International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 108-123
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.35

Simple Shear Mechanism to Revealing Geological Complexity of Geosite Assessment in the Bukit Duabelas National Park Jambi Province, Indonesia

Hari Wiki Utama[1,2], Rakhmatul Arafat[1], Bagus Adhitya[1], Yulia Morsa Said[1], Arsyad AR[3], Gindo Tampubolon[3], Agus Kurniawan Mastur[3], Itang Ahmad Mahbub[3], Yusmansyah Siregar[1], Ignatia Tri Astuti[1], M. Fauzi[1,3]

[1]Geological Engineering, Universitas Jambi, [2]Merangin Jambi UNESCO Global Geopark Management, [3]Agroecotechnology, Universitas Jambi

Article Info

Article history:
Received Aug 21, 2023
Revised Sept 20, 2023
Accepted Nov 24, 2023

Keywords:
Simple Shear Mechanism,
Geological Complexity,
Geosite Assessment

ABSTRACT

Bukit Duabelas National Park (BDNP) Jambi Province is a national protected area that has geodiversity. BDNP forms northwest – south-east oriented, morphologically connected to the Barisan Mountains by the Bangko Basin. Digital elevation model observations show that the morphological orientation of these hills is surrounded by valleys and plains occupied by Paleogene-Neogene sedimentary rocks. The presence of Schist Terantam Formation provides interesting information about the exposed basement. This research uses remote sensing, field observations and stratigraphic analysis, as well as assessing geological complexity. The BDNP Territory is geologically influenced by geological structures such as faults and folds as a result of the simple shear deformation mechanism. Schist from the Terantam Formation and Granite and Pegmatite Intrusions are a consequence of simple shear mechanisms and tectonic orogenesis. Geological complexity of geosite assessment based on the criteria of petrological features, landscape, age of formation, fossil appear, tectonic basement, basement group, cultural diversity, other geological information. The proposed geosite is Terantam Inselberg which is composed of the Terantam Formation of Carboniferous and Jurassic-age of Granite and Pegmatite. The uniqueness of this proposed geosite is that the rocks exposed are the oldest basement rocks on the Sumatra Island. The landscape with Inselberg morphology, of course, is unique and is very rarely found in other areas, then the presence of ethnic groups from the Inner Child Tribe who inhabit the area characterizes cultural diversity. Comparing this proposed geosite with geosites of national and international value in the MJUGGp Territory, it can be concluded that the Terantam Inselberg Geosite is in between the two positions.

This is an open access article under the CC BY-SA license.

Corresponding Author:
Hari Wiki Utama
Email: hariwikiutama@gmail.com

1. INTRODUCTION

Bukit Duabelas National Park (BDNP) Jambi Province is a national protected area that not only has biodiversity and cultural diversity, but also geological diversity. The BDNP, which forms hills with alignment ridges-valley oriented northwest – southeast. There is clearly visible as a characteristic features of this BDNP Territory, which is morphologically connected to the Barisan Mountains by the fore-land basin

International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 108-123
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.35

of the Bangko Basin which forms a physiographic series of the Barisan Range (Crow et al., 2019; Utama et al., 2021; Metcalfe, 2017; 2013; Hall, 2012; 2013). Administratively, BDNP is included in the administrative divisions of Sarolangun Regency, Batanghari Regency, Merangin Regency, and Tebo Regency (Figure 1). Based on observations on satellite images and digital elevation models, supported by previous research, it shows that the morphological orientation of these hills is surrounded by valleys and plains occupied by Paleogene-Neogene sedimentary rocks and volcaniclastic sedimentary rocks (Barber and Crow, 2009; Najili et al., 2021; Utama, 2020; Henstock et al., 2016). This morphology is known as inselberg or also known as monadnock (Yunfeng et al., 2017; Kale et al., 2014). This morphology certainly has its own uniqueness from other natural landscapes, where there are elongated hills surrounded by plains or valleys with rocks that are different from these two morphologies (Yuexia et al., 2015). This uniqueness provides something meaningful regarding the geological information that can form these hills. Certainly, the morphological orientation of the hills and the geological structures that form are an indication of the geological structural mechanisms that influence the formation of these hills.

The presence of Schist from the Terantam Formation in BDNPof Carboniferous age provides interesting information about the basement rock of Sumatra Island (Crow et al., 2019; 2015; Simandjuntak et al., 1994; McNeill et al., 2014; Otofuji et al., 2017). Apart from providing information about basement rock and tectonic blocks, there is something more important than that, namely the potential of this geological site to be of educational geological value to be used as a geological heritage (Natawidjaja, 2015; 2017; 2018; Moufti and Nemeth, 2016). Rock outcrops that only span the Carboniferous age range on Sumatra Island and even western Indonesia are very difficult to find. Most Carboniferous rocks have an age range up to the Permian, such as metamorphic and metasedimentary rocks in the Tigapuluh Mountains from the Mentulu Formation, the Mentulu Formation of the Condong Member, the Gangsal Formation, and the Pangabuan Formation (Utama et al., 2022; Akbar and Utama, 2021). When compared with rocks in the Barisan Mountains such as the Ngaol Formation, the Limestone Member Ngaol Formation which is exposed in the northern part of the UNESCO Global Geopark Merangin Jambi Territory also has a Carboniferous to Permian age (Utama et al., 2023; Van Waveren et al, 2018). Thus, this evidence is certainly unique geologically regarding the basement rock exposed in Jambi Province. This explanation needs to be carried out geological assessment, to reveal geological complexity with educational value at an existing geological site, so that it can be used as a geological heritage.

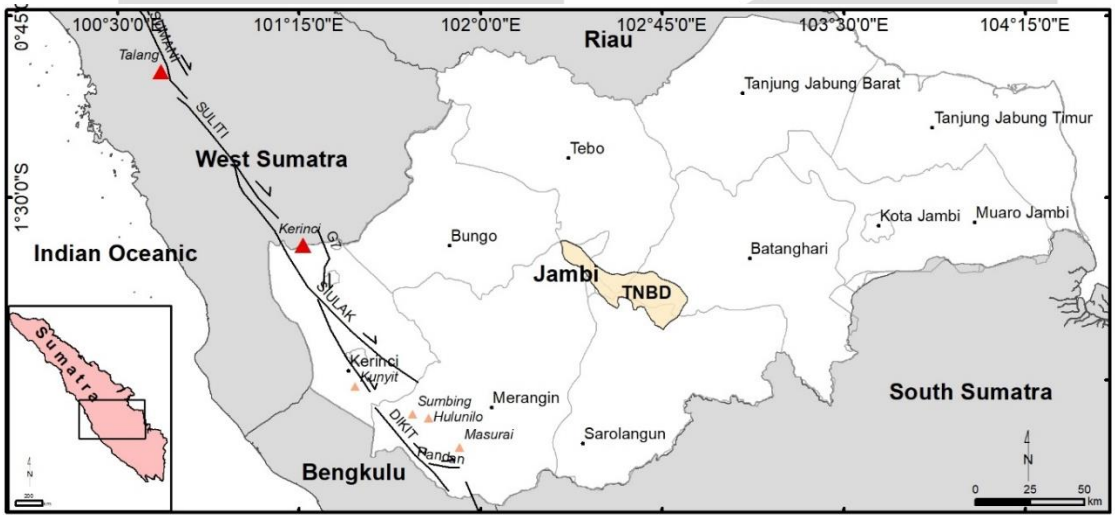


Figure 1 Map situation of Bukit Duabelas National Park (BDNP or TNBD) in Jambi Province. This morphology has ridge orientation of northwestern - southeastern

In achieving sustainable development launched by the Indonesian Government to achieve sustainable development goals, one of which is the tourism aspect with special interest tourism on an educational basis known as geotourism. To achieve this goal, it is important to conserve the existing geological heritage as a form of preserving the natural environmental ecosystem that exists on earth (Antic and Tomic, 2017; Prasetya et al., 2017). One of the conservation efforts undertaken is to make it a geological heritage based

on the protection of the National Earth Park which aims in the long term as a Global Earth Park or Geopark. (Moufti and Nemeth, 2016). One of the geological heritage conservation efforts in the BDNP Territory requires the involvement of academics and researchers to explore information and geotourism potential in this area. The term geotourism is intended for special interest tourism based on geological diversity, conservation and education (Farsani et al., 2012). This effort is through research to explore hidden geotourism potential in the area, through geological complexity assessment studies to understand the characteristics of potential geological site or geosites that are important to geological conservation in this area. In a geological assessment of the potential of a geological site that can be used as a geological heritage, it is necessary to understand the special components of the geological site information, and of course it is unique from other geological site, such as in terms of rock age, rock type, landscape, fossils, and so on related to geological diversity (Chen and Ng, 2015; Farsani et al., 2011).

An important point in this research is the form of conservation efforts for the geological heritage at BDNP. Therefore, research is needed to explore the unique potential of geotourism. Geotourism is a new term created for tourism activities carried out primarily based on geological aspects or a natural tourism activity that focuses on the geological appearance of the earth's surface in order to encourage understanding of the environment and culture, appreciation and conservation, and local wisdom (Entezari and Aghaipour, 2014). In simpler terms, geotourism is defined as tourist activities by visiting attractions that are unique from a geological perspective and involve different experiences before and after tourism (Cooper, 2010; Brahmantyo, 2013). This geotourism development can later be used as a natural laboratory that provides education about the unique geological heritage. The potential of geotourism as a conservation effort should be able to be increased to become one of the leading geotourism in BDNP which in time will role as an geopark (Utami et al., 2013; Mulyasari et al., 2019; Nabella et al., 2019). This research applies geological complexity as a form of assessment of geological potential locations that have an impact on geological heritage conservation in the BDNPTerritory, Jambi Province.

2. METHODS

The data needed in this research is topographic data, including contour lines, drainage pattern, toponimi, which can be downloaded from the Inageoportal by Geospatial Information Agency (2023). Other data needed are digital elevation models as well as digital images and geological maps. The methods used in this research include remote sensing methods based on geographic information systems and basic geological concepts, then geological observation methods in the field, geological complexity assessment methods.

This research begins with an observation method using digital elevation model images and direct observation in the field is the initial stage in this research. Observations through high resolution imagery using Digital Elevation Model Image data. The data is in the form of contour lines which are then interpolated from a scale of 1:50,000 to a scale of 1:25,000. The Digital Elevation Model data is then analyzed using geological remote sensing concepts to determine valley alignments which are identified as tectonic alignments or geological structures. The data analysis method is also strengthened by identifying drainage patterns with the aim of identifying geological structures (Rosenbaum, 2014; Siregar and Utama, 2023; Ariani and Utama, 2022). Drainage pattern is a function of lithology, slope and rock resistance, so this data can provide important information on the geology of the research area. This analysis method is integrated with the Geological Map. This analysis using remote sensing studies also considers geomorphic shape boundaries.

The second stage is observing geological outcrops in the field. This method was carried out to see and documentations the geological diversity of the presence of outcrops in the BDNP Territory which are believed to form "inselberg" towers from the stratigraphic site and morphology of the surrounding stratigraphy. Apart from that, rock samples were taken at each rock outcrop which represents the distribution of existing rocks. Rock sampling aims to observe the rock composition megascopically by observing the mineralogical composition of the rock, rock texture and rock structure. Identifying geological diversity, and also considering biodiversity and cultural diversity, however in this research the focus is on assessing

International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 108-123
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.35

geological diversity from rock stratigraphy and geological manifestations in the BDNP Territory. This geological complexity assessment will later be carried out as well as comparative studies of the same rock types in different areas of the BDNP Territory.

The geological complexity assessment aims to provide a perspective on the quality of a geological location in the BDNP Territory. This assessment includes the petrological characteristics of the rock, the natural landscape, the assessment status of whether it is of local, national or international value. This assessment is based on geological data. The presence of rock outcrops is another factor that must be met, the educational value obtained, then the comparability of geological site in the BDNP Territory with other areas that have been recognized nationally or internationally in the National Geopark and UNESCO Global Geopark categories such as the Merangin Jambi UNESCO Global Geopark. Comparative studies from geological complexity assessments, at least provide an idea of the quality of the proposed Geosite in the BDNP Territory.

3. RESULT AND DISCUSSION

Geological Remote Sensing

Remote sensing studies show that in the BDNP Territory, it is a hills with a ridge that extends in a northwest – southeast direction, which has the same orientation as the direction of Sumatra Island. Observations using high resolution imagery clearly show the span of the three-dimensional model of the BDNP Territory. These hills form a cliff with relatively steep cliffs in the southwest, while relatively gentle slopes in the northeast (Figure 2a). The morphology of hills like this indicates the presence of lithological control and also geological structure in their formation. In the southwest part, it is believed that there are thrust fault and strike-slip fault structures, with high rock resistance from metamorphic and igneous rocks, so it is very possible to form a relatively steep morphology when compared to the northeastern part. The relatively sloping hills in the northeastern part indicate that there is deposition of sedimentary rocks with geological structures from differences in the position of bedding planes as an indication of fold structures and also horizontal faulting. In terms of geological position, the BDNP Territory is in the eastern part of the Bangko Basin which is a fore-land basin and is also in the south-southwestern part of the Tigapuluh Mountains, and is also associated with the back arc basin of Jambi back-arc basin (Figure 2b).

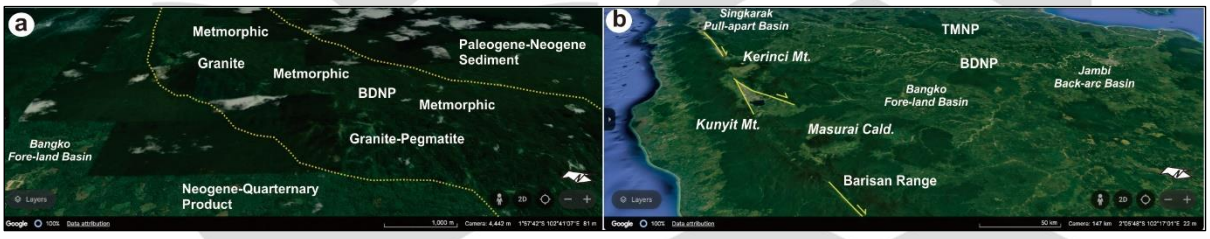


Figure 2. Overview of Bukit Duabelas National Park, which a) morphology and toponimi hills and geological formation composed, b) geological situation of Bukit Duabelas National Park to other geological features, like Bangko basin, Tigapuluh Mountains (TMNP). Source high resolution image of Google earth 2023

Processing of topographic data that forms a digital elevation model image with a scale of 1:50,000 to 1:25,000 shows that the valley alignments oriented towards the ridge straightness show a dominant orientation in a northwest – southeast direction and only a small portion is oriented north – south and northeast – southwest orientation, and almost none are oriented west-north (Figure 3a and Figure 3b). With this alignment orientation, a tectonic stress model can be created which influences the formation of BDNP. Thus, the tectonic stress model forms a simple shear (Davis et al., 2012; Liu et al., 2021; Lange et al., 2018; Zahirovic et al., 2015; 2019). This model is a model that has experienced more than one phase of

International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 108-123
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.35

deformation. The first deformation phase is shearing stress and the second phase is followed by compressional stress (Figure 3c). Modeling like this refers to structural modeling by (Fossen, 2010; Allen and Allen, 2005). Shearing stress is the main role in causing the orientation of the BDNPhills, while compressional stress causes the formation of existing geological structures such as thrust faults and strike-slip faults. Thus, the morphological cross-section model of BDNPshows that there are integrated zones between the different constituent rocks, in the dominant topography composed of high-resistance rocks such as igneous and metamorphic rocks, while other parts are composed of sedimentary rocks and volcanic sediments (Figure 3d).

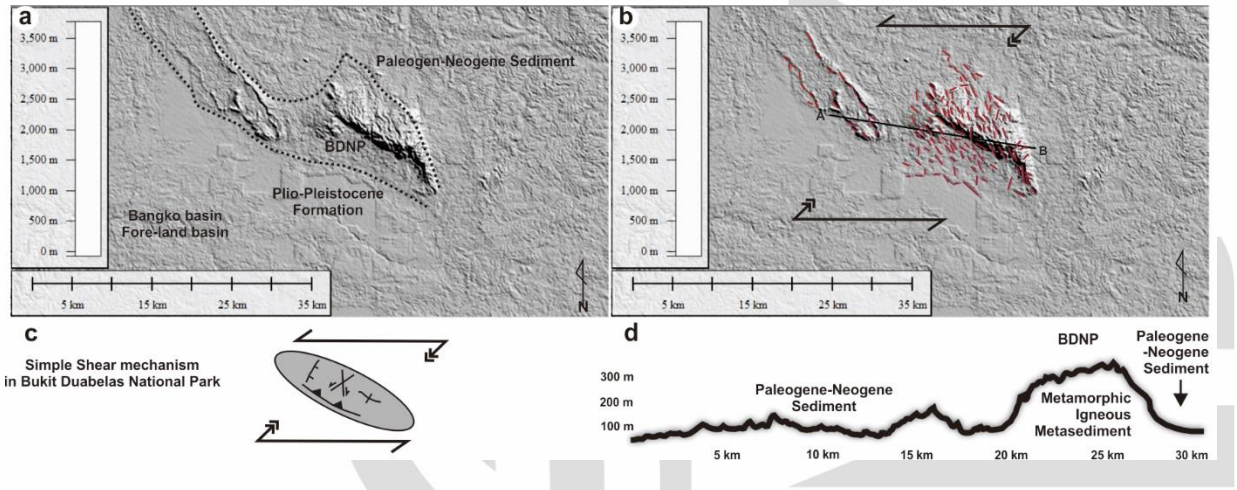


Figure 3. Representation of BDNP using digital elevation model source of USGS, which a) orientation is northwestern – southeastern, b) valley lineament (red line) is oriented to ridge of BDNP the indicated of structural geology cotrolled, c) simple shear mechanism forming BDNP with oriented. Simple shear is combination stress of shearing and compressional stress, d) cross section vertical sub-surface of BDNP which consist of metamorphic and igneous rock is central of BDNP, meanwhile other side consist of sedimentary rock and sediment-volcanic rock

Geological Field Observation and Stratigraphic

Field observations are carried out to collect geological data, such as rock characteristics or rock petrology, rock distribution, and rock stratigraphic position. Based on the results of field observations and geological analysis carried out on the stratigraphic position of rocks in the BDNP Territory from old to young, they are composed of the Terantam Formation (CT) of Carboniferous, Granite Intrusions (Jgr) and Pegmatites (Jpg) of Jurassic age. These three rock formations are present as basement (Crow et al., 2019; Zahirovic et al., 2016; 2014; 2012). Then it is covered unconformably by sedimentary rocks from the Lahat Formation (Teol) of Eocene-Early Oligocene, the Talangakar Formation (Tomt) of Late Oligocene-Early Miocene, the Gumai Formation (Tmg) of Middle Miocene, the Airbenakat Formation (Tma) of the end Middle Miocene-Late Miocene, the Kasai Formation (QTk) Pliocene-Pleistocene, and Alluvial Deposits (Qa) (Figure 4).

Basement Terantam Formation

This formation is composed of metamorphic rocks such as mica schist, marble, quartzite, and metasedimentary rocks such as siltstone, metapelite, and metapsamite. This formation is a group of Pre-Tertiary rocks of Carboniferous from the Tapanuli Peusangan Group and occupies the ridge of the BDNP Territory. The petrological characteristics of schist as the main lithologies stratigraphic formation are gray to bluish green; the schistose foliation structure is a characteristic feature of this formation and forms a slight palimsest structure; crystalloblastic-lepidoblastic texture; constituent mineralogy with stress and anti-stress minerals such as muscovite, biotite, phlogopite, quartz, chlorite; This lihtology is generally found in a deformed condition characterized by the presence of fault structures that deformation the foliation structure of this metamorphic rock. This formation is well exposed in the Terantam River (Utama et al., 2023). These rocks are generally also found in conditions that have undergone hydrothermal alteration changes

International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 108-123
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.35

caused by Granite Intrusions, but still show the presence of quartz minerals, k-feldspar with hydrothermal alteration minerals such as montmorillonite and illite which are interpreted as changes to the k-feldspar minerals. Outcrops of this rock are also generally found to have quartz veins which have been identified as being associated with pegmatite veins from igneous rocks which cut into the foliation plane, parallel to the foliation plane, and form a slightly sigmoidal shape. Quartzite is found locally among areas of schist foliation, while marble is found in the form of hydrothermal alteration characterized by garnet and pyroxene minerals, such as those exposed around the Terantam River. Metasedimentary rocks such as metapellite and metasiltstone are found in the upstream part of the Terantam River which is interpreted as the upper part of the Schist section of the Terantam Formation. This metapellite locally resembles shale, but if observed in detail it shows that the rock has undergone clay to crystalline deformation. The existence of this formation is believed to be part of the exposed basement or kraton high or basement high. The rock basement is believed to be part of the West Sumatra Block.

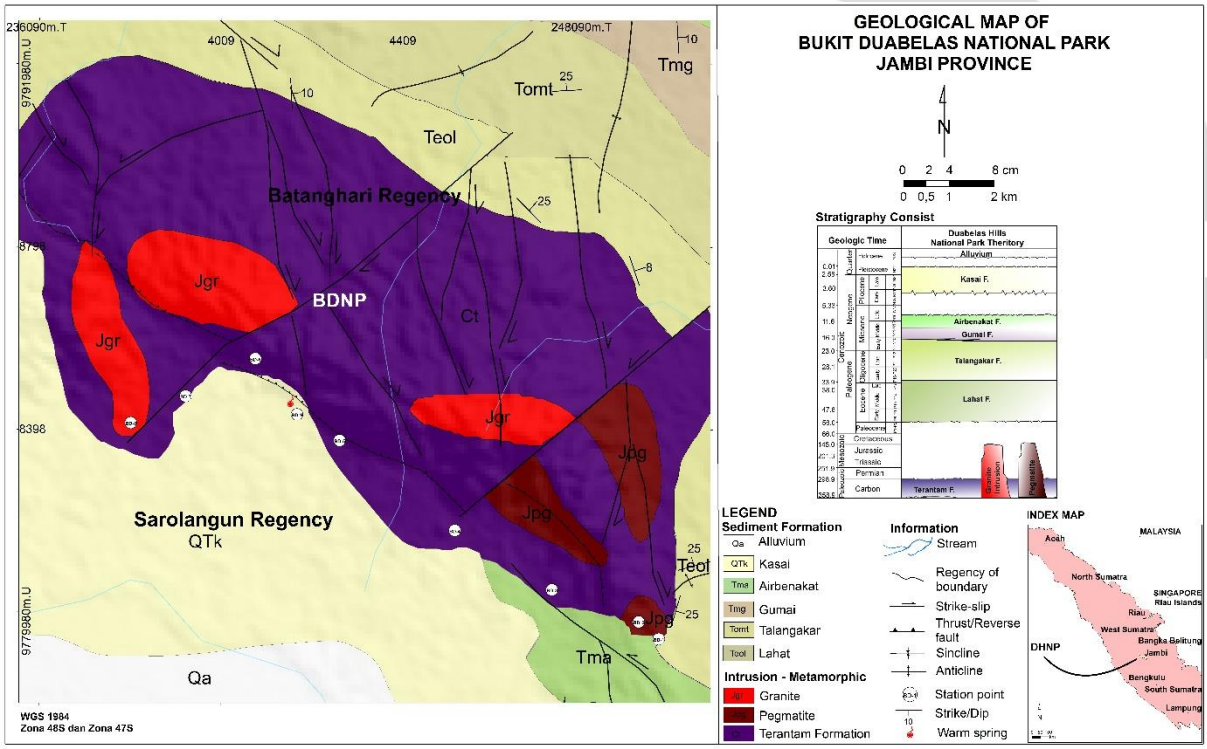


Figure 4. Geological map of Bukit Duabelas National Park, modified from (Utama et al., 2023). Detailed stratigraphic consist (Figure 5)

Basement Granite

Duabelas Hills Granite is a part of Woyla Group. These rocks intrusion of the Schist rocks of the Terantam Formation. The characteristics of this rock are a type of intrusion rock that is Jurassic in age (Utama et al., 2023). This typical granite intrusion is exposed intrusion to the Terantam Formation Schist, so it is commonly found in a form that has undergone hydrothermal alteration. The characteristic mineralogy of this intrusion still clearly shows the presence of the mineral quartz, k-feldspar, while minerals such as biotite and muscovite are difficult to find, these are believed to have undergone hydrothermal alteration to form the mineral chlorite. Based on the mineralogical composition of the granite, it is certain that this rock has an S-type granitoid, however according to (Najili et al., 2021) believe this granitoid is A-type resulting from orogenic and post-collision processes, meaning a combination of S-type Granitoid and I-Type Granitoid. If the S-Type Granitoid is the result of post-collision melting, while the I-type Granitoid is the result of the subduction process, like the Langkup Granitoid which is in the southern part of Bangko City and is in the Barisan Mountains Zone (Syaifullah and Utama, 2021; Said and Utama, 2023; 2021). The natural landscape of the intrusive body and Terantam Formation forms like a ridge that is isolated from the rest which forms a flat morphology, this morphological form is known as inselberg (Yunfeng et al., 2017). The

International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 108-123
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.35

presence of granite that cross-cutting to the schist of the Terantam Formation and is associated with thrust faults and strike-slip faults, so it is believed that this intrusion is of the dike type for strike-slip faults and the dike type is followed by a sill which characterizes thrust faults.

Granite Intrusions associated with strike-slip faults are a characteristic of intrusions in dykes that are present in the igneous rock itself or can occur in plutonic or sub-volcanic rocks. Meanwhile, thrust faults indicate the presence of basement rock or bedrock such as metamorphic rock, limestone metamorphism of orogenesis, in this case it can be proven by the exposure of the Tarentam Formation Schist which is associated with Granite Intrusions. The petrogenesis of this intrusion was identified as the result of a local process of anatexis which experienced melting of ultra-metamorphic sedimentary rocks in the collision continental crust setting.

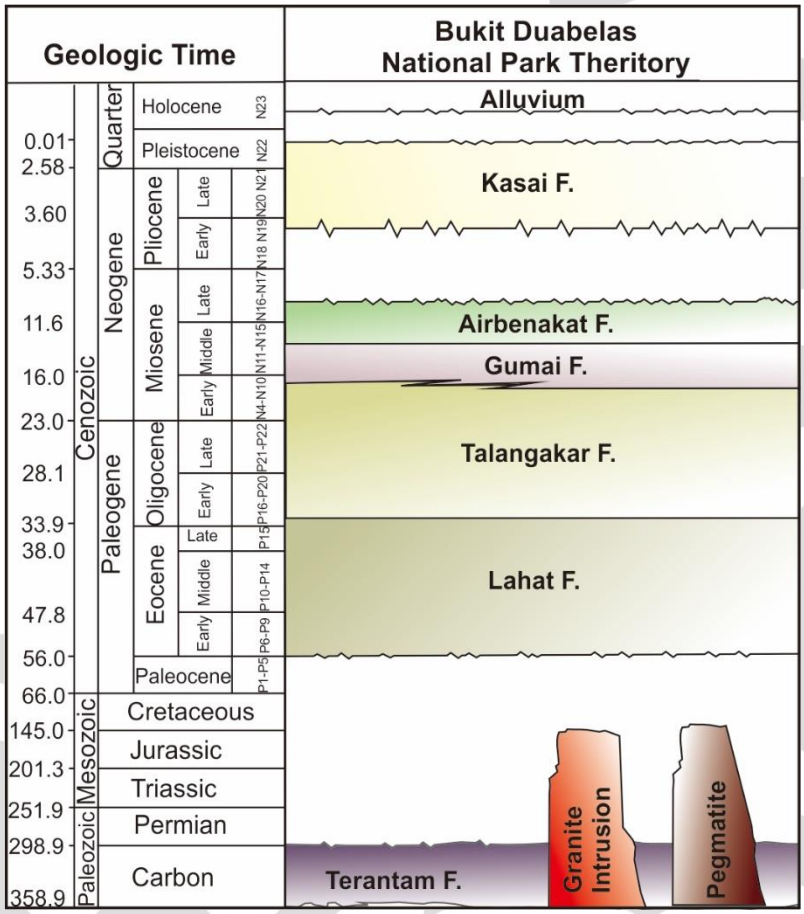


Figure 5. Stratigraphy consist of Bukit Duabelas National Park

Pegmatite

Pegmatites in the BDNP Territory presence of cross-cutting from the Terantam Formation Schist, some of which form hydrothermal veins (Figure 6). The characteristics of this lihtology are a type of intrusive rock that is Jurassic and the associated with Granite Intrusions (Utama et al., 2023). This rock intrusion is composed of pegmatites with metamorphic rock xenoliths from the Terantam Formation schist which is exposed on the peak to the medial slope of the BDNP. The intrusive body forms a morphological series with Granite Intrusions and Terantam Formations. The presence of this intrusion is believed to be the result of the subduction of the Ngalau Plate against the West Sumatra Terrane which occurred during the Jurassic - end of the Early Cretaceous which initiated obduction (Advokaat et al., 2018). This lithology is classified of Woyla Group. Pegmatite is formed from the melting process of metamorphic rocks generally from greenschist to eclogite facies (Van Leeuwen et al., 2016). The melting of this schist facies indicates that there are traces of regional dynamothermal facies (Winter, 2014). This identification also confirms that the BDNP Territory was formed by local orogenesis processes from the presence of Granite and Pegmatite

International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 108-123
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.35

Intrusions followed by the fault mechanism of simple shear (see Figure 3b and Figure 3c). This BDNP Territory can also be said to be an orogenic belt with a magmatic arc that is Jurassic terrain.



Figure 6. Overview of stratigraphy consist based on geological field datas, a) warm spring appear on tuffaceous sandstone of Kasai Formation the associated with Tarentam Formation, b) landscape of Terantam River consist of lithology by TErantam Formation and Granite Intrusion with altered, c) Terantam Formation features with schict, metapsamite, metapelite, d) the associated Pegmatite vein and quartz vein to Schist Tarentam Formation, e) cultural diversity with "Inner Child Tribe" of guider in the field observation

Lahat Formation

This formation unconformity overlies which nonconformity the basement rocks. This formation is exposed in the northern and eastern parts of BDNP. Conglomerate and sandstone are the main consist of formations formed in alluvial fan environments sedimentary facies. Conglomerate is characterized by a yellowish white to brownish yellow color; massive structure; texture of pebble-cobble, round-subrounded shape grain, well sorted, closed fabric with points–length of contact; grains supported; mineralogical composition of granite fragments, quartzite, schist, phyllite, sand matrix, silica cement. Apart from conglomerate as the main consist of this formation, there are sandstone inserts which are characterized by a yellowish white color; layered structure; coarse sand grain size texture, rounded, well sorted, closed packing with contact

points; grains supported; composition with quartz fragments, k-feldspar, plagioclase, clay matrix, silica cement. This formation is the first sedimentary deposition to fill the Jambi back-arc basin and a little of the Bangko fore-land basin at the beginning of the expansion of the basin formation.

Talangakar Formation

The transgressive sequence fills the spreading zone that forms the graben and fills the northern part of the Lahat Formation with a conformities relationship between the two formation stratigraphic. The characteristics of this formation are composed of sandstone and tuffaceous sandstone which in the braided stream facies depositional environment. The physical characteristics of this rock are yellowish white: layered-laminated structure; coarse sand grain size texture, rounded, well sorted, closed packing with contact points; grains support each other; mineralogical composition with quartz fragments, plagioclase, k-feldspar, muscovite, volcanic ash tuff, clay matrix. The genesis of this formation coincided with the bending of the Jambi back-arc basin as a result of Australia collision with the eastern part of the Eastern Indonesia (Hutchison, 2014), causing this formation to form a braided stream of fluviatile sedimentation environment.

Gumai Formation

Sedimentary facies formed in deep sea environments at maximum transgressive sequences to fluvio-deltaic sedimentary depositional environments. This formation is composed of sandstone, shale and claystone. Brown sandstone color: layered-laminated structure; medium sand grain size texture, rounded, poorly sorted, open fabric; mineralogical composition with hornblende and quartz fragments, wacke clay matrix, silica cement; mud supported. Shale is brown color; layered-shaled structure; clay texture; mineralogical composition of clay. Claystone, with the same characteristics as shale, can only be distinguished from its structure, namely by its characteristic brownish grey color; layered structure; clay texture; mineralogical composition of clay. The stratigraphic arrangement of this formation is believed to be the end of the transgressive sequence of Jambi back-arc basin sedimentation. This formation is exposed in the northern part of the Talangakar Formation. This formation, along with the Lahat Formation and Talangkar Formation, experienced deformation to form anticline and syncline zones as well as strike-slip faults (see Figure 4). This structural zone is a separate part of the simple shear mechanism of the BDNP Territory.

Airbenakat Formation

Stratigraphically, the facies of this formation are composed of sandstone, mudstone, and tuffaceous sandstone which were formed in a transitional environment from the lacustrine facies to the delta front. The formation of the Middle Miocene formation was accompanied by the isostatic uplift process of the Duabelas Hills, Tigapuluh Mountains, and Barisan Range which offset the sagging phase in the Seumatran back-arc basin (Hutchison, 2010). This formation is deformed which is characterized by the presence of fault structures and folding. This formation is exposed in the southern part of BDNP. This formation was formed in a regressive sequence as a response to the simultaneous uplift of the Barisan Mountains, counterbalanching the continued collision of Australia against the eastern part of Indonesia.

Kasai Formation

This formation is composed of tuffaceous claystone and tuffaceous sandstone. Stratigraphically, it is composed of volcanic products from sedimentary volcaniclastic along the Barisan Mountains of Plio-Pleistocene, including tuff, pumice intercalated with tuffaceus sandstone, local tuffaceous claystone, conglomerate, and silicified wood and charcoal. This volcanic product unconformably covers granite intrusions, pegmatites and terantam formations in the BDNP Territory, especially in the valley parts of the hills which also form anticline hills and syncline valleys. This formation is exposed in the southern part of BDNP. The genesis of this formation is related to volcanism that occurred sedimentary volcaniclastic during Plio-Pleistocene time (Hutchison, 2009; 2005). The aapearance of geothermal manifestations like warm spring is associated with this formation and the Terantam Formation (see Figure 6a). This manifestation linkage to fault system of BDNPwith non-volcanic geothermal system.

Geomorphology

International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 108-123
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.35

Geomorphic units in the BDNP Territory can be divided into Structural Hills, Granitic Inselberg, Structural Valley, Volcanic Denudational Plain, and Fluvial Plain. Based on morphochronology, the division of geomorphic units follows the stratigraphy unit of the rocks from the BDNPstratigraphic formation (Figure 7). This division of geomorphic units takes into account morphology, morphogonesis and morphochronology. The core part of the BDNPis a geomorphic unit with a hilly morphology with two geomorphic units. This division of geomorphic units aims to make it easier to understand the morphology and morphogenesis of the formed landforms.

The Structural Hills (SH) landform is a geomorphic unit with rocks from the Terantam Formation of Carboniferous. This geomorphic unit forms a hills morphology with elongated ridges. The orientation northwest – southeast. This morphology covers the Inselberg Granitic geomorphic unit and is surrounded by the Structural Valley geomorphic unit in the north and east, while in the south it is bounded by the Volcanic Denudational Plain geomorphic unit. This geomorphic is associated with thrust faults and strike-slip faults as part of morphogenesis.

The Granitic Inselberg (GI) landform is also classified as an Intrusion Hill or Intrusion Dome geomorphic unit. This term is to explain that the geomorphic units of these hills are surrounded by geomorphic land, although in fact the term inselberg precisely describes the geomorphic units of Granitic Inselberg and Structural Hills which are surrounded by land morphology. This Inselberg landform is composed of stratigraphy from Granite and Pegmatite Intrusions of Jurassic. Similar to the Structural Hills geomorphic unit, the presence of strike-slip and thrust fault structures which form fault esscarpment is the controlling morphogenesis of this unit.

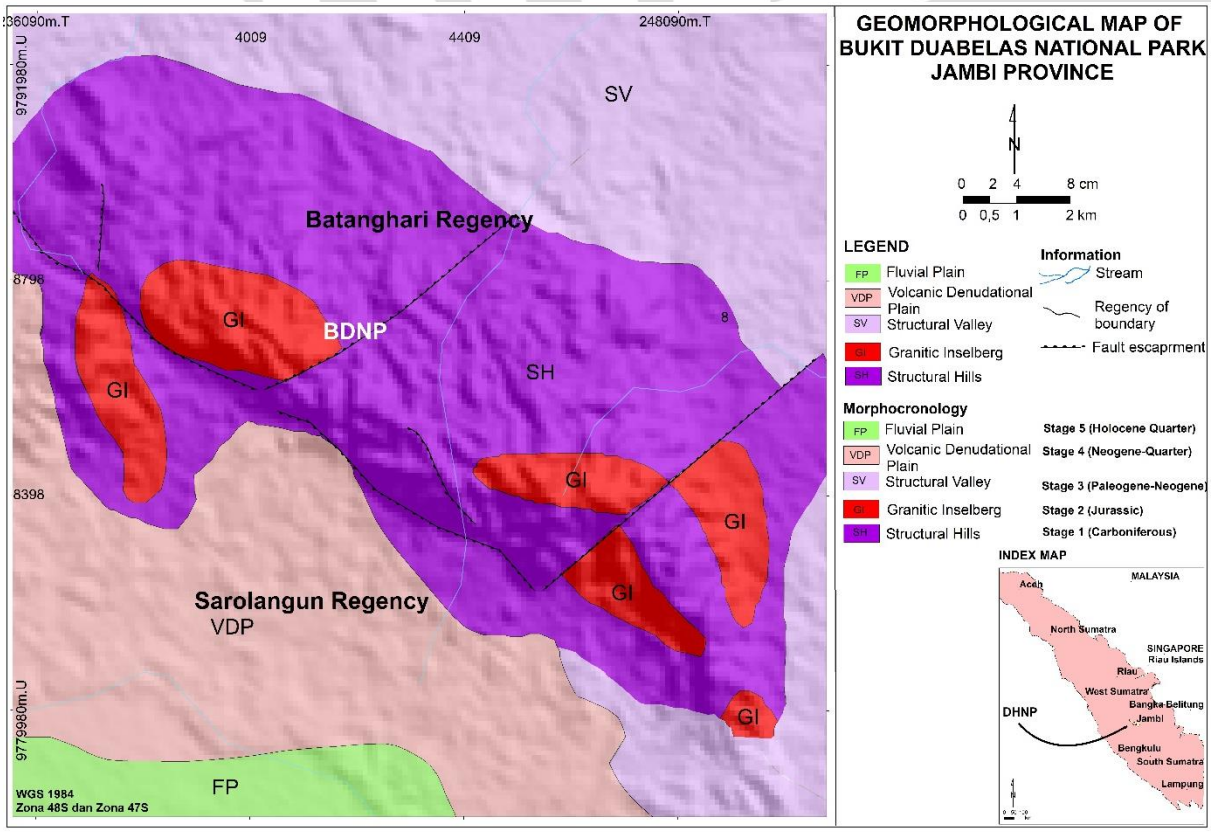


Figure 7. Geomorphology map of Bukit Duabelas National Park. Classified based on morphology, morphogenesis, and morphocronology

The Structural Valley (SV) landform occupies the eastern and northern parts of the BDNP Territory. This geomorphic unit is composed of rocks from the Lahat Formation, Talangakar Formation, Gumai Formation, and Airbenakat Formation which are of Paleogene-Neogene age. This formation forms a valley morphography of the BDNPwhich is controlled by the presence of geological structures such as anticline

International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 108-123
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.35

folds, syncline folds and strike-slip fault structures. This geomorphic unit was formed in the third stage of geomorphic formation in the BDNP Territory.

The Volcanic Denudational Plain occupies the southern part of BDNP. This geomorphic unit is composed of rocks from the Kasai Formation of Pliocene-Pleistocene age with volcaniclastic sedimentary rocks. The naming of volcanic geomorphics is based on the consisting of lithology being dominated by pyroclastic properties such as tuff and tufffaceous, while denudational is to emphasize the existence of exogenetic processes acting on this geomorphic unit.

The Fluvial Plain occupies the smallest part of the geomorphic unit in the BDNP Territory which is in the southern part of the Volcanic Denudational Plain geomorphic unit. This geomorphic unit is characterized by homogeneous sediment lithology.

Geological Assesment

The geological assessment is focused on the uniqueness of the Terantam Formation which is of Carboniferous and the shape of the geomorphic unit that forms Inselberg, namely a combination of the Structural Hills geomorphic unit from the Terantam and Inselberg Granite and Pegmatite Intrusions. In this unit there are also manifestations of warm water which may also be commonly found in other areas, but the Inselberg with its Carboniferous and some of its Jurassic from Granite and Pegmatite Intrusions has its own uniqueness from the conditions of other geological locations. The location and naming of the proposed location as a National Geological Ssite is the Terantam Inselberg Geosite, which means morphology with an Inselberg formation with rocks exposed in the hills of the Terantam area or BDNP Territory, namely the Terantam Formation of Carboniferous and Granite Intrusions and Pegmatites OF Jurassic . This geological assessment is based on petrological characteristics of rocks, landforms, age of rocks, presence of fossils, bedrock or tectonics, and other geological information (Table 1). The most important thing is to compare it with other geological locations that have national or even international geological site value, such as those in the Merangin Jambi UNESCO Global Geopark (MJUGGp) Territory.

Table 1. Geological assesment based on geological complexity of geosite potential in the Bukit Duabelas National Park which is comparison to international national geosite on the MJUGGp

Geological Assesment	International Geosite MJUGGp	National Geosite MJUGGp	Propose Geosite BDNP
Geosite	Teluk Gedang Wood Fossil	Kumbang and Mabuk Crater Lake Complex of Masurai Caldera	Terantam Inselberg
Petrology features	Wood fossil of Araucarixylon Fossil	Volcanic rock of dasitic-andesitic lava and pyroclastic	Mica schist, granite, and pegmatite
Landscape	Structural valley	Volcanic caldera	Inselberg
Age of formation	299 Ma (Cisuralian Permian)	33 Ka – 21 Ka (Late Pleistocene)	Mica shist (Mississippian – Pennsylvanian Carbon) Granite and Pegmatite (Jurassic)
Fossil appear	Wood fossil	Non identified	Non identified
Tectonic basement	Non basement, but related basement features of Cathaysianland of West Sumatra Block	Non basement, but young stratified	Gondwana and Cathaysianland of West Sumatra Block
Basement group	Peusangan	Young stratified	Tapanuli
Cultural diversity	Origin ethnic	Ethnic mixing	Inner Child Tribe ethnic
Biodiversity	Coffee plantation	Coffee plantation	Palm plantation

Other geological information	Only one in the world, remnant of Cathaysianland	The latest caldera discovery in Sumatran caldera series and in Indonesia	The oldest basement rock exposed in Sumatra and even Indonesia

4. CONCLUSION

Based on the results of the current research, it can be concluded that the BDNP Territory is an area that is geologically influenced by geological structures, such as thrust faults, strike-slip faults, anticline folds and syncline folds. Composition of geological structures as a result of rock deformation in geological structures using a simple shear mechanism. This mechanism is a combination of shearing or horizontal movement and compressional stress. Then the exposure of metamorphic rocks from the Terantam Formation which are of Carboniferous and also Granite Intrusion and Pegmatites of Jurassic is a consequence of the simple shear mechanism that occurs in BDNP and also the orogenesis of the Granite Intrusion. The orogenesis of the BDNPcannot be separated from the regional orogenesis process, including the Barisan Range which isostasically balances the global tectonic conditions of the collision of Australia towards the eastern part of Indonesia. Geological complexity of geological site assessment based on the criteria of petrological features, landscape, age of formation, fossil appear, tectonic basement, basement group, cultural diversity, other geological information. The proposed geosite is Terantam Inselberg which is geologically composed of the Terantam Formation of Carboniferous and Granite Intrusions and Pegmatite of Jurassic. The uniqueness of this proposed geological site is the rocks exposed on the island of Sumatra, and its presence as the oldest basement discovered to today. Then the landscape that forms the morphology of Inselberg is of course unique geomorphologically and is very rarely found in other areas, and finally there are ethnic groups from the Inner Child Tribe who inhabit the area. By comparing the proposed geological site with the national and international geological site value in the MJUGGp Territory, it can be concluded that the Terantam Inselberg Geological Site is in between the two positions.

REFERENCES

[1] Advokaat, E.L., Bongers, M.L.M., Rudyawan, A., Fadel, M.K.B., Langereis, C.G., and van Hinsbergen, D. J.J. (2018). Early Cretaceous origin of the Woyla Arc (Sumatra, Indonesia) on the Australian Plate. Earth and Planetery Science Letters, vol. 498, pp. 348-361.https://doi.org/10.1016/j.epsl.2018.07.001

[2] Akbar, A.R., Utama, H.W. (2021). Analisis Fasies Sedimen Batulempung Airbenakat Sub-Cekungan Jambi, Cekungan Sumatra Selatan Berdasarkan Profil Penampang Stratigrafi di Daerah Sungai Rotan, Tanjung Barat. Lembaran Publikasi Minyak dan Gas Bumi, vol. 55, pp. 13-24.https://doi.org/10.29017/LPMGB.55.1.573

[3] Allen, P.A., & Allen, J.R. (2005). Basin Analysis Principles and Applications, Second Edition. Blackwell Publishing, Malden, United State of America

[4] Ariani, R.P., Utama, H.W. (2022). Petrogenesis and Geological Structure of Tantan Granitoidin Sungai Manau District, Merangin Regency, Jambi Province. Eksplorium, vol. 43, pp. 79-88 .https://doi.org/10.17146/eksplorium.2022.43.2.6415

[5] Antić, A., and Tomić, N . (2017). Geoheritage and geotourism potential of the Homolje area (eastern Serbia). Acta Geoturistica, 8(2), 67–78. https:// econpapers.repec.org/RePEc:vrs:actgeo:v:8:y:2017:i:2:p:67-78:n:4

[6] Barber, A. J., Crow, M.J. (2009). Structure of Sumatra and its implications for the tectonic assembly of Southeast Asia and the destruction of Paleotethys. Island Arc, vol. 18, pp. 3-20.https://doi.org/10.1111/j.14401738.2008.00631.x

[7] Brahmantyo, B. (2013). Geotourism in Indonesian perpectives. Dalam Proceeding HAGI-AIGI Joint Convention, Medan

[8] Chen, A., Lu, Y., & Ng, Y. C. Y. (2015). The Principle of Geotourism. Springer, 264.

[9] Cooper, P. E. (2010). Geotourism in Volcanic and Geothermal Environments: Playing with Fire? Geoheritage, 187–193.

[10] Crow, M.J., Van Waveren, I.M., Hasibuan, F. (2019). The geochemistry, tectonic and paleogeographic setting of the Karing Volcanic Complex and the Dusunbaru pluton, an early Permian volcanic-plutonic centre in Sumatra, Indonesia. Journal of Asian Earth Sciences, vol. 169, pp. 257-283.https://doi.org/10.1016/j.jseaes.2018.08.003
[11] Crow, M.J., Van Waveren, I.M., Hasibuan, F. (2015). Two Hg-Au occurrences in the West Sumatra Permian Volcanic-Plutonic Arc west of Bangko, Sumatra. In: PACRIM 2015 Congress. Hong Kong, pp. 573–578
[12] Davis, G. H., Reynolds, S. J., & Kluth, C. F. (2012). Structural Geology of Rock and Regions: Third Edition. United States of America: John and Wiley and Sons, Inc
[13] Farsani, N.T., Coelho, C., & Costa, C. (2011). Geotourism and Geoparks as Novel Strategies for Socio-economic Development in Rural Areeas. International Journal of Tourism Research, 13(1), 68–81.
[14] Farsani, Neda Torabi, Coelho, C., & Costa, C. (2012). Geotourism and Geoparks as Gateways to Socio-cultural Sustainability in Qeshm Rural Areas, Iran. Asia Pacific Journal of Tourism Research, 17(1), 30–48. https://doi.org/10.1080/10941665.2011.610145
[15] Fossen, H. (2010). Structural Gology. Cambridge, United Kingdom: Cambridge University Press
[16] Hall, R. (2012). Late Jurassic–Cenozoic reconstructions of the Indonesian region and the Indian Ocean. Tectonophysics, vol. 570-571, pp. 1-41. https://doi.org/10.1016/j.tecto.2012.04.021
[17] Hall, R. (2013). The palaeogeography of Sundaland and Wallacea since the Late Jurassic. Journal of Limnology, 72, 1-17.https://doi.org/10.4081/jlimnol.2013.s2.e1
[18] Henstock, T. J., McNeill, L. C., Bull, J. M., Cook, B. J., Gulick, S. P. S., Austin, J. A., Permana, H., dan Djajadihardja, Y. S. (2016). Downgoing plate topography stopped rupture in the A.D. 2005 Sumatra earthquake. Geology, vol. 44, pp. 71–74
[19] https://doi.org/10.1130/G37258.1
[20] Hutchison, C.S. (2014). Tectonic evolution of Southeast Asia. Bulletin of the Geological Society of Malaysia, vol. 60, pp. 1-18. https://doi.org/10.7186/bgsm60201401
[21] Hutchison, C.S. (2010). Oroclines and Paleomagnetism in Borneo and South-East Asia. Tectonophysics, vol. 496, pp. 53-67.doi:10.1016/j.tecto.2010.10.008
[22] Hutchison, C.S. (2005). Geology of North-West Borneo. Elsevier, Amsterdam, 421 hal. Geology of North-West Borneo - 1st Edition (elsevier.com)
[23] Hutchison, C.S. (2009). Metamorphism, Chapter 11, In: Hutchison, C.S. and Tan, D.N.K. (eds.) Geology of Peninsular Malaysia. Geological Society of Malaysia & University of Malaya, Kuala Lumpur, pp. 233-247.doi:10.1016/j.jseaes.2009.12.012
[24] Kale, V.S., Sengupta, S., Achyuthan, H., Jaiswal, M.J.K. (2014). Tectonic controls upon Kaveri River drainage, cratonic Peninsular India: Inferences from longitudinal profiles, morphotectonic indices, hanging valleys and fluvial records. Geomorphology, vol. 227, pp. 153-165.https://doi.org/10.1016/j.geomorph.2013.07.027
[25] Lange, D., Tilmann, F., Henstock, T., Rietbrock, A., Natawidjaja, D.H., Kopp. H. (2018). Structure of the central Sumatran subduction zone revealed by local earthquake travel-time tomography using an amphibious network. Solid Earth, vol. 9, pp. 1035-1049.https://doi.org/10.5194/se-9-1035-2018
[26] Liu, S., Suardi, I., Xu, X., Yang, S., Tong, P. (2021). The Geometry of the Subducted Slab Beneath Sumatra Revealed by Regional and Teleseismic Traveltime Tomography. Journal Geophysics Reservoir Solid Earth, vol. 126, pp. 1-29. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2020JB020169.
[27] McNeill, L. C. dan Henstock, T. J. (2014). Forearc structure and morphology along the Sumatra-Andaman subduction zone, Tectonics, vol. 33, ha. 112–134, https://doi.org/10.1002/2012TC003264
[28] Metcalfe, I. (2013a). Gondwana dispersion and Asian accretion: Tectonic and palaeogeographic evolution of eastern Tethys. Journal of Asian Earth Sciences, 66, 1-33.https://doi.org/10.1080/08120099608728282
[29] Metcalfe, I. (2013b). Tectonic Evolution of the Malay Peninsula. Journal of Asian Earth Sciences, 76, 195–213.https://doi.org/10.1016/j.jseaes.2012.12.011

[30] Metcalfe, I. (2017). Tectonic Evolutions of Sundaland. Bulletin of the Geological Society of Malaysia, vol. 63, pp. 27-60.https://doi.org/10.7186/bgsm63201702
[31] Moufti, M. R., & Nemeth, K. (2016). Geoheritage of Volcanic Harrats in Saudi Arabia; Geoheritage, Geopark, and Geotourism. Springer, 194
[32] Mulyasari, R., Utama, H.W., Haerudin, N. (2019). Geomorphology study on the Bandar Lampung Capital City for recommendation of development area. IOP Conf. Series: Earth and Environmental Science 279, 012026. The International Conference on Geoscience, Makassar, Indonesia, vol. 279, pp. 012026-1 – 012026-13.doi:10.1088/1755-1315/279/1/012026
[33] Nabella, F., Utama, H.W., Said, Y.M. (2019). Geology and Genesis of the Tanco Isolated Hill on the Kerinci Lake, Jambi. IOP Conf. Series: Earth and Environmental Science 279, 012027. The International Conference on Geoscience, Makassar, Indonesia, vol. 279, pp. 012027-1 – 012027-13.https://doi.org/10.1088/17551315/279/1/012027
[34] Najili, A., Sendjaja, P., Priadi, B., Setiawan, V.E., Hartono, B.M. (2021). Petrogenesis of Pre-Tertiary A-Type Granitoid in Jambi Area and its Implications of Rare Earth Element Potential on Main Range Sumatra Belt. Indonesian Journal of Economic Geology, vol. 1, pp. 49-71.https://doi.org/10.51835/ijeg.2021.1.1.342
[35] Natawidjaja, D.H. (2015). Siklus mega-tsunami di wilayah Aceh-Anda-man dlam konteks sejarah. RISET, vol. 25: 49–62. doi:10.14203/risetgeotam2015.v25.107
[36] Natawidjaja, D.H. (2018). Major bifurcations, slip rates and a creeping segment of Sumatran fault zone in Tarutung–Sarulla–Sipirok–Padangsidempuan, Central Sumatra, Indonesia. Indonesian Jour-nal of Geoscience, vol. 5: 137–160.doi:10.17014/ijog.5.2.137-160
[37] Natawidjaja, D.H. (2017). Updating active fault maps and sliprates along the Sumatran Fault Zone, Indonesia. Dalam: Qlobal Qolloqium on Geoscience and Engineering 2017. IOP Conf. Series: Earth and Environmental Science , 118 (012001). doi :10.1088/1755-1315/118/1/012001
[38] Otofuji, Y., Moriyama, Y.T., Arita, M.P., Miyazaki, M., Tsumura, K., Yoshimura, Y., Shuib, M.K., Sone, M., Miki, M., Uno, K., Wada, Y., Zaman, H. (2017). Tectonic evolution of the Malay Peninsula inferred from Jurassic to Cretaceous paleomagnetic results. Journal of Asian Earth Sciences, vol. 134, pp. 130-149.DOI:10.1016/j.jseaes.2016.10.007
[39] Prasetya, N., Lubis, D. E. U., Raharjo, D., Saptadji, N. M., & Pratama, H. B. (2017). Smart Geoenergy Village Development by Using Cascade Direct Use of Geothermal Energy in Bonjol, West Sumatera. IOP Conf. Series: Earth and Environmental Science, 1–14.
[40] Rosenbaum, G. (2014). Geodynamics of oroclinal bending: insights from the Mediterranean. Journal of Geodynamics, vol. 82, pp. 5-15.https://doi.org/10.1016/j.jog.2014.05.002
[41] Said, Y.M., Utama, H.W. (2023). Late Cretaceous Andesite Intrusion within Strike-slip Fault of Geological Field Features and Landscape, Jambi, Indonesia. AIP Conference Proceedings 2598, 020005. 4th International Conference on Earth Science, Mineral and Energy, Yogyakarta, Indonesia, vol. 2598, pp. 020005-1 – 020005-11.https://doi.org/10.1063/5.0126836
[42] Said, Y.M., Utama, H.W. (2021). Analisis Morfologi Fisik Kaldera Masurai Jambi Menggunakan Citra Satelit Resolusi Tinggi. Jurnal Geofisika Eksplorasi, vol. 7, no. 3, pp. 178-190.https://doi.org/10.23960/jge.v7i3.161
[43] Simandjuntak, T.O., Budhitrisna, T., Surono, Gafoer, S., Amin, T.C. (1994). Peta Geologi Lembar Muarobungo,Sumatra Skala 1:250.000. Pusat Penelitian dan Pengembangan Geologi, Bandung.
[44] Syaifullah, M., Utama, H.W. (2021). Petrogenesis Intrusi Granitoid Langkup di Desa Rantau Kermas dan Sekitarnya, Kecamatan Jangkat, Kabupaten Merangin, Provinsi Jambi. Jurnal Geosains dan Remote Sensing, vol.2, pp. 41-48.https://doi.org/10.23960/jgrs.2021.v2i1.59
[45] Siregar, A.D., Utama, H.W. (2020). Petrologi dan Struktur Geologi Daerah Panas Bumi Citando Banten. Journal Online of Physics, vol. 6, pp. 32-37.https://doi.org/10.22437/jop.v6i1.10613
[46] United State Geological Survey (USGS): Shuttle Radar Topography Mission (SRTM) 30 M, http://earthexplorer.usgs.gov/ (Retrieved July 07, 2023)
[47] Utama, H.W. (2020). Struktur Geologi dan Vulkanostratigrafi; Analisis Model Elevasi Digital dan Citra Landsat 8. Jurnal Geofisika Eksplorasi, vol. 6, no. 2, pp. 156-168.https://doi.org/10.23960/jge.v6i2.80

[48] Utama, H.W., Mulyasari, R., Said, Y.M. (2021). Geothermal Potential on Sumatra Fault System To Sustainable Geotourism in West Sumatra. Jurnal Geofisika Eksplorasi, vol. 7, no. 2, pp. 126-137.https://doi.org/10.23960/jge.v7i2.128

[49] Utama, H.W., Said, Y.M., Ritonga, D.M.M., Kurniantoro, E. (2021). Geodynamics Relationship of Sabak Back Arc Volcanic and Geragai Geothermal Features, Tanjabtim, Jambi, Indonesia. Atlantis Press; Advances in Engineering Research. Proceedings of the 3rd Green Development International Conference (GDIC 2020), Jambi, Indonesia, vol. 205, pp. 376-382.10.2991/aer.k.210825.065

[50] Utama, H.W., Said, Y.M., Siregar, A.D., Adhitya, B., Mastur, A.K. (2023). Geochemical Data for Geothermal Exploration on Grao Sakti, Jambi, Indonesia. AIP Conference Proceedings 2482, 080008. The 3rd International Conference on Engineering, Technology and Innovative Researches, Purbalingga, Indonesia, hal. 080009-1 – 080009-8.https://doi.org/10.1063/5.0111332

[51] Utama, H.W., Sutarto, Widagdo, A., Wahyudi, E. (2023). Paleovolcanic Karing Reconstruction in The Merangin Jambi UNESCO Global Geopark Territory Based on Petrological and Geochemical Approach. Journal Online of Physics, 9 (1), 66-79.https://doi.org/10.22437/jop.v9i1.28588

[52] Utama, H.W., Said, Y.M., Siregar, A.D., Adhitya, B. (2021). The Role of Sumatra Fault Zone of Dikit Fault Segment to Appearance of Geothermal Features on the Grao Sakti, Jambi, Indonesia. Atlantis Press; Advances in Engineering Research. Proceedings of the 3rd Green Development International Conference (GDIC 2020), Jambi, Indonesia, vol. 205, pp. 367-375.10.2991/aer.k.210825.065

[53] Utama, H.W., Said, Y.M., Siregar, A.D. (2023). Releasing Bend Structures of Dikit Fault Segment on Grao Sakti, Jambi: Its Related Strike-slip Fault Zone. AIP Conference Proceedings 2482, 080009. The 3rd International Conference on Engineering, Technology and Innovative Researches, Purbalingga, Indonesia, hal. 080009-1 – 080009-11.https://doi.org/10.1063/5.0112809

[54] Utama, H.W., Adhitya, B., Arafat, R., Siregar, Y., Astuti, I.T., Fauzi, M., Aulia, M. (2023). Kajian Petrologi Dalam Konservasi Warisan Geologi di Taman Nasional Bukit Duabelas (TNBD) Kabupaten Sarolangun, Jambi. Jurnal Geosains dan Remote Sensing, 4 (2), 91-102.https://doi.org/10.23960/jgrs.ft.unila.190

[55] Utami, P., Khasani, Warmada, I, W., & Wijaya, S. Y. C. (2013). Berwisata dan Belajar Tentang Energi Panas Bumi di Lahendong (1st ed.). Pustaka Geo (Smartania Publishing Group) dan Pusat Penelitian Panas Bumi Fakultas Teknik Universitas Gadjah Mada

[56] Van Leeuwen, T., Allen, M.C., Elburg, M., Massonne H.J., Palin, J.M., Hennig, J. (2016). The Palu Metamorphic Complex, NW Sulawesi, Indonesia: Origin and evolution of a young metamorphic terrane with links to Gondwana and Sundaland. Journal of Asian Earth Sciences, vol. 115, hal. 133-152.http://dx.doi.org/10.106/j.jseaes.2015.09.025

[57] Van Waveren, I.M., Booi, M., Crow, M.J., Hasibuan, F., Van Konijnburg-Van Cittert, J.H.A., Putri Perdono, A., Schmitz, M.D., Donovan, S.K., 2018. Depositional settings and changing composition of the Jambi palaeoflora within the Permian Mengkarang Formation (Sumatra, Indonesia). Geol. J. 1–22.

[58] Winter, J.D. 2014. Principles of Igneous and Metamorphic Petrology (Second Edition). Pearson. USA, 736 pp.

[59] Yuexia, D., Zongju, Z., Zhonghong, C., Jianguo, W., Faxiong, G., Peixi, W., Heyuan, W., Ruining, C., Gang, Z., (2015). Exploration potential and signification of Ordovician carbonate karst monadnock traps in Nanpu Sag. Acta Petrolei Sinica, 36(6): 653–663 https://doi: 10.7623/syxb201506002

[60] Yunfeng, Z., Fei, T., Haizhou, Q., Zhiqi, Z., Yong, L., Xinsheng, L., Zhenyu, W., Fang, Q. (2017). Karst monadnock fine characterization and reservoir control analysis: A case from Ordovician weathering paleokarst reservoirs in Lungu area, Tarim Basin, NW China. Petroleum Exploration And Development, vol. 44, pp. 758-769.https://doi:10.1016/S1876-3804(17)30086-1

[61] Zahirovic, S., Müller, R. D., Seton, M., Flament, N., Gurnis, M., Whittaker, J. (2012). Insights on the kinematics of the India-Eurasia collision from global geodynamic models, Geochem. Geophy. Geosy., 13, Q04W11 doi:10.1029/2011gc003883

[62] Zahirovic, S., Matthews, K.J., Falment, N., Muller, R.D. Hill, K.C., Seton, M., Gurnis, M. (2016). Tectonic evolution and deep mantle structure of the eastern Tethys since the latest Jurassic. Earth Sci. Rev., vol. 162, pp. 293-337. 10.1016/j.earscirev.2016.09.005

[63] Zahirovic, S., Muller, R.D., Seton, M., Flament, N. (2015). Tectonic speed limits from plate kinematic reconstructions. Faculty od Science, Medicine and Health-Paper part A. 4238 https://ro.uow.edu.au/smhpapers/4238

[64] Zahirovic, S., Flament, N., Muller, D., Seton, M., Hill, K.C., Gurnis, M. (2015). 3-D Plate Tectonic Reconstructions of New Guinea Since the Triassic. SEG Global Meeting Abstracts. https://doi.org/10.1190/ice2015-2211479

[65] Zahirovic, S., Seton, M., Muller, R. (2014). The Cretaceous and Cenozoic tectonic evolution of Southeast Asia. Solid Earth, vol. 5, pp. 227-235. https://doi.org/10.5194/se-5-227-2014

[66] Zahirovic, S., Flament, N., Muller, R.D., Seton, M., Gurnis, M. (2016). Large Fluctuations of Shallow Seas in Low-lying Southeast Asia Driven by Mantle Flow, vol. 17, pp. 3589-3607. doi:10.1002/2016GC006434

[67] Zahirovic, S., Salles, T., Muller, D., Gurnis, M., Wenchao, C., Braz, C., Harrington, L., Ibrahim, Y., Garrett, R., Williams, S., Anqing, C., Mingcia, H., Ogg, J.G. (2019). From Paleogeographic Maps to Evolving Deep-time Digital Earth models. Acta Geologica Sinica, vol. 93, pp. 73-75. doi:10.1111/1755-6724.14250