E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 03 No 02 2018

Structure and Tectonic Reconstruction of Bayah Complex Area, Banten

Jemi S. Ahnaf[1,*], Aton Patonah[1], Haryadi Permana[2], Ismawan[1]
[1] Geological Engineering Department, Padjadjaran University, Bandung-Sumedang Highway, Jatinangor 45363, Indonesia
[2] Research Center for Geotechnology of Indonesia Institute of Sciences (LIPI), Sangkuriang Street, Bandung 40135, Indonesia

*Corresponding author: jemi14001@mail.unpad.ac.id
Tel.: +62-87828909836
Received: 2 May, 2018. Revised : 20 May 2018, Accepted: 26 May, 2018, Published: 1 June 2018
DOI : 10.24273/jgeet.2018.3.2.1554

Abstract

The research aimed to reconstruct the geological structures and tectonics of the Bayah complex area. The structures found that grouped into regional structural patterns used to determine the ages and the events that responsible to its formation. Field survey carried out to map the outcrops and record geological structures data such as as fractures, slickenside, and metamorphic foliation using geological compass, GPS, tape measurement, and geological hammer. Based on the survey, 3 faulted outcrops, 7 highly fractured outcrops, and 2 reconstructed folds have been recorded. The geological structure of the Bayah has varying patterns and ages. The fracture patterns show N-S and E-W direction which is belong to Sundanese and Java Pattern formed in range of the Early Eocene to Pliocene. While the faults that have direction of SW-NE and E-W are classified into Meratus and Java Pattern. However, metamorphic rock foliations show NW-SE and N-S direction that belonging to the Pre-Tertiary Sumatra Pattern. The three faults of this research are estimated to be formed by the effect of orogenesis that occurring in different events and ages. JSA-014 fault is predicted to form due to orogeny I or orogeny II in the Early Oligocene - Middle Miocene, this fault classified as the 2nd order right lateral wrench fault. JSA-034 fault is formed by orogeny I in Early Oligocene - Middle Miocene, this fault is also classified as the 2nd order right lateral wrench fault. While JSA-080 fault has relatively young age that formed due to orogeny III in the Middle Miocene - Pliocene and belonging to the 3rd order left lateral wrench fault.

Keywords: Structure, tectonic, orogeny, wrench fault, Bayah.

1. Introduction

1.1 Research Background

Bayah is one of the area in western Java Island that administratively located in Lebak Regency, Banten Province. This area known to has complex structure patterns as it is affected by the collision between the Indo-Australian Plate and the Eurasian Plate. According to Sukarna et al. (1993), the collision of these two plates occurred in the Early Cretaceous or at least the Late Cretaceous that caused the Indo-Australian Plate subducted under the Eurasian Plate formed the island-arc system. The collision also resulted in varied structural patterns that developed in various rock types from Early Tertiary to Quaternary rocks. In addition, the diversity of litologies due to volcanism and magmatism also contribute to the complexity of its geology setting.

This research aimed to reconstruct geological structures based on the regional structural pattern that already compiled by Pullunggono & Martodjojo (1994), the structures found especially the faults will also be modeled based on the wrench fault system suggested by Moody & Hill (1956). The results of the structures reconstruction were then used to support the tectonic reconstruction. Field data such as outcrops, fractures, slickenside, and metamorphic foliation were collected from three villages namely Cikadongdong, Lebakpendeuy, and Barunai which included in Cigemblong and Cihara District, Lebak Regency, Banten Province. The field data taken during the research is restricted to 5.5 km^2.

1.2. Geology Setting

The research area has a complex geological setting that displayed by three different types of rocks (igneous, sedimentary, and metamorphic) in the same region. Based on Sujatmiko & Santosa (1992), the rocks are grouped into Bayah Formation, Cikotok Formation, Granodiorite Cihara, and Metamorphic Groups where the contacts among the four formations are nonconformity.

- Metamorphic Group

This rock group is exposed in the Cigaber and Cisanun River, the rocks found including metapelites and metamafics derived from protolith of sedimentary and igneous rocks. These rocks are thought to be Early Tertiary ages that were uplifted to the surface through a retrograding process before the Bayah Formation was formed.

- Bayah Formation

This formation is exposed on the Cipager River, Cigaber River, and Cisanun River respresented by claystone and sandstone which is sometimes found as interlayered. Based on U-Pb radioactive dating from Clements & Hall (2008), the rocks in this Formation have the oldest age of the Middle Eocene and formed from the siliciclastic material of Malay Peninsula and Indonesia Tin Islands. This formation is deposited on neritic-paralic environment that causes the rocks carbonaceous and not carbonaceous (Sujatmiko & Santosa, 1992).

- Cikotok Formation

This formation is exposed in the Ciguling River as tuff, porphyry diorite, and porphyry andesite. Outside of Lebakpeundeuy Village, this formation is also clearly exposed as andesite in the Cihara River of Barunai Village. Based on Sujatmiko & Santosa (1992), these rocks are the Late Eocene to Late Oligocene age in which formed from the oldest vulcanism in Bayah geological history.

- Granodiorite Cihara

This rock group dominated the research area and oxposed in many rivers from several villages. The rocks are exposed on the Cigaber, Cisanun, and Cipeusing River as granodiorite. The rocks of this group have an Early Oligocene to Late Oligocene age (Sujatmiko & Santosa, 1992) and according to van Bemmelen (1949) lifted by orogeny that breaks through the rocks above it. From this research, metamorphic rocks are thought to have risen as a result of the break through of these rocks which later became the Metamorphic Group, although most of the other metamorphic rocks have been uplifted first in the Early Tertiary.

1.3. Structures and Tectonic Regional

Java Island has complex tectonic setting due to collision of Indo-Australian Plate to Eurasian Plate that forming a subduction zone. Deformation of this collision manifestated by various geological structures in the rocks such as faults, fractures, and folds. Based on the research of Pulunggono & Martodjojo (1994), the geological structures in the western part of Java Island have a distinctive pattern divided into Late Cretaceous to Early Eocene Meratus Pattern which has NE-SW direction, then the Early Eocene - Early Oligocene Sundanese Pattern which shows N-S direction, and the Oligocene - Holocene Javanese Pattern displayed by E-W structures direction. In spite of the three structural patterns already mentioned, there is another that also develops in the research area i.e. Pre-Tertiary Sumatra Pattern that represented by structures of N-S and NW-SE direction (Heidrick & Aulia, 1993).

Regarding to the structures, van Bemmelen (1949) also relates the structures in the research area to the existing orogeny events. Orogeny is one of geological process that contributes to the uplifting, mountain building and formation of geological structures. According to van Bemmelen (1949), the Bayah and its surroundings have undergone three orogenesis, each of which produces a distinctive structure. Orogeny I occurring in the Early Oligocene to the Early Miocene produces normal faults, slip faults, and folds with E-W and NE-SW direction. Orogeny II occurring in the Early Miocene to Middle Miocene produces normal faults and slip faults with NE-SW direction, and also produces folds with E-W direction. Whereas orogeny III occurring in the Middle Miocene to Pliocene results in normal faults, slip faults, and diagonal faults with N-S, NE-SW, NW-SE direction and folds that have E-W and NE-SW direction (van Bemmelen, 1949).

2. Method

The methods applied in this research are field survey and studio method. The field survey conducted to collect outcrop data including its features such as fractures, slickenside, and metamorphic foliation using equipment as GPS, geological compass, geological hammer, tape measurement and so on. While studio method practiced to reconstruct and process structure data using the aid of various computer programmes and softwares. The fractures data acquired from the field work processed to display rose diagram in accordance to Hansen et al. (1999) which are also exemplified by Kulikowski et al. (2015). The slickenside data such as strike/dip, pitch, and sense of movement are then processed to display the R. Optim diagram to show the stress and the block movement, in addition, the faults will also be classified and modeled following the wrench fault model as proposed by Moody and Hill (1956).

3. Result and Disscusion

3.1 Geology and Stratigraphy

There were 160 outcrops successfully mapped during this study. These rocks are derived from various types of lithology which its distribution can be seen in Outcrop Map in Fig 1. These rocks are regionally classified as Endut Volcano Materials for tuff and volcanic breccias, Granodiorite Cihara for dacite, diorite, and granodiorite, Cikotok Formation for brown volcanic breccia and andesite, Bayah Formation for sandstones and claystone, and Metamorphic Group for metamorphic rocks. Based on lithology and structure reconstruction, the research area divided into nine rock units i.e. Tuff Unit (Ktf), Volcanic Breccia Unit (Kbv), Dacite Unit (Tmids), Diorite Intrusion (Tmidr), Granodiorite Intrusion (Toig), Brown Volcanic Breccia Unit (Tebv), Andesite Unit (Tead), Claystone Unit (Tebl), and Metamorphic Group (Ptmm) respectively from young to old. The border and distribution of these rock units represented in Structural Geology Map in Fig 3.

- Tuff Unit (Ktf)

This tuff unit is composed of tuff and some quaternary andesite rocks. The tuff have fresh color brownish-gray, weathered color reddish-brown, fine grained, round grain shaped, and well sorted. In few locations, the rocks experiencing low to moderate intensity alteration. While the andesites show fresh color bright gray, weathered color brownish-gray, mesocratic, fine texture (aphanitic), and equigranular.

- Volcanic Breccia Unit (Kbv)

This rock unit is dominated by volcanic breccias which megascropically have fresh color dark gray, weathered color darki brown, pebble to boulder sized components, angular shaped components, and poor sorted. The constituent components are andesite and basalt, while the matrix is tuff.

- Dacite Unit (Tmids)

This rock unit is composed of dasitic rocks and bordered to the Andesite Unit (Tead). Dacites found to have fresh color bright gray, weathered color yellowish-brown, mesocritic, medium texture (porphyritic), and sub-equigranular. Phenocryst minerals such as quartz and plagioclase well observed using loupe.

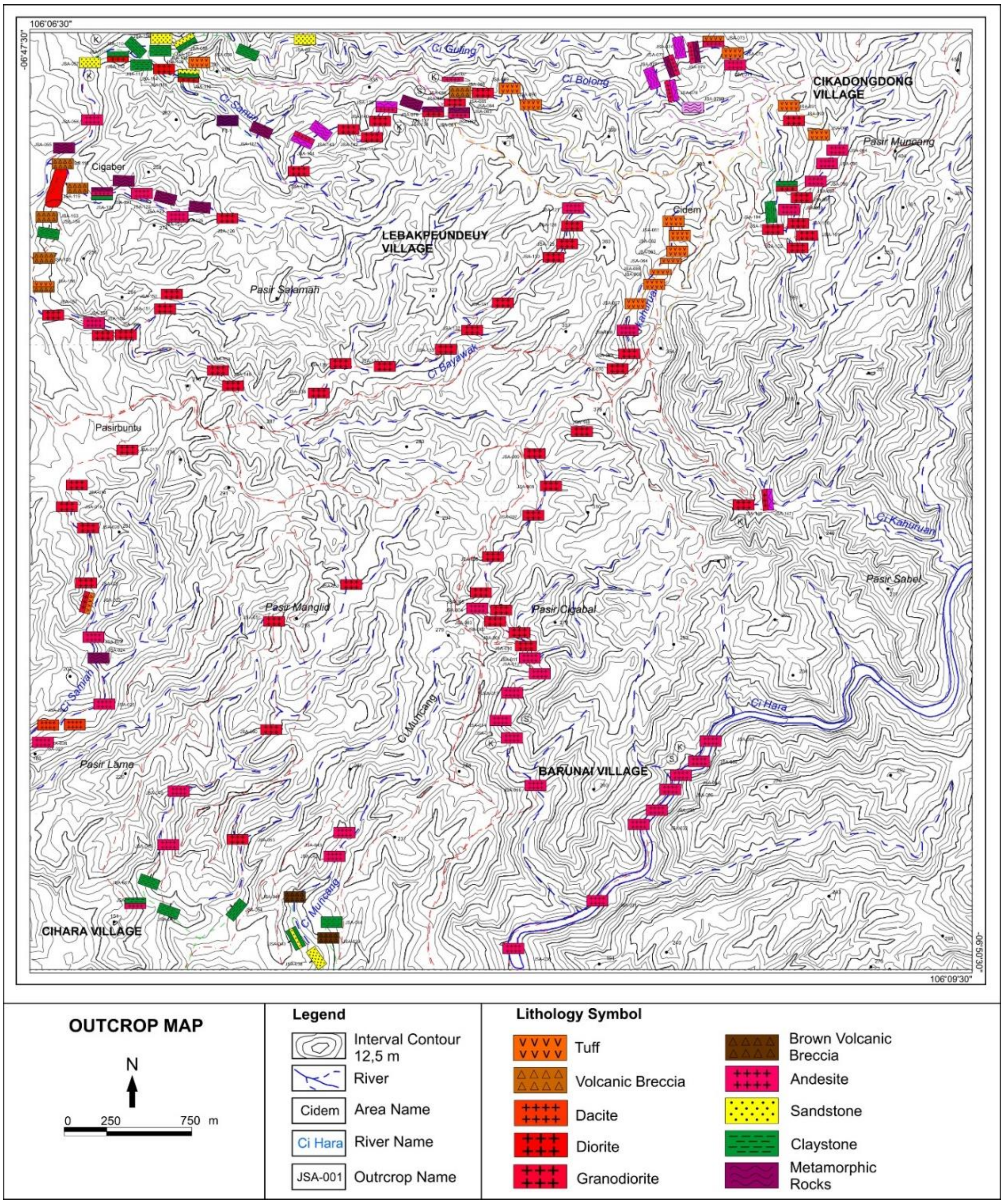

Fig 1. Outcrop map and its distribution in the research area.

- Diorite Intrusion (Tmidr)

This rock unit is composed of diorite rocks which bordered to the Claystone Unit (Tebl). Diorites show fresh color bright gray, weathered brownish-gray, leucocratic, medium texture (porphyritic), and equigranular. Phenocryst minerals such as quartz and biotite are well observed directly using loupe.

- Granodiorite Intrusion (Tmidr)

This rock unit is made up of granodiorite which become the most dominant unit of all rock units in the research area. The granodiorites show fresh color bright, weather color dark brown, leucocratic, medium-coarse texture (porphyrytic-phaneritic), and sub-equigranular. These rocks are rich in gray-white quartz. Phenocryst minerals such as quartz, biotite, and feldspar able to be observed directly by using loupe.

- Brown Volcanic Breccia Unit (Tebv)

This rock unit is composed of polymic breccias and bordered to the Andesite Unit (Tead) and the Claystone Unit (Tebl). The breccias show fresh color brownish-gray, weathered color yellowish-brown, coarse sand to pebble sized components, angular shaped components, and medium sorted. The constituent components are sandstone and andesite while the matrix is clay-sand. The breccia surface undergoes high intensity oxidation.

- Andesite Unit (Tead)

This rock unit composed of andesites which become the second most common discovered unit after Granodiorite Intrusion (Toig). The andesites found to have fresh color bright gray, weathered color brown, mesocratic, fine texture (aphanitic), and equigranular. In some locations these rocks are mineralized in low intensity.

- Claystone Unit (Tebl)

This rock unit made of claystones and sandstones. Claystones generally have fresh color black, weathered color brown, and not carbonate. While the sandstones show fresh color gray, weathered color brownish-gray, medium sand components, round grain shaped, well sorted, and not carbonate.

- Metamorphic Group (Ptmm)

The lihologies that fall into this unit include slates, phyllites, schist, and metagabbros. These rocks found to have fresh color bright gray, weathered color orange-brown, fine-coarse texture, and distinctly foliated for phyllites and schist.

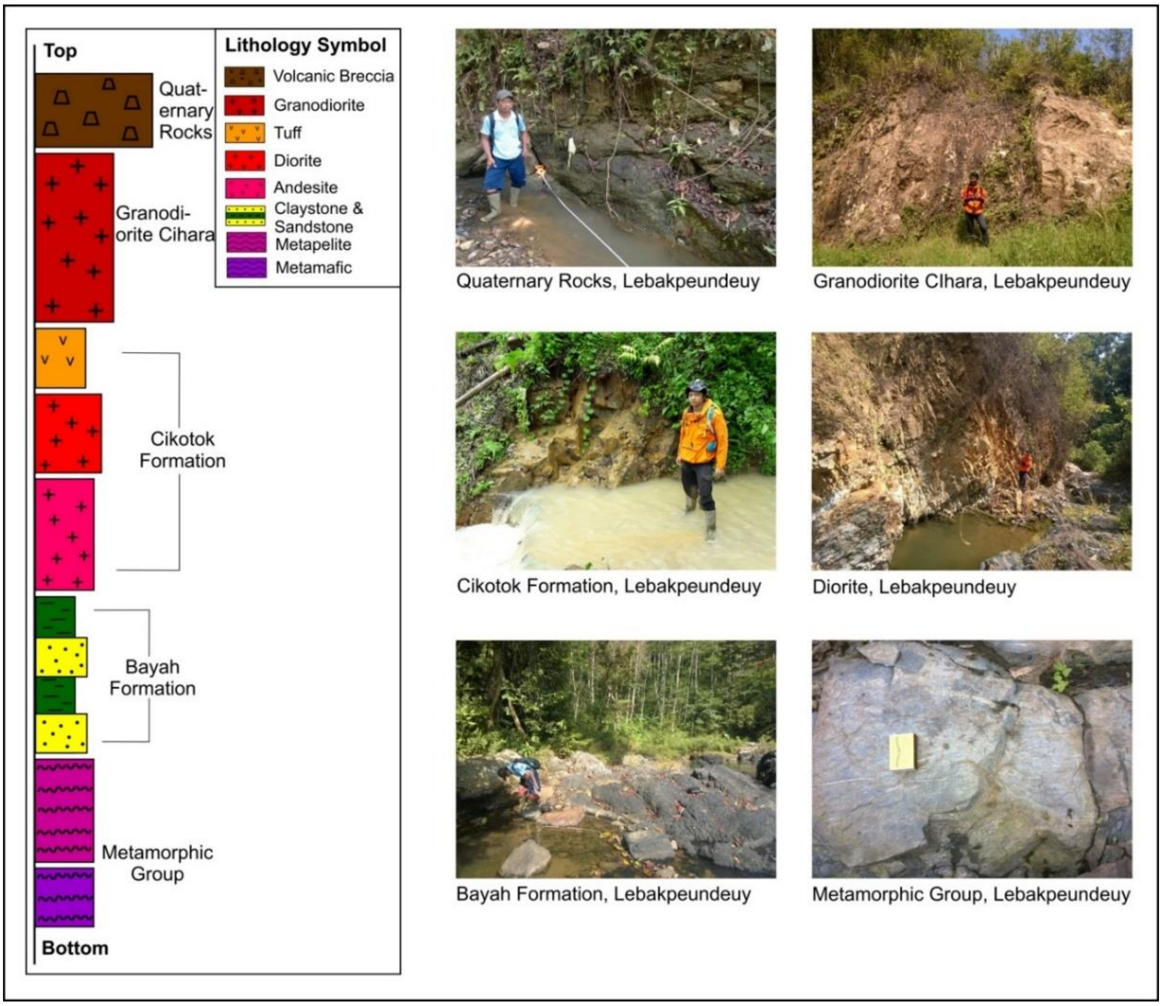

Fig 2. Lithostratigraphy log and the outcrops of the Cigaber, Cisanun, and Ciguling River depicting variation of the Metamorphic Group, Bayah Formation, Cikotok Formation, and Granodiorite Cihara.

Lithostratigraphically, Metamorphic Group found at the bottom followed by Bayah Formation, Cikotok Formation, and Cihara Granodiorite different from Sujatmiko & Santosa (1992); Sukarna et al. (1993) which stated that Bayah Formation is the oldest rock in the Bayah. Variations of these four formations are most clearly observed from the outcrops in the Cipager, Cigaber, Cisanun, and Ciguling River of Lebakpeundeuy Village which is represented by lithostratigraphy log in Fig 2.

3.2 Geological Structures

The geological structure data obtained of this research i.e. 3 faulted outcrops and 7 highly fractured outcrops, in addition to the result of reconstruction of strike/dip also obtained 2 folds. The 3 faulted outcrops of the Cikotok Formation and Granodiorite Cihara include JSA-014, JSA-034, and JSA-080. Based on Rickard's fault classification in Ragan (2009), these 3 faults are named right lag slip fault, normal right slip fault, and normal left slip fault respectively for JSA-014, JSA-034, and JSA-080. While 7 fractured outcrops taken from the Metamorphic Group, Cikotok Formation, and Granodiorite Cihara i.e. JSA-014, JSA-034, JSA-057, JSA-080, JSA-110, JSA-138, and JSA-146 as seen in Structural Geology Map in Fig 4. Two folds reconstructed of this research i.e. anticline in the northwestern and syncline in the southwestern part of the research area, these two folds occur in the Bayah Formation. Beside faults, fractures, and folds, analysis of geological structures are also observed from metamorphic rock since the rocks indicate distinct foliation direction. The measurement of foliation direction is useful in determining the direction of the deformation and its structures.

3.3. Geological Structure Reconstruction

Structural patterns of both fractures and faults have variety direction. Fractures data from JSA-034, JSA-057, JSA-080, and JSA-110 show N-S to NW-SE pattern that indicating relatively E-W stress, while fractures from JSA-014, JSA-034, and JSA-080 show E-W to SW-NE which indicating relatively N-S stress. In addition, for the JSA-014 and JSA-034 fault both have SW-NE direction while the JSA-080 fault has E-W direction. Faults are usually accompanied by fractures, and it might be the vice versa. Regarding to the structural direction mentioned, it is known that some of the fractures are well synchronized with the faults and some of them are not. Beside of fractures and faults, metamorphic rock foliation data taken from the Cigaber and Cisanun Rivers show uniform direction of NW-SE and N-S.

Fig 3. Strike-slip faulted outcrop (A) with its trace movement features (A2-A3) and fractured outcrop (B-C) of the research area.

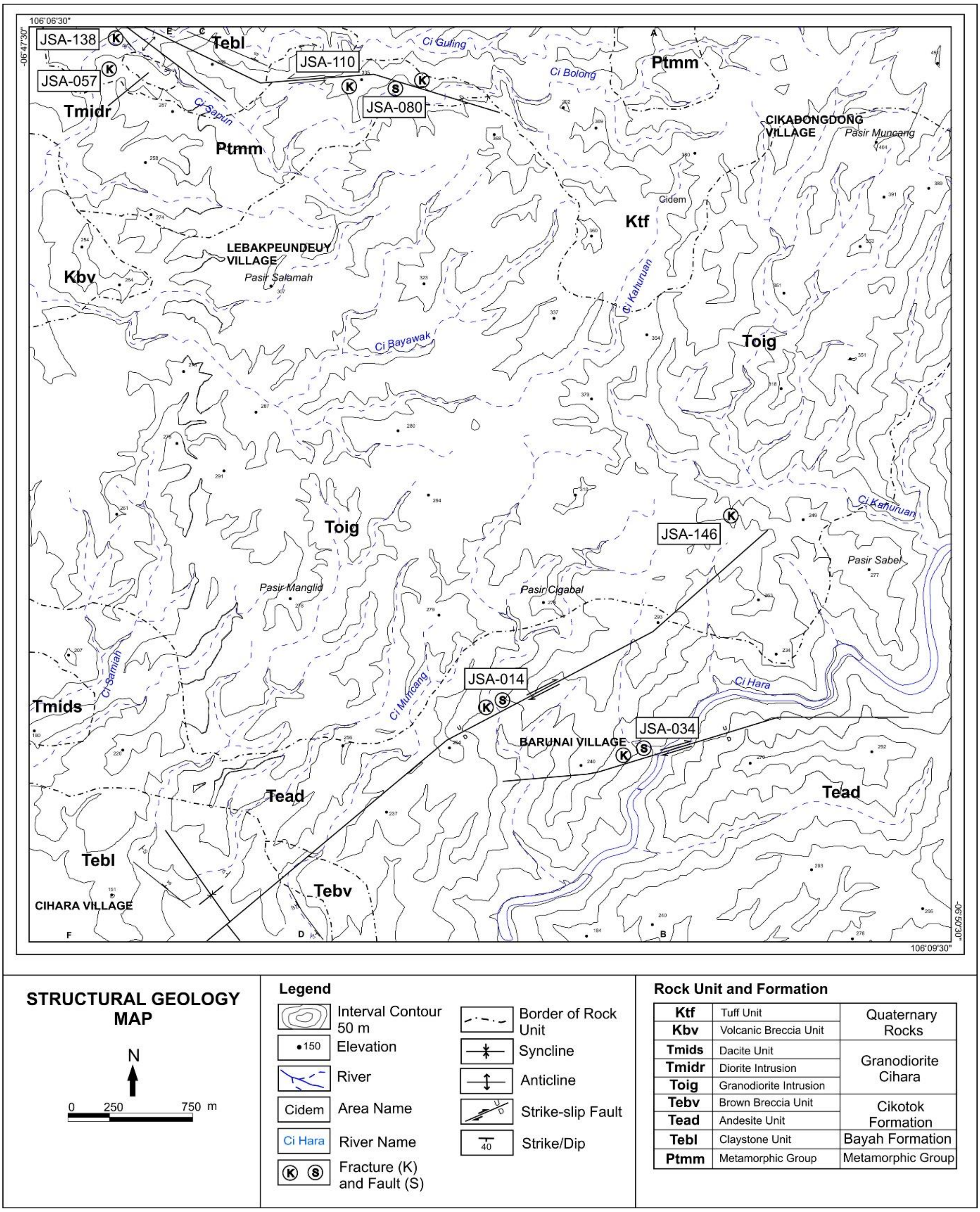

Fig 4. Structural geology map of the research area.

Based on the previous mentioned structural patterns of Meratus, Sumatra, Sundanese, and Java Patterns, it is estimated that the structures recorded in this research come from variety patterns formed from Pre-Tertiary to Holocene. Fracture patterns that occurs in the Metamorf Group, Cikotok Formation, and Granodiorite Cihara have the direction of N-S and E-W which is belong to the Sundanese and the Java Pattern formed in range of the Early Eocene to Pliocene as seen in Fig 5. While the faults of Cikotok Formation and Granodiorite Cihara that have direction of SW-NE and EW are classified in Meratus and Java Pattern as seen in Fig 6. However, the fault categorized in Meratus Pattern is not valid because the rocks itself formed at least in the Late Eocene while Meratus Pattern is formed at Late Cretaceous - Early Eocene. Because of that, the fault is estimated show indeterminate direction and to be formed as a local fault that influenced by the main fault, while the fault belonging to the Java Pattern has good validity. The Java pattern itself may be formed as reactivation from previous patterns such as the Sundanese or Meratus Pattern (Hilmi & Haryanto, 2008). The most surprising structural pattern of the this research is the metamorphic foliations which show the direction of NW-SE and N-S. The direction of the foliations are belongs to the Sumatra Pattern formed in Pre-Tertiary to Early Tertiary. The result of this pattern is supported by lithostratigraphy log that indicating Metamorphic Group located beneath the Middle Eocene Bayah Formation which means that the Metamorphic Group is formed in the old age estimated to be Early Tertiary.

3.4 Fault Model and Formation

The age of three faults estimated no older than the Oligocene and formed as impact of orogenesis. Based on the orogenesis specifications of van Bemmelen (1949), the SW-NE JSA-014 fault was formed by orogeny I/II occurring within the Early Oligocene to Middle Miocene. SW-NE JSA-034 fault was formed by orogeny I in the Early Oligocene to Early Miocene, while the E-W JSA-080 fault was formed by orogeny III in the Middle Miocene to Pliocene which well-synchronized to the Oligocene to Pliocene Javanese Pattern as seen in Table 1.

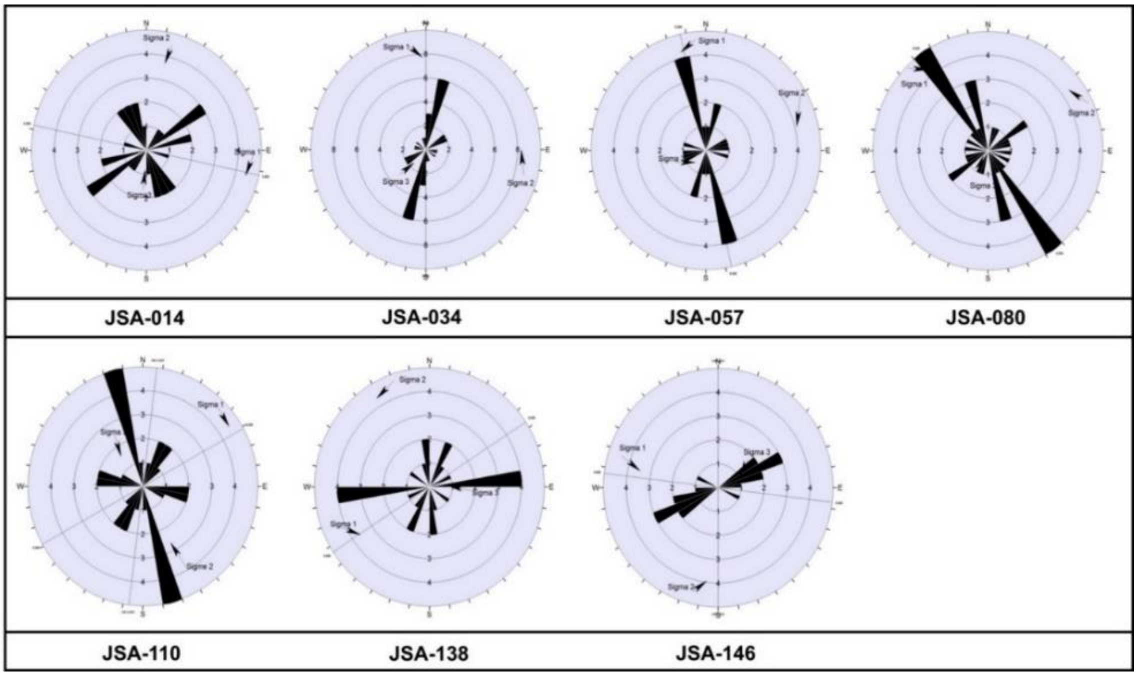

Fig 5. Rose diagram showing trend and sigma of each fractured outcrop.

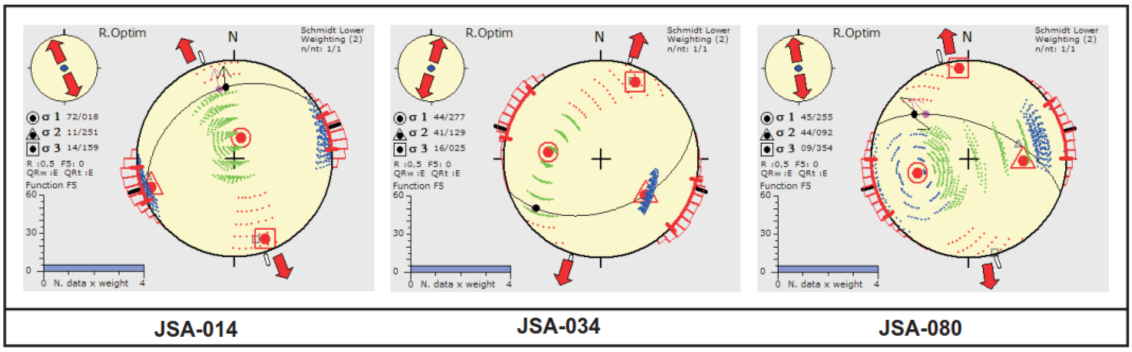

Fig 6. R. Optim diagram showing the stress and block movements of each faulted outcrop.

Table 1. Reconstruction and model of the faults. The direction I shows pure direction, direction II shows rotated direction, and direction III shows rotated and adjusted direction due to Java rotation and primary stress.

Outcrop	Pitch	Direction (N-E)			Movement	Wrench fault model	Estimated event	Geology age
		I	II	III				
JSA-014	70°	240	270	250	Right-handed	2nd order right lateral Wrench fault	Orogeny I/II	Early Oligocene-Middle Miocene
JSA-034	25°	71	101	81	Right-handed	2nd order right lateral Wrench fault	Orogeny I	Early Oligocene-Early Miocene
JSA-080	34°	290	290	270	Left-handed	3rd order left lateral Wrench fault	Orogeny III	Middle Miocene-Pliocene

Fault modeling in the western part of Java usually follows two models i.e. wrench fault or Riedel shear. Riedel shear itself according to Davis et al. (2000), is a model for single discrete strike-slip fault that used to link the master fault that was responsible for the formation of Riedel shear zone in cover rocks. While wrench fault model which proposed by Moody & Hill (1956), is used for all types of strike-slip faults that have direction and sense of movement in accordance to the wrench fault angle. In this case, the wrench fault model is more suitable than Riedel shear because the primary stress in the research area is already known. Wrench fault modeling is performed to find out the fault order based the fault direction, sense of movement, and the known primary stress. However prior to modeling, rotation and main stress adjustments must be made. The direction of fault in the study area should be rotated because Java itself has been rotated counterclockwise by 30° which occurred in in past 20 to 10 Ma (Hall, 1996). Moreover, the main stress subduction of Indo-Australian to Eurasian Plate is known to be N20°E and because of that the direction of the fault that has been rotated also need to be adjusted with the primary stress. Even though, the JSA-080 fault is not rotated because it has a younger age than the event of Java rotation, whereas the main stress adjustment it is all necessary.

3.5 Tectonic Reconstruction

This tectonic reconstruction is succinctly represented by Fig 7. During its formation, there are three important times related to the tectonic history of the research area i.e. Pre-Tertiary, Late Eocene, and Middle Oligocene which are in detail described as follows:

- Pra-Tertiary

In Pre-Tertiary or Late Cretaceous subduction occurs between the Indo-Australian and Eurasian Plate which the Indo-Australian plate subducted under the Eurasian Plate. The siliciclastic sediments of the Malay Peninsula and Indonesia Tin Islands are laid on the Eurasian Plate (terrestrial) to the Indo-Australian Plate (marine). The sediments in the trench and subducted Indo-australian plates then experience regional metamorphisms due to pressure and temperature resulting from the collisions and magma of the mantle. The magma then rises through the crust of the Eurasian Plate causing the cracking of the upper crust and producing continental rifting which becomes the marker of volcanic origin in the island-arc system.

- Late Eocene

In the Early Eocene, the metamorphosed trench sediments and oceanic plate (Indo-australian Plate) were uplifted to the surface become the Metamorphic Group. At that time the siliciclastic sediments (Pre-Bayah Formation) were not yet formed. This uplifting event is possible because magmatic activity also occurs in eastern Sundaland (part of Eurasian Plate) due to continental fragments approaching the subduction zone causing the uplifting. It is estimated that the continental fragment is detached from Godwana and moving to the north approaching the subduction zone (Sribudiyan et al., 2003). At that time, siliciclastic sediments have been litified become the Bayah Formation above the Metamorphic Group. Afterward, in the Late Eocene there was old volcanism activities produced volcanic materials such as lava, tuff, and breccias which then become Cikotok Formation.

- Middle Oligocene

Since the Early Oligocene, the movement of the Indo-Australian Plate against the Eurasian Plate has slowed from 18 cm/year to 3 cm/year (Hall, 2002; Sribudiyani et al., 2003). Because of this slowing, there was an increase in the angle of dip subduction which then causes general uplifting marked by the appearance of large amount of reverse faults. This uplifting become dominant geological process that occurs over that time and generates several important geological events. In the Oligocene, the volcanic materials produced in the Late Eocene have became Cikotok Formation above the Bayah Formation. The uplifting also led to the rise of magma into the body of intusion which came to be known as the Granodiorite Cihara. The intrusion and reverse faults also re-exposed metamorphic rocks that previously uplifted at the beginning of the Eocene. At the end of the Middle Oligocene, the rocks of Metamorphic Group, Bayah Formation, Cikotok Formation, and Granodiorite Cihara have been exposed to the surface and resulted in the complexity of the geological setting.

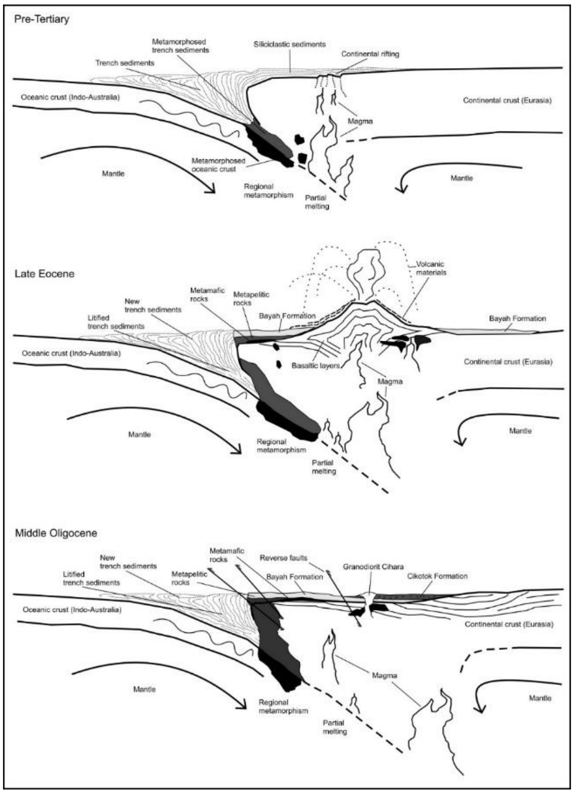

Fig 7. Tectonic reconstruction and the rock formation of the research area.

4. Conclusion

The Bayah is a complex area because of its lithology and geological structure. This complexity largely influenced by the collision of Indo-Australian and Eurasian Plate which causes various events such as orogeny, uplifting, magmatism, and volcanism. The research area is composed of rocks from the Metamorphic Group, Bayah Formation, Cikotok Formation, and Granodiorite Cihara, respectively from old to young. The analysis of the faults, fractures, and foliation of metamorphic rocks concluded that the research area has diverse structural pattern i.e. Sumatra, Sundanese, and Java Pattern. The Sumatra pattern itself only develops in metamorphic rocks indicating that the rocks are old (Pre-Tertiary to Early Tertiary), this result is supported by lithostratigraphy data that stating these rocks located beneath the Middle Eocene Bayah Formation. The structure reconstruction indicating that faults formed by the effect of orogenesis that occurs three times in orogeny I, II, and III during the Early Oligocene to Pliocene. Besides, the faults in the research area are classified as 2nd and 3rd order of wrench fault system.

Acknowledgements

The authors would like to thank M. Q. Filayati, T. Ramadhan, V.H. Ar-rahman and F. Alamsyah who helped in collecting field data. The authors are also grateful to colleagues at Geological Engineering Faculty of Padjadjaran University and Research Center for Geotechnology of Indonesia Institute of Sciences (LIPI) who served as discussion partner during the research.

References

Clements, B. and Hall, R., 2008. U-Pb Dating of Detrital Zircons from West Java Show Complex Sundaland Provenance. Proceeding of 32nd Indonesia Petroleum Association Annual Convention.

Davis, G.H., Bump, A.P., Garcia, P.E., Ahlgren, S.G., 2000. Conjugate Riedel Deformation Band Shear Zone, Journal of Structure Geology, 22, pp. 169-190.

Hall, R., 1996. Reconstruction Cenozoic SE Asia; Hall, R. And Blundell, D. (eds), Tectonic Evolution of Southeast Asia. Geological Society Special Publication, 106, pp. 153-84.

Hall, R., 2002., Cenozoic Geological and Plate Tectonic Evolution of SE Asia and the SW Pacific: Computer-Based Reconstruction, Model, and Animation. Journal of Asian Earth Science, 20, pp. 353-431.

Hansen, B.P., Stone, J.R., and Lane, J.W.Jr., 1999. Characteristics of Fractures in Crytalline Bedrock Determined by Surface and Borehole Geophysical Surveys, Eastern Surplus Superfund Site, Meddybemps, Maine. Water-Resorces Investigation Report 99-4050 of U.S. Geological Survey.

Heidrick, T.L. and Aulia, K., 1993. A structural and Tectonic Model of The Coastal. Plain Block, Central Sumatera Basin, Indonesian.Proceeding of 22th Indonesian Petroleum Assosiation Annual Convention, Jakarta, pp. 285-316.

Hilmi, F. and Haryanto, I., 2008. Pola Struktur Regional Jawa Barat. Bulletin of Scientific Contribution, 6 (1), pp. 57-66.

Kulikowski, D., Amrouch, K., Barwani, M.A., Liu, W., Cooke, D., 2015. Insights Into the Tectonic Stress History and Regional 4-D Natural Fracture Distribution in the Australian Cooper Basin Using Etchecopar's Calcite Twin Stress Inversion Technique, 2-D/3-D Seismic Interpretation and Natural Fracture Data From Image Logs and Core, AAPG/SEG International Conference & Exhibition, Melbourne, Australia, paper #41752.

Moody, J.D., Hill, M.J., 1956. Wrench-Fault Tectonics, Bulletin of the Geology Society of America, 67, pp. 1207-1246.

Pulunggono, A. and Martodjodjo, S., 1994. Perubahan Tektonik Paleogen dan Neogen Merupakan Peristiwa Tektonik Terpenting di Jawa. Proceeding on Geology and Geotechnic Java Island since Late Mesozoic to Quaternary, pp. 37-50.

Ragan, D.M., 2009. Structural Geology: an Introduction to Geometrical Techniques, 4th Edition. Cambridge University Press, Cambridge.

Sribudiyani, Muchsin, N., Ryacudu, R., Kunto, T., Astono, P., Prasetya, I., Sapiie, B., Asikin, S., Harsolumakso, A.H., and Yulianto, I., 2003. The Collision of the East Java Microplate and Its Implication for Hydrocarbon Occurrences in the East Java Basin. Proceeding of 29th Indonesian Petroleum Association Annual Convention.

Sujatmiko and Santoso, S., 1992. Peta Geologi Regional Lembar Leuwidamar. Pusat Penelitian dan Pengembangan Geologi, Bandung.

Sukarna, D., Mangga, S.A., and Brata, K., 1993. Geology of the Bayah Area: Implication for the Cenozoic Evolution of West Java, Indonesa. Geology Society of Malaysia, 33, pp. 163-180.

Van Bemmelen, R.W., 1949. The Geology of Indonesia. Martinus Nijhoff, Den Haag.