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Basic Geometrical Models in Geology: Werner's Topological Model[1]

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Werner's topological model is the most fundamental geometrical model in geology. It takes into account only order and continuity of geological bodies. Within this model, stratigraphic and geochronologic concepts of simultaneity, scale, stratigraphic units, facies, discordances, and so forth are defined, and algorithms for solving practical correlation problems may be worked out. Application of algorithms is illustrated by computer correlation of sections in East Kamchatka.

KEY WORDS: stratigraphy, correlation, stratifying sequence, geochronological scale.

CONSTRUCTION OF A MODEL

If a search for mineral resources is the primary aim of geology, a geological map is the main tool to use. It serves as a necessary start and basis for investigation because it allows us to obtain information on distribution of material and structural characteristics in space and their change in geological time.

The fundamental role of a geological map can be inferred from any definition of geology as the science about the structure and history of earth. Structure of the studied object must be determined in order to reconstruct history; structure, in its turn, is a set of spatial relations of geological objects also representing spatial bodies. Spatial characteristics and relations of geological bodies are determined with the help of a geological map.

Beginning with A. G. Werner, a map showing distribution of stratigraphic units in space (i.e., bedded rock masses different from overlying and underlying rock masses) is regarded as a geological map.

In a succession of geometrical models to be constructed, the first must be a topological model that describes spatial characteristics invariant under geometrical transformations such as distorting lengths, squares, relationships of

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parallelism, perpendicularity, properties of convexity, curvature, or smoothness. Topological transformations retain only continuity of any lines of the figure; infinitessimally close points remain infinitessimally close, and finitely distant points remain finitely distant. Topological characteristics of undislocated bedded rock masses do not change after folding.

A topological model for a bedded rock mass is, for example, Werner's model. In accordance with it, "The whole globe had been environed by a succession of distinct aqueous formations disposed round the nucleus of the planet, like the concentric coats of an onion" (Lyell, 1865, p. 94). The name "coats of an onion" was fixed on Werner's scheme after Lyell's "Elements" (1865). The essence of this scheme is in earth's structure approximated by a system of stratified rock complexes overlying one another. Werner's principal contribution to geology is a stratigraphic approach to geological mapping. As stated by Weller (1960, p. 563), "Stratigraphy had its origins in the German school of Wernerian geology." Spencer (1866) gave the most precise formulation of this approach in which continuous strata lie one above the other in a regular order like "coats of an onion" throughout earth. This statement evidently shows that no geometrical characteristics but only topological properties of continuity and succession (order) are used.

The model which serves as a basis for practical and theoretical geology during the last 200 years deserves formalization.

Initial Concepts

Let us construct "an onion" model answering all requirements. This makes us define all concepts and explicitly present a succession of construction steps without gaps and circles. Let us try to minimize the number of concepts in the system, the number of steps in the procedure of construction, and the number of initial premises. We shall try to attain maximum simplicity of construction.

The author has been developing his own scientific approach since 1970, at first in Novosibirsk together with Yu. A. Voronin and others (1971, 1972), then in Khabarovsk together with Ye. I. Goncharova and others (Salin, 1974, 1976, 1979, 1983; and Goncharova et al, 1977). In our early works a stratigraphic problem was formulated for the first time as a problem of ordering, and stratigraphic concepts were defined on the basis of set theory.

Works of Hay (1972), Hay and Southam (1978), Dienes (1974a, b), Dienes and Mann (1977), and Rubel (1976, 1978) can be treated as closest in mathematical geology. Hay employs probabilistic characteristics besides relations of order. Other authors do not use such characteristics.

Dienes's and Rubel's constructions as well as ours are based on relations of order and other concepts of set theory. In one of his first papers, Dienes (1974a, p. 138) writes that among previous works on ordering of geological bodies by deterministic mathematical methods there is "only one pioneer paper, that of

Yu. A. Voronin et al., 1973." Rubel (1976) in his first work on the subject under discussion employs results obtained by Yu. A. Kosygin, Yu. S. Salin, and V. A. Soloviov (1974), and other works. My approach can be called "mathematical formulation of traditional methods tested during centuries of geological practice." The specific feature of my approach is that I do not use mathematical systems and methods worked out in other sciences, and for other purposes (pattern recognition, cluster analysis, polynomial approximation, method of principal components, etc.). Methods and instruments used are: Werner's model, Steno's and Smith-Werner's laws, concepts of stratigraphic relations, guide species, zonal sequences, and geochronological scale.

Both concepts (a section and an attribute) are defined directly or indirectly by some operations of observations and measuring.

Besides initial geological concepts, basic concepts of geometry are used. They are "a point," "a line," "to situate on . . ." (for example, "two points are situated on one and the same line").

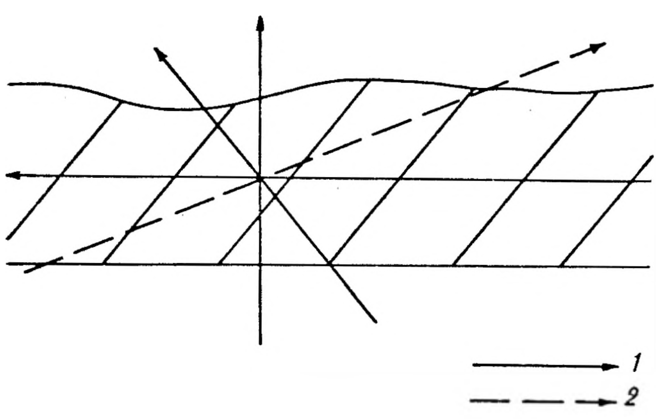

Fig. 1. Permissible (1) and impermissible (2) deviations from plumb line.

Let only observed data on the distribution of points possessing the studied attributes in sections be initial data.

Stratigraphic Relations, Stratifying Sequence, a Geochronological Scale

Let us introduce the concept of stratigraphic relations first for points and second for attributes.

Two points, m and n, have stratigraphic relations if they are in the same section. If m follows n, then a relation of m to n is a stratigraphic relation "above," and a relation of n to m is a stratigraphic relation "under." Points have no stratigraphic relations if they are not in the same section.

The same relations between attributes are determined in earlier works (Rubel, 1976, 1978; Salin, 1974, 1976). Hay (1972), Hay and Southam (1978) when constructing a matrix of relationships of events define a matrix element as number $a_{ij} = n_{ij}/N_{ij}$, where n_{ij} is the number of stratigraphic sections in which i precedes j. N_{ij} is the number of stratigraphic sections, in which either i precedes j, or j precedes i.

Dienes and Mann (1977) introduce 25 spatial relations of precedence. It is difficult to say what purpose such a great number of introduced concepts serves. In our system, the aim of determination of relations between attributes is to construct sequences with their help. The "above-under" relations permit us to construct sequences; absence of stratigraphic relations does not hinder us when constructing sequences, and establishment of unstratifying relations between A and B prohibits use of pair A and B in the same sequence, and so relations of inclusion, coincidence, interbedding, and intersection in this sense are absolutely equal.

The concept of a "stratifying sequence" is defined as a sequence of attributes in which every attribute is above the immediately preceding one and has no other stratigraphic relations with any other preceding attribute. In other words, it must not have the "under" relations with other preceding attributes and must not be "unstratifying." It may be only above, or have no relations.

The concept of a stratifying sequence is the key concept in the model. In a stratifying sequence, relations of age ordering and equivalence may be introduced unambiguously and without contradiction on the basis of Steno' and Smith-Werner's superposition laws. In the sequence A, B, C, D, E, for example, a point with attribute C may be regarded as age equivalent to any other point with attribute C younger than all points with attributes A and B but older than points with attributes D and E.

Contradictions can arise in the process of determination of age relations by different stratifying sequences. To exclude contradictions, the best sequence among all sequences built on a basis of a given set of described sections must be selected. Age relations established by the best sequence will be considered true by definition. The best sequence will be called a geochronological scale, and its members will be called guide attributes.

The best sequence provides the most detailed subdivision, and the most distant tracing of discriminated units. A quantitative criterion must be established which allows us to evaluate both subdivision and tracing qualities.

Let us imagine a stratifying sequence $A, B, C, D, \ldots$, and arrange stratigraphic units determined by these attributes on a horizontal plane. A stratigraphic unit determined by attribute A will be placed near a stratigraphic unit determined by attribute B. A unit determined by attribute C will be placed near the preceding unit; then we'll place a unit by attribute D, and so forth. The size of such a horizontal representation of a stratifying sequence will grow with an increase of vertical resolution (i.e., with an increase in number of stratigraphic units singled out in the same fragment of earth's crust), and with an increase of each unit's distance of tracing. Contrarily, size will diminish with a decrease of both vertical resolution and distance of tracing. Size of horizontal representation can be measured in kilometers and square kilometers.

One more measure for size of a horizontal representation can be proposed. If attribute A occurs in five sections, we say that its frequency equals 5. Attribute B has, for example, frequency equal to 3, frequency of attribute C equals 8, and so forth. Let us calculate the sum of frequencies of all members of the sequence $A, B, C, D, \ldots$. In this paper, the best stratifying sequence was selected among all sequences according to the greatest sum of frequencies.

Dienes (1978) defines a standard scale, which he calls a time scale, in another way: "An event is termed first if it is not preceded by any other events and its number is the smallest. An event is termed second, if it is either not preceded by other events excluding the first event, or if this does not exist, an event which is preceded by one event and its number is minimal."

Let us imagine a widespread geological situation. Many shallow Neogene wells and three deep Silurian wells have been drilled. Among attributes occurring at the bottom of Neogenes many attributes will be absent from deep wells. Together with Silurian attributes they will occur at the bottom of the scale. But according to Dienes's algorithm from two events that are preceded by no other event, the event with the smallest number is chosen. But then a key moment in all actions should be a procedure of the events' numbering, and this is not given.

Rubel (1976, 1978) orders a set of attributes on the basis of a square matrix of attributes relationships. The symbol "–" is placed at the intersection of ith row with jth column, if i precedes j; symbol "+" is used if i succeeds j; and symbol "0" is used if intervals i and j overlap. Order of attributes is established by decreasing number of minuses and increasing number of pluses. However, in many geological situations such ordering may lead to incorrect results.

For example, in Korf coalfield of Kamchatka, a continental rock mass is the youngest. It has been elaborately studied and more than 200 taxa of plant remains have been recognized. Several less extensively studied marine rock masses are older. Only about 50 attributes were fixed. In available sections, continential rock masses superposed only the uppermost sea horizon—"echinoid's" horizon. In other sections, "echinoid's" horizon superposed other marine rock masses. Direct relations of these older marine rock masses with coal-bearing deposits were observed nowhere. According to Rubel, attributes of "echinoid's" horizon must be regarded as the oldest, having up to 200 symbols "–", whereas attributes of the oldest marine rock masses cannot get more than 50 symbols "–".

Age Range and Geological Age

In order to use all available data for synchronization, the concept of age range is introduced.

Let us number members of the geochronological scale from 1st (the oldest) to Nth (the youngest). Let I and J be members of the scale, J younger than I, and so $J > I$. If attribute K is above the $(I - 1)$th member of the scale and has no other stratigraphic relations with preceding members and if it is under the $(J + 1)$th member and has no other stratigraphic relations with subsequent members, its age range includes all members of the scale from I to J. Let us designate it as $[I, J]$.

Therefore, the geochronological scale (a succession of guide attributes) will serve as a standard for age evaluation of all other attributes.

By definition, age range of guide attribute I is attribute I itself.

Earlier, a range in relation to a standard scale representing an ordered set of events, attributes, or their boundaries was likewise established by Dienes (1978) and Salin (1974, 1976).

At some point in the section, in a certain stratum, several different attributes can be fixed, so that a concept of an interval of intersection (i.e., common part, as is accepted in geometry and set theory) of age ranges of these attributes must be introduced. Ranges [3, 7] and [5, 11] have the interval of intersection (common part) [5, 7]; ranges [2, 15], [3, 6], [6, 16], [4, 11] have the interval of intersection [6, 6], and so forth.

The concepts proposed are sufficient to define the concept of "geological age." Pavlov (1897) considered geological age of a bed as its place in a general system of beds. A system of beds is built by their temporal relations determined with the help of the scale. Therefore, position in the geochronological scale is called the geological age of a bed, point, or other space object.

Position of a geological body in the scale is determined by finding the intersection of age ranges of all attributes fixed in this body. If only the Ith member of the scale will be such an interval, we say that a given object has the Ith age. If the interval of intersection is some part of the scale from the Ith to Jth member, the object's age is $[I, J]$; available data are insufficient for determinating a narrower age interval.

Stratigraphic Units and Concordant Complex

We now introduce the concept of stratigraphic relation between geological bodies: In all sections where points a of body A and points b of body B occur, if all points a are above any b, then body A is above B, and B is under A. Bodies for which the relation "above" is true are called stratified with respect to one another.

Stratified bodies, even if not introduced in the explicit form, are widely used in geology. When a geologist traces two units throughout a great distance and observes their contact in a single location (where unit A is above unit B), he/she concludes that unit A overlies unit B throughout the total area of those units' occurrences.

Stratigraphic units are connected simply and stratified in relation to one another domains of space, each of which includes points with one and the same (for a given domain) Ith single age range, but may also include points with a wider range than the Ith age range.

The definition says nothing of points with unknown age; their presence in a stratigraphic unit is not prohibited.

All connected bodies geometrically are divided into simply connected and multiply connected. A body is simply connected if any closed curved line (within limits of a given body) can be contracted to a point. Otherwise, a body is multiply connected. A domain with a hole can exemplify a multiply connected body. A closed curved line around the hole can be contracted to a point only beyond bounds of the domain, in space occupied by the hole.

So, an "onion coat" (stratigraphic unit) is constructed. Now we may proceed to building Werner's model. A concordant complex is a simply connected domain, filled with stratigraphic units each of which contacts only two other units. They are an overlying (according to the geochronological scale immediately younger) and an underlying unit (according to the scale immediately older).

Werner's model is easily recognized in a concordant complex. All requirements (continuity, similar order, persistence in the lateral direction within limits of any given area) have been fulfilled.

Practical Results

Regional stratigraphic objects can be built by means of processing initial data of some described sections in accordance with all conditions in a chain of definitions. A procedure of Werner's model construction was realized in an algorithm and program (Goncharova et al., 1977; Salin, 1979, 1983).

Solution of practical problems on a computer is illustrated by construction of a geological map for Ust-Kamchatka. Rock masses of this region are difficult to interpret. It took several years of elaborate and thorough work to map them by traditional geological methods.

Initial data are 15 sections where distribution of 149 lithological and paleontological attributes have been studied. Separate points on each section are grouped into intervals, which may be called strata. Bed numbering in each section is independent of numbering in other sections. As usual, it is done upward starting from 1.

A list of fixed attributes is indicated for each stratum; distribution of each attribute throughout the studied territory is established. For example, distribution of lithological attribute "flysch" is designated by two lines of numbers

107	61	3	13	13	16	6	5	3	2	4	3	4	0	0
27	7	2	13	13	5	5	1	2	2	2	1	1	0	0

Numbers in the lower line designate the serial number of lowest stratum in which flysch was observed in the first section (27), in the second section (7), in the third section (2), and so forth. Numbers in the upper line indicate the serial number of the uppermost stratum in which flysch was observed in each section. For example, uppermost occurrence of flysch in the first section is in stratum 107. If flysch were not found, its absence is designated by zeros in both lines.

Distribution of the mollusc *Nuculana alferovi* will be written as follows

104	52	0	0	0	13	0	3	0	0	0	0	0	0	0
24	50	0	0	0	10	0	2	0	0	0	0	0	0	0

A square matrix of stratigraphic relations of attributes is constructed on the basis of results of comparison of attributes (each with each). Symbol "1" is placed at the intersection of line A and column B if A is above B; symbol "2" is put down if A is under B, and symbol "3" indicates that A and B are not stratifying attributes with respect to one another. Symbol "0" shows that attributes A and B have no stratigraphic relations.

All possible stratifying sequences can be constructed only after fixing those attributes which could serve as starting points of sequences; no symbol "1" must be in lines corresponding to them. Stratifying sequences are built from all possible starting points separately: attribute B is found which has relation "1" with the first starting point, attribute A. Then we test whether attribute B can serve as a direct continuation of the sequence beginning with A: we attempt to find attribute C having a relation "1" with A, and relation "2" with B. If such an attribute does exist, B is removed, and replaced by C. Once again we test whether attribute D can be found between A and C. When a direct continuation of K is found, sequence AK is increased: attribute L is found which has relation "1" with K, and relation "0" or "1" with other members of the sequence under construction. A sum of frequencies is calculated for each constructed sequence. The sequence having the greatest moment sum of frequencies is stored. If a constructed sequence has a greater sum of frequencies, it replaces the previous standard; if a sum is equal or less than the previous one, the old standard remains. The last standard kept in the storage will be the solution after construction of all stratifying sequences. It is printed out as a geochronological scale. Complete algorithms of geochronological scale construction and correlation are presented in other papers (Goncharova et al., 1977; Salin, 1983). A total of 13 376 sequences were built on the basis of given material. The sequence with the greatest sum (equal to 47) was chosen as the geochronological scale of the region studied (Table 1).

Distribution of each attribute is compared to distribution of members of the scale. The fossil *Nuculana alferovi* occurs above the fourth and below the tenth members of the scale. Their age range is [5, 9]; the age range of flysch is [6, 11], and so forth. The age of each stratum is established by determination of intersection intervals of fixed attribute age ranges.

Those strata of the same section that could not be distinguished by age are united into a stratigraphic unit. For example, all strata (from 32th to 47th) in section I along the Gorbusha River are referred to unit 7; strata 50, 51, 52 in section II along the Khvalensky Stream refer to unit 9, and so forth (Fig. 2). We need only to suppose (according to Werner's model) that if unit 7 is present in sections I, II, III, then between sections and farther beyond them it extends above unit 6 and under unit 8 and is not interrupted at the margins of the studied region.

Not every bed is marked by a single age index. For example, bed 3 of section XIY is dated by nonsubdivided units [1, 2], bed 1 of section XII by nonsubdivided units [6, 9], and so forth (Fig. 2). Although the age index [1, 2] is of no use when we draw boundaries between stratigraphic units 1 and 2—through point [1, 2] the boundary is plotted as across empty space—the boundary between units 2 and 3 is drawn unambiguously; it must be plotted above the point with index [1, 2] (Fig. 2).

Thus, certain results were obtained after purely mechanical calculations. They fully coincide with previous results obtained by traditional geological

Table 1. Geochronological Scale–the Best Stratifying Sequence According to the Sum of Frequencies

No. geochronological units	Attributes	Sections														
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
11	54 Yolidia sp. 2	0	0	0	0	0	0	0	0	3	2	2	0	0	0	0
		0	0	0	0	0	0	0	0	3	2	2	0	0	0	0
10	23 Gritstone black unconsolidated	106	60	0	0	0	15	0	4	1	1	1	2	3	0	0
		106	60	0	0	0	15	0	4	1	1	1	2	2	0	0
9	68 Prevalence Nuclulana alferovi in complex	104	51	0	0	0	13	0	3	0	0	0	0	0	0	0
		99	50	0	0	0	13	0	2	0	0	0	0	0	0	0
8	20 Olistoliths	83	48	0	0	0	12	0	0	0	0	0	0	0	0	0
		64	24	0	0	0	9	0	0	0	0	0	0	0	0	0
7	148 Many Nuculana tumiensis and many Yoldia chehalisensis	45	23	3	0	0	0	0	0	0	0	0	0	0	0	0
		42	23	3	0	0	0	0	0	0	0	0	0	0	0	0
6	149 Echinoid and many Yoldia nitida	29	3	0	0	0	5	5	0	0	0	0	0	0	0	0
		29	3	0	0	0	5	5	0	0	0	0	0	0	0	0
5	52 Yoldia deformis	24	6	0	0	0	0	0	0	0	0	0	0	0	0	0
		24	6	0	0	0	0	0	0	0	0	0	0	0	0	0
4	15 Argillite grey firm with concretions	23	4	1	11	11	3	3	0	0	0	0	0	0	0	0
		19	1	1	11	9	3	3	0	0	0	0	0	0	0	0
3	11 Glassy flint	17	0	0	10	8	2	2	0	0	0	0	0	0	0	0
		16	0	0	10	8	1	2	0	0	0	0	0	0	0	0
2	38 Thuja	10	0	0	7	0	0	1	0	0	0	0	0	0	0	0
		10	0	0	7	0	0	1	0	0	0	0	0	0	0	0
1	3 Green crossbedded conglomerats	6	0	0	5	0	0	0	0	0	0	0	0	0	2	2
		1	0	0	2	0	0	0	0	0	0	0	0	0	2	1

methods. This confirms a clear geological sense to all accepted definitions and premises.

Except for Ust-Kamchatka region, the algorithm was applied for correlation of 6 Neogene sections of the Korf coalfield (North-East Kamchatka, 270 attributes–lithology, molluscs, flora), 37 Paleogene and Neogene sections of the Khatyrka Basin in Chukotka with a total of 1000 attributes: lithology, fauna (molluscs in general), microfauna (foraminifera), microflora (diatoms, silicoflagellats), well logging, mineralogy and chemistry; 27 sections of the Amur-Zeyskaya depression with 469 attributes (lithology, fauna, flora, palynology, mineralogy, and chemistry), and on other territories. Good results were obtained in all instances. In the Khatyrka Basin, our algorithms gave the same results without application of seismo-stratigraphic materials, which could be obtained by traditional methods only after application of seismo-stratigraphic data. On the Uglovaya square of the Khatyrka Basin, those well sections were correlated which could not be correlated by other methods. More detailed description of these results is given in other publications.

EXTENDING AND SUPPLEMENTING THE MODEL

In the simplest Werner's model, stratigraphic units extend continuously in a similar order between any two possible sections within limits of any studied area. All other characteristics of versatile geological reality are introduced into the model during the process of its successive extending and supplementing.

Discordances

Let us introduce a new concept: a concordant relation is a contact of a stratigraphic unit with an overlying unit (in the geochronological scale immediately younger) and with an underlying unit (immediately older). A contact of the given stratigraphic unit with anything else except an overlying, immediately younger one, and an underlying, immediately older one, will be a discordant relation or discordance.

According to the accepted definition a discordance includes various relations known in geology.

First of all, relations defined through a gap in a stratigraphic sequence—unconformities, hiatuses, gaps, nonevident disconformities, stratigraphic disconformities, nonsequences, discontinuities—belong here. Tectonic discordances (faults), truncation of bedded rock masses by surfaces of modern and ancient relief, and cut off by intrusions, dikes, and veins also belong here. All these discordances can be determined by stratigraphic methods, that is, by establishing a succession of geological bodies in sections, and comparing this succession with the geochronological scale of a given area.

A stratigraphic unit has concordant limitations only at the bottom and top.

But from the side, on the lateral, No concordant limitations are assumed. This is equivalent to the statement of the absence of lateral finiteness of stratigraphic units by themselves within limits of any area. Stratigraphuc units can be made finite only by cutting them off by discordant, improper boundaries—faults, erosional surfaces, or surfaces of magmatic intrusive and veined bodies. Earth's surface and boundaries of a studied territory can also be ascribed to discordant boundaries cutting off stratigraphic units; in other words, everything that a geologist usually considers as secondary boundaries in contrast to primary ones, that is, concordant. Any geological map convinces us that lateral finiteness of a stratigraphic unit is impossible without discordant boundaries.

Facies

Because a stratigraphic unit is a part of space possessing only geometrical and age (but not material) characteristics by definition, a concept of a "geological body" must be defined. A geological body is a connected domain of space all points of which possess attributes of one and the same class of a certain classification. Most often, bodies are singled out by their lithological attributes.

A two- or three-dimensional model depicting distribution of geological bodies in a studied space fragment is constructed by means of identification; that is, determination of two comparable intervals of different sections belonging to the same continuous geological body. Let us introduce two conditions simplifying the task of model construction: (1) All bodies are simply connected; and (2) the studied domain also is simply connected, meaning that it is completely filled with bodies—no points within it do not belong to a body.

The third condition permitting age concepts to be used for constructing a volumetric model of material geological bodies is as follows: Only those one-dimensional geological bodies of different sections, which are included in the same stratigraphic units, are united into the same continuous two- or three-dimensional geological body. But if geological bodies included in the same stratigraphic unit in different sections have different lithological composition, they are called facies.

Further Elaboration on Werner's Model

Because the introduced concept of a discordant boundary is extremely general, stratigraphic and tectonic discordant boundaries should first be distinguished, and erosional surfaces should be separated from faults.

After separating faults from erosional surfaces, the next step must be to single out subclasses from each of these classes. Even this is an extensive sphere of geological investigations, embracing a considerable part of tectonics and structural geology.

To single out specific types of discordances on a geological map will be possible only after a procedure is formulated for defining them. As in synchronization, it will be enough to process initial data (on descriptions of sections) in accordance with definitions.

At present, such definitions and classifications do not exist. However, they clearly must be as close as possible to traditional ones practically used in geological work. This seems not to be difficult.

Many unambiguous geometrical classifications of faults by such characteristics as position of a fault plane in space, amplitude, and direction of block displacement exist.

Works on technical realization of construction procedures of Werner's model with supplements have not been started yet. Those procedures are: working out computer algorithms and programs and computer processing of initial data on discordances, overturned beddings, and facies. Moreover, the necessity of automating these procedures must be analyzed first. Automatic processing is not always preferable. Sometimes, manual data handling is more rational because it takes less time than preparing initial data to input to the computer. Automation is not the primary aim, but unambiguous results and constructions are. Because of this, the essence of the problem is in strict definitions and formulations that can be used both on the computer and without it.

Werner's supplemented model (facies, discordances, overturned beddings) is a topological model of geological bodies' relationships. It reflects only topological space characteristics of geological bodies and their sets: succession, continuity, simple-connectedness, and contact. This model does not contain information on form and dimensions of geological bodies, their dislocations, exact position in a coordinate system, parallelism of their boundaries, rectilinearity or curvilinearity, convexity or concavity, angularity or smoothness of boundaries; in other words, information on metric, affine, projective, and differential geometrical properties and relations. In order to construct a geological map, we must augment the scheme of stratigraphic correlation by geometrical information of nontopological nature.

Paleogeography and historical geology are based on stratigraphy and therefore on Werner's model. Stratigraphic concepts and models are used in other geological disciplines operating with geological time characteristics. And, at last, a search for mineral resources may be regarded as a final stage of any research where data on stratigraphy, tectonics, geological mapping, paleogeography, and historical geology are necessary. Mathematical formulation of further additions to Werner's model is to be considered later, but even today this model serves as a basis for geology.

REFERENCES

Dienes, I., 1974a, Subdivision of geological bodies into ordered parts: Matematikai módszerek, szamítástechnika a nyersanyagkutatásban, Magyarhoni Földtani Jarsulat, Budapest, p. 138–149.

Dienes, I., 1974b, General formulation of the correlation problem and its solution in two special situations: Jour. Math. Geology, v. 6, no. 1, p. 73–81.

Dienes, I., 1978, Methods of plotting temporal range charts and their application in age estimation: Comput. Geosci., v. 4, p. 269–272.

Dienes, I. and Mann, C. J., 1977, Mathematical formulation of stratigraphic terminology: Jour. Math. Geol., v. 9, no. 6, p. 587–603.

Goncharova, Ye. I., Salin, Yu. S., and Soldatov, O. B., 1977, Algorithm for building composite stratigraphic scales and sections correlating: Principles of tectonic analysis, Institute of Tectonics and Geophysics Far Eastern Science Center of Acad. Sci. USSR Vladivostok, p. 34–41, (In Russian).

Hay, W. W., 1972, Probabilistic stratigraphy: Ecolog. Geol. Helvet., v. 65, n. 2, p. 255–266.

Hay, W. W. and Southam, J. R., 1978, Quantifying biostratigraphic correlation: Ann. Rev. Earth Planet. Sci., v. 6, p. 353–375.

Lyell, Ch., 1865, Elements of geology, 6th ed., London, 734 p.

Pavlov, A. P., 1897, Fifty years in the history of science about fossils: Moscow, 88 p (in Russian).

Rubel, M. P., 1976, On biological construction of time in geology: Eesti NSV Tead. Akad. Toimetised. Keemia. Geologia, v. 25, no. 2, p. 136–144 (in Russian).

Rubel, M. P., 1978, Principles of construction and use of biostratigraphical scales for correlation: Comput. Geosci., v. 4, p. 243–246.

Salin, Yu. S., 1974, Stratigraphic correlation on the computer: Problems of general and theoretical tectonics, Institute of Tectonics and Geophysics Far Eastern Science Center of Acad. Sci. USSR Khabarovsk p. 139–154 (in Russian).

Salin, Yu. S., 1976, Algorithm of stratigraphic correlation: Mod. Geol., v. 5, p. 191–199.

Salin, Yu. S., 1979, Constructive stratigraphy: Nauka, Moscow, 173 p (in Russian).

Salin, Yu. S., 1983, Stratigraphic correlation: Nedra, Moscow, 157 p (in Russian).

Spencer, H., 1866, Illogical geology: Works, v. 3, p. 277–335 (in Russian).

Voronin, Yu. A., Borovikov, A. M., Salin, Yu. S., Soloviov, V. A., and Burkhanov, H. H., 1971, Stratigraphic constructions at the computer, *in* Mathematical problems of geophysics: Computer Center of Siberian Branch of Acad. Sci. USSR Novosibirsk, p. 295–304 (in Russian).

Voronin, Yu. A., Borovikov, A. M., Salin, Yu. S., Soloviov, V. A., and Titov, A. A., 1972, The improvement of theoretical constructions in stratigraphy with the help of modelling at the computers, *in* Mathematical methods and computer application when searching for minerals: Computer Center of Siberian Branch of Acad. Sci. USSR Novosibirsk, p. 45–79 (in Russian).

Weller, J. M., 1960, Stratigraphic principles and practice: Karper and Brothers, New York, 725 p.