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Geochemical Characteristics of the Mallawa Formation, and its Relationship with the History of Source Rock Formation in the South Makassar Basin, South Sulawesi

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Abstract. A hydrocarbon system to determine the hydrocarbon potential in an area can be determined by the presence of three main components that ensure its existence together, one of main components are source rock. The South Makassar Basin has the potential to have a petroleum system that acts as a source rock for the Mallawa Formation. Source rock is a component of the petroleum system that has the ability to produce and store hydrocarbons, where this rock is generally a rock with fine grains such as coal or shale. Oil and gas exploration in Indonesia is a common thing because there are many prospect areas that have the potential to produce hydrocarbons. The South Makassar Basin is a Tertiary sedimentary basin of land type which is geographically located along West Sulawesi to South Sulawesi and this basin occurs due to tectonics or structures with high frequency. The South Makassar Basin was formed as a result of the expansion of the Makassar Strait which occurred at no younger than the Early Paleocene age where the tectonic consequences would influence the maturation process of the source rocks in the South Makassar Basin. Apart from that, in this research a geochemical method was carried out in the form of laboratory analysis to determine the maturity of the source rock using cuttings samples. So this research provides something new in the exploration of the maturity of source rocks, which in the South Sulawesi area has a complex tectonic setting.

1 Introduction

The background to this research is to reveal facts that describe the problem of a hydrocarbon system to determine the hydrocarbon potential in an area. Its existence can be determined by the presence of three main components which are confirmed to exist together, namely: source rock potential, reservoir rock potential and sealing rock potential. The South Makassar Basin is located in South Sulawesi Province, which has the potential to have a petroleum system that acts as a source rock for the Mallawa Formation which is of Early Eocene – Late Eocene age. Therefore, in writing this thesis, we will discuss the influence of tectonic events over a

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certain period of time so that they influence the formation of the geochemical characteristics of the source rock in the South Makassar Basin in the research area (**Fig. 1**).

According to Hunt (1996) source rock is a type of rock that has the ability to store and produce hydrocarbons to accumulate so that oil and natural gas can be found, where this source rock is generally a rock with fine grains such as coal, shale. Source rocks can be grouped into 2 types of source rocks, namely potential source rocks and effective source rocks. Potential source rock is source rock that is immature to produce oil and natural gas (petroleum) in its natural setting. In other words, rocks can be called effective source rocks if they can produce oil and natural gas. Apart from that, it can be called an ineffective rock if it is otherwise unable to produce oil or natural gas due to certain processes, for example due to uplift accompanied by erosion and cooling.

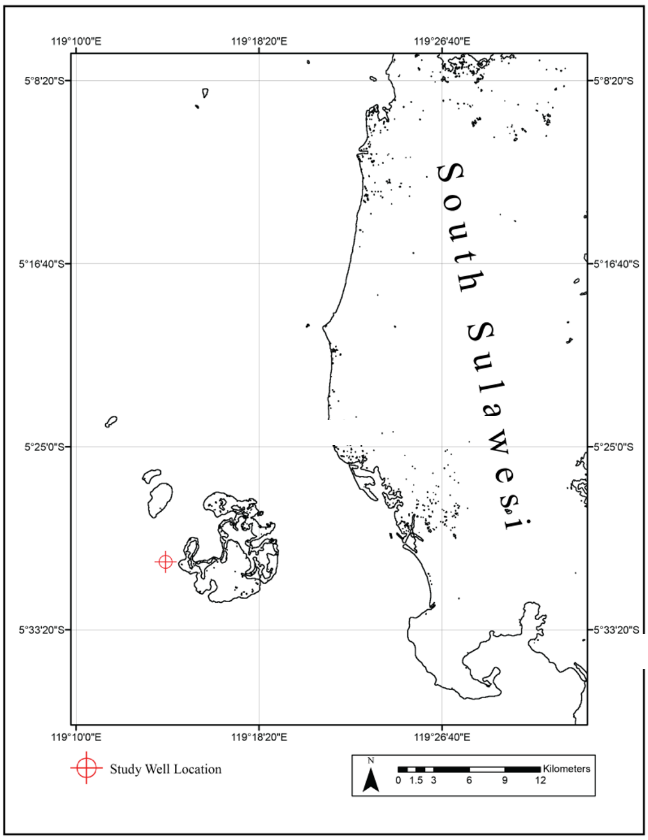

Fig. 1. Research well location map

The need for oil and natural gas in Indonesia is still very high for various sectors. Currently, national oil reserves are 4.17 billion barrels with proven reserves of 2.44 billion barrels. Petroleum reserves in Indonesia will be available for the next 9.5 years if there are no new discoveries. More massive exploration is needed to maintain these reserves (ESDM, 2021). Intensive exploration activities are very important to determine the source of oil and gas reserves in Indonesia, plus the development of the times has given rise to many new technologies to assist in oil and gas exploration that were previously unexplored by humans. Until now, exploration and exploitation activities in South Sulawesi Province, especially in the South Makassar Basin, are still being carried out to increase reserves and increase oil and gas production.

The South Makassar Basin is a sedimentary basin with a foreland basin type which is geographically located between the islands of Kalimantan and Sulawesi. Based on tectonics, this basin is an area affected by complex structures and is located at the meeting of three tectonic plates that developed from the Paleogene to the Neogene era, namely the Indian-Australian Plate which moved northward, the Eurasian Plate which moved southeastward and the Pacific Plate which moved northward. west direction. The regional stratigraphy of the research area located in the South Makassar Basin is known to originate from the Sunda Land Margin or part of Kalimantan which was separated due to the expansion of the Makassar Strait. Stratigraphy in the South Makassar Basin includes the Bedrock Complex, Balangbaru Formation, Toraja/Mallawa Formation, Tonasa Formation, Camba Formation and Walanae Formation (**Fig. 2**).

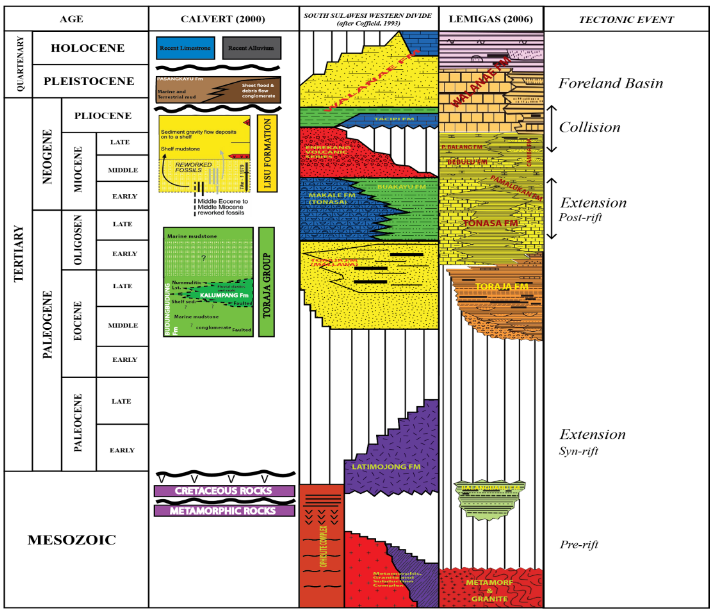

Fig. 2. Stratigraphy of the study area modified by Calvert (2000), South Sulawesi Western Divide (after Coffield, 1991) and LEMIGAS (2006)

The structuration of the Makassar Strait can be correlated with the initial formation of the Makassar Strait, so it can be said that this basin originated from a rifting process which, according to [3], the rifting that caused the formation of the Makassar Basin occurred no younger than the Early Paleocene age. Starting from the escape tectonic event due to the collision of the Indian Plate which caused an indentation of the Eurasian Plate which moved towards the east-southeast, resulting in the movement of the Indochina microcontinent towards the southeast via a horizontal fault 'red river fault' (Brahamntyo, 2009). The initial opening of the Makassar Strait resulted in the initiation of horizontal faulting in a northwest-southeast direction (wrench fault) followed by rifting in the western segment of Kalimantan towards east-southeast. The existence of this pair of horizontal faults (wrench fault) supports the movement of the East Kalimantan segment towards the southeast accompanied by rifting to form asymmetrical horst and graben structuration. Based on previous researchers, the formation of the South Makassar Basin was originally part of the edge of the Sunda Mainland (Kalimantan) which was then separated due to the expansion of the Makassar Strait. The South Makassar Basin is a product of expansion during the Paleogene period which was the result of back-arc stretching due to plate collision (subduction) to the southwest of Sulawesi

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Island (Thompson et al., 1991), apart from that there are many extensional faults due to the plate collision.

2 Method

2.1 Laboratory analysis

At the laboratory analysis stage, sample preparation is carried out, where in this case there are 2 different preparation methods, namely during sample preparation to analyze the % Total Organic Carbon (TOC) which after that can be continued to analyze Rock Eval Pyrolysis (REP) and sample preparation for analyzing Vitrinite Reflectance (VR) and Kerogen Type (KT). The samples used at this stage need to be ground and dissolved with a chemical solution which aims to remove silica and carbonate levels and remove kerogen.

2.2 Geochemical analysis

This geochemical analysis includes 2 things, namely determining organic material and determining the type of kerogen and hydrocarbon maturity. To determine the organic material which is the result of the TOC calculation tool, it is necessary to pay attention to the %TOC and S1 + S2 values, after which from these values the level of organic material richness in the sample can be determined using the Peters and Cassa (1994) classification (**Table 1**). Meanwhile, to determine the type of kerogen and hydrocarbon maturity (**Table 2**), the aim is to identify the characteristics of organic material in the source rock, carry out quantification of the source rock, calculate total organic carbon and evaluate temperature changes during hydrocarbon formation (Bordenave, 1993). Analysis can be carried out with a cross plot using a Van Kravelen diagram where the values are considered.

Table 1. Classification of source rocks based on %TOC

Quantity	TOC (wt%)	S1 (mg HC/g rock)	S2 (mg HC/g rock)
Poor	0-0.5	0-0.5	0-2.5
Fair	0.5-1	0.5-1	2.5-5
Good	1-2	1-2	5-10
Very good	2-4	2-4	10-20
Excellent	>4	>4	>20

Table 2. Classification of kerogen type and hydrogen index

Kerogen Type	Hydrogen Index (mg HC/g TOC)	S2/S3	Atom H/C	Main Products
I	> 600	> 15	> 1.5	Oil
II	300-600	10-15	1.2-1.5	Oil
II/IIIb	200-300	5-10	1.0-1.2	Oil and Gas
III	50-200	1-5	0.7-1.0	Gas
IV	< 50	< 1	< 0.7	No Hydrocarbon Production

Table 3. Maturity classification based on %Ro value

Oil-prone generation		Gas-prone generation	
Generation stage	%Ro	Generation stage	%Ro
Immature	< 0.6	Immature	< 0.8
Early oil	0.6-0.8	Early oil	0.8-1.2
Peak oil	0.8-1.0	Peak oil	1.2-2.0

Late oil	1.0-1.35	Late oil	> 2.0
Wet gas	1.35-2.0		
Dry gas	> 2.0		

2.3 Tectonostratigraphic analysis

Tectonostratigraphic analysis of the geochemical characteristics of the source rock based on regional stratigraphic and regional tectonic data can be carried out to analyze the relationship between the geochemical characteristics of the source rock and the tectonic event in the research area as well as knowing the role of structures that play a role in the formation of the source rock, in addition to knowing how the South Makassar Basin was formed, especially its characteristics. geochemistry of the Mallawa Formation.

3 Result and discussion

3.1 Result analysis of geochemical samples in research area

Geochemical data analysis is carried out to determine the quantity, quality and maturity of the source rock through selected well samples (**Table 4**). Of course, this is very necessary to know the level of maturity of the source rock in producing hydrocarbons and in the maturation process the chemical properties of the organic material will change over time due to geological processes either due to tectonics or sediment loading. Therefore, geochemical analysis is needed, such as analysis of Total Organic Carbon, Rock Eval Pyrolysis and Vitrinite Reflectance, Kerogen Type.

Table 4. Geochemical data result

No	Depth	Lithology	Formation	TOC	S1	S2	S3	TMAX	PI	HI	OI	RO	PY
1	3910 - 3920	50%SH, + 20%SST, lt gy, fn gnd, 30% COAL, blk	Mallawa	**4.83**	0.1	6.76	2.4	428	0	140	49	0.36	6.85
2	3930 - 3980	60%SH, + 40% COAL, blk	Mallawa	**6.11**	0.2	7.36	2.3	425	0	120	38	0.33	7.51
3	3990 - 4040 (A)	80%SH, + 10%SST, lt gy, fn gnd, 10% COAL, blk	Mallawa	**3.82**	0.1	4.42	1.7	426	0	116	45	0.38	4.52
4	3990 - 4040 (B)	80%SH, + 10%SST, lt gy, fn gnd, 10% COAL, blk	Mallawa	**3.87**	0.1	2.54	1.3	427	0	66	34	0.33	2.59
5	4050 - 4100	70%SH, + 30% COAL, blk	Mallawa	**5.6**	0.2	12	2.2	425	0	214	39	0.31	12.16
6	4110 - 4160	80%SH, + 20% COAL, blk	Mallawa	**3.22**	0.1	5.62	1.4	427	0	175	44	0.31	5.69
7	4170 - 4210	90%SH, + 10% COAL, blk	Mallawa	**2.3**	0.1	4.24	0.9	429	0	184	40	0.35	4.3
8	4220 - 4280	90%SH, lt gy + 10% SST, lt gy, fn gnd	Mallawa	**1.92**	0	3.03	0.9	429	0	158	49	0.33	3.06
9	6610 - 6650	40%SH, dk gy + 60%SST, lt gy, fn gnd, qrtz	Balangbaru	**1.46**	0.2	1.46	0.8	428	0.1	100	55	0.51	1.69

No	Depth	Lithology	Formation	TOC	S1	S2	S3	TMAX	PI	HI	OI	RO	PY
10	7080 - 7110	40%SH, dk gy + 60%SST, lt gy, fn gnd, qrtz	Balangbaru	**7.41**	4.7	16.4	9.5	335	0.2	221	128	0.89	21.02
11	7140 - 7170	80%SST, lt gy, fn gnd + 20%SST, lt gy, crs	Balangbaru	**1.09**	0.6	3.79	3	334	0.1	348	276	0.97	4.39
12	7320 - 7350	70%SST, lt gy, crs + 20%SST, lt gy, fn gnd + 10%SH, dk gy	Balangbaru	**1.74**	0.7	3.64	3.4	330	0.2	209	195	0.93	4.33

3.2 Result analysis of total organic carbon

To determine the total organic carbon content in a rock, the Peters and Cassa (1994) classification is used, which determines the good or bad percentage of organic carbon content in the rock being analyzed. In the research area there are 62 cuttings samples which have been analyzed to determine the total organic carbon content taken from certain depths.

In **Table 5**, which is a sample from the research area well taken from several depths for %TOC analysis, it shows that there are variations in the level of presentation of organic carbon content in each sample. In the research area well, 2 formations were found, namely the Mallawa Formation which was indicated as the source rock and the Balangbaru Formation, where after carrying out %TOC analysis on the Mallawa Formation, according to the classification of Peters and Cassa (1994), 3 samples were found which were classified as fair, 1 sample which was classified as good, 4 samples were classified as very good and 3 samples were classified as excellent. Meanwhile, in the Balangbaru Formation, after carrying out the %TOC analysis, 37 samples were classified as poor, 11 samples were classified as fair, 2 samples were classified as good and 1 sample was classified as excellent.

Table 5. Total organic carbon result analysis

No	Depth (*feet*)	Sample Type	Formation	TOC	Peters and Cassa Classification (1994)
1	3760 - 3800 UW	Cuttings	Mallawa	0.77	Fair
2	3820 - 3850 UW	Cuttings	Mallawa	0.79	Fair
3	3910 - 3920 UW	Cuttings	Mallawa	4.83	Excellent
4	3930 - 3980	Cuttings	Mallawa	6.11	Excellent
5	3990 - 4040 (A)	Cuttings	Mallawa	3.82	Very Good
6	3990 - 4040 (B)	Cuttings	Mallawa	3.87	Very Good
7	4050 - 4100	Cuttings	Mallawa	5.6	Excellent
8	4110 - 4160	Cuttings	Mallawa	3.22	Very Good
9	4170 - 4210	Cuttings	Mallawa	2.3	Very Good
10	4220 - 4280	Cuttings	Mallawa	1.92	Good
11	4290 - 4340	Cuttings	Mallawa	0.99	Fair
12	4350 - 5010	Cuttings	Balangbaru	0.58	Fair
13	5020 - 5070	Cuttings	Balangbaru	0.23	Poor
14	5080 - 5140	Cuttings	Balangbaru	0.29	Poor
15	5150 - 5200	Cuttings	Balangbaru	0.32	Poor
16	5200 - 5250	Cuttings	Balangbaru	0.53	Fair
17	5210 - 5260	Cuttings	Balangbaru	0.99	Fair
18	5260 - 5310	Cuttings	Balangbaru	0.36	Poor
19	5280 - 5330	Cuttings	Balangbaru	0.57	Fair
20	5320 - 5370	Cuttings	Balangbaru	0.27	Poor

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No	Depth (*feet*)	Sample Type	Formation	TOC	Peters and Cassa Classification (1994)
21	5340 - 5390	Cuttings	Balangbaru	0.16	Poor
22	5380 - 5430	Cuttings	Balangbaru	0.22	Poor
23	5400 - 5450	Cuttings	Balangbaru	0.28	Poor
24	5450 - 5500	Cuttings	Balangbaru	0.25	Poor
25	5460 - 5510	Cuttings	Balangbaru	0.27	Poor
26	5470 - 5530	Cuttings	Balangbaru	0.48	Poor
27	5510 - 5570	Cuttings	Balangbaru	0.19	Poor
28	5520 - 5570	Cuttings	Balangbaru	0.18	Poor
29	5560 - 5620	Cuttings	Balangbaru	0.14	Poor
30	5580 - 5610	Cuttings	Balangbaru	0.07	Poor
31	5580 - 5630	Cuttings	Balangbaru	0.07	Poor
32	5640 - 5690	Cuttings	Balangbaru	0.1	Poor
33	5650 - 5680	Cuttings	Balangbaru	0.24	Poor
34	5700 - 5750	Cuttings	Balangbaru	0.05	Poor
35	5710 - 5760	Cuttings	Balangbaru	0.04	Poor
36	5760 - 5810	Cuttings	Balangbaru	0.03	Poor
37	5780 - 5830	Cuttings	Balangbaru	0.13	Poor
38	5860 - 5890	Cuttings	Balangbaru	0.27	Poor
39	5920 - 5950	Cuttings	Balangbaru	0.34	Poor
40	5980 - 6010	Cuttings	Balangbaru	0.33	Poor
41	6050 - 6080	Cuttings	Balangbaru	0.34	Poor
42	6110 - 6160	Cuttings	Balangbaru	0.28	Poor
43	6190 - 6240	Cuttings	Balangbaru	0.21	Poor
44	6250 - 6300	Cuttings	Balangbaru	0.07	Poor
45	6310 - 6340	Cuttings	Balangbaru	0.21	Poor
46	6370 - 6400	Cuttings	Balangbaru	0.26	Poor
47	6430 - 6460	Cuttings	Balangbaru	0.18	Poor
48	6490 - 6520	Cuttings	Balangbaru	0.28	Poor
49	6550 - 6580	Cuttings	Balangbaru	0.31	Poor
50	6610 - 6650	Cuttings	Balangbaru	1.46	Good
51	6670 - 6700	Cuttings	Balangbaru	0.3	Poor
52	6820	Cuttings	Balangbaru	0.17	Poor
53	6990	Cuttings	Balangbaru	0.56	Fair
54	7020 - 7050	Cuttings	Balangbaru	0.78	Fair
55	7080 - 7110	Cuttings	Balangbaru	7.41	Excellent
56	7140 - 7170	Cuttings	Balangbaru	1.09	Good
57	7200 - 7230	Cuttings	Balangbaru	0.82	Fair
58	7260 - 7290	Cuttings	Balangbaru	0.56	Fair
59	7320 - 7350	Cuttings	Balangbaru	1.74	Good
60	7380 - 7410	Cuttings	Balangbaru	0.91	Fair
61	7393 / 7499	Cuttings	Balangbaru	0.74	Fair
62	7440 - 7470	Cuttings	Balangbaru	0.57	Fair

3.3 Result analysis of kerogen type

To analyze the type of kerogen in this study, a cross plot was carried out between the Hydrogen Index (HI) vs Tmax values using the Van Krevelen Diagram modified by Hunt (1996). The HI and Tmax values were obtained based on the results of the ¬Rock Eval-Pyrolysis analysis where in (**Fig. 3**) the results of the comparison of these values showed that the sample results in the Mallawa Formation showed an immature level and tended to produce gas which was shown in type III. Meanwhile, in the Balangbaru Formation, several samples show an immature level and tend to produce oil and gas of type II/IIb.

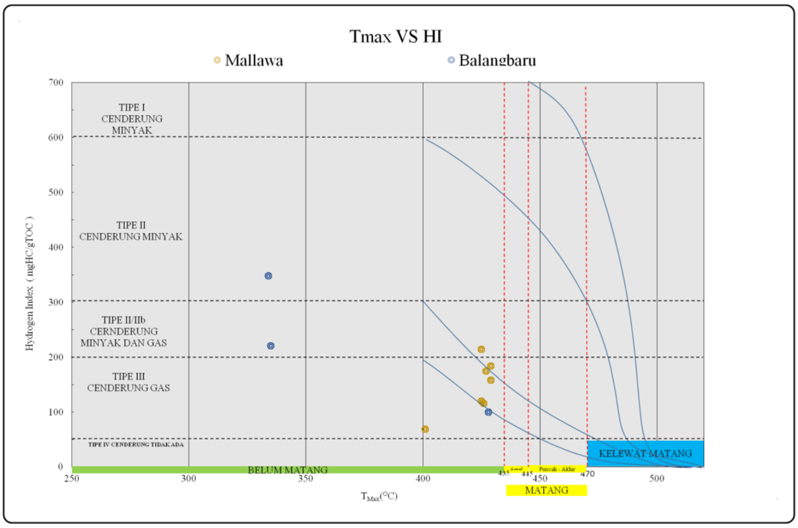

Fig. 3. Crossplot results of Hydrogen Index (HI) vs Tmax values for research area using the Van Krevelen Diagram.

3.4 Result analysis of vitrinite reflectance

In this research, vitrinite reflectance (Ro) analysis was also carried out to determine the maturity of the source rock, where in the research area well several samples were taken at certain depths representing each formation. In **Table 4** which shows the results of the Rock Eval-Pyrolysis analysis, TOC and vitrinite reflectance shows that the Mallawa Formation has an average vitrinite reflectance value of 0.31% – 0.38%, the maturity classification is based on the % value. Ro according to Dow (1977) Senftle and Landis (1991) shows that the condition of the samples is immature. Meanwhile, the Balangbaru Formation has an average value of 0.51% - 0.97% (**Table 3**). Maturity classification is based on the %Ro value according to Dow (1977) Senftle and Landis (1991), et al, shows that the condition of the sample is at immature - peak mature.

3.5 Results of analysis of the relationship between tectonic events and the geochemical characteristics of the research area

The South Makassar Basin is a foreland basin type basin where this basin was formed as a result of a fairly long tectonic period or tectonic phase. According to previous research, many people say that the South Makassar Basin or Makassar Strait experienced rifting for the first time in the Middle Eocene - Late Eocene, but in this research it refers more to researcher Sutadiwiria (2019) who said that rifting occurred in the South Makassar Basin or Makassar Strait at this age. not younger than the Early Paleocene, which is supported by the biostratigraphy data that has been obtained. After analyzing the nannofossils, it was found that the stratigraphic column and tectonic event of the research area well had a formation unit with the oldest age, namely Upper Cretaceous to Early Paleocene, which is the Balangbaru Formation with lithological units in the form of interbedded mudstone (black shale) with breccia-inserted sandstone. In this time period, a tectonic period occurred in the form of a pre-rift, which was the beginning of the subduction process of the Bantimala complex due to plate collisions. Apart from that, in the research area well there are also other formations which have an age of Early Paleocene to Middle Oligocene which is the Mallawa/Toraja Formation with lithological units in the form of interbedded mudstone with coal-insulated limestone. In the Early Paleocene period, a tectonic period occurred in the form of the beginning of the syn-rift where the Makassar Strait opened and the beginning of the formation of the South Makassar Basin which had an asymmetrical shape in the form of a half graben due to structuration in the form of mega shear, namely in the form of an electric fault which has a plane that slopes downwards and this period also the beginning of the deposition of Tertiary age sediments. After that, the Early Oligocene age continued with the tectonic period in the form of post-rift which was interpreted to mean that at that age rifting had stopped and continued with a decrease in temperature in the earth's crust and volcanic activity.

In **Fig. 4** shows the results of tectonic stratigraphy through seismic reinterpretation in the Makassar Basin from West Sulawesi - South Sulawesi, which shows the tectonic events in this basin so that later it can be concluded that what kind of geological structural influence can influence the maturity of the source rock so that it can produce hydrocarbons in the research area in the South Makassar Basin. So that later on the research well, which already contains the formation age of the formation and the type of lithology with each geochemical characteristic it has will be connected to tectonic events in order to determine the maturity of the source rock in the research area and its geochemical characteristics (**Fig. 5 - 7**).

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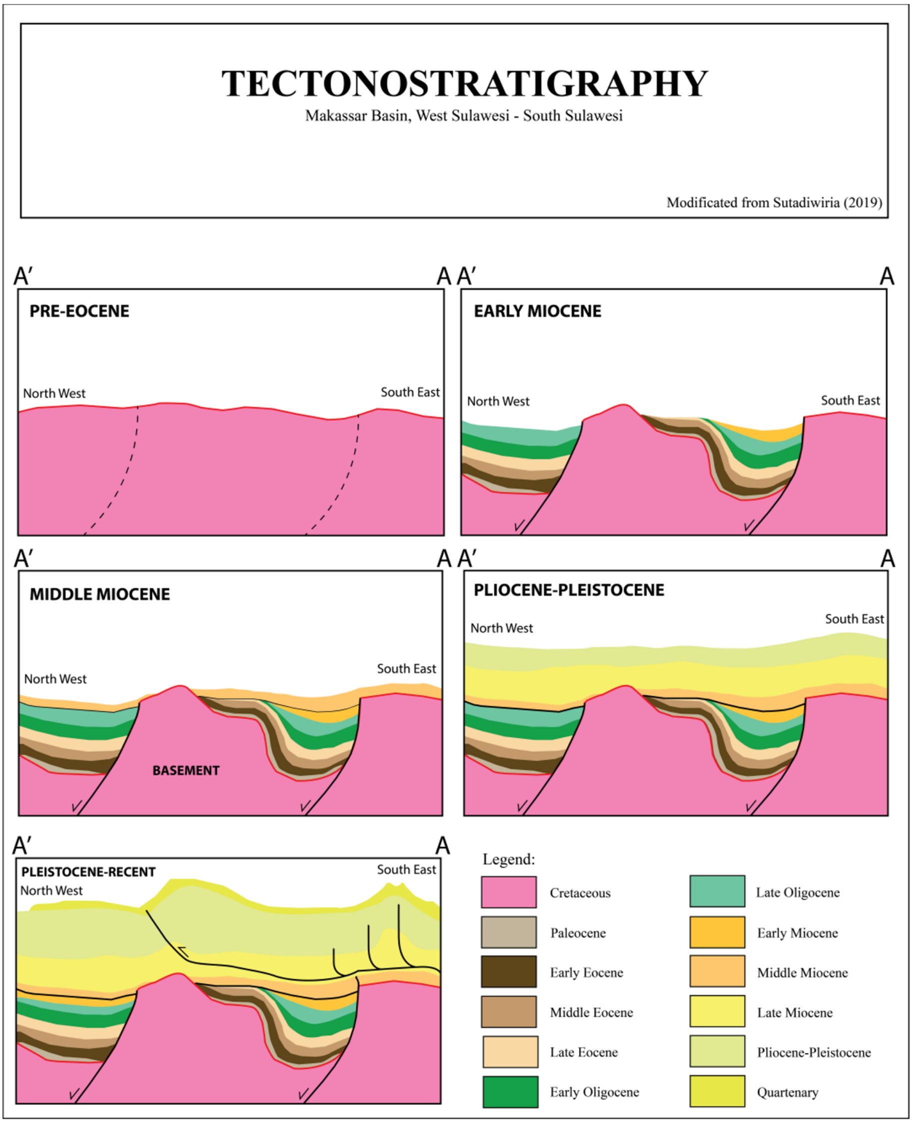

Fig. 4. Tectonostratigraphic of the Makassar Basin, West-South Sulawesi through seismic reinterpretation

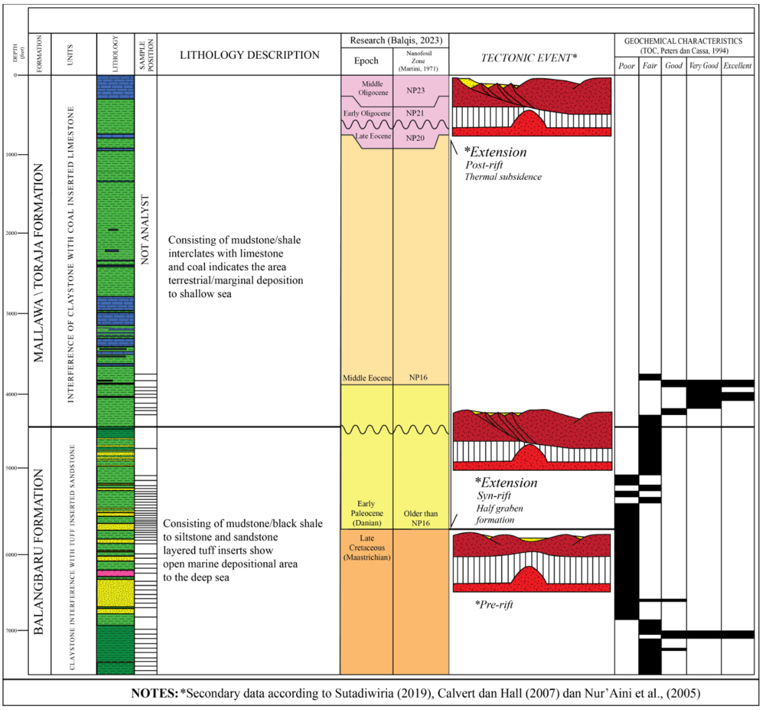

Fig. 5. The relationship of tectonic events to the geochemical characteristics (TOC) of the research area in the research area well

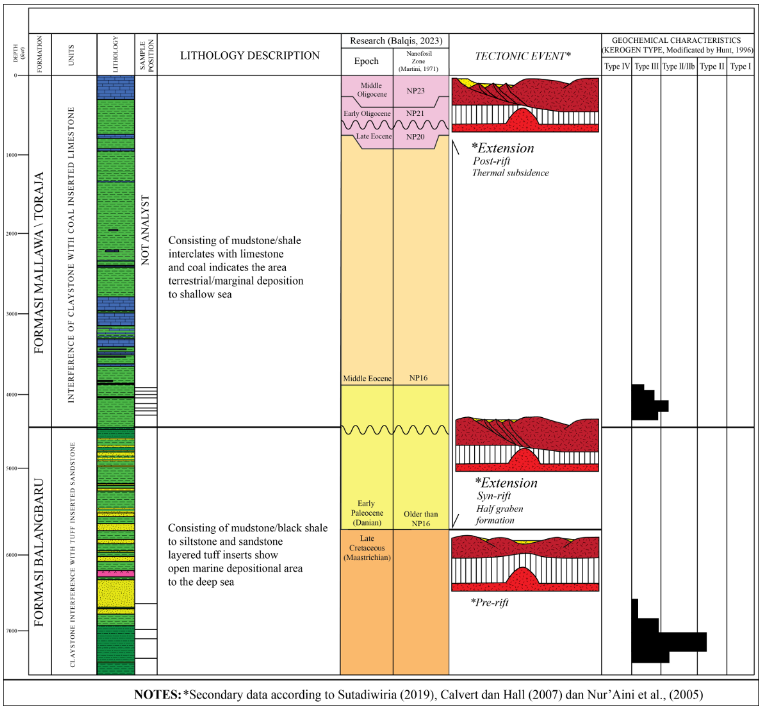

Fig. 6. Relationship of tectonic events to geochemical characteristics (Kerogen Type) of the research area in the research area well

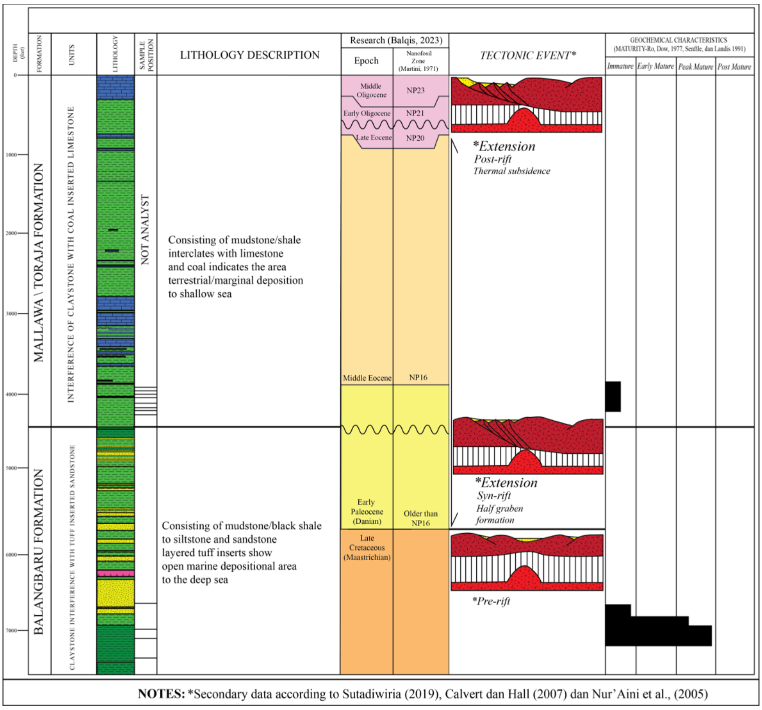

Fig. 7. The relationship of tectonic events to the geochemical characteristics (Ro maturity) of the research area in the research area well

4 Conclusion

Based on the results of geochemical research which can be correlated with tectonic events over a certain period of time in the research well in the research area. The research area well has 2 different formations with different units, where the oldest formation in this well is the Balangbaru Formation which has an age of Late Cretaceous - Early Paleocene with units in the form of interbedded black shale with tuff-inserted sandstone. The tectonic event that occurred in the Late Cretaceous – Early Paleocene period was the pre-rift period, in the Late Cretaceous age according to Calvert and Hall (2007) the deposition of bedrock which had a lithology in the form of black shale, volcanic and metamorphic rocks, where deposition. These black shales and volcanic rocks are the result of fore-arc basin deposits in the western part of the subduction zone where the direction of subduction was towards the west during the Late Cretaceous period which is located along the southernmost route of Kalimantan. Meanwhile, at an age not younger than the Early Paleocene, according to Sutadiwiria (2019), based on the results of biostratigraphic analysis, this is the beginning of rifting or the initial opening of the Makassar Strait, which has an asymmetrical shape in the form of a half graben, so it is interpreted as the beginning of the formation of the South Makassar Basin. As a result of the tectonic period, this formation after geochemical analysis was carried out in the form of total organic carbon (TOC) analysis, which to determine the quantity showed a percentage with an average of 0.07% - 7.41% (poor - excellent) according to the classification of Peters and Cassa (1997). Meanwhile, to determine the type of kerogen, a cross plot was carried out between the HI and Tmax values (modificated from Hunt, 1997) which were obtained through Rock Eval-Pyrolysis (**Fig. 4**) to produce kerogen types Type III - Type II (tending to gas - tending to oil). To determine maturity, an analysis is carried out using the %Ro value produced through Rock Eval-Pyrolysis where in this formation after carrying out this analysis a value is obtained with an average of 0.51% - 0.97% (immature - peak mature) according to the classification of Dow (1977) Senftle and Landis (1991), et al.

In the research area in the research area well, a formation that is younger than the Balangbaru Formation has been deposited, namely the Mallawa Formation, where this formation has an Early Paleocene - Middle Oligocene age with units in the form of interbedded mudstone with coal-insulated limestone. The tectonic event that occurred during the Early Paleocene – Middle Oligocene period was rifting not younger than the Early Paleocene (Sutadiwiria, 2019) based on the biostratigraphic analysis that has been obtained. In this time period, it is interpreted that the opening of the asymmetrical shape of the Makassar Strait in the form of a half graben resulted in the deposition of Tertiary age sediments which were deposited unconformably on top of the Balangbaru Formation or on bedrock in the South Makassar Basin. The occurrence of this rifting is interpreted to have occurred from no younger than the Early Paleocene to the Middle Oligocene, which is the Late Eocene age where the rifting process stopped and thermal subsidence or a decrease in deposition temperature occurred in the Early Oligocene (Nur'Aini et al., 2005). As a result of the tectonic period, this formation after geochemical analysis was carried out in the form of total organic carbon (TOC) analysis, which to determine the quantity showed a percentage with an average of 0.77% - 6.11% (fair - excellent) according to the classification of Peters and Cassa (1997). Meanwhile, to determine the type of kerogen, a cross plot was carried out between the HI and Tmax values (modificated from Hunt, 1997) which were obtained through Rock Eval-Pyrolysis (**Fig. 4**) to produce Type III kerogen (tends to gas). To determine maturity, analysis is carried out using the %Ro value produced through Rock Eval-Pyrolysis where in this formation after carrying out this analysis a value is obtained with an average of 0.31% – 0.38% (immature) according to the classification of Dow (1977) Senftle and Landis (1991).), et al.

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