Semiquantitative and Quantitative Biostratigraphy for Correlation and Depositional Environment Analysis

Case Study Kedinding Hill Area, Blora, Central Java

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***Abstract*—Biostratigraphy has a significant role in petroleum exploration, especially for correlation and depositional environment analysis. This research located in Kedinding Hill Area, Blora, Central Java, Indonesia. We uses semiquantitative graphic correlation method and quantitative constrained cluster analysis with data taken from measuring section of Kedinding River Track (Section-1) and Kalen River Track (Section-2). Both sections generate crossover in biostratigraphic event sequence that trouble the biozonation determination which resolved by Graphic Correlation Method and generate FAD *Neogloboquadrina humerosa* – LAD *Globorotalia merotumida* – LAD *Globigerina venezuelana* as regional biostratigraphic event sequence. Constrained Cluster Analysis method generate five cluster for depositional environment in both Section-1 and Section-2. Depositional environment of each cluster in Section-1 are: Cluster 1 (unpredictable), Cluster 2 (deep middle – outer shelf), Cluster 3 (outer shelf), Cluster 4 (outer shelf), Cluster 5 (outer shelf – upper slope), meanwhile in Section-2: Cluster 1 (inner shelf), Cluster 2 (deep middle – outer shelf), Cluster 3 (deep middle shelf), Cluster 4 (deep middle shelf), Cluster 5 (outer shelf – upper slope).**

Keywords — biostratigraphy, constrained cluster, correlation, depositional environment, micropaleontology

I. Introduction

Age correlation and depositional environment analysis are the main application of micropaleontology, especially in petroleum exploration. Both of these application use the microfossils distribution chart such as foraminifera, nannoplankton, pollen, spores, *etc* as tool for analyzing data. Visual analysis of the microfossils distribution chart is enough to determine biozonation and depositional environment. However for the most case we found that it's difficult to correlate data and determine the depositional environment because of various factor that affect the microfossils distribution, whether natural or technical. Therefore we need semiquantitative and quantitative approach to make biostratigraphic correlation and depositional environment analysis more convenient. This research will use graphic correlation methods (Shaw, 1964 *op. cit* Gradstein, *et al.*, 1985) for correlation and constrained cluster for depositional environment analysis.

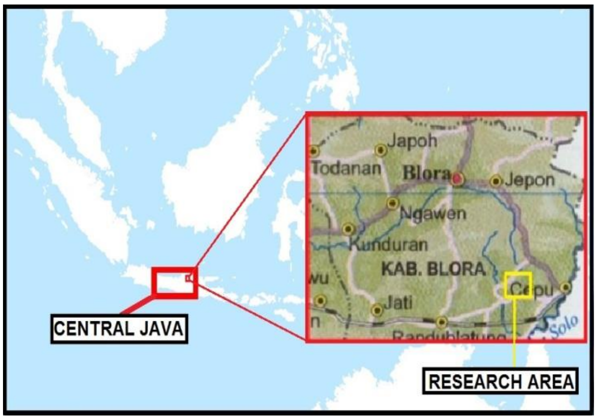

Figure 1. Research Area without scale (modified from Puspaningrum, 2014)

The research data taken from measuring section of Kedinding River and Kalen River in Kedinding Hill Area, Kedungtuban District, Blora Residence, Central Java Province, Indonesia (Figure 1). Geographically.

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Research area located at UTM WGS 84 49S zone with coordinat 9208000-9212000 mU dan 555300-560000 mT (Puspaningrum, 2014). Regionally, the research area belong to North East Java Sedimentary Basin. Physiographically, Kedinding Hill Area belong to Rembang Anticlinorium Zone (van Bemmelen, 1949).

II. BIOSTRATIGRAPHIC CORRELATION

A. *Visual Methods*

The first step we do is analyze the foraminifera distribution chart from Section-1 (Table I) and Section-2 (Table II) visually where every samples were quantitatively analyzed or the amount of every taxa in the samples counted to get the preliminary biozonation. In section-1 there are five biozonation (Blow, 1969 *op. cit* Bolii, *et al.*, 1980), they are :

- *Neogloboquadrina humerosa* Partial Range Zone (NI7 – older): older than FAD (First Appearence Datum) of *Neogloboquadrina humerosa,*
- *Neogloboquadrina humerosa-Globorotalia merotumida* Range Zone (N18): bordered by FAD of *Neogloboquadrina humerosa* (Lower) and LAD (Last Appearence Datum) of *Globorotalia merotumida* (Upper),
- *Globorotalia merotumida-Globigerina venezuelana* Range Zone(N19): bordered by LAD of *Globorotalia merotumida* (Lower) and LAD of *Globigerina venezuelana* (Upper),
- *Globigerina venezuelana-Sphaerodinellopsis seminulina* Range Zone (N20): bordered by LAD of *Globigerina venezuelana* (Lower) and LAD of *Sphaerodinellopsis seminulina* (Upper),
- N21 *Sphaerodinellopsis seminulina* Partial Range Zone (N21 – younger): younger than LAD of *Sphaerodinellopsis seminulina*.

TABLE I. BIOZONATION BY VISUAL ANALYSIS OF SECTION-1

Age	Blow Planktonic Zonation (1969, 1979)	Biostratigraphic Note	Distance from Start Measuring Point (m)	Sample Number
Upper Pliocen - Younger	N21 - Younger		0	PPS01001 S1
			6	PPS01005 S1
Lower Pliocene	N20	LAD *Sphaerodinellopsis seminulina*	10,5	PPS01008 S1
			16,5	PPS01012 S1
			21	PPS01015 S1
			25,5	PPS01018 S2
			27	PPS01019 S1
	N19	LAD *Globigerina venezuelana*	28,5	PPS01020 S1
			30	PPS01021 S1
			33	PPS01023 S1
			36	PPS01025 S1
Upper Miocene	N18	LAD *Globorotalia merotumida*	37,5	PPS01026 S2
			40,5	PPS01028 S1
			51	PPS01035 S1
		FAD *Neogloboquadrina humerosa*	52,5	PPS01036 S1
Upper Miocene - Older	N17 - Older		57	PPS01039 S1
			58,5	PPS01040 S1

Meanwhile in section-2 there are three biozonations (Blow, 1969 *op. cit* Bolii, *et al.*, 1980), they are:

- *Globorotalia merotumida* Partial Range Zone (N18 – Older): last until the LAD of *Globorotalia merotumida*,
- *Neogloboquadrina humerosa-Globigerina venezuelana* Range Zone (N19): bordered by LAD of *Globorotalia merotumida* (Lower) and LAD of *Globigerina venezuelana* (Upper),
- *Globigerina venezuelana* Partial Range Zone (N20 – Younger): younger than the LAD of *Globigerina venezuelana.*

There are three biostratigraphic event that can be found in both sections, they are LAD *Globorotalia merotumida*, FAD *Neogloboquadrina humerosa*, and LAD *Globigerina venezuelana*, however their order is different. The difference in biostratigraphic event order (cross-over) will cause a trouble for correlation process in order to determine the regional biozonation in the research area. This trouble happened because the occurence of foraminifera was affected by many variable such as nutrition, sunlight, salinity, tidal, waves, temperature, *etc*. Its also happened because those variable can be different in every part of the basin despite in the same sedimentary basin.

B. Graphic Correlation Method

To overcome the cross-over of biostratigraphic events in both section, we use a semiquantitative approach named graphic correlation method (Shaw, 1964 *op. cit* Gradstein *et al.*, 1985). This method chosen because we have only two sections that makes probabilistic-based methods such as ranking-scalling and unitary association will generate inaccurate result. Therefore the graphic correlation method is deterministic-based method which its accuracy not affected by the numbers of data.

First, we choose one section with the most occurence of biostratigraphic events and longest track as the standard reference, in this case is section-1 (Kedinding River Section). Then, we plot the distance from measuring point of both section (Table III), section-1(standard reference) as axis and section-2 as ordinat.

TABLE II. BIOZONATION BY VISUAL ANALYSIS OF SECTION-2

Age	Blow Planktonic Zonation (1969, 1979)	Biostratigraphic Notes	Distance from Start Measuring Point (m)	Sample Number
Lower Pliocene- Younger	N20 - younger		0	PPS 02001 S1
			0	PPS 02001 S2
			3	PPS 02003 S1
			6	PPS 02005 S1
			10,5	PPS 02008 S1
			13,5	PPS 02010 S1
			15	PPS 02011 S1
Lower Pliocene	N19	LAD *Globigerina venezuelana*	16,5	PPS 02012 S1
			18	PPS 02013 S1
			21	PPS 02015 S1
		FAD *Neogloboquadrina humerosa*	24	PPS 02017 S1
Upper Miocene - Older	N18 - older	LAD *Globorotalia merotumida*	25,5	PPS 02018 S1
			28,5	PPS 02020 S1

TABEL III. BIOSTRATIGRAPHIC'S DISTANCE FROM START MEASURING POINT

EVENT	Distance from Start Measuring Point (m)	
	Section-1	Section-2
LAD *Globorotalia merotumida*	37,5	25,5
FAD *Neogloboquadrina humerosa*	52,5	24
LAD *Globigerina Venezuelana*	28,5	16,5

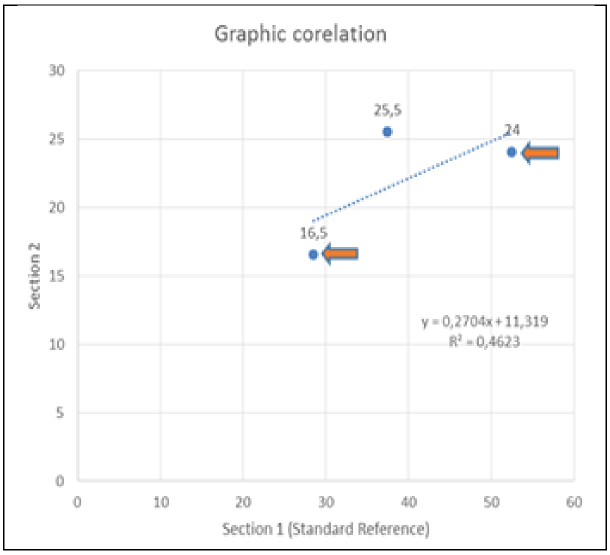


Figure. 2 Biostratigraphic Event Distance from Start Measuring Point Plots

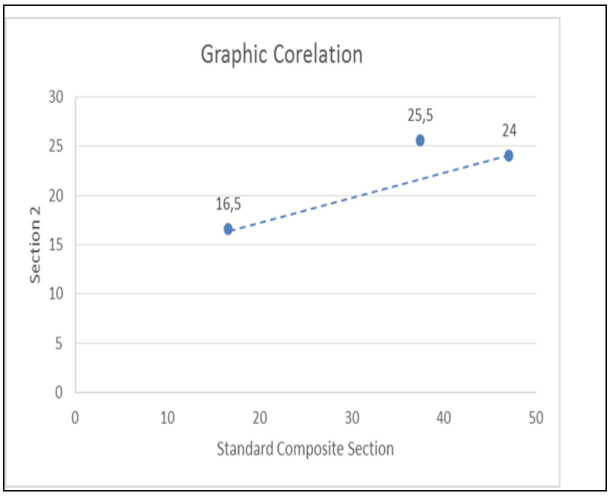


Figure 3. Biostratigraphic Event Plot after correction to standard reference

After plotting, we make linear regression line with considering the event dispersion trend. Then we drag the event that have a higher axis value than regression line alongside axis (Figure 2) until it placed on the regression line (Figure 3). After that, corrected section-1 become the standard composite section with biostratigraphic event distance given in the Table IV.

TABLE IV. BIOSTRATIGRAPHIC EVENT DISTANCE OF STANDARD COMPOSITE SECTION

EVENT	Distance from Start Measuring Point (m)
LAD *Globorotalia merotumida*	37,5
FAD *Neogloboquadrina humerosa*	46,89
LAD *Globigerina Venezuelana*	16,67

Next, we plot the biostratigraphic event distance of standard composite section (axis) and section-2 (ordinat).

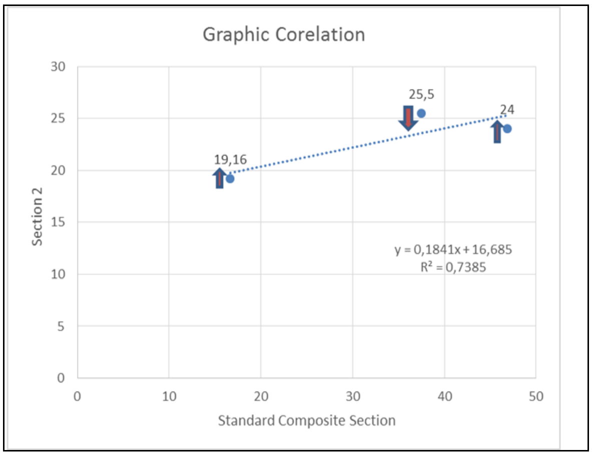


Figure 4. Biostratigraphic Event Distance Plot of Standard Composite Section to Section-2

Afterwards we make linear regression line considering the biostratigraphic event plot dispersion. Then we drag all of the biostratigraphic event alongside ordinat (Figure 4) until it placed on the regression line (Figure 5). From these correction we get the real biostratigraphic event distance from start measuring point of section-2 that can be use for correlation (see Table V).

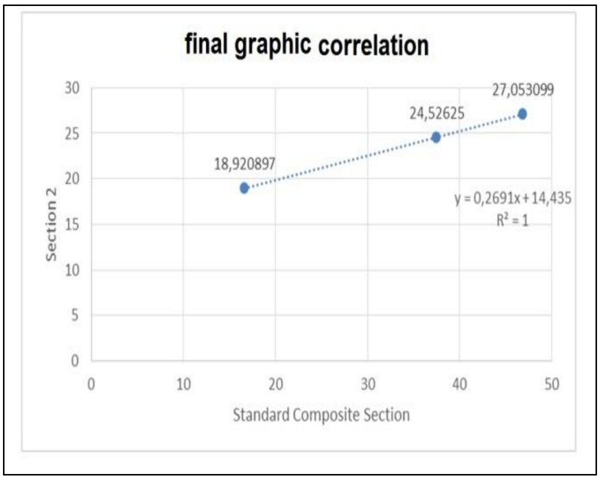


Figure 5 Biostratigraphic Event Distance Plot of Standard Composite Section to Section-2 After Correction

TABLE V BIOSTRATIGRAPHIC EVENT DISTANCE OF SECTION-2 AFTER CORRECTION

EVENT	Distance from Start Measuring (m)
LAD *Globorotalia merotumida*	24,52625
FAD *Neogloboquadrina humerosa*	27,0531
LAD *Globigerina Venezuelana*	18,9209

III. DEPOSITIONAL ENVIRONMENT ANALYSIS

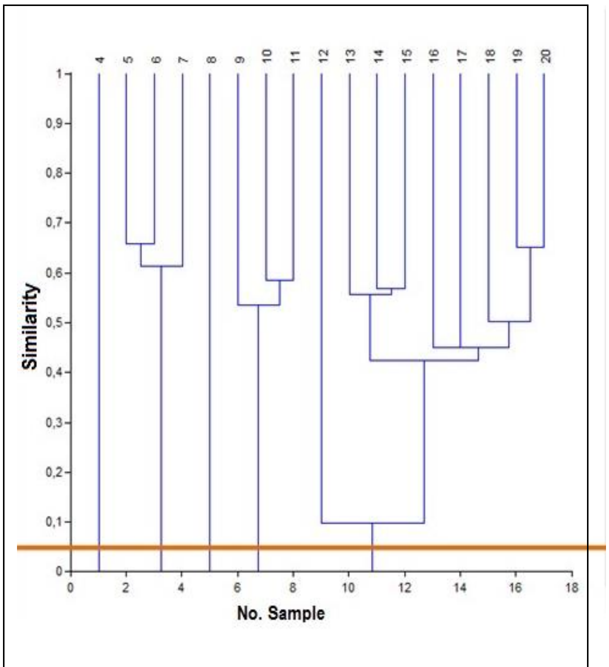
The depositional environment analysis for section-1 and section-2 assist by constrained cluster method in PAST open source program. This method is one of multivariate analysis method (Rencher, 2002) where the cluster that generated by the program will consider the stratigraphical order. From this process we obtain several cluster that consist of 1 – 5 samples. Then by visually observe the foraminifera distribution chart of each section (observe the occurence of foraminifera taxa), we determine the depositional environment for each cluster. The separator line that we use to decide the number of cluster was determined by consider the trend of foraminifera occurence in the distribution chart.

A. Section-1 (Kedinding River Section)

In section-1 (Figure 6) we get five cluster, they are Cluster 1 (Sample 4), Cluster 2 (Sample 5 – 7), Cluster 3 (Sample 8), Cluster 4 (Sample 9 – 11), and Cluster 5 (Sample 12 – 20).

B. Section-2 (Kalen River Section)

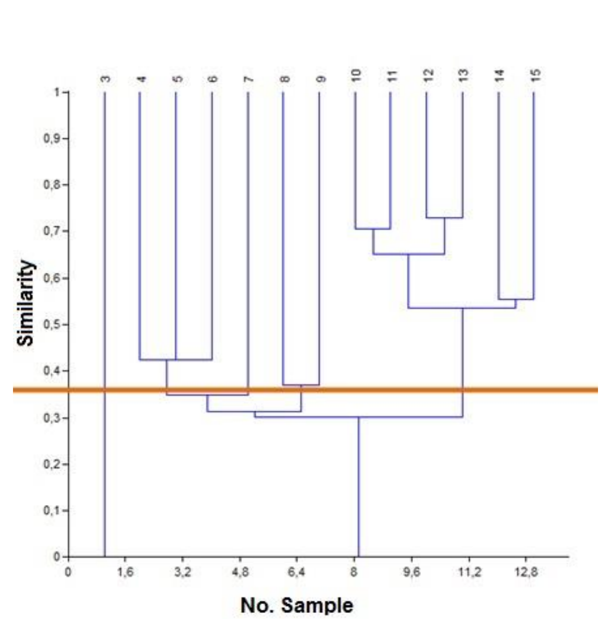
In section-2 (Figure 7) we get five cluster, they are : Cluster 1 (Sample 3), Cluster 2 (Sample 4 – 6), Cluster 3 (Sample 7), Cluster 4 (Sample 8 – 9), Cluster 5 (Sample 10 – 15).



Note:

Sample 4 : PPS01001 S1	Sample 13: PPS01023 S1
Sample 5 : PPS01005 S1	Sample 14: PPS01025 S1
Sample 6 : PPS01008 S1	Sample 15: PPS01026 S2
Sample 7 : PPS01012 S1	Sample 16: PPS01028 S1
Sample 8 : PPS01015 S1	Sample 17: PPS01035 S1
Sample 9 : PPS01018 S2	Sample 18: PPS01036 S1
Sample 10: PPS01019 S1	Sample 19: PPS01039 S1
Sample 11: PPS01020 S1	Sample 20: PPS01040 S1
Sample 12: PPS01021 S1	Separator Line

Figure 6. Constrained Cluster Analysis Result of Section-1



Note:	
Sample 3 : PPS02001 S1	Sample 10: PPS02012 S1
Sample 4 : PPS02001 S2	Sample 11: PPS02013 S1
Sample 5 : PPS02003 S1	Sample 12: PPS02015 S1
Sample 6 : PPS02005 S1	Sample 13: PPS02017 S1
Sample 7 : PPS02008 S1	Sample 14: PPS02018 S1
Sample 8 : PPS02010 S1	Sample 15: PPS02020 S1
Sample 9 : PPS02011 S1	Separator Line

Figure 7. Constrained Cluster Analysis of Section 2

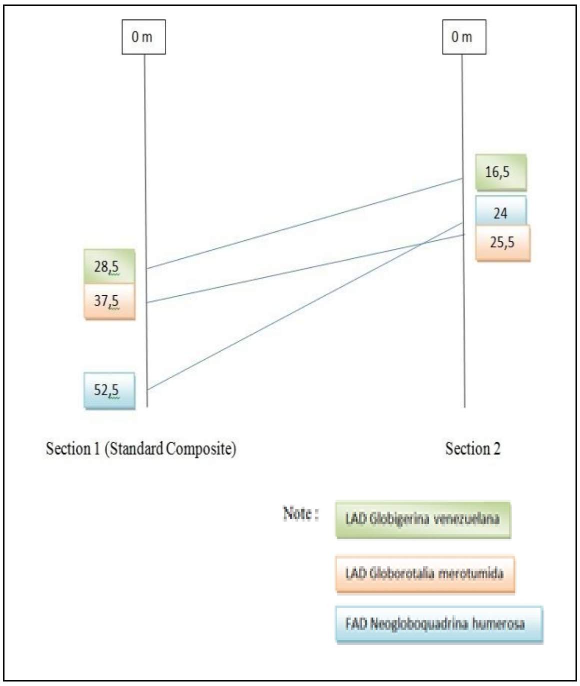


Figure 8. Biostratigraphic Correlation Before Graphic Correlation Method

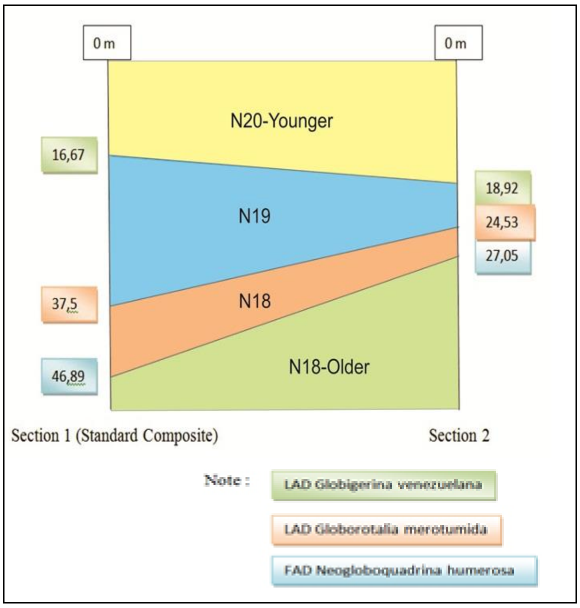


Figure 9.Regional Biozonation of Research Area

IV. RESULT

A. *Biostratigraphic Correlation*

Before applying the graphic correlation method, we find a different biostratigraphic event between two sections (Figure 8). After applying that method we obtain the regional biostratigraphic event order which is (old – young) FAD *Neogloboquadrina humerosa* – LAD *Globorotalia merotumida* – LAD *Globigerina venezuelana* (Figure 9).

Finally, we can determine the regional biozonation of research area which is consists of four biozonation, they are:

- *Globigerina venezuelana* Partial Range Zone (N20 – Younger): younger than LAD of *Globigerina venezuelana,*
- *Globorotalia merotumida-Globigerina venezuelana* Range Zone (N19): LAD of *Globorotalia merotumida* (lower) – LAD of *Globigerina venezuelana* (upper),
- *Neogloboquadrina humerosa-Globorotalia merotumida (*N18): FAD of *Neogloboquadrina humerosa* (lower) – LAD *Globorotalia merotumida* (upper),
- *Neogloboquadrina humerosa* Partial Range Zone (N18 – Older): older than FAD of *Neogloboquadrina humerosa*

B. DEPOSITIONAL ENVIRONMENT

For depositional environment determination we consider several factors including P/B ratio and the assemblages of benthic foraminifera that present. (Murray, 2006 ; Robertson Research, 1983; Loeblich & Tappan, 2006)

i) Section-1 (Table VI)

- Cluster 1

Distinguished by the absence of planktonic foraminifera and consists of just 2 specimen of *Gyroidina braechiana*. Despite of the absence of planktonic foraminifera we assume that the depositional environment of this cluster is deep middle shelf-outer shelf because of short interval distance from Cluster 2.

- Cluster 2

Characterized by P/B ratio 85-87%, abundance occurence of *Asterorotalia multispinosa*, and small amount of *Cibicides* spp., *Florilus* spp., and *Nodosaria* spp.. In addition, we found *Uvigerina peregrina*, *Sphaeroidina bulloides* and small amount of *Bullimina costata*. Supported by few amount of planktonic foraminifera, limited only *Globigerinoides* spp., we can assume that the depositional environment of this cluster is deep middle shelf-outer shelf.

- Cluster 3

This cluster depositional environment is outer shelf which is assumed from cluster 2 and 4. This assumption based on the cluster only consist of sample 8 which is none of foraminifera specimen founded. This possibility controlled by litological fasies change.

- Cluster 4

This cluster consist of sample 9,10, and 11 with P/B ratio 75-90 %. Characterized by abundance amount of *Uvigerina asperula*, *Uvigerina peregrine*, *Gyroidina* spp., and *Nodosaria* spp.. This cluster depositional environment assumed as outer shelf.

- Cluster 5

This cluster consist of sample 12-20 with P/B ratio 70 – 100%. Characterized by quite abundance amount of *Uvigerina asperula*, *Uvigerina peregrina*, *Gyroidina* spp. and *Bullimina costata*. In addition of *Karreriela opercuralis* occurrence, we assume this cluster depotional environment is outer shelf-upper slope.

TABLE VI DEPOSITIONAL ENVIRONMENT OF SECTION-1

Depositional Environment						Distance from Start Measuring Point (m)	Sample Code	Sample Number in Picture
Litoral	Inner Shelf	Middle Shelf		Outer Shelf	Upper Slope			
		Shallow	Deep					
						0	PPS01001 S1	4
						6	PPS01005 S1	5
						10,5	PPS01008 S1	6
						16,5	PPS01012 S1	7
						21	PPS01015 S1	8
						25,5	PPS01018 S2	9

						27	PPS01019 S1	10
						28,5	PPS01020 S1	11
						30	PPS01021 S1	12
						33	PPS01023 S1	13
						36	PPS01025 S1	14
						37,5	PPS01026 S2	15
						40,5	PPS01028 S1	16
						51	PPS01035 S1	17
						52,5	PPS01036 S1	18
						57	PPS01039 S1	19
						58,5	PPS01040 S1	20

ii) Section-2 (Table VII)

- Cluster 1

Planktonic foraminifera are absent (P/B ratio 0%), benthonic foraminifera consists of 5 *Amphistegina* spp. individu. This species indicates the inner shelf environment so we conclude that it's the depositional environment of this cluster. Despite in the same stratigraphical level with sample 4 (Cluster 2) the contrast depositional environment may indicates a lithological facies change or disconformity.

- Cluster 2

P/B ratio 50-70%, from older strata to younger strata the depositional environment became shallower considering the abundance of *Ammonia* spp. and *Elphidium* spp., *Uvigerina peregrina*, and *Gyroidina* spp., also *Asterorotalia multispinosa* and *Cibicides* spp. commonly found. Considering those facts we conclude that this cluster depositional environment is deep middle – outer shelf.

- Cluster 3

P/B ratio 92%, benthonic foraminifera consists of 2 individu of *Lenticulina* spp.. Supported by the occurence of planktonic foraminifera other than *Globigerinoides* spp. and *Globigerina* spp., we conclude that this cluster depositional environment is outer shelf.

- Cluster 4

P/B ratio 80-90% with the abundance occurence of *Asterorotalia multispinosa*, few occurence of *Ammonia beccarii* and *Elphidium* spp., planktonik foraminifera other than *Globigerinoides* and *Globigerina* spp. such as *Globorotalia tumida*. Based on those facts we conclude that this cluster depositional environment is outer shelf.

- Cluster 5

P/B ratio 80-90%, *Bullimina costata*, *Globocassidulina* spp., and *Pullenia bulloides* are abundance, *Cibicides* spp. commonly found. Based on those facts we conclude that the depositional environment ofthis cluster is outer shelf – upper slope.

TABLE VII DEPOSITIONAL ENVIRONMENT OF SECTION-2

Depositional Environment						Distance from Start Measuring Point (m)	Sample Code	Sample Number in Picture
Litoral	Inner Shelf	Middle Shelf		Outer Shelf	Upper Slope			
		Shallow	Deep					
						0	PPS 02001 S1	3
						0	PPS 02001 S2	4

						3	PPS 02003 S1	5
						6	PPS 02005 S1	6
						10,5	PPS 02008 S1	7
						13,5	PPS 02010 S1	8
						15	PPS 02011 S1	9
						16,5	PPS 02012 S1	10
						18	PPS 02013 S1	11
						21	PPS 02015 S1	12
						24	PPS 02017 S1	13
						25,5	PPS 02018 S1	14
						28,5	PPS 02020 S1	15

Based on Table VI and VII, depositional environment correlation from Section-1 and Section-2 can be made to see its spreading in certain distance (Figure 10).

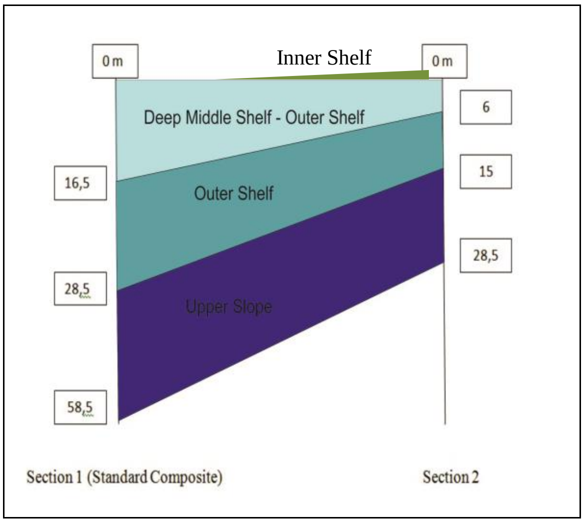


Figure 10. Depositional environment Correlation

V. CONCLUSION

The regional biostratigraphic event sequences (old to young) are FAD *Neogloboquadrina humerosa* – LAD *Globorotalia merotumida* – LAD *Globigerina venezuelana*.

According to Planktonic Foraminifera Biozonation (Blow, 1969 *op. cit* Bolii, *et al.*, 1985) there are four biozonation can be determined from the research area, they are :

- *Neogloboquadrina humerosa* Partial Range Zone (N18 – Older)
- *Neogloboquadrina humerosa-Globorotalia merotumida* (N18)
- *Globorotalia merotumida-Globigerina venezuelana* Range Zone (N19)
- *Globigerina venezuelana* Partial Range Zone (N20 – Younger)

Depositional environment of each cluster in section-1 are: Cluster 1 (unpredictable), Cluster 2 (deep middle – outer shelf), Cluster 3 (outer shelf), Cluster 4 (outer shelf), Cluster 5 (outer shelf – upper slope), whereas in cluster-2, namely: cluster 1 (inner shelf), cluster 2 (deep middle – outer shelf), cluster 3 (deep middle shelf), cluster 4 (outer shelf), cluster 5 (outer shelf – upper slope).

For the next research we suggest that foraminifera distribution chart from core or cutting data should be used instead of measuring section to get more bisostratigraphic events. In addition we should use more section (more than 3) and consider the section location dispersion to get the more representative regional biozation and depositional correlation.

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