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Erosion and its Implication on Hydrocarbon Generation in 'ARD' Block, Akimeugah Basin, West Papua

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ABSTRACT. Akimeugah Basin in the western part of Aru Trough is included as a Paleozoic Basin which is one of the potential hydrocarbon-producing basins in Eastern Indonesia. Tectonic evolution in Akimeugah Basin during Cambrian to present has produced a very significant erosion that affected the hydrocarbon generation process. 'ARD' Block study uses three exploratory well data including well report and 26 lines of 2D seismic data with a total length of 5,812.55 kilometers and the distance between seismic lines ranging from 10 to 15 kilometers. Seismic data is processed with IHS Kingdom software for tectonostratigraphy analysis, while calculation and erosion analysis are performed by combining well data consisting of sonic, vitrinite reflectance and seismic. To get a burial history model and generation & expulsion period, this study utilizes Petromod software.

Five phases of the tectonic evolution led to four times of erosional period with a sediment thickness of 290 – 3,370 feet were loss. The erosion of the sedimentary rocks causes the maturation process delayed more than 200 million years. Burial history in the study area with the erosion absence assumption results a hydrocarbon generation starting from around 210 million years ago. Meanwhile, by considering the loss of eroded sedimentary rocks during four tectonic phases, hydrocarbon generation time just occurred 3.1 million years ago.

Keywords: Western part of Akimeugah basin · Erosion · Tectonostratigraphy · Hydrocarbon generation.

1 INTRODUCTION

The ARD block is located in the offshore of the northwestern part of Arafura Sea (Figure 1). Geologically, this research block is bounded by Merauke Ridge in the south, Aru Trough in the west, Papua Central Fold Belt-northern Akimeugah Basin in the north and Arafura Exposure in the east. The findings of minor oil show on wells around the ARD Block (Aldha, 2008), show that the petroleum system is well-established.

Erosional process can affect the critical period of hydrocarbon generation due to temperature change caused by addition or reduction of sediment loading. Erosions occurring in the Akimeugah Basin are closely related to five tectonic events in the research area since the Cambrian rifting to present (Harahap, 2012). Miharwatiman (2013) stated that there is a tectonic period that causes an uplifting and erosion up to 15,000 feet in the Aru (Arafura Exposure) structure.

In this study, erosion thickness analysis is carried out based on information of erosional events obtained from tectonostratigraphy studies. The thickness value is used to make basin modeling for predicting the hydrocarbon generation and expulsion period.

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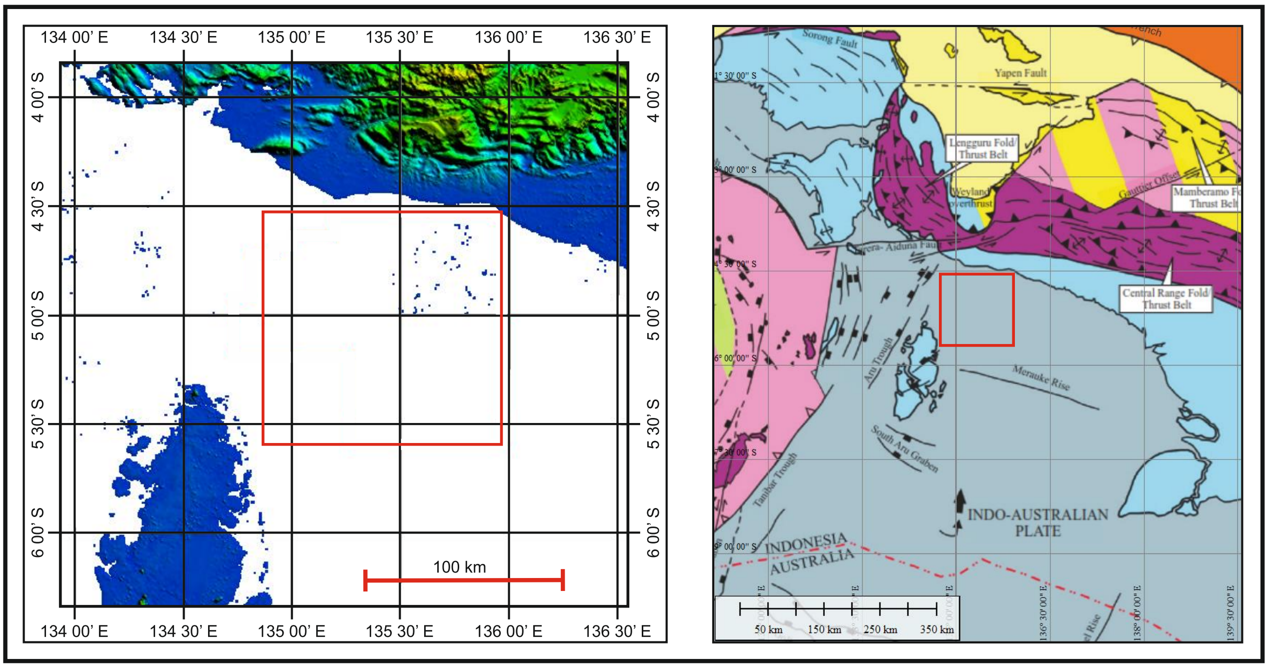

Figure 1: Study location of Akimeugah Basin, West Papua (basemap taken from DEM ASTER data and Harahap (2012)).

2 Regional Geology and Petroleum System

2.1 Tectonics

There are five regional tectonic phases occurring in southern Papua and Arafura sea (Harahap, 2012), including pre-rift/syn-rift, continental transform, uplifting, syn-genetic convergence and compression phases. Before syn-rift phase occurred, the study area and surrounding was dominated by basement rocks including Pre-Cambrian sediments and gabbro metamorphized with varying degrees of metamorphism with several minor unconformities (Miharwatiman, 2013). The syn-rift phase occurred in Permian – Triassic formed a graben or half-graben continuously filled by the deposition of sandstones and shales from the fluvio-deltaic environment, then turning into a passive margin phase during the Jurassic–Cretaceous.

The next phase is continental transform (transform fault zone) known as Fitzroy movement which initiates folding, seafloor deepening, uplifting and erosion during Cretaceous which caused an uplifting and erosion of Aru structure up to 15,000 feet (Miharwatiman, 2013). In accordance with the previous research, the end of Triassic – Early Jurassic, a large-scale uplifting and erosion also occurred (Gleadow & Duddy, 1982; Gleadow *et al.*, 1983 in McLennan *et al.*, 1990) and the environment turned into estuarine – shallow sea and coast to exposure (Harahap, 2012). During the Late Jurassic, the basin rifted and triggered a marine transgression followed by regional deposition of sandstones, shales and some carbonate rocks. The sedimentation was terminated in Eocene due to the initiation of the northeast-southwest-trending compression force. Subsequently, a syngenetic convergence phase occurs in the Oligo-Miocene causing the formation of shear fractures such as Sorong and Tarera-Aiduna shear fractures (Harahap, 2012). The final phase is the compression phase of the Mio-Pliocene (Figure 2), caused by the development of the foreland basin.

2.2 Stratigraphy

Sedimentary rocks in research study reaches thickness up to 10,000 feet comprising siliciclastic rocks and carbonates which can be grouped into 11 formations. The detail stratigraphy of Akimeugah Basin can be seen in Figure 2.

Basement rocks in Akimeugah Basin are metamorphic rocks of Kemum Formation and dolomites of Modio Formation (Harahap, 2012). These formations were interpreted to be deposited in Silurian – Mid Devonian (Patra Nusa

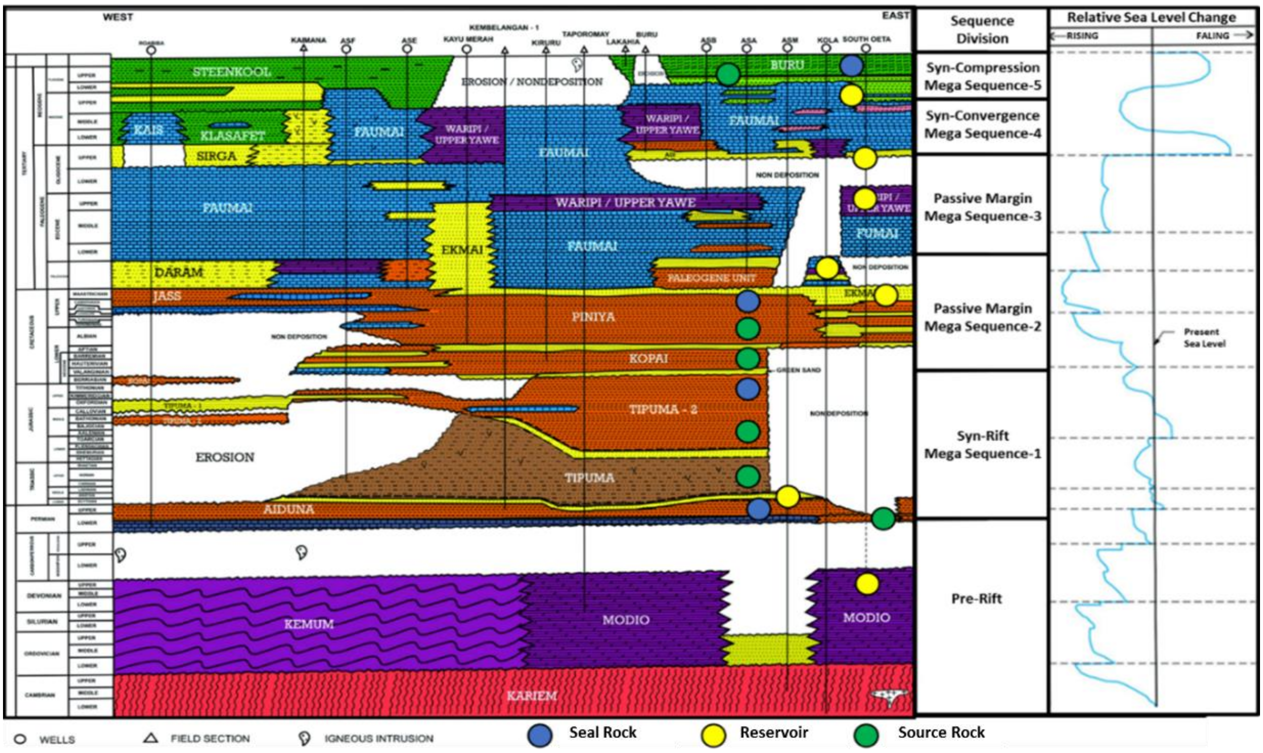

Figure 2: Tectonostratigraphy and Elements of Petroleum Systems (Harahap, 2012 with modification).

Data, 2006). These basement rocks are unconformably overlain by the Permian-Pleistocene sedimentary successions consisting of shale, sandstone, carbonates, and volcanic rocks in several parts. Generally, formations in Akimeugah Basin can be described as follows:

The oldest rocks in the study area which were deposited above the basement comprise coarse sandstones intercalated with shale and clay, sometimes there is an insertion of coal (Patra Nusa Data, 2006) which are grouped as the Permian Aiduna Formation. Contemporaneously, Triassic-Jurassic Tipuma Formation was deposited comprising volcanic sandstones, tuffaceous sandstones and fluvio-terrestrial deposits. The above succession is the Late Jurassic to Late Cretaceous Kembelangan Group consisting of Kopai, Woniwogi, Piniya and Ekmai which are deposited in coastal area to shelf. Kopai Formation is composed by glauconite sandstones with the intercalation of siltstone and mudstone, conglomerates, calcarenites and calcilutite, Woniwogi Formation is composed by quartz sandstone intercalated with mudstone, Piniya Formation is composed by mudstone, sandstone and siltstone, and Ekmai Formation is composed by massive and thick sandstones (Patra Nusa Data, 2006).

The deposition continued with the Neogene sediments of New Guinea Limestone Group (NGL) and Buru Formation. The NGL Group consists of the Faumai, Waripi and Yawee Formation that are composed of calcarenite, biocalcarenite, limestone, sandstone and siltstone with marl deposited on a shallow shelf. The youngest succession is the Buru Formation deposited in shallow marine environments, composed by mudstone, sandstone and limestone (Patra Nusa Data, 2006).

2.3 Petroleum systems

a) Source rock

Potential source rocks within this study area are shale and the thin layer of coal in Aiduna Formation, Middle Triassic mudrock (Mapenduma Formation), shale on Kopai Formation & Piniya Formation, and thin layer of coal and layers rich in organic material of the Formation Akimeugah and Formation Buru (Kendrick & Hill, 2001). The Cretaceous source rock are generally prone gas/type III whereas in Jurassic age it contains the source rock having kerogen type II / III, therefore it can be a source of oil or gas (Powell & Boreham, 1991 and Scott, 1992 in Kaufman, Phelps, & Kveton, 1997). Meanwhile, Buru Formation has the potential to be a source rock with a total organic carbon content (TOC) ranging between 1 - 3 wt.% and hydrocarbon index (HI) ranging from 200 to 300. Lower Buru Formation is generally the best gas producer containing kerogen type III (KNOC, 2006 in Aldha & Ho, 2008).

b) Reservoir rock

Reservoir rocks in the study area consist of sandstones of Aiduna Formation, Tipuma Formation and Kembelangan Group (Woniwogi and Ekmai Formations) (Foresmant *et al.*, 1975; Panggabean, 1983; and Dow *et al.*, 1985 in Panggabean & Hakim, 1986). In addition, the Dolomitic Limestone of the Modio Formation and the limestone of the Nuginea Limestone Formation also have the potential to become reservoir rock (Patra Nusa Data, 2006).

*c) Cap rock*set al.

Regional cap rock comes from Piniya Formation shale which has a thickness of about 500 meters, shales of Kopai and Buru Formations that also have sufficient thickness (Patra Nusa Data, 2006). Shales within Kembelangan Group and the carbonate rocks in the Modio Formation can act as intraformational cap rocks.

d) Trap

Petroleum traps are mainly structural traps (anticlines, drag fault, faulted anticlines and tilted blocks), stratigraphic traps (reef buildups, angular unconformity and pinchout) and a combination of both (Peck & Soulhol, 1986; Patra Nusa Data, 2006).

e) Migration

The migration occurred towards the trap during Pliocene. Fluid migration can be either primary migration or derived from older traps (Kaufman *et al.*, 1997) through the fault system. Lateral migration occurs in the normal direction following the slope of the layer (up dip) through the carrier beds.

3 EROSION ANALYSES

3.1 Data Parameters

Well data

This research utilizes three well data around the research location including AAA-1, BBB-1 and CCC-1 wells. These wells have a total depth of 12,000 feet to 14,500 feet penetrating to the Pre-Modio interval (AAA-1 Well), the Modio Formation (BBB-1 Well) and the Woniwogi interval (CCC-1 Well).

Seismic data

There are 26 lines of 2D seismic data with a total length of 5812.55 km and has a grid density between 10 – 15 km. The direction of these seismic lines is northeast-southwest and northwest-southeast (Figure 3). Seismic data has been calibrated and corrected, including navigation, amplitude balancing and mistie corrections. Well seismic tie (WST) is carried out on wells that are bypassed or adjacent to seismic data. The correction value shows the average value of $r^2 = 0.7$, and the correlation coefficient value in the well seismic tie is above 0.5 indicating that the data is ready for interpretation.

Geochemical data

The available data from wells is plotted on the maximum temperature diagram and hydrogen index to get the kerogen type and the degree of maturity. The data plot shows that kerogen types are mainly type III with a degree of immature – mature maturity. According to Varianto (2018), the potential source rocks in the study area are the Piniya, Kopai and Aiduna Formations.

Boundary condition

Boundary conditions include heat flow, surface water initial temperature (SWIT) and paleobathymetry. According to heat flow map of Hall & Smyth (2008), the current heat flow value in the area is 62 MW/m^2. The heat flow during the deposition is obtained from a matching simulation with Ro data. SWIT is determined by a function that has been made by Wygrala (1989) with locations using Australia at the southern latitudes of 5°. The determination of paleobathymetry was based on paleontological data on all three wells in the study area. Meanwhile,

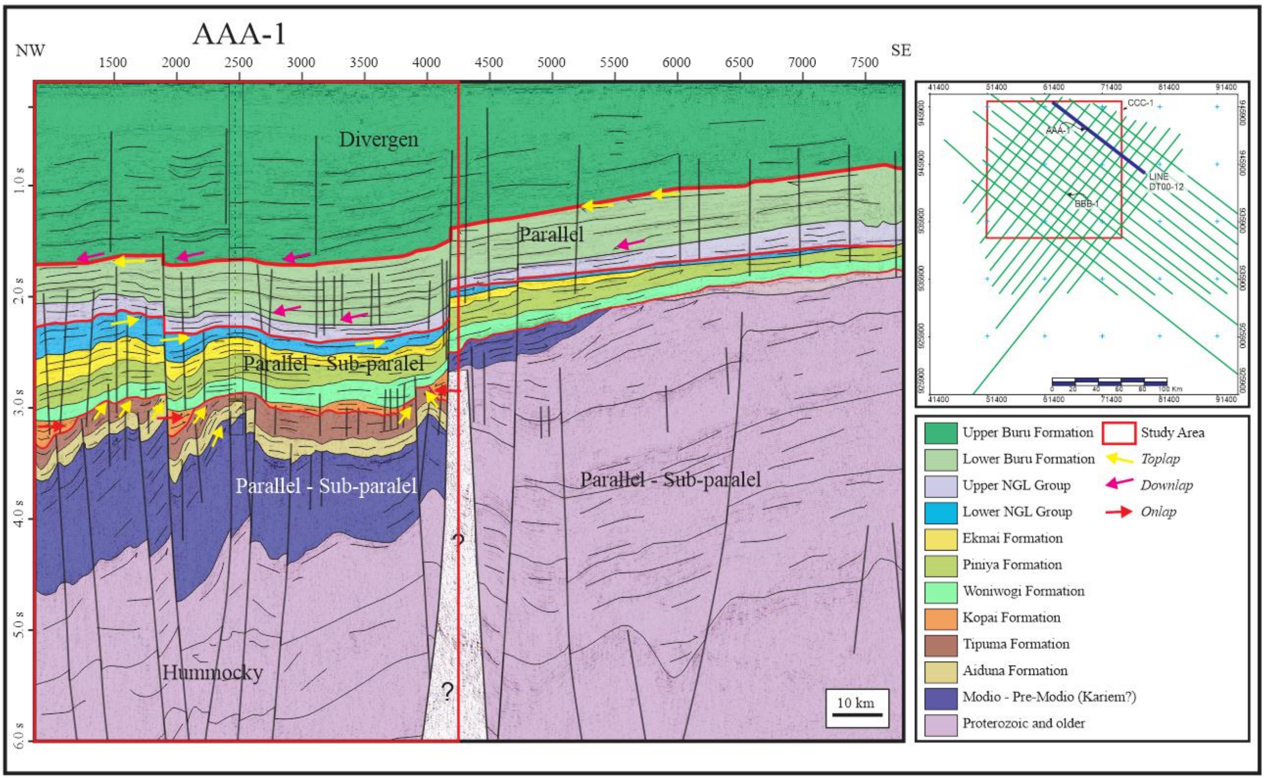

Figure 3: Results of seismic stratigraphic analysis on the DT00-12 trajectory, the analysis was performed from the Upper and older Proterozoic intervals to date; The ppearance of reflection termination and reflection configuration can be observed in the Figure above.

the kinetic model used for the 1D modeling is based on Pepper & Corvi (1995).

The heat flow scenario is adjusted by the tectonostratigraphic analysis that occurs at the study site. In the proposed scenario, there are at least three increases heat flow after the Ordovician. The first and second increases are caused by the rifting of the Silurian-Devonian and Permian-Triassic, while the last increase is caused by a collision between southern Papua and the northern Pacific plate.

3.2 Tectonostratigraphy

The tectonostratigraphy in the study are inferred based on the integration of well, seismic, regional geological data. The purpose of this analysis is to determine the occurrence of erosion within the study area. Figure 3 shows subsurface interpretation on the basis of seismic stratigraphy analysis within study area.

Pre-rift / Syn-rift

The first rifting period occurred at the Cambrian-Ordovician times marked by the rifting of the southwest-northeastern directions (Harahap, 2012). In the study area, this phase was characterized by the formation of full and half graben deposit followed by deposition of Pre-Modio (Karim?) and Modio Formations as products of transitional sediments and shallow-deep seas. This first phase was terminated due to a collision between the northern boundary of the Papuan micro-continent and paleo-Tethys at the age of Devonian, resulting erosion or a non-deposition phase. This unconformity interpreted by toplap on the boundary of Formation Modio and Aiduna Formation above it (Figure 3).

Syn-rift I - Inverse I

The second rifting period occurred at the Permian - Triassic times marked by intra-cratonic rifting trails northwest-southeast (Harahap, 2012). The rifting continues as a result of magmatic activity in the eastern part of the Papua continental micro (around the Tasman line), while study area was exposed due to its location in the Tibble arc behind areas. The second rifting terminated due to regional compression in the Late Triassic - Middle Jurassic interpreted in connection with the Fitzroy Movement (Borel *et al.*, 2002). The compression caused pop-up and erosion structures indicated by the toplap on the boundary between the Tipuma and the Kopai (Jurassic) and Woniwogi Formations (Cretaceous).

Syn-rift II - Passive margin

The third period is marked by the global sea level rise (transgression) where Kopai Formation was deposited during this period and filled up the rifts between the pop-up structure followed by sedimentation of Woniwogi, Piniya and Ekmai Formations and Lower NGL Group. Subduction between micro-continents in southern Papua and Pacific micro-continents in the north and relative sea level fall cause erosion or non-depositional phases (Harahap, 2012) characterized by a toplap on the boundary between the Lower NGL Group and the Upper NGL Group.

Syn-convergence

The fourth period begins with a relative sea level rise forming shallow sea to deep sea depositional environment. As a result, there were development of limestones from Upper NGL Group and deep-sea depositional product of Lower Buru Formation. The end of this period is marked by unconformity due to the collision between the southern continent with the Pacific microcontinent (Harahap, 2012) shown by the presence of toplap between the Lower Buru Formation and the Upper Buru Formation.

Syn-collision

The fifth period is the formation of foredeep basin due to collisions continued by the rapid deposition of Upper Buru Formation composing marine shale which has a divergent configuration. This period marked the ending of the basin development in the study area.

3.3 Calculation of Erosion Thickness

Based on seismic

The thickness of erosion is calculated by reconstructing seismic line that passes through the available wells in the study area and considering the continuity of the eroded section. The thickness unit needs to be converted from time (millisecond) to depth unit (feet) using velocity interval of each formation. The reconstruction of erosion thickness in AAA-1 and BBB-1 adjacent to seismic trajectories is shown by Figure 4 (Tipuma & Aiduna Formations) and Figure 5 (Lower NGL Formation). Calculation result for erosion thickness in both wells ranging between 465 up to 3,537.2 feet. For more detail result, see Table 1.

Based on sonic

Erosion thickness from sonic data is calculated based on trend shifting of sonic wave transit time. Sonic trend is calculated from shale with vshale number of 0.6 to get a consistent result. Based on the sonic shifting trend, the erosion thickness is between 272 feet up to 1344 feet. Overpressure predicted zone (green shadow) is not considered as sonic trend shifting. Figure 6 shows sonic velocity trend in AAA-1 well, while Table 2 provides the calculation.

Based on vitrinite reflectance

Due to data availability, the erosion thickness obtained from the vitrinite reflection data can only be performed on the AAA-1 well. The value of used vitrinite reflectance is the minimum, maximum and its measurement value. The NGL interval cannot be calculated because the interval is dominated by limestone. Similar to the sonic data, erosion thickness calculation uses vitrinite reflectance and also considers the vitrinite reflectance trend shifting to depth. By using this method, the average erosion thickness in several horizons ranges 256-932 feet (Figure 7).

4 Burial History and Hydrocarbon Generation

4.1 Burial history

To know the effect of erosion to the generation and expulsion time of oil and gas, it needs to make the burial history and thermal modeling. Modeling utilizes AAA-1 well data due to its complete data and reaches significant depth of Modio Formation. By using petromod software supported by tectonostratigraphy analysis, the erosional periods in the study area can be recognized (Figure 8) i.e. inversion I (Devonian-Carboniferous) which eroded Modio Formation, inversion II (Triassic-Jurassic) which eroded Modio, Aiduna, Tipuma

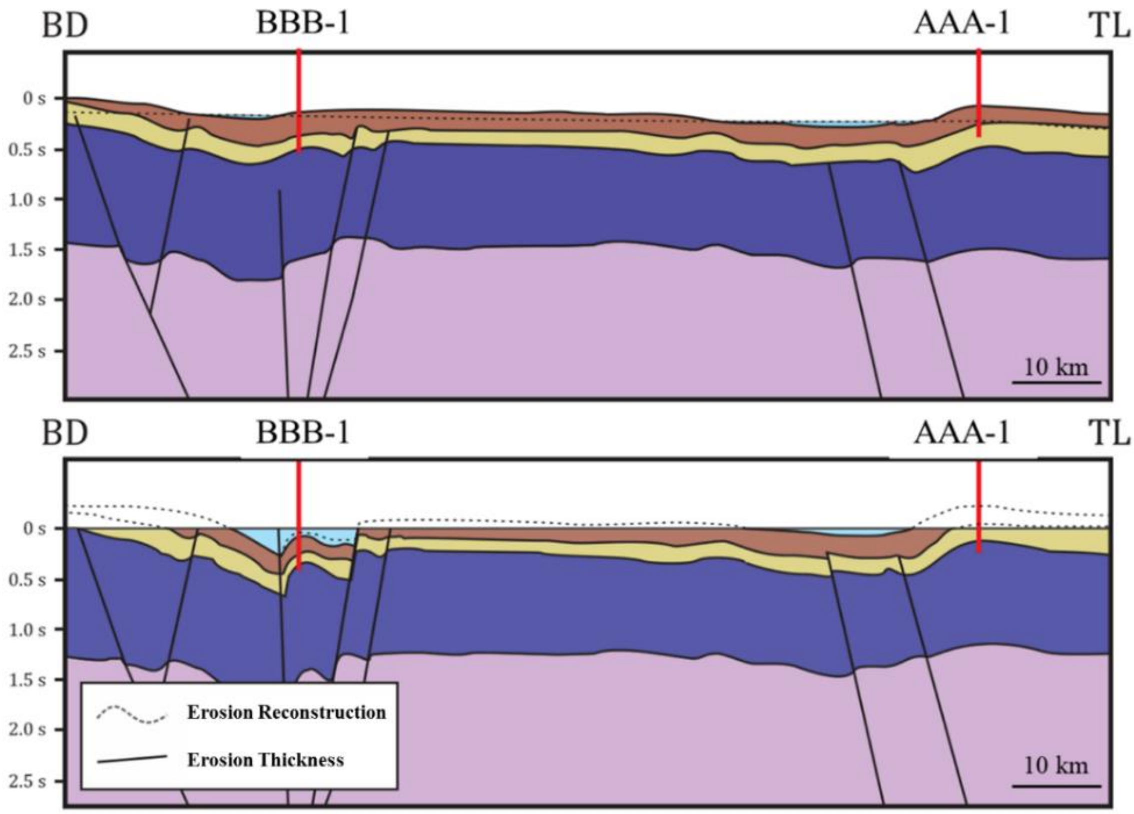

Figure 4: Reconstruction of erosion of the Tipuma and Aiduna Formation on the combined section 1, including the wells AAA-1 and BBB-1. The above figure is the condition prior to erosion. Meanwhile, figure below is after-erosion condition, the dashed black line in Figure below is the layer estimate before erosion.

Table 1: The results erosion calculation on AAA-1 & BBB-1 in depth based on seismic data.

AAA-1	Feet	
Erosion	Well	Thickened
Buru Unconformity	806.3	1099.5
NGL Group Unconformity	3377.6	3537.2
Tipuma Unconformity	1406.9	1481
Modio Unconformity	1362.4	1610.1

BBB-1	Feet	
Erosion	Well	Thickened
Buru Unconformity	568.8	850.7
NGL Group Unconformity	424.3	465
Tipuma Unconformity	957.1	2947.6
Modio Unconformity	421.4	448.3

Table 2: The results of erosion calculation on AAA-1 & BBB-1 in depth (feet) based on sonic data.

AAA-1	Interval
Erosion	AAA-1
Buru Unconformity	272
NGL Group Unconformity	-
Tipuma Unconformity	1170
Modio Unconformity	1344

BBB-1	Interval
Erosion	BBB-1
Buru Unconformity	480
NGL Group Unconformity	246
Tipuma Unconformity	654
Modio Unconformity	944

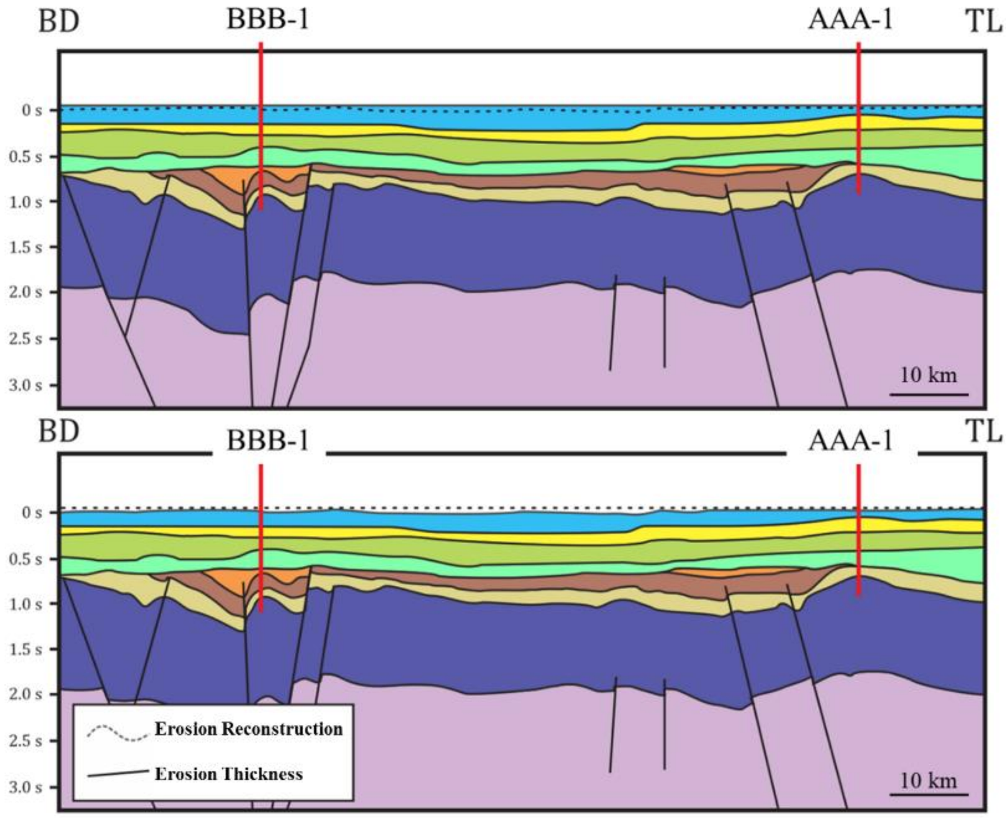

Figure 5: The reconstruction of the erosion of the Lower NGL Group on a combined track 1, including the wells of AAA-1 and BBB-1. The top figure is a condition before eroded. The bottom figure is the condition after erosion, the broken black line in the bottom Figure is the approximate layer before erosion.

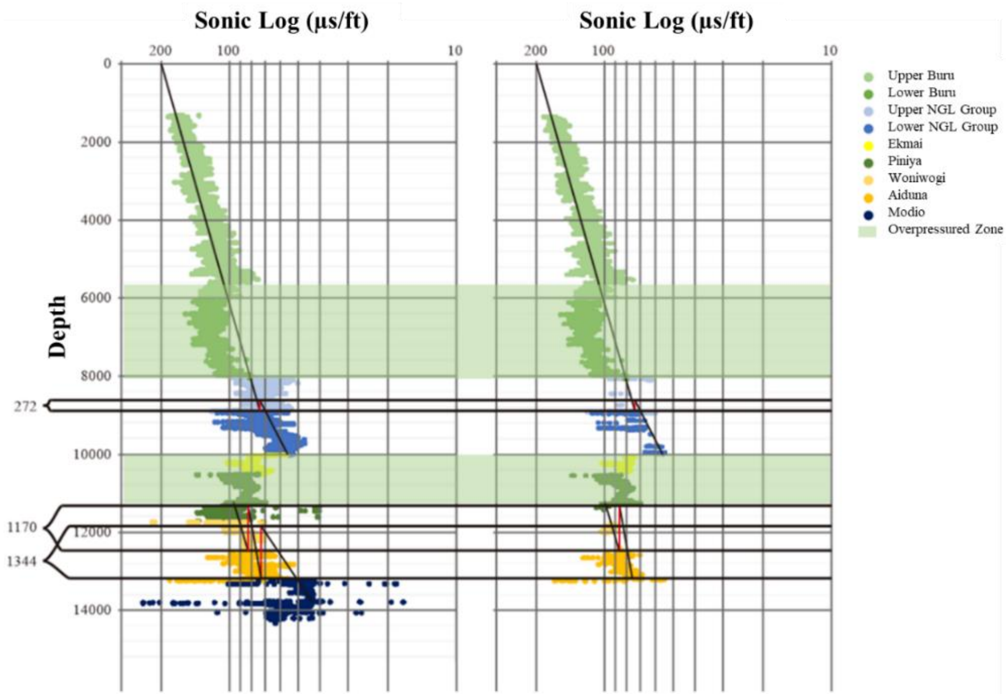

Figure 6: Erosion Analysis At AAA-1 Well, based on sonic data; the right sonic log column has been corrected for data recorded at shale content 0.6.

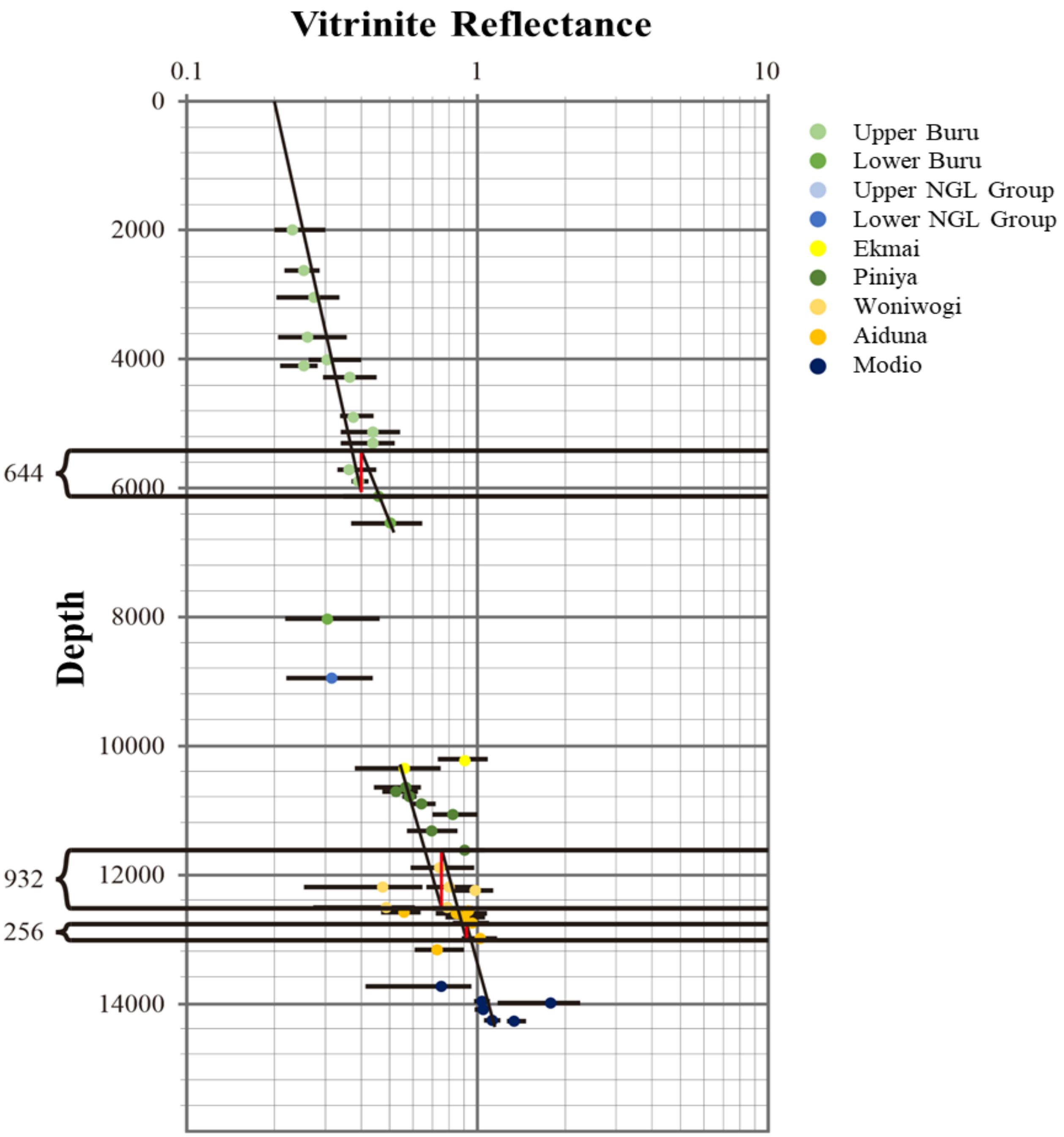

Figure 7: Erosion Analysis At AAA-1 Well based on vitrinite reflectance data.

Formations, and syn-convergence (Miocene) which eroded NGL Group.

Significant deepening of the basin occurred after the syn-convergence period due to collisions between Southern Papua with the Pacific microcontinent forming a foredeep basin in the study area. This condition generates a rapid and thick sedimentation that significantly increases overburden pressure.

4.2 Thermal modeling

Thermal modeling also inputs the data of AAA-1 well including the erosion thickness calculation from seismic, sonic and vitrinite reflectance. Heat flow data is inputted based on scenarios according to tectonic events occurred in the study area and its surrounding (Hall & Smyth, 2008) that is 62 mW / m^2. By using this heat flow, the maximum temperature of AAA-1 well reaches 160°C at a depth of 14,267 feet. The variations of erosion thickness recorded in AAA-1 well will slightly affect the time of generation and expulsion.

The 1-dimensional (1-D) modeling performed on the AAA-1 well with the consideration to three models of erosion data shows that source rocks of Aiduna, Woniwogi and Piniya Formations have generated oil (0.6% Ro), while Aiduna Formation and Woniwogi intervals also generate gas (0.8% Ro) (Figure 9). This oil generation started from 3.1 mya (Aiduna Formation) to 1.79 mya (Piniya Formation), while gas generation started 1.02 mya (Aiduna Formation) and 0.37 mya (Woniwogi Formation). As for the expulsion within the Akimeugah Basin, the oil will expel at 130°C and 150°C for gas (Varianto, 2018). 1-D modeling conducted in the AAA-1 well indicates that Aiduna Formation, Woniwogi and Piniya have reached oil expulsion, while gas expulsion was only reached by Aiduna Formation (Figure 10). This oil expulsion was reached 1.37 mya (Aiduna Formation) until 0.59 mya (Piniya Formation), while gas expulsion started from 0.13 mya (Aiduna Formation). However, the potential source rock of Buru interval is still immature.

Based on the modeling using 3 types of erosion and thickness values, there are no significant differences. The time difference is only 0.01 mya to 0.1 mya for the generation time and the expulsion temperature. A complete summary of generation and expulsion times for AAA wells can be seen in Table 3.

The time difference between generation and non-significant expulsion is due to the less intense heat flow and the less overburden pressure. This event causes even erosion will not affect the generation time and its extraction because the temperature and pressure that cause generation or expulsion have not been achieved. In addition, when erosion occurs, the temperature that causes generation has not been reached, so that generation and expulsion time will be closely related to erosion that occurs in the age range of Cenozoic. By creating burial history and thermal model without considering the occurrence of erosion, Varianto (2018) stated that source rock maturation started 211 million years ago. There is no significant erosion in the Cenozoic which may cause the generation and expulsion to occur earlier. This has caused the presence of erosion with considerable value not being able to influence the generation time and its extraction.

5 Conclusion

Erosion within the study area occurred in three periods, generally controlled by compressional tectonics in Devonian-Carboniferous (inversion I), Triassic-Jurassic (inversion II) and Miocene (syn-convergence) with the estimation of total sediment loss of 1.832 – 6,951 feet. Result of erosion calculation using seismic data, vitrinite reflectance, and sonic exhibit a significant result, although the influence is not too significant for the calculation of generation and expulsion from the all tree data. The erosion value that occurs in the research area is as follows:

Unconformity	Erosion (feet)		
	Seismic	Vitrinite Reflectance	Sonic Log
NLG Group Unconformity	806.3	644	272
Tipuma Unconformity	3377.6	-	-
Aiduna Unconformity	1406.9	932	1170
Modio Unconformity	1362.4	256	1344

Erosion in the study area has a significant effect to the maturation process and hydrocarbon expulsion,

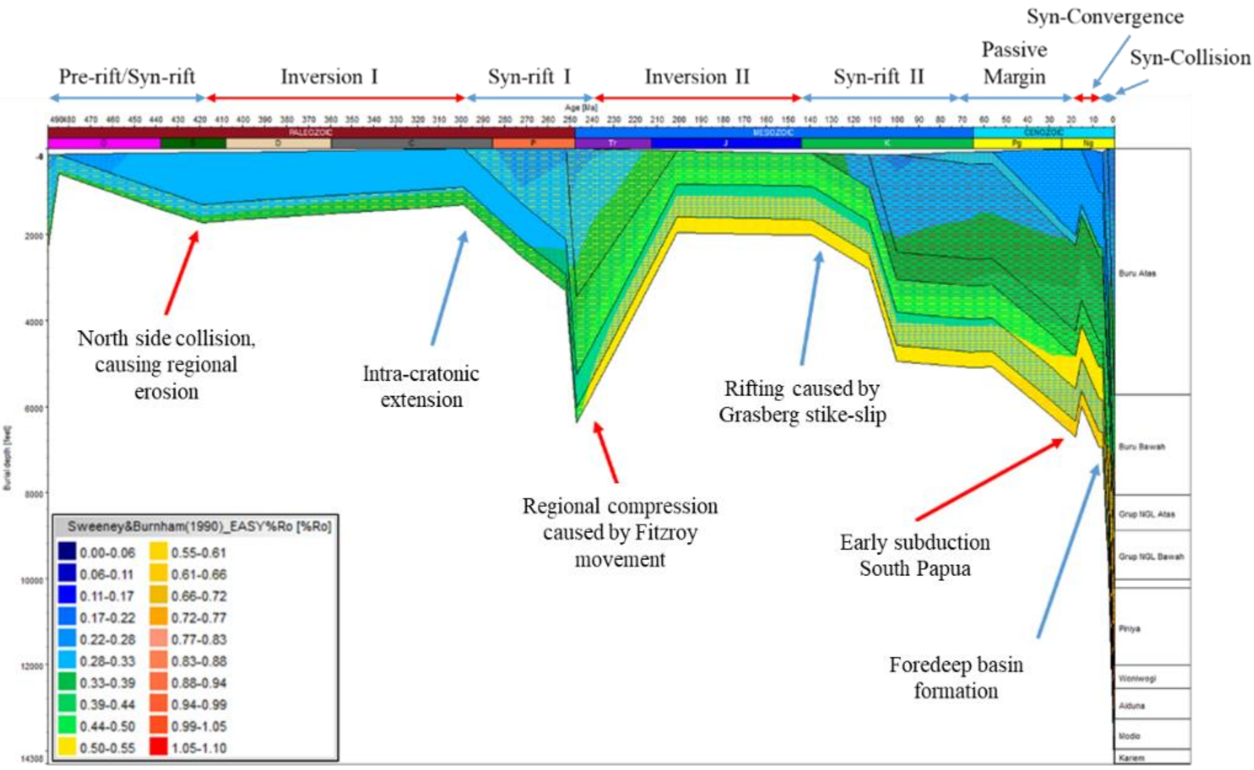

Figure 8: Burial history in AAA-1 wells. Modeling uses erosion values from seismic. Erosion occurred during the inversion I & II and syn convergence.

Table 3: Summary of generation and expulsion time for oil and gas at AAA-1 wells using erosion data from seismic, vitrinite reflectance and sonic.

Interval Formation	Early Oil Generation (0.6% Ro)	Early Gas Generation (0.8% Ro)	Oil Expulsion (T = 130 °C)	Gas Expulsion (T = 150 °C)	Erosion Remark
Buru	Not Reach	Not Reach	Not Reach	Not Reach	Seismic Data
Piniya	1.81 mya	Not Reach	0.59 mya	Not Reach	
Woniwogi	2.22 mya	0.4 mya	0.94 mya	Not Reach	
Aiduna	3.1 mya	1.02 mya	1.37 mya	0.13 mya	
Buru	Not Reach	Not Reach	Not Reach	Not Reach	Ro Data
Piniya	1.8 mya	Not Reach	0.6 mya	Not Reach	
Woniwogi	2.2 mya	0.38 mya	0.95 mya	Not Reach	
Aiduna	2.8 mya	1.00 mya	1.35 mya	0.12 mya	
Buru	Not Reach	Not Reach	Not Reach	Not Reach	Sonic Data
Piniya	1.79 mya	Not Reach	0.61 mya	Not Reach	
Woniwogi	2.18 mya	0.37 mya	0.96 mya	Not Reach	
Aiduna	2.79 mya	0.96 mya	1.36 mya	0.11 mya	

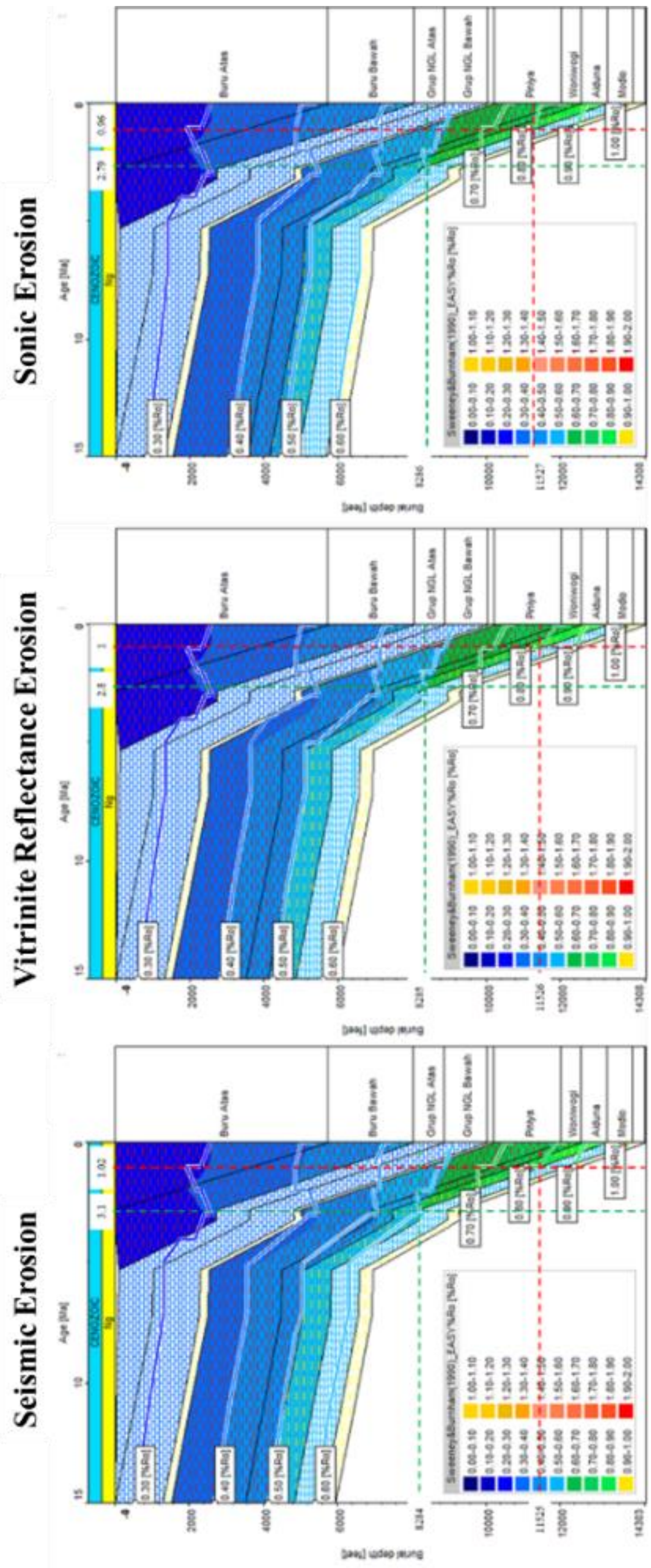

Figure 9: 1-D Modeling on AAA-1 wells to see differences in generation modeling results using different erosion values. Differences are seen in the early generations.

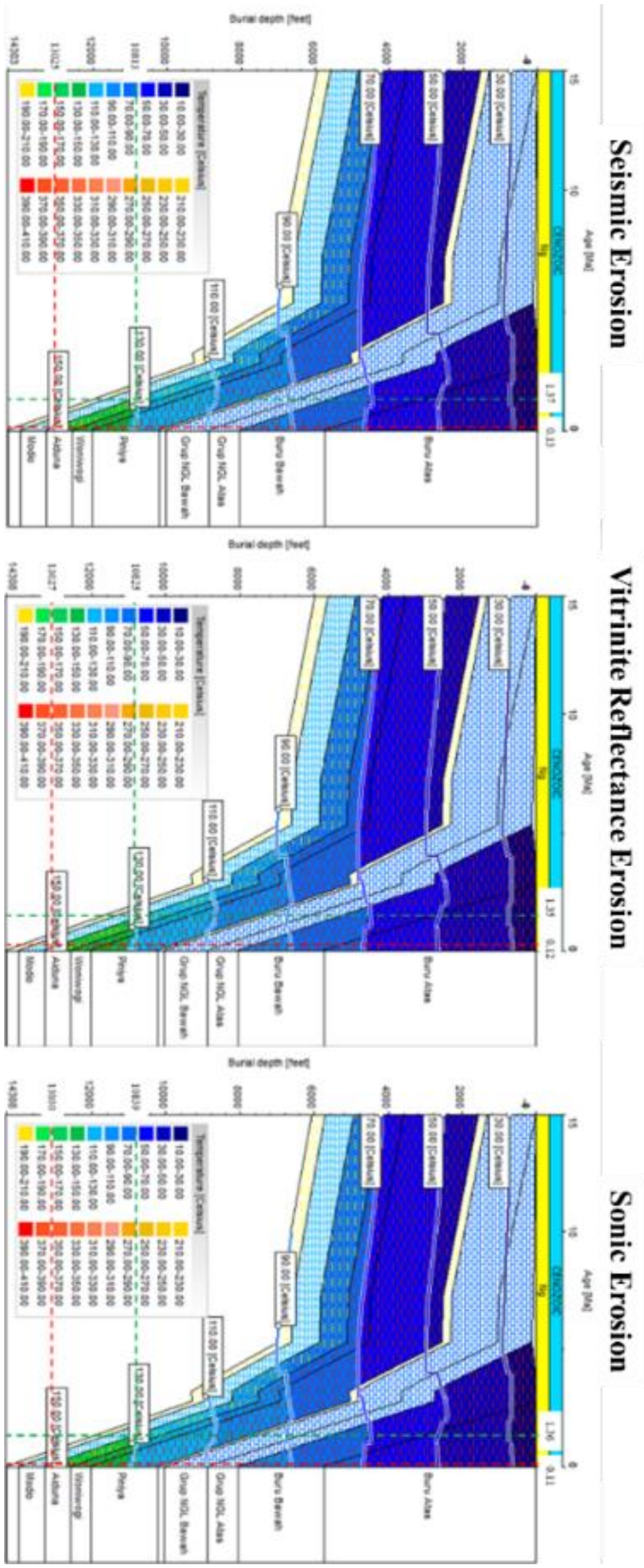

Figure 10: 1-D modeling on AAA-1 well to see differences in thermal modeling results using different erosion values.

where the time reached by both process declines of over 200 million years.

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