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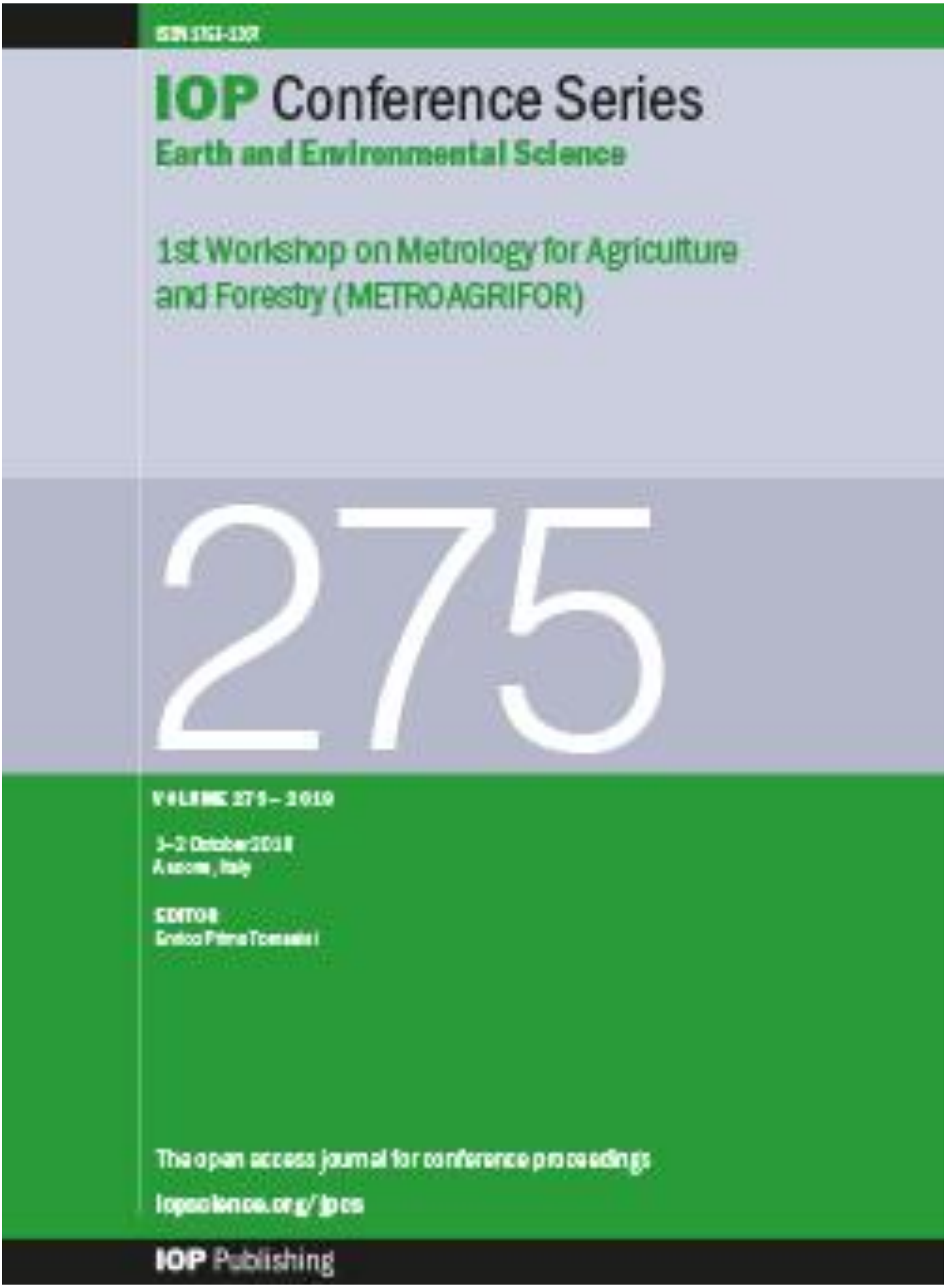

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IOP Conf. Series: Earth and Environmental Science 1104 (2022) 012045 doi:10.1088/1755-1315/1104/1/012045

Daftar Isi: https://iopscience.iop.org/issue/1755-1315/1104/1

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Published online: 23 November 2022

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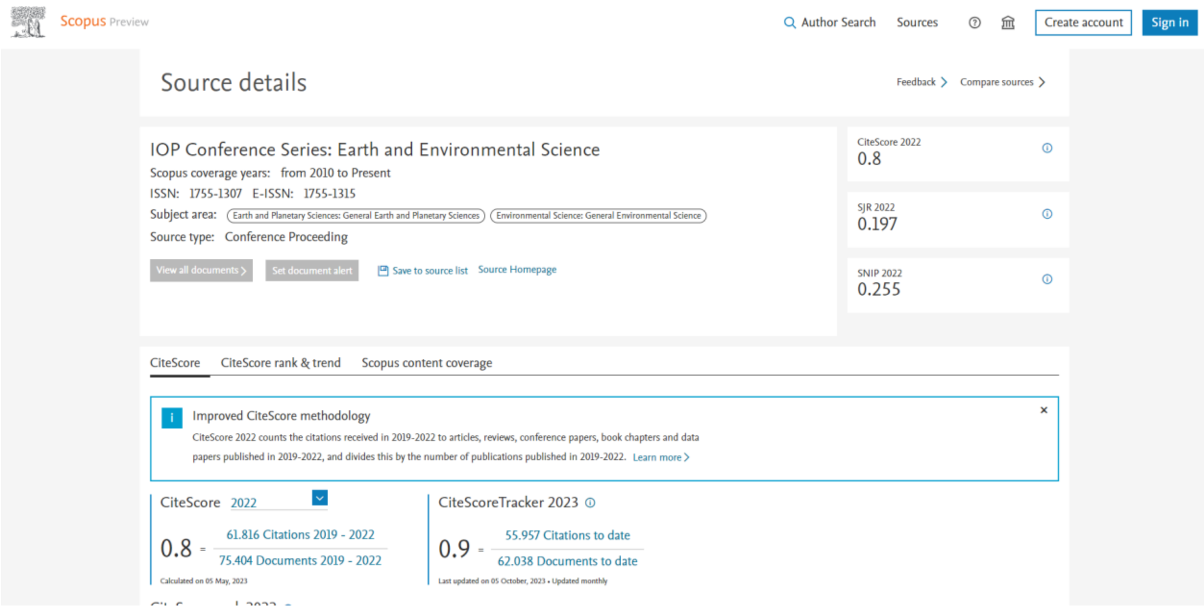
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Sequence Stratigraphy of Miocene Mixed Carbonate-Siliciclastic in Fold and Thrust Belt System, Banggai Basin

To cite this article: Firman Herdiansyah *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1104** 012045

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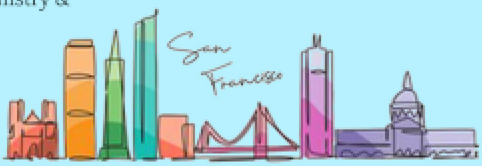

Sequence Stratigraphy of Miocene Mixed Carbonate-Siliciclastic in Fold and Thrust Belt System, Banggai Basin

Firman Herdiansyah[1*], M Burhannudinnur[1], Suryo Prakoso[2], Isranto HP[3], Dwi Kurnianto[3], Teddy Irano[4], Billy Harnest[4]

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Abstract. This study was specifically analyzed in the southern part of the Banggai Basin, precisely in the TKA Field. In the Tertiary, regional stratigraphy reveals, the Banggai Sula microplate comprises carbonate shelf and siliciclastic sequence. Several previous studies had been concluding, the tertiary limestone was deposited during the Early Eocene to Middle Miocene. Carbonate formations which has been known by Tomori and Minahaki Formation. Meanwhile, their siliciclastic dominated is Matindok Formation and Celebes Mollase. These sequences formed a distinct stratigraphic style in the geophysical well log and seismic data. Four cycles are distinguished, the lower part of Tomori Formation at the outer shelf and directly overlying by the upper part of inner shelf Tomori Formation. it was superimposed by siliciclastic sediments that have been deposited in the outer litoral during regressive phase. Whereas during rising sea level or highstand, the litoral system migrated to basinward wherein Minahaki Formation was deposited. Sequence stratigraphy provides a reliable methodology for correlate both carbonate and siliciclastic successions. It was analyzed based on 4 wells, 2D, and 3D seismic data which has been available. Sequence stratigraphy analysis using T-R sequence concept by Embry and Johanessen. Trasngressive and regressive phases were obviously determined by lithofacies, coral colony and foram that were recorded on biostratigraphic analyses. In this study, cyclic sea-level change will be recognized as system tract record of mixed carbonate-siliciclastic sequence.

Keywords: Mixed carbonate-siliciclastic sediment; Banggai Basin; sequence stratigraphy; transgressive-regressive sequence

1. Introduction

The Banggai basin Is a Mio-Plio Foreland basin which is composed of micro-continent origin from Australia and drifted northward and collided with East Sulawesi ophiolites that occurred in the the latest Miocene (1, 2, 3). It is belongs to Eastern Arm of Sulawesi, one of the complexity of geological components and greatly affects sedimentary rock (4). Stratigraphy of the Eastern Arm of Sulawesi associated with several depositional periods. First, represent a series of continental edge translation before the collision. The second one is represent by flysch-molasse sediments sequence, it was deposited in front of thrust fault migration to the eastern after collision. Stratigraphically, the Banggai Sula Micro-continent consists of Pre-Tertiary to Pelistocene deposits (5, 6). The TKA stratigraphy column explain the Miocene sediments consists of Carbonate and siliciclastic (Figure 1). The most important factors that influence sedimentary depositional environments are: regional subsidence, differential tectonic movements, esutatic sea-level, ecological boundary conditions, base level, rainfall pattern, composition of the hinterland governing siliciclastic input, waves, and currents (7, 8). In Mixed carbonate-siliciclastic lithofacies, sequence development is assumed to be reciprocal sedimentation expressed by the alternation of carbonates platform during trangressive and highstand periods. Furthermore, basinal during lowstand periods of siliciclastic material. These stratigraphic models were relatively well documented of large scale carbonate systems that interacting with major sources of siliciclastic Input (9, 10, 11). Several sub-environments such as tidal, deltas, lagoons and reefal facies can coexist, and sediment accumulation, emersion, erosion, and sediment starvation can occur simultaneously. The siliciclastic input is related to shelf exposure and erosion. Meanwhile, the bioclastic carbonate marking of sealevel transgressions and highstands [12]. The mixed carbonate-siliciclastic sequence stratigraphy commonly has more complex reservoir and source rock characterization either lateral and vertical distribution [13]. The many controlling factors in the depositional system make it difficult to identify the boundary of sequence.

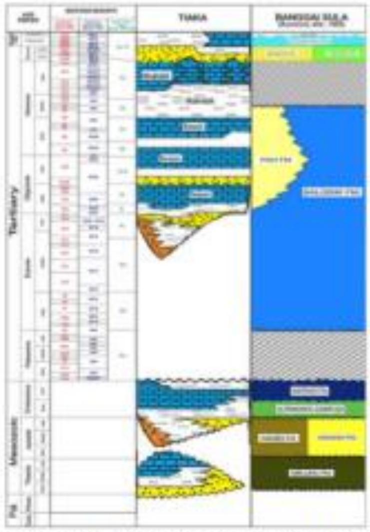

Figure 1. Stratigraphy of Banggai Sula and TKA Field [14]

Sequence stratigraphy analysis in the TKA field was analyzed using T-R sequence concept by Embry and Johanessen [15] and combined with genetic sequence stratigraphy by Galloway [16]. Galloway suggests using MFS (maximum flooding surface) as a genetic sequence boundary, wherein MFS alleviates the problem of subjectivity due to MFS was scientifically justified. However, MFS has a very wide spread and does not have genetic coherence at basin boundaries especially subaerial unconformity occurs. This problem was perfected by the fourth order defined by Embry and Johanessen. This method has been maintained sequence boundaries if subaerial unconformity occurs and also provide correlative conformity limits. The T-R sequence divides the transgressive system tract pattern at the bottom and the regressive system tract at the top with the boundary in between is MFS. The subaerial unconformity is the boundary for the change from sedimentation to subaerial erosion and MFS is the boundary of changes from transgression to regression which is used as the boundary of the sequence stratigraphic unit (Figure 2). The boundary of MFS was also adjusted to the number of individual planktonic foraminifera that recorded on biostratigraphic data.

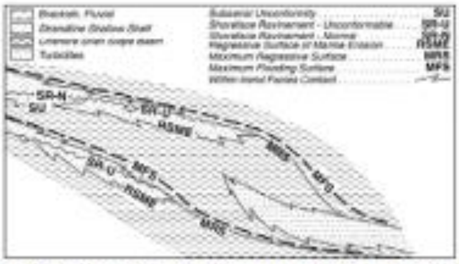

Figure 2. Scheme of sequence stratigraphy of T-R sequence [15]

2. Data and Method

The data was used for stratigraphic analysis in the TKA Field is geophysical well log correlation data, core, biostratigraphic data. TKA field composed 3 wells has micropaleontological data, based on those wells can be identified foraminiferal and calcareous nannoplankton zonation. The analysis is intended for interpretation of the lithofacies, sequence stratigraphy, facies association and stratigraphic correlations. The sequence stratigraphy analysis was determined several sequence boundaries start from the 2nd order using the Trangressive-Regressive cycle. Furthermore, the identifying of system tract either 3rd and 4th order (Figure 3). The first sequence boundary is maximum flooding surface (MFS) characterized by high specimen abundance of planktonic foraminifera and calcareous nannoplankton. Meanwhile, sequence boundary (SB) characterized by reduce level of abundance specimen.

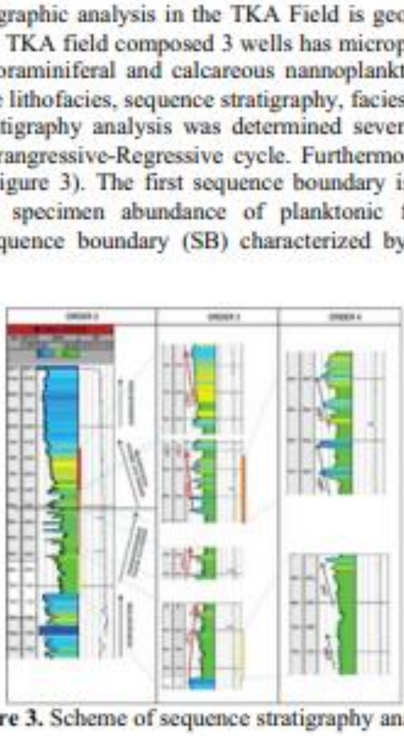

Figure 3. Scheme of sequence stratigraphy analysis

3. Result and Discussion

Stratigraphic sequence analysis is carried out by interpreting in 2nd which is then followed by 3rd order (sequence) and 4th which is more detailed known as parasequence. The 2nd order was to identify well by well transgressive-regressive cycle using vertically lithofacies changes combined with the gamma-ray log. From this order, MFS was determined with the end of transgression. The parasequence boundary is flooding surface (FS) using coal bed parameter.

3.1 Well TKA-A

In the TKA-A, sequence stratigraphy analysis start from 2nd order that show aggradation phase, transgression phase, regression phase and back to the aggradation phase. From each phase are detailed into sequence stratigraphy 3rd order, which are then bounded to each parasequence (4th order). TKA-A show that the boundaries of sequence stratigraphy and parasequence, where SB (sequence boundary) are SB type 1 with correlative conformity and FS (flooding surface) with coal seam parameter. SB-1 is equivalent with Tomori Formation, SB-2 is equivalent to the Matindok Formation, and SB-3 is equivalent with the top Minahaki Formation.

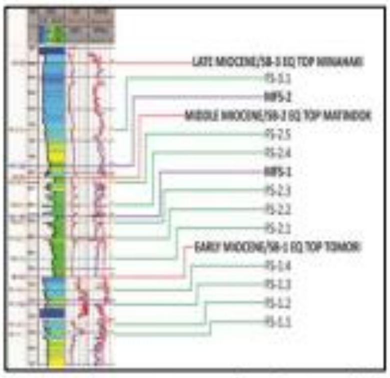

Figure 4. Scheme of sequence stratigraphy analysis of TKA-A

3.2 Well TKA-B

In the TKA-B, sequence stratigraphy analysis start from 2nd order that show aggradation phase, transgression phase, regression phase and back to the aggradation phase. Interval 560-2160' are interpreted Pleistocene-Late Pliocene and it is attributed to zone N15-N9 (Blow, 1970) But at depths below 2010 presence *Discoaster* sp which is attributed to zone NN18-NN16. At interval 7090-7840' show *Orbulina universa* which is explains these older from Middle Miocene. Nannoplankton zonation concluded this interval is attributed NN5 (Martini, 1970) based on presence *Sphenolithus heteromorphus* at 7090 ft. Based on high specimen abundance at depth 6750'and concluded as maximum flooding surface. The sequence boundary was identified at depth 7450', appropriate the thrust zone (Figure 5).

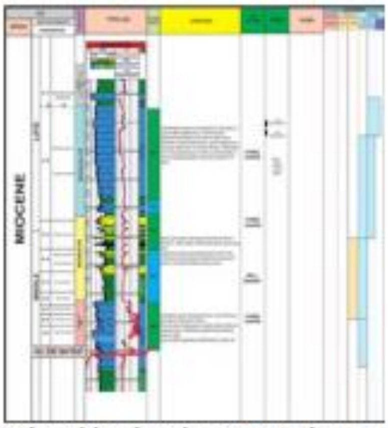

Figure 5. Type log, depositional environment, and system tract well TKA-B

3.3 Well TKA-Cst

In the TKA-B, MFS determination was clarified using abundance of planktonic foraminifers and calcareous nannoplankton. Stratigraphic sequence analysis is carried out by interpreting in 3rd (sequence) and followed by 4th which is more detailed known as parasequence (Figure 6).

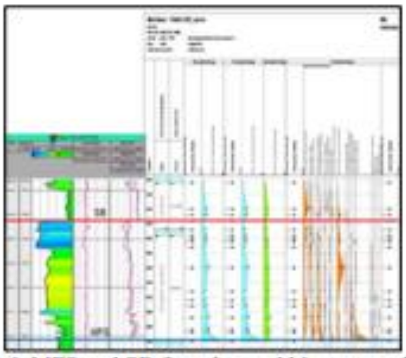

Figure 6. MFS and SB from log and biostratgraphy data

Based on structural correlation with northeast-southwestward, west-eastward, and northwest-southeastward that shows the direction of strike from thrust fault with north-south trend. The thinning layer occurs due to imbricate thrust fault that recorded at well TKA-B and Tiaka-C. Only well TKA-B and TKA-C which have log data that show repeat of sequence between hanging wall and foot wall. This is also supported by the disappearance of the top sequence (Celebes Mollase & Minahaki Formation) in the foot wall (Figure 7 and Figure 8).

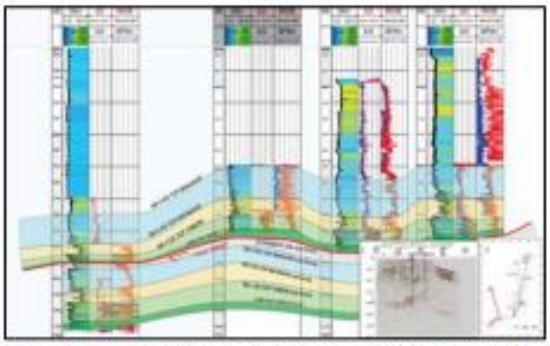

Figure 7. Structural correlation that shows several sequence boundaries in the over-thrust and sub-thrust

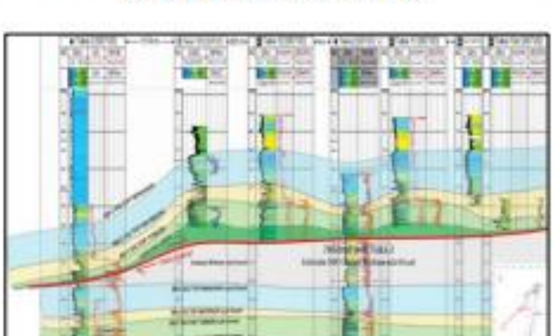

FIGURE 8. Another Structural correlation that shows several sequence boundaries in the over-thrust and sub-thrust

Based on parasequence correlation, the correlation of parasequence was conducted with the parasequence boundary is flooding surface (Figure 9 and Figure 10). Where flooding surface is the upper boundary of highstand system tract which shows the carbonate growth or sediment supply higher than increasing relative sea level.

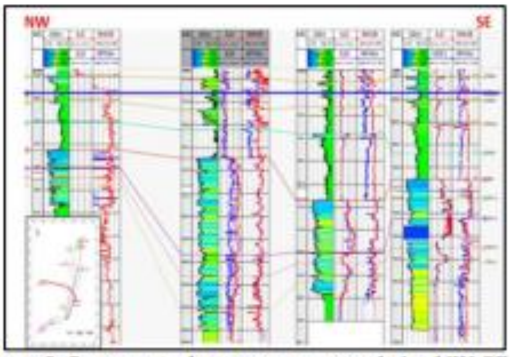

Figure 9. Sequence and parasequence correlation NW-SE

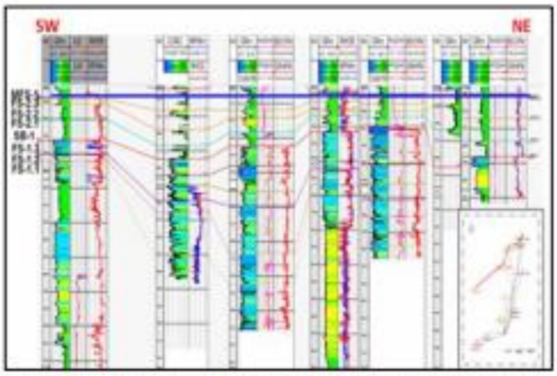

Figure 10. Sequence and parasequence correlation NW-SE

4. Conclusion

a. Sequence stratigraphy was analyze using geophysical well log correlation data, core, and biostratigraphic data. TKA field composed 5 wells has micropaleontological data, based on those wells can be identified foraminiferal and calcareous nannoplankton zonation. The maximum flooding surface (MFS) characterized by high specimen abundance of planktonic foraminifera and calcareous nannoplankton. Meanwhile, sequence boundary (SB) characterized by reduce level of abundance specimen.

b. The T-R cycle 2nd order reveale that regressive phase from Tomori limestone to Matindok clastic, and transgressive phase start from top Matindok clastic to the shallow shelf Minahaki Limestone, and back to regressive phase from top shallow shelf Minahaki Limestone to Celebes Mollase.

c. Based on structural correlation with northeast-southwestward, west-eastward, and northwest-southeastward that shows the direction of strike from thrust fault with north-south trend. The thinning layer occurs due to imbricate thrust fault that recorded at well TKA-B.

d. Parasequence boundary is FS (flooding surface). Where, flooding surface is the upper boundary of highstand system tract that shows the carbonate growth or sediment supply higher than increasing relative sea level.

Acknowledgments

The authors wish to thank JOB Pertamina-Medco-Tomori Sulawesi for contribute this research, and special thanks to Badan Afiliasi Teknologi Mineral Universitas (BATM) Universitas Trisakti to funded several laboratories.

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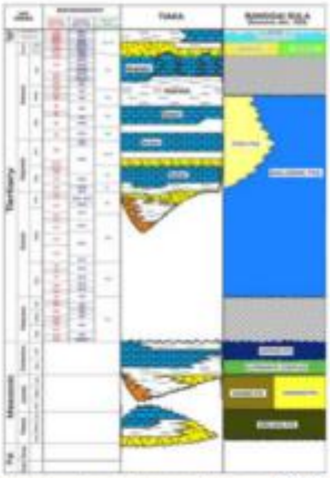

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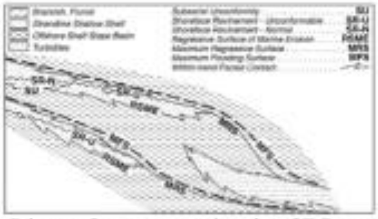

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The data was used for stratigraphic analysis in the TKA Field is geophysical well log correlation data, core, biostratigraphic data. TKA field composed 3 wells has micropaleontological data, based on those wells can be identified foraminiferal and calcareous nannoplankton zonation. The analysis is intended for interpretation of the lithofacies, sequence stratigraphy, facies association and stratigraphic correlations. The sequence stratigraphy analysis was determined several sequence boundaries start from the 2nd order using the Trangressive-Regressive cycle. Furthermore the identifying of system tract either 3rd and 4th order (Figure 3). The first sequence boundary is maximum flooding surface (MFS) characterized by high specimen abundance of planktonic foraminifera and calcareous nannoplankton. Meanwhile, sequence boundary (SB) characterized by reduce level of abundance specimen.

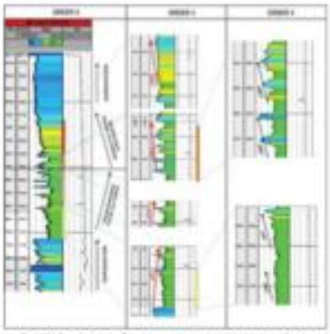

Figure 3. Scheme of sequence stratigraphy analysis

3. Result and Discussion

Stratigraphic sequence analysis is carried out by interpreting in 2nd which is then followed by 3rd order (sequence) and 4th which is more detailed known as parasequence. The 2nd order was to identify well by well transgressive-regressive cycle using vertically lithofacies changes combined with the gamma-ray log. From this order, MFS was determined with the end of transgression. The parasequence boundary is flooding surface (FS) using coal bed parameter.

3.1 Well TKA-A

In the TKA-A, sequence stratigraphy analysis start from 2nd order that show aggradation phase, transgression phase, regression phase and back to the aggradation phase. From each phase are detailed into sequence stratigraphy 3rd order, which are then bounded to each parasequence (4th order). TKA-A show that the boundaries of sequence stratigraphy and parasequence, where SB (sequence boundary) are SB type 1 with correlative conformity and FS (flooding surface) with coal seam parameter. SB-1 is

IOP Conf. Series: Earth and Environmental Science 1104 (2022) 012045 doi:10.1088/1755-1315/1104/1/012045

equivalent with Tomori Formation, SB-2 is equivalent to the Matindok Formation, and SB-3 is equivalent with the top Minahaki Formation.

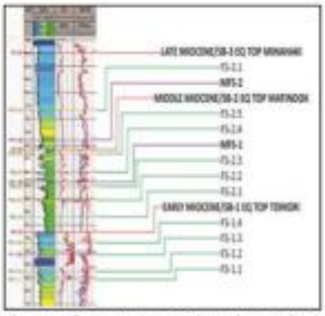

Figure 4. Scheme of sequence stratigraphy analysis of TKA-A

3.2 Well TKA-B

In the TKA-B, sequence stratigraphy analysis start from 2nd order that show aggradation phase, transgression phase, regression phase and back to the aggradation phase. Interval 560-2160' are interpreted Pleistocene-Late Pliocene and it is attributed to zone N15-N9 (Blow, 1970) But at depths below 2010 presence *Discoaster* sp which is attributed to zone NN18-NN16. At interval 7090-7840' show *Orbulina universa* which is explains these older from Middle Miocene. Nannoplankton zonation concluded this interval is attributed NN5 (Martini, 1970) based on presence *Sphenolithus heteromorphus* at 7090 ft. Based on high specimen abundance at depth 6750'and concluded as maximum flooding surface. The sequence boundary was identified at depth 7450', appropriate the thrust zone (Figure 5).

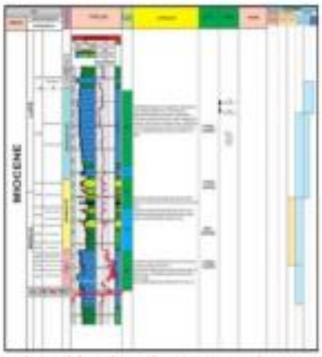

Figure 5. Type log, depositional environment, and system tract well TKA-B

3.3 Well TKA-Cst

In the TKA-B, MFS determination was clarified using abundance of planktonic foraminifers and calcareous nannoplankton. Stratigraphic sequence analysis is carried out by interpreting in 3rd (sequence) and followed by 4th which is more detailed known as parasequence (Figure 6).

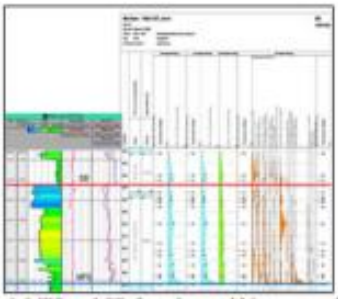

Figure 6. MFS and SB from log and biostratgraphy data

Based on structural correlation with northeast-southwestward, west-eastward, and northwest-southeastward that shows the direction of strike from thrust fault with north-south trend. The thinning layer occurs due to imbricate thrust fault that recorded at well TKA-B and Tiaka-C. Only well TKA-B and TKA-C which have log data that show repeat of sequence between hanging wall and foot wall. This is also supported by the disappearance of the top sequence (Celebes Mollase & Minahaki Formation) in the foot wall (Figure 7 and Figure 8).

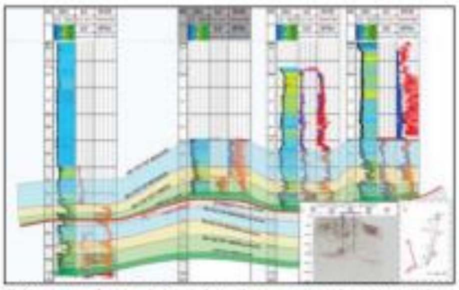

Figure 7. Structural correlation that shows several sequence boundaries in the over-thrust and sub-thrust

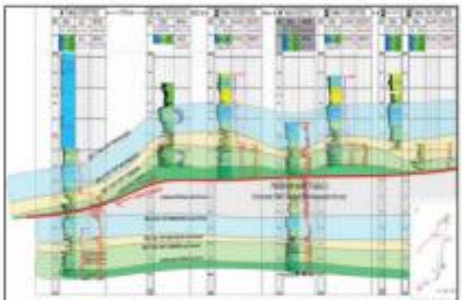

FIGURE 8. Another Structural correlation that shows several sequence boundaries in the over-thrust and sub-thrust

Based on parasequence correlation, the correlation of parasequence was conducted with the parasequence boundary is flooding surface (Figure 9 and Figure 10). Where flooding surface is the upper boundary of highstand system tract which shows the carbonate growth or sediment supply higher than increasing relative sea level.

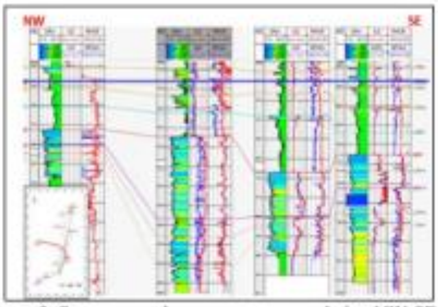

Figure 9. Sequence and parasequence correlation NW-SE

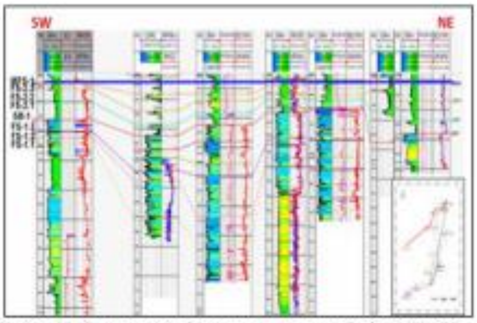

Figure 10. Sequence and parasequence correlation NW-SE

4. Conclusion

a. Sequence stratigraphy was analyze using geophysical well log correlation data, core, and biostratigraphic data. TKA field composed 5 wells has micropaleontological data, based on those wells can be identified foraminiferal and calcareous nannoplankton zonation. The maximum flooding surface (MFS) characterized by high specimen abundance of planktonic foraminifera and calcareous nannoplankton. Meanwhile, sequence boundary (SB) characterized by reduce level of abundance specimen.

b. The T-R cycle 2nd order reveale that regressive phase from Tomori limestone to Matindok clastic, and transgressive phase start from top Matindok clastic to the shallow shelf Minahaki Limestone, and back to regressive phase from top shallow shelf Minahaki Limestone to Celebes Mollase.

c. Based on structural correlation with northeast-southwestward, west-eastward, and northwest-southeastward that shows the direction of strike from thrust fault with north-south trend. The thinning layer occurs due to imbricate thrust fault that recorded at well TKA-B.

d. Parasequence boundary is FS (flooding surface). Where, flooding surface is the upper boundary of highstand system tract that shows the carbonate growth or sediment supply higher than increasing relative sea level.

Acknowledgments

The authors wish to thank JOB Pertamina-Medco-Tomori Sulawesi for contribute this research, and special thanks to Badan Afiliasi Teknologi Mineral Universitas (BATM) Universitas Trisakti to funded several laboratories.

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