使用计算机对下塔尔克乌砂岩组中浊积岩(罗马尼亚东喀尔巴阡山)的马尔科夫链分析

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如复理石沉积那样的垂向连续型韵律序列的研究能揭示有关生成过程和沉积区域的重要信息。无论不同岩性的垂向组合是否随机的,甚至没有沉积层序的优选次序,也能进行马尔科夫链分析这样的统计分析。此类分析适用于下塔尔克乌砂岩组(罗马尼亚东喀尔巴阡山)的复理石沉积,注意这些沉积物保存的发生程序并给以储存,而那些沉积物(至少被研究的层段)是浊流作用的产物,这些浊积物堆积在水道化沉积亚环境(诸如水道化的中深海扇之类)具良好分带的沉积区中。

APPLICATION OF MARKOV CHAIN ANALYSES USING COMPUTER IN TURBIDITES OF LOWER TARCAU SANDSTONE FORMATION (EAST CARPATHIAN MOUNTAINS, ROMANIA)

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ABSTRACT

Study of the vertical succeeding type of the rhythmic sequences such as flysch deposits can offer interesting informations concerning the generating processes and the depositional areas. Statistical analysis, such as Markov chains analyses, can establish if the different lithologies vertical association is random or not and, if not, which is the sedimentary sequences preferential order. This type of analysis was applied to the flysch deposits from the Lower Tarcau Sandstone Formation (East Carpathian Mountains, Romania), which were observed on the presence of a generating process with a memory and thus these deposits, at least for the studied interval, are the products of turbiditic processes accumulated in a sedimentary area with good zonation of depositional subenvironments such as channeled middle deep-sea fan.

The Palaeocene Ypresian Formation of Lower Tarcau Sandstone is part of Tarcau Nappe from the East Carpathians(Romania)and is constituted mostly of coarse and medium grained sandstones with intercalations of green and red pelites. An interval of thirty meters from the lower part of these deposits was studied in detail ,recording thickness,internal and external sedimentary structures,contacts and maximum grain size at the base of the beds.

At a first and general view these deposits show all the characters for sediments deposited from turbidity currents:rhythmicity and grading of internal sedimentary structures and, also special sedimentary features of texture as a result of turbulence.

The aim of the study was to establish the general trend of the bedding using a mathematical model that best fit the facies model in order to conclude the features of sedimentary distribution system and the hydrodynamic conditions. The first order Markov chain is such a mathematical model that investigates the relationship between rhythmic sequences and the generating process(which are considered to be random),using a transition procedure from one type of sediment to another,knowing the bed thickness distribution. Inside the stochastic models,the first order Markov chains searches for one-step memory in the vertical sequences of sediments,in the sense that a given state of the system depends on the last preceding one ,but not on earlier ones. A"step" means simply the deposition of a bed,a "state"is a lithologic or bedding type and the "memeory"involved in the process represents the influence of the past on present of future deposition since the deposition process is thought as a successive movement from one state to another,as the sedimentation proceeds with time. So ,over time,a preferred vertical stacking of facies will tend to occur. Such a preferential sequence was studied by recording the upward transitions between states,using the embedded procedure as the bed thickness distributions were found to be normal (lognormal). The result was the transition count matrix D(Table 1). The states were established in the field as being the divisions described by Bouma with the improvements of Einsele(1992)for coarse and fine grained turbidites:bs=basal scours,gr=graded sandstone (Ta Bouma),mv=massive and graded fine grained sandstone(without Bouma correspondent), ls = planar laminated sandstone(Tb Bouma),cb=cross-bedded or oblique laminated sandstone(Tc Bouma) and lm = laminated mud and mud without internal structures(Td,e Bouma).

Table 1 Transition count matrix D

	bs	gr	mv	ls	cb	lm
bs	0	9	5	0	2	0
gr	0	3	3	65	0	0
mv	1	1	0	33	1	0
ls	7	44	17	2	37	4
cb	7	9	8	12	0	14
lm	1	4	2	1	10	0

$P(\chi^2_{exp} > \chi^2_{obs}) = 4 \cdot 10^{-51}$

Departure from random behaviour was tested by standard chi-square statistic using a computer program for statistical analyses,the result being the probability of the two sets of data(the observed values against the expected ones)to be independent. The extremely low value of this test strongly suggests the existence of memory in the system and a first order Markov behaviour for the analysed sediments. This means that there is a recognisable pattern in upward succession of sedimentary facies that can relieve shifts in deposition environment through time, or trend in environmental parameters such as flow size, through time.

Memory is related to "conditional probability" that is "the probability of state given another state", that means their joint occurrence. Calculation of these probabilities from the data matrix D will offer the probability matrix P(Table 2).

Table 2 Probability matrix P

	bs	gr	mv	ls	cb	lm
bs	0.01	0.54	0.30	0.01	0.13	0.01
gr	0.01	0.01	0.05	0.91	0.01	0.01
mv	0.02	0.02	0.01	0.92	0.02	0.01
ls	0.06	0.39	0.15	0.03	0.33	0.04
cb	0.14	0.18	0.16	0.23	0.02	0.27
lm	0.06	0.23	0.10	0.05	0.55	0.01

The elements of this matrix $P_{ij} = D_{ij}/D_i$, where D_{ij} represent the total transitions from state i to state j(elements of matrix D)and D_i the total occurrences of state i; the elements P_{ij} range from zero to one: one means a certain transition from i to j and zero means that the transition from i to j can never occur. The probability matrix effectively describes the sedimentary rhythms and it was obtained from this matrix the preferred transitions diagram together with transport and deposition mechanisms' interpretation (Fig. 1)

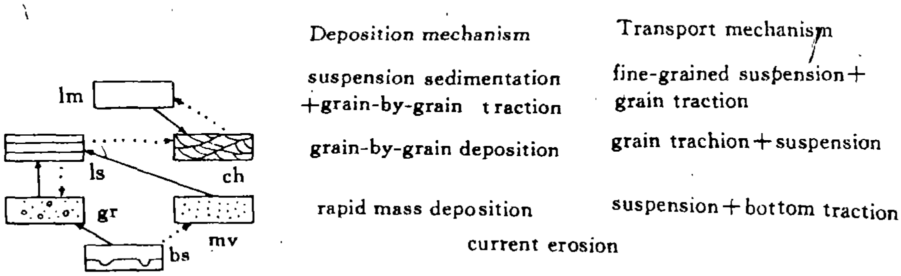

Fig. 1 Preferred transitions diagram. The solid arrows indicate a probability of transition higher than 50% and the dotted arrows a probability of transition higher than 25% but less than 50%

From this transitions diagram two general average bed models were obtained, one for the sand turbidites TS and one for the mud turbidites TM(Fig. 2).

It seemed necessarily from the beginning to separate these two types of turbidites as a result of two kinds of generating processes: high density turbidity currents and low density turbidity currents, as an expression of changes in source area or in frequency of turbidity events. Since the proportion of TS layers is very large(81%)compared with TM layers, that is, important changes in the source area not being expected, a low time of recurrence between the two events is more probable.

As it stands, Markov analyses take no account of the nature of contacts between the various states. For a correct interpretation of the rhythmic processes it is obviously important to document the nature of contacts, recording in field the transitions between states in terms of erosional, gradational or unknown(poor exposure)contacts. Form these data two preliminary matrices are derived: gradation matrix G and erosion matrix E, and then the

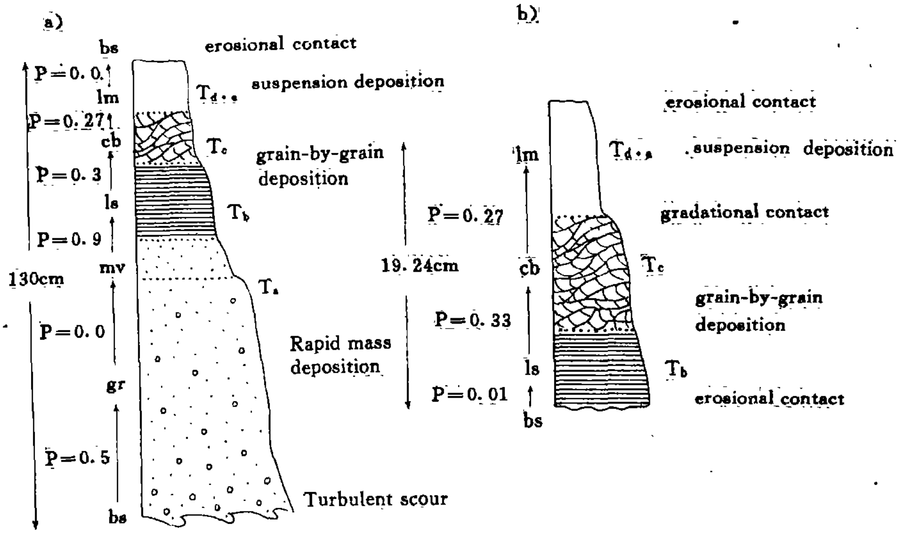

Fig. 2　General average bed model: a) sand turbidites TS: high density turbidity currents; b) mud turbidites TM: low density turbidity currents

contact matrix C can be constructed, consisting of elements obtained as follows: $C_{ij} = (G_{ij} - E_{ij})/(G_{ij} + E_{ij})$ (Table 3).

Values in contact matrix are from -1 to 1; negative scores indicate a preponderance of erosion contacts, positive scores indicate a preponderance of gradational contacts. Zeros indicate equal numbers of contact types or no data. If the facies are arranged in order of decreasing grain size and sedimentary structure scale from right to left and bottom to top, it is quite easy to see that, in studied formation, there are gradational relationships for the fining-upward transitions (this being the net trend for the observed interval) and, also, each new turbidite has an erosional base.

Table 3　Contact matrix C

	lm	cb	ls	mv	gr
lm	0	−1	−1	−1	−1
cb	1	0	0.5	−1	−1
ls	1	0.68	−1	−1	−1
mv	0	1	1	0	0
gr	0	0	1	1	−1

For a preliminary hydrodynamic interpretation the bed thickness was plotted on logarithmic scale against maximum grain size present at the base of the bed (Fig. 3). Since maximum grain size is a reflection of flow competence, it was deemed essential to select a single grain type, in order to minimise the variation in grain properties other than size and the quartz grains were an obvious choice. The measurements were made using slides.

This graph represents the vertical grading curve and reflects temporal decaying of competence in the tail of the turbidity current at a single location. It also indicates that the internal structures, such as cross-bedded (cb) and laminated sand (ls) occur within a restricted range of maximum grain size and thickness. It is clear from the graph that the logarithms of bed thickness and maximum grain size are correlated and the regression is curvilinear with a parabolic trend, as a reminiscence of the shape of fall-velocity curve plotted as log grain size against log velocity: it is steep at grain sizes between 0.2—2.0mm and distinctively less steep at finer grain sizes. This kind of parabolic trend is characteristic for the middle part of a submarine fan, where the turbidity currents are channelled and so, their upper zone can be spilled over the channel banks and can form levee and overbank deposits, which include fine, thin, graded beds of "distal" type turbidites, but occur in a distinctive proximal association as gr and mv. It must be said that, overbank deposits as ls-lm divisions from TS, and the thin, fine-grained mud turbidites TM plot together on this graph.

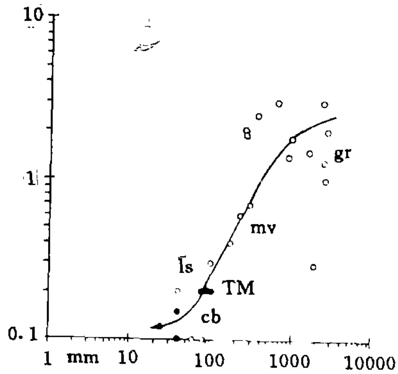

Fig. 3 Grain size (vertical axes, logarithmic) — bed thickness (horizontal axes, logarithmic) vertical trend

As a few conclusions may be retained:

-the existence of vertical memory in the system demonstrates a systematic, horizontal zonation of the deposition environment, such as a channelled submarine fan and also a vertical zonation inside the turbidity currents;

-the thicker and coarser divisions of TS without internal structures, such as gr and mv were deposited as channel sediments by rapid mass deposition from suspension, since the thinner and finer-grained divisions of TS (ls, cb and lm) represent levee and overbank deposits, generated by a fractionation of a thick, high density turbidity current. The result is a thinning and fining upward sequence;

-the thin and fine-grained mud TM turbidites are probably the product of low density turbidity currents, rather as increasing in events frequency than major changes in the source areas;

-the vertical preferential succession of the sequences is related to lateral shifts of deposition environments through time, with approximate maintenance of boundaries and to the fact that the turbiditic processes are dynamic, non-stationary process.

At the end it must be said that these preferential successions or transitions depend rather of probabilities than certainties and the only stable part of the Markovian model is the tendency.

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