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Zonal biochronological method for solving long-living problems of general stratigraphy

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Research subject. Some problematic issues of general stratigraphy have been considered: the Karpinsky principle, the standardization of autonomous zonal biochronological scales (BCS), the basics of stratigraphic classification, correlations of zonal biostratigraphic and chronostratigraphic units. *Materials and methods*. Conventional solutions of the issues are analyzed. An attempt is made to reveal some logical sources of controversies and to define possible routes for a non-contradictory synthesis. *Results*. It is proposed that a successful solution of the above problems requires not identifying the biochronological scale with a geological section. Recognizing a zone as the smallest unit of the biochronological scale implies the linearity of the scale zonal subdivision, which makes it a correct tool for conducting principal stratigraphic operations such as subdividing the section, specifying and correlating the boundaries of the stratigraphical units. Strict differentiation of the scale and the section examined by this scale makes it possible to meet all of the requirements of the Karpinsky principle with respect to the subdivision of the mixed-fauna horizons. This precise condition provides a basis for developing a stratigraphical classification that should be preceded by clear separation between the material ("mappable") stratigraphic subdivisions of the Earth's crust and the subdivisions of the chronological scales used for correlations. The merging of these two conditions into an integral "dualistic» stratigraphic classification fails to produce any satisfactory results. The development of autonomous zonal scales should be preceded by specifying the biozones for the species used to construct those scales and should be made in accordance with the zonal scale that is normative (standard) for the given stratigraphic interval. Taking into account the minimal dimension of the zonal subdivisions of the standard scale, the zones of the autonomous scales identified by this method correspond to a whole number of normative zones, and consequently, the boundaries of the stratozones established on the basis of autonomous scales, in this case, will certainly coincide with any boundaries of the stratozones identified on the normative scale. This procedure makes it possible to perform the unification of autonomous zonal biochronological scales (BCSs) based on different groups of fossils. A zonal BCS performs correlational functions, whereas zonal subdivisions are a tool for chronological identifications of remote geological objects, including the boundaries of chronostratigraphic units, but are not included in their hierarchy. *Conclusions.* A biochronological scale is a model of biochronological calculation of geological time and cannot be identical to what it models. The differentiation of the scale from the section being studied is an indispensable condition that precedes and ensures the successful solution of long-lived problems of general stratigraphy.

Keywords: *Karpinsky principle, unification of biochronological scales, stratigraphic classification, chronostratigraphical subdivisions, zonal subdivisions*

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GENERAL COMMENTS

The leading role of the zonal biochronological method in the determination and correlation of the boundaries of the Phanerozoic stratigraphic units has been emphasized by numerous authors (Rauzer-Chernousova, 1967; Menner, 1980; Gladenkov, 1991, 2001, 2004). B.S. Sokolov (1971) was probably the most certain about it in his writings.

The correct construction and usage of zonal biochronological scales involve the acceptance and implementation of terms that seem to be trivial, but are frequently not implemented.

Herein it is proposed that the requirement for a strict differentiation between the biochronological units and the physical units of a particular geological section is the most general and important one. Simply put, it is necessary to make strict distinctions between the biochronological scale as a model idea of geological time and the material (substrate) geological section, with the time recorded in it as particular events that may be used, among other purposes, for scale construction.

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It would seem that the generally accepted recognition of substrate chronostratigraphic units (erathem, system, series, stage, chronozone) and the corresponding geochronological (time) units (era, period, epoch, age, phase) fully comply with this requirement. Indeed, stratons represent rock aggregations, whereas geochronological subdivisions represent time scale units, or "the geological time interval, during which the rocks within the given stratigraphic unit were formed, including the time of internal breaks" (Stratigraphic…, 2019, p. 10). The final part of the text, relevant to including the interior breaks in geological time, leaves no doubt that we are talking about physical, ordinary time. The geochronological scale itself should be understood as an external graduated scale of physical time.

The use of physical time was of serious consequences for the development of theoretical stratigraphy. In particular, it first gave rise to H. Hedberg's chronostratigraphic definitions, and then served as the basis for the formulation of the GSSP concept, with the mandatory use of chronometrical markers to substantiate the limitotype of the lower boundary of the general stratigraphic units (Cowie et al., 1986; Remane et al., 1996).

Recently, the chronostratigraphic directives have been removed from the latest issues of the Russian Stratigraphic Code (2006, 2019), and the concept of the GSSP has been seriously criticized (Gladenkov, 2001; Zhamoida, 2004; Tesakov, 2015). Nevertheless, no changes have taken place as regards to the provision on the existence of the stratigraphic and geochronological units, although the latter ones do not play any constructive role in geological chronology. O. Schindewolf (1975, p. 45) is completely certain about this: "… such concepts as the Triassic, the Cretaceous, etc. may be (without any additional definitions) used in a double, i.e., in chronological and stratigraphic sense, with absolutely no fear of confusion. If it is still necessary, the concept of *time* may be added for all the units. The concept of the Triassic *time*, the Late Devonian *time* or the *Manticoceras time* render similarly unambiguous meanings as the concepts of the Triassic *period*, the Late Devonian *epoch*, the *Manticoceras age* or the Adorfian *age*".

Alongside with that, a situation may be present when there is no clear differentiation between the existing stratigraphic units of the section and the units of the chronological scale used for geological age determination and for unit correlation. In the Russian stratigraphic codes, as well as in foreign stratigraphic handbooks, the definitions of the stratigraphic scale units begin with the words "the body of rocks" or "the body of strata", thus, all of those "scales" prove to be substrate constructions – stratigraphic columns of the rocks.

It should also be noted that the introduction of geochronological units into the stratigraphic classification obscures the absence of the true chronological scales of the units that are equivalent to the general stratigraphic units. One may frequently come across the expression "stage stratigraphic scale", when essentially a stage stratigraphic column is meant, with its units representing just the stages (rock bodies determined from the regional geological data), but not the chronological units, with not so much as an adequate naming. The stage geochronological equivalent – age – is a unit of physical time, but not a subdivision of a chronological scale. Similar comments could be made with respect to epoch, period, era, etc.

Clearly, it would be quite helpful to differentiate between the biostratigraphic and the zonal biochronological scales.

A biostratigraphic scale is traditionally understood as a section divided into formations, stages, alongside with the specified markers (assemblages of paleontological remnants) enabling us to identify those stratons in various coeval sections. In this sense, the International Stratigraphic Scale (ISS) of the Phanerozoic represents a composite section of the stratisphere, with its units provided with a complex (and primarily paleontological) characteristic that make it possible to recognize the ISS units distinguishable as stratotypes of the ISS from other sections.

Until recently, there was no strict marking of the boundaries of the subdivisions of the ISS units themselves, because the boundaries were to be determined based on fossil assemblages, which led to ambiguous definitions of straton boundaries in different sections.

Currently, in accord with the GSSP concept accepted in modern stratigraphic research, the boundaries of the general stratigraphic units provide a zonal biochronological scale of high correlation potential. Even here, however, a recommendation is formulated vaguely without any allusion to zonal biochronological scales and where it is hoped that a boundary and a point can be selected within an evolutionary lineage. A reservation is made that "identification of such lineages may be subjective and not necessarily more accurate than identification of a definite complex zone" (Cowie et al., 1986, p. 7). However, the long practice of using certain assemblages of fossil organisms for defining the boundaries between the chronostratigraphic units does not leave any doubts as to the unreliability of such marking.

The biochronological zonal scales (and only the zonal biochronological scales, thus far) constructed upon an evolutionary basis, are regarded as truly chronological event scales, since the zonal units of such scales are distinguished based on similar (equivalent) events – the organism species existence in their evolutionary sequence. Such biochronological scales (BCS) are used for marking the boundaries of the earlier recognized formations, stages and other stratons within specific sections. Only after the construction

of zonal biochronological scales (and rejection of complex zonal markers) has the exact (unambiguous) determination of the individual straton boundary position become possible. Even at the present time, however, this possibility is not used as it should be and results in the recognition of a biochronological scale zone as the smallest chronological unit. If this provision is strictly considered, the boundaries of all the Phanerozoic stratigraphic units will be marked as this or that zone of the biochronological scale (Chernykh, 2014, 2016).

A standard (nominal) zonal BCS should be selected for each stratigraphic interval of the stratisphere, which should be constructed based on the evolutionary sequence of a species of an orthostratigraphic group of fossil organisms. If (in accord with the GSSP concept) all the Phanerozoic unit boundaries from the International Stratigraphic Scale (ISS) are marked with the zones of the nominal zonal biochronological scales, the ISS may be regarded as a tool for identifying its units in definite geological sections. However, if we strictly approach the determination of the age of deposits according to the ISS, then the main role in this procedure is played and will continue to be played by the zonal BCS. The precise units of the so-called General or International Stratigraphic Scale (in fact, a stratigraphic column of the stratisphere composite section) serve as an international chronological language (Meyen, 1981). As noted above, there are still no proper chronological scales and their constituent chronological units that are built upon similar event bases for the general stratigraphic units (stages, series, systems, etc.). Maybe there is no need for that, if zonal biochronological scales are available. Those possibilities are to be discussed below.

ZONAL BIOCHRONOLOGICAL SCALES (BCS). ZONAL METHOD

The negative effects from the lack of strict differentiation between a stratigraphic scale and a geological section are most obvious when it comes to zonal biochronological scales, since the terms “zone” and “biostratigraphic zone” are generally used to denote “the sum of the layers” (Stratigraphic…, 2019, p. 34), whereas the zonal units of the biochronological scales are not even mentioned in the Codes. Besides, it is allowable to divide a zone “into subzones that add up to make the total stratigraphic extent of a zone” (ibid.). There are no comments as regards the way to match this conjecture with declaration of a zone to be the smallest unit of the biochronological scale.

The main feature of a zonal biochronological scale (BCS) is in the fact that it consists of the minimal chronological units – zones. As any chronological scale, the BCS is an ordinal scale (Gomankov, 2007), based on the succession of similar events in the evolution of certain fossil groups. The BCS is a tool for the biological reckoning of geological time, and the elemental event used for its construction is represented by the “species existence” event, that marks the zone and grants the name of this species as the zone proper name. Species replacement in the evolution of the certain group makes it possible to present the temporal sequence of such events as a zonal biochronological scale. Each successive event closes the preceding zone and opens a new, the following one. The incompletely preserved retrospective systems of the past such as the geological sections used to acquire information for the BCS construction, fail to show the true positions of the events associated with the evolutionary sequence of the species used to build the BCS. Thus, the first finding of the species A remnants in a particular section cannot serve as the evidence of the species “generation” event, just like the disappearance of the species A from the section cannot be interpreted as the “species A extinction” event. The finding of some fossil species remnants suggests merely the fact of its *existence.* It is this event that should be made the basis for construction of the zonal biochronological scales.

Despite the fact that all the data on the fossils to be used for scale construction is obtained from the section, this cannot be regarded as the reason to identify the scale within the section. Moreover, if the species evolutionary succession is used to build the scale, it is absolutely independent of how exactly this particular section is divided into stages, formations, and any other stratons from whose deposits we extract fossils, and the succession is determined exclusively by the features of the evolutionary process itself that are further used as the basis for constructing a zonal BCS.

As the *scale* minimal unit, the zone does not have any boundaries on the scale. All the zones *in the scale* are non-dimensional (a zone is a moment of chronological time), discrete (there are no gradual transitions between adjacent zones), equivalent (equipollent), and they differ only in their positions in the scale. Essentially, the zones here represent linear marks, notches recording their positions on the scale (Fig. 1).

Within a ***section***, a zonal unit corresponds to a ***stratozone*** – a rock interval from the first-appearance level of the index species to the first-appearance level of the succeeding index species. Without discriminating between the zonal scale and the section, i.e., without specifying a zone as a scale unit and the corresponding stratigraphic unit (stratozone) in the section, it is impossible to understand why the zone is regarded as the minimal unit, if (within the section) it may be divided into layers down to a millimeter wide. A zone makes the minimal unit exactly on the chronological scale, because the event of “species existence” cannot be subdivided into any parts without the loss of the event itself.

Likewise, the common expression “in the lower (middle, upper) part of the zone one may come across…” may refer only to a stratozone, whereas it loses any sense if applied to a zone in a scale. As mentioned

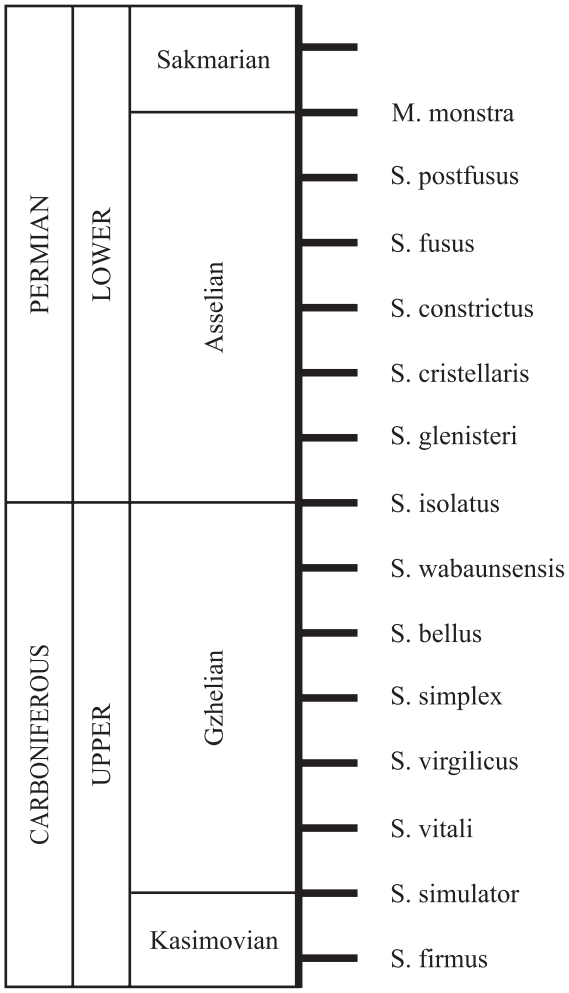

Fig. 1. Zonal scale of the Gzhelian and Asselian Stages based on conodonts.

S. – Streptognathodus, M. – Mesogondolella.

above, a zone as a scale minimal chronological unit is homogenous and cannot possess any parts.

Relying on the principle of superposition, one may claim that the stratozone lower part within the section is older than the upper one. Meanwhile, the chronological ages of any stratozone part and of any object within the limits of this stratozone are similar and correspond to an eponymous zone on the scale. Therefore, any part of a stratozone and all the objects within its limits are chronologically identical and geologically coeval. This is exactly the extreme accuracy of the age determination provided by the zonal chronological scale. Thereupon, the lower, the middle and the upper parts of the stratozone and all the objects within its limits in the section have the same zonal dating in the chronological scale.

On this assumption, the boundary of any stratigraphic unit, that happens to fall within a stratozone, should also be dated as a complete zone and coincide with the corresponding zone – mark on the scale (Fig. 1).

The next conclusion that follows – the zonal biochronological *boundaries* of any stratigraphic units (stratons) represent a definite zone, i.e., are linear (two-dimensional) **in a scale**, but always volumetric (three-dimensional) in a section – cannot be understoodwithout differentiating between a scale and a section.

The purpose of the zonal method consists in determination (identification) and correlation of the stratigraphic boundaries by means of a zonal BCS. It can be said that a zonal division has no other purpose at all. G.P Leonov (1974, p. 53) is the one to state this idea with complete certainty: “Zonal subdivision, as biostratigraphically understood, is primarily the method of section comparison. Zonal stratification should precede this comparison and should bet independent of it”.

If the proposed concept of discriminating between the scale and the section is accepted and the zonal nature of the stratigraphic boundaries is considered, one may overcome some traditional long-lasting contradictions and simplify the solution procedures associated with the stratigraphy classification and nomenclature problems.

Specific examples are presented below to illustrate this statement.

The Karpinsky principle

S.N. Nikitin and F.N. Chernyshev (1889) first, and A.P. Karpinsky (1945) later on, followed by L.L. Khalfin (1970), used to negate the sharp dividing lines between the units of the International Stratigraphic Scale and to maintain that the adjacent ones are interconnected by means of mixed-fauna horizons; they thought of the ISS as of the stratisphere composite section, composed of material (real) units (stratons), and considered their paleontological characteristic (biochronological scale) to be an integral part of this composite section. This interpretation is exemplified by S.N. Nikitin’s and F.N. Chernyshev’s ideas that “units of similar orders should be equivalent to each other as much as possible, as they make cycles of paleontological development” (1889, p. 143)[1]. L.L. Khalfin (1980, p. 75) states that “the ISS reflects the development history of the Earth’s organic world, and its units correspond to the qualitatively different stages of this history”. It should be noted, that the majority of contemporary stratigraphers agree with the perception of the ISS as of the stratisphere composite section (see, for example, Ganelin, 1992; Stratigraphic…, 1992, 2006, 2019; Naidin, 1994). This viewpoint is most definitely claimed and grounded in the paper by A.V. Gomankov (2007).

With the view of the ISS as a column of the stratisphere composite sections, the continuity requirement to the stratigraphic sequence of its units (“as

[1] Note, that the cited contemplations of those researchers fully correspond to the zonal units of the biochronological scale as I see it. But this refers to the chronological scale precisely, and not to a section.

a consequence of purely regional synthesis", Sokolov, 1971, p. 160) is absolutely correct. If this requirement is fulfilled, the column of the stratons (without gaps and overlaps) represented by stratotype sections, may serve as a material standard of geological time. The wish of the authors of the early attempts of ISS construction to make the boundaries between its units sharp is quite natural, understandable and righteous. Sure enough, the unit boundaries in any *scale*, used as a measuring tool, should certainly be distinct, linear. And if a scale is envisaged as a section, it is necessary to have clear dividing lines between the ISS units. It is this viewpoint that S.N. Nikitin and F.N. Chernyshev (1889, p. 138) believed to express the teleological world outlook and considered it to have been "bequeathed to geology by Cuvier's cataclysm theory". But, however you qualify this viewpoint and whoever it has been bequeathed by, the very wish to have a scale with clearly specified linear unit boundaries is motivated by the functional purpose of the scale as a measuring tool and cannot be made a target for criticism.

On the other hand, if the biochronological component is regarded as the ISS integral part (exactly like S.N. Nikitin, F.N. Chernyshev and their followers do), one is forced to accept, that the biochronological computation of geological time is based on the events of the organic world evolution history, that "is devoid of any breaks, gaps: succeeding faunas (floras) are continuously connected" (Khalfin, 1980, p. 54). Consequently, the boundaries of any stratigraphic units should be peculiar for the layers ('transitional horizons" according to A.P. Karpinsky), comprising mixed faunas (floras), and such transitional horizons should be distinguished as independent units. L.L. Khalfin proposed to accept this A.P. Karpinsky's conjecture (1890) as the Karpinsky principle and to regard the transitional horizons with mixed faunas as the natural boundaries between the ISS (Khalfin, 1969, p. 133).

It is still unclear how to make the boundaries of the chronostratigraphic scale units (similarly to other scales viewed as measuring tools) distinct, linear, and how to make the equivalent boundaries of the geological section units representative of the "transitional mixed-fauna horizons".

At present, the boundaries of all the Phanerozoic stratigraphic units are *determined* by means of the zonal biochronological scale. As noted above, any object, inclusive of the required *stratigraphic boundary,* that happens to fall within a certain zone of a particular zonal BCS, is dated as a complete zone (due to its minimal chronological dimension). In other words, the boundary between any adjacent stratons is represented by a definite zone of the said scale. It is just the zone (in the scale) that separates, e. g., two adjacent stages, and serves (in the scale) as a dividing line between the adjacent stages, systems and any other superstage stratons (Fig. 1). *Acceptance of the minimality condition for the zone unit provides the boundary linearity of the zonal scale units.* In the scale, a zone is indicated by a dimensionless mark line, and the zonal boundary between the adjacent stages, systems *in the scale* is linear, sharp (there are no transitional units between the adjacent zones), as it should be between the minimal units of the scale, used as a measuring tool. At the same time, the dividing line–zone *in the section* (stratozone) is not linear (as in the scale), but an interval (voluminous), with a certain thickness and lateral extent; it makes the very "mixed-fauna horizon" mentioned by A.P. Karpinsky and L.L. Khalfin.

In the practice of geological survey, this dividing zone is customarily ascribed to the upper one of the adjacent stages. This choice, however, does not influence its position in the scale – it is intermediate between two adjacent stratons (Fig. 1), just the position suggested by the above authors. Despite the fact, that the boundaries between the superzonal units *in the scale* are two-dimensional, linear, this result cannot be accounted for by any teleological world outlook "bequeathed by Cuvier's cataclysm theory". As mentioned above, the linear character of the straton boundaries in the zonal scale ensues totally from accepting the minimal dimension of the zone unit on the biochronological scale.

If no strict discrimination between the chronological scale and the section is stipulated, and the scale is regarded as a composite section, with stratons as the scale units, any discussion involving the sharp boundaries of the scale units and the transitional horizons between the stratons may be long and fruitless.

This outcome can be illustrated by means of a specific example. In his paper "Introduction to the theory of stratigraphy" S.V. Meyen has reserved § 97 and § 98 to discussion of "the Karpinsky principle". Running somewhat ahead, I should admit my total agreement with Meyen in regards to the status of the so-called "Karpinsky principle". It is certainly not a principle, but rather a technical recommendation: while defining the inter-straton boundaries, one should choose continuous sections, with gradual transitions between the paleontological references. Below, however, I will show this agreement to be grounded on a different logical basis.

Thus, I would venture to present an extensive quotation from Meyen's paper relevant to the subject under discussion. It is exactly here that he is having dispute with L.L. Khalfin, who defends the viewpoints proposed by A.P. Karpinsky, S.N. Nikitin and F.N. Chernyshev.

"A view has been advanced, – says Meyen, – that the idea of the two-dimensional (planar) character of the ISS boundaries is a relic of catastrophism (Khalfin, 1970) and even of the teleological world outlook (Nikitin, Chernyshev, 1889, p. 138)". "We have repeatedly claimed, that the ISS reflects the history of the Earth's organic world, and its units correspond to the qualitatively different stages of this history

(Khalfin, 1959, 1960). But the organic world evolution does not know any gaps or breaks; its steps are connected by transitional intervals, corresponding to the ISS transitional horizons; the latter ones represent the natural boundaries between the units, whereas the distinct levels devoid of the third dimensions are artificially introduced into the ISS, while actually having been inherited from Cuvier's catastrophe theory (Khalfin, 1970, p. 5)".

"This viewpoint, – Meyen keeps on, – was also shared by A.P. Karpinsky, who, as far back as in the last century, suggested that transitional layers should not be included in any boundary units, but should rather be recognized as independent transitional units… L.L. Khalfin has raised the Karpinsky' view to the status of a universal principle, allegedly corresponding to the dialectical insight into development of the Earth's organic world".

"This judgement, – Meyen goes on, – was opposed by a valid reason: by recognizing transitional layers as independent units we obtain two disputable levels instead of one. In response, Khalfin claims that this is not the case, since a boundary unit (e. g., a stage) is no longer included into any system. The issue of system boundaries is not to be discussed, just the stage boundaries remain. Regretfully, Khalfin fails to specify what is to be done about other boundaries of the ISS. If his logic is to be followed, we should distinguish transitional layers between all the other ISS units, inclusive of the stages and even zones. Suppose, we have introduced a transitional unit, acting as a boundary between the zones. This unit should also have three-dimensional boundaries. It will be necessary to introduce a still lower order unit, and so on to infinity" (Meyen, 1989, p. 99-100).

Having revealed, that the Karpinsky principle "leads to absurd through vicious infinity", and that "therefore, there can be no talk of dialectics in Khalfin's conjecture" (ibid., p. 101), S.V. Meyen presents his vision of handling the dialectical contradiction: "The deepest sources of the contradiction should be uncovered, the contraposition (antinomy, antitheses) clearly articulated and a way to a noncontradictory synthesis should be looked for" (p. 100).

From my point of view, the principal source of contradictions lies in the fact that neither Meyen, nor his opponents in the persons of L.L. Khalfin and A.P. Karpinsky, distinguish between the concepts of a "geological section" and a "zonal biochronological scale". Besides, S.V. Meyen has forgotten that a zone makes the scale smallest unit and, therefore, it is impermissible to "introduce a unit of a still lower order". Lastly, it is also important, that at "all the levels of the hierarchical system of the Phanerozoic stratigraphy, the unit boundaries should be defined only from the species zones, irrespective of the included range variety of taxons and other (non-zonal) fauna groups" (Sokolov, 1971, p. 175).

If the ISS scale is regarded a chronological scale–section, it is impossible to acknowledge a zone as the smallest (linear) unit: ***in the section***, it will inevitably be three-dimensional and it will be possible to subdivide it into subzones, zonules, biohorizons, etc. In this instance, we may reduce the Karpinsky principle to "vicious infinity". If the boundaries of the ISS units are discussed with the ISS regarded not as a section, but as a scale, the boundaries of its units are defined from the zonal biochronological scale as particular zones. Due to the minimal dimensions of the zonal units in the scale, those boundaries are linear, and, as such, they separate stages, series and systems (Fig. 1).

Accordingly, a common viewpoint may be advanced that the chronological boundaries of the stratons of any grade are three-dimensional within a section, whereas in the zonal biochronological scale, the same boundaries of all the stratigraphic units are represented by zones, which, being the smallest units, should be considered as linear, two-dimensional. This idea, however, goes exclusively with accepting the condition of minimal sizes of the zonal units and bears no relation to "the catastrophe theory".

Using the zonal scale to mark the stratons of the stage ranks and higher, alongside with the strict differentiation between the scale and the section, measured by means of this scale, allows meeting all the requirements in terms of the mixed-fauna dividing horizons, so much talked about by L.L. Khalfin and unaccepted by most researchers. Specifically, as shown above, zonal units represent the linear boundaries in the biochronological scale. Meanwhile, in the section, they represent a certain stratigraphic interval, occupied by a corresponding stratozone, regarded as a "mixed-fauna horizon" between the adjacent stratons. This is the resolution of the long-living problem, defined by L.L. Khalfin as "the Karpinsky principle".

Stratigraphic classification by V.A. Zubakov

V.A. Zubakov (1980) has once proposed his own scheme for "advanced stratigraphic classification". He considers it to be dualistic, since it combines "the entire totality of stratons … into two types: geostratigraphic units, representing mappable geological bodies, and chronostratigraphic units, *representing a tool for correlation*" (Zubakov, 1980, p. 28, italics supplied – V.Ch.). As is customary, both, the chronostratigraphic and the geostratigraphic units are regarded as stratons, i.e., as the section subdivisions. The general scale units (stages, series, etc.), horizons and Oppel-zones, for example, fall among the chronostratigraphic ones.

Though the general idea of classification, forwarded by V.A. Zubakov, is quite sound, clear indication of the initial step is required to implement it to the full extent. In my view, Zubakov's proposal is pimarily related not so much as to classification of the stratigraphic units, as to the strict differentiation between the units

of the *chronological scales*, that really do represent *correlation tools*, and the *sections* of the Earth's crust stratigraphic units, that may be regarded as "mappable geological bodies", and may be recognized and correlated by means of those scales.

It is only upon this operation that one may substantively discuss a version of the stratigraphic classification, proposed by Zubakov or any other author, with hardly any reason to insert chronostratigraphic scales and "mappable geological bodies" into it. The scale classification, if it is really necessary, should be autonomous and independent of any separate, self-consistent classification of stratons (section substrate units).

Therefore, differentiation between the chronologic scales and the sections represents the starting action for solving the problems of stratigraphic correlation, as well.

Unification of autonomous zonal scales, or the way to get over Schindewolf's ladder

Making use of the zonal scales, based on different fossil groups, for distinguishing (specifying) and correlating the stratigraphic boundaries, produces disparate results. The reason is commonly believed to lie in the phenomenon known as "Schindewolf's ladder" and called forth by the chronological mismatch of the evolution stages in taxons of various groups. This mismatch is recorded directly in the section relative to a certain boundary of the stratigraphic unit determined from various groups of fossil organisms. In the Aidaralash stratotype section (Kazakhstan), for example, the lower boundary of the Permian system, determined from conodonts, is 6.3 m and 26.8 m lower, than the same boundary, determined from fusulinids and ammonoidea respectively. It is exactly the different levels ***in the section***, when the stratigraphic boundary markers, based on various fossil groups, first appear, that are meant when Schindewolf's ladder is spoken of. And it is extremely difficult, frequently impossible, to unify the zonal scales on the basis of this factual data.

We believe, the mismatching boundaries of the stratigraphic units, determined from various fossil groups, result, to a substantial degree, from the customary confusion of the zones (stratozones), recognized within a section, and the zones, defined in the scales. The problem may be solved through choosing the zonal scale of higher priority (standard zone) for this stratigraphic interval, based on the definite orthostratigraphic fossil group; all of the remaining (autonomous) zonal scales should be marked in accord with this group.

Scales are to be marked as follows. First, the standard scale is used to determine the biozones of all the species, used to build autonomous scales for the given stratigraphic interval. Thus, the condition of minimal sizes of the standard zone zonal units should be strictly observed. In accord with this condition, any biozone to be determined may be represented only by a *whole number of the zonal units* of the standard scale. The biozones thus obtained are used to construct individual (autonomous) scales, based on each group of fossils. The boundaries of the autonomous scales should be defined according to the same criterion, as used for the standard scale. If the condition of minimal dimensions of the standard scale zonal units was strictly observed in the course of biozone identification, the zonal units of the constructed autonomous scales will coincide with certain units of the standard scale. Therefore, all the autonomous scales will be unified. If all of the above operations are made correctly, it will also be clear which boundaries of the stratozones, defined from the normative scale, may or may not be identified from the autonomous one (Fig. 2). It follows from our experience, however, that most boundaries of the stratozones, defined from the normative scale, may be identified from the autonomous scales constructed by means of the above method.

The character of the procedure and the results thus obtained may be illustrated by the example of constructing an autonomous zonal scale based on brachiopods from the Late Devonian of the Urals western slope (Chernykh, Kucheva, 2016). The zonal conodont scale was used as the normative zonal scale. The data on brachiopod occurrences was taken from Tagariyeva, Mizens (2015). The zonal scale, based on brachiopods (ZBI-ZBV), allows identification of almost all of the conodont zone boundaries within the sections (except for theLower crepida zone) and provides complex characteristic of certain zones of the normative scale, which makes its correlational potential higher (Fig. 2, outlined with a rectangle).

Comparison of the scales, constructed by means of the above method, shows that some stratozone boundaries on the brachiopod scale do not have any analogues on the conventional ZA scale, and conversely, the boundary of the ZAIV stratozone has no corresponding boundary among the brachiopod stratozones. Similar uncorrelated boundaries are marked with arrows in Figure 2. Thus, one of the scales cannot be used to correlate the individual stratigraphic levels that are well fixed by means of some other scale. This kind of information will help to avoid unnecessary discussions on defining the boundaries of some straton (stage, series, system) by means of several autonomous scales, based on various fossil groups.

In concluding the discussion of the subject, I would like to return to the issue of the boundary between the Carboniferous and Permian systems, based on the conodont, ammonite and fusulinid scales for the Aidaralash section. If the conodont zonal scale is accepted as the normative one, the above boundary between the systems, determined from the ammonite and the fusulinid scales, falls in the isolatus conodont zone – the boundary zone between the Carboniferous

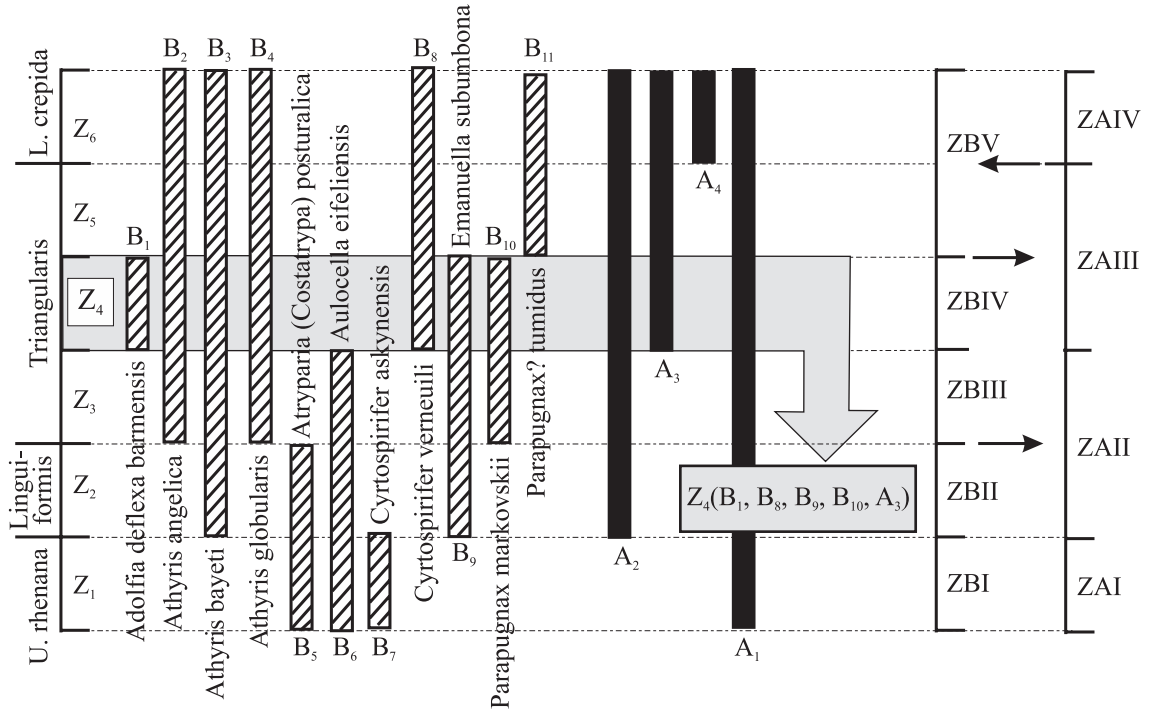

Fig. 2. Biozones of the species of Late Devonian brachiopods (B_1–B_{11}) and species of a conditional group of organisms (A_1–A_4), established according to the standard (normative) conodont scale (zones Z_1–Z_6).

Explanation in the text.

and the Permian systems. Therefore, this operation makes it possible to reach a conclusion on the chronological coevality of the boundary between the Carboniferous and Permian, specified in the Aidaralash section from conodonts, fusulinids and ammonoids.

The relationship of zonal biochronological and chronostratigraphic units

The issue, named in the title of this section, is close to the one considered in the paper of G.P. Leonov (1974, p. 72) that I am going to refer to repeatedly. Of all the "chronostratigraphic units", i.e., of the general stratigraphic units, stage units will be considered. But, everything to be said below on the relationships of the stage and the zonal biochronological units is true of all the chronostratigraphic (not just the stage ones) units.

Contrary to the opinion on the unity of the chronostratigraphic and the zonal biostratigraphic units, forwarded by G. Callomon and D. Donovan, G.P. Leonov argues his point on the independence of the international scale units of the stage and higher ranks ("chronostratigraphic units"), no different in this respect from the units of the regional-stratigraphic origin. They should not be united with the zonal units, biological by their nature, and one should not determine the extents of the chronostratigraphic units, primarily of the stages, from the constituent standard zones. "Analysis of historical data, – G.P. Leonov states, – does not leave any doubts that the extents and the positions of the majority of both stages and larger chronostratigraphic units are defined by the regional-stratigraphic data, – the extents and the boundaries of the regional prototypes of the corresponding units of the international scale. That is exactly why various stages, inclusive of the Jurassic ones, enclose various numbers of standard zones, with the numbers defined by the initial extent of every given stage, and not by any biostratigraphic considerations" (Leonov, 1974, p. 75).

Thus, the zonal units of the biochronological scale, biological by their nature, have nothing in common with the units of the general stratigraphic scale, recognized based on the regional-stratigraphic data. The zonal BCS performs correlational functions, and this is its sole purpose.

This conclusion might be made without any lengthy disputation, just through considering the principal, substantial difference between a scale and a section, and accepting differentiation between a scale and a section as the basic statement. Since something that is called MSS represents the stratisphere composite section (Naidin, 1994), and since the units of this "scale" represent the rock aggregates (geological bodies), they should be separated from the zonal paleontological scales, which constitute a model view (biochronological calculation) of geological time.

Besides, with the minimal sizes of the zonal units considered, certain zones make the boundaries of

the stage and of the higher order units, distinguished by means of the zonal biochronological scale. This observation makes the maximum accuracy, provided by the zonal BCS in the course of dating any object within a corresponding statozone in a section (Fig. 1). For example, on the conodont scale, the Streptognathodus isolatus zone makes the boundary between the Carboniferous and Permian systems, while simultaneously representing the boundary between the Gzhelian and Asselian stages. In the scale, this zone does not belong either to the Carboniferous or to the Permian systems' it is not a part of either the Gzhelian or of the Asselian stages. In the scale, this zone represents a dividing linear boundary. In the section, the substrate analogue of this boundary zone – stratozone – is customarily assigned to the higher position of the adjacent statons, and the stratozone lower boundary is combined with the lower boundary of the Asselian stage. This is a purely conditional, negotiated action, providing a linear boundary for outlining the geological bodies during geological (cartographical) surveying. It is impossible to determine what exact part (the lower, the middle or the upper one) is the stratozone represented in a particular sections, since any stratozone part, irrespective of its representation within a section, is dated according to a corresponding complete zone in the scale.

Let us consider the exact meaning of the "stage scale". Recall, that G.P. Leonov insists on the fact that almost all the international scale units of the stage and higher orders, by their nature, belong to the units of the regional-stratigraphic origin, with their extents and boundaries determined from the regional-geological data.

According to the Russian Stratigraphic Code, the general stratigraphic units to which the stage belongs, represent "the rock masses (geological bodies) that occupy definite positions within a complete geological section of the Earth's crust and have been formed during the geological time interval recorded in the stratotype section and (or) by means of limitotypes" (Stratigraphic…, 2019, p. 15). In other words, the stage scale in the conventional sense is a composite column of the rock stratotype sections arranged in the order of their stratigraphic sequence. Certain variances in the definitions of the general stratigraphic scale (which, without doubt, include the stage scale) in Russian and foreign reference guides do not alter the statement of the scale being a rock aggregate. To make this column of the composite section of the Earth's crust, composed of the stage units, look like a time scale, it is proposed to introduce the geochronological analogues of the stage units and to rename the stages as ages (the Gzhelian age, the Asselian age, etc.). The indication that a geochronological unit is "a geological time interval during which the rocks within the given stratigraphic unit have been formed, inclusive of the time of interior breaks)" (ibid., p. 10), allows one to understand, that physical time is meant here. In other words, the so-called "geochronological units" are actually chronometrical ones. This observation is also evidenced by the procedure of limitotype detection within the MSS in accord with the modern GSSP concept that involves radioisotope estimation of the "absolute age". To make the stage (age) stratigraphic sequence function as a physical time scale, isotopic tags should be introduced for the lower boundary age at every stage–age. In our case, this looks as follows (in million years): Gzhelian age (303.7), Asselian age (298.9), Sakmarian age (295.5). For obvious reasons, however, the potentials of such scale for the Phanerozoic stage translation (correlation) are rather limited. And most importantly, this scale of intervals (scale of durations) cannot be united with the scale of order, such as the biochronological zonal scale (Chernykh, 2014). Therefore, figure 1 is eclectic by its nature: it brings together various scales: the chronometric (stage) scale of intervals and the biochronological scale of order (zonal). The sole purpose of the figure is to demonstrate that the lower boundaries of the units from the general stratigraphic scale (stages, series, systems) correspond to certain zones on the biochronological conodont scale, and may be tracked as such over the development area of the geologically (chronologically) coeval deposits by means of this scale.

This observation does not mean, however, that a stage is determined "from the biostratigraphic data reflecting the evolutionary changes and (or) the stagewise development of the organic world and represents a set of chronozones, combined according to a definite feature", as believed by the authors of the latest Stratigraphic Code (2019, p. 17). Above, G.P. Leonov's view has been cited. From analyzing the history of the ISS straton indication, he has shown the extents and the boundaries of those units to have been based on the regional-geological data. The particular sections, based on these stages, have later on been accepted as the standard ones (stratotypes). Only when the established stage boundaries within the stratotypes have been marked by means of the zonal biochronological scales, was it possible to recognize the age analogues of the stages in other particular sections. Note once more: zonal BCS had nothing to do with stage determination.

G.P. Leonov also presents M.S. Messezhnikov's (1966) view on general doubts regarding the appropriateness of assigning a zone to the scale of general stratigraphic units. The principal conclusion is the "standard zonal column" should be primarily regarded as the standard for correlation. "This last remark, – G.P. Leonov goes on – should probably be understood in the sense that, in Messezhnikov's opinion, there is good reason to regard the zones as a special, distinct from the stratigraphic ones, category of stratigraphic (biostratigraphic) units" (Leonov, 1974, p. 78). Although M.S. Messezhnikov, when

speaking of a zonal scale, conventionally regards it as "a standard zonal column", i.e., a stratozone sequence in a section; he obviously inclines towards the correlational function of this "column" and the special status of the zonal unit. This interpretation is quite close to my idea of the BCS status and functional purpose: "Its units – zones – represent a tool for chronological identifications of remote geological objects, including the boundaries of the GSS stratigraphic units, but do not belong to its hierarchy" (Chernykh, 2005, p. 15). If only Messezhnikov and Leonov could clearly distinguish between the zonal scale and the section, the presumptive view, proposed by Messezhnikov, would have been replaced by complete confidence in the correlational purpose of the zonal biochronological scale and in the special status of a zone as the scale smallest unit.

To avoid any new questions on the stage paleontological description, that should allegedly be composed of "widely occurring species (and genera) found in both the stage stratotype and in other coeval deposits" (Stratigraphic…, 2019, p. 17), it is necessary to realize a simple thing at last: the strict marking and correlation of the stratigraphic boundaries of the stage units is made by means of zonal biochronological scales. Those scales should not be combined with the tangible, material sections of the stratons (geological bodies) that are compared and traced by means of those scales, but the units of those scales do not make parts of the stage stratons. Distinguishing stratozones within a section is a preliminary, preparatory operation, preceding the straton boundary correlations through a particular zonal scale. A stage boundary, distinguished within a definite startozone, is marked by an eponymous zonal unit of the scale. When correlation of the stage stratigraphic boundaries is accomplished, no one ever thinks about the stratozones defined in a section.

Therefore, the zonal biochronological units should not be incorporated with the chronostratigraphic units of the general (international) stratigraphic scale. The stratigraphic unit extents and boundaries are determined based on the regional-geological features of the sections. To construct a biochronological scale, we obtain the zonal extent from analyzing the process of evolutionary changes within a certain group of organisms; this process is fixed in the paleontological record. Thus, the zonal biochronological units are evolutionary-biological units by their nature. A zonal biochronological scale serves as a tool for correlating the boundaries of the stratigraphic units of the stage and higher ranks, but the zonal units do not belong to the hierarchy of stratons, because they are determined by an absolutely different, qualitatively different basis, and do not serve any function, except for identification and correlation. This result is especially obvious in the case of geological mapping, when zonal scales are widely used to map formation or stage deposits, but no stratozones are ever mapped.

A zone (chronozone) does not represent "a unit of the General stratigraphic scale subordinate to a stage", as specified in the Russian Stratigraphic Code (Stratigraphic..., 2019, p. 18). It is impossible to set a zone directly in the section of some stage before a zonal BCS is built. The stratozone position within a section, determined from the zonal BCS, does not need to coincide with the stage boundary. Usually, they do not coincide. Conventional matching of the stage boundaries with the spatially nearest stratozone in a section pursues the practical aims: to trace the particular stage by means of correlating its boundaries through the medium of a zonal BCS. The lack of insight in regards to the essence of this conventional procedure leads to a wrongful identification of the stratozone boundaries with the boundaries of the stage units, and to a zone incorporation into the hierarchy of the General stratigraphic scale units.

The stage (and any other superstage units of the General scale) boundaries, determined from the zonal scale, represent the corresponding BCS units. In the section, the stages have been identified in the stratotype location on the basis of historical-geological data. Designation of its boundaries in accord with the requirements of the GSSP concept involves the use of a zonal scale, preferably built on an evolutionary basis (Stratigraphic…, 1992, p. 76). This procedure is necessary not so much for substantiating the stage boundaries (those have been substantiated earlier and upon a different basis), as for their demarcation, recognition and the subsequent correlation.

The zonal biochronological scale is a scale for the biological calculation of geological time. By its nature, this scale is a paleontological, chronological, event scale; it belongs to the scales of order. Such scales are based on a fixed order of object arrangement in accordance with the degrees of manifestation of their specific property.

The principal feature of the organic evolution process in a certain organism group consists in the fact that this process is irreversible, and the sequence of the events and the very events within this process (the living sequence of the species of the same phratry) do not repeat. The order of the event succession ("existence of the A, B, C and so on") is set according to their stratigraphic sequence. In this instance, the order of the species arrangement in the stratigraphic (chronological) sequence is accepted as the special property of certain species – the "earlier than" property. This relationship is exactly similar to Mohs hardness scale, with the hardness standards arranged in the ascending order of the standard numbers: each successive standard mineral in the scale is by one unit "harder", than the previous one. The hardness numbering is purely conventional, and orthoclase (hardness 6) is not twice as hard as calcite (hardness 3). Likewise, each successive zone in the scale increases its "earlier than" property by one zonal unit, but the chronometrical duration of any two

zones combined is not twice as long as that of any of them.

Besides, we can frequently discern the alteration trend in a definite feature of a specimen structure during the process of the group evolution. In this case, the zonal paleontological scales, based on a morphological trend, fully comply with the "scale of order" concept, based on the fact that the zone sequence is arranged in accord with the convergence degree of the special property, from its initial state to the final one.

By definition, the scale of order should comprise at least three units. It is only in this case that one can discern any directions of the changes in the property, used to grade the scale. Such three-zone biochronological scale had been earlier named the "elementary BCS" by the author (Chernykh, 2005). The elementary zonal BCS should be used for marking and identifying the boundaries of the stratigraphic units.

The events used for the chronological scale construction and that represent the evolutionary process of some organism group, should be qualitatively equal. The monotaxon zonal units, distinguished from studying the evolutionary sequence of the species from the closely related groups, tend to meet these requirements.

It is impossible to build an order scale of stages, since each one of those has been distinguished in its own way, according to a group of features (lithological, cyclostratigraphic, paleontological, etc.), and it is apparently difficult to find two similarly distinguished stages. It is possible to reveal a general stratigraphic sequence of the thus distinguished units (i.e., to build a composite section) only by means of the already constructed scale, usually a biochronological scale. Precise marking of the stage boundaries themselves is possible exclusively by means of the zonal biochronological scale. And even after that, the stage sequence will look more like a calendar of the events, encased within each stage unit, than as a true order scale, since it is impossible to provide equal quality of the events, used as the basis for the stage unit detection within stratotypes in various remote sections. The only thing that may be attained after the stratigraphic sequence of the general scale units has been determined, is a single language, used to record the history of the geological events in a particular regions.

CONCLUSIONS

1. At the present time, it is obvious that it is necessary to introduce the concept of "zonal biochronological scale" into the practice of stratigraphy, to provide it with a strict definition, including the definition of the scale smallest (zonal) unit, and to specify the functional purpose of the scale. It is also timely to emphasize the necessity of making a distinction between the zonal biochronological scale as a model idea of geological time and the geological section as the material equivalent of that time. As shown in the present paper, such a reform may result in attaining a common viewpoint on numerous disputable problems of stratigraphy.

2. In stratigraphy, there are no true chronological scales built on a single substantive basis, except for the zonal BCS. This situation is being comprehended quite slowly, without any adequate reasoning, by feel and touch. The long practice of identifying the boundaries of the chronostratigraphic units on the basis of complex paleontological characteristics and the relevant endless dispute on the precise boundary position in particular sections have ultimately led to accepting the need to draw those boundaries by means of a zonal biochronological scale constructed on the evolutionary basis (the GSSP concept). No matter how much the concept is criticized, it comprises a sound idea of using the true chronological scales – the zonal BCS – for the stratigraphic boundary identification.

3. And the last. It should be noted that the application of the zonal biochronological method for the stratigraphic boundary detection has certain peculiarities that have not been clearly assessed by specialists, as yet. In the scale, the boundary, based on this method, corresponds to the smallest chronostratigraphic unit – a zone, and hence, is linear. In the stratigraphic equivalent (in the geological section), this boundary becomes three-dimensional, voluminous, and corresponds to a stratozone as a whole. Perception of the linear character of the zonal biochronological scale gradation and of the voluminous character of the corresponding stratigraphic boundaries of the geological objects, determined by means of this scale, is of basic importance for the correct statement and correct solution of the problems of general stratigraphy.

REFERENCES

Chernykh V.V. (2005) Zonal method in biostratigraphy. Zonal scale of the Lower Permian by conodonts. Ekaterinburg, IGG UrO RAN, 217 p. (In Russ.)

Chernykh V.V. (2014) Zone chronological scales and the stratigraphic boundaries. *Lithosphere (Russia)*, (3), 3-10. (In Russ.)

Chernykh V.V. (2016) The basics of zonal biochronology. Ekaterinburg, IGG UrO RAN, 268 p. (In Russ.)

Chernykh V.V., Kucheva N.A. (2016) Polytaxonomic and monotaxonomic zonal biochronological scales in biostratigraphy. *Lithosphere (Russia)*, (5), 5-16. (In Russ.)

Cowie J.W., Ziegler W., Boucot A.J., Basset M.G., Remane J. (1986) Guidelines and statutes of the International Commission on Stratigraphy (ICS). *Courier Forschungsinstitut Senckenberg*, **83**, 1-14.

Gladenkov Yu.B. (1991) Modern problems of zonal stratigraphy. *Izv. AN SSSR. Ser. Geol.*, (10), 3-8. (In Russ.)

Gladenkov Yu.B. (2001) Cenozoic of Sakhalin – modern stratigraphic schemes and correlation of geological events. *Stratigr. Geol. Korrel.*, **9**(2), 77-91. (In Russ.)

Gladenkov Yu.B. (2004) Biosphere stratigraphy (Stratigraphic problems in the Early XXI century). Moscow, GEOS Publ., 120 p. (In Russ.)

Goman'kov A.V. (2007) Geological time and its measurement. Moscow, KMK Publ., 58 p. (In Russ.)

Karpinsky A.P. (1945) About Ammonians of the Artinskian Stage and about some Carboniferous forms similar to them. *Collected works.* V. I. Moscow; Leningrad, AN SSSR, 479-496. (In Russ.)

Khalfin L.L. (1970) A.P. Karpinsky's and the boundaries of units of the International Stratigraphic Scale (ISS). *Tr. SNIIGIMS i MS. Regional geology*, vyp. 110, 4-10. (In Russ.)

Khalfin L.L. (1980) Theoretical question of stratigraphy. Novosibirsk, Nauka Publ., 200 p. (In Russ.)

Leonov G.P. (1974) Bases of the stratigraphy. V. 2. Moscow, MGU, 486 p. (In Russ.)

Menner V.V. Zones in the practice of stratigraphic research (history of establishment, types and nature). *Izv. AN SSSR. Ser. Geol.*, (3), 5-17. (In Russ.)

Mesezhnikov M.S. (1966) Zones of regional stratigraphic scales. *Sov. Geologiya*, (7), 3-16. (In Russ.)

Meyen S.V. (1981) From the general to the theoretical stratigraphy. *Sov. Geologiya*, (9), 58-69. (In Russ.)

Meyen S.V. (1989) Introduction into the theory of the stratigraphy. Moscow, Nauka Publ., 216 p. (In Russ.)

Naidin D.P. (1994) So, What Is Stratigraphy? *Stratigr. Geol. Korrel.*, **2**(2), 3-11. (In Russ.)

Nikitin S.N., Chernyshev F.N. (1889) International Geological Congress and its recent sessions in Berlin and London. *Gornyi zhurnal*, **1**(1), 115-150. (In Russ.)

Rauser-Chernousova D.M. (1967) On the zones of the united and regional scales. *Izv. AN SSSR. Ser. Geol.*, (7), 104-118. (In Russ.)

Remane J., Basset M.G., Cowie J.W., Gohrbandt K.H., Lane H.R., Michelsen O., Noiwen W. (1996) Revised guidelines for the establishment of Global chronostratigraphic standards by International Commission of Stratigraphy. *Episodes*, **19**(3), 77-81. https://doi.org/10.18814/epiiugs/1996/v19i3/007

Shindewolf O. (1975) Stratigraphy and stratotype. Moscow, Mir Publ., 136 p. (In Russ.)

Sokolov B.S. (1971) Biochronology and stratigraphic boundaries. *Problems of general and regional geology*. Novosibirsk, Nauka Publ., 155-178. (In Russ.)

Stratigraphic Code of Russia. (2006) 3rd ed. St.Petersburg, VSEGEI, 96 p. (In Russ.)

Stratigraphic Code of Russia. (2019) 3rd ed., revised and enlarged. St.Petersburg, VSEGEI, 93 p. (In Russ.)

Stratigraphic Code. (1992) 2nd ed., enlarged. St.Petersburg, VSEGEI, 120 p. (In Russ.)

Tagarieva R.Ch., Mizens L.G. (2015) Cross-sections of the western slope of the Southern Urals, promising to select the point of the lower boundary of the regional stratotype Famennian stage. *Lithosphere (Russia)*, (3), 33-56. (In Russ.)

Tesakov Yu.I. Correlation of chronostratigraphic and biostratigraphic units (example of the Silurian System). *Geol. Geofiz.*, **56**(4), 805-829. (In Russ.)

Zhamoida A.I. (2004) Problems Related to the International (Standard) Stratigraphic Scale and Its Perfection. *Stratigr. Geol. Korrel.*, **12**(4), 3-13. (In Russ.)

Zubakov V.A. (1980) Stratigraphic classification and geohistorical periodization: the search for new ways and solutions. *Ecosystems in stratigraphy*. (Ed. by V.A. Krasilov, N.I. Blokhina). Vladivostok, DVNTs AN SSSR, 22-37. (In Russ.)