Oligocene Cyclic Sedimentation Deduced from Taphonomic Analysis of Molluscs in Lacustrine Deposits of the Pematang Group, Pesada Well, Central Sumatra Basin

Aswan[1], Satia Graha[2], Dodi Suryadi[1], Taufan Wiguna[1] & Sri Iman Qivayanti[2]

[1]Department of Geological Engineering, Faculty of Earth Science Technology, Institut Teknologi Bandung (ITB), Jl. Ganesha 10, Bandung, 40132, Indonesia
[2]Chevron Pacific Indonesia, Rumbai, Riau
Email: aswan_gl@gc.itb.ac.id

Abstract. The Oligocene cycle of Pesada Well, Central Sumatra Basin, Indonesia is composed of a deepening-upward series of depositional cycles in a lacustrine environment affected by oscillations of the water level. Taphonomic analysis of gastropod molluscs was used to interpret the cycle architecture of the Brown Shale (Pematang Group). Four types of shell concentrations were identified. The early transgressive deposit has a distinct erosion surface at the base, contains concretions, is formed of coarse-grained sediment with abraded and broken shells, and is interpreted as reworked deposits. The late transgressive deposit contains a hiatal concentration formed by continuing lake level rise, with many complete shells preserved in life position. The maximum transgressive deposit has complete shells in life position or that have been transported, as well as juvenile molluscs and broken shells. The early regressive deposit contains alternating shell-rich and shell-poor layers. Since the lacustrine system shows no tectonic effects and also no marine influenced indications, the seven sedimentary cycles identified in the Pesada Well are likely to have been affected by oscillations between monsoonal and dry periods.

Keywords: *dry period; lake; molluscs; monsoonal period; Pematang; Pesada; sedimentary cycles; taphonomy.*

1 Introduction

The Central Sumatra Basin is a Tertiary sedimentation basin. Based on its tectonic position, the Central Sumatra Basin is a back-arc basin that developed through the Sunda Shelf because of the subduction of the Indian-Australia Plate under the Eurasian Plate. From a geological perspective, the Central Sumatra Basin is bordered by Bukit Barisan on the southwest, the Sunda Shelf on the east, Busur Asahan on the north, and Tinggian Tigapuluh on the southeast [1]. The Central Sumatra Basin is the largest hydrocarbon producing basin in Indonesia, making this an interesting study region. Exploration and exploitation of hydrocarbon in this area continue to be undertaken.

Received May 26th, 2014, 1st Revision August 3rd, 2015, 2nd Revision December 14th, 2015, Accepted for publication March 11th, 2016.
 ISSN: 2337-5760, DOI: 10.5614/j.math.fund.sci.2016.48.1.7

This study was based on a 10 m long core from the Pesada Well, located in the Central Sumatra Basin where the Pematang Formation (Brown Shale) is well preserved in the well (Figure 1).

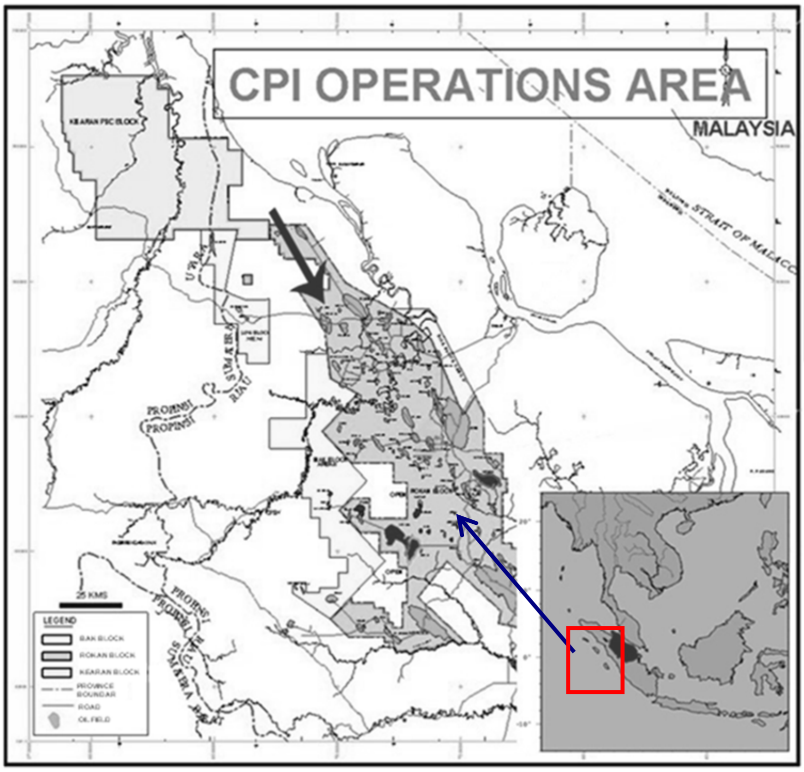

Figure 1 Maps showing the location of the well (upper arrow).

This study is based on a description of the sedimentary cycle based on taphonomic analysis, particularly of the mollusc-rich layers. The objective of this work was to analyze changes in the water level of the lake.

2 Geological Setting

The island of Sumatra was formed as a result of the subduction of two microcontinents at the end of the Mesozoic and is now part of the Sunda Shelf Plate. Ocean crust that was formed in the Indian Ocean and was part of the India-Australia Plate subducted along the Sunda Trench, which created the Sunda Volcanic Arc in Java Island and the surrounding region.

Sumatra consists of three major basins: the North Sumatra Basin, the Central Sumatra Basin and the South Sumatra Basin. The research area is located in the Central Sumatra Basin.

The Central Sumatra Basin is a back-arc basin that developed along the western and southern side of the Sunda Shelf, which is located in the southwestern part of Southeast Asia. This basin was formed as a result of the subduction of the Indian Ocean Plate under the Eurasian Continental Plate in the early Tertiary (Eocene-Oligocene) and as a series of half grabens was separated by horst blocks. This basin has an asymmetric shape and trends northwest-southeast. The deepest part is located in the southwest and it shallows to the northeast. Some parts of this half graben are filled with non-marine clastic sediment and lake sediment [1].

The Pematang Group was deposited unconformably on the Pre-Tertiary basement. This formation consists of non-marine deposits; silliclastic layers were deposited in tropical climate conditions. The thickness of this formation is more than 2500 m locally in the area near the border fault system of the half graben.

The Pematang Group is interpreted as being of Eocene-Oligocene age (50-24 Ma), but the age remains uncertain owing to a lack of age-diagnostic fossil data. Ostracoda, fresh-water gastropods, spores, pollen, dinoflagellates, algae and ferns have been obtained from cores and cuttings. The disappearance of foraminifera and the appearance of fresh water gastropods indicate a non-marine depositional environment. The occurrence of *Magnastriatites howardii* near the base of the middle claystone-mudstone succession of the Pematang Formation indicates an Oligocene age and suggests that the lower part of the Pematang Formation, the Lower Red Bed, may be Eocene. The presence of *Florschuetzia trilobata* in the upper part of the Pematang Formation, also called the Upper Red Bed Formation, also indicates an Oligocene age [1].

The research area is in the Brown Shale Formation. The lithology consists of well-laminated shale, rich in organic matter and brown to black in color, indicating a depositional environment with calm water conditions. In the deeper part of the basin, sandstone intercalations occur, which are thought to have been deposited by turbidity currents [2].

In general, oil and gas in Central Sumatra have been derived from the organic-rich lake clay from the middle part of the Pematang Formation, also called the Brown Shale Formation [2].

3 Methods

This study was based on analysis of a total of 10 m core from the Pesada Well located in the Central Sumatra Basin, Indonesia. The core is currently stored at the Technical and Support Laboratory (T & S Laboratory) of Chevron Pacific Indonesia (CPI), Pekanbaru, Riau, Sumatra, Indonesia. We studied mollusc fossils that are very abundant in this core series. All the mollusc fossils contained in the studied cores are freshwater taxa. The analysis performed included taphonomic evaluation, specifically of the orientation of mollusc fossils with respect to the bedding.

The study of taphonomy was first introduced in 1940 by Russian scientist Ivan Efremov and developed by Shipman in 1981 [3]. Taphonomic analysis indicates whether the mollusc fossils were buried in life position. If the long axes of the gastropod fossils are generally parallel to the bedding, this indicates in-situ and tranquil flow conditions during deposition. In contrast, if most gastropod specimens do not lie parallel to the bedding, the depositional environment is likely to have been high-energy. Observations were also obtained about the condition of fossil shells in the cores, such as whether they are intact or broken. Shell size was also measured: large shells represent adult specimens and small shells are juvenile specimens. We classified the beds within the succession into groups on the basis of these observations and used these groups as the basis for identification of shallowing or deepening water levels in order to obtain a series of water level changes [4].

4 Molluscs Fossils from Core

The molluscs found in the core area are dominated by gastropods. Both fragmentary and complete shells were recovered. Gastropod specimens were deemed to be in life position when they were found unbroken and preserved parallel to the sedimentary laminations. The molluscs found in the core included *Brotia* sp., *Thiara* sp. and *Paludina* sp. The life position of these genera can be seen in Figure 2.

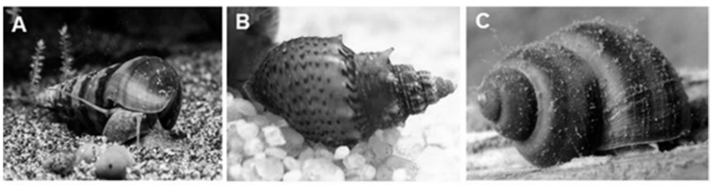

Figure 2 *Brotia* sp. [5] (A), *Thiara* sp. [6] (B) and *Paludina* sp. [7] (C) in life position. Long axis of each genera parallel to the bottom surface of the lake, which later became sediment surface.

On the basis of the mollusc associations, the core is interpreted as having formed in a lacustrine depositional environment.

4.1.1 *Paludina* sp./*Viviparus* sp. (Figure 3)

A genus of Viviparidae characterized by being turbiniform and widely umbilicate. Spiral cords faint, sigmoidal traces of former outer lips and siphonal (anterior) notch. Moderate size for family (height 12-15 mm) turbiniform, spire 0.6 total height, widely umbilicate. Protoconch small, apparently smooth, of a little more than 1 whorl. Teleoconch of 4-4.5 whorls, spire whorls strongly convex and rather flat, with curved sutural shelf. Growth lines weak on last whorl, obsolete on first and second whorls. The only sculpture is faint, low, sigmoidal traces of former outer lips, randomly situated up the spire. Aperture semilunular, lightly thickened and rounded inner lip, outer lip prosocline with sharp siphonal (anterior) canal.

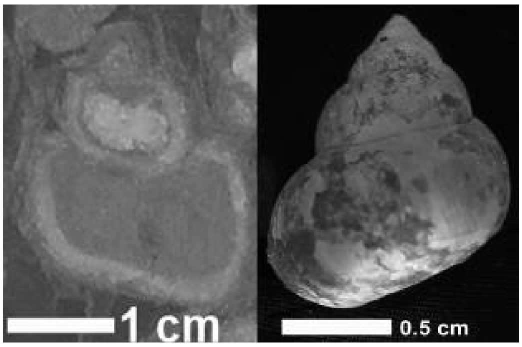

Figure 3 *Paludina* sp./*Viviparus* sp. (left: in the core; right: from outcrops in [8]).

4.1.2 *Brotia* sp. (Figure 4)

This genus is characterized by its small size (height 20-25 mm), turreted, smooth, slightly thick, with lightly curved early whorls, wide shells, moderately wide spires, evenly rounded bases, wide shoulders below the whorls. Last whorl is evenly rounded on others, widely open, very weakly twisted. Aperture is slightly thinner, ovate and largely open. The only sculpture is faint, low, sigmoidal traces of former last whorl, randomly situated up spire, weakly sculptured area around slightly convex sutural ramp.

From comparison of this fossil and other taxa, and also from the lithologic type that the species is found in, the habitat of this species is interpreted as having been low-energy water masses, such as lakes or pools near river mouths [8-9].

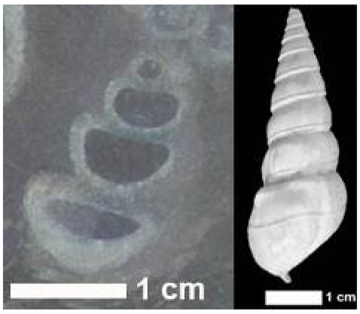

Figure 4 *Brotia* sp. (left: in the core; right: from outcrops in [8]).

4.1.3 *Thiara* sp. (Figure 5)

Genus of Thiaridae characterized by possession of varices or axial costae and spines. Shell is generally small, fusiform or cylindrical. Aperture narrow, elongated with plicae (a fold) on the columellar lip. Outer lip smooth inside. Siphonal canal absent. Size moderate for genus (height 15 to 20 mm), fusiform, spire 0.4-0.5 total height. Last whorl convex in some specimens. Teleoconch of 5-6 whorls, shouldered at or above middle of spire, sutural ramp concave with low subsutural swelling (more pronounced in some shells than in others), sides strongly convex. Last whorl has a rounded periphery. Axial sculpture of

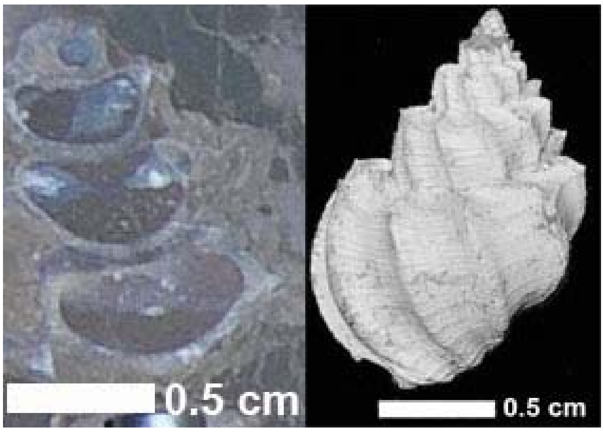

Figure 5 *Thiara* sp. (left: in the core; right: from outcrops in [8]).

prominent, opisthocline (inclined forwards from the upper suture), sharp-crested costae, more prominent on swellings than between, typically nodular on the peribasal angulation. Costae extend from suture to suture on spire, but barely extend onto base; 10-12 costae on penultimate whorl. Spiral sculpture, apparently absent from early whorls, was present on later whorls as numerous closely spaced threads over the whole surface. Spiral sculpture rather variable, with weak threads (on a few specimens obsolete) on ramp and considerably stronger cords below, extending over base and neck of the last whorl. Aperture has a weakly sigmoidal outer lip and lightly thickened inner lip; the only sculpture is faint, low, sigmoidal traces of former outer lips, randomly situated up spire.

Based on the extant common species of Thiaridae, this species lives in a lake habitat. This genus was found in the core.

5 Lake Water Level Cycles

This research was aligned with efforts to determine the characteristics of ancient lake levels that can be directly analyzed from the patterns and changes of the genetic units (architectural elements) that make up the components of a cycle. Since there are no scientific reports about marine influenced indications to the lacustrine system, the seven sedimentary cycles that were identified in the Pesada Well are likely to have been affected by oscillations between monsoonal and dry periods. The short interval of the core with no tectonic evidence along the core also indicates there was no significant tectonic event during the sediment's interval deposition.

6 Stratigraphic Units Based on Taphonomic Characteristics

Shellbed facies have the potential to be used for identification of cycle architecture, particularly in massive rock layers of which the stacking pattern cannot be identified.

6.1 Transgressive Depositional System

A transgression is a rise in the water level, which may result from a reduction in sediment supply or an increase in accommodation space. The surface at which the water level reaches its maximum landward position is termed the maximum transgression [10-11].

6.1.1 Early Transgressive Depositional System (ETDS)

ETDS commences on a ravinement surface. Because of the distinct erosional surface at the base, the coarse grain-size of the sediment and the abrasion and fragmentation of shells, this concentration is interpreted as having been formed by reworking of previously deposited sediments [12]. Concretions can also be a marker for this ETDS [13] (Figure 6).

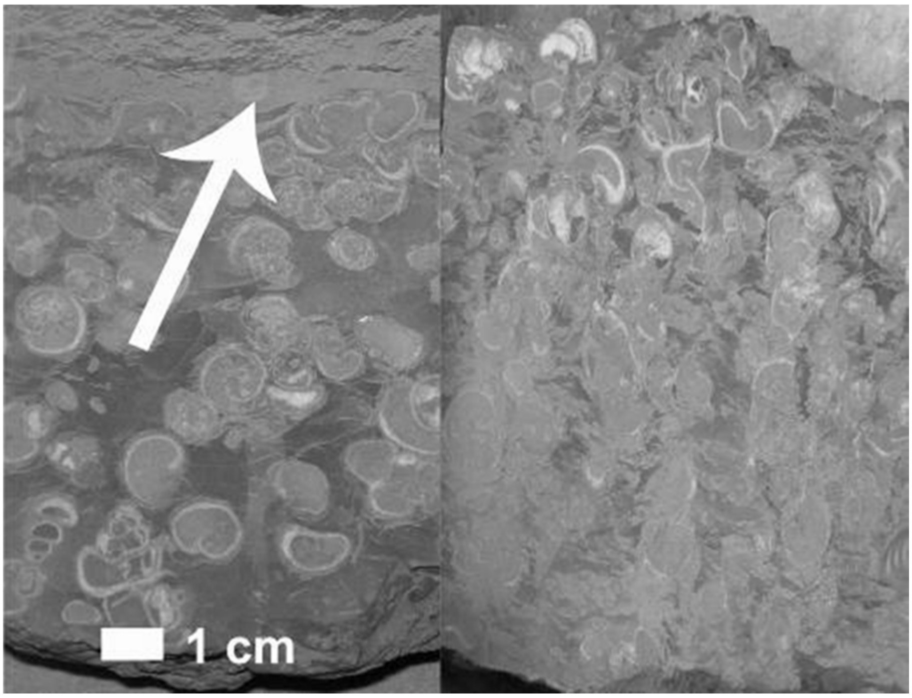

Figure 6 Early Transgressive Depositional System in core samples as a concretion (left) and fragmented shells (right).

6.1.2 Late Transgressive Depositional System (LTDS)

The LTDS deposit is a hiatal concentration that was formed as a result of continuing lake level rise. The LTDS is characterized by a high concentration of unfragmented shells preserved in life position. This concentration accumulated a high rate of biogenic hard part production as a result of increased accommodation space and a low sediment rate. During this interval, the water was clear and the molluscs could flourish [12] (Figure 7). Sediment lamination orientation in each figure are parallel to the top and bottom of each figure.

6.1.3 Maximum Transgressive Depositional System (MTDS)

In the MTDS, molluscs preserved as entire shells can still be found locally in life position or having been transported. Many juvenile molluscs and fragmented shell molluscs were found because of the start of the relative water level fall. This can be explained by restrictions on mollusc growth caused by increased turbidity [12] (Figure 8).

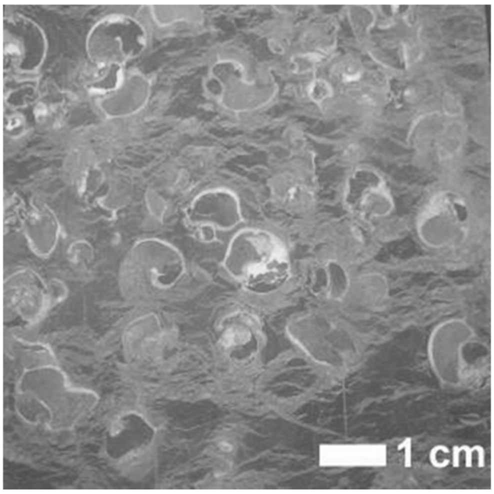

Figure 7 Late Transgressive Depositional System from core, unfragmented shells in life position.

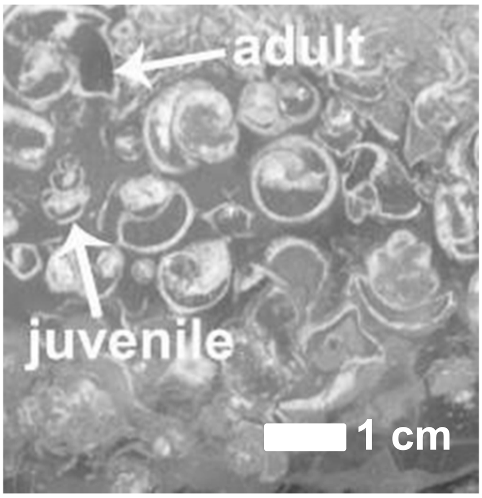

Figure 8 Juvenile and adult shells in live position indicating Maximum Transgressive Depositional System.

6.2 Regressive Depositional System

A regression occurs when the water level rise is lower than during the MTDS, thus causing the relative sediment supply to be similar to the change in accommodation space. This results in the end of transgression and the beginning of regression. Regression deposits are formed when the sediment supply is greater than the accommodation space, particularly at the beginning of the early regressive system.

6.2.1 Early Regressive Depositional System (ERDS)

The ERDS is characterized by intercalations of beds with abundant mollusc fossils and beds barren of mollusc fossils [12] (Figure 9).

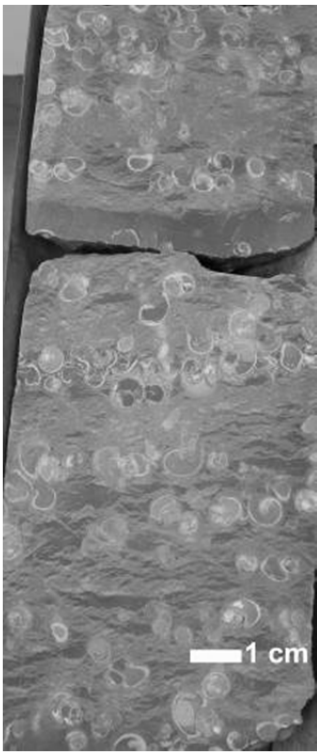

Figure 9 Alternation of layers with abundant molluscs and barren layers indicate an Early Regressive Depositional System.

7 Discussion

In this research, four types of shell concentrations were identified in the sedimentary cycle of the research area. These four types were found in the deposit cycle of the research area: early transgressive depositional system (ETDS), late transgressive depositional system (LTDS), maximum transgressive depositional system (MTDS), and early regressive depositional system (ERDS).

In general, each cycle does not represent a complete cycle (ETDS, LTDS, MTDS, and ERDS): this observation is interpreted as being the result of erosion of some deposits. Figures 10-16 illustrate the taphonomic analysis and depositional system interpretation of Cycles 1-7 in Pesada Well.

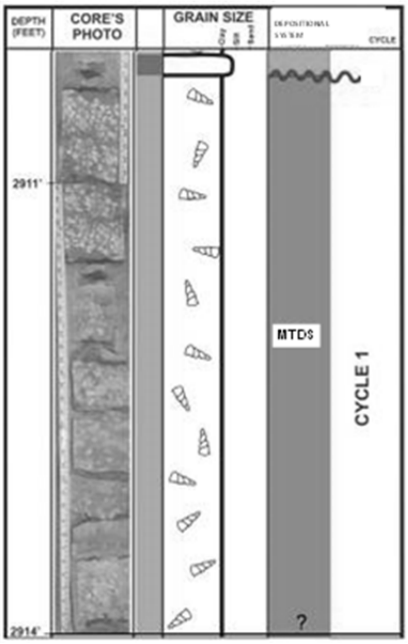

Figure 10 Taphonomic analysis and depositional system interpretation of Cycle 1. Gastropod symbols reflect the original position in the bedding (half gastropod symbols represent broken or fragmented gastropod shells).

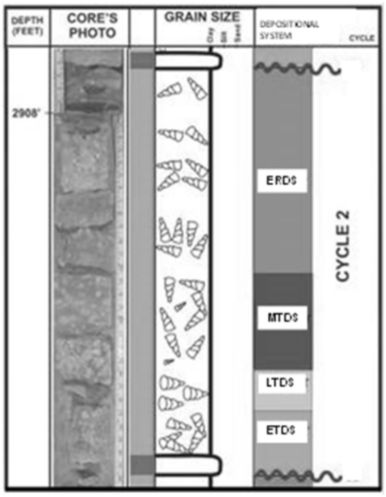

Figure 11 Taphonomic analysis and depositional system interpretation of Cycle 2. Gastropod symbols reflect the original position in the bedding (full rounded gastropod symbols represent intact gastropod shells whereas small gastropod symbols represent juvenile gastropods).

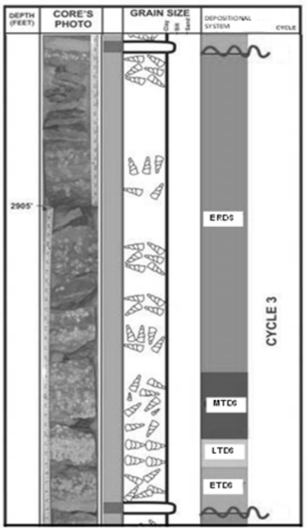

Figure 12 Taphonomic analysis and depositional system interpretation of Cycle 3. Gastropod symbols reflect the original gastropod positions in the bedding (half gastropod symbols mean broken or fragmented gastropod shells, full rounded gastropod symbols represent intact gastropod shells whereas small gastropod symbols represent juvenile gastropods).

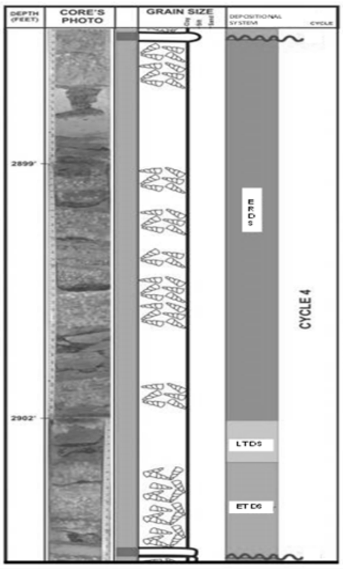

Figure 13 Taphonomic analysis and depositional system interpretation of Cycle 4. Gastropod symbols reflect the original gastropod positions in the bedding (half gastropod symbols represent broken or fragmented gastropod shells).

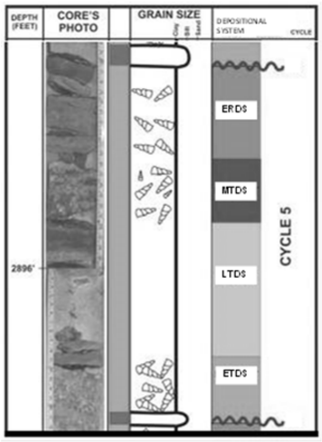

Figure 14 Taphonomic analysis and depositional system interpretation of Cycle 5. Gastropod symbols reflect the original gastropod positions in the bedding (half gastropod symbols mean broken or fragmented gastropod shells and small gastropod symbols represent juvenile gastropods).

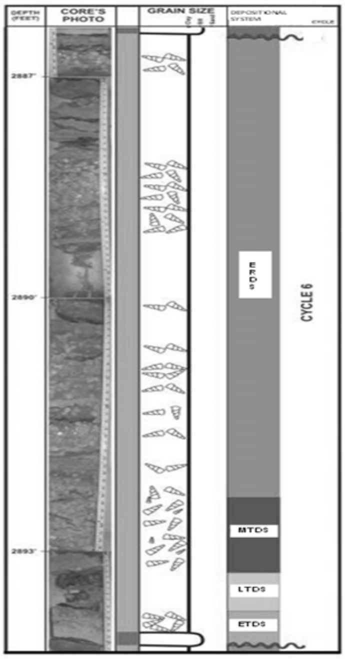

Figure 15 Taphonomic analysis and depositional system interpretation of Cycle 6. Gastropod symbols reflect the original gastropod positions in the bedding (half gastropod symbols represent broken or fragmented gastropod shells and small gastropod symbols represent juvenile gastropods).

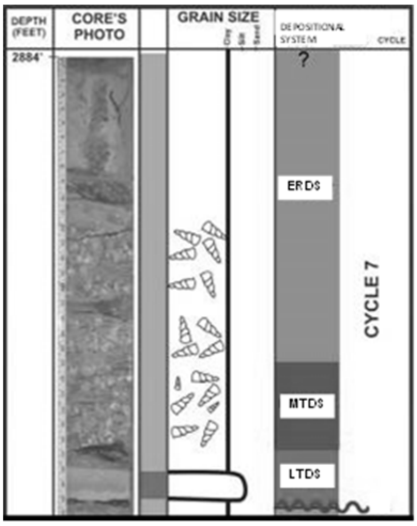

Figure 16 Taphonomic analysis and depositional system interpretation of Cycle 7. Gastropod symbols reflect the original gastropod positions in the bedding (half gastropod symbols represent broken or fragmented gastropod shells and small gastropod symbols represent juvenile gastropods).

8 Conclusions

The molluscs in the research area are mostly gastropods. The fossils were found in fragmented and complete conditions. Gastropod fossils were found as both fragmented and complete remains. A gastropod was regarded as having been preserved in life position when its shell was unbroken and preserved parallel to the sedimentary laminations. A variety of molluscs was obtained from the core, including *Brotia* sp., *Thiara* sp. and *Paludina* sp.

On the basis of the molluscs found in the deposits, the research area is interpreted as a lacustrine depositional environment. Four types of shell concentrations could be identified from the taphonomic analysis. The early transgressive deposit is characterized by a distinct erosional surface at the base, coarse-grained sediment with abraded and broken shells (interpreted as reworked sediments), and concretions. The late transgressive deposit contains many unbroken shells in life position and had a high rate of production of biogenic hard parts as a result of increases in the accommodation space and a low sedimentation rate. The water became clearer and molluscs could flourish. The maximum transgressive deposit is characterized by local occurrences of complete mollusc shells, either in life position or having been transported, as well as the appearance of juvenile molluscs and fragmentary shells. The early regressive deposit is characterized by multiple-event concentrations, such as repeated alternations of layers containing abundant shell fragments and relatively barren layers.

Seven sedimentary cycles were identified from Pesada Well and are suggested to have been affected by oscillations between monsoonal and dry periods.

Acknowledgements

We are extremely grateful to Dr. P. Suryono Adisoemarta from Chevron Pacific Indonesia (UPP program) and all of PT. Chevron Pacific Indonesia HRD staff for the opportunity to study the core samples. We also thank all the staff of the Chevron Technical & Support Laboratory for kindly providing core samples, and Dr. Alan G. Beu, Prof. Dr. Yahdi Zaim, Karsani Aulia, MSc., Dr. Dardji Noeradi and an anonymous reviewer for reviewing and for their helpful comments for the improvement of this paper.

References

[1] Heidrick, T. L. & Aulia, K., *A Structural and Tectonic Model of The Coastal plains Block Central Sumatra Basin Indonesia*, Proc. 22nd Ann. Conv. As. IPA, pp. 285-304, 1993.

[2] Aditya, A.K.P., Aswan & Rizal, Y., *Sequence Architecture Interpretation of Brown Shale (Pematang Group) Lacustrine Deposit based on Mollusk Taphonomic Analysis in Kiliranjao, West Sumatra*, Proceedings Indonesian Geologist Association Annual Convention XXXVII, 2008.

[3] Shipman, P., *Life History of A Fossil: An Introduction to Taphonomy and Paleoecology*, Harvard University Press., pp. 5-232, 1981

[4] Aswan, *Taphonomic significance and Sequence stratigraphy of The Lower Part of Nyalindung Formation (Middle Miocene), Sukabumi*, Bulletin of the Department Geology–-Institut Teknologi Bandung, **38**(3), pp. 131-144, 2007.

[5] Wirbellose, T. & Zubehör, T., *Mokka Tower Snail, Tom's Garnelenshop*, http://www.garnelen-tom.de/zwerggarnelen-shop/Riesen-Turmdeckelschnecke-Brotia-herculea, (1 March 2016). (Text in Germany)

[6] Barrette, B., *Banded Mysterysnail*, Aquatic Biodiversity Monitoring Network, http://www.rsba.ca/recherche_espece/fiche_espece.php?recordID=516&lan=en, (1 March 2016).

[7] Wilken, S., *Fish: Prickly Tower Snail*, Aqua4you, http://www.aqua4you.de/fischart1199.html, (1 March 2016). (Text in Germany)

[8] Aswan, Zaim, Y. & Rizal, Y., *Distribution of Quarternary Freshwater Molluscs Fossils in Jawa*, S. Sartono: Dari Hominid ke Delapsi dengan Kontroversi, Penerbit ITB, Yahdi Zaim, Yan Rizal, Aswan, Bayu Sapta Fitriana, pp. 109-120, 2006.

[9] Aswan, Zaim, Y., Rizal, Y. & Prasetyo, U., *Molluscan Evidence for Slow Subsidence in the Bobotsari Basin during the Plio-Pleistocene, and Implications for Petroleum Maturity*, Journal of Mathematical and Fundamental Sciences, **47**(2), pp. 167-184, 2015.

[10] Posamentier, H.W., Jervey, M.T. & Vail, P.R., *Eustatic Controls on Clastic Deposition I – Conceptual Framework, Sea-Level Changes – An Integrated Approach*, Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A. & van Wagoner, J.C., Society of Economic Paleontologists and Mineralogists Special Publication, No. 42, pp. 125-154, 1988.

[11] Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S. & Hardenbol, J., *An Overview of Sequence Stratigraphy and Key Definitions, Sea Level Changes: An Integrated Approach*, Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A. & van Wagoner, J.C., Special Publication-Society of Economic Paleontologists and Mineralogists, No. 42, pp. 39-45, 1988.

[12] Parras, A. & Casadio, S., *Taphonomy and sequence Stratigraphic Significance of Oyster-dominated Concentrations from the San Julian Formation, Oligocene of Patagonia, Argentina*, Palaeogeography, Palaeoclimatology, Palaeoecology, **217**(1), pp. 47-66, 2004.

[13] Cantalamessa, G., Di Celma, C. & Ragaini, L., *Sequence Stratigraphy Of The Punta Ballena Member Of The Jama Formation (Early Pleistocene, Ecuador): Insights from Integrated Sedimentologic, Taphonomic and Paleoecologic Analysis of Molluscan Shell Concentrations*, Palaeogeography, Palaeoclimatology, Palaeoecology, **216**(1), pp. 1-25, 2004.