Cyclic Sedimentation of the Amiran Formation for Subsurface Characterization in the Zagros fold–thrust belt (Application of Markov Chain Method in depositional sequences interpretation).

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Abstract

This paper proposes an extension of Markov chain model to characterize of geological formations and to make conditioning on any number of well data possible. In this study, lithofacies cycles of the Amiran Formation at type and Pirshamsedin sections are examined by Markov method and entropy analysis as well as field observations, and depositional environment has interpreted by proposed ideal sequence. To do this, deposits of this formation have divided into six lithofacies associations including olive green shale, channel conglomerate, alternation of shale and sandstone with ripple and parallel lamination, alternation shale and sandstone, fine to coarse grained sandstone and conglomerate with chert pebbles. The chain statistics reveals a fining-upward cyclical order of superposition throughout the Raniganj sequence. Markov chain analysis shows that Amiran Formation's sediments are formed from coarsening upward cycles. A complete cycle from base to top consists of shale with ripple and laminated sandstone interbeds, shale, conglomerate with chert pebbles and channel conglomerate. The entropy analysis also shows coarsening upward cycles are asymmetrical. Ideal sequence obtained from the Markov's method is similar to Bouma model that reveals sedimentation is done by deep sea turbidity currents in lower to upper part of sub marine fans. The deposits of debris flows and high density turbidity currents are also interpreted as Channel and inter-channel deposits facies.

Keywords: Markov Chain, Entropy Analysis, Bouma sequence, Amiran Formation.

1- Introduction

Vertical variations of lithofacies within a given sequence play an important role in the recognition of depositional environment and their lateral dispersal. It is of particular importance in the context of the widely accepted law of the correlation of facies as proposed by Walther (1893) and elaborated by Middleton (1973), Reading (1991) and recently by Sengupta (2006). According to this law, only those facies can be superimposed which can be observed beside each other at a given time. Importantly, only a gradual transition from one facies to another implies that the two facies represent environments that once were adjacent laterally. Observations of outcrop sections of the Bouma bearing formation indicate a systematic repetition of fining upward sequences. Hence, information obtained from 2 outcrops from Amiran formation, precise record of lithologic transitions has been utilized for various statistical analyses. In order to determine the depositional architecture and its regional variations, a check of the results obtained so far (Tewari and Singh 2008) by mathematical means seemed desirable.

Markov chain is one of the statistical methods that can be used to study the possibility of Occurrence and repeat of different rock units at the time of deposition and based on proposed and interpreted the depositional model. Several researchers have used this method to provide an ideal sedimentary sequence (Carr, 1982; Billinton, 1992; Hota and Pandya, 2002; Hota *et al*., 2003; Hota and Maejima, 2004; Alpaydın, 2010).

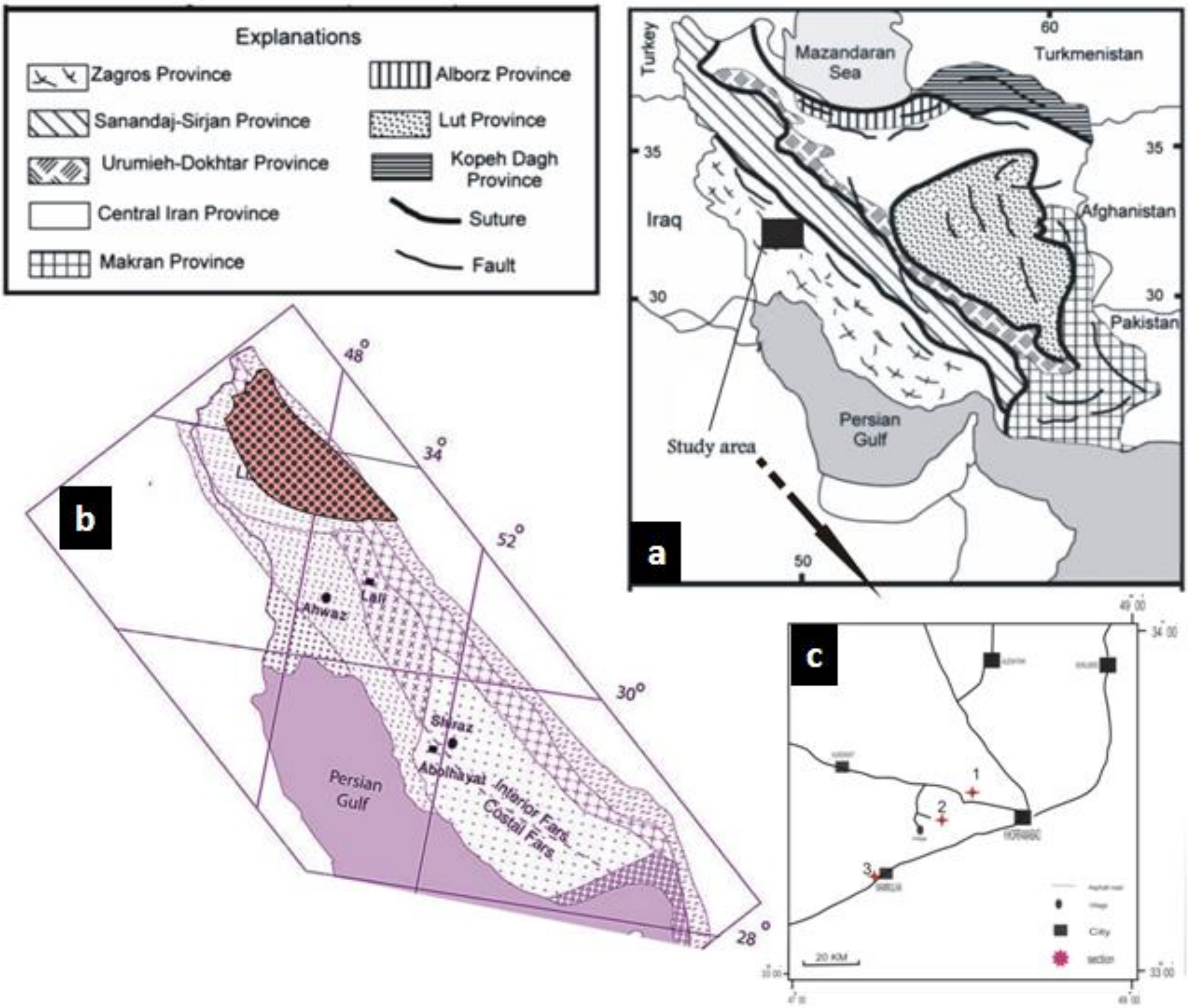

Figure 1: a) General map of Iran showing eight geologic provinces. The study area is located in Zagros province (adopted from Heydari et al. 2003). b) Subdivisions of the Zagros province, after Motiei (1993) with situation of the study sections in Lorestan province.c) Location of the study area in Lorestan province.

The purpose of this study is using the Markov method to investigate the possibility of Occurrence of different rock units in the Amiran formation based on field observations to provide an ideal sequence to present a sedimentary model for this formation. Moreover, given that parts of this formation are not exposed, using this method to predicted the type of rock units. Amiran Formation is one of the siliciclastic formations in the Zagros basin with age Maastrichtian - Paleocene (Alavi, 2004). This formation in the Type and Pirshamsadin sections is formed of 924 and 920 meters shale and dark olive green to brown sandstone and conglomerate. The age of Amiran formation in Lorestan is Paleocene and in the Kermanshah-Khorram Abad region, is Maastrichtian (Alavi, 2004) and it laterally altered into the Pabdeh and Gurpi formations. Geological background and Study area The NW-SE–trending Zagros orogenic belt, which extends for about 2000 kilometers from Turkey to south-eastern Iran, with its numerous supergiant hydrocarbon fields, is the most resource-prolific fold-thrust belt of the world, and it represents a large segment of the Alpine-Himalayan collisional system (e.g., Berberian and King, 1981).

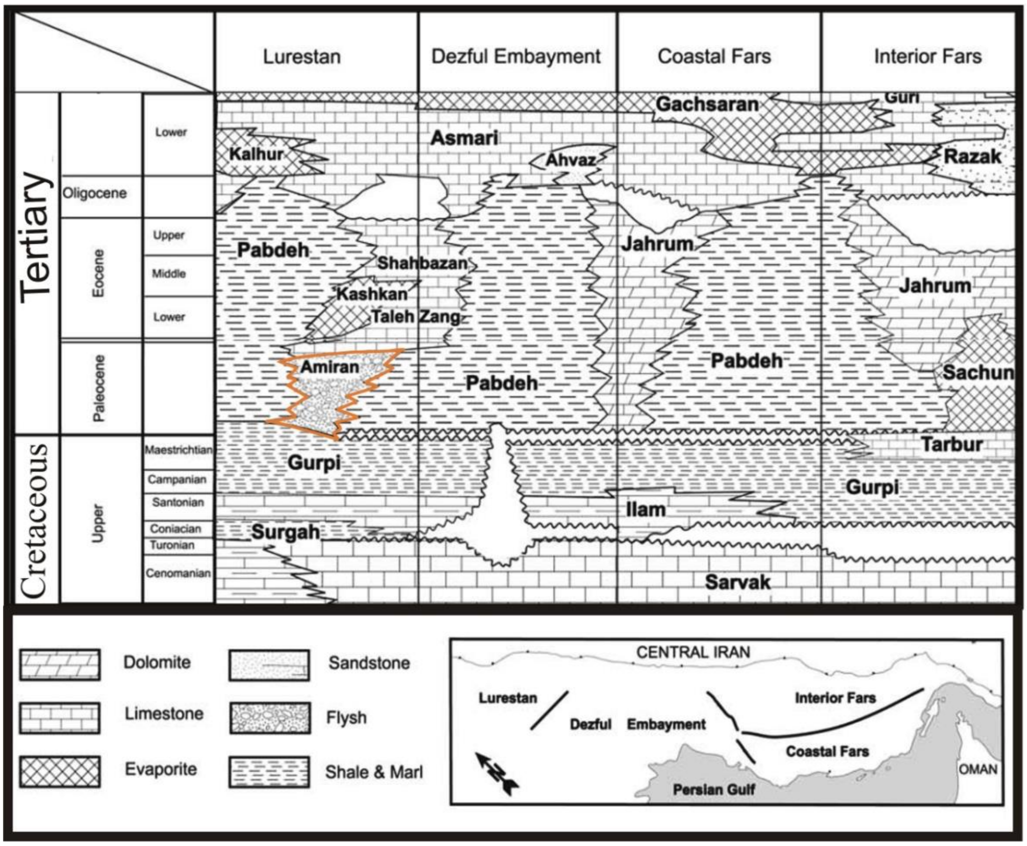

Figure 2) Correlation chart of the Cenozoic deposits of southwest Iran (Modified from Ala, 1982).

In fact, the Zagros fold–thrust belt lies on the northeastern margin of the Arabian plate and has been divided into NW–SE trending structural zones (imbricated and simply folded belt) parallel to the plate margin separated by major fault zones such as the High Zagros and Mountain Front Faults (Fig. 1). The thick sedimentary sequences of the Zagros basin contain rocks ranging in age from Cambrian to Recent. The cover sequence exhibits significant thickness and facies variations both along and across the belt (Fig. 2). The geological evidence suggests that the Zagros region was part of a passive continental margin, which subsequently underwent rifting during the Permo-Triassic and collision during the Late Tertiary (Stocklin, 1974; Berberian and King, 1981; Beydoun *et al*., 1992). Also according to Alavi (2007), the Zagros fold–thrust belt is a result of the structural deformation of the Zagros (peripheral) proforeland system, whose present-day expression is the marine Persian Gulf basins (Baltzer and Purser, 1990), and underlying pre-proforeland, mostly platformal and continental shelf deposits. Following the Permo-Triassic rifting episode, the Zagros basin was divided into two main basins. The Lorestan and Fars basins with very different sedimentary successions are located in NW and in SE of Iran, respectively (Setudehnia, 1978). During the Jurassic–Cretaceous, the Fars basin to the SE part of the Dezful Embayment undergoing slow and steady subsidence which resulted in the deposition of shallow marine sediments until the Late

Cretaceous. In contrast in the Lorestan basin and NW part of the Dezful Embayment, the Lower Cretaceous contains deeper water sediments (Setudehnia, 1978; Berberian and King, 1981; Beydoun *et al*., 1992). In Lorestan Province (NW Zagros), thrust sheet emplacement was associated with the formation of a flexural basin that was initially filled by calcareous deep-marine sediments (Gurpi Formation) followed by ophiolite- and radiolarite-derived clastic sediments (e.g., the Amiran flysch Formation and the conglomeratic Kashkan Formation).

Meanwhile, in the interior parts of the Zagros fold-thrust belt, detrital units of the Amiran Formation and Kashkan Formation, which were derived from the ophiolite complexes (James and Wynd, 1965; Alavi, 1994), as a prograding siliciclastic wedge grade laterally in a southwest ward direction to the alternating greenish-gray paralic siltstones, glauconitic sandstones, and dark gray shales (flysch) which interfinger with the Gurpi Formation. Farther to the southwest, the Amiran Formation's pinchesout, and Globotruncana-bearing argillaceous lime mudstones of the Gurpi Formation, with deep-marine lithic and faunal characteristics, overlie Sarvak limestones (Alavi, 2004).

In the Lorestan Province, the exposed Mesozoic-Cenozoic stratigraphic column consists of ~4–5 km of pre-orogenic strata and 4–5 km of synorogenic deposits. The Mesozoic preorogenic succession is composed mainly of passive-margin carbonate units. The overlying synorogenic deposits include, from bottom to top, the Amiran-Kashkan detrital succession, the Shahbazan-Asmari shallow-marine carbonate platform, the evaporitic Gachsaran Formation, and the siliciclastic Aghajari and Bakhtyari Formations. Our study is restricted to the succession of the Amiran Formation (upper Maastrichtian-Paleocene) (Fig. 2). Extensive outcrops of the succession of the Amiran Formation are exposed in the Lorestan Province (NW Zagros) (Fig. 1). The lower contact with the Gurpi Formation is gradational; the upper contact is conformable, followed by the lenticular limestone of the Taleh Zang Formation. From the central Lorestan Province to the south and southwest, the beds of the Amiran Formation interfinger with marl of the Gurpi and Pabdeh formations. In the present study, three new surface stratigraphic sections have been measured and sampled in the Lorestan Province. Geographical coordinates for the studied sections in area Lorestan include: A (Maemolan): N33°10′46″, E48°3′21″ and, B (Pirshamsadin) N33°42′4″, E47°51′24″ (Fig. 3).

2- Methods

Markov approach is used for modeling of sedimentation systems that changed continuously or discontinuously with times or locations and then so called random process (Powers and Easterling, 1982; Nath and Sahoo, 2009). Although the overall in the Marcov method can be applied the space and time continuously or discretely, but in this study the time and space to be considered continuously because in a continuous sedimentary sequence, the units that are located vertically to each other, are depend on the adjacent sedimentary environments. This case of continuity that follows from the low Walter is called Markov chain (Billinton, 1992; Gallagher *et al*., 2009). In this research is used from the field observations, the type of stones, type of contacts (gradual and sharp) and number of them and finally the thickness of each these units. In this study is used the MATLAB software for the Markov chain modeling.

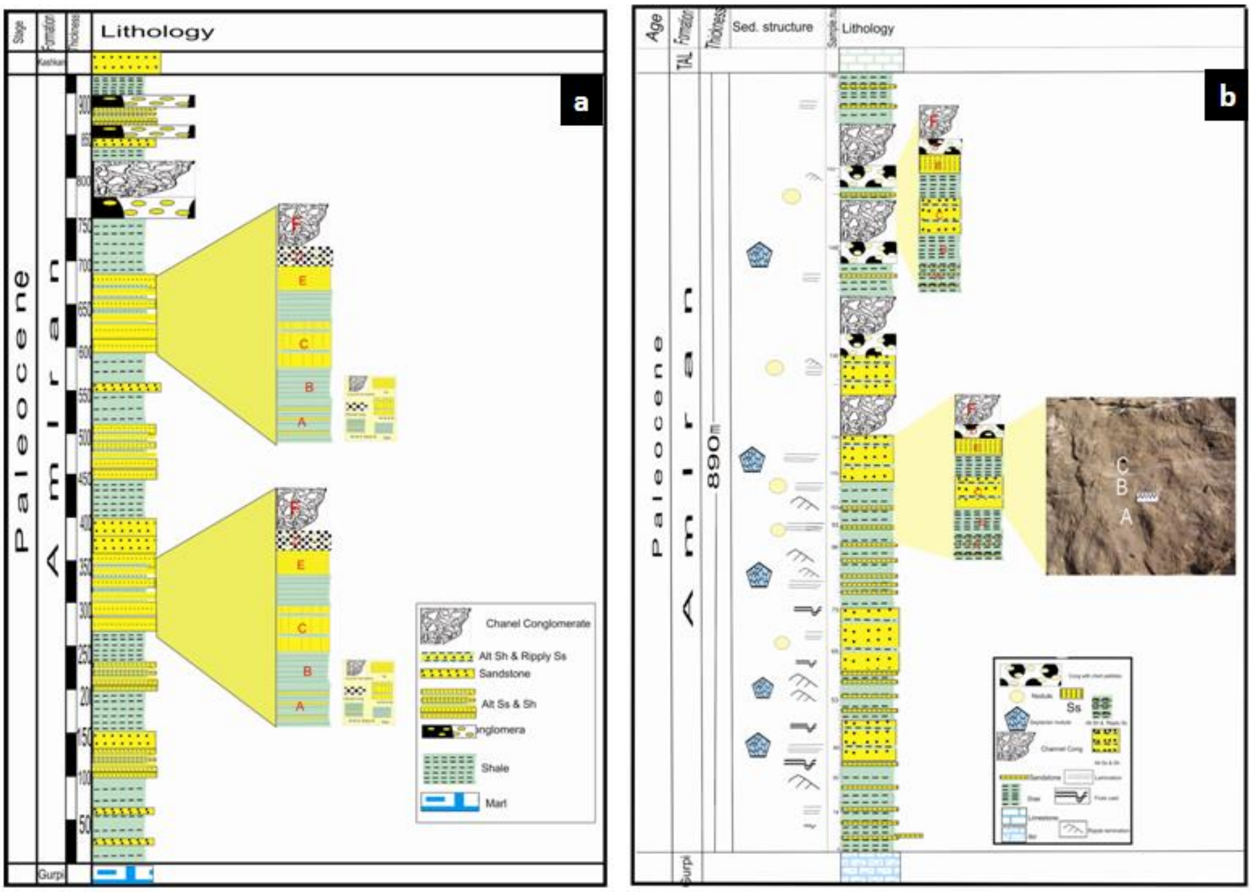

Figure 3) Representative stratigraphic section showing the sedimentological characteristics and depositional environments of the Amiran Formation in Pirshamsadin and Maemulan sections. a) Sedimentary log of Pirshamsadin section in the central Lurestan sub-basin. b) Sedimentary log of Maemulan section in the southwest sub-basin.

With use this software, the Markov method formulas programs were supplied and then the results are getting by using field data and these programs.

Table 1) The matrix of observations F (Pirshamsadin section)

Matrix F						
	A	**B**	**C**	**D**	**E**	**F**
A	44	8	7	0	0	0
B	8	13	0	2	4	4
C	5	1	8	0	2	0
D	0	0	1	0	1	3
E	5	0	0	0	1	0
F	3	2	0	1	0	1

For convenience and to avoid of errors in calculations of Markov (Miall, 1973; Casshyap, 1975), Amiran Formation is divided to 6 facies associations that consists of alternating of shale and sandstone with parallel and ripple Lamination (A facies), olive-green shales (B facies), alternating of sandstone with interbeds of shale (C facies), Conglomerate with chert pebbles (D facies), fine to coarse sandstones (E facies), and channel conglomerate (F facies).

Table 2) The matrix of observations F (Type section)

Matrix P						
	A	**B**	**C**	**D**	**E**	**F**
A	**42**	**9**	**5**	**0**	**0**	**0**
B	**6**	**12**	**0**	**1**	**2**	**2**
C	**4**	**1**	**7**	**0**	**0**	**0**
D	**0**	**0**	**0**	**0**	**0**	**1**
E	**2**	**0**	**0**	**0**	**0**	**0**
F	**2**	**1**	**0**	**0**	**0**	**0**

Read and Dean (Read and Dean, 1967) and Kashyap (1984) have suggested the minimum thickness of a stratum for the Cycles of Markov are 30 cm and 1 meter, respectively, but in this study, more than 1 m thick is used for the Markov chains.

Table 3) The probability of matrix P (Pirshamsadin section)

Matrix P						
	A	**B**	**C**	**D**	**E**	**F**
A	O.85	0.26	0.1	0	0	0
B	0.36	0.621	0	0.053	0.096	0.096
C	0.433	0.063	0.783	0	0.053	0
D	0	0	0.063	0	0.063	0.076
E	0.95	0	0	0	0.063	0
F	0.876	0.543	0	0.063	0	0.063

Also in this study, unlike other studies (Hota *et al*., 2003; Hota and Maejima, 2004; Alpaydın, 2010) is considered the probability of transition from one facies to the same facies.

Table 4) The probability of matrix P (Type Section)

Matrix P						
	A	**B**	**C**	**D**	**E**	**F**
A	**0/75**	**0/16**	**0/089**	**0**	**0**	**0**
B	**0/26**	**0/521**	**0**	**0/043**	**0/086**	**0/086**
C	**0/333**	**0/083**	**0/583**	**0**	**0**	**0**
D	**0**	**0**	**0**	**0**	**0**	**1**
E	**1**	**0**	**0**	**0**	**0**	**0**
F	**0/666**	**0/333**	**0**	**0**	**0**	**0**

According to field observations, the number of contacts of each A to F lithofacies is set to form a square Matrix (matrix of observations, the F matrix) (Tables 1 and 2). This matrix is showing the number of repeat of each the facies to each other (e.g., the A facies, has showed 44 times on the A facies in Pirshamsadin section; Table 1). Numbers of zero indicates that in the field observations, this facies never been in contact with each other. From the matrix of observations F, is calculated the probability matrix P (Tables 3 and 4). It is important to note that in these matrixes (F and P matrixes) Drayeh (the numbers) on the original diameter are not zero, because the sampling were based on thickness, it means that, a single type of stone may be seen several times.

To calculate the matrix P is used the following equation:

$$P_{ij} = \frac{f_{ij}}{s_i}$$

In this equation the f_{ij} is the number of i row and *j* column of matrix, *f* and S*i* are the sum of *i* row of matrix *f*. With use the equation above, the possibility of locating the different rock units is calculated by multiplying the probability of matrix in itself. For example, with a multiplication P-matrix operation in itself is obtained entries matrix P_2, that indicating the possibility of existing of next facies. This principle is applies to any power of *P* matrix and therefore the elements of P_{ij}^n matrix will be represent the probabilities of state j at step of *n*. Since the state of system is determined at the start of the system (*P* (0)) (first facies can be defined for formula), the P_n matrix should be assessed with the coefficient that is named vector of probability of initial conditions or the *P* (0). Therefore, following general equation is used to obtain the probability of various states in the neighborhood of *n*:

$$P(n) = p(0) \times P^n$$

For the purpose, it begins from a particular facies and considering the other facies is evaluated the possibility of locating on them in the sequence. For example, if we start from A Facies:

$$P(0) = [1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$$

This means that the probability of facies A in the step is 100 and the other facies is zero. Or probability of facies D and F equals and other facies of zero will be considered as follows:

P(0) = [0 0 0 0/5 0 0/5]

Similarly, it can be calculated for different modes P(0). Figure 4 shows probability of facies in the four of first stages and with possibility of initial conditions P(0)=[0 0 0 0/5 0 0/5] that value of D and F is equal and the other facies are not exist. Similarly, the probability of occurring of facieses can be obtained for each step by using Markov chain. As shown in Figure 4, the likelihood for facies A in fourth step is most of the other facies that it is adapted with real data of Amiran formation.

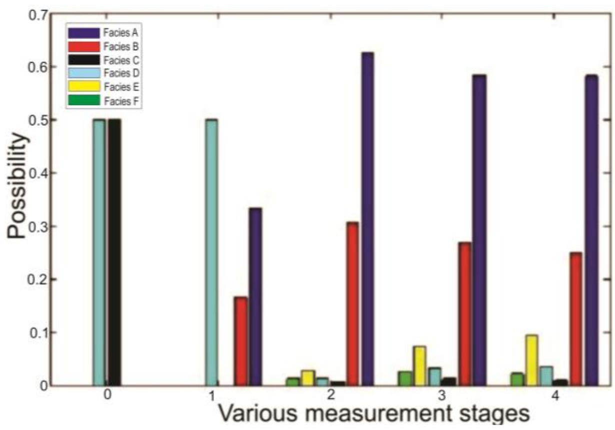

Figure 4) Probability diagram modes occurrence at different stages.

The various patterns of sedimentary cycle (symmetrical, asymmetrical, and random patterns) in sedimentary sequences are investigated by analysis of entropy. This position entropy for different facies (A to F) is shown in table using the following relationship.

$$Ei = -\sum_{i=1}^{6} pij\ log2pij$$

Where *i* is the number of facieses, and *p* is the Probability matrix.

The t matrix is obtained by following equation:

$$tij = \frac{fij}{T}$$

That f_{ij} is the number of *i* row, *j* column in *t* matrix and *T* is total of rows.

Since the values of entropy are associated with the number of positions of facies, their normalization is perfomed by formula:

Normalized Entropy (*R*) = $E / E_{(max)}$

$E_{(max)}$ = - log[1/(n-1)] = - log (1/4) = 2

E and *n* are the facies type. For example, in the fifth facies attention to above equation (nomination of *R*) and Table 3, the value of R5 will be zero (E_{max}= 2.123).

Table 5) The values of entropy of different facies (Pirshamsadin section).

E1	E2	E3	E4	E5	E6
2.046	2.804	2.280	0	0	1.180

Table 6) The values of entropy of different facies(Type section).

E1	E2	E3	E4	E5	E6
1/046	1/046	1/046	1/046	1/046	1/046

The entropy of sedimentation processes is obtained by following formula (E_{system}= 2.88):

$$(E_{(system)}) = -\sum_{i=1}^{5}\sum_{j=1}^{5} t_{ij}.\log_2 t_{ij}$$

3- Discussion

Based on matrix *F* and *P*, it has been determined how the relationship of various facies (type of stones, contact type) and number of them (Figs. 5 and 6).

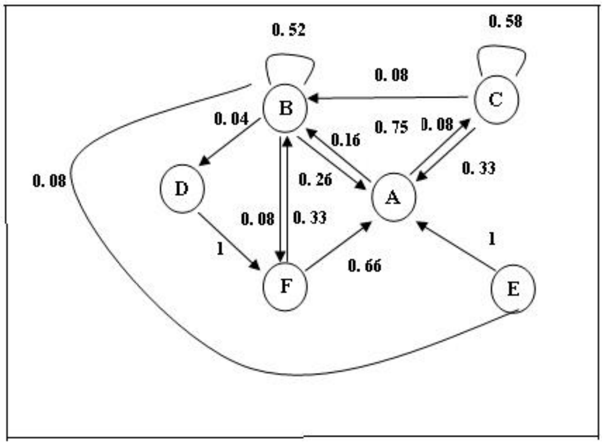

Figure 5) The probability of locating the types of facies on the other in the Amiran formation.

This chart shows that the facies F and A, have most (44) and lowest (0) frequency of contact than the other facies, respectively (Table 1).

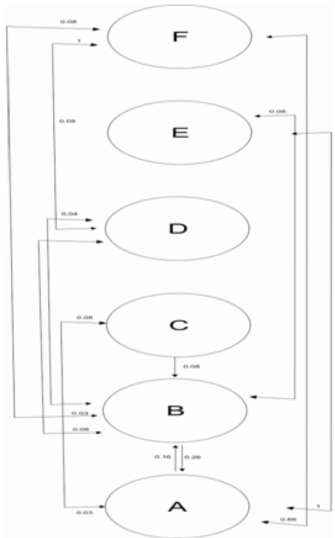

Figure 6. The probability of locating the types of facies on the other in Pirshamsadin section.

The likelihood of exposure of facies B and C on the facies A is 0/26 and 0/1, respectively (Table 3), therefore the A facies can be considered as the base of ideal sequence at the type and pirshamsadin sections. The probabilities of occurring the facies F, D and E on the facies A is zero (Figs. 5 and 6, Tables 3 and 4) that the abundant of matrix of observations shows this subject, too (Tables 1 and 2).

The matrix P indicate the probability of locating facies E on facies B and the likelihood of exposure facies F on facies D more than the other facies (Figs. 5 and 6). Therefore the ideal cycle based on the Markov method can be started from the alternation of shale unit and interbeded of sandstones with ripple and parallel lamination at the base of the unit and then via the shale unit lead to the conglomerate with cherty pebbles and the channel conglomerate facies (Fig. 9).

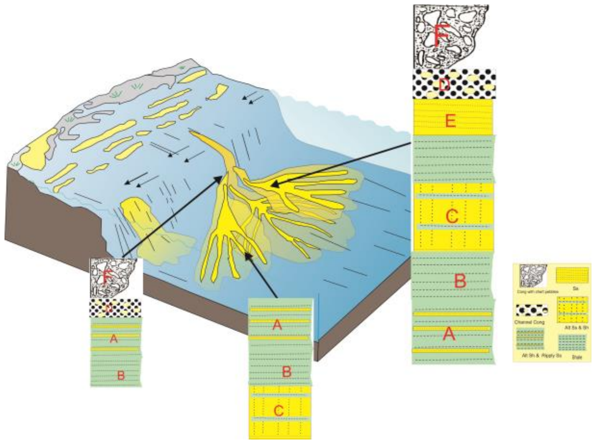

Figure 7) The models of sedimentation environment of the Amiran formation that has been showed the situation of each cycle.

This ideal cycle is equivalent of different units of Bouma sequence cycle that sampling in the field studies and is repeated several times in different parts of the Amiran formation(Fig. 3).

Table 7) The matrix of states of entropy (pirshamsadin section)

Matrix t						
	A	B	C	D	E	F
A	0.5439	0.0742	0.0862	0.0000	0.0000	0.0000
B	0.0718	0.2237	0.0000	0.0303	0.0606	0.0406
C	0.0512	0.0203	0.0371	0.0000	0.0271	0.0000
D	0.0000	0.0000	00.0371	0.0000	0.0371	0.0203
E	0.0406	0.0000	0.0000	0.0000	0.0371	0.0000
F	0.0406	0.0203	0.0000	0.0371	0.0000	00.0371

In addition to, based on the data matrix (matrix of *F* and *P*), there is the probability of the other two cycles (cycles A and B).

In a cycle A of facieses B and C the highest and lowest frequency of contacts than the other facies, respectively, therefore Facies B is considered as the base sequence. The possibility of locating facies C on the facies B and facieses A, B, C, E on D is zero and the possibility of locating facies D, E and F on facies B, respectively, 0.043, 0.086 and 0.086 (Fig. 5, Table 2). Matrix *P* shows the probability of locating facies F on facies D. Therefore, based on the Markov method, cycle A can be started from a base shale unit and then by shale with interbeded of sandstone lead to the conglomerate with cherty pebble and channels conglomerate.

Table 8) The matrix of states of entropy (Type section).

Matrix t						
	A	B	C	D	E	F
A	0/4329	0/0927	0/0515	0	0	0
B	0/0618	0/1237	0	0/0103	0/0206	0/0206
C	0/0412	0/0103	0/0271	0	0	0
D	0	0	0	0	0	0/0103
E	0/0206	0	0	0	0	0
F	0/0206	0/0103	0	0	0	0

The cycle B started from a base sandstone unit with interbeded of shale and then lead to shale with interbeded of sandstone with parallel Lamination (Fig. 5, Table 2). The ideal cycle of A, B, C and D units of Bouma sequence, is including of shale with interbeded of sandstone facies, fine to medium sandstone and shale facies (FigS. 3 and 9). Other cycles resulting from the Markov method (A and B) can be equivalent to Bouma sequence that is deposited in various parts of the sedimentation environment.

Based on field observations, repeating the cycles, the levels of stratification, relation of lateral of layers, the type and boundary of layers and the results of the Markov method, three sedimentary cycles can be divided into Amiran formation that belonging to the lower, middle and upper submarine fan.

Table 9) The values of normalized entropy for various facies (pirshamsadin section).

R1	R2	R3	R4	R5	R6
0.452	0.754	0.326	0.000	0.000	0.815

Facies association of lower submarine fan: Facieses A and B formed volumetrically of deposits of fine grain shale and siltstone and Ratio of shale to sandstone shows high increase than the collection of facies C, D, E and F. Also, in this facies association, the thickness of layer and various units of Bouma show severe reduction than the middle and upper parts of fan (Fig. 8: L, N, Q). Patterns of sediment and texture like alternating layers of fine grain shale and siltstone with parallel lamination and f sandstone layers with wave ripple and complex lamination, planar parallel to wave ripple Lamination and no erosion at the base of facies A, B and C confirms the effect of low-density turbidity currents (Fig. 8). In the facies, fine grain shale and siltstone layers with parallel to complex lamination (Fig. M8) are another Witness the effect of lower density turbidity flows in the form of them than the middle fan facies association that deposited within the active complex of braided channel, active lobes, and natural levee sediment in the middle fan. Fine grain nature of these deposits indicate the presence of mud and diluted flows with low density that no limited the such flows to channels, is cause to reducing the velocity of turbidity flows and creation the fine grain sediment to broad and widespread form in the lower fan. Also, the lack of erosional base in the sandstone layers in this facies association showed the lack of channels of carrying sediment and presence diluted turbidity flows in flat and wide form (Deptuck *et al*., 2007). The lack of evidence of channel in this facies causes the alternative shale and sandstone deposits to be the lower section of the fan instead of the levee or channel margin in the middle fan (Saller *et al*., 2004). The probability of deposition of facies A and B on the C is 0.08 that indicate deposition in deeper parts of the sea and it was high sea level and low energy environment. Therefore the frequency of this facies type is very low.

Complex facies Middle submarine fan: Facieses A and C are followed by the E, D and F facieses (Fig. 3). This state is seen more in a middle fan facies association that it is probably due to submarine channels that are the main way of communication the coarse grain sediment with the deep sea parts. The deposits in this set are form the most existing deposits in Amiran formation. Textural and structural patterns in the facies association such as the massive thick layers of coarse-grained sandstones with erosion base (Fig. 8: E, F, H), the middle layer of sandstone with erosion base and effects of the groove cast (Fig. 8: J, K) confirmed the effect of high-density turbidity flows than the facies association in lower fan.

Bouma sequence in this facies from bottom to top is include of coarse grain pebble sandstones with graded bedding (Ta), mass medium grain sandstones and rarely parallel stratification (Tb) and the fine-grained sandstones with ripple current Lamination (Tc) (Fig. G8).

In most cases, these sandstones are associated with interbeded of shale and siltstone. Sedimentary and textural patterns in this facies confirm the effect of high-density turbidity currents in form them to the lower fan facies set. Also, the thick layer of sandstones are other evidence on the existence of high density turbidity flows (than lower facies) and limit the flow in braided channels in the middle part of the fan.

Complex facies upper submarine fan: facies A and B are followed by facies D and F. These states are seen more in the upper part of fan (Navarro *et al*., 2007). The sedimentary and textural patterns such as destruction contact with the masses of sandstones and rarely Trough cross-bedding with parallel lamination, Scour-and-fill Structures in the conglomerate layers with graded bedding in the upper part of fan (Fig. C8), grain supported conglomerate and no bedding with lenses of coarse grain sandstone (Fig. a, B8) and conglomerate with weak sorting (Fig. D8) in facies D and F are shown the effect of high density turbidity flow in formation of deposits. Such flows are formed in the proximal parts namely in the upper part of fan (Navarro *et al*., 2007). High density turbidity flows can be carried a lot of coarse sand and gravel due to turbulence of flow, pressure from the contact of grains and inner force (floating of ground) to the upper part of fan.

The existence of very thick of mass coarse sandstones and erosion base is the other evidence of high sedimentation rates and turbulent flows with a high density in steep channels of submarine in the upper part of the fan (Navarro *et al*., 2007). The several factors are led to the transport of deposits from the shallow part to the deep part of sea that from most important of them can be noted the turbidite flows (Saller *et al*., 2004).

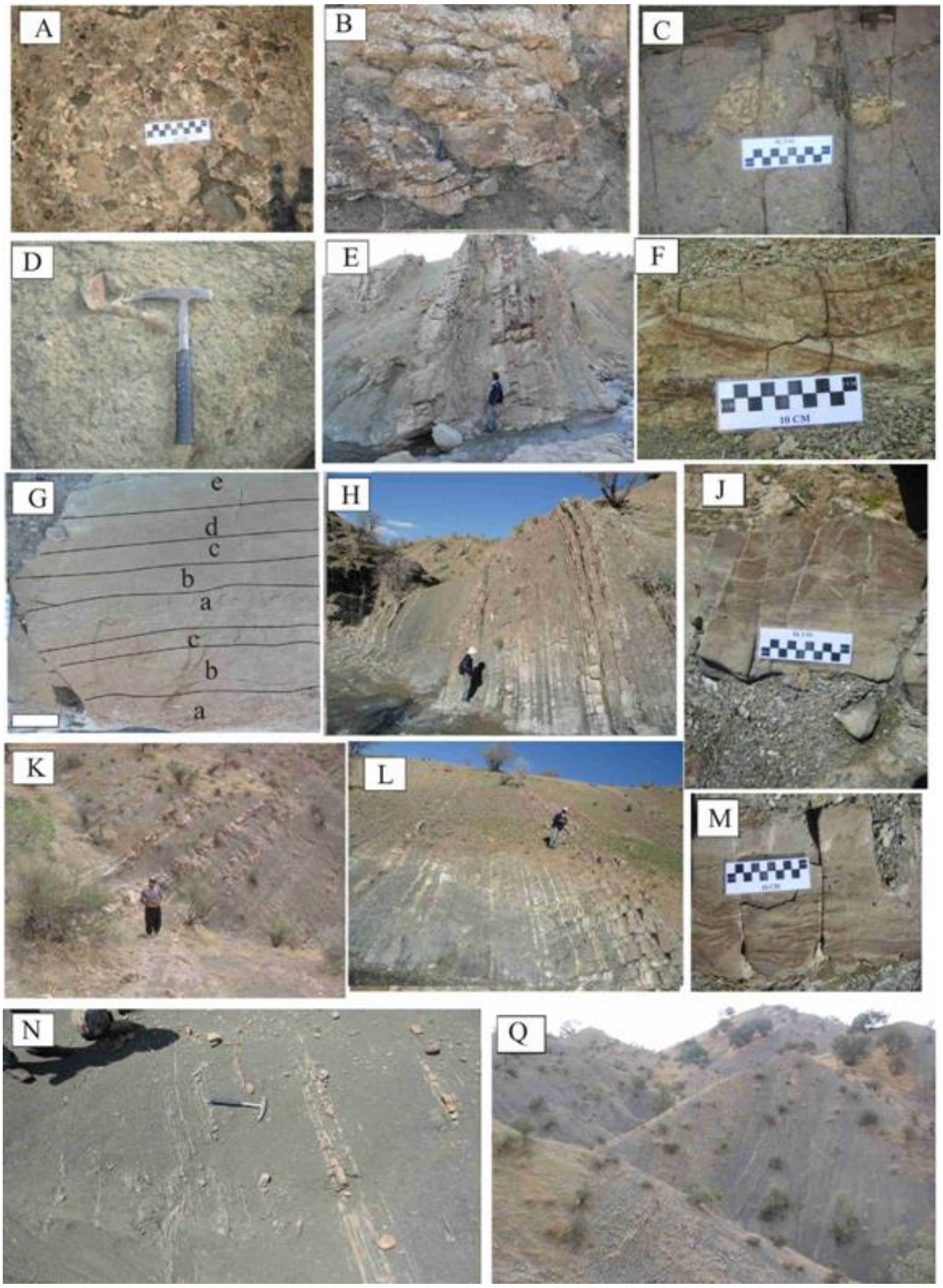

Figure 8. A-Grain supported conglomerate with high roundness and without stratification, in pebble to cobble size and medium sand matrix. B- Grain supported conglomerate that variation to massive coarse grain sandstones upward. C- Weak sorting conglomerate in fine grain clay-silt matrix representative existing of debris flows. E & F- Massive-thick coarse grain to pebbly sandstones with erosion base and score and fill structures and groove cast. G- The cycle of Bouma sequence in this facies from bottom to top is include of coarse grain pebbly sandstones with graded bedding (Ta), massive medium grain sandstones (rarely with parallel bedding))Tb), fine grain sandstones with parallel lamination (Tc), fine grain sandstones with ripple-current lamination)Td) and the uppermost part form from fine grain sediments(Te).H- Coarsening upward sandstones in middle fan transform upward to lower fan facies and massive Shales on the floor basins. J & K- coarsening upward medium grain sandstones with erosion base, groove cast and massive sandstones of Bouma sequence cycle (Tb), complex and wavy lamination (Tc). L and M- Medium bedding turbidites in lower part of fan with formation of Bouma sequence from the upper parts of Tcd and fine grain shales without structure (Te). N & Q- Medium bedding turbidites in lower part of fan with fine grain shale and silt layers and too contain of massive to parallel lamination of Bouma sequence Tde.

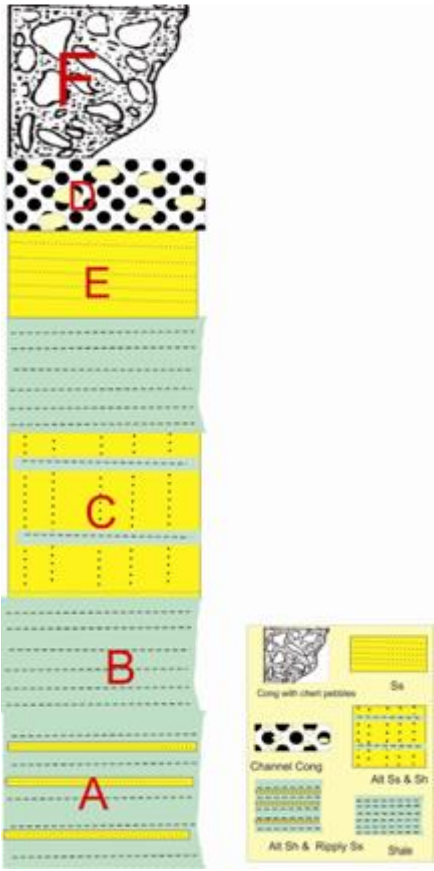

Figure 9) The ideal cycle attained to the Markov chain.

Also, some of the cycles in the Amiran formation are caused by turbidity flows, which may be complete or incomplete. So we can conclude that the sedimentary environment of Amiran formation links to the lower to the upper parts of submarine fan that interpreted by the results of Markov method and field observations.

4- Entropy Analysis

Entropy Analysis is used to determine the type of sedimentary cycles of Amiran formation. the frequency of Entropy analysis of E1, E2 and E3 (Tables 5 and 6) of alternating of sandstone and shale, shale and alternating of shale and sandstone with parallel and ripple Lamination shows that is more the probability of locating this facies on each other, that it also is observed in the sequences obtained from the Markov method (Fig. 9), field studies (Fig. 3) and Markov matrixes (Table 1). In this study the possibility of entropy E1, E2 and E3 are not equal, so it can be indicated the asymmetric repeat of facies A, B and C in the sequences obtained from the Markov method (Tables 5, 6, 7, and 8). The entropy E4 and E5, are zero and shows that facies D and E, will not be repeated symmetrically in facies A, B and C (Fig. 10).

In other words, is not the probability that the Conglomerate to be covered by sandstone, which is quite consistent with field observations. This could be due to sedimentation in deep-sea areas (mostly in the upper part of the observed sequence) and submarine channels that is the main way of communication with the deep sea sediment. Therefore, the difference in the distribution of entropy in the facies A to F show that the facies are not repeated symmetrical on the other. On this basis, the cycle of deposits in the Amiran formation is the type of asymmetrical coarsening upward cycle, however, in the between of them, is observed the smaller fining upward cycles than the cycle (Fig. 3).

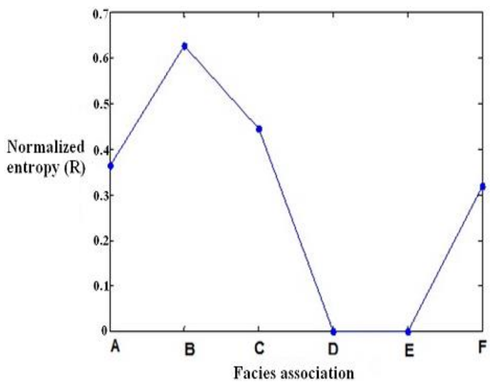

Figure 10) The normalized entropy diagram for various facies in Amiran formation.

The entropy of sedimentary cycles of Amirian formation (Fig. 10) shows that the highest value is to facies B and lowest the entropy is in facies D and E.

5- Conclusions

In Amiran formation has been studied six lithofacies using Markov method consists of olive green shale, channel conglomerate, alternation of shale and sandstone with parallel and ripple Lamination, alternation of sandstone and shale, fine to coarse sandstone and conglomerate with cherty pebbles. On this basis, facies A, B and C show the most thickness of the sequence that it is consistent with Field studies and the Markov method. Markov chain and entropy analysis indicates the respect of Amiran formation facieses in the coarsening upward asymmetric cycles. Calculate the probability of occurrence of each facies at each stage of the deposition processes using Markov chain shows that the possibilities of this approach is consistent with field observations. Based on field observations and the results of the Markov method, three sedimentary cycles are separated in the Amiran formation that belong to the upper, middle and lower of fan. The coarse conglomerate facies is belonging to the upper parts, mainly sandstone with shale facies depend on low to middle parts and mainly shale facies is related to the upper fan. The results of this study show that the Markov chain method can be used to provide the ideal sequence and a sedimentary model, too.

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