DETERMINATION OF POTENTIAL HYDROCARBON AND TECTONOSTRATIGRAPHY ANALYSIS BASED ON 2D SEISMIC IN PADAMARANG SUB-BASIN, BONE BASIN, SOUTH PART OF SULAWESI

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ABSTRACT

Sulawesi is a main island in Indonesia that has a complex geological setting. This complexity is caused by assemblage of 3 major plates called as triple junction. Repercussions of these plates assemblage is emerging many basins in Sulawesi area, Bone Basin is one of it. Bone Gulf is a prospect basin for petroleum exploration. Bone Gulf is a frontier area for hydrocarbon exploration. In order to understand and to determinate lead of a frontier area, Seismic interpretation through 2D seismic data is required. 2D seismic interpretation in this area of study using tectonostratographic approach. This study could be a reference and recommendation for further hydrocarbon exploration in this area. This study shows a result that in Bone Basin has 3 main sub-basins (Padamarang, North Kabaena, and South Kabaena) separated by basement highs and this research focused in Padamarang Sub-basin. There are 4 Tectonostratigraphic units in Padamarang Sub-basin, these are include basement (Unit X), Early Rifting (Unit A), Rifting (Unit B), Post Rift (Unit C), dan Post Rift (Seabed/ Unit D & E). There are 2 lead located in Late Miocene Carbonate buildups (represents in seismic section as mounded seismic horizon) showed in BN07-06 and BN07-07 seismic cross section on Padamarang Sub-basin.

Keywords: *Sulawesi, Bone Gulf, Padamarang, tectonostratigraphy, hydrocarbon potential*

INTRODUCTION

Indonesia is a country rich in natural resources. The Oil and Gas sector is one of them. This is indicated by Indonesia's membership in the oil and gas exporter country organization called OPEC in 1962. However, over time the productivity of Indonesia's oil and gas production declined. The decline in production is indicated by oil production statistics from SKK Migas, stated that there was a decline in production starting from 2006, which amounted to 1006 bpd until 2015 as many as 786 bpd and the same trend continued until 2018. Meanwhile, oil and gas consumption in Indonesia itself continued to increase, from 1303 bpd in 2005 to 1628 bpd in 2015. The decline in production and increased consumption of oil and gas caused Indonesia to import these raw materials. This is certainly a challenge for Indonesia to be able to meet energy needs independently. According to data stated by the Director General of Oil and Gas, out of 128 sedimentary basins and only 40% of them have been explored and only a few have produced. These data indicate that there is still a large potential for oil and gas exploration in eastern Indonesia. According to data released by the Geological Survey's Geological Center that the bone bay has 239.79 MMbo of oil and 1,157.27 bscf of gas, which means bay bone has the potential of oil and gas. This is the background of this research. The purpose of this study is to analyze tectonostratigraphy based on 2D seismic data which aims to determine the hydrocarbon potential (lead) of the Padamarang Sub-basin, Bone Bay, Southern Sulawesi. The purpose of this study is to analyze tectonostratigraphy which is useful for identifying faults and horizons in the Padamarang Sub-basin, identifying Leads in the Padamarang Sub-basin, and evaluating the Petroleum System Sub-basin of Padamarang.

LITERATURE STUDY

Tectonostratigraphy is the identification of megasequence and interpretation within the scope of tectonic conditions when sediment accumulation is in process (Watkinson, et al., 1997). Research-based tectonostratigraphy studies in one basin with stratigraphic schemes constructed from synthetic data in the form of seismic profiles and well data. The tectonostratigraphic unit is a combination of all lithostratigraphic units (layers, members, and formations) that accumulate in certain tectonic conditions. Therefore, a tectonostratigraphic unit has at least one or several chronostratigraphic units which are included in one epoch (time) on the geological time scale. The duration of the epoch depends on the complexity of the evacuation of the geological

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history and its level of investigation. Examples of tectonostratigraphic units are pre-rift, rifting, post rift, syninversion, and synfolding (syn kinematic). Tectonostratigraphic units can also be subdivided into several sub-units such as sediments which are related to pre-rifts which can be divided into different rock complexes. To analyze each tectonostratigraphic unit can be seen from its seismic profile.

Lead is a term used in exploration in the oil and gas industry. In the process of hydrocarbon exploration itself there are several stages in general, namely lead, prospect, and play. Lead itself means a structure that indicates hydrocarbon accumulation, prospect means a lead that has been evaluated and is ready to drill, and play is a proven petroleum system that has hydrocarbon accumulation in it. To identify leads, there is a need to combine time-structure maps and isochron maps.

METHODS

There are 4 stages carried out in this study, namely the preparation stage, the stage of data collection, the research phase and data analysis, and the preparation of the report.
The preparatory phase includes the management of research licensing, the study of literature in the established research area, problem formulation and problem limitation. Literature study is done by collecting and studying secondary data and theories that are in accordance with the field of study to be taken. The problem formulation is to determine the problem to be raised for research in accordance with the field of study. Limitation of the problem is needed so that the research conducted does not come out of the subject matter specified.

The preparation stage is done before processing and analyzing the data so that the researcher has an overview of the area to be studied.

At the stage of data collection data collection is in the form of gravity data and 2D seismic data. The data used is data from the TGS company.

At the research and data analysis stage is the stage where the researcher processes primary data through 2D seismic data that has been given and analyzed by the author assisted with secondary data in the form of literature studies and regional geology to obtain results in the form of hydrocarbon leads in the related area.

RESULT AND DISCUSSION

Gravity Interpretation

Exploration in basins that are still in the early stages of exploration lack geological information. Interpretation of gravity data can be a reference from the direction of the structure in the study area. Data gravity measures the difference in rock density in a study area. In this study in the Padamarang Sub-basin, gravity data is used to determine the regional structure trends that exist in the study area. The gravity data used is provided by TGS NOPEC on the INDONESIA FRONTIER BASINS project located in Bone Bay and prepared by Getech. Data acquisition took place from April - June 2007 (Figure 1).

Collecting gravity data in this study area. done by the method of acquisition of Multibeam Swath Bathymetry. Based on the Bouger Anomaly map that has been displayed (Figure 2), an outline of the density distribution in the Padamarang Sub-basin is outlined. Based on the map it is divided into 3 density areas namely the northwest, southeast, and southwest. At the northwest of Padamarang, low density is very dominant. Indicates that rocks in the northwestern part of Padamarang are of low density, in the southeast part of the Padamarang shows the high rock density, the southwest also shows the same value as the Southeast Padamarang which has high density. The distribution of density values contained in the gravity map where in the northwest are smaller in density than in the southeast and southwest, this indicates a difference in lithology which has drastically changed. This difference in density can be caused by a structure in line with the changing boundary of the density value which is drastically changed or from stratigraphic lithological changes. Based on Satyana (2006) Tectonic escape post docking produces regional shear faults in the form of Palu-Koro, Kolaka, Lawanopo, Hamilton, Matano, and Balantak faults. Where these regional shear faults are relatively north-south direction. Based on the gravity map, there is a north-south alignment which is the boundary between low and high density rocks (Figure 2). This can be a clue that straightness becomes a low and high density area boundary limited by a fault.

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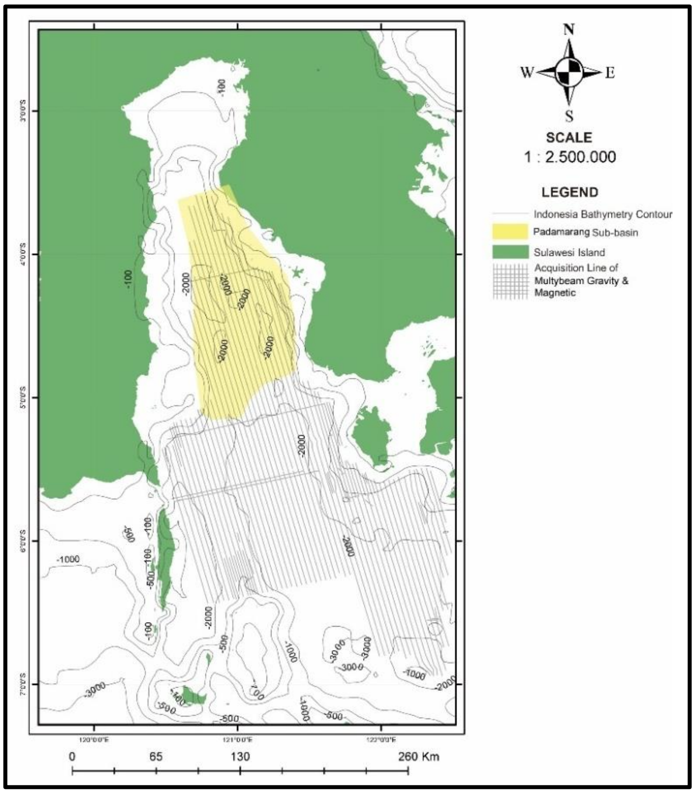

Figure 1. The area of research on gravity acquisition maps

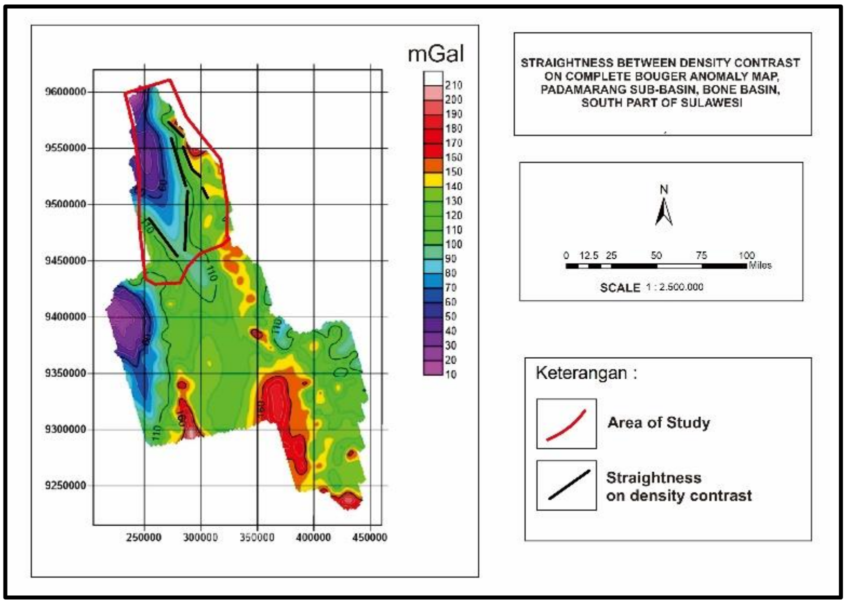

Figure 2. Lineament on complete bouger anomaly map that bordered between contrast density

Seismic 2D Interpretations & Tectonostratigraphy Analysis

This survey is located in the Bone Basin, which is an offshore part of the south of Sulawesi where the water column is approximately 20-4000 meters thick. The survey in the Bone Basin area is the latest survey in this area designed to comprehensively study the prospects of the Bone Basin (Figure 3).

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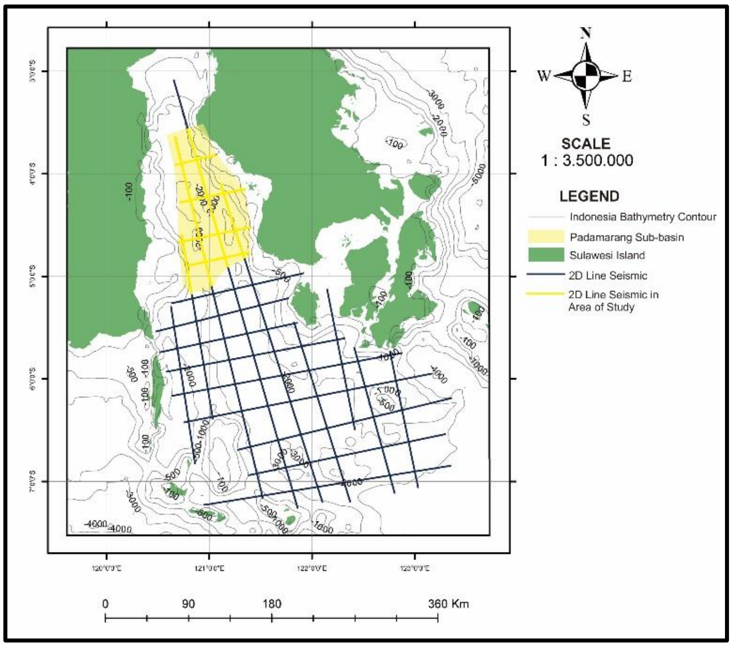

Figure 3. Survey map of seismic acquisition lines in the Bone Basin (Acquisition Report of TGS, 2007)

Fault Interpretation

In this study analysis of 2D seismic data was carried out within the Bone Basin and limited to the south so that several seismic crossings in the southern part of the Bone Basin were not analyzed. The author concentrates the analysis on the Padamarang Sub-basin so that the analysis results shown are only from seismic cross sections BN07-01 (west-east), BN07-03 (West-east), BN07-05 (west-east), BN07-07 (west- east), BN07-01 (north-south), and BN07-03 (north-south) which cuts off the area of the Padamarang Sub-basin.

In the North-south cross section depicted on seismic BN 07-06, it is revealed that there are 2 large sub-basins in the Bone Bay separated by a base stone high. Tinggian is also interpreted as Camplin and Hall (2013) as Tinggian Basa which is a strike-slip fault zone with the direction of WNW-ESE segmenting the Gulf of Bone. Based on observations of Camplin and Hall (2014) on land, this horizontal fault fault is the result of the structure of the bedrock at the pre-neogene age, where the fault at Tinggian Basa was initially active and the activity stopped. Based on the interpretation of faults in the Padamarang Sub-basin, the Basa Tinggian is limited by the West Bone Fault Zone (Figure 4).

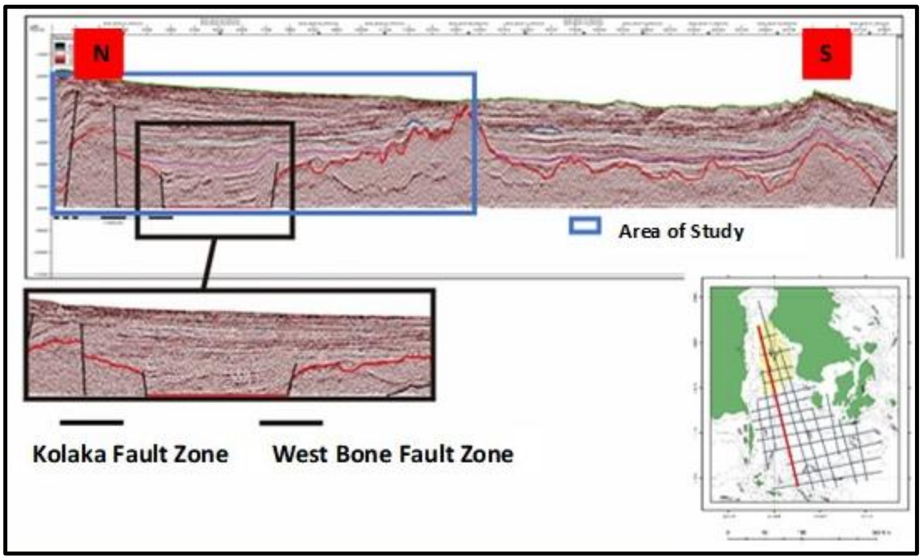

Figure 4. The BN07-06 cross section which cuts North-south Bone Bay and there is a deposit nearby Talagian Kolaka

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The BN07-05 seismic cross section of east-west direction is well illustrated by the basin boundary in the Padamarang Sub-basin in the west and east. In this seismic cross section, there is a height associated with normal faults until the bedrock in the western and eastern boundaries acts as a basin boundary (Figure 5). Based on Camplin and Hall (2013) the basin boundary in the western part is called Bone Platform and at the eastern boundary is called Tinggian Maniang. Based on the interpretation of faults, the fault that limits the Bone Platform with the Padamarang Sub-basin is referred to as the Bone West Fault Zone and fault which limits Tinggian Maniang with the Padamarang Sub-basin named as the East Bone Fault Zone. The regional structure of Bone Bay which is the result of extension is also seen in the Padamarang Sub-basin (Figure 5). Extensional features are seen in the BN07-05 seismic cross section in the form of a normal slope fault. The steep one forms a half graben. The Padamarang sub-basin is bounded by the western boundary fault fault Bone West Zone which limits Padamarang to the Bone Platform and the Eastern Bone East Fault Zone which limits the Padamarang to Tinggian Maniang. Deposenter is located at the boundary of the West Bone Fault Zone when viewed from this seismic section where thickening is directed towards the barrier fault on the west.

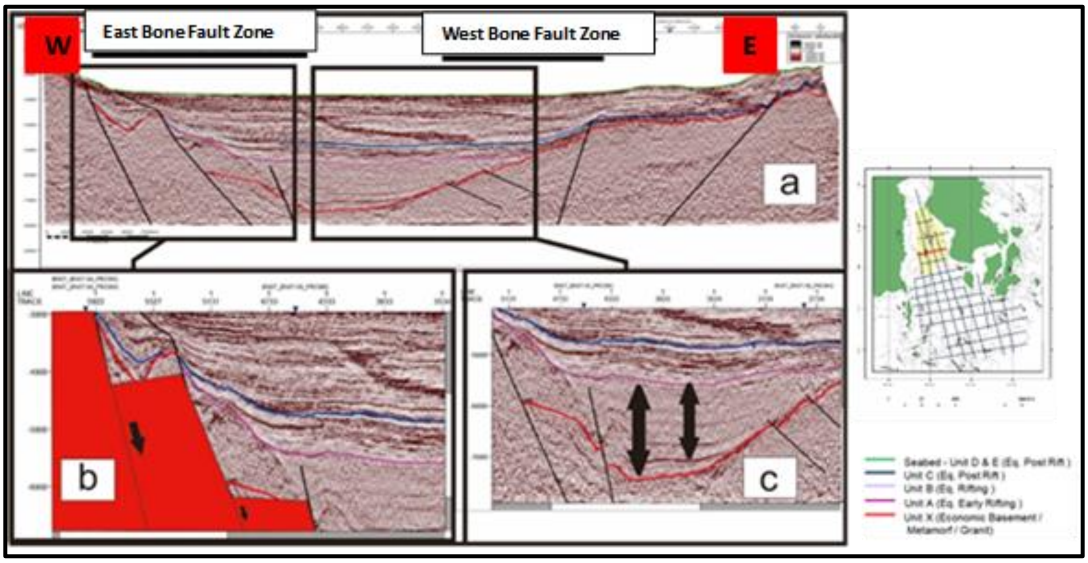

Figure 5. (a) the result of interpretation of the structure in the Padamarang Sub-basin (b) There is a block faulting feature that forms a half graben as a result of an extensional style (c) Visible thickening of the sediments to the west, indicating characteristics

In BN07-01, only part of the Kolaka Tinggian was seen in the west from the seismic crossing as a divider between the Bulupulu Sub-basin and the Padamarang Sub-basin which traversed northwest-southeast. In BN07-03, there was a deposenter seen also in the seismic cross section BN07-06 north-south direction. Then in the eastern part of the cross section, there is a boundary fault fault in the East Bone Fault which limits the eastern Padamarang Sub-basin with Tinggian Maniang. Normal fault forms a half graben. The Padamarang sub-basin is bounded by the western boundary fault called West Bone Fault Zone which limits

Padamarang to the Bone Platform and the Eastern Bone East Fault Zone which limits the Padamarang to Tinggian Maniang.

Depocenter is located at the boundary of the West Bone Fault Zone when viewed from this seismic section where thickening is directed towards the barrier fault on the west.

Horizon Interpretation

After interpreting the fault in the study area, the next step is to interpret the horizon. interpretation of the subsurface horizon or what is called horizon picking is done by the tectonostratigraphic approach. Where the author divides the tektonostratigrafi package into 3 packages, namely early syn-rift, rifting, and post rift.

In the post rift package there is Unit C which is Carbonate Buildups. In the process, the writer determines the boundaries of each seismic unit based on the seismic reflection unit boundary and defines the seismic configuration that exists between the reflection unit boundaries (internal reflection), and sees the external formation of seismic units based on Mitchum (1977). After the sesmik unit is divided, the writer performs a tectonostratigraphic approach by connecting each seismic unit to a tectonic process that takes place based on Prosser (1993).

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Unit X (*Basement*)

Basement in this study is called Unit X. Basement in this study shows that there is no good stratification or internal reflection to be interpreted, known as Chaotic (Mitchum, 1977). This variation of internal reflection shows that the basement is formed from varying lithology. Reflection limits from the Basement indicate the presence of younger strata on the Basement. Basement in the Padamarang Sub-basin has a variety of lithology types due to collisions and upward faults (Sukamto, 1975; Katili, 1978) which have an age ranging from late Oligocene to early Miocene (Bergman, et al., 1996; Sudarmono, 2000 ; Milsom, et al., 2001; Hall, 2002).

Unit A (Early Rifting)

Early Rifting in this study was represented by Unit A. Based on Prosser (1993) the initial movement of cesarean caused sediment deposited by gravity. In the Early Rifting phase a form of shaping is formed where the thin part is in the high topography of the hanging wall. Prosser (1993) also mentions that internal reflection in the Early Rifting phase forms Hummocky and the continuity of seismic reflection includes discontinuous. The form of the drill in the Early Rifting phase illustrates that sedimentation is equivalent to the process of decline, this makes seismic reflection of the shape of the wedge overlapping rather than forming onlap. The shape of the wedge thickens towards the fault line. Based on studies in the Padamarang Sub-basin, Unit A seismic reflection shows continuity of discontinuous internal reflection and Hummocky. The external form of this phase is the drill where the reflector thickens towards the west of the West Bone Fault Zone. The lower limit of this phase of seismic reflection is onlap against the Basement. The spread of this phase sediment in the study area is limited only between the two limiting faults, namely the West Bone Fault Zone and the East Bone Fault Zone. The lithology compiled the Rifting Initiation phase in the form of siliciclastic sediment and shallow marine carbonate rocks. The presence of shallow marine carbonates that may be present in this phase is considered equivalent to the early Miocene planktonic limestone and claystone clay in the Sengkang Timur basin (Camplin and Hall, 2013).

Unit B (Rifting)

The rifting phase is represented by Unit B. The Rifting phase according to Prosser (1993) is when sedimentation loses quickly with the process of decline. The facies of the deposition system in the Rifting phase varies depending on many factors including weather, the composition of the source of sediment and the position of the relative height of the sea level, the geometry and the relationship of each reflector based on the strata horizon. Internal seismic reflection shows the presence of talus aggressions, the presence of Mounded formation near footwall, retrogradation formation due to sea level rise, and divergent forms as a result of the continued influence of the declining process.

In the seismic cross section that has been interpreted, Unit B has a high amplitude, continuous continuity, and high frequency. Seismic reflection on Unit B is included in the divergent which has baselap in the form of onlap against Unit X on the western boundary. The external form of Unit B is a bit of a drill showing that Unit B is still affected by the downward process on the hanging wall. The geometry of this study is westward and is limited by the Bone West Fault Zone. This indicates that when the Bone East Fault Zone moves, the Bone West Fault Zone is still moving, resulting in an asymmetrical graben half (Camplin and Hall, 2013). Westward observations indicate that the main sediment source originates from the west side. The existence of a bad image on the normal fault line in the west and east illustrates the presence of coarse sediments accumulated, Camplin and Hall (2013) refer to it as Talus deposits. The upper limit of Unit B is Unit C which is rock carbon carbon. The boundary between Unit B and C is very difficult to determine because seismic reflection limits in some places show truncated whereas elsewhere have onlap limits. The presence of Unit C covering Unit B is estimated due to sea level rise in the rifting phase. Unit B was interpreted as the middle-end Miocene age based on an analogue of the Camba formation in the Sengkang East Basin (Grainge and Davies, 1985 in Camplin and Hall, 2013) with coarse claystone lithology associated with Middle Miocene-Late Miocene Sandstones. Unit B is also estimated to be equivalent to limestone clay and thin limestone seen in BBA-1X wells (Sudarmono, 2000; Camplin and Hall, 2013).

Unit C (Post Rift)

In the interpretation of the seismic cross section which cuts the Padamarang Sub-basin, the Post rift phase is divided into Unit C and Seabed. In general, seismic reflection in this phase has a high amplitude and has an external form of seismic reflection in the form of Carbonate Mounds spread from the middle part of the Sub-basin to Tinggian Maniang. At Tinggian, the internal seismic reflection does not show perfect strata. Clinoform was found which showed the existence of back-stepping

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so that it was interpreted that there was a sea level rise so that retrogradation occurred and in some places Pinnacle's formation was interpreted to mean a phase where the sea level rose suddenly and then slowed back called the catch up phase. Unit C located in the central part of the Padamarang sub-basin shows good internal strata seismic reflection and can be found along the Padamarang Sub-basin. Based on Ascaria (1997) Unit C is interpreted as equivalent to the Middle Miocene to Pliocene Tacipi Formation Carbonate which is in the eastern part of the southern arm of Sulawesi. Carbonate rocks of the Miocene-Pliocene age were found to be locally oppressed in an inconsistent manner in metamorphic and ultramafic rocks in the southeastern arm of Sulawesi (Surono and Sukarna, 1996) which were interpreted as equivalent to Unit C at Tinggian Maniang (Camplin and Hall, 2014).

Seabed (Post Rift)

Seabed included in the Post rift phase of this study. Seabed has parallel seismic reflections where the strata is more clearly visible at the top with better amplitude. The internal reflection of seabed at the top is also more continuous and there are many extraneous forms of seismic refleki in the form of cut and fill which are interpreted as rivers originating from the north of the Padamarang Sub-basin. According to Camplin and Hall's (2014) interpretation, the first sediments to fill were coarse clastic sediments including conglomerates, carbonates, and sedimentary complexes that were driven by mass transportation, which was Pliocene to recent.

Tectonostratigraphy

Tectonostratigraphy in the study area began when the late Oligocene to the early Miocene where it relates to the obduction which produces upward faults. When the force of this obduction ends, there is a Stress Release that produces the first deposit in the Padamarang Sub-basin, Unit A (Early Rifting). Then the rifting phase continues until the final miocene resulting from the anti-clock wise movement of the southeastern Sulawesi arm which deposits Unit B which is equivalent to the Rifting phase. Then in the Pliocene tectonic activity ends and enters the post-rift phase which settles Unit C and seabed (Figure 6).

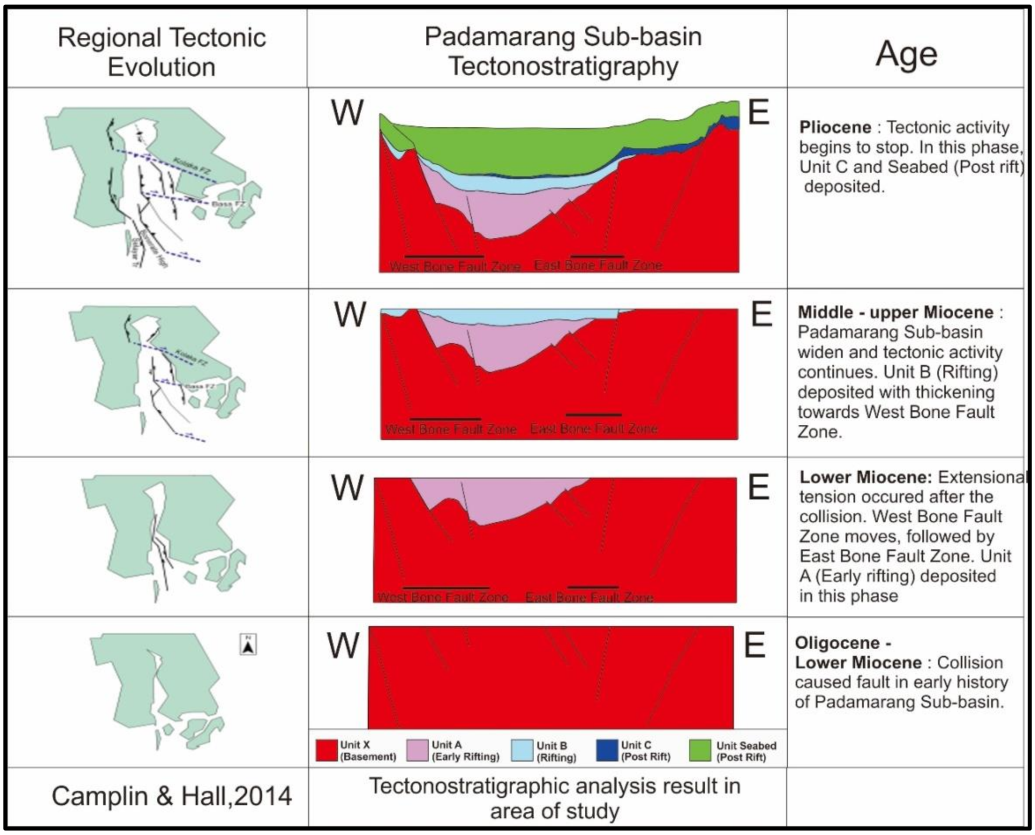

Figure 6. Result of tectonostratigraphic analysis

Hydrocarbon Potential Determination

After performing a seismic interpretation, a map of the time structure and the isochron map can be displayed. Time thickness map shows the location of the structure at the subsurface also shows the subsurface contours of each horizon that have been interpreted.

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The isochron map is a map made to display the thickness of each unit that has been interpreted from each seismic cross section. This map can be determined where the leads in the Padamarang Sub-basin.

The time structure map (Figure 7) shows that there is topographic diversity. It is seen that there is a height and depth that form the morphology of Unit X. Tinggian on this map is depicted in green to red while the depth is depicted in blue to purple and straightness of the structure is illustrated with black lines. Dalaman is generally seen climbing in a relatively north-south direction where the depth is limited by the height in the west and east. This elevation is seen to be limited by a structure that has a similar direction to the internal trends in this Sub-basin. Tinggian in the west is called the Bone Platform which is limited by the Bone West Fault Zone and in the western part of the interior there are Tinggian maniang which are limited by the East Bone Fault Zone. Then in the northern part, there is an interior which is separated by the height of the northwest-southeast trend. Tinggian is called Tinggian Kolaka. Tinggian separates the Padamarang Sub-basin with the Bulupulu Sub-basin in the northernmost part of the Gulf of Bone. The height of Kolaka is limited by the Kolaka Fault. On the time structure map of Unit A, it can be seen that there are diverse morphologies in the Padamarang Sub-basin. The time structure map shows that Unit A fills the depth in the study area. This is interpreted based on the existence of a changing color, in Unit X morphology in the inner part of purple and fairly deep, when the map structure map when unit A is produced, the Purple area on Unit X becomes shallower in Unit A In the North of the Padamarang Sub-Basin there is a deeper depth than the surrounding near the southern boundary of Tinggian Kolaka. On the time structure map of Unit B there are still various morphologies in the Padamarang Sub-basin. Tinggian in Unit X and Unit A still appears on this time structure map. There is a siltation in the depths of this Sub-basin. The limiting structure still visible on this map shows that the sediment in Unit B is still subject to tectonic factors. On the time structure map of Unit C, it has a variety of colors indicating various morphologies. The time structure map of Unit C with Unit B shows no significant changes. This is because Unit C is deposited thinly above Unit B. On the time structure map it is imaged that there is widespread siltation in the Pdamarang Sub-basin. Looks light blue that covers the inner areas that are in the middle of the sub-basin. The structure in this research area is no longer covered by Seabed. This shows that the tectonic has been affected again. The isochron map is a map made to display the thickness of each unit that has been interpreted from each seismic cross section. This map can be determined where the leads in the Padamarang Sub-basin. The isochron maps presented are Ironchron Unit A (thick from the upper limit of Unit A to the upper limit of Unit X), Ironchron Unit B (from Unit B to Unit A), Ironchron Unit C (from Unit C to Unit B), and Synchronous seabed (the thickness of the boundary is up to the limit of Unit C) (Figure 8).

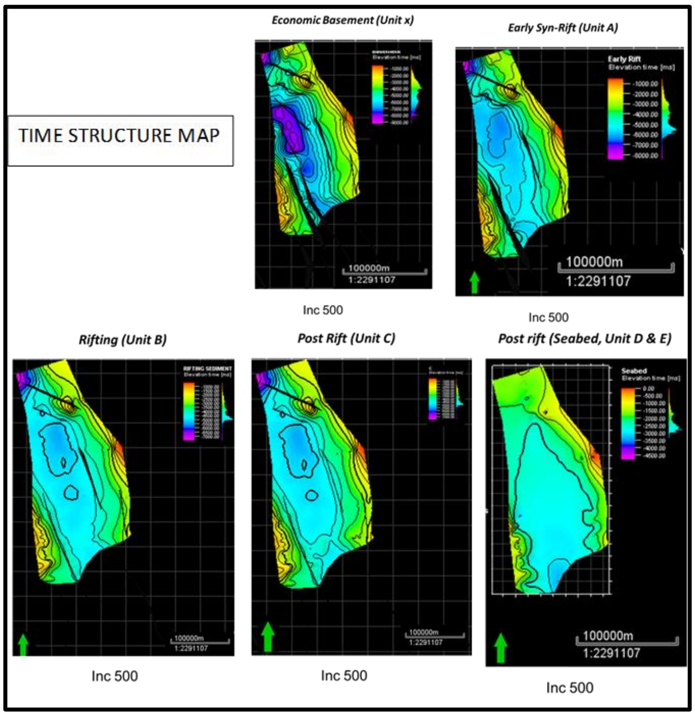

Figure 7. Time Structure Map

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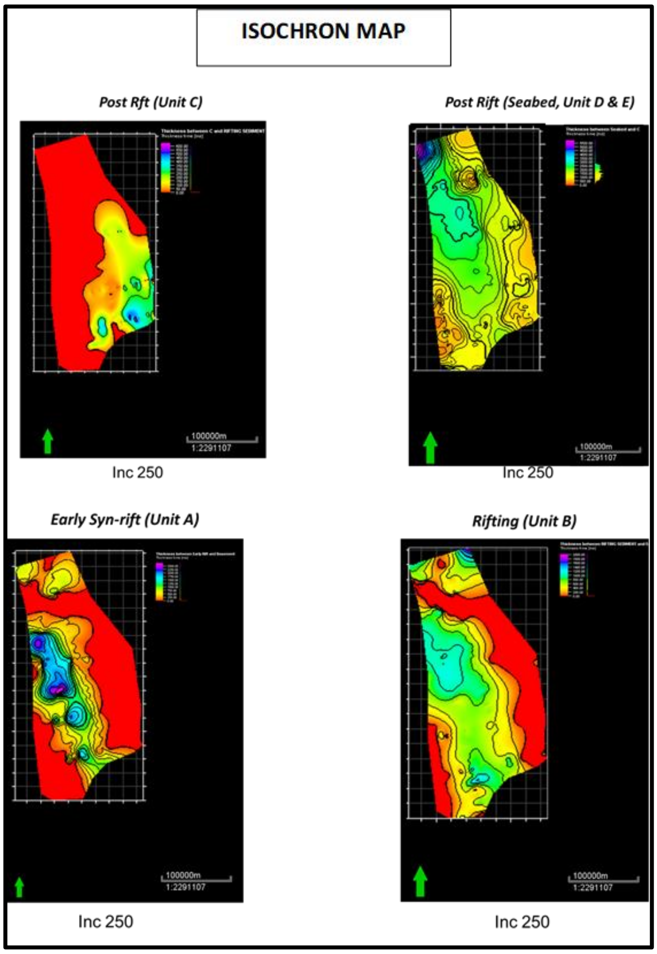

Figure 8. Isochron Map

Next, the author determines areas that have the potential to lead from hydrocarbon accumulation. This hydrocarbom potential is taken in Unit C which is composed of carbonate rocks that grow at high altitudes. Due to good porosity and permeability in allocthonous carbonate rocks, Unit C has the potential as a good reservoir rock in the study area. There are 2 leads taken as areas that have the potential as a place for hydrocarbon accumulation (Figure 9). Lead 1 is seen from a cross section of BN07-07 which cuts the basin in the east-west direction. When viewed from the seismic cross section, the location of the carbonate body is in the middle of the sub-basin and overlap Unit B. The thickness of this Lead 1 is around 400 - 450 ms for the thickest part then thinner to the side. The formation of Lead 1 describes the keep up phase in carbonate growth, where the growth of carbonate is equivalent to the increase in sea level. Lead 2 in the seismic crossing BN07-06 which traverses north-south. It appears in this seismic crossing that the carbonate body grows on the Tinggian Basa which overlaps Unit B. The thickness of Lead 2 itself is in the range of 150 to 200 ms. The external form of Lead 2 is in the form of mounded carbonate which reflects the growth of the keep up phase where the sea level rises slowly and the carbonate grows at a speed that rides sea level rise.

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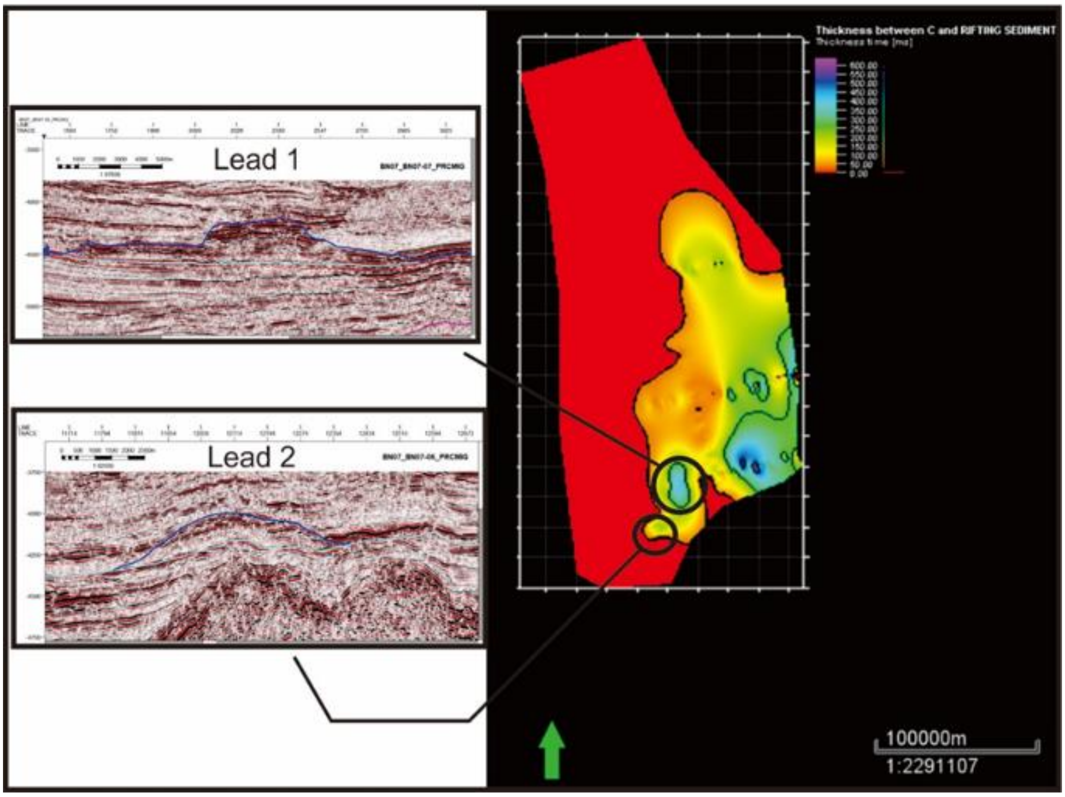

Figure 9. Determination of 2 leads in Unit C as targeted reservoirs in the Padamarang Sub-basin

CONCLUSION

1. Identification of faults and horizons in the Padamarang Sub-basin can be identified, i.e. there is a basin bounding structure that traverses north-south and there is also a boundary structure trending northwest-southeast which is identified as a result of transtensional forces.

2. There are 4 units in the form of Unit X, Unit A, Unit B, Unit C, and Seabed. The results of the tectonographic distribution in this study are Early Rifting, Rifting, and Post Rift. In the Early Rifting phase a divergent formation will occur in its internal seismic reflection and form a study to the west where thick sediments are at the arat boundary of the Padamarang Sub-basin.

3. Leads in the research area can be identified. 2 leads were found in the study area. These predetermined leads were taken on Unit C which is a carbonate buildup and potentially as a place for accumulation of hydrocarbons seen from good reservoir quality which can be seen from its analogues in the East Sengkang Basin. Unit C was also chosen because it was covered by Seabed which is a fine sediment deposit covering Unit C.

4. The results of an evaluation of the petroleum system based on found leads, show that the source of hydrocarbons originates from 3 main rock schemes, namely Eocene parent rock analogous to Eocene coal in the Sengkang Tiimur Basin, Mesozoic parent rock which is analogous to that is in Buton, and Early Miocene Mother Rock which is the oldest sedimentary deposit in the Padamarang Sub-basin and analogous to the carbonic claystone in the East Sengkang Basin, namely Formation at the Late Miocene Age to the Pliocene. Hydrocarbons in this area are charging reservoirs at the age of plistocene. This is because the target reservoirs of the Pliocene and Seal ages are formed in the plistocene-to-resen. The charging process from the host rock to the reservoir passes through limiting faults such as the West Bone Fault Zone. In Lead 1 hydrocarbons it will migrate to the Bone West Fault Zone and then fill Unit B as the Carrier bed and accumulate in Unit C which has a stratigraphic trap. For Lead 2, the process of migration from the main rock to the reservoir passing through the Kolaka fault zone in the north can occur but the fact shows that there is oil seepage in the Kolaka Fault Zone, the possible scheme is migration through the Bone West Fault Zone which will fill Unit C by passing the Unit B as a Carrier bed.

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