral movement along a weak zone which is triggered by the volcanic overburden. Volcanic-triggered faults in the Dieng field predominantly trend in the E-W direction for younger lithology units. This trend is superimposed with normal faults that have resulted from the extensional tectonics regime. This evidence shows a close relationship between the volcanic-triggered faults and tectonics faults in the Dieng field. Volcanic gravitational deformation is interpreted to be controlled by tectonics faults reactivation, which is located under the volcanic deposits.

5. CONCLUSION

Based on the structural geology and volcano-stratigraphy analyses, some changes occur sequentially, in terms of the structural geology, between the N-S and NW-SE directions in the Dieng field. The volcano-tectonic history of Dieng Field could be described as follows:

1) Dieng Field volcanism started with the appearance of the Prau volcano in Late Pliosen,
2) The partial collapse of the Prau volcano towards NW is interpreted as being triggered by the uplifting of the North Serayu Geanticline in Late Pliosen. This interpretation is based on the Prau volcano location in the northeastern edge of North Serayu Geanticline. The NW-SE trending structure of the North Serayu Geanticline is believed to be responsible for this partial collapse,
3) The next volcanism activities come from the Nagasari and Bisma volcanoes in the Late Pliocene-Early Pleistocene, which fill the tectonics fracture that trends in the NW-SE direction, as derived from the Prau partial collapse,
4) In Middle Pleistocene, two particular volcanism trends appear: a) Pagerkandang – Sigemplong volcanoes appear with a N-S trend between the Nagasari and Prau volcanoes, followed by the b) Merdada – Pangonan – Kendil volcanoes appearing with a NW-SE trend between the Paru and Bisma Volcanoes,
5) In Late Pleistocene, there appears to be a particular volcanism in the eastern part of the Dieng Field with a N-S trend that resulted in the Pakuwaja – Seroja volcanoes,

6) Early Holocene is interpreted as the last tectonic regime with the appearance of a dextral fault trending NW-SE in the middle of Dieng field. This fault is believed to be responsible for the alluvial distribution in the northern part of Pangonan – Merdada volcanoes. It controls the current hydrothermal system in the Dieng field.

Based on the analysis of the stratigraphy and structural geology, there are three major structural trends that control the Dieng Field, in terms of volcanic activity and hydrothermal systems. These are the N-S, E-W, and NW-SE directions. Having understood these major structural trends would give an advantage in understanding the Dieng field geothermal system. Another advantage is for developing the field in the future.

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