KRZYSZTOF JAWOROWSKI
Geological Institute, Warsaw

NEW TECHNIQUES IN REGIONAL SEDIMENTOLOGICAL ANALYSIS

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Among sedimentological phenomena there is one which particularly successfully „escapes" quantitative or semiquantitative approach. This is the occurrence of sedimentary structure. In the broad sense of the term it is still purely descriptive concept devoid of any quantitative aspect. It should be clarified here that this remark refers to the „quantity" of sedimentary structure and not to the thickness of deposits in which such a structure is observed. Thickness of deposits is obviously easy to express quantitatively but this should not be confused with the „quantity" of sedimentary structure itself.

For example, if cross-bedding occurs in a sandstone bed 10 metres thick, it does not mean that this bedding is equally distinct and equally frequent throughout the whole bed both when its vertical and lateral variabilities are concerned. Therefore, 10 metres mentioned above cannot be accepted as a proper measure of „quantity" of cross-bedding.

The lack of quantitative, numerical measure of the occurence of sedimentary structure is a serious problem in regional, sedimentological mapping.

In the attempt to solve this problem it is assumed here that the „quantity" of sedimentary structure may be determined on the basis of its frequency. In a given section, every sedimentary structure which occurs with adequate frequency is believed to occur in large quantities. The question arises, however, how to measure the frequency of sedimentary structure and what its adequate frequency is? In other words, how to transform the vague concept of frequency of sedimentary structure into a numerical, mappable value?

In the course of studies on the oldest marine transgression in Poland some simple quantitative and semiquantitative techniques have been elaborated and successfully applied. The basic principles of the techniques are explained in Fig. 1.

As an example the geological section shown there is examined and deposits belonging to β stratigraphic unit are a subject of detailed study. The boundaries of β unit are defined palaeontologically. Hence, the top boundary of β unit does not coincide with the change in lithology and is drawn within the bed of medium-grained sandstone.

The data necessary for quantitative or semiquantitative evaluation of various sedimentological properties are collected in the form of sedimentological

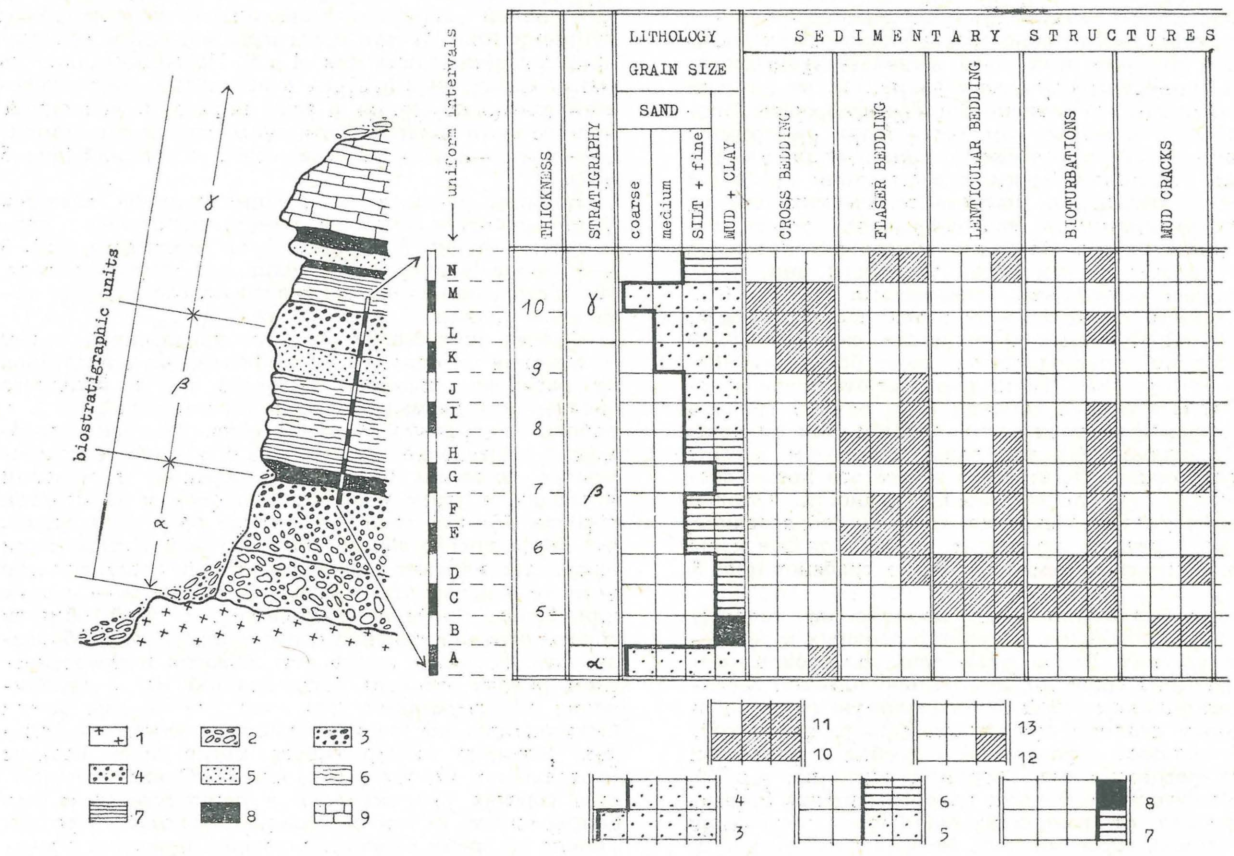

Fig. 1. Sedimentological logging by uniform interval method.

Lithological symbols: 1 — crystalline basement, 2 — conglomerates, 3 — coarse-grained sandstones, 4 — medium-grained sandstones, 5 — fine-grained sandstones, 6 — alternating sand/mud laminae (sand predominates), 7 — alternating mud/sand laminae (mud predominates), 8 — clay and/or mud, 9 — limestones. Frequency of sedimentary structures: 10 — abundant, 11 — common, 12 — rare, 13 — absent. Detailed explanations in the text.

Ryc. 1. Profilowanie sedymentologiczne metodą odcinka jednorodnego.

Symbole litologiczne: 1 — podłoże krystaliczne, 2 — zlepieńce, 3 — piaskowce gruboziarniste, 4 — piaskowce średnioziarniste, 5 — piaskowce drobnoziarniste, 6 — przekładańce piaszczysto-mułowcowe (przeważa materiał piaszczysty), 7 — przekładańce mułowcowo-piaszczyste (przeważa materiał mułowcowy), 8 — iłowce i/lub mułowce, 9 — wapienie. Częstotliwość struktur sedymentacyjnych: 10 — bardzo częste, 11 — częste, 12 — rzadkie, 13 — brak. Szczegółowe objaśnienia w tekście.

graphic log. Such a log is presented to the right of the section shown in Fig. 1.

In regional, sedimentological analysis graphic logs have to be set up for every surveyed section separately. Many methods of graphic representation of rock succession have been developed and published. The most popular are those proposed by A. Bouma (1) and R. C. Selley (5). The technique advanced here is based on the uniform interval method. The latter is of essential importance for turning sedimentary structures into mappable, numerical values.

In the method of uniform interval a geological section is subdivided mentally into a number of artificial „beds" of the same thickness (2). Each of these „beds" constitutes one uniform interval. The thickness of a uniform interval depends on the precision needed and on the object of study. It can be of the order of 1 metre when monotonous, thick sequence is surveyed in the field; it can also equal 1 millimetre, or even less, when a thin-section is measured under the microscope.

In Fig. 1, the uniform intervals are marked as white and black sectors of the rod placed across the beds of β unit. To facilitate further discussion, all the uniform intervals have been marked with capital letters.

Every uniform interval is considered as being lithologically homogenous and is represented by the rock type which prevails in a given interval. For example, in the second uniform interval of β unit, that is in C interval, alternating mud and sand is major rock type. This observation is recorded in graphic log (Fig. 1, column LITHOLOGY) with corresponding lithological symbol. The position of the thick line in sedimentological graphic log should be noted. It shows the dominant grain-size for every uniform interval (f.e. in C interval mud predominates).

Frequency of every sedimentary structure observed in the section is recorded separately for every uniform interval. It is shown by hatched areas in the column designed for a given structure. The semiquantitative, subjective measure of frequency was adopted. The hatched area (see Fig. 1, symbols 10, 11, 12, 13) measures 3 unit squares when a given sedimentary structure is abundant in a given interval; 2 unit squares — when it is common; and 1 unit square — when it is rare. Blank unit squares in the column of a given sedimentary structure mean that this structure does not occur at all. For example, in the uniform interval D, lenticular bedding is abundant, bioturbations are common, mud cracks and flaser bedding are rare and cross-bedding is absent.

The term „unit square" mentioned above requires an explanation. This is a square with a side equal to the adopted thickness of uniform interval drawn on a scale adopted for compiling graphic log.

To describe numerically sedimentological properties of a geological section the following semiquantitative and quantitative indices were introduced.

Frequency-index of sedimentary structure *(FS)* given by

$$FS = \frac{z'}{z}$$

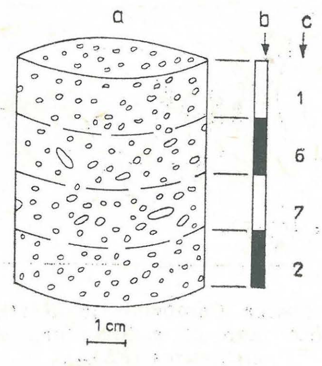

Fig. 2. Data for calculating average maximum-grain size (MG).

a — geological section (fragment of drill core), b — uniform intervals. c — maximum-grain size (in millimetres). Detailed explanations in the text.

Ryc. 2. Dane do obliczenia średniej wielkości ziarna maksymalnego (MG).

a — profil geologiczny (fragment rdzenia wiertniczego), b — odcinki jednorodne, c — wielkość maksymalnego ziarna (w mm) dla każdego odcinka. Szczegółowe objaśnienia w tekście.

where z' stands for the area hatched in the column used to record a given sedimentary structure (that is total number of hatched squares in this column), and z for the maximum area which can be hatched in the column used to record a single sedimentary structure. In other words z expresses total number of squares which can be hatched in a single column. It is equal to the number of uniform intervals, within the boundaries of stratigraphic unit under consideration, multiplied by 3. Thus, FS is the ratio of hatched area of the column of a given sedimentary structure to the total area of this column.

Here is another example. Frequency-index of mud cracks (FS_{mc}) in the section studied (Fig. 1), is 4 divided by 10 × 3, where 10 is the thickness of β unit expressed in terms of uniform intervals. The resultant value is 4/30, that is 0.13.

No-structure index (NS) defined as

$$NS = \frac{kz - \sum_{t=1}^{k} z'_t}{kz}$$

where z is the same as above, z'_t is the area hatched in the column used to record sedimentary structure t, and k is the number of all sedimentary structures recorded in the graphic log. Hence, NS is a ratio of non-hatched area in all the columns to their total area. This may be taken as a measure of an internal homogeneity of sediments.

In case of graphic log presented in Fig. 1, k is 5, and non-hatched area equals $5 \times 30 - (4 + 12 + 12 + 10 + 4) = 150 - 42 = 108$. Then $NS = 108/150 = 0{,}72$.

Another useful index is frequency-index of contacts (FC) given by

$$FC = \frac{a}{l-1}$$

where a is the total number of contacts between different rock types in a given section within the boundaries of stratigraphic unit under consideration, and l is the total number of uniform intervals within these moundaries. It means that $l - 1$ is the maximum number of contacts between different lithologies within the boundaries of an examined stratigraphic

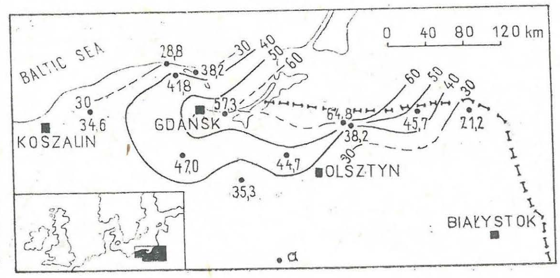

Fig. 3. The Lower Cambrian in Northern Poland: frequency-index map of bioturbations (FS_{biot}).

a — sections examined (boreholes).

Ryc. 3. Dolny kambr w północnej Polsce: wskaźnik częstotliwości bioturbacji (FS_{biot}).

a — zbadane profile (wiercenia).

unit when both the bottom and the top contacts of this unit are omitted.

With regard to the example shown in Fig. 1 (column LITHOLOGY), it can easily be found that a is 6 and l is 10. Which means that $FC = 6/9 = 0{,}67$.

Variability of grain size can easily be characterized by average maximum-grain size (MG) defined as

$$MG = \frac{\sum_{j=1}^{l} M_j}{l}$$

where M_j is the largest dimension of maximum grain observed in j-th uniform interval, and l is the total number of uniform intervals in a given section within the boundaries of stratigraphic unit under consideration.

In Fig. 2 the maximum grains visible on the outer surface of core fragment attain 1, 6, 7, and 2 millimetres in size respectively. As there are 4 uniform intervals, we obtain $MG = (1 + 6 + 7 + 2) : 4 = 16/4 = 4.0$ mm

MG is clearly quantitative notion. The remaining indices (FS, NS, FC), mainly semiquantitative in nature, are relative measures and their values vary within the range 0 to 1.

By the use of the above presented indices, many sedimentological properties, including even those usually characterized only descriptively, can be easily mapped. The numerical values of the indices are simply plotted on due maps at location points of sections examined and then contour lines are drawn.

An important reservation must be made here regarding the interpretation of the maps showing variability of the occurrence of sedimentary structures. Frequency-indices of sedimentary structures are not accurate, objective measures. Hence, when interpreting the maps, exact values of the indices are not so important as their lateral variability. First of all, the arrangement of contour lines, and the distribution of local highs and lows, are of interest.

An interesting example of what can be achieved with these techniques is given by the report on Cambrian marine transgression in Northern Poland (3). The report was published last year by Geological Survey of Poland. Fig. 3 shows the location of the sections examined. It should be noted here that Lower Cambrian deposits encountered in Northern Poland occur at a depth ranging from 5 000 metres in the west to 1 000 metres in the east. They have been examined by means of deep boreholes.

Fig. 3 demonstrates sketch-map of frequency-index of bioturbations. This map indicates areas of relatively slow and fast accumulation. The interpre-

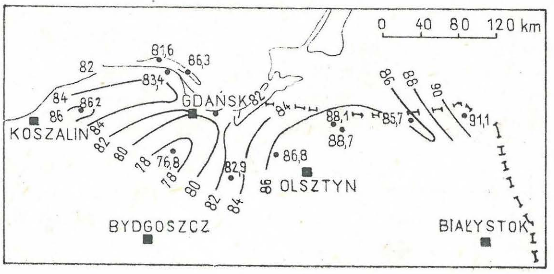

Fig. 4. The Lower Cambrian in Northern Poland: map of no-structure index (NS).

Ryc. 4. Dolny kambr w północnej Polsce: mapa wskaźnika braku struktur sedymentacyjnych (NS).

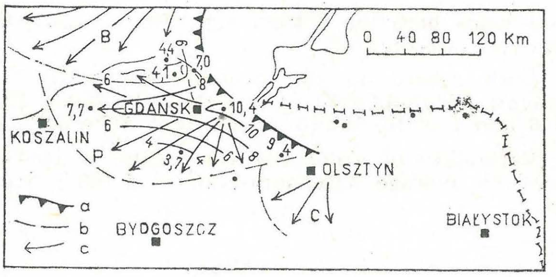

Fig. 6. Precambrian alluvial fans in Northern Poland (Żarnowiec Series): map showing average maximum-grain size (MG).

B — supposed Baltic fan, P — Pomeranian fan, C — Ciechanów fan, a — escarpment in crystalline basement, b — boundaries of alluvial fans, c — transport directions.

Ryc. 6. Prekambryjskie stożki aluwialne w północnej Polsce (seria żarnowiecka): mapa średniej wielkości ziarn maksymalnych (MG).

B — przypuszczalny stożek bałtycki, P — stożek pomorski, C — stożek ciechanowski; a — skarpa w podłożu krystalicznym, b — granice stożków aluwialnych, c — kierunki transportu.

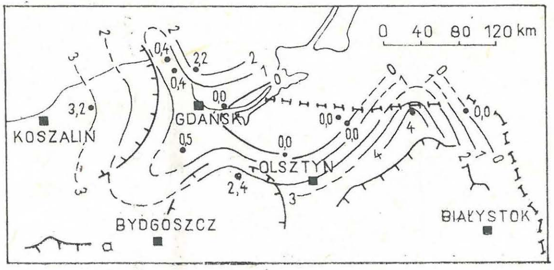

Fig. 5. The Lower Cambrian in Northern Poland: frequency-index map of sedimentary deformational structures (FS_{def}).

a — boundaries of granite massifs in crystalline basement (after S. Kubicki, W. Ryka, J. Znosko, 4).

Ryc. 5. Dolny kambr w północnej Polsce: wskaźnik częstotliwości sedymentacyjnych struktur deformacyjnych (FS_{def}).

a — granice masywów granitowych w podłożu krystalicznym (wg S. Kubickiego, W. Ryki, J. Znoski — 4).

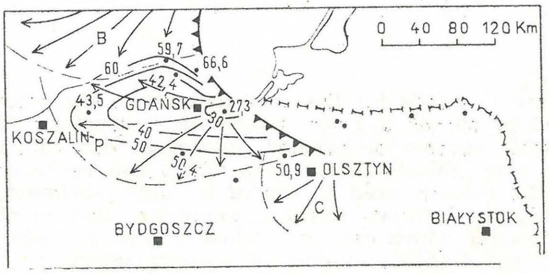

Fig. 7. Precambrian alluvial fans in Northern Poland (Żarnowiec Series): frequency-index map of contacts (FC). Explanations as in Fig. 6.

Ryc. 7. Prekambryjskie stożki aluwialne w północnej Polsce (seria żarnowiecka): wskaźnik częstości kontaktów (FC). Objaśnienia jak na ryc. 6.

tation follows from the fact that frequency of bioturbation can be taken as a simple measure of accumulation rate. Leaving aside other factors such as availability of food, aeration of bottom waters, bioturbation structures are produced mainly in the areas of slow sedimentation. Of special interest is the fact that this map (Fig. 3) presents quite different picture than the map of no-structure index (Fig. 4). The latter is here interpreted as an illustration of the lateral variability in rate of deposition (not to be confused with accumulation rate !). While accumulation rate is a ratio of sediment thickness to the time-span of the whole stratigraphic unit represented by this sediment, the deposition rate is a ratio of sediment thickness related to a single continuous process to the time-span of its uninterrupted, depositional action.

Higher values of no-structure index correspond to higher values of deposition rate. Distinct differences between the patterns of contour lines visible on the maps discussed (Figs 3, 4) indicate that sedimentary environment of Lower Cambrian deposits in Northern Poland was characterized by highly varying accumulation and deposition rates. Such a situation is typical feature of tidal zones, which is in good agreement with the general interpretation of the deposits discussed.

The sketch-map shown in Fig. 5 demonstrates lateral variability of frequency-index of sedimentary deformational structures. These are mainly load-casts and small-scale synsedimentary folds. It is of interest to note that the arrangement of contour lines in Fig. 5 entirely differs from those visible in the maps of other sedimentary structures. At the same time, the pattern of contour lines in Fig. 5 follows fairly well the outlines of granite massifs occurring in the crystalline basement (cf. 4). The massifs are surrounded and separated by younger (Svecofenno — Karelian) metamorphic rocks. It is believed that during subsidence of crystalline basement in marginal zones of the massifs there were small seismic tremors. Such tremors could act as a trigger mechanism which released internal readjustment movements in plastic deposits of different density.

Fig. 6 illustrates the lateral variability of the average maximum grain-size in the so-called Żarnowiec Series, the Uppermost Precambrian. The Series was formed in environment of alluvial fans. The pattern of contour lines in Fig. 6 shows the directions of transport of clastic material and location of feeding point where this material was delivered into sedimentary basin. The feeding point of the fan occurring in Northern Poland was in the vicinity of Gdańsk, from where clastic material was radially distributed.

The above interpretation is supported by that of the sketch-map of frequency-index of contacts in the

Żarnowiec Series (Fig. 7). Frequency-index of contacts indicates how far depositional process had taken the „opportunity" of arranging alternately different rock types. This is the ratio of observed number of contacts in a given section to the maximum possible number of contacts in the section. The maximum possible number of contacts clearly depends on adopted thickness of uniform interval. The discussed map (Fig. 7) clearly demonstrates the arrangement of marginal zone of the fan occurring in Northern Poland. In the marginal or, more exactly, the transitional zone between inner and outer-fan, various deposits occur recurrently. That is why the values of frequency-index of contacts increase towards this zone.

Summarizing this short review of the application of the techniques discussed, it can be concluded that these techniques promise a reliable research tool. Although extremely simple, they stem from the field of mathematical geology. The latter meets rather diverse emotions of geologists. It should be emphasized that the techniques presented here do not require any special assumptions which are inevitable when more sophisticated mathematical methods are employed. Such assumptions usually have one disadvantage: they do not agree with geological reality. The techniques discussed in this paper are free from that irksome defect.

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STRESZCZENIE

W jaki sposób określić „ilość" struktury sedymentacyjnej? Jak ustalić czy proces depozycyjny często miał „okazję" do składania na przemian różnych rodzajów skał?

Niniejsza praca stanowi próbę rozwiązania tych problemów. Wprowadzono proste wskaźniki numeryczne umożliwiające ilościową ocenę następujących parametrów sedymentologicznych: 1) występowanie struktur sedymentacyjnych, 2) jednorodność wewnętrznej struktury osadu, 3) zmienność rozmiarów ziarn największych, 4) względna częstość wzajemnych kontaktów różnych rodzajów skał. Obliczenie wskaźników wymaga zebrania wszystkich danych w formie graficznych profilów sedymentologicznych. Profile te muszą być zestawione zgodnie z metodą odcinka jednorodnego. Sporządza się je osobno dla każdego badanego profilu geologicznego. Dzięki wskaźnikom omawianym w pracy niektóre parametry sedymentologiczne, zwykle charakteryzowane jedynie opisowo, mogą być łatwo skartowane. Wszystkie obliczenia są bardzo proste.

Przedstawione metody były z powodzeniem stosowane w badaniach osadów prekambryjskich i kambryjskich północnej Polski.

РЕЗЮМЕ

Как установить „количество" седиментационной текстуры? Как определить, часто ли депозиционный процесс имел „оказию" складывать попеременно разные типы горных пород? Настоящая статья является попыткой решения этих вопросов. Приведены простые численные показатели, которые делают возможной количественную оценку следующих седиментологических параметров: (1) распространение седиментационных текстур, (2) однородность внутренней текстуры осадков (3) изменчивость размеров самых больших зерн, (4) относительная частота взаимных контактов разных типов горных пород.

Для расчёта этих параметров необходимо собрание всех данных в форме графических седиментологических разрезов. Эти разрезы следует составлять согласно методу однородного интервала, отдельно для каждого исследованного геологического разреза. Учитывая приведенные в статье показатели можно картировать некоторые седиментологические параметры, которые до сих пор были характеризованы только описательным способом. Все расчёты очень простые. Представленные в статье методы были успешно применяемые в исследованиях докембрийских и кембрийских осадков северной Польши.