THE SINISTRAL STRIKE SLIP FAULT AS AMPANA BASIN CONTROLLER IN CENTRAL SULAWESI

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ABSTRACT

The presence of gas seepage born in Tanjungapi precisely in the southwestern part of the basin. This remission is supposed to be formed from main rocks of Mesozoic aged. The condition of Ampana Basin formation cannot be separated from the effect of the relatively northeast-southeast sinistral strike-slip-fault. Based on the 43 outcrop, the main deformation product was identified as an extensional/hybrid joint with a relatively west-east fault line structure on average shear strain (η) = 58^o (+) to (η) = 60^o (+) and in form of the relatively northwest-southeast strike-slip-fault structure line with the range of shear strains value between (η) = 45^o (+) to (η) = 54^o (+). The kinematics movement of relatively vertical main stress gives a subsidence impact on the surface of Mesozoic-Paleogenic aged rock. The sedimentation process of Neogene-aged clastic, from the Bongka Formation, Kingtom Formation, and Lonsio Formation ran fast and make the lower Mesozoic-Paleogene-aged rock being burdened by the upper younger rocks. The tectonic development in Ampana Basin is recorded in Lonsio Formation, Bongka Formation, and limestone in the form of structural indication and deformation showing the period of Central Miocene to Holocene tectonic with the relatively west-east direction of the main regional stress.

Keywords: *Ampana basin, deformation, strike slip fault, Sulawesi, Tanjungapi*

INTRODUCTION

The Ampana Basin and surroundings area are administratively part of two territories namely Tojo Una Una and Banggai Regency, Central Sulawesi. The research location is in 121° 2' 47.636" E - 122° 49' 50.896" E and 0° 18' 43.465" S - 1° 21' 13.9" S and geologically classified into Paleogene-aged foreland basin system.

The basin is bordered by two major highs namely Togian Island High in the north and Ultramafic Complex High in the south.

Precisely, in the eastern arm of Sulawesi Island. The Togian Island High is dominated by Lonsio Formation volcanic rocks of the late Miocene-Pliocene age widespread to the east of Togian Island, Talatakoh Island, Waleakodi Island, and Waleabahi Island. The distribution in the central part of the archipelago contains Bongka Formation clastic sediments of the late Miocene-Pliocene. While the Ultramafic Complex High located in the relatively southwest-northeast to the south or spread from Poso to Luwuk.

GEOLOGICAL SETTING

Tectonic

In order to understand the current tectonic system of East Indonesia, we should know the geological history of Banda Sea and the west of Pacific Ocean. The magnetic measurements (Hinschberger et al., 2000) proposed that Banda Sea was the centre of sea floor spreading in the Late Miocene - Early Pliocene (6.5-3.5 Ma).

The beginning of the Tomini Basin - Gorontalo formation used as a reference for Ampana Basin formation, which was caused by the fracture and clockwise rotation of North Sulawesi's arms at Neogene at about 5 Ma (Hamilton, 1979; Walpersdorf et al., 1998) or 3.5 Ma (Hinschberger et al., 2000), followed by the back arch thrust and subduction inactivity in the southern part of Sulawesi Oceanic Plate (LLS) (Jezek et al., 1981). This was caused by a collision between the East Sulawesi Arms and the Banggai - Sula microcontinent. Another possibility is the back arc rifting relatively to subduction from the LLS and North Arm Volcanic Arc to the south at the end of Paleogene.

Stratigraphy of Ampana Basin

Ampana Basin located in the offshore zone which has not been drilled. Thus, the stratigraphy is not known for sure. This basin lies between Togian Island and the eastern arm of Sulawesi; therefore, the stratigraphy of the Ampana Basin constituent will be analogous to the Togian Island and the eastern arm of Sulawesi.

The stratigraphic formation of Togian Island, according to Rusmana et al. (1993) in Geological Map of Luwuk Sheet (Figures 1), is divided into: Alluvium (Qa), quarter coral reef/ Luwuk Formation (Ql), Holocene volcanic rock (Qhv), Pleistocene volcano rock (Qpv), Bongka

Formation (Tmpb), Lonsio Formation (Tmpl), and Lamusa Formation (MTl). While in the east area of Sulawesi and Banggai Sula, the ultramafic rock dominates the eastern arm of Sulawesi consisting of the combination of mafic, ultramafic, and pelagic sediments containing chert. The *Mandala* Banggai-Sula consists of coarse clastic rocks and metasediments suspected to be deposited on the edge of Banggai - Sula's microcontinent.

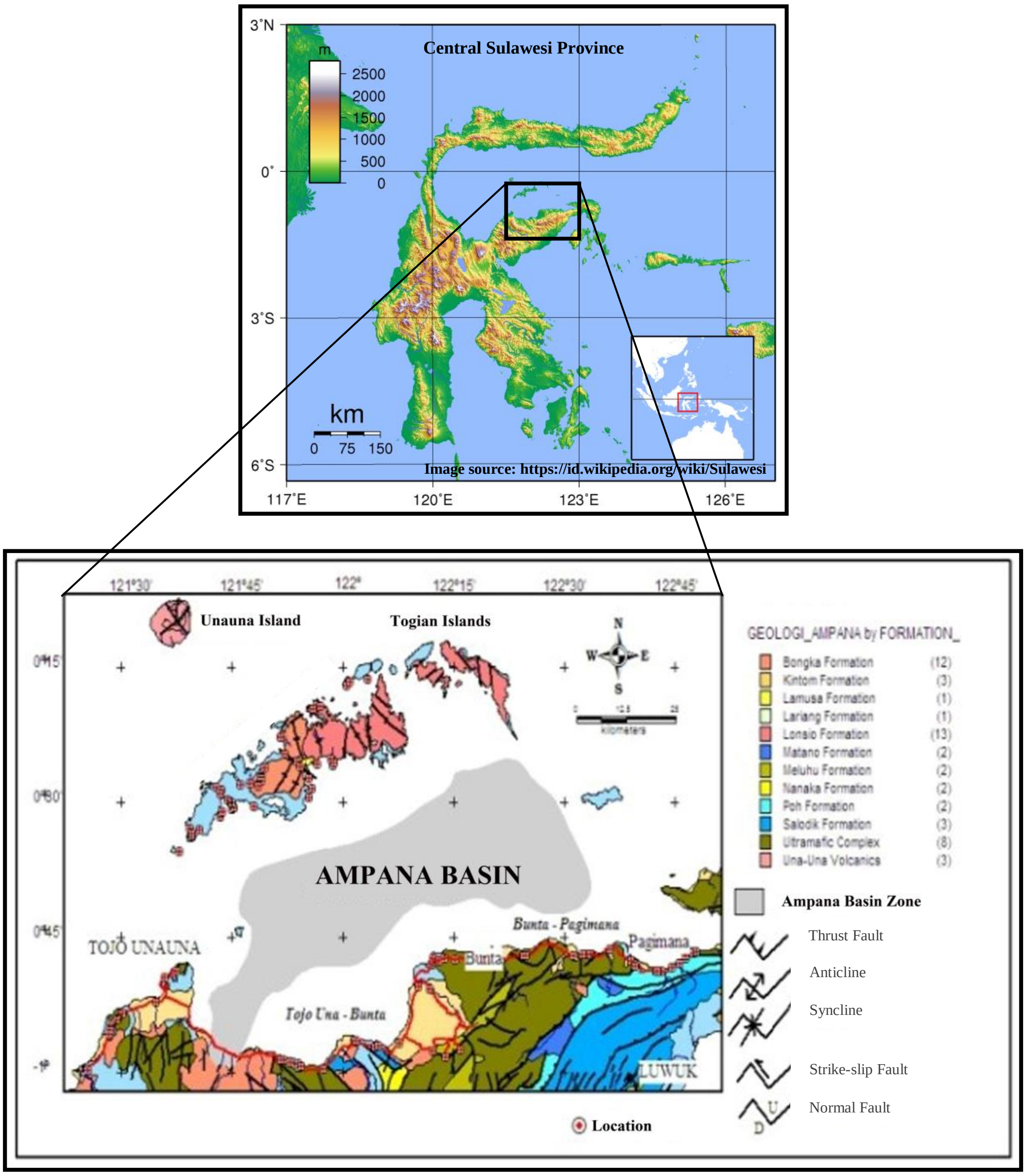

Figure 1. Geological map of the research area (Rusmana et al., 1993)

The oldest rock unit in Luwuk Sheet Geological Map is Meluhu Formation consisting of slate, meta-sandstone, phillyte and schist, shale, and allegedly aged Trias to Jura. The Nanaka Formation (Jn) allegedly overlapped them unconformity in the form of quartz sandstone with coal and conglomerate insertion, Jura aged (Simandjuntak et al., 1997). The Nambo Formation (Jnm) is predicted to overlap the Meluhu Formation unconformity, consisting of marl and Jura ages.

The ultramafic rock (Ku) consisting of harzburgite, dunit, pyroxenite, serpentinite, gabbro, diabas, basalt and diorite. The age is not known for sure and it is suspected to be in Cretaceous. The schist, amphibolite, phyllite, and meta-gabbro are also found nearby allegedly part of the oceanic crust. The Matano Formation (Km) is a limestone with the chert and argillite insertion; Cretaceous aged (Simandjuntak et al., 1997).

Salodik Formation (Tems) is in the form of Eocene to Late Miocene limestone, overlaps Nanaka Formation (Jn) and Nambo Formation (Jnm). During Oligocene Late Miocene, the Poh Formation (Tomp) was sedimented in form of marl, limestone, and sandstone, conformity with the upper Salodic Formation. The Molasse Group (Bongka Formation, Lonsio Formation, and Kintom Formation) overburdened the older rocks unconformity, in form of coarse clastic sediments of Miocene to Pliocene suspected age.

Cottam et al. (2011), proposed the revision and addition of new formation names based on the latest research results in the Togian Island (Figure 2 and 3), namely the Eocene to Lower Miocene Walea Formation, the Lower Miocene to Upper Miocene Paledan Formation, and the Fortress Intrusion of Pliocene-Pleistocene aged.

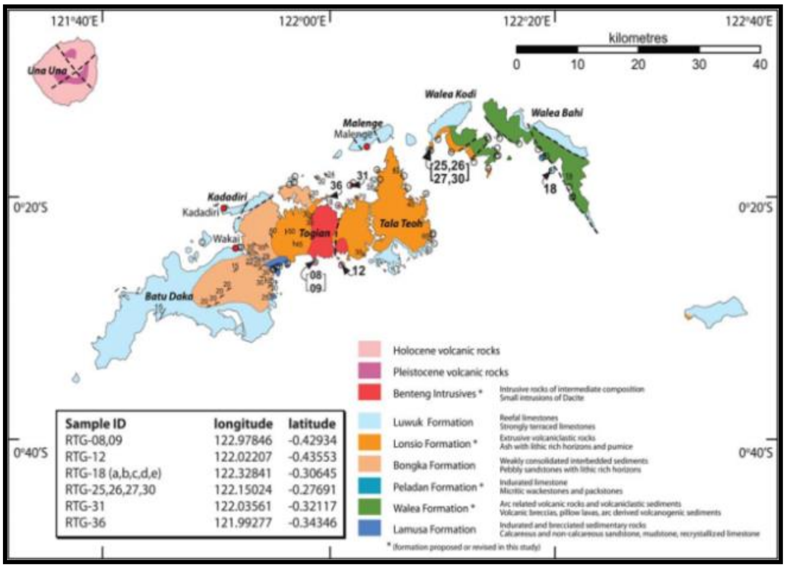

Figure 2. Geological Map of the Togian Island (modified from Rusmana et al., 1993 in Cottam et al., 2011)

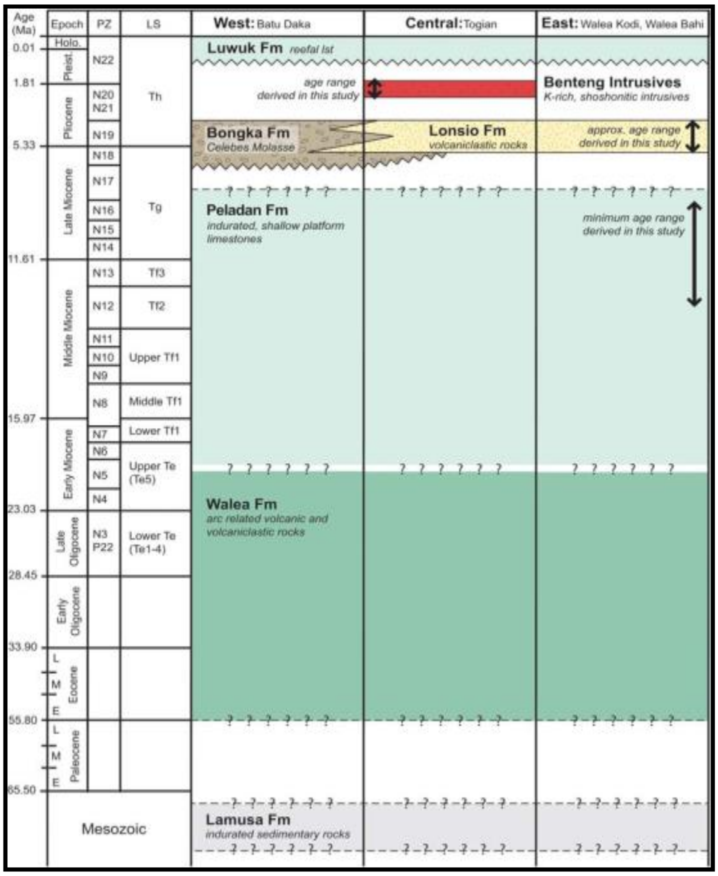

Figure 3. The stratigraphy of Togian Island (from BouDagher-Fadel, 2008 in Cottam et al., 2011)

RESEARCH METHODS

The research method used is by local structures measurement in the form of companion fields. The structural analysis uses 5.1 version of dips program. The structured study is the deformation type and structural level of fault based on modification by Park, 1988 and McClay, 1991 in structural level of fault/shear zone and deformation type. The naming of fault type is based on the position of main stress/genetic-kinematic (Anderson, 1951), and the geometric-descriptive fault classification is based on the value of fault slope, rake/pitch of the fault, and the sense of fault movements (Rickard, 1972).

RESULT AND DISCUSSION

The Fault Analysis Based on Local Structure Companion Field

To obtain an indication of a sinistral strike-slip-fault, the observation and measurement of structural areas conducted in the Togian Island region as its analogue. The measurement is based on 43 points of outcrop location along the archipelagic tracks in terms of the presence of locally developed structures and their type of rocks.

Some of the measurement outcrop location displays indicate that the local area structure generally consists of rising field and horizontal field, normal field, hybrid joint, and shear joint in which its dimension ranging from 0.10 to 8.6 meters (Figure 4, 5, 6, 7, and 8).

The outcrop location 15/RT-34tg (Figure 4) shows a sketch of the local structure of a rising field, with the average range of the companion field between N00°E/16° to N05°E/45°, with observable dimensions of 2.3-6.5 meters and observed field distance interval of 0.3 - 1.2 meters. Locally, the hybrid joints exist to form an average field with the average of N350°E/47° paired with N190°E/46°, with the long dimension observed from 0.15 to 0.42 meters and observed field interval of 0.1 to 0.21 meters.

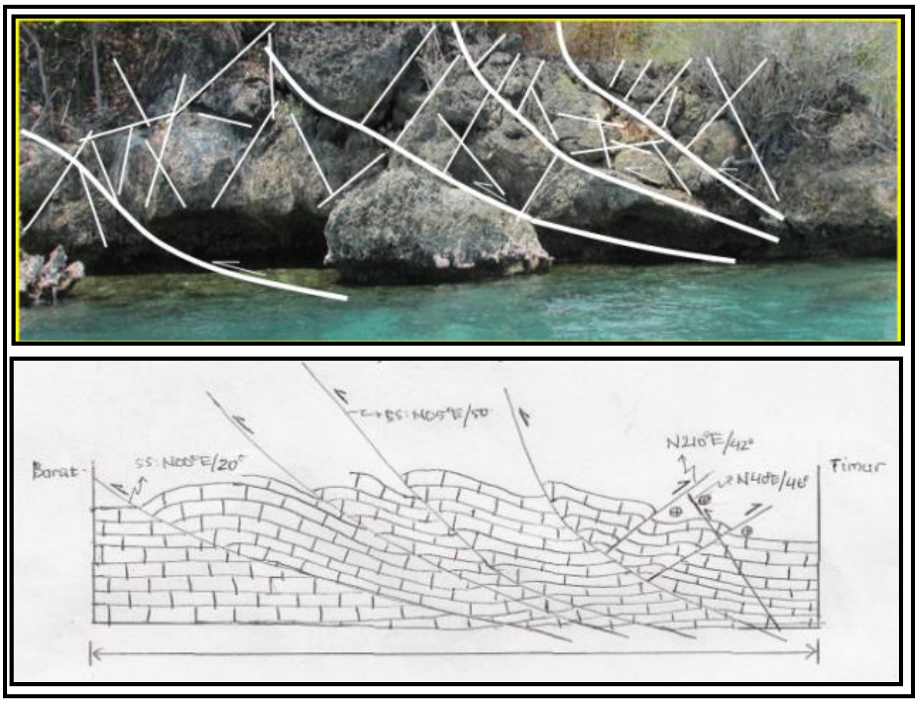

Figure 4. Photographs and sketches of local structures indicate the uplifting field of the Pliocene-Pleistocene-aged limestone at coordinates of -0° 30' 35.2" S to 121° 45' 16.8" E, the outcrop location of 15/RT-34tg

The segment analysis of N175°E – N355°E Lindo Fault is calculated toward field geometry of local companion structure (the sketch of outcrop location 15/RT-34tg) in the stereography of projected equal area (Figure 5) shows the shear strain (η) = 36°(+). The genetical fault type naming is thrust fault while the geometrically it is called thrust-right slip fault, with mainline (σ1) formed relatively west-east (N272°E – N92°E).

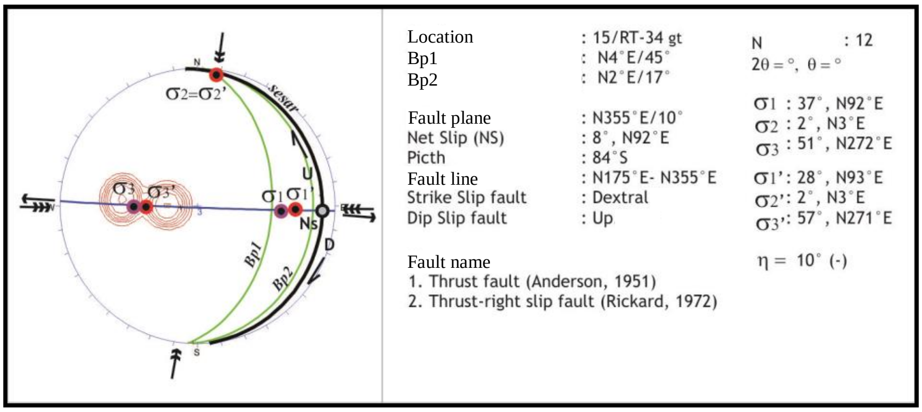

Figure 5. Fault segment analysis of Lindo N175°E – N355°E based on the local companion structure field in projected stereography of equal area at the outcrop location of 15/RT-34tg

The outcrop location 15/RT-42tg (Figure 6) consists of the local structure sketch of a rising field with the average range of the companion field between N350°E/75° to N05°E/80°, with observed long dimensions of 2.5 to 8.6 meters, and field distance interval of 1.3 - 4 meters. Locally, there is a normal field present with the companion field ranging from the average N260°E/78° to N270°E/65 °, with observable long dimensions of 1.3 to 4.5 meters, and field distance interval of 0.6 to 2.2 meters.

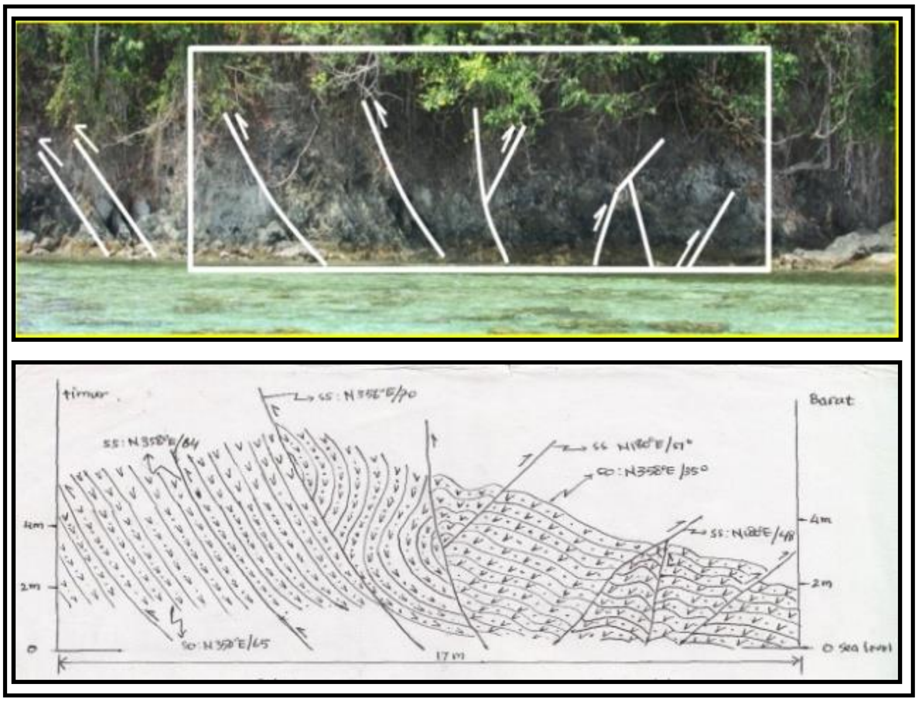

Figure 6. Photographs and sketches showing the rising fields, the Late Miosen – Pliocene-aged Lansio Formation at the -0°25' 52,2" S to 121° 58' 42,2" E, the outcrop location is 15/RT-42tg

The analysis of Enam Island fault with direction is calculated against the geometry of the local companion structure field (the sketch of outcrop location 15/RT-42tg) directed N305°E/75° - N5°E/80° in the stereography of the projected equal area (Figure 7) which shows the shear strain value (η) = 37°(+); on the acquisition of the angle of the two companion fields (BP-1 and BP-2) dihedral angel of shear 2Θ = 120° (kink fault + foliation), a type of deformation obtained namely ductile deformation and for fault structure level is categorized as ductile shear zone. The naming of the type is genetically sinistral wrench fault and geometrically left-reverse slip fault, with the main stress (σ1) defined relative west-east (N281°E – N101°E).

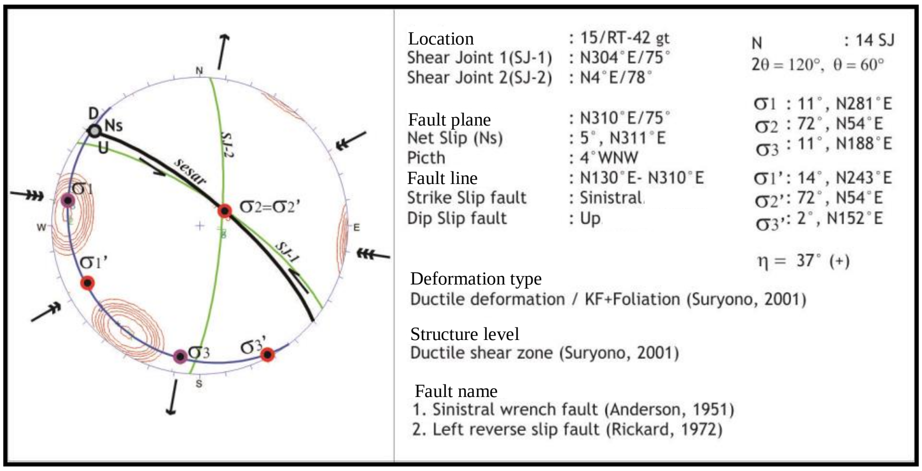

Figure 7. The fault segment analysis of Enam Island N130ºE - N310ºE based on companion structure field in the stereographic projection same area of outcrop location 15/RT-42tg

The location of outcrop 15/RT-17tg (Figure 8) consists of local structure field sketch a rising local flower-structure with an average companion field of N00ºE/65º to N05ºE/61º and between the field of N160ºE/62º to N185ºE/59º, with the observable long dimension of 1.8 – 7.7 meter, field distance interval of 7.4 – 14.6 meter.

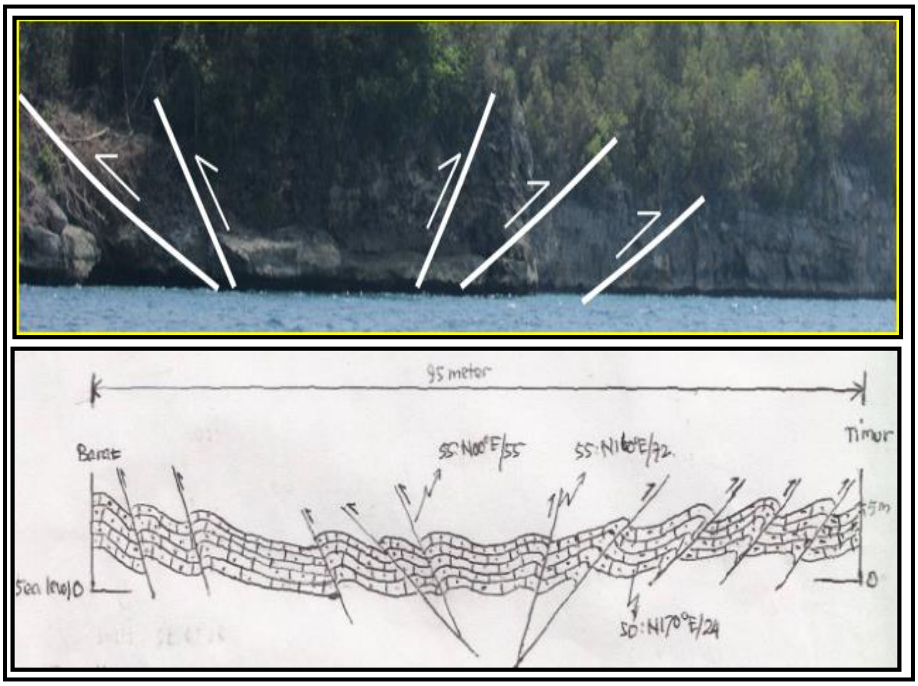

Figure 8. Photographs and sketches show the flower-structure rising field in the Pliocene-Pleistocene limestone at -0° 19' 06.2" S to 122° 56' 28.9" E, outcrop location 15/RT-17tg

The analysis of Katupat Fault Segment with direction N132ºE – N312ºE is calculated against the geometry of the local companion structure field (the sketch of outcrop location 15/RT-17tg) in the stereography of the projected equal area (Figure 9): shear stress (η) = 46º(+); on the acquisition of the angle of the two companion fields (BP-1 and BP-2) dihedral angel of shear 2ϴ = 58º (hybrid joint), a type of deformation is obtained namely brittle deformation and for fault structure level is categorized in brittle fault zone. The naming of the type is genetically categorized in thrust fault and geometrically in left-thrust-slip fault with main stress (σ1) forms relative west-east (N275ºE – N95ºE).

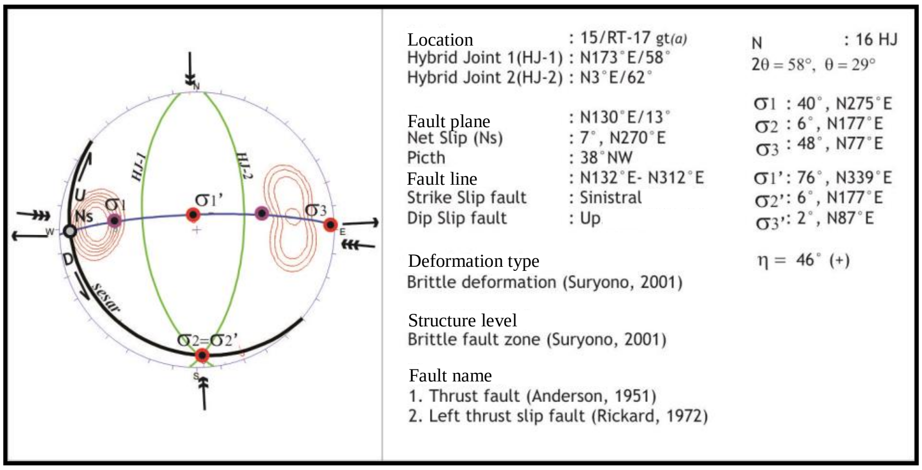

Figure 9. The Katupat fault segment analysis of N132°E-N312°E based on the corresponding field structure in the same stereographic projection area at the outcrop location of 15/RT-17tg

Quantitative Identification of Local Structures

The identification of local structure was obtained from the total of 65 outcrop locations (563 unit of local structure fields) in Batudaka Island, Togian Island, Talatakoh Island, and Walea Island. The stereographic diagram is projected on the equal area and the rose diagram. While the result of point, sector position and Lineament position measurement plotting of the local structure can be seen in Figure 10(a,b,c).

From the calculation of measured local structures sector in Middle Miocene to Holocene rocks in Figure 10b, it is obtained:

The dominance of 65 outcrop locations is 22 outcrops indicating a rising field in the relative west-east main stress (σ1) with the general direction of companion structure between N12°E/48° and N175°E/47°, in the average axial field of N184°E/89°. The two major companion structural lineaments have a dihedral angel of shear value of $2\Theta = 84°$ or $\Theta = 42°$, deformation type categorized as semi ductile deformation (shear joint) assuming that the deformation depth between 8.25 - 10 km at a pressure between 2.3 - 2.75 Kbar and the temperature of 207.5° – 250°C.

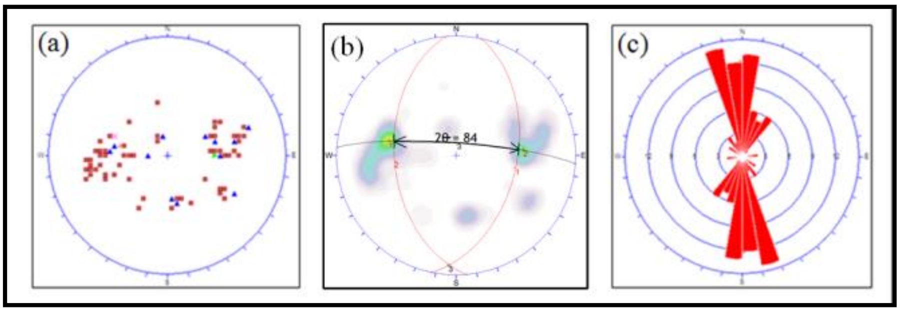

Figure 10. Local positioning structure in 65 outcrop location shows: (a) measurement distribution, (b) the average position of the local structure (c) the lineament of local main structure, located on Middle Miosen – Holocene age, projected in stereographic and rose diagram

The Deformation and Lineament of Macroscopic

The deformation modelling can be reviewed through simple shear on the local measurement of some outcrop locations then considered to be averaged to generate the value of simple shear for its macroscopic coverage (Figure 11).

The lineament of macro-faults is identified by satellite imagery lineament interpretation using DEM SRTM and bathymetry. From this interpretation analysis, the group of lineament is obtained (Figure 12).

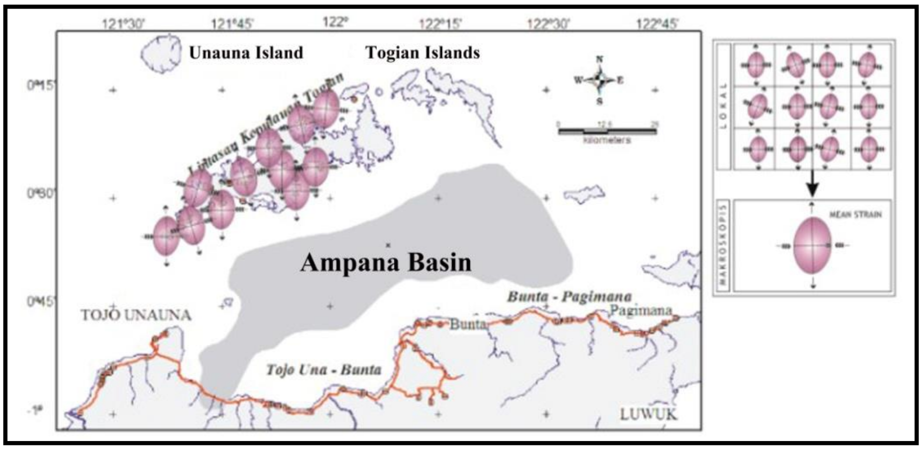

Figure 11. The simple modelling of shear in local deformation produces macroscopic simple shear.

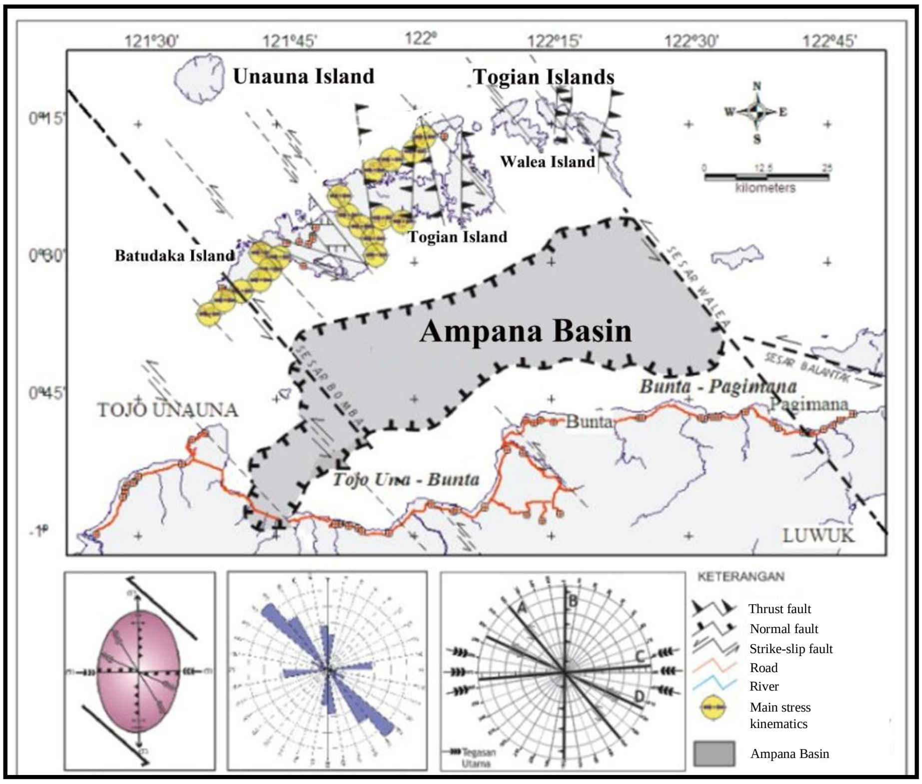

Figure 12. The deformation of Togian Islands in the late Miocene-Holocene shown in the simple shear method resulting in macroscopic faults

The fault structure lineament group in the macroscopic dimension is related to the local structure and deformation of the relative east-west main stress kinematics resulting in a fault in macro simple shear modelling as follows:

1. Structure Lineament Group A in which the direction intensity range is [N310°E - N130°E] - [N340°E - N150°E] with the total lineament presentation of 46.4% from the researched area, it is the fault section on the sinistral strike slip, raising dip slip, pitch averaging between 46° NW- 52°NW, fault slopes averaging between 14° - 21°, resulting in thrust-left slip fault geometrically. The average value of shear strain between (η) = 45°(+) to (η) = 54°(+) on deformation type of brittle (hybrid joint/extensional).
2. Structure Lineament Group B in which the direction intensity range is [N350°E – N160°E] - [N10°E – N190°E] with the total lineament presentation of 25.0% from the researched area, it is the fault section on right strike slip, raising dip slip, pitch averaging between 72°-N - 76° N, the fault sector averaging between 54° - 61°, resulting in reverse-right slip fault geometrically. The average value of shear strain between (η) = 1°(-) to (η) = 4°(+) on deformation type of semi ductile (shear joint).

3. Structure Lineament Group C in which the direction intensity range is [N280°E – N100°E] - [N80°E – N260°E] with the total lineament presentation of 21.4% from the researched area, it is the fault section on the sinistral strike slip, normal dip slip, pitch averaging between 4°E - 8° E, the fault field averaging between 9° - 16°, resulting in left-lag slip fault geometrically. The average value of shear strain between (η) = 58°(+) to (η) = 60°(+) on deformation type of brittle (hybrid joint/extensional).
4. Structure Lineament Group D in which the direction intensity range is [N280°E – N100°E] - [N310°E – N130°E] with the total lineament presentation of 7.2% from the researched area, it is the fault section on the sinistral strike slip, raising dip slip, pitch averaging between 26° WNW - 31° WNW, the fault field averaging between 12° - 20°, resulting in left-thrust slip fault geometrically. The average value of shear strain between shear strain (η) = 54°(+) on deformation type of brittle (hybrid joint/extensional).

Based on the above lineament group, it can be interpreted that Ampana Basin is included in extensional system, which is relatively west-east strike-slip-fault, formed by the tension stress (σ3) which is relatively north-south, on the dihedral angel of shear value of 2Θ = 49° to 58°

The tectonic activity of the Ampana Basin is interpreted to be influenced by convergent tectonics in the eastern part of the basin, where the *composite plate movement* of the Philippine Plate is expected to occur in the late Miocene to Resen. The active movement of the Philippine Plate is thought to contribute subduction to the west against the North Moluccan Sea plate giving birth to a group of volcanic arcs in the eastern Halmahera Island and volcanic arc group in the northern part of Sulawesi Island (Manado Zone). Hypothetically, this activity also influences the research area especially in this age range, especially marked by the presence of local-macro structure field group (the group of structure lineament of A, B, C, and D).

The effect of the main fault order-1 is in the form of a sinistral strike-slip-fault, includes the Bomba Fault segment, Walea Fault segment with the general direction range of (N320°E – N140°E), and the Balantak Fault segment with (N295°E – N115°E) general direction in the onshore and offshore region. This main fault contributes primarily to the Ampana Basin formation, which is the movement of the fault block dynamics rotating clockwise in the lateral position and is then controlled by rifting in the average range of shear strain values between (η) = 45° (+) to 54° (+) with the main stress rotation between σ1 to σ1′ which denotes anti-clockwise.

Based on the zoning, the basin local tectonics, in the region offshore part, indicates that the strike-slip-fault is affected by rifting transtensional movement. The order-2 fault structure segment is a reverse fault including Katupat fault segment, Enam Island fault segment, Malenge fault segment, with the general direction range [N352°E – N172°E] to [N11°E – N191°E]. This fault is macroscopically seemed to cross the island arc located on Togian Island, Talatakoh Island, and Walea Island. It is suspected that the uplifting activity occurred with the emergence of volcanic activity from the Lonsio Formation at the late Miocene – Pliocene.

Tectonically, based on the interpretation of some experts, it is caused by continental collision tectonic activity, which results in the smelting of the lower crust-continent (Priadi et al., 1994; Walpersdorf et al., 1998). The reverse fault segments on Togian Island, Walea Island, and Talatakoh have the shear value average ranges between (η) = 1° (-) to (η) = 4° (+), with the main stress spin between σ1 to σ1′ which denotes clockwise and anti-clockwise.

The formation process is essentially uplifting by volcanic activity forming Togian and Walea islands. This is further controlled by the strike-slip-fault movement reactivity results in kink fault (counted on the average shear strain between (η) = 1° (-) to (η) = 4°(+) on the reverse faults segment). The local tectonic zonation interpretation is basically estimated by lifting transpressional.

In contrast to Batudaka Island, the reverse fault segment with the same general direction and have separate colors from Togian and Walea Islands. The fault has the shear strain value (η) = 50° (+). The interpretation indicates that the reverse fault of Batudaka Island undergoes a reversal phase after the uplifting of the area and then reactivates to form the release joint/normal section.

The influence of the main field (order-1) in the form of a sinistral strike-slip-fault has an association with the sediment deposition in the younger basin. This occasion makes Mesozoic-to-Paleogene-aged to be graben by sedimentation of Neogene in the Molasse Group or interpreted as the presence of rapid sediment or gravity flow at the upper part so that the Mesozoic – Paleogene-aged sediments at the bottom get rapid burdened.

The presence of gas seepage in Tanjungapi (Figure 13) shows an indication of potential gas in the Ampana Basin. It is considered as source rock of Mesozoic sediment in form of shale from Meluhu Formation. These shale are found in the Podibay River track approximately 10 km to the southeast of the gas seepage location.

Figure 13. The flammable gas seepage exposed above breccia to conglomerate rocks at the site Tanjungapi, the southwest of the basin

The process of gas formation is assumed to be influenced by the very active basin opening which is accompanied with the above sediments burdening. The gas seepage is assumed to migrate on the order-1 fault of sinistral strike-slip-fault line as the relatively northwest-southeast main control. While the trap is predicted to be in order-2 fault in form of relatively north-south pop up path, reverse fault path, and anticline path.

6. CONCLUSION

The tectonic activity which forms Ampana Basin is interpreted to be influenced by the convergent tectonics in the eastern part of the basin, where the active movement of Philippine Plate moves westward and collides the northern of Moluccan Sea plate. This activity forms a macroscopic fault structure in the form of sinistral strike-slip-fault to the relatively northwest-southeast in Ampana Basin area. This main fault becomes a controller in the basin formation as an rifting zone and makes Mesozoic to Paleogenic aged rocks 'graben' followed by sediment deposition of Neogene at the top of Molasse Group. Another possibility, there is a gravity flow occurs so that the rocks at the bottom get rapidly burdened.

From the local tectonic zonation view, the offshore of the basin area indicates that the strike-slip-fault is affected by the transtension rifting movement in the average range of shear strain values between (η) = 45^o (+) to 54^o (+) with the main force rotation between σ1 to σ1' denotes anti-clockwise.

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