Quantitative Sequence Analysis: A Geostatistical Approach

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ABSTRACT

The oil field where present study has been carried out is one of the largest oil fields in north- eastern state of Assam in India (fig-1). Commercial production from this field started in 1968 from clastics of Tertiary age.

The Formation is deposited under prograding deltaic environment enclosing discretely stacked sand bodies known as LBS sands. It has been numbered from LBS- II to LBS- 6 in stratigraphic order from bottom towards top. Focus of the present study is on LBS- II sands.

Total 28 wells have been considered in the present study wherein 14 wells are vertical and 14 are inclined. Surface and sub- surface positions of these wells are shown in figure- 2.

Cores were available in five wells viz. L- 51, 66, 228, 325 and 456 as shown in figure-2. Gross lithologies of these cores are clastic facies like shale, silt and sand intercalated with coaly streaks at places. In well L- 456, presence of about half a meter thick conglomeratic facies has also been noticed, indicating break in deposition and/ or sub- aerial exposure, affirming fluvio- deltaic environment.

Log studies revealed that LBS- II becomes shaly towards south and west of the study area. The total thickness of LBS- II formation remains more or less constant between 30- 35 meters.

With this background sequence analysis of facies to evaluate depositional processes in LBS- II was carried out in two steps.

In the first step field wise distribution of gamma ray values recorded in 26 wells were statistically analyzed to derive electro facies. These values in each well were considered at every half a meter interval, covering 25 meters below and above LBS- II. A distribution curve (fig- 3) showing ranges of gamma ray values and their frequency of occurrence was made. By visual examination of this curve six lithofacies viz. coal, sand, sandy silt, silt, shaly silt and shale were identified along with their ranges in terms of gamma ray values.

Using above definition, litho- logs in all the 26 wells were prepared covering LBS- II and 25 meters above and below it. These litho- logs were used to carry out correlation in north- south and east- west directions. One such correlation in north- south direction is shown in fig- 4.

On detailed examination of these litho- logs, it has been possible to identify a dividing layer (silty/ shaly) within LBS- II in many wells. Consistency of occurrence of this layer in the larger part of the area points to division of LBS- II into two sub layers viz. LBS- II (A) the lower portion and LBS- II (B) the upper portion. The dividing layer signifies a change in geological episode.

Authenticity of lithofacies definition as derived above by evaluation of gamma ray values, was established through megascopic core descriptions in wells L- 228, 325 and 456. Figure-5 compares the lithofacies derived from gamma ray logs and as outlined in the core description. Match between the two is fairly good in wells L- 228 [fig- 5 (a)] and L- 325 [fig- 5 (b)]. However, in well L- 456 [fig- 5 (c)] some deviation is noted against carbonaceous shale. This is obvious because the gamma ray values against coal and shale are at extreme end. In a situation like this a shale layer will be represented as sand.

From preceding comparison it could thus be concluded that an overall gross correlation exists between actual lithofacies represented by core and lithofacies derived from gamma ray logs.

To generate proportion of lithofacies plot, base of LBS- II was brought to a common datum plain and made flat. Proportion of various lithofacies at every half a meter was plotted, covering LBS- II and some portion at the top and bottom of LBS- II (fig- 6). This plot gives a relative idea of the sedimentary input, in space, at every half a meter stratigraphic interval.

In fig- 6 it can be seen that LBS- II is a pack of coarser facies sandwiched between finer facies at the bottom and the top. It is composed of two Coarsening Upward Sequences (CUS) capped by Fining Upward Sequence (FUS), which ultimately merges with transgressive/ flooding surface at the top.

From these observations it could be derived that LBS- II, probably, got its genesis from two progradational events. Based on this LBS- II unit could be divided into LBS- II (A) and LBS- II (B) sub- units, separated by finer (silty) facies. Also, this layer though may not be a perfect divider through out the field, so as to influence hydraulic communication between them. Because in that case the finer facies (shown in green colour in fig- 6) would have extended right upto the extreme left side of the diagram.

In order to simplify subsequent modeling exercises, lithofacies descriptions have been reduced from six elements to four elements by merging sand and sandy silt in one group and shaly silt and shale in another group. Thus four facies considered for subsequent exercises are coal, sand, silt and shale as shown in fig- 7.
In the second step an attempt has been made to quantify the upward increasing, decreasing or constant trends, observed qualitatively in gamma ray or self-potential logs fig- 8. To develop the concept and methodology, some of the

theoretical sequences have been considered (figs- 9, 10 and 11). Markovian probabilities of one facies following the other have been calculated using Transition Frequency Table and Transition Probability Table.

Fig- 9 is the theoretical example of a stratigraphic unit composed of coarsening upward sequences i.e. shale grading to silt grading to sand. Further thickness of each facies is assumed to be constant. A transition frequency table has been prepared (fig- 9, upper table) which records number of times sand is followed by sand, silt and shale respectively. Similarly, number of times sand, silt and shale following silt and shale respectively can also be counted and recorded.

For example, starting from the base of stratigraphic unit and keeping the sampling interval equal to the thickness of each facies, it could be counted that sand occurs zero times after sand, silt also follows zero times after sand whereas shale occurs at three places after sand. Similarly sand follows four times after silt, and silt and shale follow zero times after silt. Likewise, silt occurs at three places after shale, whereas sand and shale never occur after shale.

All these numbers have been recorded in the table as shown and the last column records the total of each row in the transition frequency table. From this table, transition probability table (fig- 9, lower table) can be prepared, which records the probability of one facies following the other. It has been calculated by dividing each number in the transition frequency table row by the sum total of that row.

Once transition probability table is complete, probabilities of occurrences of various sequences viz. fining upward, coarsening upward, barrel shaped sand, silt and shale can be computed in the stratigraphic column under consideration (fig- 9). Barrel shaped sand, silt and shale here corresponds to monotonous deposition of sand, silt and shale respectively.

This exercise as done in fig- 9, demonstrates that probabilities of all other types of sequences are zero except that of coarsening upward sequence that is one. It thus confirms the theoretical case considered in the present example.

Through similar approach it can be confirmed that probability of getting fining upward sequence in a stratigraphic unit composed of fining upward sequences, is one and probabilities of all other types of sequences are zero (fig- 10).

In the preceding examples, sequence analysis has been carried out considering those cases wherein thickness of each facies was constant (figs- 9 and 10). However, this analysis was extended further to include those cases with varying thicknesses of each facies in order to know the effect of these variations on the probabilities of various types of sequences.
Fig- 11 outlines three types of stratigraphic units with unequal thickness. Qualitatively, all of them seem to be examples of fining upward sequences wherein sand is succeeded by silt that in turn is succeeded by shale. However,

Markovian probabilities for various types of sequences, following the same methodology as before, come out to be different.

From above illustrations, it could be concluded that as the thickness of a particular facies increases, probabilities of getting Barrel Shape in that facies also increases.

Following this concept, Markovian probabilities for different types of sequences for the interval of LBS- II was calculated, by keeping sampling interval to half a meter, in each well. For this purpose, lithologs derived from gamma ray anomaly were used restricting to three lithofacies viz. sand, silt and shale only. Coal facies was dropped from the sequence analysis as three- component sedimentation model with sand, silt and shale was more convenient and representative for such analyses.

Percentage of sandy facies within LBS- II was also calculated for each well.

Markovian probabilities for various types of sequences were contoured alongwith percentage of sandy facies and shown in figs- 12 and 13.

Comparative study of extent of colored areas representing more than 50% probabilities of getting barrel shaped sand, silt and shale in fig- 12 indicates that out of these three types of sequences, barrel shaped sand is the most dominant one. Similarly, a comparison between coarsening upward and fining upward sequences (fig- 13, where colored areas represent more than 5% probabilities of getting these types of sequences) reveals that out of these two types of sequences, coarsening upward sequence is the most dominant type of sequence.

It may be noted that in the second case cut off limit was kept at 5% and not 50% as in the previous case. This was done because, probabilities of getting either coarsening upward or fining upward sequences in the area under study is very low as compared to probabilities of getting barrel shaped sand, silt or shale.

Similarly, distribution pattern of sandy facies (fig- 13, where colored area represents more than 50% of sandy facies within LBS- II) reveals a decreasing trend toward south.

To conclude, the study carried out here provides a new workflow and quantitative approach for mapping facies stacking patterns and sequence analysis and thus helps model regional geology for better exploration decisions.

Figures

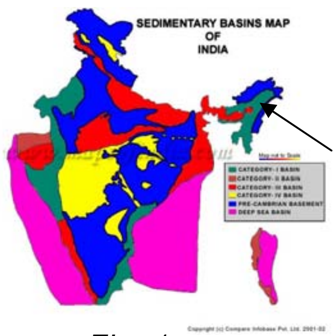

Fig- 1

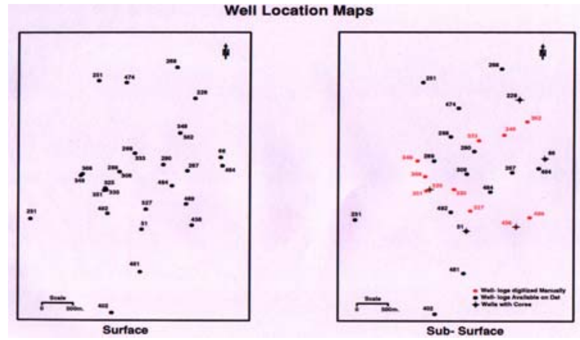

Fig- 2

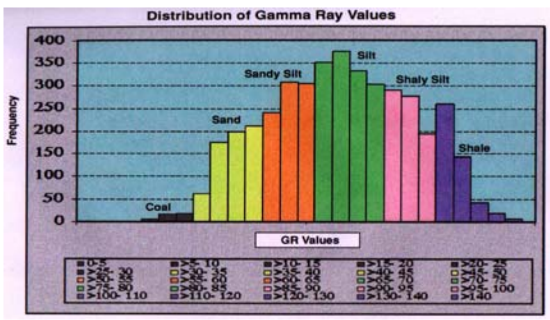

Fig- 3

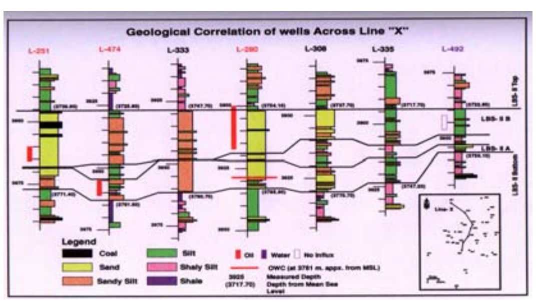

Fig- 4

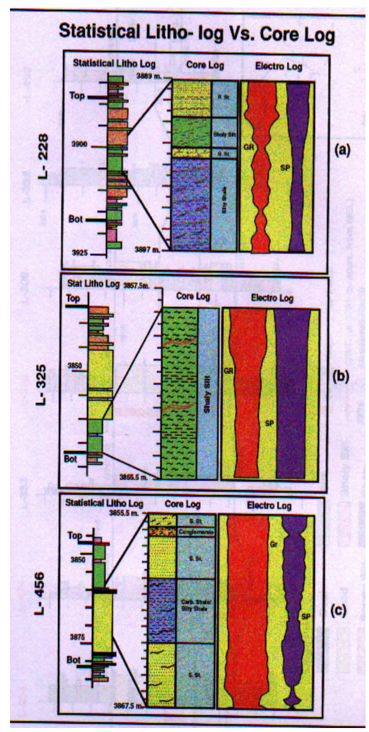

Fig- 5

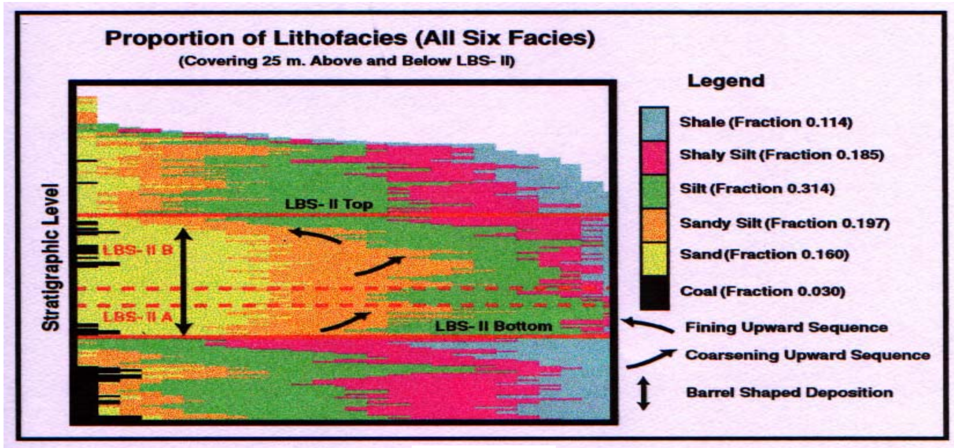

Fig- 6

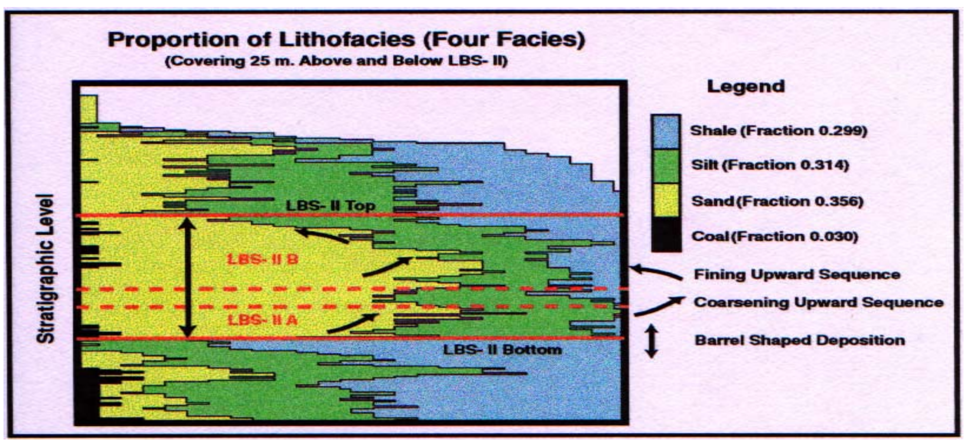

Fig- 7

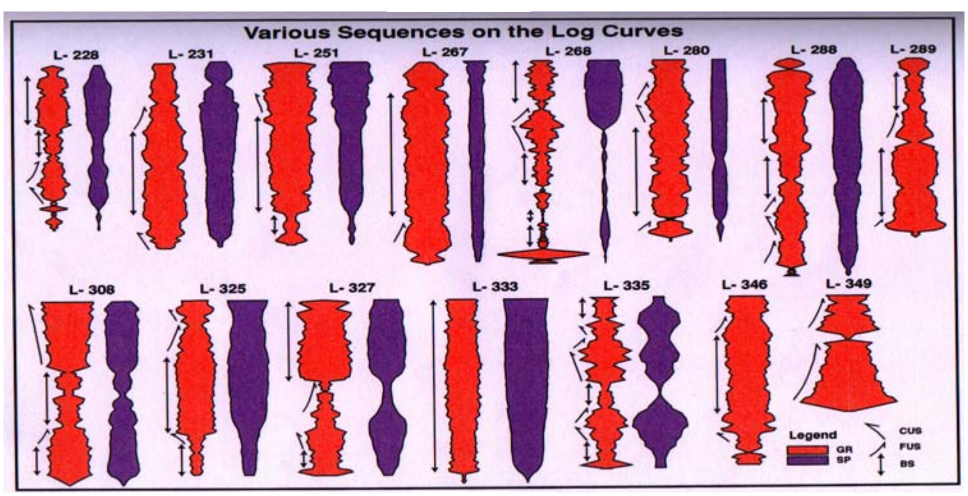

Fig- 8

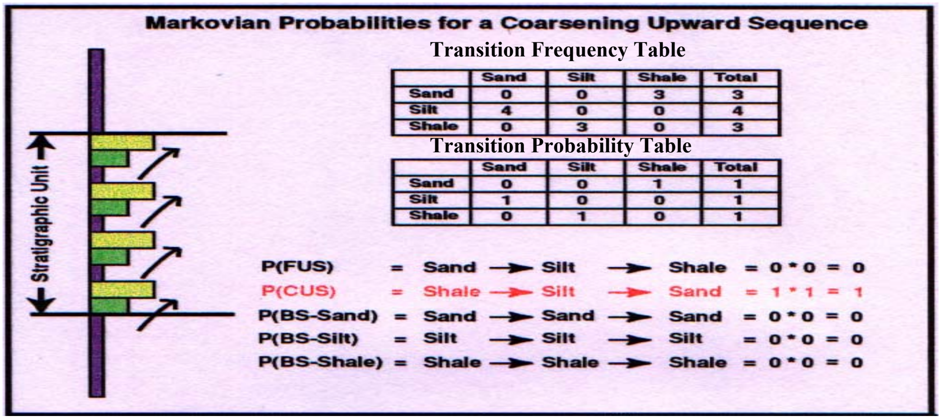

Fig- 9

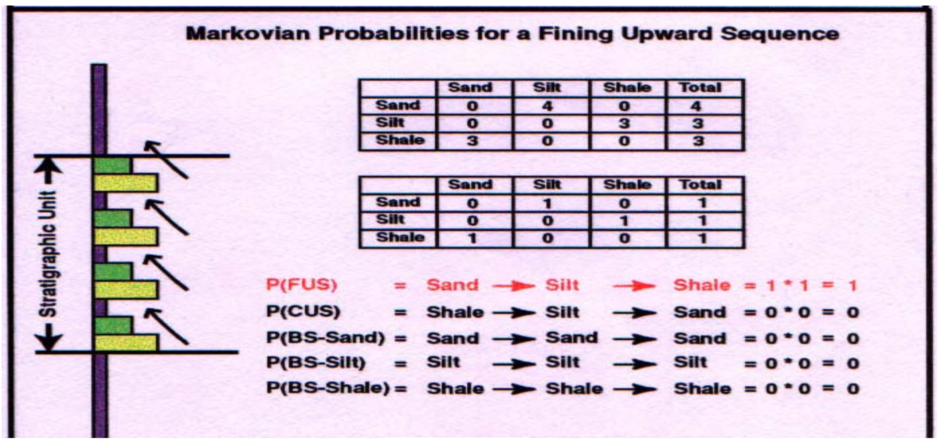

Fig- 10

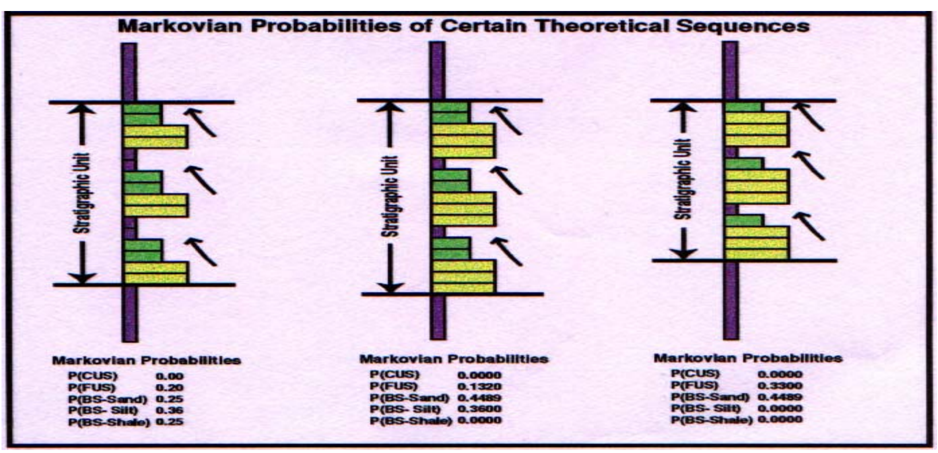

Fig- 11

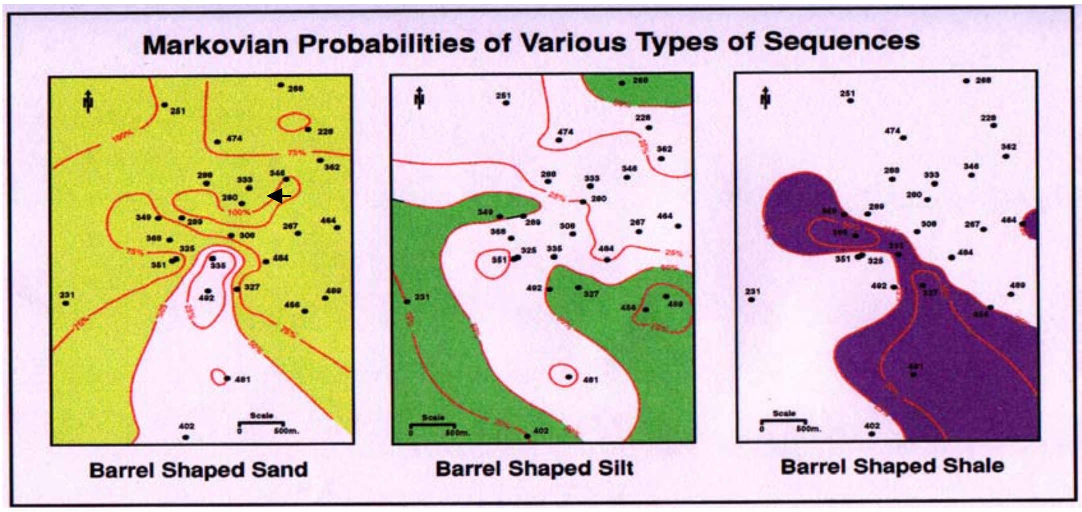
Markovian Probabilities of Various Types of Sequences
Barrel Shaped Sand
Barrel Shaped Silt
Barrel Shaped Shale

Fig- 12

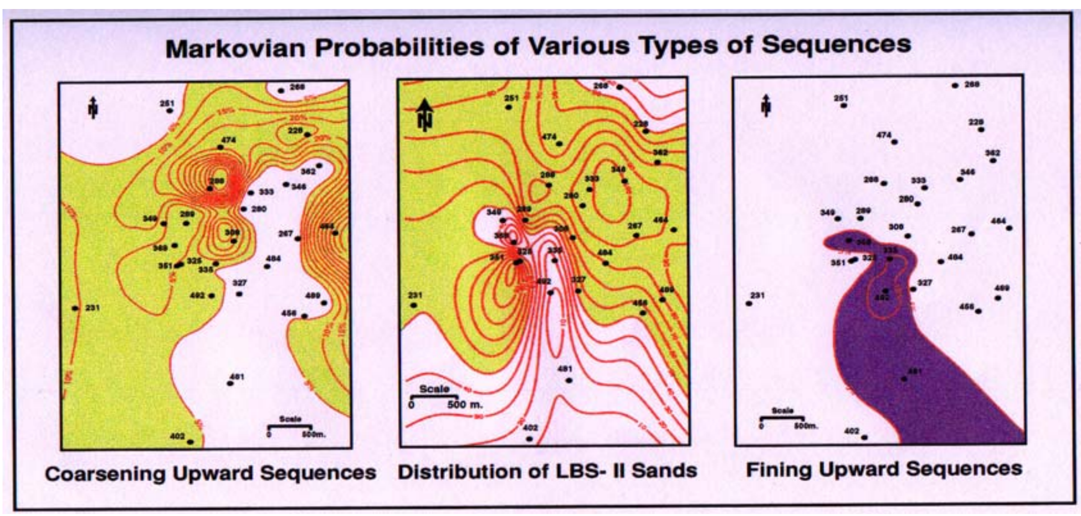
Markovian Probabilities of Various Types of Sequences
Coarsening Upward Sequences
Distribution of LBS- II Sands
Fining Upward Sequences

Fig- 13