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

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 9 No 2 2024

RESEARCH ARTICLE

Metamorphic Complex Deformation in North Bangka Island Based on Macrostructures and Microstructures Evidences

Rezki Naufan Hendrawan[1]*, Windi Anarta Draniswari[2], Fitri Indah Wahyuni[1], Benjamin Sapiie[3], Nurcahyo Indro Basuki[3]

[1] *Sumatera Institute of Technology, Geology Departement, South Lampung, Lampung, Indonesia*
[2] *Research Center for Geological Disaster, National Research and Innovation Agency, Bandung, West Java, Indonesia*
[3] *Bandung Institute of Technology, Geology Department, Bandung, West Java, Indonesia*

* Corresponding author : rezki.hendrawan@gl.itera.ac.id
Tel.:+62878-2284-0540
Received: Jun 22, 2023. Accepted: May 22, 2024.
DOI : 10.25299/jgeet.2024.9.2.13379

Abstract

The northern Bangka Island is composed of Pemali metamorphic complex which is indicated by the collision between Indochina and Sibumasu blocks. These features are interesting to observe because the metamorphic rocks could be recorded in some geological structures at different times. The study began by conducting field observation on Pemali Metamorphic Complex as objects. Field observation aims to collect lithological data, structural data, and oriented rock samples. The results of field pitching were processed to determine macrostructures, microstructures, and mineral distribution. The data was analyzed based on kinematic, descriptive, and deformation mechanisms to determine the deformation patterns that occurred in the study area.

Field and oriented thin section data show structures and occurred in different deformation conditions. The analysis based on macrostructures and microstructures showed that the northern part of Bangka Island experienced three different deformation phases. Deformation begins with the formation of folds that are associated with collisions between Sibumasu-Indochina, followed by a second deformation that forms a fold with different verging. Both deformations are formed in the ductile zone and the brittle-ductile transition zone. The third deformation occurs when rocks have been lifted to the surface by the presence of faults, joints, and veins. The sequence of the deformation model is similar to the deformation experienced in the Bentong-Raub suture zone formed in the shear zone.

Keywords: Metamorphic Complex, Bangka Island, Microstructures, Deformation

1. Introduction

The northern part of Bangka Island is an interesting area to study as it contains a complex geological history that is recorded in its metamorphic rocks. The Pemali Metamorphic Complex in this region has a similarity with Bentong-Raub suture zone (Fig. 1) that is indicated to have formed due to the collision between the Indochina and Sibumasu blocks during the Neoproterozoic era (Metcalfe, 2013, 2001, 2000).This study aims to understand the deformation processes that have taken place in this region by conducting field observations, macro- and microstructural analysis, and mineral distribution analysis. The result of this study can provide valuable insights into the tectonic history of the northern part of Bangka Island and the broader region of Southeast Asia.

Field observation and sample collection were conducted on the Pemali Metamorphic Complex to gather information about the lithology, structures, and mineral distribution (Metcalfe, 2001). The data obtained from the field was analyzed using kinematic, descriptive, and deformation mechanism analysis to understand the patterns of deformation that have occurred in the study area (Metcalfe, 2001; Passchier and Trouw, 2005). The study does not examine any chemical anomalies or changes in the area. The goal is to provide a comprehensive understanding of the geological condition of the northern part of Bangka Island through macro- and microstructures analysis.

2. Regional Geology

The research area was located on North Bangka Island which is unique due to the presence of ancient rocks that provide a significant geological history of the region (Hendrawan et al., 2021). Studying these rocks in North Bangka is essential to understanding the regional geology history and tectonic evolution to provide a basis for future geological exploration and mineral resources assessment (Khin Zaw et al., 2014; Sapiie et al., 2017; Zhang et al., 2019). In addition, Northern Bangka has composed of the metamorphic Pemali complex, Tanjunggenting Formation, S-type granite, and Ranggam formation (Fig. 2) (Barber et al., 2005; Cobbing et al., 1986; Mangga and Djamal, 1994; Margono et al., 1995; Sugiono, 2014).

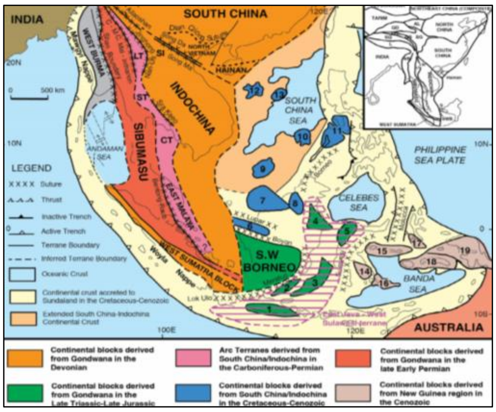

Fig. 1. Distribution of continental blocks, fragments, terranes, and principal sutures of Southeast Asia (Metcalfe, 2013).

The Bentong-Raub Suture Zone (BRSZ) is a geological structure located as part of Peninsular Malaysia and also extended to Indonesia in a southerly direction (Barber et al., 2005; Cobbing et al., 1986; Hutchison, 1994; Metcalfe, 2013; Pour et al., 2018; Rozalli et al., 2020; Song et al., 2021) (Fig. 3) which is formed from the collision between the Sibumasu and Indochina blocks, which occurred during the late Mesozoic era (Hutchison, 1994; Irfan et al., 2023; Metcalfe, 2013, 2000). The location of the BRSZ extends from Peninsular Malaysia to Central Sumatra (Barber et al., 2005; Beddoe-Stephens et al., 1987; Gasparon and Varne, 1995; Hashim et al., 2018; Pour et al., 2018, 2016; Sapari et al., 2016; Sato, 1991), but some researchers argue that the suture zone passing through the northern part of Bangka Island (Barber et al., 2005; Cahyana et al., 2021; Ng et al., 2017) or cuts through the northern and southern parts of Bangka Island, with the island located between the two lines of separation (Hutchison, 1994).

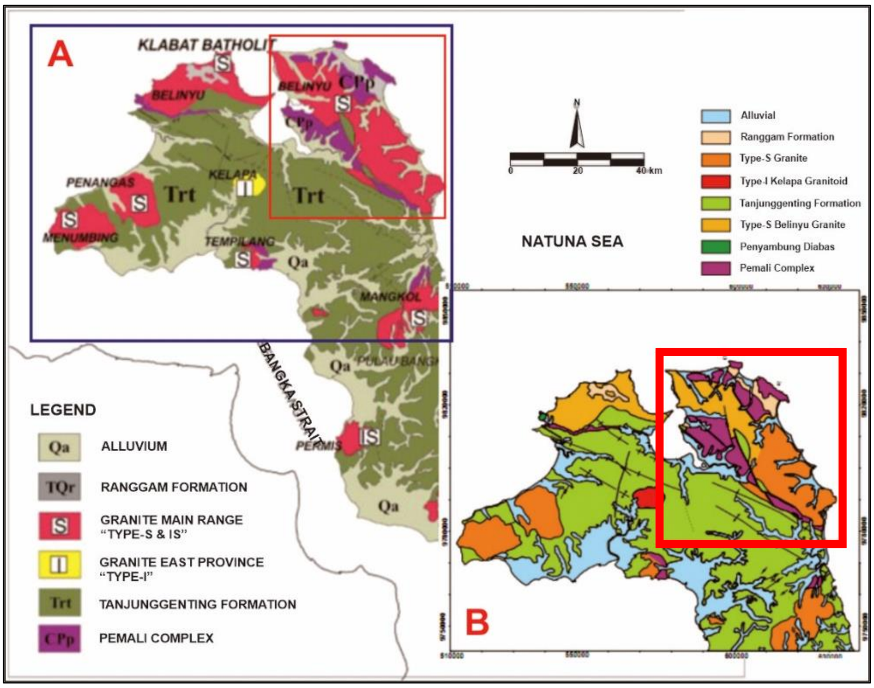

Fig. 2. (A) Geology map of Bangka with red square as a research area (Barber et al., 2005; Cobbing et al., 1986; Mangga and Djamal, 1994; Margono et al., 1995; Sugiono, 2014) (B) Map of granite type in northern Bangka Island.

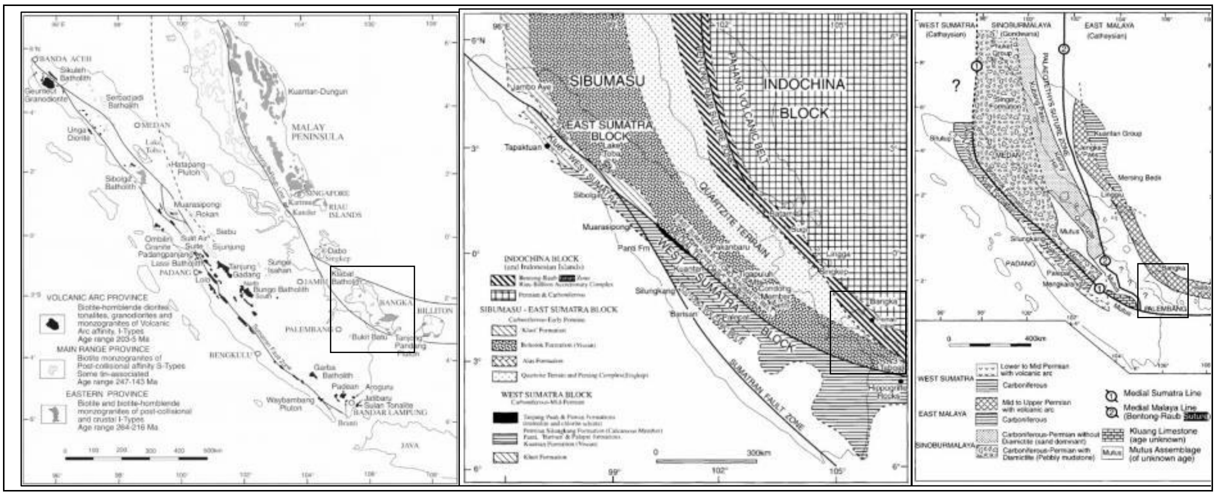

Fig. 3. Tectonic unit map in Peninsular Malaysia (left image) (Hutchison, 1994), Pre-Triassic West Sumatra and East Sumatra block map (centre image) (Barber et al., 2005) and Rocks distribution map in Sumatra (Beddoe-Stephens et al., 1987; Gasparon and Varne, 1995; Sato, 1991).

The northern part of Bangka Island is of particular interest for geological study because it exposes the Pemali Metamorphic Complex, which is believed to be a product of the BRSZ (Barber et al., 2005). The focus of this research is limited to the macrostructures and microstructures of the area, with attention given to the relationships between structures and the occurrence of overprinting structures (Fossen, 2016; Passchier and Trouw, 2005; Pound et al., 2014).

3. Methods

The research methodology used in this study involved the collection of samples using random sampling at the metamorphic Pemali complex, followed by a collection of both the fractures and foliation structures as part of macrostructures (Fossen, 2016; Ibrahim and Musa, 2020; Mukherjee, 2020; Passchier and Trouw, 2005). Furthermore, rocks sample are taken by marking the orientation of the position of the rock sample (Passchier and Trouw, 2005; Xian et al., 2019).

Thin sections were then prepared from the samples, and microscopical analysis was conducted using polarized microscopy to determine the lithological name from the mineral composition and distribution of microstructures. Moreover, thin section data provided an overprinting relationship on microstructures to dividing the order in which the structure was formed that was subsequently interpreted to understand the deformation phases (Blenkinsop, 2000; Passchier and Trouw, 2005, 1996). The combination of structural mapping and microscopy analysis allowed for a comprehensive study of the microstructure and deformation of the rock at the Pemali Complex.

4. Result and Discussion

According to field mapping, found 12 outcrops of metamorphic rocks, consisting of schist and phyllite, and also 3 outcrops of sedimentary rocks including sandstone and conglomerate, were found in the study area (Fig. 4). Field observation revealed various macrostructures such as lithological contacts, parallel foliation, S-C fabric, large-scale folds in metamorphic rocks, crenulation cleavage, en-echelon veins, fractures as fault or shear fractures, and shear band cleavages. These macrostructures were recorded by describing their geometrical shapes, describing their characteristics, and measuring the structural planes as strike-dip values. The data obtained from these observations will be analyzed to better understand the study area’s deformation history and tectonic evolution (Fig. 5). Several macrostructures (Table 1) had a number of directions, but almost northwest-southeast strike direction. Amount of directions should be divided into a number of the part according to an overprinting relationship of structures.

Table 1. Mineral rock composition from several outcrops in the research area.

Sample	Percentage Mineral (%)				
	Quartz	Muscovite	Epidote	Opaque	Oxide
M-05	76.8	21.1	1.1	1	0
M-06	71.6	21.1	0	2	5.3
M-09	70.5	26.3	1.1	1	1.1
M-12	63	25	1	1	10
M-13	76.1	10.9	1.1	4.3	7.6
M-14	71.4	11	1.1	5.5	11
M-16	60	25	1	1	13
M-17	70.1	25.8	2.1	1	1
M-18	40	55	0	5	0
M-19	67	30	0	2	1
M-20	82.7	15.3	1	1	0
M-21	43	48	3	3	3

After collecting rock samples from the study area, thin sections were prepared and observed under a microscope to examine lithological names from mineral composition and microstructures data. Mineral distribution (Table 1) presented quartz as the most dominated mineral in all thin section. From sample M-18 and M-21, muscovite has a much greater percentage than quartz. Based on macroscopic and microscopic observation, M-18 and M-21 identified as phyllite muscovite quartz and others namely as schist quartz muscovite (Fig. 4). Based on the mineral distribution, diversity exists in phyllite, therefore in these rocks various microstructures features can be found.

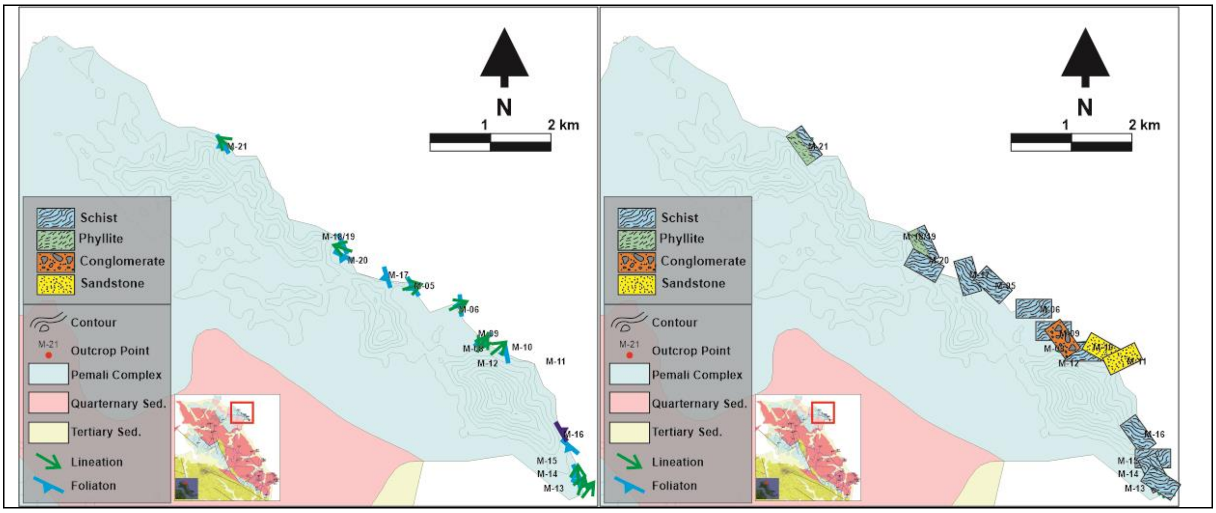

Fig. 4. Structural map with foliation and lineation (A) Outcrop distribution in the research area (B).

Several microstructures (Table 2) were identified (Passchier and Trouw, 2005), including undulose extinction, kink band, dynamic recrystallization, deformation lamellae, deformation band, porphyroclast, and fish mica. These microstructures provide insight into the deformation mechanisms and conditions that the rocks have undergone. The presence of undulose extinction indicates that the rocks have undergone plastic deformation, while kink bands suggest that the rocks have experienced brittle deformation. Dynamic recrystallization and deformation lamellae are features that form during ductile deformation, while deformation bands and porphyroclasts are more commonly associated with brittle deformation. The presence of fish mica can indicate that the rocks have undergone shearing or intense deformation. By analyzing these microstructures, we can gain a better understanding of the deformation history of the rocks in the study area.

Table 2. Structural distribution in the research area.

Macrostructures Occurrences (Passchier and Trouw, 2005)	Microstructures Occurences (Passchier and Trouw, 2005)
Lithological Contact	Quartz-Mica Intercalation
Foliation	Undulose Extinction
Isoclinal Fold	Kink Band
Shearband Cleavage	Dynamic Recrystallization
Boudinage	Elongate Quartz
Horsetails vein	Deformation Lamellae
Ladder vein	Crenulation Cleavage
En-echelon vein	Phorphyroclast
Disaggregation band	Sigmoid
fractures	Fish Mica
	Fringe/Strain Shadow
	Dark seams dislocation
	Intragranular fractures
	Deformation band

Based on the macrostructures and microstructures observed in the research area, the data can be divided into four parts according to structural type and overprinting relationships. The first part is S0, which is based on lithological contact. The second part is S1, which is based on the presence of shear band foliation. The third part is S2, which is parallel with S0 but exhibits folding in certain lithologies. Finally, the fourth part is S3, which is characterized by compressional crenulation cleavage (Fig. 6). These structural types were recorded and analyzed by describing their geometric shapes, noting the presence of any measurable structural planes, and determining their overprinting relationships to understand the deformation pattern in the study area.

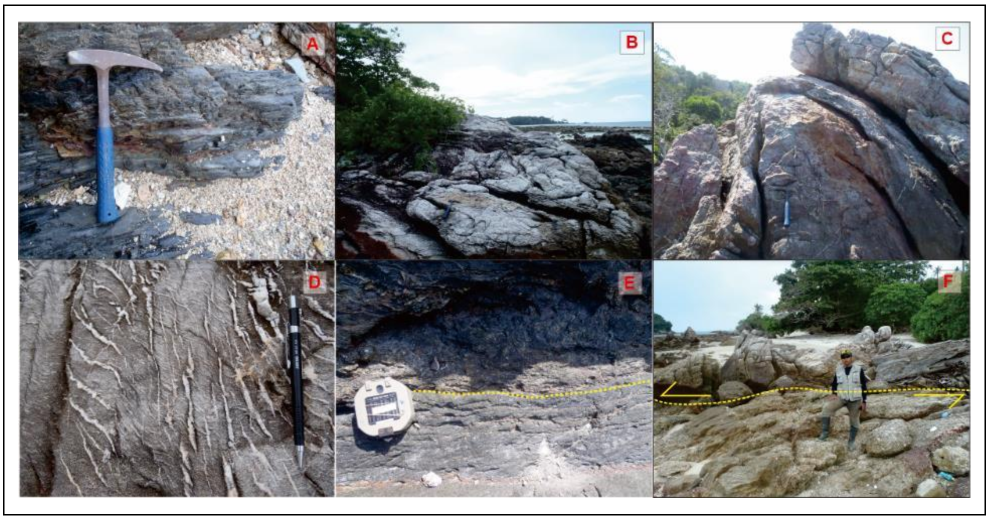

Fig. 5. Several macrostructures occurrences in field area (A) parallel foliation, (B) Foliation in schist, (C) Fold in crystalline rocks, (D) En-echelon vein and crenulation cleavage, (E) S-C fabric, (F) Strike-slip fault.

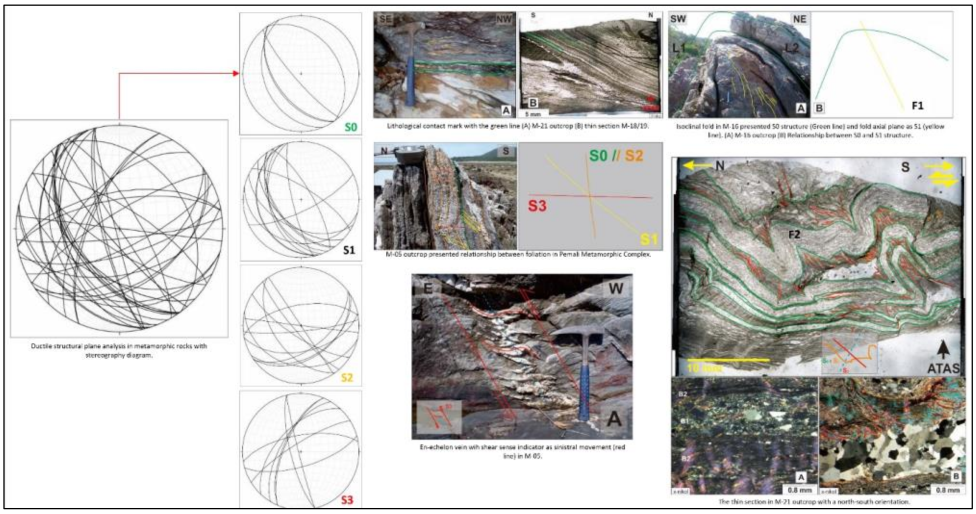

Fig. 6. Scheme of foliations list in the research area.

The study area displays complex deformation events that have been revealed by various macro and microstructural features. Based on the observations, the deformation events can be classified into three phases. The first deformation phase (D1) is characterized by the presence of northwest-southeast directed F1 fold, shear band foliation, emergence of S-C fabric, core-mantle phorphyroclast structure, and shear band boudinage. This phase is also marked by an extensional regime and a ductile deformation zone. The second phase (D2) is dominated by northeast-southwest directed F2 fold, compressional crenulation cleavage, and a brittle-ductile deformation transition. Lastly, the third phase (D3) is represented by the presence of fault and joint, northeast-southwest stress orientation, and a brittle deformation mechanism. These structures provide evidence of the deformation events that have occurred in the study area and the different tectonic regimes that have influenced it over time (Fig. 7 and Fig. 8).

The research area shows three distinct deformation periods, with two being ductile and one brittle, while the Bentong-Raub suture in the Malay Peninsula records four different deformations, with two being ductile and two brittle. The similarity between the research area and the northern part of Bangka Island lies in their deformation aspects, which are comparable to those of the Bentong-Raub suture in Malaysia. The deformation history of the research area and the Bentong-Raub suture can be traced back to the collision between Sibumasu and Indochina, which led to the formation of these geological features. The deformation events recorded in the research area and the Bentong-Raub suture provide insights into the tectonic history of the region and contribute to our understanding of the geological evolution of Southeast Asia. The result of this study shows that the northern part of Bangka Island has experienced three different deformation phases, including two ductile deformations and one brittle deformation. The deformation sequence is similar to that experienced in the Bentong-Raub suture zone, indicating that this region has a complex tectonic history (Metcalfe, 2001, 2000).

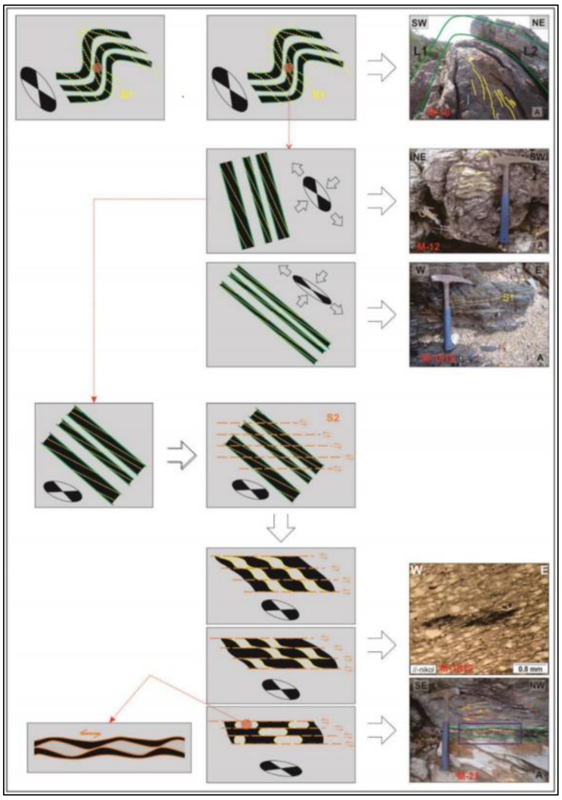

Fig. 7. First deformation phase (D1) associated with emergence fold (F1) and foliation S1 (yellow line) and foliation S2 (orange line).

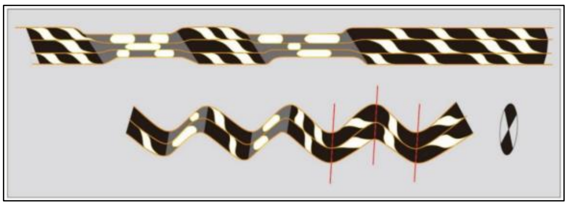

Fig. 8. Second deformation phase (D2) associated with fold (F2) and foliation S1 (yellow line), foliation S2 (orange line), and foliation S3 (red line) modified from (Schavemaker et al., 2012).

5. Conclusion

In conclusion, the deformation history of North Bangka Island can be divided into three distinct phases from several lithologies that identified from mineral composition and microstructures. The first phase (D1) involved folding in a Northwest-Southeast direction and occurred during the Permian-Upper Triassic period. The second phase (D2) saw the emergence of folds with an NNE-SSW direction, generated in the shear zone by the brittle-ductile transition plastic deformation mechanism. Finally, the third phase (D3) was characterized by brittle deformation mechanisms, resulting in the formation of faults and joints. The Bentong-Raub suture zone, which resulted from the collision between the Sibumasu and Indochina Blocks, extended southward to North Bangka Island.

Acknowledgments

We would like to express our gratitude to the LPDP Thesis program in 2018, which is organized by the Ministry of Finance, for providing the financial support needed to conduct this research. We are also grateful to the Geodynamic Research Group in the Department of Geological Engineering at ITB for their financial support and assistance throughout the research process. Without their valuable contributions and guidance, this research would not have been possible.

References

Barber, A.J., Crow, M.J., J. S. Milsom, 2005. Sumatra: Geology, Resources and Tectonic Evolution, GEOLOGICAL SOCIETY MEMOIRS NO. 31. https://doi.org/10.1017/CBO9781107415324.004

Beddoe-Stephens, B., Shepherd, T.J., Bowles, J.F.W., Brook, M., 1987. Gold mineralization and skarn development near Muara Sipongi, West Sumatra, Indonesia. Economic Geology 82. https://doi.org/10.2113/gsecongeo.82.7.1732

Blenkinsop, T., 2000. Deformation Microstructures and Mechanisms in Minerals and Rocks, 1st ed. Springer Dordrecht, New York. https://doi.org/https://doi.org/10.1007/0-306-47543-X

Cahyana, F.H., Restiko, F.A., Hidayat, T.N., 2021. Structural Control on Primary Tin Deposit at Paku Area, Payung Subddistrict, South Bangka District, Bangka Belitung Province. jointconvex.or.id.

Cobbing, E.J., Mallick, D.I.J., Pitfield, P.E.J., Teoh, L.H., 1986. The granites of the southeast Asian tin belt. Journal of the Geological Society 143. https://doi.org/10.1144/gsjgs.143.3.0537

Fossen, H., 2016. Structural geology. books.google.com.

Gasparon, M., Varne, R., 1995. Sumatran granitoids and their relationship to Southeast Asian terranes. Tectonophysics 251. https://doi.org/10.1016/0040-1951(95)00083-6

Hashim, M., Misbari, S., Pour, A.B., 2018. Landslide mapping and assessment by integrating Landsat-8, PALSAR-2 and GIS techniques: a case study from Kelantan State, Peninsular Malaysia. Journal of the Indian Society of Remote Sensing. https://doi.org/10.1007/s12524-017-0675-9

Hendrawan, R.N., Sapiie, B., Basuki, N.I., Artikel, R., 2021. Persebaran Struktur Geologi Dan Batuan Pra-Tersier Pada. Journal of Science, Technology, and Visual Culture 2, 102–106.

Hutchison, C.S., 1994. Gondwana and Cathaysian blocks, palaeotethys sutures and cenozoic tectonics in South-east Asia. Geologische Rundschau 83. https://doi.org/10.1007/BF00210553

Ibrahim, A.K., Musa, A.I., 2020. Mapping geology and structural features of Kazaure SE, NW Nigeria: Justifying groundwater potential model. Zbornik radova Departmana za geografiju, turizam i hotelijerstvo 49, 1–21.

Irfan, U.R., Langkoke, R., Alimuddin, I., Bahar, A.M.A., Putra YS, A.R.I.A., 2023. Geological heritage as a basis for geoscience development: A case study of Bentong-Raub Suture in Lojing District, Gua Musang District, Kelantan, Malaysia, in: IOP Conference Series: Earth and Environmental Science. iopscience.iop.org. https://doi.org/10.1088/1755-1315/1134/1/012053

Khin Zaw, Meffre, S., Lai, C.-K., Burrett, C., Santosh, M., Graham, I., Manaka, T., Salam, A., Kamvong, T., Cromie, P., 2014. Tectonics and metallogeny of mainland Southeast Asia — A review and contribution. Gondwana Research 26, 5–30. https://doi.org/https://doi.org/10.1016/j.gr.2013.10.010

Mangga, S.A., Djamal, B., 1994. Geological Map of The North Bangka Sheet, Sumatera, Systematic. ed. Geological Research and Development Centre,

Bandung.
Margono, U., Supandjono, R.J.B., Partoyo, E., 1995. Geological Map of The South Bangka Sheet, Sumatra, Systematic. ed. Geological Research and Development Centre, Bandung.
Metcalfe, I., 2013. Tectonic evolution of the Malay Peninsula. Journal of Asian Earth Sciences 76, 195–213. https://doi.org/10.1016/j.jseaes.2012.12.011
Metcalfe, I., 2001. The Bentong-Raub Suture Zone, Permo-Triassic Orogenesis and Amalgamation of the Sibumasu and Indochina Terranes. Gondwana Research 4. https://doi.org/10.1016/S1342-937X(05)70498-6
Metcalfe, I., 2000. The Bentong–Raub Suture Zone. Journal of Asian Earth Sciences 18, 691–712. https://doi.org/https://doi.org/10.1016/S1367-9120(00)00043-2
Mukherjee, S., 2020. Atlas of structural geology. books.google.com.
Ng, S.W.P., Whitehouse, M.J., Roselee, M.H., Teschner, C., Murtadha, S., Oliver, G.J.H., Ghani, A.A., Chang, S.C., 2017. Late triassic granites from Bangka, Indonesia: A continuation of the main range granite province of the South-East Asian tin belt. Journal of Asian Earth Sciences 138, 548–561.
Passchier, C.W., Trouw, R.A.J., 2005. Microtectonics, Microtectonics. https://doi.org/10.1007/3-540-29359-0
Passchier, C.W., Trouw, R.A.J., 1996. Microtectonics. Microtectonics. https://doi.org/10.1016/s0191-8141(97)84094-1
Pound, K.S., Norris, R.J., Landis, C.A., 2014. Eyre Creek mélange: An accretionary prism shear-zone mélange in Caples terrane rocks, Eyre Creek, northern Southland, New Zealand. New Zealand Journal of Geology and Geophysics. https://doi.org/10.1080/00288306.2013.837395
Pour, A.B., Hashim, M., Makoundi, C., Zaw, K., 2016. Structural Mapping of the Bentong-Raub Suture Zone Using PALSAR Remote Sensing Data, Peninsular Malaysia: Implications for Sediment-hosted/Orogenic Gold Mineral Systems Exploration. Resource Geology. https://doi.org/10.1111/rge.12105
Pour, A.B., Hashim, M., Park, Y., 2018. Gondwana-Derived Terranes structural mapping using PALSAR remote sensing data. Journal of the Indian Society of Remote Sensing 46, 249–262. https://doi.org/10.1007/s12524-017-0673-y
Rozalli, M., Mankhemthong, N., Morley, C.K., Limtrakun, P., 2020. Indosinian Orogeny Structure in Ban Pong and Ban Hong Quarries, Chiang Mai and Lamphun Provinces, Northwestern Thailand. 3rd Asia Pacific Meeting on Near Surface Geoscience & Engineering. https://doi.org/10.3997/2214-4609.202071055
Sapari, N.K., Zabidi, H., Ariffin, K.S., 2016. Geochemical prospecting of tin mineralization zone at Belukar Semang prospect, Gerik, Perak. Procedia Chemistry.
Sapiie, B., Nugraha, M.A., Wardana, R.K., Rifiyanto, A., 2017. Fracture Characteristics of Melange Complex Basement in Bantimala Area, South Sulawesi, Indonesia. Indonesian Journal on Geoscience 4, 121–141.
Sato, K., 1991. K-Ar ages of granitoids in central Sumatra, Indonesia. Bulletin of the geological survey of Japan 42, 111–123.
Schavemaker, Y.A., De Breser, J.H.P., Van Baelen, H., Sintubin, M., 2012. Geometry and kinematics of the low-grade metamorphic “Herbeumont shear zone” in the High-Ardenne slate belt (Belgium). Geologica Belgica 15.
Song, W., Yu, Y., Gao, S.S., Liu, K.H., Fu, Y., 2021. Seismic anisotropy and mantle deformation beneath the central Sunda plate. Journal of Geophysical Research 126. https://doi.org/10.1029/2020JB021259
Sugiono, D., 2014. Geochemistry and petrography analysis in granitoid at North Bangka Island. Bandung Institute of Technology.
Xian, H., Zhang, S., Li, H., Xiao, Q., Chang, L., Yang, T., Wu, H., 2019. How Did South China Connect to and Separate From Gondwana? New Paleomagnetic Constraints From the Middle Devonian Red Beds in South China. Geophysical Research Letters 46, 7371–7378. https://doi.org/10.1029/2019GL083123
Zhang, S., Xiao, K., Chen, J., Xiang, J., Cui, N., Wang, X., 2019. Development and future prospects of quantitative mineral assessment in China. China Geology 2, 198–210. https://doi.org/https://doi.org/10.31035/cg2018097