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# APPLICATION OF MARKOV CHAIN AND ENTROPY FUNCTION FOR CYCLICITY ANALYSIS OF OLIGOCENE FORMATIONS OF NGAPE-YENAMA AREA, SOUTHERN PART OF MINBU BASIN, MYANMAR

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## Abstract

The area under investigation lies between Padan (Minbu District) to the north and Yenama (Thayet District) to the south. The exposed stratigraphic sections in the study area are from Cretaceous Formation at the base to Pleistocene Formation at the top. The main structure of the study area is mainly monocline structure. The main target research interests on Shwezetaw Formation, Padaung Formation, and Okhmintaung Formation. To prove similar cyclic arrangement in the lithofacies of the study area, the Markov property and entropy analysis was applied to test for the presence of order in the sequence of structures or descriptive facies in the Minbu Basin. The presence study is based on the outcrop and stratigraphic columnar section. According Markov Chain analysis, shaly sandstone facies to trough-cross bedded sandstone facies, shaly sandstone facies to thick-massive sanstone facies, shale facies to thinly laminated sandstone facies and arenaceous shale facies can be cyclical in Shwezetaw Formation. Shale facies to thinly laminated sandstone facies can be cyclical before pass to carbonaceous sandstone facies. Transition directed from shale facies to thinly laminated sandstone facies skipping sandy shale in Shwezetaw Formation. No transition from sandy shale to thinly laminated sandstone and carbonaceous sandstone to shaly sandstone. Shale facies to sandy limestone facies can be cyclical in Padaung Fomation. Shale facies to massive sandstone facies can be cyclical in Okhmintaung Formation.

**Keywords:** Lithofacies, Markov chain analysis, cyclicity, transition.

## Introduction

The area is located between latitudes 19°46′00″N to 20°04′00″ N, and longitudes 94°25′00″ E to 94°40′00″ E, covering approximately 9.3 miles (15km) in width and 24.8 miles (40 km) in length. It is situated in the western flank of Salin syncline and also situated between Padan to the south and Yenanma to the north, Figure (1). There are two major streams which generally flow from west to east and locally named Mann Chaung in the northern part and Sabwet Chaung in the southern part. These streams flow into the Ayeyarwaddy River. Generally, pattern of the main streams and its tributaries are mainly developed parallel to the regional strike, and tectonic structure such as faults and fractures. The topography of the eastern region is characterized by flat lying and the mountainous rugged terrains in the western margin, trending NNW-SSE direction.

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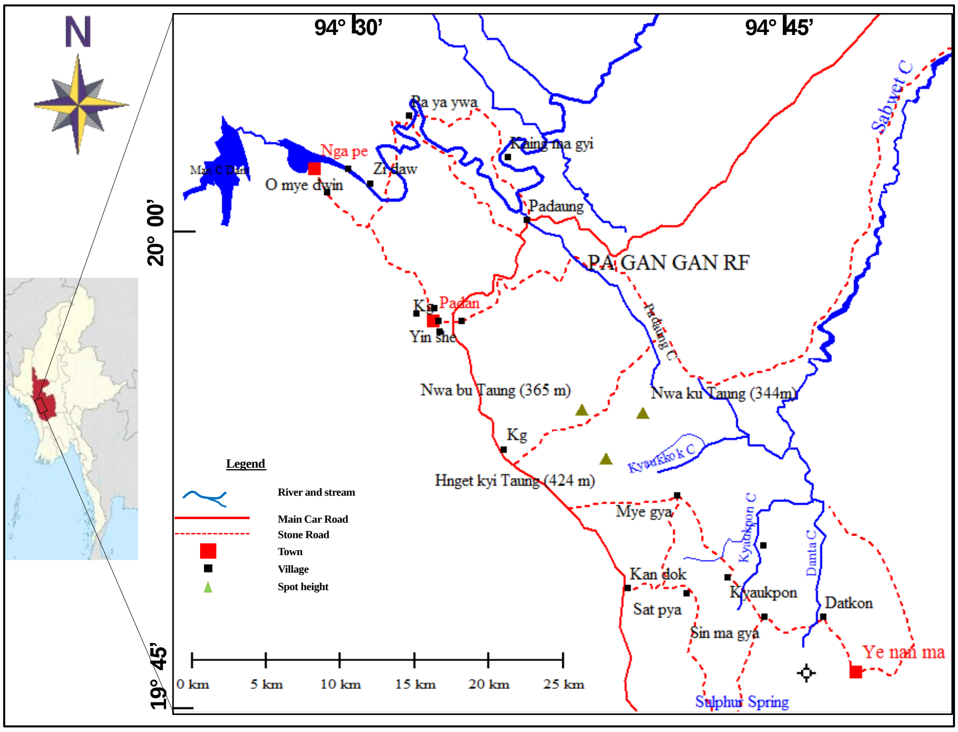



**Figure 1** Location map of the study area

## Regional Geology

The study area consists of the following formations and the litostratigraphic correlation is shown in Table (1). This research mainly focused on the Oligocene Formations such as Shawezetaw Formation, Padaung Formation, and Okhmintaung Formation.

### Shwezetaw Formation

Type section of this formation is at the Shwezetaw Hill (Shwezetaw Pagoda) in the Mann Chaung area. The stratigraphic thickness of the Shwezetaw Formation is 3200-4600 ft. It is made up of yellowish brown sandstones interbedded blue gray shales from north to South. The lower part of the Shwezetaw Formation is composed of yellowish brown to bluish grey, soft, fine-grained calcareous thinly bedded sandy shale interbedded with bluish grey, carbonaceous shale and sand-shale alternation. The Shwezetaw Formation may be assigned to the Early Oligocene age. Shwezetaw Formation was deposited in low to high energy conditions. Figure (2A) and figure (2B).


**Figure 2** Sandstone unit of Shwezetaw Formation; (A) Medium bedded sandstone interbedded with thinly latminated shale in the middle part of Shwezetaw Formation at Shwezetaw-Ngape road section, facing NE (Lat: 20° 05′ 44″N, Long: 94° 31′ 37″E), (B) Medium-to thick-bedded sandstone in the upper part of Shwezetaw Formation at Shwezetaw Pagoda, facing NE (Lat: 20° 05′ 44″N, Long: 94° 31′ 40″E)

## Padaung Formation

It is well developed along the Mann Chaung and its tributaries. The maximum stratigraphic thickness of the Padaung Formation is 1500- 3200ft. It is composed of massive and lumpy deep bluish gray to gray, nodular sandy shale in which gastropod and lamellibranch shells are embedded. The middle and upper parts of the Padaung Formation are characterized by the development of fossiliferous sandy limestone and yellowish, fine- to medium-grained, medium- to thick-bedded. Vertical and horizontal burrows, larger forams occurred in the sandy limestone. Bluish gray shale, shaly sand and sandy limestone sequence are observed in the middle and upper parts. The age of the Padaung Formation as Middle Oligocene in age. The Padaung Formation is deposited in low energy environment, offshore area. Figure (3A) and (3B).

## Okhmintaung Formation

The Okhmintaung Formation occupies a part of the Salin Syncline. It is well exposed at the bank of the Mann Chaung in south of U-Yin and in north of Kaingmagyi villages. The stratigraphic thickness of the Okhmintaung Formation along the Mann Chaung is 2640 ft. It is composed of light yellowish brown, moderately hard, fine to medium-grained sandstones, massive and micro-current bedded with ferruginous gritty and pebbly sandstone lenses.

In the lower part, bluish gray sandstones with concentrated carbonaceous materials and gypsum flakes along the bedding planes. Gastropods and lamellibranches also observed in the sandstone. Fossil bed (3-5 cm thick) is intercalated between sandy shale and sandstone in the middle part. The upper part of this formation is made up of yellowish, fine- to medium-grained, thick-bedded sandstone. Ferruginous concretion and climbing ripples are observed in the sandstone unit and thin gypsum layers are occurred along bedding plane. Okhmintaung Formation is Late Oligocene in age. Okhmintaung Formation was deposited in intertidal to subtidal area in near shore environment. Figure (4A) and (4B).

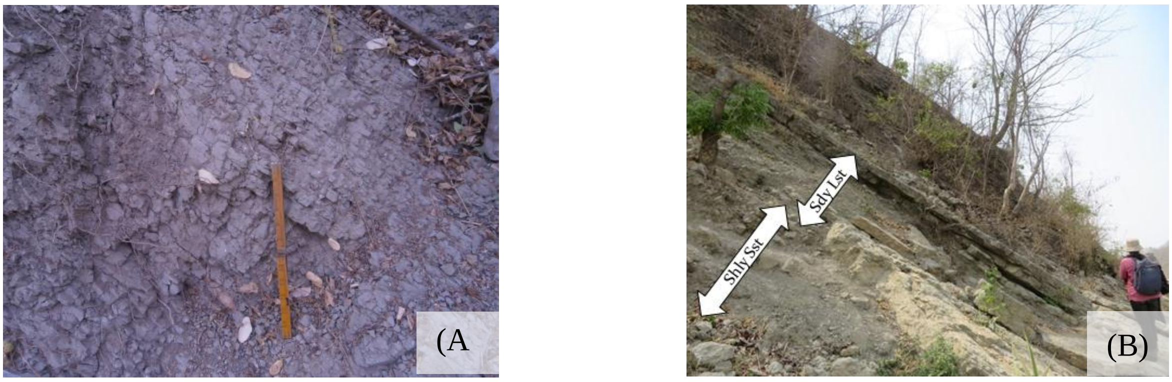



**Figure 3** Lithologic unit of Padaung Formation; (A) Light gray and nodular sandy shale in lower part of Padaung Formation near Auk set taw yar, facing WNW(Lat: 20° 06′ 43″N, Long: 94° 31′ 38″E), (B) Bluish gray shale-shaly sand-sandy lime sequence in the middle part of Padaung Formation near Payaywa, facing WNW (Lat: 20° 06′ 51″N, Long: 94° 31′ 38″E)

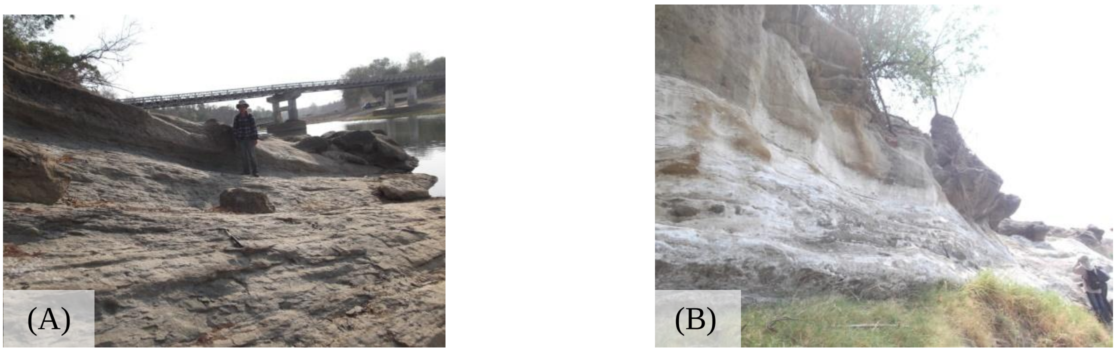



**Figure 4** Sandstone unit of Okhmintaung Formation; (A) Sandy upward sandy shale layers in the middle part of Okhmintaung Formation near Uyin Village, facing E (Lat: 20° 03′ 51″N, Long: 94° 35′ 32″E), (B) Thick-bedded to massive sandstone in the upper part of Okhmintaung Formation near Uyin Village, facing WNW (Lat: 20° 03′ 55″N, Long: 94° 35′ 40″E)

The general structural trends of the study area is NNW-SSE in direction. All of the beds of formations are nearly NE in directions.Major fold is a broad monoclinal syncline. In the western part of the study area, steep dips towards the east in dip amount of 45° to 60°. In the eastern part of the study area, become gradually shallow to the east towards the Minbu syncline, 20° to 15°. In the southern part of the study area, dip amount of the monocline gradually decrease from 30° to 10°.Monocline is cut-cross by a series of E-W trending cross faults, more abundant in distribution and longer in length to the south of the study area, figure (6).

**Table 1 Correlation table of the stratigraphic unit of the Myanmar (Dr Maung Thein, Nov, 2000) and revised May, 2010**

| GEOLOGICAL AGE | | CHIN HILL & N. RAKHINE YOMA | MINBU BASIN | NORTHERN SHAN STATE West East | S. SHAN STATE & KAYAN STATE | KAYAN & MON STATE & TANINTHAYI |
|---|---|---|---|---|---|---|
| Holocene | | Mountain Soil | Alluvium | Terrarossa soil Travertine & cave deposits Gem gravels of Mogok | Terrarossa soil Travertine, cave & lake deposits | Alluvium Laterites |
| Pleistocene | | | Terraces Maw Gravels | | | |
| Pliocene | | | Irrawaddy Fm | Sand, Pebbles bed, Lignite | | Oil Shale Of Htichara Basin |
| Miocene | L | | | | | |
| | M | | Pegu Group: Obogon Fm | | | |
| | E | | Kyaukkok Fm; Pyawbwe Fm | | | |
| Oligocene | L | | Okhmintaung Fm | | | |
| | E | | Padaung Fm; Shwezetaw Fm | | | |
| Eocene | L | | Yaw Fm; Pondaung Fm | | | |
| | M | Gwa Fm; Kennedy Fm | Tabyin Fm | | | |
| | E | Khayingyi Fm | Tilin Fm; Laungshe Fm | | | |
| Paleocene | L | Ngapali Fm | Paunggyi Fm | | | |
| | E | | Kabaw Fm | | Kalaw Red Bed | |
| Cretaceous | L | Nayputaung Ls | Paung Chaung Ls | | | |
| | E | Rangfi Fm | Orbitolina Ls | | | |

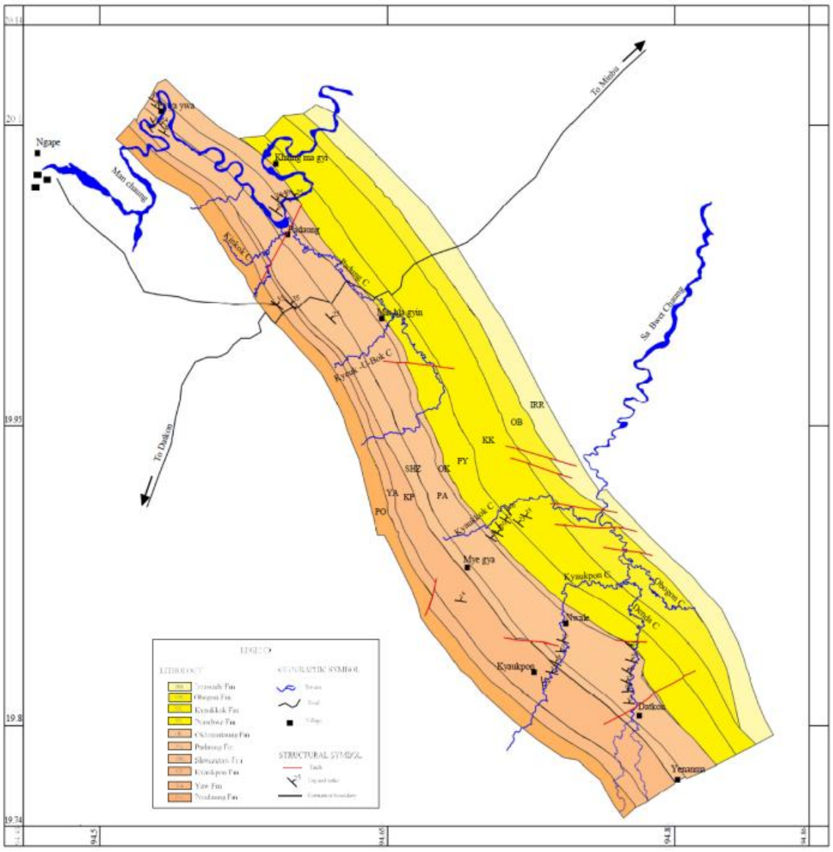


**Figure 6** Geological map of the study area (Based on M.O.C, 1982)

## Cyclic Sedimentation and facies relationship based on Markov Chain Analaysis

### Structuring data for Markov chain

### Vertical sequence profile

Seventeenlithological sections were considered for studying the vertical and a real distributions of the lithofacies within the research area.

### Nature of Data

The dataused in the study is different lithofacies in a verticalsed imentary log sequence codedint of inite number of states for the statistical a nalysis. In this study twelve sublithofacies for Shwezetaw Formation, six sublithofacies for Padaung Formation, and six sublithofacies for Okhmintaung Formation areused which are clearly marked in outcropsection as well as ineach sedimentary logand this is alsodoneinorder to prevent diffusion of transitions between two lithofacies (Maejima, 2004).

For the statisticalinter relationships between ifferentlithofacies, following twelvevariables were extracted from the tenverticallog successions for Shwezetaw Formation, six variables were extracted from the four vertical log successions for Padaung Formation, and six variables were extracted from the three log successions for Okhmintaung Formation. The lithofaciesvariables (descriptive characteristicis in the previous section) and the symbolsused to designate the mare as follows:

**Sub-lithofacies variations of Shwezetaw Formation**

F1 : Shale

F2 : Sandstone

F3 : Sandy Shale

F4 : Carbonaceous Sandstone

F5 : Shaly Sandstone

F6 : Current Ripple Cross-laminated Sandstone

F7 : Fossiliferous Sandstone

F8 : Sandstone with planar lamination

F9 : Low-angle cross-bedded sandstone

F10 : Trough cross-bedded sandstone

F11 : Thick to massive sandstone

F12 : Gluconitic gritty sandstone

**Sub-lithofacies variations of Padaung Formation**

F1: Nodular shale facies

F2: Cross-bedded sandstone facies

F3: Gritty sandstone facies

F4: Sandy shale facies

F5: Shaly sand facies

F6: Fossiliferous Sandy limestone facies

**Sub-lithofacies variations of Okhmintaung Formation**

F1: Nodular shale facies

F2: Massive sandstone facies

F3: Thickening-upward current ripple cross laminated sandstone facies

F4: Sandy shale facies

F5: Shaly sandstone facies

F6: Thick- bedded to massive sandstone facies

## Calculation of frequency count matrix (F)

Frequency count matrix is calculated from the vertical sequence profile of sedimentary logs. Since we are using Markov chain which has memory less property i.e. the geologic situation at point (n-1) governs the event that will happen at n. That's why all seventeen sedimentary logs can be used to calculate matrix F without loss of information. Subsequently, data for all logs are added and matrix is structured at the basin level (Tewari et al., 2009). Number of transition from facies i to j is represented in row i and column j of matrix F, which signifies number of times state j followed immediately after state I in the sedimentary logs.

The frequency count matrix is structured into embedded Markov chain (definition below) considering only transition of lithologies and not their thickness as stated elsewhere. Since a transition is supposed to occur only when it results in a different lithology, the diagonal elements are all zero's in the resulting frequency matrix (Tewari et al., 2009).

## Analytical procedure

In the present study, the embedded Markov matrix is used for structuring the frequency count matrix ($F_{ij}$), where i, j is the row and column number respectively. When i=j, zero is present in the matrix, this implies that the transition from one facies to another has only been recorded where there is an abrupt change in the lithofacies. The advantage of the embedded Markov matrix over the regular Markov matrix is that it is used to identify an actual order in facies transition, if present, regardless of the thickness of the individual bed (Hota and Maejima ,2004).

**Transition frequency matrix (F):** It is a two dimensional array which records the frequency of the vertical transitions that occur between the different lithofacies in a given stratigraphic succession. The lower facies of each transition couplet are given by the row numbers of the matrix, and the upper facies by the column numbers.

**Upward transition probability matrix (P):** The upward transition probability matrix calculates the probability of upward transition of lithofacies in a succession and is calculated in the following manner:

$$P_{ij}=F_{ij}/S_{ri}$$

Where, $S_{Ri}$ is the corresponding row total.

**Downward transition probability matrix (Q):** Downward transition probability determined by dividing elements of the transition frequency matrix (F) by the corresponding column total, i.e.

$$Q_{ji}=F_{ij}/S_{Cj}$$

Where, $S_{Cj}$ is the column total. It calculates the probability of downward transition of lithofacies in a given succession i.e probability of facies i overlain by facies j.

**Independent trail matrix (R):** This matrix represents the probability of the given transition that occur in a random manner and is given by,

$$R_{ij}=S_{Cj}/(S_T - S_{Ri})$$

Where, $S_T$ represents total number of facies transition. The diagonal cells are filled with zeros assuming each transition represent an abrupt change in facies characteristic.

**Difference matrix (D):** A difference matrix is calculated which highlights those transitions that have a probability of occurrence greater than if the sequence were random. By linking positive values of the difference matrix, a preferred upward path of facies transitions can be constructed which can be interpreted in terms of depositional processes that led to this particular arrangement of facies.

$$D_{ij}=P_{ij}-R_{ij}$$

A positive value in difference matrix indicates that a particular transition occurs more frequently and a negative value indicates that it occurs less frequently. In difference matrix the values in each rows of the matrix sum to zero. If the values are close to zero, a vertical succession with little or no ‘memory’ indicates independent nature of deposition of facies in a basin.

**Expected frequency matrix (E):** Expected frequency Matrix represents the expected number of transition from facies i to facies j and is given by

$$E_{ij}=R_{ij} \times S_{Ri}$$

It is necessary to calculate an expected frequency matrix, since chi – square tests should only be applied when the minimum expected frequency in any cell not exceeds 5.

**Test of significance:** Non-parametric chi-square ($\chi^2$) test has been applied to ascertain whether the given sequence has a Markovian 'memory' or no memory. To test null hypothesis, chi-square ($\chi^2$) values are calculated for vertical successions.

$$X^2 = 2 \sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} \log (p_{ij}/f_j/t)$$

Where, Fij=transition count matrix or observed frequency of elements in the transition count matrix; Eij=Expected frequency matrix; ν=degree of freedom given (n2–2n), where n denotes rank of the matrix.

If the computed values of chi-square exceed the limiting values at the 0.5% significance level suggests the Markovity and cyclic arrangement of facies states.

## Entropy Concept

The concept of entropy to sedimentary successions is applied to determine the degree of random occurrence of lithofacies in the succession (Hattori, 1976). (Hattori, 1976) recognized two types of entropies with respect to each lithological state; one is post–depositional entropy corresponding to matrix P and the other, pre–depositional entropy, corresponding to matrix Q.

**Transition matrix (F matrix, $F_{ij}$) of Shwezetaw Formation**

| | f1 | f2 | f3 | f4 | f5 | f6 | f7 | f8 | f9 | f10 | f11 | f12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| f1 | 0 | 23 | 12 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 |
| f2 | 22 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| f3 | 12 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| f4 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| f5 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 |
| f6 | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| f7 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| f8 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| f9 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| f10 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| f11 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| f12 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Transition probability matrix (P matrix $P_{ij}$) of Shwezetaw Formation**

| | f1 | f2 | f3 | f4 | f5 | f6 | f7 | f8 | f9 | f10 | f11 | f12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| f1 | 0 | 0.589744 | 0.307692 | 0 | 0.025641 | 0.025641 | 0 | 0.051282 | 0 | 0 | 0 | 0 |
| f2 | 0.88 | 0 | 0 | 0.04 | 0.04 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 |
| f3 | 0.8 | 0.066667 | 0 | 0.133333 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| f4 | 0 | 0.5 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| f5 | 0 | 0.2 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0.2 | 0.2 | 0.2 |
| f6 | 0.8 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| f7 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| f8 | 0.666667 | 0 | 0 | 0 | 0 | 0 | 0.333333 | 0 | 0 | 0 | 0 | 0 |
| f9 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| f10 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 |
| f11 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| f12 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

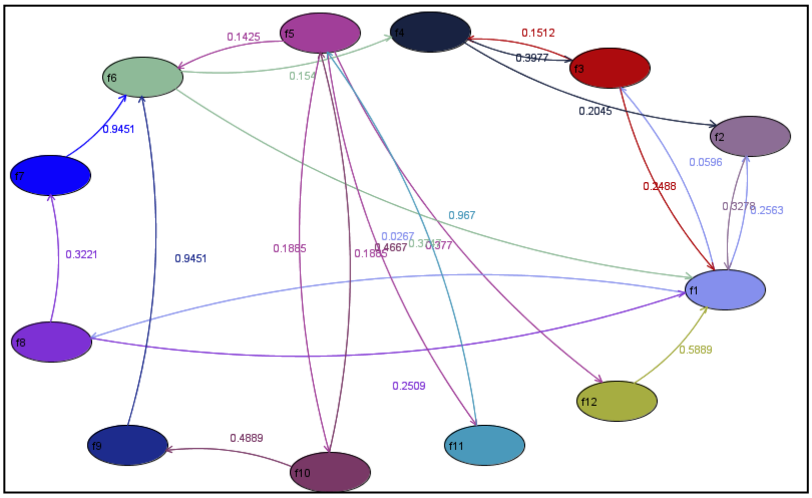
**Expected frequency transition matrix ($E_{IJ}$) of Shwezetaw Formation**

| | f1 | f2 | f3 | f4 | f5 | f6 | f7 | f8 | f9 | f10 | f11 | f12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| f1 | 0 | 0.396825 | 0.238095 | 0.063492 | 0.079365 | 0.079365 | 0.015873 | 0.047619 | 0.015873 | 0.031746 | 0.015873 | 0.015873 |
| f2 | 0.506494 | 0 | 0.194805 | 0.051948 | 0.064935 | 0.064935 | 0.012987 | 0.038961 | 0.012987 | 0.025974 | 0.012987 | 0.012987 |
| f3 | 0.448276 | 0.287356 | 0 | 0.045977 | 0.057471 | 0.057471 | 0.011494 | 0.034483 | 0.011494 | 0.022989 | 0.011494 | 0.011494 |
| f4 | 0.397959 | 0.255102 | 0.153061 | 0 | 0.05102 | 0.05102 | 0.010204 | 0.030612 | 0.010204 | 0.020408 | 0.010204 | 0.010204 |
| f5 | 0.402062 | 0.257732 | 0.154639 | 0.041237 | 0 | 0.051546 | 0.010309 | 0.030928 | 0.010309 | 0.020619 | 0.010309 | 0.010309 |
| f6 | 0.402062 | 0.257732 | 0.154639 | 0.041237 | 0.051546 | 0 | 0.010309 | 0.030928 | 0.010309 | 0.020619 | 0.010309 | 0.010309 |
| f7 | 0.386139 | 0.247525 | 0.148515 | 0.039604 | 0.049505 | 0.049505 | 0 | 0.029703 | 0.009901 | 0.019802 | 0.009901 | 0.009901 |
| f8 | 0.393939 | 0.252525 | 0.151515 | 0.040404 | 0.050505 | 0.050505 | 0.010101 | 0 | 0.010101 | 0.020202 | 0.010101 | 0.010101 |
| f9 | 0.386139 | 0.247525 | 0.148515 | 0.039604 | 0.049505 | 0.049505 | 0.009901 | 0.029703 | 0 | 0.019802 | 0.009901 | 0.009901 |
| f10 | 0.39 | 0.25 | 0.15 | 0.04 | 0.05 | 0.05 | 0.01 | 0.03 | 0.01 | 0 | 0.01 | 0.01 |
| f11 | 0.386139 | 0.247525 | 0.148515 | 0.039604 | 0.049505 | 0.049505 | 0.009901 | 0.029703 | 0.009901 | 0.019802 | 0 | 0.009901 |
| f12 | 0.386139 | 0.247525 | 0.148515 | 0.039604 | 0.049505 | 0.049505 | 0.009901 | 0.029703 | 0.009901 | 0.019802 | 0.009901 | 0 |

**Probabilities difference matrix ($d_{ij}$)of Shwezetaw Formation**

| | f1 | f2 | f3 | f4 | f12 | f5 | f6 | f7 | f8 | f9 | f10 | f11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| f1 | 0 | 0.230905 | 0.055229 | -0.054054 | -0.040541 | -0.040541 | -0.045828 | -0.013514 | 0.016451 | -0.013514 | -0.013514 | -0.013514 |
| f2 | 0.318741 | 0 | -0.139535 | -0.0171 | -0.034884 | -0.005472 | -0.028728 | -0.011628 | -0.023256 | -0.011628 | -0.011628 | -0.011628 |
| f3 | 0.304582 | -0.268194 | 0 | 0.105121 | -0.028302 | -0.028302 | -0.04717 | -0.009434 | -0.018868 | -0.009434 | -0.009434 | -0.009434 |
| f4 | -0.439655 | 0.189655 | 0.396552 | 0 | -0.025862 | -0.025862 | -0.043103 | -0.008621 | -0.017241 | -0.008621 | -0.008621 | -0.008621 |
| f12 | 0.564103 | -0.307692 | -0.102564 | -0.034188 | 0 | -0.025641 | -0.042735 | -0.008547 | -0.017094 | -0.008547 | -0.008547 | -0.008547 |
| f5 | -0.447368 | -0.315789 | -0.105263 | -0.035088 | 0.473684 | 0 | 0.122807 | -0.008772 | -0.017544 | -0.008772 | 0.157895 | 0.157895 |
| f6 | 0.356522 | -0.313043 | -0.104348 | 0.165217 | -0.026087 | -0.026087 | 0 | -0.008696 | -0.017391 | -0.008696 | -0.008696 | -0.008696 |
| f7 | -0.428571 | -0.302521 | -0.10084 | -0.033613 | -0.02521 | -0.02521 | 0.957983 | 0 | -0.016807 | -0.008403 | -0.008403 | -0.008403 |
| f8 | 0.230769 | -0.307692 | -0.102564 | -0.034188 | -0.025641 | -0.025641 | -0.042735 | 0.324786 | 0 | -0.008547 | -0.008547 | -0.008547 |
| f9 | -0.428571 | -0.302521 | -0.10084 | -0.033613 | -0.02521 | -0.02521 | 0.957983 | -0.008403 | -0.016807 | 0 | -0.008403 | -0.008403 |
| f10 | -0.432203 | -0.305085 | -0.101695 | -0.033898 | -0.025424 | 0.474576 | -0.042373 | -0.008475 | -0.016949 | 0.491525 | 0 | -0.008475 |
| f11 | -0.428571 | -0.302521 | -0.10084 | -0.033613 | -0.02521 | 0.97479 | -0.042017 | -0.008403 | -0.016807 | -0.008403 | -0.008403 | 0 |

**Facies relationship diagram of Shwezetaw Formation using Walker Method**




## Cyclicity of Shwezetaw Formation

According to the Markov chain analysis, Shwezetaw Formation have cyclicity from shale facies to trough cross-bedded sandstone facies, shaly sandstone facies to thick-bedded to massive sandstone facies, shale facies to sandstone with horizontal planar lamination facies, shale facies to sandy shale facies may be cyclical before passing to carbonaceous sandstone facies.

Moreover, there have no transition from sandstone facies to sandy shale facies, carbonaceous sandstone facies to shaly sandstone facies, and sandstone with horizontal planar lamination facies to low angle cross-bedded sandstone facies.

Then, transition directed from shale facies to sandy shale facies skipping sandstone facies. In this study, current action from offsore to lower shoreface can be cyclical before pass to Lower intertidal region in the Shwezetaw Formation.

**Transition natrix (F matrix) of Padaung Formation**

| | f1 | f2 | f3 | f4 | f5 | f6 |
|---|---|---|---|---|---|---|
| f1 | 0 | 0 | 2 | 30 | 0 | 0 |
| f2 | 1 | 0 | 0 | 0 | 0 | 0 |
| f3 | 0 | 2 | 0 | 0 | 0 | 0 |
| f4 | 25 | 0 | 0 | 0 | 2 | 2 |
| f5 | 2 | 0 | 0 | 0 | 0 | 0 |
| f6 | 2 | 0 | 0 | 0 | 0 | 0 |

**Probability matrix (P matrix) of Padaung Formation**

| | f1 | f2 | f3 | f4 | f5 | f6 |
|---|---|---|---|---|---|---|
| f1 | 0 | 0 | 0.0625 | 0.9375 | 0 | 0 |
| f2 | 1 | 0 | 0 | 0 | 0 | 0 |
| f3 | 0 | 1 | 0 | 0 | 0 | 0 |
| f4 | 0.862069 | 0 | 0 | 0 | 0.068966 | 0.068966 |
| f5 | 1 | 0 | 0 | 0 | 0 | 0 |
| f6 | 1 | 0 | 0 | 0 | 0 | 0 |

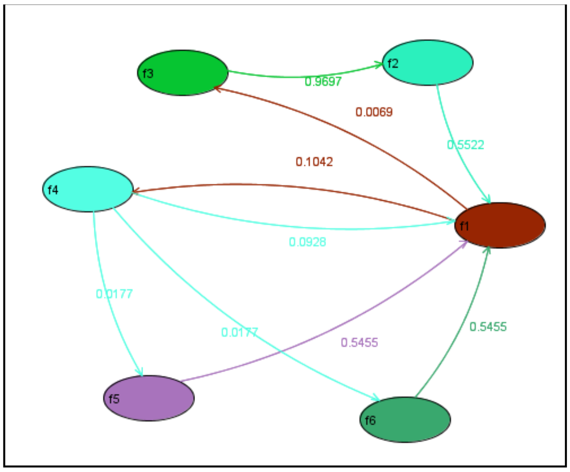
**Expected frequency transition matrix ($E_{IJ}$) of Padaung Formation**

| | f1 | f2 | f3 | f4 | f5 | f6 |
|---|---|---|---|---|---|---|
| f1 | 0 | 0.055556 | 0.055556 | 0.833333 | 0.055556 | 0.055556 |
| f2 | 0.447761 | 0 | 0.029851 | 0.447761 | 0.029851 | 0.029851 |
| f3 | 0.454545 | 0.030303 | 0 | 0.454545 | 0.030303 | 0.030303 |
| f4 | 0.769231 | 0.051282 | 0.051282 | 0 | 0.051282 | 0.051282 |
| f5 | 0.454545 | 0.030303 | 0.030303 | 0.454545 | 0 | 0.030303 |
| f6 | 0.454545 | 0.030303 | 0.030303 | 0.454545 | 0.030303 | 0 |

**Probabilities difference matrix ($d_{ij}$) of Padaung Formation**

| | f1 | f2 | f3 | f4 | f5 | f6 |
|---|---|---|---|---|---|---|
| f1 | 0 | -0.055556 | 0.006944 | 0.104167 | -0.055556 | -0.055556 |
| f2 | 0.552239 | 0 | -0.029851 | -0.447761 | -0.029851 | -0.029851 |
| f3 | -0.454545 | 0.969697 | 0 | -0.454545 | -0.030303 | -0.030303 |
| f4 | 0.092838 | -0.051282 | -0.051282 | 0 | 0.017683 | 0.017683 |
| f5 | 0.545455 | -0.030303 | -0.030303 | -0.454545 | 0 | -0.030303 |
| f6 | 0.545455 | -0.030303 | -0.030303 | -0.454545 | -0.030303 | 0 |

**Facies relationship diagram of Padaung Formation using Walker Method**



## Cyclicity of Okhmintaung Formation

According to the Markov chain analysis, Okhmintaung Formation has cyclicity from nodular shale facies (f1) to massive sandstone facies (f2), and from massive sandstone facies (f2) to thick- bedded to massive sandstone facies (f6). Moreover, there have no transition from thickening-upward current ripple cross laminated sandstone facies (f3) to thick- bedded to massive sandstone facies (f6). Therefore, prodelta to delta front can be cyclical in the Okhmintaung Formation.

### Summary and Conclusions

According to the Markov chain analysis, current action from offsore to lower shoreface can be cyclical before pass to Lower intertidal region in the Shwezetaw Formation.

In Padaung Formation, prodelta to shallow marine condition can be cyclical by transgression and regression. Moreover, prodelta to delta front can be cyclical in the Okhmintaung Formation.

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